MANUAL ON RADIATION PROTECTION
IN HOSPITALS AND GENERAL PRACTICE
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IN HOSPITALS
AND GENERAL PRACTICE

Volume 3
X-Ray Diagnosis

B. E. KEANE
Principal Physicist, Medical Physics Department, Royal Sussex County Hospital,
Brighton, England

K. B. TIKHONOV
Professor and Director, Central Research Institute for Röntgenology and Radiology,
Leningrad, USSR

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REVIEWERS

Dr G. M. Ardran, Nuffield Institute for Medical Research, Oxford, England
Dr C. B. Braestrup, Consultant Physicist, Lenox Hill Hospital, New York, USA
Dr Tawan S. Bunnag, Director, Chulalongkorn Memorial Hospital Medical School, University of Medical Sciences, Bangkok, Thailand
Professor R. H. Chamberlain, Chairman, Department of Radiology, Hospital of the University of Pennsylvania, Philadelphia, USA
Professor D. Frost, Director, Department of Radiation Physics, Rudolf-Virchow Hospital, Berlin
Dr H. Jammet, Head, Department of Health Protection, Atomic Energy Commission, Centre for Nuclear Studies, Fontenay-aux-Roses, France
Professor F. G. Krotkov, Academic Secretary, Academy of Medical Sciences, Moscow, USSR
Dr Bo Lindell, National Institute for Radiation Protection, Karolinska Hospital, Stockholm, Sweden
Dr O. G. Machado, Director, Radiotherapy Department, National Cancer Institute, Rio de Janeiro, Brazil
Professor P. Pellerin, Director, Central Service for Protection against Ionizing Radiations, Le Vesinet, France
Dr K. J. Vikterlöf, Radiation Physics Department, The Regional Hospital, Örebro, Sweden
Dr L. R. Whittaker, Kenyatta National Hospital, Nairobi, Kenya

JOINT SECRETARIAT

Dr H. T. Daw, International Atomic Energy Agency, Vienna
Mr E. Hellen, International Labour Office, Geneva
Dr W. Seelentag, World Health Organization, Geneva
Dr B. Waldeskog, World Health Organization, Geneva
Preface

Much technical material has been published at the national and international levels on radiation protection in the nuclear power industry, nuclear research, and conventional industries. On the other hand, the subject of radiation protection in hospitals and general practice, where a large proportion of public and occupational radiation exposure occurs, has not yet received much attention in the international literature.

The International Labour Organisation, the International Atomic Energy Agency, and the World Health Organization all have a long-standing interest in these problems from various points of view. They therefore decided to collaborate in the preparation of a Manual on Radiation Protection in Hospitals and General Practice in several volumes, with each agency taking special responsibility for the volumes that concern it most. However, to simplify distribution and to make it easier for readers to purchase the various volumes, the entire work is being published by WHO.

The manual as a whole deals with the radiation protection of patients, occupationally exposed persons, and the public and is written for the reader having a basic general knowledge of radiation and biology. It is hoped that it will be found helpful not only to those who are directly engaged in radiation protection in hospitals and general practice but also to national authorities, hospital administrators, supervisors, hospital workers, teachers in training centres, and all those who have some responsibility in the subject.

The present volume, the third in the series, deals with radiation protection in X-ray diagnosis. The authors discuss the organization of radiation protection, the choice of X-ray equipment, the siting and construction of radiology departments and the conduct of radiation surveys, and throughout the book they give guidance on good practice, which is perhaps the most significant means of reducing the hazards to which patients and staff may be exposed. The book should be used in conjunction with Volume 1—a general review of the basic requirements of radiation protection.

The preparation of the volume was undertaken by Mr B. E. Keane and Professor K. B. Tikhonov, and the final text was completed in collaboration with Drs B. Waldeskog and W. Seeentag (WHO).

The draft was reviewed by the experts listed on page 7, some of whom are the authors of other volumes in the series. The observations received were taken into account in the preparation of the final text, and the contributions are gratefully acknowledged.
Introduction

When setting up radiation protection for an X-ray facility it is insufficient simply to design protective thicknesses and order standard apparatus. There is a need to take an interest in the organization of the whole radiological department. Radiation protection should not be forgotten once the protective equipment has been installed. Its purpose must be understood and good radiation protection practices must be encouraged until they become habitual.

The functioning of an X-ray diagnostic facility is inevitably influenced by the level of medical care with which it is associated, which may range from the highly specialized teaching hospital to the small clinic served by a single X-ray machine. The reader will find it useful to identify the approximate level of the X-ray facility with which he is concerned (see pp. 13–14) so that he may concentrate on those parts of the text most relevant to him. This will enable him to make a rapid assessment of his immediate situation. Later he may study other levels, if a change is desirable.

Any X-ray diagnostic installation passes through a series of familiar phases in its life-cycle, from conception and construction through routine operation to eventual replacement. It will be helpful for the reader to attempt to identify the point that has been reached in the life-cycle of his own installation so that he may be aware of all the present problems and may anticipate those likely to arise in the immediate future.

Radiation protection in X-ray diagnosis should be viewed in relation to the other branches of radiology. In a well regulated X-ray department of modern design and staffed by trained personnel the radiation exposure to staff can be less than the dose limits for the general public. This may not be true in a nuclear medicine and radiotherapy department, where the staff have to contend with the additional hazards of contamination, high-energy radiation, and patients who emit radiation continuously, but in X-ray diagnosis full containment of undesirable stray radiation is a realistic objective, which should be pursued at every opportunity.

Chapter 1 provides an administrative approach to radiation protection and is intended as a guide to the rest of the volume.

Chapters 2 to 5 present information suitable for planning a new installation but may nevertheless be useful when checking the radiation protection in one that already exists. They are addressed primarily to the head of a department and may be brought to the attention of the manufacturers, architects, and engineers concerned with the installation.
Chapters 6 and 7 on radiation surveys and monitoring of staff may be applied immediately to existing installations and should be referred to by all persons directly responsible for radiation protection.

In all matters of radiation protection the advice of an expert should be available. However, it is appreciated that in some remote circumstances it may be difficult to obtain access to such a person. If the approach is to be by correspondence it is important to ask the right questions, and to know to whom they should be addressed. It is hoped that this volume will help those concerned with radiation protection in X-ray diagnosis not only to take action themselves but also to seek aid when they need it.
1. Organization of Radiation Protection

Diagnostic radiology at various levels of medical care

In highly developed medical care possibly a third of all important medical decisions use information obtained by diagnostic radiology. At the opposite end of the scale, in many provincial and rural areas particularly in developing countries there is no radiological equipment, and even if there were there would be no one trained to operate it or to interpret the radiographs. At intermediate levels, the contribution of diagnostic radiology to medical care varies widely, and the types of X-ray examination that are most customary depend on the disease pattern of the area.

For the purpose of considering radiological protection facilities, the following arbitrary levels of medical care have been adopted as a general guide.

Level 0 — Clinics and health stations operated by a nurse or medical assistant without any direct medical supervision. No radiological facilities are provided, because radiology should always be conducted under direct medical supervision.

Level 1 — Small clinics, health stations or general practices under the supervision (at least part time) of a general practitioner who can undertake emergency work and refer patients to other levels. The work is predominantly with outpatients but there may be a few beds for routine maternity care and for patients awaiting transfer to other hospitals. The population served is in the range 10,000–100,000. At this level, radiography is required only of the chest, fractures (mainly extremities), and, in exceptional cases, plain abdomen. No fluoroscopy should be undertaken.

Level 2 — District hospitals or rural hospitals staffed by a small number of doctors and undertaking general medical care and minor surgery. Abdominal and other major surgery is attempted only on an emergency basis. Such a hospital may well have up to 100 beds and extensive outpatient work. Some private hospitals and clinics and some charity hospitals may be included in this group. The population served is in the range 50,000–500,000. The radiographic examinations required include the chest, simple abdomen, fractures, and possibly some fluoroscopy using opaque media such as barium.

The levels of medical care described are based on the report of a WHO seminar on the use of medical radiological apparatus and facilities, Singapore, 1970. Copies of the report (RHL/71.2) are available from Radiation Health, World Health Organization, 1211 Geneva 27, Switzerland. The population figures quoted under the various levels of medical care refer only to some developing countries. In industrialized countries the population served by a given hospital or health centre is considerably smaller, possibly by an order of magnitude.
meals (particularly in inaccessible areas where it is difficult to transfer a patient to another hospital).

**Level 3** — Medium-sized regional or provincial hospitals that undertake all routine hospital work such as general medical care and routine surgery including abdominal surgery. The medical staff will include specialists in such main fields as obstetrics and internal medicine. Some training of nurses and radiographers may be carried out. The hospital will have a few hundred beds and serve as a reference hospital for a population varying from 500,000 to a few million. All general radiological work is needed in such a hospital, including, for example, tomography, angiography, and urography. Work with opaque media is certainly carried out and includes barium meals and enemas and cholecystography.

**Level 4** — Large central or general hospitals that are not university teaching hospitals but are responsible for the teaching of nurses and other personnel such as radiographers. A substantial portion of the work is of a general nature, with a heavy load of straightforward routine work, and there may also be a limited amount of specialized work. A large hospital of this kind may have 500 or more beds and serve a population of 3–5 million. A wide variety of radiological work is required, including such special examinations as lymphangiography and neuroradiology.

**Level 5** — University teaching hospitals. Not only does such a hospital cover a large region as a referral centre but it tends to have a selection of the most difficult cases and rare types of disease. It undertakes a wide range of general and specialized medical care involving a number of sub-specialities such as cardiac surgery and the treatment of metabolic diseases. Teaching is conducted at both undergraduate and postgraduate levels, and the hospital also engages in research. It may have 500 or more beds. All types of general and specialized radiological work is required, including research. Special examinations form a substantial part of this work and may have to be integrated with the work of other departments (e.g., angiocardiology in collaboration with the cardiology department).

It is strongly recommended that wherever possible in hospitals at levels 3, 4, and 5 all X-ray diagnostic examinations should be carried out by the diagnostic radiology department. Even when X-ray equipment is installed in other departments, the head of the radiology department should have responsibility for the radiological aspects of any examinations performed.

It is important to note that level 1 refers to a rural or remote area where no other radiological service is available and the supervision is that of a general practitioner with limited skill in radiology. No fully qualified radiographer may be available at this level, and the X-ray equipment may be operated by a nurse or laboratory technician who has had additional training in radiography. In areas where a more comprehensive radiological service is available, no attempt should be made to provide a level 1 radiological service.
The reader will find it helpful to identify his own situation with one of the foregoing levels of care, because reference is made to them throughout the volume. He may thus read the text selectively or use it for rapid reference.

**Responsibility for radiation protection**

Some measure of responsibility for radiation protection is held at all levels of the hospital, from the employing authority to the workers carrying out radiological procedures.

The authority in charge of the establishment is ultimately responsible for the protection of all staff, patients, and members of the public who may come within range of any radiation from its X-ray equipment. Therefore hospital administrators would be well advised to establish a radiation safety committee, which would in turn designate a radiation protection officer to supervise the safety of all radiation areas.

In small establishments with one X-ray laboratory at levels 1 and 2 this person should be the one with the most knowledge of radiation and might well be the X-ray technician or radiographer. In private practice the physician in charge has to take full responsibility. In larger establishments at levels 3 and 4 it could be the head radiologist or, if he is not a full-time staff member, the chief X-ray technician. At levels 4 and 5 a medical physicist may be specifically employed for radiation protection, teaching, and general advice. Since it is unwise to expect the radiation protection officer to bear his responsibilities unaided, the radiation safety committee should also designate a local protection officer in each X-ray department to take care of day-to-day measures.

However small the X-ray establishment, the services of a physicist experienced in the properties and effects of radiation should be sought to act as radiation protection adviser. He should help to plan new radiological services and should regularly review existing services for X-ray protection with the aid of radiation surveys.

Adequate protection equipment must be made available to satisfy the requirements of the expert adviser and the local protection officers. Failure to do this shifts the responsibility directly to the administrator. X-ray workers and others concerned must be kept informed of the hazards involved, preferably by written instructions posted in a suitable position.

In areas where the radiation dosage is likely to exceed three-tenths of the maximum permissible dose, special control should be exercised. This will include regular personnel monitoring (e.g., using film badges), periodic radiation surveys, and health surveillance of radiation staff by a medical officer with a knowledge of radiation reactions.

Responsibility for requesting diagnostic radiology (and thus for irradiating the patient) is shared between the physician and the radiologist.
Finally, the administrator is responsible for ensuring that the general public is not subjected to any stray radiation beyond the levels laid down for the protection of the public. To this end he must insist on good planning and regular environmental monitoring.

Regular radiation protection surveys, the continuous monitoring of exposed personnel, and determination of radiation doses to patients and personnel would normally be the responsibility of a medical physicist. He might be a medical physicist loaned from a hospital at level 4 or 5, or a physicist made available for this purpose from a national radiation protection institution. Expert advisory services on radiation protection problems should be provided by a team consisting of a radiologist experienced in radiation protection, a medical physicist (or a physicist from a national radiation protection service), and a radiological engineer.

It is necessary to emphasize the importance of including radiation protection in the training of radiologists and X-ray technicians and of the nurses who are involved in radiation work. This training would normally be given by a medical physicist.

In the remaining part of this chapter, X-ray protection is presented from the viewpoint of the hospital administrator; thus the head of department or person responsible for protection may recognize all the necessary actions to be taken and realize the importance of correct timing of these actions.

Administrative phases in the life-cycle of diagnostic X-ray installations

Efficient and economic radiological protection requires careful planning and organization of the X-ray facilities concerned.

The successive phases in the life-cycle of new or additional X-ray facilities is presented below and in Fig. 1. The relative timing of some events is flexible, and the overall time to complete a full cycle, from new equipment to replacement of worn and outdated equipment, varies widely. For research equipment in a level 5 teaching hospital the cycle may be as short as 1–3 years. In a private practice at level 1, operating with a low workload of a few patients a week, the owner may well wish the cycle to last a lifetime. Nevertheless, it is essential to be conscious of the chain of events constituting the cycle. If the X-ray facility being considered is not new, its phase in the cycle should be identified as a guide to those events most likely to require action.

Phase 1 — Decision to provide a new, additional, or replacement X-ray facility. Adequate funds are assumed to be available. The decision may arise from the desire to meet a need for X-ray facilities, to extend existing facilities so that new techniques can be used, or to replace obsolete equipment that is no longer functioning well.
Phase 2 — Definition of the scope of the X-ray examinations to be performed with the proposed installation.

Phase 3 — The choice of suitable X-ray equipment to carry out the examinations. It may be possible at this point to anticipate future needs and provide equipment capable of more than the immediate requirements. However, limitation of funds will often preclude this. Consideration must

FIG. 1. ADMINISTRATIVE PHASES IN THE LIFE-CYCLE OF AN X-RAY INSTALLATION
be given in this phase to the quality of the mains supply on which the maximum power of the unit will depend, the efficiency of the maintenance and repair services, and the availability of spare parts.

**Phase 4** — Decisions on the number and type of staff required to operate the X-ray equipment and on the supporting facilities that will be needed, such as waiting rooms, darkrooms, offices, electrical and water supplies, temperature control, and transport.

**Phase 5** — The designing of suitable rooms for the equipment, staff, and facilities. A completely new building may be required or an existing suite of rooms may have to be modified. When planning new accommodation it is important to ensure that space exists for future expansion.

**Phase 6** — Preparation of cost estimates (both capital and running costs), and submission of the estimates for approval. This is the stage at which many projects are terminated. Termination is, however, preferable to partial approval granted on the assumption that more funds will be available in the near future. Partial approval may well lead to the provision of inadequate facilities and should be discouraged, particularly from the point of view of radiation protection.

**Phase 7** — Ordering of equipment and placing of building contracts. If there has been a long delay before approval it may be found that costs have risen and economies are necessary. Any such economies should not be at the expense of radiation protection.

**Phase 8** — The installation and testing of equipment, and the appointment of staff. These two developments should be carried out more or less concurrently, otherwise there is a danger that the equipment and facilities will lie idle until such time as staff are available. When the staff do eventually arrive there is a large backlog of work, which may impede the next phase in the cycle.

**Phase 9** — Familiarization of the staff with the equipment, facilities, and procedures to be carried out. This must be done before serious work is started. In the past, the first few exposures on human beings were of an experimental nature and enabled the exposure factors for the new equipment to be accurately determined. This is highly undesirable from a protection point of view (see Annex 2).

**Phase 10** — Routine operation and normal functioning of the X-ray facility. This phase represents the optimum usage of the X-ray installation, and the length of time for which normal functioning can continue depends very much on the degree of anticipation that has been used in the earlier phases. After this the cycle begins to regress.

**Phase 11** — Demand for additional techniques, and increase in workload beyond original expectations. This is a process that tends to arise
insidiously; it begins with small demands that gradually grow in magnitude until they become intolerable.

**Phase 12** — Staff changes and deterioration of equipment as a consequence of phase 11. The staff changes may be controlled by careful attention to morale but the equipment has a finite life, not only because of wear but also because of obsolescence caused by increasingly stringent codes of practice.

Phases 11 and 12 lead inevitably back to phase 1 — the decision to provide a new, additional, or replacement X-ray facility. And so the cycle repeats.

This type of classification will be familiar to hospital administrators but is frequently overlooked by the heads of radiology departments. The neglect of a single phase can create frustration and delays, which will tend to cause unnecessary trouble with the manufacturers, staff, and financial authorities. For example, if radiation protection has not been considered until phase 7, the cost will not have been allowed for in the estimates and a further application for finance will be necessary. Moreover, if the building operations are partly completed it may be both difficult and expensive to add to the protective thickness of the various structures.

**Radiation protection considerations throughout the cycle**

After the decision has been made to have a new X-ray facility, it is necessary first of all to consider the level of radiological care that must be provided during the life-cycle of that facility or, in other words, to define the scope of the X-ray examinations (see Fig. 2). At this point the organization of the facility must be considered, since it is possible to centralize the equipment in one department or to install various items in other medical and surgical units. Centralization is usually the solution to be preferred because it is conducive to higher efficiency and provides better cover for staff absences. It also facilitates the sharing of specialized services between various departments and makes it easier to carry out radiation protection measures.

