Chapter 11

Radiobiology and Radiation Safety

Learning Objectives

At the conclusion of this chapter, you will be able to:

- State the units used to measure radiation exposure, absorbed dose, and dose equivalent using the Système International
- Discuss the potential effects of radiation injury to cells
- Define and compare radiation risks according to type: somatic vs. genetic and short-term vs. long-term
- Discuss the risks of exposure to low doses of ionizing radiation and compare these with other familiar health risks
- Explain the significance of the ALARA (as low as reasonably achievable) principle
- List and explain methods for minimizing patient dose during radiography
- Explain what is meant by "low-dose techniques"
- List and explain precautions for the safety of limited operators
- List potential risks of radiation exposure during pregnancy and explain ways to reduce these risks

Key Terms

absorbed dose (D)
acute radiation syndrome (ARS)
air kerma
ALARA (as low as reasonably achievable) principle
biologic damage
chromosomes
cumulative effective dose (CumEfD)
deoxyribonucleic acid (DNA)
dominant genes
dose equivalent
effective dose (EfD)
entrance skin exposure (ESE)
erythema
free radicals
genes
gonad shields
gonads
Gray (Gy)
ionizing radiation
linear energy transfer (LET)
mutations
optically stimulated luminescence (OSL)
oxygen enhancement ratio (OER)
radiation protection
radiation weighting factor
recessive genes
Sievert (Sv)
Système International (SI)

The health risks involved in radiation use are not well understood by the general public. Diagnostic radiography involves low doses of radiation, and the risks to both patients and limited operators are extremely small. It is important to understand the risks associated with radiography and to commit to the practice of radiation safety in all aspects of radiography work. When used properly, radiation from x-ray examinations also has benefits. The diagnostic information that the patient's physician receives from the x-ray examinations far outweighs the risks.

Ionizing radiation is radiation that, when passing through the body, produces positively and negatively charged particles. **Radiation protection** is the measures taken to safeguard patients, personnel, and the public from unnecessary exposure to ionizing radiation.

This chapter is about the measurement of radiation, the effects of radiation exposure, and the ways in which limited operators can minimize the potential hazards to their patients, their co-workers, themselves, and future generations.

RADIATION MEASUREMENT

Two systems were used for many years to measure radiation and radiation dose: the units of the conventional (British) system and the **Système International (SI)** units established by the International Commission on Radiation Units in 1980. The conventional system is now gone, and the SI system is the predominant system used by the scientific community, the government, and all foreign countries. Table 11.1 lists the three key radiation measurements used today and their associated units in the SI system. *All units in this chapter will be stated in the new SI units*. Should you encounter an old conventional value in a reading, you can simply multiply that value by 0.01 to obtain the value in the SI system.

Unit of Exposure

Air kerma is the SI unit term for radiation exposure. It represents a measurement of the radiation intensity *in the air*. This is determined by the ionization of air resulting from interaction with the x-ray beam. Air kerma is measured with an ionization chamber (Fig. 11.1). A simple way to describe "exposure" is to think of the amount of x-rays that are in the air between the x-ray tube and the patient. It is also the volume of x-rays that strike the surface of the body.

TABLE 11.1
SI Units of Exposure and Dose

SI Unit of	SI Term
Exposure	Air Kerma (Gy-$_a$)
Absorbed dose	Gray (Gy-$_t$)
Dose equivalent	Sievert (Sv)

SI, Système International.

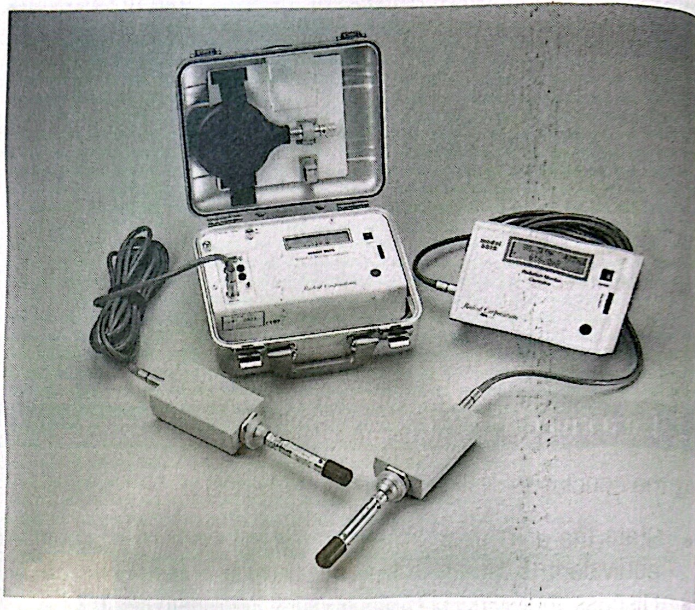

Fig. 11.1 An ionization chamber dosimeter used for accurate measurement of diagnostic x-rays.

The measuring unit of exposure in the SI system is the **Gray**, abbreviated Gy-$_a$. The subscript "a" is used with the unit Gy to indicate "air."[a,b] Many exposures in radiology are very low and therefore the prefix "milli," which is {1/100} of the unit it precedes, is very often used with the Gy to make numbers easier to relate to. For example, the very small exposure value 0.012 Gy would be stated as 12 mGy. *To convert Gy to mGy, multiply Gy* × 1000.

Unit of Absorbed Dose

Absorbed dose (D) is the amount of energy (x-ray) absorbed by the irradiated tissue. It is an important value because it measures the amount of energy that is absorbed by the patient. To measure specific tissue doses received in diagnostic applications, the SI unit is also the Gray. The subscript "t" is used with the unit Gy to indicate "tissue."[a,b] Dose values are indicated as Gy-$_t$. Therefore Gy-$_a$ is the exposure in *air* value and Gy-$_t$ is the absorbed dose in *tissue* value. Similar to exposure, dose values can be quite low and the prefix "milli" is used with the Gy to make the numbers easier to relate to. For example, if a patient received an absorbed dose of 0.150 Gy, this could be stated as 150 mGy.

It is important for the limited operator to understand that for every x-ray projection taken, the patient receives both an exposure and an absorbed dose. For example, for

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[a] Wagner LK, Archer BR: *Minimizing risk from fluoroscopic x-rays*, PRM, 2007.

[b] Bushong SC: *Radiologic science for technologists*, ed 10, St. Louis, 2013, Mosby.

an abdomen x-ray series, the patient may receive an *exposure* of 16 mGy-$_a$ and from that exposure an *absorbed dose* of 1.2 mGy-$_t$. The absorbed dose will always be less than the initial air exposure. The differences between the units, *exposure*, and *absorbed dose* are also determined by their very words. Whenever "exposure" is used, it means radiation in air. Whenever "absorbed dose" or "dose" is used, it means absorbed dose in the body.

Unit of Dose Equivalent

The biologic effect of radiation exposure varies according to the type of radiation involved and its energy. Equal doses of various types of radiation will not necessarily result in equal biologic effects. Some radiation workers, such as engineers in nuclear power plants or technologists in nuclear medicine laboratories, may be exposed to several types of radiation with unequal levels of biologic effect. Neither the Gray-$_a$ nor the Gray-$_t$ is a useful unit for measuring the occupational dose of combined radiations with different levels of effects. **Dose equivalent** is the term used to describe or clarify the absorbed dose in the body based on the *type* and *energy* of the radiation the person was exposed to. For example, a nuclear power plant worker receives a much different type of radiation and energy than a limited operator in a clinic. The **Sievert (Sv)** is the SI system's unit of dose equivalent. Similar to exposure and absorbed dose described earlier, many dose equivalent values are small, and therefore the prefix "milli" is used with Sv to make the numbers easier to relate to. For example, a dose equivalent of 0.200 Sv could more easily be stated as 200 mSv.

To simplify the process of measuring occupational dose, a **radiation weighting factor** is assigned to each type of radiation, based on the variation in biologic damage that is produced when an individual receives exposure from different types of radiation. Table 11.2 lists the radiation weighting factors for the different types of radiation. For example, if a worker received an absorbed dose of 10 Gy-$_t$ of protons, the total dose equivalent would be 20 Sv. The dose equivalent is obtained by multiplying the absorbed dose by the weighting factor.

Understanding the dose equivalent is made easy for limited operators and others who work in diagnostic radiology. Because the weighting factor for x-ray photons is "1" (see Table 11.2), the *absorbed dose* and the *dose equivalent* are always identical numbers.

TABLE 11.2

Radiation Weighting Factors for Different Types of Ionizing Radiations

Type of Radiation	Radiation Weighting Factor
X-ray photons	1
Gamma photons	1
Low-energy internal protons	2
Fast neutrons	20
Alpha particles	20

In our everyday work, the dose equivalent is primarily used for radiation protection purposes. Specifically, occupational doses such as the readings from radiation dosimeters and the doses patients receive from radiation, as well as the occupational doses published in journals, are stated as dose equivalent. Limited operators will receive regular dose-related communications in the radiology department from state and federal entities. Depending on the nature of the material, the radiation values could be stated in exposure, absorbed dose, or dose equivalent values. Some communications may have all three values stated.

