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Diagnostic Imaging Journeyman

Volume 2. Radiographic Fundamentals

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THIS second of five volumes consists of six units presenting topics related to the radiographic fundamentals in the 4R051 Diagnostic Imaging Journeyman course. The information discussed within this volume covers all the background information you need in order to produce good quality radiographs. This volume contains the technical aspects of radiologic science. Mastery of these technical aspects and concepts is pivotal in your progression as a professional radiologic technologist.

Unit 1 starts the discussion off with a review of atomic theory and ionizing radiation. Unit 2 ventures into the role of electric current, magnetism, and electromagnetic induction in the production of X-radiation and the introduction of the X-ray imaging system. Unit 3 speaks about the production of the useful beam with the use of X-ray tubes and then breaks down the factors that affect beam quantity and quality.

Principles of image quality are covered in Unit 4. You will progress through topics that discuss radiographic density, radiographic contrast, controlling the remnant beam, the affect of geometric factors, and standardized exposure techniques. Unit 5 provides a short discussion about film, intensifying screens, and wet film processing. Unit 6 wraps things up with important talking points about radiobiology, radiation protection, and in general, radiology safety program topics.

A glossary is included for your use.

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This volume is valued at 21 hours and 7 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Page

Unit 1. Basic Atomic Theory

RADIOLOGIC Technologist is a title many people in our career field carry. Someday many of you will also earn technologist status. When you do, you'll no doubt be quite proud of your accomplishment because you know it is not a title that is handed out to just anyone who can shoot a chest or a sinus series. Rather, it is reserved for those individuals who have diligently applied themselves to the study of radiologic science.

It would be a relatively simple task to teach someone basic sets of rules for positioning patients and adjusting control panel settings. That person could then probably produce technically adequate radiographs under normal circumstances with reasonably healthy patients. However, if they encountered an unusual situation (such as severe trauma) that did not fit this basic set of rules, they would be lost. This type individual could not adapt to abnormal imaging situations because they would not understand the fundamental concepts of how radiographic images are produced.

For this reason, this volume will cover what most individuals consider to be the more difficult aspect of our science: the physics of X-radiation (X-ray) production. Unit one begins with basic atomic theory and the concepts of ionizing radiation. By understanding these concepts, you'll be one step closer to becoming a technologist rather than just a button-pusher.

1–1. Atomic Theory

To use radiation to produce quality diagnostic images of the body, you need to understand certain fundamental concepts regarding matter and energy. Knowledge of the functional relationship between matter and energy helps you understand how to produce X-rays, how they behave, and how they affect the human body. We begin by answering the question: "What is matter?"

201. Properties of matter

Have you ever considered the fact that everything around you is matter? *Matter* is anything that occupies space and has weight; it is impossible to name a physical substance or object that is not matter. Coal, water, wood, gas, even the air you breathe are all examples of matter.

Matter

Matter is made up of very small units called *molecules,* which in turn are made up of *atoms*. There are five forms of matter—solids, liquids, gases, plasma, and Bose condensation (or Bose-Einstein condensation). Depending on the substance, matter can exist in any one or a combination of these forms. A *substance* is any material that has a definite, constant composition, and is usually classified as an element or a compound. A primary characteristic that distinguishes matter is mass. Though weight and mass in this discussion are considered to mean the same thing, one must understand that in reality, they are definitely *not* the same. *Mass* is described as the quantity of matter and its equivalent energy while *weight* is measured by how much force is put on the body while under the effects of gravity.

Elements

Elements are the simplest form of any substance. Elements are a substance that cannot be divided or reduced to a simpler form by chemical means. To clarify, gold is an example of a naturally occurring element. If you break down gold to its smallest part, you would end up with one atom of gold. Other examples of elements are pure iron, silver, copper, hydrogen, and oxygen. Currently, the periodic table of elements lists 112 substances (elements) that have been identified, of which, 92 are naturally occurring and the other 20 were created artificially using high-energy particle accelerators. These elements, or combinations of them, make up all the things in our world.

Speaking of combinations, elements may combine in two ways to make additional complicated substances such as compounds or mixtures.

Compound

A compound is a combination of elements that can be separated only by chemical means. Examples of some compounds are pure water (comprised of the elements hydrogen and oxygen) and salt (comprised of the elements sodium and chlorine). A compound is a complex substance that exhibits properties different from the elements that comprise it. The smallest subdivision of a compound is a molecule.

Mixture

A mixture, on the other hand, is a combination of two or more substances (elements or compounds)—each retaining its own physical and chemical properties. For example, salt and sand may be combined to form a mixture. Generally, these components are unchanged and are separable by physical means. To separate the salt and sand mixture, add water to the mixture; the salt dissolves into the water. Next, filter the mixture thus removing the sand. Lastly, using a heat source, the water can be evaporated away leaving only the salt behind.

Molecules

The smallest part of a substance that can exist by itself and retain all the properties of the original substance is a molecule. A molecule is made up of two or more atoms that are attracted to each other because of certain properties in their valence shells, which we'll discuss later. We find that a drop of water can be divided until the parts are no longer visible, yet each part still keeps the characteristics of the original drop. A single drop of water consists of millions of molecules. The chemical formula for a molecule of water is H_2O—meaning that each molecule is made up of two distinct elements (hydrogen and oxygen). H_2O stands for the combination of two atoms of the element hydrogen (H_2) and one atom of the element oxygen (O). The water molecule has a very simple structure consisting of only two common elements. Molecules of other substances may be more complex, sometimes consisting of hundreds or even thousands of atoms of different elements.

202. The atomic model

If all matter is composed of atoms, then what is an atom?

Atoms

The word "atom" is a Greek word meaning "indivisible." An atom is the smallest unit of an element that retains the characteristic properties of that element. Tiny particles called protons, neutrons, and electrons make up an atom. In 1913, Niels Bohr, proposed in theory that an atom could be viewed in essence as a miniature solar system in which electrons (planets) revolve around the nucleus (the sun). In the Bohr Theory on atom content, the atom houses a small, dense, positively charged central nucleus comprised of protons and neutrons surrounded by negatively charged electrons that revolve or orbit the nucleus in a fixed and well-defined manner. It is normal that atoms are

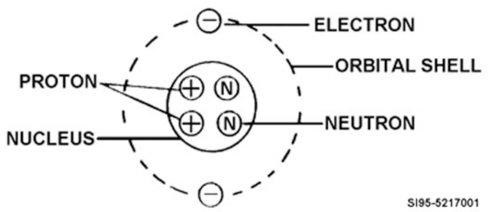

Figure 1–1. Example atomic model of Bohr's Atom.

electrically neutral, meaning the number of negative particles (electrons) orbiting the nucleus is equal to the number of positive particles (protons) in the nucleus. Figure 1–1 is an illustration of Bohr's atom.

Fundamental particles of an atom

There are three fundamental particles of an atom; they are protons, neutrons, and electrons. Protons and neutrons are located within the nucleus and are called *nucleons.* Electrons are very small particles that orbit around the nucleus like planets in our solar system rotating around the sun. We will discuss these "sub-atomic" particles in more detail since they are vital to our understanding of X-ray production.

Protons

Protons are positively charged particles found in the nucleus of an atom. They are about 2,000 times heavier than the mass of an electron even though the positive charge of a proton is equal to the negative charge of an electron. Each atom of an element carries a number of protons that is unique to that element. The number of protons in the nucleus is what determines the atomic number of the element, and is indicated by the variable letter "Z." For this reason, the number of protons is often called the Z number.

Neutrons

Neutrons are also about 2,000 times heavier than the mass of electrons; however, they are electrically neutral meaning they have no charge. The number of neutrons is designated by an "N" within the nucleus formula. Protons and neutrons are both located within the nucleus and are thus termed nucleons. Since nucleons make up the vast majority of the mass of an atom, the sum of the number of neutrons and protons is called the mass number of an element. This mass number is represented by the variable letter "A."*Isotopes* are atoms of the same element that have the same atomic number (number of protons), but a different mass number (number of neutrons) in their nucleus. Because elements consist of a group of isotopes with different atomic weights, one should realize that the mass number of an element is an average rather than a whole number. The mass number ("A") and atomic number ("Z") for an element are written next to the chemical symbol for the particular element to distinguish that element from its isotopes. The notation looks like this:

$$^{A}_{Z}\mathrm{X}$$

Where:

A = mass number
Z = atomic number
X = chemical symbol of the element

For example, the symbol for tungsten is $^{184}_{74}\mathrm{W}$. Its mass number is 184, and its atomic number is 74.

To identify the changes in isotopes, we use the Nucleus Formula. The formula is demonstrated below:

$$A = Z + N$$

Where:

A = mass number
Z = atomic number
N = number of neutrons

Electrons

The third type of particle in an atom is the electron. Electrons, although extremely light compared to protons and neutrons, carry one unit of negative electrical charge that is equal to but opposite the charge of a proton. Electrons whirl around a nucleus in continual motion and are arranged in shells, or energy levels. Each shell has a given letter designation, as shown in figure 1–2. Each shell can hold only a limited number of electrons. We can calculate this number using the formula $2n^2$, where n designates the number of the shell from the nucleus. For example, the M shell is the third shell of an atom. Therefore:

$$n = 3$$

$$2n^2 = 2(3)^2$$

$$= 2(9)$$

$$= 18$$

Using the formula, the M shell can hold a maximum of 18 electrons.

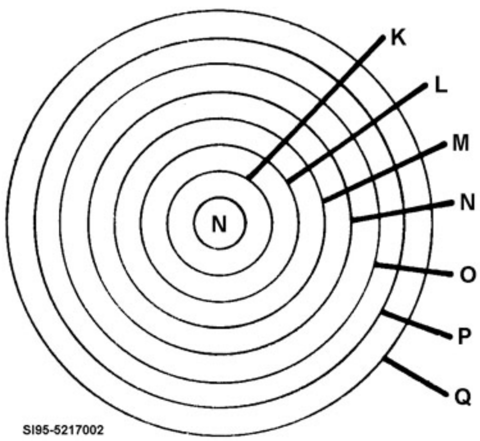

Figure 1–2. Electron shell designation.

Have you ever been on a merry-go-round? If so, then one might wonder why an electron wouldn't spontaneously drift off out of orbit away from the nucleus. What prevents this is called *centripetal (center-seeking) force*. Centripetal force is a result of the electrical law that states opposite charges attract while similar charges repel each other. So if centripetal force is pulling the electrons inward, then why don't they all collapse upon nucleus? Well, there is also another force at work called centrifugal force. *Centrifugal force* is what causes objects to fly-out-from-the-center when spinning around a central point. This force is what you feel when riding a merry-go-round and as the merry-go-round is spun faster and faster, you feel like you are being pulled off and away from the center. It is the delicate balance between centripetal and centrifugal forces that allows electrons to maintain a consistent distance from the nucleus of an atom when orbiting around it.

When the atom is in the stable or neutral state, electrons (negative charges) are balanced against the protons (positive charges) of a nucleus. Once this balance in atomic charge is disrupted by the loss or gain of an electron, the atom becomes an ion, or charged particle. We'll discuss ionization in detail later in this course.

203. Atomic characteristics

All atoms of a particular type behave the same chemically and electrically. This is because they each possess certain characteristics that determine how they react to their environment.

Valence

Valence electrons are those electrons found in the outermost shell (valence shell) of an atom. Their number, which can *never* be more than eight, is indicated by the family or group the element falls within on the periodic table and it helps indicate the valence of the atom.

An atom's valence is a number that indicates the chemical characteristics (ability to combine with other atoms) and electrical characteristics (ability to conduct electric current) of an element. The valence of a particular element depends upon the number of valence electrons, which is specified as follows:

Number of Valence Electrons	Valence
1	+1
2	+2

Number of Valence Electrons	Valence
3	+3
4	±4
5	–3
6	–2
7	–1
8	0

There are two exceptions to the previous table:

- Hydrogen with one valence electron is considered to have a valence of +1 or –1.
- Helium with two valence electrons has a valence of 0.

Helium is in the 8th family or group of the periodic table. Every element in the 8th group is stable according to the Bury-Bohr principle. The Bury-Bohr principle, also known as the Rule of Octet, states that a valence shell cannot contain more than 8 electrons. Helium is unique because it only contains 2 protons, which is stabilized with two electrons rotating its fixed K shell.

Elements with a positive valence have a tendency to give up their valence electrons when chemically combining with other elements. Elements with a negative valence have a tendency to accept electrons from other elements in chemical combination. Elements with a valence of ±4 may either give up or accept electrons. Finally, elements with a valence of zero (0) are highly resistant to chemical combination.

Elements with a positive valence are generally good conductors of electricity. More specifically, elements with a valence of +1 are better conductors than those with a valence of +2, and +2 valance elements are better conductors than the +3 valence elements. Elements with a negative valence are electrical insulators (resistant to electrical conduction). Elements with a valence of ±4 may act as either conductors or insulators under different circumstances and are called semiconductors.

Energy levels

Energy level and *shell* are two terms sometimes used interchangeably. It is probably more convenient to think of energy level as representing the relative amount of energy possessed by a shell or more precisely, possessed by the electrons in a shell. A shell farther from the nucleus has a higher energy level than a shell nearer the nucleus.

From the preceding discussion, we may assume that the L shell is at a higher energy level than the K shell; consequently, an electron in the L shell is also at a higher energy level than an electron in the K shell. If an electron is somehow removed from a shell other than the valence shell, an electron located in a shell with higher energy may replace the missing electron. If these two events occur, the electron that moved from the higher to the lower energy level (shell) releases part of its energy as either electromagnetic energy (an X-ray photon) or heat. The amount of energy released by the electron is equal to the difference in energy levels between the two shells.

Binding energy

The energy required to remove an electron from its shell to a point just outside the atom is called the *binding energy*. Some authors refer to binding energy as negative energy since an electron is “missing” the energy to escape the atom.

The binding energy is the same for all electrons of a particular shell of a particular element and is expressed in electron volts (eV) or kiloelectron volts (keV). For example, the binding energy of tungsten’s K shell is about 69,500 eV (69.5 keV).

The binding energy for electrons is different from shell to shell of a particular atom. The electrons with the greatest binding energy are those electrons that are closest to the nucleus. For example; the binding energy for tungsten's L shell is about 12,000 eV while that of the M shell is about 2,000 eV. A shell closer to the nucleus has higher binding energy because the electrostatic force of attraction between the positive nucleus and negative electrons is greater at shorter distances. Thus, more energy is needed to overcome this force and free electrons from shells closest to the nucleus.

The binding energy of a particular shell also varies from one element to another—the higher the atomic number, the higher the binding energy of similar shells. The K shell binding energy of tungsten (Z=74) is 69.5 keV while that of barium's (Z = 56) K shell is about 37 keV. This difference is due to the number of protons in the nucleus. More nuclear protons increase the positive charge of the nucleus, which increases the electrostatic force of attraction.

204. Energy and its relationship to matter

Energy is an even more basic form than matter. In other words, all matter is comprised of energy—a fact that Albert Einstein proved with his formula $E=mc^2$. Since this is an equation, one side can be converted to the other under the right circumstances.

Energy

Energy is common to all forms of matter. Unlike matter, energy is not a substance and it does not occupy space. Energy is defined as the capacity to perform work. The following are different types of energy: potential, kinetic, chemical, electrical, thermal (heat), nuclear, and electromagnetic energy.

Potential

Potential energy is the energy of position or stored energy waiting to be released under the right circumstances. An example of potential energy is water being held back by a dam.

Kinetic

Kinetic energy is the energy of motion. When potential energy is released, it becomes kinetic energy. In keeping with our previous example, if we were to open the floodgates on the dam, the water would begin rushing through. The moving water has kinetic energy that can be harnessed by placing turbines in the path of the flowing water. The turbines produce electricity that could be stored in batteries thus converting the energy back into potential energy. Energy is constantly being changed from one form to another.

Chemical

Chemical energy is energy that is a result of a chemical reaction. Examples of chemical release of energy are a firecracker exploding or even the energy we receive from the molecules in the food we eat.

Electrical

Electrical energy is created when an electron moves through an electrical potential difference. Even as you read this paragraph, electrical energy is being released all around you in order for the lights, a fan, a heater, or even a personal computer to function.

Thermal

Thermal energy is the energy created at the molecular level with motion. Molecules of a substance vibrate and this vibration releases thermal energy. The faster the molecules vibrate in a substance means there is more thermal energy to use but it also means the temperature of the substance will increase as well.

Nuclear

Energy that comes from within the nucleus of an atom is called nuclear energy. When we control the release of energy from atoms, we can use it to power entire cities with electricity. An atomic bomb is an example of an uncontrolled release of this type of energy.

Electromagnetic

Though most people are probably unfamiliar with this type of energy, electromagnetic energy cannot go unmentioned because it is the type of energy that is used in an X-ray. In a radiology department, electrical energy is used to power the imaging unit (system) which then creates electromagnetic energy, an X-ray, which then is changed to chemical energy when it interacts with radiographic film. When electromagnetic energy is released and transferred through space, it is called *radiation*. When a guitar string vibrates, it radiates sound. The sun at the center of our solar system radiates electro-magnetic energy in the form of visible light. When matter gets in the way of electromagnetic energy, it is said to have absorbed it in part or whole and therefore is irradiated (exposed).In the next section of this unit, we will talk in more detail about a special type of electromagnetic radiation that includes X-rays called ionizing radiation.

Transformation of energy

All changes in the universe involve the transformation of energy. The law of conservation of energy states that energy may be changed from one form to another; however, it cannot be either created or destroyed. Thus, the total amount of energy in the universe is constant. Albert Einstein's mass-energy equivalence formula, $E=mc^2$ (energy equals mass times the speed of light squared in a vacuum) illustrates his theory of relativity that matter and energy are interchangeable. With that said, matter can be converted to other types of matter, energy to energy, matter to energy, or energy to matter (or there can be a partial change of each). An atomic explosion illustrates how a tiny amount of matter is converted into a relatively large quantity of energy. The matter that seems to be destroyed is actually converted to energy.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

201. Properties of matter

1. What is the definition of matter?

2. What are the five forms of matter?

3. What is the definition of an element?

4. What is a compound?

5. What is a molecule?

202. The atomic model

1. What is an atom?

2. What is the electrical charge of a normal atom?

3. Name the three fundamental particles of an atom.

4. Protons and neutrons are located in the nucleus and are called what?

5. What determines the atomic number of an element?

6. Briefly describe what the 184 stands for in the symbol ${}^{184}_{74}W$.

7. What is an isotope?

8. Using figure 1–2 and the formula $2n^2$, what is the maximum number of electrons the M shell can hold?

203. Atomic characteristics

1. What are valence electrons?

2. What does an atom's valence number indicate?

3. What are atoms with a valance of ±4 called?

4. What happens when an L shell electron drops down to fill a vacancy in the K shell?

5. Define binding energy.

6. Which electrons have the greatest binding energy?

204. Energy and its relationship to matter

1. Define potential energy.

2. Define kinetic energy.

3. What is radiation?

4. What is the law of conservation of energy?

1–2. Ionizing Radiation

As discussed with electromagnetic energy in the previous lesson, radiation is a term that describes energy emitted and transferred through matter (space). In diagnostic imaging, we are primarily concerned with a particular type of *ionizing* radiation known as X-rays. We begin with the discovery of X-rays.

205. The discovery of X-rays and sources of ionizing radiation

On November 8, 1895, Wilhelm Roentgen accidently discovered X-rays while researching cathode rays (electrons) using a partially evacuated glass tube (the Crookes tube). It is important to note here that X-rays were discovered, not developed.

The discovery

On the day of discovery, Wilhelm Roentgen was in his darkened laboratory and had covered the Crookes tube with black photographic paper that allowed no light to escape the tube. Out of chance, Roentgen had a plate coated with a fluorescent material (barium platinocynide) sitting on top of a nearby bench. During his research that day, he noticed the plate glowed and the intensity of the glow increased when the plate was put in closer proximity to the Crookes tube.

Roentgen called the substance making the plate glow, "X-light," with the letter "X" representing the unknown. In the weeks that followed, Roentgen investigated the X-light feverously by exposing it to different materials like wood, metal, and even his own hand. Shortly after the New Year in 1896, using his wife's hand, he successfully produced and published the first medical X-ray image. Most of the properties he used to describe X-radiation in those early weeks of research are still recognized throughout our profession even today.

Sources of ionizing radiation

Radiation, in its simplest form, is the transfer of energy through space. Though most types of radiation energy is harmless, like sound from a guitar string or ripples produced when a rock is dropped into a calm body of water, ionizing radiation can cause life threatening effects on humans. There are two fundamental sources of ionizing radiation—natural environmental and man-made radiation.

Natural environmental radiation

Three areas comprise natural environment radiation exposure; they are cosmic rays, terrestrial radiation, and internally deposited radionuclides. Cosmic rays are produced by the sun and stars. Terrestrial radiation exposure is from certain minerals in the earth like uranium. Internally deposited radionuclides are natural metabolites like potassium-40 that have been with us since the beginning of time. The biggest source of natural environmental radiation is from a radioactive gas called *radon* that is created when uranium decays. Radon gives off alpha particles that are not strong enough to penetrate matter but are present in all earth-based materials like concrete and gypsum wallboard. Natural environmental radiation contributes approximately 300 millirem (mrem) to the United States population annual dose.

Man-made radiation

The main source of man-made radiation is diagnostic X-rays for medical purposes. In 1990, the population's dose exposure estimate was around 39 mrem per year. However, with the increased use of multislice spiral computed tomography and fluoroscopy, current estimates put the population's dose exposure around 320 mrem per year. Since the benefits of diagnostic X-rays definitely outweigh the risks, the responsibility typically falls on the frontline-worker in diagnostic imaging, the technologist, to reduce unneeded medical exposures to patients and colleagues. More discussion on radiation protection will take place in unit 6 of this volume.

206. Types of ionizing radiation

In general, ionizing radiation refers to any type of energy that has the ability to remove an orbital electron from an atom. *Ionization* is a term used to describe this type of interaction between radiation and matter. Ionization of an atom occurs when an X-ray passes close enough to an orbital electron and transfers enough energy to the orbiting electron to remove it from the atom. There are two types of ionizing radiation known to man: particulate radiation and electromagnetic radiation.

Particulate radiation

Sub-atomic particles possessing sufficient kinetic energy have the ability to ionize matter. Such particles, when in motion, are called particulate radiation. One of the main sources of this type of radiation is radioactive nuclei. These are atoms with inherently unstable nuclei that *decay* or give off particles. This is the basis for nuclear medicine—a branch of diagnostic imaging.

Nuclear medicine involves the injection or ingestion of specific types of radionuclides into the body that are designed to be selectively absorbed by various organs or systems of the body. For instance, when a radioactive isotope of iodine (^{131}I) is ingested, it concentrates in the thyroid gland. After a certain amount of time elapses, technologists can image the thyroid using special cameras designed to measure the radiation given off by the radioactive material (^{131}I).

Electromagnetic radiation

Electromagnetic energy is energy that has both electric and magnetic properties and travels at the speed of light. We use many types of electromagnetic energy in our daily lives to include radio waves, light, microwaves and, of course, X-rays. Electromagnetic energy is often grouped together and represented graphically by what is known as the electromagnetic spectrum (fig. 1–3). The lowest energy radiations lie to the left of the spectrum with the higher energies progressing farther and farther to the right. While not all parts of the electromagnetic spectrum are capable of ionizing matter, the portion we are most concerned with (X-rays) is capable.

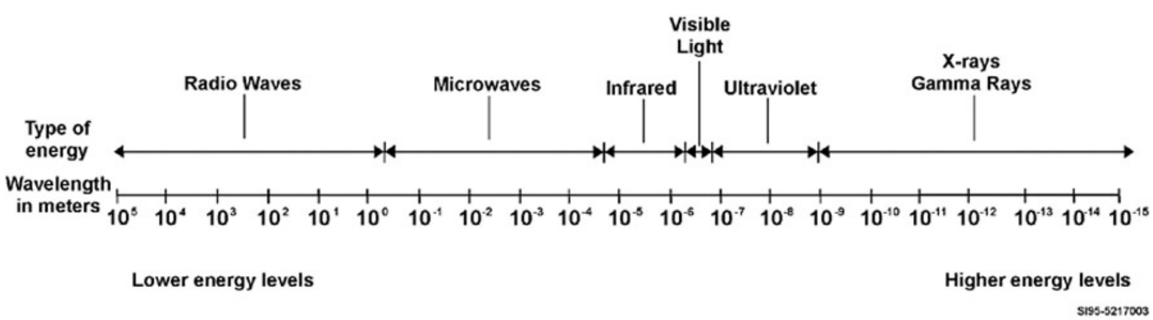

Figure 1–3. The electromagnetic spectrum.

X-rays and gamma rays

X-rays and gamma radiation occupy the same portion of the electromagnetic spectrum. They are identical except for their origin. X-rays are produced in the electron cloud of an atom and are the result of an artificial stimulation such as bombardment of the electron shell with electrons. Gamma radiation is emitted spontaneously from the nuclei of radioactive atoms.

Characteristics of electromagnetic radiation

All forms of electromagnetic radiation possess certain properties that distinguish them from one another. For purposes of discussion, it is often helpful to visualize these properties. For this reason, the sine wave (fig. 1–4) is often used in physics to represent various forms of energy which includes electromagnetic energy. Specific properties of an energy form may be represented by a sine wave. These include amplitude, velocity, frequency, and wavelength.

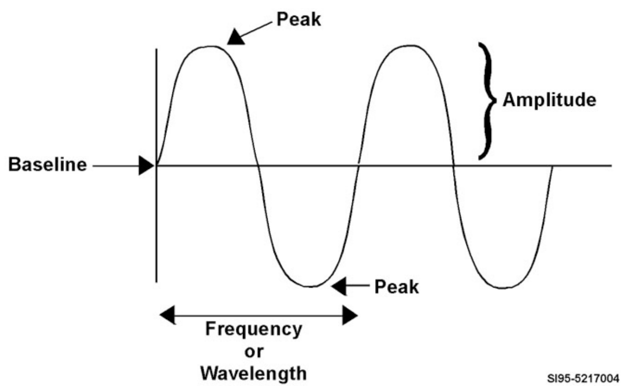

Figure 1–4. The sine wave.

Amplitude

Amplitude always refers to the height of the peak of the sine wave from the baseline. It usually represents the strength or energy level of the energy form it represents. However, due to certain properties of electromagnetic radiation, the energy level may be deduced from either frequency or wavelength. Therefore, amplitude is relatively unimportant in our discussion of X-radiation.

Velocity

Velocity is, of course, the speed at which the energy form travels. It cannot be directly represented by a sine wave, but it may be determined by taking the product of frequency and wavelength. The formula is as follows:

$$v = f \times \lambda$$

Where:

v = velocity

f = frequency

λ = wavelength

However, we already know that electromagnetic radiation, hence X-rays, always travel at the speed of light. The speed of light is a known constant throughout the universe of approximately 186, 282 miles per second. Therefore, it is often represented by a “c” in mathematical equations.

Frequency

Frequency, as its name implies, refers to how often a cycle is repeated. A cycle is equal to one peak and one valley of the sine wave. The unit of measurement for frequency is hertz (Hz). One Hz is equal to one cycle per second. The prefixes “kilo” and “mega” are often used in association with hertz to mean one thousand and one million cycles per second, respectively. Frequency can be represented by a sine wave providing the base line is a measurement of time rather than distance.

Wavelength

The distance from peak to peak or from valley to valley on the sine wave represents the wavelength of the energy form. In looking at the velocity formula, substitute the constant "c" (the speed of light) for the variable "v" (velocity) we end up with

$$c = f \times \lambda$$

Since we now have a constant on the left side of the equation, it is easy to see that frequency and wavelength are inversely proportional to one another. That is to say, as one value increases, the other value must decrease proportionally in order for their product to remain constant.

In electromagnetic radiation, frequency and wavelength are directly related to the energy level of the radiation. We find that, as the energy level of a beam of radiation increases, the frequency of the beam also increases and, therefore, the wavelength decreases. The reverse is also true; as the energy level decreases, frequency decreases and wavelength increases.

207. Electron interactions with matter

Within matter, X-rays are produced when electrons interact with either the nucleus of an atom or by dislodging orbital electrons. Typical interactions are classified as either bremsstrahlung or characteristic radiation.

Bremsstrahlung radiation

Bremsstrahlung (German for "braking") radiation is produced as a result of an incident electron interacting with the nucleus of an atom. When a negatively charged electron approaches the positively charged nucleus of an atom, the attractive force of the nucleus may deflect or change the electron from its original course or direction. This change of direction causes a deceleration of the electron or a loss of some of its kinetic energy. Since we know that energy cannot be destroyed, something must happen to the lost energy. The energy lost by the electron may be converted into an X-ray photon. The energy of the resultant photon depends upon the original kinetic energy of the electron, how close the electron comes to the nucleus, and the charge of the nucleus.

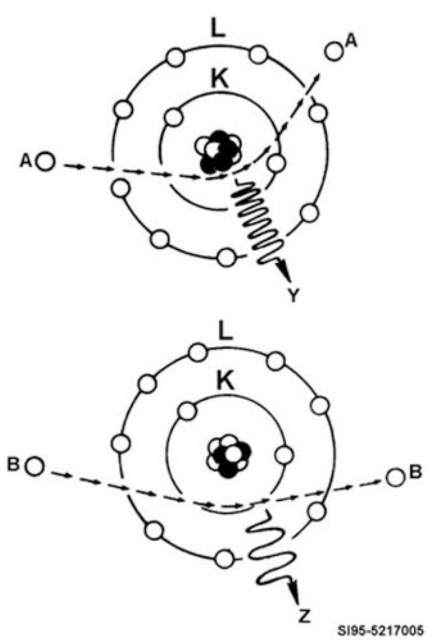

Figure 1–5. Bremsstrahlung radiation.

Figure 1–5 shows two separate radioactive interactions. The two electrons, A and B, have been deflected from their original direction by the attractive force of the nucleus. The wavy lines represent the emitted X-ray photons. (**NOTE:** Electron A, which passes closer to the nucleus, had its original direction deflected more than electron B.) In this example, if electron A and B approached the nucleus with the same kinetic energy, then photon Y would have more energy than the photon Z, because of greater electron deceleration.

Since in this type of interaction the electron loses only a portion of its kinetic energy, it may have one or more interactions with other atoms before expending all its energy. In this manner, it would produce several photons with various energies. Figure 1–6 shows how an electron might interact with more than one atom to produce photons with a wide range of energies.

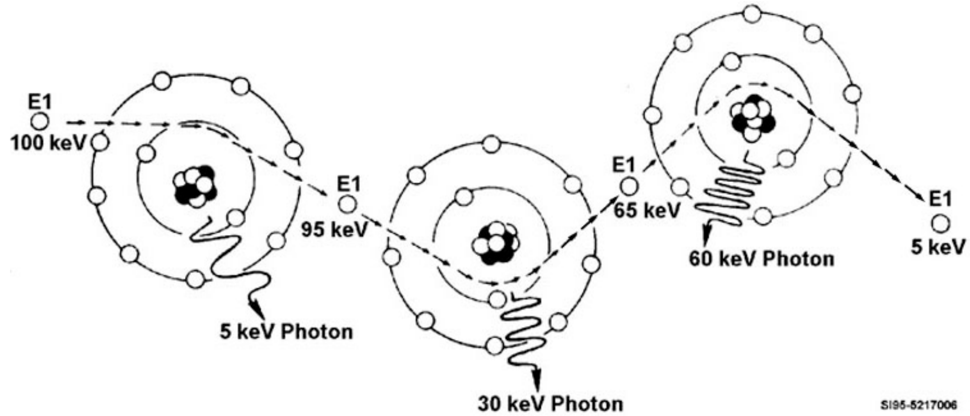

Figure 1–6. Multiple "braking" interactions.

Bremsstrahlung radiation energy levels can range from very low to the total amount of energy possessed by the impinging electron depending on how much deceleration takes place.

Characteristic radiation

The discussion up to this point dealt with how X-rays are generated when electrons interact with the nucleus of an atom. *Characteristic* radiation is radiation that is produced when an electron from a higher energy shell drops down to fill a vacancy in a lower orbital shell.

In this type of interaction, an electron collides with a tightly bound orbital electron, such as an electron in the K shell of an atom of tungsten as in figure 1–7. As a result of the collision, the K electron is ejected from its shell, and energy is absorbed by the atom equal to the binding energy of the shell. The interaction leaves the atom in an excited state with an excess of energy and an electron vacancy in the shell.

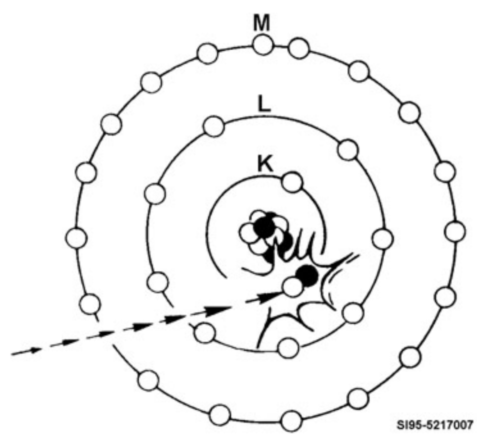

Figure 1–7. Collision of a projectile electron with a K-shell orbital electron.

Immediately after excitation, the atom returns to a normal state by emitting the energy it absorbed as an X-ray photon. Since the potential energy of an electron in the L shell is higher than that of an electron in the K shell, the L electron loses energy in the transition. The energy lost is equal to the difference in the binding energies of the K and L shell and is given off as an X-ray photon.

Although a photon has been emitted, the process is not yet completed because there is now a vacancy in the L shell, and the atom still has an excess of energy. This vacancy is almost immediately filled by another electron, such as one from the M shell, and the atom emits another photon equal to the energy of the difference of the transition. This chain reaction continues with a photon given off for each electron transition until the atom has no shell vacancies and again is in a normal state. (The vacancy in the last shell is filled by a free electron.)

Figure 1–8 shows an atom of tungsten with only the K, L, and M shells demonstrated. The binding energy of tungsten's K, L, and M shells are 69.5, 12, and 2 keV, respectively. In the top illustration, the impinging electron collided with and ejected a K shell electron from its shell, and both electrons leave the vicinity of the atom. In the bottom illustration, as the electron transitions take place, two photons are emitted with energies of 57.5 keV (the difference in binding energies of the K and L shells) and 10 keV (the difference in binding energies of the L and M shells).

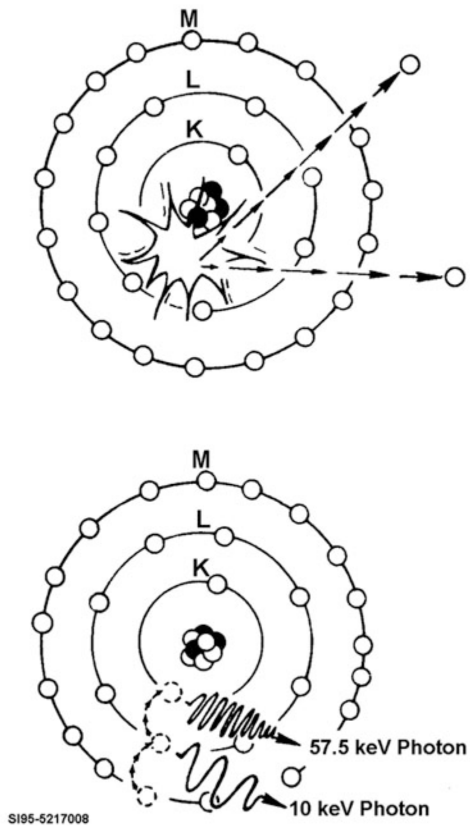

Figure 1–8. Production of characteristic radiation.

The radiation produced in this manner is called characteristic radiation because its energy is characteristic of the shell of the atom from which it came. Of course, the energy level of characteristic radiation varies with the type of target material and is dependent on the binding energy of the shells involved. For example, the binding energy of the K shell in copper is 9 keV; therefore, the maximum energy of characteristic radiation that could be generated in copper would be 9 keV, an amount not usable in radiology. Tungsten, however, can generate characteristic radiation with a maximum energy level of 69.5 keV, some of which is usable in diagnostic radiology.

To produce characteristic radiation, an electron must be ejected from its shell. The energy required to remove an electron from its shell must be equal to or greater than the binding energy of the shell. Since the binding energy of tungsten's K shell is 69.5 keV, it would require an electron with at least 69.5 keV of energy to eject the K electron and thus generate useful characteristic radiation from tungsten. You should note that 12 keV of electron energy could eject an L electron (12-keV binding energy) from tungsten, thereby producing characteristic radiation. However, this radiation's maximum energy would be 12 keV, which is not useful in radiology and would be filtered out.

Throughout the discussion, we have dealt with one electron and its interaction. When millions of electrons interact with millions of atoms in both manners (Bremsstrahlung and characteristic) as described, obviously a wide range of photon energies is generated. Also, this section presented the production of X-rays at the atomic level. Later, we'll show the equipment and process necessary to produce the atomic interaction we explained here.

208. X-ray interactions with matter

The term "interaction" is one force or body having a measurable effect on another force or body. One can see daily evidence of interaction in a bowling alley, at the lake watching a moving sailboat, or on the job in many uses of electrical transformers. The interaction we will focus on in this lesson takes place when a beam of X-ray photons passes through any type of matter.

Photon interactions

An X-ray beam transfers its energy to the matter through which it is passing. The matter can be air, a piece of X-ray film, or the living tissue of a radiologic technologist or patient. This transfer of energy is not as simple as that seen in bowling, sailing, or electrical transformers. In many cases, radiation interactions are not immediately evident without complicated devices to detect these events.

Some, if not all, of the X-ray energy seems to disappear in certain material; this phenomenon is called *absorption.* Absorption is the process by which an X-ray photon transfers its inherent energy to the medium through which it is passing. Some results of this absorption are chemical changes in film emulsion, electrical changes in a radiation detection instrument, and biological changes in living tissue. These changes are all brought about by a process called *ionization.*

Ionization

Specifically, *ionization* is any process that results in the removal or addition of an orbital electron from or to an atom or molecule, thereby leaving the atom or molecule with an overall positive or negative charge. Ionization can occur when a photon strikes an electron, at which time an energy transfer takes place. Although it is technically possible for this energy transfer to take place in the nucleus, chances for a photon reaching the vicinity of the nucleus are extremely remote. After an ionizing event occurs, the remaining particles are called an *ion pair* (in the case of electron removal). Parent atoms (minus an electron) have an overall positive charge and are known as a *positive ion.* The ejected electron has a negative charge and is known as a *negative ion.* Figure 1–9 illustrates this process of ionization.

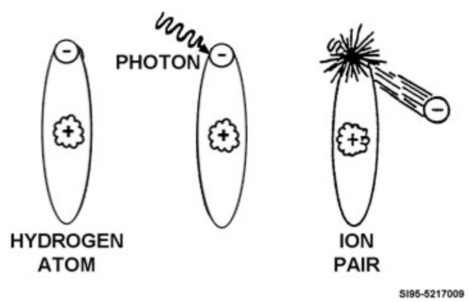

Figure 1–9. The ionization process.

We measure radiation according to the number of ion pairs produced in air. Whenever a large number of ions are produced in air, a large number of electrons are liberated. A large number of freed electrons create an electrical charge. Whenever 2.58×10^{-4} coulombs of electrical charge are generated in 1 kilogram (kg) of air, we can say that 1 roentgen (R) of radiation exposure is present. Thus, a roentgen is the quantity of radiation exposure in air and applies only to X-rays and gamma rays. One roentgen (1R) equals about 2 billion ion pairs in 1 cubic centimeter (cc) of air at standard pressure and temperature.

Types of interactions

There are five basic ways in which X-ray photons interact with matter. Although we'll discuss all five, only two are common to the diagnostic range of X-radiation (20 to 150 keV). We'll begin with these two—the photoelectric effect and the Compton effect.

Photoelectric effect

The *photoelectric effect* (PE), illustrated in figure 1–10, occurs when an incident photon imparts all of its energy to an inner-shell electron, after which the photon no longer exists. The ejected electron, called a *photoelectron*, departs the atom with kinetic energy equal to the difference between the energy of the incident X-ray photon and the binding energy of the electron. The photoelectron can cause secondary ionizations due to its increased kinetic energy. In the meantime, the excited atom—now a positive ion—quickly attracts another electron to fill the vacant "hole," and a characteristic radiation photon is produced as the atom returns to its normal state. Thus, three end products always result from a PE interaction:

- Characteristic radiation.
- A negative ion (the photoelectron).
- A positive ion.

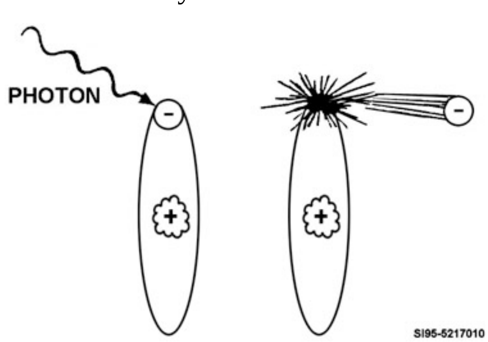

Figure 1–10. The photoelectric effect.

The probability of a PE occurring depends on two factors: (1) the energy of the incoming photon and (2) the atomic number (Z number) of the absorber. The energy of the incident photon must be greater than the binding energy of the target electron. As the energy of incident photons increase, the probability of PE interaction decreases (an inverse relationship). Therefore, PE interactions are most likely to occur with low energy photons. In fact, PE normally occurs with photon energies up to 100 keV, and more often at lower energies.

The other factor that greatly affects the probability of a PE occurrence is the atomic number of the matter through which the photon passes. This is a direct relationship; the greater the Z number, the greater the probability of a PE occurrence.

Photoelectric effect is undesirable from the viewpoint of the patient because of the absorption of photon energy by the patient; this could lead to biological changes in the tissues. On the other hand, we must have PE interactions to produce radiographic contrast.

Compton effect

The *Compton effect,* or Compton scattering (CS), is the result of a partial transfer of energy from an incident photon to an outer-shell electron (fig. 1–11). In this case, the photon strikes a glancing blow to an outer-shell electron and ejects it from its orbit. (Outer-shell electrons are involved with Compton effect interactions because they have lower binding energies.) After striking an outer shell electron, the photon continues in a slightly different direction with less energy as a "scattered" photon. Both the scattered photon and the Compton electron (the ejected outer-shell electron) may have additional ionizing interactions if enough energy still exists. Eventually, the scattered photon disappears via a final PE interaction. As the Compton electron loses its kinetic energy, it ends up filling a vacancy in another atom's shell created by other ionizing interactions.

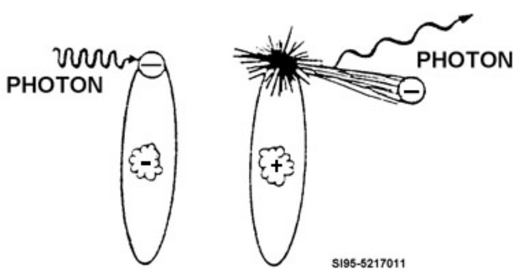

Figure 1–11. The Compton effect.

The probability of CS is dependent upon the energy of the incident photon. In figure 1–12, we can see the relationship of photon energy, and production of PE and Compton interactions. Notice that as photon energy increases, the relative number of CS decreases. As photon energy increases far beyond the diagnostic radiology range (not shown in fig. 1–12), the probability of a CS interaction (and a PE, for that matter) is greatly reduced because high-energy photons are more likely to pass through the body without significant interaction.

You may also notice in figure 1–12 that PE is prevalent below 60 keV. Above that level, the Compton effect is the predominant interaction (within the diagnostic radiology range). In summary, then, we can state that as keV increases, the total number of interactions by PE and CS decreases, and of those interactions above 60 keV, most within the diagnostic energy range are CS.

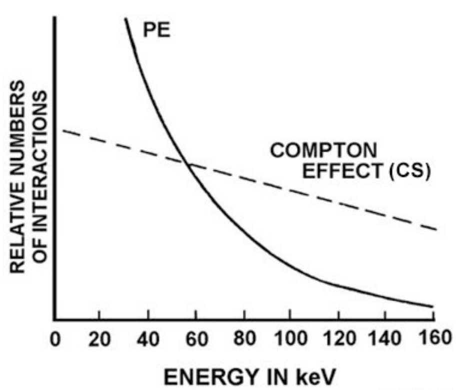

Figure 1–12. The relationship between keV energies and the relative quantity of interactions produced.

Coherent scatter

Coherent scatter, also called *Thompson scatter or classical scattering,* results when a low-energy photon encounters an orbital electron and changes direction without any transfer or loss of energy (see fig. 1–13). This interaction occurs only with photons of only a few keV of energy. Although it can cause some scattered radiation, which could cause image fog, only a small percentage of radiation undergoes coherent scattering (as compared with PE and CS); therefore, it is of little concern to us.

Pair production

When a high-energy gamma or X-ray photon passes very close to the nucleus of a heavy atom, it can interact with the nuclear force in such a way that the photon vanishes. Its energy is converted into two particles: an electron, known as a negatron, and a positron. Both particles have equal mass but opposite electrical charges. In addition, both particles can cause additional ionizations (Compton and PE) until their energies are expended. The negatron and positron, when chemically combined, exist for 10^{-10} seconds before annihilating each other through the process of annihilation reaction. This process releases 2 new X-ray photons, each with half the energy of the incident photon.

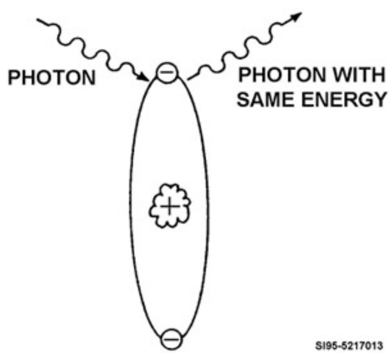

Figure 1–13. Coherent scattering.

Pair production only occurs at photon energies greater than 1.02 million electron volts (MeV) and is the predominant interaction among photons with energies in the 5 to 12 MeV range. For that reason, pair production is not a major concern within the diagnostic radiology range; however, it is very important in the field of Nuclear Medicine for positron emission tomography (PET) imaging.