In the choice of X-ray equipment (phase 3) it is necessary to consider the radiation protection specification of the proposed machines before making a final decision. The manufacturers should be asked to satisfy at least the minimum requirements indicated in Chapter 4 and to provide sufficient ancillary equipment to ensure that the desired examinations may be carried out adequately.

When deciding the number and type of staff (phase 4), one should ensure that at least the more senior members of the staff have had some training in radiation protection. In this phase, too, the facilities required for the radiation protection of staff, patients, and general public (as given in Chapters 2 and 3) should be considered.
In the design of suitable rooms for the equipment, staff, and facilities (phase 5), the shielding requirements should be calculated with respect to the maximum possible workload. Such details as the positioning and shielding of doors and windows (as indicated on page 43) should now be considered. Efficient radiation protection depends on the incorporation of adequate rooms for reading and reporting on radiographs, waiting rooms, darkrooms, and facilities for darkening fluoroscopy rooms.

It is essential in the approval of cost estimates (phase 6) to ensure that there is no last-minute substitution of, for example, highly desired X-ray or medical equipment for the original protection provisions in the estimates. If the economics of different shielding materials has been taken into account in phase 5, the estimates for protection will already be minimal and no further cuts should be tolerated.
The ordering of equipment (phase 7) should be so timed that delivery does not occur before adequate storage space is available. Ideally the main building should be finished before the installation of the X-ray equipment but protective devices must arrive very soon afterwards, otherwise there will be insufficient protection for the installation engineer and delay in familiarizing the radiological staff with the equipment. While the building is in progress the quality of the building materials should be inspected to ensure that there has been no substitution of materials that are inferior in X-ray attenuation properties. Often a simple visual inspection of the site will reveal some such errors.

During the testing of equipment after installation (phase 8), the main radiation survey should be carried out. Arrangements for this should be made well in advance so that there is no delay when the equipment is ready for use. Details of radiation surveys are given in Chapter 6. At the time of appointment of staff, one person should be designated as responsible for radiation protection so that there is no subsequent misunderstanding.

Before staff begin the familiarization procedures (phase 9), they should be instructed in radiation safety and local rules and should be issued with radiation monitors and protective clothing.

The phase of routine operation and normal functioning (phase 10) tends to be the longest of any in the cycle, and it is essential not to relax the initial high standards of safety. Personnel monitoring must be maintained, and radiation surveys should be carried out at regular intervals. Any new or temporary staff member should be instructed in radiation protection, local rules, etc., before he starts work.

If, as the workload rises (phase 11), personnel monitoring indicates that radiation doses are rising appreciably, it is wise to consider carrying out a survey before the next regular one is due. If, in emergencies, techniques are called for that go beyond those foreseen for the defined level of radiological care, it is essential to apply all the knowledge available, especially knowledge of the kind given in Annex 2, to avoid a breakdown in protection. If possible one should obtain advice from those with experience of the new techniques to be undertaken. One must guard against the tendency for improvisations to become permanent, and it is necessary to make proper provision for special techniques.

During phase 12, as time passes, it is important to make regular inspections of the condition of all radiographic equipment and to ensure that repairs and servicing are carried out promptly. One should try to anticipate the deterioration of radiation protective materials and order timely replacements of such equipment as flexible lead rubber shields, aprons, and gloves. Contacts should be established with the appropriate authorities to ensure that the radiology department is immediately informed of all changes in national or international recommendations. Eventually, as soon as the overall performance of the X-ray equipment shows signs of declining (as
indicated, for example, by the need for unusually increased exposures or by lack of reproducibility of results), it is important to obtain funds for a new installation well in advance of ultimate breakdown.

It is obvious that only by constant vigilance can efficient radiation protection be maintained throughout the whole life-cycle of an X-ray installation. The radiation protection officer would be well advised to lay down a definite timetable for reviewing all aspects of radiation protection once the initial installation is complete.

It is often necessary to include adequate financial provision for the running costs of personnel monitoring, the maintenance and replacement of protective equipment, and repeated radiation surveys. This should properly be introduced in phase 6.
2. Staff Radiation Protection Facilities

The factors governing the exposure of the staff to radiation may be divided into two categories. The first group comprises those factors that are under the control of the staff themselves and include the time that the equipment is switched on, the presence or absence of the staff, and the beam size. The factors in the second group are fixed and include the structural shielding, the layout of the X-ray room, and the design of the X-ray equipment. Both aspects are present in all the work undertaken in a radiology department.

Radiography

In general radiography, the staff can usually be positioned behind protective shields during the exposure, and only when carrying out special techniques does a member of the staff need to be in the room, wearing a protective apron and gloves if necessary. The patient is placed in a comfortable position, the film is supported mechanically, and there is no need to restrain either patient or film. When a member of the staff has to be present—for example, when young children have to be held by hand—special rules apply.

The whole aim of radiography is to produce a fixed exposure on the film, and all the stray radiation arising is consequential on the film itself receiving the correct exposure. The exposure is of brief duration in order to reduce the blurring of the image due to movement of the subject. There is plenty of time between exposures for any preparations to be made under non-radiation conditions. Then during the relatively short exposure everyone, including accompanying nurses, can take shelter behind protective shields.

During the exposure, even though it is of short duration, the radiation is of high intensity. Therefore to minimize stray radiation the beam size should be kept as small as possible while ensuring adequate coverage of the area under investigation. The reduction in beam size will improve the quality of the image.

With a completely new installation and building, the X-ray controls may be sited in a protective cubicle that is effectively outside the X-ray room, provided there is an adequate view through a lead glass window and a method of speaking to the patient. This means that staff need enter the room only when the equipment is switched off, and in these conditions it may be possible for even pregnant technicians to continue working nor-
nally. For this system to function adequately, there must be mechanical supports for films and for those patients who are very ill.

Fluoroscopy

One of the most important properties of fluoroscopic equipment is that it can be switched off. All the time it is switched off no irradiation of patient or staff takes place. Therefore as much preparation and manipulation of the patient and equipment as possible should be done with the beam switched off. This ensures that the beam is switched on for a minimum time and that only essential persons are present during exposure. It is of considerable advantage to have the fluoroscopy switch spring loaded so that it is not left on unnecessarily or accidentally. An overall timer that gives an audible warning and finally switches off after a few minutes is also useful to restrict the switch-on time of the equipment. It is most inadvisable, however, to couple the fluoroscopy switch with the room's red light, so that the room is illuminated as soon as the equipment is switched off. Light is not always wanted because it disturbs the fluoroscopist's dark adaptation and so leads to unnecessary irradiation of the patient. This is particularly true when the examination involves a succession of brief exposures. The fluoroscopy switch and the red light should always be independently operated.

It is a fundamental principle that if sufficient information can be obtained from radiography alone (this is often the case with chest examinations) then fluoroscopy should not be attempted.

The beam size markedly affects the scattered radiation to the staff and it should therefore be kept as small as possible, showing only those parts that the fluoroscopist really needs to see. This will also reduce the dose to the patient and it will be found to improve the image quality since a smaller amount of scattered radiation appears on the fluoroscopic screen.

Operating procedure has a considerable influence on the safety of the staff during fluoroscopy. Only those staff who are absolutely necessary in the room should be present. They should wear protective aprons and gloves as required, but most important of all is the position they take up within the fluoroscopy room, making use of protective shields. With conventional equipment, adequate dark adaptation is essential otherwise the exposure time will be unnecessarily protracted. It is important to allow for the hazard where radiography is to take place during the fluoroscopy procedure since one must consider the equipment as a pure radiography apparatus during these exposures. In this sense, it is as well to remember that a radiographic exposure of 60 mAs is equivalent to fluoroscopy at 1 mA at the same voltage for a period of one minute, and pro rata.

A good image intensifier, if properly adjusted and carefully used, can reduce the X-ray output required by a factor of up to 10, but if not so used
the radiation exposure to patients and staff may be even worse than with conventional fluoroscopic equipment. Some image intensifiers are fitted under the fluoroscopy couch, the X-ray tube being positioned over the couch. This is particularly hazardous where staff have to be present in the room during fluoroscopy. Back-scatter from the patient (see Annex 3) can spread unhindered throughout the fluoroscopy room, whereas with the X-ray tube under the fluoroscopy couch such back-scatter is normally trapped by the sides of the couch. Under-couch intensifiers are really designed for use with expensive fluoroscopy equipment operated by remote control. With equipment of this kind, which includes a remote couch-tilting machine and power-assisted injectors for special techniques, the staff need never enter the fluoroscopy room and may observe the procedure in safety through the lead glass window of the control panel shield. Such equipment would probably be justified only at levels of medical care higher than level 3.

**Efficient room layout**

Inside the X-ray room the layout of equipment should be designed to avoid unnecessary movement around obstacles *en route* to the darkroom, to the patient, and to the protected control panel. The uninterrupted X-ray beam should not be able to fall on the darkroom wall and should not routinely point towards doors or windows. When members of the staff have to be present in the room for some particular examination it is good practice to place the protective shields near to the source of radiation rather than at a distance from it, since for the same protection a smaller shield area will then be required.

When funds and facilities are severely limited there is always a temptation to install several pieces of equipment in one room. This involves particular hazards; for example, staff setting up a patient on one side of the room may be irradiated by exposures taking place on the other side. This may be prevented by having only one generator per room and by mounting warning lights on each X-ray tube head and the control panel of the generator. As soon as the rotating anode or the filament in one of the tube heads is energized, the appropriate light comes on, so that, if the wrong tube has been connected, a warning is given before the actual exposure is made. Adequate protective screens should be provided between each X-ray tube area.

For each special technique such as tomography, angiography, or plain chest fluorography, a separate room should be provided. Any X-ray room should be of adequate size for the full facilities likely to be needed (e.g., not less than 6 m × 4 m for simple radiography at level 1). At all levels of radiological care separate record rooms, offices and waiting rooms should be provided. Physicians or radiologists reporting on films must not be in the room in which radiography is being carried out; separate viewing rooms
that can be darkened should be provided. At levels 3, 4, and 5 it is desirable to have at least one patient preparation and recovery room for special procedures involving anaesthetics. As a general principle, protective screens should be provided for all the positions in which staff are required to be during exposures in the X-ray room.

**Protective equipment and clothing**

Wherever possible, staff should not be present in the X-ray room when radiography or fluoroscopy is being carried out. When this is not possible and staff must be present for some purpose, protective aprons and (when necessary) gloves should be worn, even when fixed protective barriers are available for the special technique. For example, when handing barium meal to a patient for fluoroscopy it is not sufficient to rely on the couch-side shield alone; the person carrying out this function must wear a protective apron of at least 0.25 mm lead equivalent. Obviously, the physician performing fluoroscopy should always wear a protective apron preferably of 0.5 mm lead equivalent. Similarly, the introduction of electron image intensifier fluoroscopy does not mean that protective aprons can be dispensed with. The reduction in dose due to these image devices, even when adjusted for optimum performance, is not such that the scattered radiation can be ignored by staff. For procedures such as surgery under X-ray control, bronchography, and angiocardiography, where an appreciable number of people may be involved, care should be taken that enough protective aprons are available.

**Rules for radiological procedures**

Whatever the level of radiological care involved, it is good practice to have simple rules posted at the control panel of every X-ray equipment. These rules are primarily to remind the skilled operator of the equipment that he has responsibilities not only to himself but to others who may come into the room, some of whom may have had no previous experience of X-ray work. Examples of such rules are given in Annex 1. It is important to realize that these are only basic suggestions for rules, and the radiation protection adviser, together with the local radiation protection officer, will add special provisions to suit the local conditions. At the same time it is undesirable to have a very long list of rules unless they consist of small groups with clear headings suitable for quick reference when a practical situation arises.
PROTECTION OF STAFF

Personnel monitoring and medical care

When a new X-ray facility goes into operation, all staff members who at any time may enter the department should initially be issued with radiation monitoring badges. After the first few periods of monitoring it will become obvious that some staff members—clerks, for example—are not exposed to significant quantities of radiation under any circumstances. Radiographic staff, on the other hand, may show low exposures and may also be at risk in emergencies that arise in the course of their work. As a result of such preliminary monitoring, coupled with site monitoring during the radiation surveys, those people may be identified whose exposure is likely to exceed three-tenths of the annual maximum permissible dose, and these people should be monitored regularly.

Every staff member should be medically examined on his initial appointment and at any time when the exposure levels as indicated by personnel monitoring are sufficiently high. An example of this would be a staff member whose exposure was normally very low suddenly receiving an isolated high exposure, which might be above the usual level for a short period but still within the maximum permissible level when averaged over a longer period. In the unlikely event of a staff member exceeding the maximum permissible dose for the full period by a substantial amount, the person concerned may be regarded as a potential radiation casualty and should be examined by an expert.
3. Protection of Patients and the General Public from Unnecessary Irradiation

Once the clinical decision has been taken that an X-ray examination is necessary in the interests of the patient, it is of prime importance that the examination should provide the diagnostic information required. It is as much a matter of radiation protection as of good diagnosis that the best available X-ray technique should be used. For example, when trying to obtain an image of a small area through a thick part of the body, the use of an unnecessarily wide beam not only irradiates a large volume of the patient but increases the scattered radiation, which may reduce the contrast of the X-ray image to such an extent that the anatomical details required for diagnosis are not demonstrated. Similarly, one should not attempt to use low powered X-ray equipment when, to reduce movement during the exposure, high powered equipment is required. Such wrongly conceived procedures do not help the patient’s diagnosis and only expose him to unnecessary radiation. Needless to say, the physician in charge must have enough knowledge of X-ray diagnosis to interpret the radiograph correctly, otherwise the exposure of the patient will have been useless.

The clinician or technician operating the X-ray equipment should be aware of its limitations; where these limitations are not known the advice of an expert should be sought (see Annexes 2 and 3).

X-ray equipment should always be well maintained, while processing methods and the performance of image intensifiers should similarly be kept at a high standard.

Relative risks to patients of diagnostic procedures

Humans are subject to finite risks of developing various diseases under normal conditions of nature, and insurance companies use such statistics in calculating their premiums. When appreciable radiation is given to a patient these risks may be altered. For example, radiotherapy may reduce the risk of a patient developing secondary cancer, or stray radiation in X-ray diagnosis may increase the risks to a patient who is not already suffering from a serious disease.

Irradiation of the bone marrow tends to increase the natural risk of developing blood diseases such as leukaemia, and irradiation of the gonads increases the natural risk of genetic abnormalities in the offspring. With low doses such as those defined as maximum permissible levels for staff, the increase of risk may be so small as to be undetectable. With very large doses of whole-body irradiation the risks may be so great as to produce 50%
fatality. In between these extremes there lies a whole spectrum of dosage where the increased risk may be justified if the benefit of radiology to the patient is greater than the radiation risk involved. For a more comprehensive account of radiation risks the reader should consult Volume 1 of this manual.

The somatic effects are also reduced if only part of the body is irradiated, hence the advantage of keeping the area of the X-ray beam as small as possible.

Where alternative methods of arriving at a diagnosis exist, it may be worth considering these in the interests of the patient. For example, placenta localization using simple nuclear medicine procedures may achieve the same diagnostic result and give as little as 1/500th of the dose to the fetus that is given by one X-ray film exposure of the lower abdomen.

However, within the field of X-ray diagnosis alone, the hazard to the patient varies considerably from one examination to another, as shown in the table on page 31. The gonad dose grouping refers to the genetic hazard, the bone-marrow dose grouping to the somatic-stochastic hazard. The doses quoted are intended only as a rough guide to what might be expected when using reasonably good techniques. In general, the groups with the highest hazards include those examinations where patient protection is more difficult and attention to detail most rewarding. Readers interested in a more detailed description of the genetically significant exposure are referred to Annex 5.

Techniques of patient protection

In general, patient protection can be improved wherever it does not impair the diagnostic result, by:

1. decreasing the field size until it lies within the film area.
2. increasing the distance between the gonads and edge of the beam and using a posterior-anterior view, if they lie outside the beam.
3. shielding the gonads if they lie within or near the beam.
4. keeping the focus-skin distance reasonably long (at least 60 cm).
5. using compression for soft parts of the body to reduce the thickness.
6. using an appropriate filter where the changing of filters is possible.\(^1\)
7. ensuring efficient collimation to remove off-focus radiation.

The simplicity of some practical methods of improving radiographic techniques is illustrated by Fig. 3 and 4. Figure 3 shows the effect of technique on gonad exposure in abdominal radiography. The bad technique uses too large a beam size, inaccurate exposure, and poor darkroom procedure. The good technique shows how the gonad dose might be reduced by up to 32 times.

\(^1\) It is, however, strongly recommended that fixed filters should be used (see page 38).
Fig. 4 shows protection of the patient by suitable positioning. A good technique for radiographing the hand ensures that no part of the patient’s body (the lower extremities for example) is irradiated by the direct beam. The patient is seated to one side of the couch and only the hand is placed.

**FIG. 3. EFFECT OF TECHNIQUE ON GONAD EXPOSURE IN ABDOMINAL RADIOGRAPHY**

The magnitude of the gonad dose in each method is represented by the volume of a cube. Restriction of the X-ray beam area, optimum choice of exposure factors, and good processing reduce the gonad dose by a substantial amount.