The conversion of any of the units of exposure, absorbed dose, and dose equivalent from the stated value to a milli-value, or from a milli-value to its stated value, can be better understood by reviewing a series of common radiation dose values side by side. Table 11.3 shows a scale of Gy-$_t$ values converted to mGy-$_t$. It should be evident why most values in radiology are stated as "milli" values. Note that by changing to mGy-$_t$ the stated numbers become easier to relate to than numbers with many zeros and decimal points. Conversion of Gy-$_a$ and Sv to "milli" values will demonstrate the same effect. When large exposures are discussed, the value is typically not converted to milli. For example, an exposure of 20 Gy-$_a$ would not be converted to 20,000 mGy-$_a$.

Estimation of Dose from X-Ray Exposure Factors

Radiographers and limited operators usually think of radiation dose in terms of the prime factors of milliampere-seconds (mAs), kilovolts peak (kVp), and source–image receptor distance (SID). These values for a given x-ray exposure will determine the absorbed dose a patient receives. On a daily basis, limited operators never have to calculate dose for x-ray examinations. Also, dose is not tracked in patient histories. Knowing how dose can be affected with changes in the prime factors can help in understanding radiation. A special graph is necessary to convert technical factors into units of dose. Appendix G

TABLE 11.3

Conversion of Gy-$_t$ to mGy-$_t$

Gy-$_t$	mGy-$_t$
0.005	5
0.010	10
0.050	50
0.100	100
0.250	250
0.500	500
1.00	1000
2.50	2500

TABLE 11.4

Typical Exposures and Doses for Radiographic Examinations

Examination	Entrance Skin Exposure (mGy_{-a})[a]	Mean Bone Marrow Dose (mGy_{-t})	Gonad Dose (mGy_{-t})
Skull	2.00	0.10	<1
Chest	0.1	0.02	<1
Cervical spine	1.5	0.20	<1
Abdomen	4.0	0.30	1.25
Pelvis	1.5	0.20	1.50
Limb	0.5	0.02	<1

[a] Note how much higher the exposure (in air) is compared with the absorbed dose (in tissues).

Modified from Statkiewicz Sherer MA, et al: *Radiation protection in medical radiography*, ed 7, St Louis, 2014, Mosby.

contains the dose curve for exposures. Use this chart only to see how the dose changes when mAs, kVp, or SID changes.

Patient dose in radiography is usually calculated according to the exposure level at the skin. This is called the **entrance skin exposure (ESE)**. Some typical doses for radiographic exposures are listed in Table 11.4. Note the differences in exposure for various examinations and compare the ESE with the dose to bone marrow and gonads (reproductive organs). It is apparent that the highest ESE exposures are received with examinations of the skull, abdomen, and lumbar spine, although the greatest bone marrow and gonad doses are associated with examinations of the abdomen, lumbar spine, and pelvis.

BIOLOGIC EFFECTS OF RADIATION EXPOSURE

Cellular Response

To understand how cells are affected by radiation exposure, it is helpful to understand something of the composition of a typical cell. Fig. 11.2 is a simplified diagram of a cell. The cell is surrounded by the plasma membrane. At its center is the nucleus, which contains the nucleoli. Inside the nucleoli are 23 pairs of **chromosomes**, microscopic bodies that contain the **genes**. Genes are the determiners of heredity and are made of a unique protein called **DNA** (deoxyribonucleic acid). The chromosomes contain the coded "information" that the cell needs to function.

As discussed in Chapter 4, x-rays can ionize substances, removing electrons from their orbits. This process results in a free, negatively charged electron and leaves the remainder of the atom with a positive charge. When cells are irradiated, ionization may occur to any part of the cell, such as the material that makes up its membrane, the water within the membrane, or the DNA.

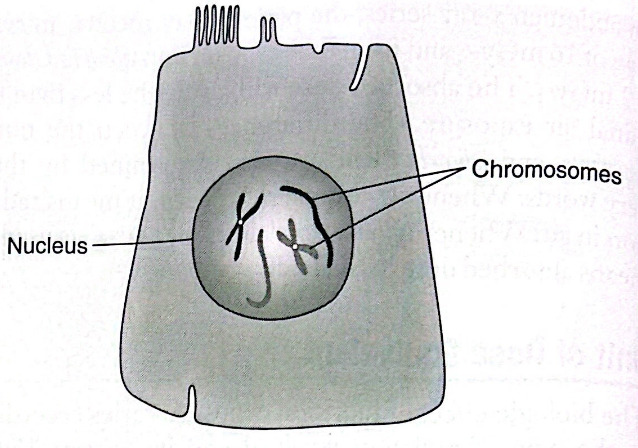


Fig. 11.2 Simplified diagram of a typical human cell.

A cell may be so injured from radiation that it cannot sustain itself and will die. Cell death is not serious unless it involves large numbers of cells. A cell may be damaged in such a way that its DNA "programming" is changed and the cell no longer behaves normally. This type of injury may cause malfunction of the cell or may affect its ability to divide and multiply. Another possible result is the runaway production of new, abnormal cells, causing cancer or a malignant blood disease such as leukemia.

Radiation Damage

Understanding the effect of radiation on tissues involves several concepts. **Linear energy transfer (LET)** is the amount of x-ray energy transferred on average, per the length of passage through the tissue. It explains how much radiation was absorbed in a given section of tissue corresponding to the path through the tissue of the x-ray photons. Radiation with high LET transfers a large amount of x-ray energy into a small area and can do more biological damage than radiation with low LET. The oxygen level in tissues is also a factor in the amount of radiation a patient receives. The **oxygen enhancement ratio (OER)** is another concept that describes radiation absorbed in tissues. When there is more oxygen in the tissues, it is more sensitive to radiation compared to tissues with low oxygen. This is often referred to as the *oxygen effect*; the OER can measure these values. Most tissues in healthy individuals are highly oxygenated and therefore lead to part of the absorbed dose individuals receive.

Law of Bergonié and Tribondeau

The relative sensitivity of different types of cells is summarized in the Bergonié-Tribondeau law, which states that cell sensitivity to radiation exposure depends on four characteristics of the cell:

1. *Age.* Younger patient cells are more sensitive than older ones.

2. *Differentiation.* Simple cells are more sensitive than highly complex ones.
3. *Metabolic rate.* Cells that use energy rapidly are more sensitive than those that have a slower metabolism.
4. *Mitotic rate.* Cells that divide and multiply rapidly are more sensitive than those that replicate slowly.

According to this law, blood cells and blood-producing cells have characteristics that cause them to be very sensitive. Cells that are in contact with the environment are quite simple, have relatively short lives, and are quite sensitive. These include the cells of the skin and the mucous membranes that line the mouth, nose, stomach, and bowel. Some glandular tissue is also particularly sensitive, especially that of the thyroid gland and the female breast. The tissues of embryos, fetuses, infants, children, and adolescents tend to be more sensitive than those of adults both because of their age and because of their higher metabolic and mitotic rates. Nerve and muscle cells, which have a long life and are quite complex, are much less vulnerable to radiation injury. Cortical bone cells are also relatively insensitive.

Ionizing radiation produces **biologic damage** as it interacts with the body tissue. The destructive interactions occur at the atomic level, leading to cellular damage. Table 11.5 provides the known biologic effects of different radiation dose equivalents.

Classification of Radiation Effects

Radiation effects are classified in various ways. The most common are *short-term, long-term, somatic,* and *genetic.* The likelihood of these effects occurring after radiation exposure to x-rays is proportional to the dose received.

TABLE 11.5

Radiation Dose Equivalent and Subsequent Biologic Effects Resulting from Acute Whole Body Exposures

Radiation Dose Equivalent	Subsequent Biologic Effect
250 mSv	Blood changes (e.g., measurable hematologic depression, decreases in the number of lymphocytes present in the circulating blood)
1500 mSv	Nausea, diarrhea
2000 mSv	Erythema (diffuse redness over an area of skin after irradiation)
2500 mSv	If dose is to gonads, temporary sterility
3000 mSv	50% chance of death; lethal dose for 50% of population over 30 days (LD 50/30)
6000 mSv	Death

NOTE: Radiation exposures are delivered to the entire body over a time period of less than a few hours.

Adapted from Statkiewicz Sherer MA, et al: *Radiation protection in medical radiography*, ed 7, St Louis, 2014, Mosby.

Short-term effects are those observed within 3 months of the exposure. They are associated with high radiation absorbed doses, typically greater than 500 mGy-$_t$. These effects are referred to as **acute radiation syndrome (ARS).** Patients become sick very fast because they receive whole-body doses in a very short period of time. Short-term, or ARS, effects may be further categorized according to the body system affected: *hematologic system* (blood), *gastrointestinal system* (digestive tract), and *central nervous system* or *CNS* (brain and spinal cord). Today, there are rare short-term effects seen from diagnostic x-ray procedures.

Long-term effects, sometimes referred to as *latent effects,* are not observed until several years after exposure; in fact, they may not be apparent for as long as 30 years. In general, it is the long-term effects that we are most concerned about in diagnostic radiology. These would be the effects shown after a patient has undergone many years of average to high radiation exposure.

Somatic effects are those that affect the body and tissues of the individual who is irradiated. There are both short-term and long-term somatic effects. We should always be concerned about the somatic effects and think of this effect every time we set a technical exposure value on the generator and repeat an x-ray.

Genetic effects occur as a result of damage to the reproductive cells of the irradiated person and are observed as defects in the children or grandchildren of the irradiated individual.

