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ICRP PUBLICATION 57

Radiological Protection of the Worker in Medicine and Dentistry

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RADIATION PROTECTION

ICRP PUBLICATION 57

Radiological Protection of the Worker in Medicine and Dentistry

A report of a Task Group of Committee 3 of the
International Commission on Radiological Protection

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CONTENTS

PREFACE

Committee 3 of the International Commission on Radiological Protection is concerned with the protection of patients, workers and research volunteers in medicine and dentistry. Three recent ICRP publications have dealt with protection of the patient, viz:

ICRP Publication 34 (1982) Protection of the Patient in Diagnostic Radiology
ICRP Publication 44 (1985) Protection of the Patient in Radiation Therapy
ICRP Publication 52 (1987) Protection of the Patient in Nuclear Medicine

This publication is concerned with protection of the worker. It was prepared by a Task Group which was set up in 1986 with the following terms of reference:-

The document should be one of the series addressed predominantly to members of the professions exposed to radiation. The document should deal with applications of the Commission's dose limitation system to specific situations of workers' protection in diagnostic applications of X rays, in beam therapy, in uncollimated therapy, in diagnostic and therapeutic applications of radiopharmaceuticals, in laboratory uses of radionuclides in medicine and with radiation protection of workers exposed to radon in balneology.

The Commission is preparing revised basic recommendations for publication, probably in late 1990 or early 1991. These new recommendations are likely to necessitate a revision of this report. Meanwhile, this report is consistent with the Commission's current recommendations.

The members of the Task Group who prepared this document for Committee 3 of the Commission were:

J H E Carmichael (Chairman)
R J Berry (from September, 1987)
W F Bland (from September, 1986)
J J Conway
E T Henshaw
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The help of J E Shaw and H R Stockdale is gratefully acknowledged.

The membership of Committee 3 at the time of the preparation of the report was:

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1. INTRODUCTION

1.1. The Role of ICRP

(1) The International Commission on Radiological Protection has been functioning since 1928, when it was established by the Second International Congress of Radiology to give guidance on the safe use of radiation sources in medical radiology. As a result of rapid developments in the field of nuclear energy and natural radiation, the Commission has subsequently expanded its area of guidance to cover more widespread uses of radiation sources, while strengthening its traditional relationship with the medical field.

(2) This report furthers this objective by providing advice on the radiological protection of the worker in medicine and dentistry. It is consistent with the basic recommendations of the Commission in *ICRP Publication 26* (ICRP, 1977b) and in subsequent statements (ICRP, 1980, 1984a, 1985a, 1987a) and with other ICRP publications in the general and medical fields, notably the following:

ICRP Publication 33 — Protection Against Ionizing Radiation from External Sources used in Medicine (ICRP, 1982a).
ICRP Publication 34 — Protection of the Patient in Diagnostic Radiology (ICRP, 1982b).
ICRP Publication 35 — General Principles of Monitoring for Radiation Protection of Workers (ICRP, 1982c).
ICRP Publication 37 — Cost-Benefit Analysis in the Optimization of Radiation Protection (ICRP, 1983).
ICRP Publication 41 — Nonstochastic Effects of Ionizing Radiation (ICRP, 1984b).
ICRP Publication 44 — Protection of the Patient in Radiation Therapy (ICRP, 1985b).
ICRP Publication 49 — Developmental Effects of Irradiation on the Brain of the Embryo and Fetus (1986b).
ICRP Publication 51 — Data for Use in Protection Against External Radiation (ICRP, 1987b).
ICRP Publication 52 — Protection of the Patient in Nuclear Medicine (ICRP, 1987c).
ICRP Publication 55 — Optimization and Decision-Making in Radiological Protection (ICRP, 1989a).

This report completes the updating of *ICRP Publication 25* (ICRP, 1977a) — Handling, Storage, Use and Disposal of Unsealed Radionuclides in Hospitals and Medical Research Establishments — which has been withdrawn from circulation.

In accordance with the practice adopted in earlier reports, the word "shall" indicates that which the Commission considers necessary; the word "should" indicates that which the Commission considers to be desirable.

1.2. The Workers in Medicine Likely to be Exposed

(3) In establishments for medical diagnosis, treatment and research, widespread use is made of ionizing radiations from x-ray and other machines and from radionuclides. This report discusses the protection measures applicable to workers involved either directly or indirectly in such uses; in particular, it deals with the protection measures applicable to radiologists, radiation oncologists,

nuclear medicine physicians, medical physicists, radiographers, scientists, technicians, radiopharmacists, engineers, nurses and others (such as cardiologists and orthopaedic surgeons), when their work involves exposure to radiation.

(4) Throughout this document the term "practitioner" includes, as appropriate, radiologists, radiation therapists, radiation oncologists, nuclear medicine physicians, other physicians and surgeons, dentists, osteopaths, chiropractors, and others licensed by an appropriate authority to practice their particular speciality.

(5) The term "radiographer" in this document includes radiological technologist, medical technical assistant and medical radiological technician.

(6) The term "technician" in this document includes nuclear medicine technician and technologist, dental technician and radiotherapy technician.

(7) This document is also applicable to both medical and non-medical workers in balneotherapy, who may be occupationally exposed to radon.

1.3. To Whom The Report is Directed

(8) This report is directed particularly towards the managing authority in each hospital or medical establishment and to the workers involved in work with radiation at such establishments. However, the report is also drawn to the attention of the relevant statutory authorities, whether national, regional or local, that are responsible for the enforcement of safety standards and for establishing training standards for workers.

(9) The report is also intended for those responsible for the planning and provision of medical and associated technical services, since safety can only be assured if adequate standards are incorporated in the initial planning and design stage of a facility and if there is proper provision of equipment and of adequately trained staff.

1.4. How to Read The Report

(10) The first three sections of this report are general and should be read by all workers to acquire an understanding of radiation protection.

(11) Section 1 is this introduction; Section 2 covers the basic concepts of radiation; Section 3 addresses the practical problems common to all users of radiation in medicine and dentistry.

(12) Sections 4 to 8 are specialist sections, covering practical aspects of protection of the worker in diagnostic radiology, dental radiography, use of unsealed radionuclides, brachytherapy and external beam radiotherapy, respectively. Those who work with unsealed radionuclides will find that specialist Section 6 is further divided into a general section (6.1) and specialist sub-divisions for diagnostic uses (6.2), therapeutic uses (6.3), and laboratory medicine uses (6.4).

(13) Section 9 covers protection of the worker in balneotherapy. While outside the mainstream of medical uses of radiation, balneotherapy entails significant radiation safety considerations for those workers involved.

2. BASIC CONCEPTS

2.1. Introduction

(14) Radiation is the term used to describe the transfer of energy through space or matter in the form of either electromagnetic fields or sub-atomic particles. Ionization is the process by which atoms lose,

or sometimes gain, electrons and thus become electrically charged, being then known as ions. This energy transfer is a random process and the spatial distribution of energy influences the effects of the radiation. Ionizing radiations encountered in medicine and dentistry comprise X rays, gamma rays, electrons and sub-atomic particles.

(15) External exposure of the worker refers to exposure to sources of radiation outside the body, which may arise from X rays or other machine-produced radiations and from beta, gamma or characteristic X rays emitted by radionuclides.

(16) Internal exposure of the worker may arise when radionuclides enter the body by ingestion, inhalation, through wounds or by direct absorption through intact skin.

2.2. Radiobiological Effects

(17) Radiation energy absorbed in living tissues initiates physical and chemical reactions that may result in biological changes. The detrimental effects that may arise from these changes are either somatic (i.e., they occur in tissues of the irradiated person) or hereditary (i.e., they occur in progeny of the irradiated person).

(18) Most organs and tissues of the body are unaffected by the loss of even substantial numbers of cells, but if the number lost is large enough, there will be an observable injury or loss of tissue function. The probability of causing such an injury will be zero at small doses up to some hundreds of millisieverts or more. But above some level of dose (the threshold) the damage will increase rapidly, the severity of the injury increasing with dose. This type of effect is called "nonstochastic".

(19) Nonstochastic effects that may arise in specific tissues include, among others, cataract in the lens of the eye; non-malignant damage to the skin; gonadal cell damage (leading to impairment of fertility); cell depletion of the bone marrow (causing haematological deficiencies); and cell depletion in other organs causing, if severe, impairment of organ function. Other generalised nonstochastic effects may arise in the blood vessels or connective tissues that are common to most organs of the body. *ICRP Publication 41* (ICRP, 1984b) deals in detail with the nonstochastic effects of ionizing radiation.

(20) The outcome is very different if the irradiated cells are modified rather than killed. The clone of cells resulting from the reproduction of a modified but viable somatic cell is almost always eliminated or isolated by the body's defences. If it is not, it may well result, after a prolonged delay called the latent period, in the development of a malignant condition, a cancer. The probability of a cancer resulting usually increases with dose in a way that is roughly proportional to dose, probably with no threshold. The severity of the malignant condition is not influenced by the initiating dose. This kind of injury is called "stochastic", meaning "of a random or statistical nature". If the original damage is done in stem cells in the testes or ovaries, whose function is to transmit genetic information to later generations, the effects, which may be of many different kinds, may be expressed in later generations.

2.3. Dosimetric Quantities

2.3.1. *Absorbed dose*

(21) The fundamental assumption in describing in a quantitative way the interaction of radiation with matter is that the relevant measure of the interaction is the energy deposited per unit mass. This energy deposition, the absorbed dose, D, can result from all types of radiation, and is defined by the relationship

$$D = \frac{d\bar{\varepsilon}}{dM}$$

where $d\bar{\epsilon}$ is the mean energy imparted by ionizing radiation to the matter in a volume element and dm is the mass of the matter in the volume element. The SI unit for absorbed dose is the joule per kilogram ($J\ kg^{-1}$) and its special name is the gray (Gy). The previous unit for absorbed dose was the rad ($1\ rad = 0.01\ J\ kg^{-1}$).

2.3.2. *Dose equivalent*

(22) There is a need in radiation protection for a well-defined numerical relationship between the assessed quantity describing the radiation exposure and its biological effects. The Commission has therefore used the quantity dose equivalent, H, which is intended to indicate sufficiently well the biological implications of radiation exposure at the levels of absorbed dose encountered in normal radiation protection. H is defined by

$$H = DQN$$

where Q is the quality factor and N is the product of all other modifying factors specified by the Commission. For the present the Commission has assigned a value of unity to N. Since both Q and N are dimensionless, the SI unit of dose equivalent is the same as for absorbed dose, namely the joule per kilogram, but to avoid confusion it has been given the special name, the sievert (Sv). The previous unit for the dose equivalent was the rem ($1\ rem = 0.01\ J\ kg^{-1}$).

(23) The quality factor allows for the different effectiveness of different types of radiation and represents a considered judgement of the different values of relative biological effectiveness (see paragraph (28)) for a given radiation for a range of biological endpoints. It is assumed to be dependent on the energy imparted per average track length in the tissue of interest and to be independent of the type of effect or endpoint. The value of Q has therefore been precisely defined by the Commission as a function of the collision stopping power, L_∞ in water at the point of interest. The Commission has specified the relationship at a number of values of L_∞ as shown in Table 1. Other values can be obtained by linear interpolation.

(24) If the absorbed dose is delivered by particles having a range of values of L_∞, an effective value $\bar{Q}$ at the point of interest can be calculated. When the distribution of L_∞ is not known, it is permissible

Table 1. Specified relationship between Q and L_∞

L_∞ in water (keV m^{-1})	Q
< 3.5	1
7	2
23	5
53	10
> 175	20

Table 2. Recommended permissible approximation of $\bar{Q}$ for various types of radiation

Type of radiation	Approximate value of $\bar{Q}$
X-rays, gamma rays and electrons	1
Alpha particles and multiple-charged particles (and particles of unknown charge) of unknown energy	20

to use approximate values for $\bar{Q}$. The Commission has recommended such approximate values for all common types of ionizing radiation; these are given in Table 2.

(25) The quality factors are chosen to represent the effectiveness of different types of ionizing radiation in producing harmful stochastic effects at low doses. It is therefore important that the dose equivalent should not be used to assess all the likely consequences of accidental exposures in man which may involve severe non-stochastic effects. For that purpose, absorbed dose is the appropriate quantity after weighting for the relative biological effectiveness (RBE) of each type of radiation for the effects at high doses.

(26) The Commission issued the following statement from its meeting in Paris during March 1985 on the value of the quality factor in the case of neutrons (ICRP, 1985a). "The information now available on the relative biological effectiveness (RBE) for neutrons for a variety of cellular effects *in vitro*, and for life shortening in the mouse, is being reviewed by the Commission. The implications of this information will be considered as part of a larger review of recommendations to be undertaken by the Commission over the next four years or so. Meanwhile, in the case of neutrons, the Commission recommends an increase in Q by a factor of 2. The permitted approximation for $\bar{Q}$ for fast neutrons thus changes from 10 to 20. These changes relate only to neutrons, and no other changes in Q are recommended at this time."

(27) A report on the quality factor in radiation protection is currently being considered by the Commission (ICRU, 1986) as part of this larger review. Since the change in Q for neutrons recommended in the Commission's 1985 statement may not be introduced into all national procedures at the same time, statements of the dose equivalent for neutrons should indicate whether the change has been applied.

(28) The relationship between Q and RBE is often misunderstood. RBE is defined as the ratio of the absorbed dose of a reference radiation to the absorbed dose of a test radiation to produce the same level of biological effect of the same extent and/or nature, other conditions being equal. Since Q has been defined without reference to any particular biological endpoint, it therefore does not correspond to any particular value of RBE.

2.3.3. *Effective dose equivalent*

(29) The probability of occurrence of a stochastic effect in an organ or tissue is assumed to be proportional to the dose equivalent in the organ or tissue for radiation protection purposes. The constant of proportionality may differ for the various tissues of the body, but in assessing health detriment the total risk is usually required. If the irradiation is uniform throughout all the tissues of the body then a single overall risk coefficient can be used, and assessment and comparisons can be made solely on the basis of the dose equivalent throughout the whole body. However, if the irradiation of different tissues is non-uniform — as is particularly the case with irradiation from most internally deposited radionuclides — then a further quantity is necessary to represent the total risk.

(30) The Commission has recommended a quantity to allow for the different mortality risks associated with irradiation of different organs, together with a proportion of the hereditary effects. This quantity is defined by the sum:

$$\sum_{T} W_T H_T$$

where W_T is the weighting factor specified by the Commission to represent the proportion of the stochastic risk resulting from irradiation of tissue T to the total risk when the whole body is irradiated uniformly, and H_T is the mean dose equivalent in tissue T. This sum is currently called effective dose equivalent, H_E.

(31) In assessing effective dose equivalent it does not matter in principle whether the dose equivalent in any particular tissue results from internal or external irradiation. All that is needed is to assess the dose equivalent in each tissue from all sources, multiply by the appropriate weighting factor and sum the results. If all the tissues in the body were uniformly irradiated then the result would be numerically equivalent to the whole body dose equivalent. Nonetheless, in many practical situations it is easier to assess separately the contributions from internal and external radiation.

(32) The values of W_T recommended by the Commission are shown in Table 3; they are considered by the Commission to be appropriate for protection for individuals of all ages and both sexes, i.e., for workers and members of the public. The value for gonads includes an allowance for serious hereditary effects, as expressed in the first two generations (i.e., the children and grandchildren of the irradiated individual). In practice the "remainder" organs or tissues are taken to be the five not specifically listed in Table 3 that receive the highest dose equivalents; a weighting factor W_T of 0.06 is applied to each of them, including the various portions of the gastrointestinal tract, which are treated as separate organs. This procedure assigns the same risk coefficient to all organs or tissues not named in Table 3. This simplification affects only the method of calculating the effective dose equivalent. The definition itself covers all tissues.

(33) There has been some confusion over whether skin should be treated as a "remainder tissue". The Commission, in a statement of clarification (ICRP, 1978), said that it did not intend the hands and forearms, the feet and ankles, the skin and the lens of the eye to be included in the "remainder", and that these tissues should therefore be excluded from the computation of effective dose equivalent. This exclusion may be taken to apply to the assessment of effective dose equivalent in the context of the protection of individuals. The definition of effective dose equivalent includes all tissues and the Commission statement refers to the exclusion of certain tissues from the computational procedure. The method for dealing with skin irradiation in the context of exposures of a population group is dealt with elsewhere (ICRP, 1978, 1984b).

(34) The effective dose equivalent, while still a dosimetric quantity, is an indicator of the risk of death from somatic effects and the risk of hereditary effects in the first two generations, assumed to result from any irradiation, whether uniform or non-uniform, from both external and internal sources. It does not include hereditary effects in subsequent generations, nor any allowance for non-fatal somatic effects such as most cases of thyroid or skin cancer.

2.3.4. *Committed dose equivalent*

(35) Another quantity used by the Commission is the Committed Dose Equivalent, H_{50}, to a given organ or tissue from a single intake of radioactive material into the body. This quantity is the dose equivalent that will be accumulated over 50 years following the intake. The 50 years is meant to represent a working lifetime. The use of committed dose equivalent for intakes in each year allows

Table 3. Weighting factors recommended in *ICRP Publication 26* for calculation of effective dose equivalent

Organ or tissue	Weighting factor W_T
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30

for any potential build-up of radionuclide in the organ or tissue over a prolonged period of exposure, to ensure compliance with dose limits.

2.4. Hazards and Risks

(36) When radiation was initially used in medicine, concern was primarily with the hazards arising from the exposure of a few workers to relatively large radiation doses. Concern has now been extended to include deleterious effects that might be expected to arise from the exposure of a large number of workers to relatively small radiation doses. The anticipated detriment is mainly a small increase in the incidence of cancer.

(37) Epidemiological data on cancer are being collected for a number of groups — principally persons who have been medically irradiated (e.g. Darby *et al.*, 1986; Boice *et al.*, 1988), atomic bomb survivors (Shimizu *et al.*, 1987; 1988) and occupationally exposed persons (e.g. Forman *et al.*, 1987; ICRP, 1985c). In 1977, the Commission concluded that the risk coefficient for radiation-induced fatal cancers at low doses and low dose rates was of the order of 10^{-2} Sv^{-1} averaged for both sexes and all ages (ICRP, 1977b, paragraph 60).

(38) The Commission (ICRP, 1987a) has given particular consideration to the expected increases in estimates following the updating of the Life Span Study, but its deliberations on application of these revised cancer risk estimates in relation to radiation protection are not yet completed.

(39) Of all malignant neoplasms, leukaemia appears earliest, with a peak incidence occurring a few years after irradiation. There is little or no additional risk after approximately 25 years. The average latent (or induction) periods for other cancers are considerably longer.

(40) The lifetime cancer mortality risk estimates currently used by the Commission are given in Table 4, based upon extrapolation of data obtained at high doses and high dose rates with an appropriate reduction factor applied to allow for the less carcinogenic effects of radiation delivered at low doses and low dose rates.

(41) Hereditary effects caused by ionizing radiations have not been observed in human beings, and genetic risk estimates are based on laboratory animal data. The Commission's estimate in *ICRP Publication 26* was 0.2×10^{-2} Sv^{-1} (gonad dose equivalent) for severe hereditary disorders in the first two generations of offspring after exposure of an average individual in the total population, and about twice that value for the harm in all generations. More recent estimates by UNSCEAR (1986, 1988) do not quantify all components of the hereditary harm, but UNSCEAR (1988) concluded that "the risk

Table 4. Cancer mortality risk estimates by site*

Site of cancer	Mortality risk (10^{-3} Sv^{-1})
Red bone marrow	2.0
Lung	2.0
Breast	2.5
Bone surfaces	0.5
Thyroid	0.5
Total of all other tissues	5.0

Note: Data are averaged for sex and age. The age-average risk estimate for the female breast is therefore twice the value given above, and zero in the male.

*These estimates are currently under review. The UNSCEAR (1988) report indicates higher risks.

of severe hereditary harm in the first generation of offspring to the exposed individual does not appear to be higher than the present estimate of the cancer risk".

(42) In addition, consideration needs to be given to the possible effects of radiation on the developing embryo or fetus. Developmental effects have been observed in both animal studies and in human beings. Their nature and frequency depend on the stage of development at which exposure occurs, on the absorbed dose received and on the quality of the radiation. There is also the possibility that radiation-induced cancers will be expressed during childhood or in adult life. Again, in estimating this risk, the type and frequency of such effects depend upon the stage of gestation at which the exposure occurs.

(43) Ovulation occurs typically about the midpoint of the menstrual cycle and rarely takes place earlier than 10 days after the first day of the last menstrual period. In humans, the conceptus begins to attach to the uterine wall at 5 or 6 days after fertilization, but its subsequent development is relatively slow. Extra-embryonic tissues are the first to develop, and formation of the primitive streak begins only at 15 days after fertilization. Further organogenesis begins a few days later and, in the case of most organs, continues for the next month; the major phase of cell proliferation in the human forebrain, however, begins still later, at about 8 weeks after fertilization.

(44) Loss of a small proportion of the cells from extra-embryonic tissues would not be expected to influence subsequent development of the conceptus. The month following the first day of the last menstrual period, during which organogenesis is unlikely to be occurring, is not, therefore, likely to be a critically radiosensitive period for the induction of malformations in the embryo, though exposure to radiation might increase the probability of spontaneous abortion.

(45) In the following period of 2 – 8 weeks after conception, during which major organogenesis proceeds, an increased sensitivity is assumed, based upon malformations observed in exposed experimental animals at corresponding stages of development. Such malformations have not, in fact, been observed in humans in the 2 – 8 week period. The relatively slower development of organs in the human embryo, as compared with small laboratory animals, would be expected to reduce susceptibility to their induction by a brief exposure to radiation because of the smaller proportion of cells dividing at any one time.

(46) The most intensive period of development of the human forebrain starts at about 2.5 months from the first day of the last menstrual period. Evidence from the Japanese atom bomb survivors indicates an excess of severe mental impairment in children who received a brief radiation exposure *in utero* during the period 8 – 15 weeks after conception (Otake and Schull, 1984; ICRP, 1986b, 1987a; Schull *et al.*, 1989). From these data, it may be concluded that the risk of severe mental retardation is a function of the dose equivalent. A non-threshold linear dose-response relationship with a risk coefficient of about 4×10^{-1} Sv^{-1} has been proposed. However a curvi-linear relationship (concave upwards) is also consistent with the data, and on this basis a threshold of about 0.2 Sv could be postulated. Up to 8 weeks after conception the risk is apparently zero. Between 15 – 26 weeks, the risk is less than between 8 – 15 weeks; and after 26 weeks the risk is very low. Nevertheless it would seem prudent in radiological protection practice to assume no threshold in the most sensitive period of pregnancy.

(47) Supporting evidence comes from other studies performed in Japan which indicate that children exposed *in utero* in the period 8 – 15 weeks after fertilization have a lowered performance at school, with the reduction in IQ being dependent on the absorbed dose. Unprovoked seizures have also been observed in some children. At later stages of gestation the extent of mental retardation and reduction in mental performance were smaller, and such effects were not observable after about 26 weeks (ICRP, 1986b; UNSCEAR, 1986).

(48) According to UNSCEAR (1986), the risk of congenital malformations, (natural probability 6%), or of developing a malignancy after irradiation *in utero* with doses of the order of 0.01 Gy over

the whole pregnancy is assumed to be about 0.2%.

(49) The above-mentioned risk coefficients will not apply concurrently when the conceptus is irradiated acutely. It is likely that the quoted risk coefficients tend to overestimate the issue, in the sense that the respective dose–response relationships (except for tumours) are sigmoid in shape.

2.5. Aims of Radiation Protection

(50) Most decisions about human activities are based on an implicit form of balancing benefits against costs or disadvantages, leading to the conclusion that a particular course of action or practice either is, or is not, worthwhile. Less commonly, it is also recognized that the conduct of a practice should be adjusted to maximize the net benefit to the individual or to society. This is not a simple process because the objectives of the individual and society may not coincide. In radiological protection as in other areas, it is becoming possible to formalize the process of reaching these decisions, (WHO, 1983, 1987) and sometimes to quantify them. In doing so, attention has to be paid, not only to the advantages and disadvantages for society as a whole, but also to the protection of individuals, particularly when the benefits and detriments are not received by the same members of the population.

(51) The aims of radiation protection, as stated in *ICRP Publication 26,* paragraphs 9 – 11 (ICRP, 1977b) are:

(a) to prevent nonstochastic effects,

(b) to limit the probability of stochastic effects to levels deemed to be acceptable, and

(c) to ensure that practices involving radiation exposure of persons are justified by ensuring that the benefits outweigh the detriment.

(52) The prevention of nonstochastic effects is achieved by setting dose-equivalent limits for individual organs and tissues at sufficiently low values such that, even following exposure at this level through the total period of normal working life, the cumulative dose would not exceed the threshold for any of these effects.

(53) Limitation of the probability of stochastic effects is achieved by keeping all justifiable exposures as low as is reasonably achievable, economic and social factors being taken into account, and always within the appropriate limits for the effective dose-equivalent.

(54) In summary, the Commission recommends (ICRP 1977b, paragraph 12) the adoption of a system of dose limitation based upon the following principles:

(a) No practice shall be adopted unless it results in a positive net benefit — ***Justification of the practice***.

(b) All exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account — ***Optimization of Protection***.

(c) The dose equivalents to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission — ***Dose Limits***.

2.6. Dose Limits for Workers

(55) To avoid nonstochastic effects to the worker, the Commission currently recommends an annual dose-equivalent limit of 0.5 Sv for all tissues except the lens of the eye, for which a special limit of 0.15 Sv is recommended.

(56) To limit stochastic effects, the Commission currently recommends an annual effective dose-equivalent limit of 0.05 Sv.

(57) With regard to internal exposure arising from the intake of a radionuclide, the Commission has calculated Annual Limits of Intake (ALI) for each radionuclide corresponding to the activity of that nuclide which, if taken into the body, would give a worker over a period of 50 years either a committed effective dose equivalent equal to the annual effective dose equivalent limit; or, if more restrictive, a mean dose equivalent, to any individual organ, equal to the annual nonstochastic dose-equivalent limit for that organ (ICRP, 1979).

(58) In order to ensure that the annual dose limitation for stochastic effects is not exceeded, when a worker receives both external and internal dose equivalents, the exposure of the worker shall be controlled so that the addition of the proportion of the annual dose equivalent received externally and the proportion of the annual limit of intake received internally does not exceed unity (ICRP, 1977b, paragraph 110; ICRP,1978).

2.7. Exposure of Women of Reproductive Capacity and of Pregnant Women

2.7.1. *Occupational exposure of women of reproductive capacity*

(59) When women of reproductive capacity are occupationally exposed under the limits recommended in *ICRP Publication 26* (ICRP, 1977b), and when this exposure is received at an approximately regular rate, it is unlikely that any embryo could receive more than 5 mSv during the first 2 months of pregnancy (NEA, 1988). Having regard to the circumstances in which such exposures could occur, the Commission believes that this procedure will provide appropriate protection during the essential period of organogenesis.

(60) No risk comparable with mental retardation, as described by Otake and Schull (1984) and Schull *et al.* (1989), is incurred from irradiation in the period prior to the first missed menstruation.

2.7.2. *Occupational exposure of pregnant women*

(61) It is likely that any pregnancy of more than 2 months' duration would have been recognized by the woman herself or by a physician. The Commission recommended in *ICRP Publication 26* (ICRP, 1977b) that when pregnancy has been diagnosed, arrangements should be made to ensure that the woman can continue to work only in Working Condition B; namely that the conditions of occupational exposure of women diagnosed as being pregnant should be limited to those in which it is most unlikely that annual exposures would exceed 3/10 of the dose-equivalent limits.

(62) The Commission concluded that the new information published by Otake and Schull, (1984) and Schull *et al.* (1989) does not increase substantially the total risk previously judged by the Commission to result from occupational exposure of a pregnant woman (including her fetus) under these conditions. However, the new information, which shows that the risk of inducing mental retardation is confined to a limited period of time, makes some additional recommendations appropriate.

(63) The methods of protecting pregnant women at work should provide a standard of protection for the fetus broadly comparable with that provided by protection of members of the general public. If, under Working Condition B, as would be expected, substantial irregularities in the dose rate do not occur, the dose received by the fetus over the critical period of 8 – 15 weeks post-conception would not be expected to exceed about 1 mSv. The Commission recommends that specific operational arrangements should be made to avoid irregularities in the rate at which the dose could be received and to keep the dose to the fetus as low as reasonably achievable.

3. PRACTICAL ASPECTS OF THE RADIATION PROTECTION PROGRAMME

3.1. The Control of Radiation Hazards

3.1.1. *The control of external radiation*

(64) In many applications of radiation in medicine the only danger to health arises from irradiation from sources outside the body with no possibility of radioactive material being taken into the body. In such cases, of which the use of x-ray machines and of teletherapy sources is typical, the methods of control are basically very simple, although, in practice, they may be difficult to apply sufficiently rigorously.

(65) The successful control of external exposure requires the use of suitable equipment and techniques. The primary source of exposure is the radiation source itself, e.g. the x-ray tube or the radioactive material. The strength and nature of this source will depend primarily on the use to which it is put, but, if there is a choice, the source should be no stronger than necessary and the emitted radiation should be no more penetrating than necessary.

(66) The most effective protection measures are those applied at or near the source. The shielding of the primary source is therefore of major importance. When the source is in use, there will be secondary sources of exposure due to scattering of the primary radiation by the patient and by other material in the vicinity. Local shielding should be provided between the sources, both primary and secondary, and the workers whenever this shielding will not be detrimental to the care of the patient. The use of an interlocking system also provides extra protection against inadvertent exposure of the worker.

(67) Further protective measures include limiting the time spent by workers in the vicinity of primary and secondary sources, and by wearing appropriate protective clothing. These measures depend on the consistent use of good working practices; they should not form the main basis of protection unless this is necessary for the conduct of the medical procedure or for the care of the patient.

(68) The provision of these various protective measures is appropriate to the control of any sources of external exposure. In the case of installed equipment, much of the responsibility of their provision falls on the designer and supplier of the equipment. Nevertheless, there always remains some responsibility for ensuring design goals are met and establishing and maintaining necessary good working practices. Technical data for dealing with all these problems are given in *ICRP Publication 33* (ICRP, 1982a) and in Appendix B.

3.1.2. *The control of contamination*

(69) When dealing with unsealed radionuclides, the problems of external radiation are at least as important as when dealing with sealed sources, but they have to be supplemented by the control of contamination. The principal aims are to contain the radioactive materials at or near the point of use and to achieve a high standard of cleanliness so that contamination of the worker or the workplace does not build up. These topics are discussed in Section 6.

3.2. Overall Organization

(70) Detailed planning and design aspects of radiation protection are dealt with in Sections 4 to 9 under the headings of practical aspects of protection of the worker in diagnostic radiology, dental

radiography, nuclear medicine, brachytherapy, external beam therapy and balneotherapy.

(71) The safety measures described in this report are a desirable standard of protection on which the standards of any national, regional or local statutory authority should be based. However, it should be noted that statutory authorities may require radiation safety measures that are different from, or additional to, those recommended in this report.

(72) The management in each establishment has an overall responsibility for radiation safety. Within the management structure, there should be a clear chain of responsibility down to the worker, with the delegation of duties and responsibilities for radiation protection at each level.

(73) In those establishments, such as an independent practice or a small group of practitioners, where there is a less formal or detailed management structure, the chief practitioner should make arrangements to accomplish these duties and responsibilities for radiation protection, as appropriate to the size and nature of the establishment.

(74) The safe use of radiation in medicine depends greatly on the individual worker observing safety procedures. These should normally be issued in the form of written instructions (e.g. local rules) and their observance should be regarded as essential to ensure adequate protection of the worker.

3.3. Expert Advice and Technical Assistance

(75) In each facility where work with radiation is undertaken, a person should be appointed or a member of staff designated to act as Radiation Safety Officer. The duties and responsibilities of this person should include the following:

(a) to prepare written safety instructions in collaboration with the head of department and the radiation protection adviser (see paragraph 77);
(b) to deal with day-to-day matters of radiation protection;
(c) to assist management in ensuring that the radiation safety measures drawn up by the radiation protection committee (see paragraph 78) are implemented;
(d) to be readily available for consultation if problems in radiation protection arise that require immediate attention;
(e) to take appropriate emergency action if any abnormal incidents of radiation exposure occur, and to record the details and report the occurrence appropriately to the management;
(f) to notify the head of department, and the management, of any unsatisfactory radiation safety conditions;
(g) to arrange for new workers to receive appropriate instruction and training in radiation protection;
(h) to report to the radiation protection committee on radiation protection matters;
(i) to ensure that appropriate records are maintained of the dose equivalents received by workers for the lengths of time specified by the competent statutory authority.

(76) Radiation safety officers will require appropriate training in order to perform these duties, which may constitute a full time commitment or, as is more usual, be additional to their existing duties in the department.

(77) The management should have access to expert advice in radiation protection, particularly in the following areas.

(a) the planning and design of any medical radiation facility;
(b) the definition of performance specifications for equipment that have radiation protection implications;
(c) the radiation protection implications of new installations, processes and equipment, prior to their acceptance;
(d) the training and instruction of radiation safety officers (see paragraph 75) and other

workers;

(e) the identification of controlled and supervised areas and working conditions;

(f) the specification of appropriate monitoring procedures and the provision, maintenance and calibration of suitable monitoring equipment;

(g) the performance of environmental monitoring surveys of facilities prior to use;

(h) the drawing up of safe working procedures and the monitoring of their effectiveness;

(i) the design, implementation, and supervision of quality assurance programmes;

(j) the interpretation and significance of radiation exposures;

(k) the assessment of potential hazards from foreseeable incidents and the drawing-up of contingency plans;

(l) the investigation of the circumstances when there is reason to believe that a worker has received an abnormally high dose;

(m) the assessment of radiation protection hazard arising from the loss or theft of radioactive material.

This advice may be available from the Radiation Safety Officer or may be provided by a Radiation Protection Adviser who may be a member of staff or an external consultant in radiation protection.

(78) In large institutions there are advantages in establishing a Radiation Protection Committee in each facility or group of facilities, to recommend radiation safety policy, to draw up written guidelines and to approve broad working principles intended to optimize protection. Such a committee should include radiologists, physicians and other persons who have a special knowledge of the hazards of radiation and are experienced in radiation protection. The radiation protection adviser, the radiation safety officer and a representative of the management should also attend. Such a committee should also endorse local rules and should review standards of safety in the facility at regular intervals.

