RADIATION HEALTH SERIES

No. 1

GUIDANCE NOTES

ON

RADIATION PROTECTION

FOR

DIAGNOSTIC RADIOLOGY

Radiation Health Division
Department of Health

Foreword

The Radiation Health Series serves to provide some basic information on the safe use of ionizing radiation in medicine, industry and education in the Hong Kong SAR.

We have prepared these information brochures on the basis of the recommendations made by notable international authorities, such as the International Commission on Radiological Protection (ICRP), World Health Organisation (WHO), International Labour organization (ILO) and International Atomic Energy Agency (IAEA). We hope you find the information useful in safeguarding your own health, as well as the health of your neighbours, when you work with ionizing radiation.

If you have questions on the contents of these documents or have suggestions on improvements, please contact us at the

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INTERPRETATION AND REGULATIONS

Ionising Radiation means electromagnetic radiation (e.g. x-ray, gamma ray) or corpuscular radiation (e.g. alpha particles, beta particles, electrons, positrons, protons, neutrons or heavy particles) being electromagnetic radiation or corpuscular radiation capable of producing ions and emitted from a radioactive substance or from a machine that is intended to produce ionising radiations, or from a machine in which electrons are accelerated by a voltage of not less than 5 kilovolt.

Irradiating Apparatus means any apparatus which –

(a) is intended to produce or emit ionising radiation; or

(b) is capable of producing or emitting ionising radiation at a dose rate exceeding of 5μSv per hour at a distance of 5cm from any accessible point of the surface of the apparatus.

Radioactive Substances means any substance which consists of or contains any radioactive chemical element whether natural or artificial and whose specific activity exceeds 75 becquerel of parent radioactive chemical element per gram of substance.

Radiation Work means work by any person involving the operation of irradiating apparatus in which the person may be liable to receive a dose of radiation exceeding 6 millisievert to any part of the body in any calendar year. Such a person shall be classified as a radiation worker.

THE RADIATION ORDINANCE

All activities involving ionising radiation in Hong Kong are controlled by the Radiation Ordinance (Cap 303), Laws of Hong Kong and its subsidiary Regulations:

Radiation Ordinance (Cap 303)

Radiation (Control of Radioactive Substances) Regulations

Radiation (Control of Irradiating Apparatus) Regulations

Under this Ordinance and Regulations,

(1) No persons shall, except in accordance with a licence issued under this Ordinance and Regulations:-

(a) manufacture or otherwise produce; or

(b) sell or otherwise deal in or with; or

(c) have in his possession or use,

any radioactive substance or irradiating apparatus

(2) Any person who contravenes any of the provisions shall be guilty of an offence and shall be liable to a fine of $50,000 and to imprisonment for 2 years

1.1 Radiation Units

Radiation

It is the term used to describe the transfer of energy through space or matter in the form of electromagnetic wave or sub-atomic particles.

Ionisation

It is the process by which atoms lose, or sometimes gain, electrons and thus become electrically charges, being then known as ions. Ionising radiation encountered in medicine and dentistry comprises x-rays, gamma rays, electrons and sub-atomic particles.

Absorbed Dose

In simple term is the energy imparted by ionising radiation to unit mass of matter. The unit of absorbed dose is **gray (Gy)**.

Radiation Weighting Factors

It is recognised that different types of ionising radiations will have different degree of harmless to human body even the absorbed dose is the same. Radiation weighting factors are used to account for the difference. For example, neutrons are more damaging than x-ray and so a factor of 20 is given to neutrons. The radiation weighting factor for x-ray is 1.

Equivalent Dose (H_T)

It is defined as the product of average absorbed dose in an organ or tissue and the radiation weighting factor. The unit of equivalent dose is **sievert (Sv).** A millisievert (mSv) is one-thousandth of a sievert and a microsievert (μSv) is one-millionth of a sievert.

Tissue Weighting Factors (W_T)

The probability of occurrence of some radiation effects in an organ or tissue is assumed to be proportional to the equivalent

dose in the organ or tissue for radiation protection purposes. The effects of radiation may differ for various tissues of the body. Tissue weighting factors are therefore introduced to represent the proportion of the risk resulting from irradiation of an organ or tissue of the body to the total risk when the whole body is irradiated.

Effective Dose (E)

The effective dose, E is the sum of the weighted equivalent doses in all the tissues and organs of the body. It represents the total risks to the whole body due to partial irradiation of body organs. It is given by the expression $E = \Sigma W_T H_T$

1.2 Biological Effects of Radiation

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).

In many organs and tissues of the body there is a continuous process of loss and replacement of cells. An increase in the rate of loss, for example following exposure to radiation, may be compensated for by an increase in the replacement rate, but there will be a transient, and sometimes permanent, net reduction in the number of cells available to maintain the functions of the organ or tissue. Most organs and tissues of the body are unaffected by the loss of even substantial numbers of cells, but if the number of 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 millisievert or more, the severity of the injury increases with dose. This type of effect is called “deterministic”.