Photodisintegration

Photodisintegration occurs when very high energy (usually above 10 MeV) photons are absorbed directly by a nucleus. The instant this occurs, the nucleus is in an excited state, because of its excess energy, and ejects a nucleon. A chain of ionization events then develops until the energy of the nucleon is used up. Photodisintegration—like pair production—occurs only at energy levels well outside the diagnostic radiology range; therefore, it is of no major concern to radiologic technologists although both are important to radiation therapy technologists.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

205. The discovery of X-rays and sources of ionizing radiation

1. When and by whom were X-rays discovered?

2. When X-rays were originally named X-light, what did the “X” stand for?

3. What is the biggest source of natural environmental radiation?

4. Who is responsible for reducing unneeded radiation exposures to patients and colleagues?

206. Types of ionizing radiation

1. What is one of the main sources of particulate radiation?

2. Define electromagnetic energy.

3. What is the difference between X-rays and gamma rays?

4. What is frequency and how is it measured?

5. How does frequency relate to wavelength?

207. Electron interactions with matter

1. Describe bremsstrahlung radiation.

2. What determines the energy of a photon of bremsstrahlung radiation?

3. What is characteristic radiation?

4. What determines the energy level of characteristic radiation?

208. X-ray interactions with matter

1. Define absorption.

2. Define ionization.

3. What is a roentgen and what is it equal too?

4. What two types of X-ray interactions with matter are common to the diagnostic range of X-radiation (20 to 150 keV)?

5. What three end products always result from a PE interaction?

6. What two factors control the probability of a PE interaction?

7. The Compton effect is the result of what?

8. When does coherent scatter occur?

Answers to Self-Test Questions

201

1. Anything that occupies space and has weight.
2. Solids, liquids, gases, plasma, and Bose condensation.
3. A substance that cannot be divided or reduced to a simpler form by chemical means.
4. A combination of elements that can be separated only by chemical means.
5. The smallest part of a substance that can exist by itself and retain all the properties of the original substance.

202

1. It is the smallest unit of an element that retains the characteristic properties of that element.
2. Electrically neutral.
3. Protons, neutrons, and electrons.
4. Nucleons.
5. The number of protons in the nucleus of one atom of the element.
6. The mass number, which is the total number of protons and neutrons in an atom of an element.
7. Atoms of the same element that have the same atomic number (number of protons), but a different mass number (number of neutrons) in their nucleus.
8. 18.

203

1. Those electrons found in the outermost shell (valence shell) of an atom.
2. The chemical characteristics and the electrical characteristics of an element.
3. Semiconductors.
4. The electron that moved from the higher to the lower energy level (shell) releases part of its energy as either electromagnetic energy (an X-ray photon) or heat.
5. The energy required to remove an electron from its shell to a point just outside the atom.
6. Those electrons that are closest to the nucleus.

204

1. Energy of position or stored energy waiting to be released under the right circumstances.
2. Energy of motion.
3. When electromagnetic energy is released and transferred through space.
4. Energy may be changed from one form to another; however, it cannot be either created or destroyed.

205

1. On November 8, 1895, Wilhelm Roentgen.
2. Unknown.
3. A radioactive gas called radon.
4. The diagnostic imaging technologist.

206

1. Radioactive nuclei.
2. Energy that has both electric and magnetic properties and travels at the speed of light.
3. X-rays are produced in the electron cloud of an atom and are the result of an artificial stimulation such as bombardment of the electron shell with electrons. Gamma radiation is emitted spontaneously from the nuclei of radioactive atoms.
4. Frequency is how often a cycle is repeated, and it is measured in hertz.
5. They are inversely proportional to one another.

207

1. "Braking" radiation that is produced as a result of an incident electron interacting with the nucleus of an atom.
2. The original kinetic energy of the electron, how close the electron comes to the nucleus, and the charge of the nucleus.
3. Radiation that is produced when an electron from a higher energy shell drops down to fill a vacancy in a lower shell.
4. It varies with the type of target material and is dependent on the binding energy of the shells involved.

208

1. The process by which an X-ray photon transfers its inherent energy to the medium through which it is passing.
2. Any process that results in the removal or addition of an orbital electron from or to an atom or molecule, thereby leaving the atom or molecule with an overall positive or negative charge.
3. It is the quantity of radiation exposure in air and applies only to X-rays and gamma rays. One roentgen (1R) equals about 2 billion ion pairs in 1 cc of air at standard pressure and temperature.
4. The photoelectric effect and the Compton effect.
5. Characteristic radiation, a negative ion, and a positive ion.
6. The energy of the incoming photon, and the atomic number (Z number) of the absorber.
7. A partial transfer of energy from an incident photon to an outer-shell electron.
8. When a low-energy photon encounters an orbital electron and changes direction without any transfer or loss of energy.

Complete the unit review exercise before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (201) What are three of the five forms in which matter can exist?
   a. Solid, liquid, and gas.
   b. Liquid, element, and plasma.
   c. Liquid, plasma, and compound.
   d. Solid, element, and Bose condensation.

2. (201) Which substance type cannot be reduced to a simpler form by chemical means?
   a. Liquid.
   b. Mixture.
   c. Element.
   d. Compound.

3. (202) What is the smallest unit of the element Tungsten that retains all of the characteristic properties of Tungsten?
   a. Atom.
   b. Nucleus.
   c. Electron.
   d. Molecule.

4. (202) What type of atomic particle is indicated by the "Z" number (or atomic number) of an element?
   a. Proton.
   b. Neutron.
   c. Nucleon.
   d. Electron.

5. (202) What formula is used to calculate the total number of electrons that can be held in any given shell?
   a. 2n.
   b. n^2.
   c. $2n^2$.
   d. $2n^3$.

6. (202) What type of force keeps electrons from spontaneously drifting off out of orbit away from the nucleus?
   a. Magnetic.
   b. Centripetal.
   c. Centrifugal.
   d. Gravitational.

7. (203) What is the maximum number of valence electrons that the M shell can hold?
   a. 2.
   b. 8.
   c. 18.
   d. 32.

8. (203) An atom with a valence number of +1 is considered to be
   a. an isotope.
   b. an insulator.
   c. a conductor.
   d. a semiconductor.

9. (204) Energy is defined as
   a. mass in motion.
   b. the opposite of matter.
   c. the capacity to perform work.
   d. a movement of free electrons.

10. (204) The law of conservation of energy states
    a. like charges repel; unlike charges attract.
    b. energy cannot be either created or destroyed.
    c. when x-radiation interacts with matter, energy is created.
    d. when x-radiation interacts with matter, energy is destroyed.

11. (205) Who accidentally discovered X-rays?
    a. Wilhelm Roentgen.
    b. William Crookes.
    c. Albert Einstein.
    d. Nikola Tesla.

12. (206) What type of radiation is X-ray?
    a. Thermal radiation.
    b. Particulate radiation.
    c. Electromagnetic radiation.
    d. Radio frequency radiation.

13. (207) What type of radiation is produced by the interaction of an incident electron with the nucleus of a target atom?
    a. Gamma.
    b. Compton.
    c. Characteristic.
    d. Bremsstrahlung.

14. (208) What three end products always result from a photoelectric effect interaction?
    a. A nucleon, a positive ion, and characteristic radiation.
    b. A positive ion, a negative ion, and characteristic radiation.
    c. A positive ion, a negative ion, and bremsstrahlung radiation.
    d. Characteristic radiation, bremsstrahlung radiation, and a nucleon.

15. (208) What type of X-ray interaction occurs only at very low energy levels of a few kiloelectron volts (keV)?
    a. Photoelectric effect.
    b. Compton scatter.
    c. Coherent scatter.
    d. Pair production.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Electromagnetism

THE Laws of electricity and magnetism play a major role in our everyday lives. Getting through an entire day without using electricity would be difficult for most of us. In the same way, electricity and electromagnetism play a vital role in diagnostic imaging (DI). In fact, without the use of these forces, our career field would not exist at all. For this reason, this unit begins with a discussion to understand basic electric and magnetic characteristics. From there, we will break down how a typical X-ray system is put together and how it uses electricity to produce X-rays. We begin with a review of electric current and magnetic fields.

2–1. Electric Current and Magnetic Fields

What makes a light bulb illuminate and a toaster heat up? The answer is, of course, electricity. Mankind has developed thousands of ingenious ways to harness electrical power to do things that makes our daily activities more fun but also easier to complete. Even the most basic combustion engine needs electric current to generate a spark. This unit is going to explore what electricity is and how it is used to do work.

209. Basic review of electrical principles

The #1 purpose of an X-ray unit is to convert regular electric energy (electricity) into electromagnetic energy. As the energy conversion takes place in the X-ray tube, most of the electric energy is changed into heat and the rest into X-rays. In this lesson, we will review the electric principles so you can better understand what happens when you set your "technique" and depress the exposure button.

Electrostatics

Electrostatics is the study of stationary electric charges. In fact, if you rearrange the word "electrostatics," you get static electricity. Static electricity occurs whenever objects acquire an excess or shortage of electrons. The object is then said to be *electrified.* Electrification can happen by friction, contact, or induction, a concept we'll discuss later in this unit.

Have you ever walked across a room and touched someone or something only to receive a shock? This happens because the friction of your shoes against the carpet causes electrons to be transferred to you and unknowingly, you have become electrified. The shock you feel is the act of transferring some or all of a charge (either too few or too many electrons) to another object or person.

Another common example is rubbing a balloon against your hair. What happens when you then let go of the balloon? It sticks to your head. Why? Again, a transfer of electrons occurs, this time between your hair and the balloon. This transfer leaves the balloon with an excess of electrons and your hair with a deficit. The balloon then sticks because of the first law of electrostatics: **like charges repel;**

unlike charges attract. Stated more specifically, electrons repel other electrons, protons repel other protons, and electrons and protons attract one another (fig. 2–1).

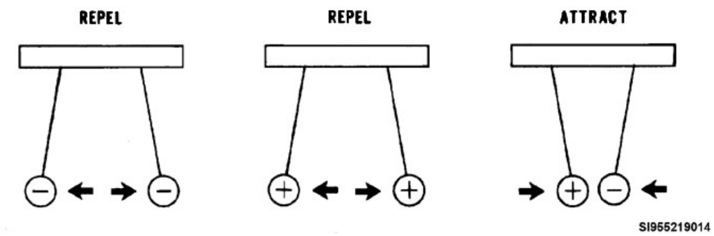

Figure 2–1. Like charges repel; unlike charges attract.

The force of attraction of unlike charges or the repelling of like charges is known as *electrostatic force*. Electrostatic force is strongest when charged objects are closest but as the objects separate, their force of attraction or repulsion decreases quite quickly. Because of the nature of atoms, protons are tightly bound in the nucleus therefore; electrons are the only charged particles capable of moving, or flowing, from object to object. Like electrically charged particles have potential energy because when they are positioned close to one another, work can be performed in the form of kinetic energy when they fly apart.

Obviously, there has to be a way of measuring this electric potential. Electric potential is designated by the letter "*E*" and the v*olt* is the unit of measurement. The greater the voltage means the greater the *potential* exists to do work.

Electrodynamics

Electrodynamics is the study of electric charges in motion (electricity). When an electric potential is imparted on an object, say for example, typical household copper wiring, electrons move along the wire from one end to the other. This movement or flow of electrons is called electrical current. Electric current always flows from a point that has an excess of electrons to a point that has a deficiency of electrons. Figure 2–2 demonstrates this with two containers of water connected by a pipe. Let's assume each droplet of water is an electron; because the left container has more water (a surplus of electrons), the water flows through the pipe to the right container (which has a shortage of electrons) until the both containers have the same amount of water (electrons). So what causes electrons to move and produce an electric current? Three factors are needed to produce current flow: difference in potential, a conductor, and resistance.

Figure 2–2. Demonstrating the flow of electrons from a surplus to a deficit.

If we compare two objects and find that one has a relatively high number of excess electrons compared to the other, we can say that a *difference in potential* energy exists between the two objects. If the two objects are connected with something that is capable of transferring electrons, a conductor, then current is allowed to flow from the negative to the positive until the charges are balanced. A *conductor* is any material or substance that allows electrons to easily flow from an abundance to a deficiency. Whether we say electrons move, drift, or flow through a conductor the important thing to remember is that a particular electron does not enter one end of a conductor and exit the other end. Electron flow through a conductor is the result of a chain of ionizing events. As one electron enters one end of a conductor, a different electron exits the opposite end. Electron flow is easier to understand if you remember we are talking about billions of atoms and billions of electrons in that conductor.

The unit of measure for a specific number of electrons is a *coulomb*. By counting the number of coulombs that pass a given point in 1 second of time, we can measure the rate of current flow. The unit of measurement for current flow is the *ampere* and is designated by the letter "*I*." Since the term "ampere" means coulombs per second, the ampere is a measures of the *rate* at which electrons are moving through a material, or in other words, the intensity of the current. If there is 1 ampere of current flowing when 1 coulomb of electrons passes a point in a conductor in 1 second, then there is 1 amperes when 1 coulombs pass a point in 1 second, etc.

Resistance in referring to electricity is the opposition of current flow. All objects resist current flow to some degree. The resistance of a wire conductor, or any object for that matter, depends upon four factors: the material it is made of, length of the conductor, cross-sectional area of the conductor, and temperature of the conductor.

The unit of measurement for resistance is the *ohm.* It is that amount of resistance that allows exactly 1 ampere of current to flow when 1 volt is applied across the resistance. An ohm value is designated by the symbol Ω and we use the letter *R* to designate resistance.

Though most radiology techs will never view the electrical schematics for an imaging system, figure 2–3 is presented here for reference as you continue through this unit.

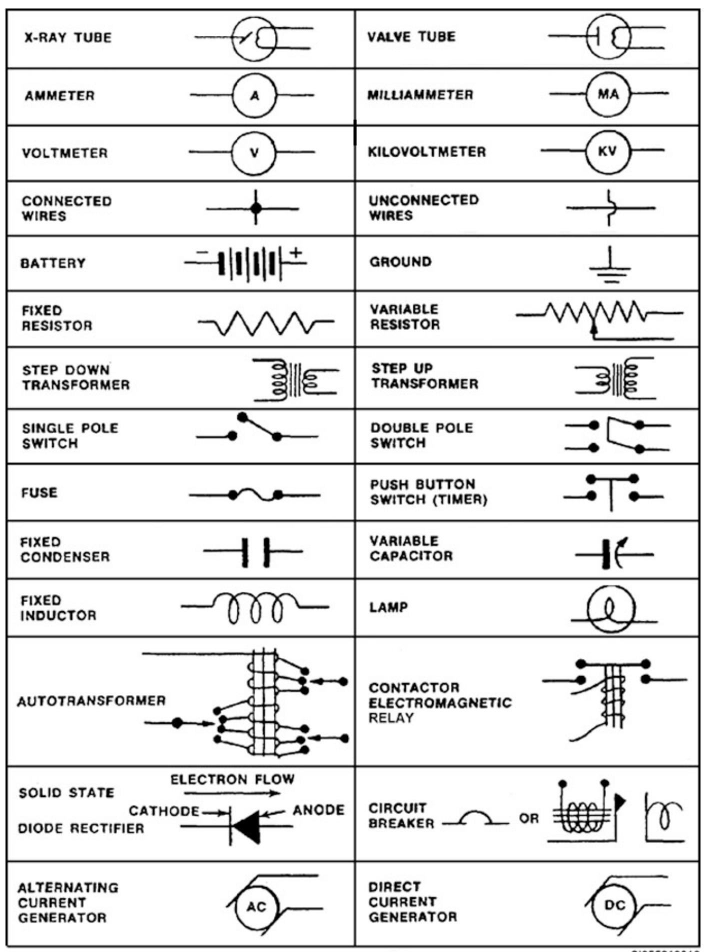

Figure 2–3. Common symbols used in electrical designs.

Electrical circuits

When resistance is controlled and conductors are formed into a closed path or loop, an electrical *circuit* is created. Within a circuit, electricity may flow in the form of *direct current* (DC) or an *alternating current* (AC). Electrical circuits are very complex, whether you're talking about a television, mobile phone, or an X-ray imaging system. No matter the complexity though, most electrical circuits are classified according to the way their components are arranged or connected. The three types of circuits are *series, parallel,* and *series-parallel* (fig. 2–4).

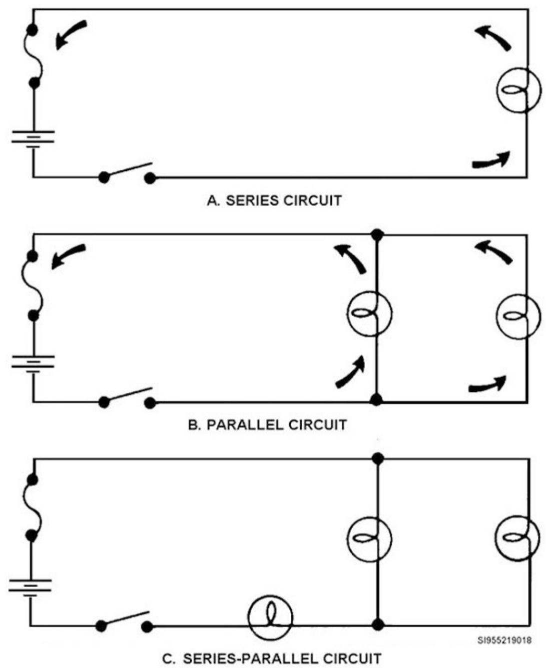

Figure 2–4. Types of circuits.

Series circuit

A series circuit is one in which the components are connected end-to-end and there is only one path for the current to flow. The following rules can be used to characterize series circuits:

1. The current is the same at all points.
2. The total voltage is equal to the sum of the individual voltages (or voltage drops).
3. The total resistance is equal to the sum of the individual resistances.

Parallel circuit

It is often necessary to connect electrical devices in a circuit so that the total voltage is applied across each device. A circuit in which two or more devices are connected across a common power source is called a parallel circuit. The following rules apply to parallel circuits:

1. The current in the main lines is equal to the sum of the currents in each branch.
2. The voltage across each branch is the same as the source (applied) voltage.
3. The total resistance is the reciprocal of the sum of the reciprocals of the individual resistances.

Series-parallel (compound) circuit

A series-parallel circuit simply consists of two or more parallel components connected in series with one or more components.

Types of electrical current

Up to this point, our discussion of current flow has related to DC, where electrons continuously flow in one direction through a circuit. The most common types of DC circuits are those powered by batteries. The electricity flowing through commercial power lines into homes, businesses, and hospitals is AC. In AC, electrons move first in one direction and then reverse themselves and move in the opposite direction.

The characteristics of AC can best be understood by referring once again to a sine wave, as shown in figure 2–5. A sine wave shows the relative values of voltage and current (assuming voltage and current are in-phase with one another) plotted against time through a full 360° cycle. Beginning with the horizontal line representing zero or no current flow, AC gradually increases in magnitude (voltage and current values) until a peak is reached. The peak values represent the maximum amplitude of the sine wave and are the maximum voltage and current in the circuit. For example, in a 110-volt circuit drawing 5 amperes (amps), those values are reached at the particular point in time at 90° and 270° on a 360° scale. Before these "peak" values are reached, the voltage and current values gradually increase, beginning with zero. Once the peak values are reached, AC gradually decreases to zero at the 180° point on the sine wave. From this point, AC again increases in magnitude (staying below the zero reference line) until peak or maximum amplitude is reached at the 270° point on the sine wave. This swing of the sine wave below the zero reference line represents a reverse in polarity (i.e., current flows in the opposite direction from that above the zero reference line). From this point, notice that the voltage and current then decrease to zero at the 360° point on the sine wave, as shown in figure 2–5.

That portion of the sine wave above the zero reference line is known as the *positive alternation* or positive amplitude, and that portion below the reference line is known as the *negative alternation* or negative amplitude. These alternations are also called impulses or *pulses.* Two consecutive alternations (pulses) are known as a *cycle.* As stated before, the sine wave represents AC values plotted against time. In the case of a standard 110-volt household current, there are 60 cycles per second. This means that 60 cycles or 120 alternations occur in every 1 second interval. The number of cycles occurring in a second is called the AC *frequency.* AC frequency is expressed in *hertz* (Hz). For our purposes in this CDC, we shall be concerned mostly with 60-cycle AC, although higher frequencies are used in other fields.

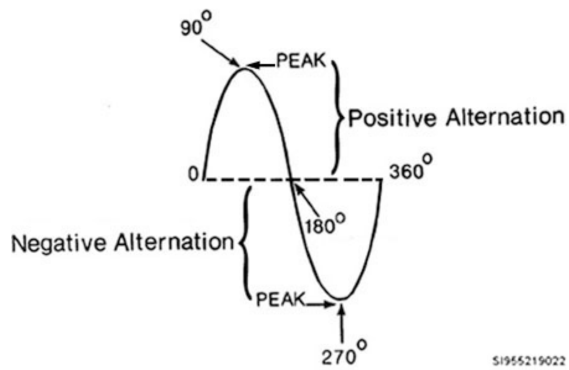

Figure 2–5. An AC sine wave.

Measuring electrical power

The power of a DC circuit is the amount of work the current can do each second, and is measured in *watts* (W). A watt is equal to the power in a circuit in which 1 ampere of current flows across a potential difference of 1 volt. Household appliances need electrical power levels anywhere from 30 W to 1500 W. An X-ray machine may use 100 kW (kilowatts; 1 kW = 1,000 W) of power.

We can compute the power of a circuit with this formula:

$$P = I \times E, \text{ which means:}$$

$$\text{Power (watts)} = \text{(amps)} \times \text{(volts)}$$

Ohm's law

So far, our discussions of current, voltage, and resistance have dealt mostly with the relative values of those elements. Now, let's see how we can determine the specific value of any one of the three elements when we know the values of the other two.

The relationships between current, voltage, and resistance are expressed in Ohm's law. The law states: the voltage of a circuit or any portion of the circuit is equal to the current times the resistance. Using Ohm's law, if we know two of the three values, we can determine the other value. The formula follows:

E	=	I	×	R
Electrical potential (volts)	=	Intensity of current (amps)	×	Resistance (ohms)

If we look at the circuit in figure 2–6, we see a battery that provides 6 volts. The lamp has a resistance of 2 ohms when the switch is closed, and the problem is to find the unknown value (current). Since we are looking for current, we can rearrange the formula to solve for amps, and we get

$$I = \frac{E}{R}$$

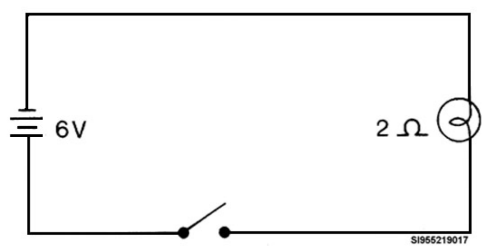

Figure 2–6. A simple circuit.

When we substitute the two known values for E and R, you have $\frac{6}{2}$. Therefore, $I = \frac{6}{2}$ or $I = 3$ amps.

Even though we know all the values in this circuit, let's use the formula for practice to prove each value. First, let's solve for R. The formula is:

$$R = \frac{E}{I}$$

Substituting values, we have $\frac{6}{3}$, or $R = 2$ ohms.

To solve for E, the formula is

$$E = I \times R$$

Therefore, $E = 3 \times 2$, or $E = 6$ volts.

210. Basic laws of magnetism

Whether we realize it or not, magnetism plays a part in just about every aspect of our lives. In radiology, the laws of magnetism govern many of the fundamental principles we use on a daily basis.

Laws of magnetism

Since there is a definite relationship between electricity and magnetism, a study of electricity must include a discussion of magnetism. It is of special importance to you because magnetism is involved in the operation of the X-ray machine and related equipment. Magnetism can be defined as a force that attracts iron, steel, or other magnetic substances.

The three basic laws of magnetism are as follows:

- Every magnet has two poles, one at each end, called north and south poles.
- Like magnetic poles repel each other; unlike poles attract each other.
- The force of attraction or repulsion between two magnetic poles varies directly with the strength of the poles, and inversely with the square of the distance separating the poles. In other words, doubling the strength of one pole doubles the force between the poles. When the distance between two poles is doubled, the force of attraction (or repulsion) between the poles is reduced to one-fourth its original strength. Tripling the distance reduces the force to one-ninth of its original strength.

Magnetic classifications

All matter can be classified in regards to how they interact with an external magnetic field. A lot of materials are not affected by magnetic fields at all. These materials are considered *nonmagnetic* and examples are wood, copper, and glass. Other materials are weakly repelled by either magnetic pole and cannot be magnetized artificially. These materials are called *diamagnetic*. Substances strongly attracted by a magnetic field are called *ferromagnetic.* These substances can usually be permanently magnetized by induction (exposure to a magnetic field). Examples of ferromagnetic substances are iron, cobalt, and nickel. The final category of materials is called *paramagnetic*. These materials fall in-between the ferromagnetic and nonmagnetic spectrum because their attraction to a magnetis field is very slight and they are not readily influenced by an external magnetic field. Magnetic resonance imaging contrast agents are examples of paramagnetic materials.

Magnetic domains

Scientists theorize certain elements have special magnetic properties called *magnetic dipoles*, or *magnetic domains.* These result from the orbiting movement of electrons in outer shells of certain atoms. Each of these atoms creates a magnetic domain at the atomic level. When these dipoles are arranged at random in an unmagnetized bar of iron or steel (fig. 2–7, A), the cumulative strength of the dipoles is neutralized. If a magnetizing force is applied to the iron bar, the dipoles become aligned so that all their net poles point in one direction (fig. 2–7, B). With the dipoles aligned in this manner, their magnetic strengths are combined, and the results are lines of force otherwise known as a magnetic field (fig. 2–7, C).

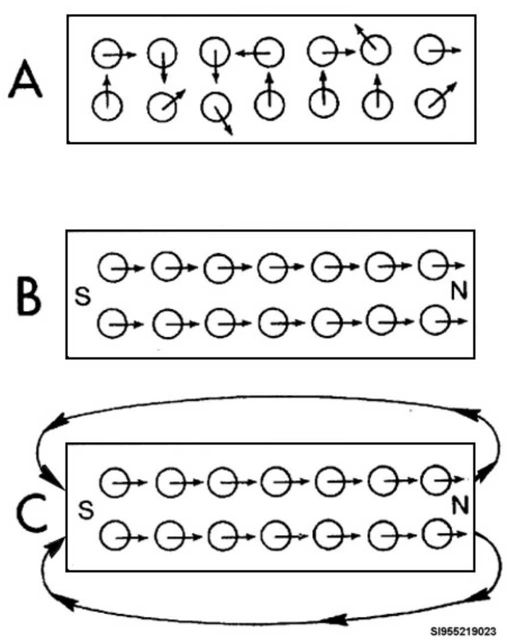

Figure 2–7. Magnetization of an iron bar.

Magnetic field

A magnet, regardless of shape or size, has a North Pole and a South Pole, as shown in figure 2–8. Also shown is an invisible magnetic field, which is present around and inside a magnet. We can visualize this magnetic field by placing a piece of paper over a bar magnet and sprinkling iron filings on the paper. Tap the paper gently, and the iron filings will arrange themselves to coincide with the magnetic field (fig. 2–9). The magnetic field is composed of *lines of force,* also called *flux lines.* These lines of force travel from the North Pole to the South Pole outside the magnet and from the South Pole to the North Pole within the magnet. These lines of force are continuous and always form closed loops. Magnetic lines of force never cross one another, and can pass through all materials, both magnetic and nonmagnetic. The strength of a magnetic field depends upon the number of lines of force per unit area: the more concentrated the lines, the stronger the field. These lines are more concentrated at the poles.

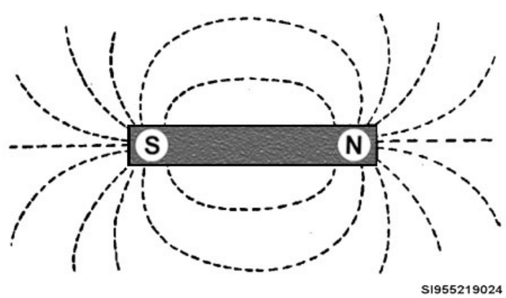

Figure 2–8. Magnetic poles and magnetic field.

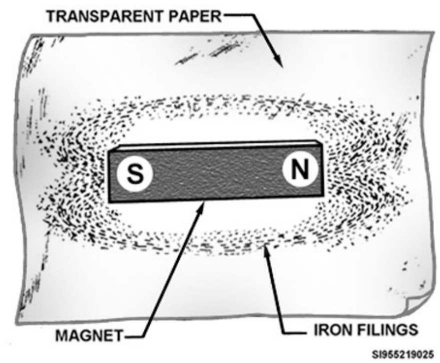

Figure 2–9. Demonstration of the magnetic field.

Magnetic induction

Magnetic induction results when an unmagnetized substance, such as iron, is brought within the influence of a magnetic field. The unorganized domains will align themselves with the magnetic field. The previously unmagnetized material is now magnetized and behaves as a magnet while it is within the magnetic field of influence. When it is removed from the magnetic field, its magnetic domains again become disoriented and its magnetism is lost.

Magnetic permeability and retentivity

Some materials are easily affected by magnetic induction. The ease with which a material can be magnetized by induction is called its *magnetic permeability.* If a material has high permeability it means the substance is easily magnetized by the process of induction. Soft iron is an example of a material that has high permeability because it is easily magnetized.

Some materials, once they become magnetized, do not readily become demagnetized. In other words, they retain their magnetism quite well. Materials having this characteristic have high *magnetic retentivity.* Hard steel resists demagnetization. Thus, it has high retentivity.

The general rule for permeability and retentivity states that a metal that is easily magnetized is also easily demagnetized. On the other hand, a metal that is difficult to magnetize is also difficult to demagnetize.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

209. Basic review of electrical principles

1. When you touch another object or person and feel a shock, what just happened?

2. What is electrostatic force?

3. What is the unit of measurement for electric potential?

4. What is a conductor?

5. What is an ampere?

6. What is electrical resistance?

7. What is an electrical circuit?

8. What is a series circuit?

9. Describe a parallel circuit.

10. How is electron movement in AC different from that in DC?

11. How many alternations (pulses) occur in one cycle?

12. How many pulses occur per second in standard household current?

13. What does ohm's law state?

14. Using the ohm's law formula, how many amps are present if a lamp has 6 volts and 2 ohms of resistance?

210. Basic laws of magnetism

1. What are the three basic laws of magnetism?

2. Name the four magnetic classifications of matter.

3. What does it mean if a substance has high magnetic permeability?

4. What is the general relationship between magnetic permeability and retentivity?

2–2. Electromagnetic Induction

So far in this unit, our discussions have dealt with electricity and magnetism separately. However, electricity and magnetism are actually parts of the same fundamental force called *electromagnetism*. Electromagnetism is very important in the production of X-rays. Without proper understanding and application of the electromagnetic effect, it would be impossible to generate the tens of thousands of volts necessary for X-ray production.

211. The electromagnetic effect

Every electric current generates a magnetic field. Likewise, any magnetic field can be made to generate an electric current. The discovery of these two phenomena in the 19th century led to the branch of physics known as electromagnetism.

Electromagnetism

An electron is constantly spinning on its axis. This spinning is true whether the electron is in the fixed shell of an atom or moving freely through space. Normally, electrons spin in pairs but with magnetic fields opposing each other, thus canceling out. When an electron is removed from its shell and moves through a straight, current-carrying conductor, it generates magnetic lines of force that are circular and at right angles to the direction of current flow (fig. 2–10). The direction of the electromagnetic field can be determined with the “left-thumb rule,” which states “if a current-carrying wire is grasped in the left hand with the thumb pointing in the direction of electron current flow (negative to positive), then the fingers encircling the wire indicate the direction of the lines of force (flux lines) around the current.” The magnetic field in this case does not have a North or South Pole.

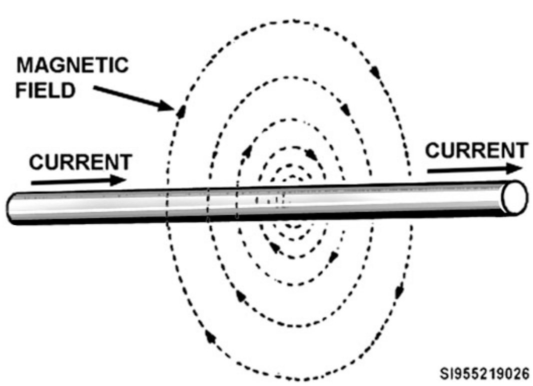

Figure 2–10. Electromagnetic field around a straight, current-carrying conductor.

If a current-carrying conductor is formed into a loop (or coil), as illustrated in figure 2–11, the lines of force pass through the inside of the coil,as shown. As a result, a north pole is created on one side of the loop and a south pole on the other. The direction of the lines of force is the same as that of a bar magnet, with the inside of the coil representing the magnetic bar.

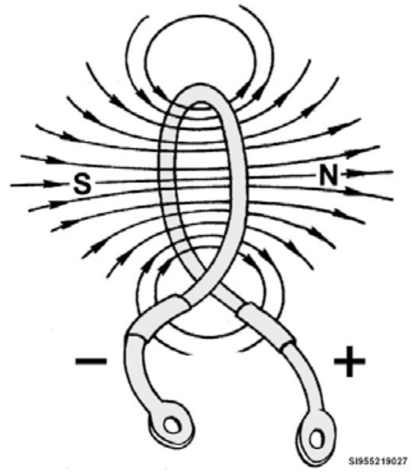

Figure 2–11. Electromagnetic field around a looped conductor.

Solenoids and electromagnets

As shown in figure 2–12, a current-carrying wire conductor that is formed into many loops (coils) is called a *solenoid*. As the lines of force around the individual loops combine, they form a larger and stronger magnetic field. A north and a south pole are then established at opposite ends of the coil.

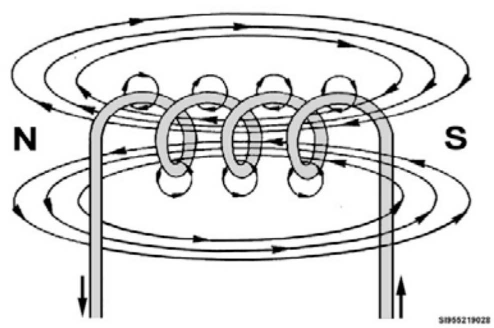

Figure 2–12. Electromagnetic field around a solenoid.

When a conductor is wound into a coil, the lines of force around each coil combine with those from the other coils to form one magnetic field. It follows that the more coils or turns per unit area—or we can say *the more turns per inch*—the stronger the field. Also, as the current through the conductor increases, so does the number of lines of force around the conductor; consequently, a higher current also produces a stronger magnetic field.

An *electromagnet* is created when a current-carrying wire coil is wrapped around an iron core (a ferromagnetic material) as seen in figure 2–13. By wrapping the wire around an iron core, the magnetic field is further intensified. The iron core affects magnetic strength in two ways:

1. The core itself becomes magnetized; which adds to the magnetic strength of the coil.
2. The core provides an easier pathway for the lines of force to travel; thus, the lines of force concentrate themselves within the core.

Soft iron is usually used as core material because it has a high permeability. Electromagnets are frequently used in X-ray system components such as relays and locking devices in the tube stand and table.

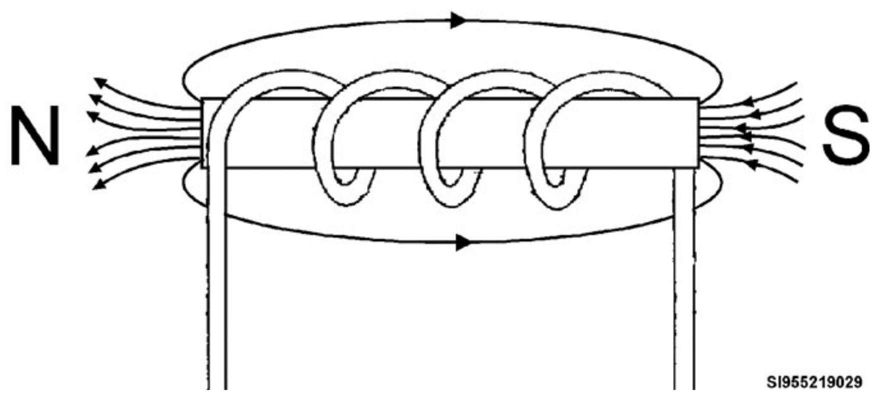

Figure 2–13. An electromagnet.

212. Principles of electromagnetic induction

If electricity can make magnetic fields, can a magnetic field make electricity?

Induced current

If a conductor is moved through a magnetic field and cuts the lines of force (or flux) as illustrated in figure 2–14A, an electromotive force (EMF) is induced in the conductor. Similarly, if the conductor is stationary and the magnet moves, as illustrated in figure 2–14B, an EMF is also induced in the conductor. This process of producing an EMF from the relative motion between a conductor and a magnetic field is called *electromagnetic induction.* According to Faraday's Law, the three requirements for electromagnetic induction are: a conductor, a magnetic field, and relative motion.

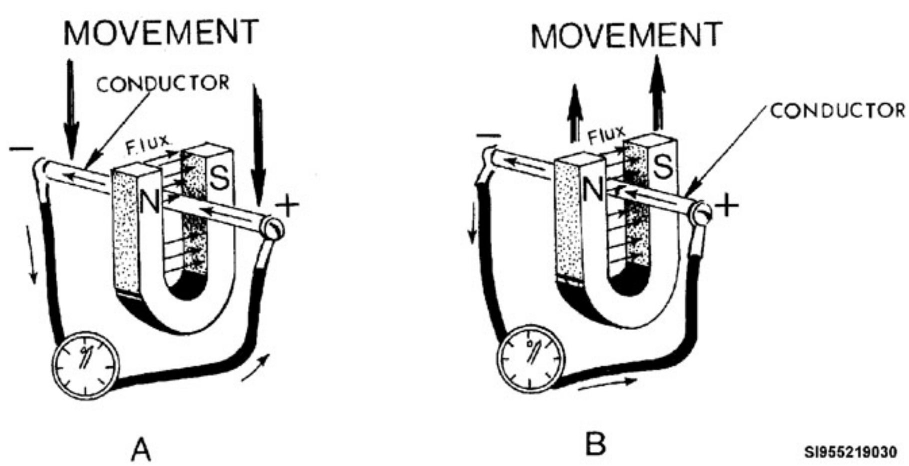

Figure 2–14. Electromagnetic induction.

The magnitude of the induced EMF depends upon the number of lines of force cut per unit time; the greater this number, the higher the induced EMF. Two ways of increasing the induced EMF are:

- To increase the relative motion or speed at which the lines of force are cut.
- To increase the strength of the magnetic field.

The magnitude of the induced EMF also depends upon the number of conductors in which the EMF is induced; the more conductors—or as we will see when we discuss transformers, the more turns in a coil—the higher the induced EMF.

Types of induction

Electromagnetic induction is the principle by which all generators, electric motors, and transformers operate. There are two basic types of induction: *self-induction* and *mutual induction*.

Self-induction

Now that you have some basic information about electromagnetic induction, let's see how to induce EMF or current in a conductor without moving the conductor or the magnet. Refer to figure 2–15. Detail A shows a conductor formed into a coil, and detail B shows an AC sine wave. At time zero in detail B, there is actually no current flowing through the coil. From time zero to time 1, current flow increases in the direction indicated by the arrows on the coil. You will recall that when current flows through a conductor, a magnetic field is produced around the conductor. Although the magnetic field is shown at only two points in the coil in detail A, the magnetic field is actually present all along the conductor. You now have two of the three requirements for induction: a conductor and a magnetic field.

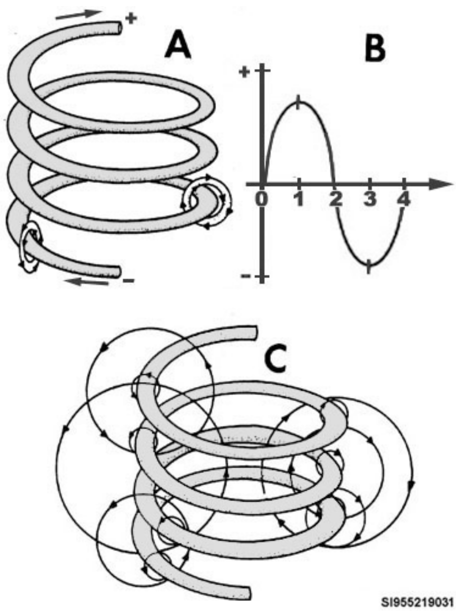

Figure 2–15. Self-induction.

So what about the third requirement: relative motion? As the current increases during the interval from zero to 1, the magnetic field increases in strength and expands to a point where it cuts the conductor in other loops, as shown in detail C of the figure. As the current decreases from maximum to zero during the interval of 1 to 2 in detail B, the magnetic field decreases in strength. As the field decreases, it cuts the loops in the opposite direction. When the magnetic field of a coil induces current into the coil itself, the process is known as *self-induction.* The relative motion for self-induction comes from the expanding and collapsing magnetic field generated by AC and the constant change in direction of the current; which is necessary to induce EMF or current into the other loops of the conductor.

Mutual induction

Mutual induction is the process of introducing current or voltage in a circuit by varying the current or voltage in a neighboring circuit. Figure 2–16 shows an AC generator furnishing power to coil A. Coil A is not electrically connected to coil B. As the expanding and collapsing magnetic field around coil A cuts the loops of coil B, current and voltage are induced into coil B. Again, notice the three requirements for induction with the relative motion resulting from the expanding and collapsing magnetic field.

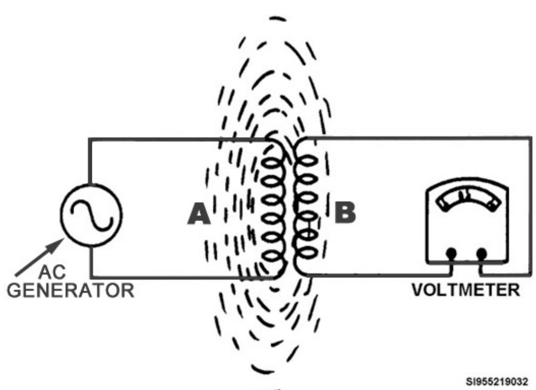

Figure 2–16. Mutual induction.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

211. The electromagnetic effect

1. What 19th century discovery led to the branch of physics known as electromagnetism?

2. What is the result if a current-carrying conductor is formed into a loop (or coil)?

3. What is a solenoid?

4. How is an electromagnet created?

212. Principles of electromagnetic induction

1. What is electromagnetic induction?

2. What are the three requirements for electromagnetic induction?

3. Where does the relative motion come from in self-induction?

4. What is mutual induction?

2–3. The X-ray Imaging System

Though there are various manufacturers of different types of imaging systems, each system is made up of certain basic components. In this section you will learn about two of the three main components: the operating console and the high-voltage generator. You will also be introduced to several different types of rectification used in the voltage generator as well as the advantages of single-phase and three-phase generation systems. At the end of this section we will close by reinforcing electrical safety practices that will keep you and your patients from harm.

213. The operating console

Operating consoles vary from unit to unit based upon the manufacturer. However, all consoles perform the same task for a technologist. The operating console is what the technologist uses to control the electricity supplied to the imaging system to create a usable X-ray beam.

Purpose of the operating console

As previously discussed, the #1 purpose of an X-ray unit is to convert regular electric energy (electricity) into electromagnetic energy. Line compensation, kilovoltage peak (kVp), milliamperage (mA), and length of exposure time are controlled by the operating console to set X-ray tube current and voltage so that production of usable X-rays is possible in a safe manner. Automatic exposure control (AEC) systems also have controls built-in to most modern operating consoles. Whether your operating console is digital (touch-screen) or still the dial-selector type, it is important that you understand the features, functions, and purpose of the imaging system settings you are using to produce a diagnostic image for the radiologist to interpret.

X-ray systems are set up to operate on 110 to 440 volts; however, most typically, systems run on 220 volts. Whether in your apartment, house, or place of work, the power supplied by the local power company is not consistent and can vary up to 5 percent. These variations in power can affect your ability to produce high-quality images. X-ray imaging equipment has a built in compensator for any deficiencies called a *line compensator*. The line compensator measures the incoming voltage to the imaging unit and then adjusts it to be precisely the voltage that is required (for example, a steady 220 volts).

Autotransformer

The electricity supplied to the imaging system from the power company through the hospital is first delivered to the autotransformer. The autotransformer (generally the kVp selector of the unit) controls the voltage that enters the primary coil of the high-voltage transformer of the X-ray machine. Consider for a moment a transformer consisting of one continuous winding on a long, laminated iron core. When voltage is applied across only one section of it, voltage will be induced in the turns that are not connected directly to the line in the same way that voltage is induced in the secondary coil of a conventional transformer. In fact, the section across which the line voltage is applied is called the *primary*, and the balance of the winding is called the *secondary*.

If the voltage is measured across various sections of a typical autotransformer, a system similar to that shown in figure 2–17 would result. A series of taps or connections to the different turns provides a convenient method of getting a wide variety of voltages to apply to the primary of the high-voltage transformer. In the circuit shown in figure 2–17 (this circuit has a constant number of volts per turn), the following voltages could be acquired by setting the selector switch on the various taps:

- Tap #1—50 volts.
- Tap #2—100 volts.
- Tap #3—150 volts.
- Tap #4—200 volts.

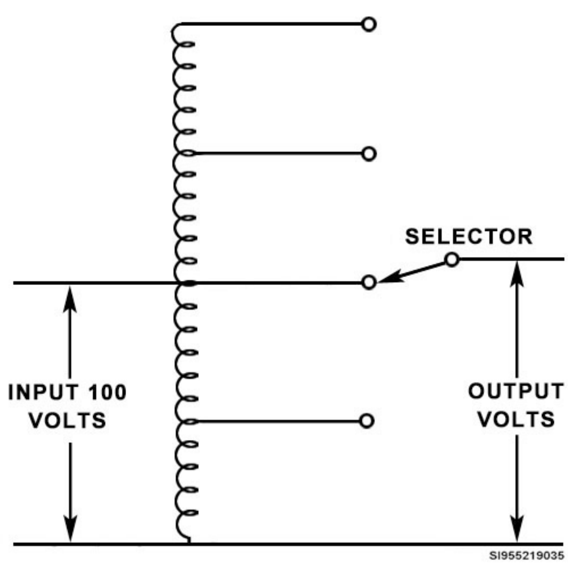

Figure 2–17. Autotransformer circuit—constant volts per turn.