3.4. Education and Training

(79) Adequate education and practical training in radiological protection should be provided for all who work with radiation in the medical, dental and associated professions. Not only do they require initial training in radiation protection but also continued education throughout their professional lifetime.

(80) Those persons entering the fields of radiology, nuclear medicine and radiation therapy need a thorough basic education in radiation protection, which should include a broad knowledge of radiation biology, dosimetry and radiation physics, together with a detailed knowledge within their own professional sphere.

(81) The education and training of scientists and technicians assisting in the medical and dental applications of radiation should include a similar syllabus.

(82) Other practitioners (see paragraph 4) involved in radiological procedures, particularly cardiologists and orthopaedic surgeons, should receive extra instruction in the practices of radiation protection above that received as part of their general medical education and training.

(83) Medical or health physicists working in the medical radiation field should receive comprehensive education in the theoretical aspects, and practical training in radiation protection, including the physical principles and practices related to the medical applications of radiation. A knowledge of basic human anatomy, physiology and radiation biology is required.

(84) Radiographers and technicians (as defined in paragraphs 5 and 6) should undergo a course of study which includes radiation physics, radiation biology and radiation protection. This should enable them to perform their duties with a full appreciation of the theoretical and practical aspects of their work, paying full attention to the needs of radiation protection.

(85) Nurses may be involved in many radiodiagnostic and radionuclide examinations, and in the

practical nursing of patients to whom therapeutic doses of radionuclides have been administered, or in whom brachytherapy sources have been placed. It is essential, therefore, that their training should include relevant information concerning the principles of radiation protection and the appropriate practical aspects involved in nursing such patients.

(86) Engineers and maintenance workers, who work in a medical radiation facility, must be aware of the potential radiation hazards, the possibility of high exposure and the precautions that need to be taken.

(87) The management should ensure that all staff understand the need to carry out their duties in a safe manner and to avoid exposing themselves and others to more radiation than is reasonably necessary.

(88) Any person involved in the administration of radiation to patients must have a level of specialized training appropriate to the task performed. Regulatory authorities may wish to define the appropriate levels of training required.

(89) The simplest example of this might concern a person who is occasionally required to perform a simple radiological examination (e.g. chest X ray) in accordance with precisely defined written instructions, after having received appropriate practical training.

3.5. Planning and Design

(90) General aspects of planning and design are dealt with in this section but each of the succeeding sections has a sub-section devoted to the specific requirements of that particular use of radiation.

(91) Before any construction work begins, the final plans of a new medical radiation facility or of major modifications to an existing installation should be reviewed by the radiation protection adviser (see paragraph 77). When construction is completed, copies of the plans, including the shielding specifications, should be retained, updated when necessary, and be readily available at the site.

(92) Adequate protection may be achieved by controlling the distance of workers from radiation sources, the shielding available and the duration of exposures. The shielding requirements depend upon careful siting of the equipment and on the limitation of the possible directions of the primary radiation beam.

(93) When the shielding of a source is being planned, two basically different situations should be considered; firstly, it is necessary to consider the thickness of the primary shields to prevent excessive leakage of radiation from therapeutic or diagnostic installations emitting penetrating radiation. These shields have to conform with International Standards (*ICRP Publication 33* (ICRP, 1982a), *ICRP Publication 51* (ICRP, 1987b)). They have been developed taking account of optimization. Most of the currently manufactured equipment conforms with these requirements. In addition, consideration must be given to secondary shielding against primary beams as well as that required to attenuate further leakage and scattered radiation emitted by diagnostic and therapeutic installations, and to radiation emitted by sealed and unsealed radioactive sources in nuclear medicine and brachytherapy. Planning must aim to keep the exposure of workers and general public as low as reasonably achievable. To achieve this aim, application of optimization procedures is required. They have been described in detail in *ICRP Publication 55* (ICRP, 1989).

(94) In the design of a radiation facility, account should be taken of the maximum expected workload; in the absence of precise information it is prudent to overestimate the expected workload.

(95) The shielding requirements should take into account the occupancy of, and accessibility to, surrounding areas by workers, patients and members of the general public.

(96) In order to assess shielding requirements realistically, it may be possible to employ "occupancy factors" and "use factors" as part of the design of protection. However, since the values employed for these factors may differ widely between installations, no recommendations regarding their

magnitude are given in this report. Where such factors are used, relaxations of shielding requirements always need careful consideration and should conform with the requirements of the relevant statutory authority. Should any change occur in the appropriate value of the factors to be used, then shielding requirements will need to be reassessed. As a rule, subsequent alterations to shielding requirements are more difficult and expensive to incorporate.

(97) In calculating the degree of shielding required against the primary radiation beam, patients or removable objects (e.g., phantoms) which may partly absorb the beam, should not normally be taken into account (*ICRP Publication 33*, paragraph 61) (ICRP, 1982a).

(98) Stray radiation is radiation other than the useful beam, and includes leakage and secondary radiation. In calculating the shielding required against stray radiation, those conditions which give rise to the maximum amounts of leakage and secondary radiation should be assumed (*ICRP Publication 33*, paragraph 62) (ICRP, 1982a).

(99) Where the primary beam strikes material, secondary radiation will be produced. Attention should be given to the choice of absorbing material and the arrangement of the absorbers in order to minimize secondary radiation, which will include X rays when electrons or beta particles are absorbed (*ICRP Publication 33*, paragraph 63) (ICRP, 1982a).

(100) Where shielding is provided by the walls of a room in which work with radiation is undertaken, any windows or doors in these walls should also provide adequate shielding.

(101) Shielding that incorporates lead shall be so mounted that it cannot sag under its own weight. All shields shall also be protected against mechanical damage. If concrete is used to provide shielding, care must be taken to ensure that the shield is sufficiently homogeneous and of the specified composition and density.

(102) In designing and building a radiation installation, it is necessary to ensure that the shielding is not impaired at joints, where nails or bolts, etc. are used in construction, in the installation of pipework, conduits and louvres, and at the edges of doors and windows. At a joint between two different shielding materials, the overlap shall provide shielding at least equivalent to the required thickness of the material having the lower attenuation.

(103) Design should be such that workers should not need to use rooms where radiation work is undertaken as thoroughfares in order to gain access to other areas.

3.6. Classification of Areas and Working Conditions

(104) There is a wide variation in the scale and nature of the problems of radiation protection of workers. It may sometimes be useful to introduce a system of classification of working conditions. The Commission's recommendations propose two such classes (*ICRP Publication 26*, paragraph 161) (ICRP, 1977b).

(105) ***Working Condition A*** is one where the annual exposure might exceed three-tenths of a dose equivalent limit.

(106) The main aims of defining Working Condition A are: to ensure that workers who might otherwise reach or exceed the dose-equivalent limits are subject to individual monitoring.

(107) ***Working Condition B*** is one where it is most unlikely that the annual exposure would exceed three-tenths of a dose-equivalent limit. The value of three-tenths of the dose-equivalent limit is not intended to be used as a limit but as a reference level for use in organizing protection measures.

(108) Although in Working Condition B individual monitoring is not necessary, it may be carried out in order to confirm that standards of radiation safety in the working environment are satisfactory (*ICRP Publication 35*, paragraph 79) (ICRP, 1982c).

(109) Where the exposure is unconnected with the work, and where the work is in premises not containing the radiation sources giving rise to the exposure, the working condition should be such that

the limits applicable to members of the public are observed.

(110) Practical application of a system of classifying working conditions may be greatly simplified by introducing a corresponding system of classifying workplaces. The minimum requirement is to define "controlled" areas as being those where continued operation would give rise to working condition A and to which access is limited. The demarcation of controlled areas depends on the operations involved, but frequently it will be convenient to use existing structural boundaries. Outside controlled areas, annual dose equivalents to workers should be most unlikely to exceed three tenths of the limit.

(111) In some circumstances it may also be convenient to specify a further class of workplace, viz. ***"supervised"*** areas. These areas have boundaries where the annual dose equivalents to workers are most unlikely to exceed one tenth of the limit. However, experience has shown that in medical radiation practice where rudimentary optimized procedures have been introduced, workers should rarely receive doses in excess of one-tenth of a dose-equivalent limit. Under these circumstances there may be no practical advantage to be gained by the introduction of supervised areas in addition to controlled areas.

(112) The parallel between the classification of areas and that of working conditions is not straightforward because conditions are rarely uniform throughout the area, nor do area classifications take into account the time spent by workers in the area or the use made of any protective clothing. In particular, some workers in controlled areas can still be regarded as working in Working Condition B.

(113) Access to controlled areas must be adequately indicated e.g., by warning signs. In order to avoid any doubts regarding the extent of classified areas, these should coincide with the structural boundaries (i.e. walls) wherever practicable. Under some circumstances inside controlled areas it may be necessary to define regions where compliance with authorized limits can only be achieved by limiting the time spent in that region or by using special protective clothing.

(114) The local rules for a facility should specify the conditions under which a controlled area may be regarded temporarily as non-controlled. Examples are:

(a) in diagnostic radiology — when the mains switch for a fixed x-ray installation is in the "off" position, or when any residual charge in a mobile condenser discharge x-ray unit has been discharged;

(b) in areas where unsealed radionuclides have been used — when monitoring has shown that there is no significant contamination in the area and all radiation sources are secure;

(c) in beam therapy — when the apparatus has been isolated from the mains supply and sufficient time has elapsed, depending upon the type of machine and local circumstances, for any residual induced activity to have decayed away;

(d) in brachytherapy — when all radiation sources have been removed from the patient and returned to the sources store.

(115) In order to identify the need for individual monitoring, it is usual to classify individual workers. The underlying aim is to relate the classification to the class of working conditions under which they operate, but, in practice, workers are usually classified according to the type of work they do, the areas they occupy and the time spent in those areas, where this can be reliably predicted.

(116) The management should request a female worker to inform the head of the department, radiation safety officer or occupational health physician attached to the establishment, as soon as she knows she is pregnant. Consideration can then be given to the conditions under which she is to be employed during the remainder of the pregnancy, in order to ensure compliance with the Commission's recommendations.

(117) The conditions under which a pregnant worker continues to work will depend upon the nature of the radiation (X rays, gamma rays etc.), the range of x-ray tube voltage encountered and the

potential effectiveness of any protective clothing that may be worn.

(118) For instance, the use of a lead rubber apron will be highly effective in the range of x-ray tube voltage normally used in diagnostic radiology. Russell and Hufton (1988) quote a transmission of only 5.8% through an apron of 0.35 mm lead equivalence at 125 kVp. Taking into account the attenuation afforded by maternal tissues in early and mid-pregnancy, the wearing of such an apron would provide adequate protection.

(119) However, in work with radionuclides that emit radiations of higher energies than those in diagnostic radiology, the wearing of a protective apron is much less effective. For instance, the transmission of radiation from a caesium-137 source through an apron of 0.5 mm lead equivalence would be 94%.

(120) While it is acceptable, under strict working conditions, for a pregnant worker to continue to work with radionuclides in diagnostic work, it would not be acceptable in therapeutic activities.

3.7. Radiation Monitoring Programmes

3.7.1. *General recommendations*

(121) Before any equipment or installation is brought into use for the first time, a survey shall be carried out to establish that the planned safety requirements have been met, and that the shielding and operating conditions will ensure adequate protection of all persons, in accordance with the requirements of the statutory authority and the recommendations of the Commission. Subsequent surveys shall be performed whenever the equipment, installation or conditions of use are modified in any way that might affect the standards of protection.

(122) In addition, a programme of monitoring should be introduced and should be designed to check that conditions remain satisfactory whenever the facility is in operation. The frequency and extent of monitoring should be determined by the nature of the facility.

(123) The monitoring programme may involve measurements of radiation levels in the working environment, may take the form of individual monitoring, or both.

(124) The radiation protection adviser shall determine which radiations can be produced in a given installation and shall specify appropriate measuring instruments and monitoring procedures.

(125) All radiation measuring devices shall be regularly tested for consistency of performance. The test should consist of simple methods to check that the energy response and the dose-rate response of the measuring device are consistent with the original specification.

(126) Records of the results of environmental and individual monitoring shall be retained (see paragraphs 75 and 77). The purpose of record keeping, together with the content, scope and extent of the records, is influenced by legal requirements. These in turn are based upon the need to evaluate trends in exposure, to evaluate collective or average dose equivalents, to use the records for medical and legal purposes, and to use the data as epidemiological databases (*ICRP Publication 35*, paragraphs 26–29) (ICRP, 1982c).

(127) A principal function of the monitoring records is to allow the management of a facility, aided by appropriate advisers, to review the performance of its radiological protection programmes (see paragraph 78). Where the result of monitoring indicates an increase in the level of exposure above that normally to be expected for a particular operation, the circumstances should be investigated in order to identify the cause.

3.7.2. *Individual monitoring*

(128) The majority of persons working with radiation in the medical field can be categorized as working in condition B. Individual monitoring is not required for such workers, since the assessment of conditions in the working environment by area monitoring is usually sufficient. However, because

individual external monitoring is relatively simple to implement, provides a continuous check, and may be easier to adopt than a comprehensive programme of area monitoring, it may frequently be carried out in order to confirm that radiation safety standards and individual practices by the workers are satisfactory.

(129) A minority of persons working with radiation in the medical field may require to be categorized as working in condition A and will need to be subject to individual monitoring. Persons who are likely to be included in this category are interventional diagnostic radiologists, cardiologists, workers dispensing and administering unsealed radionuclides and workers associated with the treatment and care of patients who are being treated with unsealed radionuclides or sealed sources (brachytherapy) for therapeutic purposes.

(130) The external dose to the individual worker is assessed by means of a suitable dosemeter carried on the person. Dosemeters should be designed to provide adequate reliability, sensitivity and accuracy for measurement of the types of radiation likely to be encountered. If only one dosemeter is used, it should be placed in a position representing the most highly exposed part of the surface of the trunk (*ICRP Publication 35*, paragraph 84) (ICRP, 1982c).

(131) In special situations, where protective clothing provides significant attenuation of the incident radiation, the doses to unprotected parts of the body may make a considerable contribution to the effective dose-equivalent. In these circumstances, if a single dosemeter is used it should be worn outside the protective clothing, usually high on the trunk. This will normally overestimate the effective dose equivalent. A more accurate estimate of the effective dose equivalent may be made by wearing two dosemeters, one beneath and one outside the protective clothing (Faulkner and Harrison, 1988).

(132) In some circumstances, significant dose equivalents may be received by the extremities or by areas of the skin, and one or more additional dosemeters will need to be worn if the dose equivalent approaches three-tenths of the relevant limit. In particular, this situation may arise when the hands of workers are required to be close to radionuclide sources or primary radiation beams.

(133) Where the dose equivalent to the lens of the eye may approach three-tenths of the dose-equivalent limit, this can be assessed by wearing a dosemeter on the forehead. Dose equivalents assessed in this manner may indicate the need for additional safety measures to be taken, such as the provision of additional shielding (e.g. special eye shields or spectacles of lead glass), and/or for changes in working practices (Ardran and Crooks, 1978).

(134) If an individual dosemeter is mislaid or damaged, the worker shall report the fact immediately in order that another dosemeter may be issued. An investigation should be carried out and provided there are no unusual circumstances pertaining to the worker's recent exposure history then an estimated dose equivalent, based upon previous dose assessments for that worker, should be entered in the dose records.

3.7.3. *Environmental monitoring of the workplace*

(135) Monitoring may be conveniently divided into three distinct categories; routine, operational and special monitoring. Routine monitoring is associated with continuous operations; operational monitoring is performed to provide information about a particular procedure; special monitoring is applied to an actual or suspected abnormal situation (*ICRP Publication 35*, paragraphs 36 to 38) (ICRP, 1982c).

(136) Routine monitoring of the workplace should be carried out to confirm that the working environment is satisfactory for continued operations and that no significant changes have occurred which would require a reassessment of the adequacy of the layout of the facility and the operating procedures.

(137) Operational monitoring should be carried out when it is necessary to assess the hazard arising from a particular operational procedure and also to provide information necessary for immediate decisions to be taken regarding the conduct of the procedure.

(138) Special monitoring may be required when:

(a) there is insufficient information available about a particular situation to decide what safety measures are needed, or,

(b) a procedure is being carried out in abnormal circumstances.

(139) In operational or special monitoring it may be necessary to use direct reading dosemeters in order that an immediate decision can be made regarding the need to limit the time workers spend in a potentially high dose procedure.

3.8. Medical Surveillance

(140) The occupational physician supervising the health of a group of radiation workers needs to be familiar with the tasks and working conditions of the workers. He then has to decide on the fitness of each worker for the intended tasks. It is very rare that the radiation component of the working environment has any significant influence on that decision.

(141) A routine medical examination of a radiation worker, including any laboratory tests that might be required, is of no value other than to establish the general level of health of the worker.

(142) The Commission considers that, with the present system of dose limitation, no special administrative arrangement is appropriate for workers as far as radiation risks are concerned. In particular, no special arrangement is required with respect to working hours and length of vacation.

(143) When it is suspected that a worker may have received an abnormally high exposure, capable of producing nonstochastic damage, it becomes necessary to make a more accurate assessment of the absorbed dose. To achieve this, analysis of chromosomal aberrations in peripheral blood lymphocytes is at present the principal diagnostic procedure. This method is available only in specialized centres (a list is obtainable from IAEA, Vienna) that should be promptly contacted and provided with a blood sample of the individual involved. If the worker has any clinical sign of radiation damage, prompt referral of the worker to a specialized centre becomes essential.

4. PRACTICAL ASPECTS OF THE PROTECTION OF THE WORKER IN DIAGNOSTIC RADIOLOGY

4.1. Introduction

(144) Workers in diagnostic radiology are exposed exclusively to external irradiation; X-rays generated at peak potentials between 50 and 200 kV are relatively easily attenuated a thousand-fold by shields of thickness equivalent from a fraction of 1 mm to 2.5 mm of lead.

(145) The exposure of radiographers, if they work according to elementary rules of radiological protection, is very low. Fluoroscopy is a source of a significantly higher exposure, particularly to the practitioner, and in the case of interventional radiology to all those who are in close contact with the patient, and therefore near the tube. Direct fluoroscopy, without image intensification, still used in many parts of the world, is a greater source of exposure to radiologists than the modern procedure employing image intensifiers. Direct fluoroscopy should be replaced, therefore, by image intensification as soon as economically feasible.

4.2. Planning and Design

(146) In diagnostic radiology, the planning and design of each room in which x-ray equipment is housed has an important influence on the radiation exposure of the workers. In each x-ray room there is normally a shielded area where workers may stand when the x-ray machine is in use. This is often referred to as the protective cubicle, and the control console of the x-ray machine is generally located in this area.

(147) In rooms where examinations are to be performed which will involve an extensive series of exposures (e.g. use of rapid film changer, digital subtraction techniques, angiography) and where, because of the operational procedure or the patient's general condition, some workers are unable to retreat behind a protective screen, the size of the room should be sufficient to allow for additional mobile protective barriers, and to permit workers to occupy safe positions at an adequate distance from the x-ray tube and patient, during x-ray exposures.

(148) An indication of the required degree of shielding is provided in *ICRP Publication 33*, paragraph 256 (ICRP, 1982a). However, in determining this, consideration needs to be given to such factors as:

- the directions in which the primary beam will be aimed;
- the anticipated magnitude of secondary and leakage radiation;
- the expected workload and the types of radiological examinations;
- occupancy of the x-ray room;
- possible future use of the room and future changes in equipment.

(149) Table 5 (adapted from Table 7, *ICRP Publication 33*, ICRP, 1982a) shows how a cost evaluation for shielding may be carried out for an x-ray room. If the cost assigned to the unit collective dose equivalent for radiation protection purposes (α), is taken to be for example, 3,000$ per man Sv, then the optimal solution is the first situation.

(150) The incremental costs of dose averted arising from the use of protective lead screens (fixed or mobile) and protective aprons of different lead equivalence are given in Table 6.The data for protective aprons are provided both for doses received by an average radiologist and for the higher doses received by interventional radiologists (Russell and Hufton, 1988). Optimization would then indicate which additional steps were justified, taking into account any generally or nationally accepted figure for cost per man Sv averted.

(151) In rooms dedicated to radiographic work only, all workers should be able to position themselves in a shielded area. The cost per man sievert averted by such shielding is indicated in Table 6B.

(152) In rooms where fluoroscopy is undertaken, one or more workers will be outside the shielded area, and design should allow for additional shielding to protect them. They should also be wearing appropriate protective clothing. The data in Table 6A are relevant here; particular note should be taken of the increased protection required by interventional work, and the need therefore to assess the nature of the proposed work in a fluoroscopy room before specifying the protection requirements.

(153) A major factor in limiting the exposure of workers is satisfactory equipment design. This can reduce the magnitude of secondary and leakage radiations, for example, through the appropriate design of x-ray beam collimators and tube housings.

(154) The design of the protective screen for the worker will be influenced in the planning stage by the directions in which the primary x-ray beam is likely to be directed. This in turn will depend upon the types of examination that will be undertaken in the room and the proposed equipment layout, e.g. vertical chest stand, vertical and horizontal screening positions, use of a rapid film changer.

(155) The protective screen at the control console should contain lead glass window/s of the same lead equivalence as the screen, which, in addition to providing the worker with a clear view of the

Table 5. Cost evaluation of shielding for a radiographic room*

	Cost of shielding resulting in dose equivalent per week of		
	1.0 mSv	0.1 mSv	0.01 mSv
Cost of shielding **	$3600 (£2118)	$4500 (£2647)	$6300 (£3706)
Incremental cost increase		$900 (£529)	$1800 (£1059)
Reduction in collective dose (man Sv) ***		3.6	0.36
Cost per man Sv averted		$250 (£147)	$5000 (£2942)

* Primary x-ray beam at peak potentials: 80 kV (500 mA per week); 100 kV (125 mA per week); or 150 kV (25 mA per week).
** Based on Braestrup and Wyckoff (1973) corrected for inflation to 1988 and expressed in £ sterling, assuming $1.70 = £1.00.
***Assuming a useful life of 20 years for the installation and four full-time workers to be protected.

Table 6. Costs per unit collective dose equivalent averted using shielding of increased lead equivalence (primary x-ray beam : 100 kV at peak potential)

	Lead equivalence mm	Extra cost of 1 man Sv averted as compared with step above (£ sterling)	
A.	Use of protective apron by radiologists	Average radiologist	Interventional radiologist
	0	-	-
	0.1	360	16
	0.25	2,800	130
	0.35	18,000	820
	0.50	25,000	1,200
B.		Use of protective screen by radiographers	
	0	-	
	0.5	62,000	
	1.0	140,000	
	1.5	710,000	
	2.0	3,500,000	

patient, ensures clear views of any workers who may be required to work in the room outside the shielded area and also of the entrances to the room.

(156) In addition to assessing the likely directions in which the primary x-ray beam will be aimed, the equipment layout should be planned so that the primary beam does not have to be directed towards the protective cubicle, nor towards any entrance to the room, either through the main door or the door of a patient dressing cubicle. The natural boundaries of the room formed by the walls, floor and ceiling should be so constructed that they provide adequate shielding for all persons in all adjacent areas. The area within these boundaries is normally regarded as the controlled area. All doors and associated

doorframes leading into the room, together with any wall penetrations for ductwork and electrical conduits, should be equipped with an appropriate thickness of shielding material.

(157) In radiographic procedures not associated with fluoroscopy, the exposure switch should be so mounted that it is impossible to make a radiographic exposure from outside the protective cubicle.

(158) A radiation warning sign shall be prominently displayed at all entrances to the x-ray room. At the main entrance to the room, particularly a fluoroscopic room, a warning light should be installed at eye level. This should be linked to the preparation circuit of the x-ray generator in order to indicate that the x-ray machine is switched on and is generating, or is about to generate, X rays. This should enable workers to decide when the time is suitable to enter the room. The use of an interlocking system also provides extra protection against a person inadvertently entering the room when the machine is operating.

(159) If it is not possible to avoid directing the primary x-ray beam at an entrance to the x-ray room, then appropriate measures should be taken to prevent persons from entering the room by this entrance during such an exposure.

(160) An indication that X rays are being generated shall be provided at the control panel. Where there is more than one x-ray tube in the room capable of being selected from a single location, warning lights should be fitted on or close to the tube assemblies to indicate which tube has been selected.

(161) During fluoroscopy, and in special procedures such as angiography, one or more workers may need to stay close to the patient during radiation exposures. Under these circumstances, additional shielding should be provided by the side of the x-ray table, which may take the form of protective drapes suspended from the ceiling or from the support for the image intensifier/fluoroscopic screen. In designing a fluoroscopy room a choice is made between positioning the image intensifier above the x-ray table (with undercouch tube) or below the x-ray table (with overcouch tube). While working conditions may be easier with the latter system, the potential exposure of workers is two to three times greater compared with the former. If an overcouch tube/undercouch intensifier system is not operated by remote control, additional protective drapes shall be provided to ensure adequate protection of the operator.

(162) Provision for absorbing the primary beam after it has passed through or around the patient, and for absorbing scattered radiation, should be as close as possible to the patient. While the worker can be expected to avoid the primary beam, protection of the worker from scattered radiation should rely on the provision and use of adequate radiation shielding.

(163) In order to encourage the preferred practice of performing diagnostic x-ray examinations in the closely controlled environment of the x-ray department, entrances to x-ray rooms should be wide enough to allow beds to pass through.

(164) On acceptance of a new installation and prior to use, a radiation survey shall be undertaken in the room. This should include checks to confirm that the shielding that has been provided complies with the standard originally specified.

4.3. Classification of Areas

(165) Certain areas will normally be classified as controlled radiation areas. The requirements will vary depending upon whether fixed, mobile or portable x-ray equipment is in use.

(166) *In fixed installations* the entire x-ray room should be a controlled area, unless the equipment is switched off from the electrical mains supply.

(167) The use of controlled areas around mobile/portable x-ray equipment is less useful than in the case of fixed equipment. It is more appropriate to establish working procedures to control access to the vicinity of the equipment. In particular, the procedures should require an assessment to establish whether additional temporary shielding is needed to provide protection for staff in nearby areas. In

areas where there may be regular use of mobile equipment, the need for permanent shielding should be considered.

4.4. Operational Procedures

4.4.1. *General working practices*

(168) Persons should only be permitted to use radiation for medical applications after they have received appropriate training and have been authorized to practice by the appropriate national or local regulatory authority. Special attention should be paid to the training of non-radiologists (e.g. cardiologists), many of whom are involved in procedures in which workers are likely to receive higher than average effective dose equivalents.

(169) Access to all controlled areas shall be restricted to:

(a) those persons authorized by the head of the department to enter the area [see also paragraph (172) below];

(b) patients undergoing an x-ray examination;

(c) any accompanying person needed to give support to the patient and authorized by the worker responsible for performing the x-ray examination.

(170) All workers who enter a controlled area shall comply with the local rules for radiation safety applicable to the area.

(171) X-ray equipment shall only be used when the equipment is functioning correctly and when there is adequate protection for all persons in all surrounding areas. This is normally achieved by utilizing one or more of the following:

(a) appropriate shielding;

(b) appropriate protective clothing;

(c) adequate distances between parts of the body and the x-ray tube and patient;

(d) specifying the maximum workload that can be safely undertaken in the area;

(e) limitation of time spent in the vicinity of the x-ray tube and patient.

(172) Whenever practicable, all persons present in the x-ray room should remain in the protected area behind the protective screen when the x-ray machine is operated. The protected area behind the screen should be defined by appropriate floor markings.

(173) To reduce the possibility of accidental exposure, a rigidly enforced procedure should be in place whenever an x-ray machine is operated. Those workers involved shall be made aware of this procedure and shall clearly understand the extent of their own responsibilities. This procedure should include a check on the exposure control settings and should also include a check on the positions occupied by other workers present during the examination. Other workers and patients should also receive adequate instructions in relation to their respective roles.

(174) If workers cannot remain in the protected area when the x-ray machine is operated, they shall wear a protective apron of at least 0.25 mm lead equivalence. As far as is reasonably practicable they should occupy areas of the room where the levels of radiation exposure are low. Any person required to stand within 1 metre of the x-ray tube or patient when the machine is operated at tube voltages above 100 kV should wear a protective apron of at least 0.35 mm lead equivalence. Protective gloves should be of at least 0.35 mm lead equivalence. All such protective clothing should bear an identifying mark and should be examined at yearly intervals. Defective items should be withdrawn from use.

(175) Thyroid protection, if deemed necessary can be achieved either by wearing a collar of suitable lead equivalence, or by the use of a protective apron with a high neckline (Boothroyd and Russell, 1987).

(176) Workers should not expose any part of their body to the primary x-ray beam, even if they are

wearing protective aprons or gloves. The worker operating the x-ray machine shall ensure that no person other than the patient is directly irradiated (see paragraph 185).

(177) Although the practice is not desirable and should be eliminated wherever possible, particular attention shall be given to the procedures adopted in x-ray rooms where two or more x-ray tubes are operated from a common generator. Careless working practice may lead to a worker being unnecessarily exposed when attending to one patient, while another patient is undergoing an x-ray examination in the same room.

(178) Whenever possible, all x-ray examinations should be carried out in the x-ray department; mobile x-ray examinations in wards and in operating theatres should be reduced to a minimum, as the image quality obtained is normally less than optimum, and radiation protection is more difficult to implement.

(179) Mechanical devices to ensure immobilization should be used to support weak or anaesthetized patients.

(180) If small children need to be held during an x-ray examination, immobilizing devices should be used. If these are not available, the child should be held by a parent or other accompanying adult, rather than a member of staff of the x-ray department. In order to avoid causing alarm to the person performing this duty, a simple explanation should be given beforehand of the safety procedures to be observed.

(181) Persons who hold a patient shall wear a protective apron and ensure that no part of their body is exposed to the primary x-ray beam. Particular attention shall be given to correct collimation of the primary beam. If the hands are likely to be close to the primary beam, protective gloves should be worn. When neonates are held, the exposure will normally be so small that it will not be necessary to wear protective gloves. A pregnant woman should not hold a patient during an x-ray examination.

(182) If immobilization devices are considered to be inadequate and patients undergoing x-ray examinations need to be held, no single worker should perform this task. Instead, this duty should be shared between several workers.

(183) A person required to work in a controlled area, but not on a regular basis, (e.g. a surgeon or theatre nurse, or a person holding a patient during an x-ray examination) should do so in accordance with the following conditions:

(a) the work in the area should be authorized by the head of the radiology department, either as laid down in the local departmental rules for radiation safety, or for a special purpose on a specific occasion;

(b) all work practices in the area should comply with the conditions laid down in the local departmental rules for radiation safety and, if appropriate, protective clothing should be worn;

(c) an individual dosemeter need not be worn, provided a survey of the work practice has shown that the radiation exposure will not exceed 2.5 μSv in any one hour or 100 μSv in any week. If these levels are exceeded, the advice of the radiation protection adviser should be sought.

(184) Depending upon the nature of the work undertaken in an x-ray room or upon the results of monitoring, additional protective screens may need to be provided. To ensure adequate protection, workers shall always make full use of the protective screens provided. Additional screens are likely to be required in the lengthy fluoroscopic procedures of interventional radiology, cardiology and angiography. Screens may be suspended from the image intensifier or from the ceiling. In addition to using such screens, workers should also continue to stand as far away from the x-ray tube and patient as is reasonably practicable.

(185) Whenever possible, fluoroscopy with an overcouch tube/undercouch intensifier system should be undertaken by remote control. Such a system gives rise to approximately a threefold increase in scattered radiation to workers in the room by comparison with an undercouch tube/overcouch intensifier system. The advice of the radiation protection adviser shall be sought if workers

are required to remain close to the patient during the examination. Under these conditions, additional protective screens may be required, and a contour map of the dose rates around the examination table will enable workers to choose positions of least exposure. The increased exposure of workers arising from the use of such systems raises doubts (from the point of view of radiation protection) of their suitability for interventional procedures where high exposures are likely to be encountered.

(186) When an undercouch intensifier system is used, palpation of the patient during fluoroscopy shall always be performed by means of a mechanical device, never manually. With an overcouch intensifier system, palpation should be reduced to a minimum and only undertaken manually at the exit surface of the patient; a protective glove of at least 0.5mm lead equivalence shall be worn.

4.4.2. *Mobile radiography outside the x-ray department*

(187) All relevant recommendations described in paragraphs 168 to 186 under the headings 'General working practices' and in paragraphs 196 to 201, 'Avoidance of unnecessary radiation', shall be observed when radiography is undertaken outside the x-ray department.

(188) The head of the x-ray department should be responsible for ensuring that x-ray equipment used in the facility outside the main x-ray department is operated in accordance with written radiation safety procedures. The radiation safety officer should regularly check that such equipment is used in accordance with the safety procedures and should draw the attention of the head of the x-ray department to any instances when these are not observed. Only those workers who have undergone an appropriate course of practical training and instruction should be permitted to use such x-ray equipment. It is essential that they clearly understand their duties and responsibilities when operating x-ray equipment.

(189) Whenever mobile or portable x-ray equipment is used, the worker operating the x-ray machine shall ensure that no unnecessary persons are present in the controlled area (see paragraph (167)).

(190) The worker operating the x-ray machine shall wear a protective apron and, whenever practicable, should occupy a position at least 2 metres from the x-ray tube and the irradiated area of the patient under examination.

(191) The operator shall ensure that no person other than the patient is in direct line with the primary x-ray beam unless the beam has been adequately attenuated (see paragraph 167). This requires the operator to be aware of the adequacy of attenuation afforded by any barrier to the primary beam (e.g. walls, floors) that is likely to be encountered. Where the attenuation is not known, the advice and assistance of the radiation protection adviser should be sought.

(192) The provisions of paragraphs 179 to 183 regarding the support of patients apply equally to mobile radiography.

4.4.3. *Use of mobile fluoroscopic screening equipment*

(193) A radiologist or radiographer should be present when mobile fluoroscopic x-ray equipment is used. Otherwise, only persons who have been trained in the operation of mobile fluoroscopic equipment (paragraph 188) shall be permitted to use the x-ray machine.

(194) Radiography performed in conjunction with mobile fluoroscopy invariably produces images of poorer diagnostic quality than that obtained with fixed equipment. It should therefore be avoided whenever possible and, if unavoidable, it should only be undertaken by a suitably trained person.