Deterministic 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 functions.

The outcome will be 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 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 causing a cancer 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 effect may be expressed in later generations.

1.3 Hazard and Risks

When radiation was initially used in medicine, concern was primarily with the hazard arising from the exposure of a few workers to relatively large 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.

Epidemiological data on cancer are being collected for a number of groups — principally persons who have been medically irradiated, atomic bomb survivors and occupationally exposed person. The risk for radiation induced fatal cancers at low doses and low dose rate was of the order of 5×10^{-2} per Sv average for both sexes and ages.

Hereditary effects caused by ionizing radiation have not been observed in human beings, and genetic risk estimates are based on laboratory animal data. The risk factor for severe hereditary disorders from low dose and dose rate over all generations of offspring is estimated to be 0.5×10^{-2} per Sv.

The effects on the conceptus of exposure to radiation depend on the time of exposure relative to conception. When the number of cells in the conceptus is small and their nature is not yet specialized, the effect of damage to these cells is most likely to take the form of a failure to implant or of an undetectable death of the conceptus. It is thought that any cellular damage at this stage is much more likely to cause the death of the conceptus than to result in stochastic effects expressed in the live-born child, despite the fact that the central nervous system and the heart are beginning to develop in the third week. During the rest of the period of major organogenesis, malformations may be caused in the organ under development at time of exposure. These effects are deterministic in character with a threshold in man, estimated from animal experiment, to be about 0.1Gy.

1.4 The Aim of Radiological Protection

The primary aim of radiological protection, as stated in *ICRP Publication 60*, is "to provide an appropriate standard of protection for mankind without unduly limiting the beneficial practices giving rise to radiation exposure".

Several features of medical practice require an approach to radiological protection that is slightly different from that in other practices:

(a) The exposure of patients is deliberate. Except in radiotherapy, it is not the aim to deliver a dose of radiation, but rather to use the radiation to provide diagnostic information or to conduct interventional radiology. Nevertheless, the dose is given deliberately and cannot be reduced indefinitely without prejudicing the intended outcome.

(b) The patient needs a special relationship with the medical and nursing staff. For this reason, the system of protecting the staff from the source, e.g. shielding, should be designed to minimise the sense of isolation experienced by the patient. This is particularly relevant in nuclear medicine and brachytherapy, where the source is within the patient.

(c) In radiotherapy, the aim is to destroy the target tissue. Some deterministic damage to surrounding tissues and some risk of stochastic effects in remote non-target tissues are inevitable.

(d) Hospital and radiology facilities have to be reasonably accessible to the public, whose exposure is thus more difficult to control than it is in the industrial premises.

2. General Measures for Radiological Protection

2.1 The Three Principles of Radiological Protection

(a) Justification of a Practice

No practice involving exposure to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes.

Most of the assessments needed for the justification of a practice are made on the basis of experience, professional judgement, and common sense, but quantitative decision-aiding techniques are available and, if the necessary data are accessible, should be considered.

There are three levels of justification of a practice in medicine:

i) At the first and most general level, the use of radiation in medicine is accepted as doing more good than harm. Its justification is now taken for granted.

ii) At the second level, a specified procedure with a specified objective is defined and justified, e.g. chest radiographs for patients showing relevant symptoms. The aim of this generic justification is to judge whether, in most cases, the radiological procedure will improve the diagnosis or treatment or will provide necessary information about the exposed individuals.

The generic justification of the procedure is a matter for national professional bodies, sometimes in conjunction with national regulatory authorities. The total benefits from a medical procedure include not only the direct health benefits

to the patient, but also the benefits to the patient's family and to society. Although in medicine, the main exposure is to patients, the exposures to staff and to member of the public who are not connected with procedures should be taken into account. The possibility of accidental or unintended exposures should also be considered. The decisions should be reviewed from time to time as new information becomes available about the risks and effectiveness of the existing procedure and about new procedures.

The justification of diagnostic investigations for which the benefit to the patient is of the primary objective needs special consideration. In the use of radiography for insurance purpose, the primary benefit usually accrues to the insurer, but there may be some economic benefit for the individual examined.

iii) At the third level, the application of the procedure to an individual patient should be justified, i.e. the particular application should be judged to do more good than harm. Beyond checking that the required information is not already available, no additional justification is needed for the application of a generically justified simple diagnostic procedure to an individual patient with the symptoms or indications for which the procedure has already been justified generically. For complex diagnostic procedures and for therapy, generic justification may not be sufficient. Individual justification by the radiological practitioner and the referring physician is then important and should take account of all the available information. This includes the details of the proposed procedure and of any alternatives, the characteristics of the individual patient, the expected dose to the patient, and the availability of information on previous or expected examinations or treatment.

