1 Nature and Scope of Radiation Protection

Chapter at a Glance

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Dose Management Techniques
Pregnancy: Radiation Protection Considerations

Radiation protection is one of the most important subjects in the education and practice of medical imaging technologies using ionizing radiation, because it deals with the safe use of ionizing radiation when imaging patients for the purpose of restoring their health.

The purpose of this chapter is to orient both students and practicing technologists to the nature and scope of radiation protection specifically in diagnostic x-ray imaging (radiography/radiology) and to provide a brief overview of topics essential to the theory and practice of radiography.

What is Radiation Protection?

Radiation protection is concerned with the protection of persons from the harmful effects of exposure to radiation. In radiography/radiology radiation protection deals with the protection of patients and operators, as well as members of the public. Why?

- Patients are exposed to varying amounts of radiation from the x-ray tube, depending on the type of examination.
- Personnel may be exposed to radiation scattered from the patient and the equipment.
- Members of the public, in this instance, are individuals who are working or waiting in close proximity to an x-ray room. These include, for example, radiology support staff and family members of patients.

Scope of Radiation Protection

The scope of radiation protection includes knowledge and understanding of the following:

- ***Physical factors***. These are related to the physics of radiation, including energy dissipation in matter, characteristics of radiation, interaction of radiation with matter, and the physical and chemical factors of radiation.

- ***Technical factors***. These include a range of topics such as technical components of imaging systems that affect dose, standards of radiation protection, dose management techniques, and shielding considerations.
- ***Procedural factors***. These relate to personnel practices during the examination and include such tasks as equipment set-up, patient communication and positioning, selection of technical factors, gonadal shielding, image processing, and image assessment.
- ***Biologic factors***. The biologic effects of radiation result from the physical and chemical interaction of radiation with matter (tissue). Bioeffects can be somatic (effects that appear in the individual exposed to radiation) or they can be genetic (effects that appear in the offspring of the individual exposed). Bioeffects are now classified as stochastic and deterministic (nonstochastic) effects. These are described further in Chapter 3.

Diagnostic Radiology Modalities

The diagnostic radiology modalities that are described in this book are digital radiography, fluoroscopy, and computed tomography (CT). The basic approaches to exposing a patient to the radiation beam during imaging, depend on the beam geometry. These approaches are described in brief later in the chapter.

Why Protect Patients and Personnel in Diagnostic Radiology?

There are several major reasons for protecting patients undergoing radiographic examination as well as for protecting the personnel conducting the examination. These reasons include:

- Biologic effects data demonstrate beyond question that radiation exposure is harmful to humans.

- Patients receive more radiation exposure from diagnostic radiology compared with any other man-made radiation sources.
- No dose of radiation is considered safe (there is no risk-free dose of radiation).
- Various research studies reveal that some diagnostic x-ray examinations, particularly involving fluoroscopy and CT, deliver high doses of radiation to patients.
- Technologists assume full responsibility for all aspects of the radiographic examination, including radiation exposure of the patient. Protection of patients and operators (technologists and radiologists) depends on the technical expertise of both the technologist and the radiologist.
- Radiation safety is guided by several principles and actions set forth by the International Commission on Radiological Protection (ICRP); these are meant to keep all exposures as low as reasonably achievable (ALARA).

Framework for Radiation Protection

A *framework* refers to a supporting structure or a basic system. A *radiation protection framework* includes a number of concepts intended to prevent and minimize the harmful effects of radiation exposure.

The ICRP offers one comprehensive framework that is accepted by various national radiation protection organizations, including the National Council of Radiation Protection and Measurements (NCRP) in the United States, the Radiation Protection Bureau (part of Health Canada), the National Radiological Protection Board (NRPB) in the United Kingdom, as well other radiation protection organizations around the world.

The ICRP framework encompasses several notable concepts, including the types of exposure from which individuals can receive a dose of radiation and a concept of significance to technologists and radiologists called the two triads of radiation protection.

The types of exposure include:

- ***Occupational exposure***. Exposure from work activities.
- ***Medical exposure***. Exposure from diagnostic and therapy procedures, which does not include occupational exposure.
- ***Public exposure***. All other exposures from natural sources of radiation, such as radon gas.

There are several other concepts that constitute the ICRP framework. However, the two triads of radiation protection are discussed here. These two triads define current radiation protection standards and include:

- Radiation protection principles.
- Radiation protection actions.

Radiation Protection Principles

Radiation protection principles include the following three fundamental guiding concepts:

- ***Justification***. This concept focuses on net benefit. That is, there must be a benefit associated with any new modality, procedure, or exposure.
- ***Optimization***. This concept dictates that all exposures be kept as low as reasonably achievable (ALARA), taking into consideration social and economic factors.
- ***Dose limitation***. By establishing dose limits to persons exposed to radiation, certain harmful effects can be prevented and others can be minimized. These limits are numerical values representing an upper limit of exposure annually. For example, the ICRP recommends an annual dose limit to the lens of the eye of 150 millisieverts (mSv) or 15 000 millirem (mrem) for occupationally exposed individuals.