Short-Term Somatic Effects

Short-term somatic effects occur with high doses of radiation and they are predictable. One observable short-term effect is reddening of the skin, called **erythema.** This phenomenon is sometimes called a *radiation burn.* This burn can be observed with a dose to the skin of 2000 mSv. In the very early days of radiation use, the amount of radiation necessary to produce reddening of the skin was called the *erythema dose* and was the first unit used to measure radiation.

Other short-term effects have been observed and studied in radiation therapy patients and in the victims of nuclear accidents and atomic bomb blasts. This type of radiation involves vastly more exposure than is delivered by diagnostic x-ray machines. Extremely high doses produce CNS effects, causing seizures and coma and resulting in death in a short period of time. Lesser doses result in "radiation sickness," a gastrointestinal effect in which the mucosal lining of the digestive tract is damaged, breaks down, and becomes infected by the bacteria that normally inhabit the bowel. These victims also have a compromised immune system, caused by the death of white blood cells, and are unable to fight the infection. Radiation sickness is usually fatal, but suffering may be prolonged. A lesser dose, affecting primarily the blood and blood-forming cells of the bone marrow, results in hematologic effects: anemia and compromise of the immune system. These victims are prone to infectious diseases that may or may not be fatal, depending on the radiation dose and the severity of the disease process.

Human beings who receive whole-body doses of radiation in excess of 5000 mGy-$_t$ may die within 30 to 60 days because of the effects related to depletion of the stem cells and of the hematopoietic system. The whole-body radiation dose that is fatal to 50% of the irradiated human population within 30 days is stated as a "lethal dose" (LD). We therefore use "LD 50/30" to describe this situation. The LD for human beings is generally estimated to be 3000 to 4000 mGy-$_t$ without treatment.

Long-Term Somatic Effects

The time required for long-term effects to become apparent is generally considered to be 5 to 30 years, with the greatest percentage of effects occurring between 10 and 15 years.

Short-term radiation effects are predictable, and the quantity of exposure required to produce them is well documented. Long-term effects, on the other hand, are random. They may involve repeated small doses, such as those used in radiography.

Long-term radiation effects are not predictable because they occur so long after exposure and because these same effects also occur in the absence of radiation exposure. Only extensive research with large populations using computer analysis can demonstrate the role of radiation in causing these effects. The incidence of certain conditions is shown to be increased when results for irradiated groups are compared with those for nonirradiated control groups. The documented latent effects of low doses of ionizing radiation include the following:

- *Cataractogenesis:* the formation of *cataracts*, clouding of the lens of the eye. This effect is of concern to radiologists and radiographers who work extensively in fluoroscopy and who perform other work that involves repeated exposure to the eyes.
- *Carcinogenesis:* increased risk of malignant disease, particularly cancer of the skin, thyroid, and breast, and leukemia, a malignant disease of the blood that has been clearly demonstrated to be associated with radiation exposure.
- *Lifespan shortening:* shorter lifespan than for those who were not exposed to ionizing radiation. A study of the lifespan of radiologists who died during a 3-year period before 1945 showed that they had shorter lifespans than physicians who did not use radiation in their practices. This group of radiologists included those who had been using radiation since the early days of x-ray science. More recent studies show that the decreased occupational exposure typical today has no measurable effect on the lifespan of radiologists. Radiation exposure is still definitely linked to lifespan shortening, however. This is a public health concern and another reason to practice a high level of radiation safety.
- *Leukemia:* cancer of the blood or bone marrow. In the early 1900s when x-ray was in its infancy, this was one of the earliest effects seen in people who worked in radiology and in people who received x-rays.

Genetic Effects

Genetic effects are changes or **mutations** to the genes of the reproductive cells. They occur as a result of radiation exposure to the reproductive organs called **gonads**, the female ovaries or the male testes. In the female, all the ova (egg cells) that the individual will ever produce are present in the ovaries in an immature state at birth. Because no new egg cells are produced as the individual ages, the effect of radiation exposure to the ovaries is cumulative. Radiation to the testes also has longer-term genetic effects than might at first be presumed because damage to the stem cells that produce the sperm may result in the continued production of sperm that carry the genetic mutation. The vast majority of genetic mutations are considered to be negative, or to make cells less well suited to survival than nonmutated cells.

Reproductive cells have only half the number of chromosomes of other cells. Each parent contributes one chromosome to each pair in the new individual, and nature makes the choice as to which gene of each pair will determine the characteristics of the offspring. Those genes that are "chosen" are said to be **dominant genes** and those that are not selected are called **recessive genes**. Genes that have mutated are usually recessive and so do not affect the characteristics of the child. Both dominant and recessive genes, however, occur in the reproductive cells of the child and may be passed on to future generations.

Because the population is exposed to radiation from natural, occupational, and health care sources, there is likelihood that individuals will be conceived with mutation of both genes in a strategic pair, resulting in some type of deformity, defect, or characteristic that is less well suited to survival. Mutations may appear as cleft palates, spina bifida, polydactyly, and more. Public health officials and governments are very concerned about preserving the integrity of the population's gene pool by minimizing radiation that may cause defects in future generations. This concern should motivate those who use ionizing radiation to minimize gonad doses in every way possible. Gonad shielding for this purpose is addressed later in this chapter.

Genetic effects from mutations caused by x-ray exposure have long been demonstrated in animal research. Interestingly, very little genetic effect has so far been confirmed by continuing research involving the Japanese populations exposed to radiation when the atomic bombs were dropped on Hiroshima and Nagasaki during World War II. Individuals who were children at that time are now becoming grandparents. Studies of this new generation and those that follow will be necessary before the genetic effects on bomb survivors can be evaluated completely.

Comparative Risks

The average American was, in earlier times, exposed to an annual dose of 3.6 mSv of radiation from all sources—natural and man-made. The natural sources of radiation remain the same today, but unfortunately the man-made radiation (from x-ray examinations) has soared. Today the average American is exposed to 6.3 mSv, a 75% increase. The increase is primarily because of increases in dose from computed tomography (CT) and interventional procedures. Naturally occurring radiation from space, from the earth, and from radon gas accounts for 82% of this exposure (Fig. 11.3). Today, a greater percentage of the dose Americans receive is from medical x-ray examinations, and this dose equals 3.2 mSv. The remaining dose, 3 mSv, comes from natural sources.

The increase in patient radiation dose requires that radiographers and limited operators exercise more control over medical imaging. We must be more aware of the appropriateness of performing x-ray examinations and gain control over unnecessary examinations.

Certainly the percentage of observable effects from the radiation involved in typical x-ray examinations is extremely low, and the risk to any one patient is minimal. Most of us take greater risks daily when we drive a car or cross a busy street.

Many people may be outdoors during a thunderstorm. Few, if any, will be struck by lightning. People struck by lightning may be killed or only slightly injured. The chance of being struck by lightning is extremely remote, but it is greater if you make a habit of standing in high places during thunderstorms. Scientists can predict fairly accurately the annual rate at which lightning will strike human beings, but it is impossible to predict who will be struck and who will not.

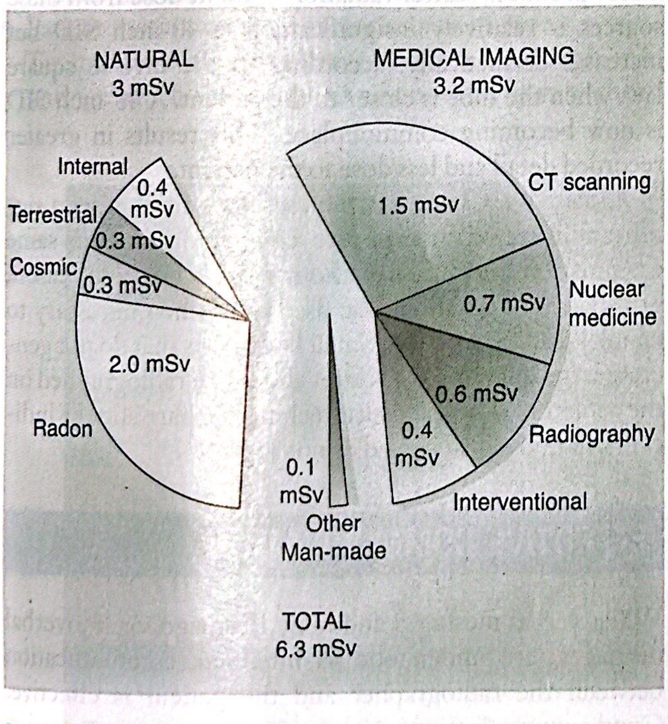


Fig. 11.3 Current estimated levels of human radiation exposure. For the first time, medical imaging exposure values have exceeded natural background exposures. *CT*, Computed tomography.

Similarly, radiation causes increased risk of the effects outlined, but the effects cannot be predicted with respect to any one individual. Table 11.6 provides some interesting comparisons between the risks involved in radiography and other more familiar risks.