(b) **Optimisation of Protection**

In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposure where these are not

certain to be received should all be kept as low as reasonable achievable, economic and social factors being taken into account.

The Optimisation of protection is the most powerful of the components of the system of radiological protection. It should pervade all stages of the use of radiation in medicine. The underlying idea of Optimisation can be expressed by the question:

Are There Any Reasonable Steps That I Can Take To Improve Protection?

The basic aim of Optimisation of protection is to adjust the protection measures relating to the application of a source of radiation within a practice in such a way that the net benefit is maximized.

As with justification, experience, professional judgement, and common sense play major roles in the procedures of Optimisation, all of which are consistent with the good practice of medicine.

(c) Dose Limits

The exposure of individuals resulting from the combination of all the relevant practices should be subject to dose limits as stipulated in the Radiation Ordinances (Cap 303), Laws of Hong Kong.

Individual dose limits have been set for occupational and public exposure so that a continued exposure just above the dose limits would result in additional risks from the relevant practices that could reasonably be described as ‘unacceptable’ in normal circumstances.

Provided that the doses to patients have been properly justified, it is not appropriate to apply dose limits to medical exposures, because such limits would often do more harms than good. They would sometimes prevent diagnostic information from being obtained and would prevent all radiotherapy. Furthermore, the benefits and detriments from medical exposures apply to the same individual, the patient; there is no inequity.

The dose limits stipulated in the Radiation Ordinance (Cap 303), Laws of Hong Kong are mainly given in Table 1:

Table 1 Dose Limits

Exposure Scenario	Exposed body regions	Dose Limit
Public	**Whole body**	**1mSv in any calendar year**
Occupational	**Whole body**	**20mSv in any calendar year**
	Individual organ / tissue (other than lens of the eye) or any body extremity or area of skin average over any 1cm^2	**500mSv in any calendar year**
	Lens of the eye	**20mSv per calendar year, averaged over any 5 consecutive calendar years or 50mSv in any calendar year**
	Abdomen of a woman with reproductive capacity	**5mSv in any consecutive 3 months interval**
	Fetus	**1mSv during the pregnancy of the women**

2.2 Classification of Areas

One of the most important functions of management requirements is that of maintaining control over the sources of exposure and over the workers who are occupationally exposed. The control of sources of exposure is helped by requiring that the workplaces be formally designated. There are two designations of workplaces:

a) Controlled Areas

A controlled area is one in which normal working conditions, including the possible occurrence of minor mishaps, require the workers to follow well-established procedures and practices aimed specifically at controlling radiation exposures.

The entrance to controlled area should be marked with a warning notice which should state that the area is controlled. It should incorporate a radiation warning sign; it may also include other precise information, such as the reason why

the area is controlled, e.g. "X-radiation", and whether or not entry is permitted together with any conditions. Appendix A shows some samples of these warning notices.

In Radiology Department, certain areas will normally be classified as controlled areas. The requirements will vary depending upon whether fixed, mobile or portable x-ray equipment is in use. In fixed installations the entire x-ray room should be a controlled area, unless the equipment is switched off from the electrical main supply. 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.

b) Supervised Area

A supervised area is one in which the working conditions are kept under review, but special procedures are not normally needed. The supervised area is set up with the aim of ensuring that the doses to workers can confidently be predicted to be less than 3/10 of the occupational dose limit.

In defining these areas, account should be taken both of the expected levels of exposure and of the likely variations in these exposures. The aim should be to ensure that any one outside the designated areas will not need to be regarded as occupationally exposed. The dose limits are intended to apply to all workers, but should enable the actual doses received outside the designated areas to be kept below the dose limits for public exposure.

2.3 Personal Monitoring

Employer should provide to their employees, who are classified as radiation workers or required to work in controlled areas

under a written system of work, a suitable personnel radiation monitoring device of a type approved by Radiation Board, to monitor their radiation doses. Each dosimeter is normally worn for 1 month. Dosimeter should be returned promptly after use for dose assessment and replaced with new ones.

Employees who are issued with dosimeter should wear it as instructed **all the time** they are at work. Care should be taken to prevent the dosimeter, while not being worn, from being exposed inadvertently to ionising radiation or subject to other conditions, e.g. heat, which could affect the assessment of doses. A dosimeter should normally be worn on the trunk at chest or waist height.

2.4 Medical Surveillance

Persons who are classified as radiation workers shall be medically examined by the Medical Panel of the Radiation Board within 4 months immediately preceding their first employment and again in a period of not more than 14 months for continued employment.

3. Responsibilities

3.1 Responsibility of 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 ionising radiation.

3.2 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 imperfect. 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 request 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 the 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.

3.3 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.