The same results can be obtained by connecting the input line to a number of selected taps and leaving the output connected to a given pair of taps, as in figure 2–18. In actuality, autotransformers are usually provided with many taps in the primary and secondary circuit, with the result that you have an almost unlimited choice of voltage outputs. The autotransformer becomes, in this way, the basic regulatory source of all the supply voltages needed for operating the many components of the X-ray generator.

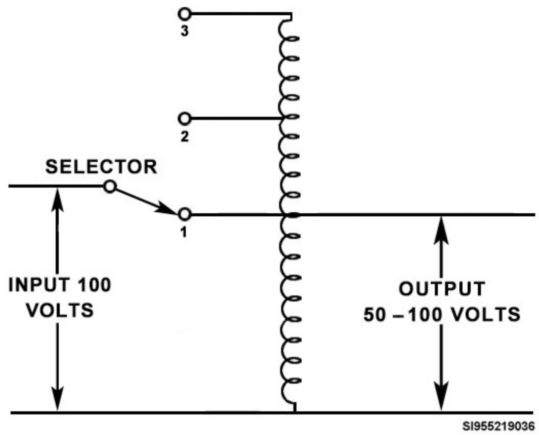

Figure 2–18. Autotransformer circuit—variable volts per turn.

In figure 2–19 notice that one side of the supply line is connected through a line voltage compensator. Incoming line voltage is not stable, varying from day to day, hour to hour. This instability is caused by other consumers using equipment connected to the same power supply as the X-ray machine.

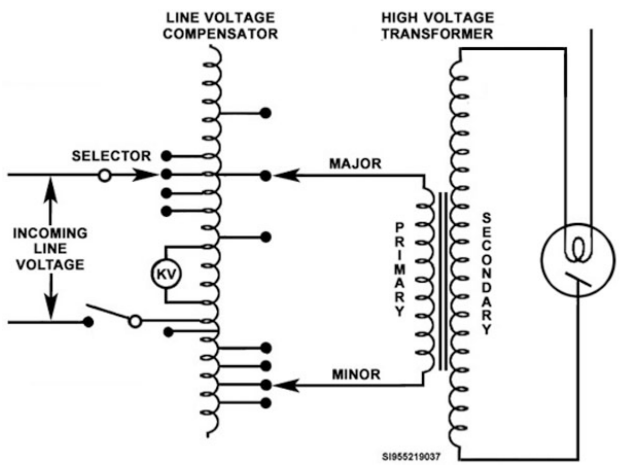

Figure 2–19. Autotransformer circuit—dual selectors.

The line voltage compensator does not step up or step down the incoming voltage. It simply shares the available incoming voltage with more or fewer turns on the autotransformer. For example, normal incoming line voltage is 230 volts; however, the incoming line voltage may fluctuate as low as 220 volts. If an autotransformer is simply adjusted to step down all incoming voltage by 10 volts, the resulting output voltage would be less than desired. Consequently, this would result in an underexposed radiograph. To compensate for this, you adjust the line voltage compensator. The line voltage compensator increases or decreases the number of turns used in the primary of the autotransformer. Thus, the same volt per turn ratio is maintained and the output remains stable. This process has been called *red-lining* a machine. (Note: In modern X-ray units, this process is done automatically. There is no need to manually “red-line” the unit.)

This compensated voltage is set by the major and minor kVp selectors (which you adjust on the X-ray machine control panel) and supplied to the primary winding of the high-voltage transformer.

In summary, we can point out these characteristics of an autotransformer:

- One coil of windings, instead of two.
- Both the input and output voltages may be varied because of various tap-off points.
- Used for only small changes in voltage; therefore, it is not suitable for use as a high-voltage transformer.

Kilovoltage peak

Modern imaging system consoles typically have one adjustment setting of kVp while older systems sometimes had two kVp settings; one major and one minor. As we will discuss later in this course, kVp is the main factor that determines the quality of the X-ray beam.

Milliamperage

The unit of measurement for the amount of current crossing from the cathode to the anode within the X-ray tube is mA. Again, the operating console is the point at which this setting is controlled. Some consoles have one adjustment setting for mA while other consoles combine the mA setting with the next item—timers.

Timers

A timer is a mechanism that measures or controls the specific duration of an event. An exposure timer's responsibility is to *stop* the exposure at a specified time after the technologist initiates the exposure. The timer circuit of an X-ray system is kept separate from other circuits. The most basic concept of an exposure timer is to allow or eliminate high-voltage flow from the cathode to the anode. There are four types of timer circuits utilized in an X-ray imaging system. They are synchronous timers, electronic timers, milliamperage seconds (mAs) timers, and AEC. Of these four, the first three circuits are adjusted and controlled by the technician while the last one, AEC, is sensor controlled. We will only discuss the last two.

Milliamperage seconds timer

Our X-ray systems utilize seconds as the unit of measure for time which is represented by the letter "s." When mA and time ("s") settings are separate, both must be adjusted to control the quantity of electrons available during a given exposure. When mA and time ("s") are combined, *mAs* is the result. If a console has the mA and s (time) setting combined, by adjusting the console settings for mAs, the technologist is actually adjusting a circuit within the imaging system called the *mAs timer*. The sole purpose of the mAs timer is to monitor the amount of mA and length of exposure time so that it may terminate the exposure when the correct mAs is achieved.

Automatic exposure control

This type of timer is automatic and is often used in chest radiography, where consistent exposure is necessary, to monitor pathology over a period of weeks, months, or longer. An AEC is a mechanism that measures the amount of X-radiation that reaches the image receptor (or film) and then automatically shuts off the exposure when a predetermined charge has been reached in the image receptor indicating the image has received enough exposure. The technologist's role in setting the AEC is to set up the desired mA, kVp, and choose the applicable sensors (one, two, or all three) needed for the part being exposed. For example, if AEC is utilized for a standard two-view chest study, select the two outer sensors for the posterior-anterior view and for the lateral view select only the center sensor. For the protection of the patient, an additional electronic timer is typically built-in as a back up to shut off the exposure at no more than 1.5 seconds to prevent over exposure.

214. High-voltage generator

A typical high-voltage generator houses three main parts: the high-voltage transformer, the filament transformer, and rectifiers. In this lesson we will first explain the functions of the high-voltage and filament transformers, and then describe transformer laws regarding voltage and current. We will reserve our explanation of the rectifiers used in the high-voltage generator for the next lesson.

High-voltage transformer

In general, a discussion about transformers is a continuing discussion of electromagnetic induction. A transformer uses interacting magnetic fields created by changing electric currents to increase or decrease electric potential and current. Keep in mind though, a transformer does not change one type of energy to another type.

Electric energy is supplied to the high-voltage generator by the autotransformer. Within the high-voltage generator is the high-voltage transformer (also referred to as the high-tension transformer). The job of the high voltage transformer is to increase the voltage to the appropriate kVp setting needed to produce X-rays. As you can probably guess, this type of transformer is known as a *step-up* transformer. A step-up transformer:

- Increases the voltage in the secondary windings (circuit)—which is why it is called the high-voltage transformer.
- Decreases the amperage in the secondary windings.
- Has a turn's ratio of greater than 1.

Filament transformer

Also within the high-voltage generator is the *filament transformer*. The job of the filament transformer is to decrease the line voltage before providing the filament with current to heat up and release electrons. The filament transformer is a *step-down* transformer. A step-down transformer:

- Decreases the voltage in the secondary windings.
- Increases the amperage in the secondary windings.
- Has a turns ratio of less than 1.

Transformer laws

All transformers operate on certain laws, or principles, used to determine current output. An important factor of transformers is the *turns-ratio,* which is the ratio of the number of turns in the secondary windings (second coil) to the number of turns in the primary windings (first coil). This is determined by dividing the two factors:

N_s = Number of turns in the secondary coil

N_p = Number of turns in the primary coil

As stated already in this section, if the turns-ratio is greater than one (1), it is a step-up transformer. If the turns ratio is less than one, it is a step-down transformer. For example, the turns ratio of the closed-core transformer shown in figure 2–20, detail A, is 10 to 2. Using our formula (N_s/N_p) we find the turns ratio to be 0.20 (2/10 = 0.20). The transformer in detail B of figure 2–20 has a turns ratio of 4 (8/2 = 4). The turns-ratio of a transformer is important to the transformer laws.

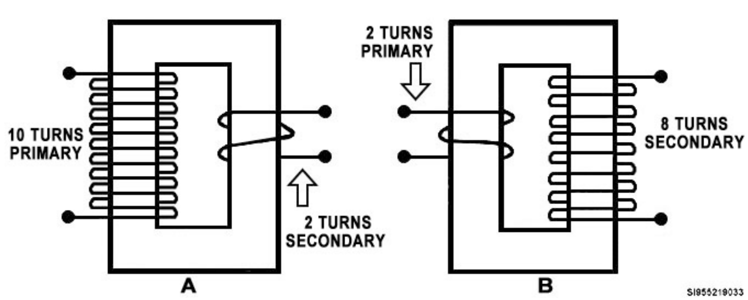

Figure 2–20. Transformer turns ratio.

NOTE: Transformers are not 100 percent efficient. But for ease of calculating values, and for learning purposes in this CDC, we'll consider them to be so.

The transformer law regarding voltage

The induced voltage is directly proportional to the turns ratio or in other words, the voltage in the secondary windings (the induced voltage), as compared to the primary voltage, is directly proportional to the turns ratio. To determine transformed secondary voltage, we use this formula:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

V_s = Voltage in the secondary windings

V_p = Voltage in the primary windings

N_s = Turns in the secondary coil

N_p = Turns in the primary coil

For example, referring again to figure 2–20, if transformer A, which has a turns-ratio of 0.20, has a primary voltage of 100 volts, then the secondary (induced) voltage should be 0.20 of the 100V. Let's check it to see if it's true:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$\frac{V_s}{100} = \frac{2}{10}$$

$$10(V_s) = (100)(2)$$

$$10(V_s) = 200$$

$$V_s = \frac{200}{10}$$

$$V_s = 20$$

Our secondary voltage (20) is proportional with our turns-ratio because the 20V is 0.20 of our primary voltage (100V).

The transformer law regarding current

The secondary current (amperage) is ***inversely*** proportional to the turns-ratio. In other words, if you know the primary circuit's amperage, you can determine the secondary amperage of a transformer by multiplying the primary amperage with the ***inverse*** of the turn's ratio:

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

$$I_s = (I_p)(\frac{N_p}{N_s})$$

I_s = Current (amperage) in the secondary windings

I_p = Current in the primary windings

$$\frac{N_p}{N_s} = \text{Inverse of the turn's ratio}$$

Again, refer to figure 2–20. If transformer B had a primary amperage of 4 amperes and a turns ratio of 4 (N_s/N_p = 8/2 = 4), then the secondary amperage must be 1 ampere because 1 ampere is the product of the input (primary) amperage (4) multiplied by the inverse of our turns ratio (the inverse of 4 is 1/4). Therefore, (4) (1/4) = 1. We can prove this with our amperage formula:

$$I_s = (I_p)(\frac{N_p}{N_s})$$

$$I_s = 4(2/8)$$

$$I_s = (4)(.25)$$

$$I_s = 1 \text{ amp}$$

The secondary current is inversely proportional to the secondary voltage

To simplify, we can say a transformer that increases a voltage by a given ratio decreases the current by the same ratio. We can show this inverse relationship of current and voltage with this formula:

$$\frac{I_p}{I_s} = \frac{V_s}{V_p}$$

This is so because there can be no more energy coming out of a transformer (power output) than is put in (power input). Recall that we measure power in watts (watts = amperage times voltage). Therefore, we can say that the product of the primary voltage and primary amperage (input power) must equal the product of the secondary voltage and secondary amperage (output power):

$$(V_p)(I_p) = (V_s)(I_s)$$

Let's see how this works in an example. If we apply 10 volts at 10 amps to the primary of a 1 to 10 step-up transformer (turns ratio of 10), as shown in figure 2–21, detail A, the voltage in the secondary will be 100 volts and the secondary current will be 1 amp. Remember our earlier rules: secondary voltage is directly proportional to the turn's ratio; secondary current is inversely proportional to the turn's ratio. In detail B of figure 2–21, the current in the secondary is increased by the same ratio that the voltage is decreased:

$$(V_p)(I_p) = (V_s)(I_s)$$

$$(100)(1) = (10)(I_s)$$

$$I_s = \frac{100}{10}$$

$$I_s = 10$$

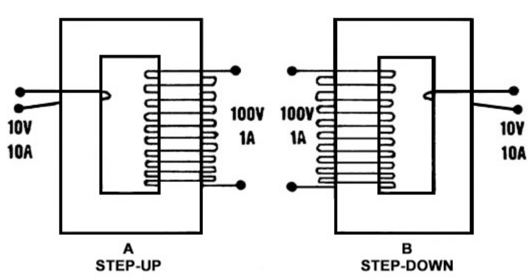

Figure 2–21. Relationships of input and output currents and voltages in step-up and step-down transformers.

Notice that the secondary current did indeed increase by the same ratio that secondary voltage decreased.

215. Types and purposes of rectification

X-ray imaging systems are powered by AC. However, X-ray tubes only function using DC. Rectification is the term used to describe the conversion of AC to DC.

Rectification

You are no doubt aware, by virtue of your previous training, that X-rays are produced when electrons travel from the X-ray tube filament to the target (the anode). Of course, you do not want electrons traveling in the opposite direction from the target to the filament as would be the case if AC were utilized. In fact, this condition could quickly damage the filament and the tube would become inoperable. To prevent the possibility of this *inverse current* (current flowing from anode to the filament) and to operate the X-ray tube more efficiently, the AC, which is available from the secondary side of the high voltage (step-up) transformer, must be converted to DC. To simplify, *rectification* is the process of converting AC to DC. In X-ray generators, AC is converted to pulsating DC, not pure DC.

Rectification is accomplished by adding *rectifiers* in the X-ray circuit between the high-voltage transformer and the X-ray tube. A rectifier must perform two important functions: (1) it must allow current to readily pass through it in one direction; that is, it must *conduct* in one direction, and (2) it must block the flow of current in the opposite direction.

There are two basic types of rectifiers—valve tube diodes and solid-state diodes. Valve tubes have been replaced by solid state devices in newer machines, but both perform the same function.

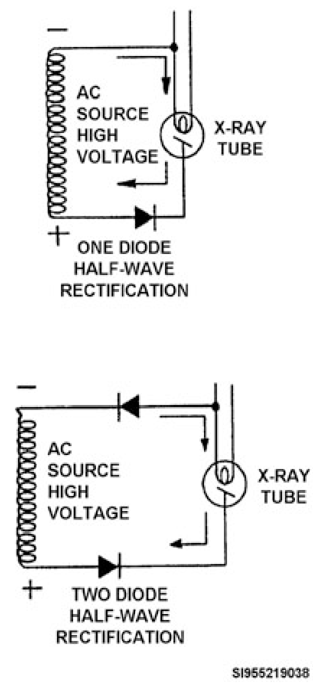

Figure 2–22. Half-wave rectification circuit

Types of rectification

We can better understand the rectification process if we analyze the types of rectification and the waveforms each produces. The types of rectification used are half-wave rectification and full-wave rectification.

Half-wave rectification

Half-wave rectification is accomplished by placing one or two rectifiers in series with the X-ray tube to eliminate reverse voltage across the tube. If two rectifiers are used; one is placed on each side of the tube circuit (figure 2–22). Notice that when the polarity of the transformer is as shown, current and voltage can flow across the tube; however, current will not flow across this circuit when the transformer polarity reverses. The addition of the rectifiers also prevents the reverse flow of voltage across the tube and the reverse flow of free electrons if the anode became hot enough during operation to be a source of electron emission. Figure 2–23 shows the resulting waveform.

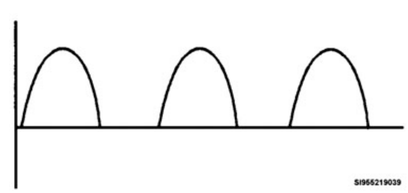

Figure 2–23. Half-wave rectified current waveform.

Full-wave rectification is when at least four rectifiers (diodes) are used in a circuit that allows both alternations of a cycle to be used to produce X-rays. This is a major advantage when compared to half-wave rectification. We can look at this process more closely with the help of figure 2–24, which shows a full-wave rectification circuit.

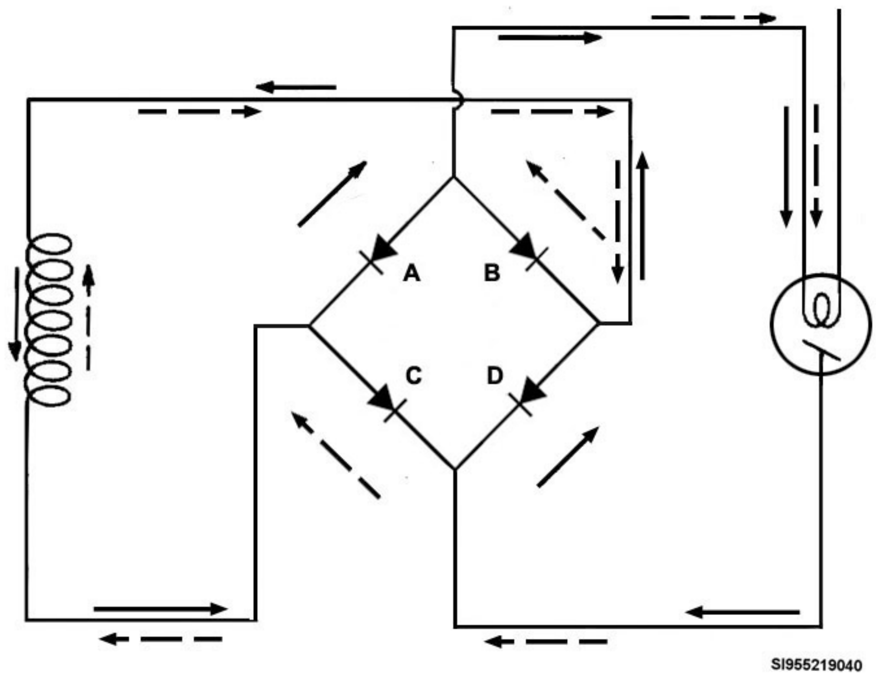

Figure 2–24. Full-wave rectification.

Notice the polarity and current flow for diodes A and D (indicated by the solid arrows). When the current reverses (as indicated by dashed arrows), notice the polarity and current follows a different path through diodes B and C in the rectification circuit. The point here is that current is constantly directed across the tube from cathode to anode in a way that both halves of each cycle of AC are applied to the X-ray tube for the production of X-rays. In essence, a full-wave rectification circuit is nothing more than a switching network that always keeps the cathode connected to the negative side of the transformer and the positive side connected to the anode.

The resulting full-wave rectified waveform is shown in figure 2–25. Compare that waveform to figure 2–23. Notice that with full-wave rectification the negative impulse, or alternation, is rerouted in the same direction as the positive alternation, producing two pulses per cycle across the X-ray tube. Compared to a one-pulse waveform, the two-pulse waveform produces twice as much radiation in a given time period if all other factors are equal. We can also say that a one-pulse waveform produces one pulse of radiation every 1/60 second (one per cycle), whereas, a two-pulse waveform produces two pulses of radiation every cycle (one pulse each 1/120 second for 120 pulses in a second).

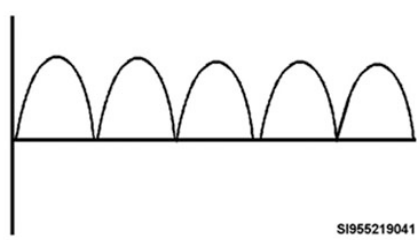

Figure 2–25. Full-wave rectified current waveform.

Full-wave rectification permits a considerable increase in the tube-rating capacity, which means we can make larger exposures without damaging the tube. On the other hand, the major disadvantage is when using the entire AC sine wave, a higher percentage of low energy X-ray photons are produced. (Later we’ll see how this problem is alleviated with the use of 3-phase generators.)

216. Single-phase and three-phase generator systems

Our discussion to this point dealt with X-ray generators that operate from single-phase AC. Specifically, we discussed circuits that produce one-pulse per cycle (half-wave) and two-pulses per cycle (full-wave). Many modern X-ray generators now operate from three-phase AC power. Three-phase AC can be rectified to produce six-pulses per cycle or twelve-pulses per cycle. There are some unique differences between the two.

Comparison of sine waves between single-phase and three-phase generators

The sine wave of single-phase AC has a different appearance from that produced with three-phase systems. Figure 2–26 shows a single-phase waveform and a three-phase waveform. Notice that the single-phase waveform has one positive alternation and one negative alternation in each cycle. Three-phase AC, on the other hand, consists of three single-phase currents out of step with each other by one-third of a cycle, or 120°. The result is constant voltage applied across the X-ray tube.

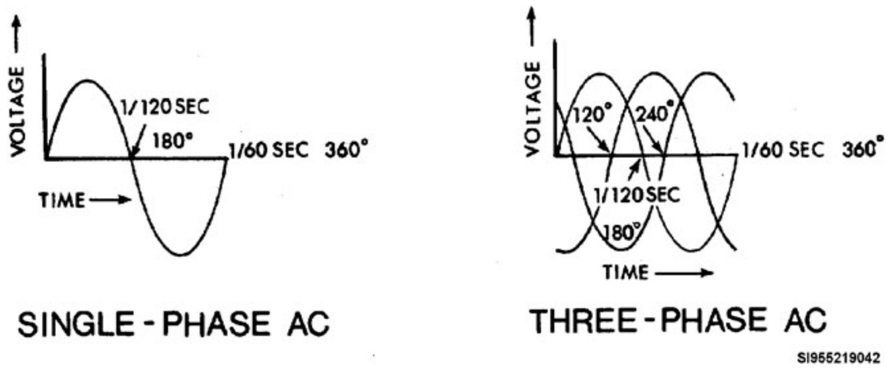

Figure 2–26. Sine waves for single-phase and three-phase AC.

Comparison of voltage ripples between single-phase and three-phase generators

Another major difference between single-phase AC and three-phase AC that can be graphically demonstrated is the voltage ripple. *Voltage ripple,* also called *voltage fluctuation,* is the difference in percentage between the peak voltage and the minimum voltage of each pulse. Figure 2–27 shows what we mean by voltage ripple difference. Notice that with single-phase AC, both one-pulse and two-pulse, there is a 100-percent voltage ripple meaning that the voltage varies from zero to its maximum voltage strength. The three-phase voltage ripples are only 14 percent for six-pulse and 4 percent ripple for 12-pulse because their currents overlap.

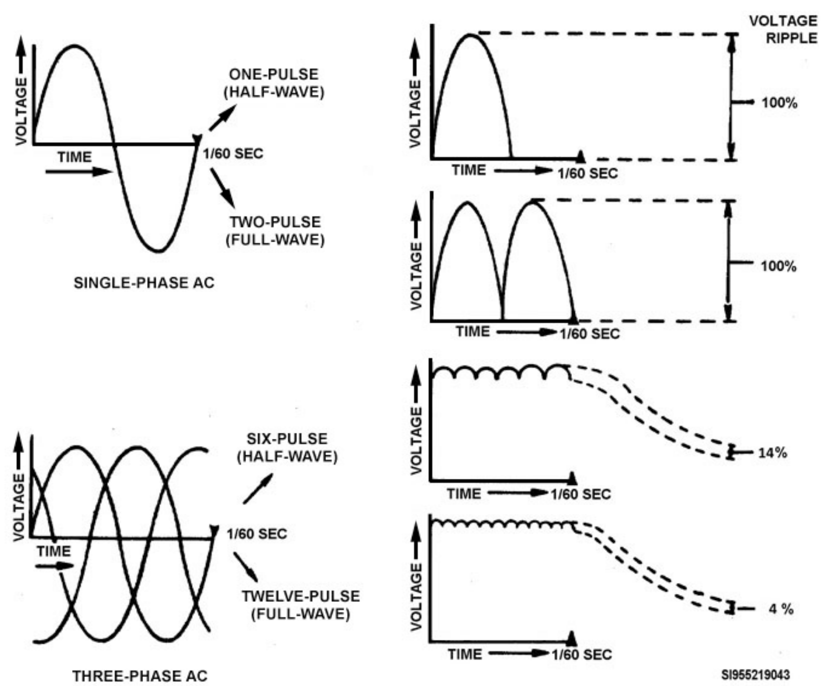

Figure 2–27. Single-phase versus three-phase voltage ripple.

Let's look at another comparison of voltage ripple to help us better understand its significance. Figure 2–28 shows a wave pattern produced in a single-phase, two-pulse generator and another produced in a three-phase, 12-pulse generator. With the two-pulse wave, the voltage rises to a peak and then falls to zero (100-percent ripple). This rise and fall of the voltage causes the speed of the electrons across the X-ray tube to vary accordingly, which affects the energy level of the photons produced.

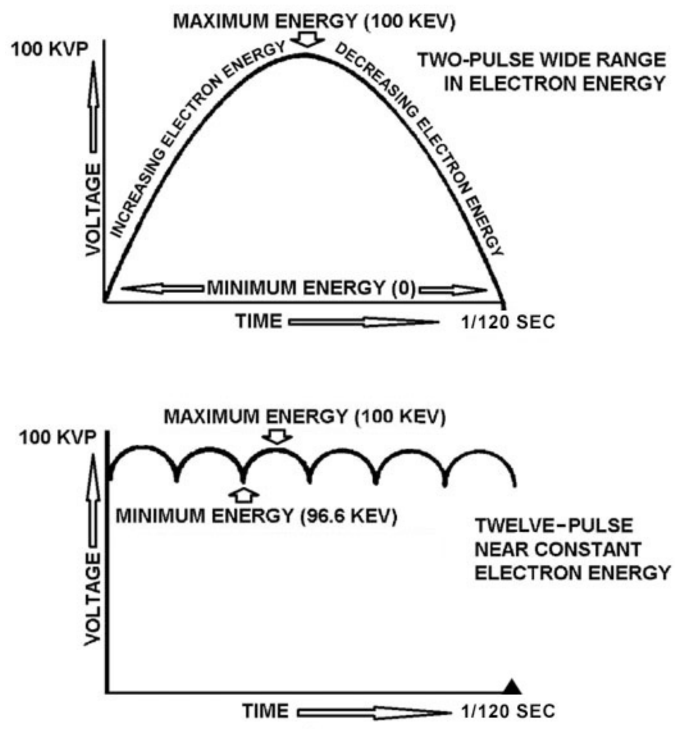

Figure 2–28. Comparison between electron energies of two-pulse and 12-pulse waveforms.

Consequently, if 100 kVp is applied to the X-ray tube, the kinetic energy of the electrons, and the photons produced from them, theoretically ranges from zero when the voltage is at zero to 100 keV when the voltage value is at its peak. As you know, keV stands for kiloelectron volts and is a unit of energy. The 12-pulse wave from a three-phase generator does not drop to zero. As stated earlier, it drops only 4 percent below peak value.

In other words, the kinetic energy of the electrons (at 100 kVp) in a 12-pulse system theoretically ranges from 96.5 keV to 100 keV. This means that the average kinetic energy imparted to the electrons is much higher in the 12-pulse system than in the two-pulse system. Following this same line of reasoning, you can see that the average electron energies of one-pulse and six-pulse waveforms also vary according to the voltage ripple.

A point of emphasis though is that the qualitative difference between the two beams is in *average* photon energy. Both systems, in fact, produce low-energy photons. The difference is in the proportion.

Comparison of technique factors between single-phase and three-phase generators

The average energy level of the beam of radiation produced by a three-phase unit is higher than that produced by a single-phase unit when both are adjusted for the same peak kV. To produce radiographs with the same general scale of contrast, it is necessary to use higher kVp with a single-phase unit. For a given mA station, it requires approximately twice as much exposure time (mAs) for a single-phase unit as for a three-phase (12-pulse) unit. Therefore, it is more logical to make the technique compensation by increasing input voltage (kVp) rather than by lengthening exposure time (mAs).

Increasing the (single-phase) kVp by 15 percent increases the average energy of the beam to a point where the single-phase unit produces radiographs of approximately the same scale of contrast (and density) as those produced by the three-phase unit using the same mAs. In addition, the increase in kVp tends to keep the absorbed dose of the patient to a minimum. The absorbed dose decreases as kVp increases because the X-ray beam has an overall higher energy level. A beam with a higher energy level has fewer low energy photons to be absorbed by the patient and at the same time produces less scatter radiation.

217. Electrical safety

DI departments, like your home, are full of electrical devices. We can reduce electrical hazards by using common sense and following some basic safety precautions.

Specific reactions to electrical shock

One person's reaction to an electric shock may be very different from another person's reaction. As medical professionals, we must realize that electric shock can have both a psychological (mental) and physiological (physical) effect on the body. Psychological effects from an electric shock may be similar to a narrow escape from a traffic accident or a reaction to a very frightening event. Physiological effects from an electric shock may range from tingling, slight pain, muscular contractions, fainting, minor burns, and temporary numbness or paralysis.

In severe electric shock situations, the brain's neurologic impulses can be blocked or disrupted affecting a person's breathing and/or heart beat. Under normal circumstances, the heart operates with a steady, rhythmic beat. *Ventricular fibrillation* is a condition where the heart flutters with a series of uncoordinated, rapid, weak pulsations. It can occur when an electrical shock disrupts the brain's messages to the body which results in a loss of pulse and blood pressure. This condition, if not immediately treated (corrected) by trained emergency medical personnel, may be fatal. The use of an automated external defibrillator (AED) is typically required to correct the electrical impulses that control the rhythm of the heart.

Factors affecting severity of electrical shock

The five factors that affect the severity of an electrical shock are:

1. The amount of current involved.
2. The length of time the shock is received.
3. The area of the body involved.
4. The state of health of the person involved.
5. The type of current.

The amount of current involved

No medical authority will state the minimum amount of current required to kill someone because other factors are always involved. However, we can show some approximate values of current and their associated physiological effects:

- 0.001 amperes—This is considered to be the minimum that can be perceived; in other words, the threshold of perception. This small amount of current (1 mA) can produce a tingling sensation.
- 0.016 amperes—This amount is the "can't let go" current that causes muscular contraction, thereby preventing a victim from releasing a conductor.
- 0.050 amperes—This amount of current is capable of causing pain, possible fainting, exhaustion, and mechanical injury (possibly minor burns or temporary paralysis). The heart and respiratory functions would continue.
- 0.100–3.0 amperes—This range causes ventricular fibrillation, which could lead to death. Any amount above 0.100 ampere should be considered life threatening.

The length of time the shock is received

The longer a victim is in contact with a current, the more severe the injury. Chances of survival improve if the shock is of short duration.

The area of the body involved

If a current of 0.050 amperes flows from the hand to the elbow, the effects would probably be minor. On the other hand, if the same amount of current would flow from hand to hand through the heart, it could be fatal. Vital organs, in particular the heart or brain, are more susceptible to electrical current than are, for example, the legs and arms.

The state of health of the person involved

An elderly person or one in poor health won't tolerate electric shock as well as a young, healthy person.

The type of current

Direct current (DC) is more dangerous than alternating current (AC). Usually, we are concerned with AC in our radiology departments, although DC is present in some instances.

Fuses

A fuse is a protective device designed to protect an electrical circuit within a piece of equipment or the walls of a building. A fuse is a device that "burns out" and stops the flow of current when the current exceeds the maximum rating of the fuse. The size of a particular fuse is based upon the amount of current in amperes that the circuit is designed to handle.

Here is an example of why it is important to replace a fuse with the same ampere size. A 15-ampere fuse blows out in your home breaker-box. You replace it but it blows out again. This time you replace it with one rated at 25 amperes. Good, the 25-ampere fuse doesn't blow out and all is well…at least for the time being.

A few weeks later, it's a rainy weekend and a good time to get some work done around the house. Your spouse is ironing, one child is watching TV, another is using the toaster, and you are using the vacuum cleaner. Suddenly the house is on fire. You barely manage to get everyone out of the burning house. As you watch your home go up in flames, you ask, "What happened?"

Do you know what happened? By replacing the 15-ampere fuse with a 25 ampere fuse, too much current was allowed to pass through the circuit and wiring. This excessive current allowed the wires in the walls to get red-hot and set the house on fire.

Perhaps you think this example was over-dramatized, but if a fuse blows out, there is a reason and that reason should be investigated by the appropriate electrical professional. In the case of medical equipment, contact a biomedical equipment technician (BMET) to get to the bottom of the situation

Grounding

An electrical *ground* is a conducting connection (pathway) from an electrical circuit (or piece of equipment) to the earth or some other conducting body. The earth is essentially an infinite reservoir of electrons and therefore any charged body can be neutralized (same number of positive and negative charges) if it is grounded by a conductor to the earth.

The most important safeguard to protect you and your patients from electrical shock is the proper grounding of equipment. Since current always takes the path of least resistance, your X-ray machine has to be properly grounded. Otherwise, the path of least resistance could be through you or your patient. Failing to consistently ground electrical equipment in your workplace can be potentially lethal.

Let's consider an example of improper grounding to help make our point. Faced with using a power cord with a three-prong plug and finding there are only two-prong outlets available, you remove (break off) the ground prong from the cord so the plug now fits into a two-prong outlet. Now say the power cord is plugged into a light used for a special study in your X-ray room. It is possible that if you come in contact with another piece of electrical equipment while touching the housing of the ungrounded light, you could very well be shocked. Basically, a circuit would be formed from the housing of the light, through your body, through the housing of the second machine, and out the ground wire.

It is your responsibility to always ensure electrical items in the radiology department are properly grounded. In addition, there should be no visible defects present on or about the power plugs or any other outside wiring of the equipment designated for use in patient care. Make it a habit to check the equipment you use at the beginning of your duty day and if a problem is identified, contact a BMET.

Common grounding of patient care equipment

As your radiology career progresses, you may get the opportunity to get some on-the-job training in sub-specialty areas like interventional radiology or computed tomography (CT). For many of the exams performed in interventional radiology or CT, an automatic power injector is used to inject contrast media into the blood stream in order to assist the radiologist in diagnosing the patient's condition.

When contrast media is injected via an automatic injector intravenously, there is an extra electrical shock hazard that cannot be overlooked. All patient care machines in a radiology suite must be grounded to the same, common ground. Though this responsibility typically falls to a qualified service technician from the equipment manufacturer or a BMET, it is important for you to understand where the danger comes from.

Here is the scenario. The patient is lying on the interventional radiology or CT table. The imaging system and table are both grounded to the same, common ground. As the patient lies on the imaging table, they too are grounded. For the sake of this example, let's say the automatic power injector is grounded separately and *not* to the same, common ground, as the imaging system and table. Since the patient's skin barrier has been bypassed by the intravenous catheter, any difference in potential between the injector and the other imaging equipment could result in a transfer of current through the contrast media directly into the patient's bloodstream to their heart in the form of an electric shock. Even if this shock is minimal, because the skin's resistance has been bypassed, it only takes approximately 1/1000 of the lethal skin current to electrocute a patient or possibly cause ventricular fibrillation. As you should remember, ventricular fibrillation is when the heart flutters with a series of uncoordinated, rapid, weak pulsations—a condition that can be fatal.

In this example, the hazard existed not because of faulty or damaged wires, but because the different pieces of equipment were not grounded to the same, common ground.,

Patient protection

Because of its importance, be alert to the basics discussed earlier. Do not alter the power plugs, wiring, or anything else affecting the equipment ground. In addition, check *all* support equipment used during exams in which the skin resistance is bypassed. Remember, it your responsibility as the technologist to make sure accessory items, such as examining lamps, film changers, etc., are grounded through the use of three-prong, heavy-duty line plugs. Finally, *before each examination,* inspect the equipment for frayed line cords, broken plugs, deteriorated insulation, or other equipment defects. If any problems are identified, make sure to notify your noncommissioned officer in charge (NCOIC) and contact a BMET to report the problem.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

213. The operating console

1. What is the #1 purpose of an X-ray unit?
2. Briefly describe the function of the line compensator.
3. Briefly describe the function of the autotransformer.
4. What is the main factor that determines the quality of the X-ray beam?
5. What is the sole purpose of the mAs timer?

214. High-voltage generator

1. What is the job of the high-voltage transformer?
2. What is the turns-ratio of a transformer that has 10 turns in the primary coil and 20 turns in the secondary coil?
3. How does the secondary current in a transformer relate to the turns ratio?

215. Types and purposes of rectification

1. Define rectification.
2. Describe half-wave rectification.
3. Describe full-wave rectification.

216. Single-phase and three-phase generator systems

1. What is three-phase AC?

2. Describe the voltage ripples for single-phase, three-phase six-pulse, and three-phase twelve-pulse current.

3. If a three-phase X-ray unit produces a radiograph with appropriate contrast at 100 kVp, what type of adjustment would be necessary to produce essentially the same contrast using a single-phase X-ray unit?

217. Electrical safety

1. What is ventricular fibrillation?

2. List the five factors that affect the severity of electrical shock.

3. Match each potential effect of electrical shock in column B with its threshold current value in column A. Each item may be used only once.

Column A	*Column B*
____ (1) 0.001 amperes.	a. Muscular contraction.
____ (2) 0.016 amperes.	b. Tingling.
____ (3) 0.050 amperes.	c. Ventricular fibrillation.
____ (4) 0.100–3.0 amperes.	d. Mechanical injury.

4. What is the purpose of a fuse?

5. What is the most important safeguard to protect you and your patients from electrical shock?

6. What fraction of the lethal skin current can electrocute a patient or possibly cause ventricular fibrillation because the skin's resistance has been bypassed?

Answers to Self-Test Questions

209

1. It is the act of transferring some or all of a charge (either too few or too many electrons) to that object or person.
2. The attraction of unlike charges or the repelling of like charges.

3. Volt.
4. Any material or substance that allows electrons to easily flow from an abundance to a deficiency.
5. A measures of the rate at which electrons are moving through a material, or in other words, the intensity of the current.
6. The opposition of current flow.
7. When resistance is controlled and conductors are formed into a closed path or loop.
8. An electrical circuit in which the components are connected end-to-end and there is only one path for the current to flow.
9. An electrical circuit in which two or more devices are connected across a common power source.
10. In DC, electrons continuously flow in one direction through a circuit. In AC, electrons move first in one direction, and then in the opposite direction.
11. Two.
12. 60 cycles or 120 alternations (pulses).
13. The voltage of a circuit or any portion of the circuit is equal to the current times the resistance.
14. 3 amps.

210

1. (1) Every magnet has two poles, one at each end, called north and south poles.
   (2) Like magnetic poles repel each other; unlike poles attract each other.
   (3) The force of attraction or repulsion between two magnetic poles varies directly with the strength of the poles, and inversely with the square of the distance separating the poles.
2. Nonmagnetic, diamagnetic, ferromagnetic, and paramagnetic.
3. The substance is easily magnetized by the process of induction.
4. The general rule for permeability and retentivity states that a metal that is easily magnetized is also easily demagnetized. On the other hand, a metal that is difficult to magnetize is also difficult to demagnetize.

211

1. Every electric current generates a magnetic field. Likewise, any magnetic field can be made to generate an electric current.
2. A north pole is created on one side of the loop and a south pole on the other.
3. A current-carrying wire conductor that is formed into many loops.
4. When a current-carrying wire coil is wrapped around an iron core.

212

1. The process of producing an EMF from the relative motion between a conductor and a magnetic field.
2. A conductor, a magnetic field, and relative motion.
3. From the expanding and collapsing magnetic field generated by AC and the constant change in direction of the current.
4. The process of introducing current or voltage in a circuit by varying the current or voltage in a neighboring circuit.

213

1. To convert regular electric energy (electricity) into electromagnetic energy.
2. Measures the incoming voltage to the imaging unit and then adjusts it to be precisely the voltage that is required.
3. Controls the voltage that enters the primary coil of the high-voltage transformer of the X-ray machine.
4. kVp.
5. Monitors the amount of mA and length of exposure time so that it may terminate the exposure when the correct mAs is achieved.

214

1. Increase the voltage to the appropriate kVp setting needed to produce X-rays.
2. 2.
3. It is inversely proportional to the turns-ratio.

215

1. The process of converting alternating current to direct current.
2. Half-wave rectification is accomplished by placing one or two rectifiers in series with the X-ray tube to eliminate reverse voltage across the tube.
3. When at least four rectifiers (diodes) are used in a circuit that allows both alternations of a cycle to be used to produce X-rays.

216

1. Three single-phase currents out of step with each other by one-third of a cycle, or 120°.
2. There is 100-percent voltage ripple for single phase AC, 14 percent ripple in three-phase six-pulse, and 4 percent ripple in three-phase twelve-pulse.
3. Increase kVp by 15%.

217

1. A condition where the heart flutters with a series of uncoordinated, rapid, weak pulsations.
2. The amount of current, length of time, area of the body, state of health, and type of current.
3. (1) b.
   (2) a.
   (3) d.
   (4) c.
4. A protective device designed to protect an electrical circuit within a piece of equipment or the walls of a building.
5. Proper grounding of equipment.
6. 1/1000.

Complete the unit review exercise before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

16. (209) Current that flows in one direction and then reverses itself to flow in the opposite direction is
    a. wave current.
    b. direct current.
    c. parallel current
    d. alternating current.

17. (209) The peak values of an alternating current (AC) sine wave represent maximum
    a. velocity.
    b. voltage only.
    c. current only.
    d. voltage and current.

18. (210) In an unmagnetized iron bar, the magnetic dipoles of the material are
    a. arranged at random.
    b. pointed toward the periphery.
    c. molecular in size and arranged in a definite pattern.
    d. arranged so that their north poles point in one direction.

19. (210) Materials which retain their magnetism well are said to have high
    a. magnetic moment.
    b. magnetic retentivity.
    c. inherent magnetism.
    d. magnetic permeability.

20. (211) A straight, current carrying conductor has a magnetic field
    a. with few lines of force.
    b. with no North or South poles.
    c. only if the current is direct current (DC).
    d. that does not expand or collapse with current fluctuations.

21. (212) What are the three requirements for electromagnetic induction?
    a. Conductor, magnetic field, iron core.
    b. Conductor, magnetic field, relative motion.
    c. Relative motion, iron core, alternating current.
    d. Alternating current, magnetic field, relative motion.

22. (212) What are the two types of electromagnetic induction?
    a. Self-induction and mutual induction.
    b. Self-induction and relative induction.
    c. Relative induction and mutual induction.
    d. Relative induction and thermal induction.

23. (213) What is the main purpose of an X-ray imaging unit?
    a. Increase input voltage.
    b. Convert X-rays into light.
    c. Convert electricity into electromagnetic energy.
    d. Provide line compensation for the incoming voltage.

24. (213) Electricity supplied to the imaging system from the power company through the hospital is first delivered to the
    a. system console.
    b. autotransformer.
    c. high-voltage generator.
    d. high-tension transformer.

25. (213) When an exposure is made, what is the exposure timer's responsibility?
    a. Stop the exposure.
    b. Start the exposure.
    c. Measure the duration of the exposure.
    d. Measure the circuit strength during the exposure

26. (213) Of the four types of timers in an X-ray imaging system, which one shuts the exposure off when a predetermined charge has been reached in the image receptor?
    a. Electronic.
    b. Synchronous.
    c. Automatic exposure control.
    d. Milliampere and time (mAs).

27. (214) Which statement is true concerning step-down transformers?
    a. They have a turns ratio of less than one (1).
    b. They have a turns ratio of greater than one (1).
    c. They increase the voltage in secondary windings.
    d. They decrease amperage in the secondary windings.

28. (215) The process of converting alternating current (AC) to direct current (DC) is called
    a. induction.
    b. conversion.
    c. rectification.
    d. transformation.

29. (215) How many alternations are used each cycle to produce radiation with a full wave rectified unit?
    a. 1.
    b. 2.
    c. 60.
    d. 120.

30. (216) If 100 kVp is used for a radiograph taken with a three-phase X-ray unit, what kVp should be used to produce the same contrast using a single-phase unit?
    a. 85.
    b. 90.
    c. 115.
    d. 120.

31. (217) What set of factors affect the severity of electric shock?
   a. Age, amount of current, gender.
   b. Body habitus, age, amount of current.
   c. Amount of current, type of current (alternating or direct), body habitus.
   d. Length of exposure, amount of current, type of current (alternating or direct).

32. (217) The purpose of a fuse is to
   a. restrict current flow to only one direction.
   b. protect an electric circuit from current overload.
   c. protect equipment operators from electric shock.
   d. prevent reverse voltage from flowing across an X-ray tube.

33. (217) When the resistance from skin is bypassed, what fractional amount of the lethal skin current is needed to electrocute a patient or possibly cause ventricular fibrillation?
   a. 1/1000.
   b. 1/100.
   c. 1/10.
   d. 1/5.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Production of X-radiation

X-RAYS are produced when high-speed electrons undergo a loss of energy because of their interaction with matter. There are three conditions necessary to produce X-rays: a source of electrons, a means of accelerating, and then a means of rapidly decelerating those electrons. The most efficient way to provide these factors is with the use of an X-ray tube.

3–1. X-ray Tubes

An X-ray tube (sometimes referred to as a *thermionic diode tube*) is a special kind of electronic vacuum tube that is encompassed within a glass or metal enclosure. The major parts of an X-ray tube are the protective housing, the tube enclosure, the cathode, and the anode.

218. Purpose of the protective housing and tube enclosure

Our discussion of the X-ray tube will begin with the protective housing for the X-ray tube and the tube enclosure that surrounds the cathode and the anode.

Protective housing

An X-ray tube is mounted inside a protective housing as shown in figure 3–1. A typical protective housing is made of metal and lined with lead. It has four basic functions: shielding, insulation, heat dissipation, and physical protection.

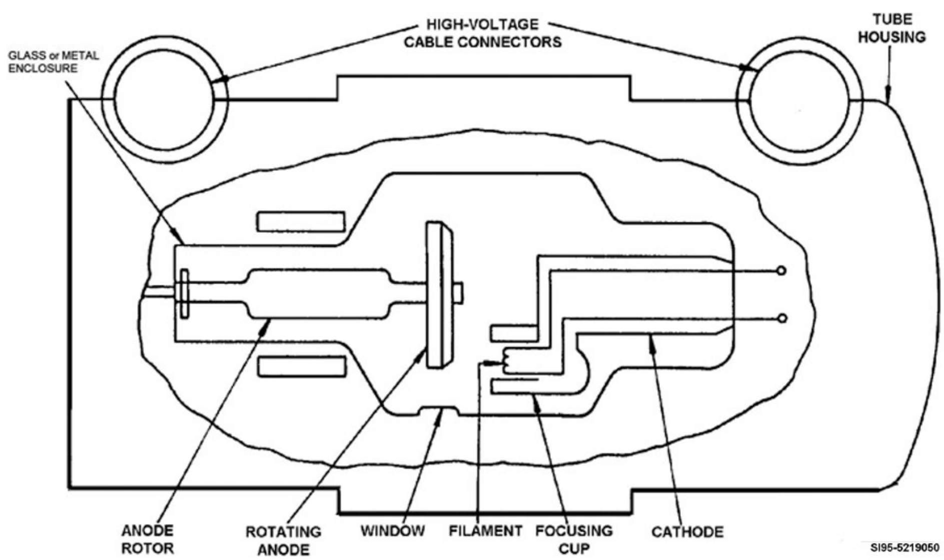

Figure 3–1. Diagram of an X-ray tube inside its protective housing.

