TENTH EDITION

PATIENT CARE in RADIOGRAPHY

WITH AN INTRODUCTION TO MEDICAL IMAGING





Ruth Ann Ehrlich | Dawn M. Coakes

ELSEVIER

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TENTH EDITION

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PREFACE

During the past 35 years, *Patient Care in Radiography* has expanded to meet the changing needs of students and technologists in radiography and other medical imaging modalities. It is a resource that provides an introduction to these professions and an orientation to the hospital environment. First and foremost, however, it is a fundamental text on patient care, designed and written to help radiographers meet patient needs. The reader learns to care for the patient effectively while functioning as a responsible and valuable member of the health care team from the patient introduction, through routine procedures, and the final recording of events in the medical record.

Although the primary goal is centered on patient care, concern for those who provide that care is also an essential focus in this text. Discussions of significant aspects of self-care and professional development are included in the following chapters:

- Chapters 3, 5, 7, and 10 incorporate important self-care concepts.
- Chapter 4 contains discussions on health care delivery, the health care team and career.
- Chapter 5 describes professional attitudes, patient rights, legal considerations, and medical records.
- Chapter 6 includes communication strategies for many situations, including dealing with patients of all ages, patients' families and coworkers, plus transcultural encounters and those who have communication impairments.
- Chapter 9 provides Standard Precautions and additional guidelines for infection control as recommended by the Occupational Safety and Health Administration (OSHA) and the Centers for Disease Control and Prevention (CDC).

Applying these principles is critical to your well-being and your ability to provide good care to others.

NEW TO THIS EDITION

As in previous editions, the tenth edition of *Patient Care in Radiography* contains updated and new information designed to keep student and practicing radiographers current on important topics in this rapidly changing field:

- Every effort has been made to address the content of the American Society of Radiologic Technologists (ASRT) curriculum for radiography that falls within the general scope of the text and to provide both content and learning tools that will aid in implementing the ASRT curriculum guidelines.
- Content has been updated to reflect current information and infection control guidelines from the CDC and to be consistent with Occupational Safety and Health Administration (OSHA) recommendations. This information will help to ensure the well-being of radiographers by raising practice standards in the workplace and by minimizing risks of exposure to blood-borne pathogens.
- Chapter 2 has new information about digital radiography, which has replaced film-screen technology.
- Chapter 21 has new information on surgical laparoscopic cholecystectomy.
- Chapter 5 has two new tables with information on crimes and torts that help to clarify this content for students.
- Chapter 9 has new information on enteric contact precautions.
- The Answer Key (now printed in the text) helps students evaluate learning.

KEY FEATURES

The reading level is comfortable for the student radiographer without being overly simplistic. Again, we have done our best to retain the features that readers have appreciated in previous editions:

- Content outlines accompany each chapter.
- Smaller chapters segregate material and facilitate readability.
- Callout boxes are used to indicate key items for learning, and warning boxes alert students to issues of safety.
- Step-by-step procedures are shown in photo essays, and patient care is integrated with procedural skills.
- Additional pedagogical elements, such as learning objectives, key terms, illustrations, tables, boxes, comprehensive summaries, review questions, and critical thinking exercises, have been retained and improved.

These features can be incorporated into classroom objectives and activities and will also enhance the effectiveness of individual study.

The chapters of this text were designed to be used consecutively; each section builds on the preceding information. A basic glossary is included for quick reference, but please note that it is not intended to replace the more detailed definitions and discussions in a good medical dictionary.

We hope that this book proves to be a valuable resource to you as you care for patients in the challenging field of medical imaging.

EVOLVE: ONLINE RESOURCES

The instructor resources for *Patient Care in Radiography* are available online on Evolve and consist of:

- A test bank offering more than 450 questions
- An image collection with all the images from the text
- PowerPoint slides

The student Evolve site includes an image collection, as well as check-off forms for students to use for documentation of clinical objectives related to patient care. For more information, visit http://evolve.elsevier.com/Ehrlich/radiography/ or contact an Elsevier sales representative.

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We are especially grateful to Dr. Ly Huynh, a radiologist with Radiology Specialists of the Northwest, for his consultation in reviewing several chapters. His expertise, insight, and suggestions have helped beyond measure. Thank you to Providence Portland Medical Center and the medical imaging staff for allowing us access to their facility when we created color illustrations. In addition, they have been an excellent and most welcome resource when questions arose about hospital policies and procedures.

We have been privileged to benefit from the photographic expertise of Jeff Watson; his technical ability is top notch, and it is applied with a sharp eye, a deep understanding of clinical practice, and a delightful sense of humor.

As always, it has been a pleasure to work with the professionals at Elsevier: Jamie Blum, Senior Content Strategist; Luke Held, Senior Content Development Manager; Umarani Natarajan, Senior Project Manager; and the fine staff at Elsevier. Our sincere gratitude to all of you!

Ruth Ann Ehrlich and Dawn M. Coakes

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Introduction to Radiography

OBJECTIVES

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

- Name the discoverer of x-rays, state the place and date of the discovery, and describe the discovery.
- Name four other pioneers in the development of radiography and describe their contributions.
- Summarize the history and development of radiography education.
- List four essentials for the production of x-rays.
- Draw a diagram of a simple x-ray tube and label the parts.
- Briefly describe the process by which x-rays are produced in the tube.
- List five different types of electromagnetic wave radiation and identify those that are ionizing.
- List six characteristics of x-radiation.
- Define *wavelength*, *frequency*, and *velocity* with respect to a sine wave and state which of these factors is a constant.
- Describe the differences between primary radiation, scatter radiation, and remnant radiation.
- Correctly identify the essential devices found in a typical radiographic room and state the purpose of each.
- Demonstrate the vertical, horizontal, and angulation motions of an x-ray tube.

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KEY TERMS

amplitude
anode
attenuation
bucky
cathode
collimator
detent
electromagnetic energy
electron stream
filament
fluoresce
fluoroscope
focal spot
frequency
grid
grid cap
image intensifier
image receptor (IR)
latent image
photon
photostimulable p hosphor
quantum (*pl.* quanta)
remnant radiation
scatter radiation
sine wave
space charge
target
Trendelenburg position
wavelength

The study of radiography includes many topics, and each topic is best understood when a host of others have already been mastered. Obviously, something has to come first. As you progress in your radiography education, you will discover that learning occurs somewhat like the peeling of an onion—one layer at a time will be revealed. You will visit topics again and again, each time building a broader understanding based on your previous learning and experience. The subject matter in this section is treated on an introductory level to provide a starting place for your radiography education. All these topics will be presented in depth at a later time in your program; some are the subjects of entire courses in the radiography curriculum. Eventually, this information will be woven together to provide a sound basis for clinical practice and decision making. Have patience and confidence in yourself as you take the first steps in your new profession.

Some radiography programs combine the topics of patient care with an introduction to medical imaging, and instructors find that the five chapters of Part I provide a suitable beginning. The curriculum designs of other schools may include this introductory material under a different course heading. Regardless of whether the content of this chapter is a part of your current course, it may serve as a useful resource.

Entering a hospital radiology department as a student for the first time can be both exciting and bewildering. The equipment, language, and activities unique to this environment require some guidance for comprehension. A good way to introduce you to radiography might be to guide you through a medical imaging department, exploring and pointing things out. Think of this chapter as the textbook version of such a tour. But before we enter the modern world of radiology, let's take a moment to see how it all began more than a century ago.

HISTORY

Discovery of X-Rays

In the 1870s and 1880s, research involving electricity was the cutting edge of physical science, and many physicists were experimenting with a device called a *Crookes tube* (Fig. 1.1), a cathode ray tube that was the forerunner of the fluorescent lamp and the neon sign. Although Crookes tubes also produced x-rays, no one detected them.

Then, on November 8, 1895, Wilhelm Conrad Roentgen, a German physicist (Fig. 1.2), was working with a Crookes tube at the University of Würzburg. In his darkened laboratory, he enclosed the tube with black photographic paper so that no light could escape. Across the room, a plate coated with barium platinocyanide crystals (a fluorescent material) began to glow. Roentgen noted that the plate fluoresced in relation to its distance from the tube, becoming brighter when the plate was moved closer. He placed various materials, such as wood, aluminum, and his hand, between the plate and

Fig. 1.1 Pear-shaped Hittorf–Crookes tube used in Roentgen's initial experiments. (Courtesy of Eastman Kodak, Rochester, New York.)

the tube, noting variations in the effect on the plate. He spent the next few weeks investigating this mysterious energy that he called "x ray," *x* being the symbol for the unknown. By the end of the year, Roentgen had identified nearly all the properties of x-rays known today. He was awarded the first Nobel Prize in Physics in 1901 in recognition of his discovery.

> In November of 1895, Wilhelm Conrad Roentgen discovered x-rays while working with a Crookes tube in his laboratory at the University of Würzburg in Germany.

X-Ray Pioneers

Early radiography often required as long as 30 minutes to create a visible image. Over the years, many advances in this technology have reduced the time and radiation exposure involved in radiography. The early sources of electricity were not powerful enough to be efficient and could not be easily adjusted until H.C. Snook, working with an alternating current generator, developed the interrupterless transformer. William Coolidge designed the hot cathode x-ray tube to work with Snook's improved electrical supply. The *Coolidge tube* (Fig. 1.3), introduced in 1910, was the prototype for the x-ray tubes of today.

Roentgen used a glass plate coated with a photographic emulsion to create the first radiograph. Soon after Roentgen's discovery was published, Michael

Fig. 1.2 Photograph of W.C. Roentgen, the discoverer of x-rays, taken in 1906. (Courtesy Wellcome Library, London.)

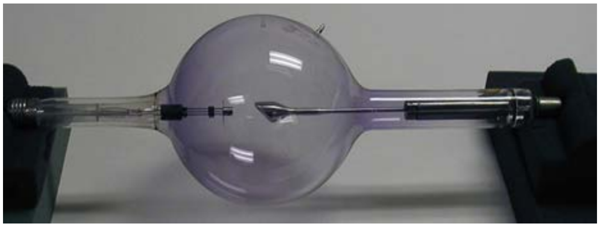

Fig. 1.3 The Coolidge "hot cathode" x-ray tube, prototype of modern tubes, was introduced in 1910.

Idvorsky Pupin demonstrated the radiographic use of fluorescent screens, now called *intensifying screens*. He used light emitted by fluorescent materials when activated by x-rays to expose photographic plates.

In 1898, Thomas Edison began experiments with more than 1800 materials to investigate their fluorescent properties. He invented the first fluoroscope and discovered many of the fluorescent chemicals used in radiography over the intervening years. Edison abandoned his research when his assistant and long-time friend, Clarence Dally, became severely burned on his arms as a result of serving as a subject for many of Edison's x-ray experiments. Dally's arms had to be amputated, and in 1904 he died from his exposure. His death was the first recorded x-ray fatality in the United States.

Until World War I, glass photographic plates were used as a base for x-ray images. During the war, manufacturers of photographic plates for radiography could not obtain high-quality glass from suppliers in Belgium, and the U.S. government turned to George Eastman, founder of the Eastman Kodak Company, for help. Eastman had invented photographic film using cellulose nitrate, a new plastic material, as a substitute for glass. He produced the first radiographic film in 1914.

Early in the 20th century, radiation injuries, such as skin burns, hair loss, and anemia, began to appear in both doctors and patients. Measures were taken to monitor and reduce exposures; this process is still ongoing. Lead apparel, protective barriers, and exposure limitations have substantially decreased the amount of radiation received by those involved in the use of x-rays.

> Today, because of improved technology and safety precautions, x-ray examinations are much safer for patients, and radiography is considered to be a very safe occupation.

Early Radiographers

During his early experimentation with x-rays, Roentgen produced the first anatomic radiograph—an image of his wife's hand. The first documented medical application of x-rays in the United States was an examination performed at Dartmouth College in February 1896 of a young boy's fractured wrist.

The first radiographers were physicists familiar with the operation of the Crookes tube. As equipment for generating x-rays was installed in hospitals and physicians' offices, physicians learned to take radiographs and soon developed techniques to demonstrate many different anatomic structures. These physicians began to train their assistants to develop the photographic plates and to assist with x-ray examinations. In time, many of these assistants became skilled in radiography and were called *x-ray technicians*.

Radiography Education

On-the-job training of x-ray technicians in hospitals evolved into hospital-based educational programs. Formal classes and clinical experience were combined to provide students with the knowledge and skills needed to take radiographs and to assist with radiation therapy (x-ray treatments). As the fields of diagnostic and therapeutic radiology became more complex and specialized in the decade of the 1950s, education for radiation therapy technologists was separated from that for radiographers.

Colleges were first involved in radiography education because hospital-based radiography programs took advantage of the academic offerings at local colleges. Radiography students often attended college part-time to learn basic science subjects such as anatomy and physiology.

After World War II, with many returning soldiers wanting to attend college with the financial assistance provided by the GI Bill, junior colleges were developed to provide the first 2 years of academic education for university-bound students. In the 1960s, these institutions expanded and multiplied into the community college system that is currently a significant part of national public education in the United States. In the process of this expansion, more emphasis was placed on vocational education. Community colleges formed effective partnerships with companies and institutions that provided on-the-job training. Following this trend, many hospital-based radiography programs became affiliated with community colleges to provide the necessary academic courses. Some 4-year colleges and universities also began to offer educational programs in radiologic technology.

As the requirements for accreditation of educational programs in radiography have increased over the years (see Chapter 4), the organizational structure of colleges has proved to be well suited to the management of these programs. Today, colleges and hospitals still cooperate to provide education in radiography.

> Although many outstanding hospital-based programs exist, the majority of radiography programs are based in colleges.

OVERVIEW OF RADIOGRAPHIC PROCEDURE

Educational preparation provides the radiographer with the necessary knowledge and skills to confidently obtain a patient's radiographic images. To do this, the radiographer positions the patient's anatomic area of interest over the **image receptor (IR)** (Fig. 1.4A). The IR is placed on the tabletop to image small body parts, such as extremities. For larger anatomic areas, it can be placed in a tray beneath the table surface, or some digital tables have built-in IRs (see Chapter 2). The x-ray tube

Fig. 1.4 A, A radiographer aligns patient anatomy to an image receptor in a bucky tray. B, A radiographer aligns an x-ray tube to the patient and image receptor.

position is adjusted to align the x-ray beam to the IR (see Fig. 1.4B). The radiographer then goes to the control booth, sets the exposure factors on the control console, and activates the exposure switch.

During the exposure, x-rays from the tube pass through the patient. Different types of tissue absorb different amounts of the radiation, resulting in a pattern of varying intensity in the x-ray beam that exits on the opposite side of the patient. The radiation then passes to the IR and exposes it. The IR then has a pattern of exposure that is referred to as the **latent image.** Depending on the type of IR, a digital image may appear immediately on a monitor or the photostimulable IR plate may be scanned by a laser in a special processor to produce a digital image. Processing converts the latent image into a visible one. All imaging systems include methods for identifying images with the patient's name, the date, and the name of the facility.

As you may have suspected, many details were omitted from the previous paragraphs. This is only a brief introduction to the radiographic process. Next, we consider how x-rays are produced, their physical nature, and how their various characteristics relate to the process of radiography.

X-RAY PRODUCTION

Our tour will include a close look at a number of pieces of x-ray equipment. To better appreciate their purposes, it will be helpful to understand how x-rays are produced. There are four basic requirements for the production of x-rays:

1. A vacuum
2. A source of electrons
3. A target for the electrons
4. A high potential difference (voltage) between the electron source and the target

The container for the vacuum is the x-ray tube itself (Fig. 1.5), sometimes referred to as a *glass envelope*. It is made of borosilicate glass to withstand heat and is fitted on both ends with connections for the electrical supply. All the air is removed from the tube so that gas molecules will not interfere with the process of x-ray production.

The source of electrons is a wire **filament** at the electrically negative **cathode** end of the tube. It is made of the element tungsten, a large atom with 74 electrons orbiting around its nucleus. An electric current flows through the filament to heat it; this accelerates the movement of the electrons and increases their distance from the nucleus. Electrons in the outermost orbital shells get so far from the nucleus that they are no longer held in orbit; instead, they are flung out of the atom, forming an "electron cloud" around the filament. These free electrons, called a **space charge,** provide the needed electrons for x-ray production.

The **target** is at the electrically positive **anode** end of the tube, the end opposite the filament. The smooth, hard surface of the target is the site to which the electrons travel and is the place where the x-rays are generated. The target is also made of tungsten, which has a high melting point and withstands the heat produced at the anode during x-ray exposure.

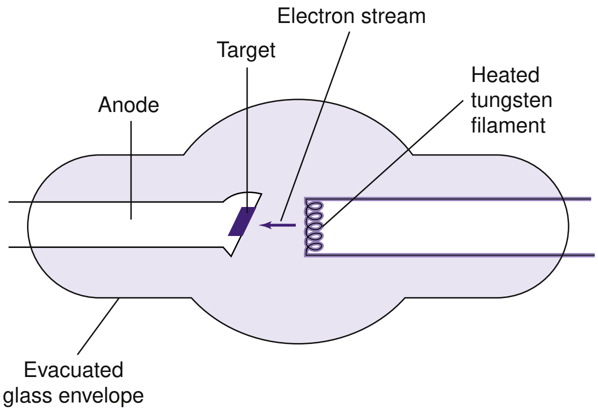

Fig. 1.5 Diagram of Coolidge tube simplifies understanding of x-ray production.

The voltage required for x-ray production is provided by a high-voltage transformer. The two ends of the x-ray tube are connected in the transformer circuit so that, during an exposure, the filament or cathode end is negative and the target or anode end is positive. The high positive electrical potential at the target attracts the negatively charged electrons of the space charge, which move rapidly across the tube, forming an **electron stream.** When these fast-moving electrons collide with the target, the kinetic energy of their motion must be converted into a different form of energy. The great majority of this kinetic energy is converted into heat (>99%), but a small amount is converted into the energy form known as *x-rays.*

> When fast-moving electrons collide with the target of an x-ray tube, the kinetic energy of their motion is converted into other forms of energy: heat and x-rays.