If two or more medical imaging procedures are readily available to 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.

The radiologist should not allow any person to operate x-ray equipment unless they are qualified persons as stipulated in the Radiation Ordinance, or they are working under direct supervision of radiologists.

4. 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 specific 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 special indications.

5. X-ray Examinations Not Directly Associated with Illness

5.1 X-ray Examinations Used in Health Assessment

Health assessment 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.

5.2 X-ray Examinations Used in Screening for Specified Diseases

For x-ray examinations used in screening for specified 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 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.

6. X-ray Examination of Women

6.1 X-ray Examination during Pregnancy

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 irradiating from a diagnostic procedure very rarely justifies terminating a pregnancy. Exposure of the embryo in the first three weeks following conception is not likely to result in deterministic or stochastic effects in the live born child. A pregnant patient is likely to know, or at least suspect, that she is pregnant after one missed menstruation, so the necessary information on possible pregnancy can, and should, be obtained from the patient herself. If the most recent expected menstruation has been missed, and there is no other relevant information, the woman should assumed to be pregnant. Diagnostic and therapeutic procedures causing exposures of the abdomen of women likely to be pregnant should be avoided unless there are strong clinical indications.

6.2 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 minimise 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. For Example :

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

6.3 Obstetric Radiography

In many instances, particularly in the evaluation of foetal maturation and placental localisation, ultrasonic examinations are preferable to x-ray examinations. Ultrasonic examinations do not utilize ionising 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.

6.4 Other X-ray Examination 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 examinations is indeed indicated at that time and that it should not be delayed until after the pregnancy. Sometimes the 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 minimise the irradiation time or number of radiographs and to minimise 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 area 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. Protection of Workers in Diagnostic Radiology

7.1 The Control of External Radiation

Workers in diagnostic radiology are exposed exclusively to external irradiation. 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.

The successful control of external exposure requires the use of suitable equipment and techniques. The primary source of exposure in diagnostic radiology is the x-ray tube. The most effective protection measures are those applied at or near the x-ray tube. The shielding of the primary radiation 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 the 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.

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 practice; 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.

7.2 Expert Advice and Technical Assistance

7.2.1 In each facility where work with radiation is undertaken, a person should be appointed or a member of staff should be designated to act as Radiation Safety Officer/Supervisor. 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

b) to deal with day-to-day matters on radiation protection

c) to assist management in ensuring that the radiation safety measures 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 condition

g) to arrange for new workers to receive appropriate instruction and training in radiation protection

h) to ensure that appropriate records are maintained of the effective dose received by workers

7.2.2 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 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 drawing-up contingency plans

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

m) informing Radiation Board of any radiation incident

7.3 Planning and Design

a) 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.

b) 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 conditions, 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.

c) 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 wear appropriate protective clothing. 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.

d) The design of 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 rapid film changer.

e) The protective screen at the control console should contain lead glass windows of the same lead equivalence as the screen, which, in addition to providing the worker with a clear view of the 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.

f) 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. If radioactive substances of high energy gamma radiation are to be used in the examination room, such as the use of iridium-192 in catheterisation laboratory, special attention

shall be made to the effective shielding of surrounding walls, floor and ceiling.

g) 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.

h) A radiation warning sign shall be permanently displayed at all entrances to the x-ray room. The warning sign may take the form as shown in Appendix A. 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-ray. The use of interlocking system also provides extra protection against a person inadvertently entering the room when the machine is operating.

i) 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 under-couch tube) or below the x-ray table (with over-couch 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 over-couch tube/under-couch intensifier system is not operated by remote control, additional protective drapes shall be provided to ensure adequate protection of the operator.

j) 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.

7.4 General Working Practices

a) Persons should only be permitted to use irradiating apparatus for medical applications after they have received appropriate training and qualifications and have been authorized to practice. 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 equivalent doses. Access to all control areas shall be restricted to :

   i) those persons authorized by the head of department to enter the area

   ii) patients undergoing an x-ray examination

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

b) All workers who enter a controlled area shall comply with the local rules of radiation safety applicable to the area. (Appendix B.)

c) 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 the following :

   i) appropriate shielding

   ii) appropriate protective clothing

   iii) adequate distances between parts of the body and the x-ray tube and patient

   iv) specifying the maximum workload that can be safely undertaken in the area

   v) limitation of time spent in the vicinity of the x-ray tube and patient

d) Whenever practical, 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.

e) 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 setting 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.

f) If worker cannot remain in the protected area when the x-ray machine is operated, they shall wear a protective apron of a least 0.3mm lead equivalence. As far as reasonably practicable they should occupy areas of the room where the levels of radiation exposure are low. Any person who is required to stand within 1 metre of the x-ray tube or patient when the machine is operated at tube voltages above 100kV should wear a protective apron of at least 0.35mm lead equivalence. Protective gloves should be of at least 0.35mm 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.

g) Thyroid protection, if deemed necessary can be achieved by wearing a collar of suitable lead equivalence or by the use of a protective apron with a high neckline.

h) 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.

i) 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.