When electrons traverse the tube from the cathode to the anode and produce X-rays, they are produced *isotropically*, or in other words, in every conceivable direction with like intensities. X-rays pass through a special *window* at the bottom of the tube. The X-rays that exit the tube through this window form the *useful beam*. Any X-rays that happen to exit the housing other than through the window are called *leakage radiation.* Leaked radiation does nothing to contribute to a diagnostic image; it only causes unnecessary exposure to the patient and the technologist. Because leakage radiation is useless, the National Council on Radiation Protection and Measurements (NCRP) has set a minimal allowance of leakage radiation to never exceed 100 milliroentgens per second (mR/s) at a 1-meter distance from the tube head.

The protective housing also serves as an electrical insulator to protect operators from the possibility of accidental electrical shock. Special high voltage receptacles and oil surrounding the tube enclosure add to the electrical safety of the tube.

Another function of the protective housing is heat dissipation. The oil surrounding the tube enclosure, in conjunction with an external cooling fan, serves as a thermal cushion to facilitate heat dissipation. The final function of the tube housing is to support the tube assembly and to protect it from damage.

The tube enclosure

The tube enclosure surrounds the functioning parts of the tube: the cathode and the anode. The tube enclosure is typically constructed of glass or metal. Within the enclosure, a vacuum is maintained to provide more efficient production of X-rays and it extends the tube's overall life. Though early tube enclosures were made of glass, most modern tubes incorporate metal as part or all of the tube enclosure. Metal enclosures further extend the life of the tube by better maintaining a constant electric potential. As mentioned earlier, the bottom of the tube enclosure has a window approximately 5 centimeters squared (cm^2). The window is typically very thin, which allows for minimum absorption of the useful X-ray photons. In some cases, X-ray tubes are designed especially for soft tissue imaging where low energy photons are allowed to exit the window. In these types of tubes, the window is made from *beryllium.* Beryllium has an extremely low atomic number that reduces the inherent filtration of the glass window. In Mammography, beryllium glass windows are the norm because low energy photons are necessary in order to achieve the appropriate long scale of contrast needed on a mammography image.

219. Characteristics of cathode design and function

There are two electrodes within the X-ray tube. The negative electrode is called the *cathode.* The cathode assembly has two major parts: the *filament* and the *focusing cup*. This lesson will explain the function of these two standard cathode components and will also describe the unique design of the grid-controlled X-ray tube.

Filament

The filament is a small-coiled wire approximately 2 millimeters (mm) in diameter and no more than 2 centimeters (cm) in length. The small diameter and distance of the filament creates a high resistance to electron flow. When the filament is provided with a current of 3 to 5 amps (or 3,000 to 5,000 mA), the filament is heated to a high temperature and electrons from the outer shells of the filament atoms are "*boiled off*" to form an "*electron cloud*" around the filament. The process by which electrons are made available for X-ray production is known as *thermionic emission.* The free electrons created by thermionic emission will eventually interact with the target of the anode to produce X-rays. The electron cloud around the filament is called the *space charge;* it tends to limit the emission of more electrons from the filament. This restriction of electron emission is called the *space charge effect.*

Remember the rule that states, "Like charges repel"? The space charge effect actually holds back the emission of electrons until they have acquired sufficient thermal energy to overcome this force of repulsion of the space charge. When electrons leave the filament, the loss of negative charges causes the filament to acquire a slightly positive charge. The filament then attracts some electrons back to itself; this condition is helped along by the space charge effect. In this case, the rule is "unlike charges attract one another."

In addition, we can say that the space charge effect limits the electron emission at a particular mA current because an equilibrium is quickly reached between the number of electrons returning to the filament and the number of electrons being emitted. Therefore, the number of free electrons that can be controlled and made available to produce X-rays is determined by the filament temperature, which is controlled by the mA setting.

Unfortunately, within certain ranges, an independent change in the applied kilovoltage (kV)—without a change in mA—actually causes a slight increase in the number of free electrons available to produce radiation. To correct this situation, a *space charge compensator* is introduced into the filament circuit to automatically lower filament current to just the right amount to compensate for the rise in applied kV.

Since a filament is routinely heated to extremely high temperatures, it must be able to withstand those high temperatures repeatedly. The material of choice for filament construction is thoriated tungsten because of its high melting point of 3410 degrees Celsius (° C) and because it does not vaporize easily. In addition, 1 to 2 percent of thorium is added to the tungsten filament, which increases efficiency of thermionic emission and increases overall tube life.

Extending filament life

Over time, tungsten metal does eventually vaporize. When it does, tungsten becomes deposited on the internal components of the tube, which negatively affects the electrical characteristics of the tube, which can cause arcing within the tube. When arcing occurs, it tends to cause an abrupt tube failure. The technologist role in extending filament life is simple. Practice good habits when “ramping-up” (heating the filament) the machine for X-ray production. When the rotor button is depressed and the filament heats up (boiling off the needed valence electrons), make it a habit to take the exposure immediately when the machine is ready instead of continuously holding down and running the rotor for an extended period of time. Another way the technologist can improve filament life is by using lower mA settings.

Focusing cup

The filament is enclosed in a negatively charged metal focusing cup (fig. 3–1). The purpose of the focusing cup is to confine the emitted electrons to a small area around the filament. Confining the emitted electrons is necessary because the electrons, which repel each other because of their negative charge, have a tendency to spread out as they travel to the anode. This spreading of the electrons is called *blooming* and makes the focal spot larger. The focusing cup is maintained at the same negative potential as the filament so that its electrical force condenses the electron stream and “aims” it to a smaller area on the target. The effectiveness of the focusing cup depends upon its size and shape, the magnitude of its negative charge, the size and shape of the filament, and the position of the filament within the focusing cup.

Most modern X-ray tubes have two different sized filaments in one focusing cup set parallel to each other. Due to their different sizes, the two filaments create a large or a small focal spot relative to their size.

Grid-controlled X-ray tubes

Another modification in tube design is the *grid-controlled tube.* This type of tube is a *triode* because it has three electrodes: a cathode, an anode, and a grid. Functionally, the advantage of a grid-controlled tube versus a conventional tube is that the grid-controlled tube allows the exposure to be turned on and off more rapidly.

A grid-controlled X-ray tube uses the focusing cup as a grid. A negative potential called *negative bias* or *grid bias* is placed across the focusing cup. The negative bias acts as a gate to prevent electrons from leaving the focusing cup when the exposure is to be terminated. Removal of the negative bias allows the electrons to leave the focusing cup and starts the exposure.

The term “gird” actually originates from the electronics of a vacuum tube and it serves as a switch within the tube to quickly turn on or off the flow of electrons across the tube. Examples of equipment in which grid-controlled tubes are commonly used include portable capacitor discharge systems, digital angiography, and cineradiography where exposures must be repeatedly started and stopped in rapid succession.

220. Characteristics of anode design and function

Previously, we stated that the third requirement for the production of X-rays is a means to rapidly decelerate the high-speed electrons. This allows the kinetic energy of the electrons to be converted to X-rays. That task of rapid deceleration is accomplished by the anode; the positively charged electrode of an X-ray tube.

Purposes of the anode

The anode has three distinct purposes: serve as an electrical conductor, provide support for the target, and to dissipate heat (thermal conduction).

As an electrical conductor, the anode completes the circuit for electron flow from the cathode, through the tube, to the connecting cables, and back to the high-voltage section of the X-ray machine. The anode provides mechanical support for the target, which is made of tungsten or a tungsten-rhenium alloy because of its high melting point and high atomic number. The target is embedded into the face of the anode, directly across the tube from the focusing cup and filament (fig. 3–1). The anode must quickly move the heat away from the target before the target melts or is otherwise damaged. For this reason, most modern anodes are made of copper, molybdenum, and graphite.

Preventing target damage

Targets can be damaged in a variety of ways. One cause of target damage is *thermal shock.* Thermal shock is a term used to indicate the reaction of a *cold* anode to a high exposure. A cold anode is one that has not been used for several hours. If we subject a cold anode to a high exposure, there is a possibility that the anode disc will crack. To prevent thermal shock to the anode, make sure to follow the tube manufacturer’s specific procedures for warming up a cold tube. Tube warm-up procedures usually consist of making a specific number of low factor exposures over a specified period of time. Another possible reaction to a single, high-energy exposure without warming up the tube is anode pitting. The heat created in the cold anode causes a portion of the target to melt away, leaving a missing portion of tungsten on the target.

Types of anodes

The two types of anodes used are the rotating anode and the stationary anode. Stationary anodes are used in some portable imaging machines, dental units, and other special-purpose X-ray machines that do not require high tube current and power. Tubes with rotating anodes are found in general-purpose X-ray units because they can produce high-intensity X-rays in a short time without damaging the tube. The rotation of the anode spreads out the heat produced during an exposure over a larger area. Thus, tubes with a rotating anode have higher tube rating than do tubes with a stationary anode.

Before the development of the rotating anode, another design feature of X-ray tube targets was based on the *line-focus principle* which places the target area at an angle. Angling the target area allows the effective area of the target to become smaller than the actual area where the electron interaction takes place. Most tubes produced today for diagnostic purposes have a target angle of 5 to 20 degrees. By angling the target and using the line focus principle, it allows for an increase in spatial resolution and is another factor in allowing a higher target heat capacity.

Focal spots

We will discuss two types of focal spots, the *actual* focal spot and the *effective* focal spot.

Actual focal spot

A constant problem in tube design is constructing a tube to withstand high heat while at the same time maintaining good detail. One of the tube components that affects the heat capacity is the size of the *actual focal spot.* The actual focal spot is the rectangular area on the target that is actually bombarded by the electrons, and is measured at right angles to the target surface (fig. 3–2).

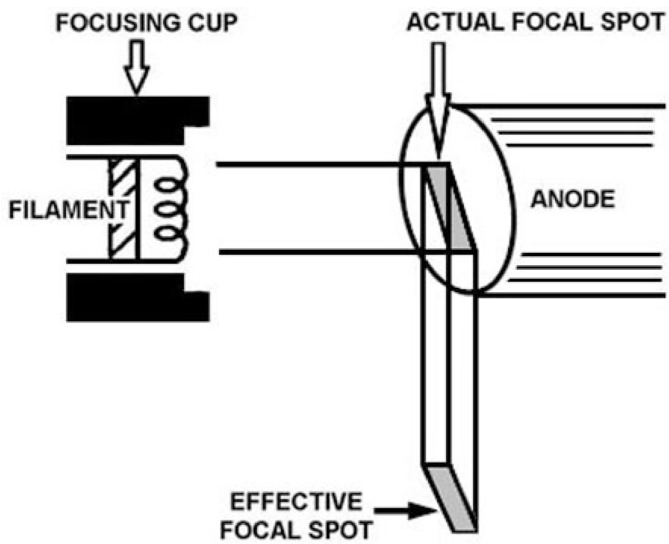

Figure 3–2. Actual and effective focal spots.

The size of the *actual* focal spot significantly affects the heat-loading capacity of the anode—the larger the actual focal spot, the greater the heat-loading capacity. Think for a moment about why the size of the electron bombardment area (the actual focal spot) affects the heat capacity. For example, if you hold out your hand into direct sunlight, chances are you will feel heat but not any discomfort. If you use a magnifying glass to concentrate the sun's rays on a small spot on your hand, chances are you would feel the heat more intensely to the point of getting burned. The same is true with the actual focal spot.

Three factors determine the size of the actual focal spot: the size of the filament, the shape of the focusing cup, and the angle of the target surface.

Effective focal spot

The *effective focal spot* is the area that is projected towards the patient and image receptor at a right angle to the electron stream. Notice in figure 3–2 that the effective focal spot appears smaller than the actual focal spot. The size of the *effective* focal spot is determined in part by the size of the actual focal spot and the angle of the target surface. Figure 3–3 shows two anodes of different angles and their effect on the effective focal spot size. Notice that if the size of the electron stream remains the same, then the size of the effective focal spot is determined by the target angle. Therefore the basic relationship between the two can be stated as such; the smaller the target angle, the smaller the effective focal spot—when all other factors remain constant. In figure 3–3, the effective focal spot produced with the 10° target angle is smaller than the one produced with the 17° anode. Although a small effective focal spot is desirable for better spatial resolution (detail), a small target angle can present some problems when a larger field size is needed.

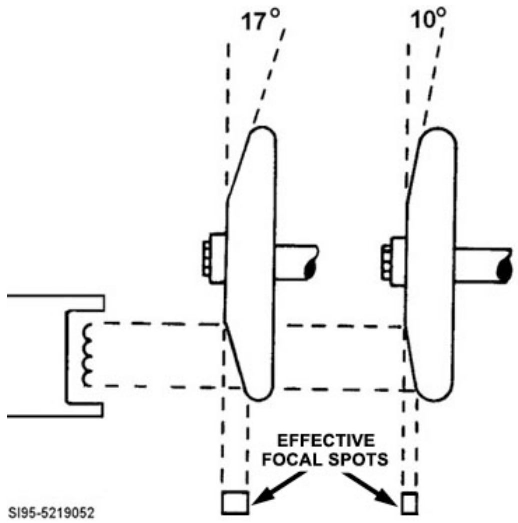

Figure 3–3. Diagram showing the relationship between target angle and the size of the effective focal spot.

Effects of target angle

One of the things associated with target angle is the size of the X-ray field, or in other words, the area that the X-ray beam covers at a given source-to-image distance (SID). The size of the X-ray field is greater with larger target angles, when compared to smaller target angles at the same SID (fig. 3–4). For example, a target with a 10° angle at a 40-inch SID covers a 14-inch-square area while a 7° angle covers only a 9.5-inch-square field. Obviously, the smaller target angle cannot be used to radiograph an anterior-posterior (AP) abdomen at 40 inches because the beam will not cover the entire abdomen. Tubes utilizing a smaller target angle are effectively used where X-ray beam coverage is not as critical as the requirement for good detail. An example where a tube like this could be used is in an interventional radiography room where the beam sufficiently covers the smaller films used in automatic film changers. A 12° target is the smallest angle that adequately covers a 14- by 17-inch film at a 40-inch SID.

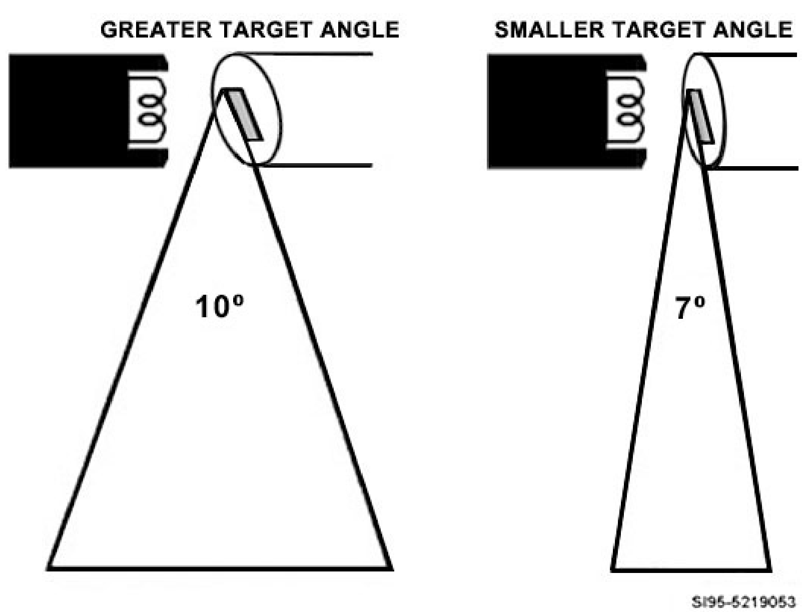

Figure 3–4. The relationship between target angle and X-ray field coverage.

Another factor greatly affected by the target angle is the *anode heel effect.* The anode heel effect refers to the phenomenon that produces a variation in intensity of the radiation within the useful beam along the long axis of the X-ray tube. This is caused because the X-rays in the useful beam closer to the anode side have to pass through the thicker portion of the target than those X-rays closer to the cathode side. This, unfortunately, is a negative effect of the line-focus principle.

Using the central ray (CR) in figure 3–5 as our starting point, let's see how the intensity varies. As we move away from the CR on the anode side (to the right), we find that the intensity becomes less and less the farther we go. Also, when we move away from the CR on the cathode side, we find that the beam becomes more intense as compared to CR area or on the anode side. The area of increased intensity is limited however, as we continue to move in the direction of the cathode away from the CR, we find that the intensity again decreases. The intensity percentages at different angles of emission of a 20° anode are illustrated in figure 3–5 for discussion purposes. Keep in mind, the variation in intensity can vary as much as 45 percent across the longitudinal axis of the useful beam.

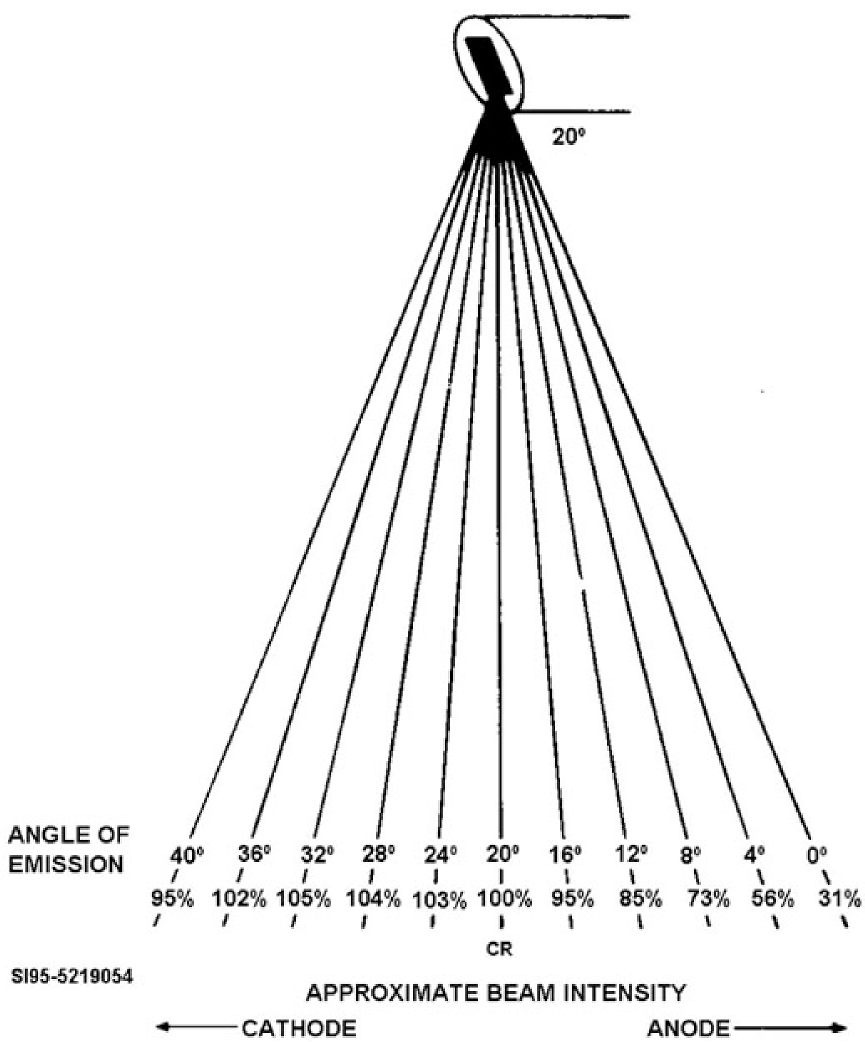

Figure 3–5. The intensity of the primary beam varies with the angle of emission from the target.

The variation in intensity is due to the angle of the anode. Some photons are emitted from within the target material, rather than from the target surface. As you can see in figure 3–6, photons emitted from within the target toward the anode side of the tube travel through more target material, which

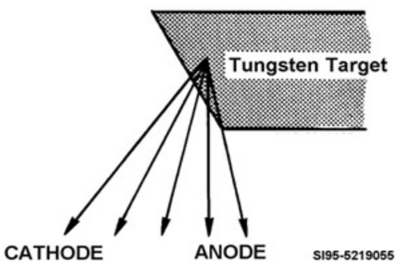

Figure 3–6. The anode heel effect.

means more of these photons are have increase absorption. On the other hand, since photons emitted toward the cathode side of the tube travel through less target material allowing for less absorption.

So what is the relationship between the target angle and the anode heel effect? Simple, the smaller the target angle, the more pronounced the anode heel effect.

Regardless of the target angle of the tube, another factor to consider regarding the anode heel effect is SID. Consider figure 3–7. If part 1 is radiographed, the intensity range is 85 percent to 104 percent. If part 2 is radiographed, the intensity range is 31 percent to 95 percent. The intensity range for part 1 is not sufficient to cause objectionable density variation on a radiograph, while the intensity range for part 2 certainly will. You can see the reason for the difference in the intensity percentage range if you will compare the total area of the primary beam required to radiograph each part in figure 3–7.

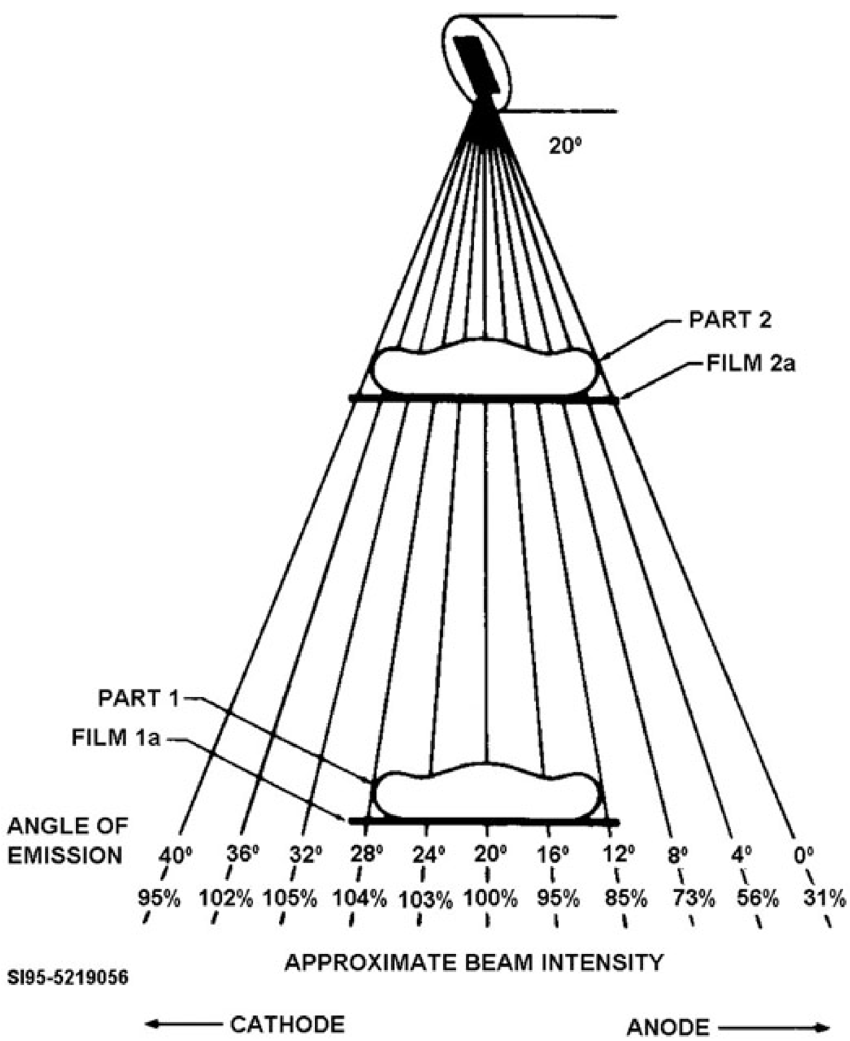

Figure 3–7. The anode heel effect as it relates to SID.

Another factor to consider pertaining to the anode heel effect is the image receptor size. Notice in figure 3–8 that if two different sized receptors are used at a specific SID, the heel effect is more pronounced with the larger image receptor. Therefore, you can conclude that at a given SID, larger image receptors are more affected by the anode heel effect than smaller image receptors.

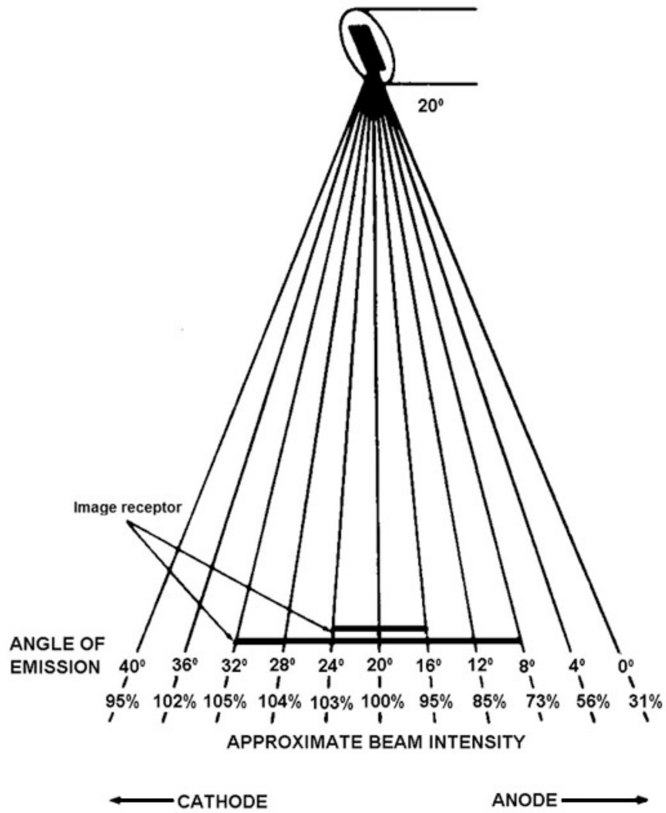

Figure 3–8. The anode heel effect as it relates to film size.

Although the anode heel effect at times can cause unbalanced density on a radiograph, you can use it to your advantage when X-raying certain parts of the body. Consider, for example, an AP thoracic spine. The thickness of the chest over the upper part of the spine is not as great as over the lower part. If you position the patient so that the anode side of the tube is over the upper spine and the cathode side over the lower spine, the anode heel effect can help maintain density in spite of uneven body thicknesses. The leg and femur are two other parts where the anode heel effect should be used to its greatest advantage. It is best to place the thicker portion of the body part under the cathode side of the tube.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

218. Purpose of the protective housing and tube enclosure

1. Name the four functions of the X-ray tube protective housing.

2. What is leakage radiation?

3. What two items facilitate heat dissipation?

4. Why is a vacuum maintained within the tube enclosure?

5. What is reduced when a beryllium window is used in tubes designed especially for soft tissue imaging?

219. Characteristics of cathode design and function

1. Explain the process of thermionic emission.

2. What setting controls the filament temperature?

3. What is the material of choice for filament construction? Why?

4. What is the purpose of the focusing cup?

5. What is the advantage of having a grid controlled tube?

220. Characteristics of anode design and function

1. Name the three purposes of the anode.

2. What material is used to make the target? Why?

3. What can you do to prevent thermal shock to the anode?

4. What significantly affects the heat-loading capacity of the anode?

5. Name the three factors that control the size of the actual focal spot.

6. What two factors control the size of the effective focal spot?

7. What is the relationship between the target angle and the anode heel effect?

8. If the surface-to-image distance is kept constant, what relationship exists between the size of the image receptor and the anode heel effect?

3–2. X-ray Emission

There are many variables involved in the production of high quality diagnostic radiographs. Properly adjusting these variables to your advantage is often as much an art as it is a science. If you know the rules and principles affecting the science of radiography, you can apply them in unique circumstances and obtain favorable results.

221. Factors of X-ray beam quantity

When we speak of X-ray quantity (or intensity), we are referring to the total number of X-ray photons produced out of all energy levels in the useful beam. In the diagnostic energy levels of X-radiation (20 to 150 kVp), X-ray quantity is measured in roentgens (R) or milliroentgens (mR). The roentgen is a measurement of the number of ion pairs formed in a quantity of air by a beam of radiation. Specifically, one roentgen equals 2.08 X 10^8 ion pairs per cubic cm of air. Another unit of measurement, coulombs per kilogram (C/kg), comes from the International System of Measurements. It is a measure of electrical charge per unit mass of air. Specifically, one roentgen equals 2.58 X 10^{-4} C/kg. We continue this lesson with a discussion about the factors affecting the quantity of the X-ray beam.

The four factors that affect X-ray quantity are mAs, kVp, distance, and filtration. The reason for discussing them now is that X-ray quantity (intensity) is one of the primary factors that control radiographic density. Radiographic density will be discussed in more detail in the next unit; however, we begin this discussion about mAs.

Milliampere-seconds

Milliampere-seconds (mAs) is an arbitrary number that represents the milliamperage (mA) station setting multiplied by the time (in seconds) of the exposure. Each of these factors separately can affect the quantity of radiation produced.

Milliamperage

The mA setting directly affects intensity by controlling the amount of current that is applied to the filament when the rotor is engaged. To understand this, let’s go back again to the electrons that travel from the filament in the X-ray tube to the target. An increase in mA results in a higher filament temperature and more electrons available to traverse the tube for interaction with the target, thereby increasing the quantity of X-rays produced. As more electrons interact with the target, more photons are produced. Furthermore, the increase in the number of photons is proportionate to the increase in the number of electrons. For example, if the number of electrons is doubled, the number of photons, and consequently the intensity, is doubled. Since mA regulates the amount of electrons at a given time by controlling filament temperature, you can see how adjusting the mA regulates the intensity of the primary beam.

Time

As an exposure factor, *time* (symbolized by the letter “s”) refers to the duration that a potential difference exists between the cathode and anode across the X-ray tube measured in seconds or a fraction thereof. Exposure time has an identical effect on the quantity or intensity of the useful X-ray beam as mA.

When all other factors but time are constant, the quantity of X-rays emitted by the X-ray tube increases or decreases in direct proportion to the time of exposure. Suppose we apply 100 mA to the X-ray tube for 1/10 sec. If we then increase the exposure time to 1/5 sec, electrons are emitted from the filament at the same rate, but the period of time during which they are emitted is twice as long (1/10 × 2 = 1/5). In effect, this change in the exposure time doubles the number of electrons interacting with the target and, consequently, doubles the number of photons produced. Therefore, increasing the time increases the intensity and vice versa.

Milliamperage and time relationship

Based on this relationship between mA and s (time), it is important to remember that if one of these factors increases the other must decrease proportionally in order to keep the overall exposure intensity constant. Therefore, if the mA required for a given X-ray beam intensity is increased by a certain amount, then the time (s) must decrease inversely and by the same amount (proportionally) for exposure intensity to remain constant. This rule may be expressed with the formula:

$$mA_1 \times sec_1 = mA_2 \times sec_2$$

Where:

$mA_1 =$ Original mA

$mA_2 =$ New mA

$sec_1 =$ Original time in seconds

$sec_2 =$ New time in seconds

Now, let's apply this to a working situation. Suppose, for example, your original technique factors were 300 mA at 0.10 second. Let's assume that because of trauma the patient is semiconscious and unable to fully cooperate with you. To reduce the possibility of motion affecting the image, you choose to cut the exposure time in half to 0.05 second. In order to maintain the same beam intensity, what is your new mA selection? Consider the following:

$$mA_1 \times sec_1 = mA_2 \times sec_2$$
$$300 \times 0.10 = mA_2 \times 0.05$$
$$30 = (0.05)mA_2$$
$$mA_2 = \frac{30}{0.05}$$
$$mA_2 = 600\, mA$$

In this example, the new mA is 600 and when the new mA setting is used with the new time (0.05), the new mAs equals the original mAs:

$$mA_1 \times sec_1 = mA_2 \times sec_2$$
$$(300)(0.10) = (600)(0.05)$$
$$30\, mAs = 30\, mAs$$

Milliampere-second relationship to X-ray quantity

X-ray quantity (measured in roentgens) is directly proportional to the selected mAs setting. When the mAs setting is doubled, the amount of electrons that hit the target material are also doubled which means that the amount of X-rays produced is doubled. This relationship is shown with the following formula:

$$\frac{I_1}{I_2} = \frac{mAs_1}{mAs_2}$$

Where:

$I_1 = mAs_1$ (original intensity)

$I_2 = mAs_2$ (new intensity)

To apply this formula in action, let's assume an original posterior-anterior (PA) chest technique calls for 110 kVp at 5 mAs which results in an X-ray intensity of $16\,mR$ at a given distance. If the mAs is increased to $10\,mAs$, what is the resulting new intensity?

$$\frac{I_2}{I_1} = \frac{mAs_2}{mAs_1}$$

$$\frac{I_2}{16mR} = \frac{10mAs}{5mAs}$$

$$I_2 = \frac{(16mR)(10mAs)}{5mAs}$$

$$I_2 = \frac{160}{5}$$

$$I_2 = 32\,mR$$

Kilovoltage

As applied kVp increases, so does the difference in potential applied across the tube which in-turn increases the kinetic energy of the electrons that strike the target material. The result on beam intensity (quantity) is the production of photons with higher energy levels and the production of more photons in general. The reason for the production of more photons is due to the greater potential for interaction that exists within the higher energy electrons.

Of the four prime exposure factors, kVp has the greatest proportional effect on the radiographic image. A change in kVp has a direct effect on intensity, but not on a linear scale. In other words, we cannot say that a 50 percent change in kVp causes a 50 percent change in intensity. In fact, the intensity of the useful beam is proportional to the square of the kVp. Therefore, if the kVp is doubled, the intensity (quantity) of the useful beam would also increase by a factor of four. This is represented by the following formula:

$$\frac{I_1}{I_2} = \frac{(kVp_1)^2}{(kVp_2)^2}$$

Respectively, I_1 and I_2 are the beam intensities for kVp_1 and kVp_2.

To apply this formula, let's assume that the original radiograph was taken using $50\,mAs$ at $80\,kVp$ and the resulting beam intensity at the receptor was $100\,mR$. If we were to repeat the exposure, increasing the kVp to 95 and keeping all other factors constant, what is the new intensity of the beam?

$$\frac{I_1}{I_2} = \frac{(kVp_1)^2}{(kVp_2)^2}$$

$$\frac{100mR}{I_2} = \frac{(80kVp)^2}{(95kVp)^2}$$

$$\frac{100mR}{I_2} = \frac{6400}{9025}$$

$$\frac{100mR}{I_2} = 0.71$$

$$100mR = I_2(0.71)$$

$$I_2 = \frac{100mR}{0.71}$$

$$I_2 = 141mR$$

As the equation demonstrates, the new intensity of the beam is $141mR$. Notice that a 19 percent increase in kVp resulted in a 41 percent increase in beam intensity.

Distance

Another factor that influences the intensity of the useful beam is distance, otherwise referred to as source-to-image distance (SID). When X-rays are emitted from a source, such as the target, their intensity decreases exponentially as the distance from the source increases. This is known as the *inverse square law*, which states: *the intensity of a beam of radiation is inversely proportional to the square of the distance from its source*. The inverse square law is mathematically demonstrated with this formula:

$$\frac{I_1}{I_2} = \frac{(D_2)^2}{(D_1)^2}$$

This formula may also be shown as two sets of ratios that are proportional to one another (expressed as "I_1 is to I_2 as $(D_2)^2$ is to $(D_1)^2$"):

$$I_1 : I_2 :: (D_2)^2 : (D_1)^2$$

Where:

I_1 = Intensity at original distance

I_2 = Intensity at new distance

$(D_1)^2$ = Original distance squared

$(D_2)^2$ = New distance squared

Suppose the intensity of an X-ray beam was 100 mR at a distance of 2 feet from the X-ray tube. What would the new intensity be at a distance of 4 feet? We can calculate the new intensity as follows:

$$\frac{I_1}{I_2} = \frac{(D_2)^2}{(D_1)^2}$$

$$\frac{100}{I_2} = \frac{(4)^2}{(2)^2}$$

$$\frac{100}{I_2} = \frac{16}{4}$$

$$\frac{100}{I_2} = 4$$

$$I_2 = \frac{100}{4}$$

$$I_2 = 25\,mR$$

Here's another example: Suppose the intensity of radiation of an X-ray beam was 100 mR at a distance of 72 inches from an X-ray tube. What would the new intensity be at 36 inches? Consider the following:

$$I_1 : I_2 :: (D_2)^2 : (D_1)^2$$

$$100 : I_2 :: (36)^2 : (72)^2$$

$$100 : I_2 :: (1296) : (5184)$$

$$(I_2)(1296) = (100)(5184)$$

$$I_2 = \frac{518{,}400}{1296}$$

$$I_2 = 400\,mR$$

Thus, as the distance from the tube increases, the intensity of the beam decreases. If you double the distance, the intensity decreases by one-fourth. Conversely, if you halve the distance, the intensity increases four times. This variation in intensity is the result of divergence of the beam. Figure 3–9 illustrates this relationship. Notice that the primary beam at 72 inches covers an area 4 times as great as at 36 inches because of its divergence. For comparative purposes, assume that the blocks in the figure measure 1 square inch and the intensity at 36 inches is 20 X-ray photons per square inch, or 80 photons, for blocks 1, 2, 3, and 4. At 72 inches, because of the divergence of the beam, the 80 photons are now spread over 16 square inches, or 5 photons per square inch. Thus, the intensity is reduced to one-fourth at twice the distance. **NOTE:** When discussing variations in intensity according to the inverse square law, it is in reference to only the number of photons per unit area; photon energy does not enter into the picture.

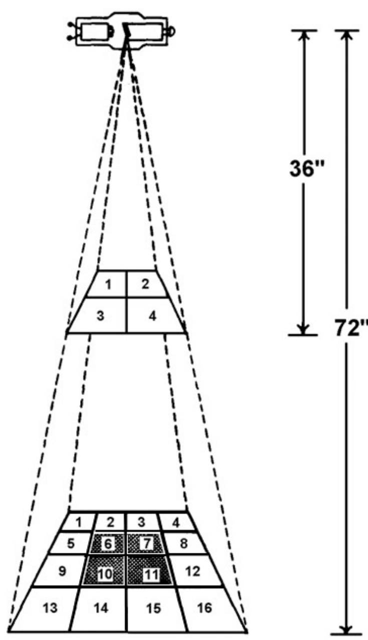

Figure 3–9. The primary beam and the inverse square law.

Filtration

Filtration affects beam quantity (intensity) by absorbing the low energy photons, which consequently reduces the total number of photons in the useful beam. All X-ray imaging systems used for diagnostic medical imaging have anywhere from 1 to 5 mm of metal filters (usually aluminum) built into the path of the useful beam. The purpose of aluminum filters is to absorb the low energy photons within the useful beam. Low energy photons do not add anything positive to the radiographic image because the patient typically absorbs them. The primary advantage of adding filtration into the path of the useful beam is that it reduces the patient's radiation dose. The downside in adding filters to the useful beam is that it decreases image contrast because the beam hardens with only high energy X-ray photons left to penetrate the body part and reach the image receptor. We will further discuss beam hardening, beam quality, and filtration in the next lesson.

222. Factors of X-ray beam quality

The term quality as applied to a beam of X-radiation refers to the beam's ability to penetrate matter. As you know, a beam with higher energy photons is able to penetrate deeper, or more efficiently, than a beam with lower energy and is therefore considered to be of higher quality. X-ray beam quality is an important concept to grasp as a technologist for two reasons: first, beam quality plays a major role in radiographic contrast; and second, it helps determine the beam's ability to produce biological damage in an organism. We will discuss each of these areas later in this volume, but first we need to discuss the concept of half-value layers and the factors that affect the quality of the X-ray beam.

Half-value layer

The way in which X-ray beam quality is expressed numerically is with half-value layers (HVL). The half-value layer is defined as the thickness of an absorbing material required to reduce an X-ray beam to half its original intensity. For example, if a beam measures 100 mR at a distance of 40 inches, the HVL for that beam would be the thickness of an absorber that would reduce it to 50 mR at the same distance. Though HVL can be measured using just about any type of absorbing material, for the purposes of diagnostic X-ray, it is usually measured in mm of aluminum (Al). X-ray beams in the diagnostic energy range generally have an HVL of 3 to 5 mm Al.

As an exercise, let's calculate how many half-value layers a beam with an original intensity of 600 mR has passed through to end up at 75 mR. To figure out this problem, we must remember that for each HVL the beam passes through, its intensity is halved. So, after the first HVL, the beam intensity would be 300 mR; after the second HVL, the beam intensity would be 150 mR (half of 300 mR); and, after the third HVL, it would be 75 mR.

It should be noted, at this point, that it is a simple matter to determine the relative quality of two beams of radiation if their HVLs are measured in ***like*** absorbers. For instance, a beam with an HVL of 4 mm Al is of higher quality than a beam with an HVL of 2 mm Al. We can come to this conclusion because if the first beam has to pass through more aluminum to half its intensity, then its energy level must be greater. What if you are given the HVLs of two beams measured in ***different*** absorbers? For instance, one beam with an HVL of 2 mm Al, and a second beam with an HVL of 2 mm Pb (lead). In this case, the second beam would be of higher quality because even though the absorber thicknesses are the same, the atomic density of the second absorber (lead) greatly exceeds that of the first. It is, therefore, a more efficient absorber.

Factors affecting beam quality

There are two factors where the technologist controls what can affect the energy level of the beam and therefore, the quality of the beam: kVp and filtration. Distance and mAs have essentially no affect on beam quality.

Kilovoltage peak

When kVp is changed, the result is a either an increase or decrease in the average energy level of the beam, therefore we can say that kVp controls beam penetrability. Since X-ray quality is defined as a beam's ability to penetrate matter, it is obvious that kVp has a controlling affect on beam quality. By controlling the beam's energy level, kVp controls the beam's ability to penetrate matter.

Filtration

An X-ray beam is made up of photons with energies ranging from zero to the applicable kVp setting. As discussed previously in the X-ray beam quantity lesson, the purpose of filtration is to remove as many of these low-energy photons from the beam since they do nothing to contribute to the image. Therefore, by filtering the useful X-ray beam and removing the low-energy photons, we are increasing the mean energy level, or quality, of the beam. *As we increase filtration, we increase quality*. An important aspect to mention again is that the primary benefit of using filtration is it reduces the patient's exposure to useless radiation.

Types of filtration

The filters placed between the target and patient are broken down into two types—inherent and added. *Inherent filtration* is filtration provided by the tube enclosure. You have no control over this filter since it is a permanent part of the X-ray tube. However, you should be aware of the aluminum equivalency of the inherent filtration within a typical X-ray imaging system. The inherent filtration in a general-purpose tube is usually equivalent to 0.5 mm Al. In mammography, where the window is made of beryllium instead of glass, the inherent filtration is normally equivalent to 0.1 mm Al.

Examples of inherent filtration are the window (whether glass or beryllium), the oil in the tube enclosure, and any possible tungsten build-up that may be present on the window. The second type of filtration, *added filtration*, makes up the remainder of the total filtration of the X-ray beam. This type of filtration is simply what we would add to the port of the X-ray tube. Things such as collimators, which contain a silver plated mirror for reflecting the light field, and thin aluminum plates, are common types of added filtration. Inherent filtration plus added filtration equals *total filtration*.

Another type of added filter is a *compensating* filter. Compensating filters are special filters designed to help a technologist produce a high quality image with uniform intensity even though the thickness or composition of the body part being imaged differs a lot. Most compensating filters are made of Al but it is possible for them to be made of other materials. A "wedge" filter is thick on one end and thin on the other end. This type of filter is typically used in radiographing the foot. The thick portion would be placed over the toe area and the thin side of the wedge would be over the tarsal bones. Another type of compensating filter is called a "bow-tie" filter. Bow-tie filters are typically used in computed tomography imaging units to compensate for the uneven thicknesses of the head and/or body. Another type of compensating filter that can be used is a 500 or 1000 milliliter saline bag. For example, when imaging the AP thoracic spine (T-spine), the superior portion of the chest is not as thick as the middle thorax region. In order to compensate for this variance in body part thickness, place the saline bag just below the jugular notch and the saline in the bag will filter some of the photons to provide a more even exposure from the top to the bottom of the T-spine image. Compensating filters are good for maintaining the quality of the image but do not improve radiation protection for the patient.

Minimum filtration requirements

For patient protection, general purpose imaging systems must filter the useful beam with a minimum Al equivalency, dependent upon the operating kVp, according to the following table:

kVp	Minimum Total Filtration
Below 50	0.5 mm Al
50 to 70	1.5 mm Al
Above 70	2.5 mm Al

For example, when you use 80 kVp, you must have a minimum total of 2.5 mm Al filtration. The total filtration standard for a fluoroscopy unit must be at least 2.5 mm Al equivalent since most fluoro is performed at relatively high kVp settings.

Technique compensation for filtration

If all other factors remain constant, adding or removing filtration alters the resultant quantity of radiation, average photon energy, and radiographic density. Therefore, in rare instances, some minor compensation in radiographic technique may be necessary to maintain optimum density when the amount of total filtration is changed. A direct adjustment of 2 kVp for each mm of Al equivalent filtration difference is usually sufficient.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

221. Factors of X-ray beam quantity

1. What is X-ray quantity, and how is it measured?

2. List the four factors that affect X-ray quantity.

3. Explain how an increase in mA affects the quantity of X-rays produced.

4. As an exposure factor, what does “time” refer to?

5. Suppose you shoot an X-ray on a pediatric patient using 150 mA at 0.3 seconds. The resultant radiograph has adequate density, but there is part motion on the film. You decide to repeat the radiograph using a 0.1 second exposure time. In order to maintain density, what is your new mA station?