Dose limits are discussed in Chapter 5.

Radiation Protection Actions

Radiation protections actions are based on the following three concepts:

- ***Time***. Because dose is directionally proportional to the length of time of exposure, it is important to decrease the time of the exposure to decrease the dose. If the time is decreased by a factor of two, then the dose will be reduced by a factor of two.
- ***Shielding***. To reduce the dose to patients and others, it is essential to place a shield between the source of radiation (x-ray tube) and the individual exposed (patient). Gonadal shielding is a prime example of this concept.
- ***Distance***. The dose an individual receives is inversely proportional to the square of the distance. This factor is known as the inverse square law and it is expressed as

$$I = 1/d^2$$

  where I is equal to the intensity of the radiation and d equals the distance from the source of the radiation to the individual exposed. As the distance is increased, the dose is reduced proportionally to the square of the distance.

Basic Schemes for Patient Exposure in Digital Radiography, Fluoroscopy, and Computed Tomography

The basic scheme for patient exposure refers to the beam geometry used to expose the anatomical area of interest, as illustrated in Figure 1.1, for radiography, fluoroscopy, and CT. The beam geometry refers to the size and shape of the x-ray beam emanating from the x-ray tube. Beam geometry also refers to whether the beam is fixed or is moving during the exposure. Whereas in radiography, the beam is fixed during the exposure

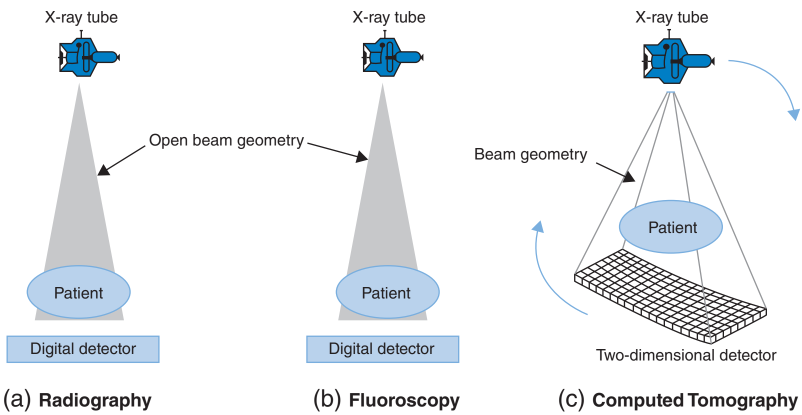

Figure 1.1 The basic scheme for patient exposure refers to the beam geometry used to expose the anatomical area of interest, as illustrated for (a) digital radiography, (b) fluoroscopy, and (c) computed tomography (CT).

(with the exception of digital radiographic tomosynthesis), it is moved about the patient during a fluoroscopic examination. In CT, the beam rotates around the patient during the exposure. The details of each of are described in later chapters.

Digital Radiography

In radiography, specifically digital radiography:

- The beam geometry describes an open beam (Figure 1.1a) shaped by the collimator to fall on the area of interest on the patient.
- The beam is fixed on this area of interest during the exposure.
- The beam is collimated to the size of the digital image receptor used for the examination.
- Radiographic exposure technique factors, such as mA, kV, and exposure time in seconds, are used to produce the x-rays needed to create images of the patient.
- Images are static and each image requires a separate x-ray exposure.

Fluoroscopy

In fluoroscopy (conventional or digital):

- The beam geometry describes an open beam (Figure 1.1b) shaped by the collimator to fall on the regions of interest being imaged.
- The beam is moving during fluoroscopic exposures. This movement is necessary to track the flow of contrast media through the anatomy, such as the gastrointestinal tract.
- The beam is collimated to the size of the image receptor.
- Fluoroscopic exposure technique factors, generally low mA (approximately 1–3 mA) and high kV, are used to show fluoroscopic images displayed on a television monitor. The x-ray tube is energized for longer periods compared with the short exposure times used in radiography.
- Radiographic exposure technique factors are used by the technologist who records "overhead" images after the fluoroscopic portion of the examination. This is the radiographic component of a routine fluoroscopic examination.

Computed Tomography

In CT, the x-ray beam is a cone (Figure 1.1c) that rotates 360° around the patient while the patient moves through the CT scanner gantry opening during the collection of transmission x-ray readings, to build up a sectional image of the anatomy being imaged.

Factors Affecting Dose in Diagnostic Radiology

To protect patients, personnel, and members of the public from radiation in diagnostic radiology, it is mandatory that technologists have a firm understanding of the various factors affecting dose. In this text, only essential dose factors in radiography, fluoroscopy, and CT are considered.