ELECTROMAGNETIC ENERGY

X-rays are among several types of energy described as **electromagnetic energy,** or electromagnetic wave radiation. They have both electrical and magnetic properties, changing the field through which they pass both electrically and magnetically. These changes in the field occur in the form of a repeating wave, a pattern that scientists call a *sinusoidal form* or **sine wave.**

Several characteristics of this waveform are significant. The distance between the crest and valley of the wave (its height) is called the **amplitude** (Fig. 1.6). More important to radiographers is the distance from one crest to the next, or **wavelength** (Fig. 1.7). The **frequency** of the wave is the number of times per second that a crest passes a given point.

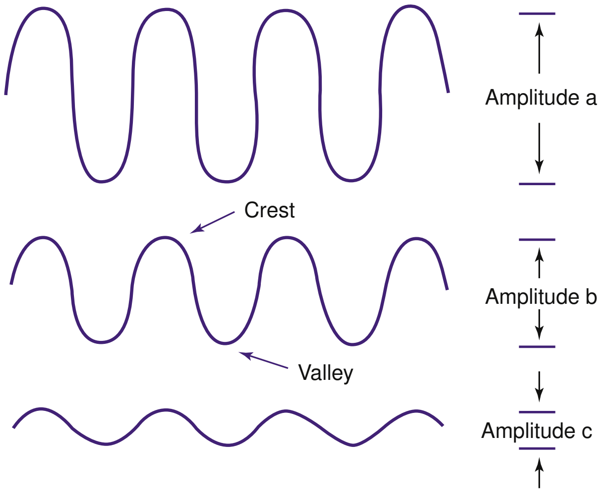

Fig. 1.6 These three sine waves are identical except for their amplitudes. (From Bushong SC: *Radiologic science for technologists*, ed 11, St Louis, 2017, Elsevier.)

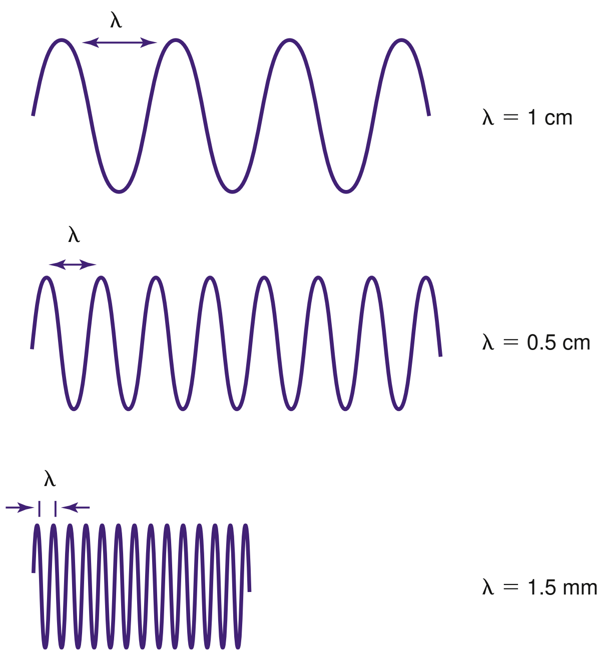

Fig. 1.7 These three sine waves have different wavelengths. The shorter the wavelength, the higher the frequency. (Note that the symbol for wavelength is the Greek letter lambda: λ.) (From Bushong SC: *Radiologic science for technologists*, ed 11, St Louis, 2017, Elsevier)

Because all electromagnetic energy moves through space at the same velocity—approximately 186,000 miles/sec, which is 30 billion (3×10^{10}) cm/sec—it is apparent that a relationship exists between wavelength and frequency. When the wavelength is short, the crests are closer together; therefore more of them will pass a given point each second, resulting in a higher frequency. Longer wavelengths will have a lower frequency; this can be expressed mathematically as follows:

$$\text{Velocity (v)} = \text{Wavelength } (\lambda) \times \text{Frequency (f)}$$

The more energy the wave has, the greater will be its frequency and the shorter its wavelength. We can therefore use either wavelength or frequency to describe the energy of the wave. In radiologic science, wavelength is more often used to describe the energy of the x-ray beam. The average wavelength of a diagnostic x-ray beam is approximately 0.1 nanometer (nm), which is 10^{-10} (0.0000000001) m, or approximately one-billionth of 1 inch.

The wavelength of electromagnetic radiation varies from exceedingly short (shorter than that of diagnostic x-rays) to very long (more than 5 miles). This range of energies is known as the *electromagnetic spectrum;* it includes x-rays, gamma rays, visible light, microwaves, and radio waves (Fig. 1.8). Radiation with a wavelength shorter than 1 nm (10^{-9} m) is said to be *ionizing radiation* because it has sufficient energy to remove an electron from an atomic orbit. X-rays are one type of ionizing radiation.

The smallest possible unit of electromagnetic energy (analogous to the atom with respect to matter) is the **photon,** which can be thought of as a minute "bullet" of energy. Photons occur in groups or bundles called **quanta** (singular, **quantum**).

> The smallest possible unit of electromagnetic energy is the photon, which can be thought of as a minute "bullet" of energy.

CHARACTERISTICS OF RADIATION

Because x-rays and visible light are both forms of electromagnetic energy, they share some similar characteristics. Both travel in straight lines, and both have a photographic effect. It is also important to remember because accidental exposure can occur when image receptors are placed near x-ray sources.

Both x-rays and light have a biologic effect; that is, they can cause changes in living organisms. Because of their greater energy, x-rays are capable of producing

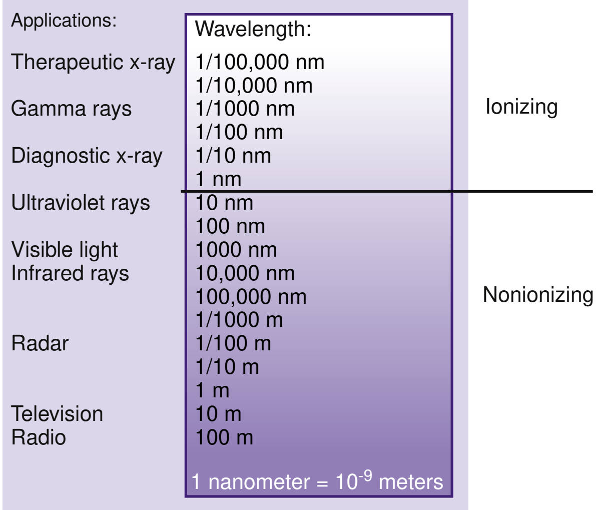

Fig. 1.8 Electromagnetic spectrum.

more harmful effects than light. Unlike light, x-rays cannot be refracted by a lens. The x-ray beam diverges into space from its source until it is absorbed by matter.

Unlike light, x-rays cannot be detected by the human senses. This fact may seem obvious, but it is important to consider. If x-rays could be seen, felt, or heard, we would have an increased awareness of their presence and radiation safety might be much simpler. Because they are undetectable, however, safety requires that you learn to know when and where x-rays are present without being able to perceive them.

X-rays can penetrate matter that is opaque to light. This penetration is differential, depending on the density and thickness of the matter. For example, x-rays penetrate air readily. There is less penetration of fat or oil, even less of water, which is approximately the same density as muscle tissue, and still less of bone. The effect on the x-ray beam caused by passing through matter is called **attenuation.** X-rays that have passed through the body are referred to as **remnant radiation** or exit radiation. Attenuation results in the absorption of a portion of the radiation and produces a pattern of intensity in the remnant radiation. This pattern reflects the absorption characteristics of the body through which it has passed; this pattern is recorded to form the image.

X-rays cause certain crystals to **fluoresce,** giving off light when they are exposed. Among crystals that respond in this way are barium platinocyanide, barium lead sulfate, calcium tungstate, and several salts consisting of rare earth elements. These crystals are used to convert the x-ray pattern into a visible image that can be viewed directly, as in fluoroscopy, or recorded on photographic film. The use of fluorescent intensifying screens to expose radiographs greatly reduced the quantity of radiation needed to produce images compared with that required for direct exposure of film. The combination of film and intensifying screens was the conventional IR for decades, but is now largely replaced by filmless technology that produces digital images. This topic is explored further in Chapter 2.

THE PRIMARY X-RAY BEAM

X-rays are formed within a very small area on the target (anode) called a **focal spot.** The actual size of the largest focal spot is no more than a few millimeters in diameter. From the focal spot, the x-rays diverge into space, forming the cone-shaped *primary x-ray beam* (Fig. 1.9). The cross section of the x-ray beam at the point where it is used is called the *radiation field*. A photon in the center of the primary beam and perpendicular to the long axis of the x-ray tube is called the *central ray*.

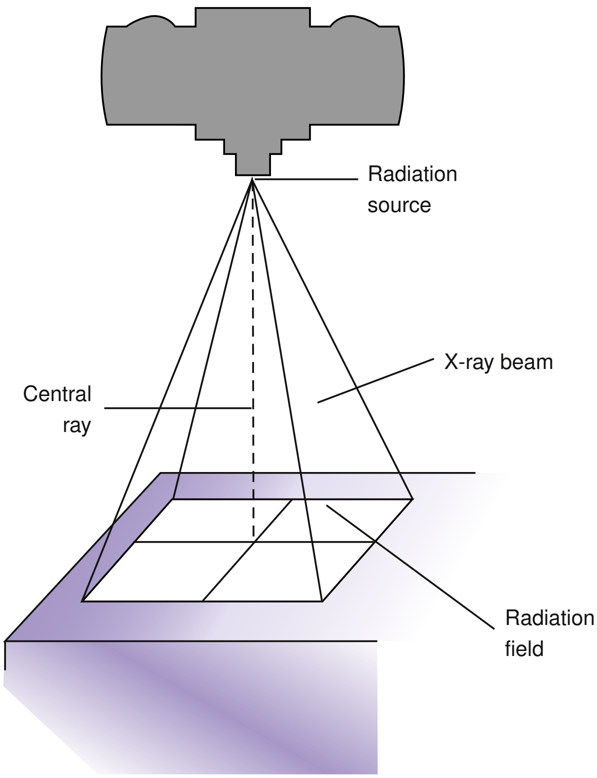

Fig. 1.9 A cross section of the x-ray beam is called the *radiation field;* an imaginary perpendicular ray at its center is called the *central ray*.

The x-ray beam size is restricted by the size of the port, the opening in the tube housing. Attached to the housing is the **collimator,** a device that enables the radiographer to further control the size of the radiation field.

SCATTER RADIATION

When the primary x-ray beam is attenuated by any solid matter, such as the patient or the x-ray table, a portion of its energy is absorbed. This results in the production of **scatter radiation** (Fig. 1.10). Scatter radiation generally has less energy than the primary x-ray beam, but it is not as easily controlled. It emanates from the source (usually the patient) in all directions, causing unwanted exposure to the IR and posing a radiation hazard to anyone in the room.

> Scatter radiation is the principal source of occupational exposure to radiographers.

The characteristics of primary radiation, scatter radiation, and remnant radiation are summarized for comparison in Table 1.1.

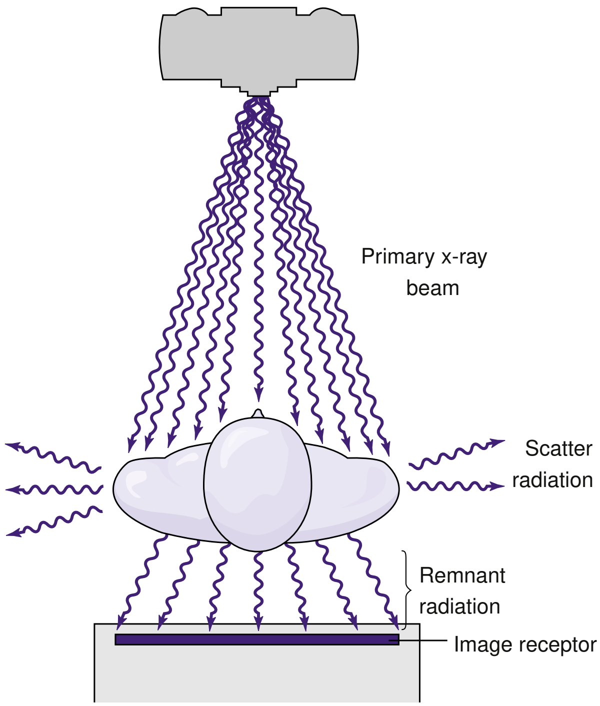

Fig. 1.10 Scatter radiation forms when the primary x-ray beam interacts with matter. (From Bushong SC: *Radiologic science for technologists*, ed 11, St Louis, 2017, Elsevier)

RADIOGRAPHIC EQUIPMENT

X-ray rooms vary in design, depending on their purpose. For example, a room dedicated to upright chest radiography might not have an x-ray table because the patients in this room would be standing for their examinations, not lying down. A room designed for gastrointestinal examinations would be equipped for both radiography and fluoroscopy. This dual-purpose equipment is described later in this chapter. A typical room designed for general radiography (Fig. 1.11) is suitable for many different types of x-ray examinations. In a hospital setting, the room will be fairly large, perhaps 18 × 20 feet in size, with wide doors to accommodate hospital beds and stretchers. Physical features will include the radiographic table, the x-ray tube and its support system, an upright IR cabinet against one wall, and a shielded control booth that contains the control console.

The X-Ray Tube

The x-ray tube is the source of the radiation. Modern multipurpose x-ray tubes (Fig. 1.12) are dual focus tubes. Their cathode assemblies contain two filaments, one large and one small (Fig. 1.13). Each is situated in a focusing cup that directs its electrons toward the same general area on the target portion of the anode. When the small filament is activated, its electrons are directed to a tiny focal spot on the target. The small filament and focal spot provide finer image detail when a relatively small exposure is appropriate—for example, when imaging a small body part such as a toe or wrist.

The large filament provides more electrons and is aimed at a somewhat larger target area. The combination of large filament and large focal spot is used when a large exposure is required, such as for radiographs of the lumbar spine or the abdomen, because the greater number of electrons meets the exposure requirements of the larger body part and the large focal spot can better handle the resulting heat at the anode. The anode is disk-shaped and rotates during the exposure (Fig. 1.14), distributing the anode heat over a larger area than the focal spot itself and increasing the heat capacity of the tube. It is the rotation of the anode that causes the whirring sound heard just before and after the exposure.

X-Ray Tube Housing

The x-ray tube is located inside a protective barrel-shaped housing (Fig. 1.15). The housing incorporates shielding that absorbs radiation that is not a part of the useful x-ray beam. The housing protects and insulates the x-ray tube while providing a base for the attachments that allow the radiographer to manipulate the x-ray tube and to control the size and shape of the x-ray beam.

TABLE 1.1 X-Ray Beam Attenuation

Type of Radiation	Definition	Travel Pattern	Energy Level
Primary radiation	The x-ray beam that leaves the tube and is not attenuated, except by air.	It originates at the tube target and expands in a cone-shaped beam that is perpendicular to the axis of the tube. Its direction and location are predictable and controllable.	Its energy is controlled by the kilovoltage setting.
Scatter radiation	Radiation scattered or created as a result of the attenuation of the primary x-ray beam by matter.	It travels in all directions from the scattering medium and is difficult to control.	Generally, it has less energy than the primary beam.
Remnant (exit) radiation	What remains of the primary beam after it has been attenuated by matter.	Its travel pattern is a continuation of the pattern of the primary beam.	Because the pattern of densities in the matter results in differential absorption, this pattern is inherent in remnant radiation. The pattern of intensity of remnant radiation creates the radiographic image.

Fig. 1.11 A typical room designed for general radiography.

X-Ray Tube Support

The tube housing can either be attached to a ceiling-mounted tube hanger or mounted on a tube stand. Both types of mountings provide support and mobility for the tube. A tube hanger (Fig. 1.16) is suspended from the ceiling on a system of tracks to allow positioning of the tube at locations throughout the room. This ceiling mount is useful when positioning the tube over a stretcher or when moving the tube for use in different locations. A tube stand is a vertical support with a horizontal arm that supports the tube over the radiographic table. The tube stand rolls along a track that is secured to the floor (and sometimes also the ceiling or wall), permitting horizontal motion.

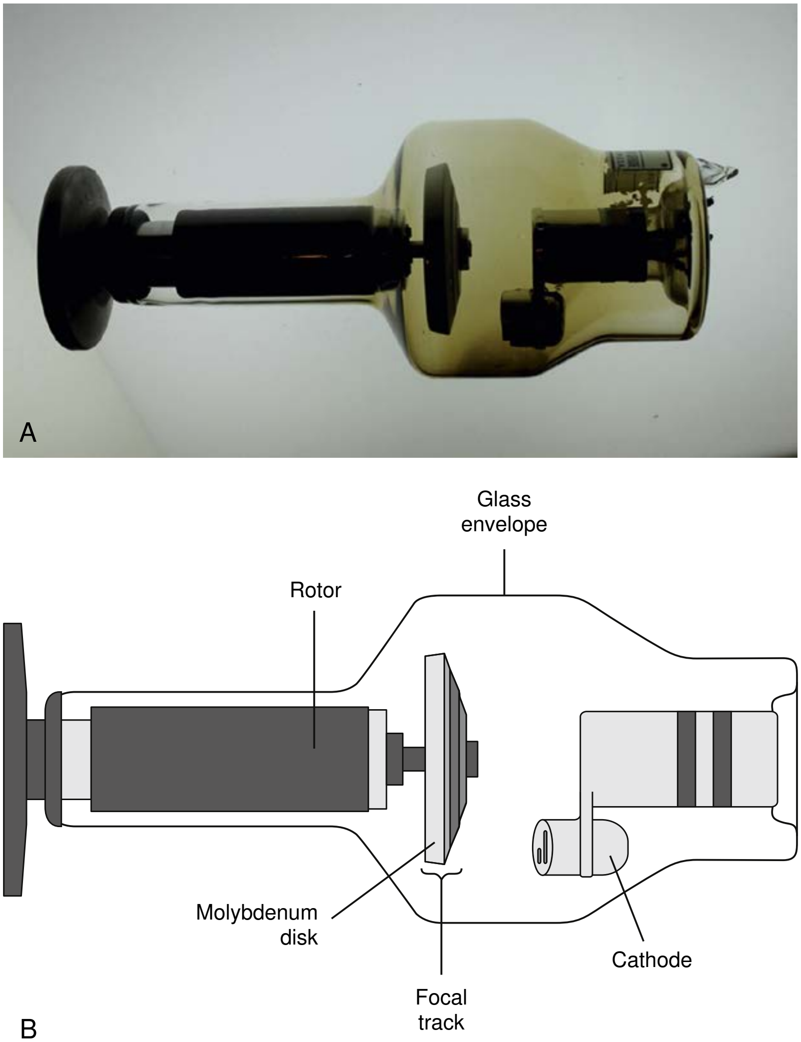

Fig. 1.12 A, Modern rotating-anode x-ray tube. B, Diagram of typical x-ray rube with key parts labeled.