(195) Any person who remains within 2 metres of either the x-ray tube or the patient when the x-ray machine is operated, should wear a dosemeter and should wear a protective apron. All other persons should stand as far away from the x-ray tube as practicable. If local experience shows that the doses received are insignificant, neither a dosemeter nor a protective apron need be worn.

4.4.4. *Avoidance of unnecessary exposure*

(196) If the irradiation of the patient is reduced to that considered necessary to provide the diagnostic information required, the dose to the worker will likewise be reduced. This is particularly true in fluoroscopy, and in radiography associated with fluoroscopy, where the worker must remain close to the patient, and cannot retreat to the protective cubicle.

(197) Dose reduction in fluoroscopy can be achieved by the operator in the following ways:

(a) use of short periods of fluoroscopic exposure;
(b) temporary removal of the anti-scatter grid;
(c) in cine-fluoroscopy, by using frame speeds not exceeding 30 frames per second, and by cine-runs of 3-5 seconds only.

(198) Dose reduction to the worker can be aided by careful selection of fluoroscopic apparatus. Such factors include:

(a) use of pulsed systems;
(b) use of image storage systems, particularly in fracture work;
(c) use of carbon fibre products (Hay *et al.*, 1981; Hufton and Russell, 1986);
(d) provision of a timing device with audible warning; display of the fluoroscopic time on the image monitor;
(e) use of properly adjusted automatic brightness control (Henshaw and Kennedy, 1975).

(199) The efficiency of measures to reduce worker dose from fluoroscopy can be judged by the recording and review of operator fluoroscopic times and the number of radiographs taken during fluoroscopic examination.

(200) Some dose reduction to the worker can be achieved in pure radiography by the following methods:-

(a) use of fastest screen/film combination that will give the diagnostic information; use of digital radiography (Tateno *et al.*, 1987);
(b) setting the developer temperature at the recommended level; this is commonly set too low (Russell and Carmichael, 1987) with the result that extra radiation is given to achieve the necessary photographic blackening;
(c) regular review of rejected films aimed at detection and elimination of prevailing causes of rejection (Carmichael, 1984);
(d) use of carbon fibre products (grid facing and interleaving; table top; cassette fronts).

(201) Further information may be obtained from *ICRP Publication 34* (ICRP, 1982b) and its simplified version (ICRP, 1989b) where measures to avoid unnecessary irradiation of patients are discussed.

4.5. Quality Assurance

(202) A quality assurance (QA) programme should be implemented that applies to all the major components within the total imaging system, irrespective of the type of imaging systems used. Such a programme will contribute to the safety of the worker by enabling radiation to be used more reliably and by improving the standard and consistency of performance (image quality) of the x-ray equipment (Garrett *et al.*, 1988; Moores *et al.*, 1988). Quality assurance should be extended to safety-related measuring equipment.

(203) Fluoroscopic procedures account for the greatest contribution to the total dose received by workers in diagnostic radiology. Particular attention should therefore be paid to the efficiency of the performance of x-ray image intensifier television systems, in order to avoid the use of high exposure rates to compensate for poor image quality. This situation may arise if any component of the imaging

chain is either deficient (e.g. the x-ray to light conversion efficiency of the intensifier is low) or incorrectly adjusted (e.g. by a stopped-down lens between intensifier and video camera, or by high dose-rate setting of automatic brightness control).

(204) When x-ray machines not equipped with image intensifiers are used for fluoroscopy, special attention should be devoted to proper beam alignment relative to protective shielding of the fluorescent screen. In no situation shall cross dimensions of the beam be allowed to exceed those of the fluorescent screen.

5. PRACTICAL ASPECTS OF THE PROTECTION OF THE WORKER IN DENTAL RADIOGRAPHY

5.1. Planning and Design

(205) Exposure of workers to X-rays in dental radiology (exclusively radiography) is generally very low if properly maintained equipment is used.

(206) The room in which it is proposed to undertake dental radiography shall be large enough to provide safe accommodation for any worker required to be present during the x-ray examination. Factors which need to be taken into account include the provision of adequate space for a protective screen (fixed or mobile) and for the operator to be able to stand at least 2 metres from the x-ray tube.

(207) All directions in which the primary beam will be aimed should be identified beforehand. Adequate shielding shall be provided by walls, floors etc. to ensure the safety of persons in adjacent areas — including those above and below the x-ray room.

(208) The x-ray machine and examination chair should be so sited in the room that it will not normally be necessary to direct the primary x-ray beam towards a door. If the room is on the ground floor, the primary beam should not be directed towards a window.

5.2. Organization and Responsibilities

(209) All workers have a responsibility for radiation safety, and there should be a clearly defined chain of responsibility laid down from senior dental practitioner to individual worker (see paragraphs 72 and 73).

(210) All radiation work should be carried out in accordance with written procedures.

(211) Only those persons who have received adequate training shall direct a dental exposure. The degree of training should be in accordance with national or local standards.

(212) X-ray examinations should not be performed unless there is a clear clinical requirement.

5.3. Classification of Areas

(213) If a separate examination room is provided for x-ray examination, this room should be classified as a controlled area unless the x-ray equipment has been switched off. The room, including the floor and windows should be appropriately shielded or protected by restriction of the direction of the x-ray beam.

(214) If the x-ray equipment is used in the dental surgery, the designation of a controlled area is not likely to be helpful. An assessment of the workload and of the operating procedures should be made of the degree of protection of occupants of adjacent rooms. Extra shielding (beyond that provided by the structure of the building) should be considered if the direct x-ray beam may be directed towards

occupied areas, or if the workload is likely to exceed:

— 150 mA min per week for panoramic tomography (i.e. approximately 60 panoramic films), or
— 30 mA min per week for other procedures (i.e. approximately 150 bite-wing films).

5.4. Operational Procedures

5.4.1. *General procedures*

(215) Under normal operating conditions, personal dosemeters need not be regularly worn unless a considerable workload is undertaken by each worker (e.g. 150 intra-oral films per week). Individual monitoring in dental radiography on an intermittent basis may be useful to indicate that workers are not receiving abnormally high doses and to reassure individual workers.

(216) All persons whose presence is not essential shall be excluded from controlled areas when the x-ray equipment is in use.

(217) Access to areas where dental x-ray examinations are undertaken shall be restricted to patients undergoing an x-ray examination and to those persons authorized by the head of the dental x-ray clinic to enter the controlled area. A notice to the effect that access is restricted to authorized persons only, and incorporating the radiation warning sign, shall be prominently displayed at the entrance to all rooms where x-ray examinations are performed.

(218) Exposures should not normally be made if anyone other than the patient and those authorized by the head of the dental x-ray clinic are in the controlled area. If, on rare occasions, a small child or infirm patient needs to be supported during a dental x-ray examination, the person providing support shall wear a protective apron of at least 0.25 mm lead equivalence and shall ensure that no part of their body is in direct line with the primary x-ray beam, either in front of or behind the patient. To avoid causing alarm to the person performing this duty, a simple explanation should be given beforehand of the safety precautions to be observed. Whenever possible, this duty should be undertaken by the person accompanying the child. No one person shall hold patients regularly. A pregnant woman should not hold a patient undergoing a dental x-ray examination.

(219) If a protected area is provided, workers shall occupy this area when the x-ray machine is operated. If a fixed protective screen is not provided, a mobile protective screen of adequate lead equivalence should be provided.

(220) Workers shall make full and proper use of personal protective equipment. If neither fixed nor mobile protective screens are available, a lead-impregnated apron of at least 0.25 mm lead equivalence shall be worn.

(221) Lead-impregnated protective aprons shall bear an identifying mark. Care shall be taken to store aprons correctly in order to avoid damage. All such protective clothing should be examined at yearly intervals and defective items that are no longer fit for use shall be withdrawn.

(222) Persons operating the x-ray machine should always ensure that they have a clear view of the patient and of the entrances to the room. They should always check that no unauthorized person is in the room when the x-ray machine is operated.

(223) Under normal circumstances, the simultaneous examination of patients with two or more dental x-ray machines in the same room should not be permitted, in order to prevent the unnecessary irradiation of workers. If this is unavoidable, the advice of the radiation protection adviser shall be sought regarding safe working practices and the need for additional protective screens.

(224) The primary x-ray beam should not be directed towards any entrance to the x-ray room. If this cannot be avoided, measures shall be taken to ensure that the x-ray machine is operated only when the door is closed, and that the door provides adequate shielding.

(225) Operators of dental x-ray machines shall ensure that patients, staff and escorts are properly instructed in their respective roles prior to x-ray examinations being undertaken.

(226) Whenever dental x-ray equipment is not in use it should be switched off at the mains so that unintentional exposure cannot occur.

(227) The person operating the x-ray equipment shall always check that the exposure warning light on the equipment comes on at the start of the exposure and goes off again at the end of the intended exposure time. Should the warning light fail or should there be some other reason to believe that the machine is not performing correctly (e.g. unreliable timer, damage), the machine shall be switched off or disconnected from the electrical mains supply and its use discontinued until it has been repaired.

(228) If a dental film cannot be kept in position it should be held by the patient. It shall never be hand-held by anyone else. Exceptionally it may be held by someone other than a patient, but a remote handling device (e.g. forceps) shall always be used to avoid direct irradiation of the fingers. Under these circumstances, the person holding the film in position shall always wear a lead-impregnated protective apron of at least 0.25 mm lead equivalence.

(229) A strict procedure should be adopted when operating x-ray machines. All members of staff shall be aware of this procedure and clearly understand the extent of their responsibilities. Such a procedure should include a check of the exposure factors (e.g. kV, mA settings etc.) and other relevant conditions (e.g. positions of persons present in the area) before making an exposure.

5.4.2. *Avoidance of unnecessary exposure*

(230) If the irradiation of the patient is reduced to a minimum, and is no greater than that considered necessary to provide the diagnostic information required to fulfil the clinical objective of the examination, then the dose to the worker will likewise be reduced. Information on methods to avoid unnecessary irradiation of patients can be obtained from *ICRP Publication 34* (ICRP, 1982b) and from the simplified version of *ICRP Publication 34* (ICRP, 1989b).

5.5. Quality Assurance

(231) A quality assurance (QA) programme should be implemented that applies to all the major components within the total imaging system, irrespective of the type of imaging systems used. Such a programme will contribute to the safety of the worker by enabling radiation to be used more reliably and by improving the standard and consistency of performance (image quality) of the x-ray equipment.

6. PRACTICAL ASPECTS OF THE PROTECTION OF THE WORKER IN THE USE OF UNSEALED RADIONUCLIDES

6.1. General Recommendations Common to all Uses of Unsealed Radionuclides

6.1.1. *Introduction and categorization of hazard*

(232) The use of unsealed sources of radionuclides in medicine covers a wide variety of techniques and procedures. In nuclear medicine, which includes procedures involving the introduction into the human body of radionuclides in the form of radiopharmaceuticals, diagnostic techniques should be considered separately from those used in therapy.The former employs, as a rule, radionuclides with short half-lives, the most common being technetium compounds, which are pure gamma emitters.

This allows one to use activities of up to 1000 MBq resulting in moderate values of the effective dose equivalent to the patient. As the radiopharmaceuticals are used predominantly in the form of non-volatile solutions or colloidal suspensions, the hazard of internal contamination to workers — if elementary rules and good practices are followed — is minimal, but that from external irradiation may be substantial. This applies, to a high degree, both to the preparation and administration of radiopharmaceuticals.

(233) Basically, a similar situation applies in the therapeutic use of radionuclides. However, procedures which involve very high activities for thyroid ablation and treatment of metastatic cancer of the gland, constitute — in addition to external irradiation — a substantial hazard to workers from internal contamination with ^{131}I, due to the volatility of the iodine leading to intake of the nuclide, either during iodination of radiopharmaceuticals (see paragraphs 296 – 298), or from the air exhaled by patients (Krzelsniak *et al.*, 1987; Pochin, 1972; Pochin and Kermode, 1975).

(234) Procedures involving iodination of radiopharmaceuticals can constitute a substantial potential internal contamination hazard. The use of very short-lived positron-emitting radionuclides for positron emission tomography (PET) is no different in this respect from conventional diagnostic nuclear medicine. However, it includes hazards specific to working procedures with cyclotrons, which are described in Section 8.5.

(235) Radiation protection in the use of unsealed radionuclides requires the control both of external exposure and of contamination. The control of external radiation should be based on the methods outlined in Section 3. The control of contamination is dealt with in general terms in the first part of this section and this is applicable to all users of radioisotopes. This is followed by sections dealing specifically with diagnosis, therapy, and laboratory work. All these sections include some recommendations relating also to external radiation. These should be applied with due allowance for the type and activity of the radionuclides used. In particular, some of the recommendations will be relevant only if the radionuclides emit gamma radiation.

(236) The bases of contamination control are the containment of the radioactive materials at or near the point of use and the maintenance of clean conditions to avoid the build up of contamination in the workplace. Contamination control should be achieved by the careful choice of equipment and operating procedures so as to provide a system of defence in depth extending from the unsealed sources out to the limits of the facility.

(237) A significant contribution to the safety of the worker can be made by appropriate planning of the clinical nuclear medicine department and any other areas in the medical institution where work with radionuclides is proposed. The degree of radiation safety needing to be incorporated into the design of the department will depend upon the amount of activity used, the radionuclide in use and the type of operation. To determine this the concept of weighted activity can be useful.

(238) To determine the weighted activity, first assess the largest activity likely to be encountered at any time in the area to be planned. This figure is multiplied by a modifying factor according to the radionuclide being used (Table 7). Thus ^{3}H would have a lower weighted activity, and ^{125}I a higher one.

Table 7. Weighting factors according to radionuclide

Class	Radionuclide	Weighting factor
A	^{75}Se, ^{89}Sr, ^{125}I, ^{131}I,	100
B	^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{51}Cr, ^{67}Ga, ^{99m}Tc, ^{111}In, ^{113m}In, ^{123}I, ^{201}Tl	1.0
C	^{3}H, ^{14}C, ^{81m}Kr, ^{127}Xe, ^{133}Xe	0.01

(239) The figure obtained is now multiplied by a second modifying factor (Table 8) determined by the type of operation. This, for instance, takes account of the higher hazard of complex radiopharmaceutical preparation, and of the lower hazards of storage and patient bed area after diagnostic injection.

Table 8. Weighting factor according to type of operation

Type of operation or area	Weighting factor
Storage	0.01
Waste handling Scintigraphic counting/imaging when administration is made elsewhere Patient waiting area Patient bed area (diagnostic)	0.1
Local dispensing Radionuclide administration Scintigraphic counting/imaging when administration is made in same room Radiopharmaceutical preparation, simple Patient bed area (therapeutic)	1.0
Radiopharmaceutical preparation, complex	10

(240) The final figure obtained after the two steps above gives the weighted activity. From Table 9 the category of hazard can then be determined.

Table 9. Categorization of hazard

Weighted activity	Category
Less than 50 MBq	Low hazard
50 to 50,000 MBq	Medium hazard
Greater than 50,000 MBq	High hazard

(241) Once the category of hazard has been determined, the broad requirements of planning can then be determined from Table 10.

Table 10. Facilities required for radiation protection in relation to category of hazard

Category of hazard	Floor	Surfaces	Fume cupboard*	Room ventilation	Plumbing	First aid
Low	Cleanable	Cleanable	No	Normal facilities	Standard	Washing
Medium	Non-permeable easily cleanable	Cleanable	Yes	Good	Standard	Washing & decontamination facilities
High	Continuous sheet welded to walls	Cleanable	Yes	Extractor fan	May require special plumbing	Washing & decontamination facilities

*Laboratories only

6.1.2. *General principles*

(242) The work area in rooms where radionuclides are handled should be large enough to provide ample space not only for the workers and patients but also for essential equipment used in the procedure.

(243) All materials should be chosen with reference to their resistance to corrosion by chemicals, heat and fire. Consideration should also be given to the need for work surfaces and floors that will not absorb liquids containing radioactive substances. Where special floor coverings are required (see Table 10), consideration should be given to non-slip properties and ease of decontamination.

(244) Work surfaces, including surfaces inside fumehoods, should be designed to carry the weight of any necessary shielding. When radionuclides need to be stored under refrigeration, it may be necessary to do this within a shielded and ventilated store room if it is not possible to provide shielding within the refrigerator. Work surfaces should be of sufficient strength to support the heavy weight of shielded source containers.

(245) Work areas should be brightly lit and shadow free.

(246) Hand-washing facilities should be provided and sited conveniently in each working area or near to the exit from each room where radionuclides are to be handled. In laboratories of medium and high hazard categories, it should be possible to operate the taps without using the hands, and disposable towels or hot air driers should be provided. An appropriate monitor should be provided at the site in laboratories of low hazard category and shall be provided in laboratories of medium and high hazard categories. A shower should be available for use in an emergency.

(247) In laboratories of medium and high hazard categories, sinks for washing contaminated articles (e.g. glassware) should be so constructed that the taps can be operated without using the hands.

(248) The drains from any sinks used for hand-washing, washing contaminated articles and for the authorized disposal of liquid radioactive waste should be connected as directly as possible to a main sewer. The traps should be accessible for periodic monitoring. A separate drainage system with delay tanks may sometimes be necessary for radioactive waste; such a system should have sealed joints. The marking and labelling of such pipes and drains should be checked at regular intervals to ensure that maintenance staff are able to identify any pipes that may be contaminated.

(249) In rooms ranked in the category of "high" hazard, any drains to the main sewer used for the disposal of high activities of radioactive liquids should be short and be capable of taking a high water flow.

(250) In any area where radionuclides of very long half life may be disposed of, the drains should be marked so that monitoring can precede maintenance work.

(251) A fumehood, operating under negative pressure, is necessary for certain procedures in the production of radiopharmaceuticals. If sterile procedures are employed, a fully exhausted vertical laminar flow system under positive pressure is recommended. This should discharge to the outside of the building, at least 10 metres away from any air supply vents. If practicable, it is desirable to fit a charcoal filter to remove radioiodine (Bolton, 1985). The concentrations of radioactivity in the exhaust gases should not be allowed to exceed the limits imposed by the appropriate regulatory authority.

6.1.3. *Design aspects of specific areas*

Radionuclide laboratories (medium and high hazard classification)

(252) The laboratories in which radionuclide sources are stored and prepared for use are controlled areas. They should have locks fitted to the entrances, in order to prevent access by unauthorized persons when the rooms are not in use. Occupancy of these rooms by authorized personnel should be

limited to the time required for source preparation and manipulation. Other than the making of appropriate entries in record log books, all administrative work should be performed outside these rooms.

(253) Workbenches should have impervious surfaces that can be easily cleaned, and which are free from cracks in which small amounts of radioactive material may lodge. Benches should be equipped with shields to protect workers standing close by. Bench tops should also provide a similar degree of shielding, particularly against radiation that exposes the worker obliquely or exposes areas of the body below the bench at which the worker is seated. The shielding material and thickness required depends upon the type and activity of the radionuclides used. A typical shielding specification should attenuate the radiation by a factor of at least 1000 (i.e. ten half-value layers).

(254) In addition to the shielding required to protect the worker directly in front of the workbench area, adequate shielding shall also be provided around the handling area and the room enclosure; this is in order to provide appropriate protection for workers in other parts of the room and in surrounding areas, where their work necessitates their continued presence.

(255) During work with radionuclide sources, direct viewing is preferable to the use of mirrors. A typical viewing panel is made of lead glass. Because lead glass of the required thickness may reduce light transmission, the area viewed through such a panel should be brightly illuminated. A means of viewing the sources by magnification should also be provided to facilitate inspection and to enable identification markings to be clearly seen with minimum of exposure of the worker. The provision of a device for measuring source strength (e.g. a well ionization chamber) is highly recommended.

(256) There shall be adequate provision for the storage of all sources when they are not in use. The storage container or safe should have adequate built-in shielding to permit staff to work safely in the immediate vicinity. The degree of shielding required will depend upon the type and activities of the radionuclides used. Storage containers or safes should be partitioned in order that the worker is only exposed to a small amount of the total source activity when access is required to a specific radionuclide. Safes shall be equipped with locks to prevent unauthorized access.

(257) In order to manipulate high activity, gamma emitting sources, design of the shielding should be such as to permit the use of long handled tools or remote handling devices.

Radiopharmacy

(258) The planning of this area with respect to radiation protection of the worker is most complex. It is in this area that the greatest amount and variety of radionuclides are present. Each administered aliquot is handled in this area. Adequate storage space, appropriately shielded, is necessary for the radionuclides and radionuclide generators in use. Working surfaces should be non-porous and easily cleanable. An aseptic preparation area should be available with laminar airflow, and positive or negative airflow should be controllable. A fumehood may be required. Proper ventilation is essential. All floor, wall, ceiling and worktop areas should have non-absorbent surfaces which can be cleaned easily in the event of contamination.

Radioactive waste storage area

(259) The space allocated for this area should be adequate for both short-term and long-term storage. It should be readily accessible from both the nuclear medicine department and the waste dispatch area. Good ventilation and appropriate plumbing are essential (see paragraphs 247–250). The area should be secured under lock and key, and access restricted to authorized workers. Washing facilities, work benches and freezer storage may be required for radioactive biological waste. The floor surface should be non-porous and a central drainage basin would be ideal for easy cleaning.

(260) The design of air exhaust outlets should allow for the installation of a simple monitoring

system. The air outlet should be sited so that it is impossible for the radioactive exhaust to re-enter occupied areas or another air intake (see paragraph 251).

Toilet facilities

(261) In order to reduce the possibility of worker contamination, the toilet facilities provided for workers should be separate from those provided for patients to whom radionuclides have been administered.

6.1.4. *Classification of areas and monitoring procedures*

(262) The classification of areas to assist in the control of external radiation in a nuclear medicine department, including a radiopharmacy, follows the principles stated in Section 3.6 of this report, and in paragraphs 162 to 165 of *ICRP Publication 26* (ICRP, 1977b), which describes controlled and supervised radiation areas. In addition it is often useful to define controlled contamination areas. These are areas in which the likelihood and extent of contamination is such that both entry to and egress from the area should be restricted as part of the contamination control procedures. The establishment of a controlled area will thus be aimed at limiting the spread of contamination beyond the working area. It will not be defined solely in terms of the potential dose to workers. Exceptionally, it may be useful to establish a supervised area to provide an additional line of defence between the controlled and non-controlled areas, particularly in laboratory medicine.

(263) Area monitoring is related to the nature of the radionuclides and the type of work undertaken. In the presence of a relatively high radiation background, the direct detection of significant levels of surface contamination may not be possible, and wipe tests to assess the degree of loose contamination may be necessary. In areas where surface contamination may arise or its presence is suspected, the entire area and contents should be regarded as being contaminated until monitoring indicates otherwise. If, after decontamination procedures have been carried out, a significant level of fixed contamination remains, then consideration should be given to the magnitude of the external radiation hazard. Distance or local shielding may minimize the hazard if the contamination cannot be physically removed. Routine monitoring for airborne radioactivity is not normally necessary in nuclear medicine departments unless extensive use is made of volatile materials or radioactive gases.

(264) Area monitoring of external radiation levels should be carried out to assess the adequacy of protective shielding and to check the efficacy and observance of safe working practices. In deciding upon the content and extent of the whole monitoring programme, the advice of the radiation protection adviser should be sought. The programme should be regularly reviewed and random periodic checks should be carried out to ensure that the programme is correctly implemented.

(265) Individual monitoring for external radiation is required where the effective dose equivalents received by workers may exceed three-tenths of the dose-equivalent limits (see paragraphs 128 to 134). However, even when the doses are likely to be well below these limits, the routine monitoring of those regularly working in controlled areas serves as an additional check on the safety of the environment and on the observance of safe working practices.

(266) Monitoring for internal contamination may be necessary for those workers who regularly work with large activities of volatile radioactive materials. Whole or partial body monitoring and/or urine analysis may be necessary to assess the dose equivalent received by internal contamination. To estimate dose equivalents to skin from external contamination, it will be necessary to measure both the degree and persistence of contamination and the area of skin affected.

(267) In estimating dose equivalents to skin received as a result of contamination, the results of monitoring should be averaged over an area of 100 cm^2. This will inevitably lead to a considerable

degree of uncertainty in the dose estimate, which may amount to two orders of magnitude (*ICRP Publication 35*, paragraph 112) (ICRP, 1982c). Such estimates should therefore be regarded as qualitative and considered separately from the results of conventional individual monitoring for external radiation. Nevertheless, if the estimated dose equivalent exceeds one-tenth of the dose equivalent limit, this should be entered in the worker's dose records. Appropriate decontamination procedures are described in Section 6.1.7 and in Appendix A.

6.1.5. *Storage and movement of radioactive materials*

(268) Information regarding radioactive materials delivered to the nuclear medicine department shall be recorded without delay in the source records (e.g. type and quantity of radionuclide, results of wipe tests).

(269) Radioactive storage areas should be kept in an orderly fashion and inspected regularly by the radiation safety officer. Only authorized persons shall be permitted to enter the radionuclide storage area.

(270) The radiation safety officer should be responsible for ensuring that appropriate records are kept of the quantities of radionuclides received and stored. Their use and disposal shall be documented. Containers in which radionuclides are stored should be clearly labelled with radiation hazard warning signs and a statement of the type of radionuclide, the activity and the date.

(271) During the storage and transport of radioactive materials, containers should be used that ensure that, in the event of any displacement of the contents, no external contamination of the container will occur. The containers shall also incorporate shielding adequate to protect those involved in the transport, and they should be designed to protect the contents from accidental damage (IAEA, 1985, 1986). The external surface of any container transporting radioactive materials through non-controlled areas in the facility should always be free of contamination as far as reasonably practicable; the level of contamination shall not however exceed the limit appropriate to a non-classified area (see Table 11).

6.1.6. *Operational procedures*

(272) Access to all controlled areas shall be limited to authorized persons.

(273) Workers shall not eat, drink, smoke or apply cosmetics in controlled or supervised areas.

(274) Working procedures shall be designed to contain the radioactive substances and to limit both the causes and spread of contamination. In particular, manipulation of unsealed sources should be carried out over trays lined with disposable absorbent material.

(275) Containers shall be provided in controlled and supervised areas which are reserved for the disposal of radioactive waste. These containers should bear radiation warning labels and, if appropriate, clearly indicate whether the container is for radioactive waste of short or long half-life. Consideration may need to be given to the shielding of these containers, and to their frequent emptying.

(276) Before a worker enters a controlled area, any break in the skin should be appropriately protected by a waterproof covering. Wounds or breaks in the skin that occur while a worker is in a controlled area should be attended to immediately. They should be cleansed and, if appropriate, monitored to check that they are not contaminated (see paragraphs 299 to 302). If contamination has occurred, the radiation safety officer for the area should be promptly notified.

(277) When radioactive materials are received, the outside of the container should be monitored to check that the integrity of the containment has been maintained during transport. Impervious gloves

should be worn during unpacking to guard against the possibility of contamination inside the container. A wipe test should be performed on the external surface of the contents to ensure that there is no contamination.

(278) Controlled areas should be kept free of any procedures and articles that are not relevant to the work undertaken in these areas.

(279) In general, radiopharmaceuticals should be administered to patients in the radiopharmaceutical administration area or in the investigation area. Particular care is required if such administrations have to be performed in non-controlled areas.

(280) The injection syringe containing the radiopharmaceutical should be appropriately shielded to avoid unnecessary irradiation of workers. In circumstances where administration is difficult, the syringe may be removed briefly from any shielding to expedite the administration of the radiopharmaceutical or the measurement of the activity. A label that clearly describes the contents shall be attached to the syringe or shield.

(281) A tray lined with disposable absorbent material should be placed under the injection site during administration in order to contain possible contamination. Where it is not practicable to use a tray, extra disposable absorbent material should be used instead.

(282) When radiopharmaceuticals are to be administered other than by injection (e.g. orally), the radionuclide should be shielded for as long as possible prior to the actual administration.

(283) In order to guard against contamination, workers handling radionuclides, and anyone assisting, should wear impervious gloves and a protective laboratory coat or plastic apron. After work with radionuclides, gloves should be carefully removed to avoid contamination, and placed in the radioactive waste container. The hands shall be washed and monitored before any other work is undertaken (see paragraph 246). If found to be contaminated above the limits for an uncontrolled area, protective coats and aprons shall be removed before leaving the area.

(284) After use, syringes and needles should be transferred to a special container for sharp objects. This container may require to be shielded prior to disposal of the contents.

(285) Hands should be washed and monitored before leaving a controlled area. If it is suspected that workers or their clothing are contaminated, they shall be monitored before leaving a controlled area. If contamination is measured above the levels specified in Table 11, appropriate action shall be taken. If skin contamination persists above the specified level, a record of the incident shall be noted. The radiation protection adviser should estimate the skin dose arising from the incident and, if above the dose limit for the skin, this should be recorded in the worker's individual dose records.

(286) Disposable absorbent material should be readily available in all controlled and supervised areas to enable any spillage of radioactive materials to be immediately contained. Gloves, overshoes and protective gowns should be readily at hand. Should any individual or area become contaminated, appropriate action should be taken, as specified in Section 6.1.7 and Appendix A.

(287) Before removal from a controlled area, all items should be checked to ensure that they are not contaminated above the levels specified in Table 11.

(288) A routine monitoring survey for contamination of accessible areas shall be performed at regular intervals in all areas where work with unsealed radionuclides is undertaken. Any areas or items found to be significantly contaminated should be decontaminated to a level below that specified in Table 11.

(289) In general, for radionuclides of half-life less than 1 month (which includes the great majority of those used in medical applications), contamination remaining on working surfaces after scrubbing may be covered with impervious covering or absorbent paper during the period necessary for adequate radioactive decay. Fixed contamination with long-lived radionuclides may necessitate removal of the surface or permanent covering of the contaminated area. In the latter case, precautions shall be taken against the subsequent escape of radioactive material, and the area should be clearly marked.

Table 11. Derived limits for surface contamination

Surface	Radionuclide Class[a]		
	A	B	C
	Bq cm^{-2}		
Surface and equipment in controlled areas	30	300	3000
Surfaces of the body	3[b]	30	300
Supervised and public areas, personal clothing, hospital bedding	3	30	300

(a) Use Table 7 for classification of radionuclides.
(b) Use a tenth of this value for alpha emitters.

The above levels do not apply to volatile compounds or radionuclides which can readily penetrate the skin. (Source of table — Wrixon *et al.*, 1979; Wrixon and Linsley, 1982.)

(290) Equipment may often be cleaned adequately by washing with detergent followed, if necessary, by the use of complexing agents or ultrasonic methods. Equipment that cannot be satisfactorily decontaminated shall be stored until the activity has decayed sufficiently or shall be discarded as radioactive waste.

(291) The levels of surface contamination on walls, floors and benches in controlled areas should be kept as low as is reasonably achievable. The use of disposable absorbent coverings on benchtops is good practice which will help to control this hazard. Cleaning equipment should remain within the controlled area unless monitored and found to be free of significant contamination. Heavily contaminated cleaning equipment that cannot be decontaminated shall be stored to allow decay to an acceptable level or shall be disposed of as radioactive waste. Wet or moist cleaning methods should be employed in preference to dry sweeping or brushing.

(292) Whenever possible, a monitor should be used for the direct measurement of contamination; otherwise wipe tests should be used. Frequent use should be made of check sources to confirm that survey instrumentation is functioning satisfactorily.

(293) Every effort should be made to ensure that the levels of contamination are maintained as low as reasonably achievable. Suggested guidelines are given in Table 11.

(294) Measurements of contamination of surfaces of the body should be averaged over the most appropriate area, which in any case should not exceed 100 cm^2. For floors, walls and ceilings, the measurements should be averaged over an area not exceeding 1000 cm^2; for other surfaces, over an area not exceeding 300 cm^2. If it is suspected that discrete particles of a beta emitter may be embedded in clothing, the latter should be monitored, averaging over an area of 1 cm^2.

(295) All radiation records and work areas should be inspected by the departmental radiation safety officer to check that safe working practices are being complied with and are adequate to cope with any changes in either workload or working conditions.

Iodination of radiopharmaceuticals

(296) Iodination procedures are particularly hazardous because of the danger of inhaling the volatile radioactive material or of absorbing it through the skin. Such procedures shall only be undertaken in a fumehood.

(297) Workers involved in iodination procedures should undergo frequent thyroid monitoring, in order to establish whether the operational controls provide an adequate safeguard against internal contamination.

(298) The attention of female workers of reproductive age should be drawn to the possible dangers that iodine radioisotopes may cross the placenta to reach the fetal thyroid. Hence female workers involved in iodination procedures should be requested to inform the head of department, radiation safety officer or occupational health physician if they become pregnant, in order that they might be transferred to other duties (Working Condition B) during the remaining period of their pregnancy (see paragraphs 116, 117, 119 and 120).

6.1.7. *Decontamination of the worker*

(299) Contaminated skin should be washed with mild soap and water, particular attention being paid to cleaning under the fingernails. If this fails to reduce contamination to an acceptable level, washing with an appropriate decontamination solution is recommended.

(300) If the skin is accidentally broken, or a wound is sustained and this is also contaminated, the injury should be irrigated immediately. If it is suspected that the wound is still contaminated then the measures described in Appendix A should be taken.

(301) Workers should be trained in appropriate methods of washing contamination from the mouth and eyes. Training should also be given in methods of administering blocking and ion exchange materials, in accordance with standing instructions from the medical adviser; this is of particular importance in locations where delays may arise in obtaining medical assistance.

(302) In the event of extensive contamination of the surface of the body, external decontamination should be completed as soon as possible in order to permit any subsequent assessment of internal contamination.

6.1.8. *Handling of radioactive waste*

(303) All radioactive liquid and solid wastes should be removed from the working area without unnecessary delay.

(304) All solid radioactive waste, including unbroken glassware should be placed in the radioactive waste container, which should be impervious to leakage and of adequate strength to contain the weight of the contents without risk of leaking or bursting.

(305) Contaminated syringes and needles and broken glassware shall be placed in an appropriate shielded container reserved for sharp objects, to guard against internal contamination from accidental contact.

(306) All bags and containers of solid radioactive waste should be securely sealed and labelled before being transferred to the radioactive waste storage area. If transported through non-controlled areas, the additional safeguard of double containment by enclosure in an impervious heavy duty bag is recommended.

(307) In controlled or supervised areas liquid radioactive waste shall only be disposed of down designated sinks that are designed specifically for this purpose. The activities disposed of in this manner shall be within the limits stipulated by the appropriate statutory authority. Washings from decontamination procedures shall also be disposed of down designated sinks or sluices.