**FIG. 4. PROTECTION OF THE PATIENT BY POSITIONING**

Reducing the beam size and repositioning the patient so that the gonads lie outside the X-ray beam and are shielded by the patient’s own body can effect a large reduction in gonad dose. The dose magnitude is represented by the volume of a cube beneath each drawing.
GROUPING OF RADIODIAGNOSTIC PROCEDURES ACCORDING TO HAZARD

Gonad dose grouping—adults

**Procedures involving a high gonad dose (over 100 mrad)**
- Lumbar spine, lumbosacral vertebrae
- Pelvis
- Hip and femur (upper third)
- Urography
- Retrograde pyelography
- Urethrocystography
- Lower gastrointestinal tract
- Abdomen
- Obstetric abdomen
- Pelvimetry
- Hysterosalpingography

**Procedures involving a moderate gonad dose (10–100 mrad)**
- Stomach and upper gastrointestinal tract
- Cholecystography, cholangiography
- Femur, lower two-thirds

**Procedures involving a low gonad dose (less than 10 mrad)**
- Head (including cervical spine)
- Dental (full mouth)
- Arm (including forearm and hand)
- Bony thorax (ribs, sternum, clavicle, shoulder)
- Dorsal spine
- Lower leg, foot
- Chest (heart, lung) including mass miniature radiography

Gonad dose grouping—children

**Procedures involving a high gonad dose (over 100 mrad)**
- Lumbar spine, lumbosacral vertebrae
- Pelvis
- Hip and femur (upper third)
- Urography
- Retrograde pyelography
- Urethrocystography
- Lower gastrointestinal tract

**Procedures involving a moderate gonad dose (10–100 mrad)**
- Dorsal spine
- Stomach and upper gastrointestinal tract
- Cholecystography, cholangiography
- Femur (lower two-thirds)
- Abdomen

**Procedures involving a low gonad dose (less than 10 mrad)**
- Head (including cervical spine)
- Dental (full mouth)
- Arm (including forearm and hand)
- Bony thorax
- Lower leg, foot
- Chest (heart, lung) including mass miniature radiography

Bone-marrow dose grouping

**Procedures involving a high bone-marrow dose (400–2000 mrad)**
- Pelvimetry
- Lower gastrointestinal tract
- Urography

**Procedures involving a moderate bone-marrow dose (50–400 mrad)**
- Retrograde pyelography
- Urethrocystography
- Hysterosalpingography
- Stomach and upper gastrointestinal tract
- Lumbar or dorsal spine, lumbosacral
- Pelvis, abdomen
- Cholecystography, cholangiography
- Bony thorax (ribs, sternum, clavicle, shoulder)

**Procedures involving a low bone-marrow dose (less than 50 mrad)**
- Femur, hip
- Head, chest, heart, lung
- Dental (full mouth)
- Extremities (hand, foot)
actually in the beam. The beam size is restricted to the minimum necessary for the actual exposure. In this way, not only is undesirable irradiation of the extremities avoided but the gonad dose itself can be reduced by a factor of over 3000.

With conventional fluoroscopy, the necessity for adequate dark adaptation of the fluoroscopist before he commences is illustrated in Fig. 5. Fig. 5a shows the rapid rise in sensitivity of the eyes that occurs about 15–20 minutes after the beginning of adaptation. Fig. 5b shows what happens if the fluoroscopist neglects this adaptation. Initially he endeavours to turn up the beam output so as to produce a visible image and this involves a very heavy superficial dose to the patient. Only as his adaptation improves is he able to turn down the X-ray output dose. Under these very undesirable conditions, dose rates as high as 30 R/min on the skin of the patient can be involved. Under no circumstances can this be justified, and it is highly recommended that the output of the fluoroscope should be restricted electrically so that it cannot exceed 6 R/min at the patient’s skin.

Complete darkness in the room during fluoroscopy is essential. Even such a small source of light as that entering through the keyhole in the door can reduce the contrast on the screen. Thus particular efforts should be made to ensure that the room is totally screened from outside light. A red safelight should be used during the preparation of the patient and equipment.

Fig. 6 shows a device intended to help the radiologist form good habits. It is particularly useful in teaching. It consists of a meter that indicates the product of the exposure rate and the area of the beam. During fluoroscopy a continuous warning is given by the frequency of a series of sound pulses emitted from the machine. As the fluoroscopist opens the diaphragm wider or increases the output of the X-ray equipment, so the frequency of these sound pulses rises and imparts a sense of urgency to the operator. At the end of the examination, the integrated product of exposure and area can be read from the meter. Where such a device is in routine use, the reading, which is relevant to somatic and marrow dose, can be filed with the patient’s notes. The reading also gives some indication of the scattered radiation produced, which is important from a staff protection point of view.

Similar considerations apply when the fluoroscope is used in conjunction with an image intensifier and a television display, except that adaptation is no longer necessary and the patient can be observed in subdued light. Such lighting is of considerable advantage when examining children and infirm patients who require much attention. However, the usefulness of an image intensifier system in reducing patient dosage depends on the adjustment of the intensifier. If regularly adjusted for optimum performance, the intensifier can effect a reduction in patient dose of up to 10 times. Under unfavourable circumstances, where the intensifier setting is neglected, the dose can actually be higher than with conventional fluoroscopy. Therefore regular servicing of television intensifier systems is an essential part of patient protection.
FIG. 5. ADAPTATION OF THE EYE FOR FLUOROSCOPY

(a) The retinal sensitivity increases as a function of time spent in the dark. Note the rapid rise in sensitivity between 15 and 20 minutes.

(b) Excessive X-ray output demands by a fluoroscopist who does not wait for his eyes to become adapted to the darkness.
Protection of unexposed X-ray film

It is not irrelevant to include the protection of X-ray films under the heading of protection of patients, since accidental fogging of X-ray film can cause repeat exposures and therefore unnecessary radiation doses. The sensitivity of the film makes protection difficult. An exposure as small as 1 mR may be sufficient to spoil a film stored in a cassette. Therefore any films that are not for immediate use should not be kept in the X-ray room, even in a lead-lined cabinet. Only a limited amount of film should be kept in the darkroom, and the direct X-ray beam should not be pointed at the darkroom wall unless extra thicknesses of lead have been incorporated into it. All films not likely to be used within a few days should be kept in a separate store, well away from the radiation area (see Annex 4). This is particularly true for unpopular sizes of film, which may remain in stock for considerable periods. Special precautions are needed when patients are to be radiographed during treatment with radionuclides.

Protection of the general public

For the purpose of radiation protection the public may be defined as including all staff who are not directly employed in radiation work and all patients who are not in the process of undergoing X-ray examination or treatment.
To keep the genetic risk to the whole population within reasonable bounds it is necessary to define the dose limit to individuals as three-tenths of that allowed for radiation workers. This means that careful attention must be paid to the protection of all areas around, above, and below X-ray rooms. Quite apart from adequate protective thicknesses of walls, floors, ceilings and doors, it is important to check that an unprotected window does not allow the public outside to be irradiated, either by the direct beam passing a chest stand or by the scatter from heavy exposures.

Not only must stray radiation be prevented from reaching waiting rooms, but one patient must not use a curtained corner of an X-ray room to change clothing while another is being radiographed in the same room. Separate protected changing cubicles should be provided, preferably outside the X-ray room.

An easily overlooked source of irradiation of the public can be the open door of an X-ray room. Local rules should always include an instruction to ensure that the lead-protected door is closed during an X-ray examination. Such considerations are particularly important in private practice where the radiologist's room may be in the centre of a block of flats occupied for long periods by members of the general public. Similarly, the staff serving a mobile unit for mass radiography must exercise constant vigilance, especially when the position of the waiting area may vary from place to place. Where ward mobile X-ray machines are used, particular care should be taken to avoid irradiating other patients in the same ward occupying adjacent beds. In the particular case of radiography of children when a parent may be required to be within the X-ray room, full precautions are needed; the parent should wear protective clothing and stay as far away as possible from the irradiated part of the room.
4. Choice of X-ray Equipment from the Point of View of Radiological Safety

The first requirement for good radiological protection is that the X-ray equipment itself should be adequate for its purpose. For example, at level 1 of radiological care a good stationary X-ray tube and generator should be employed. The improvisation of a mobile machine in an odd room used for other purposes should not be tolerated under any circumstances. If the X-ray machine is for routine general radiography, it is essential that the necessary ancillary apparatus be provided at the same time—e.g., a chest stand and a stationary couch with grid and film tray. The darkroom should be close to the X-ray room so that cassettes can be reloaded without delay. If there is a large turnover of films it may be more economical and certainly more reliable to install an automatic film-processing unit. For emergency work and surgical aid, where the results of an X-ray examination are needed before the operation can proceed, the high-speed film-processing unit is invaluable. At level 3 and above, the possible expansion of the workload should be anticipated when new equipment is installed. For instance, a simple chest fluoroscopy unit will be quite inadequate if barium meal examinations are later required. Similarly, the addition of fluoroscopy facilities to a radiography unit at a later date involves considerable extra protection requirements.

When additional protection is required it is not sufficient to rely on the manufacturer or X-ray engineer to provide it. The advice of an expert in radiation protection should always be sought.

Rating of X-ray tube, generator, and power supplies

Although the X-ray equipment should be chosen with the medical purpose primarily in mind, one must also take account of the local power supplies. Ideally, electric power for an X-ray unit should be separate from that for other power equipment such as lifts, radiotherapy machines, and other X-ray units. Failure to allow for this can result in many retakes owing to a drop in mains voltage just at the instant of exposure. Where power supplies are particularly unreliable and it would be prohibitively costly to improve them, some thought should be given to the use of battery-operated or condenser discharge equipment, which gives relative immunity from power supply variations for short periods.

Wherever possible the power supply should be adjusted to suit the maximum possible load of the X-ray generator. It is unwise to install an X-ray
tube head of lower rating than that of the generator since there is the danger that a tube of higher rating may be subsequently fitted as replacement without attention being paid to the increased radiation protection required. The maximum rating envisaged for the equipment on installation should be taken as the basis for all radiation protective measures.

**Exposure controls**

The importance of exposure controls in radiation protection cannot be overemphasized. Meters are required that give a clear indication of voltage, current, and milliampere-seconds at all times.

For radiography, the choice of timer requires careful consideration, particularly when high-powered X-ray units are involved. The timer must be capable of making sufficiently short exposures, not only to arrest movement but also to avoid overexposing the film when radiographing very thin parts of the body such as the extremities.

On fluoroscopic units with automatic compensating control, the meters should be visible from the control panel and provision should be made to override the automatic control when certain factors such as patient thickness take the apparatus outside its normal range. It is also important to check with manufacturers that the fluoroscopy current is accurately recorded; it is frequently found that even with the ammeter reading zero a visible picture is obtained on the fluoroscopic screen.

All fluoroscopy equipment should be fitted with a time switch that gives an audible warning after a preset period (e.g., 3–4 minutes) and terminates the exposure if not reset within one minute. Equally useful for limiting patient exposure (though more expensive) is the device illustrated in Fig. 6. This gives an audible warning during the whole period of fluoroscopy, indicating the product of X-ray output and area irradiated.

**Tube head protection and collimation**

Although most manufacturers now offer tube heads with protection up to ICRP standards, it is always necessary to check that the fitting of a different type of collimator from that originally designed for the tube head does not reduce the standard of protection. One should ensure that there is at least a diaphragm very close to the tube window with an aperture designed to restrict the beam area to the maximum required by the subsequent diaphragms. A poor diaphragm will permit the emission of off-focus radiation, which not only produces poor image quality but also causes some radiation outside the confines of the direct beam (Fig. 7). Occasionally, insufficient protection is provided around the diaphragm box itself. This will be revealed by the radiation survey, but if the survey expert is readily available it may be worth while seeking his advice before choosing the equipment.
A practical point that is often overlooked is the level of lighting in which the equipment is to be used. For example, when the sun is shining into the room light beam diaphragms often fail to give a satisfactory indication of the field on the patient. A possible alternative to the light beam under these circumstances is a viewfinder device for beam alignment in which a picture of the patient is seen reflected through the diaphragms. With such devices the field of view must be adequate for the part being radiographed to be recognized. For most purposes rectangular diaphragms are to be preferred, but other types may be more suitable in dentistry and angiography, when radiographs are taken during fluoroscopy, and where compression is required for special shapes (e.g., mammography).

In all such cases, where cones are used, the shape of the cone should conform closely to the shape of the beam so that the operator can judge whether the beam will lie within the confines of the film (see Fig. 8).

Ward mobile machines with intensifiers for fluoroscopy require a spacer cone of adequate length to ensure that the focus–skin distance is not less than 30 cm under any circumstances, otherwise the skin dose becomes excessive.

**Filtration**

For general radiography and fluoroscopy a fixed total filtration is recommended of 3 mm of aluminium. Although it has been suggested that various kinds of filtration should be used according to the task in hand, any change of filtration on a general purpose X-ray unit is highly undesirable. Only when an X-ray unit is used exclusively for one special technique may the filter be
chosen specifically for that purpose. In mammography, for example, where soft radiation is specifically required, an aluminium filter 3 mm thick is inappropriate, but the thickness should not in any case be reduced to less than 0.5 mm. The only other exception is a dental X-ray unit used exclusively for intra-oral radiography, when the total filtration may be fixed at 2 mm of aluminium.

Mounting and ancillary apparatus

Radiation safety can be influenced by the mounting of the X-ray equipment. For radiography at level 1, for example, a fixed stand requires a movable couch or trolley. Alternatively, a track mounted column may be used with a fixed couch. Ceiling suspension for the X-ray tube head is best reserved for levels 3, 4, and 5 because unrestricted directional movement of X-ray units creates problems in radiation protection and requires a higher ceiling, which may be unduly expensive at these levels.

The apparatus should permit a focus–film distance of at least 1 metre for all normal radiography and of up to 2 metres for chest radiography. Distance and position scales on the tube column or mounting aid accurate setting up, thereby reducing repeat exposures.

In fluoroscopy, a check should be made that the manufacturer has adhered to ICRP recommendations, that the focus–skin distance is adequate (preferably 60 cm for chest fluoroscopy), that the couch sides are protected against scattered radiation and that the adjustable beam diaphragms have been restricted so that the X-ray beam does not exceed the area of the
conventional fluoroscopic screen, even at maximum distance from the tube. When image intensifiers that provide a circular field of view are used in conjunction with rectangular diaphragms for radiation beam control, enough external shielding must be provided to enable the whole viewing area to be used safely when required. The X-ray tube and fluorescent screen should be permanently connected, and an automatic switch must prevent the tube from being energized when the screen is out of position. Although many fluoroscopic couches have an under-couch X-ray tube, some intensifier systems use X-ray tubes positioned over the couch. This produces back-scatter that cannot be trapped by the couch sides, and such installations are best operated by remote control so that staff do not have to enter the room during fluoroscopy. Equipment of this kind is normally found only at levels 4 and 5.

In the rare event that fluoroscopy is required for special procedures with mobile equipment, an image intensifier must be incorporated permanently as part of the equipment, which should be so constructed that the radiation beam is fully intercepted by the image intensifier or a lead shield surrounding it. Some combined mobile fluoroscopy units of this kind are designed for use in operating theatres, and it is not always obvious to the uninitiated which end of the apparatus contains the X-ray tube. This should be clearly marked so that surgeons and others present at the time of the examination may know which side of the apparatus presents the greatest hazard. A spacer cone at least 30 cm in length should be used to prevent the patient's skin or the surgeon's hand from being too close to the focus of the X-ray tube and a warning device with automatic time switch must be fitted as for large fluoroscopy units.

**Protective clothing and shields**

Protective aprons and gloves should be constructed of strong flexible material of not less than 0.25 mm lead equivalent. The useful life of such protective clothing depends considerably on the amount of use to which it is subjected (especially folding) during normal work and in storage. It is an advantage if the protective material is actually visible so that early signs of cracking and deterioration may be observed without removing a cover. Manufacturers produce protective aprons with various degrees of flexibility and methods of fastening. When coming to a decision one should bear in mind that staff will prefer clothing that is easy to put on and take off and that the length of life of the protective garment may be more important than its flexibility.

With fluoroscopy equipment built to ICRP standards, the protective fluoroscopic screen should contain lead glass of 2 mm lead equivalent for equipment having a maximum rating of 100 kV or 2.5 mm for a maximum rating of 150 kV. It is not satisfactory to accept a lower figure for the lead equivalent on the ground that fluoroscopy never exceeds, say, 100 kV if,
during the fluoroscopy, some radiography is to take place at a potential of 120 kV or higher. The protective apron or drapes attached to the side of the fluoroscopic screen should be of not less than 0.5 mm lead equivalent and $45 \times 45$ cm in size. They should be capable of swivelling to the side for horizontal fluoroscopy or, alternatively, additional panels should be fitted to achieve the same result, preferably on both sides of the couch. When an under-couch tube is used not only should the sides of the couch offer protection but the Bucky slot should be covered by a flexible lead rubber shield. Such components are easily supplied with new equipment but may be very difficult to fit on older types.

For special procedures such as angiography and urography, ceiling-suspended and counterbalanced flexible shields are usual to protect the surgeon and anaesthetist during the examination (see Fig. 9).

As a general principle, flexible shields should be used when they come in contact with the person; in other positions rigid shields may be less expensive or offer more protection.

**FIG. 9. SPECIAL SHIELDS FOR ANGIOGRAPHY**

Flexible lead rubber sheets with lead glass windows, slits, and cut-out may be suspended from the ceiling to give protection to hospital staff. Note the syringe outside the shield.
5. Building Structure and Radiation Protection

Siting and facilities

The planning of a building for a new X-ray department should be carried out from the start by a team comprising not only architects, engineers, and management representatives but also the radiation safety adviser and the radiologists, physicians, and chief X-ray technicians who are going to use the department.

The siting of an X-ray room is influenced by the associated facilities required, such as offices, waiting room, level approach, lifts, transport for outpatients, and access for staff.

Doors should be so constructed that it is possible for patients’ beds to be wheeled into the X-ray room; double doors are particularly convenient for this purpose, one of them being sufficient for normal traffic and both being opened to admit stretchers or beds. The corridors leading to the X-ray room also need to be fairly wide and there should be enough space outside the X-ray room for stretchers or beds to be manoeuvred into the room. Attention to such matters can often avoid the need for a mobile X-ray unit.

Darkrooms should be at least 6 m² in area, but a somewhat larger room may be necessary under particularly difficult conditions of temperature and humidity. The darkroom should be placed centrally within the X-ray department, preferably with direct connexion (through hatches) to all X-ray rooms and with easy access to the main X-ray room.

At least two changing cubicles of 1.5 m² minimum size should be available outside an X-ray room so that only one patient need be in the room during the time that the equipment is switched on.

The X-ray room should be built strongly enough to carry the equipment it will contain and be so constructed as to provide adequate radiation protection for people outside the room, who may well have no knowledge of radiation or radiation protection requirements. Examples of the rooms required at different levels are given below:

Level 1. The basic essential is a single X-ray room with darkroom, the sizes being as specified above. There should be facilities for changing and, in addition, an office, a toilet, and a waiting area. These facilities could, if necessary, be shared with an adjacent department.