6. What is the result on the intensity of the beam when kVp is increased?

7. State the inverse square law.

8. If the intensity of a beam of radiation is 900 mR at a distance of 3 feet, what is the intensity at 9 feet?

9. How does filtration affect beam quantity?

222. Factors of X-ray beam quality

1. How is beam quality expressed numerically?

2. Define half-value layer.

3. If a 400 mR beam passes through two half-value layers, what is the resultant intensity of the beam?

4. How does kVp control beam quality?

5. What is the primary benefit of filtration?

6. Identify the following types of filtration as inherent or added by placing an “I” or an “A” in the space before each number.
   ____ 1. Beryllium window.
   ____ 2. A 1000 milliliter saline bag.
   ____ 3. Oil in the tube enclosure.
   ____ 4. Collimator.
   ____ 5. Aluminum plates.
   ____ 6. Tungsten build-up on the glass window.

7. What is the minimum total filtration for a fluoroscopic unit?

Answers to Self-Test Questions

218

1. Shielding, insulation, heat dissipation, and physical protection.
2. Any X-rays that happen to exit the housing other than through the window.
3. The oil surrounding the tube enclosure and an external cooling fan.
4. To provide more efficient production of X-rays and it extends the tube’s overall life.
5. The inherent filtration of the glass window.

219

1. When the filament is provided with a current of 3 to 5 amps, the filament is heated to a high enough temperature, and electrons from the outer shells of the filament atoms are boiled off to form an electron cloud around the filament.
2. The mA setting.
3. Thoriated tungsten; because of its high melting point.
4. To confine the emitted electrons to a small area around the filament.
5. Grid controlled tubes allow the exposure to be turned on and off more rapidly.

220

1. Serve as an electrical conductor, provide support for the target, and to dissipate heat (thermal conduction).
2. Tungsten or a tungsten-rhenium alloy, because of its high melting point and high atomic number.
3. Make sure to follow the tube manufacturer's specific procedures for warming up a cold tube.
4. The size of the actual focal spot.
5. The size of the filament, the shape of the focusing cup, and the angle of the target surface.
6. The size of the actual focal spot and the angle of the target surface.
7. The smaller the target angle, the more pronounced the anode heel effect.
8. Larger image receptors are more affected by the anode heel effect than smaller image receptors.

221

1. Quantity refers to the total number of X-ray photons produced out of all energy levels in the useful beam. It is measured in roentgens (R) or milliroentgens (mR).
2. Milliampere-seconds (mAs), kilovoltage peak (kVp), distance, and filtration.
3. An increase in mA results in a higher filament temperature and more electrons available to traverse the tube for interaction with the target thereby increasing the quantity of X-rays produced.
4. The duration that a potential difference exists between the cathode and anode across the X-ray tube measured in seconds or a fraction thereof.
5. 450 mA.
6. The production of photons with higher energy levels and the production of more photons in general.
7. The intensity of a beam of radiation is inversely proportional to the square of the distance from its source.
8. 100 mR.
9. By absorbing the low energy photons, which consequently reduces the total number of photons in the useful beam.

222

1. With half-value layers.
2. The thickness of an absorbing material required to reduce an X-ray beam to half its original intensity.
3. 100 mR.
4. By controlling a beam's energy level and, thus, its ability to penetrate matter.
5. Filtration reduces the patient's exposure to useless radiation.
6. (1) I.
   (2) A.
   (3) I.
   (4) A.
   (5) A.
   (6) I.
7. 2.5 mm Al.

Complete the unit review exercise before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

34. (218) Why is the protective housing of an X-ray tube filled with oil?
    a. Physical protection and heat dissipation.
    b. Electrical insulation and heat dissipation.
    c. Physical protection and radiation shielding.
    d. Electrical insulation and radiation shielding.

35. (218) What substance is sometimes used in the window of X-ray tubes that are designed for soft tissue radiography?
    a. Tungsten.
    b. Rhenium.
    c. Beryllium.
    d. Molybdenum.

36. (219) What is the process by which electrons are made available for the production of X-rays?
    a. Electron blooming.
    b. Thermionic emission.
    c. The anode heel effect.
    d. The space charge effect.

37. (219) The purpose of the space charge compensator is to
    a. raise the tube voltage to compensate for a dip in filament current.
    b. lower the tube voltage to compensate for a rise in filament current.
    c. raise the filament current to compensate for a dip in applied kilovoltage (kV).
    d. lower the filament current to compensate for a rise in applied (kV).

38. (220) What is the positively charged electrode of an X-ray tube?
    a. Anode.
    b. Filament.
    c. Focusing cup.
    d. Space charge compensator.

39. (220) Which factors determine the size of the actual focal spot?
    a. The line focus principle, the size of the filament, and the target angle.
    b. The size of the filament, the shape of the focusing cup, and the target angle.
    c. The size of the filament, the shape of the focusing cup, and the size of the effective focal spot.
    d. The shape of the focusing cup, the size of the effective focal spot, and the line focus principle.

40. (221) The unit of measurement for the number of ion pairs formed in a quantity of air by a beam of radiation is
    a. rad.
    b. rem.
    c. curie.
    d. roentgen.

41. (221) A radiograph was taken at 200 mA and 0.20 second which had adequate density, but showed part motion. If we reduce the time to 0.05 second to eliminate the motion, what should the new mA setting be to maintain density?
    a. 50.
    b. 80.
    c. 500.
    d. 800.

42. (221) According to the inverse square law, if distance is doubled, what happens to the intensity of the beam?
    a. Intensity is quartered.
    b. Intensity is halved.
    c. Intensity is doubled.
    d. Intensity is quadrupled.

43. (222) Which half-value layer indicates the beam with the highest quality?
    a. 2 mm aluminum.
    b. 2 mm lead.
    c. 4 mm aluminum.
    d. 4 mm lead.

44. (222) Which factors control beam quality?
    a. kVp and mAs.
    b. mAs and SID.
    c. SID and filtration.
    d. kVp and filtration.

45. (222) What is the minimum amount of aluminum (Al) filtration that must be used for an 80 kVp technique?
    a. 0.5 mm.
    b. 1.5 mm.
    c. 2.5 mm.
    d. 3.5 mm.

Please read the unit menu for unit 4 and continue ➔

Unit 4. Principles of Image Quality

As radiologic technologists, we strive to produce radiographic images that present maximum diagnostic information to the radiologist with the least amount of ionizing radiation exposure to the patient. There are multitudes of variables that affect the radiographic image. While we can control many of these variables directly, there are others for which we can only compensate. First, however, we must be able to recognize optimal image quality in a radiograph. A radiologic technologist who cannot recognize quality, or lack thereof, in a radiograph will not be able to make the appropriate technical adjustments necessary to correct an imaging problem.

In this unit, we examine principles and methods that impact image quality including density and contrast, remnant beam management, geometric factors, and exposure techniques. We begin with density.

4–1. Radiographic Density

Each radiograph you produce must have a certain technical balance to be diagnostically useful. One parameter we strive for is a proper optical density. A radiograph is diagnostically useless if it has too much or too little density. Let's look more closely at what affects radiographic density.

223. Defining radiographic density

The degree of blackening of a radiograph after exposure and processing is called "radiographic density." Radiographic density (also known as optical density) is similar to photographic density; however, the density we are referring to in this discussion cannot be confused with the density of a structure (referring to atomic tissue mass density).

The expression of density

Radiographic or optical density (OD) is expressed as a number that is actually a logarithm representing the relative amount of light that can pass through a piece of film:

$$D = \log_{10}\frac{I_0}{I_T}$$

Where:

D = Density

I_O = Amount of light incident to the film

I_T = Amount of light transmitted through the film

The relationship of transmitted light on density

The spectrum of OD can vary on an image (or film) from totally black, where no light passes through the film, to totally clear, where most all light is allowed to pass through the film. An image that is totally black has an OD numerical value of 3 or more whereas an image that is totally clear has an OD numerical value of 0.2. Images that are overexposed (having a high OD) come out too black which means too many X-ray photons made it to the image receptor (IR). In contrary, an image that is underexposed (having a low OD) comes out too light because not enough X-rays made it to the IR. OD is measured with an electronic instrument called a *densitometer.* A densitometer is an electronic instrument that performs the density formula calculations for us by assigning a numerical value to the OD readings taken from radiographic film.

The relationship of OD on a radiographic image to the amount of light allowed to pass through a piece of film is demonstrated in the following table:

Percent of light transmitted	Fraction of light transmitted	Optical Density level
100	1	0
50	1/2	0.3
10	1/10	1.0
1	1/100	2.0
0.1	1/1000	3.0
0.01	1/10,000	4.0

Though OD readings range from 0 to 4, in diagnostic radiography, the useful range of optical densities is only from about 0.25 to about 2.5.

224. Controlling radiographic density

From the previous lesson we learned that radiographic density is a measure of the quantity of radiation energy absorbed by the IR.So, if we can control certain factors that determine the quantity of radiation, then we should be able to control the resultant OD. There are four *prime exposure factors:* milliamperage (mA), exposure time (s), kilovoltage peak (kVp), and source-to-image distance (SID). **NOTE:** Combining “mA” and “s” will be referred to as “mAs.” The most effective way to control OD is by adjusting mAs and SID.

Milliampere-time and density relationship

As we discussed in the previous unit, mAs has a direct, proportional effect on the quantity of radiation produced. For this reason, we can also state that mAs has a direct and proportional effect on density. Exactly how much of mAs is necessary for adequate density is dependent on many factors including type of exam and amount of kVp used. However, we can say that good background density generally indicates the sufficient amount of mAs was used. Should you need to alter an image’s density because an original radiograph is either too light (underexposed) or too dark (overexposed) due to an incorrect amount of mAs, then keep in mind that it takes at least a 30-percent change in mAs to produce a discernible change in OD. As a standard of practice, if only mAs is adjusted to alter the density of an image, then either double or halve the initial mAs value.

Kilovoltage peak and density relationship

In some instances, you may determine that a radiograph has an appropriate background density, but the body part is either over- or under-penetrated. In a case like this, kVp can be used to adjust OD. When changing kVp, remember, this value affects the penetrability of the beam, scatter radiation, dose to the patient, and especially the scale of contrast. For these reasons, kVp is ***not*** the prime exposure factor of choice used to affect a change in OD. In order to visualize a discernible change in OD using kVp, the kVp setting must be adjusted by approximately 4 percent. Since the relationship between kVp and density is nonlinear, we reference the 15 percent rule whenever kVp is used to affect a change in OD. The 15-percent rule states:

- An increase in kVp by 15 percent will approximately double the OD.
- A decrease in kVp by 15 percent will approximately halve the OD.

Source-to-image and density relationship

Understanding the SID-to-OD relationship is not difficult if we first review the inverse square law: the intensity of a beam of radiation is inversely proportional to the square of the distance from its source.

We can clearly state the relationship between SID and OD in the following manner:

- As SID increases, density decreases.
- As SID decreases, density increases.

While SID should never be adjusted for the sole purpose of controlling density, there are instances in which SID must be altered for other reasons. To maintain the desired density in these instances, the quantity of radiation *produced* can be manipulated to compensate for changes in SID. Since mAs controls the total quantity of X-rays produced, appropriate changes in this factor can be made to maintain image density and compensate for changes in SID.

NOTE: An exception to this rule occurs when only a small change in SID takes place. In this case, the compensation can be made by adding or subtracting 1 kVp for each inch of a like change of SID up to six (6) inches.

Taking into account the directly proportional relationship between mAs and OD and the inversely proportional relationship between distance and OD, we are able to develop an equation to maintain density by compensating mAs for a change in distance. The equation is known as the *mAs-distance formula* or in some cases the *new-mAs formula,* and it looks like this:

$$\frac{mAs_1}{mAs_2} = \left(\frac{SID_1}{SID_2}\right)^2$$

To give a practical application of this formula, suppose that a technique chart specifies 10 mAs using a 72-inch SID for imaging a given body part. Due to equipment limitations and the patient's condition, you are only able to use a 36-inch SID. What new mAs setting is required to maintain the original image's OD? Let's substitute the known technique values into the formula:

$$\frac{mAs_1}{mAs_2} = \left(\frac{SID_1}{SID_2}\right)^2$$

$$\frac{10}{mAs_2} = \left(\frac{72"}{36"}\right)^2$$

$$mAs_2 \times (72")^2 = 10 \times (36")^2$$

$$mAs_2 \times 5184" = 10 \times 1296"$$

$$mAs_2 \times 5184" = 12960"$$

$$mAs_2 = \frac{12960''}{5184''}$$

$$mAs_2 = 2.5$$

Therefore, your new mAs value is 2.5.The above example provides us with an interesting observation. Notice that the square of the new SID (1296) is one-fourth of the square of the original SID (5184). Also, note that the new mAs (2.5) is one-fourth of the original mAs (10). Thus, concerning the mAs-SID formula, we can make this assumption: When compensating for a change in SID, the new mAs needed to maintain density is directly proportional to the original mAs in the same manner as is the relationship between the squares of the SIDs. In other words, the squares of the SIDs increase or decrease, so too must the mAs if density is to remain constant. We can see this when using the mAs-distance formula (short method).

To calculate new mAs when compensating for a change in SID, we can use the mAs-distance formula (short method) by following these steps:

1. Divide the new distance by the original distance.
2. Square this answer.
3. Multiply the square answer by the original mAs (this gives the new mAs to use at the new distance).

Let's solve a couple of mAs-distance problems by using the short method. Suppose you want to find the new mAs to use at a 36-inch SID from an original technique of 10 mAs at 72 inches. Follow each step to solve the problem:

Step 1: 36″ (new distance) ÷ 72″ (original distance) = 0.5″

Step 2: $(0.5)^2 = .25$

Step 3: $.25 \times 10$ (original mAs) $= 2.5$ (new mAs)

The new mAs at 36 inches is 2.5.

When you don't have time to do the calculations to make precise mAs changes required because of a change in SID, you can get close by using the following general rule-of-thumb. When the SID is doubled, use four times the original mAs to maintain OD. On the other hand, when the SID is halved, use one-fourth the original mAs to maintain OD. Additionally, if the SID is increased by 50 percent, use twice the original mAs.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

223. Defining radiographic density

1. Define radiographic density.

2. What is the density level if 100 percent of the incident light is transmitted?

3. What is the useful range of densities in diagnostic radiography?

224. Controlling radiographic density

1. Explain the relationship between mAs and density.

2. How much of a change in mAs is required to produce a discernible change in OD?

3. When you want to approximately double the OD on a radiographic, how do you do it using the 15 percent rule?

4. State the inverse square law.

5. You normally use 20 mAs at 72 inches SID for a given body part. Use the mAs-distance formula to find the new mAs value if only 40 inches SID is utilized.

6. Assuming you don't have time to do the calculations using the mAs-distance formula, use the general rule of thumb to determine the new mAs if a portable radiograph normally acquired at 60 mAs and 60 inches SID is now acquired at 30 inches SID.

4–2. Radiographic Contrast

Along with density, each radiograph must have a balance of contrast. Our discussion of contrast includes a definition of contrast, a description of the types of contrast, a listing of factors affecting it, and finally, an explanation of how it is controlled.

225. Defining radiographic contrast

The job of radiographic contrast is to make anatomy easier to visualize on an image. Therefore, contrast is one of the most important prime exposure factors affecting the quality of a radiograph.

Types of radiographic contrast

Radiographic contrast, commonly called *subject contrast,* is defined as the visible difference in density between two areas or structures within the radiographic image. In other words, contrast is the result of how the X-ray beam is absorbed as it passes through the different tissues of the body. Contrast is measured by referencing a gray scale. A *gray scale of contrast* is basically the range of changes from the whitest to the blackest areas on an exposed image. Contrast on an image is typically classified as either short-scale or long-scale.

Short-scale contrast

A *short scale of contrast* has relatively few shades of gray with greater differences in density between each shade. This can be visualized by referring to image "B" in figure 4–1. Notice that the number of useful densities represents only a short portion of the scale. Short scale is also referred to as high contrast or more contrast because there is greater difference in densities between adjacent structures on the image.

Long-scale contrast

A *long scale of contrast* has many shades of gray with little noticeable difference in density between each shade. Notice that in image "A" of figure 4–1, the number of useful densities comprises a much larger portion of the scale. This type of contrast is also referred to as low contrast or less contrast because there is very little difference between adjacent shades of gray.

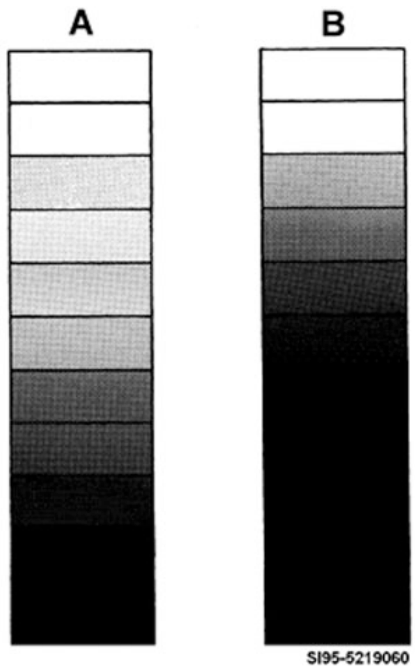

Figure 4–1. Scales of contrast.

An acronym to remember the relationship between a short and long scale of contrast versus high or low contrast is S.H.A.L.L. (**S**hort is **H**igh **A**nd **L**ong is **L**ow).

Relative properties of contrast

You should realize by now that there is no definite line separating the two types of contrast. Contrast is a *relative* measure of the difference between densities on a radiograph.A particular radiograph may exhibit short-scale contrast when compared to another radiograph, but its scale of contrast may be long when compared to a third radiograph. For instance, when comparing a hand radiograph taken at 60 kVp to a chest radiograph taken at 120 kVp, we would say that the hand has a relatively short scale of contrast. However, if we were to compare the same hand radiograph to a mammogram taken at 25 kVp, we would say the hand has a relatively long scale.

226. Understanding the factors that affect contrast

Various parameters affect the differing degrees of grayness (contrast) and allow us to "see" the information in a radiographic image. Here we will discuss the subject contrast parameters that affect the degree of grayness on an image and how to alter the subject contrast levels using the 50/15 rule.

Subject contrast

Subject contrast depends upon the selective absorption of X-ray photons by the various body parts being irradiated. When a beam of x-radiation is directed toward a body region, such as the chest, some parts of the region absorb more X-ray photons than do others. For example, the heart absorbs more photons than lung tissue. Consequently, the portion of the IR beneath the lung tissue receives more photons and, when processed, appears darker than that portion of the image beneath the heart. As you can see, selective absorption results in different densities, or contrast, on a radiograph.

Since subject contrast depends on selective absorption, we need to know and understand the factors that affect selective absorption. They are: part thickness, atomic number, tissue density, and kVp.

Part thickness

If an X-ray beam is directed at two different thicknesses of the same material, the number of photons transmitted through the thick part is less than the number of photons transmitted through the thin part. Stated another way, thicker parts absorb more photons than do thinner parts, and thinner parts allow more photons to pass through them than do thicker parts. Figure 4–2 shows how part thickness affects photon absorption.

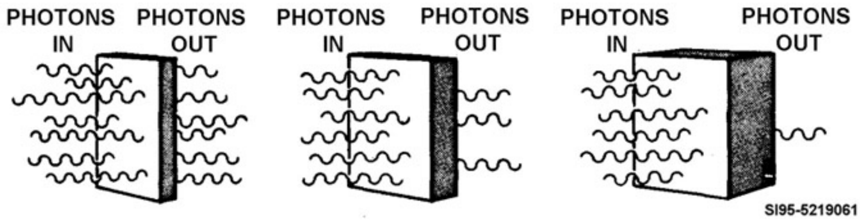

Figure 4–2. Absorber thickness affects photon absorption.

An example of this is an AP radiograph of the leg. The fibula, which is thinner than the tibia, absorbs fewer photons than does the tibia. Consequently, the fibula appears a little darker on the radiograph. The greater the difference in part thickness, the greater the difference in the densities appearing on the radiograph, or the higher the contrast.

Atomic number

The atomic numbers (Z number) of the various structures (or tissues) also affect the selective absorption of photons. The greater the difference between the atomic numbers in adjacent tissues, the greater the absorption differences in those tissues and, consequently, the higher the contrast between those tissues on the radiograph. The reason for the difference in absorption is that materials with higher atomic numbers have an increased incidence of photoelectric effects.

Recall for a moment the two radioactive interactions that are predominant in diagnostic radiography: photoelectric effect (PE) and Compton effect. Compton effect is independent of the atomic number (photon energy directly affects the probability of Compton interaction). However, atomic number does directly affect the probability of PE ionization. The greater the Z number, the greater the probability of a PE will happen. When a photon is fully absorbed during a PE interaction, the photon is absent from the exiting remnant beam. Thus, the intensity of that portion of the remnant beam is somewhat decreased and the radiographic density of tissues beneath that part would also be decreased.

The atomic numbers for bone, muscle, and adipose (fat) are approximately 12, 7.5, and 6, respectively. When comparing bone and muscle or bone and adipose, because of the atomic numbers, there is more contrast (a shorter scale or high contrast) between the different types of tissue. When comparing muscle and adipose, the atomic numbers are very close to each other therefore low contrast (a longer scale or low contrast) is displayed. Of the three tissues given, bone to adipose would have the highest subject contrast because the difference in atomic density is greatest between them, which results in the greatest difference in selective absorption between these two types of tissues.

Tissue density

The difference between the structural densities of absorbers is another factor that affects the selective absorption of photons. By "density" we mean the number of atoms per unit area. The higher the density of an irradiated tissue means the greater the attenuation of the useful beam. In-turn, the greater the difference between the densities then would mean the greater the difference in absorption—consequently, the higher the subject contrast.

Kilovoltage peak

Remember, when we speak of the quality of the useful beam, we actually mean the ability of the beam to penetrate matter or, more specifically, human tissue. The ability of an X-ray photon to penetrate tissue depends on its energy, which is controlled by kVp. High-kVp X-rays have greater energy and therefore greater penetrating ability when compared to low-kVp photons. As the penetrating ability of the useful beam increases, it means more photons will reach the IR and produce more shades of gray.

Wavelength is another term associated with beam quality—the shorter the wavelength of the X-ray photons, the greater the penetrating power. Since the *energy* of a photon is directly related to its wavelength, energy is yet another term closely associated with beam quality. Keep in mind that although we may speak of the energy or wavelength of a single X-ray photon, there are actually millions of photons in a useful beam of X-radiation all with different wavelengths and energy levels. It is the *average* energy level (or wavelength) of the beam, which can be controlled by the DI technologist, that determines beam quality. The technologist has direct control of the useful beam's ability to penetrate, its wavelength, and its energy level when adjusting kVp on the control panel.

To summarize, beam quality affects subject contrast in that a higher kVp setting produces a long-scale of contrast (low contrast) because more photons reach the IR allowing for more shades of gray on the processed image. On the other hand, lower kVp settings produce photons that are more readily absorbed by the thicker body parts, resulting in fewer photons reaching the IR. This results in fewer shades of gray or a short-scale of contrast (high contrast).

Using the 50/15 rule to alter subject contrast

With digital imaging, the scale of contrast can easily be changed with a click and slide of the computer mouse. However, it is important for you to understand how to change the scale of contrast of an already properly exposed image quickly and easily. Many times, the scale of contrast is changed to help the radiologist better visualize and diagnosis certain pathology. The purpose of the 50/15 rule is to give the technologist a mechanism for changing the scale of contrast without negatively affecting the background density of the original diagnostic image.

We know from our prior discussions that while mAs is directly proportional to density, kVp does not follow a linear scale in relationship to density. Therefore, proportional adjustments must be made to both mAs and kVp in order to lengthen or shorten the scale of contrast while maintaining the background density of the original image. By following the 50/15 rule as stated below, the technologist will make the proper proportional adjustments to mAs and kVp:

- **To lengthen the scale of contrast and produce low contrast**, halve the mAs setting and increase the kVp by 15 percent.
- **To shorten the scale of contrast and produce high contrast**, double the mAs setting and decrease the kVp by 15 percent.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

225. Defining radiographic contrast

1. Define radiographic contrast.

2. Describe the difference between short-scale and long-scale contrast.

3. Explain why contrast is considered a *relative* property.

226. Understanding the factors that affect contrast

1. What is subject contrast dependent upon, and what factors affect it?

2. Which pairing would have the highest subject contrast; bone to muscle, bone to fat, or muscle to fat? Why?

3. When a higher kVp setting is used, what scale of contrast is produced? Why?

4. What is the purpose of the 50/15 rule?

5. A radiograph is taken using 60 mAs and 80 kVp. How should you change the mAs and kVp settings to lengthen the scale of contrast while maintaining the background density of the original image?

4–3. Controlling the Useful Beam

Early in the history of radiography, pioneers in the field became aware of a serious problem affecting image quality. The problem was image fog due to scatter radiation. To overcome this condition, certain devices were developed to control the amount of scatter radiation that reached the film (or image receptor). In this section, we discuss beam restricting devices and grids as they relate to the control of scatter radiation and the subsequent improvement of image quality. We begin this section with a closer look at scatter radiation.

227. Controlling scatter radiation

Three types of radiation comprise the remnant beam (that part of the beam that exits the patient): primary, secondary, and scatter. Photons that pass through a body part without interacting with the body part remain a part of the useful beam and are instrumental in forming the image. Secondary radiation is low-energy radiation produced when photons interact with atoms in the body. Since these photons are produced by a chain of ionizing events in the atoms of the tissue that is being irradiated, they represent characteristic radiation of extremely low energy and are usually quickly absorbed by the body part. Relatively few secondary radiation photons ever reach the IR. Scatter radiation (SR), on the other hand, comprises a large part of the remnant beam and has a major effect on radiographic image quality.

Scatter radiation

Scatter radiation results whenever primary photons have undergone a change of direction after interacting with atoms. This change in direction can cause the photon to deposit its information on a different part of the image causing fog or image noise. Most SR in the diagnostic energy levels are a result from the Compton effect which was discussed in unit one of this volume.

Factors affecting scatter radiation production

There are three factors that influence the production of SR: patient thickness, field size of the X-ray beam, and kVp.

Patient thickness

The amount of SR varies directly with the thickness of the body part being irradiated. Thicker body parts emit more SR than do thinner ones. You can readily see this if you compare the detail and contrast of an abdomen radiograph (taken without a grid) with that of a hand. The radiograph of the hand appears much sharper because of reduced SR. The radiograph of the abdomen will most likely look dull and foggy, with some structures blurred. This is because the photons experience multiple scattering in thicker body structures.

Of the three factors that influence the amount of SR produced, patient thickness is the only one you cannot control. However, you can minimize its effects by using grids and beam restricting devices which will be further described in subsequent lessons in this unit.

Field size of the X-ray beam

The amount of SR produced by an X-ray beam is relative to the field size of the X-ray beam. In other words, increasing the field size of the useful beam will increase SR and a decrease in field size will decrease SR.See figure 4–3 as it illustrates the same body part projected by both a large and a small X-ray field. For a part of this size, a relatively small image area is needed. If the field size of the useful beam is restricted to only the portion of the IR that is needed, as in drawing A, there is a relatively small amount of scatter radiation reaching the IR. If the field size of the beam is enlarged so that it covers a larger area, as in drawing B, then the result of the larger field size is an increase in the scatter radiation reaching the IR.

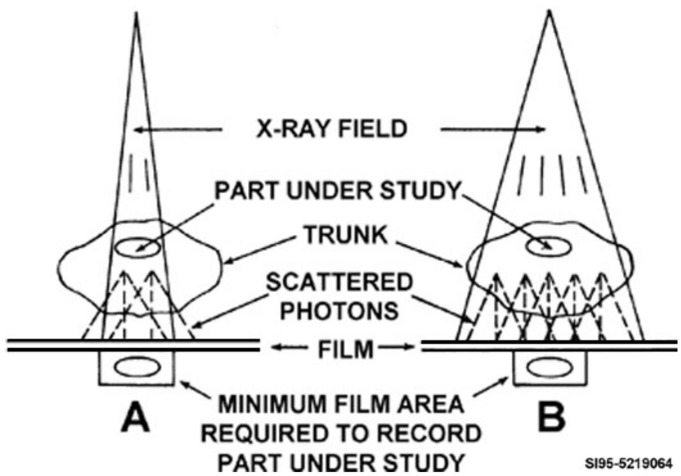

Figure 4–3. The effect of field size on scatter radiation.

Notice the increase in scatter reaching the IR not only occurs in the areas of the IR that do not record the image, but also occurs directly over the image itself. This is because scatter radiation has “ricocheted” from a different body part to strike an area of the IR not directly beneath that body part. For the purposes of increasing radiation protection and decreasing SR production, you should always collimate so that only the anatomy of interest is exposed to the useful X-ray beam.

Kilovoltage peak

At higher diagnostic energies (above 60 kVp), Compton scatter is the most common interaction between X-rays and body tissues. Since almost all SR is Compton scatter, the amount of SR produced is directly affected by kVp settings. You can therefore conclude that higher kVp techniques produce more SR that, in turn, causes more fogging of the image, decreased contrast, and decreased detail. As kVp increases, the incidence of Compton effect increases and the resultant SR produced has a higher energy level, which makes it more likely to reach the IR.

Since low kVp techniques do minimize some of the negative image quality effects found when high-kVp techniques are used, it might seem logical to conclude you should always use the lowest kVp possible in order to improve image quality. Unfortunately, using low kVp techniques are not always feasible because they typically cannot produce the desired scale of contrast and it also increases the exposure dose to the patient. No matter what though, both high and low-kVp techniques do have their place in radiography.

228. Beam restricting devices

Various types of beam restrictors are used in radiography: diaphragms, cones, cylinders, and variable-aperture collimators. When used, these simple beam restrictors are very effective in restricting the size and shape of the useful beam while also improving the overall quality of the beam. Diaphragms, cones, and cylinders are very simple beam restrictors that have been widely employed since the early days of radiography. We begin with the purpose and benefits of beam restricting devices.

Purpose and benefits of beam restricting devices

The purpose in using any beam restricting device is to restrict (or limit) the field size of the useful beam. The useful beam should be confined to a size and shape that just covers the area of diagnostic interest. Two major benefits immediately arise whenever the useful beam is restricted. The first and most important benefit is that the radiation exposure to the patient is reduced. Secondly, image quality is improved because there is a reduction in the amount of SR produced.

By limiting the size and divergence of the useful beam to only the area of interest, beam-restricting devices reduce patient radiation exposure, which should always be an important concern to any technologist. Image quality is improved because of a sequence of events: the size of the useful beam is limited, which causes a reduction in the area of irradiated tissue, which causes a reduction in the amount of SR that is produced, which results in a reduction in image fog. Additionally, when image fogging (due to SR) decreases, then image quality is enhanced because density decreases, contrast increases (more short-scale contrast because fewer gray tones), and detail improves. Conversely, this sequence of results reverses if the size of the useful beam is enlarged.

Collimators

The variable aperture collimator (or *collimator* for short) is the most commonly used beam-restricting device because of its versatility and ease of use. When a collimator is used to adjust the field size of the useful beam, this action is commonly called *collimation*. The main parts of a collimator are the first-stage entrance shutters, the mirror, the second-stage long shutters, and the second-stage cross shutters. On the outside of the collimator are adjustment knobs used to adjust the second-stage long shutters and second-stage cross shutters into either a square or rectangular field. **NOTE:** Both sets of second-stage shutters work in pairs. The shutters, or leaves, are typically made of lead of at least 3 mm in thickness. The mirror and a small lamp inside the collimator housing provide the light-localization that all technologist and patients "see" when setting up for an X-ray image.

Most collimators made today come with an option known as positive beam limitation (PBL). When this feature is utilized, the collimator automatically adjusts the shutters to the size of the IR or cassette that is placed in the bucky. Some PBL units will operate at virtually any SID while others require the tube to be placed at specific SIDs, such as 40 or 72 inches. This option is obviously of great benefit, because it ensures that parts of the body outside the area of interest will not be exposed. When the area of interest is smaller than the automatic collimation size, you must still consider whether to override the automatic collimation and reduce the field size even further.

Depending upon tube capacity, additional filtration may be required in order to consistently produce the best quality radiographic images. Most collimator housings are designed for the insertion of added filtration in levels up to 3 mm aluminum equivalency. The added filtration is typically included during system installation and calibration by a qualified service technician.

Collimator requirements

Multipurpose X-ray units are required to be equipped with an adjustable rectangular collimator containing a light localizer that defines the entire X-ray field.

In addition, periodic checks must be performed to ensure "light localizer" is properly aligned with the "actual" X-ray field to within two (2) percent of the SID. This requirement is based upon a CR perpendicular to the plane of the IR. For example, if the lighted field measures 8 by 10 inches at a distance of 40 inches, the short side of the X-ray field must measure between 7.2 and 8.8 inches (2 percent of 40 is 0.8), and the long side must measure between 9.2 and 10.8 inches.

To check the X-ray field against the lighted field, place a cassette on the table and turn on the collimator light. Adjust the collimator until the lighted field is at least 2 or 3 inches smaller than the IR. Place four small pieces of wire, each bent to form a 90° angle, so that the angles correspond to the corners of the lighted field. Measure the borders of the lighted field and record the information. Place some sort of orientation marker on the IR so that you can identify the sides of the collimator out of adjustment. Make one exposure; then open the collimator to cover the entire IR and make another exposure. After processing, measure the sides of the first exposure and compare them to the measurements of the lighted field. If any side of the X-ray field deviates by more than 2 percent of the SID, contact a BMET and report that the collimator must be adjusted.

Figure 4–4 is a drawing of a test radiograph. This drawing shows one side of the collimator, AB, to be out of adjustment. Sides AC and BD of the X-ray field are shorter than the corresponding light field sides. Whether the collimator meets the required standards depends upon whether sides AC and BD are off by more than 2 percent of the SID. Also, notice that the "wires" near corners A and B would not have been on the radiograph if the second exposure had not been made.

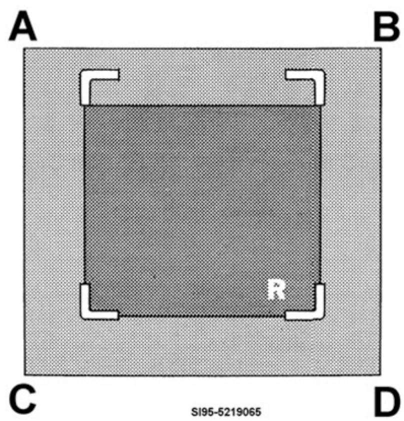

Figure 4–4. Collimator accuracy test.

Technique compensations

A final fact to remember about beam restrictors is that their use affects radiographic density because a smaller X-ray field produces less SR. For this reason, fewer photons reach the IR, thereby decreasing density. As a result, some compensation in radiographic technique may be needed to keep image density constant whenever you collimate.

The compensation is always an increase in either kVp or mAs. The exact amount of increase varies and is dependent upon such factors as the thickness of the body part, the amount of collimation, the types of film and screens used, etc. Therefore, we cannot state an exact technique compensation to use in all situations. Through experience, you learn to make these technique compensations.

229. Characteristics and functions of grids

While the use of a collimator contributes substantially to the reduction of image fog caused by SR, collimation by no means solves the problem completely. Considerable image fog can still occur unless an additional device is used between the patient and the IR; this device is called a *grid.*

Function and operation of grids

Grids are made of very small strips of lead placed side by side and held in place by plastic or some other radiolucent material. Between each radiopaque lead strip is a radiolucent, interspace material that is either aluminum or fiber. The purpose of a grid is to absorb SR, thus improving image quality by reducing the amount of SR that reaches the IR. A grid is placed between the patient and the IR. SR is emitted from many points and in many directions from the patient (and the radiographic table top, too). Because the greatest portion of the scattered rays strike the grid at an angle, most of them are absorbed. Most of the primary remnant beam, on the other hand, passes through the grid because the useful beam strikes the grid at the appropriate angle. Figure 4–5 shows the relationships between the angles of the lead strips and the direction from which primary and scatter radiation approach the lead strips. Since some body parts do not emit enough scatter radiation to significantly fog a radiograph, these do not require the use of a grid. As a rule, body parts that measure 10 cm and larger should be radiographed with a grid.

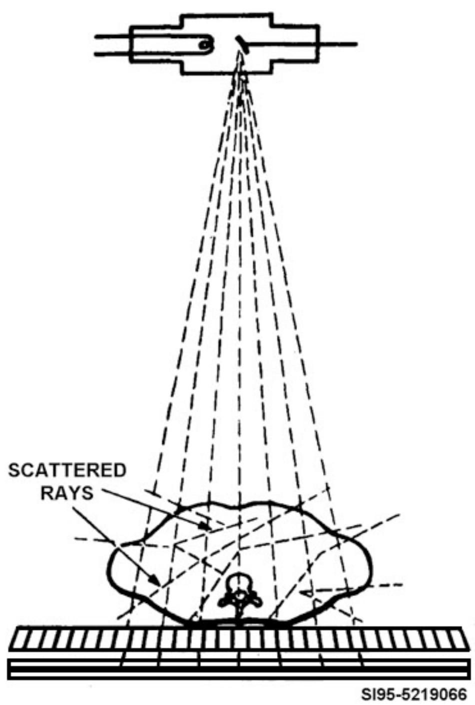

Figure 4–5. Grid function.

Grid design characteristics

There are many different grids on the market today. Each is designed to be used under specific conditions. In order for you to use the grid that best fits your particular needs, you need to be aware of the elements of grid design.

Grid ratio

The height of a lead strip in relation to the width of the space between two strips is called the *grid ratio* (fig. 4–6). The grid ratio is not directly related to the thickness of the grid or to the number of lines (lead strips) per inch. Consequently, a thin and a thick grid can have the same ratio and an 80-line grid can have the same ratio as a 100-line grid. Each grid has a specified ratio, and it can usually be found on the tube side of the grid. Common grid ratios are 5:1, 8:1, 12:1, and 16:1. The higher the grid ratio means it is more effective at cleaning up the SR. In fact, a 16:1 grid can get rid of as much as 97 percent of the SR whereas a 5:1 grid may clean up around 85 percent of the SR.

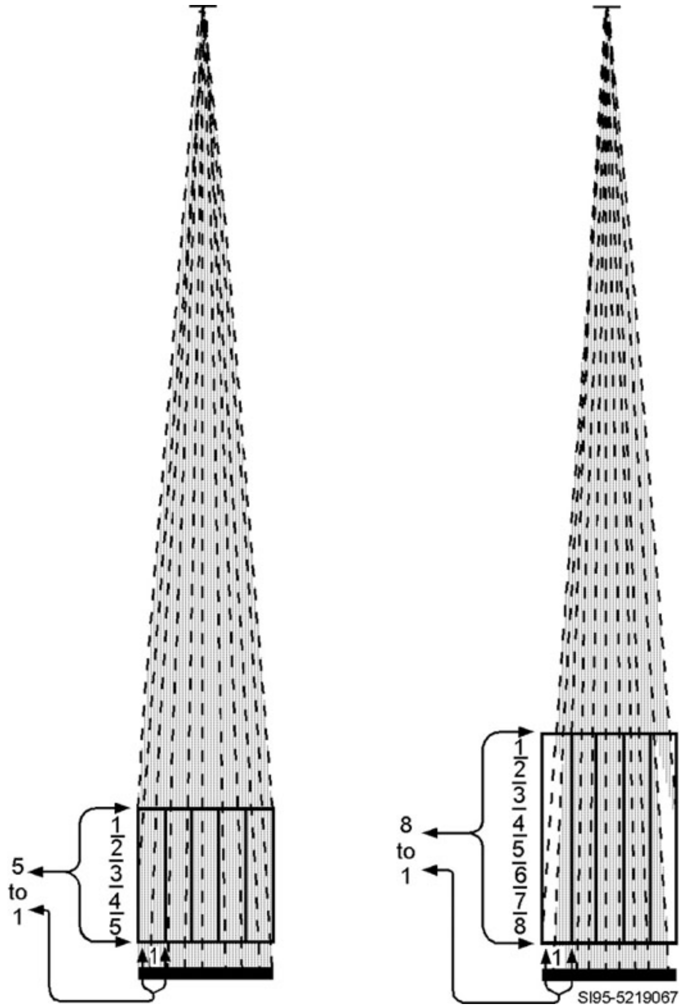

Figure 4–6. Grid ratio.

Grid efficiency refers to the amount of SR absorbed compared to the amount of primary radiation absorbed. Ideally, a grid would absorb all the SR while allowing all the primary photons to pass through to the IR. However, due to the lead content in a grid, there is always a small portion of the primary (useful) beam inadvertently absorbed. Consequently, grids are not 100 percent efficient.

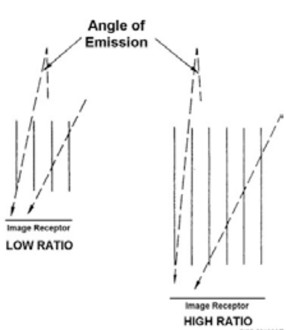

Figure 4–7. The effect of grid ratio on efficiency.

Figure 4–7 illustrates how a grid with a higher grid ratio is more efficient. This figure shows lead strips from two grids with different ratios. Notice that the angle of emission, by which scattered photons can reach the IR between the lead strips, is larger with the low ratio grid. Consequently, the smaller ratio grid absorbs fewer photons. In addition, notice a scattered photon must penetrate more lead strips to reach the IR through the high ratio grid; as a result, the photon has a better chance of being absorbed.

Unfocused versus focused grids

An *unfocused* grid is designed with lead strips that are positioned perpendicular to the plane of the grid and run parallel to each other. In a *focused* grid, the lead strips are angled towards the center progressively more as you move away from the center of the grid to coincide with the divergence of the beam. in figure 4–08 image “A” represents an unfocused grid, while image “B” represents a focused grid. The inherent problem with an unfocused grid is that X-ray photons do not travel in parallel lines; rather, they diverge from a central point. Therefore, unfocused grids tend to absorb a progressively larger portion of the useful beam as you move from the center to the outside edges of the grid. For this reason, angling the lead strips in a focused grid is designed to coincide with the divergence of the useful beam (again, see figure 4–08 image “B”).

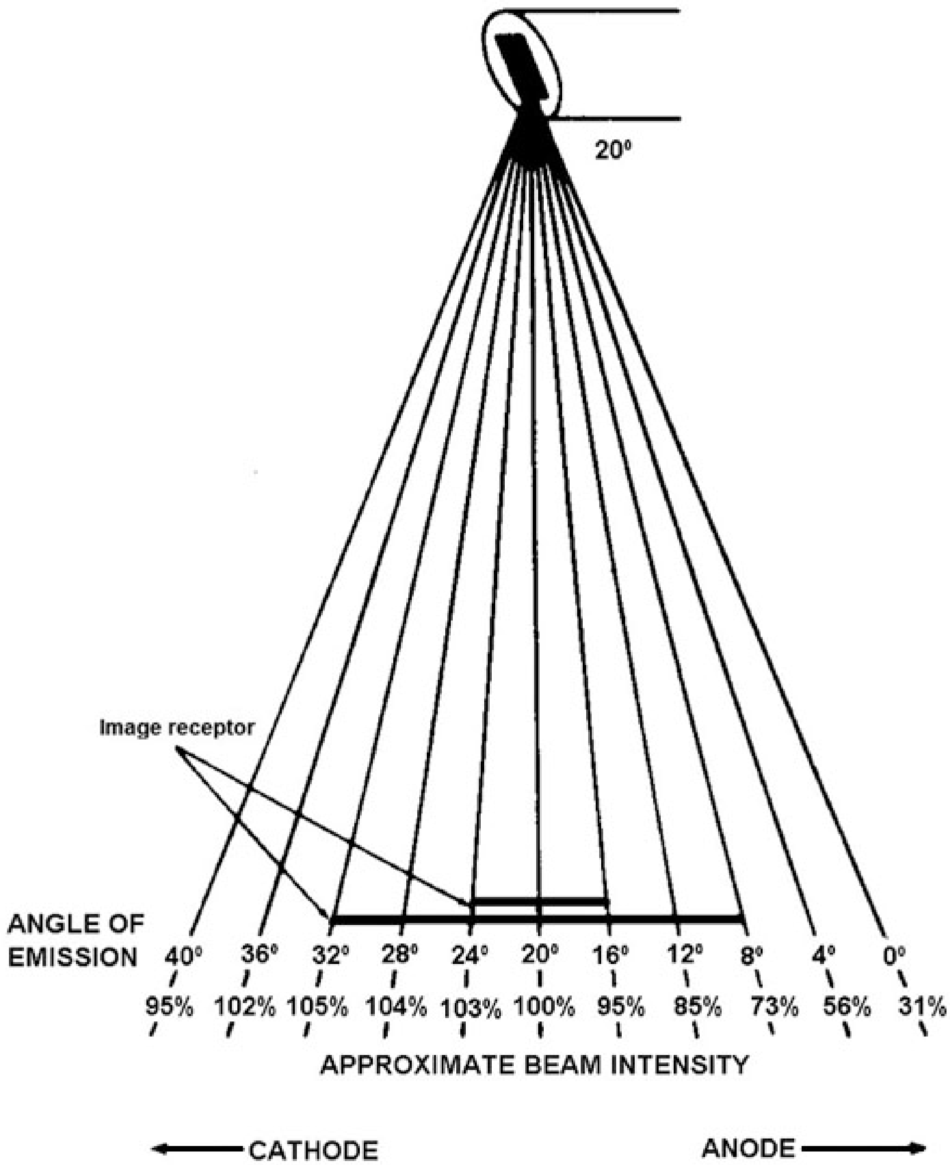

Figure 4–08. Unfocused and focused grids.

Because the lead strips are angled toward the center of the focused grid, focused grids have a *grid radius* (or a focal distance) which correlates to the distance (SID) at which a focused grid is supposed to be used. To visualize the grid radius, imagine if the angled lead strips are all extended upward to a point in which all the lines eventually meet. The grid radius is that point where the lines all meet. Figure 4–09 shows the lines extended from the angled lead strips up to the grid radius. Focused grids are all marked with their grid radius and with which side is supposed to face upward towards the tube.