6.1.9. *Emergency procedures*

(308) Radiation incidents are unplanned events during which potential or actual exposure of personnel is likely to be more than normal for the operation. In this section an accident is considered to refer to unplanned events during which potential or actual exposure of personnel can lead to doses

greater than the dose limits recommended by the Commission. Such events may occur from improper handling, from mislaying of sources, from incorrect administration of large activities of radionuclides, and from fire and explosion. In all these events the concomitant or subsequent radioactive contamination shall be considered, but when a fire or explosion has occurred the immediate counter-measure shall be the safeguarding of life.

(309) It is important that such radiation incidents and accidents be recognized quickly and that the necessary emergency procedures are instituted promptly. This will normally require the development of an emergency plan. Such a plan should delineate lines of responsibility, required training, written procedures and periodic rehearsal. The overall emergency plan should be the responsibility of the authority in charge of the institution.

(310) In each room where radionuclides are handled, simple instructions shall be displayed, setting out the measures to be taken in emergency situations. The name and location of the person responsible for radiation protection in that area shall be clearly indicated.

(311) Emergency equipment shall be provided and be readily available. Consideration should be given to the inclusion of the following:

(a) protective clothing, including overshoes and caps;
(b) decontamination materials, including absorbent material for wiping up spills;
(c) decontamination materials for individuals, and first aid kit;
(d) warning notices and fencing-off material;
(e) tools, cans and plastic bags for handling, temporary storage and disposal of contaminated articles;
(f) portable monitoring instruments, including personal monitoring devices;
(g) sundry items such as adhesive tape, labels, torch, notebook and pencils.

Such equipment should be kept on a dedicated trolley for convenient transport.

(312) A first aid and medical casualty service shall be provided either at the facility or at a nearby hospital. The extent of this service will depend on the radiation risks that may be encountered. A higher level of service is required if nuclides belonging to Group A (see Table 7) are handled or if the activities handled lead to classification as a "high hazard" (see Table 10). In any case, the following provisions shall apply:

(a) first aid facilities and advice shall be immediately available;
(b) arrangements for referring casualties and contaminated individuals to medical services at an appropriate stage should be clearly defined and made known.

6.1.10. *Fire or explosion accidents involving radiation*

(313) In the event of fire, the hazard associated with unsealed radioactive material is relatively small and consequently the first concern must be for the safety of patients and staff.

(314) Working techniques shall be planned to minimize the risk of fire or explosion as well as to avoid dispersion of activity in the event of such an occurrence.

(315) Fire-fighting teams who may be involved should receive some instruction on the nature and level of any hazard from unsealed radionuclides so that necessary procedures in an emergency will not be held up by confusion over the extent of any precautions which may be necessary at the time or after control of the fire. Clear instructions shall be provided on how the person responsible for radiation protection precautions at the institute may be contacted.

(316) There shall be prior liaison with the local fire fighting services in order to advise them of the nature and magnitude of the radiation hazards likely to be encountered, and so enable them to devise adequate emergency plans. When the attendant fire fighting services arrive, they should be notified of the presence, and if possible the site, of radionuclide sources on the premises and of the possibility of contamination.

(317) When the emergency is ended, access to the affected area should be restricted to those persons assigned to monitor the area and to determine the extent of any contamination. Only after any appropriate decontamination procedures have been carried out should these restrictions be withdrawn.

6.1.11. *Quality assurance*

(318) The purity and standardization of radionuclides, and the efficiency of labelling of radiopharmaceuticals, indirectly affects the standard of radiation protection of the workers concerned, because failure may result in repeated tests.

(319) If the detection sensitivity of equipment used in clinical investigations of the patient is inadequate, excessive activities are liable to be administered to patients to compensate for the equipment deficiencies. Workers will then be exposed to unnecessarily high levels of radiation during both administration of the radionuclides and the subsequent investigation. Detailed information regarding quality assurance in nuclear medicine may be found in Hamilton and Paras (1984), and in *ICRP Publication 52* (ICRP, 1987c).

6.2. Recommendations Specific to Diagnostic Uses of Unsealed Radionuclides

6.2.1. *Design aspects of specific areas*

(320) A nuclear medicine department should be designed to aid the workflow and locate the relevant clinical areas close to each other in a logical progression, i.e. starting with the radiopharmacy and the radionuclide storage area, followed by the radionuclide administration area, the patients waiting area with toilets, and finally the investigation area. Such close proximity will make it easier to restrict access to these areas and thus to avoid unnecessary passage of other workers through the areas.

Radiopharmaceutical administration area

(321) Radiopharmaceuticals should be administered in a room that is separate from the investigation area. However, some procedures such as dynamic scintigraphy and lung ventilation studies require the patient to be in position at the gamma camera as the administration is made. Appropriate decontamination solutions should be readily available. A wash sink and suitable facilities for the disposal of radioactive waste should also be provided.

Waiting area for radioactive patients

(322) A separate waiting area, which includes toilet facilities, is recommended for radioactive patients, adjacent to the radiopharmaceutical administration and investigation areas, but located where the exposure of workers and cameras will be insignificant.

6.2.2. *Monitoring procedures*

(323) The doses received by the fingers and eyes may be higher than those received by other parts of the body. If they are expected to approach the relevant limits, appropriate monitoring should be carried out in order to decide if additional shielding or alternative protective measures are needed.

6.2.3. *Operational procedures*

(324) The data in Table 12 indicate that after the diagnostic use of radionuclides, it will rarely be necessary to establish a controlled area around a patient. For example, if 600 MBq of ^{99m}Tc MDP is administered for a bone scan, the dose equivalent rate at 0.3 metres from the patient is 7.8 μSv h^{-1} immediately after administration and 4.2 μSv h^{-1} after 2 hours. At 1 metre from the same patient the

Table 12. Examples of dose equivalent rates at various distances and times from a typical adult after administration of a radiopharmaceutical (from Table 3 of *ICRP Publication 52*).

Investigation	Radio-pharmaceutical	Typical range of administered activity (MBq)	Absorbed dose equivalent rate (nSv h^{-1} per MBq)					
			Immediately after			After 2 hours		
			Close(*)	0.3m	1m	Close(*)	0.3m	1m
Bone scintigraphy	^{99m}Tc MDP	150 - 600	27	13	4	13	7	2
Liver scintigraphy	^{99m}Tc colloid	10 - 250	27	13	4	20	10	3
Blood pool determination	^{99m}Tc RBC	550 - 740	27	13	4	20	10	3
Myocardial scintigraphy	^{201}Tl	50 - 110	36	18	6	36	18	6

(*) At the body surface over the relevant tissue.

dose equivalent rate is 2.4μSv h^{-1} immediately after administration and 1.2μSv h^{-1} after 2 hours. Hence, even if bed or seat centres are only 2 metres apart, the exposure of workers from such a patient is low. It will only be necessary to define a controlled area in the vicinity of the patient if the dose equivalent rate exceeds 7.5μSv h^{-1}.

(325) Because the dose rates from patients to whom radionuclides have been administered for diagnostic purposes are relatively low, the radiation hazards to workers during surgical procedures on such patients can generally be ignored.

6.3. Recommendations Specific to Therapeutic Uses of Unsealed Radionuclides

6.3.1. *Introduction*

(326) All forms of therapy involve substantial activities and doses to workers and the public require serious consideration. Many of the following paragraphs apply to protection measures needed in the use of high activities of gamma-emitting radionuclides requiring the declaration of a controlled area and the retention of the treated patient in hospital. Nevertheless the quality of the radiation emitted must be taken into account as in certain circumstances (e.g. after administration of ^{90}Y — see paragraph 335) it will not be necessary to declare a controlled area around the patient.

(327) Reference to the classification of the hazard likely to be encountered has been made in paragraphs 237 to 241 and in Tables 7,8,9 and 10. From this it may be deduced that the area around a patient's bed is likely to be classified as a "high hazard" area. Nevertheless it should not be assumed that this situation requires the patient to remain in the hospital, if there is no other medical reason for retention (Buchan and Brindle, 1971). For instance, in the treatment of a patient for hyperthyroidism, the area around the patient's bed might be classified as "high hazard" for staff constantly subject to occupational irradiation. However this classification may not bar the discharge of the patient, provided that those in the home who require to be in contact with the patient are given suitable written instructions.

6.3.2 . *Planning and design*

General aspects

(328) In the planning and design of a facility where therapy is to be undertaken with unsealed

radionuclides, the following need to be considered:

(a) the type of radionuclide and activities likely to be administered;
(b) laboratories where unsealed radionuclides are used and stored;
(c) special areas, wards or treatment rooms where patients are housed during treatment;
(d) provision for the safe transport of sources and of patients treated with radionuclides.

Specific aspects

(329) Laboratories should be located as close as practicable to the wards where patients are to be housed during treatment. In this way, the transport of radioactive sources or patients treated with radionuclides through non-controlled areas such as corridors and elevators is minimized.

Waiting area for radioactive patients

(330) The patient should be returned to a controlled area on the ward immediately after a therapeutic activity of radionuclide has been administered. If this is not possible, a separate patient waiting area equipped with appropriate shielding may be required to safeguard workers from radiation emitted by the patient.

Ward design

(331) Patients to whom a therapeutic activity of radionuclide has been administered should be kept in a separate area specifically designed for that purpose until the level of radiation they emit no longer constitutes a significant radiation hazard. Guidance is given in Tables 5 and 5A in the NRPB Guidance Notes (NRPB, 1988). Worker protection is achieved by providing barrier shielding in the room enclosure, maintaining as great a distance as possible from the patient, if necessary using additional shields, usually mobile, in the patient's room and limiting the time workers spend in the vicinity of the patient.

(332) The required thickness of protective walls, floors and ceiling depends upon the type and activity of the radionuclides in use and upon the location and dimensions of the room. If the room contains windows, and if justified by the magnitude of the activity and the nature of the radionuclide administered, access to the immediate area outside the windows should be restricted, or else a protective barrier should be sited between the patient and the window. Mobile protective shields positioned at the side of the bed may reduce the dose rates significantly, both outside and inside the room.

(333) Because of the possibility of contamination, patients to whom a therapeutic activity of radionuclides has been administered should use bath, shower and toilet facilities separate from those provided for workers and for other patients.

(334) If it is not possible to provide appropriately shielded rooms to house patients to whom a therapeutic activity of radionuclide has been administered, special areas shall be set aside and designated for this purpose using the principle of distance as the primary means of reducing dose rates. Depending on the type and activity of the radionuclides in use, this area may be in the corner of a ward or in an isolated room. Under such circumstances it is particularly important to consider the use of appropriately positioned mobile bedside shields. In addition, contamination and control procedures may have to be instituted, otherwise significant radiation doses may be received by workers attending nearby patients.

6.3.3. *Classification of areas and monitoring procedures*

(335) The area housing patients to whom a therapeutic activity of radionuclide has been administered is normally a controlled area. Occasionally (e.g. if using ^{90}Y) this is not necessary. The limits of this area shall be defined by the radiation safety officer. The extent of these limits may depend upon

the type and activity of the radionuclides in use, and on the use made of fixed and mobile radiation shields. The definition of these limits should take into account the composition and thickness of the walls, floor, ceiling and door and the occupancy of adjacent areas. The radiation dose contour maps provided as an example in Appendix B indicate areas of low dose rate and the effect of radiation shields. This may assist in identifying the safest positions in which to work.

6.3.4. *Operational procedures*

(336) Radiation safety measures shall be rigidly enforced within the controlled area. Appropriate radiation hazard warning notices should be prominently displayed at the boundary of the area. Appropriate barriers should be placed at the entrance to the area to prevent inadvertent entry by unauthorized workers. Persons entering the controlled area shall wear protective clothing (e.g. gown, gloves, overshoes) to guard against the contamination of personal clothing. Working procedures shall be designed to contain the radioactive substances and to limit both the causes and spread of contamination. In particular, manipulation of unsealed sources should be carried out over trays lined with absorbent disposable material.

(337) In general, the administration of therapeutic amounts of unsealed radionuclides to patients should be undertaken in a specific radionuclide administration area. Particular care is needed when radionuclide administration is undertaken in an area that is not normally a controlled area.

(338) Immediately after the radionuclide has been administered for therapeutic purposes, the following details should be entered in the patient's medical record:

(a) type and activity of radionuclide;
(b) date and time administered;
(c) dose rate measured at 1 metre from the patient.

(339) The immediate area around a patient's bed (e.g. within 1.5 metres) or maybe the whole room if only one patient is present, may need to be considered a controlled area. No person should enter this area except when it is necessary to attend to the patient. The patient should use a toilet in preference to a bedpan. Ideally, there should be separate toilet and washing facilities. The patient should be discouraged from leaving the controlled area. All items that have come in contact with the patient, including disposable gloves worn by workers, should be placed in a container for radioactive waste located in the controlled area.

(340) The patient's bed linen, towels, clothing and other personal effects should not be handled by workers any more than is necessary. Disposable crockery and cutlery should be used. Other non-disposable items, including the bed, should not be returned to general use unless monitoring has shown them to be free of significant contamination.

(341) Only essential nursing should be provided for the patient. Nursing care should be performed quickly. The exposure of nurses is minimized by ensuring that they generally maintain an adequate distance from the patient or that they are appropriately shielded. In addition, limited access to the patient ensures that the nurses will not be significantly exposed to any ^{131}I exhaled by the patient. Disposable plastic gloves should be worn when attending to the patient and especially when disposing of the patient's excreta. When workers leave the controlled area, hands should be washed after each occasion when manual contact has been made with the patient or with any other items in the area.

(342) Individual dosemeters shall be worn by all workers required to attend to the patient regularly.

(343) Any obvious contamination, such as that arising from an accidental spillage of urine or other excreta, should be brought to the immediate attention of the radiation safety officer. Contaminated areas and items should be identified and decontaminated. The monitoring and control of contamination is described in Sections 6.1.4 and 6.1.7, and in Appendix A.

(344) Following intra-cavitary injections of any radionuclide, bandages and dressings should be treated as contaminated items after use and disposed of as radioactive waste.

(345) Patients to whom a therapeutic activity of radionuclide has been administered should be transported in a manner that minimizes the exposure of workers. Shielded trolleys are not practicable because of the excessive weight, so that time and distance factors are of paramount importance. Only a minimum number of specially trained workers, consistent with adequate patient care, should be employed in the transport of these patients. Workers should stand as far away from the source of radioactivity as is practicable. Crowded waiting areas and busy corridors should be avoided and only attendant staff should occupy elevators with such patients.

(346) When the patient arrives at the nursing room/area, it may be necessary to carry out an area radiation survey in order to locate regions of high dose rate. A radiation warning sign should be prominently displayed at the entrance/s to this room. A radiation survey should also be performed on all material leaving the room.

6.3.5. *Surgery*

(347) Surgical staff should seek the advice of the radiation protection adviser whenever a patient scheduled for surgery has recently received a radionuclide for therapeutic purposes.

(348) Whenever possible, surgery should be delayed until after the radioactivity in the patient has decreased to a level acceptable for general care, without the need to observe radiation safety precautions.

(349) If surgery cannot be delayed, certain radiation safety precautions such as the rotation of staff during the operation may be advised by the radiation safety officer. The possibility of contamination from body fluids should also be taken into account.

(350) If the surgical procedure is likely to be lengthy, the radiation safety officer should indicate how long workers may remain close to the patient before consideration needs to be given to their replacement by other workers during the course of the operation.

(351) During surgery, consideration should be given to the possibility of shielding those organs or regions of the patient that contain high levels of radioactivity, in order to minimize the exposure of surgical and theatre staff.

(352) Individual dosemeters should be issued to workers who are involved in surgical procedures on patients who have received a therapeutic activity of radionuclide.

(353) Any wounds sustained by workers during surgery on patients to whom therapeutic activities of radionuclides have been administered, shall be promptly decontaminated. The magnitude of the hazard should be evaluated by the radiation safety officer.

(354) If an emergency operation is performed before the issue of individual dosemeters was possible, retrospective dose estimates should be made by the radiation protection adviser and an appropriate entry should be made in the workers' dose records.

(355) On completion of surgery, the operating theatre, dressings, drapes and other appropriate apparatus should be monitored for contamination.

6.3.6. *Autopsy, cremation or embalming*

(356) Advice may be required concerning the radiation safety precautions that need to be taken when performing an autopsy on a patient who has died shortly after being treated with therapeutic quantities of a radionuclide, or when such a patient is to be cremated or embalmed.

(357) Table 13 gives guidance regarding the maximum activities in the body below which special precautions are not required for autopsy, cremation or embalming.

(358) Any autopsy performed soon after substantial therapeutic quantities of a radionuclide have

Table 13. Maximum activities of radionuclides for disposal of corpses without special precautions (activities in MBq)

Radionuclide	Post-mortem/Embalming	Burial	Cremation
^{131}I	10(1)	400(3)	400(3)
^{198}Au grains	10(2)	400(3)	100(5)
^{125}I seeds	40(2)	4000(3)	4000(3)
^{90}Y colloid	200(1)	2000(4)	70(5)
^{198}Au colloid	400(3)	400(3)	100(5)
^{32}P	100(1)	2000(4)	30(5)
^{89}Sr	50(1)	2000(4)	20(5)

NOTE: The values for post-mortem, embalming and burial relate to the greatest risk to those persons involved in the procedures.
(1) Based upon the contamination hazard.
(2) Based upon the extremity dose limit.
(3) Based upon dose rate external to the body.
(4) Based upon bremsstrahlung dose at 0.5m.
(5) Based on contamination hazard assuming that these radionuclides remain in the ash.
(6) Table 13 is based upon Wrixon *et al.* (1979), Wrixon *et al.*(1982) and on "Guidance notes for the protection of persons against ionizing radiations arising from medical and dental use" (NRPB, 1988).

been administered to a patient should conform with the radiation safety measures recommended for surgery in paragraphs (347) to (355). If practicable, the autopsy should be delayed until the activity has decayed substantially.

(359) The wearing of heavy autopsy gloves will reduce the level of irradiation of the fingers by beta radiation.

(360) If any tissue is removed for histological examination, the possibility that this tissue is significantly radioactive should be taken into account. If checks confirm this, the histological examination should be delayed until the activity has decayed to an insignificant level.

(361) The autopsy room should be monitored on completion of the examination, particularly because of the likelihood of contamination from body fluids.

6.3.7. *Emergency arrangements*

(362) In an emergency, the safety and medical care of the patient must take precedence over any radiation safety requirements.

(363) In the event of a medical emergency involving a patient undergoing therapy with an unsealed radionuclide, the physician in charge of the patient, and the radiation safety officer, should be informed immediately. Advice concerning the precautions to be taken should be given by the physician or the radiation safety officer to those workers caring for the patient, and who may be unaware of, or unfamiliar with the radiation hazards.

(364) A list of the emergency telephone numbers of appropriate radiation safety personnel shall be readily available in the area, for use in the event of any emergency involving these patients.

(365) Written radiation safety instructions should be available in all radiation areas where an emergency may arise. These instructions should contain a detailed description of how to manage a patient in the event of a medical emergency, and the action required in other emergency situations, such as fire. The safety of patients who have received therapeutic activities of radionuclides takes precedence over the potential hazard to workers. After evacuation, such patients should be segregated.

6.4. Recommendations Specific to Uses of Radionuclides in Medical Laboratory Procedures

6.4.1. *Introduction*

(366) The use of radionuclides "*in vitro*" for analytical purposes in laboratory medicine (e.g. ^{3}H, ^{14}C and ^{125}I) constitutes a low degree hazard in respect of internal contamination, and only then if basic rules of containment and avoidance of contamination of the working environment are neglected.

6.4.2. *Classification of areas and monitoring procedures*

(367) All areas of the laboratory where work with radionuclides is undertaken, except where iodination procedures are carried out, should be generally classified as supervised radiation areas depending upon the levels of activity in use (see paragraphs 237 to 241, paragraph 262 and Tables 7, 8, 9 and 10). These normally include:

(a) the room or section of room where work with radionuclides is carried out;
(b) the radionuclide storage area;
(c) the radioactive waste storage area.

(368) An area no longer needs to be regarded as a supervised area when all of the following conditions apply:

— all such work has ceased;
— all sources of radiation have been removed from the area (including the patient);
— no significant levels of contamination remain in the area;
— the radiation safety officer has declared the area to be no longer a supervised area;
— the radiation hazard warning sign has been removed or obscured.

(369) Iodination procedures shall be carried out in a fumehood (see paragraph 251 and Table 10), which should be located in a controlled area. A radiation hazard warning sign shall be displayed at the entrance to the controlled area (see Section 3.6). Only authorized persons shall be permitted to enter this area.

(370) Individual dosimetry is not required in supervised areas, except on an intermittent basis to confirm that the working environment is safe and that safe practices are being observed.

7. PRACTICAL ASPECTS OF THE PROTECTION OF THE WORKER IN BRACHYTHERAPY

7.1. Introduction

(371) The exposure of workers in brachytherapy is almost exclusively from external radiation, and its magnitude varies considerably, depending on the methods used. The exposure is relatively high among workers who prepare the sources for use. The degree of exposure of those who implant the sources into the patient depends on the manual skill of the operator, and, more importantly, on whether after-loading techniques are used. The degree of exposure of nursing staff is not lessened at all by the use of manual after-loading, but is lessened by the use of automatic after-loading.

(372) In manual after-loading the necessary tubes are placed in position in the operating theatre. The position of the tubes is then checked by diagnostic radiographs. Only then are the radioactive sources inserted. Thus there is a significant dose reduction to staff in the operating theatre and the radiology department (Table 14). There is no dose reduction to staff in the ward area, as compared with the dose received after the use of non-after-loading techniques.

Table 14. Average annual doses recorded in 1985 in radiotherapy departments in the Mersey Region, Liverpool, U.K.

Radiotherapy departments	Annual dose mSv
Radiotherapists	1.30 (1.30)
Radiographers	0.80 (1.00)
Mould room technicians	0.60 (2.20)
Physics staff	1.20 (0.50)
Radium custodians	1.00 (4.00)
Nursing staff	0.90 (4.00)

Figures in brackets are annual doses received prior to replacing most of the radium work with automatic after-loading caesium sources.

(373) In automatic after-loading the tubes are again inserted in the operating theatre, and their position checked, and only then is the patient transported to a specially-equipped room. This should be fully protected, and contain the special high dose-rate sources. These are automatically inserted into the patient after connection of the tubes to the protected source container. The sources are automatically returned to the protected container when anyone enters the room, and thus radiation of the nursing staff is considerably less. Although more expensive than manual after-loading, the technique can be cost-effective (Fleishman *et al.*, 1983).

(374) For use in brachytherapy, radionuclides should be selected that, without detracting from clinical effectiveness, give rise to lower radiation doses to the workers. In this respect, the use of ^{125}I has supplanted that of ^{198}Au in many situations; also, partly due to the reduced risk of contamination, ^{60}Co, ^{137}Cs and ^{192}Ir should replace radium as rapidly as is economically feasible.

7.2. Planning and Design

(375) The planning and design of a brachytherapy facility should consider radiation protection in the following areas:

(a) the laboratory where sealed and other solid radionuclides are stored and prepared for use,
(b) special areas, wards or treatment rooms where patients are housed during treatment,
(c) operating theatres,
(d) a diagnostic x-ray facility for determining the position of sources in patients,
(e) provision for the safe transport of sources and patients.

7.2.1. *Radioactive source laboratory*

(376) This laboratory, in which radioactive sources are stored and prepared for use, is a controlled area, which should have locks fitted to the entrances, in order to prevent unauthorized access.

(377) The workbench shall have an impervious surface that can be easily cleaned and which is free from cracks in which small amounts of radioactive material may lodge. The bench shall be equipped with a shield to protect workers standing close by. The bench-top shall also provide a similar degree of shielding against radiation that exposes the worker obliquely or exposes areas of the body below the bench at which the worker is positioned. The shielding material and thickness required depends upon the type and activity of the radionuclides used. A typical shielding specification would normally require attenuation of the radiation by a factor of about 1000.

(378) In addition to the shielding required to protect the worker directly in front of the workbench area, shielding should also be provided around the handling area and the room enclosure, in order to

provide appropriate protection for any workers who are required to occupy other parts of the room and surrounding areas.

(379) A suitable radiation monitoring device should be present in the area, preferably switched on at all times, to indicate when any radionuclides have been inadvertently left out of their shielded containers. This device should be tested periodically.

(380) During work with radioactive sources, direct viewing is preferable to the use of mirrors. A typical viewing panel is made of lead glass (lead equivalence of about 5 cm). Lead glass of the required thickness may reduce light transmission, so the area viewed through such a panel should be brightly illuminated. A means of viewing the sources by magnification should also be provided to facilitate inspection and enable identification markings to be clearly seen with a minimum of exposure of the worker. The provision of a device for measuring activity (e.g. an ionization chamber) is highly recommended.

(381) There shall be adequate provision for the storage of all sources when they are not in use. The storage container or safe shall have adequate built-in shielding to permit staff to work safely in the immediate vicinity. The degree of shielding required will depend upon the type and activities of the radionuclides used and should be subject to an optimization exercise. Storage containers or safes should be partitioned in order that workers who require access to a particular radionuclide will only be exposed to a small portion of the total source activity. Such safes should be equipped with appropriate locks to prevent unauthorized access.

(382) The use of radium should be strongly discouraged, but, where this cannot be avoided, the storage facility shall be equipped with ventilation to the building exterior in order to extract any radon gas leaking from the radium sources. The ventilation duct should be carefully sited with the aim of reducing the possibility of radon gas re-entering the building or exposing any person in adjacent areas. A radiation detector may be installed in the ventilation duct to provide an alarm in the event of gross source leakage.

(383) In order to manipulate the sources, design of the shielding should be such as to permit the use of long handled tools or remote handling devices.

(384) The source storage safe should be located close to the workbench to reduce source movement to a minimum. The laboratory should also be located as close as practicable to the wards where patients are to be housed during treatment. If after-loading techniques are not used, the storage safe should also be as close as practicable to the operating theatre where the sources are to be inserted into the patient.

(385) There shall be provision in the laboratory or operating theatre, or both, for the cleaning, sterilization and disinfection of sources and for their temporary storage. If sources are damaged during use, the contingency arrangements described below (particularly in paragraph 426) should be put into operation. Cleaning of the sources should be carried out behind a suitable protective shield.

(386) In the preparation and cutting of radioactive materials such as iridium wire, small radioactive fragments may be produced. This operation shall therefore be performed where the fragments can be collected and transferred to a suitable container for radioactive waste. Instruments used in this operation for cutting and handling also may become contaminated, and should be kept in a safe secure area until decontaminated. Therefore a contamination monitor should be provided outside the preparation area, readily available for use inside the area.

7.2.2. *Ward design*

(387) Patients into whom sources have been inserted should be kept in a separate area specifically designed for that purpose until such time as the sources are removed. Worker protection is best achieved by using automatic after-loading systems. If these are not available then worker protection is achieved by:

(a) providing barrier shielding in the room enclosure;

(b) using additional shields, usually mobile in the patient's room;

(c) limiting the time workers spend in the vicinity of the patient;

(d) maintaining as great a distance from the patient as is consistent with patient care.

(388) When high dose rate remote automatic after-loading techniques are employed, a special shielded treatment room is necessary because of the very high dose rates that may arise due to the extremely high activity of the sources used in this technique. An interlock shall be provided at the entrance to the patient's room to ensure that the sources are automatically withdrawn to a safe storage position before anyone enters the room. If the source fails to return to its safe storage position, this shall be indicated by a visible or audible radiation alarm system incorporated into the design.

(389) The required thickness of protective walls, floors and ceiling depends upon the type and activity of the radionuclides in use and upon the location and dimensions of the room and should be subject to an optimization exercise. If it is impracticable to equip the entrance door to the room with adequate shielding, a maze should be incorporated in the room design. If the room contains windows, access to the area immediately outside the windows should be restricted, or else a protective barrier should be sited between the patient and the window. Mobile protective shields positioned at the side of the bed may reduce the dose rates significantly both outside and inside the room.

(390) Exposure of workers will be reduced by keeping patients under closed-circuit television surveillance, thereby reducing the need for workers to enter the room.

(391) An audible radiation alarm should be provided at the exit from the room in order to provide a warning if radionuclide sources are removed inadvertently from the area. This will also give warning if, contrary to instructions, a patient leaves the room.

(392) If it is not possible to provide appropriately shielded rooms to house brachytherapy patients, special areas shall be set aside and designated for this purpose. These areas shall be specifically chosen to minimize the radiation hazards to workers and patients. Depending on the type and activity of the radionuclides in use, this area shall be in the corner of a ward or in an isolated room. Consideration should also be given to the potential exposure of workers and patients in adjacent rooms and corridors; under such circumstances it is particularly important to consider the use of appropriately positioned mobile bedside shields typically of 2.5 cm thickness of lead (see *ICRP Publication 33*, ICRP, 1982a). Otherwise significant radiation doses may be received by workers in the vicinity.

(393) Separate toilets should be provided for patients into whom sources have been inserted. Their design should ensure that any source lost down the effluent drain will be trapped (e.g. by provision of a dosemeter which, when activated by the passage of a source, triggers a stop device; alternatively, the use of bed pans should be encouraged.

7.2.3. *Operating theatre design*

(394) Operating theatre walls may require additional shielding to offer greater radiation protection if theatre usage includes regular work with sealed sources. The rooms adjacent to the operating theatre may need to be declared a controlled area if protection is inadequate.

(395) Special equipment required in the operating theatre includes (a) shielded trolleys for source dispensing and storage, and (b) the provision of shielded cleansing and sterilizing facilities.

7.2.4. *Diagnostic x-ray examination*

(396) Diagnostic x-ray services are required to indicate the position of the after-loading device containing dummy sources, or, when applicable, the actual radioactive sources. This service may be provided in the diagnostic x-ray department or by a simulator or similar item of equipment sited in the radiotherapy department. With most after-loading techniques, no radioactive sources are present in the applicators when the diagnostic x-ray examination is carried out, hence the only radiation safety

precautions to be taken are those applicable to the use of diagnostic X rays, as described in Section 4.

(397) When it is necessary for the sources to be present in the patient while a localizing radiograph is being taken, the safety measures described in Section 4 applicable to diagnostic radiological examinations should be taken. In addition adequate radiation protection is generally achieved by maintaining as great a distance as practicable from the patient and by conducting the examination as rapidly as possible. This latter action is also necessary to reduce the extent to which the radiograph is fogged by the therapeutic radiation and thus to avoid the possibility of spoiling the film and of having to repeat the examination.

(398) In some instances, depending upon the type of radionuclide used and the frequency with which such applications are performed, it may be necessary for portable radiation shields to be provided or for additional shielding to be incorporated in the design of the walls, floor and ceiling of the examination room.

7.2.5. *Provision for the safe transport and movement of sources*

(399) Adequately shielded containers shall be used in the transport of radioactive sources. These may be extremely heavy and a mechanical hoist may be required to aid lifting.

(400) The source storage area, the wards and the operating theatres should be located close together, in order to minimize source movement and the attendant hazards.

7.3. Classification of Areas and Monitoring Procedures

(401) The brachytherapy source preparation laboratory is a controlled area to which access is restricted to authorized personnel. When not in use the room shall be kept locked to prevent unauthorized entry. Occupancy of the room by authorized personnel should be limited to the time required for source preparation and manipulation. Other than making appropriate entries in the record logbook, all administrative work should be performed outside the room.

(402) The operating theatre shall be a controlled area when sources are present. When all sources have been removed from the operating theatre and this has been confirmed by both monitoring and accountancy procedures, the theatre need no longer be regarded as a controlled area.

(403) The area in which brachytherapy patients are housed is a controlled area. The limits of this area shall be clearly identified. The extent of these limits depends upon the type and activity of the radionuclides in use, and on the use made of fixed and mobile radiation shields. In defining these limits it will also be necessary to take into account the composition and thickness of the walls, floor, ceiling and door and the occupancy of adjacent areas. The radiation dose contour maps provided as an example in Appendix B indicate areas of low dose rate and the effect of radiation shields. This may assist in identifying the safest positions in which to work.

(404) Areas immediately surrounding a controlled area may need to be designated as supervised areas. The extent of the limits of these areas should be identified in a manner similar to that described in the paragraph above.

7.4. Operational Procedures

7.4.1. *General*

(405) The physical location of each sealed source shall be known at all times. A suitable record shall be maintained, indicating the location and movement of all sources both inside and outside the preparation room and of the individual responsible. A radiation warning sign shall be prominently

displayed at the entrance to any room containing a radionuclide source, either in storage or inserted in a patient.

(406) Sources shall be moved in the facility under the control of trained authorized workers and in containers providing adequate shielding for those involved and others in the vicinity. When sources are in transit within a facility they shall not be left unattended. If sources are involved in an accident during movement within a facility, the radiation safety officer shall be informed immediately.

(407) All workers who work regularly with, or in the vicinity of brachytherapy sources shall wear individual dosemeters. Because significant dose equivalents may be received by extremities, workers who prepare or manipulate such sources should also wear finger dosemeters. Consideration should be given to the need for a separate dosemeter to measure the dose equivalent to the eyes.

(408) It is important to maintain a balance between encumbering the operator with protective devices, which reduce the dose received by the operator, and the associated increase in exposure time, which the use of these devices may entail. The optimum balance will vary with the type of radionuclide in use and the experience of the operator.

(409) Sealed sources shall be tested for leakage at regular intervals. Wherever accessible, individual sources should be leak-tested or wipe-tested. If any source is found to be leaking, contingency plans should be put into effect (see paragraph 426). Checks for contamination should also be made on the handling tools used with that source. Where the general level of background radiation in the vicinity is high, these measurements of contamination levels may only be possible by wipe test methods.

(410) The presence of contamination on the transfer tubing of after-loading equipment may be sufficient to indicate source leakage. If significant contamination is discovered, sources should be removed from the system and checked individually. To avoid excessive exposure, special care should be exercised by the workers conducting leakage tests because of their close proximity to the sources.

(411) Sources should never be handled directly by the fingers. Any manipulation should be carried out with instruments. The instrument handles should be as long as possible and yet permit ease of source manipulation. Sources should always be manipulated with care in order to avoid damage and the likelihood of a leak developing.

(412) In order to reduce the possibility of source damage by conventional instruments, special handling devices should be designed for use in specific procedures with specific types of sources. These devices should be appropriately labelled, and stored separately from the general surgical instruments.