Scientists agree that any one individual's risk from radiography is *extremely small*, but the exposure of the entire population does pose public health risks. The increase in the average dose, however, is a growing discussion in the radiography and governmental communities. Even when the chance of serious effects is one in a million, that adds up to 250 serious problems in a nation of 250 million people. Although the risk from a chest x-ray is frequently quoted as typical, the dose for a lumbar spine examination may be 50 times greater, increasing the risk. All who are involved in applying ionizing radiation to human beings share the

TABLE 11.6

Decrease in Life Expectancy from Various Causes

Cause	Days
Unmarried male	3500
Cigarette-smoking male	2250 (20 cigarettes/day)
Heart disease	2100
Unmarried female	1600
Overweight 30%	1300
Coal miner	1100
Overweight 20%	900
Less than eighth-grade education	850
Cigarette-smoking female	800 (20 cigarettes/day)
Low socioeconomic status	700
Stroke	520
Pipe smoking	220
Increasing food intake 100 cal/day	210
Job with radiation exposure (1 rem/year for 40 years)	40
Natural radiation (BEIR)	8
Medical x-ray films	6
Coffee consumption	6
Oral contraceptive use	5
5 rem/year (occupational exposure)	5
Diet drink consumption	2
Reactor accidents	0.02[a]
Radiation from nuclear industry	0.02[a]
Papanicolaou test	−4
Smoke alarm in home	−10
Airbags in car	−50
Mobile coronary care unit	−125

BEIR, Biologic effects of ionizing radiation.

[a] These items assume that all U.S. power is nuclear.

responsibility for ensuring that everything possible is done to keep these risks as low as possible.

RADIATION SAFETY

Clearly, exposure to x-rays creates some risk for patients, limited operators, radiographers, and radiologists. It is therefore an essential part of your education and your ethical responsibility to be knowledgeable about radiation safety and to use this knowledge to prevent all unnecessary radiation exposure to your patients, your co-workers, and yourself.

The federal government issues regulations and recommendations to ensure the safety of patients and radiation workers. State agencies incorporate federal guidelines into the state regulations. Additional laws and regulations may apply in individual states. The state radiation control agencies are responsible for the administration of both state and federal regulations. Your state may have a regulation that requires the posting of a summary of the regulations that apply to your facility. Limited operators are responsible for knowing and following the laws and regulations that apply to their work.

Patient Protection

There is no arbitrary limit on the amount of radiation exposure a patient may receive. The guiding philosophy is called the **ALARA principle**. The ALARA principle states that all radiation exposure to humans should be limited to levels that are "as low as reasonably achievable." Radiation control agencies use this guideline to compare the quantities of radiation used for specific procedures within the community. If the average ESE for a specific examination in your community is 0.20 mGy, this provides evidence of what is reasonably achievable. If the dose in your facility for the same examination is much greater than the average, the level is unacceptable and must be reduced to meet regulatory requirements. The limited level can reduce radiation to patients by reducing repeat exposures, avoiding mistakes, using the smallest radiation field, using the highest kVp, and maintaining the SID at 40 inches.

The greatest cause of unnecessary radiation to patients that can be controlled by limited operators is repeat exposures. Repeat exposures are undesirable for many reasons. They require extra time and materials that increase health care costs, in addition to increasing patient dose, so it is important to avoid the need for repeats. On the other hand, exposures *must* be repeated when image quality is inadequate. Reduction of patient dose is not a valid reason for failing to repeat an image that is not diagnostic.

To minimize the need for repeat exposures, limited operators must take care to avoid mistakes. Double-check requisitions and patient identification so that the right patient gets the right examination. Establish good routine procedures and follow them strictly so that careless errors do not necessitate repeat exposures. Provide clear instructions to patients so that they will cooperate in obtaining a successful examination.

Another cause of unnecessary exposure that limited operators control is the size of the radiation field. Radiation exposure can be substantially controlled by the proper use of collimation. *Use the smallest radiation field that will cover the area of clinical interest.* In no case should the size of the radiation field be greater than the size of the film. Whenever possible, collimate to exclude sensitive tissue, such as the eyes, the thyroid gland, the female breasts, and the gonads. As you practice positioning and centering with precision, you will gain confidence that the essential anatomy can be visualized successfully without using an excessive field size.

In addition to developing good habits of procedure and collimation, the limited operator can reduce patient exposure by using "low-dose techniques." Low-dose techniques involve using optimum kVp and a minimum SID of 40 inches (with 48 inches preferred).

The highest kVp that will produce acceptable contrast results in less exposure to the patient than a low-kVp technique. An increase in kVp with no other change will increase the patient dose rate slightly. However, when the mAs is adjusted down to compensate for the kVp increase, the net result is a reduction in dose. The use of the 15% rule to increase kVp and decrease mAs (see Chapter 10) results in a dose reduction of approximately 34%.

Routine radiography should never be performed at less than a 40-inch SID. The tube housing permits leakage of some radiation that increases patient dose without being useful in image formation. In addition, interaction between the primary x-ray beam and the parts of the collimator produces scatter radiation. Patient dose from these sources is relatively insignificant at a 40-inch SID but increases dramatically, according to the inverse square law, when the tube is closer to the patient. A 48-inch SID is now becoming commonplace. This results in greater recorded detail and less dose to the patient.

As stated in Chapter 9, the use of a grid requires a significant increase in exposure compared with the same examination performed without a grid. For this reason, grids and Buckys should be used only when necessary to control scatter radiation. Small body parts that do not generate large quantities of scatter should be radiographed on the tabletop. The exposure technique chart should indicate whether a grid is used or not.

EFFECTIVE COMMUNICATION

When verbal messages and body language, or nonverbal messages, are understood as intended, communication between the radiographer and the patient is effective. Good communication:

- Encourages reduction in anxiety and emotional stress.
- Enhances the professional image of the x-ray operator as a person who cares about the patient's well-being.

- Increases the chance for successful completion of the x-ray examination, thereby reducing the potential of repeat exposures.

Everyone in the x-ray department should always behave as a compassionate professional. Patient protection during a diagnostic x-ray procedure should begin with clear, concise instructions. When x-ray operators do not thoroughly explain procedures, patients fear the unknown and become anxious. To alleviate the problem, the radiographer must take adequate time to explain the procedure in simple terms that the patient can understand.

VULNERABILITY OF CHILDREN TO RADIATION EXPOSURE

Children are much more vulnerable to late effects of radiation than are adults. Therefore, children require special consideration when they undergo diagnostic x-ray exams. Because children have a greater life expectancy, they may easily survive long enough to develop leukemia induced by radiation or develop a radiogenic malignancy such lung or thyroid cancer. Published studies indicate the risk of a radiation-induced leukemia in children after a substantial dose of ionizing radiation is approximately *two times that of adults*. X-ray operators should take every precaution to minimize exposure to all pediatric patients. The following should be initiated to reduce the dose to children:

- Gain cooperation by having entertainment and distraction devices. Use restraint equipment in a fun manner and always smile.
- Patient motion can be a major source of repeat x-rays. To minimize the problem of motion, use high mA settings which reduce the exposure time to very short levels. This may require using manual exposure techniques.
- Use gonad shielding.
- Collimate. Smaller children may be imaged on larger cassettes and the operator should always collimate as close to the part as necessary to see only the part being examined.
- All scoliosis images should be done using the PA projection, and should not be done AP.

Gonad Shielding

Lead shields that prevent unnecessary radiation to the reproductive organs are required by regulation in most jurisdictions. **Gonad shields** are used to reduce the likelihood of genetic radiation effects. Gonad shields must be used when the patient is of reproductive age or younger, whenever the gonads are within the primary x-ray beam, and when the shield will not interfere with the purpose of the examination. Generally, this applies to most patients under the age of 55. A shield device consisting of at least 0.5 mm lead equivalent is placed between the x-ray tube and the patient. Shields attached to the collimator are called *shadow shields*. The limited operator positions them by viewing their shadows within the collimator light field (Fig. 11.4). Shields placed on or near the patient's body are called *contact shields* and are somewhat more effective than shadow shields (Fig. 11.5). Both types meet the legal requirements for gonad shielding. Fig. 11.6 demonstrates shield placement for both males and females. It is helpful to note that the pubic symphysis (the center of the pubic bone) is at the same level as the greater trochanter of the femur, which avoids the necessity of palpating the pubic bone for proper shield placement.