A system of electric locks holds the tube support in position. The control system for all, or most, of these locks is an attachment on the front of the tube housing. To move the tube in any direction, the locking device must be released. Moving the tube without first releasing the lock can damage the lock, making it impossible to secure the tube in position.

> Do not attempt to move the x-ray tube without first releasing the appropriate lock.

Typical tube motions (Fig. 1.17) include the following:

- Longitudinal—along the long axis of the table
- Transverse—across the table, at right angles to longitudinal
- Vertical—up and down, increasing or decreasing the distance between the tube and the table

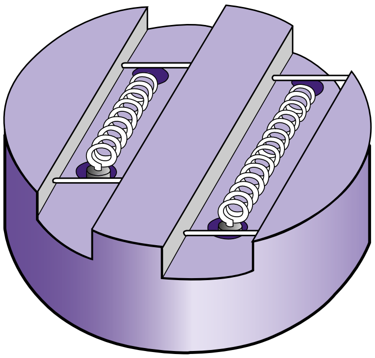

Fig. 1.13 Dual focus x-ray tube has focusing cups with large and small filaments. (From Long B, Frank E, Ehrlich RA: *Radiography essentials for limited practice,* ed 5, St Louis, 2017, Elsevier.)

- Rotation—allows the entire tube support to turn on its axis, changing the direction in which the tube arm is extended
- Roll (tilt, angle)—permits angulation of the tube along the longitudinal axis and allows the tube to be aimed at the wall rather than the table

A **detent** is a special mechanism that tends to stop a moving part in a specific location. Detents are built into tube supports to facilitate placement at standard locations. For example, a vertical detent will indicate when the distance from tube to IR is 40 or 48 inches, common standard distances. Other detents provide "stops" when the transverse tube position is centered to the table and when the tilt motion is such that the central ray is perpendicular to the table or to the upright IR cabinet.

Collimator

Another attachment to the tube housing is the collimator, a boxlike device mounted beneath the port. Collimators allow the radiographer to vary the size of the radiation field and to indicate with a light beam the size, location, and center of the field (Fig. 1.18) There is usually also a centering light that helps to align the IR. Controls on the front of the collimator allow the radiographer to adjust the size of each dimension of the radiation field. The collimator has a scale that indicates each dimension of the field at specific source-image distances. A timer controls the collimator light, turning it off after a certain length of time—usually 15 to 30 seconds. This helps to avoid accidental overheating of the unit by prolonged use of its high-intensity light.

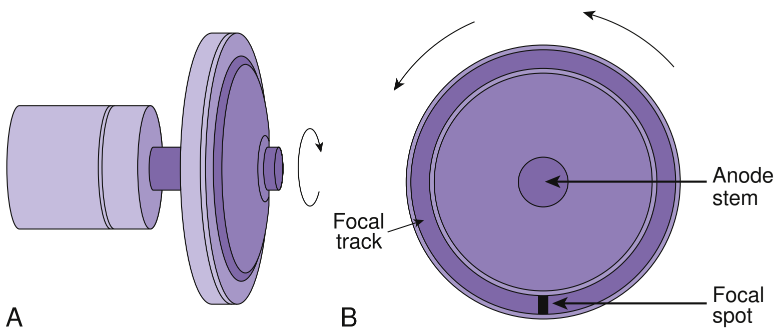

Fig. 1.14 Rotating anode. Electrons strike the anode in the tiny focal spot area, but the heat is spread around the entire focal track of the spinning anode face. A, Side view. B, View from cathode. (From Long B, Frank E, Ehrlich RA: *Radiography essentials for limited practice,* 5th ed, St Louis, 2017, Elsevier.)

Fig. 1.15 The tube housing *(arrow)* shields the tube and provides mounting for tube motion controls and collimator.

Fig. 1.16 Ceiling-mounted tube support.

Radiographic Table

The radiographic table (Fig. 1.19) is a specialized unit that is more than just a support for the patient. Although the table is usually secured to the floor, it may be capable of several types of motion: vertical, tilt, and "floating" tabletop.

For vertical table motion, a hydraulic motor, activated by a hand, foot, or knee switch, raises or lowers the height of the table. This motion allows the lowering of the table so that the patient can sit on it easily and permits the table to rise to a comfortable working height for the radiographer. Adjustments to exact stretcher height can be made to facilitate patient transfers. There will be a detent at the standard height for routine radiography. This standard table position corresponds to indicated distances from the x-ray tube. Because it is important that standard tube–IR distances be used, it is necessary to return the table to the detent position after lowering it for patient access. Not all tables are capable of vertical motion.

A tilting table (Fig. 1.20) also uses a hydraulic motor to change position. In this case, the table turns on a central axis to attain a vertical position; this allows the patient to be placed in a horizontal or vertical position or at any angle in between. The table can also tilt in the opposite direction, allowing the patient's head to be lowered at least 15 degrees into the **Trendelenburg position.** A detent stops the table in the horizontal position. Tilting is an essential feature of fluoroscopic tables and may also be a feature of a radiographic unit.

Special attachments for the tilting table include a footboard and a shoulder guard system to provide safety for the patient when tilting the table (Fig. 1.21). Pay particular attention to the attachment mechanisms so that you will be able to apply these devices correctly when needed.

> Before tilting a patient on the table, always test the footboard and shoulder guards to be certain that they are securely attached.

The motor that tilts the table is powerful and can overcome the resistance of obstacles placed in the way. Many step stools and other pieces of movable equipment have been damaged because they were under the end of the table and out of view when the table motor was activated. Such a collision can also damage the table motor.

> **!**
> Be certain that the spaces under the head and foot of the table are clear before activating the tilt motor.

A floating tabletop allows the top of the table to move independently of the remainder of the table for ease in aligning the patient to the x-ray tube and the IR. This motion may involve a mechanical release, allowing the radiographer to shift the position of the tabletop manually, or it may be power-assisted, activated by a small control pad with directional switches. Power-assisted movement is usual for fluoroscopic tables.

Grids and Buckys

You will recall from an earlier part of this chapter that when primary radiation encounters matter, such as the patient or the x-ray table, the resulting interaction

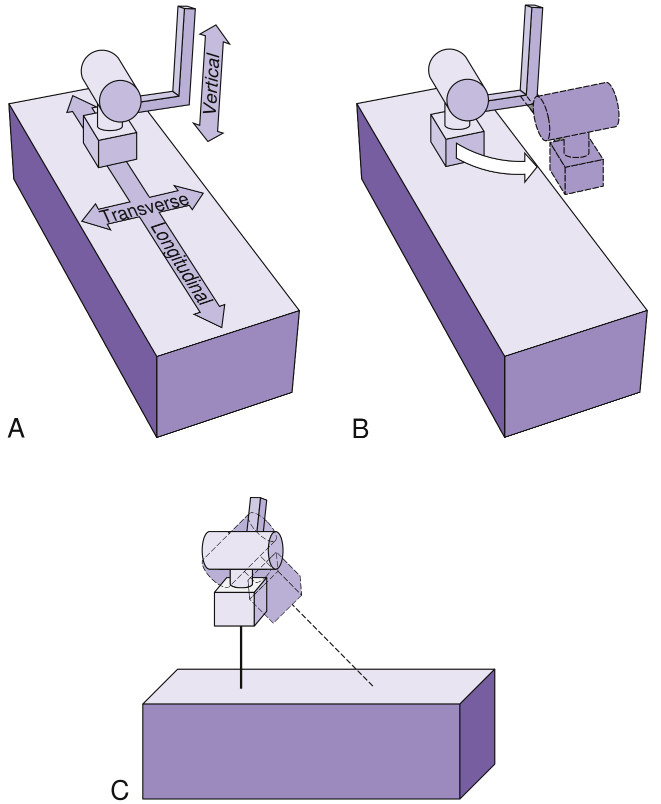

Fig. 1.17 Tube motions. A, Longitudinal, transverse, and vertical. B, Rotation. C, Angulation. (From Long B, Frank E, Ehrlich RA: *Radiography essentials for limited practice,* ed 5, St Louis, 2017, Elsevier.)

Fig. 1.18 Collimator light defines the radiation field and aids in the alignment of the bucky tray.

Fig. 1.19 Radiographic table.

produces scatter radiation. Most of the scatter produced during an exposure originates within the patient. This scatter radiation causes fog on the radiographic image, a generalized exposure that compromises the visibility of the anatomic structures. **Grids** and **buckys** are devices to prevent scatter radiation from reaching the IR.

> Grids and buckys prevent scatter radiation from reaching the IR and producing fog that degrades the image.

A bucky is usually located beneath the table surface; it is a moving grid device that incorporates a tray to hold the IR (Fig. 1.22). The entire unit can be moved along the length of the table and locked into position where desired. The grid that is incorporated into the bucky device is situated between the tabletop and the IR (Fig. 1.23). It is a plate made of tissue-thin lead strips, mounted on edge, with radiolucent interspacing material (Fig. 1.24). The strips must be carefully aligned to the path of the primary x-ray beam, so precise alignment of the x-ray tube is essential. In most radiographic units, the grid moves during the exposure. The purpose of moving the grid is to blur the image of the thin lead strips so that they are not visible on the radiograph. When the table has a floating tabletop, the bucky mechanism and IR tray do not move with the tabletop.

Fig. 1.20 The hydraulic fluoroscopic table tilts to change the patient's position. A, Semi-upright position. B, Trendelenburg position.

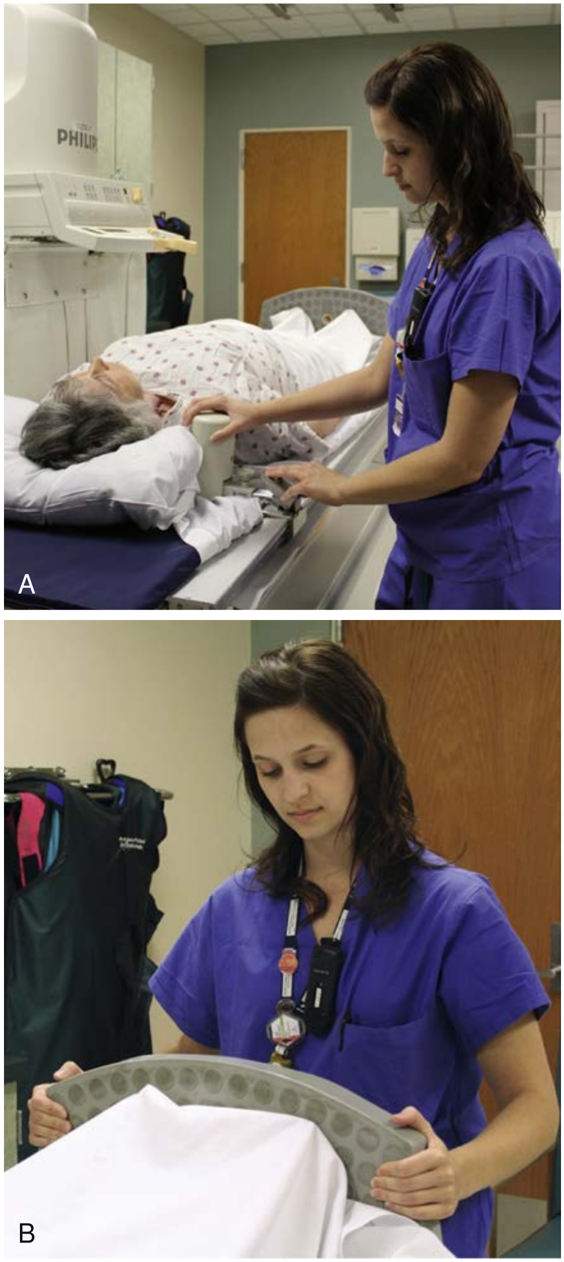

Fig. 1.21 Table attachments must be secured carefully for patient safety before tilting the table. A, Footboard. B, Shoulder guard.

Stationary grids that do not move during the exposure serve the same purpose as a bucky. A grid can also be incorporated into a device called a **grid cap,** which is a grid mounted in a frame that can be attached to the front of an IR for mobile radiography and other special applications.

Grids or buckys are generally used only for body parts that measure more than 10 to 12 cm in thickness. (The average adult's neck or knee measures 12 cm.) When a grid is not needed, the IR is placed on the tabletop.

> Grids or buckys are generally used only for body parts that measure more than 10 to 12 cm in thickness.

Fig. 1.22 The bucky tray holds the image receptor within the x-ray table.

Upright Image Receptor Units

An upright device holds the IR in position for upright radiography (Fig. 1.25). It is adjustable in height and can incorporate a grid. Even if the table tilts to the upright position, it is common to have a separate upright unit for some examinations, such as those of the cervical spine and the chest. When the patient is sitting or standing at the upright device, the tube is angled to direct the x-ray beam toward the IR. The distance may be adjusted to 40, 48, or 72 inches, depending on the requirements of the procedure.

Transformer

Cables from the tube housing connect the x-ray tube to the transformer, which provides the high voltage necessary for x-ray production. Some transformers look like a large box or cabinet, which may be located within the x-ray room. Newer transformer designs are much smaller and may be incorporated into the control console.

Control Console

The control console, located in the control booth, is the access point for the radiographer to determine the exposure factors and to initiate the exposure (Fig. 1.26). Radiographic control consoles have buttons, switches, dials, or digital readouts for some or all of the following functions:

- Off/On—controls the power to the control panel
- mA—allows the operator to set the milliamperage, the rate at which the x-rays are produced; determines the focal spot size

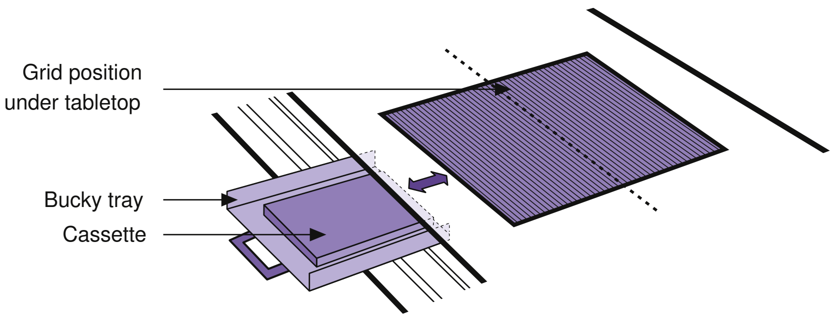

Fig. 1.23 The bucky device for scatter radiation control incorporates a tray for the image receptor and is mounted under the tabletop. Note that the lead strips are parallel to the long axis of the table. (From Long B, Frank E, Ehrlich RA: *Radiography essentials for limited practice,* ed 5, St Louis, 2017, Elsevier.)

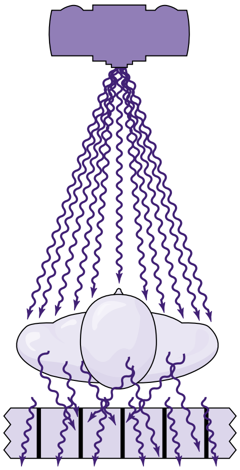

Fig. 1.24 Lead strips in the grid absorb scatter radiation emitted from the patient; remnant radiation passes through the grid and exposes the image receptor. (From Bushong SC: *Radiologic science for technologists*, ed 11, St Louis, 2017, Elsevier.)

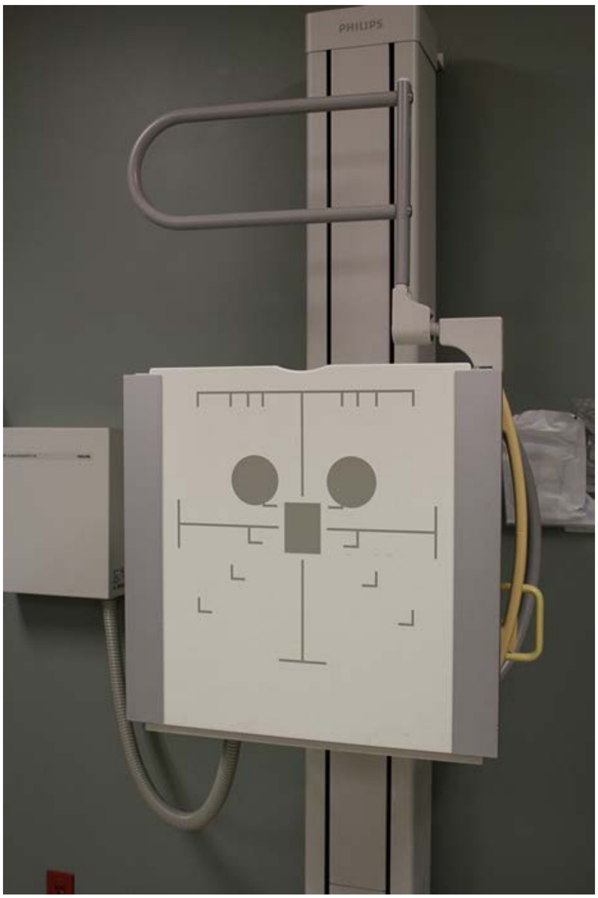

Fig. 1.25 Upright image receptor device.