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

k) 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.

l) Persons who hold a patient shall wear a protective apron and ensure that no part of their body is exposed to 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.

m) 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.

n) 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 :

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

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

o) Depending upon the nature of 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 make full use of the protective screen 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.

p) Whenever possible, fluoroscopy with an over-couch tube/under-couch 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 under-couch tube/over-couch 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 such 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.

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

7.5 Mobile Radiography Outside X-ray Department

a) The head of x-ray department should be responsible for ensuring that x-ray equipment used in the facility outside the main x-ray department is operate 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 qualified workers who have undergone an appropriate course of practical training and instruction should be permitted to use mobile x-ray equipment. It is essential that they clearly understand their duties and responsibilities when operating such kind of x-ray equipment.

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

c) the operator shall ensure that no persons other than the patient is in direct line with the primary x-ray beam unless the beam has been adequately attenuated. 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.

7.6 Use of Mobile Fluoroscopic Screening Equipment

a) A radiologist should be present when mobile fluoroscopic x-ray equipment is used.

b) 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 radiographer.

c) Any person who is involved in the examination of patients and is required to stand near the x-ray tube or the patient when the x-ray machine is operated should wear a dosimeter and should wear a protective apron. All other persons should stand as far away from the x-ray tube as practicable.

7.7 Avoidance of Unnecessary Exposure

a) 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.

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

   i) use of short period of fluoroscopic exposure

   ii) temporary removal of the anti-scatter grid

   iii) in cine-fluoroscopy, by using frame speed not exceeding 30 frames per second and by cine-runs of 3-5 seconds only

c) Dose reduction to worker can be achieved by careful selection of fluoroscopic apparatus. Such factors include :

   i) use of pulse system

   ii) use of image storage systems, particularly in fracture work

   iii) use of carbon fibre products

   iv) provision of a timing device with audible warning; display of the fluoroscopic time on the image monitor

   v) use of properly adjusted automatic brightness control

d) The effectiveness 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.

e) Some dose reduction to worker can be achieved in plain radiography by the following methods:

   i) use of the fastest screen/film combination that will give the diagnostic information and use of digital radiography

ii) setting the developer temperature at the recommended level (this is commonly set too low with the result that extra radiation is given to achieve the necessary photographic blackening)

iii) regular review of rejected films aimed at detection and elimination of prevailing cause of rejection

iv) use of carbon fibre products (grid facing and interleaving; table top; cassette fronts)

8 Reduction of Patient Dose in Diagnostic Radiology

8.1 Avoidance of unnecessary dose

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 radiation risk. However, there should be no excuse for x-ray examination to be carried out with unnecessarily high doses. The basic principle of optimisation that individual doses be kept 'as low as reasonably achievable', economic and social factors being taken into account' should always apply.

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, it is necessary to:

i) 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

ii) limits as far as is practicable the irradiation of other parts of the body

iii) reduce the frequency of unnecessary repeat irradiation

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 radiation 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.

8.2 Size of X-ray Field

Amount 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 appropriate size is usually of benefit to the patient. The decrease in x-ray field size usually 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.

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 devices is used in examining areas smaller than the smallest available radiographic film, the beam limitation should be adjusted so that 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 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 commonly occurs during 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.

8.3 Shielding of Organs

The gonads should be shielded when, of necessity, they are directly in the x-ray beam or within 5cm 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 examination involving high 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 to 75% by shielding the eyes. The use of posterior-anterior projection rather than anterior-posterior projection can reduce the absorbed dose in the eyes by 95%.

8.4 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. In radiography and fluoroscopy with mobile x-ray equipment, the focal spot-to-skin distance should not be less than 30cm. In radiography and fluoroscopy with stationary x-ray equipment, the focal spot-to-skin distance should not be less than 45cm. For focal spot-to-image receptor distance less than about 100cm, 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 radiography of the chest should be performed with a focal spot-to-image receptor distance of at least 120cm.

8.5 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 value 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 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 2.5mm of aluminium, of which 1.5mm should be permanent. Mammography requires lower x-ray tube voltages than conventional radiography and its total filtration should not be less than 0.03mm of molybdenum for screen-film mammography or 0.5mm of aluminium for xeromammography.

8.6 Carbon Fibre Material

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 80kV, the use of carbon fibre materials enables the absorbed dose in the skin of the patient to be reduced. The overall reduction of absorbed dose in the skin of the patient facing the x-ray tube, from the combined use of carbon fibre in patient supports, anti-scatter grids and radiographic cassettes, is in the range of about 30% to more than 50%.