Gonad shields should also be used when the primary radiation field is *near* the gonads, even though this may

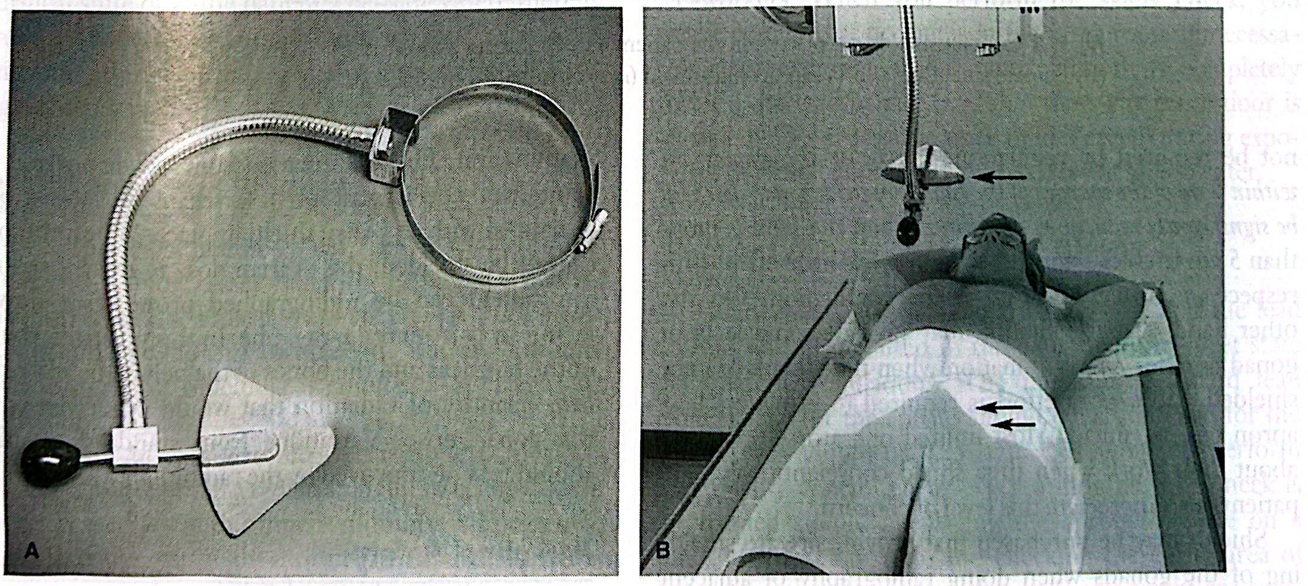


Fig. 11.4 Shadow shield is attached to the collimator or tube housing (A) and placed by observing the location of its shadow (*arrows*) in the collimator light field (B).

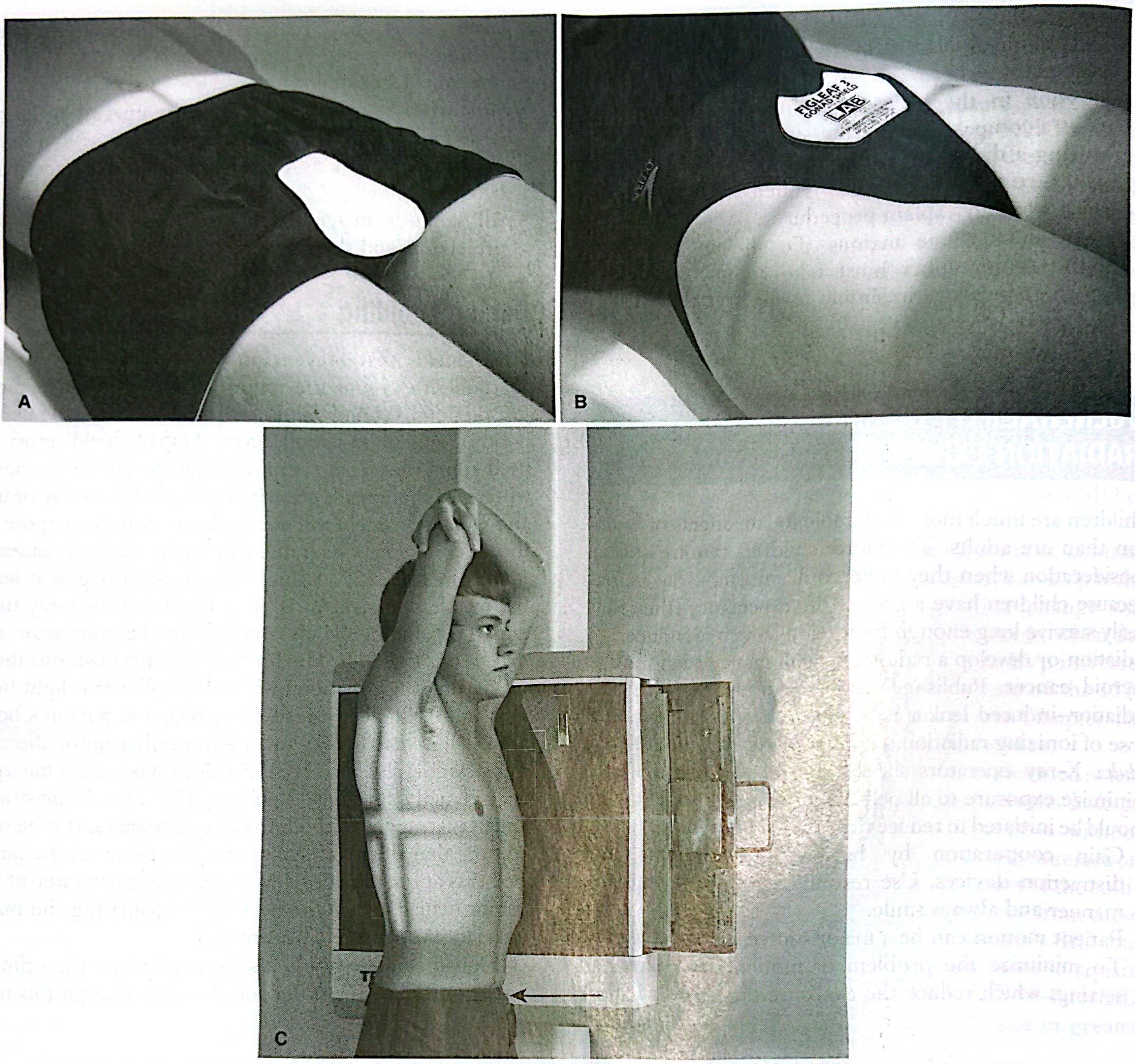


Fig. 11.5 Contact shields are placed on the patient's body during exposure. (A) Male shielding. (B) Female shielding. (C) Wrap-around shield (*arrow*) is placed on the waist for a chest x-ray.

not be required by regulation. *Whenever the gonads are within 5 cm of the margin of the radiation field, gonad dose will be significantly reduced by shielding*. When the field is more than 5 cm from the gonads, shielding has little effect with respect to protection from primary radiation. On the other hand, scatter radiation may provide some level of gonad dose for *any* examination when the gonads are not shielded. Little extra effort is required to provide a lead apron or lead shield. Most limited operators feel better about their work when they shield conscientiously, and patients also appreciate this level of concern.

Shields may be purchased that provide precise shielding of the gonads when doing radiography of adjacent structures. It is almost always possible to shield the male gonads, regardless of the examination. A female gonad shield may sometimes interfere with the purpose of the examination. The abdomen, sacrum (pelvic portion of the spine), and coccyx (tailbone), for example, cannot be well visualized with an ovary shield in place. When the ovaries cannot be shielded, the ovarian dose is greatly reduced if the patient can be radiographed prone (face down) or facing away from the x-ray tube. In this position, the tissue of the buttocks and the bones of the pelvis absorb a significant quantity of radiation that would otherwise increase the gonad dose. Variations from standard positioning should first be approved by the radiologist.

Personnel Safety

Limited operators may potentially be exposed to radiation either from the primary x-ray beam or from scatter radiation. Because limited operators are considered to be

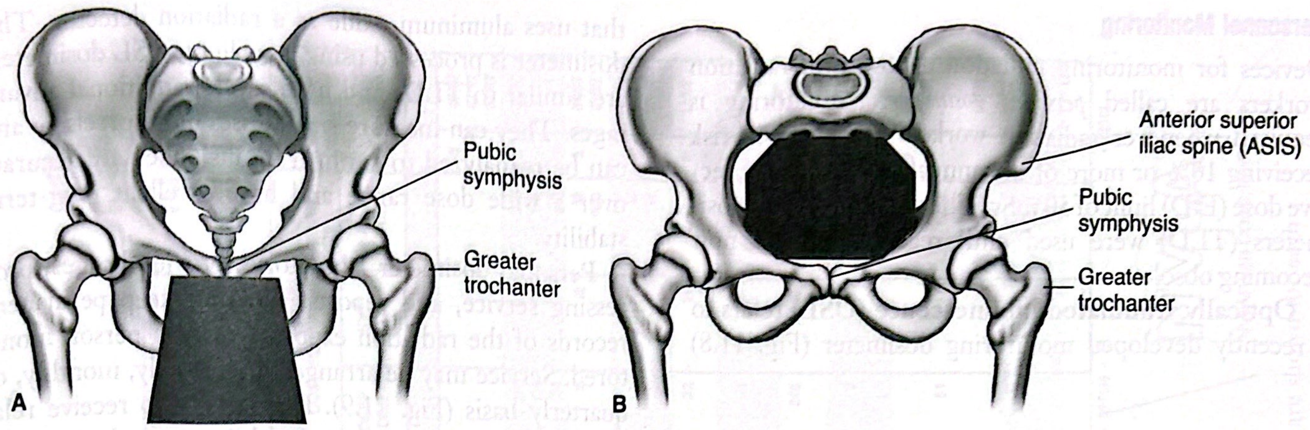


Fig. 11.6 Shield placement. (A) The top of the male shield is 1 inch inferior to the top of the pubic symphysis, which is at the level of the greater trochanter. (B) The female shield is placed in the midline, midway between the level of the anterior superior iliac spine and the pubic symphysis.

"occupationally exposed individuals," they are prohibited from activities that would result in direct exposure to the primary x-ray beam. This means that *limited operators are not allowed to hold patients or image receptors during x-ray exposures*. Nonoccupationally exposed personnel, who are not pregnant and who are wearing protective apparel, should hold patients whenever possible.