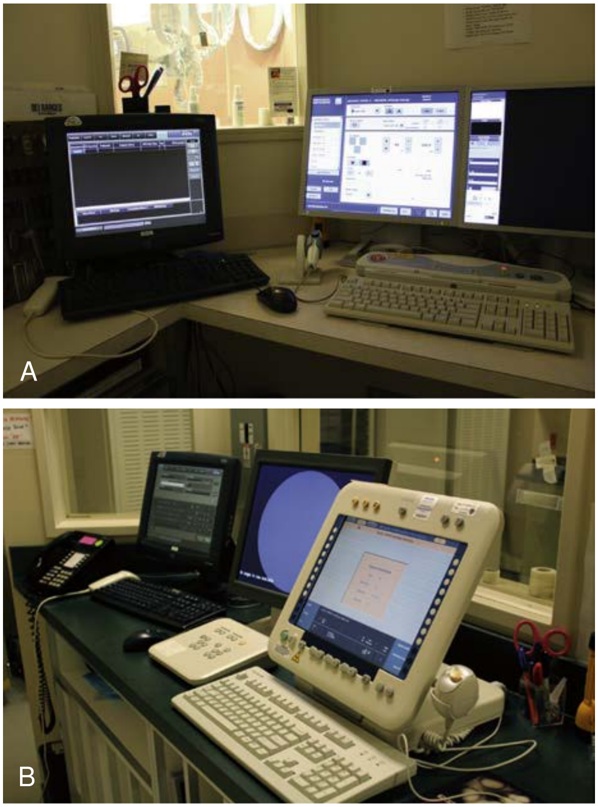

Fig. 1.26 Examples of x-ray control consoles. (A) Simple computerized radiographic controls. (B) Controls for filmless radiography with digital fluoroscopy.

- kVp—controls the kilovoltage, and thereby the wavelength and penetrating power, of the x-ray beam
- Timer—controls the duration of the exposure
- mAs—some units have an mAs control instead of mA and time settings; the mAs (the product of mA and time) determines the total quantity of radiation produced during an exposure
- Bucky—activates the motor control of the bucky device so that the grid will move during the exposure
- Automatic exposure controls—special settings available on units that allow termination of exposure when a certain quantity of radiation has reached the IR
- Meters or digital readouts to indicate the status of the settings
- Prep (ready or rotor) switch—prepares the tube for exposure and must be continuously activated until exposure is complete

- Exposure switch—initiates the exposure and must be continuously activated until the exposure is complete
- Accessories—other controls may also be present, depending on the equipment and its specific features

FLUOROSCOPY

Whereas routine radiography produces still or *static* images, fluoroscopy permits the viewing of *dynamic* images, or x-ray images in motion. Fluoroscopy is usually performed by radiologists with the assistance of radiographers. Fluoroscopic procedures are a routine aspect of every radiographer's clinical education.

Fluoroscopic Equipment

A **fluoroscope** is an x-ray machine designed for direct viewing of the x-ray image. This equipment permits the radiologist to view and record radiographic images in motion in real time. Early fluoroscopes consisted simply of an x-ray tube mounted under the x-ray table and a fluorescent screen mounted over the patient. The physician watched the radiographic image on the screen while turning the patient into the desired positions to view various anatomic areas. Because the fluoroscopic image was dim, dark adaptation was required and the procedure was performed in a darkroom.

> A fluoroscope is an x-ray machine designed for direct viewing of the x-ray image. This equipment permits the radiologist to view and record x-ray images in motion in real time.

Modern equipment is far more sophisticated. Most fluoroscopic units are properly called *radiographic/fluoroscopic* (R/F) units because they can be used for both radiography and fluoroscopy. This is convenient because most fluoroscopic examinations also have a radiographic component.

"Spot films" are taken during fluoroscopy to record the image as seen on the fluoroscope. These are static images taken by the radiologist that use the under-table fluoroscopic tube. After the fluoroscopic portion of the study is completed, additional images may be taken by the radiographer, using the spot images.

The radiation required for a fluoroscopic study has been greatly reduced by the use of the **image intensifier.** This electronic device is in the form of a tower that fits over the fluoroscopic screen (Fig. 1.27). Inside is a series of photomultiplier tubes that brighten and enhance the image formerly seen by looking directly at the fluoroscopic screen. The enhanced image is digitized or photographed by a video camera to provide direct viewing on a video monitor. A computer or video recorder can be used to make a record of the entire study. The fluoroscope and spot film device can be moved out of the way when the table is used for radiography.

Fig. 1.27 Typical radiographic/fluoroscopic unit. The tower *(arrow)* contains the image intensifier.

The control console of an R/F unit is more complex than that of a basic radiography unit. There must be separate mA and kVp settings for the control of the radiographic (overhead) and fluoroscopic (under-table) tubes, and special settings for spot film radiography. The radiologist activates the fluoroscope intermittently during an examination. When the fluoroscope is activated so that x-rays are being produced, a timer on the control advances and an alarm sounds after a preset period, usually 5 minutes. This warning is a reminder to reduce fluoroscopy time, and thus minimizes the radiation exposure received by all involved.

> **!** When the fluoroscope is activated so that x-rays are being produced, a timer on the control advances and an alarm sounds after a preset period of exposure, usually 5 minutes. This warning is a reminder to reduce fluoroscopy time, and thus minimizes the radiation exposure received by all involved.

Radiographer's Duties in Fluoroscopic Examinations

For a fluoroscopic examination, the duties of the radiographer can include the following:

- Taking the patient's history, including information on the success of dietary or bowel cleansing preparation (see Chapter 18).
- Filling out necessary preprocedural paperwork such as Contrast Media Consent, Time-Out, and Patient Education forms
- Assisting the patient to undress and don a gown
- Explaining the procedure to the patient
- Taking and processing any required preliminary images
- Setting the control panel correctly for fluoroscopy and spot film radiography
- Positioning the patient for the start of the procedure
- Preparing the equipment for fluoroscopy, including attaching the footboard and shoulder guard.
- Entering patient data into the computer image acquisition
- Preparing contrast agents as needed
- Assisting the radiologist as needed, which can involve helping the patient assume various positions; assisting the patient and/or the radiologist with the contrast medium; or electronically handling digital images
- Taking follow-up radiographs, if applicable
- Providing postprocedural care and instructions to the patient

Your orientation to the fluoroscopy suite may be to observe or assist with fluoroscopic studies of the gastrointestinal tract. These x-ray examinations of the stomach and/or the bowel are described in detail in Chapter 18. Other examinations involving fluoroscopy are discussed in Chapters 19 through 22.

SUMMARY

- W.C. Roentgen discovered x-rays in Würzburg, Germany, in 1895, while experimenting with a Crookes tube.
- Other x-ray pioneers include the following:
  - Edison, who experimented with many phosphors
  - Snook, who invented the interrupterless transformer
  - Eastman, who made the first x-ray film
  - Coolidge, who invented the hot cathode x-ray tube
- Radiography education began in hospitals as physicians trained their assistants to help with x-ray examinations. Hospital-based programs still exist, but most radiography education today takes place in college programs affiliated with medical centers.
- A simple x-ray tube contains a vacuum, a filament to provide a source of free electrons, and a target at which the electrons are directed. When a high voltage is applied to the tube, the free electrons collide with the target, decelerate suddenly, and produce both heat and x-rays.
- X-rays are a form of electromagnetic energy that occurs in units called *photons*. Photons occur in bundles called *quanta*. X-ray energy occurs in a sine waveform, changing the field through which it passes both magnetically and electrically.
- Electromagnetic sine wave characteristics include amplitude, wavelength, frequency, and velocity. The wavelength multiplied by the frequency equals the velocity (the speed of light).
- The characteristics of x-rays are similar to those of light except that x-rays cannot be refracted by a lens, are not detectable by the human senses, and are capable of ionizing matter.
- The primary x-ray beam is that which exits the x-ray tube and is unattenuated except by air; its location and direction are predictable and controllable.
- Scatter radiation is that created by the interaction between radiation and matter; it travels in all directions from the scattering medium and is difficult to control.
- Remnant radiation is what remains of the primary beam after it has been attenuated by the patient; its pattern of intensity represents the pattern of absorption and is the pattern that creates the radiographic image.
- Ceiling mounts or tube stands support x-ray tubes and provide a means to secure them in position. Tube motions include horizontal, vertical, angulation, and rotational movements.
- A collimator is a device attached to the x-ray tube housing for the purpose of controlling the field size; it has a light that indicates the location of the field, the location of the central ray, and the alignment of the x-ray beam to the IR.

- Grids and buckys are devices placed between the patient and the IR to prevent scatter radiation from degrading the image; they are located beneath the top of the radiographic table, in upright cabinets, and in grid caps for mobile radiography.
- The control console is the access point for the radiographer to control the exposure settings and initiate the x-ray exposure. Certain settings and readings are typical of all control consoles and should be recognized and understood by radiographers.
- Fluoroscopes are special x-ray machines that permit viewing of the x-ray image in motion in real time. Radiographic units are often combined with fluoroscopes, and fluoroscopic examinations often have a radiographic component.

REVIEW QUESTIONS

1. X-rays were discovered in 1895 in:
A. the United States
B. England
C. Germany
D. China

2. The inventor of the hot cathode x-ray tube was:
A. Crookes
B. Roentgen
C. Coolidge
D. Edison

3. The majority of radiography education programs are based in/on:
A. colleges
B. clinics
C. hospitals
D. the Internet

4. A cassette containing a photostimulable phosphor plate is one form of:
A. fluoroscope
B. image receptor
C. grid device
D. transformer

5. Which of the following is not a basic requirement for the production of x-rays?
A. A vacuum
B. A source of electrons
C. A photostimulable phosphor
D. A target

6. When fast-moving electrons collide with the target of an x-ray tube, the kinetic energy of their motion is converted into x-rays and:
A. a space charge
B. heat
C. potential difference (voltage)
D. scatter radiation

7. Of the following types of electromagnetic energy, which has the shortest wavelength?
A. Radio waves
B. Gamma rays
C. Microwaves
D. Ultraviolet light

8. Which of the following is *not* an accurate statement regarding the characteristics of x-rays?
A. They can penetrate matter that is impenetrable to light.
B. They can be refracted by a lens.
C. They have an exposure effect on photographic emulsions.
D. They cannot be detected by the human senses.

9. The characteristic most often used to describe the energy of an x-ray beam is its:
A. velocity
B. space charge
C. wavelength
D. amplitude

10. An x-ray beam that has been attenuated by matter is called:
A. remnant radiation
B. primary radiation
C. secondary radiation
D. scatter radiation

11. A device used to indicate the location of the radiation field and to control its size is called a:
A. grid
B. collimator
C. transformer
D. control console

12. An x-ray machine that permits viewing of the x-ray image in motion in real time is called a:
A. control console
B. fluoroscope
C. collimator
D. bucky

Answers can be found in the Answer Key on pages ________.

CRITICAL THINKING EXERCISES

1. Crookes and others worked with Crookes tubes before Roentgen did. Why didn't one of them discover x-rays? What important characteristics of x-rays did Roentgen display during and after the discovery?
2. When did your radiography program begin? How does its history correspond with the history of radiography education in this chapter?
3. List characteristics of x-rays that are similar to those of light and those that are different. Which characteristics of x-rays are useful in radiography?
4. Compare and contrast radiography and fluoroscopy.

2

Image Quality Factors

OBJECTIVES

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

- Define milliamperage and state its significance with respect to radiographic exposure.
- Explain the significance of exposure time with respect to optical density.
- Explain the significance of mAs with respect to image quality.
- Describe the effects of an increase in kVp with respect to both the x-ray beam and the radiographic image.
- State the content and purpose of an x-ray technique chart.
- Define OID and state its significance with respect to radiographic quality.
- Explain the effect of an increase in source-image distance on both optical density and image detail.
- List three types of image receptor system and describe each.
- List the two types of image distortion and state the cause of each.
- Differentiate between images that exhibit high contrast and those with low contrast.
- List factors that influence image contrast.
- List possible causes of poor image detail.
- List three digital pitfalls and explain how they should be avoided.

CHAPTER OUTLINE

Factors of Radiographic Exposure, 22
Exposure Time, 22
Milliamperage, 22
Kilovoltage, 23
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KEY TERMS

annotation
automatic exposure control (AEC)
computed radiography (CR)
cropping
digital radiography (DR)
distortion
electronic masking
exposure index (EI) number
exposure time (T)
image contrast
image detail
inverse-square law
kilovoltage (kV or kVp)
milliamperage (mA)
milliampere-seconds (mAs)
object-image distance (OID)

optical density (OD)
picture archiving and communication system (PACS)
postprocessing
shuttering
source-image distance (SID)

As radiographers are responsible for controlling the quality of the images they produce, it is important to understand the terms used to discuss image quality and the factors that can be changed to influence the appearance of the image. This chapter introduces image quality factors and the language you will need to learn more about this important aspect of radiography.

FACTORS OF RADIOGRAPHIC EXPOSURE

The four prime factors of radiographic exposure are exposure time (T), milliamperage (mA), kilovoltage (kVp), and source-image distance (SID). Each factor contributes to the amount of exposure affecting the image receptor (IR), and each influences radiographic quality. When you have learned the basics of these four factors, we will then consider how they affect radiographic quality and examine additional factors affecting the appearance of the image

Exposure Time

Exposure time is a measure of how long the exposure will continue and is measured in units of seconds, fractions of seconds, or milliseconds (thousandths of seconds). Electronic timers provide a wide range of possible settings, allowing the radiographer to precisely control the length of exposure. Exposure time settings can vary from as short as 1 millisecond (msec, 0.001 second) to as long as several seconds. Together with mA (see following section), exposure time determines the total quantity of radiation that will be produced. When a variation in the quantity of exposure is desired, the exposure time is varied. Because a longer exposure time results in the production of more x-rays, when all other factors are equal, a longer exposure time will produce a darker radiographic image. A decrease in exposure time will result in less radiation exposure and a lighter image. Patient dose is directly proportional to exposure time.

> Exposure time is a measure of how long the exposure will continue and is measured in units of seconds, fractions of seconds, or milliseconds. When all other factors are equal, a longer exposure time will produce more exposure and a darker radiographic image; a shorter exposure time will result in less radiation exposure and a lighter image.

Most x-ray table and upright IR units have automatic timers called **automatic exposure control (AEC).** These devices terminate the exposure when a specific quantity of radiation has reached the IR. The operator selects the appropriate chambers of an AEC to determine the portion(s) of the IR where the remnant radiation will be measured.

Milliamperage

Milliamperage (mA) is a measure of the current flow rate in the x-ray tube circuit. It determines the number of electrons available to cross the tube and thus the rate at which x-rays are produced. Think of mA as an indication of the number of x-ray photons that will be produced per second. Thus, the mA setting will determine how much time is required to produce a given amount of x-ray exposure. High mA settings are used to shorten the needed exposure time when motion during a longer exposure would likely cause blurring of the radiographic image.

The number of possible mA settings is limited and is usually in whole numbers that are divisible by 50 or 100. For example, a typical radiographic unit may have the following mA settings: 50, 100, 200, 300, 400, and 500. Some x-ray machines can produce as much as 1000 or 1500 mA.

> Milliamperage (mA) is a measure of the current flow rate in the x-ray tube circuit. It determines the number of electrons available to cross the tube and thus the rate at which x-rays are produced.

The relationship between mA and exposure time is simple. When the mA is multiplied by the exposure time, the product is given in units of **milliampere-seconds (mAs)**. The mAs indicate the amount of radiation in the exposure. Exposures made with the same mAs quantity will be similar in appearance, regardless of the quantities of mA and time used. For example, an exposure made at 100 mA and 0.1 sec would produce the same amount of radiation as an exposure using 200 mA and 0.05 sec. Both exposures equal 10 mAs, but the second exposure is shorter and its image is less likely to be blurred if the patient moves.

The product of mA and time is milliampere-seconds (mAs), an indicator of the total quantity of radiation produced in the exposure. This relationship is represented by the following formula:

mA × Time (seconds) = mAs

Most control consoles today provide the option of setting the mAs directly, whereas older models usually require the operator to set mA and exposure time separately. The mAs settings for various applications commonly range between 1 and 500.

Changing the mA has other effects as well. In dual focus tubes, specific mA stations control each filament. In general, mA settings of 150 or lower use the small filament and the small focal spot, whereas mA settings of 200 or higher are associated with the large filament and large focal spot. On controls that permit the operator to select the mA setting, each setting will have an indication of which focal spot is associated with it. Controls that provide mAs selection without specific mA settings will have a separate means of selecting focal spot size.

In addition to varying the focal spot size, changes in mA will affect the amount of heat that accumulates in the anode during the exposure and will be a cause for concern when very large exposures are required. As a rule, an x-ray tube can handle larger exposures when the desired mAs is obtained with a lower mA setting and a longer exposure time, assuming the same focal spot is used in both cases.

Kilovoltage

The **kilovoltage (kV or kVp)** is a measure of the potential difference across the x-ray tube. kVp is the abbreviation most commonly used; it stands for *kilovoltage peak*, because the kV is measured at the peak of the electrical cycle. One kilovolt is equal to 1000 volts. kVp determines the speed of the electrons in the electron stream; this determines the amount of kinetic energy each electron has when it collides with the target and therefore determines the amount of energy in the resulting x-ray beam. This energy is expressed by the wavelength of the photons. X-ray photons with shorter wavelengths have more energy and are more penetrating than those with longer wavelengths. For this reason, an increase in kVp results in a more penetrating x-ray beam; this will cause more exposure to the IR because a higher percentage of the x-rays produced will pass through the patient and reach the receptor. Thus, an increase in kVp will produce a darker image, whereas a decrease in kVp will produce a lighter image.

Kilovoltage (kVp) is a measure of the potential difference across the x-ray tube. An increase in kVp results in a more penetrating x-ray beam and a greater degree of exposure to the IR, producing a darker image.