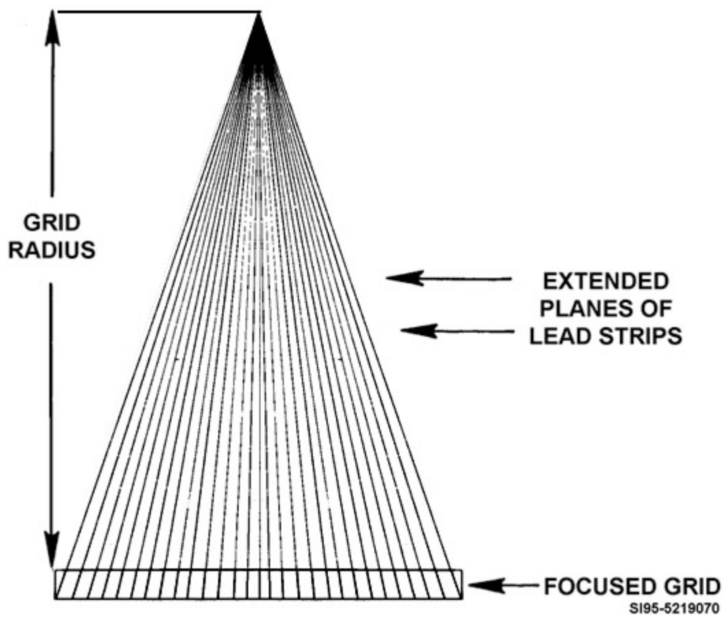

Figure 4–9. Grid radius.

Grid frequency

Grid frequency is the number of leaded strips per inch. A high frequency grid has more lines per inch, while a low frequency grid has fewer lines per inch. For example, a 12:1 grid may have either 80 or 100 lines per inch. The greatest advantage of using a high frequency grid (one with many lines per inch) is that the lead strips are less visible on the radiograph because they are thinner and therefore, interfere less with interpretation. This reduced thickness of the lead strips also reduces the total lead content of the grid. When a grid with many lines per inch is used with high-kVp, the energy level of the scattered radiation may be high enough to penetrate the lead strips and fog the image. Consequently, at high-kVp ranges, a grid with many lines per inch is less effective than one with fewer lines per inch.

Arrangement of lead strips

Grids are made with the lead strips in either a linear or a crossed pattern. A linear grid is one with lead strips running in one direction only, lengthwise (or longitudinal). Linear grids may be either focused or unfocused. Most grids in X-ray tables are linear, focused grids. Linear grids are also available in gridded cassettes and as regular portable grids. The direction of the lead strips with respect to the longitudinal axis of the X-ray table, grid cassette, and portable grid are shown in figure 4–10.

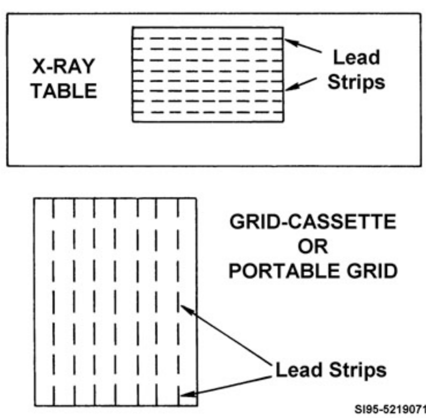

Figure 4–10. Examples of linear grids.

A crossed grid (sometimes called cross-hatched) consists of two sets of lead strips arranged as shown in figure 4–11. Crossed grids are designed for use during procedures that produce unusually high amounts of scatter radiation (e.g., biplane angiography). They are not found in X-ray tables used for general radiographic work.

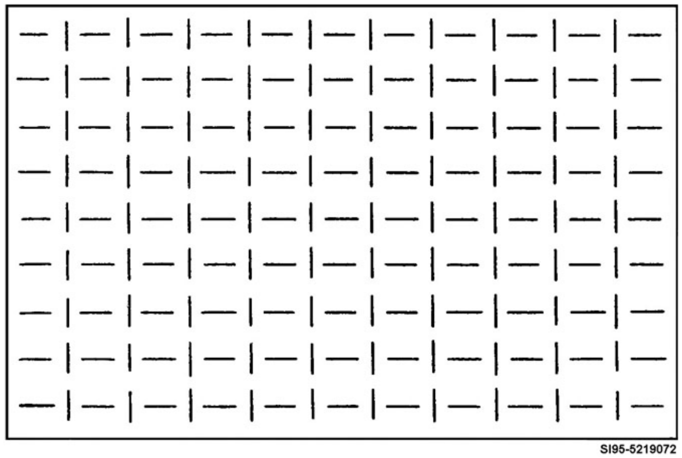

Figure 4–11. A crossed grid pattern.

There are advantages and disadvantages to using both linear and crossed grids. A linear grid permits photons from the useful beam to pass between the strips when tube angulation is in a direction parallel to the length of the strips (see fig. 4–12 image A). Angulation perpendicular to the strips of the linear grid results in virtually all of the photons of the useful beam being absorbed by the lead strips (see fig. 4–12 image B). This undesired absorption of photons making up the useful beam is referred to as “grid cutoff” and will be explained in greater detail in the next lesson. Crossed grids are generally used in special procedures using biplane techniques. Since a crossed grid is actually made up of two superimposed linear grids, its effective ratio is about twice its nominal ratio. For example, an 8:1 crossed grid has an effective ratio of about 16:1. The inherent problem with crossed grids is that virtually *any* tube angulation results in grid cutoff.

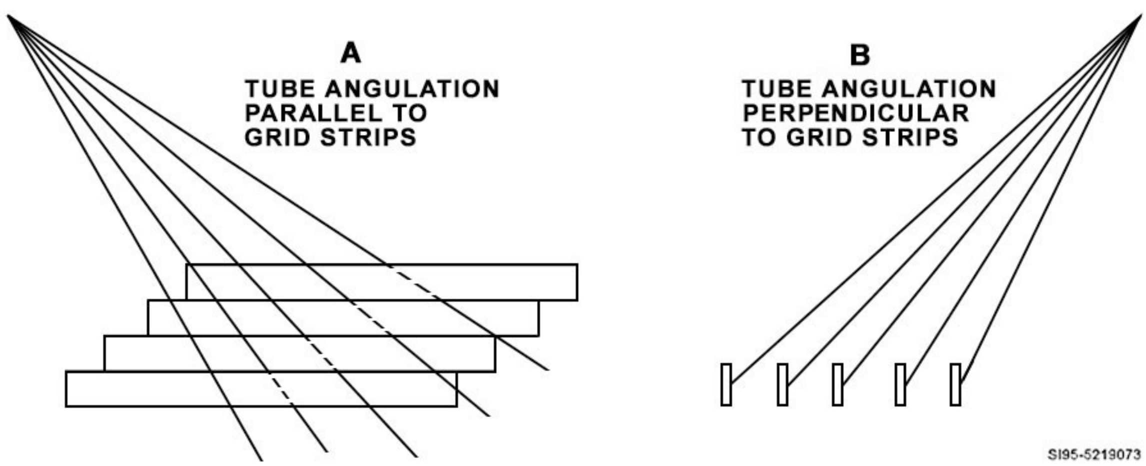

Figure 4–12. Tube angulation for linear grids.

Moving grids

To this point in the discussion about grids, we have been referring to stationary grids. One of the disadvantages of any stationary grid is that they can show the grid lines on the image. Grid lines show up on the radiographic image when too many of the useful X-rays are absorbed by the lead strips of the grid itself. In 1920, Hollis E. Potter came up with a simple idea to combat the grid lines showing up on the processed image; his idea was to move the grid a little bit while the exposure was made. Currently, the Potter-bucky diaphragm or simply, the “bucky” is the standard moving grid device in most fixed imaging systems. There are two types of moving grid apparatuses in use currently; they are the reciprocating grid and the oscillating grid.

The *reciprocating* grid is motor-driven and it moves back and forth throughout the exposure moving approximately two (2) cm. The *oscillating* grid has spring-like devices on each corner that keeps the grid centered within the bucky. With 2 to 3 cm of space around each edge of the grid, an electromagnet is used to pull the grid in one direction as the rotor is activated and then the grid is released when the exposure is taken. The result is the grid moves in a circular motion within the frame of the bucky because of the springs at each corner.

Though the motion induced by moving grids can cause an increase in image blur, the benefits of moving grids clearly out-weigh any disadvantages.

Exposure compensation

Grids absorb a significant portion of the useful (remnant) beam before it reaches the film. For this reason, you must adjust your technique (increase kVp and/or mAs) when switching from a nongrid to a grid procedure, and when changing grid ratios to maintain density. This increase in exposure technique, and subsequent increase in patient dose, is the primary disadvantage of using grids. In most instances though, the increased image quality derived from using a grid is well worth the moderate increase in patient exposure.

Various radiologic references offer different suggestions concerning technique compensations. It’s impossible to state absolutely that this amount of mAs or that amount of kVp is the right amount of compensation for all cases. However, we can suggest a rule of thumb that works well in most cases: Add or subtract 5 percent of the applied kVp per ratio change. Thus, when you change to a higher grid ratio, increase the kVp, and vice versa. An additional 5 percent of the applied kVp is needed when you change from a nongrid technique to a grid technique. Although it is possible to compensate for grids using mAs, increasing the kVp is preferred because this causes a smaller increase in radiation exposure to the patient. (Remember, increasing kVp increases beam quality.)

The table below shows kVp technique compensations you can use when changing grid ratios. Remember that these are only starting points—the exact compensation depends on kVp range, number of lines per inch, type of interspace material, and whether you’re using film or a digital IR.

Table 4–1. Technique compensation for grid changes.

	16:1 Grid Ratio	
↓	**5% kVp change**	↑
	12:1 Grid Ratio	
↓	**5% kVp change**	↑
	8:1 Grid Ratio	
↓	**5% kVp change**	↑
	5:1 Grid Ratio	
↓	**10% kVp change**	↑
	Non-grid	

↓= Decrease kVp ↑= Increase kVp

230. Problems and selection considerations associated with grids

The primary problem associated with the use of grids is improper positioning of the tube and/or grid which causes grid cutoff.

Grid cutoff

Improper placement of a grid is likely to result in *grid cutoff*. Grid cutoff is the undesirable absorption of useful (image-producing) radiation by a grid that results in a loss of radiographic density and detail.

Grid cutoff can result from a variety of problems including: focused grids used upside down, distance decentering, lateral decentering, combined lateral and distance decentering, and off-angle alignment.

Upside down focused grid

Since the lead strips in a focused grid are angled, all focused grids have a tube side identified that must face the tube in order to line up correctly with the divergent X-ray beam. When a focused grid is used upside down, remnant radiation can only pass through the middle section of the grid while the two lateral borders of the upside down focused grid will absorb the useful beam causing severe peripheral cutoff. The result is only a wide band of density down the middle of the radiographic image. The corrective action for this problem, of course, is to turn it over so the “tube side” of the grid faces the tube.

Distance decentering

Also called *off-focus* or *off-distance* cutoff, distance decentering refers to the use of a SID that is more or less than the specified grid radius. The result on the radiograph is similar to upside down focused grid cutoff with a reduction in density over both lateral borders of the image. However, in distance decentering, the effect is not quite as pronounced. The specific loss in density over the lateral borders is dependent upon the amount of decentering, the grid ratio, and the direction (near or far) of the decentered tube. There is a certain amount of tolerance for this type of decentering built in to most focused grids. The tolerance depends partly upon the grid ratio. A grid with a high ratio will not tolerate as much distance decentering as will a grid with a low ratio. Most focused grids give a range of SIDs that may be employed with that particular grid (e.g., 36 to 44 inches). Exposures may be made at any distance within the range without very much appreciable cutoff.

Lateral decentering

Lateral decentering, also called *off-center* cutoff, is a problem frequently encountered in using a portable grid, because there is no mechanical means of centering the tube to the IR. Lateral decentering causes an even loss of density over the entire image. As the amount of decentering increases, so does the undesired absorption of the useful beam.

Transmission of primary radiation begins to decrease with any amount of lateral decentering; however, lower grid ratios are more tolerant for lateral decentering than higher grid ratios. For this reason, you should select the lowest practical grid ratio for portable exams.

Lateral decentering plus distance decentering

When lateral and distance decentering occur together, they are unique in that they produce a radiograph with a loss of density on only one lateral margin of the image. If the X-ray tube is misaligned in both directions and the focus-grid distance is greater than the grid radius (fig 4–13 image A), the lateral margin of the image beneath the tube will be underexposed. If the focus-grid distance is less than the grid radius (fig. 4–13 image B), the lateral margin of the image most remote from the tube is underexposed.

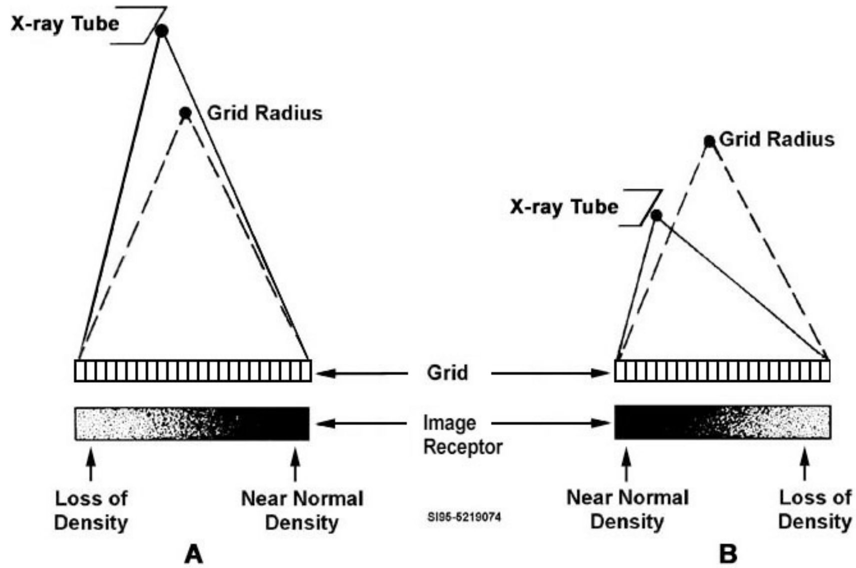

Figure 4–13. Effect of lateral decentering plus distance decentering on image density.

Off-angle alignment

If the X-ray tube is excessively angled across the lead strips, or if the grid is angled in respect to the useful beam, there is an even loss of density over the entire image. The amount of loss depends upon the degree of the angle and grid ratio.

Factors to consider when selecting a grid

Selecting a proper grid requires an understanding of some interrelated factors and is usually a compromise of sorts. The first of these factors to discuss is kVp. Generally, you should select a high-ratio grid when using high-kVp techniques. Keep in mind though, with higher grid ratios, the patient dose increases because of the need for increased exposure techniques. For this reason, use the lowest practical grid ratio for the examination.

When using higher kVp techniques, you must also consider grid frequency and how it affects the grid's efficiency. Remember, earlier we determined that at higher kVp levels, such as above 120 kVp, the SR produced is at an energy level that is sufficient enough to still penetrate the thinner lead strips found in grids with high-grid frequencies (above 100 lines per inch). Therefore, when using high-kVp techniques, the grid characteristics of choice are high ratio (12:1 to 16:1) with low frequency (60–80 lines per inch).

The trade-off of increased cleanup with a high-ratio grid is that the patient exposure dose increases considerably and tube alignment becomes more critical. You also have to weigh the value of a better quality radiograph against your obligation to minimize patient exposure. Therefore, use the following general guidelines when selecting grids:

- When the applied kVp is below 90, grid ratios up to 8:1 are satisfactory.
- When the applied kVp is above 90, grid ratios above 8:1 are acceptable.
- When the applied kVp is above 120, grids with high ratios (12:1 to 16:1) and low frequencies (60–80 lines per inch) should be used.
- When the thickness of the selected body part to be X-rayed is at least 10 cm, a grid should be employed.
- During portable radiography, a 16:1 grid ratio should ***not*** be used because it will not tolerate very much lateral decentering.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

227. Controlling scatter radiation

1. Define scatter radiation.

2. What are the three factors that influence the production of scatter radiation?

3. How can you minimize the effects of SR produced due to patient thickness?

4. What should you do to increase radiation protection and decrease SR production?

5. What happens as kVp increases?

228. Beam restricting devices

1. What is the purpose in using any beam-restricting device?

2. What are the two major benefits whenever the useful beam is restricted?

3. What are the main parts of a collimator?

4. When the PBL feature is utilized, what does the collimator automatically do?

5. What is the tolerance for agreement between the size of the “lighted” X-ray field and the size of the actual X-ray field?

6. What are the limits for a light field if a beam is collimated to 10 inches (wide) by 12 inches (long) at a 40” SID?

229. Characteristics and functions of grids

1. What is the purpose of a grid?
2. As a rule, what body parts should be measured with a grid?
3. Explain grid ratio.
4. Explain the difference between a focused and an unfocused grid.
5. What does the grid radius correlate too?
6. Define grid frequency.
7. What is the advantage of a high frequency grid?
8. What type of grid—linear or cross-hatched—may be used with an angled CR?
9. Name the two types of moving grids.
10. How should technique be compensated when changing from a 5:1 to a 12:1 grid ratio?

230. Problems and selection considerations associated with grids

1. What is grid cutoff?
2. Name the five causes of grid cutoff.
3. Which two causes of grid cutoff result in a loss of density over both lateral margins of the film?

4. How does grid ratio affect off-center cutoff?

5. Which two types of grid cutoff cause an even loss of density over the entire film?

6. What is the proper relationship between grid ratio and kVp?

7. What are the grid characteristics of choice when using high kVp techniques?

8. What type of grid should be avoided for portable use? Why?

4–4. The Affect of Geometric Factors on the Image

In our high school days, we may have learned that geometry is a branch of mathematics that deals with measurements and relationships of lines, points, and angles. In radiography, we are concerned with certain other geometric factors that affect image formation. In this section, we address three of these specific geometric factors—focal spot size, SID, and object-to-image distance (OID)—and we'll discuss how each affects detail, magnification, and distortion.

231. Radiographic detail and its relation to focal spot size

Producing a sharp image is important in the diagnosis of your patient's condition. It is important for you to understand what affects image detail and how the focal spot size helps produce a high-quality crisp image. We begin by defining detail.

Radiographic detail

Recall for a moment what comprises good radiographic quality. In your earlier radiologic education, you learned that radiographic quality is a composite of parameters affecting the visibility and sharpness of the image. Density and contrast are the parameters most affecting the visibility of structures, whereas, distortion and recorded detail make up the sharpness of structures. We define *detail* as it applies to a radiographic image as the visual demonstration of the structural lines and contours of an image. There are other terms used when referring to detail; for example, you could say an image with good detail has a high degree of sharpness, or good *definition.*

The opposite of sharpness is unsharpness or *blur*. It is normal when an image is blurry to assume some kind of part movement took place during the exposure. Another type of blur that takes place on nearly every radiograph exposure to some degree is *focal-spot blur*. Focal-spot blur occurs because our source of radiation—the target—is more of a rectangular area rather than a single point. "Penumbra" was the term used to describe this phenomenon in the past, but since this is a term borrowed from astronomy, the term "focal-spot blur" is now commonly used to describe this effect unique to radiographic imagery.

Although many things influence detail, we generally consider focal-spot blur to be most affected by the following three factors: OID, SID, and focal-spot size. A high degree of blurring is caused by: a large focal-spot size, a short SID, and a long OID. By contrast, image sharpness results from—among other things—a combination of a small focal-spot size, a long SID, and a short OID.

Focal spot size and detail

No doubt, you have been told many times to use the smallest focal spot possible. Note the use of the word "possible." It is not always possible (or practical) to use a small focal spot when imaging larger body parts because a small focal spot cannot produce the higher mAs techniques that are typically required.

So why does a small focal spot produce better detail than a larger one? To answer that question, refer to figure 4–14. Notice we have drawings of three focal spots projecting an image. Image A shows the focal spot as a point source of the X-ray photons. Image B represents a small focal spot, and image C represents a large focal spot. Notice that we did not refer to the "point source" in image A as a small focal spot; this is because we have no focal spots that are actually small enough to be considered "point sources" in radiology. They usually range from 0.3 to 2.0 mm. We show the point source in image A merely to illustrate the difference in the projection of the image.

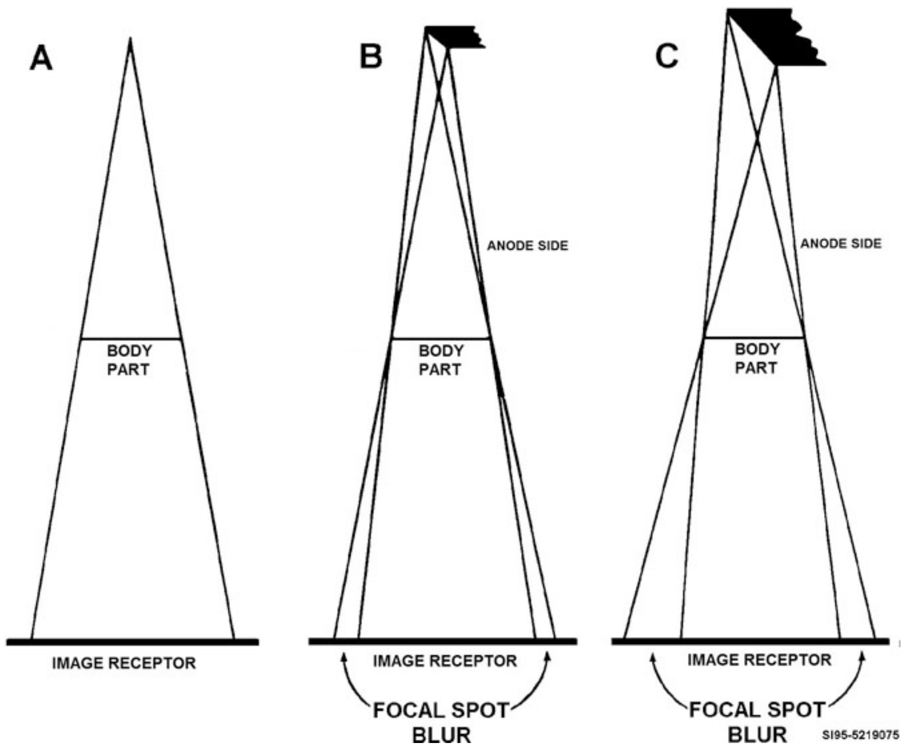

Figure 4–14. The effect of focal spot size on image blur.

Notice that all edges of the part in image A, figure 4–14, are projected to one spot on the IR, while in images B and C each edge is projected to a different spot. The reason that each edge is projected to a different spot is that the edge is projected by photons from many points within the target. For simplicity, we have shown only the photons from each side of the target in images B and C of figure 4–14, which determine the maximum area of blurring. When the border of the body part is projected in this manner, it is called focal-spot blur and the image will have a "fuzzy" or "unsharp" appearance.

As you can see, there is less blurring present on the image of the part projected by the smaller focal spot. A smaller focal spot causes less blurring because the edges are projected by photons from fewer point sources that are closer together.

Refer to figure 4–14 B and C once again. Did you notice the difference between the amounts of focal-spot blur from the anode side of the tube to the cathode side? As you can see, the amount of focal-spot blur produced is greater on the cathode side of the tube. What does this difference mean? It means that the edge of the part on the anode side is being radiographed with a smaller effective focal spot than the edge on the cathode side. Of course, the important aspect to note is that radiographs have better detail on the anode side. Figure 4–15 gives you an idea of the relative focal spot sizes in the center and at both edges of the beam. The one in the center represents the size listed on your tube-rating chart.

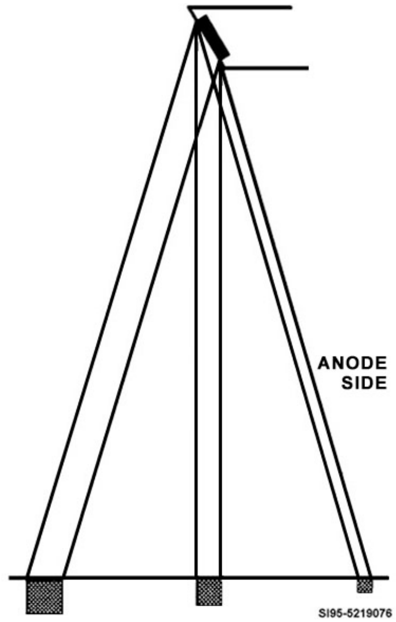

Figure 4–15. Focal spot sizes as seen from different parts of the X-ray field.

232. How geometric factors affect magnification and shape distortion

How you position the body part, where in relationship to the IR the part is positioned (OID), and the SID all contribute to the amount of magnification and/or distortion. As a technologists, it is important for proper radiologist interpretation to project the body part correctly on the finished image. So what is magnification?

Magnification

As it pertains to a radiographic image, *magnification* is defined as a form of size distortion causing enlargement of a body part on the image relative to its true size. We can determine the amount of magnification with this formula:

$$\text{Magnification} = \frac{Size-of-the-image}{Size-of-the-object} = \frac{Size-of-the-image}{Size-of-the-object}$$

For example, suppose the actual size of an object you X-rayed is 8 cm but the projected image size is 10 cm. How much magnification occurred? We can solve this problem by substituting the known values into our magnification formula:

$$\text{Magnification} = \frac{10}{8}$$

$$\text{Magnification} = 1.25$$

In this example, the image size is 1.25 times larger than the actual size of the part. Thus, some magnification has occurred.

Magnification should normally be kept to a minimum so that the part is projected as near as possible to its actual size. Increased magnification increases the effect of focal-spot blur on a radiograph, which causes lower clarity on the image. In addition, enlargement of some body parts is a sign of disease. If the part is magnified because of the projection, the radiologist may have a difficult time making a diagnosis. The best way to image a part as near as possible to its actual size is to use OID and SID properly.

Factors affecting magnification

Basically, two factors affect magnification: SID and OID. If you make two radiographs of a particular body part using the same OID but different SIDs, then the radiograph with the longer SID will show less magnification. To illustrate how SID affects magnification, refer to figure 4–16, where we have illustrated the same size part projected by three different SIDs. Notice that a more divergent beam projects the part on the IR at the short SID. It is this greater divergence that increases the magnification.

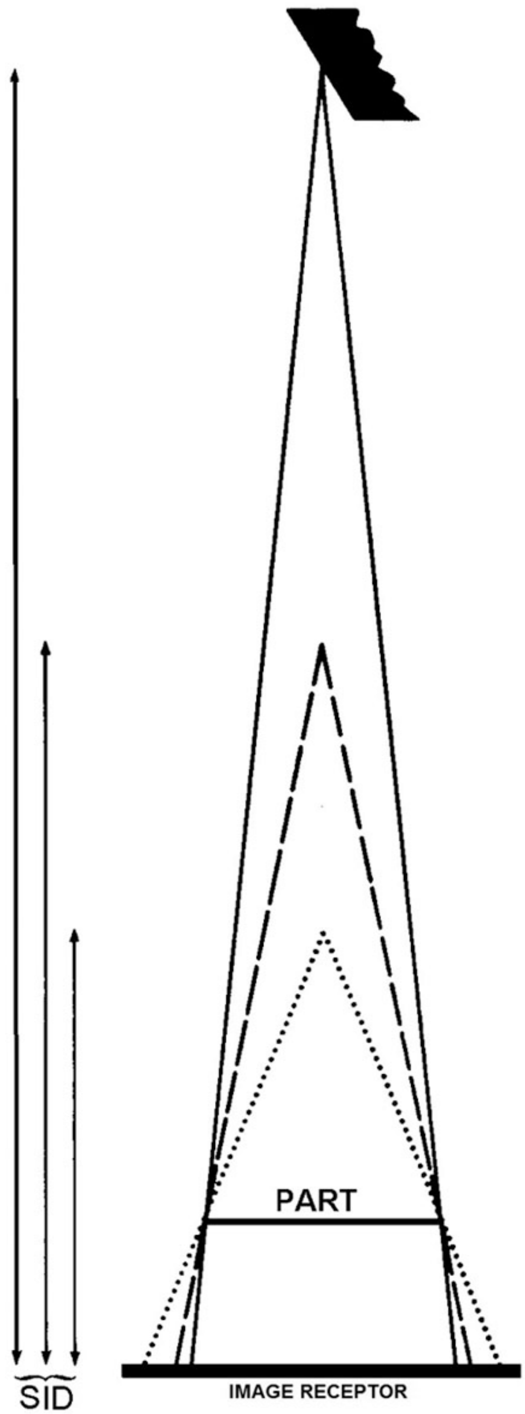

Figure 4–16. How SID affects magnification.

The OID (object-to-IR distance) also has a pronounced effect on magnification when the SID remains constant. Notice in figure 4–17, three different equal sized parts are projected by the same SID. The only difference is in the OID. Part A, which is farthest from the IR, is magnified most, while parts B and C, which are nearer the IR, are magnified progressively less. Magnification due to an increase in OID occurs for the same basic reason as magnification from decreased SID—that is, the part is projected by a more divergent beam.

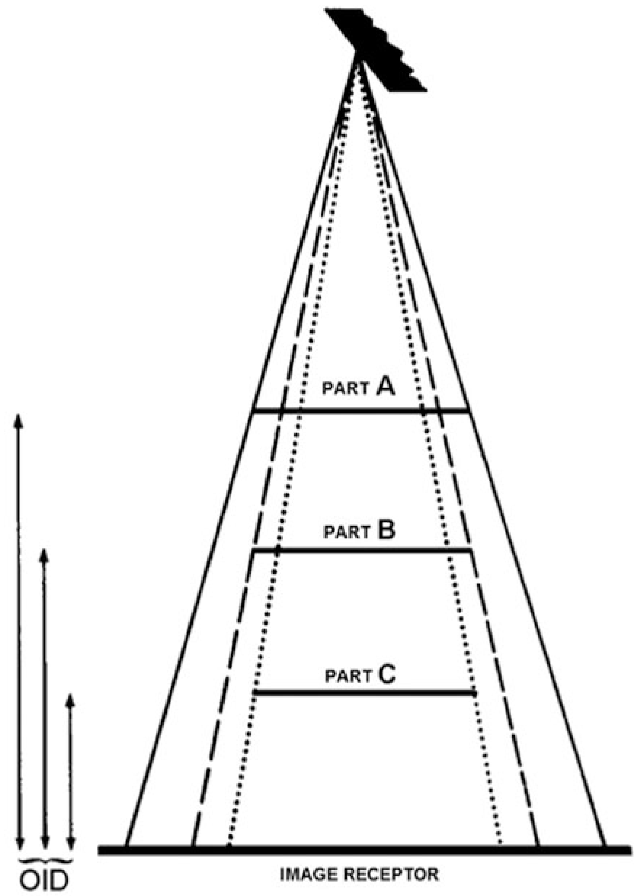

Figure 4–17. The effect of OID on magnification.

In summary, to reduce magnification of a structure as much as possible, you should use a long SID and a short OID.

Shape distortion

We say a body part is distorted when the body part is not projected on the image in its true shape and size. From that definition we can say that there are two types of distortion: size distortion (magnification) and shape distortion. Since we've already discussed magnification, we will cover only shape distortion. For clarification purposes, when you see the term *distortion* used alone, it is most commonly referring to shape distortion.

There are two types of shape distortion: elongation and foreshortening. Elongation is created when the tube or IR are angled to the body part while foreshortenting occurs when the tube and IR remain perpendicular to each other with the body part angled. Normally, you should try to keep elongation and foreshortening to a minimum on your radiographs so that the part appears in its normal shape in order for the radiologist to recognize an abnormality easier. In some instances, we use distortion to free a part from superimposition over another part. An example of acceptable distortion is the inferosuperior, or axial, projection of the clavicle. Distortion is necessary in this case to demonstrate the clavicle free from superimposition of the ribs. Other examples of acceptable distortion include the PA Caldwell projection of the sinuses and the AP axial (Towne) projection of the skull. Each of these projections intentionally introduces distortion into the radiographic image to better demonstrate specific anatomy.

Tube-part-image receptor (film) relationships

The relationships between the tube (the CR), the plane of the body part, and the plane of the IR affect distortion. In fact, we can state that the controlling factor for shape distortion is tube-part-film (IR) alignment. Specifically, the plane of the part and the plane of the IR must be parallel, and the CR should be perpendicular to the part and IR (film) to minimize distortion.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

231. Radiographic detail and its relation to focal spot size

1. Define detail as it applies to a radiographic image.

2. Why does focal-spot blur occur?

3. Name the three factors that influence focal spot blur.

4. Why is it not always possible (or practical) to use a small focal spot when imaging larger body parts?

5. Which side of the tube produces the most focal-spot blur?

232. How geometric factors affect magnification and shape distortion

1. Define magnification as it pertains to a radiographic image.

2. What is the formula for determining the amount of magnification present on a radiograph?

3. What is the affect of increased magnification on focal-spot blur and image clarity?

4. What two factors affect magnification?

5. When is a body part considered distorted on a radiographic image?

6. What are the two types of distortion?

7. Is shape distortion ever acceptable? Explain.

8. What is the controlling factor for shape distortion?

9. How should the CR be directed with respect to the part and IR (film) to minimize distortion?

4–5. The Standardization of Exposure Techniques

To ensure consistent image quality and to provide accurate guides for the selection of all exposure techniques, each radiology section should have a standard system of selecting exposure factors. The establishment of such a system is one of the greatest challenges confronting technologists—although it is a problem that could be solved easily if a universally correct exposure technique for each part could be prescribed. Unfortunately, universal techniques are not possible because of several variables including the output and the capacity of X-ray machines, the types of exposure devices, the type of IR, and the preferences of radiologists. Because of these variables, you must be able to prepare and correct your own standard system of selecting exposure factors. This section is intended to help you do so.

233. Requirements of a standardized exposure chart

The radiologist is counting on the department as a whole to produce consistent high-quality images for interpretation of pathology or disease progression/regression. Standardized exposure charts help accomplish this task with a fair amount of ease.

Consistent results

A standard system of exposure charts must meet these four basic requirements: produce consistent results, provide adequate exposure of the image, possess a certain degree of flexibility, and provide for the desired range of contrast.

The purpose of a standardized exposure chart is to produce consistent exam exposure results taken on the same patient and body part, though maybe days, weeks, or months apart, but yet appear with essentially the same scale of contrast and same degree of background density.

A supervisor's role is to enforce the rule that *all* technologists in the department use the standardized exposure chart to produce consistent results. If not enforced, technologists may use "their own" exposure techniques thereby defeating the purpose of an exposure chart.

Adequate exposure of the image

Before any radiologic examination, the optimum technique factors (mAs, kVp, and exposure time) must be selected. As a reminder, mAs is the primary factor that controls background density and kVp is the primary factor that controls the scale of contrast and penetrability. Regarding exposure time, it is generally accepted that the exposure times should always be as short as possible.

When choosing a baseline exposure technique for a standard exposure chart, the general size and shape of a patient (body habitus) must be taken into consideration. As you probably remember, there are four body habitués':

1. Sthenic—this is the average patient and is typically strong and active.
2. Hyposthenic—this patient is thinner than the average person but still has a healthy appearance.
3. Hypersthenic—this patient typically has a big frame and is usually overweight.
4. Asthenic—this last type of patient is often an elderly patient who is small and frail.

Baseline techniques must create optimal background density (mAs) and have the right amount of penetrability (kVp) for the sthenic patient.From this starting point technique, small adjustments to mAs and kVp can easily be made in order to adjust for the hyposthenic (less technique), hypersthenic (more technique), or asthenic (less technique) type patient.

Flexibility

A system of standard exposure techniques should be reasonably flexible because exposure techniques must be frequently changed to compensate for the body habitués of the patient, the patient's condition, suspected injury or pathology, and other factors. For example, a basic technique selected at the highest kVp on your control panel would not permit an increase; and on the other hand, a technique selected at the minimum kVp would not permit a reduction. Establish a baseline mAs and kVp value according to the sthenic patient that allows for increases/decreases to adjust for body habitués or the injury/condition of the patient. Using the sthenic patient to establish the baseline techniques will ensure flexibility when developing standardized exposure charts.

Desired contrast range

Any system of standardized exposure charts must be able to produce the preferred range of contrast within the capabilities and limitations of the imaging system. A radiologist will typically be heavily involved with this portion of developing a standardized technique chart so that they are happy with the level of contrast in order to properly diagnose injuries and/or pathology. Of course, kVp is the factor of choice to adjust in producing the appropriate scale of contrast.

234. Selecting radiographic techniques

Exposure charts are based on the following four principles: variable kVp techniques, fixed kVp techniques, high kVp techniques, and automatic exposure control (AEC). Whichever one is utilized in your department is typically a decision your radiologist, NCOIC, and possibly a medical physist all colaberate on and decide together. The first type of exposure chart is based upon variable kVp techniques.

Variable kilovoltage peak techniques

Under the variable kVp technique system, the mAs remains constant for each respective part while the kVp is adjusted according to part thickness measured in cm. One disadvantage of this type of standardized exposure method is that the contrast varies slightly from one examination to the next because the kVp changes the contrast scale.

Here are the steps to build a variable kVp technique chart. Suppose you decide that for an average-sized adult (sthenic body habitus), 20 mAs is sufficient to produce adequate background density for a PA skull film. Now all you need do is to determine the appropriate kVp value for each cm of thickness for the skull. For example, suppose you determine by experimenting with a phantom skull that the exposure factors of 20 mAs and 80 kVp produce the desired density and scale of contrast for a PA skull that measures 18 cm along the path of the CR. This measurement is now considered the "mean" (or the baseline) measurement for the average patient's skull size and then place this information on a working chart. From the mean of 18cm, you can now establish the kVp/cm relationship for other measurements of the same body part. You may have to add or subtract 2 kVp for each cm change. If so, you would use 82 kVp for 19 cm, 78 kVp for 17 cm, and so on. Keep in mind that the cm measurement is through the path of the CR for each projection of the skull in this example.

The 2 kVp change for each cm of part thickness given in the example above may or may not work for all body parts. Usually, kVp changes from 1 to 4 are made, depending upon the size of the part, the type of tissue being irradiated, and the kVp range available. The greatest change per cm is required when high kVp is used and for denser parts.

Once you determine the correct exposure factors for each part, construct an exposure chart, post it near the control panel, and insist that everyone uses it. Any type of chart can be constructed as long as it provides the necessary information. Figure 4–19 shows how the example we discussed might look on an exposure chart.

Part	Projection	Grid	Screens	SID	mAs	CMS / kVp											Remarks
Skull	All	12:1	Hi-Speed	40"	20	3/70	14/72	15/74	16/76	17/78	18/80	19/82	20/84	21/86	22/88	23/9	Measure CR

SI95-5219080

Figure 4–18. Example of an exposure chart.

You can also construct a *plus factor* exposure chart that permits you to determine the correct kVp without referring to the chart for every measurement. In referring back to the example of the skull, eighty kVp is used for an 18 cm measurement. Using the plus-factor technique chart, multiply the cm thickness by 2 (which gives you 36). Now, subtract 36 from 80 (your kVp at 18 cm). This gives you a plus factor of 44 that is used for all projections of the skull. In this example, you measure the size of the skull (the particular body part) on the path of the CR; next you double the cm thickness and then add the plus factor (44) to get your kVp value. Expressed as a formula, the plus factor-kVp relationship for this example looks like this:

$$kVp = (2 \times cm) + 44$$

$$kVp = (2 \times 18) + 44$$

$$kVp = 36 + 44$$

$$kVp = 80$$

Keep in mind that the plus factor is determined from a good baseline technique and again may vary from part to part.

Fixed kilovoltage peak techniques

Currently, the fixed kVp technique chart, also known as optimum kVp chart, tends to be the most commonly used. Under this system, the kVp remains constant for a particular part while the mAs is varied and selected based on the body parts average thickness in cm to provide optimal density for each patient/exposure. Fixed kVp technique charts usually use a somewhat higher kVp value in comparison to the variable kVp technique chart system. In using a higher kVp value, two distinct advantages are present when using a fixed kVp technique chart:

1. This method provides more consistent contrast levels for all examinations of a particular part because the kVp is constant.
2. The higher kVp levels mean a reduction in radiation dose to the patient.

Though adjustments to the mAs value are based upon the thickness of the part in cm, exact measurement is not that critical because with this technique charting method, part size is typically grouped as small, medium, or large. Based off of the part measurement, the mAs value is then adjusted in increments of 30 percent up or down. For example, if a medium part measures 18 to 22 cm, then you would reduce the mAs 30 percent for a smaller part measuring 11 to 17 cm and raise the mAs 30 percent for a part measuring 23 to 29 cm. **NOTE:** If the body part is swollen because of trauma, an increase of 50 percent in mAs may be required.

High kilovoltage peak techniques

High kVp exposure charts typically use kVp values above 100 and are particularly useful for chest radiography and examinations involving barium. High kVp charts use high kVp with a low mAs value to produce a long scale of contrast (in chest radiography) and to ensure adequate penetration during barium studies.

High kVp is used in many radiology departments for the following reasons: it results in less absorbed dose to the patient, the target of the X-ray tube is subjected to fewer heat units per exposure, and there is greater exposure latitude. Exposure latitude is the range of exposures that will produce density within the acceptable range of diagnostic radiography.

The major disadvantage of high kVp techniques is that secondary and scattered radiation is produced with sufficient energy to penetrate many grids (especially those with 100 or more lines per inch), thus impairing image quality. A high-ratio grid with relatively few lines per inch would afford the best cleanup of the high-energy SR produced with high kVp techniques.

Automatic exposure control systems

AEC systems (sometimes referred to as phototimers) have been around for many years. However, with their increased reliability, most departments have included them as part of a standardized system of exposure. An AEC system is a series of three radiation detectors placed in the radiographic table and vertical cassette holder (or vertical image receptor). Its purpose is to automatically terminate the exposure when a sufficient amount of radiation has reached the film (or IR) to produce a good quality radiograph.

As the technologist, you select the appropriate kVp setting and the sensor (or combination of sensors) which underlie the desired anatomy, and the AEC does the rest by cutting off the exposure when the appropriate mAs value has been achieved based off of the sensor readings. The benefits of a properly utilized AEC system are more consistent image quality and fewer repeats due to over- or under-exposure. The most important aspect in using an AEC system is that you (the technologist) ***must always position the body part accurately*** over the applicable sensor(s). Of course, AEC may only be employed when doing bucky work while table top examinations still require conventional mAs and kVp selection.

Additional considerations when selecting technique factors

There are many other things to be aware of when selecting technique factors. Most of these items don’t have a universally accepted quantitative value with technique selection. Instead, you learn about selecting (or compensating) technique due to these parameters through experience. For example, pathology affects technique selection because it affects radiation absorption (e.g., emphysema decreases tissue density of lungs resulting in less radiation absorption by lung tissues; and some cancer tumors may increase tissue densities). In these cases, your technique selection will vary but if using an AEC system, the AEC tends to automatically compensate for many of these factors dealing with patient condition and habitus.

In addition, the age of a patient, use of beam-restricting devices, calibration of X-ray equipment, use of grids, and the presence of a cast or external fixation device plays a part in what technique you choose. The point is, while technique charts are important to use and have distinct advantages, their use and effectiveness may be somewhat limited by influencing factors outside your control.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

233. Requirements of a standardized exposure chart

1. What four basic requirements must a standard system of exposure techniques meet?

2. What is the purpose of a standardized exposure chart?

3. How do we ensure flexibility when developing a standardized exposure chart?

234. Selecting radiographic techniques

1. When using the variable kVp technique system, the mAs remains constant while the kVp is adjusted according to what?

2. What is the disadvantage of using the variable kVp method?

3. What is the kVp for a projection if the part measures 20 cm and the plus factor is 38?

4. In using a higher kVp value, what two distinct advantages are present when using a fixed kVp technique chart?

5. At what increment is the mAs adjusted up or down for fixed kVp techniques?

6. High kVp exposure charts typically use what kVp value?

7. For what three reasons do many radiology departments use high kVp techniques?

8. What is the most important aspect in using an AEC system?

Answers to Self-Test Questions

223

1. The degree of blackening of a radiograph after exposure and processing.
2. Zero (0).
3. 0.25 to 2.5.

224

1. mAs has a direct, proportional effect on density.
2. 30 percent.
3. Increase kVp by 15 percent.
4. The intensity of a beam of radiation is inversely proportional to the square of the distance from its source.
5. 6 mAs.
6. 15 mAs (one-fourth the original mAs).

225

1. The visible difference in density between two areas or structures within the radiographic image.
2. Short-scale contrast has relatively few shades of gray with greater differences in density between each shade. Long-scale contrast has many shades of gray with little noticeable difference in density between each shade.
3. A particular radiograph may exhibit short-scale contrast when compared to another radiograph, but its scale of contrast may be long when compared to a third radiograph.

226

1. Selective absorption; it is affected by part thickness, atomic number, tissue density, and kVp.
2. Bone to fat. The difference in atomic density is greatest between these two types of tissues which results in the greatest difference in selective absorption.
3. A long-scale of contrast is produced because more photons reach the IR allowing for more shades of gray on the processed image.
4. The purpose of the 50/15 rule is to give the technologist a mechanism for changing the scale of contrast without negatively affecting the background density of the original diagnostic image.
5. Reduce mAs to 30 and increase kVp to 92.

227

1. Scatter radiation results whenever primary photons have undergone a change of direction after interacting with atoms.
2. Patient thickness, field size of the X-ray beam, and kVp.
3. By using grids and beam restricting devices.
4. You should always collimate so that only the anatomy of interest is exposed to the useful X-ray beam.
5. The incidence of Compton effect increases and the resultant SR produced has a higher energy level, which makes it more likely to reach the IR.

228

1. To restrict (or limit) the field size of the useful beam.
2. Patient exposure is reduced and image quality is improved because there is a reduction in the amount of SR produced.
3. The first-stage entrance shutters, the mirror, the second-stage long shutters, and the second-stage cross shutters.
4. The collimator automatically adjusts the shutters to the size of the IR or cassette that is placed in the bucky.
5. Two percent of the SID.
6. Width: 9.2 to 10.8 inches; Length: 11.2 to 12.8 inches.

229

1. To absorb SR, thus improving image quality by reducing the amount of SR that reaches the IR.
2. Body parts that measure 10 cm and larger.
3. The height of a lead strip in relation to the width of the space between two strips.
4. An unfocused grid is designed with lead strips that are positioned perpendicular to the plane of the grid and run parallel to each other. In a focused grid, the lead strips are angled towards the center progressively more as you move away from the center of the grid to coincide with the divergence of the beam.
5. It correlates to the distance (SID) at which a focused grid is supposed to be used.
6. The number of leaded strips per inch.
7. The lead strips are less visible on the radiograph because the lead strips are thinner and therefore, interfere less with interpretation.
8. Linear.
9. Reciprocating and oscillating.
10. Increase kVp 10%.