Radiographic Factors

The technical factors affecting patient dose in radiography are:

- Type of x-ray generator.
- X-ray exposure technique factors (mA, kV, and time).
- Beam energy and filtration.
- Collimation and field size.
- Distance from the x-ray tube to the patient (source-to-skin distance) and the distance from the x-ray tube to the image receptor (source-to-image receptor distance, SID).
- Patient thickness and density.
- Antiscatter grids.
- Image receptor sensitivity.
- Shielding.
- Repeat examinations.
- Patient orientation.

Fluoroscopic Factors

The technical factors affecting dose in fluoroscopy are numerous and include:

- Beam energy and tube current.
- Collimation.
- Source-to-skin distance.
- Patient-to-image intensifier distance.
- Beam-on time.
- Antiscatter grids.
- Image magnification.
- Conduct of the fluoroscopic portion of the examination.
- Conduct of the radiographic portion of the fluoroscopic examination.

The factors for radiography and fluoroscopy are elaborated further in Chapters 6 and 7 respectively.

Computed Tomography Factors

There are several technical factors affecting dose in CT. However, only the ones that are under the control of the technologist are listed here. These include:

- Exposure technique factors (mAs and kV).
- Collimation and slices.
- Pitch.
- Noise index.
- Automatic exposure control.
- Overranging and overbeaming.
- Iterative reconstruction algorithms.

These factors are described further in Chapter 8.

Dose Management Techniques

The goal of radiation protection is to reduce the dose to patients and personnel. Dose management techniques are intended to reduce and optimize the imaging process to produce diagnostic image quality using the ALARA philosophy. These techniques are governed objectively by the guidelines and recommendations of not only the ICRP but also of various national regulatory authorities and by radiation protection organizations issuing Radiation Protection Reports. The guidelines and recommendations for dose management in radiology address the four major areas.

- ***Equipment design and performance***. Equipment must be designed or upgraded to meet certain specifications that will allow the operator to optimize image quality while protecting patients and personnel from unnecessary radiation. These guidelines and recommendations focus on specific technical parameters such as filtration, collimation, and source-to-skin distance for radiographic and fluoroscopic (fixed and mobile) equipment.
- ***Personnel practices***. These recommendations focus on the conduct of the examination using the ALARA

philosophy. For example, the primary beam must always be collimated to the size of the image receptor or smaller; technologists should not hold patients to achieve immobilization during an examination.

- ***Shielding***. Shielding is one of three radiation protection actions intended to protect individuals from radiation exposure. Recommendations for shielding address the use of lead shields to protect radiosensitive organs such as the gonads. Additionally, walls of x-ray rooms are lined with lead to prevent radiation from penetrating and exposing individuals outside the room.
- ***Education and training***. Guidelines and recommendations for the safe use of radiation also address the need for operators to be educated and trained in a wide range of subjects. These subjects include radiation physics, instrumentation, radiation risks, and radiation protection, and are intended to minimize the radiation dose to patients, personnel, and members of the public. These techniques are described further in Chapter 7.

The operations needed to observe ALARA include dose reduction and dose optimization. A good dictionary defines the term reduction as “reduce or diminish in size, amount, extent or number;” the term optimization refers to “an act, process, or methodology of marking something (as a design, system, or decision) as fully perfect, functional, or effective as possible.” Optimization is viewed as a much more involved process and requires a careful examination of reducing the dose so as not to compromise the diagnostic quality of the image. Optimization addresses both image quality and dose.

Pregnancy: Radiation Protection Considerations

This is an important topic in radiation protection for everyone working in radiology because of the sensitivity of the conceptus (any product of conception, embryo, or fetus) to radiation.

There are several major considerations with respect to in-utero exposure in radiology. It is not within the scope of this chapter to outline all of the factors relating to in-utero exposure. However, a few significant points to be noted are:

- Data suggest that, depending on the dose and gestational stage of exposure, there can be malformations and radiation-induced childhood malignancy.
- If a patient must have an x-ray examination (because the benefits outweigh the risks), then several precautions should be taken:
    - Shielding must be used only if it will not interfere with diagnostic information.
    - High-kVp techniques and increased filtration are advocated.
    - Fluoroscopy must be kept to an "absolute minimum."
    - The number of images must be kept to a minimum.
- Several factors affect dose to the fetus, including the technical factors previously mentioned. Additionally, direct exposure (fetus in the field-of-view) and indirect exposure (fetus outside the field-of-view) are significant factors.
- Fetal doses can be estimated to provide information on the risks to the fetus and on any actions to be taken.
- Following an exposure, the NCRP (Report 54) recommendations should be observed. These points are examined in Chapter 9.
- Ultrasound (rather than radiology) is now used to evaluate fetal maturation and placental localization.

Several issues and concerns surround the pregnant technologist. The pregnant technologist should notify the department of her pregnancy and use a second dosimeter for the remainder of the pregnancy (under the apron at the waist level). The work schedule of a pregnant technologist may be altered.