The procedures with greatest risk for occupational exposure are those involving fluoroscopy and mobile radiography. These procedures are not commonly performed by limited operators. Fluoroscopy involves direct observation of the x-ray image in motion during procedures commonly used to visualize the digestive tract or the circulatory system. Special fluoroscopic x-ray equipment is required. Limited operators assisting with fluoroscopy may have to be in the room to change cassettes and to assist with patient positioning and the administration of contrast media during these procedures. Mobile radiographic examinations are sometimes referred to as *portable radiography*. These examinations are performed in the surgical suite or at the patient's bedside where there is no protective control booth. Scattered radiation from the patient and other objects poses the greatest hazard for radiography personnel.

Time, Distance, and Shielding

The three principal methods used to protect limited operators from unnecessary radiation exposure are *time*, *distance*, and *shielding*. Time and distance apply principally to radiographers who are involved in fluoroscopy and mobile radiography. Shielding is employed to protect all radiographers.

The amount of exposure received is directly proportional to the time spent in a radiation field, so occupational dose is decreased when this time is minimized. For example, a limited operator might shorten the time of exposure by stepping into the control booth during fluoroscopic procedures when not required to be near the patient.

The second method involves using distance. Increasing the distance between yourself and a radiation source decreases your exposure in proportion to the square of the distance, so small increases in distance have a relatively large effect. Mobile x-ray units have long cords on the exposure switches, which enables the radiographer to get at least 6 feet away from the patient and machine while making an exposure.

The third method is shielding, and this is by far the most common method of protection. The lead wall of the control booth provides protective shielding and is the limited operator's primary defense. Limited operators are unlikely to be exposed to any significant amount of radiation when standing well within the protection of the control booth. Other types of shielding include lead aprons, gloves, and thyroid shields (Fig. 11.7). These types of shields are worn during fluoroscopic procedures and mobile radiographic examinations. They are also worn by personnel who have to hold patients.

The preexposure safety check introduced in Chapter 2 is an essential safety practice. It is the principal method used to ensure that you do not accidentally expose your co-workers. When you perform the safety check, you make certain that no one is in the x-ray room unnecessarily, that everyone in the control booth is completely behind the lead barrier, and that the x-ray room door is closed. Doors are usually open or ajar except during exposures. A closed door indicates that it is not safe to enter.

Quality Control: Aprons and Gloves

A *quality control check* is regularly performed on the lead aprons and gloves used in the department to meet state and federal regulations. The minimum standard lead equivalency for the aprons should be 0.5 mm and for the lead gloves should be 0.25 mm. Radiographers perform this quality control check every 6 months. The check is performed simply by placing the apron or glove on a fluoroscopic x-ray table and checking the entire area of lead using the fluoroscopic beam. If any cracks are seen, the apron or glove must be taken out of service. The check of these protective devices must be documented in the department's quality control logs.

Personnel Monitoring

Devices for monitoring radiation exposure of radiation workers are called *personal dosimeters*. Monitoring is required whenever radiation workers are likely to risk receiving 10% or more of the annual occupational effective dose (EfD) limit of 50 mSv. Thermoluminescent dosimeters (TLD) were used until recently but are now becoming obsolete.

Optically stimulated luminescence (OSL) refers to a recently developed monitoring dosimeter (Fig. 11.8) that uses aluminum oxide as a radiation detector. This dosimeter is processed using laser light. OSL dosimeters are similar to TLDs and have several additional advantages. They can measure small doses more precisely and can be reanalyzed to confirm results. They are accurate over a wide dose range and have excellent long-term stability.

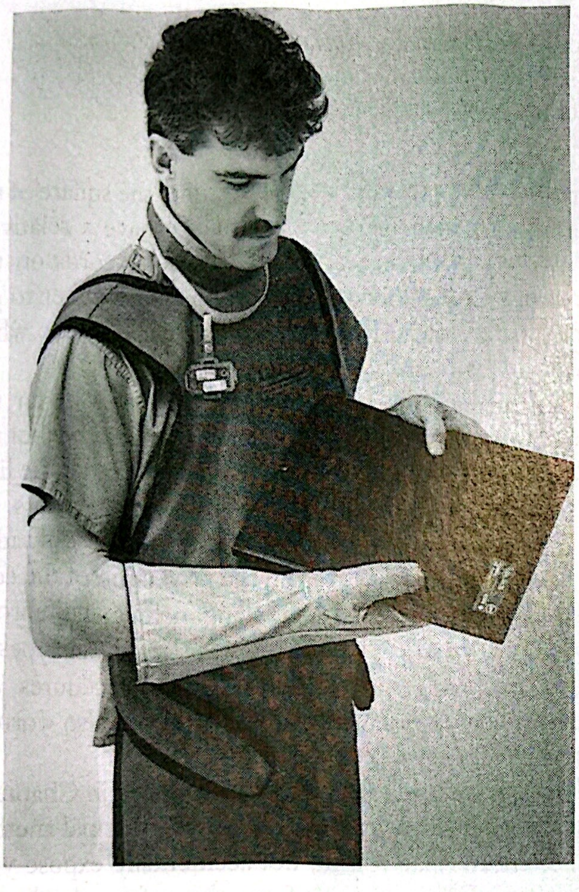


Fig. 11.7 Limited operator wears protective apparel while holding a patient or during mobile radiographic examinations. Note radiation badge worn outside the apron at the collar.

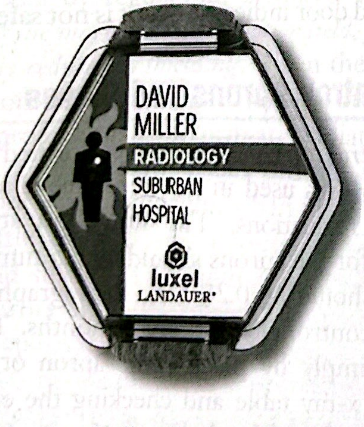


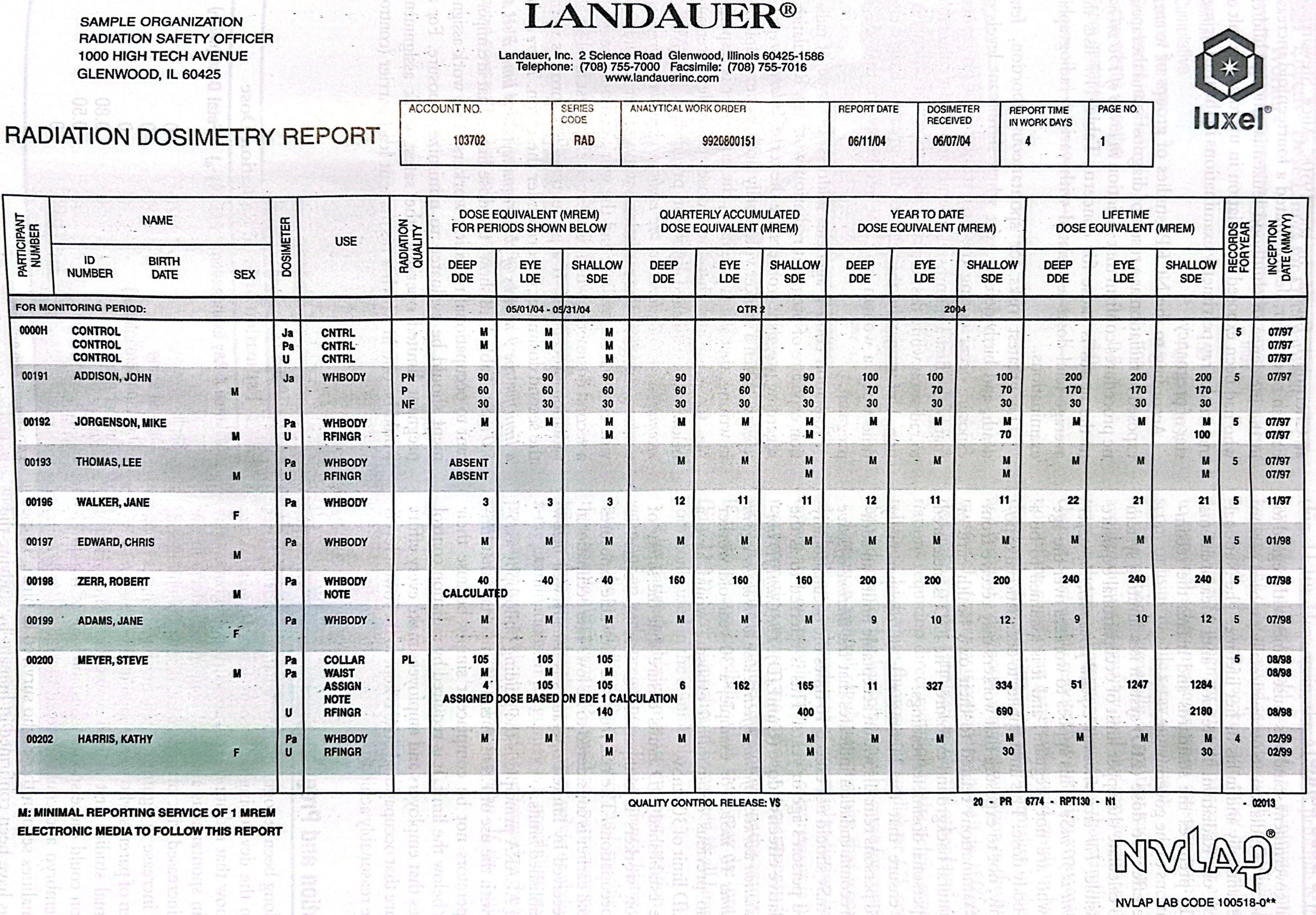
Fig. 11.8 Example of optically stimulated luminescence–type personal dosimeter.