Level 2. A single X-ray room is probably all that will be required together with the facilities described under level 1 and a store room, filing room, and X-ray reporting room.
Level 3. There will generally be a small department with two (perhaps three) X-ray rooms and a single darkroom, together with the facilities described under level 2. It is possible that at this level seminar and consultation rooms will also be required.

Levels 4 and 5. There is generally a large department having several X-ray rooms, some of them equipped with specialized apparatus and possibly more than one darkroom. Space is required for waiting, changing, filing and reporting rooms and for toilets, offices, and stores. Provision should also be made for seminar and consultation facilities.

Basic protection requirements

Since limited facilities are inevitably called upon to take larger workloads, it is highly desirable to plan the protection of an X-ray room for the maximum possible load. Roughly speaking, the radiation protection of a general purpose X-ray room about $6 \times 4 \times 3$ metres in size calls for a wall thickness in all directions equivalent to 2 mm of lead. It is important that the doors, the darkroom hatch, and the covers for services and other intrusions through the wall should be protected by the same thickness of lead. All cracks and flanges around the door should be protected by additional strips of lead (see Volume 1, Annex 2). Windows, if essential, should be at least 2 m from the ground outside the X-ray room and at least 1.6 m from the floor level inside the room; they should be sited so that scattered radiation does not pass straight through them into other windows nearby. If the control panel is within the X-ray room, care should be taken when positioning the protective shield to ensure that neither “once scattered” radiation nor direct radiation can pass round the edge of the protective shield from any part of the room where X-ray procedures are carried out.

Choice of protective materials

While lead is always accepted as the standard material for radiation protection, ordinary building materials may be equally suitable provided they are thick enough. For example, in the range 70–125 kV, 15 cm of concrete or 25 cm of brick with plaster are approximately equivalent to 2 mm of lead. If however, a prefabricated wood or metal building is being planned, it will need to be lined with lead, preferably supported by plywood to prevent the sagging of the soft metal in the course of time.

Existing structures

Where an X-ray room is being converted from an existing structure some compromise may be possible. For example, if the existing walls are of brick
and plaster 13 cm thick, another 1 mm of lead supported by plywood would probably suffice to make up the 2 mm total lead equivalent. A particular problem with old buildings arises where doorways have been blocked up with material of inferior radiation-absorbing qualities (such as coke breeze or a wooden panel) that has been covered with a thin layer of plaster so that it resembles the existing wall surface. Cavities of this nature must be sought out and tested. In case of doubt, they should be covered by additional lead ply or barium plaster. At the junction between materials of different lead equivalents, the overlaps should be at least equal to the maximum thickness of material of either type used (see Volume 1, Annex 2).

**Provision for later expansion**

At levels of radiological care 1, 2, and 3, in particular, the possibility of subsequently adding another X-ray room and other facilities should be borne in mind during the original planning. Wherever possible, the location of doors and facilities should be such as not to preclude the later addition of a second or third X-ray room in reasonable proximity to the darkroom facilities. The sending of film from one X-ray room through another to the darkroom can pose quite considerable problems. Often the most convenient route runs immediately behind the chest stand in the intervening room, so that there is a risk of the film being exposed in transit. Care in the initial planning stage can avoid this problem.
6. Radiation Surveys

There are certain minimum provisions for radiation safety without which the operation of X-ray equipment invites disaster. In a busy X-ray diagnostic department it is all too easy for the staff to concentrate on good radiography without realizing that some of the basic safety precautions may have been overlooked.

Therefore it is essential to obtain advice and inspection from an authority outside the X-ray department to ensure that the equipment is capable of being used safely and that the staff are made aware of any special requirements when they are performing their duties.

A comprehensive radiation survey should be carried out by a physicist experienced in this field, preferably assisted by a technician. The radiologist and X-ray technicians should demonstrate their working methods so that the physicist can make recommendations that entail the minimum modifications in the functioning of the department.

A radiation survey is concerned with the radiation directly absorbed, the scattered radiation, and the leakage radiation from the X-ray equipment, all of which contribute to the patient dose. It is similarly concerned with the radiation scattered outside the patient and any stray primary beam that presents a hazard to the staff, to the general public, and to the quality of the radiation image used for diagnosis. Defensive measures against these hazards are both strategic (e.g., positioning of adequate protective shielding) and tactical (e.g., control of staff procedures by local rules in the irradiated areas). Radiographic and processing techniques are also important, since the satisfactory performance of X-ray equipment and processing units and the optimum adjustment of image intensifier fluoroscopy systems can prevent unnecessary repeat examinations.

A radiation survey includes certain tests that are effectively experimental laboratory procedures. Persons carrying out such tests must therefore protect themselves adequately by whatever means are available—for example, by avoiding the direct beam, by wearing thick lead protective aprons and gloves if it is essential to stand near a source of radiation, and by retiring to a safe distance or behind a lead screen whenever possible.

Radiation survey policy

Before any new or modified X-ray equipment or building is used clinically for the first time, a radiation survey must be carried out—no matter how
urgent the clinical needs. Arrangements must be made for the survey well in advance and time allowed for its completion so that defects can be corrected before staff and patients are exposed to any hazards.

Some form of inspection should be carried out at the following stages in the development of an X-ray department:

1. during the planning of the new department (phase 5)
2. during construction of the building (phase 7)
3. immediately after installation of the equipment (phase 8)
4. when additions and alterations are made to the department or equipment or when personnel monitoring indicates adverse changes (phase 12)
5. at regular intervals when no obvious changes have taken place (phase 10).

The planning stage

When the building of a diagnostic X-ray department is to be undertaken, the services of the radiation protection adviser (an experienced radiation safety physicist) should be enlisted from the start. He should make a preliminary inspection of the chosen site to estimate and (where necessary) measure the protective values of any existing building materials that are involved in or are adjacent to the site. He should be provided with a statement of the X-ray facilities required by the radiologist and some indication of the relevant level of radiological care.

The positions of existing unprotected windows and doors and the lead equivalent thickness of relevant walls, floors, and ceilings should be marked clearly on the new plans to help in designing any additional protection that may be needed.

The proposed positions of X-ray equipment in the various rooms should be considered and estimates of workloads should be made for every room. The protection should be planned preferably on the basis of the maximum possible workload since it is cheaper and easier to install full protection initially than to start with a restricted workload and have to add extra protective thickness later on. For maximum economy, locally available protective materials may be used, and where these are of unusual composition the equivalent lead thickness should be measured. This provisional inspection provides a good opportunity for deciding the position of safety interlock switches and warning signs. The latter should include small signs on the exterior of the building, for the benefit of window cleaners and other outside workmen. The signs should not be large enough to cause alarm in buildings situated some distance away yet within sight of the X-ray department. Any additional protection measures required should be marked on the plans and

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1 The phases given in parentheses refer to the life-cycle of an X-ray facility, (see page 16).
discussed with the architects and engineers. A report should be sent to the relevant authorities notifying them of any modifications that may be required in the layout.

**Inspection during building**

If the building is of brick or stone construction, it is very helpful for those responsible for radiation protection to visit the site when the building has reached a level about 1 metre above the floor of the X-ray room. This can be very revealing of the true nature of the building structure, which may not have been entirely clear from the plans. The reduction of the protective thickness of walls due to cavities or methods of construction, and the position of holes required for essential services such as water and electricity are much easier to see at this stage. In the completed building a thin layer of plaster may obscure the defective protection.

**Radiation survey on installation**

The ideal time to begin the main radiation survey is when the X-ray engineer is just completing the electrical connexions to the X-ray equipment and he is still on site to correct any flaws that may be discovered. The first thing to be checked is the operation of the safety interlocks and illuminated warning signs. Excessive leakage of radiation from the tube head may be checked with the light beam diaphragms closed (or, in the absence of diaphragms, with 2 mm of lead placed over the cone), the machine being operated at maximum fluoroscopic rating if possible.

With the room darkened, the surface of the X-ray tube can be explored with a portable protected fluorescent screen, which will reveal sources of leakage. The eyes should be dark adapted for at least 20 minutes. When the direction in which the maximum leakage takes place has been noted, the lights are switched on and a measurement is made in that direction with an ionization chamber (or even a film badge) to discover whether the leakage exceeds the limiting value given by the ICRP—i.e., 100 mR in one hour at a distance of one metre from the focus. Alternatively the tube head may be surrounded by a “box” of films at a distance of not less than 15 cm from the surface and a suitable exposure made at the highest voltage that can be attained with the equipment. From the developed films the direction of maximum leakage can be determined, and a check measurement can be made under standard conditions with either an ionization chamber or a monitoring film. The maximum leakage should not exceed 100 mR per hour at the highest voltage and at a distance of 1 metre from the source.

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The protection afforded by the diaphragms or cones should be checked using a dosimeter and measuring the radiation with and without the diaphragms in position. The thickness of the diaphragms should be equivalent to not less than 2 mm of lead. With the diaphragms open or the normal cone in position a radiograph should be taken of the tube head by means of a pinhole camera to detect "extra focal" scattered radiation. If this appears to be excessive a hollow lead plug should be fitted at the X-ray tube window to reduce the maximum area of the X-ray beam to the maximum aperture of the diaphragms.

The alignment of light beam diaphragms or cones with the X-ray beam may be checked by exposing an X-ray film on which radiopaque markers have been placed to indicate the edge of the light beam. The X-ray engineer can easily correct any errors by adjusting the position of the light or the cone mounting. This simple procedure can prevent unnecessary repeat exposures and can cure the bad habit of using too large a beam area simply because of uncertainty about its position.

The tube head should be inspected to see whether the permanent filter is in place and whether the thickness is marked on it. The thickness should then be checked and the radiation output of the equipment should be determined with the filter in position and at a stated voltage, distance and current for a given time, using a narrow beam just wide enough to cover the ionization chamber. The measurement should be repeated using a thin extra filter (e.g., 1 mm of aluminium) and then again with one or two very thick filters (e.g., 20 mm and 30 mm of aluminium or 1 mm and 1.5 mm of copper). These values provide a basis for estimating patient dosage for standard radiographic techniques, and they are useful in establishing norms for new X-ray equipment. When the measurements are repeated at subsequent surveys, say a year later, they will indicate any deterioration of the generated voltage that may have occurred or any changes in the output and effective filtration with aging of the X-ray tube.

The overall performance of the radiographic system may be established by exposing a film in one of the cassettes provided, using the X-ray equipment with a standard test phantom, and processing the film in the processing unit that is to be in routine use in the department. The exposure conditions required to produce an acceptable film should be noted for reference in future surveys.

The overall performance of fluoroscopy equipment may be established using a suitable test phantom and measuring the dose incident on the fluoroscopic screen or image intensifier. The test phantom should consist of some material that transmits as much radiation as would a patient of rather more than average thickness and that gives some indication of contrast and resolving power (e.g., metallic wires may be included in the phantom).

If any doubts are cast on the necessity of such performance measurements in a radiation survey, it must be remembered that one of the most
common causes of excessive radiation both to patients and to staff is badly adjusted or inefficient X-ray equipment. Prolonged fluoroscopy at high radiation outputs and repeated radiographic exposures are typical of such undesirable conditions.

The faults in the X-ray equipment having been corrected by the engineer, attention should be paid to protective equipment such as shields, aprons and gloves, which should be radiographed or examined by fluoroscopy to reveal any lack of uniformity in X-ray transmission and to determine the effective thickness by comparison with a lead step wedge exposed at the same time.

The radiation absorption of the walls, floor, ceiling, and doors of X-ray rooms should be checked and the protective thicknesses marked discreetly for future reference. Particular attention should be paid to joints in protective materials to ensure requisite overlaps at door edges and at points where conduits (e.g., electrical trunking) pass through the walls. If there is any doubt, a film should be mounted (not hand held) on the far side and the X-ray beam aimed directly at the suspect protection. Then a suitable exposure, calculated for the desired thickness, should reveal the shape of any weakness in protection.

Since the standard radiographic and fluoroscopic techniques that will be used in the department are known in advance, the potentially most hazardous may be simulated with a tissue equivalent phantom. Measurements may then be made of scattered radiation and of transmitted primary radiation at strategic points around the equipment. These measurements may be compared with values calculated from standard data or using the earlier measurements of X-ray tube output. Particular attention should be paid to mobile and portable X-ray equipment.

A check should be made of the feasibility of proposed working techniques. Thus the siting of lead glass windows should permit the patient to be seen in all the likely positions in which he will be placed. If the field of view is too restricted or is on the wrong side of the patient, it may be possible to solve the problem by installing a fixed mirror in a suitable place. Similarly the design of the room and the layout of the equipment should be such that a technician can walk from the darkroom film hatch to the cassette loading point without passing through a radiation zone.

If the survey shows the need for action on certain points before the equipment goes into clinical service, immediate recommendations should be made—orally rather than in writing if that is the only way to achieve sufficiently rapid action.

Local rules for safe working methods (see Annex 1) should be issued at once and posted at the control panel of every X-ray machine, including portable or mobile ones. Only when the radiation protection adviser is satisfied may the X-ray equipment be used clinically, care being taken that every member of the department staff carries personnel monitoring badges
whether potentially exposed to radiation or not. Frequent changing of such badges, at weekly intervals for the first month, may reveal any tendencies of staff to receive high doses during the "settling in" period. After a suitable period (e.g., four weeks), when the X-ray department has assumed a routine pattern of working, monitoring badges should be fixed on the walls, floor, and ceiling and at strategic points within each X-ray room to determine the pattern of stray radiation arising from the established working methods. At the same time additional monitors should be provided wherever the circumstances warrant them (e.g., on the radiologist's hands, legs, and feet during fluoroscopy).

Finally, a brief written report of the survey inspections and the results and recommendations should be sent to the head of the X-ray department with copies to the radiation safety committee and administrative officers, who may be concerned with the financial aspects of radiation protection.

**Initial surveys of existing installations**

When existing X-ray facilities are to be inspected for the first time or after a lapse of many years, the survey should be much more rigorous than the survey of a new installation, with which the radiation protection adviser has been involved from the initial planning stage. Frequently, unsuspected hazards are revealed and require correction.

**Preliminary arrangements**

On first receiving the request for a survey, the adviser may ask for details of the X-ray department, including all the X-ray equipment, special accessories, and processing units that it contains together with a plan of the department indicating the main purpose and approximate workload of each room. A list of staff associated with the X-ray equipment may also prove to be valuable.

**Information from radiological staff**

Before performing any measurements it is desirable to discuss with the head of department and the radiation protection officer any outstanding problems of organization, policy, equipment, premises, and staff. The personnel monitoring records should then be inspected together with notes of any staff medical care arising from radiation hazards. The particular methods of patient protection being used should be ascertained and special attention should be paid to the method of booking appointments for women in relation to their menstrual cycle. The presence of patients being treated with internal radionuclides and requiring radiographic localization should also be revealed.
An equipment maintenance record book and records of checks of protective clothing should be available for inspection, as should any existing local rules.

The existence of X-ray facilities operating outside the main department (such as ward mobile units, chest fluoroscopy or fluorography equipment, and dental X-ray equipment) should be mentioned at this stage.

**Visual inspection**

The X-ray facilities should be inspected by the radiation protection adviser, accompanied by a member of the staff. The inspection should include all X-ray rooms, darkrooms, and X-ray equipment in the establishment and should be designed to answer the following questions:

1. **General**
   - Is the X-ray room of adequate size, and are the walls, floors, and ceiling protected or the space beyond unoccupied?
   - Are doors and frames protected, and are all windows at least 2 metres above the outside ground level?
   - Is the layout of equipment convenient and consistent with mechanical and electrical safety?
   - Is a warning sign provided outside each door, and do all the signs light up when the X-ray tube filament or rotating anode is energized? (This should be tested by switching on the machine).
   - Are the darkroom blackout, safelight, and processing unit adequate? (Light leakage may be tested).

2. **Radiography room**
   - Has the control panel sufficient protection in the form of a lead lined cubicle having lead glass windows giving a clear view of the rest of the room?
   - Is the main beam of X-rays normally directed away from the doors, the darkroom, and the control panel?
   - Is a beam absorber provided behind the chest stand?
   - Are adjustable diaphragms or a full set of cones provided to define the X-ray beam?
   - If there is more than one X-ray tube in the room, are warning lights provided at the control panel and at each tube head, and does a protective shield exist between the two couches?
   - Are fast film-screen combinations used where fine detail is not essential?
   - Are any grids used, and are they in good condition? (A test exposure should reveal this).
   - Are suitable gonad shields provided?
   - Are there any local rules on display, and is there a record book of persons supporting patients? (Both should be inspected).
(3) Fluoroscopic facilities

Is there a reasonable maximum limit to the tube current (e.g., 3mA at 75 kV)?

Is the blackout adequate, even for an intensifier installation? Is an alternative fluoroscopic screen available when the intensifier is not working?

Is there a time limit switch that turns the equipment off after 5 or 10 minutes of fluoroscopy?

Is the exposure switch spring loaded and protected against accidental switching on? (This should be tested).

Is the beam limited by adjustable diaphragms, and are the tube and screen linked to move together? (This is especially important where mobile units are used for fluoroscopy with an intensifier).

Is the lead glass protection for a fluoroscopic screen or the lead shielding for an intensifier adequate? (The protection should have a nominal value of 2 mm lead equivalent for up to 100kV, 2.5 mm for 150 kV, and pro rata).

Is there sufficient protection for the radiologist's legs and feet, particularly with the X-ray tube in the horizontal under-couch position? An apron at least 45 × 45 cm in size and of 0.5 mm lead equivalent should be available, while the couch should have closed sides, with protection of the Bucky slot).

Is there a sufficient number of protective aprons and gloves for the maximum number of persons required to be in the X-ray room?

Is there an interlock switch to prevent operation of the under-couch tube if the fluorescent screen or intensifier is out of position?

Are there any local rules on display, and is there a record book of persons supporting patients? (Both should be inspected).

(4) Ward mobile equipment

Is the equipment in a safe condition mechanically and electrically?

Is the distribution of appropriate electric power points sufficient to avoid the use of extension cables?

Is each mobile equipment provided with light beam diaphragms or a full set of cones to limit the X-ray beam to the area of the film?

Is the hand-switch cable at least 2 metres long?

Is a set of gonad shields available?