230

1. The undesirable absorption of useful (image-producing) radiation by a grid that results in a loss of radiographic density and detail.
2. Focused grids used upside down, distance decentering, lateral decentering, combined lateral and distance decentering, and off-angle alignment.
3. Upside down focused grid and distance decentering.
4. Lower grid ratios are more tolerant for lateral decentering than higher grid ratios.
5. Lateral decentering and off-angle alignment.
6. Higher kVps require higher grid ratios.
7. High-ratio (12:1 to 16:1) with low-frequency (60–80 lines per inch).
8. A grid with a 16:1 ratio because it will not tolerate very much lateral decentering.

231

1. The visual demonstration of the structural lines and contours of an image.
2. Our source of radiation—the target—is more of a rectangular area rather than a single point.
3. OID, SID, and focal-spot size.
4. A small focal spot cannot produce the higher mAs techniques that are typically required.
5. The cathode side.

232

1. A form of distortion causing enlargement of a body part on the image relative to its true size.
2. Magnification $= \frac{Size-of-the-image}{Size-of-the-object}$.
3. Magnification increases focal-spot blur, which causes lower clarity on the image.
4. SID and OID.
5. When the body part is not projected on the image in its true shape and size.
6. Size distortion (magnification) and shape distortion.
7. Yes. In some instances we use distortion to free a part from superimposition over another part.
8. Tube-part-film (IR) alignment.
9. Perpendicular.

233

1. (1) produce consistent results, (2) provide adequate exposure of the image, (3) possess a certain degree of flexibility, and (4) provide for the desired range of contrast.
2. Produce consistent exam exposure results taken on the same patient and body part, though maybe days, weeks, or months apart, but yet appear with essentially the same scale of contrast and same degree of background density.
3. Establish a baseline mAs and kVp value according to the sthenic patient that allows for increases/decreases to adjust for body habitués or the injury/condition of the patient.

234

1. Part thickness measured in cm.
2. The contrast varies slightly from one examination to the next.
3. 78.
4. (1) More consistent contrast levels for all examinations of a particular part because the kVp is constant.
   (2) The higher kVp levels mean a reduction in radiation dose to the patient.
5. 30 percent.
6. Above 100.
7. High kVp techniques result in less absorbed dose to the patient, the target of the X-ray tube is subjected to fewer heat units per exposure, and there is greater exposure latitude.
8. The technologist must always position the body part accurately over the applicable sensor(s).

Complete the unit review exercise before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

46. (223) If a densitometer reads 1.0, how much of the light is being transmitted through the film?
    a. 1 percent.
    b. 10 percent.
    c. 50 percent.
    d. 100 percent.

47. (223) What is the useful range of optical densities in diagnostic radiology?
    a. 0.0 to 4.0.
    b. 0.1 to 2.5.
    c. 0.25 to 2.5.
    d. 0.25 to 4.0.

48. (224) What is the relationship between mAs and density?
    a. mAs is directly proportional to density.
    b. mAs is inversely proportional to density.
    c. Density is directly proportional to the square of the mAs.
    d. Density is inversely proportional to the square of the mAs.

49. (224) If 100 mAs is used to produce an adequate film at a 72” SID (source to image distance), what should the new mAs be in order to maintain density if the SID is reduced to 36”?
    a. 25 mAs.
    b. 50 mAs.
    c. 200 mAs.
    d. 400 mAs.

50. (225) “The visible difference in density between two areas or structures within the radiographic image” is the definition of
    a. umbra.
    b. contrast.
    c. penumbra.
    d. densitometry.

51. (226) When repeating a diagnostic image, the 50/15 rule allows us to
    a. eliminate the need for a grid.
    b. change density while maintaining scale of contrast.
    c. change scale of contrast while maintaining density.
    d. compensate between single-phase and three-phase generators.

52. (227) In the diagnostic energy range, most scatter radiation is produced by
    a. pair production.
    b. the Compton effect.
    c. the Thompson effect.
    d. the photoelectric effect.

53. (227) What combination of factors influence the production of scatter radiation?
    a. kVp, patient thickness, and grids.
    b. Grids, field size of the X-ray beam, and SID.
    c. Patient thickness, field size of the X-ray beam, and kVp.
    d. Patient thickness, field size of the X-ray beam, and SID.

54. (228) What is the primary benefit of restricting the useful beam?
    a. Prolongs tube life.
    b. Reduces patient exposure.
    c. Increases scale of contrast.
    d. Eliminates the need for gonadal shielding.

55. (228) What is the most commonly used beam-restricting device?
    a. Diaphragm.
    b. Collimator.
    c. Cylinder.
    d. Cone.

56. (228) What is the maximum tolerance limit (height and width) of the “actual” X-ray field for a 10 inch square collimated light field at 40 inches SID?
    a. 9.0 to 11.0 inches.
    b. 9.2 to 10.8 inches.
    c. 9.5 to 10.5 inches.
    d. 9.8 to 10.2 inches.

57. (229) What is the primary purpose of a grid?
    a. To reduce patient exposure.
    b. To increase exposure latitude.
    c. To reduce the amount of scatter radiation produced.
    d. To reduce the amount of scatter radiation that reaches the film.

58. (229) What is grid radius?
    a. The number of lines (lead strips) per inch.
    b. The distance from the center of the grid to its border.
    c. The distance at which the grid is designed to be used.
    d. The ratio of the height of the lead strips to the distance in between them.

59. (229) If a radiograph is made using 80 kVp and an 8:1 grid ratio, what kVp should be used to maintain density if the exposure is repeated without a grid?
    a. 68 kVp.
    b. 72 kVp.
    c. 88 kVp.
    d. 92 kVp.

60. (230) What grid ratio is most tolerant for lateral decentering?
    a. 5:1.
    b. 8:1.
    c. 12:1.
    d. 16:1.

61. (230) What grid characteristics are preferred for radiographs taken above 120 kVp?
    a. low ratio (8:1); low frequency (60 lines per inch).
    b. low ratio (8:1); high frequency (100 lines per inch).
    c. high ratio (16:1); low frequency (60 lines per inch).
    d. high ratio (16:1); high frequency (100 lines per inch).

62. (230) A grid should be used when the selected body part to be X-rayed exceeds what minimum thickness?
    a. 5 cm.
    b. 10 cm.
    c. 15 cm.
    d. 20 cm.

63. (231) What combination of geometric factors would produce the most focal-spot blur?
    a. Large focal-spot size, long OID, and short SID.
    b. Large focal-spot size, short OID, and long SID.
    c. Small focal-spot size, long OID, and short SID.
    d. Small focal-spot size, short OID, and long SID.

64. (231) What area of the X-ray field, if any, has the greatest detail?
    a. The middle.
    b. The anode side.
    c. The cathode side.
    d. All areas are equal.

65. (232) Magnification reduces detail on the radiograph by
    a. increasing wavelength.
    b. increasing focal-spot blur.
    c. increasing scatter radiation.
    d. reducing selective absorption.

66. (232) To reduce magnification of projected parts, a radiologic technologist should use a
    a. long SID and a short OID.
    b. long SID and a long OID.
    c. short SID and a short OID.
    d. short SID and a long OID.

67. (233) Which of the four requirements for establishing a standard system of exposure factors requires that *all* technologists use the standardized exposure charts?
    a. Flexibility.
    b. Consistent results.
    c. Desired contrast range.
    d. Sufficient exposure of film.

68. (234) When using a fixed kVp exposure chart and the medium part thickness range is 18 to 22 cm, when would you increase the mAs by 30 percent?
    a. The part measures 16 cm.
    b. The part measures 20 cm.
    c. The part measures 24 cm.
    d. The part is swollen due to traumatic injury.

69. (234) What radiographic technique generally produces a greater exposure latitude?
    a. High kVp.
    b. Fixed kVp.
    c. Fixed mAs.
    d. Variable kVp.

Please read the unit menu for unit 5 and continue ➔

Student Notes

Unit 5. Film, Intensifying Screens, and Film Processing

MANY adancements have been made to our career field over the years. One of those is the transition from film to digital imaging. Though film is not used nearly as much as just a decade ago, it is still important to understand how an image is recorded on film, the role of intensifying screens, and finally, how film is processed.

5–1. Film and Intensifying Screens

Before digital imaging, or the "old" days, nothing could be accomplished to record a radiographic image without film. As the useful beam exits the patient, the photons interact with two intensifying screens that are within the protective cassette. The screens emit light, which "exposes" a piece of X-ray film that is physically located between the two intensifying screens. This unit will discuss the composition and characteristics of both film and intensifying screens. We begin with film.

235. Film composition and characteristics

As you will find throughout this course and the daily operations of our career field, the terms *film, cassette, and image receptor (IR)* have become synonymous with each other. Though film is not in use as much as in years past, it is still necessary for you to understand the basics of film composition and characteristics.

Composition of X-ray film

X-ray film has been the most common IR for the majority of our career field's existence. Now-a-days though, digital IRs are the *norm* in most radiology departments. X-ray film is comprised of a base, an adhesive coating, an emulsion layer, and an overcoat. Film with an emulsion layer on both sides of the base is called double-emulsion film (see figure 5–1).

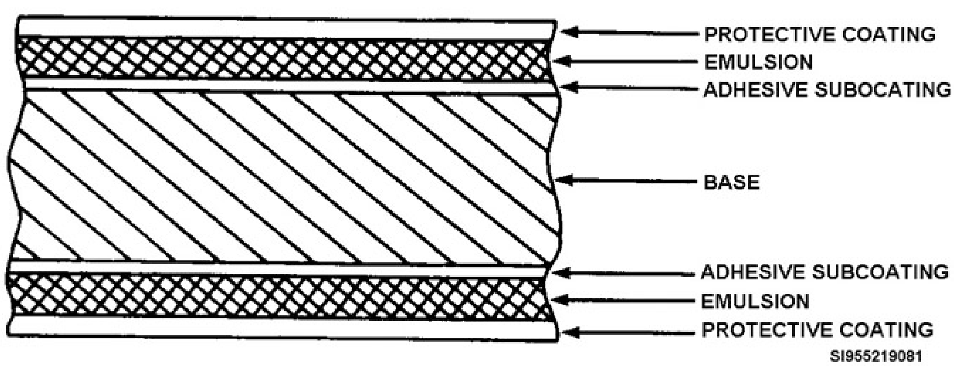

Figure 5–1. Cross section of an X-ray film.

The ***base*** is the foundation of any piece of X-ray film. The purpose of the base is to provide a surface for the emulsion to be coated onto it. The base of radiographic film is rigid and is designed to maintain its size and shape throughout use and processing. In the earliest days of radiography, the base of the film was a glass plate, but during World War I cellulose nitrate became the standard because high-quality glass became hard to come by where-as the need for medical X-rays were rapidly increasing. Unfortunately though, cellulose nitrate was flammable. By the mid-1920's, cellulose triacetate was developed with similar useful properties of cellulose nitrate, just not as flammable. Today, film manufacturers use polyester. The polyester base material provides more strength in thinner form, and is less prone to becoming warped or deformed. Though the base is transparent to light, a dye is added during the manufacturing process, which gives the film a bluish tint. The purpose of the blue tinting is to reduce eyestrain for the radiologist who would sit for hours on end reading film radiographs.

An ***adhesive coating*** (thin layer of glue) keeps the emulsion in close contact with the base.

The ***emulsion layer*** is where the actual process of converting remnant radiation into a visible image takes place. The emulsion layer consists of silver halide crystals suspended in a gelatin. Silver halide is a composition of 98 percent silver bromide. Silver iodide usually comprises the remaining amount. The primary purpose of the emulsion gelatin substance is to provide support for the silver halide crystals.

When the silver halide composition is exposed to either X-ray or light energy, the positively charged silver ions attract free electrons generated by either the Compton or photoelectric effects within the crystals. When this occurs, the silver is no longer bound to the bromine or iodine. The silver ions are then free to migrate from the crystal into the gelatin. This process creates a *latent* image in the emulsion. A latent image is basically a group of silver atoms that are deposited into the emulsion but this silver is not observable, even under a microscope. A latent image becomes a visible image after the film is processed (developed) and the bromine, iodine, and unexposed silver halide are washed out of the gelatin.

The *speed* of a particular film type is determined by the size and concentration of the silver halide crystals in the emulsion. The larger and/or more concentrated the crystals, the greater the film speed. The trade-off to larger crystals and high film speed is a decrease in detail.

The ***overcoat*** (or protective outer coating) is a thin, transparent layer of gelatin that covers the emulsion to protect the emulsion from damage during handling, processing, and storage.

Screen-film

Screen film is a type of X-ray film designed to be exposed by the light emitted from an intensifying screen when the screen is exposed to radiation. By far, it is the most common type of film used in modern radiography. While screen film comes in a variety of exposure latitudes (contrasts) and speeds, there are two basic types of screen film manufactured today: those that are sensitive to the blue-violet light emitted from calcium tungstate intensifying screens and those that are sensitive to the green light emitted by rare Earth intensifying screens. Regardless of the type of screen employed, the purpose is the same: to amplify the effect of X-radiation thereby reducing the amount of radiation required to produce a diagnostic image and in-turn, reducing the exposure dose to the patient.

The Hurter and Driffield Curve

Not all X-ray films are the same—that is, they differ in such properties as speed, contrast, and latitude. The best way to compare these properties is to refer to the film’s characteristic curve, which can be obtained from the manufacturer. The Hurter and Driffield (H and D) curve—named after its originators—shows a graphic relationship between density and exposure. Commonly called a *characteristic curve,* it shows a particular film’s response to varying exposures. Although an H and D curve may appear difficult to understand because of its logarithmic values, it can provide you with useful information even if you have a limited understanding of logarithms.

The H and D curve is obtained by exposing one type of film to a series of carefully calculated exposures and measuring resultant densities with a densitometer. The information is then plotted on a chart with the density value along the vertical axis and the log relative exposure (LRE)—mAs value required to produce a specific change in density—along the horizontal axis. In simple terms, the H and D curve in figure 5–2 demonstrates that with each 0.3 LRE interval, the density value on that type film approximately doubles. The three major portions of the curve are the toe, body, and shoulder.

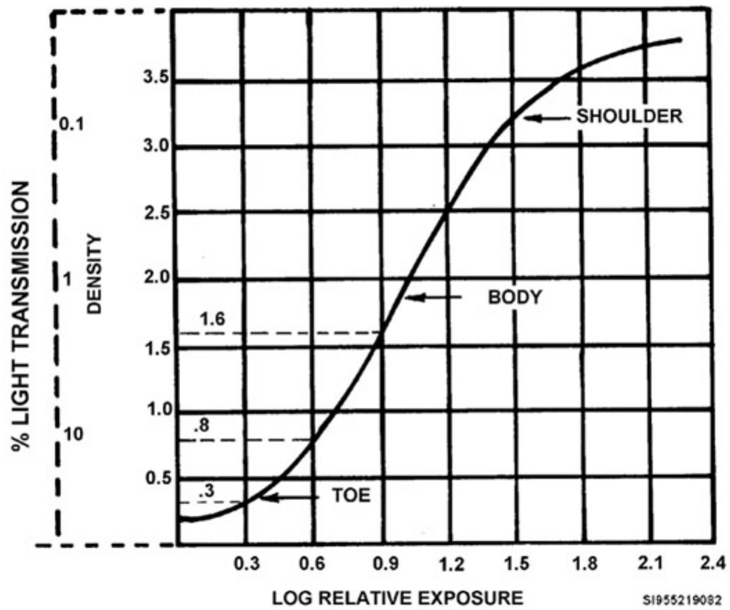

Figure 5–2. A characteristic curve.

Background fog

The toe of the H and D curve represents the background density of a film. All X-ray films have a certain amount of *background density* also called *inherent film fog*, *gross fog*, *base plus fog* (B + F), or density minimum (*D-min*). This is the minimum attainable density on an X-ray film and is present after processing even if the film is unexposed. As a rule, a background density of over a value of 0.2 is considered excessive.

Film speed

The response of a radiographic film to exposure is called *sensitivity* or *film speed.* The speed of a film is depicted by the position of the curve on the graph. The curve of the more sensitive (faster speed) film lies closer to the left side of the chart, indicating less exposure is needed to produce a certain density. For example, in figure 5–3, film A is faster than film B.

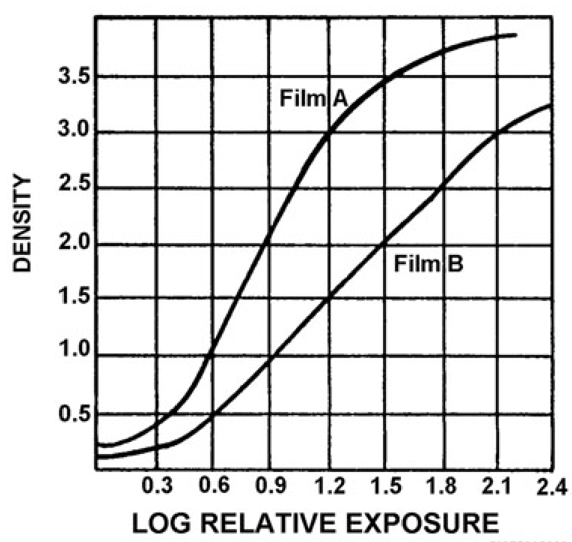

Figure 5–3. Characteristic curves of two different films.

A faster film requires less technique exposure, allows for shorter exposure times, subjects the X-ray tube to fewer heat units per exposure, and reduces the radiation dose to the patient. The down side to faster film is they usually sacrifice some detail due to the increased size of the silver bromide crystals in the emulsion, which causes a "grainy" appearance on the radiographs.

Exposure latitude

Exposure latitude, or *latitude,* is the range of exposures (mAs, log relative exposures) that produces density within the accepted range of diagnostic radiography. As a reminder, the useful range of densities is approximately 0.25 to 2.5 as measured by a densitometer.

We can identify how much latitude a film has by looking at the gradient again. A more gradual (horizontal) slope indicates more exposure latitude than does a steeper (vertical) slope. In looking at figure 5–3 again, film B has more latitude than does film A; therefore, there is more allowable margin for error in technique selection with film B.

Contrast

Film contrast can be estimated by looking at the gradient of a curve. The gradient is the slope of the straight line portion of the H and D curve. A more vertical slope indicates a film with higher contrast (more contrast; a shorter scale of contrast) when compared to a more gradual slope. Again, in figure 5–3, film A has more contrast than film B.

Density

As previously discussed in this volume, density (referring to optical density) can be represented as a number that is a logarithm of the ratio of the light incident to a film (I_O) to the light transmitted through the film (I_T). The lower the percentage of light transmission means the higher the density. Fortunately, a densitometer performs the formula calculations for optical density of film for us.

Density is usually expressed in logarithmic values. For example, the H and D curve in figure 5–2 shows the density scale along the left side. Notice the percentage of light transmission with respect to density values. You can see that as a film's density increases, the amount of transmitted light greatly reduces. If there is zero density on the film, all or 100 percent of the light is transmitted through the film. If there is a density value (logarithmic value) of 0.3, then the transmitted light is cut in half (50 percent). The density maximum (*D-max*) is the maximum attainable density of an X-ray film; this is indicated by the *shoulder* of the curve.

Handling of unexposed film

The overcoat in X-ray film design protects the film from some rough handling. Unexposed X-ray film, in general, should not be bent, rolled, creased, etc. Artifacts, which are unwanted density marks on the processed film, can appear as a result of too much rough handling of the unexposed film.

Storage of unexposed film

Ideally, X-ray film should be stored between 50 and 70° F, and 40 to 60 percent relative humidity. X-ray film should be stored in a lead lined room to keep unwanted radiation from exposing the film and adding to the base fog. All film handling in a darkroom should be in the absence of white light. If there is a light leak (whether through a crack in the wall, ceiling, or around the door), film will have an increased level of fogging. If unexposed film is completely exposed to white light (say in the event the film drawer is left open and the white overhead lights are turned on), then the entire film bin must be replaced. Safelights in the darkroom should be checked for excessive bulb wattage, cracks in the lens filter, and an incorrect light spectrum; any of these faults will add fog to the film.

Expiration date

Each box of film has an expiration date stamped on it. All film should be used before that date because film aging causes loss in speed and contrast. Film stock should be rotated so that the first films received are the first to be used. This "first in, first out" usage system reduces film waste.

Spectral matching

The type of screen film used is totally dependent upon the type of intensifying screens used. Blue-light sensitive film was used in radiology for many years and is photographically responsive to ultraviolet and blue-violet light emitted by calcium tungstate intensifying screens.

Green-sensitive film, sometimes called orthochromatic film, became increasingly popular in the early 1980s with the advent of rare Earth intensifying screens. Its photographic response is in the green portion of the visible spectrum. Advantages of rare Earth film/screen combinations are that they provide greater speed, they reduce patient exposure, and they don't sacrifice the detail offered by conventional calcium tungstate screens. It should be processed only in an automatic processor using standard rapid-processing chemicals. Since the photographic response is different, safe lighting must be modified. A red filter such as the GS–1, GSX, or equivalent is recommended. If your darkroom stores and processes both blue-sensitive and green-sensitive film, then your safelight filter should be red.

236. Composition and characteristics of intensifying screens

As previously mentioned, the vast majority of radiography performed today involves the use of intensifying screens because of their ability to reduce patient exposure. For this reason, we should have a general understanding of their operation. Our discussion of intensifying screens includes their purpose, construction, types, and characteristics.

Purpose

The purpose of intensifying screens is to convert radiation energy (X-ray photons) to visible light, which then exposes the X-ray film. Intensifying screens allow us to use much lower mAs values to produce the desired image density. Subsequently, the primary advantage of using intensifying screens is that radiation exposure to the patient is greatly reduced. Other advantages include a reduction in heat loading on the tube (thus prolonging tube life) and allowance for the use of shorter exposure times, which is important in minimizing image motion.

The reason intensifying screens are able to produce images with less radiation is because they are more apt to interact with X-ray photons. That is to say, as X-rays pass through a sheet of film, less than one percent of the beam interacts with the molecules of the film to form a latent image. By comparison, as X-rays pass through an intensifying screen, up to 30 percent of the beam interacts with the screen to produce light. As a result of this increased efficiency, fewer photons are required to produce a radiographic image. Let's look at the components of a standard intensifying screen.

Composition of intensifying screens

An intensifying screen consists of four layers of material: the base, phosphor layer, reflecting material layer, and protective coating.

The ***base*** is approximately 1 millimeter (mm) thick and made of polyester. Its purpose is to provide support for the phosphor layer.

The ***phosphor layer*** is the active layer of a screen. This layer is where the radiation is converted into light. The light emitted from the phosphor crystals is emitted in all directions, or isotropically, with equal intensity. Less than half the light is emitted in the direction of the film.

A layer of ***reflecting material*** is applied to the base so that misdirected light photons may be redirected toward the film. This action nearly doubles the number of light photons reaching the film, thus increasing the efficiency of the screen. Reflecting material is typically made of magnesium oxide or titanium dioxide.

The ***protective coating*** is the layer of the screen that touches the film. This thin layer of plastic prevents the buildup of static electricity, protects the phosphor layer from abrasions, and provides a surface for routine cleaning without disturbing the phosphor layer. Of course, the protective coating is transparent to light.

Types of intensifying screens

The phosphor is the most important part of an intensifying screen. The phosphor does the actual work of converting X-rays into light rays. Many materials have been experimented with and used throughout the years as phosphors in radiography. In early screens before 1980, this layer was made of crystalline calcium tungstate. The phosphor layers in today's screens are made of rare Earth elements like gadolinium, lanthanum, and yttrium. Rare Earth screens are "faster" than earlier screens.

Calcium tungstate screens have a conversion efficiency of about 5 percent, whereas most rare Earth screens have a conversion efficiency of nearly 20 percent. This means that one X-ray photon absorbed by a calcium tungstate intensifying screen may produce 1,000 photons of light, whereas one X-ray photon absorbed by rare Earth phosphors may produce 4,000 light photons.

Another difference between the two is the type of light they luminesce (or give off). As previously mentioned, calcium tungstate gives off ultraviolet/blue tinted light, whereas the rare Earths give off blue, blue-green, or green tinted light depending on the specific phosphor used.

Characteristics of intensifying screens

When using intensifying screens, there are three characteristics to be concerned with: screen speed, image noise, and spatial resolution.

Screen speed

Screen speeds are expressed numerically. A slow screen is identified with a number close to 100 while a fast screen closer to 1200. No matter the number assigned as the speed of a screen, the number simply represents how efficiently X-rays are converted into usable light.

Image noise

When an image is processed, any noise will appear as a speckled background. Image noise typically happens more often with a fast screen and high-kVp techniques. In general, noise negatively affects image contrast. Another component of radiographic noise is *Quantum mottle*. Quantum mottle is the unintentional variations in density on a radiograph causing film graininess and is the result of the random spatial distribution of X-ray photons on the screen. Quantum mottle is often the result of using a fast speed screen-film combination with a very small amount of exposure.

Spatial resolution

All intensifying screens reduce the detail on a radiograph below that obtained from direct film exposure, and this reduction in detail increases as the screen speed increases. Image detail is routinely used to describe image quality. Spatial resolution is the term used to state how small an object can be and still be imaged. High-speed screens produce low spatial resolution and slow (detail) screens have high spatial resolution.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

235. Film composition and characteristics

1. List the four main components of a sheet of X-ray film.

2. In the earliest days of radiography, what was used as the base of the film? What do film manufacturers use today?

3. What takes place in the emulsion layer?

4. What determines film speed of a particular type of film?

5. What are the two basic types of screen film manufactured today?

6. What does the H and D curve show?

7. What is exposure latitude?

8. What are the advantages of rare Earth film/screen combinations?

236. Composition and characteristics of intensifying screens

1. What is the purpose of intensifying screens?

2. What is the primary advantage of using intensifying screens?

3. List the four layers of an intensifying screen.

4. What is quantum mottle?

5–2. Film Processing

Film processing is the final step in bringing your radiographic image to life. When problems arise in this function, they tend to negate all your previous efforts devoted to obtaining a high-quality diagnostic radiograph. This unit will discuss chemical automatic processing systems and the importance of silver recovery.

237. Wet automatic film processing systems

We all work hard to position the body part correctly and select a proper technique but if using film, all of that hard work can go right out the door if the automatic processing system is not working properly. In this lesson, we will discuss the chemical components of the developer and fixer and the five systems of an automatic processing unit.

Processing the latent image

Once a film has been properly exposed, it contains a *latent image*. A latent image is the invisible change to the emulsion layer in the silver halide crystals. Something must be done to convert this latent image into an image visible to the naked eye. This is the process known as film *developing* or *processing*. The act of processing film is completed in four steps: developing, fixing, washing, and drying. Developing an image actually reduces the exposed silver halide crystals to black metallic silver, which converts the latent image into a visible image. Fixation stops the action of the developer and removes the unexposed silver halide crystals from the emulsion. The wash removes all residual chemicals from the film so that it is ready for the drying phase.

The developer solution

The developer solution uses a number of different components (chemicals) to perform its primary function: changing silver ions of exposed crystals into metallic silver. The developer solution contains a *wetting agent* (water) which causes the emulsion to swell so the other chemicals can penetrate the emulsion. When electrons are released by chemical means, a *developing agent* (phenidone and hydroquinone) is used to reduce silver ions to metallic silver to produce gray shades and black tones on the film. An *activator* (typically sodium carbonate) helps swell the gelatin and control the pH balance by controlling the concentration of hydrogen ions. Also included is a *restrainer* (like potassium bromide) which allows the developing agent to only affect the silver halide crystals that were irradiated. A *preservative* (usually sodium sulfite) is included to control the oxidation of the developing agent by the induction of air. The preservative keeps the developer solution clear; if the developer solution turns a brownish color, oxidation has occurred. A *hardener* (commonly glutaraldedyde) is included to keep the swelling/softening of the emulsion to just the right amount so the film can properly move through the system. Lastly, a *sequestering agent* (chelates) removes metallic imperfections and helps to keep the developing agent stabilized.

The fixer solution

The fixer solution, like the developer, also uses a number of different components (chemicals) to perform its primary function: stopping the action of the developer and removing the unexposed silver halide thereby *fixing* the image. The first component of the fixer solution is an *activator* (typically acetic acid). The activator neutralizes and stops the developer solution. A fixing agent (Ammonium thiosulfate) removes the unexposed and/or undeveloped silver halide crystals from the emulsion layer. Like in the developer solution, a *hardener* (potassium alum) is included to make the emulsion more rigid and then a *preservative* (sodium sulfite) is again used to maintain chemical balance within the fixer. The preservative is needed because there is always a small amount of chemical carryover from the developer tank to the fixer tank. A *buffer component* (acetate) maintains the fixer's pH balance. The *sequestering agent* (typically boric acids and salts) in the fixer removes the aluminum ion impurities and finally, water is added to the fixer solution to dissolve other components.

History of Automatic film processing

In earlier days of radiography, before automatic processing, films were processed by hand. This messy, time consuming, process took nearly an hour to obtain a completely dry, finished radiograph. Since drying represented about half of this time, stat films were often read before they were adequately dried. For that reason, we still refer to stat readings as "wet" reads.

The first automatic processor, developed in 1942, still dipped films from one tank to the next using a special hanger system. This system reduced the developing time from an hour to 40 minutes. In 1956, Eastman Kodak introduced the first roller transport system, which drastically reduced the developing time to only 6 minutes. Then in 1965, Eastman Kodak again improved on the automatic processor reducing the developing time down to 90 seconds. Where film and processors are still used, the rapid automatic processor is the mainstay and each one works off the same fundamental principles, regardless of the manufacturer.

Automatic film processing systems

The main systems of an automatic film processor are the transport system, the temperature control system, the circulation system, the replenishment system, and the dryer system.

The *transport system* begins at the feed tray and ends when the film drops out of the dryer section. The main components of the transportation system are the rollers, the transport racks, and the drive motor. The transport system has two functions; the first is to move film through each stage (developing, fixing, washing, and drying) of the processing cycle (fig. 5–4), and the second is to control the amount of time a film spends in each stage of development.

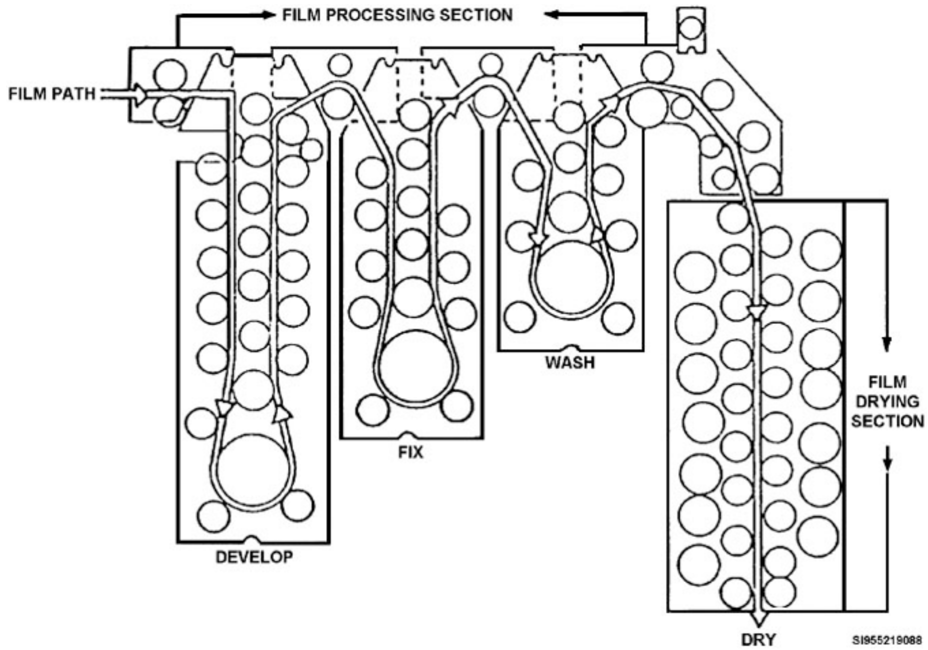

Figure 5–4. The roller-transport system of an automatic processor.

The *temperature control system* monitors temperature readings throughout each stage of the processing cycle. The developer temperature is usually maintained at 95°F.

The purpose of the *circulation system* is to provide continuous mixing of each processing solution. Individual pumps keep the developer, fixer, and wash water agitating as films are being processed. This is necessary to maintain constant temperature and chemical strength throughout the solution, and to aid the chemical action in the emulsion.

The *replenishment system* monitors the level of developer and fixer and adds more of each respective solution each time a film passes through the processor. Regarding the wash tank, it is constantly replenished because all automatic processors require an adequate supply of fresh, clean water to wash the films.

Lastly, the purpose of the *dryer system* is to remove all moisture from the processed film. It performs this task with a heater and a blower. In addition, there must be a good exhaust system to remove the warm, moist air so that only hot, dry air is directed over the film.

Daylight processing

A daylight processing system is a machine that attaches to the front of a standard automatic film processor and eliminates the need for a dark room environment when processing standard screen film radiographs. The daylight system accepts standard screen cassettes, removes the exposed film from the cassette, feeds that film into the processor, and reloads the cassette with a “clean” film before ejecting it.

Processor quality assurance

With film and wet automatic processors, you should check the processors daily using a sensitometry filmstrip. *Sensitometry* is the study of the relationship between exposure levels and the resultant density on an X-ray film. A *sensitometer* is the device used to create a *Sensitometry filmstrip* by exposing a piece of film to a predetermined amount of light so that a series of densities are recorded on the film. After processing, the densities of certain density steps are measured with a densitometer and recorded on various charts to track changes in the speed index, contrast levels, and base-plus-fog values. By recording the information on these charts, trends that indicate processor problems can be spotted and corrective actions can be taken before film quality suffers.

Maintaining a good processor quality assurance program is not easy, but it has many benefits. Film of consistently higher quality is produced, the number of repeats is lowered (resulting in lower patient doses), less film is wasted (monetary savings), and the follow-up exam is more likely to have comparable image quality (enhancing follow-up interpretations).

238. The importance of silver recovery

Silver recovery refers to the program to reclaim silver from silver-bearing materials used in radiography. This is a part of the Precious Metals Recovery Program (PMRP). The PMRP is a Department of Defense program that governs the the identification, accumulation, recovery, and refinement of precious metals from materials used by government agencies. Official Air Force policy requires all radiology departments to follow appropriate silver recovery procedures.

Silver recovery

Besides the fact that it is mandated by Air Force policy and the Environmental Protection Agency (EPA), there are several good reasons for maintaining an effective silver recovery program. For one thing, it is profitable. The economic returns help cover operating expenses for a system. In addition, silver recovery programs help conserve a natural resource. Conservation helps to ensure that silver is available for future manufacturing of X-ray film and it helps protect the environment. Hypo (a common name for thiosulfate compounds) picks up unexposed silver atoms from the silver halide crystal to form ammonium thio-silver-sulfate. Hypo solutions containing silver are toxic and can adversely affect an ecosystem. The EPA has strict guidelines governing the amount of silver that may remain in fixer as it is discharged into community sewer systems. Within a radiology department, silver is recovered from two sources: used fixer solution and scrap X-ray film.

Used fixer solution

Remember that one of the purposes of fixer is to remove, or “clear,” unexposed silver (bromide or halide) crystals from emulsion by making them soluble in solution. It stands to reason then that used fixer may contain a significant amount of reclaimable silver. The two processes most commonly used to remove silver from fixer are *metallic replacement* and *electrolytic recovery*.

Metallic replacement

The metallic replacement recovery cartridge system consists of two simple non-moving parts: the metallic replacement recovery cartridge and the circulating unit. Figure 5–5 illustrates a typical metallic replacement unit. A container packed with wire (steel) wool is attached to the fixer drain of an automatic processor. Exhausted fixer is drained through the metallic filter, causing the dissolved silver ions to come in contact with the steel wool. The more active metal in the steel (iron) goes into the solution as an ion, and the less active metal (silver) in the solution becomes silver metal. The silver metal is deposited in the container as sludge. When the filter container is full, it is turned in to Medical Logistics who eventually sells it to a laboratory so the silver can be reclaimed.

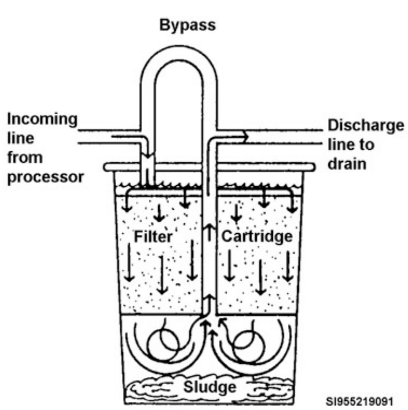

Figure 5–5. Diagram of a metallic replacement silver recovery unit.

Electrolytic recovery

Electrolytic recovery units remove silver from fixer by passing a controlled electric current between two electrodes (anode and cathode), which are suspended in a container. Exhausted fixer flows through tubing to the recovery unit where it is sprayed onto or passed over a rotating drum or disk, which serves as the cathode. Positive silver ions are attracted to the cathode by its negative charge. The silver ions become neutralized, and accumulate on the cathode as nearly pure silver. To reclaim this silver the cathode is removed periodically from the recovery unit and the silver metal retrieved (harvested) from its surface. The silver reclaimed with this method is of higher quality, but this method usually recovers less silver from hypo than does the more efficient metallic replacement method.

Scrap X-ray film

All medical X-ray film—processed and unprocessed—has silver in its emulsion. This silver must be reclaimed when film becomes scrap film. Scrap X-ray film may include old radiographs that are no longer useful, rejected films, films accidentally exposed to light, and outdated film. Developed scrap film yields about one-tenth of an ounce of silver per pound of film, whereas about four-tenths of an ounce can be reclaimed from each pound of undeveloped scrap film. On average, 1 percent of the overall gross weight of scrap film is silver. All scrap film is turned in to Medical Logistics typically on an annual basis.

Security concerns

If a radiology department still uses film and wet processors, then someone must be assigned as the PMRP monitor. Regardless of who is assigned as the PMRP monitor, everyone is responsible for complying with general security measures pertaining to precious metals. All recovery equipment, harvested silver, and film are valuable and must be safeguarded to prevent theft. Silver flake (silver extracted from spent fixer by the electrolytic process) is roughly 90 percent silver by weight. Silver sludge is approximately 22 percent silver by weight. A silver recovery cartridge after use is about 4 percent silver by weight. Scrap film and other silver-laden material awaiting turn-in must be appropriately secured.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

237. Wet automatic processing systems

1. What is a latent image?

2. What four steps are taken to process film?

3. Why are stat readings referred to as “wet” readings?

4. What are the main systems of an automatic film processor?

5. In an automatic film processor, what does the replenishment system do?

6. What is sensitometry?

238. The importance of silver recovery

1. Within a radiology department, silver is recovered from what two sources?

2. List four different types of scrap X-ray film?

3. Though someone is assigned as PMRP monitor, what is everyone responsible for regarding precious metals?

Answers to Self-Test Questions

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1. The base, an adhesive coating, an emulsion, and an overcoat.
2. A glass plate; polyester.
3. It is where the actual process of converting remnant radiation into a visible image takes place.
4. The size and concentration of the silver halide crystals in the emulsion.
5. Those that are sensitive to the blue-violet light emitted from calcium tungstate intensifying screens, and those that are sensitive to the green light emitted by rare Earth intensifying screens.
6. It shows a graphic relationship between density and exposure.
7. The range of exposures (mAs, log relative exposures) that produces density within the accepted range of diagnostic radiography.
8. They provide greater speed, reduce patient exposure, and don't sacrifice the detail offered by conventional calcium tungstate screens.

236

1. To convert radiation energy (X-ray photons) to visible light, which then exposes the X-ray film.
2. Radiation exposure to the patient is greatly reduced.
3. The base, phosphor layer, reflecting material layer, and protective coating.
4. The unintentional variations in density on a radiograph causing film graininess and is the result of the random spatial distribution of X-ray photons on the screen.

237

1. The invisible change to the emulsion layer in the silver halide crystals.
2. Developing, fixing, washing, and drying.
3. Stat films were often read before they were adequately dried.
4. Transport system, temperature control system, circulation system, replenishment system, and dryer system.
5. It monitors the level of developer and fixer and adds more of each respective solution each time a film passes through the processor.
6. The study of the relationship between exposure levels and the resultant density on an X-ray film.

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1. Used fixer solution and scrap X-ray film.
2. Old radiographs that are no longer useful, rejected films, films accidentally exposed to light, and outdated film.
3. Everyone is responsible for complying with general security measures pertaining to precious metals.

Complete the unit review exercise before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

70. (235) Which component of X-ray film contains silver halide crystals?
    a. The base.
    b. The emulsion layer.
    c. The adhesive coating.
    d. The protective coating.

71. (235) The inherent film fog is not considered excessive unless it exceeds a density of
    a. 0.1.
    b. 0.2.
    c. 1.0.
    d. 2.0.

72. (236) What layer of an intensifying screen converts radiation to light?
    a. Base.
    b. Phosphor.
    c. Protective coating.
    d. Reflecting material.

73. (237) What is the primary function of the developer solution in an automatic film processing system?
    a. Make the film more rigid.
    b. Remove the overcoat from the film.
    c. Swell the emulsion layer and control pH balance.
    d. Change silver ions of exposed crystals into metallic silver.

74. (237) What system in an automatic film processor controls the amount of time a film spends in each stage of development?
    a. Dryer system.
    b. Transport system.
    c. Circulation system.
    d. Replenishment system.

75. (237) What instrument is used to measure optical densities on a radiograph?
    a. Sensitometer.
    b. Densitometer.
    c. Penetrometer.
    d. Sphygmomanometer.

76. (238) The precious metals recovery program governs the
    a. destruction of film.
    b. reclamation of silver.
    c. use of natural resources in radiology.
    d. disposal of the fixer and developer solutions.

Please read the unit menu for unit 6 and continue ➔

Student Notes

Unit 6. Radiation Exposure Effects and Safety

IN the early days of radiology, little was known about the effects radiation had on living tissue. Because of this ignorance, the radiologist and his assistant spent much of their time working in and around the primary beam completely unprotected. It was not until radiation workers began to exhibit a higher incidence of leukemia and other illnesses that any real study of how exposure to radiation affected the human body began. Over the years, this study developed into its own branch of science and today we know it as radiobiology.

Having a working knowledge of radiobiology and radiation protection procedures is one of the most important aspects of our profession. The information covered in this unit could quite possibly save lives. Excessive exposure to ionizing radiation has been linked to everything from cancer to cataracts to shortened life spans and birth defects. You can realize just how important it is for you to understand how radiation affects the body and what measures you can take to minimize its effects on you, your patients, and fellow hospital staff members.

The first section of this unit explains radiobiology concepts. We cover how ionizing events damage biological tissue, and the various biological effects that exposure to radiation can produce. The second section refers to radiation protection procedures and standards. Finally, we will end this unit with a discussion of applicable radiology safety program topics.

6–1. Radiobiology

As mentioned, radiobiology is the branch of biological sciences concerned with the effects of radiation exposure on living tissue. Extensive research is still being conducted and there is still much to learn. Information presented in this unit may help to extend your life and the lives of your patients.

NOTE: The information presented in this unit goes hand-in-hand with unit 1–2 of this volume.

239. Mechanisms of radiation injury

Very early on in the field of radiation science, scientists demonstrated that ionizing radiation caused damage to living tissue. Humanity though, has experienced tremendous benefits from the controlled use of radiation for both medical imaging and treatment. Clearly, the immediate benefits derived from medical diagnostic radiation imaging far outweigh the potential long-term side effects. No matter the benefits, it is still your responsibility to provide the highest quality images with the lowest possible radiation exposure (dose) to your patients.

Radiation damage

Demonstrating and predicting radiation damage from excessive exposure is fairly easy; however, it is not so easy to determine the effects of repeated low-dose exposures such is the case during medical imaging. This is the problem faced by the field of radiobiology: How much radiation is too much?

Radiation damage is not necessarily permanent. That is, if cells damaged by radiation can live long enough to reproduce themselves, the damaged tissue can repair itself just as it would from any other type of non-fatal injury. We know from previous discussions that the initial interactions that radiation has with human tissue happens at the electron level. When there is an observable radiation injury to humans, this means the molecular level has incurred changes. How much of the damage is repairable depends upon many factors discussed later in this unit.

Direct and indirect effects

To understand how radiation affects humans, we must focus on the individual reactions between photons and the molecules of cells, which are the basic building blocks of all living organisms.

As a beam of radiation passes through living tissue, it interacts with the tissue's atoms and molecules imparting some of its energy to the tissue's atoms and molecules. From prior lessons, we know that if the energy imparted is great enough, ionization takes place and orbital electrons are ejected from their parent atoms. When a photon from the primary beam has an ionizing event with an atom or molecule of a cell, the radiation has a *direct* effect on that cell.

Remember, an ejected electron and the secondary photons that are created as a result of the ionizing event can go on to have other interactions with neighboring molecules or cells. These secondary interactions are called *indirect* effects of radiation. In the final analysis, it is impossible to know if radiation damage to a specific molecule or cell was the result of direct or indirect effects. Either way, the damage is identical.

The radiolysis of water

Another indirect effect that radiation can have on living tissue occurs due to the *radiolysis of water*. When water is irradiated, a portion of it breaks down into other, simpler molecular products through a process known as radiolysis of water. The actual process is somewhat complicated, with many possible results, but a simplified explanation will give you a basic understanding of the process.

As water (H_2O) is irradiated, ionizations can cause the molecular bonds that hold the hydrogen and oxygen together to break. When this happens, some of the water is converted into free hydrogen atoms (H) and hydroxyl molecules (OH). At this point, most of the H and OH molecules simply recombine into H_2O, but some of the time the OH molecules will combine with other OH molecules to form H_2O_2 (hydrogen peroxide). This process is illustrated in figure 6–1. Hydrogen peroxide is, of course, a toxic substance. In sufficient quantities, it kills the cells in which it comes in contact.

You may be wondering what this has to do with living tissue. Since the human body is about 80 percent water, the greatest percentage of radiation damage (as much as 95 percent) in vivo (within the body/cell) occurs as a result of the indirect effects.