Personal dosimeter laboratories provide badges, processing service, and reports, and they keep permanent records of the radiation exposure of each person monitored. Service may be arranged on a weekly, monthly, or quarterly basis (Fig. 11.9). Personnel who receive relatively high doses of occupational exposure change their badges most frequently. Because these dosimeters cannot accurately measure total exposures of less than 0.05 mSv, personnel who receive very small amounts of exposure will get more accurate measurements with less frequent badge changes. Personnel involved in diagnostic radiography who are always, or nearly always, in a control booth during exposures get the most accurate reports with quarterly service. Those who work in fluoroscopy and do mobile radiography are usually best monitored with monthly service.

Service companies provide an extra personal dosimeter in every batch that is marked "Control." The purpose of this dosimeter is to measure any radiation exposure that might occur to the entire batch while in transit. Any amount of exposure measured from the control dosimeter will be subtracted from the amounts measured from the other dosimeters in the batch. The control dosimeter should be kept in a safe place, away from any possibility of x-ray exposure. *It should never be used to measure occupational dose or for any other purpose.*

Radiation dosimeter service companies will want to know the name, birth date, and Social Security number of all persons to be monitored so that all records will be accurately identified. If there has been a history of previous occupational radiation exposure and the dose is known, this information should also be provided so that the record will be complete and accurate. Dosimeter reports are sent to the subscriber for each batch, and an annual summary of personnel exposure also is provided. Personnel should be advised of the radiation exposure reported from their badges and should be provided with copies of the annual reports for their own records. Occupationally exposed personnel should not leave their employment without a complete record of their radiation exposure history. Employers are required to provide this information.

Personal dosimeters should be worn in the region of the collar on the anterior surface of the body and should be outside the lead apron when a lead apron is worn (see Fig. 11.7). These dosimeters should never be clipped to straps worn around the neck, hanging near the center abdomen. Additionally, they should never be taken from the clinic or hospital to go shopping, home, or to other nonmedical areas.



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RADIATION DOSIMETRY REPORT

ACCOUNT NO.	SERIES CODE	ANALYTICAL WORK ORDER	REPORT DATE	DOSIMETER RECEIVED	REPORT TIME IN WORK DAYS	PAGE NO.
103702	RAD	9920800151	06/11/04	06/07/04	4	1

PARTICIPANT NUMBER	NAME			DOSIMETER	USE	RADIATION QUALITY	DOSE EQUIVALENT (MREM) FOR PERIODS SHOWN BELOW			QUARTERLY ACCUMULATED DOSE EQUIVALENT (MREM)			YEAR TO DATE DOSE EQUIVALENT (MREM)			LIFETIME DOSE EQUIVALENT (MREM)			RECORDS FOR YEAR	INCEPTION DATE (MM/YY)
	ID NUMBER	BIRTH DATE	SEX				DEEP DDE	EYE LDE	SHALLOW SDE	DEEP DDE	EYE LDE	SHALLOW SDE	DEEP DDE	EYE LDE	SHALLOW SDE	DEEP DDE	EYE LDE	SHALLOW SDE		
FOR MONITORING PERIOD:								05/01/04 - 05/31/04			QTR 2			2004						
0000H	CONTROL			Ja	CNTRL		M	M	M										5	07/97
	CONTROL			Pa	CNTRL		M	M	M											07/97
	CONTROL			U	CNTRL				M											07/97
00191	ADDISON, JOHN			Ja	WHBODY	PN	90	90	90	90	90	90	100	100	100	200	200	200	5	07/97
			M			P	60	60	60	60	60	60	70	70	70	170	170	170		
						NF	30	30	30	30	30	30	30	30	30	30	30	30		
00192	JORGENSON, MIKE			Pa	WHBODY		M	M	M	M	M	M	M	M	M	M	M	M	5	07/97
			M	U	RFINGR				M			M			70			100		07/97
00193	THOMAS, LEE			Pa	WHBODY		ABSENT			M	M	M	M	M	M	M	M	M	5	07/97
			M	U	RFINGR		ABSENT					M			M			M		07/97
00196	WALKER, JANE			Pa	WHBODY		3	3	3	12	11	11	12	11	11	22	21	21	5	11/97
			F																	
00197	EDWARD, CHRIS			Pa	WHBODY		M	M	M	M	M	M	M	M	M	M	M	M	5	01/98
			M																	
00198	ZERR, ROBERT			Pa	WHBODY		40	40	40	160	160	160	200	200	200	240	240	240	5	07/98
			M		NOTE		CALCULATED													
00199	ADAMS, JANE			Pa	WHBODY		M	M	M	M	M	M	9	10	12	9	10	12	5	07/98
			F																	
00200	MEYER, STEVE			Pa	COLLAR	PL	105	105	105										5	08/98
			M	Pa	WAIST		M	M	M											08/98
					ASSIGN		4	105	105	6	162	165	11	327	334	51	1247	1284		
					NOTE		ASSIGNED DOSE BASED ON EDE 1 CALCULATION													
				U	RFINGR				140			400			690			2180		08/98
00202	HARRIS, KATHY			Pa	WHBODY		M	M	M	M	M	M	M	M	M	M	M	M	4	02/99
			F	U	RFINGR				M			M			30			30		02/99

M: MINIMAL REPORTING SERVICE OF 1 MREM
ELECTRONIC MEDIA TO FOLLOW THIS REPORT

QUALITY CONTROL RELEASE: VS

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Fig. 11.9 Personnel monitoring report for a radiology department. The quarterly, year-to-date, and lifetime radiation levels are shown for each individual.

Effective Dose Limits

Federal government standards must be met with regard to the amount of radiation an occupationally exposed person receives annually and in his or her lifetime. The National Council on Radiation Protection and Measurements (NCRP) prepares the standards and makes the recommendations to the government.

The **effective dose (EfD)** system is a limiting system used to calculate the upper limit of occupational exposure permissible. *For occupationally exposed personnel, the upper EfD limit is 50 mSv.* This applies to workers over the age of 18 who are not pregnant, and it is assumed to be a whole-body dose. This limit applies to occupational exposure only, not to exposure that workers may receive from x-ray examinations related to their own health care or from natural background exposure. The EfD is measured by the personal dosimeter readings.

To ensure that the lifetime risk of occupationally exposed persons remains within acceptable limits, an additional recommendation indicates that the *lifetime effective dose* in mSv should not exceed 10 times the occupationally exposed person's age in years. This is referred to as the **cumulative effective dose (CumEfD)**. *The CumEfD limits a radiation worker's lifetime effective dose to his or her age in years times 10 mSv.* For example, a 30-year-old worker with no previous occupational exposure would have a CumEfD limit of 300 mSv.

The established EfD limits ensure that the safety of radiation workers is comparable to that of workers in other occupations. The risk from the allowable exposures indicated earlier is considered to be low. The occupational dose received by limited operators is usually well below the established limits.

The ALARA principle is the guiding philosophy associated with the use of EfD limits. It is important that limited operators not be complacent simply because their dose is below the limit. It is required by radiation control agencies that employers and employees make every effort to ensure that occupational dose is kept to the lowest levels that are reasonably achievable.

Radiation and Pregnancy

It has long been recognized that radiation exposure poses risks to the developing embryo or fetus. In general, we now know that radiation exposure during pregnancy may result in spontaneous abortion, congenital defects in the child, increased risk of malignant disease in childhood, and an increase in significant genetic abnormalities in the children of parents who were exposed before birth.

Animal studies first alerted scientists to the fact that radiation could cause spontaneous abortion of the developing embryo and could increase the rate of congenital abnormalities seen in those who survived to birth. These findings have been confirmed in humans by studying the pregnancies of women who survived the atomic bomb blasts of Hiroshima and Nagasaki and the nuclear accident at Chernobyl, Russia. In the 1950s, Alice Stewart, an English researcher, demonstrated a fourteenfold increase in the incidence of childhood leukemia among children who had been exposed to radiation in utero as a result of maternal x-ray pelvimetry examinations in the third trimester of pregnancy.

According to the NCRP, studies of groups of women exposed to radiation as a result of diagnostic and therapeutic procedures confirm that radiation *in excess of 150 mGy-$_t$* to the uterus is cause for concern. Table 11.7 lists the average fetal doses associated with various radiographic examinations.

The greatest risks for spontaneous abortion, fetal death, and birth defects exist when significant levels of exposure occur during the first trimester of pregnancy, that is, the first 3 months. The embryo is most vulnerable to radiation while tissues are in the process of differentiation. Unfortunately, this creates the greatest hazard at a time when a woman may not yet be aware that she is pregnant.