(413) The level of radiation exposure of theatre staff (both surgical and nursing) will depend upon the expertise of the persons involved. Practice procedures using dummy sources should therefore be undertaken by such persons who are being trained to work with radioactive sources.

(414) Immediately after surgery involving the insertion of sealed radionuclide sources into a patient, the dose equivalent rate 1 metre from the patient should be measured. This is typically in the range 80 to 800μSv h^{-1}. A suitable label shall be attached to a prominent site on the patient (e.g. the wrist), indicating the type of radionuclide, the implanted area, the measured exposure rate, the date and any other pertinent data. Similar data shall be entered in the patient's medical record. A suitable warning label should be attached to the outside of the medical record to draw attention to the radiation hazard involved in the care of the patient. The labels shall be removed from patient and from medical record only after removal of the source from the patient.

(415) Special precautions may be necessary in connection with the use of certain radionuclides such as ^{125}I, which emit low energy X rays, and have a long half life and possibly a long treatment time. Adequate shielding from these low energy radiations may be achieved with small barrier thicknesses, such as those provided by wearing a protective apron or by covering the implanted area with a thin layer of heavy metal (e.g. tin).

(416) Patients into whom radionuclide sources have been inserted should be transported in a manner

that will minimize the exposure of workers. Shielded trolleys are not usually practicable because of the excessive weight; time and distance considerations are therefore of paramount importance in reducing exposures. Only a minimum number of specially trained workers, consistent with adequate standards of patient care, should be employed in the transport of such patients. Workers should be instructed to stand as far away from the implanted site as is practicable. Crowded waiting areas and busy corridors should be avoided, and only attendant staff should occupy elevators with such patients. These patients shall never be left unattended during transport.

7.4.2. *Diagnostic uses of high activity sources*

(417) Bone mineral analysis may be carried out using a removable portable source (e.g. 20 GBq ^{125}I; 50 GBq ^{153}Gd). In view of the high activities involved, wipe testing of the source should be carried out at appropriate intervals. If leakage is detected, the source shall be removed from use immediately. A leaking source should be sealed in an impervious container and stored until a decision is made regarding repair or disposal. Operators should follow strict operating practice and shall always wear individual dosemeters.

7.4.3. *Area monitoring*

(418) When the patient containing brachytherapy sources arrives at the nursing room or area, an area radiation survey should be carried out in order to identify regions of high dose rate. A radiation warning sign should be prominently displayed at the entrance/s to this room or area. A radiation survey should also be performed on all material leaving the room. Trash, linen, dressings etc. should be monitored prior to leaving the room and should not be released for disposal unless declared clear of radioactive contamination, or of the presence of radioactive sources (see paragraph 424).

(419) The following monitoring procedures shall be carried out on completion of work with radionuclide sources in the area:

(a) The patient shall be monitored to confirm that all sources have been removed and that no source (e.g. iridium wire) has fragmented inside or on the patient.

(b) The general area of the operating theatre shall be monitored, together with any items that have been in contact with the patient (e.g. theatre drapes, swabs) and any instruments, such as suction units, which might contain sources.

(c) The general patient nursing areas shall be monitored, together with any items that have been in contact with the patient including dressings, as well as excreta and vomit.

7.4.4. *Emergency procedures*

(420) In the event of a medical emergency involving a patient with a radionuclide implant, the radiotherapist in charge of the patient, and the radiation safety officer in the department, should be informed immediately. When temporary removal of the implant is necessary, to allow intensive medical and nursing care, it should be removed as soon as the patient's medical condition permits. Advice concerning the precautions to be taken should be given by the radiotherapist and/or the radiation safety officer to those workers who are caring for the patient, but who may be unaware of and unfamiliar with the radiation hazards. A storage container shall be available in the immediate vicinity of patients with implants, in order to permit removal in an emergency.

(421) A list of the emergency telephone numbers of appropriate radiation safety personnel shall be readily available in the area, for use in the event of any emergency involving these patients.

(422) There should be written radiation safety instructions in all areas where an emergency may arise involving a source. These instructions should contain the action to be taken in all foreseeable emergencies.

(423) Where automatic after-loading techniques are in use, written instructions should be provided immediately outside the treatment room, to indicate the action necessary in the event of a radionuclide

source becoming lodged in the tubing during transit between the storage container and the patient.

(424) A standard procedure should be followed whenever a source cannot be accounted for. This should include monitoring the patient together with any area in which the patient may have been housed. The contents of the area should be monitored, including all associated dressings, bed linen and trash awaiting disposal. The radiation alarms at room entrances and disposal points should be checked for malfunction, in order to rule out the possibility of a source having passed a check point undetected. A re-check should be run of all the sources returned to the storage laboratory and of the records accounting for their issue and movement.

(425) If a source is still unaccounted for after the measures in the above paragraph have been carried out, a wider search should be initiated on the advice of the radiation protection adviser.

(426) If a source appears to be damaged, it should be assumed to be leaking. In these circumstances, the source should be hermetically sealed in a suitable container pending repair by the manufacturer or other competent person. Any worker who has recently used the source, and the areas in which the source has been used, should be checked for contamination.

(427) In the event of the death of a patient with a radionuclide implant, the sources should be removed immediately and returned to the storage laboratory. If it is not possible to remove the source easily, no person should be permitted to work in close proximity without being informed of the precautions to be taken. It may be possible to recover the source if an autopsy is performed (see paragraph 357 and Table 13).

(428) Prior to commencing an autopsy, all removable implants should be extracted and returned to the storage laboratory. Any permanent implant of significant activity should be removed by surgical autopsy technique and transferred to a shielded container prior to disposal.

(429) In the event of a fire, the protection of the patient against the immediate fire hazard takes precedence over the radiation protection of the worker. Normal evacuation procedures should be followed regardless of the radiation sources involved. After evacuation, such patients should be segregated, the presence and whereabouts of all sources should be checked, and any missing sources should be reported to the radiation safety officer of the department, or to another appropriate person.

(430) There shall be prior liaison with the local fire fighting services in order to advise them of the nature and magnitude of the radiation hazards likely to be encountered, and so enable them to devise adequate emergency plans. On arrival of attendant fire fighting services they should be notified of the presence, and if possible the site, of radionuclide sources on the premises and of the possibility of contamination.

(431) When the emergency is ended, access to the affected area should be restricted to those persons assigned to monitor the area and to determine the extent of any contamination. Only after any appropriate decontamination procedures have been carried out should these restrictions be withdrawn.

(432) A master list of sources should be maintained, separate from that in the storage and preparation laboratory.

7.5. Quality Assurance

(433) The following checks should be undertaken at intervals to ensure that:-

(a) sources are all located in the place recorded in the log book. If not, an immediate search should be instigated;

(b) all sealed sources are checked for leaks;

(c) all radiation alarm systems are functioning correctly;

(d) the automatic after-loading mechanism is functioning correctly;

(e) the performance of devices used to measure radiation or activity is unchanged.

8. PRACTICAL ASPECTS OF THE PROTECTION OF THE WORKER IN EXTERNAL BEAM RADIOTHERAPY

8.1. Planning and Design

(434) Exposure of workers during modern external beam therapy procedures is generally very low because contact of the personnel with the primary beam is practically non-existent, except in rare instances of technical emergencies involving stationary sealed sources of ^{60}Co and ^{137}Cs used in teletherapy. Exposure of therapy technicians during positioning of the patient is very low and limited only to leakage radiation from the radionuclide source or some induced activity in parts of the high voltage electron accelerators. Exposure during patient irradiation is essentially nil. However, in neutron therapy the exposure to gamma rays from induced activity in the installation may be substantial.

(435) The planning and design of external beam radiotherapy rooms differs from that required for diagnostic x-ray rooms because the radiation dose rates within the former are considerably higher and the staff never occupy rooms during radiation treatment. An exception may be made in the case of equipment operating at tube voltages below 140 kV; the special circumstances associated with this are described in paragraphs 456 and 457.

(436) National or local authorities or the hospital management responsible for the provision of beam therapy equipment should be prepared to replace obsolete equipment if such equipment could give rise to excessive exposure of staff.

(437) The safety of staff is achieved by structural shielding in the walls, floors and ceilings surrounding the treatment rooms and by a system of interlocks and radiation barriers. The structural shielding shall be optimized to be of adequate thickness to ensure that the levels of radiation outside the treatment room are within authorized limits. Appropriate data on shielding requirements are provided in the Appendix to *ICRP Publication 33* (ICRP, 1982a) (see Appendix C of this document), in *ICRP Publication 37* (ICRP, 1983) and *ICRP Publication 51* (ICRP, 1987b) and in *NCRP Publication 49* (NCRP, 1976).

(438) Dose rates outside the treatment room should be time-averaged to determine compliance with dose-equivalent limits. Time-averaging allows for the beam on/off ratio and beam orientation (for primary barriers only). If necessary, time-averaging may also include allowances for the field size of the beam and for attenuation by the patient. However, allowance should be made for abnormal circumstances that might invalidate the time-average calculations (e.g. protracted calibration measurements by physics staff, protracted whole body irradiation, or staff-sharing on more than one machine).

(439) The aim of planning of the area immediately outside a treatment room should be to produce an area which is neither controlled nor supervised. Time-averaging will indicate a safe level of shielding, assuming no alteration of usage of the room. Optimization will indicate if further shielding above this level is justified.

(440) If intra-operative therapy is performed in the operating theatre, then the theatre shall be protected to the same extent as the treatment room and all the safety precautions and work practices shall conform to those used in external beam therapy.

(441) When planning a treatment room the possibility of a future change in the radiation generating equipment should be considered, since currently planned equipment may subsequently be replaced by equipment generating radiation of a different type or of a higher energy. It may prove to be cheaper and less disruptive to include additional shielding in the initial building rather than to attempt major modifications at a later date.

(442) The entrance to a treatment room should be through a suitable maze or via a shielded door or

even a combination of maze and shielded door. Design of the entry passage should take into account all permitted directions of the primary beam, in addition to the levels of leakage and scattered radiation. Account should be taken of the type(s) and energy of the radiation to be used or induced (e.g. photons, electrons, neutrons). In some instances, measurements outside the treatment room have shown a significant neutron dose-equivalent rate outside the door of a labyrinth. The maze will absorb a lower percentage of neutron radiation compared with other types of radiation.

(443) A radiation warning sign shall be placed at the entrance to any treatment room. There shall also be a visual signal at the entrance, which should be linked to the control console, and this should be designed to light up several seconds prior to the radiation beam being switched on.

(444) The door to the treatment room shall be fitted with a suitable failsafe interlock system to prevent the radiation beam from being switched on unless the door is closed. If there is no door, and access to the treatment room is only through a maze, entry via the maze shall be controlled by an interlock system (e.g. a multiple light beam and photoelectric detector incorporating two detector systems). One of the detector systems should be located sufficiently close to floor level to be activated if a small child enters the maze. The interlock system shall ensure that, if either the door is opened or the light beam is intercepted, the radiation beam will be switched off immediately and can only be switched on again after the controls on the console have been deliberately reset manually [NCRP Report No. 88 (1986)].

(445) Services to the room, such as ventilation shafts and conduits for connecting cables, shall be installed in a manner that will not compromise the integrity of any protective barrier through which they pass.

(446) The construction of the roof and floor of a treatment room should provide adequate shielding in order that areas above and below the room do not need to be controlled areas. However, if the shielding is inadequate, access to these areas should be restricted and be permitted only when the equipment in the treatment room is switched off.

(447) If the floor of a treatment room is of insufficient thickness to provide adequate shielding, consideration should be given to the possibility of scattered radiation to areas below the treatment room. Similarly, if the ceiling of the treatment room is of insufficient thickness to provide adequate shielding, consideration shall be given to the possibility of sky-shine radiation (Kathren, 1985) to areas around the treatment room to a distance of tens of metres. Sky shine affects the area on the same geographic level as the treatment room — i.e. the area which would otherwise be expected to be protected by adequate *side* walls.

(448) Where there is insufficient structural shielding, particularly in a specific direction, consideration should be given to the use of a beam interceptor (stopper) as an alternative to an increase in structural shielding. Such a stopper should not transmit more than 0.1% of the primary beam. It should also reduce scattered radiation from the patient by a similar amount through an angle up to 30° from the central ray. If the beam stopper is not fixed in position, mechanical or electrical stops should be provided to ensure that the primary beam cannot be switched on when aimed in an unsafe direction unless it is intercepted by the beam stopper or another primary radiation barrier [*NCRP Publication 49* (NCRP, 1976) and *ICRP Publication 51* (ICRP, 1987b)].

(449) Inside the radiation treatment room there shall be a visible and/or audible alarm to indicate that radiation is being or is about to be emitted, especially when the radiation beam is emitted by a sealed source. There shall be an emergency shut-off system that can be operated by anyone who inadvertently remains in the room when the radiation beam is switched on. It may be necessary to provide more than one location inside the room from which the emergency shut-off system can be operated, in order to avoid the necessity of having to pass through or close to the primary radiation beam. The system shall be so designed that treatment can be recommenced only after both the shut-off system and the controls on the console have been deliberately reset manually.

(450) For therapy machines using radionuclide sources, a sufficiently sensitive radiation detector should be provided, with both visible and audible alarm signals inside and outside the treatment room. This alarm will indicate that the source is in the treatment (i.e. "exposed") position. Thus if the source is left exposed unintentionally because of a failure in the shutter or transport mechanism, adequate warning will be given. The alarm system should have a battery-powered back-up supply in case of failure of the electrical mains supply.

(451) Radiation therapy machines shall be equipped with locking devices to prevent unauthorized use.

(452) The design and radiation safety requirements for the simulator room should be in accordance with the requirements for a typical diagnostic x-ray room, as described in Section 4.2. However, unlike normal diagnostic practice, the primary beam size may exceed the image receptor area and give rise to an unexpected radiation hazard.

8.2. Classification of Areas

(453) In external beam radiotherapy, the levels of radiation throughout the treatment room, and in the entrance maze, are high when the radiation beam is switched on and this shall be designated a controlled area. Hence, during treatment, occupation of these areas shall be prohibited at all times to all except the patient being treated.

(454) Access to treatment rooms shall be restricted to those authorized to enter these areas and to patients undergoing treatment. For linear accelerators and other electrical machines designed to generate radiation, a radiation hazard exists only when the machine is energized (except for neutron therapy and for a small quantity of induced residual radioactivity produced by high energy machines). In view of this, access of authorized personnel to the treatment room need not be restricted when the radiation beam is switched off, provided a system of locks, interlocks, signals and written instructions is in operation to ensure that the machine cannot be switched on inadvertently.

(455) In therapy machines equipped with radionuclide sources such as ^{60}Co and ^{137}Cs the radiation is produced continually. Hence, access to such treatment rooms shall always be restricted. When the source is in the shielded (beam off) state, the radiation levels are low, being typically less than 10 $\mu Sv\ h^{-1}$ at 1 metre from the source housing; under these conditions entry is permissible for workers wearing personal dosemeters.

(456) If the voltage applied to the x-ray tube is less than 140 kV, the worker can be present in the treatment room, provided they occupy a special protected cubicle or area (see paragraphs 146, 150, 151, 154, 155) and wear suitable protective clothing.

(457) If the voltage applied to the x-ray tube is less than 50 kV, the worker may occupy the treatment room while the radiation beam is switched on. Under these circumstances, the worker should be provided with adequate protective clothing or shielding and the individual should wear a personal dosemeter.

8.3. Operational Procedures

(458) A worker who is required to enter treatment areas regularly should wear a personal dosemeter that is changed and assessed at regular intervals. Records should be kept of the doses received. The general principles of monitoring are dealt with in Section 3.7.

(459) To avoid an accidental exposure operators shall be certain that no one other than the patient is present in the treatment room when the radiation beam is switched on. To ensure this, the last worker to leave the room prior to the start of any treatment should carry out a visual check of the area, and

then confirm this to the operator supervising the control console prior to switching on the radiation beam.

(460) After beam therapy with sealed radionuclide sources, and before entering the treatment room, the worker should check the indicator outside the treatment room to confirm that the source is within its housing. On entering the treatment room, the worker should first check the position indicator of the source shutter, in order to confirm that the source has returned to the shielded housing. Normally, the radiation alarm system should have already alerted the worker to any failure in the shutter mechanism controlling the source.

(461) When X rays are generated above 50 kV but below 140 kV, a worker shall be permitted to remain behind a protective screen or within a protective cubicle, but shall not otherwise be permitted to remain in the treatment room during treatment.

(462) Different operational practices may be adopted when X rays are generated below 50 kV. The worker should stand behind a protective screen or within a protective cubicle. If it is necessary for the worker to be in the room and not shielded by a screen, a suitable protective apron of 0.25 mm lead equivalence should be worn. The worker should not hold the x-ray equipment by hand. Instead, suitable positioning clamps should be used. Extra care should be taken by the worker to avoid any accidental exposure to the primary beam.

(463) A sealed radioactive source of high activity (up to 30 TBq) may be used for extra corporeal irradiation of blood. All precautions relevant to the use of sealed sources in beam therapy shall be followed. Sources of similar strength may be used for the sterilization of medical products and equally, all precautions should be taken.

8.4. Emergency Procedures

(464) In beam therapy with sealed radionuclide sources, an emergency plan should be permanently displayed both within the treatment room and at the control console or entrance to the room. All workers should be familiar with the emergency plan, which should detail the measures to be taken in the event of the source failing to return automatically to the safe position. Under these circumstances, the radiation field size should be reduced to a minimum without delay by closure of the diaphragms (if necessary, manually). The patient should then be removed from the room. Suitable instruments should then be used to return the source manually to the safe position. It may be necessary to keep a small ladder available in the treatment room for this purpose, in case the source head cannot be reached from floor level.

(465) Occasionally, it may be preferable to return the source manually to the safe position before attempting to remove the patient, particularly if considerable time and effort would be required to move an ill patient. Any extra dose the patient may have received can be estimated and allowance made in the total dose to be delivered during the full treatment course.

(466) All persons involved in these emergency measures should be individually monitored and the doses they receive should be assessed immediately after these measures have been carried out.

(467) Under no circumstances should staff move across the line of the primary radiation beam when attempting to close the shutter or remove the patient.

(468) If the source cannot be removed to the safe position readily and quickly, the room should be evacuated immediately. Service personnel familiar with the design of the equipment and the required safety measures should be summoned for assistance. They should work in collaboration with the radiation safety officer (see paragraph 75).

(469) In the event of fire in a treatment room housing an x-ray source, the hazards are those of fire only, once the equipment has been switched off.

(470) In the event of fire in a treatment room housing a sealed radionuclide source, the possibility

that radioactive material may escape from the source housing cannot be ignored. However, the fire hazard will generally outweigh any radiation hazard, and the first action should be to remove the patient. When the fire emergency is over, the area, and any persons who have entered the area during the emergency, should be monitored for possible contamination. Decontamination procedures should be instituted, if necessary. Water used to extinguish the fire may become contaminated prior to drainage. In such circumstances it will be necessary to inform the appropriate water authority. Local fire-fighting personnel should be informed in advance of the type and activity of the radionuclides on the premises, in order that they may take appropriate precautions when dealing with the emergency. Workers should not re-enter the area until either the radiation safety officer or the radiation protection adviser has declared it safe to do so.

8.5. Worker Protection in Neutron Therapy

(471) The extent to which shielding is required with respect to the beam in neutron therapy is the same as that required in all forms of external beam therapy. The dose-equivalent rate from neutron radiation should be reduced to at most 1 μSv h^{-1}* outside the treatment room and to 2.5 μSv h^{-1} or less at the entrance to the labyrinth (Bonnett, 1983). Separate shielding requirements are necessary to deal with induced radioactivity, which persists after the beam has been switched off.

(472) Additional problems in neutron therapy arise from induced activity in the following areas:

(a) treatment gantry and beam limiting devices, especially the target area;
(b) treatment room couch;
(c) treatment room walls, floor and ceiling;
(d) neutron generator facility, including accelerating device, beam transport system and target;
(e) around the patient: after treatment it may be necessary to establish a controlled area around the patient for a limited period of time (typically a few hours), particularly if a large dose has been given.

(473) The induced activity may be both short-lived and long-lived. It should be made clear that activation levels depend critically upon the composition of the irradiated material and the energy of the neutrons. Typically, the major sources of induced activity within the room are the gantry and target areas.

(474) Induced radionuclides having a short half-life may include:

^{56}Mn (154.8 min),^{11}C (20.5 min), ^{28}Al(2.5 min), ^{15}O (2.05 min).

An indication of the potential dose-equivalent rate from induced activity will depend upon the installation. Typical values given by Bonnett *et al.* (1988) show that levels up to 370 μSv h^{-1} can occur around the therapy unit five minutes after the cessation of neutron irradiation.

(475) Induced radionuclides having a long half-life may include:

^{54}Mn (312 days), ^{59}Fe (45 days), ^{56}Co (77 days), ^{60}Co (5.2 years).

An indication of the potential dose-equivalent rate from long-lived induced activity around the treatment machine head at an installation is given by Bonnett *et al.* (1988), who report 5 to 33 μSv h^{-1} after a normal weekend break of 60 hours duration.

(476) The original design should endeavour to use materials in construction which will not result in induced radioactivity, or will only cause low levels of short-lived radioactivity. The use of materials which will cause long-lived radioactivity should be avoided. A table of materials, together with neutron reactions likely to give problems, has been published by Bewley (1989).

(477) Measurements should be made both of radiation from induced activity and of radiation penetration of the shielding walls, using suitable monitoring instruments to provide confirmation that

*These values of dose equivalent relates to the dose equivalent for neutrons as defined before ICRP statement on quality factors for neutrons (ICRP, 1985a).

the shielding of the neutron therapy equipment is adequate on installation. Bonnett *et al.* (1980) reported that four successive modifications to the shielding of a neutron therapy installation were required before dose-equivalent rates from neutron-induced radiation were reduced to acceptable levels. A variation in the resulting dose reduction factor from 2 to 92 was measured at various locations around the shielding of the treatment unit.

(478) Working practices in neutron therapy are similar to the normal principles of radiation protection in beam therapy, particularly with respect to the time spent near the source of radiation and the distance from it. If the dose received by the worker from short-lived induced activity is significant, it may be reduced by allowing a short time interval of a few minutes to elapse before entering the treatment room after the neutron treatment beam has been switched off. However, a significant dose may still be received from longer-lived induced activity.

(479) Individual doses received by workers may be reduced by rotating their duties to other treatment machines (e.g. only working for 3 months per annum on neutron therapy) although such rotation does not reduce the collective dose equivalent. Moreover, after such absences from work with the neutron therapy equipment, workers may lose some of the necessary manual skills and work more slowly. Consequently, they would be likely to receive increased doses. For high energy machines with a high patient work load, the highest doses are likely to be received by the radiographic staff, rather than physicists, engineers or radiotherapists.

(480) Both individual and environmental monitoring for neutron radiation is required in addition to the monitoring requirements for beta and gamma radiations. Environmental monitoring may need to include assessments of the neutron energy spectrum or the Linear Energy Transfer spectrum, in order to determine the appropriate value of the quality factor and enable the neutron radiation dose equivalents to be interpreted correctly. According to Bonnett (1983), typical annual dose equivalents received by workers in a neutron therapy facility were 2.6 mSv* from neutron radiation, and for beta and gamma radiations an average of 5 mSv with a maximum of 10 mSv. However, Jones *et al.* (1971) quote annual dose equivalents to engineering staff of 5 to 70 mSv in a cyclotron installation used for both the treatment of patients and the production of radionuclides. Further references to staff doses may be found in Rosenberg *et al.* (1984) and Eenmaa *et al.* (1987).

(481) Monitoring procedures should include:

(a) monitoring the ventilated air from the cyclotron vault for induced airborne activity. If the level is above that specified by the statutory authority, then discharge must take place at high level so that there is no risk of contamination of the workers;

(b) whole body monitoring of maintenance engineers; they are subject both to external radiation from induced activity, and internal radiation from inhaled dust, particularly ^{65}Zn produced by proton bombardment of ^{64}Cu.

(482) The highest single doses are likely to be received by those workers who carry out maintenance and repair of the neutron therapy machine (e.g. physicists, engineers). If, when working on the machine, there is likely to be a hazard from radioactive dust or other loose contamination, suitable protective clothing should be worn (e.g. overalls, respiratory masks, disposable gloves, glasses and overshoes) and contamination monitoring procedures adopted.

8.6. Quality Assurance

(483) A quality assurance programme related to the safety of the worker should be implemented. It should include the following:

(a) a daily check to confirm that the interlock system at the entrance to each treatment room functions correctly;

*These values of dose equivalent relates to the dose equivalent for neutrons as defined before ICRP statement on quality factors for neutrons (ICRP, 1985a).

(b) a daily check that the emergency system in the treatment room functions correctly. An additional emergency stop button outside the treatment room, but connected into the same electrical circuit as those inside the room, permits this check to be performed without staff being exposed;
(c) periodic checks on the function of all warning systems — this includes the radiation warning alarm in a treatment room housing a sealed radionuclide source;
(d) periodic checks, where appropriate, on the function of interlocks at access points to the basement or roof areas of treatment rooms;
(e) checks for contamination on the external surface of the sealed radionuclide therapy equipment on installation, at regular intervals and whenever the source is replaced;
(f) checks on the levels of leakage radiation through the source housing on installation, after major repairs and whenever the source is replaced;
(g) periodic checks on:
    (i) radiation beam output,
    (ii) uniformity,
    (iii) penetration (beam energy),
    (iv) accuracy of beam direction.

(484) Account should be taken of the sensitivity of any monitoring equipment to radiofrequency interference from the operation of nearby high energy electrical generators. Radiation detectors may also give false low readings around an accelerator installation because of the pulsed nature of the radiation. In order to permit the correct average level of radiation to be determined, survey instruments should be capable of responding correctly to levels of radiation a factor of 1000 times greater than the average.

(485) When atomic particle accelerators operating above 10 MeV are being serviced, consideration should be given to the possibility of radiation being emitted from induced activity on collimator parts. Particle accelerators using high voltage supplies typically emit X rays from high voltage components, e.g. magnetron and klystron tubes. Notices warning service personnel should be displayed in the vicinity of these devices.

9. PROTECTION OF THE WORKER IN BALNEOTHERAPY

(486) In many countries, radon and its daughter products in water and air are used for the treatment of non-malignant disease. The justification for these practices should conform with the recommendations in *ICRP Publication 33*, paragraphs 32 to 39 (ICRP, 1982a) and the *Statement from the 1987 Como meeting of the ICRP* (ICRP, 1987a). Once a procedure has been justified with respect to the benefit to the patients, any worker involved shall be regarded as occupationally exposed to radiation and subject to the full system of dose limitation recommended by the Commission.

(487) The exposure of staff to this type of therapy is due mainly to radon from deep-well water; or to a much lower degree from the ground underlying the therapy rooms. The exposure is exclusively from inhalation and results in irradiation of the respiratory tract by aerosols containing radon daughters.

(488) Certain countries, which regulate the practice of balneotherapy, require the radon daughters to be filtered out. This will reduce the doses to both patients and bath attendants. Doses to maintenance workers may be less affected.

(489) The risk of lung cancer associated with exposure to radon is correlated with the energy of the alpha particles emitted per unit volume of air by radon daughter products expressed in working levels (wl). However, it is more convenient to consider a "working level month (wlm)" based upon an

exposure time of 170 hours per month. The wlm is equivalent to 3.5×10^{-3} J h m^{-3}. The occupational dose limit is 4.8 wlm per year (ICRP, 1986a).

(490) The principal groups of workers who are at risk are bath attendants and maintenance workers. Levels of 0.5 to 5.0 wlm per year have been recorded for attendants and 10 to 20 wlm per year for service engineers. The doses received may therefore exceed the occupational dose limit. There is no justification for an exception to be made for work of this nature. Therefore, these workers shall be subject to the occupational dose limits, and optimization of radiological protection regarding working practices should be undertaken (e.g. wearing masks, efficient ventilation).

(491) If it is suspected that the levels of exposure exceed three-tenths of the annual dose limit, a system of individual dosimetry shall be introduced.

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Wrixon, A. D. and Linsley, G. S. (1982) Derived limits for surface contamination: supplement to Report NRPB-DL2. Available from NRPB, Chilton, Didcot, Oxon OX11 ORQ.

APPENDIX A : SKIN DECONTAMINATION PROCEDURES

A.1. Introduction

(A1) Decontamination is discussed in paragraphs (299) to (302). However, the measures described in that section might not be adequate to deal with severe skin contamination and the following more detailed procedures may need to be considered to deal with contamination arising from the use of radionuclides in medicine. If contamination cannot be dealt with by the measures described in this Appendix, the worker should be referred for specialist treatment.

(A2) Decontamination procedures should preferably be carried out near the entrance to a controlled area or in an area set aside for this purpose. All washings should be treated as radioactive liquid waste and disposed of appropriately.

(A3) Anyone assisting in decontamination procedures should wear impervious disposable gloves and other appropriate items of protective clothing (e.g. apron, cap, mask, foot cover).

A.2. Decontamination of intact skin

(A4) Monitor body surfaces and clothing carefully to identify areas of contamination. Remove clothing carefully to avoid spreading contamination. Note any wounds or abrasions and cover these immediately with an adhesive waterproof covering — give these priority treatment as described below.

(A5) First remove contamination from around body orifices, particularly the nose and mouth. Start decontamination procedures from the periphery of the contaminated area and work gently towards the centre. Avoid allowing contamination to spread to uncontaminated areas of the body.

(A6) Commence treatment with mild soap and water. Do not rub too hard. Use a soft nailbrush for fingernails; after use, thoroughly wash the nailbrush and check for contamination. If the brush is significantly contaminated, dispose of it as radioactive waste. If soap and water fail, use a weak solution of detergent. A stronger detergent solution may be used as a shampoo for contaminated hair. In the event of extensive body contamination, it may be necessary to shower. This should be delayed until after any areas of heavy contamination have been dealt with, and the shower should not lead to the significant contamination of unaffected parts of the body.

(A7) For persistent contamination carefully use a saturated solution of potassium permanganate, but ensure that no undissolved crystals of potassium permanganate come in contact with skin. Do not use these substances near the eyes or on hair. Leave the permanganate solution for a few minutes only, until the skin is deeply coloured, then wash off and allow to dry. Subsequently treat the pigmented areas with a 10% solution of sodium metabisulphite to remove coloration. If contamination still persists, the occupational health physician should be informed. This procedure may be repeated, but pay particular attention at all times to the condition of the skin. Stop immediately if redness or tenderness develops. The area may then be covered with lanolin and the treatment repeated the following day.

(A8) An alternative method of dealing with fixed contamination is to cover the affected area with adhesive plaster and leave for one or two days. The contamination may be removed when the plaster is removed. However, if all else fails, and the level of, or nature of, contamination justifies further attempts at removal, use abrasive powders with extreme care.

A.3. Contaminated wounds and burns

(A9) Treat contaminated wounds and abrasions urgently and make as accurate an assessment as possible of the type and quantity of radionuclide in order to decide whether surgical intervention is required.

(A10) Irrigate the wound with sterile water or saline. Encourage free bleeding for about 1 minute.

(A11) Subsequently use bioassay and more sophisticated monitoring techniques to establish more accurately the extent of the radionuclide intake.

(A12) Abrasions and chemical burns on skin surfaces may be more susceptible to the entry of radionuclides into the body. Treat these with extreme care; surface-acting anaesthetic agents may be needed to relieve pain during decontamination procedures.

APPENDIX B: DOSE EQUIVALENT RATES IN THERAPY WARDS AND FLUOROSCOPY ROOMS

(B1) Figures B1 and B2 are contour maps giving an indication of dose rates in μSv h^{-1} at differing distances from a patient. For ease of understanding a point source is assumed. The dose rates are typical of those likely to be experienced after a tumour implant with a source of approximately 2400 MBq of ^{137}Cs or 1600 MBq of ^{192}Ir. If the source were for gynaecological treatment, using manual afterloading, it would be approximately four times higher in activity. The dose rates therefore would be higher by approximately a factor of 4. It should be noted that the actual dose rates at any point in the shielded area would be higher due to scatter.

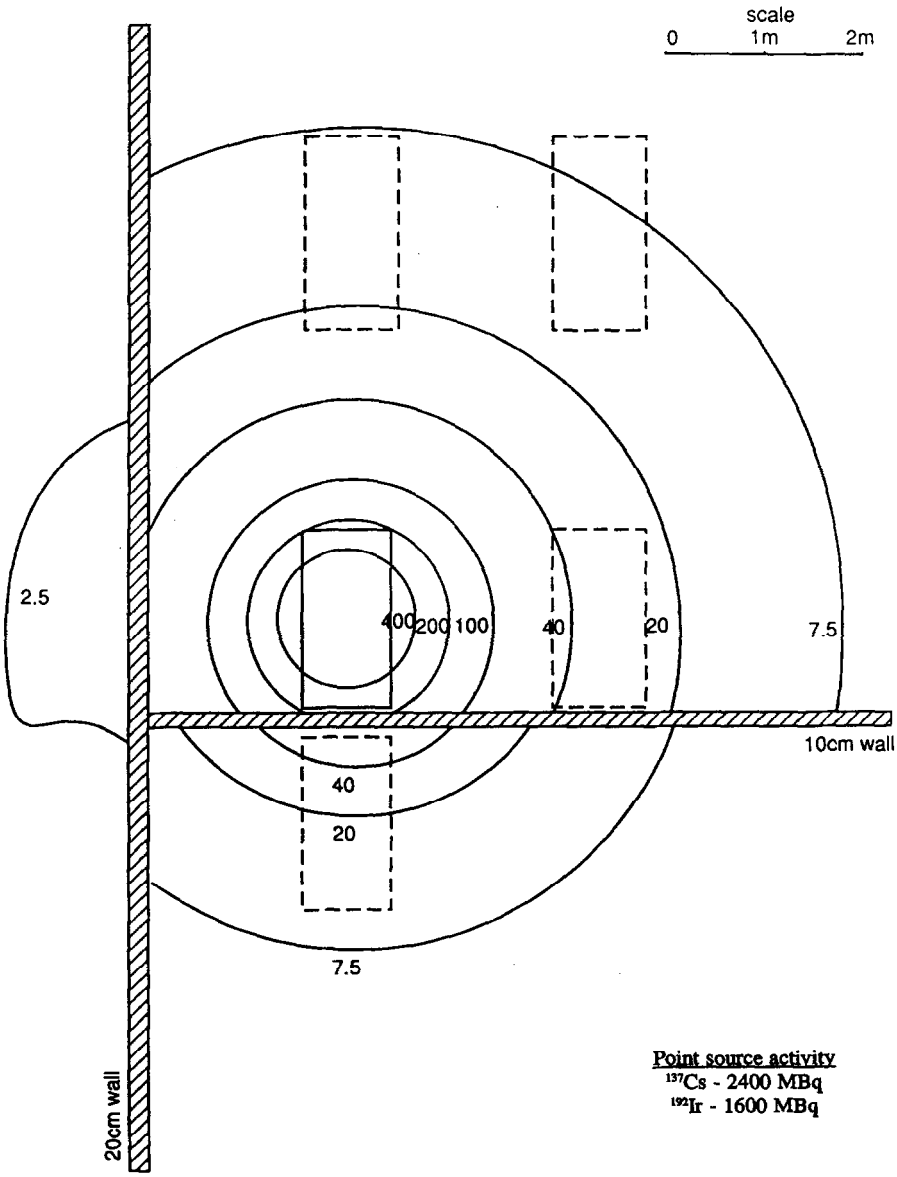


Fig. B1. Dose equivalent distribution in μSv h^{-1} around a point source, open ward, 10 cm and 20 cm walls, no lead barrier.