8.7 Control of Irradiating and Recording of Irradiating 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 irradiations 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 (“dead man”), whether operated by hand or by 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.

8.8 Intensifying Screen and Radiographic Films

Intensifying screens containing high-efficiency phosphorescent materials, such as rare earth, barium and tantalum, require less radiation than conventional intensifying screens to produce radiographs with similar image quality. 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.

8.9 Control of Radiation Scattered to the Image Receptor

Anti-scatter grids or air gaps interposed between the patient and the image receptor reduce the amount of radiation that is scattered to the image receptor while at the same time permitting transmission of the primary radiation which produces the X-ray pattern. The reduction of scattered radiation enhances the image, but increases the dose to the patient.

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

8.10 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 developer and fixer must be selected for the type of radiographic film to be used. The correct processing temperatures, development time and replenishment of

chemicals are essentials 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 sensitometer shortly before their processing. The density and contrast of the film strips should then be quantitatively evaluated. If the density or contrast is outside the specified 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.

8.11 Reduction in Number of Repeat Irradiations

The decision to repeat an irradiation should be based on the likelihood that the new radiograph will give added information which was not available on the previous radiograph, rather than for purely aesthetic reasons. In various published surveys the rate for retake of radiographs varied from 3 to 15%. The major cause of retaken 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.

8.12 Quality Assurance

The purpose of quality assurance programmes 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.

8.13 Chest Examinations

Examinations of the chest form a large proportion of all radiological examinations. They contribute a substantial fraction of population dose from diagnostic radiology. In many instances, excessive field sizes are still used, sometimes large enough to include the gonads of an adult man. It is essential to have the beam size adjustable so that, for example, small adult or child is not irradiated with a beam size suitable for the largest adult; for this purpose an adjustable light beam diaphragm is particularly useful. If a fixed aperture diaphragm is used, it is necessary to have one or two smaller apertures for this purpose; a protective screen of adjustable height can ensure that the lower edge of the beam incident on the patient is no lower than necessary. Where acceptable, high voltage air gap techniques are recommended for chest radiography.

8.14 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 minute and should be typically much lower.

Direct fluoroscopy delivers higher doses to the patient than 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-adaptation 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 rage of 10 to 50 mGy per minute. 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 examination should be replaced by radiography whenever possible because the dose to the patient from radiography can be much as one

hundred times less than for direct fluoroscopy and a permanent record becomes available.

Photofluoroscopy has been widely used for x-ray examinations of the chest in screening the population for tuberculosis, but the dose to the patient may be up to ten times greater than that for a full-size radiograph.

8.15 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 was 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.

8.16 Paediatric Radiology

In examinations of infants and children, the normal risks per milligray for fatal cancers (e.g. following whole-body irradiation) and severe hereditary disorders (e.g. following gonadal irradiation) are larger than for the general population. The requirements for correct positioning and handling of paediatric patients and the criteria for the image quality necessary to achieve the diagnostic tasks in paediatric radiology differ from those for adult x-ray examinations. Therefore, 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.

8.17 Mammography

Absorbed dose in breast tissue during mammography should be kept as low as reasonably achievable without sacrificing

necessary diagnostic information. The predominant mammography technique uses a molybdenum target and molybdenum filter with a rare-earth intensifying screen and matching radiographic film. A less frequent mammography technique uses 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 0.03mm of molybdenum for screen-film mammography or 0.5mm of aluminium for xeromammography.

9. Diagnostic X-ray Equipment

9.1 X-ray Source Assembly

Every x-ray source assembly (comprising an x-ray tube, an x-ray tube housing and a beam limiting device) should be constructed so that, at every rating specified by the manufacturer for the x-ray source assembly, the radiation leakage rate at 1m from the focal spot does not exceed 1mGy in one hour.

Every x-ray source assembly should be marked to identify the nominal focal spot position.

9.2 Beam Filtration

The inherent filtration of every x-ray tube assembly should be marked permanently and clearly on the housing. Every added filter should be marked permanently and clearly with its filtration in millimetre of aluminium equivalent. Materials other than aluminium e.g. erbium which has sharper cut-off characteristics can also be used for filtration.

The total beam filtration includes the inherent filtration, any added filtration and filtration afforded by attenuating material that permanently intercepts the beam, e.g. the mirror of a light beam diaphragm. For normal diagnostic work the total filtration

of the beam should be equivalent to not less than 2.5mm of aluminium of which 1.5mm should be permanent.

To avoid unnecessary dismantling of the tube assembly the total filtration (or its constituent parts) should be written down and kept readily available. In the case of under-table tubes, the filtration of the table top should be marked clearly in terms of millimetre of aluminium equivalent.

9.3 Beam Size

The maximum cross-section of the beam from every diagnostic x-ray source assembly should be permanently limited to that required in practice for each particular source assembly by means that take into account the need to avoid extra-focal radiation.