Radiation control agencies address the issue of radiation exposure of pregnant radiation workers. Regulations regarding pregnant workers use the term *declared pregnant woman*. When a worker voluntarily notifies her employer, in writing, that she is pregnant, the employer is responsible for ensuring that her dose equivalent remains below the established limit for pregnancy. *The NCRP-recommended EqD limit to the embryo/fetus for a pregnant worker is 0.5 mSv.* The radiation safety officer should provide essential counseling, and the worker should be given a second dosimeter, which is worn at the waist level for all radiation procedures. If a protective lead apron is worn, the second dosimeter is worn under the apron. *There is also a limit for the 9 months of the pregnancy. This limit is set at 5.0 mSv.* Table 11.8 shows the dose limits that are important to occupational radiation workers. The work assignment should be evaluated to minimize exposure. For a pregnant limited operator, the safest work assignment would be one in which a permanent lead barrier (control

TABLE 11.7

Estimation of Fetal Radiation Dose

Maternal X-Ray Examination	ESE (Gy-$_a$)	Fetal Dose (mGy-$_t$)
Skull	0.70	0
Cervical spine	1.10	0
Chest (posteroanterior)	0.10	0
Lumbar spine	2.50	0.80
Pelvis	2.95	0.50
Wrist or foot	0.05	0

ESE, Entrance skin exposure.

Modified from Bushong SC: *Radiologic science for technologists,* ed 10, St Louis, 2013, Mosby.

TABLE 11.8
Effective Dose Limits for Occupational Workers

	mSv
Annual	50
Cumulative	Age × 10 mSv
Lens of the eye	150
Skin, hands, and feet	500
Embryo/fetus (months)	0.5
Entire gestation	5.0

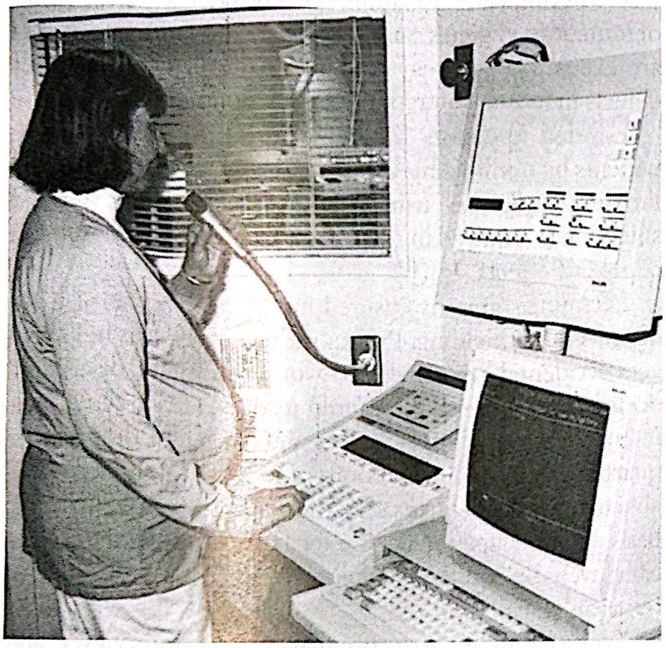

Fig. 11.10 Lead barrier of control booth protects pregnant limited operator and her unborn child.

booth) always shields the worker during exposures (Fig. 11.10). Here again, the ALARA principle is important. Every effort should be made to minimize exposure, keeping the dose received as far below the established limit as possible. Pregnant workers, or those of childbearing age who *may* be pregnant, should pay particular attention to personal safety measures when assisting with fluoroscopy or using mobile x-ray equipment.

The public is generally aware that radiation is to be avoided during pregnancy, and this may lead to irrational fears on the part of pregnant women or their families. The chance is extremely remote that a routine x-ray examination of the chest or an extremity would result in harm to the developing child. The risk of abnormality in the child as a result of a diagnostic x-ray examination in the first trimester of pregnancy is considered to be 1 in 1000 or less, depending on the examination. On the other hand, examinations requiring direct radiation to the pelvis, especially relatively high-dose fluoroscopic studies or CT scans of the abdomen or lumbar spine, may be cause for concern.

Radiation control regulations require that women of childbearing age be advised of potential radiation hazards before an x-ray examination. This requirement is usually met by posting signs in the radiology department advising women to tell the limited operator before the examination if there is any possibility that they may be pregnant (Fig. 11.11). Such signs should be written in all languages commonly used in the community.

The patient's physician is in the best position to be aware of an early pregnancy. The patient's history may indicate the possibility of pregnancy, and specific questions to rule out pregnancy should be a part of any medical history that precedes the ordering of pelvic or abdominal x-ray examinations. If pregnancy is a possibility, an early pregnancy test, easily and quickly performed in the physician's office, may clarify the situation. If the patient is

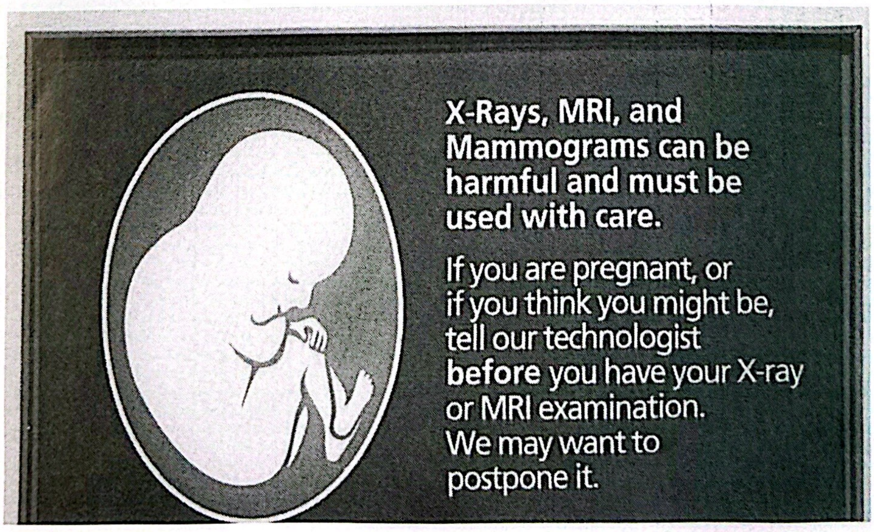

Fig. 11.11 Signs in dressing rooms, waiting areas, and imaging suites alert patients to the potential hazard of examination when pregnant.

pregnant and the proposed x-ray examination involves direct pelvic radiation, the physician must weigh the potential risks and benefits of the examination and discuss them with the patient before proceeding with the study. In the case of minor or chronic complaints, it is common to delay the examination until after the birth of the child.

In practice, however, the possibility of pregnancy may not even be considered. This is especially true in the case of accident or injury, for which the emergency room or office visit is brief and the history is limited to the injury complaint. For this reason, *it is essential that the limited operator be mindful of the possibility of pregnancy whenever the patient is a female of childbearing age*. Specific questions should be asked to determine that the patient's physician has addressed the issue of pregnancy before ordering the examination. When the radiographic examination does not involve the abdomen and pelvis, it is good practice to provide a lead apron for women of childbearing age, whether pregnant or not (usually for those aged 10 to 55).

If x-ray examinations of a pregnant patient must be done, modifications in procedure can help to minimize dose to the embryo or fetus. If the part to be examined is *not* the abdomen or pelvis, this area can be shielded with a lead apron. If the abdomen or pelvis is to be examined, the number of projections and the size of the radiation field may be minimized, and a high-kVp technique will result in less radiation exposure than that from a routine procedure. The decision to do a limited study and the determination of the exact limitations to be imposed are up to the patient's physician or the radiologist.

SUMMARY

SI units are used to measure radiation exposure and dose. *ESE* stands for *entrance skin exposure*, the most common dose measurement in diagnostic radiography.

Cellular response to radiation exposure is the result of ionization that may involve a direct hit to the DNA of a cell's chromosome or may damage the cell indirectly as a result of the ionization of water and the formation of **free radicals**. Most cellular damage is repaired within a very short period of time. Cellular sensitivity is greatest for cells that are young, simple, rapidly dividing and multiplying, and have a rapid metabolism. Blood cells and blood-forming cells are very sensitive, as are skin cells, mucosal cells, and the cells of the thyroid gland and female breast; brain cells and cortical bone cells are relatively insensitive.

Low doses of radiation, typical of those received in diagnostic radiography, produce effects that are long term. They include the formation of cataracts, cancer, and leukemia and the possibility of birth defects in children irradiated during early gestation. Genetic effects are the result of mutations in genes caused when the reproductive organs are exposed. They may result in malformations or other defects in future generations.

Limited operators can reduce radiation risk to their patients by minimizing the need for repeat exposures, collimating well, and using low-dose techniques. Gonad shielding is required in some cases to reduce the likelihood of genetic effects.

Personnel safety is ensured by the proper use of time, distance, and shielding. Preexposure safety checks help prevent accidental exposure to co-workers. Limited operators' occupational dose is monitored using an OSL-type dosimeter. It is worn on the collar and evaluated monthly or quarterly by a qualified laboratory. Reports should be available to limited operators on either a monthly or a quarterly basis. The occupational dose for limited operators is typically well below the established EfD limit of 50 mSv per year.

Warning signs, early pregnancy tests, interviews, and double-checks by the limited operator are used to prevent the possibility of inadvertent exposure of a developing embryo or fetus that would increase the risk of spontaneous abortion, birth defects, or childhood cancer.