Are protective aprons and gloves (0.25 mm lead equivalent) available for persons supporting patients?

Can the timer be reset without making an exposure? (This should be tested).

If the mobile equipment is used for fluoroscopy, is an intensifier fitted rigidly to the X-ray tube, and is there a cone to limit the focus-skin distance to at least 30 cm?

(5) Dental radiography equipment

Is a lead-protected cone provided?

Can the timer be reset without making an exposure?
Is the hand-switch cable at least 2 metres long?
Is a protective apron provided for the patient?
Are film-processing facilities adequate and well maintained?
Are any local rules on display?

Tests and measurements

After his visual inspection of the department the radiation protection adviser should proceed to make measurements and tests on:

1. The leakage from each X-ray tube head when operated at the maximum continuous rating.
2. The alignment of the diaphragms with the light beam (for radiography) or with the fluorescent screen or intensifier shield (for fluoroscopy).
3. Protective shielding such as suspect door frames, wooden partitions, lead glass, and lead equivalent thicknesses of walls and ceilings.
4. Protective clothing.
5. The performance of image intensifiers, using a test object for resolution and contrast and measuring incident dose rate.
6. Film processing efficiency (e.g., test film exposed through a step wedge penetrometer).
7. The output of all tube heads in order to estimate filtration, voltage, and radiation applied to patient in milliröntgens per milliampere-second.
8. The timers (e.g., using a spinning top).
9. The calibration of any cm²R meter for fluoroscopy.

X-ray room environmental monitoring

The inspection and measurements having been completed, environmental monitoring film badges should be placed around the walls and at strategic points to obtain the stray radiation pattern averaged over a period (e.g., 1 month).

If any especially hazardous procedures are in routine use (e.g., in the operating theatre or orthopaedic clinic), the arrangement of the X-ray and other equipment used should be studied with a view to improving the protective measures.

Administrative aspects and report

The results and implications of the survey should be discussed with the head of department and radiation protection officer. Appropriate local

1 The spinning top is a simple, cheap, and effective device for measuring the accuracy of the timer of an X-ray tube. It consists of a disc of lead in which a small hole is perforated. The disc is set spinning on top of a photographic film, and an exposure is made for a certain length of time, as controlled by the timer. Owing to the pulsating nature of the power supply, the exposed film will show a series of points arranged in a circular path. Each point represents a power supply maximum, of which there is a known number per second. The counting of the points will thus give the true exposure time.
rules incorporating any special precautions can be drawn up at this point, and copies should be included with the report.

Copies of the radiation survey report should be sent to the administrative authority responsible for providing the funds needed to implement the recommendations.

**Surveys after alterations to X-ray facilities**

When additional X-ray equipment is to be installed or when modifications are to be made to existing equipment or to the radiology building itself, the radiation protection adviser should be notified of the proposed changes well in advance. He will then be able to judge whether the proposals are likely to involve additional protective measures and may wish to visit the site beforehand to check possible geometrical arrangements.

Depending on the complexity of the alterations, the adviser can then decide on the degree of surveying that will be required when the change is completed and before the apparatus is used again. If a whole X-ray room is added to an existing department then a full survey may be required. If only a replacement X-ray tube is fitted, it may be sufficient to check the tube-head leakage and alignment of light beam diaphragms. Between these two extremes, abridged versions of the full survey may be appropriate. Only an experienced radiation safety physicist can make the decision. In doubtful cases it is always better to carry out a full survey, particularly if the working methods are changed by the modifications.

**Regular resurveys under normal conditions**

Even when there are no deliberate changes to equipment or accommodation, radiation surveys should be repeated at regular intervals of one or, at most, two years. These should include most of the checks made during a radiation survey on installation (see page 47), particular attention being paid to changes in working methods and type of workload. It may well be an advantage to place dosimeters or film badges at strategic points and observe the stray radiation pattern for a period (e.g., 1 month) immediately before the survey. Comparing this pattern with that of previous surveys will often reveal unsuspected changes in radiographic techniques that have occurred unnoticed.
7. Monitoring of Staff

To record the approximate level of whole-body exposure of staff working in an X-ray department, radiation monitoring badges are worn continuously during working hours. The badges are changed regularly for the dose received to be measured and recorded. For example, if the hazard is known to be low then the change may take place monthly. If the exposure level is higher—greater than 30 mR per week, say—the badges may be changed weekly to give early warning of any unsuspected rise approaching the maximum permissible level.

The badges are normally carried in only one position on the body, usually the coat lapel or waist band. This gives an indication of the whole-body exposure dose on the assumption that the stray radiation is diffuse and comes mainly from the front. For special procedures more than one badge may be worn wherever the hazard is likely to be greater (e.g., on the hands or feet). For recording finger doses, small detectors wrapped in black opaque tape or mounted in finger rings are sometimes used.

Records

It is important that records should be kept of all monitoring results. For each person a summary should be made every year indicating the lifetime total. When individual doses approach the maximum permissible limit, it is advisable to average them at three-monthly intervals.

It is desirable to keep the radiation monitoring records together with any medical records of the individual concerned. This does not imply that the radiation effects of doses within the maximum permissible range can be detected medically, but a persistent correlation between high doses and changes in the blood picture may indicate some hypersensitivity. Alternatively the radiation monitoring badge may not be recording the full exposure to which the body is being subjected. For example, in an unusual situation more radiation may be received from behind than from the front, and the film badge will therefore record very little of the actual incident dose, particularly when diagnostic X-rays are being used. Whenever this is suspected, additional badges should be worn for a short period on other parts of the body such as the back and the lower abdomen.

Choice of monitoring system

At the present time there are three main systems of monitoring available:
(1) Film badge services—the most popular system—are available in a number of countries. If any difficulty is encountered in a particular country, IAEA or WHO may be able to indicate where the nearest service can be found.

(2) A few systems also employ thermoluminescent dosimetry.

(3) It is possible in very favourable circumstances to use simple pocket ionization chambers.

Pocket ionization chambers require charging, reading, and discharging locally and are notorious for erroneous results due to electrical leakage of the charge in the chamber while they are being carried. The best type of pocket chamber incorporates a direct-reading electrometer so that the whole system can be hermetically sealed, but even these show some leakage, which prevents their use beyond a period of about two weeks. The main advantage of carrying a direct reading pocket chamber as well as a film badge is that at any time the dose may be inspected by looking through the microscope electrometer system. Acoustic warning devices are even more useful for indicating a higher-than-normal exposure rate (see Volume 2, page 74).

Whatever method is adopted, a rigid system should be established for the regular collection of the badges and the issuing of new ones. Staff should be encouraged to form a habit of changing their badges automatically, but the head of department or responsible person should nevertheless check that film badges are returned by the required date.

Services employing film badges and/or thermoluminescent dosimetry are usually centralized, with one laboratory supplying monitors to a large number of hospitals and other establishments. Pocket ionization chambers, on the other hand, need to be serviced by a laboratory on the premises or very close at hand.

Monitoring problems

Some physicians or radiologists attend more than one X-ray centre during the week. This involves either having a number of separate film badges, one worn at each place, or carrying one badge permanently on the person. The latter is the method of preference, since it minimizes cumulative errors at the lower end of the dose scale.

The position in which the badge is worn affects the results, particularly if the person concerned wears a protective apron for part of the time of possible exposure. Some authorities believe that the badge should be worn under the apron in most circumstances, since the maximum permissible doses for the extremities are higher than those for whole-body radiation.

The radiation monitoring badges are sometimes accidentally exposed when they are not being worn. During transit to and from the commercial
processing laboratory, for example, they may inadvertently be carried near radioactive sources. They may also be subjected to extremes of temperature and humidity in some climates, and, if not carefully packed, pressure marking may also appear. It is therefore customary to include at least one control badge in any batch that is issued. The control must be kept in a place that is not normally exposed to radiation during the whole period in which the staff are wearing their badges; it is then returned together with the badges to the processing laboratory. If the control badge shows no exposure there is no problem, but if some appreciable exposure appears inquiries have to be made to discover whether it was due to some incident in transit or whether the control badge itself was accidentally exposed. Another reason why staff monitoring badges may show unrepresentative exposure is that they may be attached to clothing that is left hanging in the X-ray room when the person is not on duty. To avoid this, all personal clothing, when not in use, should be kept in a room shielded or remote from radiation.

**Correlation of monitoring with survey results**

Since radiation surveys give an indication of the workload in the X-ray room, it may be worth attempting to correlate the workload with the personnel monitoring doses of staff working in these rooms. The careful worker can easily be identified, the careful but zealous worker will tend to show a higher exposure level because of his heavy workload, but the poorly protected worker will show a high level in a room that normally has a low workload.

When, during a radiation survey, monitoring badges are deposited in various places in the department it is convenient to arrange for all staff in or around the department to wear badges at the same time in order to confirm that those persons not normally occupationally exposed to radiation have not altered their habits.
Annex 1

SUGGESTED LOCAL RULES TO BE DISPLAYED IN RADIOTHERAPEUTICAL DEPARTMENTS

The following examples of local rules are designed to promote diagnostic radiological safety. They are to be regarded as basic rules, to which others might be added according to the particular circumstances. They should be displayed prominently for the guidance of all staff members.

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 the 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 must:
   (a) wear a protective apron and gloves and avoid the direct beam by standing to one side away from the X-ray tube,
   (b) record, in the notebook provided, his name, the date, the number of exposures, and the radiographic technique used.

A copy of these rules must be posted at the control panel of every X-ray room, together with a notebook (suitably ruled for the information required under item 7), which will be inspected during every radiation survey. The rules are a suitable basis for radiological care at level 1 and above. Additions may be necessary for special techniques at level 3 and above and for fractures at level 2.
### 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 specifically required to come close. Protective gloves must be worn when handling the patient during fluoroscopy.
4. In conventional fluoroscopy the current must not exceed 4 mA at 100 kV. With image intensifiers the current should not exceed 1 mA at 100 kV. 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. If 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 must:
   (a) wear a protective apron and gloves and avoid the direct beam by standing to one side and away from the X-ray tube,
   (b) record, in the notebook provided, his name, the date, the number of exposures, and the radiographic technique used.

A copy of these rules must be posted at the control panel of every X-ray room, together with a notebook (suitably ruled for the information required under item 8), which will be inspected during every radiation survey. The rules are intended as a basis for radiology at level 2 and above.
Local rules for ward mobile radiography equipment

<table>
<thead>
<tr>
<th>Rule</th>
<th>Description</th>
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<tbody>
<tr>
<td>1.</td>
<td>The direct beam must not irradiate any person other than the one being radiographed.</td>
</tr>
<tr>
<td>2.</td>
<td>When the radiographic exposure is being made, staff must stand as far away from the patient as possible (at least 2 m) and wear protective aprons.</td>
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<tr>
<td>3.</td>
<td>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.</td>
</tr>
<tr>
<td>4.</td>
<td>If anyone is required to support a patient or film during an exposure, he must:</td>
</tr>
<tr>
<td></td>
<td>(a) wear a protective apron and gloves and avoid the direct beam by standing to one side and away from the X-ray tube,</td>
</tr>
<tr>
<td></td>
<td>(b) record, in the notebook provided, his name, the date, the number of exposures, and the radiographic technique used.</td>
</tr>
</tbody>
</table>

A copy of these rules must be attached to the control panel of each ward mobile X-ray unit, together with a notebook (suitably ruled for the information required under item 4), which will be inspected during every radiation survey. The rules are not suitable for levels 1 and 2, where mobile equipment is not recommended.
Additional local rules for radiographing patients during their treatment with internal radionuclides or brachytherapy

1. Everything must be ready before the patient is sent for, so that the time he spends in the X-ray department is as short as possible.
2. Unused or unprocessed X-ray film must be kept at a distance from the patient.
3. The patient and the X-ray equipment must be positioned first of all, then the film cassette should be placed in position just before the exposure is made. The cassette must be removed to a safe distance (e.g., 3 metres) immediately after the exposure.
4. Staff must stay at least 2 metres from the patient except when necessary for setting up. The lead apron provides no protection against high-energy gamma rays; distance is the best safeguard.
5. Dressings on the patient must not be disturbed.
6. The patient should be sent back to the ward as soon as possible.
7. If any unforeseen difficulties arise (e.g., with new techniques), the radiologist should consult the radiation protection officer, who may refer the matter to the radiation protection adviser if necessary.

These rules are needed only where facilities for therapy with radionuclides are provided in the hospital, probably at level 3 and above.
Local rules for dental radiography

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

2. Whenever possible the dental film should be fixed in position, otherwise it should be held by the patient. It should never be held by the dentist or staff.

3. When making an exposure, the staff should stand as far away from the patient as possible to avoid the radiation that is scattered in all directions. If it is necessary to be as near as 1 metre or if the workload exceeds 1800 mAs per week, a protective apron should be worn.

4. The patient should be protected by a protective apron (0.25 mm lead equivalent) large enough to cover the whole trunk.

5. The X-ray beam size should be restricted by suitable cylindrical cones to the minimum aperture appropriate to the particular examination.

6. Radiological examinations should not be made in the absence of clear-cut clinical indications. Extensive or repeated X-ray examinations of children or pregnant women should not be undertaken without considerable forethought.

These rules are suitable for an isolated dental unit (level 1) or as part of the special services at level 3 and above. A copy must be attached to the control panel of every dental X-ray unit.
Annex 2

MEDICAL ASPECTS OF DIAGNOSTIC X-RAY PROTECTION

The decision to undertake a radiological examination

The physician requesting a radiological examination requires some knowledge of the balance of benefit and risk of his request, and the radiologist receiving the request should exercise his own judgement when faced with a procedure of doubtful value. Unnecessary and repeat examinations that give no additional information should be avoided. One should ensure that simple methods of medical diagnosis have not already given sufficient information. However, in a genuine emergency (e.g., in an accident unit) it may be unwise to delay immediate radiography until the previous films are found.

It may be decided that a radiographic examination is able to give a more rapid and accurate diagnosis than other methods; a full effort should then be made to achieve the best quality diagnosis.

Similar benefit/risk considerations apply to the mass screening of populations (e.g., of chest, stomach, or breast). Provided the technique discovers a reasonable number of persons with disease early enough to treat and provided the radiation exposure required for the examinations does not involve excessive risk, such practice should be encouraged. If any doubts arise about the value or risk of a particular type of procedure, professional advice should be sought from an experienced radiologist and physicist together.

Problems of pregnancy

The high sensitivity of the fetus to ionizing radiation requires special safeguards.

During known pregnancy the only radiological examinations that should be carried out are those that cannot be postponed without detriment to the patient. Then the X-ray technique must be chosen to keep the dose received by the fetus as low as practicable.

Since there is a possibility that any woman of reproductive capacity may be in an early stage of pregnancy, radiological examinations of the lower abdomen may involve risks at a time when the fetus is most sensitive. Such examinations should therefore be carried out only during the 10 days following the onset of menstruation. Correct timing is facilitated if the clinician requesting the examination ascertains the date of the menstrual period and mentions it in his request.

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Initial exposures on new X-ray equipment

The first series of exposures on new X-ray equipment, unless it has been specially calibrated against a known X-ray unit, must be considered in the same light as research work involving patients. This matter is considered in Volume 1 of the manual, page 34. Difficulties of this nature may be reduced by requesting suitable setting up measurements from the engineer at installation or from the physicist in charge of the radiation survey, which must always be carried out before new equipment is used.

Unavoidable radiation load on the patient in special examinations

Some special methods of X-ray examination are accompanied by a higher than normal radiation dose to the patient. Owing to the high diagnostic value of these methods, they are widely used nowadays. Since they are carried out with the help of special apparatus and devices, they must be used only by those with considerable experience in a big X-ray department at level 4 and above.

Even under the most favourable conditions of operation of equipment and with every effort made to fulfil the safety regulations, the radiation dose incident on patient and staff tends to approach the maximum permissible levels. In unskilled hands and with unfamiliar apparatus the doses will almost certainly exceed the maximum permissible limits.

These special methods of examination include cardiac catheterization, angiocardiography, X-ray cinematography, electrokymography, and certain kinds of tomography.

Cardiac and vascular catheterization and angiography

The conflicting requirements of dark adaptation for the radiologist and good lighting for surgical purposes during cardiac catheterization exclude the use of a conventional fluoroscopic screen for such purposes.

Catheterization should be carried out in a well equipped X-ray room provided with a special table fitted with lead screens (some of which may be suspended from the ceiling) and limiting devices to confine the X-ray beam. An image intensifier is essential, and it must be correctly adjusted to achieve a satisfactory image quality with minimum tube output. Since catheterization may take 8–10 minutes and the skin exposure rate on the patient can easily reach 3 R per minute, a total absorbed skin dose to the patient could amount to 30 rad.

Cardiac and aortic catheterization is particularly hazardous from the radiation point of view when children are examined. Even if the gonads are not in the direct beam they always receive a high dose because they are relatively near the edge of a direct beam, the body size being small.
During contrast examination of the upper regions of the aorta (ascending part and the arc), surgeons must resist the temptation to prevent contrast material penetrating into the carotid arteries by squeezing these arteries with their finger. This would be accompanied by irradiation of the hands with very high doses.

The contrast material is often introduced into the vessels or heart cavities with the help of automatic injectors synchronized electrically with high-speed film-taking apparatus. During the procedure the patient stays alone in the room for angiography. The radiologist and his assistants move to another room where the control panel is situated and watch the patient through a glass window.

Sometimes, when contrast material is introduced directly into the vessel, a particular organ, or selectively into one of its arterial branches (as, for example, in selective renovasography and mesentericography), the radiologist or surgeon feels the need for manual injection to avoid the damage to the vessels that may result from a non-feeling mechanical injector. To reduce the irradiation of the person carrying out the injection, a long catheter is used, but the increase in its length is limited by an increase in resistance, which makes it difficult to ensure a quick injection of contrast material. A possible solution to this problem is to use power-assisted injection, which retains the advantages of manual control while at the same time providing the high speed of automatic injection. In any case, a special protective shield must be interposed between the patient and the person carrying out the injection in order to reduce the scattered radiation spreading directly from the patient.

Under no circumstances should manual changing of cassettes be used for angiography since it exposes the person engaged on this work to rather high doses. Only if automatic cassette changers are available should angiography be undertaken.