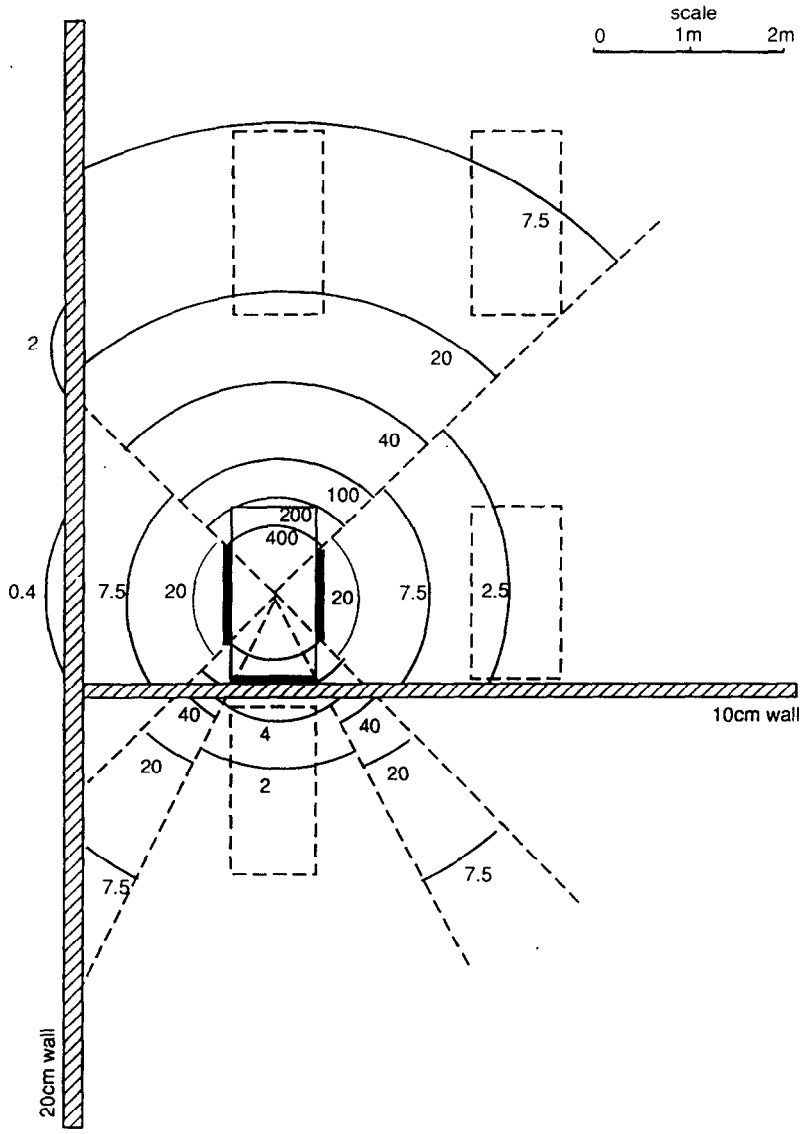
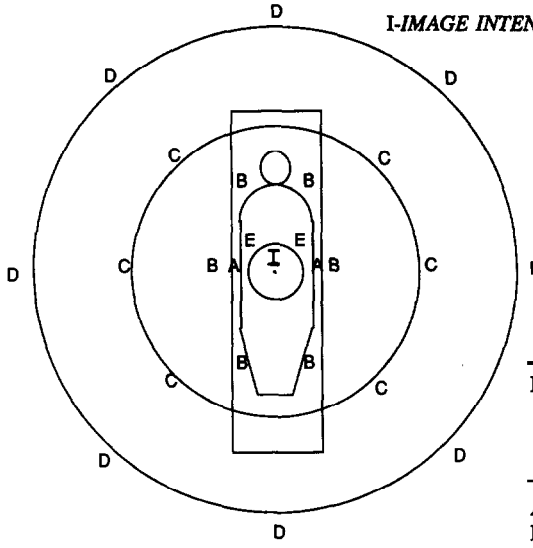


Fig. B2. Dose equivalent distribution in μSv h^{-1} around a point source, open ward, 10 cm and 20 cm walls, 2.5 cm lead barriers at head and sides of bed.

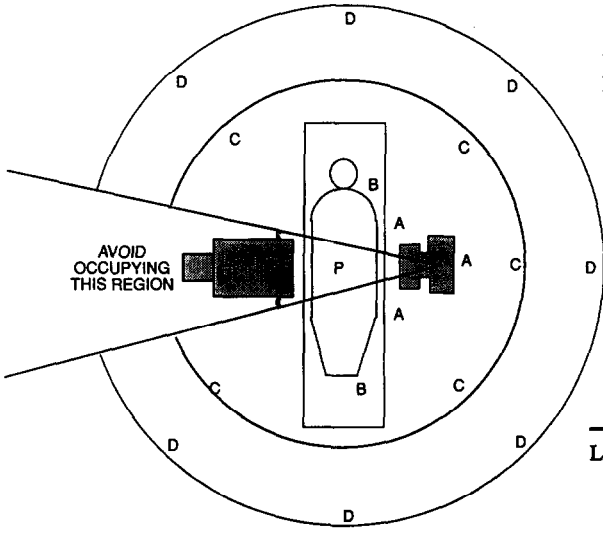
(B2) Figures B3 and B4 give dose equivalent rates in fluoroscopy rooms at various locations*. All measurements were made using a phantom lying horizontally. Figure B3 gives data for vertical fluoroscopy, and B4 for horizontal fluoroscopy. Positions A were at the side of the phantom close to the radiation field. Positions B were either at the side of the table, or at the head or foot of the phantom. Positions C and D were measured from the centre of the field (vertical fluoroscopy), and from the intersection of the centreline of the phantom with the central ray (horizontal fluoroscopy). Positions C were 90 cm from this point (approximately 60 cm from the side of the x-ray table) and positions D were 210 cm from this point (approximately 180 cm from the side of the x-ray table). For all positions of C and D, the dose equivalent rates are an average of measurements at 3 points per position, respectively 60 cm, 120 cm and 180 cm above floor level (N.B. figures are not to scale). For position E see the footnote to Fig. B4.

*Measurements were made by the Mersey Regional Radiation Protection Service (now Integrated Radiological Services Ltd.), 42 Rodney Street, Liverpool, L1 9AA, England, Director E.T. Henshaw.



Location	Radiation dose equivalent rate (μSv min^{-1}) when the x-ray machine operates at	
	75 kV 1 mA	90 kV 3 mA
A	70	350
B	10	50
C	2	10
D	1	2
*E	2000	10,000

Fig. B3. Diagnostic radiology. Vertical fluoroscopy - horizontal patient. Typical dose equivalent rates during vertical fluoroscopy with a 17 cm dia. mobile image intensifier.



Location	Radiation dose equivalent rate (μSv min^{-1}) when the x-ray machine operates at	
	75 kV 1 mA	90 kV 3 mA
A	20	100
B	10	50
C	2	10
D	1	2
*E	2000	10,000

Fig. B4. Diagnostic radiology. Horizontal fluoroscopy - horizontal patient. Typical dose equivalent rates during horizontal fluoroscopy with a 17 cm dia. mobile image intensifier.

*In Figures B3 and B4 this high dose rate will only be experienced (a) if alignment of x-ray tube and image intensifier becomes faulty; (b) during radiography with a mobile image intensifier when the film area (and therefore the field) is bound

APPENDIX C: TRANSMISSION OF X AND GAMMA RAYS THROUGH LEAD AND CONCRETE

(C1) Curves for the assessment of attenuation by concrete and lead are reproduced in this appendix. They are taken from *ICRP Publication 33* (ICRP, 1982a). Transmission of X rays through concrete is shown in Figures C1 - C3 and through lead in Figures C4 - C7. Transmission of gamma rays through concrete is shown in Figures C8 - C11 and through lead in Figures C12 - C15.

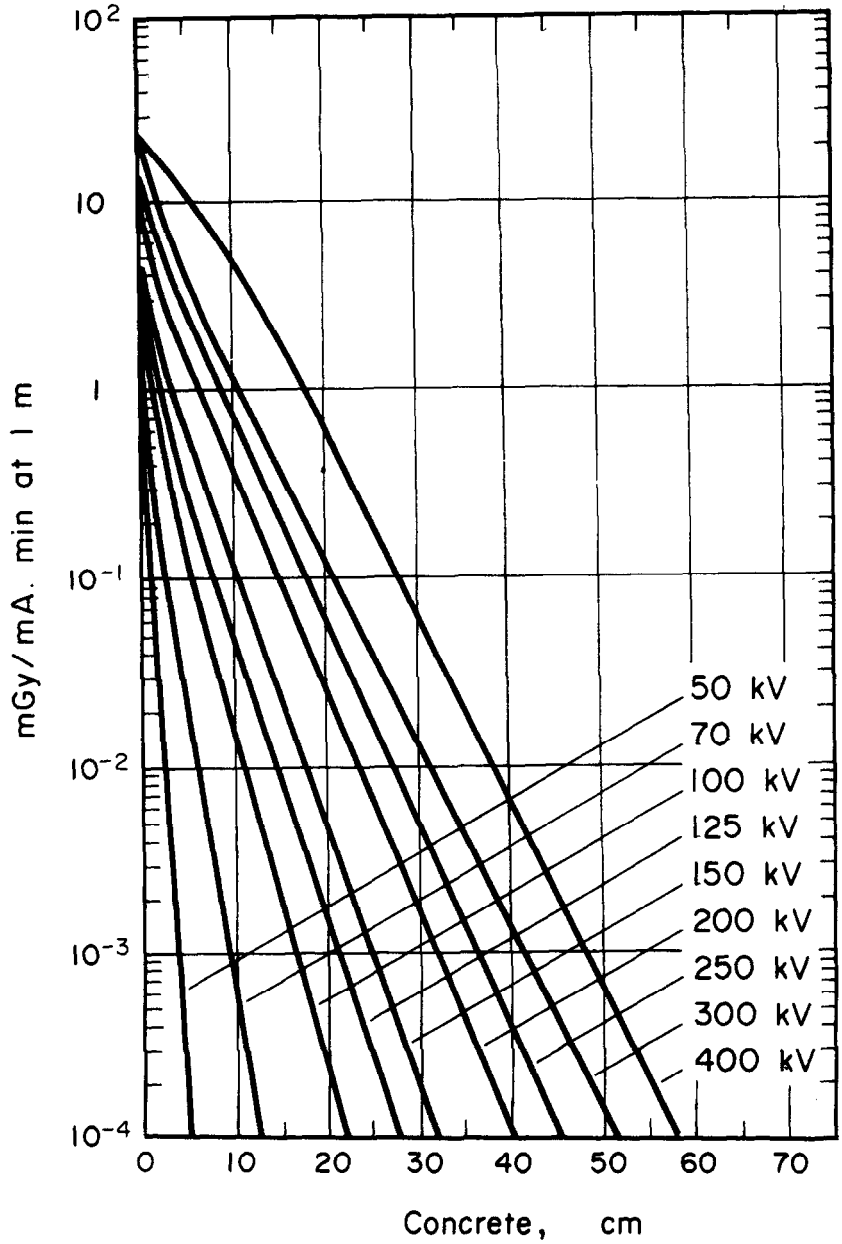


Fig. C1. Broad-beam transmission of X rays through concrete, density 2350 kg m^{-3}. 50-300 kV: half-wave generator; tungsten reflection target; total beam filtration 1 mm aluminium at 50 kV, 1.5 at 70, 2 at 100, and 3 at 125-300. 400 kV: constant potential generator; gold reflection target; 3 mm copper total beam filtration. Ordinate intercepts are 23.5 at 400 kV, 20.9 at 300, 13.9 at 250, 8.9 at 200, 5.2 at 150, 3.9 at 125, 2.8 at 100, 2.1 at 70, 1.7 at 50.

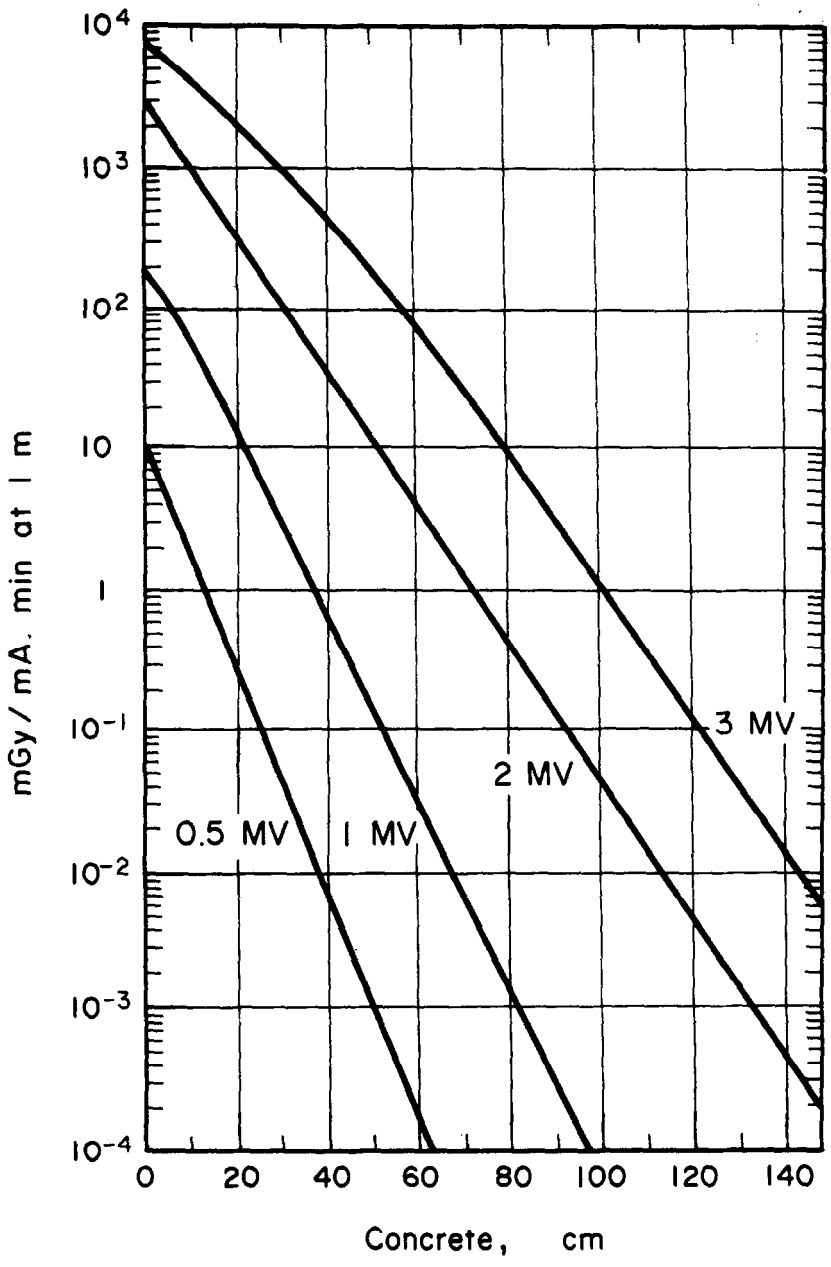


Fig. C2. Broad-beam transmission of X rays through concrete, density 2350 kg m^{-3}. Constant potential generators 0.5 and 1.0 MV: 2.8 mm tungsten transmission target followed by 2.8 mm copper, 18.7 mm water, and 2.1 mm brass beam filtration. 2 MV: high atomic number transmission target; 6.8 mm lead equivalent total beam filtration. 3 MV: gold transmission target; 11 mm lead equivalent total beam filtration. Ordinate intercepts are 7400 at 3 MV, 2600 at 2,170 at 1,9 at 0.5

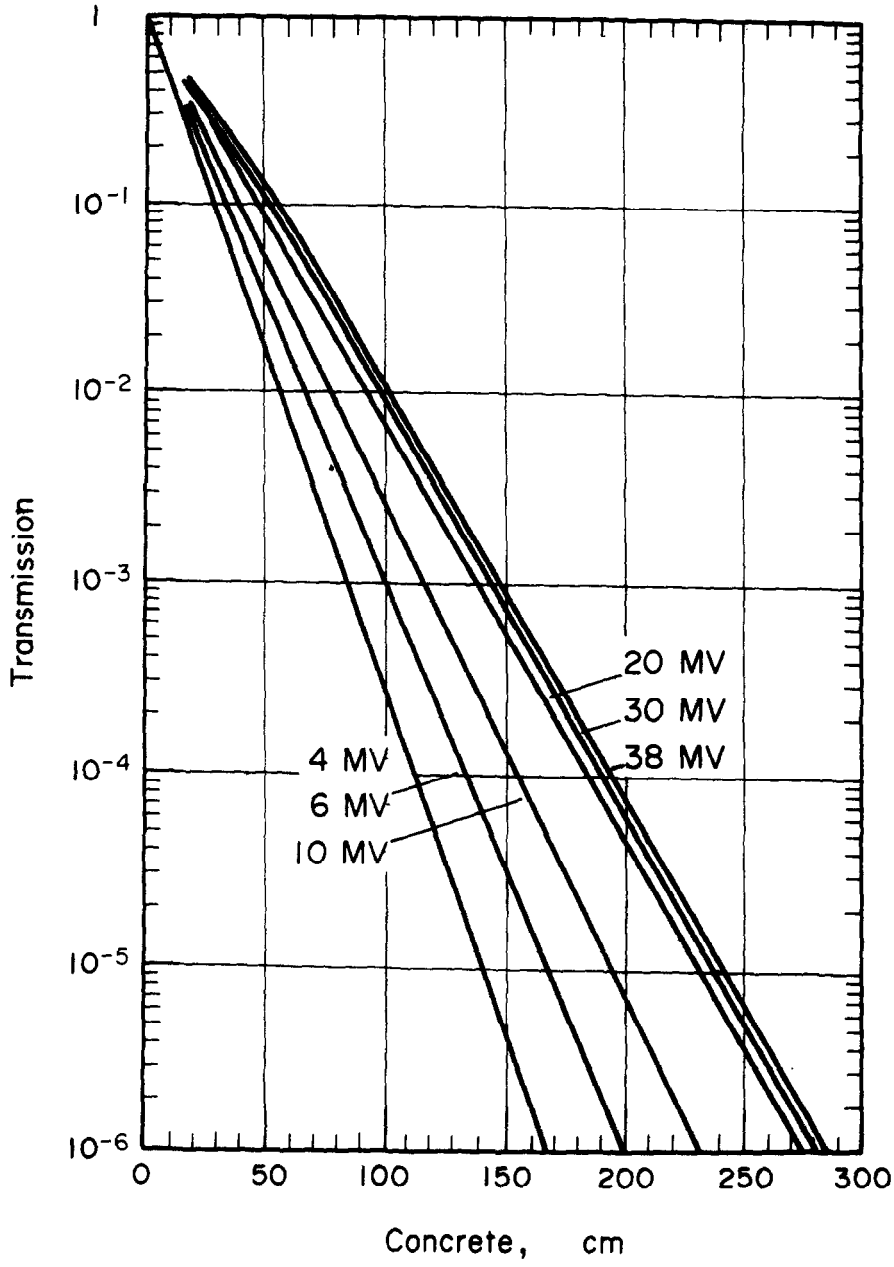


Fig. C3. Broad-beam transmission of X rays through concrete, density 2350 kg m^{-3}. 4 MV: linear accelerator; 1 mm gold target followed by 20 mm aluminium beam flattener. 6-38 MV: Betatron; target and filtration not stated. The 38 MV curve may be used up to 200 MV (Miller and Kennedy, 1956).

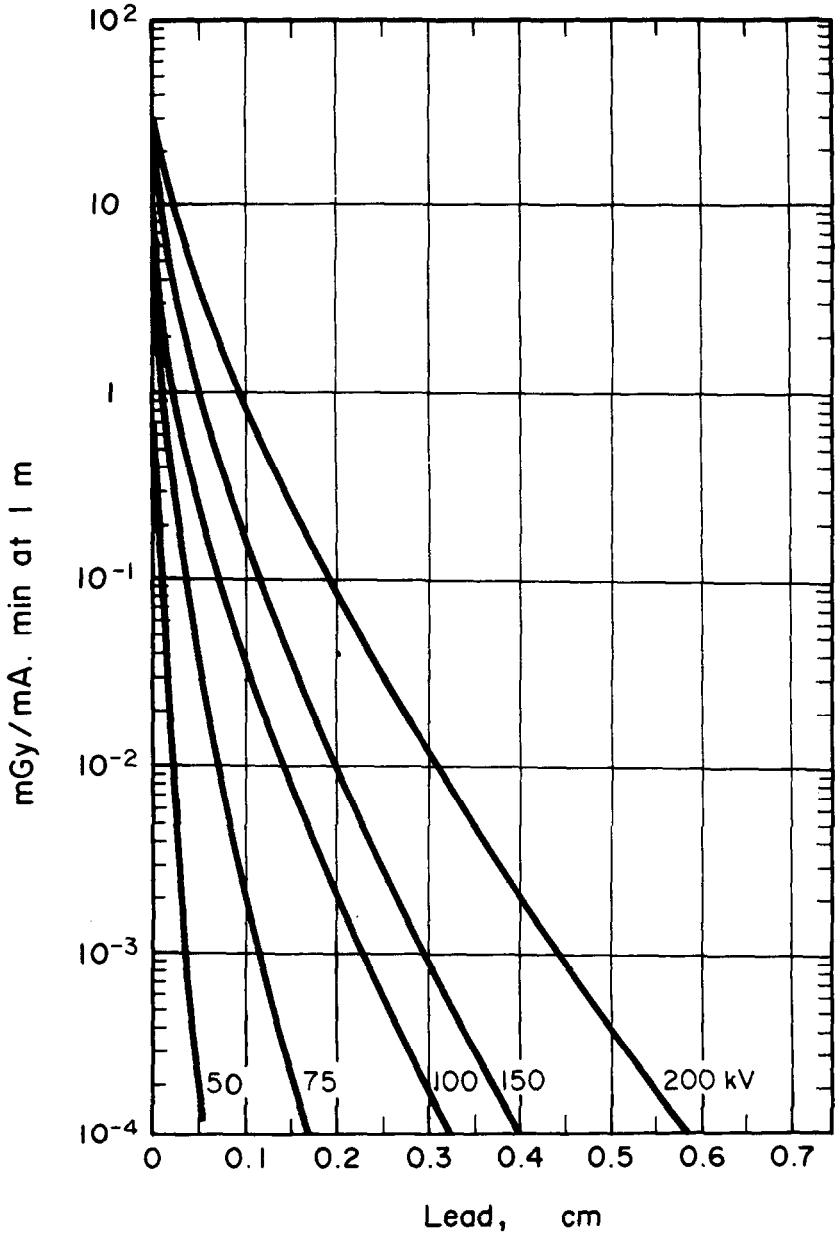


Fig. C4. Broad-beam transmission of X rays through lead, density 11 350 kg m^{-3}. Constant potential generator; tungsten reflection target; 2 mm aluminium total beam filtration. Ordinate intercepts are 28.7 at 200 kV, 18.3 at 150, 9.6 at 100, 6.1 at 75, 2.6 at 50.

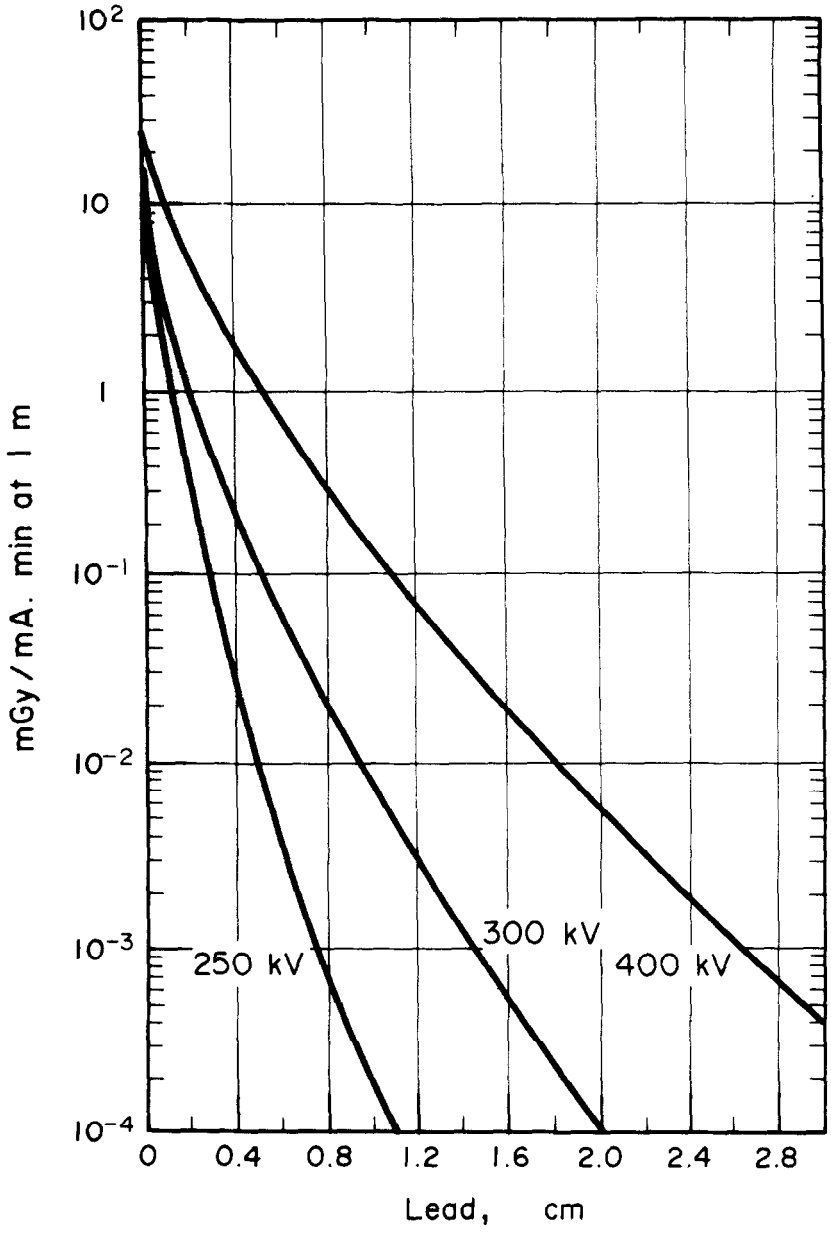


Fig. C5. Broad-beam transmission of X rays through lead, density 11 350 kg m^{-3}. 250 kV; constant potential generator; tungsten reflection target; 0.5 mm copper total beam filtration. 300 and 400 kV: constant potential generator; gold reflection target; 3 mm copper total beam filtration. Ordinate intercepts are 23.5 at 400 kV, 11.3 at 300, 16.5 at 250.

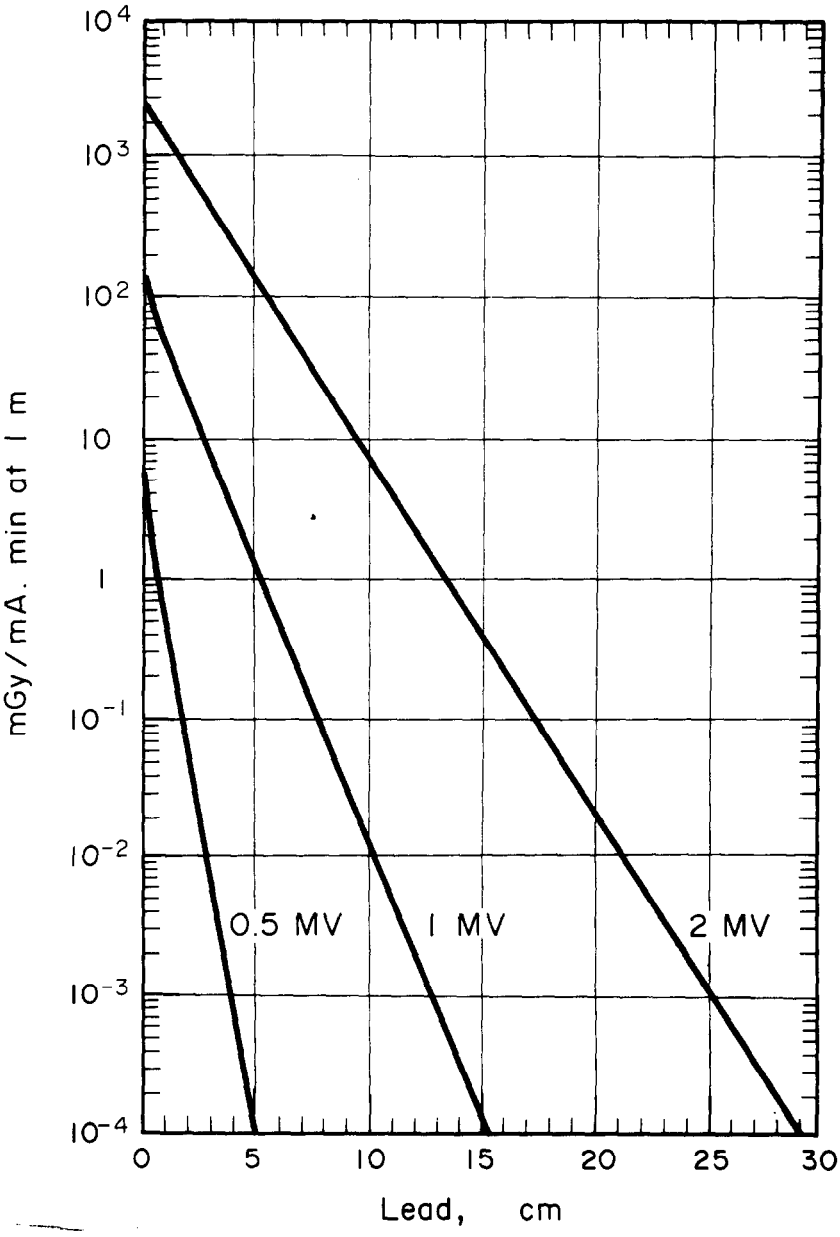


Fig. C6. Broad-beam transmission of X rays through lead, density 11 350 kg m^{-3}. Constant potential generators 0.5 and 1.0 MV: 2.8 mm tungsten transmission target followed by 2.8 mm copper, 18.7 mm water, and 2.1 mm brass beam filtration. 2 MV: high atomic number transmission target; 6.8 mm lead equivalent total beam filtration. Ordinate intercepts are 2610 at 2 MV, 174 at 1, 9 at 0.5.

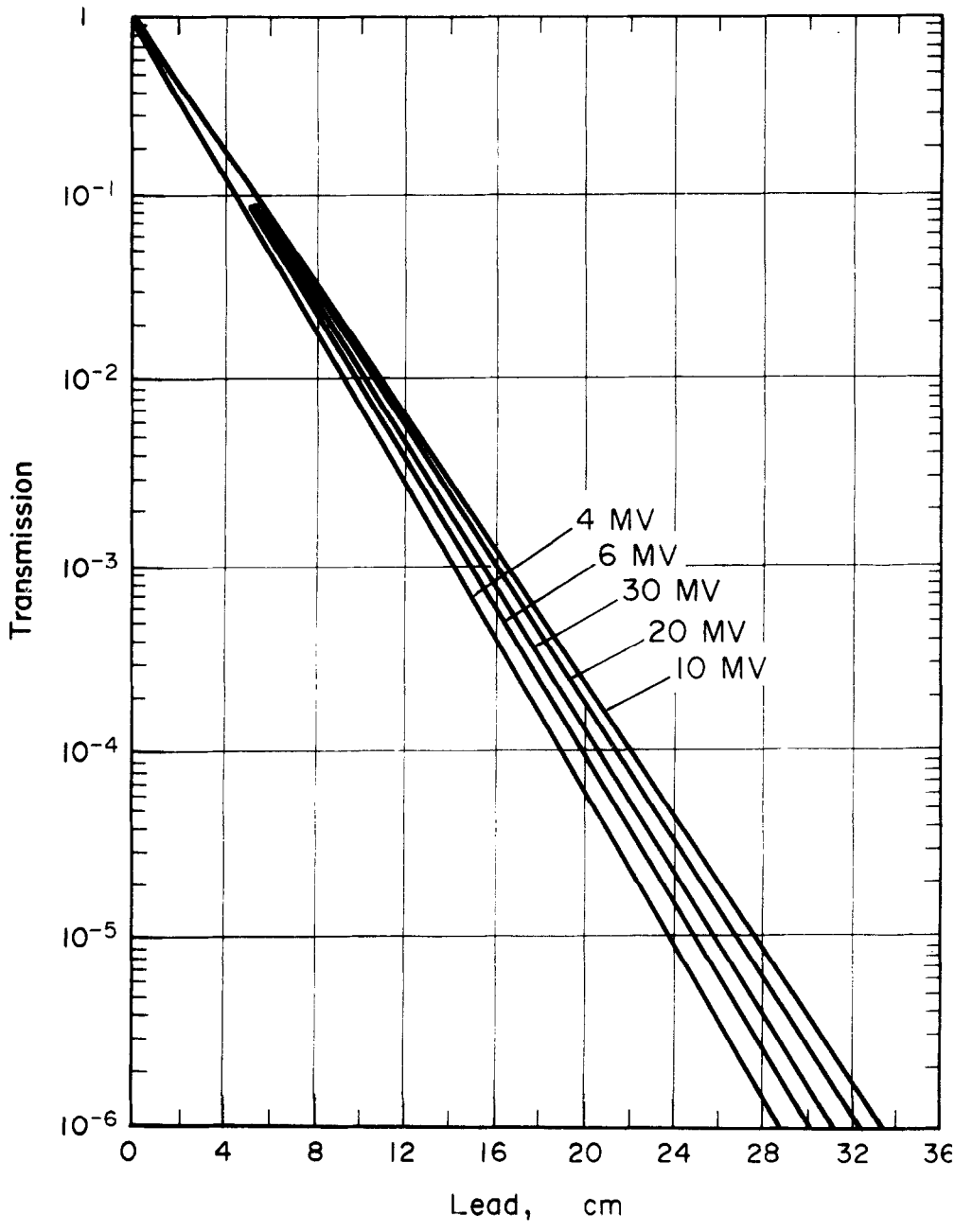


Fig. C7. Broad-beam transmission of X rays through lead, density 11 350 kg m^{-3}. Betatron; platinum wire target 2 x 8 mm; no beam filtration. For higher potential, see Miller and Kennedy (1956).