Changes in kVp will also cause other changes to the image. Because the differential penetration of the x-ray beam will be affected by wavelength, the contrast of the image will also change. As a result, the degree of difference between the darker and lighter areas of the image will be affected. Somewhere between no penetration and total penetration of the subject is the optimal amount of differential penetration that will show a contrast in exposure between the various features of the subject. The amount of kVp that produces optimal penetration varies with the examination. This concept is discussed in the section on Image Quality later in this chapter.

kVp settings for typical radiographic units range between 40 kVp and 150 kVp in increments of 1 or 2 kilovolts. Low kVp settings are used for small body parts. For example, 50 to 60 kVp is commonly used for radiographic examinations of the hand, wrist, or foot. Spine radiography typically uses settings between 75 and 85 kVp, and settings greater than 100 kVp can be used for chest radiography and for studies of the digestive tract that use barium sulfate as a contrast agent.

Distance

The distance between the source of the x-ray beam (the tube target) and the IR is referred to as the **source-image distance (SID).** This distance is a prime factor of exposure because it affects the intensity of the x-ray beam. Radiation

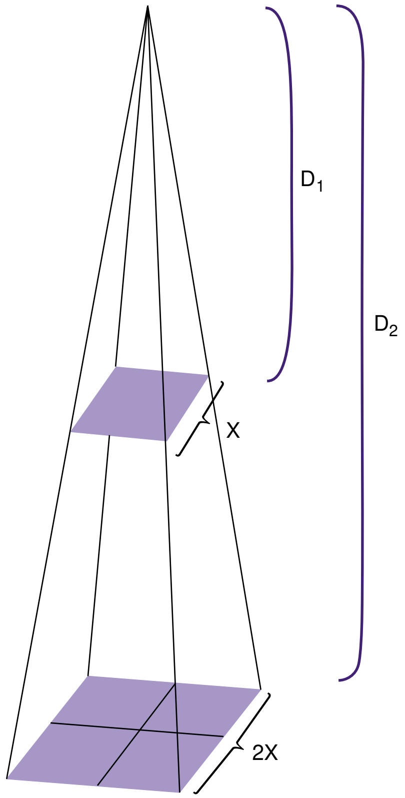

Fig. 2.1 Source-image distance affects radiation field size and radiation intensity. *D1,* Source to image distance; *D2,* twice the source to image distance; *X,* the field area, *2X,* twice the field area.

intensity can be considered as the number of photons per square inch striking the surface of the IR. Because the x-ray beam diverges from its source, the size of the beam expands as the distance from the source increases. As the total quantity of x-ray photons in the beam spreads out, there are fewer photons in any given area (Fig. 2.1).

The change in x-ray beam intensity that results from changes in the SID is expressed by the **inverse-square law**, which states that the intensity of the radiation is inversely proportional to the square of the distance. The inverse-square law is expressed mathematically in this equation:

$$\frac{I_{orig}}{I_{new}} = \frac{SID^2_{new}}{SID^2_{orig}}$$

Note in Fig. 2.1 that, as the distance is doubled, each dimension of the radiation field is doubled; therefore, the radiation field is four times greater in area. As a result, the number of photons per unit area within the field is one-fourth the original amount. Likewise, if the distance were tripled, the field area would be increased in size ninefold (i.e., 3^2), and the radiation intensity would be one-ninth the original amount.

> The distance between the tube target and the IR is referred to as the source-image distance (SID). The inverse square law states the relationship between radiation intensity and the SID: radiation intensity is inversely proportional to the square of the SID.

Of course, as the radiation intensity changes, exposure to the IR will also change. To maintain the same degree of image darkness when the SID changes, the mAs must be adjusted correspondingly. The formula for this adjustment is:

$$\frac{mAs_{orig}}{mAs_{new}} = \frac{SID^2_{orig}}{SID^2_{new}}$$

As you will learn later when you study x-ray technique calculations in more detail, this formula will enable you to maintain a given radiation intensity, and therefore a given image appearance, when changing the SID. For example, this formula will result in a fourfold increase in mAs when the SID is doubled. This increase in mAs compensates for the reduction in radiation intensity that occurs with the SID increase, with the result that the radiation intensity is unchanged.

Technique Charts

A technique chart located near the control console usually provides the radiographer with a listing of recommended mAs and kVp settings, as well as the SID, for each of the various body parts for different sizes of patients. Some computerized control consoles are preprogrammed with the required exposure settings for the selected body part and size.

IMAGE RECEPTOR SYSTEMS

There are two basic types of filmless radiography that have replaced conventional plain film and x-ray cassettes: **computed radiography (CR)** and **digital radiography (DR).**

Fig 2.2 Computed radiography cassettes come in a variety of sizes.

Computed Radiography

The IR for CR is an imaging plate that consists of photostimulable phosphors. It is exposed in a special cassette using conventional radiographic equipment (Fig. 2.2). The radiographer inserts the exposed cassette into a special processor (Fig. 2.3) and selects the type of examination from a menu so that the image will be processed correctly. A small beam from a high-intensity laser in the processor converts the latent image to a visible one that is captured by a photomultiplier tube similar to those used in fluoroscopic image intensifiers. The photomultiplier tube emits an electronic signal that is digitized and stored in a computer. The image can then be displayed on a high-resolution monitor. Hard copies can be produced using a laser film printer or burned onto a (CD) compact disc.

CR IRs come in standard sizes. You will work more effectively in the clinical area when you have learned to recognize them at a glance. The most common sizes are the following:

- 8 × 10 inches (20 × 25 cm)
- 10 × 12 inches (25 × 30 cm)
- 14 × 17 inches (35 × 43 cm)

Digital Radiography

DR does not use conventional equipment. Special radiographic tables and upright devices contain radiation receptors that react to the pattern of the remnant radiation and transmit a digital signal directly to the computer system, producing an image instantaneously on a monitor. DR systems with built-in radiation receptors (such as in the wall and/or table units) are typically 17 × 17 inches (43 × 43 cm) and require the operator to select the appropriate size of collimation for the part being imaged, although several systems will preset collimation to standard sizes similar to those used in CR. Wired or wireless DR receptors can be used for mobile DR systems and come in 17 × 17 inches (43 × 43 cm), 14 × 17 inches (35 × 43 cm), or even smaller sizes for dedicated pediatric facilities.

Fig. 2.3 Image processor for a computed radiography system. Note the computed radiography cassette storage system to the right of the image processor.

> There are two basic types of filmless radiography: computed radiography (CR) and digital radiography (DR). CR systems use conventional x-ray equipment with a cassette containing a photostimulable phosphor that must be processed in a laser device to create a digital image. DR systems have radiation receptors within the radiographic table, upright bucky, or stand-alone DR receptors that transmit digital signals directly to the computer system.

Because both CR and DR imaging systems automatically adjust the visual quality of the image, there is no telltale darkness or lightness of the image to indicate overexposure or underexposure as in earlier film/screen imaging systems. For this reason, digital processing systems usually display an exposure indicator number on the monitor, also referred to as an **exposure index (EI) number,** *S number, digital index (DI) number,* or other number, depending on the equipment. This number must be monitored by radiographers to ensure that exposures are of diagnostic quality and are not excessive.

> **!** Radiographers using digital imaging systems must monitor exposure index numbers in order to use adequate exposures for image quality and avoid excessive exposure to patients.

Once stored in the computer system, digital images from either CR or DR systems are organized and cataloged and can be accessed on monitors from multiple locations connected to the system network. These digital images can be manipulated electronically to enhance visibility.

The computer hardware and software technology used to manage digital images in hospitals and health care facilities is called a **picture archiving and communication system (PACS).** These systems provide archives for the storage of images from all digital imaging modalities, connect images with patient database information, facilitate printing or transfer of images to CD-ROM media, and display both images and information at workstations throughout the network as needed. A PACS may include transmission equipment for teleradiology, allowing images to be viewed in remote locations, such as a physician's home, and receiving images from remote locations such as outlying clinics. PACS technology can transmit images over telephone lines and via the Internet.

> The computer hardware and software technology used to manage digital images is called a picture archiving and communication system (PACS). These systems provide archives for the storage of images from all imaging modalities, connect images with patient database information, facilitate laser printing or transfer to CD-ROM media, and display both images and information at workstations throughout the network as needed.

IMAGE QUALITY

The more exposure received by a specific portion of the IR, the darker that portion of the image will be. The visibility of the radiographic image depends on two factors: the overall blackness of the image and the differences in blackness between the various portions of the image. The clarity and sharpness of the image are also important, as is the degree to which the image is a true representation of the subject. These features make up the four elements of radiographic quality: density, contrast, detail, and distortion.

Optical Density

The overall blackness of the image is referred to as the **optical density (OD),** often referred to as *radiographic density*. When the OD is optimal, the image is both dark enough and light enough to see the anatomic details clearly on the view box or monitor. Fig. 2.4 shows film radiographs of varying OD. In filmless radiographic systems, the radiographic density of the image is mostly controlled by the computer; a change in mAs exposure factors will not necessarily darken or lighten the image; however, if underexposed, a "grainy" appearing image will be produced because of the lack of sufficient x-ray photons striking the IR. An increase or decrease in exposure can best be detected by looking at the exposure indicator number.

> The overall blackness of the image is referred to as the *optical density* (OD). With CR/DR systems, OD is influenced less by exposure factors such mAs than by the computer processing techniques.

Take care not to confuse radiographic density with tissue density, which refers to the mass density of anatomic parts. Whereas increased optical or radiographic density indicates that the image is darker, an increase in tissue density will result in an image that is lighter. To avoid errors, try not to use the word *density* without an appropriate descriptor.

Image Contrast

The difference in the OD of adjacent structures within the image is referred to as the **image contrast.** Even when an image has the proper OD, it is possible for

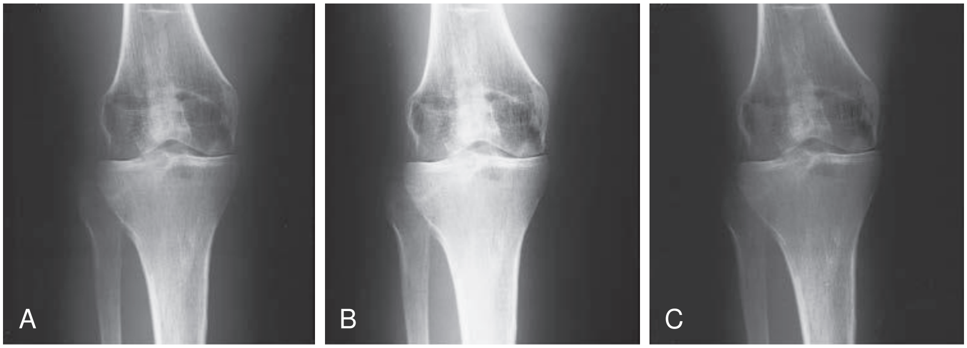

Fig. 2.4 Film radiographs of a phantom knee demonstrate differences in radiographic density. A, Optimum density. B, Underexposed. C, Overexposed.

structures to be too similar in density to be easily distinguished from one another. Fig. 2.5 shows film radiographs with high, low, and optimal contrast. Note that the high-contrast image has a black-and-white appearance. Structures in the gray areas are easily distinguished, but no details can be seen in the very dark or very light portions of the image. The low-contrast image has an overall gray appearance, and the structures tend to blend into one another. The optimal-contrast image shows details within all areas of the image, although the contrast in some areas is less pronounced.

kVp is the primary contrast control factor, but radiographic contrast is influenced by a number of other factors as well. These factors include the nature of the subject, the characteristics of the IR, and the amount of scatter radiation affecting the IR. High kVp produces an x-ray beam that penetrates more completely, leaving no white areas in the image. The dark, easily penetrated portions of the subject are not quite as dark when the kVp is high because less mAs is needed to obtain the desired radiographic density. When more (higher) contrast is desired, the kVp is decreased. Because this will result in less penetration by the x-ray beam, a beam of greater intensity is needed, and the mAs must be increased. Contrast is best evaluated when the overall radiographic density is optimal.

> The difference in the OD of adjacent structures within the image is referred to as the *image contrast*. kVp is the primary contrast control factor, but radiographic contrast is also influenced by a number of other factors, including the computer image processing algorithm.

Image Detail

The third element of image quality is **image detail.** This term refers to the sharpness of the image. When detail is high, the edges and lines that make up the image are crisp and precise; with low detail, these lines and edges are less distinct and appear somewhat blurred or out of focus. Among the factors that affect image detail are the distance between the source of x-rays and the IR (the SID) and the distance between the object and the IR, referred to as the **object-image distance (OID).** Increasing the SID sharpens the image, whereas increasing the OID reduces sharpness. Other factors include the size of the pixels in digital systems, the x-ray tube focal spot size (the smaller the focal spot, the greater the detail), and whether the patient is able to hold still during the exposure.

> Image detail refers to the sharpness of the image. Among the factors that affect image detail are the SID, the OID, the size of the pixels in digital systems, the focal spot size, and patient motion.

Distortion

The fourth element of image quality is **distortion.** This term refers to a variation in the size or shape of the image compared with the object it represents. Size distortion is always in the form of magnification, and all radiographic images are magnified to some degree. The factors that affect magnification are the OID and the SID. The angulation of the diverging x-rays that define the edges of a subject affects the degree of magnification (Fig. 2.6). When the x-ray tube is farther from the

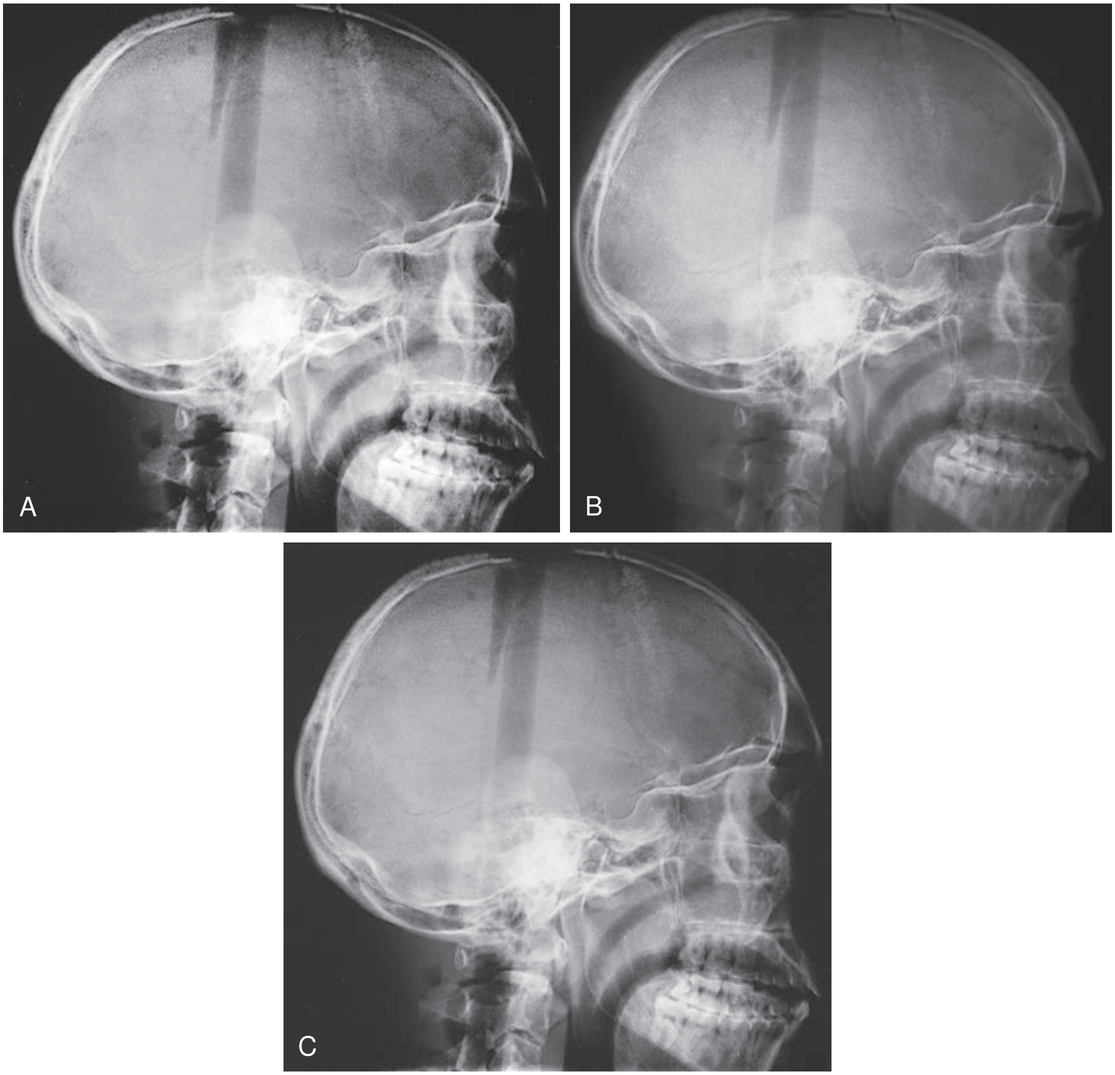

Fig. 2.5 Film radiographs of a phantom skull demonstrate differences in radiographic contrast. A, High contrast. B, Low contrast. C, Optimal contrast.

IR, the central, more parallel rays will define the subject, resulting in less magnification. When the SID is shorter, the rays that define the subject are those that diverge at a greater angle, increasing the magnification. As the x-ray beam continues past the subject to the IR, the rays continue to diverge, increasing the magnification. Likewise, when the OID is increased, the increased angle of divergence between the object and the IR causes increased magnification. The closer the object is to the receptor, the less magnification there will be.

Shape distortion is the result of unequal magnification of various parts of the subject. The least shape distortion occurs when the plane of the object is parallel to the plane of the IR and the central ray is perpendicular to it. Angulation of the x-ray beam, the IR, or the object in relation to the IR will all cause some degree of distortion (Fig. 2.7).