The use of an X-ray image intensifier for such examinations is primarily for the convenience of being able to operate in a reasonable level of ambient lighting. It does not mean that the radiation protection requirements can be in any way relaxed. The examinations should still be carried out with the utmost speed, and all proper precautions must be taken to protect both staff and patient.

**Tomography**

Tomography in its different variations is accompanied by a high radiation load. The worst type from a radiation point of view is body cross-section tomography. Here the total dose received by the patient is distributed over a circular area with a width of about 15–20 cm but its absolute value is relatively high (e.g., a dose to the skin of about 6 rad). Multilayer cross-section tomography with computer display may have about 100 times
the contrast sensitivity of film, with a skin dose of about 2 rad. Cross-section tomography is sometimes used for planning radiation treatments.

Longitudinal tomography is of high resolution and it is thus often practised. The majority of medical institutions use relatively long exposure times of 2–3 seconds. Simultaneous multi-section laminography is generally preferred to single layer tomography, but this does not mean that the patient is spared the dangerous dosage involved in the repetition of a number of single sections. Owing to the absorption in the multiple layers of the screens, the whole-body dose is much the same for the two methods, although with the multiplane system the skin dose is slightly lower.

**Kymography**

Multichannel X-ray kymography is mainly used for analysing the movement of the contours of the heart and large vessels. In this technique a lead grid containing a number of narrow, widely spaced slots is placed between the patient and the film cassette. Very little of the radiation passes through the slots to be recorded on the film, most of the radiation being wasted in the lead. All the radiation, however, has passed through the patient before reaching the lead. To reduce this unnecessary irradiation of the patient, a second grid of suitable proportions, synchronized in its movement with the first grid, may be placed between the X-ray tube and the patient. Such apparatus requires to be very accurately made mechanically and carefully positioned before use; it should not be entrusted to unskilled hands.

**Electrokymography**

Electrokymography is a very sophisticated technique used to make oscillographic recordings of heart fluctuations. Positioning of the recording device requires initial fluoroscopy with a limited field size. Ideally, several oscillograms of different parts of the vascular system should be made simultaneously to avoid unnecessary repeat irradiation of the patient. Reduction of the potential radiation hazard depends much on the skill of the user.

**X-ray cinematography and X-ray television fluorography**

X-ray cinematography is accompanied by relatively high doses to the patient. It is used in angiography, coronography, and other contrast media techniques. To obtain the maximum information from this method it is desirable to project the film at a lower speed than that at which it was taken. In typical cases the absorbed dose at the patient’s skin may lie in the range 3.6–13.5 rads. This radiation dose may be considerably reduced if a pulse system of tube switching is used in the X-ray unit.
It is usual to set up the system with television fluoroscopy before actually making the ciné-exposures, thus avoiding unnecessary repeat exposures.

In principle, X-ray television fluorography can help to reduce the radiation dose in radiography, but in practice this method is limited by the poor quality of an X-ray television image. While it is quite applicable to the examination of relatively large objects such as stomach, intestine, heart cavities, and relatively large blood vessels, fine structures such as small blood vessels, bone trabeculae, and fine stomach mucosa are not transmissible through the television system. The same disadvantages apply to the recording of the X-ray image with the help of a video tape recorder.

Recognition of inadequacy of simple X-ray examinations

Sometimes, where these special techniques are necessary for diagnosis, the usual methods of simple X-ray examinations are repeated many times without success, simply because the facilities are not available for the special technique. This is most undesirable since it does not produce the required result and only imposes a higher radiation load on the patient. In such cases the radiologist should make a careful study of all the circumstances before deciding whether to repeat a basic method or to refer the patient to a centre where the facilities exist for the special examination.

Measurement of patient irradiation dose

The biological effect of an exposure received by the patient is not the same if in one case it is absorbed by the relatively low-sensitivity tissues of the extremities and in another case by the highly sensitive abdominal organs. The quality of radiation affects the amount of the incident beam that penetrates the body and the amount that is scattered. The relative proportions of these components in turn determine the integral absorbed dose. The size of the exposure field is another factor of importance, since radiation of low intensity spread over a large field might produce as large an absorbed dose as radiation of high intensity contained in a small field.

Since certain physical parameters (e.g., field size, tube voltage, tube current, and focus-skin distance) vary during examination procedures, the somatic dose received by the patient also varies. Therefore the determination of the integral absorbed dose according to dosimeters attached to the surface of the patient's body cannot be even approximately correct. The same may be said about calculations made according to output dose measurements at different distances from the tube focus. These data are useful only as a general guide and are more accurate in radiography than in fluoroscopy.

A desirable system is one that would measure the amount of radiation reaching the surface of the patient's body over the whole area of an input field. For this purpose a wide-field dosimeter is required mounted inside
the diaphragm box. The large surface allows for dose variations depending on the field size irradiated. A measuring system suitable as a patient "dosi-
   meter" is shown in Fig. 6, page 34. This unit measures the product of dose and exposure field (R. cm²)—a quantity that can be approximately converted into the integral absorbed dose by using a factor to express the result in gram rads.

To summarize, it is desirable from the point of view of radiography to measure the output of an X-ray machine during the radiation survey. To reduce the dose during fluoroscopy a large chamber mounted in the X-ray beam collimator system and a timer with a warning device is valuable in that the audible warning draws the attention of the radiologist to the dose rate at the particular time, and if he is using too large a field the high repetition of the warning sound will help him to reduce the radiation to the patient.

Protection of personnel from radiation

Distance factor

The general principle of personnel protection involves acceptance of the fact that any dose of radiation may be a cause of injury to the organism. It is therefore necessary to maintain a constant effort to reduce the dose and to eliminate as completely as possible radiation effects on the personnel. When fluoroscopy is carried out with conventional diagnostic apparatus, only those assistants should stay in the room who are indispensable for the examination. Normally the patient is strong enough to stand by himself without any assistance and a radiologist alone can manage the examination. When cassette manipulations are required or a barium meal is to be served, the fluoroscope may be switched off without interrupting the examination process. The control panel is located in a protected control booth, which may be regarded as outside the irradiated area of the X-ray room. This means that an X-ray technician operating the equipment will also stay outside and in practice will not be subjected to the effects of radiation.

When the apparatus is supplied with an X-ray television system, the radiologist can often manage to stay outside as well, away from the patient. However, this is sometimes impossible; not every patient understands the radiologist's requests for the proper position he should take at a given moment. Sometimes the radiologist himself finds it difficult to explain exactly to a patient what kind of movement is required of him and it is easier to help the patient to take the proper position. If for such rea-
sons the radiologist is obliged to stay near the patient during fluoroscopy, the hazards and precautions are described in Chapter 2, page 26. If, however, the patient is simply afraid to be left alone with a mysterious machine, he
should be reassured by reasonable explanation; it would be wrong to subject personnel to unjustified irradiation by asking them to remain in the room solely to keep the patient calm.

When examining children or weak patients who require support in the vertical position, the assistance of other persons may be indispensable. But such an assistant should not normally be a member of an X-ray department, for it is difficult to foresee how often he will be obliged to work under radiation conditions in his future employment. This function should be performed by a nurse from the relevant department (preferably a different nurse each time, so that the work is rotated) or by the relatives of the patient. The person rendering help to the patient should wear a protective apron and protective gloves. The place that he occupies during the fluoroscopic examination should not be located in the direct beam, but it may nevertheless receive appreciable scattered radiation.

The complete protection of personnel against radiation can be achieved in angiography during injection of contrast material accompanied by a series of exposures quickly following one another. When the room for angiography is properly equipped, the procedure is completely controlled from the control panel outside the room. The automatic injector is operated by remote control, then the programming device, and finally the X-ray tube. Manual injection of contrast medium considerably reduces the possibility of providing such protection, as described on page 65.

The radiologist should constantly see to it that all the safety regulations are strictly followed by the personnel. As the person responsible for ensuring not only that proper procedures are followed during examinations but also that the health of his staff is not adversely affected, the radiologist himself should set an example of strict discipline in the observance of all the regulations. He should make it a rule not to switch on the X-ray unit if any member of the staff involved in the examination is not wearing a protective apron. A person not so equipped would either have to leave the room or keep the others waiting while he put an apron on. This rule would encourage the habit of always donning an apron when entering the room. A sufficient number of aprons should be provided, and they should be kept in a specified place, preferably near the entrance of the room so that any newcomer can easily find them.

Protective clothing

Protective clothing should be worn by all the personnel in X-ray departments and by all persons working within the radiation area when the X-ray tube is energized. It is intended to achieve the maximum reduction of individual dose from scattered radiation. Protective clothing in the form of aprons and drapes does not provide complete protection from primary radiation. It should be borne in mind that the radiation load of persons
wearing protective clothing depends to a considerable extent on their behaviour.

Aprons of 0.25 mm lead equivalent are light enough to be worn during the whole time that the member of staff is within the area of radiation hazard. When high voltages are applied in X-ray diagnosis (100-125 kV) such aprons can reduce scattered radiation to about 10% of the initial amount. Aprons with higher lead content, for example 0.5 mm lead equivalent, provide more effective protection, reducing radiation at similar potentials to about 2%. These aprons are very heavy, and people engaged in radiological procedures might be tempted to take them off, thus being left unprotected for some periods during the working day. Light aprons can be worn for a long time without being taken off, and they are therefore more effective in practice.

Protective clothing should stand treatment of its surface by detergents and disinfectants, and protective gloves should be resistant to perspiration on the inside. Light protective aprons should cover the body on the front, back, and sides from the neck down to the knees. All protective clothing and shields must be marked with the lead equivalent thickness. This value depends to some extent on the quality of the radiation; as a rule it is based on a voltage of 80 kV.

Aprons of all types should be easy to put on and take off. Any inconvenience in this process can produce the situation where the staff ignore the aprons because of the waste of time and dislike of complicated procedure. Protective gloves are intended for use against scatter, or against primary radiation only after it has been attenuated by its passage through the patient’s body. They should cover not only the hands but also the forearms. It is preferable that the shape of the fingers be curved so that the radiologist’s fingers can be kept in a slightly bent position.

It should be remembered that the intense shadow from the gloves seen on the fluorescent screen creates a false impression of complete impenetrability to X-rays. This shadow is formed by two layers of lead rubber while the radiologist’s hand inside the glove is protected by only one layer. Therefore gloves are not an adequate protection against the direct primary beam. If a patient has to be moved it should be done by holding those parts of his body that are outside the beam.

Gloves should be worn for all fluoroscopy work and not merely for gastrointestinal examinations. In the latter case the radiologist smooths out the organs with his hand to define their displacement. Some radiologists would like to use the unprotected hand in an attempt to judge the degree of resistance of the stomach mucosa during the smoothing out process, but this procedure is of little value since it is based on purely subjective reactions. Protective gloves should always be worn. Two or three compression cones should be used for obtaining pictures of the mucosa relief. Sometimes an inflatable oval can be used for large areas; care must be taken with this
device, particularly if the compression is power operated; it is very easy to break a rib with excess pressure.

**Protective devices**

Some X-ray diagnostic procedures, and especially fluoroscopy, require protective shields as well as protective clothing. The most useful types are small movable shields intended for protection against scattered radiation below the screen and the film taking assembly. The lead equivalent of the screen should be 0.5–1 mm and the value marked.

Large protective shields are also intended for use against scattered radiation and in a more restricted way against primary radiation. The height of such shields is about 2 m and the width about 80–100 cm. The bottom edge of the shield should not be more than 3 cm above the floor. A protective glass viewing window 24 × 30 cm or 30 × 40 cm in size should be provided in the shield at eye level. Such mobile or stationary screens with lead glass windows enable the radiographer to observe the patient closely for careful placing.

In fluoroscopy a small protective apron is usually attached to the lower edge of the screen holder. This apron is made of lead rubber with a lead equivalent thickness of 0.5 mm. It should be not less than 45 × 45 cm in size. For practical purposes this apron may consist of not a single panel but of three or more smaller overlapping parts. This facilitates palpation because the fluoroscopist can easily move his hands in protective gloves through the overlapping panels without breaking the necessary protection at chest level. When the stand is horizontal (tracheoscopy) the apron is located on the same side of the screen holder as the fluoroscopist and protects him from scattered radiation emerging from the patient.

The radiologist’s face is usually protected during conventional fluoroscopy by the protective glass covering the fluoroscopic screen, which should have a lead equivalent of not less than 1.5 mm for apparatus with a maximum available voltage of 70 kV and 2.0 mm for apparatus capable of a maximum voltage of 100 kV. Thereafter, the lead equivalent should be increased by 0.01 mm for every kilovolt in excess of 100 kV. If radiographs are taken during fluoroscopy, the maximum tube voltage may be higher than that used in fluoroscopy alone, and the lead equivalent thickness should allow for this.

The diaphragm should be so adjusted that its leaves cannot be opened to such an extent as to allow the direct beam to go outside the limits of the screen, even when the screen is at its maximum distance from the tube. When the diaphragm is wide open, the edges of the leaves should be visible on the screen about 1 cm inside the edge of the frame.
Operational load and the working day

While planning his working day, each radiologist should bear in mind that the proper examination of each patient should include sufficient time for reading the patient's history and studying the results of previous X-ray examinations.

A typical working day should allow for:

(1) the time not directly connected with the examination of patients but indispensable for ensuring the efficiency and safety of normal work in the procedure room, such as the arranging of the room at the beginning of the day for the work previously scheduled, its cleaning at the end of the day, communication with administration and physicians, and miscellaneous responsibilities;

(2) the time needed to study the patient's history, to question the patient, and to write down the examination results;

(3) the time needed for dark adaptation of the eyes; and

(4) the time required to examine the patient with the X-ray tube on.

Knowing the time required for examination with various X-ray diagnostic procedures and the maximum permissible dose for the personnel of the X-ray department, it is possible to calculate the number of patients who can be examined in one working shift, i.e., to state the normal workload. It should also be remembered that the maximum permissible dose is only the limit that should not be exceeded and that the daily radiation load should be kept well below the maximum permissible dose.

In practice, when all the calculations are done, it is better to work out the maximum possible load rather than the maximum permissible load. The maximum possible load is based on the time taken by the various procedures, and it is quite instructive to attempt to work out the maximum number of procedures that can be possibly squeezed into a working day. In a typical working week for an average X-ray room it is quite difficult to achieve more than 60 000 mAs of X-ray exposure, and since this figure is unlikely ever to be exceeded it can be used as the basis for the calculation of shielding.

Medical control of the health of personnel

Systematic control of the health of personnel should be maintained in X-ray departments. Once a year they should be examined by a physician and a pathologist; if required, specialists such as ophthalmologists, otorhinolaryngologists, dermatologists, and gynaecologists may be consulted. Compulsory blood examinations should include a haemoglobin test, an erythrocyte and leucocyte count, a study of the erythrocyte and leucocyte picture, a thrombocyte count, and a determination of sedimentation rate. Chest fluorography may be carried out if necessary.
When any pathological deviation attributable to radiation is observed in a member of an X-ray department, the working regime of such a person should be changed. He should either be suspended completely from radiation exposure or put on work that will severely limit his exposure. If this happens to a radiologist, his activity might be restricted to the study of radiographs or fluorographs without direct contact with X-rays. The X-ray technician also has plenty of work to do apart from radiation exposure—for example, the development and further processing of X-ray films, control panel operation outside the procedure room, and the keeping of medical X-ray records. Such restrictions should continue until the pathological deviation (e.g., blood count abnormality) disappears.

New staff members, prior to their employment in the X-ray department should undergo the same laboratory examinations as during the periodic control. Chest radiography should be included. The initial examination should be especially thorough because certain diseases contraindicate the appointment of a person to an activity that exposes him to radiation.

It is difficult to lay down hard and fast rules for physiological norms. WHO surveys have shown that there is so much variation between countries and races that it is difficult to establish standards. However, general trends can and should be recorded for all radiation workers. Fortunately, of all those involved in radiation work, diagnostic X-ray workers are probably least at risk, and most of the variations observed in medical examinations are due to non-radiation health problems. For further details of health surveillance the reader is referred to Volume 1 of the manual, page 70.
Sources of stray radiation

In assessing stray radiation during radiography it should be borne in mind that certain phenomena recur whatever geometrical configuration is used in practice. These are:

1. a part of the direct beam missing the patient,
2. scattered radiation from the patient in any direction, and
3. scattered and leakage radiation from inside the X-ray tube head.

Fig. 1 illustrates this, omitting all supports, couches, etc. and showing only the fundamental constituents of the process.

When radiographing some parts of the body, particularly the head and neck, it is almost impossible to avoid some of the direct beam passing the patient completely without being absorbed. It then strikes the film cassette,
which, unless it is lead backed, transmits quite an appreciable proportion, and eventually strikes the wall or floor of the X-ray room. It could be hazardous if this direct beam were to pass through an open doorway or window of the X-ray room, and even when it strikes the walls it generates some additional scattered radiation.

Scatter from the patient is emitted with its highest intensity in the backward direction, its intensity falling off as one moves around the patient towards the film side. At right angles to the primary beam the scattered radiation is partly filtered and attenuated by the patient himself, an extreme case of this being the radiographing of the abdomen when the scatter may have to pass through as much as 80 cm of tissue before emerging from the patient's head or feet. On the film cassette side of the patient the primary radiation transmitted may be less than the scatter radiation, even when a Bucky diaphragm or grid is used. For distances greater than 1 metre from the patient the magnitude of the scattered radiation (whatever its direction) depends markedly on field size.

The film cassette itself normally requires an exposure in the region of 1 mR, and the scatter in other directions may be expressed as a proportion of this figure. Near the edge of the beam on the incident side just outside the direct beam, the backscatter may be as much as 200 times as great as the exposure to the film (i.e., about 200 mR). At the side of the patient on which some of the primary beam is falling the scatter may be 10–50 mR, but at the side not actually touched by the primary beam the scattered radiation will be reduced by approximately a half for each 5 cm of tissue lying between the edge of the beam and the surface of the patient on that side.

Thus the safest place in an X-ray room is on the unirradiated side of the patient towards the film cassette. The worst place is in the back-scatter from the incident beam or in the direct beam that misses the patient if this is not trapped by a lead shield. Wherever one stands in an X-ray room, of course, a protective apron must be worn.