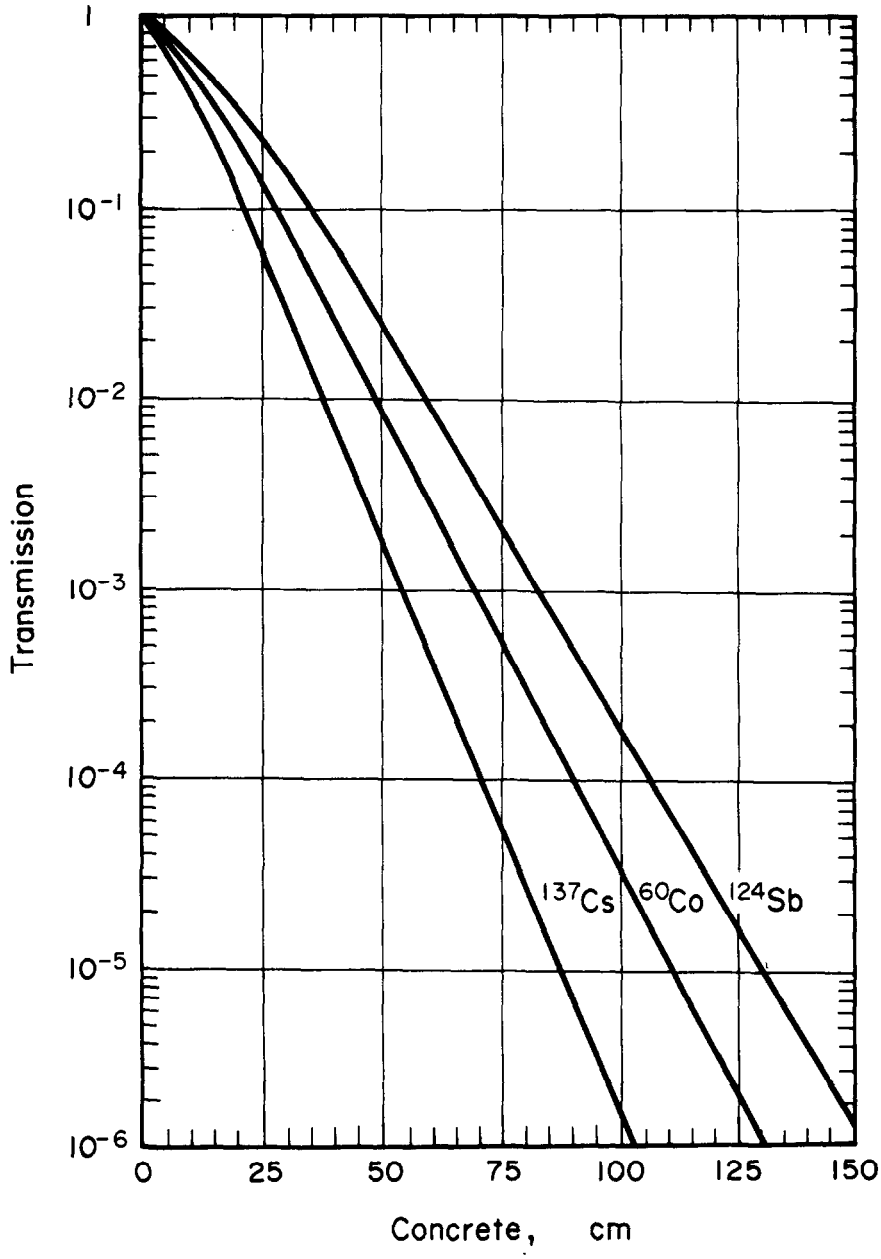


Fig. C8. Broad-beam transmission of gamma rays from various radionuclides through concrete, density 2350 kg m^{-3}.

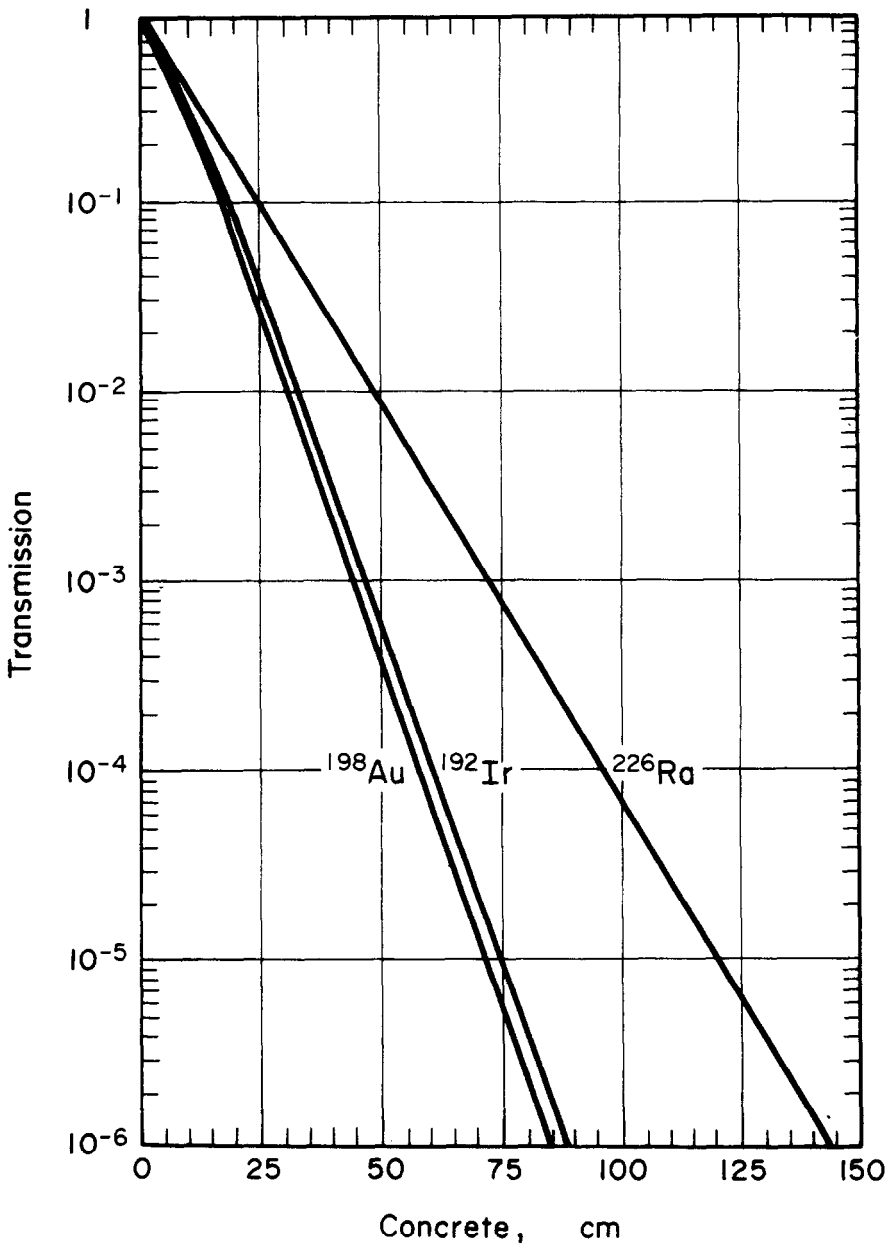


Fig. C9. Broad-beam transmission of gamma rays from various radionuclides through concrete, density 2350 kg m^{-3}.

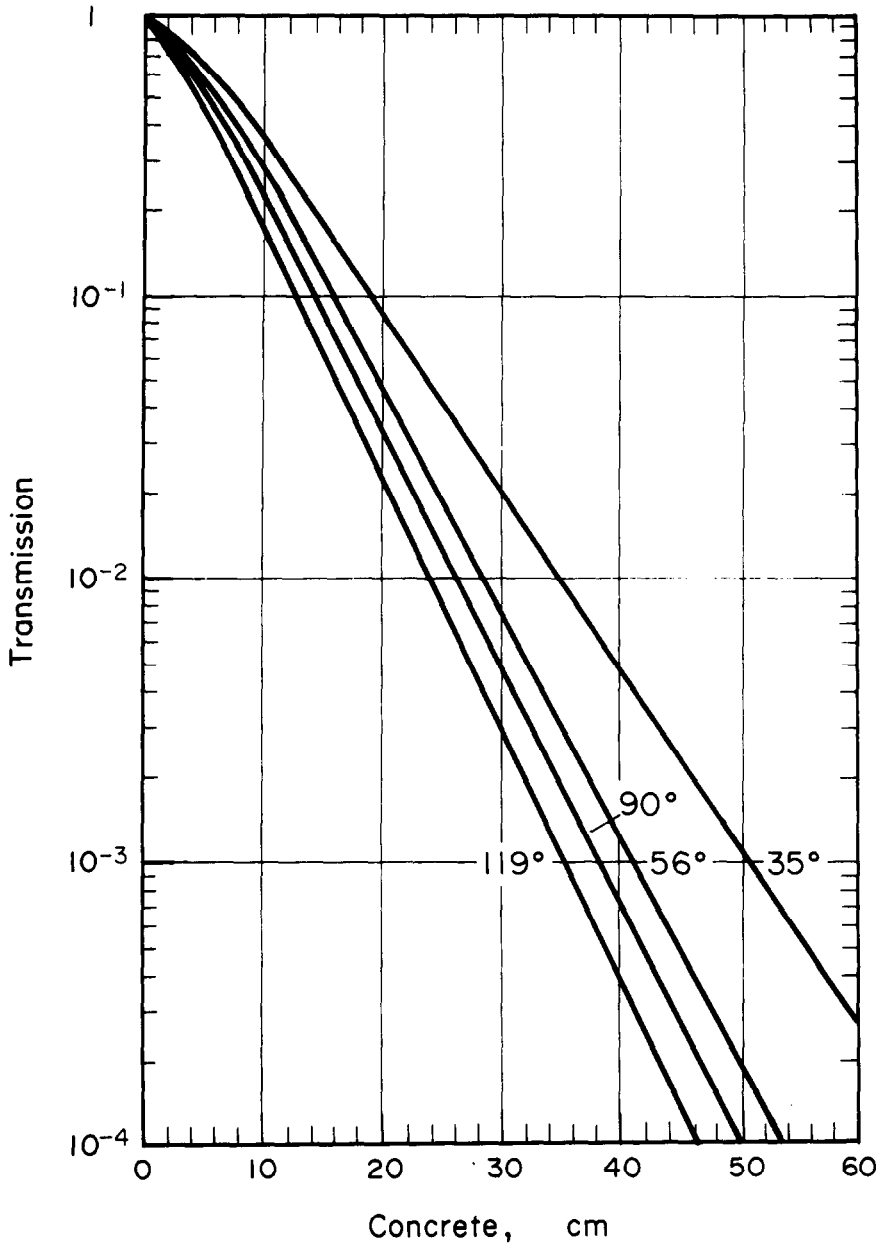


Fig. C10. Broad-beam transmission of ^{137}Cs gamma rays scattered at various angles from an oblique concrete wall through concrete, density 2350 kg m^{-3}.

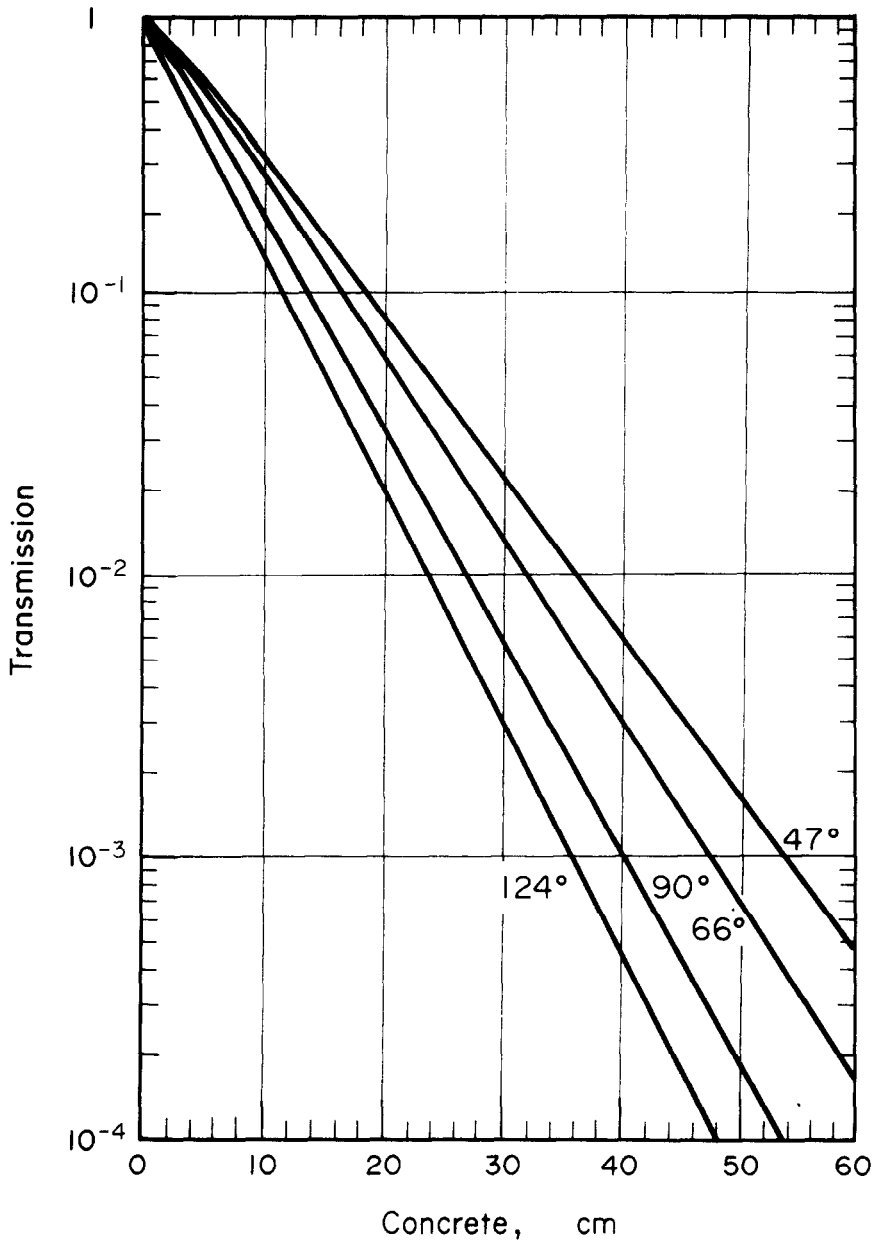


Fig. C11. Broad-beam transmission of ^{60}Co gamma rays scattered at various angles from a patient-simulating phantom through concrete, density 2350 kg m^{-3}.

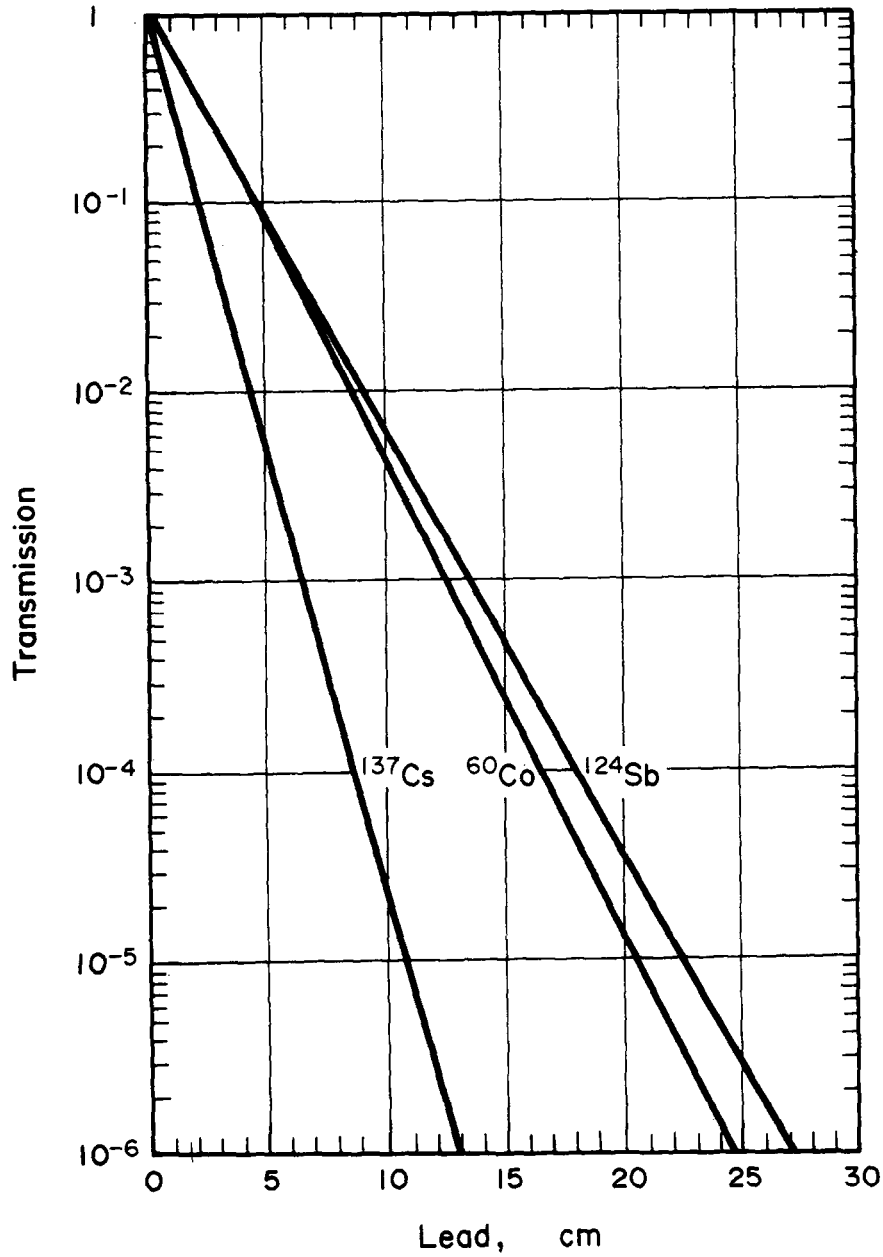


Fig. C12. Broad-beam transmission of gamma rays from various radionuclides through lead, density 11 350 kg m^{-3}.

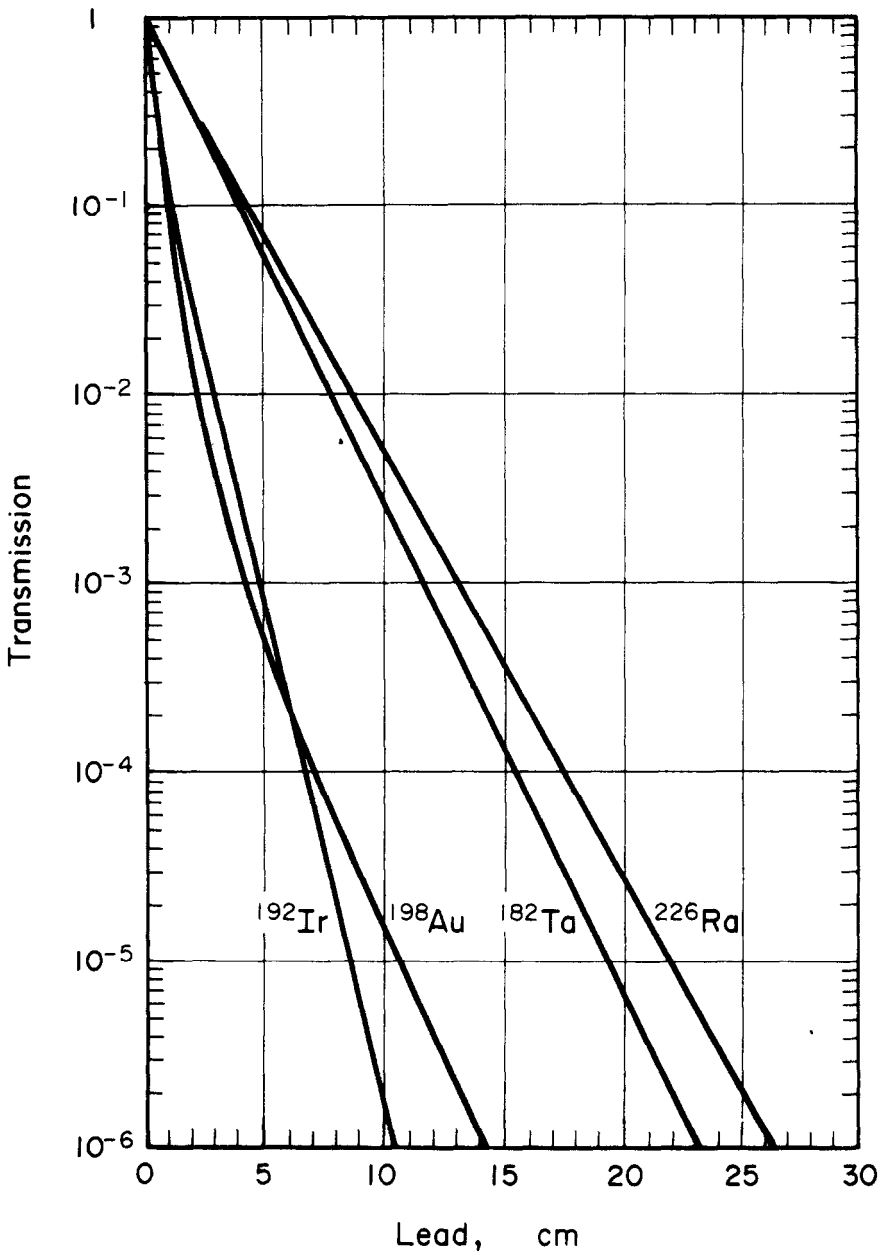


Fig. C13. Broad-beam transmission of gamma rays from various radionuclides through lead, density 11 350 kg m^{-3}.

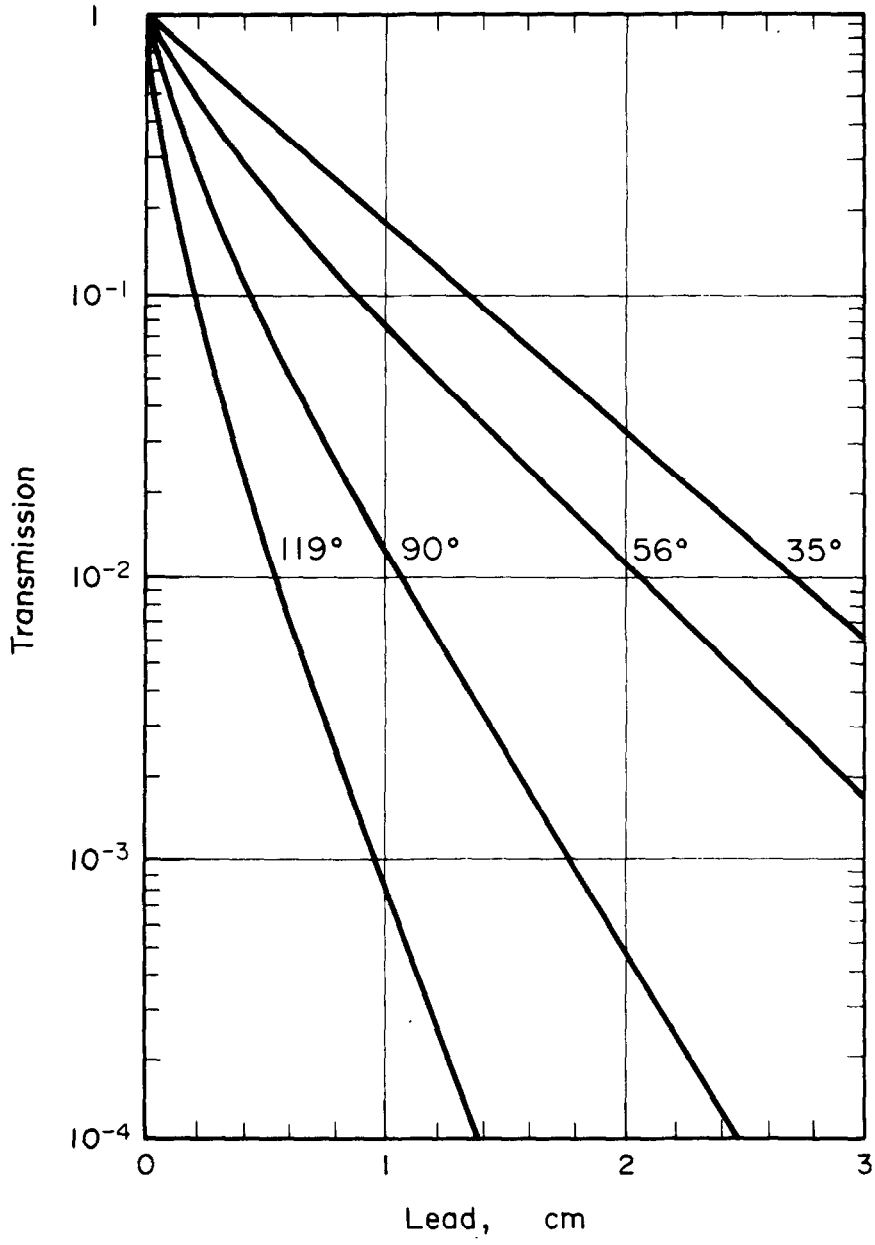


Fig. C14. Broad-beam transmission of ^{137}Cs gamma rays scattered at various angles from an oblique concrete wall through lead, density 11 350 kg m^{-3}.

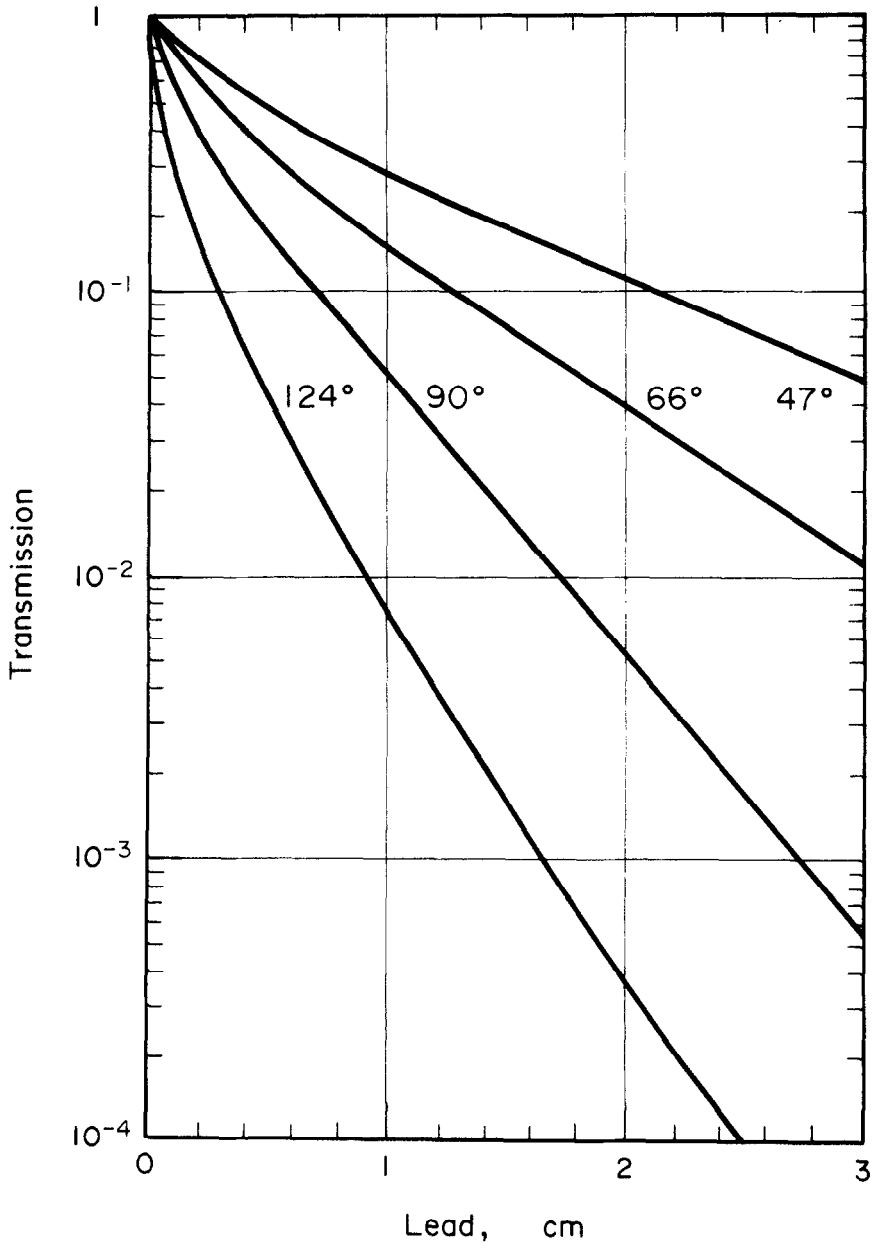


Fig. C15. Broad-beam transmission of ^{60}Co gamma rays scattered at various angles from a patient-simulating phantom through lead, density 11 350 kg m^{-3} .

RADIATION PROTECTION

Summary of the Current ICRP Principles for Protection of the Patient in Diagnostic Radiology

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

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CONTENTS

PREFACE

This summary of the basic principles for radiation protection of the patient in diagnostic radiology was prepared by the International Commission on Radiological Protection to encourage medical professionals to become aware of and to utilize these basic principles.

In 1977 the Commission published general recommendations on radiation protection in medicine in *ICRP Publication 26*. In 1982 the Commission published detailed information for radiation protection of the patient in diagnostic radiology in *ICRP Publications 33* and *34*. This document is essentially a summary of the information given in the latter of these two publications; however, it also makes use of material in some later ICRP publications and statements, a list of which is published at the end of this summary. Reference is also made to a recent scientific publication (RERF TR 16–87) relevant for updating the information with regard to severe mental retardation following irradiation *in utero*.

In *ICRP Publication 26* the Commission recommended a general system of radiation protection having the following three features:

(a) no practice utilizing radiation shall be adopted unless its introduction produces a positive net benefit;
(b) all radiation doses shall be kept as low as reasonably achievable, economic and social factors being taken into account; and
(c) the radiation dose equivalent to individuals shall not exceed the radiation dose limits recommended for the appropriate circumstances by the Commission.

Features (a) and (b) are relevant to radiation protection of the patient in medicine; the information in this summary identifies the application of these recommendations to diagnostic radiology. Feature (c), concerning the setting of radiation dose limits, is not applicable to radiation doses received by patients from diagnostic radiology: firstly, because they are direct recipients of benefits of the medical treatment; and, secondly, because differing clinical problems in different treatments must override any overall formula.

The membership of ICRP Committee 3 on Protection in Medicine during the preparation of this summary was:

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J. H. E. Carmichael
J. J. Conway
J. E. Gray
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The role of Dr Rosenstein is particularly acknowledged.

1. HEALTH EFFECTS OF IONIZING RADIATION

When x radiation interacts with matter, energy is absorbed, mainly by the process of ionization. The mean energy imparted by ionizing radiation per unit mass at a point in the human body is known as the absorbed dose in tissue. The unit of absorbed dose in the International System of Units is the gray (Gy), which is equal to one hundred times the previously used unit the rad (1 rad = 0.01 J kg^{-1}). A commonly used subunit of the gray is the milligray (mGy), or 1/1000th of a gray.

When the intent is to relate the absorbed dose to specific radiation-induced health effects, it is important to identify the particular body tissues in which absorbed doses occur, or to state a specific reference point in or on the body. In this summary, when specific tissues or reference points are discussed, the term "absorbed dose" is used and the relevant tissue or location is identified; the term "dose" is used when the intended meaning is more general.

Radiation energy absorbed in living tissues initiates physical and chemical reactions, resulting in biological changes. Some diagnostic x-ray equipment, particularly fluoroscopic equipment when obsolete or improperly operated, is capable of delivering doses that may be high enough to produce cellular reactions seen as acute tissue damage. However, in properly conducted diagnostic x-ray examinations, these acute radiation effects do not occur because the doses are well below the threshold for such effects.

1.1. Risk of Neoplasia and Hereditary Effects

There may be no threshold of dose for the initiation of some deleterious biological changes. Consequently, even a small dose may increase the risk of cancer, and small absorbed doses in the gonads may induce mutations or chromosomal changes potentially capable of inducing hereditary disorders in the offspring. These types of effect are known as stochastic; that is, the probability of occurrence of the effect depends on the absorbed dose, whereas the severity of the effect is independent of the dose. It therefore is assumed in radiation protection planning that every increment of dose to an individual may carry some risk, even though the risk for a particular x-ray examination is small.

The nominal risks (meaning the probability of occurrence) for radiation-induced serious hereditary effects and fatal cancers are given in Table 1. In addition, non-fatal cancers occur.