All radiographic x-ray equipment should be provided with properly aligned adjustable beam-limiting device or in special circumstances, e.g. skull unit cones to keep the radiation beam within limits of the x-ray film selected for each examination.

Light beam diaphragms should be provided on radiographic equipment. They should also be fitted to mobile radiographic equipment when practicable.

Equipment for fluoroscopy, except for radiotherapy treatment simulators, should be provided with the means, preferably automatic, to confine the radiation beam within the image reception area whatever the distance of the x-ray tube from the image receptor. It should be possible for the operator to adjust the field size during examination down to the equivalent of 5cm x 5cm at 1m from the focal spot.

For computed tomography scanners, the radiation beam should have no cross-sectional dimension greater than that required to cover the active element of the image receptor.

9.4 Image Receptors

Image intensifiers and television viewing systems should be used in fluoroscopy in order to increase the information obtained per unit dose received by the patient and to reduce the doses to staff.

Staff and patient doses can be reduced by the use of storage or memory devices on image intensifier systems.

The housing and support plates of an x-ray image intensifier and of the image receptor of a computed tomography scanner should provide shielding equivalent to at least 2mm lead for 100kV. From 100 to 150kV an additional lead equivalent of 0.01mm per kV.

9.5 Signals and Marking

There should be a visible indicator on the control panel, preferably including an indicator light, to show that the mains is switched on. In the context of the control panel signal “main on” indicates a state of readiness to emit radiation.

All radiographic equipment control panels should be fitted with a light giving a clear and visible indication to the operator that an exposure is taking place. The light should be triggered by conditions associated uniquely with the commencement and termination of the emission of radiation, but arranged to remain on long enough for the indication to be seen irrespective of the exposure duration. For equipment fitted with an audible warning the warning should be triggered by the same conditions.

Where it is possible, from a single location to initiate the production of x-rays from more than one x-ray tube, each x-ray tube should be provided with means for automatically giving a warning signal whilst that x-ray tube is selected to emit x-rays. The tube selection warning signal should be clearly visible in the vicinity of the x-ray tube and if practicable from the control panel. The electrical circuitry should be such that it is impossible to initiate an exposure if the warning system fails; however, the system should be designed to avoid the likelihood of a diagnostic examination being interrupted.

The exposure controls should be marked clearly. All other controls, instrument and indicating devices should be marked permanently and clearly to indicate their functions. On any equipment where x-ray tube selection is possible there should be clear and unambiguous indication on the control panel of which tube has been selected. Markings by symbols should be clear and their meaning should be described in the operating instructions.

9.6 Exposure Factors

Fluoroscopic equipment with automatic brightness control should have a range of sensitivities using different levels of air kerma rate at the input screen of the image intensifier. This can enable an optimum balance to be made between image quality and minimum dose.

9.7 Exposure Switches

Exposure switches on all x-ray diagnostic equipment, except computed tomography scanners, should be arranged so that an exposure continues only while continuous pressure is maintained on the switch and terminates if pressure is released (if not previously terminated by other means, e.g. at the end of the set exposure time).

The position of the exposure switch should be as follows :

(a) for fixed equipment, at the control panel or at the position intended to be occupied by the operator; and

(b) for mobile and portable equipment, such as to enable the operator to be outside the radiation beam and to be not less than 2m from the tube housing and from the patient.

Exposure switches should be designed to prevent inadvertent production of x-rays and should not be possible for fluids to enter the switch and cause a short circuit. Additionally, foot switches should be constructed so that exposure does not take place if they are accidentally overturned. Switches should be positioned so that they are not depressed accidentally during

stowage. If re-setting is automatic it should be ensured that pressure on the exposure switch has to be released completely before the next exposure can be made.

A key operated switch should always be provided for mobile equipment to prevent the generation of radiation by unauthorized persons:

(a) whenever radiation can be generated without connecting the equipment to the electrical mains supply; or

(b) when connected to the electrical mains supply if the equipment requires such a connection to be made for battery charging

9.8 Control of Exposure Duration

For radiography, there should be a means for terminating the exposure automatically after a pre-set time, electrical charge (mAs) or quantity of radiation or after a tomographic scan has been completed. To guard against failure, an additional means of termination should be provided which is independent of the normal means. The release of an exposure switch may be regarded as the additional means.

For fluoroscopy, the release of an exposure switch should be regarded as the normal means of termination. An additional means of termination should be provided which operates automatically when a predetermined integrated fluoroscopy time not exceeding 10 minutes has elapsed. This device should give an audible warning at least 30 seconds before termination to enable the operator to reset the device if the exposure needs to be prolonged.

The provision of automatic exposure control devices for radiography should be considered as an aid to the achievement of consistent radiographs and the reduction of repeat exposures.