The reader may recognize the example in Fig. 1 as a hip joint exposure, which is one of the heaviest given in radiography. A small reduction in field size, providing it does not obscure essential details, can reduce the scatter and appreciably improve the quality of the image. Particular note should be taken of the extent and magnitude of the back-scatter—a hazard that is easily overlooked.

The same basic diagram can be used to interpret almost any other configuration used in either radiography or fluoroscopy, as shown by the examples in Fig. 2.

Methods of confining stray radiation

The most important step to take in confining stray radiation is to trap the direct beam. If this has bypassed the patient, then the nearer the trap
is to the film cassette the smaller and less heavy will be the protective shielding required. Behind a chest stand there should be a substantial shield of at least 2 mm of lead, with sufficient area to cover the largest beam that can be obtained with the light beam diaphragms. The use of flexible shields in fluoroscopy and in carrying out special techniques has been described in Chapter 4, page 41.

When a staff member is required to be in the X-ray room during fluoroscopy a good place for him to stand is behind the fluoroscopist, whose protective screens and protective apron will cast a radiation shadow across the room. When flexible shields are used for special techniques, the nearer to the patient they can be mounted the smaller and lighter they will be, for the same protection provided.

Areas of maximum stray radiation are illustrated in Fig. 3.

Relative hazards of X-ray techniques

When radiographing or examining by fluoroscopy certain parts of the body (e.g., the chest) it is possible to achieve the same image quality using different methods (e.g., low voltage, high voltage, and various filters and grids). However, since the standard filtration of 3 mm of aluminium should remain constant (see Chapter 4, page 38), the radiologist may vary...
The measured exposure rates are for a week with a light workload. In a busy X-ray department the 100 mR/wk contours may extend outwards to fill the whole room.
only the voltage and the grids and utilize patient compression. The requirements vary with the type of examination. A female chest radiograph, for example, gives rise to side scatter to the gonads near the edge of the beam. Increasing the voltage for the same film dose will only increase the gonad dose. Moreover, although an increase in voltage will reduce the exposure required, it will also increase the hardness of the scattered radiation so that it will be more able to penetrate the lead shields that are used around the patient. It is obvious from this sort of argument that for any particular set of conditions there is an optimum choice of voltage and technique that will not only produce the optimum film quality but also minimize stray radiation around and within the patient. At present there is still much discussion on the optimization of techniques from a protection point of view, and it is hoped that information of a more precise nature will soon be available.
Annex 4

DATA FOR RADIATION PROTECTION IN THE DIAGNOSTIC X-RAY REGION

The information provided here is presented in simplified form so that in many cases the nearest available shielding thickness may be chosen with a minimum of calculation. If in doubt between two values the thicker shield should be chosen to give slight overprotection rather than risk underprotection.

Data for the design of protective barriers

The attenuation in protective barriers to be used in a diagnostic X-ray department depends on the tube potential, the initial filtration, the width of the beam and the angle of scattering. The thickness required to reduce the exposure rate to the maximum permissible level depends in addition on the workload (expressed as milliampere-minutes per week), the distance from the tube to the occupied area, the degree and nature of the occupancy, the type of area, and the material of which the barrier is constructed. Tables 1-5 at the end of this Annex show the thicknesses required under conditions commonly encountered in diagnostic radiology.

Structural details

Structural details of protective barriers are given in Volume 1 of the manual, Annex 2, together with illustrations, but a few of the most important points will be repeated here.

Doors and door frames must have the same lead equivalent as that required for the adjacent wall, and the protective lead covering of the door should overlap that of the door frame by at least 1.5 cm. Similarly the protective lead that covers the door frame should overlap the concrete or brick in the wall for a distance at least equal to the thickness of concrete or brick. The door threshold may be arranged as a baffle formed by the lead lining of the door and the concrete in the floor.

Observation windows and the frames in which they are held should have the same lead equivalent as that required for the adjacent wall, and the joint between the lead glass and the wall must be protected by an overlapping lead frame.

Darkrooms should have a protective threshold and the cassette passbox must be shielded in such a way that no radiation can penetrate into the darkroom.
Protective barrier requirements for primary radiation

Tables 1 and 2 indicate the shielding required to reduce the exposure to 10 mR per week in terms of the workload estimated in milliampere-minutes per week, assuming the worst situation—i.e., that in which primary radiation can strike the walls of the X-ray room. With a new installation it is more economical to design for the maximum attenuation conditions that are likely to be required in the future; it should be borne in mind, for example, that positions outside the room that initially have low occupancy can undergo changes of use that may not be apparent to the workers in the X-ray room itself. Again, although initially there may appear to be preferred directions in which the X-ray beam is normally pointed, unforeseen changes of technique may lead to other walls being irradiated.

Protection of unprocessed X-ray films

Exposures of the order of 0.1 mR over a portion of X-ray film can produce undesirable shadows. Such fogging can necessitate repeat exposures, which can increase the dose given to patients quite needlessly. Therefore films require more protection than do personnel, and it is important that darkrooms should have ample shielding.

It is desirable to place storerooms for unexposed films well away from X-ray rooms. If it proves impracticable to install such a storeroom other than next to the X-ray room, the separating wall or floor should have ample protection as indicated in Table 3. Similar considerations may well apply to the darkroom wall, where this is adjacent to the X-ray room.

Data for radiation survey measurements

Equipment needed for a survey

(1) Film badges, 20 per room
(2) Expanding ruler
(3) Reel of adhesive tape
(4) Aluminium filters, thickness 1, 2, 10, 20, and 30 mm
(5) Check list
(6) Fluorescent screen, protected by lead glass, for leak detection
(7) Stop watch and spinning top to check times and exposure values
(8) Adjustable stands to hold equipment
(9) A selection of large non-screen films
(10) Exposure meter with mR and mR/s ranges, calibrated for diagnostic quality radiation
(11) Penetrometer for checking voltage and filtration of X-ray tubes
(12) Torch fitted with dark-red safelight filter.
Methods of checking the coincidence of light beam and X-ray beam

One method is to place a film in a suitable light-tight wrapping on the table and to adjust the diaphragms until the light beam falls within the film with a margin of about 2 cm all round. The film and its wrapping are then pierced with a pin at the four corners of the field, and an X-ray exposure is made (e.g., at 60 kV and 2 mAs and at a distance of 1 m). After processing, the position of the pinholes can be compared with the blackening due to the radiation. An alternative method when the film is in a cassette is to mark the corners of the field with radiopaque objects such as lead arrows. Each object should be placed inside the illuminated area with one end coinciding with a corner.

A screen cassette may be used if wrapped film is not readily available. Scattered radiation is greater with a cassette but will only occasionally influence the result.

The alignment of the X-ray beam and the light beam should be well within the error limit of, say, 1 cm at 1 metre, and a light beam that is larger than the X-ray beam by more than 1 cm on any side is just as undesirable as one that is smaller since it may lead to retakes and hence to an increase in patient dose.

Adjustment of the light or mirror is not always easy and is probably best left to a service engineer, unless a member of the survey team has been trained for this.

Measurement of leakage from the tube head

The international recommendations state that the maximum leakage around the tube head when the diaphragms are closed must not exceed 100 mR per hour at 1 metre at the maximum rating of the tube. Unfortunately, the maximum rating of the tube is not always readily to hand when a survey is about to be undertaken.

If it is not possible to determine the point of maximum leakage by means of a fluorescent screen protected by lead glass (perhaps because the room is not used for fluoroscopy and therefore has no means of excluding light), it may be necessary to construct a cage of non-screen film around the tube head to detect such a point. If the measurements show that the protection of the tube head is deficient, additional shielding must be provided, values of which are indicated in Table 6.

Methods of checking protective clothing

Protective gloves and aprons should be examined visually at frequent intervals and radiographically at least once a year. A preliminary examination for flaws or cracks can be made fluoroscopically for aprons only. Any suspicious areas can then be radiographed in comparison with a lead step
wedge. Gloves cannot be examined in this way as the screen is so bright where primary radiation passes between the fingers that it is impossible to see flaws and cracks in the gloves themselves. However, a pair of gloves laid on a cassette containing fast film and intensifying screens can be exposed together with a lead step wedge as for the apron. Care must be taken to allow for the fact that the thickness of the glove recorded in this way is twice the protective thickness.

Typical exposure values that should enable a visible density to be seen through given lead equivalent thicknesses are set out in Table 7.

### TABLE 1. PROTECTIVE BARRIERS AGAINST PRIMARY RADIATION FOR DIAGNOSTIC X-RAY INSTALLATIONS

<table>
<thead>
<tr>
<th>Maximum tube voltage (kV)</th>
<th>Distance from target (m)</th>
<th>Barrier thickness</th>
<th>Concrete of density 2.35 g/cm² (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>2</td>
<td>1.8</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.6</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.2</td>
<td>100</td>
</tr>
<tr>
<td>125</td>
<td>2</td>
<td>2.1</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.8</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.3</td>
<td>110</td>
</tr>
<tr>
<td>150</td>
<td>2</td>
<td>2.2</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.9</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.4</td>
<td>130</td>
</tr>
</tbody>
</table>

The values given in the table are suitable for a workload not exceeding 150 mA min per week of radiography and should reduce the exposure at the stated distance to 10 mR in a week.

### TABLE 2. PROTECTIVE BARRIERS AGAINST SECONDARY RADIATION ARISING FROM FLUOROSCOPY, WITHOUT RADIOGRAPHY

<table>
<thead>
<tr>
<th>Maximum tube voltage (kV)</th>
<th>Distance from target (m)</th>
<th>Barrier thickness</th>
<th>Concrete of density 2.35 g/cm² (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>1</td>
<td>1.2</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.0</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.8</td>
<td>85</td>
</tr>
<tr>
<td>100</td>
<td>1</td>
<td>1.35</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.05</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.85</td>
<td>70</td>
</tr>
<tr>
<td>125</td>
<td>1</td>
<td>1.4</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.1</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.9</td>
<td>70</td>
</tr>
</tbody>
</table>

These values are suitable only for existing installations where the primary beam is trapped by the lead protection of the fluorescent screen or intensifier. For new installations and where radiography is possible the room shielding must be designed for primary radiation (see Table 1). This table is intended for fluoroscopy workloads not exceeding 300 mA min per week and a maximum permissible level of 10 mR in a week.
### TABLE 3. SHIELDING FOR UNEXPOSED X-RAY FILMS

<table>
<thead>
<tr>
<th>Storage time</th>
<th>Lead shielding thickness required at following distances from X-ray tube to stored film</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 m (mm lead)</td>
</tr>
<tr>
<td>1 day</td>
<td>2.7</td>
</tr>
<tr>
<td>1 week</td>
<td>3.4</td>
</tr>
<tr>
<td>1 month</td>
<td>3.8</td>
</tr>
</tbody>
</table>

The values given in the table assume a workload of less than 400 mA min per week at 125 kV. For other shielding materials the lead equivalents are given in Table 4.

### TABLE 4. APPROXIMATE LEAD EQUIVALENT THICKNESSES OF VARIOUS MATERIALS, ASSUMING BROAD-BEAM CONDITIONS

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
<th>50 kV</th>
<th>100 kV</th>
<th>150 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick #</td>
<td>1.8</td>
<td>100</td>
<td>120</td>
<td>195</td>
</tr>
<tr>
<td>Hollow brick #</td>
<td>1.4</td>
<td>135</td>
<td>165</td>
<td>270</td>
</tr>
<tr>
<td>Concrete #</td>
<td>2.2</td>
<td>62</td>
<td>80</td>
<td>140</td>
</tr>
<tr>
<td>Barium concrete #</td>
<td>3.2</td>
<td>15</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>Steel #</td>
<td>7.9</td>
<td>3</td>
<td>6.5</td>
<td>13</td>
</tr>
<tr>
<td>Air entrained concrete #</td>
<td>0.63</td>
<td>230</td>
<td>270</td>
<td>470</td>
</tr>
<tr>
<td>Gypsum #</td>
<td>0.84</td>
<td>140</td>
<td>100</td>
<td>—</td>
</tr>
<tr>
<td>Brick (yellow stock) #</td>
<td>1.6</td>
<td>85</td>
<td>110</td>
<td>195</td>
</tr>
<tr>
<td>Barium plaster (gypsum base)</td>
<td>2.0</td>
<td>16</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Clinker concrete #</td>
<td>1.2</td>
<td>3.1</td>
<td>2.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Brass</td>
<td>8.3</td>
<td>5.4</td>
<td>40</td>
<td>78</td>
</tr>
</tbody>
</table>

### TABLE 5. APPROXIMATE TENTH-VALUE THICKNESSES OF VARIOUS MATERIALS UNDER BROAD-BEAM CONDITIONS

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
<th>50 kV</th>
<th>100 kV</th>
<th>150 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>11.3</td>
<td>0.18</td>
<td>0.84</td>
<td>0.96</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.35</td>
<td>13</td>
<td>55</td>
<td>70</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.2</td>
<td>22</td>
<td>68</td>
<td>101</td>
</tr>
<tr>
<td>Brick</td>
<td>1.8</td>
<td>36</td>
<td>104</td>
<td>145</td>
</tr>
<tr>
<td>Hollow brick</td>
<td>1.4</td>
<td>49</td>
<td>144</td>
<td>193</td>
</tr>
<tr>
<td>Barium concrete</td>
<td>3.2</td>
<td>5.4</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Steel</td>
<td>7.9</td>
<td>1.0</td>
<td>5.4</td>
<td>13</td>
</tr>
<tr>
<td>Air entrained concrete</td>
<td>0.63</td>
<td>76</td>
<td>230</td>
<td>328</td>
</tr>
<tr>
<td>Gypsum</td>
<td>0.84</td>
<td>45</td>
<td>172</td>
<td>260</td>
</tr>
</tbody>
</table>

The tenth value thickness is the thickness of material that reduces the dose to one tenth of its value. The figures are calculated (partly extrapolated) from data in: German Standards Commission (1974) *Medizinische Röntgenanlagen bis 300 kV: Strahlenschutzregeln für die Errichtung* [Medical X-ray equipment up to 300 kV: radiation protection rules for installation], Berlin (DIN 6812); and International Commission on Radiological Protection (1973) *Data for protection against ionizing radiation from external sources: supplement to ICRP publication 15*, Oxford, Pergamon (ICRP publication 21).
### TABLE 6. ADDITIONAL SHIELDING FOR X-RAY TUBE LEAKAGE RADIATION

<table>
<thead>
<tr>
<th>Required fractional reduction of leakage radiation</th>
<th>50 kV</th>
<th>75 kV</th>
<th>100 kV</th>
<th>150 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.07</td>
<td>0.19</td>
<td>0.3</td>
<td>0.32</td>
</tr>
<tr>
<td>0.1</td>
<td>0.23</td>
<td>0.63</td>
<td>0.95</td>
<td>1.04</td>
</tr>
<tr>
<td>0.05</td>
<td>0.8</td>
<td>1.25</td>
<td>1.40</td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>1.3</td>
<td>2.0</td>
<td>2.1</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 7. EXPOSURE FACTORS FOR INSPECTING LEAD PROTECTIVE CLOTHING

<table>
<thead>
<tr>
<th>Nominal lead equivalent of shield (mm)</th>
<th>Focus–film distance (m)</th>
<th>Approximate exposure (mAs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>0.25</td>
<td>1.0</td>
</tr>
<tr>
<td>80</td>
<td>0.35</td>
<td>1.0</td>
</tr>
<tr>
<td>80</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>80</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>80</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>80</td>
<td>1.5</td>
<td>0.5</td>
</tr>
<tr>
<td>100</td>
<td>2.0</td>
<td>0.5</td>
</tr>
<tr>
<td>125</td>
<td>2.25</td>
<td>0.5</td>
</tr>
</tbody>
</table>

A fast film/screen combination should be used in the cassette and the X-ray beam should be adjusted to its minimum size. The shielding thicknesses given in the table should then be penetrated by the exposures listed in the last column. With exposures of 120 mAs and above, care must be taken not to exceed the maximum rating of the X-ray tube. If necessary, the exposure may be divided into a number of fractions, allowing time for the X-ray tube to cool between each part of the exposure.
Annex 5

GENETICALLY SIGNIFICANT DOSE TO THE POPULATION FROM X-RAY DIAGNOSIS

The genetic consequences of radiation constitute the most important problem faced by radiologists. Evident somatic effects are fairly easily detectable and, for the future, avoidable, and even somatic-stochastic effects such as leukaemia are serious only for certain individuals in the present generation, while their incidence can be reduced in the future by reducing the exposure. Genetic effects, however, once imparted to the genetic pool of a population can never be removed or stopped. Any carelessness exercised today will have to be paid for by the unborn and may affect the health of future generations for an indefinite time.

Radiologists should therefore be aware of their responsibilities to the human race. In their everyday work they should bear three facts constantly in mind:

1. The number of mutagenic factors in our environment and daily life is unknown but certainly increasing; ionizing radiation is, however, the one best known and perhaps the most serious with respect to mutagenic capacity.
2. The benefit to the individual of X-ray investigations, which counter-balances the small somatic-stochastic risk, is not a benefit to the unborn.
3. X-ray diagnosis is at present the major contributor of man-made radiation exposure of most populations.

It has to be made clear, however, that such considerations are relevant only to public health authorities and the users of radiation and their supervisors, not to the individual patient. The genetic risk to a particular patient or his direct offspring is not the question at issue. According to our understanding of genetics and our uncertain knowledge of recessive mutations, the potential genetic risk of radiation exposure depends on the sum of mutations in the genetic material (or “pool”) of all potential parents in a population. It is immaterial who contributes to that pool and to what extent. A few high doses can contribute less than many relatively low ones. This argument may help to overcome the objections of individual patients to X-ray diagnostic investigations. It is, however, important that the health authority and the radiologist and radiographer should avoid even small radiation exposures, unless they can be shown to be medically necessary.

The difference between the terms “genetically significant dose” and “gonad dose” needs, perhaps, a short explanation. The “gonad dose” (GD)
is simply the amount of radiation reaching the gonads (i.e., the testes or ovaries) of an irradiated person. The "genetically significant dose" (GSD) refers to the total dose given to the genetic pool; it is, however, frequently expressed as average dose per capita rather than as the sum of the doses. It is therefore equivalent to the individual gonad dose weighted by the probability of the individual person procreating a child after the irradiation has occurred. In practice this weighting is done by multiplying the gonad dose by a "child expectancy factor", which depends on the sex and age of the individual and the birth statistics of the relevant population. This factor is 2–3 for young people in most countries and, for instance, zero for women at and after the menopause.