Distortion refers to a variation in the size or shape of the image compared with the object it represents. SID and OID control magnification distortion. Shape distortion is caused by misalignment of the tube, part, and IR.

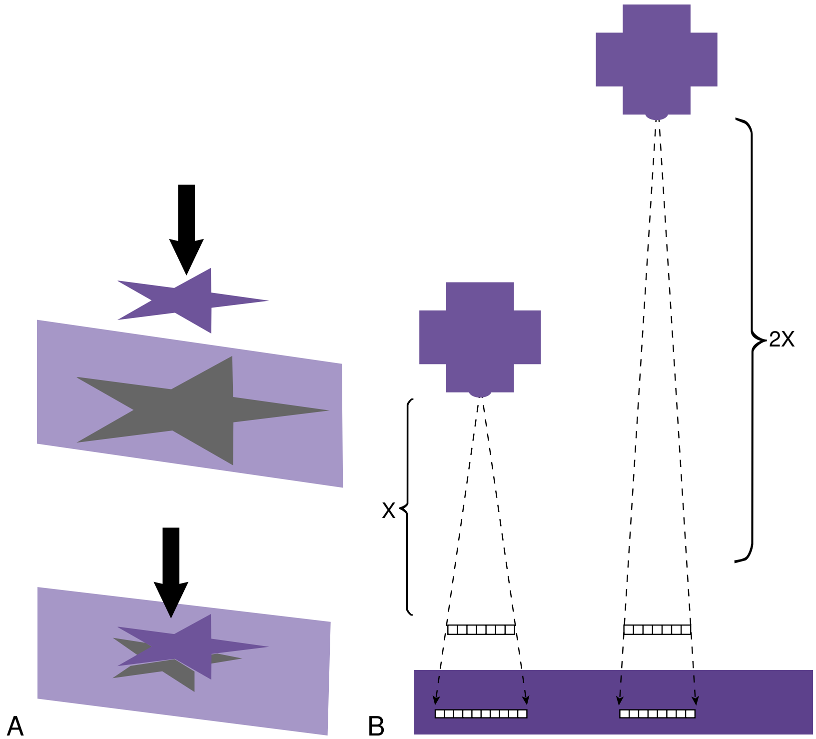

Fig. 2.6 A, Magnification is decreased as the object-image distance decreases. B, Magnification decreases as the source-image distance increases.

DIGITAL PITFALLS

Once images are acquired via CR or DR, they are viewed on a computer monitor and the technologist will have many choices on how to manipulate the image raw data using postprocessing software before sending the data to the archival system. Adjustments can be made on the contrast and brightness scale, and technologists can add annotations or anatomic markers, change the orientation of the image, and shutter, crop, or mask portions of the image that they do not want to be seen. Use of postprocessing can become a pitfall for radiographers when it replaces what should routinely be done before initiating exposure.

Both CR and DR systems excel at demonstrating both soft tissues and bony structures simultaneously. Contrast and brightness scale adjustments can be very useful postprocessing tools, as they allow both the radiographers and the radiologists to interactively adjust the gray-scale and brightness of an image to better demonstrate anatomy (Fig. 2.8). However, radiographers should be aware of the following when using contrast/brightness display postprocessing tools. First, the ability to adjust the contrast and brightness is limited when the initial image is excessively overexposed or underexposed and should not be used to fix poor exposure factors or help "pass" an image when it is not of diagnostic quality. Second, when adjustments are made to contrast and brightness before being sent to the PACS, it can limit the ability of the reading radiologists to also manipulate the contrast and brightness scales, thus affecting their interpretation and dictation.

It is easy to add digital markers, or **annotations**, to a digital image if radiographic markers were not used before exposure. Common annotations include Right (R), Left (L), Upright, Supine, Anteroposterior (AP), Posteroanterior (PA), Cross-table (XTBL), and Portable/Mobile (Fig. 2.9). Likewise, there is often a

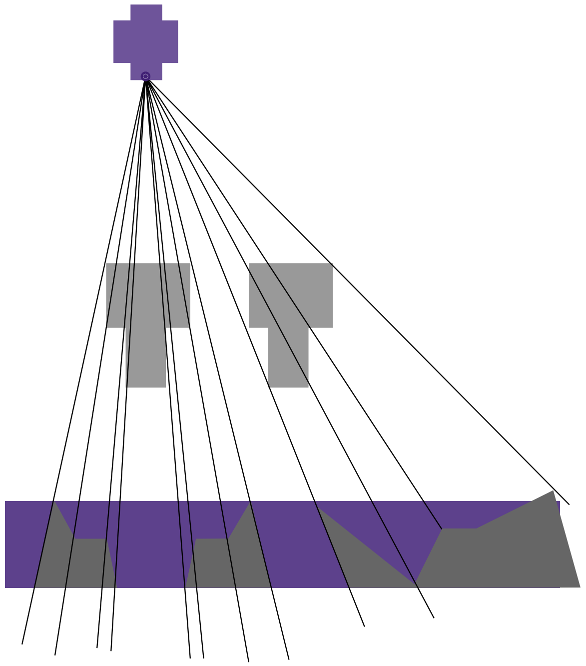

Fig. 2.7 Radiographic Distortion. Distortion is minimized when the subject is parallel to the image receptor and the central ray is perpendicular to both the subject and image receptor. Shape distortion results when there is angulation of the x-ray beam in relation to the subject or image receptor.

"free-form" box for annotations in which the technologist can type in special notes or characters, such as the performing technologist's initials or any explanatory notes for the radiologist (e.g., "best possible due to patient condition"). Be careful to put the annotated marker on the correct side of the anatomy and avoid adding digital annotations over imaged anatomy if possible. Use of annotations should not replace the use and careful placement of inherent radiographic markers.

Digital images can be reoriented, or flipped, to be displayed in true anatomic layout or in the preferred viewing perspective of the radiologist. Some software systems allow for only 90-degree increment changes, as well as vertical and horizontal flipping, whereas others will allow reorientation by 1-degree increments. For example, a left lateral chest x-ray can be flipped horizontally so that it appears that the patient is facing the opposite way if that is how the radiologist prefers to read lateral chest x-rays (Fig. 2.10). Every attempt should be made to standardize image display in correct anatomic layout in effort to assist radiologists in pattern recognition and dictation.

Another postprocessing software tool is **shuttering,** which refers to the technique of eliminating

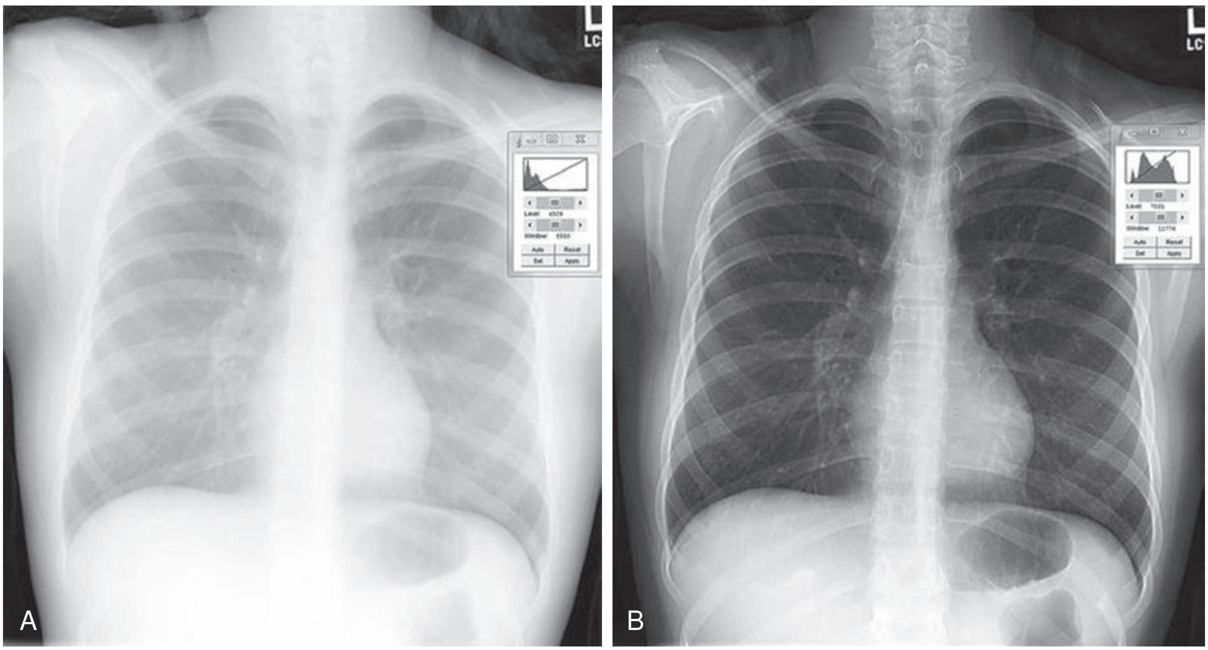

Fig. 2.8 Digital Image Contrast and Brightness. Contrast and brightness scales of raw image data can easily be manipulated with computed radiography/digital radiography postprocessing tools. (A) shows a long scale of contrast, whereas (B) appears darker with a short contrast scale.

ambient light around an image by implementing black or dark gray "shutters" to cover the perimeter's white areas normally seen from collimation (Fig. 2.11). **Cropping** refers to selecting the desired portion of an image while removing the rest of the unwanted

Fig. 2.9 **Digital Annotations.** Many types of annotations are available for technologists to add to an image before sending it to the picture archiving and communication system.

image (Fig. 2.12). The term **electronic masking** is often synonymously used for shuttering or cropping of the digital radiographic field. The practice of shuttering, cropping, or masking should only used for the sole purpose of improving the quality of the displayed image and not as a substitute for poor collimation of the original exposure. Cropping or masking off exposed anatomy is outside a radiographer's scope of practice; one must be a radiologist to determine if that anatomy is relevant or not.

Further details about CR/DR radiography best practice can be found online in the American Society of Radiologic Technologist's Position Statement document (https://www.asrt.org/docs/default-source/governance/hodpositionstatements.pdf).

> Radiographers should adhere to industry-recognized best practice when performing CR/DR radiography and not rely solely on the postprocessing software tools available to them.

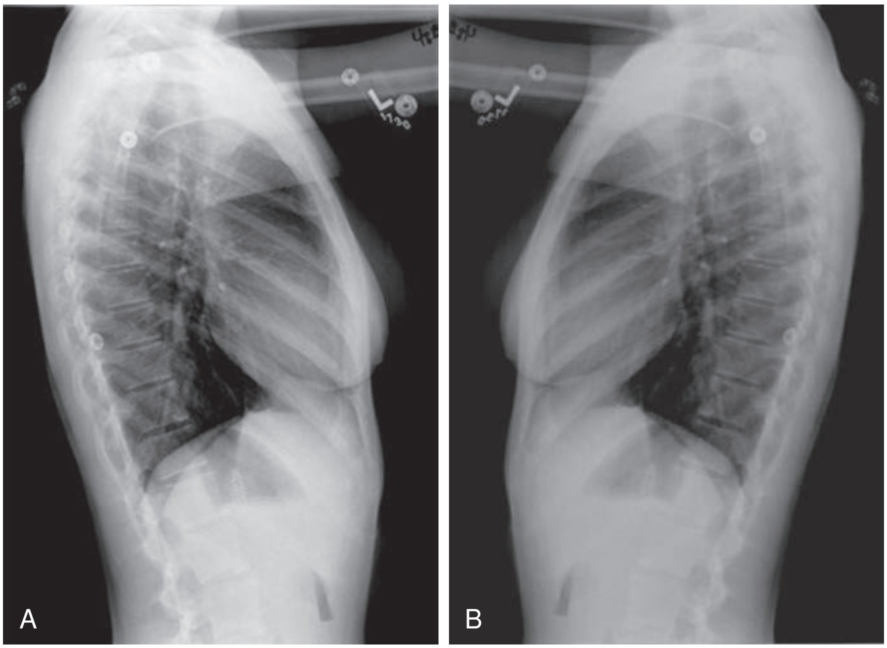

Fig. 2.10 **Reorienting an Image.** Postprocessing software allows for image rotation, flipping, and reorientation. (A) A left lateral chest x-ray was taken and then (B) was flipped to correctly display for radiologist reading protocol.

Fig. 2.11 Shuttering. An area of dark gray shuttering is seen around the black exposed area of a lateral os calcis x-ray performed with computed radiography. Shuttering is applied to eliminate the white area normally seen from collimation and to improve image appearance when displayed digitally.

Fig. 2.12 Cropping. Postprocessing software allows images to be cropped. Cropped images are sent to the picture archiving and communication system (PACS) showing only the desired part of the image, and the rest is discarded and not available for viewing on the PACS. The image on the left is seen with shuttering to the collimated field of exposure of an infant. The image on the right is the image that was cropped and sent to the PACS.

SUMMARY

- The prime factors of radiographic exposure are time, mA, kVp, and SID.
- Exposure time is the length of the exposure measured in seconds or portions of seconds.
- Milliamperage (mA) is a measure of the electron flow rate across the x-ray tube; it determines the rate of exposure.
- The milliampere-seconds (mAs) indicate the total quantity of exposure; mAs is the product of the mA and the exposure time.
- Technique charts indicate the prime factors for various examinations and for various patient sizes.
- Two types of filmless systems are computed radiography (CR) and digital radiography (DR). Filmless systems create digital images that can be viewed, stored, modified, and transmitted via computer.
- The four elements of image quality are optical density (OD), image contrast, image detail, and distortion.
- OD is the darkness of the image; it is influenced largely by computer processing and minimally by all the exposure factors, primarily by varying the mAs.
- Image contrast is the difference in OD between adjacent portions of the image. This contrast is essential for the eye to differentiate one structure from another. Contrast is primarily controlled by kVp, but it is also influenced by the subject and the amount of scatter radiation impacting the IR.
- Image detail, also called *definition,* is the sharpness of the lines that define the image. Without sufficient definition, the image appears blurred and small details are not clearly visualized.
- Distortion is variation in the size or shape of the image compared with the object it represents. Magnification distortion is affected by both SID and OID. Shape distortion occurs as a result of misalignment of the body part, IR, and x-ray tube.
- The raw data of CR/DR images can be postprocessed electronically to enhance the viewing of images as long as those techniques are implemented with industry best practice standards.

REVIEW QUESTIONS

1. The four prime factors of radiographic exposure are exposure time, milliamperage, kilovoltage, and:
   A. optical density
   B. source-image distance
   C. object-image distance
   D. image detail
2. The prime factor that controls the wavelength of the x-ray beam is:
   A. milliamperage
   B. exposure time
   C. kilovoltage
   D. object-image distance
3. The prime factor that controls the rate at which x-rays are produced is:
   A. exposure time
   B. kilovoltage
   C. milliampere-seconds
   D. milliamperage
4. The mAs value of an exposure is varied to provide control of:
   A. radiation intensity
   B. image contrast
   C. image detail
   D. radiographic distortion
5. The imaging system that provides an instantaneous digital image on a monitor is called:
   A. digital radiography
   B. computed radiography
   C. film-screen radiography
   D. anatomic programming
6. The hardware and software for managing digital images is called:
   A. PACS
   B. CR
   C. DR
   D. AEC
7. Which of the following factors is not affected by a change in the mA setting?
   A. optical density
   B. anode heat
   C. object-image distance
   D. radiation intensity
8. Which of the following factors is used to control image contrast?
   A. mA
   B. SID
   C. OID
   D. kVp
9. The inverse square law states that radiation intensity is inversely proportional to the square of the:
   A. mA
   B. SID
   C. T
   D. kVp
10. A variation in the size or shape of the image in comparison to the object it represents is called:
   A. distortion
   B. image contrast
   C. definition
   D. optical density

Answers can be found in the Answer Key on pages _________.

CRITICAL THINKING EXERCISES

1. Explain the significance of the x-ray wavelength in the production of radiographic images.
2. Compare the relative advantages and disadvantages of CR and DR imaging systems.
3. Explain the difference in purpose between AEC and anatomic programming in the determination of x-ray exposures.
4. Explain the difference between optical density and tissue density.
5. Discuss common digital pitfalls when working with CR/DR imaging systems.

3

Radiation Effects and Radiation Safety

OBJECTIVES

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

- Use appropriate units when discussing the measurement of x-radiation.
- Describe events that can occur on a cellular level as a result of radiation exposure.
- List four characteristics of a cell that affect its radiation sensitivity according to the law of Bergonié and Tribondeau.
- State the characteristics that are significant in categorizing radiation effects.
- Contrast stochastic radiation effects with deterministic effects.
- List and describe the three types of deterministic short-term radiation effects.
- Explain why stochastic radiation effects are difficult to identify and measure.
- List documented latent effects of low doses of ionizing radiation.
- Explain the significance of gene dominance with respect to genetic radiation effects.
- Describe how changes in time, distance, and shielding affect radiation exposure.
- Demonstrate practices that minimize occupational x-ray exposure.
- Explain the ALARA principle.
- List the methods used to reduce patient exposure to radiation.
- Describe the risks of radiation exposure during pregnancy with respect to both patients and health care workers.

CHAPTER OUTLINE

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KEY TERMS

ALARA principle
centigray (cGy)
coulombs per kilogram (C/kg)
deterministic
dominant
equivalent dose (EqD)
dosimeter
erythema
free radical
genetic effects
gray (Gy)
hematologic

ionization
long-term effects
mutation
optically stimulated luminescence (OSL)
radiation absorbed dose (rad)
radiation equivalent in man (rem)
recessive
roentgen (R, r)
short-term effects
sievert (Sv)
somatic effects
stochastic
weighting factor (W_R)

This chapter builds on your understanding of the nature of radiation by introducing radiation measurement, radiation effects, and radiation safety. These topics will be essential to your work as a radiographer and are covered in greater detail later in your curriculum.

RADIATION UNITS AND MEASUREMENT

Radiation measurements can be made in two different, but related, systems: the traditional (British) system, still sometimes used in the United States, and the Système Internationale (SI) units established by the International Commission on Radiation Units in 1981. These units and their relationships are summarized in Table 3.1.