Table 1. Nominal risks for serious hereditary effects (in the first two generations) in fatal cancers (life-time), for absorbed doses in the relevant tissues; and nominal ratios for total cancers to fatal cancers

Effect	Nominal risk per milligray	Nominal ratio: total cancers to fatal cancers
Hereditary (gonads)	1 in 250,000	—
Cancers	*Fatal*	
Leukaemia (active bone marrow)	1 in 500,000	1.05
Breast (females)	1 in 200,000	1.6
Lung	1 in 500,000	1.05
Thyroid	1 in 2,000,000	21
Other (combined)[a]	1 in 200,000	1.3

[a] Excludes bone and skin cancers.

Nominal (typical) ratios for total cancers (fatal plus non-fatal) to fatal cancers for each type, as presently contained in published Commission reports, are also given in Table 1.

1.2. Irradiation *In Utero*

Two possible effects of radiation on the developing embryo or foetus need consideration, namely development abnormalities and cancers which may be expressed during childhood or in adult life. The periods of sensitivity after conception and, where applicable, the nominal risks for these effects are given in Table 2.

Table 2. Nominal risks for irradiation *in utero* for absorbed doses in the embryo or foetus

Time after conception	Nominal risk per milligray
First two weeks	minimal
3rd through 8th weeks	potential for malformation of organs
8th through 15th weeks	severe mental retardation 1 in 2,500[a]
16th through 25th weeks	severe mental retardation 1 in 10,000[a]
Throughout pregnancy	childhood cancer 1 in 50,000

[a] These nominal risks do not take into account the possible presence of a threshold dose below which severe mental retardation would not occur.

The risks for maldevelopment as a result of irradiation *in utero* begin at about the 3rd week after conception and continue through the 25th week. After irradiation during the 3rd through 8th weeks, radiation detriment may be expressed as malformation of specific organs. After irradiation during the 8th through 25th weeks, radiation detriment may be expressed in the form of defective development of the forebrain, resulting in severe mental retardation. The risk is higher in the 8th through 15th weeks than in the 16th through 25th weeks. Recent data are also compatible with an absorbed dose threshold below which severe mental retardation may not be induced.

An increased risk of subsequent cancer in childhood has been correlated with *in utero* irradiation throughout pregnancy.

2. RADIATION DOSE FROM DIAGNOSTIC RADIOLOGY

Principal sources of radiation dose for members of the public are natural radiation and the medical applications of radiation. The contribution from all medical uses to the annual per capita dose varies from a few percent of the dose from natural background in developing countries to substantially higher percentages in developed countries. The largest part of this contribution comes from diagnostic radiology. Consequently, it is highly desirable to discontinue those x-ray examinations that are not expected to contribute essentially to establishing a proper diagnosis and to minimize doses in the course of beneficial x-ray examinations.

3. ABSORBED DOSE IN BODY TISSUES

The radiation dose received in a given x-ray examination will vary widely throughout the body, the maximum being to the skin on which the x-ray beam is incident. The absorbed doses in tissues for a given examination are highly dependent on the technical factors employed in radiography and fluoroscopy, the characteristics of the x-ray equipment, the characteristics of the x-ray beam, the number of radiographs made in radiography, and the irradiation time in fluoroscopy. Studies in many countries have demonstrated that the variation in doses to patients is very large, and that in a substantial fraction of cases the necessary dose is greatly exceeded.

Typical absorbed doses in tissues per x-ray examination range from a fraction of a milligray for some radiographic examinations to a fraction of a gray for specialized fluoroscopic examinations. The vast majority of diagnostic x-ray examinations deliver absorbed doses in tissues well below 10 mGy. Information on tissue doses per x-ray examination is available for various countries, and examples are included in *ICRP Publication 34*, along with practical methods for estimating absorbed doses in tissues from common diagnostic x-ray examinations. Typical absorbed doses from studies in the United States are given in Table 3.

Table 3. Typical absorbed doses in selected tissues from a few common diagnostic x-ray examinations (data for the United States)

X-ray examination	Absorbed dose (mGy) Active bone marrow	Breasts	Uterus (embryo/foetus)	Thyroid
Chest	0.04	0.1	*	0.07
Skull	0.3	*	*	2
Cervical spine	0.1	*	*	4
Thoracic spine	0.4	3	*	0.8
Lumbosacral spine	2	*	6	*
Intravenous pyelogram	1	*	8	*
Barium enema (including fluoroscopy)	10	*	35	*
Mammography (film-screen)	*	2	*	*

* Less than 0.01 mGy.

Absorbed doses in body tissues are used to indicate the risk to specific tissues. The total risk from any particular x-ray examination should ideally comprise the risks from all the radiation-sensitive tissues that are irradiated. To obtain the total risk it would be necessary to know the absorbed dose in each radiation-sensitive tissue, and the risk for each corresponding health effect. At the present time it is not practicable to include all the individual tissues; more importantly, the variation of risks according to patient age is not yet fully understood.

4. RESPONSIBILITIES OF THE PHYSICIAN

The decision as to whether an x-ray examination of a patient is justified is sometimes the responsibility of the referring physician, and sometimes of the physician who carries out the x-ray examination. In either case, it is imperative that the decision be based upon a correct assessment of the indications for the x-ray examination, the expected diagnostic yield from the x-ray examination and the way in which the results are likely to influence the diagnosis and subsequent medical care of the patient. It is equally important that this assessment be made

against a background of adequate knowledge of the physical properties and the biological effects of ionizing radiation.

4.1. Responsibility of Referring Physician

The referring physician's understanding of the concepts of benefits and risks, as applied to the rapidly changing field of x-ray diagnosis, is often incomplete. The referring physician's chief and proper concern is with the efficacy of the x-ray examination, that is, whether it will contribute to the management of the patient's health problem. However, the referring physician should refrain from making routine requests not based on clinical indications. To achieve the necessary overall clinical judgement the referring physician may need to consult with the radiologist.

The referring physician should provide a clear request describing the patient's problem and indicating the clinical objectives, so that the radiologist can carry out the correct x-ray examination. However, in situations where this information is lacking and if the clinical indications are obvious and the denial of service would place undue hardship on the patient, it is not appropriate to penalize the patient by postponing requested x-ray examinations.

Before prescribing an x-ray examination the referring physician should be satisfied that the necessary information is not available, either from radiological examinations already done, or from any other medical tests or investigations.

4.2. Responsibility of Radiologist

To achieve the necessary overall clinical judgement the radiologist may need to consult with the referring physician. This practice is to be encouraged in the interest of obtaining the maximum information at the least radiation risk and economic cost. The radiologist has the responsibility for the control of all aspects of the conduct and extent of x-ray examinations. The radiologist should advise on the appropriateness of proposed x-ray examinations, and on the techniques to be used, in the light of the clinical problem presented.

The radiologist should ensure that no person operates x-ray equipment without adequate technical competence, or performs x-ray examinations without adequate knowledge of the physical properties and harmful effects of ionizing radiation.

If two or more medical imaging procedures are readily available and give the desired diagnostic information, then the procedure that presents the least overall risk to the patient should be chosen.

The sequence in which x-ray examinations are performed should be determined for each patient. Preferably, the results of each x-ray examination in a proposed sequence should be assessed before the next one is performed, as further x-ray examinations may be unnecessary. On the other hand, the availability and convenience of the patient, as well as the urgency for the clinical information, have to be considered.

5. X-RAY EXAMINATIONS DIRECTLY ASSOCIATED WITH ILLNESS

Criteria for the use of specific diagnostic x-ray examinations are continually being improved, both as regards indications and contra-indications. Examples of x-ray examinations where reductions in frequency of use might be warranted are:

(i) Excretory urography of children for evaluation of failure to thrive when there are no additional clinical or laboratory findings suggesting urinary tract abnormalities.
(ii) Fluoroscopy of the heart without special indications.

(iii) Fluoroscopy during reduction of uncomplicated fractures.
(iv) Radiography of the paranasal sinuses for evaluation of fever when there are no localizing sinus symptoms.
(v) Radiography of the skull after injury when there are no localizing signs and symptoms.
(vi) Pre-operative chest radiography without special indications.
(vii) Chest radiography in pregnancy without special indications.
(viii) Pelvimetry in pregnancy without special indications.
(ix) Excretory urography for evaluation of hypertension without special indications.
(x) Radiological examinations using barium enemas in the absence of specific indications.

6. X-RAY EXAMINATIONS DURING PREGNANCY

Because of the radiation risk to an embryo or foetus, the possibility of pregnancy is one of the factors to be considered in deciding whether to conduct an x-ray examination involving the lower abdomen in a woman of reproductive capacity. During the first 10 days following the onset of a menstrual period, there is no radiation risk to any conceptus, since no conception will have occurred. The radiation risk to a child who had been irradiated *in utero* during the remainder of the first month following the onset of menstruation (that is, during approximately the first 2 weeks after conception) is likely to be so small that there need be no special limitation on x-ray examinations required within that time period. Nevertheless, attention should always be paid to details of x-ray examinations that would ensure minimization of absorbed dose in any embryo or foetus that may be present, whether or not the woman is known to be pregnant.

Irradiation of the pregnant patient, at a time when the pregnancy was unrecognized, often leads to her anxiety because of concern about possible effects on the foetus, even though the absorbed doses in the conceptus are generally small. Such concern may even lead to a suggestion that the pregnancy be terminated. However, on the basis of relative risk increment, foetal irradiation from a diagnostic procedure very rarely justifies terminating a pregnancy. When such concern arises, an estimate of absorbed dose, and the associated risk to the foetus, should be made by a qualified expert. With such expert and carefully worded advice, the patient should then be in a position to take a decision regarding abortion.

6.1. X-ray Examination of Women of Reproductive Capacity

It is prudent to assume that any woman presenting herself for radiography at a time when a menstrual period is overdue, or clearly has been missed, could be pregnant, unless there is firm information indicating the impossibility of pregnancy. In order to minimize the frequency of unintentional irradiation of the foetus, it is recommended that notices should be posted at several conspicuous places within diagnostic x-ray departments and other areas where diagnostic x-ray equipment is used, other than for dentistry. For example:

IF IT IS POSSIBLE THAT YOU MIGHT BE PREGNANT
NOTIFY THE PHYSICIAN OR RADIOGRAPHER
BEFORE YOUR X-RAY EXAMINATION

6.2. Obstetric Radiography

In many instances, particularly in the evaluation of foetal maturation and placental localization, ultrasonic examinations are preferable to x-ray examinations. Ultrasonic

examinations do not utilize ionizing radiation and are reliable. When available, the use of ultrasound greatly reduces the need for x-ray examinations of the gravid uterus.

While radiographic pelvimetry is sometimes of great value, it should be undertaken only on the rare occasion when this is likely to be so, and should not be carried out on a routine basis. In particular, the supero-inferior projection for the pelvic inlet, also called the brim view, should not be used in view of the unjustifiably high absorbed doses in the foetus.

6.3. Other X-ray Examinations During Pregnancy

When pregnant women require other x-ray examinations in which the x-ray beam irradiates the foetus directly, special care has to be taken to ascertain that the x-ray examination is indeed indicated at that time and that it should not be delayed until after the pregnancy. Sometimes the radiation risk to the foetus is less than that of not making a necessary diagnosis, so that the x-ray examination should still be done when medical indications are appropriate. In such cases, greater than usual care should be taken to minimize the irradiation time or number of radiographs and to minimize the absorbed dose in the foetus for each irradiation. However, alterations of technique should not be done to the undue detriment of the diagnostic value of the x-ray examination.

Radiography of areas remote from the foetus, such as the chest, skull or extremities, can be done safely at any time during pregnancy if the x-ray equipment is properly shielded and if proper x-ray beam limitation is used.

7. X-RAY EXAMINATIONS NOT DIRECTLY ASSOCIATED WITH ILLNESS

7.1. X-ray Examinations used in Health Assessment

Health assessments undertaken without reference to current illness may involve x-ray examinations. Justification of such x-ray examinations depends on the probability of obtaining information of importance for the individual's health.

Chest radiography is often a part of annual examinations and sometimes is a part of the procedure for hospital admission of patients. X-ray examinations of the chest from all applications contribute a substantial fraction of the average dose per person from diagnostic radiology in many countries. In numerous cases, particularly when young patients without any respiratory or cardiac symptoms are subject to such examinations, the chest radiography may be unjustified. In cases where indications clearly exist, the radiography should be performed with the lowest achievable dose. Several principles for achieving optimum chest radiographs are given later; if adhered to, they would reduce the contribution from this source.

Dental radiography requires particular consideration because it is carried out so widely by non-radiologists, and because many dental x-ray examinations consist of a series of x-ray fields which are partially superimposed. In addition, many of the patients are children or young adults. Although x-ray examinations are an important component of dental care, dental radiographs should be taken only after a thorough clinical examination and consideration of the dental history, preferably including study of any previous dental radiographs. Dental radiographs should not be performed routinely at every visit, but should be based on definite indications.

7.2. X-ray Examinations used in Screening for Specific Diseases

For x-ray examinations used in screening for specific diseases, the justification should be based on a balance between the advantages implied for the individuals examined and for the population as a whole, together with the disadvantages, including the radiation risk, of the screening. In general, the advantages will depend on the diagnostic yield of the screening procedure, the possibility of effective treatment of the diseases detected and, for certain diseases, the advantages to the community of the control of the disease. The benefits of screening are not always the same for different groups making up the population. Therefore, screening will often be justified only if limited to specified groups of individuals. Screening programmes should be subjected to frequent evaluation to determine whether the yield in finding significant disease is sufficiently high to warrant their continuation.

In countries where tuberculosis is a major public health problem, the use of sputum bacterioscopy or tuberculin skin testing in persons not vaccinated can identify individuals who have tuberculosis. Those in close contact with these individuals may also be at greater risk for tuberculosis. These individuals and the groups at greater risk can be studied further by chest radiography when necessary. Compared with routine chest radiography of large groups of individuals, this course reduces both the economic cost and the number of irradiations.

Recommendations concerning the use of x-ray examinations to detect carcinoma of the breast in asymptomatic women have relied on comparisons between the number of breast cancers that radiation might induce and the number of breast cancers that would be found and successfully treated. With the techniques now available, the number of breast cancers that can be detected and successfully treated by obtaining annual mammograms, beginning at age 50 years, has been shown to be significantly higher than the likely number of radiation-induced breast cancers.

8. X-RAY EXAMINATIONS FOR OCCUPATIONAL, MEDICO-LEGAL OR INSURANCE PURPOSES

X-ray examinations carried out to assess the fitness of an individual for work, to provide information for medico-legal purposes, or to assess the health of a subscriber to, or beneficiary of an insurance, may carry some direct or indirect advantages for the individual examined, but they also may carry advantages for the employer, third parties and the insurer. All these aspects should be carefully considered in assessing the justification of such x-ray examinations.

Local or national policy may require some individuals to have certain pre-employment and subsequent annual x-ray examinations. Examples include: initial and annual chest radiographs for teachers, food-handlers and hospital personnel; and "low back" radiographs for persons engaged in heavy manual labour. The indication for x-ray examinations for medico-legal, insurance, disability, retirement or other claims depends on the need to confirm or to exclude a particular medical condition, such as trauma, infection or neoplasm, or to re-evaluate a pre-existing disease. Continuing evaluation is necessary to determine whether the diagnostic yield of these routine x-ray examinations is sufficient to justify the radiation dose and economic cost.

9. X-RAY EXAMINATIONS IN MEDICAL RESEARCH

9.1. With Direct Benefits to the Individual Irradiated

X-ray examinations forming part of a medical research programme sometimes involve direct benefits for the irradiated individual and sometimes do not. When new and experimental

methods of x-ray diagnosis are capable of benefiting the patients on whom they are tested, the justification for the procedures can be judged in the same way as for other medical x-ray examinations. Nevertheless, because of the experimental character of the procedures, they should be subject to thorough review.

9.2. Without Direct Benefits to the Individual Irradiated

The decision to irradiate persons for the purpose of those research and other studies in which no direct benefit to the persons irradiated is intended, should only be undertaken by specially qualified and trained research personnel and radiologists.

The estimated risks of the irradiation should be explained to those involved, who should be volunteers fully able to exercise their free will. The higher the dose the more rigorous should be the requirements on the conditions of securing volunteers and on their ability to understand the risk.

Such irradiation should only be given with the consent of the authorities in charge of the institution where the irradiation is to take place, as advised by an appropriate expert body and subject to local and national regulations.

The individuals irradiated under these conditions obtain no direct benefit from their irradiation. It is therefore necessary to ensure that their risk remains acceptable, and thus to set authorized dose limits. However, the magnitude of the risk associated with the irradiation depends on the age and the state of health of the individual irradiated, and it is not possible to fix authorized dose limits of general applicability. Appropriate dose limits should therefore be authorized for each research programme.

Irradiation of children and other persons regarded as being incapable of giving their true consent should only be undertaken if the expected dose is low (for example, of the order of the annual dose limits applicable to individual members of the public) and if valid approval has been given by those legally responsible for such persons.

10. AVOIDANCE OF UNNECESSARY DOSE

Radiation protection in medicine has been a concern since the beginning of the century. Equipment and procedures have been developed with recognition of the harmful effects that could ensue. The degree of safety is now high, and an x-ray examination, recommended on the basis of the clinical judgement of a qualified physician, generally brings to the patient a benefit that outweighs the unavoidable risk. However, there should be no excuse for x-ray examinations to be carried out with unnecessarily high doses. The Commission's basic principle that all doses be kept "as low as reasonably achievable, economic and social factors being taken into account" should always apply. Care should be taken to apply this principle without loss of needed clinical information.

The Commission emphasizes that careful attention to the conduct of x-ray examinations would, in many cases, result in a considerable reduction of the dose due to x-ray examinations, without impairment of their diagnostic value. In particular,

REDUCE THE ABSORBED DOSES RECEIVED BY TISSUES IN THE REGION OF THE BODY UNDER EXAMINATION TO THE MINIMUM COMPATIBLE WITH OBTAINING THE NECESSARY INFORMATION FOR THE PARTICULAR PATIENT.

LIMIT AS FAR AS IS PRACTICABLE THE IRRADIATION OF OTHER PARTS OF THE BODY.

REDUCE THE FREQUENCY OF UNNECESSARY REPEAT IRRADIATIONS.

The amount of radiation incident on a patient that is necessary to generate a useful diagnostic image depends on many technical and physical factors. Factors leading to reduction of this irradiation include the elimination of radiation not contributing to the formation of the useful image and the correct choice of a sensitive image receptor suitable for the diagnostic requirements of a particular case. However, there is a limit below which the radiation incident on the image receptor contains insufficient information to be of diagnostic value.

10.1. General Techniques

10.1.1. *Size of the x-ray field*

Among the most important technical means for limiting unnecessary irradiation of the patient is the use of the smallest practicable x-ray field and its accurate positioning on the patient. Reduction of the x-ray field to the minimum practicable size is always of benefit to the patient. This decrease in x-ray field size reduces the total radiation energy delivered to the patient, and therefore the mass of the skin and internal tissues irradiated. It also reduces the amount of scattered radiation reaching the image receptor, thereby improving image quality.

In many radiographic projections, the gonads (especially the testes) can be kept outside the x-ray beam by carefully centring and adjusting the x-ray field to irradiate only the area of interest. When the testes are located just a few centimetres outside the x-ray field edge, the absorbed dose in the testes can be one-tenth or less of that when the testes are in the x-ray field (Fig. 1).

Beam-limiting devices are available which automatically restrict the x-ray beam to the size of the radiographic cassette employed in the x-ray equipment. When this type of automatic beam-limiting device is used in examining areas smaller than the smallest available radiographic film, the beam limitation should be adjusted so that only the area of interest is irradiated.

In particular, the body areas examined in infants are often smaller than the available radiographic film. Beam limitation should be used to adjust the size of the x-ray beam to the area in question, and not to the area of the radiographic film or the entire infant. This action is particularly important when an automatic beam-limiting device is used, since the x-ray field would otherwise be automatically set to the full size of the radiographic film. This situation

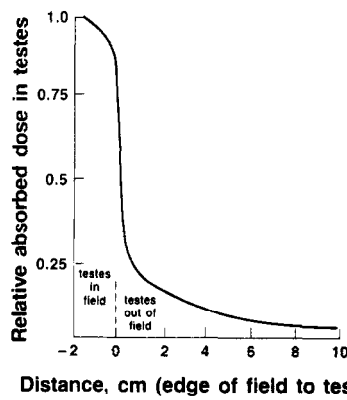

Fig. 1. Typical change in absorbed dose in the testes with distance between edge of x-ray field and testes (no shielding).

commonly occurs during an x-ray examination of the chest of a newborn infant. If the automatic beam-limiting device is not adjusted in such circumstances, even a total-body irradiation can result.

10.1.2. *Shielding of organs*

The gonads should be shielded when, of necessity, they are directly in the x-ray beam or within 5 cm of it, unless such shielding excludes or degrades important diagnostic information. The use of gonad shields can reduce the absorbed dose in the testes by up to 95%, while the reduction of absorbed dose in the ovaries, in those cases when shielding is clinically acceptable, can be about 50%.

The eyes should be shielded for x-ray examinations involving high absorbed doses in the eyes, such as conventional petrous bone tomography, when such shielding does not exclude or degrade important diagnostic information. This is especially important when multiple x-ray examinations may be needed. Absorbed dose in the eyes can be reduced by 50–75% by shielding the eyes. The use of the posterior–anterior projection rather than the anterior–posterior projection can reduce the absorbed dose in the eyes by 95%.

For dental x-ray equipment with properly maintained beam limitation, protective aprons covering the gonads are of relatively little value, particularly if the x-ray beam is directed away from the gonads.

10.1.3. *Distance from the focal spot to the skin or image receptor*

In a non-absorbing medium, the radiation intensity from a point source varies inversely as the square of the distance from the source. Therefore, when the focal spot-to-skin distance (or corresponding focal spot-to-image receptor distance) is decreased, while the x-ray field size and radiation intensity at the plane of the image receptor are kept constant, the radiation intensity rises sharply at the surface of the patient where the beam enters the body (Fig. 2).

In radiography and fluoroscopy with mobile x-ray equipment, the focal spot-to-skin distance should not be less than 30 cm. In radiography and fluoroscopy with stationary x-ray equipment, the focal spot-to-skin distance should not be less than 45 cm. For focal spot-to-image receptor distances less than about 100 cm, the quality of the diagnostic information becomes poorer as the focal spot-to-image receptor distance becomes shorter. Therefore, longer focal spot-to-image receptor distances have clinical advantages. Photofluorography and

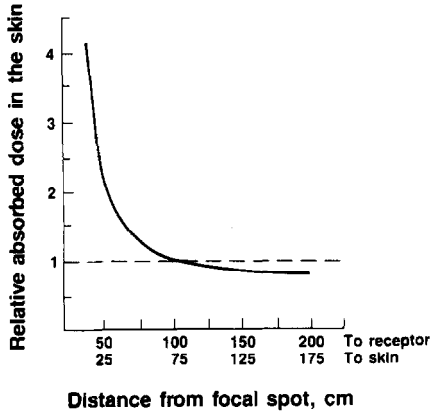

Fig. 2. Dependence of absorbed dose in the skin on the distance from the x-ray source (all other conditions unchanged); the skin-to-image receptor distance is constant at 25 cm.

radiography of the chest should be performed with a focal spot-to-image receptor distance of at least 120 cm.

10.1.4. *Total filtration in the x-ray beam*

A filter placed in the x-ray beam preferentially attenuates unwanted components of the beam, usually those with lower energy, which otherwise would be absorbed mostly in the patient and add little to the diagnostic information on the image receptor. The use of a filter of appropriate thickness results in a more penetrating radiation beam, and therefore requires a lower absorbed dose in the skin facing the x-ray tube.

Total filtration in the x-ray beam for conventional diagnostic radiology should be equivalent to not less than 2.5 mm of aluminium, of which 1.5 mm should be permanent.

For conventional dental x-ray equipment with x-ray tube voltages not exceeding 70 kV, the total permanent filtration in the x-ray beam should be equivalent to not less than 1.5 mm of aluminium. At higher x-ray tube voltages the total filtration should be equivalent to not less than 2.5 mm of aluminium, of which 1.5 mm should be permanent.

The radiation quality of an x-ray beam is expressed as the half-value-layer in millimetres of aluminium. Tabulations of radiation quality as a function of total filtration and x-ray tube voltage for diagnostic x-ray equipment are included in *ICRP Publication 34*. If the amount of total filtration in the x-ray beam is unknown, the half-value-layer for the x-ray beam should be measured. The corresponding total filtration at a particular x-ray tube voltage can then be determined.

Mammography requires lower x-ray tube voltages than conventional radiography; its total filtration requirements are given on page xxi of this summary.

10.1.5. *Carbon fibre materials*

The use of carbon fibre materials for the patient support, in anti-scatter grids and for the radiographic cassette face, in place of conventional materials, allows transmission of a larger proportion of the x-ray beam. At an x-ray tube voltage of 80 kV, the use of carbon fibre materials enables the absorbed dose in the skin of the patient to be reduced, as shown in Fig. 3. The overall reduction of absorbed dose in the skin of the patient facing the x-ray tube, from the combined use of carbon fibre materials in patient supports, anti-scatter grids and radiographic

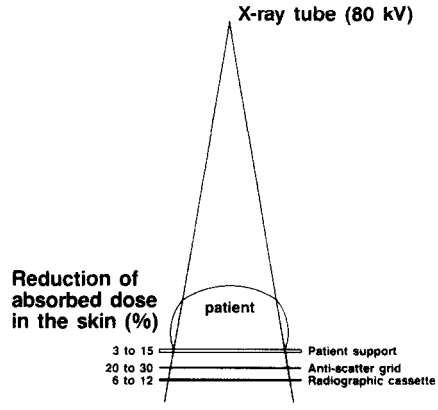

Fig. 3. Reduction of absorbed dose in the skin due to increased transmission through carbon fibre materials as compared with conventional materials.

cassettes, is in the range of about 30% to more than 50%. If the x-ray tube voltage is not changed, the percentage reductions in absorbed dose in deeper tissues will be similar.

10.1.6. *Control of irradiation and recording of irradiation time*

Switches operating all x-ray equipment should be so constructed that irradiation can be terminated manually at any time and, except in the case of special techniques where multiple irradiations are required, it should not be possible to repeat iradiations without release of the control switch.

In fluoroscopy, the operator should be aware of the irradiation time. For this purpose, the x-ray equipment should be fitted with an integrating timer, which terminates the irradiation after a pre-set time has elapsed. Before termination, an audible warning signal should be given for an adequate period of time. The timer should also be capable of being reset as necessary. The timer should not be bypassed. Switches operating fluoroscopic equipment should be of the spring-loaded type ("deadman"), whether operated by hand or foot, and should be protected from accidental operation.

The recording of irradiation time in fluoroscopy is useful in reminding operators that they should keep fluoroscopy time to a minimum.

10.1.7. *Intensifying screens and radiographic films*

Intensifying screens containing high-efficiency phosphorescent materials, such as rare earths, barium and tantalum, require less radiation than conventional intensifying screens to produce radiographs with similar image quality (Table 4). The decision as to which screen–film combination to use generally involves a compromise between minimizing dose and maximizing diagnostic information, with consideration also for initial cost. This balance will be different in different x-ray examinations and in different institutions.

Non-screen radiographic films should have no place in diagnostic radiology because they require relatively high doses and they are not able to produce images of high contrast.

10.1.8. *Control of scattered radiation to the image receptor*

Anti-scatter grids or air gaps interposed between the patient and the image receptor reduce the amount of scattered radiation reaching the image receptor while at the same time permitting

Table 4. Relative speed and resolution of selected x-ray screen–film combinations (at 80 kVp with a chest-equivalent phantom)

Nominal resolution grade	Phosphorescent material	Relative speed[a] (at density of 1)	Resolution (cycles/mm) (at 10% modulation)
Detail	Calcium tungstate	0.3 to 0.5	8 to 10
	High-efficiency	0.6 to 1	8 to 10
Medium	Calcium tungstate	1	5
	High-efficiency	2 to 3	4 to 5.5
Fast	Calcium tungstate	2	3
	High-efficiency	3 to 10	3

[a] The reciprocal of the radiation intensity required to produce a specified density on a radiographic film.

Source: *MTF's and Wiener Spectra of Radiographic Screen–Film Systems*, Volume I (FDA 82–8187, 1982) and Volume II (FDA 86–8257, 1986). Center for Devices and Radiological Health, Rockville, Maryland.

transmission of the primary radiation which produces the x-ray pattern. The reduction of scattered radiation therefore enhances the image, but increases dose to the patient.

In chest radiography, anti-scatter grid or air-gap techniques using x-ray tube voltages of 100 to 120 kV are recommended.

In fluoroscopy, and in some situations during radiography of infants, the use of an anti-scatter grid is not necessary, and not using the anti-scatter grid will reduce doses by a factor of two or more.

10.1.9. *Radiographic film processing*

Correct processing techniques are necessary to give reproducible radiographs of optimum diagnostic value with minimum dose to the patient. Incorrect processing may be a cause of rejecting radiographs and therefore a cause of otherwise avoidable repetitions of irradiation. Also, improper processing techniques can easily result in a doubling of the dose required to produce a satisfactory radiograph.

For manual processing, the correct developer and fixer must be selected for the types of radiographic film to be used. The correct processing temperatures, development time, and replenishment of chemicals are essential to develop the radiographic film with good quality.

With automatic processing, quality control is particularly important. Quality control should be carried out daily by use of film strips exposed in a sensitometer shortly before their processing. The density and contrast of the film strips should then be quantitatively evaluated. If the density or contrast exceeds control limits, corrective action should be taken before processing clinical radiographs.

Generally speaking, it is desirable that radiographers see all their radiographs immediately after processing so that they can recognize any faults in technique, equipment or processing and can correct any errors.

10.1.10. *Reduction in number of repeat irradiations*

The decision to repeat an irradiation should be based on the likelihood that the new radiograph will give additional information which was not available on the previous radiograph rather than for purely aesthetic reasons. In various published surveys the rate of retakes of radiographs varied from 3–15%. The major cause of retakes identified in most of these studies was either errors in positioning the patient or radiographs that were too dark or too light.

Use of a reference list of technical factors (i.e., kVp and mAs based on patient size) is strongly recommended as an aid to proper irradiation. Alternatively, automatic control of irradiation is of value, provided that the radiation detectors are properly chosen and maintained, and the patient is positioned properly for each x-ray examination.

10.1.11. *Quality assurance*

The purpose of quality assurance programmes in diagnostic radiology is to establish procedures for monitoring periodically or continuously the performance of radiological facilities, with the aim of obtaining optimum diagnostic information at minimum cost and with minimum dose to individual patients. All radiological facilities should establish quality assurance programmes whose structure and scope are determined by the needs and complexities of each facility.

Acceptance testing of new or used x-ray equipment that has been recently installed assures that the x-ray equipment meets the performance specifications of the manufacturers, meets the purchase specifications of the user, and complies with the standards of national radiation protection organizations and government agencies.

Medical physicists are specialists in the generation of radiation fields, the analysis of image quality, the control of radiation dose, the selection and acceptance testing of x-ray equipment, and in the training of other individuals. They should therefore be consulted on the technical aspects of quality assurance programmes.

10.2. Specific X-ray Examinations

10.2.1. *Fluoroscopy*

Fluoroscopy should be used principally to study dynamic phenomena rather than to evaluate anatomical detail. Fluoroscopy should therefore be carried out only if the required information cannot be obtained by radiography alone. The absorbed dose rate in air (at the point of the entrance surface of the patient) should not exceed 50 mGy per min and should be typically much lower.

Direct fluoroscopy delivers higher doses to the patient than does fluoroscopy with image intensification, and produces images of lower quality. The use of direct fluoroscopy should be discouraged. However, if the use of direct fluoroscopy is unavoidable, achievement of complete dark-adaption and use of the most sensitive fluorescent screens will yield acceptable results with absorbed dose rates in air (at the point of the entrance surface of the patient) in the range of 10–50 mGy per min. With a properly operating image intensifier, these absorbed dose rates can be reduced to about one-third of those in direct fluoroscopy.

Direct fluoroscopy for chest examinations should be replaced by radiography whenever possible because the dose to the patient from radiography can be as much as one hundred times less than for direct fluoroscopy, and a permanent record becomes available.

Photofluorography has been widely used for x-ray examinations of the chest in screening the population for detection of tuberculosis, but the dose to the patient may be up to ten times greater than that for a full-size radiograph.

10.2.2. *Examinations with mobile x-ray equipment in wards and operating theatres*

The principal difficulty in radiography with mobile x-ray equipment is the uncertainty in the relative positions of the x-ray tube and the radiographic film, particularly when an anti-scatter grid is used. This may lead to the necessity of repeating radiographs, with the resulting additional irradiation of the patient. The so-called "hand fluoroscope" or "head fluoroscope" should never be used. Fluoroscopy should not be carried out with mobile x-ray equipment unless an image intensifier is employed. Even then, fluoroscopy can deliver excessively high doses to the patient.

10.2.3. *Paediatric radiology*

A great saving in dose to the paediatric patient can be accomplished by having a radiographer specially trained in paediatric methods. In any institution that performs a large number of paediatric x-ray examinations, there should be at least one such radiographer assigned to perform radiography on children.

10.2.4. *Mammography*

Absorbed dose in breast tissue during mammography should be kept as low as reasonably achievable without sacrificing necessary diagnostic information. Currently, the preferred mammography techniques use either a molybdenum target and molybdenum filter with a rare-

earth intensifying screen and matching radiographic film, or a tungsten target and aluminium filter with a xerographic plate.

Mammography should be carried out with dedicated mammography x-ray equipment and not with conventional x-ray equipment intended for use at higher x-ray tube voltages. Under no circumstance should the total permanent filtration be less than 0.03 mm of molybdenum for screen–film mammography or 0.5 mm of aluminium for xeromammography.

10.2.5. *Dental x-ray examinations*

Most of the recommendations concerning other diagnostic x-ray examinations are applicable to dental radiography and should be applied. In particular, the use of high-speed radiographic film and proper filtration will help ensure that absorbed dose in the skin at the entrance of the beam is kept to a minimum.

11. POSTSCRIPT

The information in this summary represents the basic principles for protection of the patient in diagnostic radiology currently found in the Commission's published documents that are cited in the reference list attached. These documents contain full discussions of the scientific and radiation protection considerations that contributed to the formulation of the basic principles, as well as references to the original supporting scientific literature. The reader is encouraged to consult the Commission's publications and the extensive references in those publications.

The Commission is presently reviewing its basic recommendations. The revision will take into consideration new and expanded scientific information not available during the Commission's previous deliberations.

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