The practical consequence for the radiologist and radiographer is the need for particular care in applying X-ray diagnostic techniques to relatively young people. Fortunately many of the investigations belonging to the high gonad dose group are those usually indicated for older people and are therefore of limited genetic significance.

A review of gonad doses and genetically significant doses in the scientific literature demonstrates wide differences in the figures reported. Such differences are due to variations occurring in:

1. the frequencies of X-ray examinations of certain types in different countries or in different surveys of GSD;
2. the child expectancy according to age and sex in different countries;
3. the reliability of statistical data particularly with regard to population statistics, the frequency of X-ray examinations in a country, and radiation doses used in the assessment of GSD;
4. the average gonad dose applied for certain diagnostic investigations in a given institute.

GSD values reported in the scientific literature are given in Table 1. This table also gives the frequencies of diagnostic examinations in different countries and clearly shows that, on average, people in industrialized countries undergo an X-ray examination of some kind once every 1–3 years while in developing countries (or certain areas of those countries) they undergo such an examination once every 20–100 years! In these latter countries, therefore, the genetic risk is small, and much more harm is caused by the fact that so few people have appropriate access to the benefits of X-ray diagnosis. The GSD due to X-ray diagnosis in industrialized countries varies from about 15 to 60 mrad per capita per year, which is equivalent to 15–60% of the average natural radiation exposure. The forecasts for 1980, assuming an increase of about 7% per annum in the frequency of X-ray examinations in some industrialized countries, indicate a GSD of up to 100 mrad—a doubling

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1 The best available (though far from complete) information is to be found in the following report: United Nations Scientific Committee on the Effects of Atomic Radiation (1972) *Ionizing radiation: levels and effects*, New York, United Nations, vol. 1: *Levels*. 
TABLE 1. DIAGNOSTIC RADIOGRAPHY IN VARIOUS COUNTRIES, AREAS, AND CITIES: FREQUENCY OF APPLICATIONS AND THE GENETICALLY SIGNIFICANT DOSE RESULTING FROM THEM


<table>
<thead>
<tr>
<th>Population (millions)</th>
<th>No. of applications per thousand population per year</th>
<th>GSD per capita per year (mrad)</th>
<th>Mean GSD per application (mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AMERICAS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argentina, Buenos Aires, 1950–59</td>
<td>6</td>
<td>350</td>
<td>38.9</td>
</tr>
<tr>
<td>Puerto Rico, South, 1968</td>
<td>0.5</td>
<td>414</td>
<td>36.4</td>
</tr>
<tr>
<td>Puerto Rico, West, 1968</td>
<td>0.4</td>
<td>512</td>
<td>48.6</td>
</tr>
<tr>
<td>USA, 1964</td>
<td>187</td>
<td>618</td>
<td>55.0</td>
</tr>
<tr>
<td>&quot; New Orleans, 1962–63</td>
<td>0.9</td>
<td>828</td>
<td>75.3</td>
</tr>
<tr>
<td>&quot; Johns Hopkins, 1965</td>
<td>2.8</td>
<td>513</td>
<td>13.7</td>
</tr>
<tr>
<td>Texas, 1963</td>
<td>34.7</td>
<td>39</td>
<td>5.2</td>
</tr>
<tr>
<td><strong>AFRICA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egypt, Alexandria, 1956–60</td>
<td>1.4</td>
<td>40</td>
<td>7.1</td>
</tr>
<tr>
<td>Cairo, 1955–61</td>
<td>2.6</td>
<td>45</td>
<td>7.1</td>
</tr>
<tr>
<td><strong>ASIA AND OCEANIA</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan, 1958–60</td>
<td>2.6</td>
<td>730</td>
<td>39.1</td>
</tr>
<tr>
<td>&quot; 1969</td>
<td>2.6</td>
<td>2587</td>
<td>20.7</td>
</tr>
<tr>
<td>New Zealand, 1963</td>
<td>2.9</td>
<td>479</td>
<td>13.1</td>
</tr>
<tr>
<td>Greece, 1969</td>
<td>2.9</td>
<td>613</td>
<td>13.7</td>
</tr>
<tr>
<td>Thailand, 1970</td>
<td>34.7</td>
<td>39</td>
<td>5.2</td>
</tr>
<tr>
<td><strong>EUROPE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Czechoslovakia, Bohemia, 1965–66</td>
<td>4.3</td>
<td>927</td>
<td>37.4</td>
</tr>
<tr>
<td>Denmark, 1956–58</td>
<td>4.5</td>
<td>400</td>
<td>27.3</td>
</tr>
<tr>
<td>Finland, 1963–64</td>
<td>4.5</td>
<td>600</td>
<td>16.8</td>
</tr>
<tr>
<td>France, 1957–58</td>
<td>42</td>
<td>760</td>
<td>58.2</td>
</tr>
<tr>
<td>Germany, Federal Republic</td>
<td>1.8</td>
<td>690</td>
<td>17.8</td>
</tr>
<tr>
<td>Hamburg, 1957–58</td>
<td>1.8</td>
<td>690</td>
<td>17.8</td>
</tr>
<tr>
<td>Germany, Federal Republic</td>
<td>9.6</td>
<td>901</td>
<td>13.7</td>
</tr>
<tr>
<td>Bavaria, 1956–58</td>
<td>9.6</td>
<td>901</td>
<td>13.7</td>
</tr>
<tr>
<td>minimum achievable</td>
<td>maximum but not impossible</td>
<td>5.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Italy, Rome, 1957</td>
<td>1.9</td>
<td>580</td>
<td>44.3</td>
</tr>
<tr>
<td>Netherlands, 1967</td>
<td>12.6</td>
<td>810</td>
<td>20.0</td>
</tr>
<tr>
<td>&quot; Leiden, 1959–60</td>
<td>0.1</td>
<td>680</td>
<td>6.8</td>
</tr>
<tr>
<td>Norway, 1968</td>
<td>3.5</td>
<td>600</td>
<td>10.1</td>
</tr>
<tr>
<td>Sweden, 1955–57</td>
<td>7.3</td>
<td>430</td>
<td>38.2</td>
</tr>
<tr>
<td>Switzerland, 1967</td>
<td>5.2</td>
<td>830</td>
<td>22.4</td>
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<tr>
<td>United Kingdom, 1957–58</td>
<td>50</td>
<td>375</td>
<td>14.1</td>
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<tr>
<td>&quot; Sheffield, 1964</td>
<td>4.5</td>
<td>310</td>
<td>8.6</td>
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<td>USSR, Russian SF SR, 1964</td>
<td>82</td>
<td>793</td>
<td>27.0</td>
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<td>Yugoslavia, Slovenia, 1960–63</td>
<td>1.5</td>
<td>1030</td>
<td>9.1</td>
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</table>

* Mean gonad dose rather than GSD.

of the average background radiation exposure. It is clear that this increase must be stopped at some point.

The investigation of GSD in Bavaria, Federal Republic of Germany, deserves special attention, because it demonstrated that the GSD could be reduced to one-third of the calculated 14 mrad without reducing the frequency, provided all radiologists adopted the techniques used in institutes that made a constant effort to minimize gonad doses. This investigation also demonstrated the uncertainty of GSD assessments. The mean gonad
## TABLE 2. COMPARISON OF MEAN VALUES REPORTED FOR DIFFERENT INVESTIGATIONS (millirads per

<table>
<thead>
<tr>
<th></th>
<th>TABLE 2: COMPARISON OF MEAN VALUES REPORTED FOR DIFFERENT INVESTIGATIONS (millirads per)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median value (mrad)</td>
</tr>
<tr>
<td>MALES</td>
<td></td>
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<tr>
<td>High gonad dose group</td>
<td></td>
</tr>
<tr>
<td>Urography (descendant)</td>
<td></td>
</tr>
<tr>
<td>Plain abdomen</td>
<td>430</td>
</tr>
<tr>
<td>Colon, barium enema</td>
<td>580</td>
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<tr>
<td>Pelvis</td>
<td>250</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>300</td>
</tr>
<tr>
<td>Lumbosacral spine</td>
<td>300</td>
</tr>
<tr>
<td>Femur, upper third</td>
<td>920</td>
</tr>
<tr>
<td>Medium gonad dose group</td>
<td></td>
</tr>
<tr>
<td>Barium meal</td>
<td>30</td>
</tr>
<tr>
<td>Cholecystography</td>
<td>8</td>
</tr>
<tr>
<td>Femur, lower two-thirds</td>
<td></td>
</tr>
<tr>
<td>Low gonad dose group</td>
<td></td>
</tr>
<tr>
<td>Thoracic spine</td>
<td></td>
</tr>
<tr>
<td>Cervical spine</td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td></td>
</tr>
<tr>
<td>Lower extremities</td>
<td></td>
</tr>
<tr>
<td>Chest, full size film</td>
<td></td>
</tr>
<tr>
<td>&quot;miniature film&quot;</td>
<td></td>
</tr>
<tr>
<td>Dental, full mouth</td>
<td></td>
</tr>
<tr>
<td>FEMALES</td>
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<tr>
<td>High gonad dose group</td>
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<tr>
<td>Urography (descendant)</td>
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<tr>
<td>Plain abdomen</td>
<td>520</td>
</tr>
<tr>
<td>Colon, barium enema</td>
<td>520</td>
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<tr>
<td>Pelvis</td>
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<tr>
<td>Lumbar spine</td>
<td>230</td>
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<td>Lumbosacral spine</td>
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<td>Femur, upper third</td>
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<td>Obstetric abdomen</td>
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<td>Pelvimetry</td>
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<td>Hysterosalpingography</td>
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<tr>
<td>Medium gonad dose group</td>
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<tr>
<td>Barium meal</td>
<td>590</td>
</tr>
<tr>
<td>Cholecystography</td>
<td>590</td>
</tr>
<tr>
<td>Femur, lower two-thirds</td>
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<tr>
<td>Low gonad dose group</td>
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<tr>
<td>Thoracic spine</td>
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<td>Cervical spine</td>
<td></td>
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<tr>
<td>Head</td>
<td></td>
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<tr>
<td>Upper extremities</td>
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<td>Lower extremities</td>
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<tr>
<td>Chest, full size film</td>
<td></td>
</tr>
<tr>
<td>&quot;miniature film&quot;</td>
<td></td>
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<tr>
<td>Dental</td>
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<tr>
<td>Mammography</td>
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ANNEX 5

GONAD DOSES
(Examination)

<table>
<thead>
<tr>
<th>Mean values for single institutions within one investigation</th>
<th>Values of single measurements</th>
<th>Comparison of techniques</th>
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<tbody>
<tr>
<td>Median value of mean</td>
<td>Range of maximum to minimum</td>
<td>Ratio of maximum to minimum</td>
</tr>
<tr>
<td>(mrad)</td>
<td>(mrad)</td>
<td>(mrad)</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>740</td>
<td>195–2630</td>
<td>13</td>
</tr>
<tr>
<td>480</td>
<td>49–1940</td>
<td>40</td>
</tr>
<tr>
<td>650</td>
<td>255–1080</td>
<td>4</td>
</tr>
<tr>
<td>1020</td>
<td>480–1630</td>
<td>3</td>
</tr>
<tr>
<td>130</td>
<td>35–199</td>
<td>6</td>
</tr>
<tr>
<td>62</td>
<td>63–70</td>
<td>1.3</td>
</tr>
<tr>
<td>1100</td>
<td>100–2650</td>
<td>27</td>
</tr>
<tr>
<td>16</td>
<td>7.0–26</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>7.0–9.4</td>
<td>1.3</td>
</tr>
<tr>
<td>1.1</td>
<td>0.3–2.0</td>
<td>7</td>
</tr>
<tr>
<td>1.8</td>
<td>1.4–2.2</td>
<td>1.6</td>
</tr>
<tr>
<td>1.4</td>
<td>0.05–2.3</td>
<td>46</td>
</tr>
<tr>
<td>1.7</td>
<td>0.7–2.6</td>
<td>4</td>
</tr>
<tr>
<td>1.1</td>
<td>0.05–2.1</td>
<td>42</td>
</tr>
<tr>
<td>0.4</td>
<td>0.15–0.6</td>
<td>4</td>
</tr>
<tr>
<td>0.2</td>
<td>0.03–0.7</td>
<td>23</td>
</tr>
<tr>
<td>0.2</td>
<td>0.06–0.5</td>
<td>8</td>
</tr>
<tr>
<td>0.5</td>
<td>0.4–0.7</td>
<td>1.8</td>
</tr>
<tr>
<td>0.001</td>
<td>22</td>
<td>22 000</td>
</tr>
</tbody>
</table>

| 465 | 148–955 | 6 | 31–2100 | 68 |
| 57 | 48–65 | 1.4 | 4–199 | 50 |
| 1200 | 440–2380 | 5 | 134–5000 | 37 |
| 710 | 240–1180 | 5 | 153–2180 | 14 |
| 145 | 130–160 | 1.2 | 43–274 | 6 |
| 350 | 335–372 | 1.1 | |
| 2350 | 2030–2820 | 1.4 | |
| 120 | 40–168 | 4 | 17–714 | 42 |
| 35 | 28–44 | 1.6 | 3–370 | 123 |
| 1 | 0.06–2 | 33 | |
| 1 | 0.09–1.1 | 12 |
| 0.07 | 0.06–0.12 | 2 | 0.03–0.3 | 10 |
| 0.3 | 0.25–0.39 | 1.6 | |


* On children with and without gonad shielding.
* Using lead rubber apron for gonad shielding.
doses used for calculating GSD are based on several thousand measurements performed in a number of institutions, but no account is taken of the doses applied in many hundreds of clinics and private practices. The Bavarian investigation made a fresh estimate of GSD on the assumption that most of the clinics hitherto ignored would apply the highest average doses measured in any of the participating institutions. This gave a "maximum but not impossible" figure for the total GSD ten times higher than the figure actually reported and more than one and a half times higher than the average natural background exposure.

The column in Table 1 headed "Mean GSD per application" is of particular interest, since these values are independent of the number of applications a year. They do, of course, depend on the distribution of examinations by body region involved and on the genetic weighting factor, but their variation is primarily due to the mean gonad doses actually measured or taken from the literature. The values for the developing countries are the highest (above 100 mrad per application), although one would expect them to be lower than those for the industrialized countries because they mainly result from simple examinations of the chest and extremities. The great variation of this figure for industrialized countries, ranging from about 10 to nearly 100 mrad per application, is very striking indeed.

The variation is well demonstrated in Table 2. The first two columns show the range of mean values reported in the literature for the relevant application and the median value. The non-expert might well find it unbelievable that the mean values of the gonad dose for males arising from similar examinations differ not by a few per cent but by factors of up to 260. Indeed, even within the same country the mean values measured in different institutes vary by factors of up to 50, and when a comparison is made of single measurements rather than of mean values, the factor may be as great as 500—again for institutes in the same country.

The true situation is still worse, however, because the investigations on which the table is based did not include measurements in very inadequate institutions, which did not agree to participate in the programme. Experimental measurements of gonad dose were therefore performed by the investigators in their own institute, imitating the bad techniques observed in the inadequate institutions. When compared with the gonad dose using careful techniques (which did not detract in the slightest from the diagnostic value of the application) the values were found to vary by factors of up to 22 000. The conclusion to be drawn from these results is quite fantastic; they imply that a single examination performed on one person using a bad technique has the same genetic consequences as the same examination performed using a good technique on 22 000 persons of the same sex and child expectancy.

These investigations show the need for a critical review of the technical factors influencing gonad dose for various diagnostic applications of X-rays. Three classes of applications have to be considered:
(1) those in which the gonads (male or female) lie, of necessity, within the field of radiation exposure;
(2) those in which the gonads lie outside the field of radiation exposure; and
(3) those in which the gonads lie inside or outside the field according to the technique applied and the degree of responsibility exercised by the radiologist or radiographer.

It is obvious that class (3) plays the most important part in the variation of measured gonad doses. Applications normally in the medium or low gonad dose group could enter the high gonad dose group, while those in the high group would yield the highest reported values.

Applications belonging to class (2) are mostly influenced by the distance between the gonads and the edge of the irradiated field. However, other technical factors (e.g., tube voltage, filtration, and sensitivity of the imaging system) also influence the gonad doses.

For applications in class (1), the determining factors are the tube voltage, the filtration, the sensitivity of the imaging system, and the possibility of using special shielding for the gonads.

The radiologist and radiographer should therefore be highly aware of the fact that the grouping of diagnostic applications into high, medium and low gonad dose groups is of no relevance unless the gonad doses actually applied are measured or the techniques outlined in this manual adopted. They should pay special attention, in order of importance, to the four factors described below.

(1) Correct collimation of the beam. It is not sufficient merely to limit the beam to the size of the film or fluoroscopic screen; care should be taken to further restrict it to the region of the body from which information is required. Any part of the body irradiated outside that region contributes nothing to the aim of the examination but only increases the dose both to the body and the gonads. A good quality X-ray picture is characterized by the appearance on the film of an unexposed area surrounding the region of interest. The absence of evident collimation must immediately arouse suspicion that poor techniques have been used. “Automatic” beam collimation to the size of the film conflicts with the principle of optimum collimation, which can be implemented only by educated and responsible staff.

(2) Application of special gonad shields in cases where the gonads lie, of necessity, in the radiation field. The application of such shields is usually limited to the male gonads because shielding of the ovaries may obscure useful information on the film.

(3) Appropriate selection of tube voltage, current, and filtration. This is particularly important for applications in which the gonads lie within or near the primary beam. Higher voltage and filtration and lower current for fluoroscopy will almost always reduce the gonad dose.
(4) Sensitivity of the imaging systems. The gonad dose is inversely proportional to the sensitivity of the imaging system. Thus, doubling the sensitivity halves the gonad dose. Dark adaptation in conventional fluoroscopy plays an important role in this sense, as does the technical ability and semi-dark adaptation of those who use fluoroscopy with image intensifiers and television.
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