The traditional unit of radiation exposure is the **roentgen (R or r),** a measurement of radiation intensity in air. The roentgen is equal to the quantity of radiation that will produce 2.08×10^9 (more than 2 billion) ion pairs in 1 cm^3 of dry air. The SI unit for measuring radiation intensity is **coulombs per kilogram (C/kg),** specifying the quantity of electrical charge in coulombs produced by the exposure of 1 kg of dry air. One roentgen equals 2.58×10^{-4} (0.000258) C/kg.

The C/kg and R units are useful for measuring the quantity of radiation present, but are not useful dose measurements. The dose varies with the depth of measurement and the quantity of radiation energy absorbed in the exposed tissue. To measure therapeutic radiation doses, as well as specific tissue doses received in diagnostic applications, the traditional unit is **radiation absorbed dose (rad)** and is equal to 100 ergs (an energy unit) per gram of tissue. One roentgen of exposure will result in approximately 1 rad of absorbed dose in muscle tissue. The SI unit for dose measurement is the **gray (Gy).** One gray equals 100 rad, and conversely, 1 rad equals 1 **centigray (cGy, 0.01 gray).**

TABLE 3.1 Radiation Units

	SI Units	Traditional (British) Units
Exposure units	Coulombs per kilogram (C/kg) 1 R = 2.58×10^{-4} C/kg	Roentgen (R) Quantity of radiation that will produce 2.08×10^9 ion pairs in 1 cm^3 of air
Dose units	Gray (Gy) 1 Gy = 100 rad	Radiation absorbed dose (rad) 100 erg per gram of tissue
Dose equivalent units	Sievert (Sv) Sv = Gy × W_R 1 Sv = 100 rem	Radiation equivalent in man (rem) rem = rad × W_R

The biologic effect of radiation exposure varies according to the type of radiation involved and its energy. Equal doses of various types of radiation, as measured in gray or rad, will not necessarily result in equal biologic effects. Some radiation workers, such as engineers in nuclear power plants, nuclear submarine construction workers, or technologists in nuclear medicine laboratories, may be exposed to several types of radiation with unequal levels of biologic effect. Neither the radiation measurement units (coulombs per kilogram and roentgen) nor the dose units (gray and rad) are useful units for measuring the occupational dose of combined radiations with different levels of effects.

To simplify the process of measuring biologic effects, a **weighting factor (W_R)** is assigned to each type of radiation based on its absorbed energy in a mass of tissue and its relative biologic effect compared with x-rays. The W_Rs for different types of ionizing radiation are listed in Table 3.2. For example, note that alpha particles have a W_R of 20, because 1

TABLE 3.2 Radiation Weighting Factors

Radiation Type	Radiation Weighting Factors
Photons	1
Electrons and muons	1
Protons and charged pions	2
Alpha particle, fission fragments, heavy ions	20
Neutrons (energy dependent)	A continuous function of neutron energy

Summarized from the International Commission on Radiological Protection (2007).

Gy of alpha particles causes biologic effects that are approximately equal to those produced by 20 Gy of x-ray energy. The absorbed dose is multiplied by the W_R to obtain the **equivalent dose (EqD).** The resulting SI unit is the **sievert (Sv).** Thus, the worker exposed to 1 Gy of alpha particles would receive 20 Sv of occupational exposure.

$$\text{Gy} \times \text{WR} = \text{Sv}$$

The British unit used to measure dose equivalents is the **radiation equivalent in man (rem);** it is determined by multiplying the dose in rad times the W_R:

$$\text{rad} \times W_R = \text{rem}$$

and

$$1\ \text{Sv} = 100\ \text{rem}$$

The equivalent dose (EqD) is equal to the dose in either rad or gray, times the W_R. The EqD units are sievert (Sv) in the SI system and rem in the British system.

Because the radiation quantities involved in diagnostic radiology are so small, radiographers commonly use units that are 1/1000 of the common unit (for example, millisieverts [mSv]). A chest radiograph can result in a skin entrance dose of 0.15 mSv, or 15 mrad. The most common unit for the calculation of radiation doses in the United States has become the centigray (0.01 Gy). As the United States converted to the SI system, the centigray was the first and easiest unit to convert because it is equal to the rad, the dose unit in the British system.

The most commonly used dose unit in the United States is the centigray (cGy); 1 cGy = 1 rad.

Students often find it confusing to determine which radiation units should be used in a given situation. This choice is made more difficult by the tendency of many radiographers to use the traditional roentgen, rad, and rem units interchangeably. This does not cause serious inaccuracy when speaking only of diagnostic x-rays, because exposure to 1 R of x-ray energy will result in approximately 1 rad in muscle. Because the W_R of diagnostic x-rays equals one, 1 rad is also equal to 1 rem.

In general, the reason for the measurement determines which unit is the most appropriate. The coulombs per kilogram and roentgen units are used to measure the presence of x-radiation without any reference to its absorption or attenuation—that is, the quantity of radiation present in air. For example, these units can be used to measure the output of an x-ray machine or determine the radiation level in the hallway during an x-ray exposure in the adjacent room.

The gray and the rad are used to measure radiation dose and are the units used to prescribe radiation therapy. The amount of radiation absorbed by a specific tissue is what is being measured; therefore, a statement indicating the part of the body involved usually modifies the dosage unit. For example, a radiation oncologist may prescribe a therapeutic dose of 5040 cGy to the left breast. This dose can be delivered in a series of 28 treatments involving 180 cGy each. A research report might state that a patient who undergoes a routine chest radiograph receives an average thyroid dose of 4 mrad. The laboratory that processes personal radiation monitor badges will report occupational dose in dose equivalent units, usually in millisieverts.

BIOLOGIC EFFECTS OF RADIATION EXPOSURE

X-rays can ionize substances by removing electrons from their orbits. This process is called **ionization**. It results in a free, negatively charged electron and leaves the remainder of the atom with a positive charge. When human beings are irradiated, ionization can occur to any part of a living cell, such as the material that makes up its membrane, the water within the membrane, or the DNA that makes up the cell's chromosomes and directs its activity. The initial ionization can produce a domino effect, causing ionization in the surrounding area. Exposure also creates **free radicals** (temporary molecules and parts of molecules with electrical charges). Free radicals can interact directly with DNA or with other parts of the cell to produce toxic substances that are injurious to DNA.

Most effects of exposure are extremely short-lived because electrons find new homes in the orbits of other atoms and the balance of charges returns to normal. Free radicals combine to form more stable compounds. Occasionally, however, the damage is not instantly resolved. A cell may be damaged to such an extent that it cannot sustain itself and subsequently dies. Cell death is an insignificant injury unless a large number of cells are involved. Cells may sustain damage that requires several days for the body to repair. The body produces special enzymes that function to repair the DNA protein molecules. A cell can be damaged in such a way that its DNA programming is changed and it no longer behaves normally. This type of injury can eventually result in the runaway production of new, abnormal cells, causing a cancerous tumor or malignant blood disease.

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

1. *Age.* Younger cells are more sensitive than older ones.
2. *Differentiation.* Nonspecialized cells are more sensitive than highly complex ones.
3. *Metabolic rate.* Cells that use energy rapidly are more sensitive than those with a slower metabolism.
4. *Mitotic rate.* Cells that divide and multiply rapidly are more sensitive than those that replicate slowly.

According to this law, we see that blood cells and blood-producing cells are highly sensitive. Cells in contact with the environment are simple, have relatively short lives, and are highly sensitive. These cells include those of the skin and the mucosal linings of the mouth, nose, and gastrointestinal tract. 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 adult tissues because of their younger age and their higher metabolic and mitotic rates. Nerve cells, which have a long life and are highly complex, are much less vulnerable to radiation injury. Cortical bone cells are also relatively insensitive.

Radiation effects are classified in various ways. **Short-term effects** are those observed within 3 months of exposure and are associated with relatively high radiation doses (>50 cGy). Short-term effects can be further categorized according to the body system affected: central nervous system, gastrointestinal, and **hematologic** (blood-related) effects. **Long-term effects,** sometimes referred to as *latent effects,* may not be apparent for as many as 30 years. **Somatic effects** are those that affect the body of the irradiated individual directly, whereas **genetic effects** occur as a result of damage to the reproductive cells of the irradiated person and may be observed as defects in the children or grandchildren of the irradiated individual.

Short-Term Somatic Effects

Short-term radiation effects are predictable, and the quantity of exposure required to produce them is well documented. These effects are classified as **deterministic.** Deterministic effects (formerly called nonstochastic somatic effects) occur only after a certain amount of exposure. The severity of the effect depends on the dose.

> Deterministic radiation effects are short-term somatic effects associated with high-dose exposures. They are predictable and their severity is dose dependent.

One observable short-term effect is reddening of the skin called **erythema.** This phenomenon is sometimes called a *radiation burn*. In the early days of radiation use, the amount of radiation necessary to produce reddening of the skin was called the *erythema dose*. It was the first unit used to measure radiation exposure.

Other short-term effects from doses in excess of 50 cGy have been observed and studied in radiation therapy patients and in the victims of radiation accidents and atomic bomb blasts. This is vastly more exposure than is delivered by diagnostic x-ray machines. Extremely high doses produce central nervous system effects, such as seizures and coma, that can result in death in a short period of time. Lesser doses will 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 because of the death of white blood cells and are unable to fight the infection.

TABLE 3.3 Biologic Effects Resulting From Acute Whole-Body Exposures*

Radiation (EqD)	Subsequent Biologic Effects
0.25 Sv	Blood changes (e.g., measurable hematologic depression, substantial decreases within a few days in the number of lymphocytes or white blood cells that are the body's primary defense against disease)
1.5 Sv	Nausea, diarrhea
2.0 Sv	Erythema (diffuse redness over an area of skin after irradiation)
2.5 Sv	If dose is to gonads, temporary sterility
3.0 Sv	50% chance of death; lethal dose for 50% of population over 30 days (LD 50/30)
6.0 Sv	Death

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

Adapted from *Radiologic health,* unit 4, slide 17, Denver, Multi-Media Publishing (slide program); and Sherer S: *Radiation protection in medical radiography,* ed 8, St Louis, Elsevier, 2018.

TABLE 3.4 Representative Entrance Skin Exposures, Bone Marrow Dose, and Gonadal Dose From Various Diagnostic X-Ray Procedures

Examination	Exposure Factors (kVp/mAs)	Entrance Skin Dose (mGy$_t$)*	Bone Marrow Dose (mGy$_t$)	Gonad Dose (mGy$_t$)
Skull	76/50	2	0.1	<1
Chest	110/3	0.1	0.02	<1
Cervical spine	70/40	1.5	0.1	<1
Lumbar spine	72/60	3	0.6	2.25
Abdomen	74/60	4	0.3	1.25
Pelvis	70/50	1.5	0.2	1.5
Extremity	60/5	0.5	0.02	<1
CT (head)	125/300	40	0.2	0.5
CT (pelvis)	125/400	20	0.5	20

*mGy$_t$, Milligray in air.

Adapted from Bushong SC: *Radiologic science for technologists: physics, biology, and protection,* ed 11, St Louis, Mosby, 2017; and Sherer S: *Radiation protection in medical radiography*, ed 8, St Louis, Elsevier, 2018.

Radiation sickness is usually fatal, and suffering may be prolonged. A lesser dose, affecting primarily the blood and blood-forming organs, results in hematologic effects, including anemia and a compromised immune system owing to the death of white blood cells. The victims are prone to infectious diseases that can be fatal, depending on the radiation dose and the severity of the disease process. One way that scientists describe the risk of high-level radiation exposure is to calculate the whole-body radiation dose that is lethal to 50% of the irradiated population within 30 days—a calculation that is abbreviated as LD 50/30. The LD 50/30 for humans is approximately 3 Sv (Table 3.3).

Long-Term Somatic Effects

In this discussion, *long-term* refers to the length of time between the exposure and the observation of the effect. The time required for long-term effects to manifest is generally considered to be 5 to 30 years, with the greatest percentage occurring between 10 and 15 years. In contrast to the predictable nature of short-term effects, long-term effects are apparently random, and there is no threshold amount of exposure that must be received for them to occur. Effects of this type are termed **stochastic.** The likelihood of stochastic effects is rare. It is greater when the dose is increased, but there is no correlation between the dose and the severity of the effects. These effects can occur as the result of repeated small doses, such as those typically used in radiography (Table 3.4) or received as a result of occupational exposure.

> Stochastic radiation effects are random, long-term effects associated with low-dose exposure. Their likelihood is dose dependent and the severity of the effect is random.

The percentage of observable effects from the radiation involved in typical x-ray examinations is extremely low, and the risk to any single patient is minimal. Most of us take greater risks every day when we drive our cars or walk across busy streets. Nevertheless, there is a risk of long-term effects that has been demonstrated by studying large populations over long periods. The incidence of certain conditions is greater when results for irradiated groups are compared with those of nonirradiated control groups.

Long-term radiation effects are not easily identified as such because they occur years after the initial exposure and because the same effects also occur in the absence of radiation exposure. Only extensive research with large populations (epidemiologic studies) and computer analysis can demonstrate the role of radiation in causing these effects. In other words, radiation causes increased risk of these effects, but the effects cannot be predicted for any one individual. Although the individual risk may be extremely small, increasing the exposure to the entire population poses public health risks that require the attention and concern of everyone involved in applying ionizing radiation to human beings.

The documented latent effects of low doses of ionizing radiation include the following:

- *Cataractogenesis.* The formation of cataracts, or clouding of the lens of the eye, is an effect that concerns radiologists and radiographers who work extensively in fluoroscopy and those who perform other work that involves repeated exposure to the eyes.
- *Carcinogenesis.* There is an increased risk of malignant disease—particularly cancer of the skin, thyroid, and breast—and leukemia (a group of malignant blood diseases associated with radiation exposure).
- *Life span shortening.* A study of the life span of radiologists who died during a 3-year period before 1945 showed that they had shorter life spans than did physicians who did not use radiation in their practices. This group included physicians who had used radiation since the early days of x-ray science. Additional research has confirmed the link between life span shortening and radiation exposure, but recent studies show that occupational exposure no longer has a measurable effect on the life spans of radiologists.

Genetic Effects

Genetic effects in the form of changes or **mutations** to the genes can be caused when the ovaries or testes are exposed to ionizing radiation. In females, all the ova cells that an individual will ever produce are present 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. The genetic effects of radiation to the testes are manifest for a longer term than may at first be presumed because damage to the stem cells that produce the sperm can result in the continued production of sperm with the genetic mutation. The majority of genetic mutations are considered negative, or less well suited to the survival of the individual than nonmutated cells.

Because reproductive cells have only half the number of chromosomes found in all 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 affect the characteristics of the offspring. Genes that are expressed are said to be **dominant,** and those that are not expressed are called **recessive.** Mutated genes are usually recessive and therefore do not manifest their characteristics in the offspring. Both dominant and recessive genes, however, occur in the reproductive cells of the offspring and may be transmitted to future generations.

> Genes that are expressed are said to be *dominant,* and those that are not expressed are called *recessive.* Mutated genes are usually recessive.

As an increasing percentage of the population is exposed to radiation from natural, environmental, occupational, and health care sources, there is an increased likelihood that individuals will be conceived with a mutation of both genes in a strategic pair, resulting in some type of deformity or maladaptation. Public health officials and governments are highly concerned about preserving the integrity of the population's gene pool by minimizing harmful, defect-causing radiation. This concern should motivate those who apply ionizing radiation to humans 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, relatively few genetic effects have been confirmed by the continuing research into the Japanese populations affected by the atomic bombs dropped on Hiroshima and Nagasaki during World War II, and in other studies of human populations.

RADIATION SAFETY

Clearly, exposure to x-rays creates some risk for patients and radiographers. It is an essential part of your education and your ethical responsibility to be knowledgeable about radiation safety and to use this knowledge to avoid all unnecessary radiation exposure to your patients, your coworkers, and yourself. A comprehensive course on the subject of radiation biology and radiation safety will be a part of the curriculum in your radiography program.

Personnel Safety

Radiographers can be exposed to radiation either from the primary x-ray beam or from the scatter radiation that results from the interaction of the primary beam with the patient or other material in its path. Because radiographers are considered to be "occupationally exposed individuals," they may be prohibited from activities that would result in direct exposure to the primary x-ray beam. This could mean that they are not allowed to hold patients or image receptors (IRs) during x-ray exposures and must stand clear of the path of the primary x-ray beam during fluoroscopic and mobile radiographic examinations. These activities are controlled by state regulations.

As explained in Chapter 1, scatter radiation is ambient radiation in the x-ray room during an exposure. Radiographers are not exposed to any significant amount of this radiation in a typical radiographic room when they stand well behind the protective lead barrier of the control booth. The exposure increases when the radiographer assists with fluoroscopic procedures or uses mobile x-ray equipment. The three principal methods used to protect x-ray equipment operators from unnecessary radiation exposure are *time, distance,* and *shielding.*

Time

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

Distance

The second method of occupational exposure reduction involves using distance. Increasing the distance between yourself and a radiation source decreases your exposure in proportion to the square of the distance according to the inverse-square law (see Chapter 2); for example, doubling the distance between yourself and a radiation source decreases the amount of exposure to one-fourth the amount at the original distance. Therefore, small increases in distance have a relatively large effect. Mobile x-ray units have long cords on the exposure switches, enabling the radiographer to stand a considerable distance from the radiation source while making an exposure.

Fig. 3.1 Protective apparel is available for protection during fluoroscopic and mobile radiographic examinations.

Shielding

The third method is shielding, which is by far the most common method of dose reduction used by radiographers. The lead wall of the control booth provides the primary barrier and is the radiographer's principal defense. Other types of shielding include lead aprons, gloves, goggles, and thyroid shields (Fig. 3.1). These types of shielding should be worn during fluoroscopic procedures and mobile radiographic examinations.

An essential part of your clinical education will be learning to protect yourself and your coworkers from unnecessary radiation exposure. This includes doing a safety check before each exposure—making certain that all personnel are properly protected and that the door is closed before initiating exposures.