Equipment for computed tomography should have a device which terminates the exposure automatically as soon as the selected scan has been completed or scanning stops before

completion. Initiation of an exposure should not be possible if the scanning motor fails to start unless “warm up” conditions or a localization exposure have been selected.

If a “warm up” facility is provided on computed tomography equipment there should be a clear indication on the control panel when the “warm up” mode has been selected and there should be a device which de-energise the x-ray tube on completion of the desired “warm up” phase.

9.9 Protection Against Scattered Radiation for Fixed Fluoroscopy Installations

All tables and stands used for fluoroscopy should be provided with adequate protection for staff against scattered radiation from the patient and from materials between the x-ray tube and the patient. When an under-table tube is used, this protection may take the form of an “apron” in which case it should be:

(a) large enough (not normally less than 45cm wide and 45cm long)

(b) made of protective material having lead equivalence of not less than 0.5mm, and

(c) attached to the lower edge of the screen holder or intensifier support when the latter is vertical and to the operator’s side of the screen holder or intensifier support when this is horizontal

Additional protective “aprons” or fixed shields should be attached where possible to both sides of the table when the screen or image receptor of the intensifier is horizontal and to both sides of the stand when they are vertical. The beam limiting device for under-table tubes should extend as close as possible to the back of the table or stand.

APPENDIX A

Radiation Warning Signs

APPENDIX B

B1 Local Rules for X-ray Room — Radiography Only

1. Before making an exposure, close the doors of the x-ray room.
2. Do not direct the x-ray beam at windows of the room or towards the control panel or darkroom wall.
3. During radiography all staff must stand behind the protected control panel and may observe the patient through the lead glass window.
4. Gonad shields must be used on patients whenever appropriate, and the field must be adjusted to the minimum size consistent with adequate clinical diagnosis.
5. When films or patients require support, use mechanical supports whenever possible.
6. No patient should wait or change in the x-ray room while another patient is being radiographed.
7. If anyone is ever required to support a patient or film during an exposure, he/she must:
   (i) wear a protective apron and gloves and avoid the direct beam by standing to one side and away from the x-ray tube
   (ii) record, in the notebook provided, his/her name, the date, the number of exposures, and the radiographic techniques used

B2 Local Rules for X-ray Room — Radiography and Fluoroscopy

1. Before making an exposure, close the doors of the x-ray room.
2. Do not direct the x-ray beam at the windows of the room or towards the control panel or darkroom wall.
3. During radiography or fluoroscopy, all staff must either stand in the protective cubicle, observing through the lead glass window or wear protective aprons, keeping well away from the patient when not specially required to come close. Protective gloves must be worn when handling the patient during fluoroscopy
4. In conventional fluoroscopy the current must not exceed 4mA at 100kV. With image intensifiers the current should not exceed 1mA at 100kV. Examination time and field size should be kept to a minimum consistent with adequate clinical diagnosis.
5. Gonad shields must be used on patients whenever appropriate.

6. When films or patients require support, use mechanical supports whenever possible.

7. No Patient should wait or change in the x-ray room while another patient is being radiographed.

8. If anyone is ever required to support a patient or film during an exposure, he/she must:

   (i) wear a protective apron and gloves and avoid the direct beam by standing to one side and away from the x-ray tube

   (ii) record, in the notebook provided, his/her name, the date, the number of exposures, and the radiographic techniques used

B3 Local Rules for Ward Mobile Radiography

1. The direct beam must not irradiate any person other than the one being radiographed.

2. When the radiographic exposure is being made, staff must stand as far away from the patient as possible (at least 2m) and wear protective aprons.

3. Gonad shields must be used on patients whenever appropriate, and the x-ray beam size should be restricted by diaphragms or a suitable rectangular cone so as not to irradiate more of the patient than is necessary for diagnosis.

4. If anyone is ever required to support a patient or film during an exposure, he/she must:

   (i) wear a protective apron and gloves and avoid the direct beam by standing to one side and away from the x-ray tube

   (ii) record, in the notebook provided, his/her name, the date, the number of exposures, and the radiographic techniques used

Radiation Health Series

No. 1	Guidance Notes on Radiation Protection for Diagnostic Radiology
No. 2	Safe Handling of Radioactive Consignments
No. 3	Techniques to Reduce the Radiation Hazards from Using Phosphorus-32
No. 4	Guidance Notes on Radiation Protection for Dental Radiography
No. 5	Code of Practice for the Handling, Storage, Packaging, Transportation and Disposal of Radioactive Wastes
No. 6	Ionising Radiation
No. 7	Guidance Notes on the Design of Protective Shielding for Medical, Dental and Veterinary Diagnostic X-ray Facilities
No. 8	Safe Handling of Nuclear Moisture and Density Gauges