Personal Monitoring

Devices for monitoring radiation exposure to personnel are called **dosimeters.** Radiation workers who are issued single badges for monitoring whole-body dose should wear them in the region of the collar with the label facing out. When a lead apron is worn, the dosimeter

Fig. 3.2 *Left:* The current generation of personal dosimeters is the optically stimulated luminescence type. *Right:* Ring badge for workers whose hands receive more than their total body radiation exposure, such as those who handle radioactive materials.

should be outside the lead apron. Technologists who work with fluoroscopy may wear two badges, one on the collar outside the lead apron and one at the waist that is under the apron. The two dosimeters should be distinguished by color or icons indicating their intended locations. Pregnant radiographers also wear a fetal monitor badge at waist level (see the section on Radiation and Pregnant Radiographers later in this chapter).

Personnel who are issued dosimeters should wear them at all times when working in radiation areas and should keep them in a safe place, away from radiation, when off duty. In addition to whole-body badges, ring dosimeters can be worn by nuclear medicine technologists and others whose work results in more exposure to the hands than to the body.

Monitoring dosimeters using **optically stimulated luminescence (OSL)** technology are the most common type of monitoring dosimeter currently used in health care facilities (Fig. 3.2). Aluminum oxide is the radiation detector in this device, which is processed using a laser. OSL dosimeters can measure small doses precisely and can be reanalyzed to confirm results. They are accurate over a wide dose range and have excellent long-term stability.

Radiation monitor badge service laboratories provide dosimeters, processing services, and reports, and keep permanent records of the radiation exposure of each person monitored. Service can be arranged on a weekly, monthly, bimonthly, or quarterly basis. Personnel who receive relatively high doses of occupational exposure change their badges most frequently. Dosimeters cannot accurately measure total exposures that are extremely small. For this reason, personnel who receive very small amounts of exposure will obtain 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 are usually best monitored with a quarterly service. A monthly service is a better choice for those who work in fluoroscopy and those who perform bedside radiography and/or C-arm fluoroscopy frequently.

Service companies provide an extra dosimeter in every batch that is marked *Control*. The purpose of this dosimeter is to measure any radiation exposure to the entire batch while in transit. Any amount of exposure measured from the control badge will be subtracted from the amounts measured from the other badges in the batch. The control badge 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 badge service companies need to know the name and date of birth of all persons to be monitored so that all the records can 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. Exposure reports are sent to the subscriber for each batch, and an annual summary of personal exposure is also provided. Radiation workers 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. Employees exposed to ionizing radiation should not leave their employment without a complete record of their radiation exposure history. Employers are required to provide this information.

> Radiographers should monitor their exposure reports on a regular basis and maintain a record of their exposure history.

Effective Dose Limits

The **ALARA principle** is the guiding philosophy associated with all radiation use that involves exposure to humans—both patients and workers. It states that all radiation exposure to humans should be limited to levels that are ***a**s **l**ow **a**s **r**easonably **a**chievable.*

The effective dose (EfD) limit system is used to calculate the upper limit of occupational exposure that is permitted in specific circumstances. For occupationally exposed personnel, the upper EfD limit is 50 mSv (5 rem) per year. This limit applies to workers older than 18 years who are not pregnant, and it is assumed to be a whole-body dose. These limits apply to occupational exposure only, and not to exposure that workers may receive as a result of imaging or tests related to their own health care.

> For occupationally exposed personnel, the upper EfD limit is 50 mSv (5 rem) per year.

The EfD limit system also states a retrospective or cumulative dose limit that is equal to 10 mSv (1 rem) times the worker's age. For example, a 30-year-old worker with no previous occupational exposure would have a cumulative EfD limit of 300 mSv (30 rem); this is referred to as the *rem bank*. The worker is permitted to exceed the annual limits by small amounts as long as the rem bank is not depleted.

The EfD system also specifies dose limits for specific body organs and tissues. For example, workers who receive exposure to their hands while their bodies are protected may wear ring or wrist dosimeters. A higher dose limit is established for this limited exposure.

The established EfD limits ensure that the safety of radiation workers is comparable with that of workers in other safe occupations. The risk from the allowable exposure is considered to be insignificant, and the occupational dose received by radiographers is usually well below the established limit.

The upper boundaries of the occupational dose were formerly referred to as the "maximum permissible dose." This term is now out of favor because it implies that exposure in excess of the lowest achievable dose is permissible. The ALARA principle must be applied in conjunction with the use of EfD limits. It is important for radiographers not to be complacent simply because their dose is below the limit. Radiation control agencies require the occupational dose to be kept to the lowest levels that are reasonably achievable.

Patient Protection

The topic of patient protection will be addressed repeatedly in various contexts throughout your education in radiography. You will be able to understand this more completely at a later date. For now, you should be aware that radiographers are responsible for minimizing the radiation exposure to patients. The following methods are used to minimize patient dose:

- *Avoid errors.* Double-check imaging orders and patient identification so that the right patient gets the right examination.
- *Avoid repeated exposures.* Establish good routine procedures and follow them strictly so that careless errors do not necessitate repeat exposures. Note, however, that unsatisfactory images must be repeated. Radiation safety cannot be used as a reason for failing to produce a satisfactory examination.
- *Collimate.* Use the smallest radiation field that will encompass the area of clinical interest. In no case should the size of the radiation field be greater than the size of the IR.
- *Use the highest kVp that is consistent with acceptable image quality.* Patient dose is directly proportional to the mAs. High kVp permits using the lowest possible mAs to obtain an acceptable exposure. The combination of high kVp and low mAs is referred to as a "low-dose" exposure.
- *Ensure at least 40 inches of source-image distance.* This practice limits patient exposure from tube housing leakage and collimator scatter.
- *Provide shielding for the gonads, eyes, breasts, and thyroid as appropriate.*

Gonad Shielding

The purpose of gonad shielding is not so much to protect the patient as to limit the genetic effects of radiation on the gene pool of the population. Lead shields that prevent unnecessary radiation to the reproductive organs are required when the patient is of reproductive age or younger, whenever the gonads are within the primary radiation field, and when a shield will not interfere with the examination. Generally, this rule applies to most patients younger than 55 years. A shield device consisting of at least a 0.5-mm lead equivalent is placed between the x-ray tube and the patient. Shields attached to the collimator

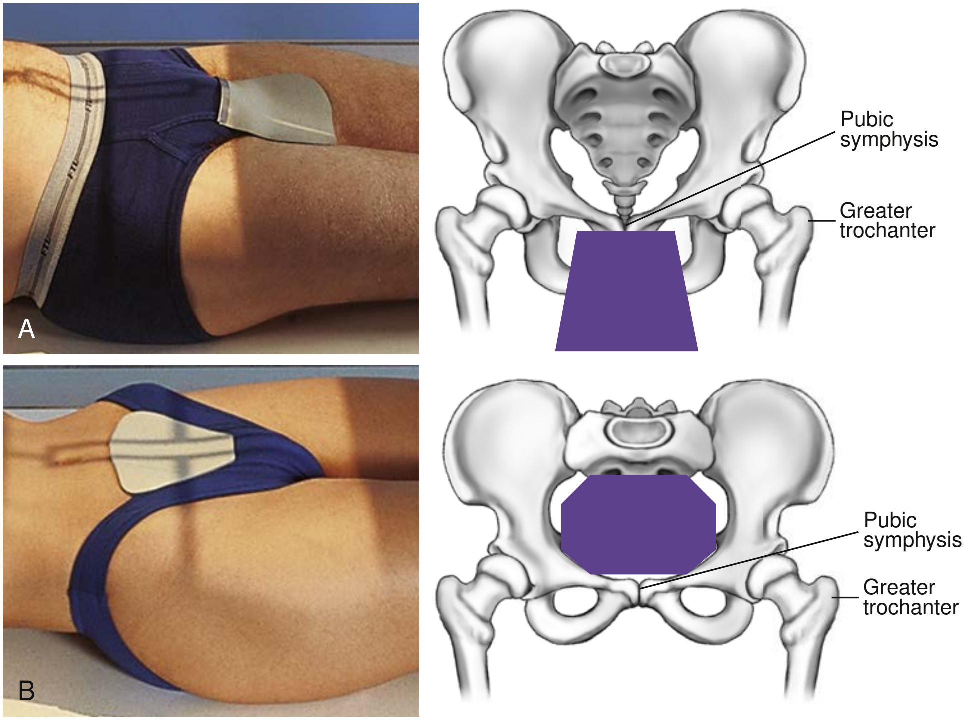

Fig. 3.3 A, The male shield is placed in the midline with its top margin 1 inch inferior to the pubic symphysis. B, The lower edge of the female shield is placed at or near the superior margin of the pubic symphysis. It is centered in the midline, halfway between the level of the anterior superior iliac spine and the symphysis pubis. Note that in both males and females the pubic symphysis is at the level of the greater trochanters. (Photographs from Long BW, Rollins JH, Smith BJ: *Merrill's atlas of radiographic positioning & procedures*, ed 13, St Louis, 2016, Mosby. Line drawings from Long B, Frank E, Ehrlich RA: *Radiography essentials for limited practice*, ed 5, St. Louis, 2019, Elsevier.)

(shadow shields) can be positioned by viewing their shadows within the collimator light field. Shields placed on or near the patient's body are referred to as *contact shields* and are somewhat more effective than shadow shields. Both types meet the legal requirements for gonad shielding.

Fig. 3.3 demonstrates the placement of shields for both males and females. The top of the male shield is placed 0 to 1 inches inferior to the symphysis pubis. The lower edge of the female shield is placed 0 to 1 inches superior to the symphysis pubis. When positioning gonad shielding, it is helpful to remember that the pubic symphysis is at the same level as the greater trochanter of the femur, which avoids the necessity of palpating the pubic symphysis for proper shield placement.

> Lead shields that prevent unnecessary radiation to the reproductive organs are required when the patient is of reproductive age or younger, whenever the gonads are within the primary radiation field, and when a shield will not interfere with the examination.

RADIATION AND PREGNANCY

Radiation and Pregnant Patients

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

Animal studies first alerted scientists that radiation could cause spontaneous abortion of the developing embryo and increase the rate of congenital abnormalities seen in those that 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 during World War II and the nuclear accident at Chernobyl in the Ukraine in 1986. Studies of smaller groups of women exposed to radiation as a result of diagnostic and therapeutic procedures confirm that radiation in excess of 5 cGy to the uterus is cause for some level of concern. In the 1950s, Alice Stewart, an English researcher, demonstrated a 14-fold increase in the incidence of childhood leukemia among children who had been exposed to radiation in utero as a result of x-ray pelvimetry examinations that were then common in the third trimester of pregnancy.

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

The public is generally aware that x-radiation is to be avoided during pregnancy, which can lead to irrational fears on the part of pregnant patients or their families. The chance is extremely remote that a routine radiographic examination of the chest or an extremity would harm a developing child. However, examinations requiring direct radiation to the pelvis, especially relatively high-dose fluoroscopic studies or computed tomography (CT) scans of the abdomen or lumbar spine, should be cause for concern (Table 3.5).

Radiation control regulations require that female patients of childbearing age be advised of potential radiation hazards before radiographic examination. This requirement is usually met by posting signs in the radiology department advising women to tell the radiographer before the examination if they may be pregnant (Fig. 3.4). These signs should be written in all the languages commonly used in the community.

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Examinations of pregnant women are a cause for concern when they require direct radiation to the pelvis, especially relatively high-dose fluoroscopic studies or computed tomography (CT) scans of the abdomen or lumbar spine.

TABLE 3.5 Representative Fetal Doses for Radiographic Examinations

Examination	Fetal Dose (mGy)
Skull (lateral)	0
Cervical spine (AP)	0
Shoulder	0
Chest (PA)	0
Thoracic spine (AP)	0.1
Lumbosacral spine (AP)	0.8
Abdomen (AP)	0.7
Intravenous urogram (IVP)	0.6
Hip*	0.5
Extremity	0

AP, Anteroposterior projection; *IVP,* intravenous urogram; *PA,* posteroanterior projection.
*Gonadal shields should be used if possible.
Adapted from Bushong SC: *Radiologic science for technologists: physics, biology, and protection,* ed 11, St Louis, 2017, Mosby. In Sherer S: *Radiation protection in medical radiography,* ed 8, St. Louis, Elsevier, 2018.

Fig. 3.4 Signs in dressing rooms and imaging suites can alert patients to the potential hazards of radiographic examination when pregnant.

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 x-ray examinations. In practice, however, the possibility of pregnancy may not even be considered. This is especially true in cases of accident or injury for which the emergency department or office visit is brief and the history is limited to the injury complaint. For this reason, *it is essential for the radiographer to consider the possibility of pregnancy in any female of childbearing age.* Ask specific questions to address the issue of pregnancy before performing the examination. Female patients of childbearing age may also be asked the date of their last menstrual period to determine whether there is a possibility that they may be pregnant. A date more than 1 month back could indicate a possible pregnancy. A woman is least likely to be pregnant during the first 10 days of the menstrual cycle, with the onset of menstruation considered to be day 1.

If pregnancy is a possibility, an early pregnancy test, easily and quickly performed in the physician's office or the ER, should clarify the situation. If the patient is 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. Pregnant patients must sign an informed consent recognizing the risks of ionizing to an unborn child. In the case of minor or chronic complaints, it is common to delay the examination until after the child is born.

If an x-ray examination of a pregnant patient must be done, modifications in the procedure can help to minimize the dose to the embryo or fetus. If the part to be examined is not the abdomen or pelvis, the area can be shielded with a lead apron. If the abdomen or pelvis is to be evaluated, the number of exposures, the size of the radiation field, or both, may be minimized, resulting in less radiation exposure than that required for a routine procedure. The decision to do a limited study, and the determination of the exact limitations to be imposed, are the prerogatives of the radiologist.

Radiation and Pregnant Radiographers

Radiation control agencies address the issue of radiation exposure to pregnant radiation workers. The EfD limit of whole-body radiation for the pregnant worker is 50 mSv over the 9-month course of the pregnancy. When a worker declares that she is pregnant by submitting a written document to her employer, the employer is responsible for providing fetal radiation monitoring and for ensuring that the occupational dose does not exceed the EfD limit for pregnant workers. Again, the ALARA principle is important. Every effort should be made to minimize exposure, keeping the dose as far below the limit as possible.

Fig. 3.5 The lead barrier of the control booth protects a pregnant radiographer.

For a pregnant radiographer, the safest work assignment would be one in which a permanent lead barrier (control booth) always shields the worker during exposures (Fig. 3.5). Pregnant radiographers, 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.

SUMMARY

- The traditional or British system of units and the Système Internationale (SI) are used to measure radiation. In the British system, exposure is measured in roentgens (R), dose is measured in rad, and dose equivalents are measured in rem.
- The SI units for these measurements, respectively, are coulombs per kilogram (C/kg), gray (Gy), and sievert (Sv); 1 Gy equals 100 rad, and 1 Sv equals 100 rem.
- Cellular responses to radiation exposure range from no effect to cell death. Although the great majority of cellular injuries are repaired by enzymatic action, cell damage from the direct or indirect action of the x-ray beam can have a negative effect on cell function and reproduction.
- The law of Bergonié and Tribondeau defines the characteristics of cells that affect their sensitivity to radiation injury: age, differentiation, metabolic rate, and mitotic rate.
- Radiation effects can be categorized as somatic or genetic, short term or long term, and deterministic (predictable) or stochastic (random).

- Effects from high doses tend to be somatic, short term, and predictable, whereas low-dose effects are long term and randomly unpredictable, and the risk of their occurrence is extremely small.
- Safety from radiation exposure requires radiographers to avoid contact with the primary x-ray beam; use time, distance, and shielding to minimize exposure; and monitor exposure using dosimeters.
- Protecting the patient from unnecessary radiation exposure involves taking care to avoid errors, using low-dose techniques, and shielding sensitive tissues.
- The effective dose (EfD) limiting system sets limits for occupational exposure. Special rules and limits apply to pregnant radiation workers.
- The EfD system is used in conjunction with the ALARA principle, which states that all radiation exposure to human beings should be as low as reasonably achievable.
- When exposing women of childbearing age to x-rays, precautions must be taken to avoid any inadvertent exposure to an embryo; they include posting signs, asking patients about the possibility of pregnancy, and sometimes using early pregnancy tests.
- Special care must be taken to minimize exposure when x-rays are necessary during pregnancy.

REVIEW QUESTIONS

1. The product of dose in grays times the W_R is equal to the equivalent dose, which in the SI system is measured in units called:
   A. rem
   B. roentgens
   C. rad
   D. sieverts
2. One centigray (cGy) is equal to:
   A. 100 rad
   B. 100 Sv
   C. 1 rad
   D. 1 R
3. The law of Bergonié and Tribondeau states that the sensitivity of cells to radiation injury depends on four principal factors. These factors are cell age, cell complexity, the rate of replication, and:
   A. the rate of energy use by the cell
   B. the cell's location within the body
   C. the rate at which the dose is delivered
   D. the weight of the individual
4. Short-term, predictable radiation effects typically occur as a result of:
   A. high doses of radiation exposure, such as those received in radiation therapy
   B. low doses of radiation, such as those received in diagnostic imaging
   C. occupational radiation exposure
   D. low-dose exposure during pregnancy
5. The term *radiation sickness* refers to:
   A. occupational radiation effects
   B. congenital illness owing to genetic effects
   C. short-term gastrointestinal effects
   D. any stochastic effect
6. The effective dose-equivalent limit for whole-body occupational radiation exposure to nonpregnant radiation workers older than 18 years is:
   A. 1.25 Gy per year
   B. 5.0 Gy per year
   C. 5.0 mSv per year
   D. 50 mSv per year
7. Long-term radiation effects that are apparently random, and have no threshold amount of exposure that must be received for them to occur, are termed:
   A. somatic
   B. genetic
   C. occupational
   D. stochastic
8. Genes that are expressed in the individual are said to be:
   A. mutated
   B. dominant
   C. random
   D. recessive