Target theory

Within the cells of any given tissue, there are thousands of molecules that comprise the cell and combine to perform the work of that cell. Most of the molecules of a cell occur in great number within that cell and, if one is damaged, there are others to take its place. In every cell though, a few "key" molecules occur in very small numbers. In fact, some molecules are unique to that cell and are the only one of their kind in the cell. If these molecules are damaged, there are no others to take their place. If direct or indirect radiation damage is significant enough to prevent these key molecules from performing their function, the cell may die.

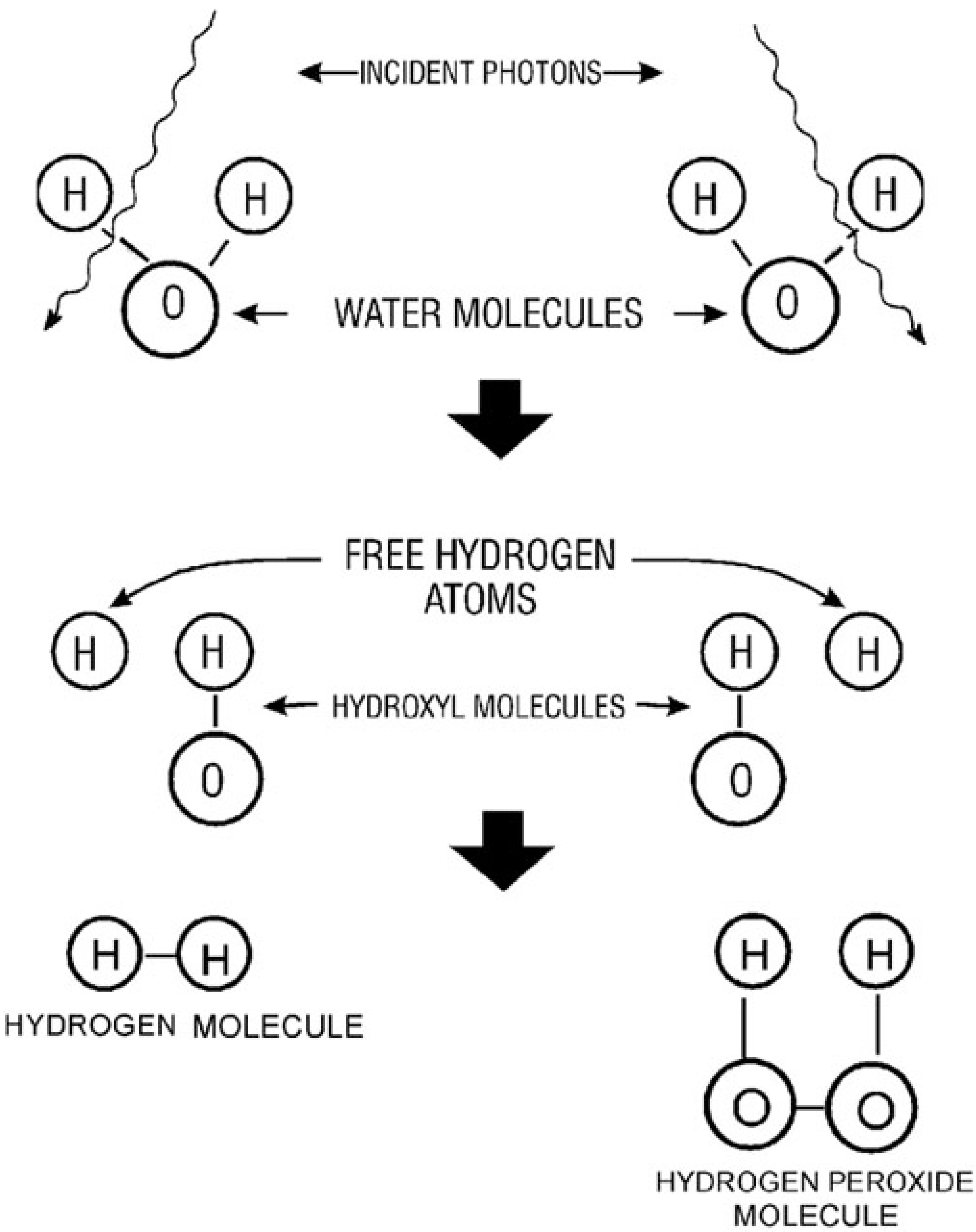

Figure 6–1. Radiolysis of water.

The target theory states a cell can absorb radiation damage and continue to function unless a key or *target molecule* within that cell is damaged. If the target molecule is sufficiently damaged, the cell dies. Keep in mind that damage to the target molecule can occur by either direct or indirect methods.

The most obvious example of a unique key (target) molecule that is present in every cell of the human body is deoxyribonucleic acid (DNA) found within the nucleus of the cell. As you know, DNA is the command molecule of the cell. It is responsible for directing the operation of the cell, and it contains all the information necessary to completely reproduce the cell.

DNA molecules are extremely large macromolecules comprised of many thousands of smaller molecules. They contain an enormous amount of information by stringing together other molecules in a specific sequence. If something happens to disrupt this sequence, the DNA molecule may not be able to carry on its function. However, the more disastrous an event is when the DNA lives on to reproduce itself in a disrupted form. When this happens, it is called a mutation.

We know that 99.99 percent of all mutations are harmful. In fact, in some instances, mutations lead to rapidly reproducing abnormal cells known as cancer. In other instances, if the genetic cells of a body (the male sperm and female egg) have been mutated, this damage can be passed on to subsequent generations and may not manifest itself for many generations.

The specific response of a given cell or organism to radiation is dependent upon many things, which we'll discuss next.

240. Factors that affect the radiosensitivity of cells

Early experimentation in the field of radiobiology clearly demonstrated some types of cells were more sensitive to radiation than others. This observation led two French scientists, Bergonié and Tribondeau, to conduct a series of experiments to determine just what caused the different responses. As a result of their work, they developed a theory that has been proven many times since and is today known as the *Law of Bergonié and Tribondeau.*

The Law of Bergonié and Tribondeau

Bergonié and Tribondeau observed the following:

- Immature cells are more radiosensitive than mature ones.
- Young tissues and organs are more radiosensitive than older ones.
- The higher the metabolism of a given cell, the more radiosensitive it will be.
- Rapidly dividing cells are more radiosensitive.

To summarize the law of Bergonié and Tribondeau, immature and rapidly dividing simple cells are more radiosensitive than mature, complex ones and those of stable tissues.

Further interpretation of the law states that cells undergoing mitosis (reproduction) like blood cells, and gonadal cells are the most radiosensitive. By contrast, humans are born with nearly all the nerve, brain, and muscle cells they will ever have; therefore, these cells are the least radiosensitive. These cells have a greater resistance to damage by radiation because they are neither immature nor rapidly dividing.

Physical factors affecting radiosensitivity

Of course, one of the main determining factors in how an organism responds to radiation is the amount of energy transferred to the tissue from the beam. For this discussion, we need to define a few other terms.

Roentgen has already been defined as the amount of radiation required to produce approximately two billion ion pairs in one cubic cm of air. The terms *rad* and *rem* are approximately equivalent to roentgen (R) for the purposes of diagnostic radiology.

$$1 \text{ R} = 1 \text{ rad} = 1 \text{ rem}$$

The difference is that a *rad* (radiation absorbed dose) is a measurement of energy imparted to an absorbing material as a beam of radiation passes through it. Rad is typically used to state the amount of radiation a patient received. The *rem* (radiation equivalent to man) is a measurement of the relative biologic effectiveness of a beam of radiation. Rem is the unit used to state the amount of radiation that radiation workers and the general population receive. Rem accounts for a person's equivalent dose which is the product of the absorbed dose and the associated radiation weighing factor that correlates to the type and energy of the radiation used.

Still today, the United States is the only country yet to adopt the International System (SI) which was adopted in 1981 by the International Commission on Radiaton Units and Measurements for expressing radiation units. Here are the conversions from customary units to the International System units:

Customary Unit Name and Symbol	International System (SI) Unit Name and Symbol	Conversion	Type of Dose
Roentgen (R)	Air kerma (Gy_a)	* Multiply R by 0.01 to convert to Gy_a * $1R = 0.01\,Gy_a$ or $1Gy_a = 100R$	Exposure Dose
Radiation absorbed dose (rad)	Gray (Gy_t)	* Multiply rad by 0.01 to convert to Gy_t * $1rad = 0.01Gy_t$ or $1Gy_t = 100rad1Gy_t = 100rad$	Absorbed Dose
Radiation equivalent to man (rem)	Sievert (Sv)	* Multiply rem by 0.01 to convert to Sv * $1rem = 0.01Sv$ or $1Sv = 100rem1Sv = 100rem$	Effective Dose

The terms rem (sievert), rad (gray), and roentgen (coulombs/kg or air kerma) define specific amounts of radiation. However, not all radiation produces the same effects in living tissue even if the amounts are the same. Several other physical factors contribute to an organism's response to radiation. The physical factors of concern include linear energy transfer, total dose, and dose rate.

Linear energy transfer

The *linear energy transfer* (LET) is a measurement of the amount of energy imparted to an absorbing material by ionizing radiation. Since ionizing radiation's ability to produce a biological response increases as the LET increases, radiation having a high LET value produces more damage to cells than radiation having a low LET value. Relative biological effectiveness (RBE) is a number that expresses a beam of radiation's ability to produce a biological response. Thus, LET and RBE are closely related terms and their relationship is simple; as LET increases, RBE increases also.

LET is usually measured in keV per micrometer of path length through which a quantity or type of radiation passes. This measurement varies with different radiations and energies. For example, high-energy gamma radiation, such as that used in radiotherapy with cobalt (^{60}CO), has a LET of 0.25 keV per micron of tissue. Diagnostic X-rays are rated at 3.0 keV. Alpha particles having 5 MeV of energy produce 100 keV of LET. In general, as the ability to penetrate matter increases, LET decreases. (Remember, alpha particles are readily absorbed.)

RBE is simply a number that represents the ratio of the dose of standard radiation required to produce a certain effect compared to the dose of radiation being measured. Standard radiation is always considered to be X-rays in the 200 to 250 kVp range. So that, if a certain type of radiation requires more rads to produce a certain effect than a 250 kVp beam of X-rays, that radiation would have an RBE of less than one. Subsequently, if a different type of radiation requires less rads than a 250 kVp X-ray beam to produce a certain effect, that radiation would have an RBE of greater than one.

To put it in practical terms, when you increase a beam's penetrability by increasing kVp and reducing mAs, you are in effect reducing its LET and, therefore, reducing its RBE. For this reason, you should always use the highest practical kVp that will still produce an acceptable contrast range for the body part you are radiographing.

Total dose and dose rate

The total amount of radiation received by an organism as well as the rate at which the radiation is received greatly affects the response that organism exhibits.

Total dose is the entire amount of radiation received with no indication of the time over which it was received. With all other factors the same, the greater the total dose, the greater the effect produced. *Dose rate,* or exposure rate, is the amount of radiation received per unit of time, such as 5 R per hour (5 R/hr). An exposure rate of 10 R/minute for three minutes results in a total exposure of 30 R. If all other factors remain the same, cell injury should increase as the dose rate increases.

The effects of radiation can be lessened if the dose of radiation is administered at a lower rate and broken up over a longer time frame. This is accomplished in radiotherapy by using the procedures of *protraction* and *fractionation.*

Protraction is the practice of delivering a radiation dose continuously but at a lower rate. Dose fractionation is the procedure of administering radiation for short periods until the entire exposure is administered; thus, the treatments are given in fractions with a repair and recovery period in between. These practices allow radiation therapists to produce the maximum effect on cancerous tissues while minimizing the effects on the surrounding healthy tissues.

Biological factors affecting radiosensitivity

Some biological factors—such as age, gender, metabolic rate, and aerobic state—also influence cellular radiosensitivity.

Age

The effects of organism age become easier to understand in the light of Bergonié and Tribondeau. Humans are most radiosensitive when cells are young and immature, such as in early embryonic and fetal life. Radiosensitivity decreases in the later stages of pregnancy, after birth, and as a person matures. In old age, humans again become somewhat more radiosensitive because of their weakened constitutions and immune systems.

Gender

Experiments conducted to determine which gender is most radiosensitive produced findings that are not all in agreement nor conclusive. However, the consensus indicates males seem to be slightly more radiosensitive than females.

Metabolic rate

Past studies have estimated that roughly 90 percent of radiation damage to cells is repairable. However, this statement is too general and the actual ability of an organism to recover from radiation damage depends on many factors. If the applied dose is not enough to kill cells before they undergo mitosis, chances are the cells will recover if given sufficient time between exposures. Thus, cell metabolism influences radiosensitivity (and recovery), but is dependent upon the type of cell, the stage of mitosis when the cell is irradiated, the type of radiation used, etc.

Aerobic state

Another factor that directly affects response is the amount of oxygen (aerobic state) in the irradiated tissue. This is called the *oxygen effect.* The oxygen effect refers to the concept that tissues have an increased radiosensitivity when irradiated in an oxygenated state.

241. Relationships between radiation dose and biological response

A substantial amount of radiobiological research is involved in establishing radiation dose-response relationships. This research benefits radiology in two ways. First, these relationships aid in designing radiotherapy treatments for patients. Second, information derived from studies associated with dose-response relationships provides a basis for radiation protection activities and guidelines.

Radiation dose-response relationships

The dose-response relationship refers to the amount of radiation received and the type of response it produces in an organism. We can diagram dose-response relationships with a graph. Each dose-response relationship graph indicates the relationship between levels of radiation dose and the amount of a particular response. Each relationship has two characteristics: it is either linear or nonlinear, and it is either threshold or nonthreshold. Thus, there can be four combinations of dose-response curves:

- Linear, threshold.
- Linear, nonthreshold.
- Nonlinear, threshold.
- Nonlinear, nonthreshold.

In a linear dose-response relationship, the effect being measured increases in direct proportion to the dose of radiation; this can be seen in figure 6–2. In nonlinear dose-response relationships, the effect is not directly proportionate to the dose (fig. 6–3). Let's take a closer look at these two curves.

Notice that a threshold exists in figure 6–3, but not in figure 6–2. A threshold dose-response is one in which the effect being measured is not observed below a certain dose. A graph of a threshold dose-response shows the curve beginning at some point along the dose axis beyond no exposure (zero dose). Therefore, the effect in figure 6–2 occurs at *all* dose levels, whereas the effect in figure 6–3 occurs only beyond a certain dose level.

Figure 6–2. Dose-response graph showing a linear, nonthreshold relationship.

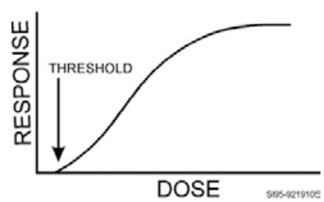

Figure 6–3. Dose-response graph showing a nonlinear threshold relationship.

Obviously, different effects are represented in figures 6–2 and 6–3. Figure 6–2 is representative of the genetic effects of radiation exposure because they appear to follow a linear, nonthreshold relationship.This means that any dose of radiation can cause genetic effects, and as the dose increases, the incidence of genetic effects increases proportionally.

Somatic effects refer to radiation damage to somatic cells of the body. The curve in figure 6–3 is typical of many types of somatic effects because no effect is observed below a certain level, and at high doses the response no longer increases proportionally with the dose. Somatic cells are all cells that make up the human body except gonadal cells (sperm and egg). Therefore, somatic effects are those effects that are experienced by the individual actually exposed (e.g., leukemia, cancer, cataracts, premature aging, etc.) but not to succeeding generations.

The ALARA principle

The ALARA acronym stands for *as low as reasonably achievable*. The ALARA principle (and radiation protection in general) is based on the conclusion that radiation dose and its exposure effects on human tissue have a linear-nonthreshold relationship. This means that *any* exposure to ionizing radiation, no matter how small, has the ability to produce negative effects to human tissue which may include an increased risk of genetic mutations and/or cancer. For this reason, every technologist is expected to practice the ALARA principle at all times and without question to protect themselves and their patients.

So how do you apply the ALARA principle? In application, always use the lowest amount of radiographic technique needed to produce a high-quality diagnostic image from which the radiologist can make accurate interpretations. In addition, radiology techs should follow three radiation safety concepts when practicing the ALARA principle:

- **Time**—Minimize exposure time whenever possible.
- **Distance**—When possible, double the distance between you and the source of radiation.
- **Shielding**—Use an absorber material (lead) to shield the patient or yourself from unnecessary radiation exposure.

These concepts are critical to radiation protection and will be discussed in more detail in the radiation protection section of this unit.

242. Acute radiation damage

We divide the specific types of radiation injuries into two groups: acute (early) effects and long-term effects. Acute effects of radiation are those that manifest within days or weeks of exposure. Long-term effects are generally not seen for many years after exposure. The reason for the distinction between the two groups is the quantity of radiation involved to produce the effects. This lesson begins with a discussion of acute radiation syndrome.

Acute radiation syndrome

Acute radiation syndrome (ARS) occurs when a very large whole-body dose of radiation exposure is received which leads to death within days or weeks. ARS is not seen in modern day diagnostic radiology. But early in our career field (before there was an awareness of radiobiology), many doctors, techs, and patients inadvertently experienced acute radiation injuries. Depending upon the amount of radiation received at the time of exposure, three major body systems are primarily affected by ARS: hematologic (blood), gastrointestinal (GI), and central nervous systems (CNS).

Hematologic syndrome

Radiation doses from 200 rad (2 Gy_t) to 1,000 rad (10 Gy_t) are capable of causing hematologic radiation syndrome. The initial or *prodromal* stage can occur within minutes or few hours after exposure and the early signs of radiation sickness may present themselves as nausea, vomiting, diarrhea, and a decreased amount of white cells in the peripheral blood otherwise known as leukopenia. This is followed by a *latent* period of 1 to 4 weeks during which the victim appears and feels well. Depending upon the size of the dose, recovery begins between 2–4 weeks after exposure and up to 6 months may be needed for a complete recovery. If the size of the dose is great enough, the decrease in blood cells will continue and if unmonitored, will lead to the demise of the body's defenses to fight infection. If this is the case, death occurs due to electrolyte imbalance, overwhelming infection, and internal bleeding.

Gastrointestinal syndrome

The GI ARS is evident in dose ranges of 1,000 to 5,000 rad (10 to 50 Gy_t). Few, if any, would survive exposure in this range. The prodromal stage occurs in the first few hours post exposure. Severe nausea, vomiting, cramps, and diarrhea are common initial symptoms. The latent period lasts only 3 to 5 days and is followed by rather severe illness. The most important features of the GI ARS illness stage include:

- Sloughing of the gastrointestinal lining caused by failure to produce new lining cells. So, as the old cells die out, they are not replaced. Massive ulcerations result.
- Gross hemorrhage from the GI tract caused jointly by the loss of platelets and the ulcerations.
- Loss of body fluid and nutrients due to hemorrhage and diarrhea.

Death from GI ARS usually occurs within 4 to 10 days of exposure and due to overwhelming damage to the intestinal cell lining.

Central nervous system syndrome

Humans exposed to dose levels above 5,000 rad (50 Gy_t) will experience symptoms with the CNS ARS and will die shortly thereafter. Within minutes after exposure, the victim experiences confusion, disorientation, extreme nervousness, syncope, a burning sensation of the skin, severe nausea, and vomiting. A short latent period of only a few hours follows. Then manifest illness develops, consisting of convulsions, watery diarrhea, and coma followed by death. In the CNS syndrome, the hematopoietic and GI symptoms don't have time to fully develop. Death occurs within hours and results from increased intracranial pressure and swelling of the brain due to fluid accumulation associated with vascular and membrane damage.

Fortunately, ARS death does not occur in diagnostic radiology because the diagnostic X-ray beam is not intense enough, and collimation prevents whole-body exposures. ARS death can occur in nuclear or radiation accidents and heavily irradiated radiotherapy patients. On the other hand, sublethal damage, such as localized inflammation of the skin, can occur because of negligent or accidental partial-body exposures. Because ARS is not typical in diagnostic radiology, your primary concern falls to long-term somatic and genetic effects.

$LD_{50/60}$

Another term associated with acute radiation exposure is the $LD_{50/60}$. This refers to the lethal dose of whole-body exposure sufficient to cause death to 50 percent of the subjects irradiated within 60 days. The $LD_{50/60}$ for humans is about 350 rad (3.5 Gy_t).

NOTE: We do not refer to the $LD_{50/60}$ for humans in terms of rems because rems are a unit that is reserved for measuring occupational exposure rates.

Localized radiation exposure effects

Several other potential acute radiation injuries may result from partial body exposure to large amounts of radiation. These localized effects vary depending upon the area of the body irradiated and the amount of radiation exposure. Examples of localized partial body radiation exposure effects include skin erythema (redness and swelling) and ulceration, temporary or permanent sterility, and depression of the immune system. In the case of temporary or permanent sterility, we need to discuss the effects of a localized high-dose exposure to the reproductive organs (the gonads).

The ***gonads*** are quite possibly one of the most important target organs in the human body. Effects have been observed in doses as low as 10 rad (100 mGy_t). In females, the ovaries are especially sensitive to radiation from fetal time through early childhood years. Doses of 10 rad can cause menstrual suppression while doses of 25–50 rad significantly increase genetic mutations. In males, 10 rad may cause a short-term reduction in the functional germ cell of the testes, the sperm. If a male receives a high enough dose to the testes, there is a likelihood for sterility. However, the male can still engage in sexual intercourse. The problem lies in this realm; if the male continues to have sexual intercourse after the high dose, this is when the highest incidence of genetic mutations is passed on during procreation. In this case, a male exposed to a dose of 10 rad or greater to the gonadal region should abstain from procreation for up to 4 months.

In general, the following response conclusions can be assumed for both the testes and the ovaries when exposed to radiation:

- 10 rad (100 mGy_t) causes the least observable response.
- 200 rad (2 Gy_t) causes temporary infertility.
- 500 rad (5 Gy_t) causes sterility.

Again, we wish to stress that the levels of radiation used in modern day diagnostic radiography are not nearly high enough to cause any acute injury. It is important though to understand the potential dangers associated with even partial body exposures; especially to the gonads.

243. Long-term effects of radiation exposure

In the previous lesson, the discussion revolved around acute (short-term) high dose radiation exposure. In this lesson, we will discuss radiation exposure effects that appear months or many years after the exposure event(s). While there are long-term effects associated with large doses of radiation, we are primarily concerned with the effects associated with repeated low-dose exposures over many years. It is important to understand that long-term effects are assumed to have a linear, nonthreshold dose-response relationship. Therefore, there is no minimum amount of radiation correlated to the production of long-term effects because long-term effects are considered nonthreshold which means we assume any radiation exposure *may* produce some long-term (or late) effects long after the initial exposure. For this reason, radiation protection standards are written based on this assumption.

Data about long-term effects has been gathered from a variety of sources. As with ARS effects, some information is obtained from survivors of atomic bomb explosions (Hiroshima and Nagasaki 1945), nuclear accidents (Chernobyl 1986 and Three-Mile Island 1979), and heavily irradiated radiotherapy patients. Besides those sources, data has also been obtained from experiments on laboratory animals, case studies on early radiation workers, and follow-up studies on uranium mine workers and radium-dial painters. Findings from all sources are grouped into two categories of long-term effects: somatic and genetic.

Long-term somatic effects

Statistically speaking, a person who is exposed to radiation has an increased probability of developing health problems long after the initial exposure as compared to someone who has not been exposed.

Somatic cells are every cell other than gonadal cells. They make up all the various tissues of the human body, such as heart, lung, liver, muscle, nerve, etc. They carry out the life functions for an individual. When radiation damage occurs to somatic cells, a person's health or life is at risk because of a variety of anomalies that can develop. Somatic cells do not pass on the damage to future generations like genetic cells (the gonads) are capable of doing. The four major types of long-term somatic effects are carcinogenesis, embryological effect, cataractogenesis, and life-span shortening.

Carcinogenesis

Researchers have discovered that cancer cells have a genetic makeup different from that of normal cells; this leads to the idea that cancer results from mutations of part of the genetic system of somatic cells. Mutations may be spontaneous, or caused by irritants, viruses, or irradiation. The evidence supporting radiation-induced cancer is overwhelming. Consider these cases:

1. Radium-dial painters. In the early 1900s, young women hand-painted watch dials with a paint laden with radium sulfate. The girls used their lips to form a point on their paint brush; this procedure caused them to ingest large quantities of radium. Radium becomes absorbed by bone, resulting in hematopoietic ARS. Some girls died and others developed bone sarcomas and other cancers later.
2. Thyroid cancer. In the first half of this century, enlarged thymus glands were treated with radiation. Because of its close proximity to the thymus, the thyroid gland received radiation, too. Approximately 20 years later, an increased incidence of thyroid cancer was discovered in those who were irradiated for thymus enlargement. Radiation-induced thyroid cancer has a linear, nonthreshold dose-response relationship.
3. Uranium miners. Miners of uranium ore in Bohemia were exposed to radon gas. After years of inhaling this radioactive gas, as well as handling ores containing radioactive uranium, these miners experienced an extremely high incidence of lung cancer.
4. Atom bomb survivors. Studies of atom bomb survivors show high incidences of various types of cancer. The strongest evidence here supports radiation-induced thyroid and lung cancer.
5. Laboratory experiments. The ability of ionizing radiation to produce cancers in mice is well documented.

6. Medical radiation personnel. Early radiation workers often developed skin cancers and other radiation-induced anomalies, including leukemia.

Leukemia is a particular kind of cancer that has been firmly linked to radiation exposure. It is a neoplasm of hematopoietic (bone marrow) tissues and is typified by the production of abnormal blood cells, excessive production of white blood cells, and certain disturbances of the normal constituents of circulating blood. Radiologists in the period of 1929 to 1963 showed an incidence of leukemia several times that of the general population. Also, atomic bomb survivors show extremely high occurrences of leukemia. Radiation-induced leukemia is considered linear, nonthreshold.

Embryological effect

The unborn child is especially sensitive to radiation, primarily because of the extremely rapid rate of cell proliferation (multiplication). The first trimester is the most susceptible time to inadvertent radiation exposure of a fetus because many women do not even realize they are pregnant for much of the first trimester. In addition, the first trimester is the most sensitive time for radiation exposure because the embryo is a rapidly developing cell system.

The major effects of embryological and fetal exposure depend on when in pregnancy the exposure is received. In the first two weeks after conception (the preimplantation period), the only known risk from irradiation is spontaneous abortion (miscarriage), and that has only been demonstrated at levels of exposure exceeding 10 rad. If an embryo is irradiated during weeks 2 through 10—the period of major organogenesis (organ forming)—there is risk of congenital abnormalities (birth defects) and neonatal death. Irradiation of a fetus after major organogenesis has not been linked to congenital abnormalities, but it has demonstrated an increased incidence of childhood malignancy if the exposure levels are high enough.

Radiation exposure levels above 10 rad are the only exposures to have demonstrated any statistically significant effects. Obviously, diagnostic radiography exposure levels are far below this level; however, we should still exercise extreme caution when X-raying pregnant females to avoid fetal irradiation when at all possible.

Cataractogenesis

Cataractogenesis is the process of which cataracts are formed. A cataract is the clouding of the normally clear lens of the eye. Most modern day literature suggests that the threshold required after an acute high-dose exposure to produce an effect is approximately 200 rad (2 Gy_t). Other data supports a theory that when exposure to the lens is approximately 1000 rad (10 Gy_t), cataracts form in nearly 100 percent of the population that was irradiated. We also have found that neutron radiation is more biologically effective for cataract production than electromagnetic radiation. In controlled settings, low-dose radiation has produced the formation of cataracts in mice. The dose-response relationship for radiation-induced cataracts appears to be threshold, nonlinear.

There is no question that radiation can induce cataracts in humans; therefore, the eyes should be protected from radiation exposure whenever possible.

Life-span shortening

Animal experiments involving rodents exposed to relatively high levels of radiation have unquestionably demonstrated life-span shortening. It is considered that radiation exposure has the same affect in humans but many sources find it difficult to translate the animal experiment data to human kind. We do not know for certain how much life-span shortening occurs with a specific dose. However, there are theories that suggest—as a *worst*-case scenario—human life (in the general population) is shortened 10 days for every rad of exposure. In the occupational setting, sources state the average life span shortening for radiation workers at only 12 days therefore our profession is easily considered a *safe* occupation.

Attempts to explain why radiation seems to shorten life span fall into two basic schools of thought:

The first theory is that radiation hastens the normal aging process so that death-dealing processes occur at a chronologically earlier time. It is the belief of some radiobiologists that the aging process is the accumulation of somatic mutations; therefore, irradiation would accelerate aging by increasing their number.

In the other theory of thought, other radiobiologists prefer the hypothesis that irradiation increases the susceptibility of the irradiated individual to certain diseases. As a result, death is accelerated by hastening the occurrence of death-dealing diseases.

The main point of this discussion about life-span shortening effects is that radiation does not produce unique diseases to cause life-span shortening. Instead, the irradiated person develops the same diseases as anyone else would—only sooner.

Long-term genetic effects

Research of radiation-induced genetic effects in humans is still not conclusive in indicating that radiation exposure actually causes genetic effects. In fact, no radiation-induced genetic effects have ever been observed in humans. This includes third-generation descendants of atomic bomb survivors. Consequently, we turn to the findings obtained from various laboratory experiments where fruit flies and rodents were irradiated.

In 1927, H. J. Muller irradiated fruit flies with rather large (above 10 Gy_t) doses and proved that radiation increases the rate of mutations in the offspring of fruit flies. Other researchers irradiated mice in the mid–1940 with varying radiation doses; their findings supported Muller's findings and confirmed that genetic effects follow a linear, nonthreshold dose-response relationship. Additional conclusions drawn from experimental studies include the following:

- Mutations are transmitted to succeeding generations.
- Mutations may be dominant or recessive.
- Mutations will eventually result in genetic death.
- There is no threshold dose for genetic effects of radiation.
- Any exposure is accompanied by the production of some mutations.
- The number of mutations is proportional to the dose.

There is no reason to believe that those findings would not apply to humans; thus, we must assume that every exposure can produce mutations that might cause some long-term genetic effects.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

239. Mechanisms of radiation injury

1. Explain the direct effects of radiation.

2. Explain indirect effects of radiation.

3. What is the process known as the radiolysis of water?

4. How does *most* radiation damage in vivo occur (directly or indirectly)?

5. Summarize the target theory.

6. Give an example of a target molecule found within every cell of the human body.

240. Factors that affect the radiosensitivity of cells

1. What is the Law of Bergonié and Tribondeau?

2. Which cells in the human body are the most radiosensitive? Which are the least?

3. What units have replaced rad and rem in the SI system of measurement?

4. What are the conversions for rad and rem to the newer units?

5. What is LET?

6. What is RBE?

7. What is the relationship between LET and RBE?

8. Define total dose and dose rate.

9. Name the four biological factors that affect the radiosensitivity of an organism.

241. Relationships between radiation dose and biological response

1. What is dose-response relationship?

2. What is meant by a linear dose-response relationship?

3. What is meant by a threshold dose-response?

4. What type of dose-response relationship do genetic effects appear to follow?

5. What does the ALARA acronym stand for?

6. Explain what it means if radiation dose and its exposure effects on human tissue have a linear-nonthreshold relationship.

7. Name and briefly describe the 3 radiation safety concepts radiology techs should follow when practicing the ALARA principle.

242. Acute radiation damage

1. When does ARS occur?

2. What three body systems are primarily affected by ARS?

3. What is the dose range for hematologic syndrome?

4. What is the principle reason for death in GI ARS?

5. What is the cause of death in CNS ARS?

6. What is the $LD_{50/60}$?

7. List three examples of localized partial body radiation exposure effects.

8. What are three response conclusions that can be assumed for both the testes and ovaries when exposed to radiation?

243. Long-term effects of radiation exposure

1. What is the minimum amount of radiation that is necessary to produce a long-term effect?

2. Name the four major types of long-term somatic effects.

3. Why is the first trimester the most susceptible time to inadvertent radiation exposure of a fetus?

4. What is the main point in the discussion about life-span shortening effects?

5. Have radiation-induced genetic effects ever been observed in humans?

6–2. Radiation Protection

The previous discussion in this unit shows how adverse biological effects can occur as a result of exposure to ionizing radiation. Consequently, radiation protection must be a primary concern of every radiologic technologist.

Besides having some knowledge of the biological effects of ionizing radiation, you must practice positive, protective measures in the exposure room. Furthermore, it is not enough to limit the protection to yourself; you must give your patients equal consideration to keep their exposures at a minimum.

The final responsibility for protecting both you and your patient from needless exposure to radiation rests with you. Health physicists, radiologists, supervisors, and other personnel are responsible for establishing and maintaining radiation protection programs within the radiology department. Effective radiation protection from ionizing radiation will not exist without your constant efforts to reduce exposure whenever possible.

This section explains dose limits, how you can minimize exposures to yourself, to patients, and to others who must be present in the exposure room.

244. Dose limits for radiation exposure

Dose limits are an important aspect of radiation protection. Establishing these limits is one of the primary functions of radiobiologists. *Occupational exposure* dose limits are set to restrict the total amount of radiation a person may receive while doing their medical diagnostic radiology job. Occupational exposure dose limits are carefully determined to minimize the risk of radiation induced somatic and genetic effects and are based on a linear, nonthreshold dose-response relationship. Please note that these limits only apply to occupational exposure, not exposure received as part of medical treatment.

Dose limit standards

Since the 1950's, a maximum permissible dose (MPD) was established for radiation workers. The MPD was used to describe the dose of radiation that occupational workers could receive and yet expect to produce no significant effects from the radiation exposure. This concept of MPD is no longer recognized in our profession and has been replaced by the concept of simply, dose limits (DLs). (Older MPD standards gave a false impression that a threshold for radiation exposure existed.)

In 1987, the National Council on Radiation Protection and Measurement (NCRP) established new recommendations for dose equivalent limits. They based these standards on the newer SI system of radiation measurement (gray and sievert) while incorporating philosophies aligned with the ALARA concept and the nonthreshold dose-response relationship. In essence, DLs are set knowing that we assume *all* radiation exposure is harmful; therefore, *all* unnecessary radiation exposure should be avoided.

Annual occupational dose limits

The accepted *annual whole body occupational DL for radiation workers* is 50 mSv per year (5000 mrem/yr). The annual whole-body DL is considered an effective dose limit which includes things like averaged exposures to different tissues and/or organs of the body based upon their RBE value. For particular parts of the human body, the NCRP also states the following DLs:

- *Skin, thyroid,* and *extremities* is 500 mSv per year (50 rem/yr)
- *Lens* of the eye is 150 mSv per year (15 rem/yr)

With good individual radiation protection habits, it is expected that actual occupational exposure readings need not exceed even 1/10 of the annual DL.

For *pregnant occupational radiation workers*, their DLs are set at 5 mSv (500 mrem) for the entire gestation with the stipulation that no monthly exposure can be greater than 0.5 mSv (50 mrem). Another group of radiation workers to consider are young adults in school to learn our profession. Students must be 18 years old or be within a few months of their 18th birthday to enter into any diagnostic imaging course. Exposure levels for *students under the age of 18 years old* should be closely monitored and never exceed 1 mSv per year (100 mrem/yr) because their cells are considered more radiosensitive.

Cumulative occupational dose limits

To this point in the discussion about DLs the focus has been on annual DLs. Going back to what was discussed in the previous lesson, we know that repeated small exposures accumulate and must be a concern. Therefore, in addition to the annual DL for occupational radiation workers, the cumulative whole-body DL is calculated by multiplying 10 mSv (1000 mrem) and the radiation workers age (in years). The table below shows how the old formula (5 times (N–18)) and the current formula (10 times N) differ in calculating cumulative DLs for occupational workers. **NOTE:** “N” represents the age of the individual).

Age of Radiation Worker	Old Formula 5(N–18)rem	Current Formula 10 mSv/yr
20 yrs	5(20–18)rem = 5 × 2 rem = 10 rem	10 mSv × 20 = 200 mSv (20,000 mrem) = 20 rem
30 yrs	5(30–18)rem = 5 × 12 rem = 60 rem	10 mSv × 30 = 300 mSv (30,000 mrem) = 30 rem
40 yrs	5(40–18)rem = 5 × 22 rem = 110 rem	10 mSv × 40 = 400 mSv (40,000 mrem) = 40 rem

Dose limit rational for radiation workers

Dose equivalent limits for radiation workers are significantly higher than those established for the general population for various reasons. First, a person becomes a radiation worker by choice, which therefore, implies an accepted risk to exposure. In other words, you are willing to accept a small degree of risk to benefit from this chosen occupation. Second, not everyone can receive occupational exposure; some segments of the population are excluded. People under 18 years of age and those with abnormal blood cell patterns are excluded. Another reason why radiation workers have higher dose limit levels is that radiation workers constitute only a small part of the total population. Therefore, from the viewpoint of the overall population's gene pool, it is acceptable for the small population group to receive greater exposure than the bulk of the general population.

Dose limits for the general public

Everyone receives natural background radiation from a variety of sources including the Sun, the stars, and the Earth itself. The human race has managed to survive in spite of any adverse effects from this radiation. Still, it's prudent and reasonable to establish guidelines to protect the public from excessive occupational exposure. We use dose levels to derive working standards, such as radiation facilities and barriers (shields) to protect those who don't work with radiation. This includes medical professionals and office workers in and around radiation facilities.

The DLs for nonradiation workers are much lower than that for radiation workers to minimize possible adverse genetic effects for the population as a whole. The DL for the general population receiving occupational radiation exposure is set at 1 mSv per year (100 mrem/yr). Medical physicists use this amount to figure the thickness of a barrier and the amount of lead needed in the walls to protect people in adjacent areas around a radiology exposure room. If a room adjacent to an exposure room is occupied by non radiology workers, then the shielding must be good enough to limit the exposure to these people to less than 1 mSv per year. If that same adjacent room is occupied by radiation workers, then the shielding is designed to ensure an annual exposure of less than 10 mSv per year (1000 mrem/yr).

245. Minimizing patient exposure

As a part of the ALARA concept, we are supposed to minimize the radiation exposure to ourselves but especially to our patients.

Protecting patients from unnecessary radiation

Responsibility for protecting your patients from needless exposure to radiation rests with you. While there are some factors (such as the types of exams requested, the frequency at which they are requested, and the specific views required) that we as technologists do not control, we can do a lot to minimize radiation exposure to patients. Let's look at several ways you can reduce radiation exposure to patients.

Eliminate unnecessary exposures

The best way to reduce your patient's exposure to radiation is to get it right the first time, in other words, by minimizing your repeats. Every image you repeat is additional, and usually avoidable, exposure to the patient. Obviously, no technologist begins an exam planning to have to do repeats. But an increased awareness of your actions, along with things like good exposure charts and/or the use of automatic exposure control systems go a long way towards reducing repeat rates. If you are performing an exam that you are unfamiliar with, don't let your pride get in the way and find someone who can competently help you with the examination. Asking for help with an exam is not a sign of weakness; it is a sign of high personal character and the desire to get it right the first time while protecting your patient from unnecessary radiation exposure.

Another important way that we as technologists can eliminate unnecessary exposures is to carefully read the patient history given on the X-ray request form. Many departments perform limited view series for certain histories such as "follow-up fracture" or "rule out foreign body." Also, many times clerical mistakes are made and the exam requested does not match the patient history. A brief review of the patient history and a little experience can help considerably in minimizing patient exposures.

Filtration

As you know, adequate filtration of the primary beam is one of the best ways to reduce the patient's skin dose. The skin dose is the radiation received by the skin at the entrance of the primary beam into the body. The majority of the skin dose comes from extremely low energy photons that are readily absorbed by the first material they encounter. When filtration is that first material, then it reduces patient radiation exposure by absorbing the low energy photons thereby reducing the patient’s skin dose.

Optimum kilovoltage peak techniques

Another way to reduce patient radiation exposure (absorbed dose) is to increase the mean energy of the beam. The mean energy of the useful beam is increased by using higher kVp values, which results in the beam having a lower LET value. By using optimum kVp techniques, we can ensure the beam quality is as high as is reasonable for the exam. By optimum kVp, we do not mean 100 or 150 kVp. We mean the highest kVp that produces a radiograph with sufficient density and contrast to adequately demonstrate the anatomical structure under study.

Let’s look at a typical examination of the knee. If you presently use 60 to 70 kVp, you may be able to raise the level to 80 to 90 kVp and still maintain satisfactory contrast. Eighty to 90 kVp is not considered high, but it is higher than you previously used, and you have taken a positive step in reducing exposure to your patient.

Aside from reducing patient exposure by increasing the mean energy of the beam, high kVp works in two other ways to reduce patient exposure: it permits shorter exposure time—which helps prevent repeat examination due to part motion, and it provides more exposure latitude, which also helps to prevent repeat examinations due to incorrect exposure factors. Of course, any action that reduces the number of repeat radiographs also helps to keep patient exposure to a minimum.

Collimation

Another way to keep patient exposure to a minimum is by restricting the primary beam to the smallest area consistent with clinical requirements. Collimation has a two-folded benefit in that it protects the patient *and* improves the resulting radiograph.

Exposing the patient to radiation in areas beyond the part under study is, in most cases, inexcusable. We emphasize “in most cases.” For example, in some trauma portable radiography, speed is often of greater importance than radiation safety for the patient. In these instances, you may wish to leave the collimator open *a little* wider to prevent accidental “clipping” of important anatomy which would facilitate the need for a repeat.

You should try to collimate as close to the desired anatomy as possible and under no circumstances should your collimation ever exceed the size of the image receptor (IR). If you collimate to an area larger than the size of the IR, you would be only adding to the patient’s radiation exposure and adding nothing to the diagnostic quality of the exam itself. The larger field degrades image quality by increasing scatter radiation which increases image fog.

As discussed previously, X-ray equipment manufactured since 1974 must have positive beam limitation (PBL). PBL is a function of the collimator that automatically adjusts the X-ray field size to correspond with the size of the IR when the cassette is placed in the bucky. When you engage PBL, the size of the X-ray field never exceeds the dimensions of the cassette. Quality control checks should verify that the PBL is accurate to 2 percent of the SID.

Gonadal shielding

A gonad shield is any material placed between the X-ray source and the gonads to reduce the radiation dose to the reproductive organs. Its main purpose is to protect the gonads from exposure to the primary X-ray beam when the gonads are within the limits of the properly collimated beam. You should use gonadal shielding in addition to proper beam limitation, not as a substitute for it.

Guidelines for using gonadal shielding

You should use gonad shields, if:

- The gonads lie within the primary X-ray field or within 5 cm of the beam despite proper beam limitation.
- The clinical objectives of the examination will not be compromised by shielding.
- The patient has a reasonable reproductive potential.

Don't use gonadal shielding, if it obscures important anatomy (for example, a kidneys ureter and bladder (KUB) on a female patient).

Types of gonad shields

Gonad shields can be classified into two basic types: contact shields and shadow shields.

Contact shields usually consist of a piece of uncontoured, lead-impregnated material, placed on or taped to the patient to cover the gonads. This type is most effective for anterior-posterior (AP) or posterior-anterior (PA) projections when the patient is recumbent. Since flat, contact shielding is difficult to secure in place, it is not well suited to fluoroscopy, nonrecumbent positions, or views other than PA or AP.

A shadow shield consists of some radiopaque material, suspended from the collimator over the patient's body to cast a "shadow" in the primary X-ray beam over the area of the gonads. Shadow shielding offers the advantages of use in a sterile field, use on incapacitated patients, and ready availability, since it may remain attached to the X-ray machine.

High-speed screens and film

If using a film-screen combination, use a high-speed intensifying screen and a high-speed film to reduce patient exposure to radiation by lowering the exposure necessary to produce the radiograph. In general, always use the fastest screen-film combination that is consistent with good diagnostic results.

When digital IRs are used, they are manufactured to perform faster than any screen-film combination. Therefore, the patient benefits from a lower dose due to the faster IR speed and high kVp/lower mAs techniques.

Protecting pregnant patients

Because of the serious biological effects that can occur if an embryo receives radiation during the early stages of development, you must use safeguards to prevent accidental irradiation in early pregnancy. Early on in the first trimester, it is common that the expectant mother may not realize they are pregnant and typically, no physical signs are visible either. For this reason, the standard of practice is to question all potentially fertile female patients whether they are possibly pregnant before any radiographic examination is performed.

You should consult a radiologist whenever there is the possibility that a patient is pregnant. If there is no radiologist available, consult the patient's physician. For routine radiographic X-rays of the abdomen and pelvis, most will be postponed until it can be determined if the patient is pregnant or not. You can safely perform skull and extremity radiography on pregnant patients providing you properly shield the abdomen.

246. Minimizing radiation exposure to technologists

When compared to radiation protection for the patient, you must consider a completely different set of factors and procedures when protecting yourself, the technologist, from unnecessary radiation exposure.

Holding patients or an image receptor

Protecting yourself from primary radiation is very simple: do not expose any part of your body to the primary beam. Occupationally speaking, the only way you can expose yourself to primary radiation is by holding a patient or IR while another technologist makes the exposure. Ideally, that should not occur but, realistically, there are *rare* exceptions that might call for you to do just that.

On occasions when someone is needed, no one person should be used routinely to hold a patient or an IR. In order of preference, here is a suggested sequence for determining who holds patients or IRs in an emergency:

1. Nonpregnant relatives or friends accompanying the patient.
2. Medical personnel accompanying the patient.
3. Other medical personnel from outside the radiology department.
4. Administrative-support personnel from the radiology department.
5. Radiologic technologists.

When someone must hold a patient during a radiographic examination, the "holder" must wear a leaded apron, thyroid shield, and, if appropriate, leaded gloves in addition to positioning themselves as far as practical from the primary beam. As always, appropriate collimation to only the area of interest should be used.

Using time, distance, and shielding

As we discuss protecting ourselves from the source of radiation, realize that there are two different entities to consider: the primary beam and the patient. Protecting yourself from the primary radiation beam is fairly easy because the primary beam (full of high energy photons) is directed from the tube by the collimator towards the patient in typically a well defined coverage area. When the beam interacts with the patient however, the radiation becomes scattered and lower energy photons go out in all directions away from the patient to virtually all parts of the exposure room. So keep in mind, as we continue this discussion, that the radiation source is the primary beam as well as the patient. With that foundation now set, let's examine the three main concepts of radiation protection: time, distance, and shielding.

Reducing exposure time lessens radiation exposure

As mentioned in previous lessons, the length of the exposure *(time)* correlates to the dose received by the patient. The way to use this concept is pretty simple; always use the least amount of time necessary to make the exposure while not sacrificing image quality. When we say the least amount of time, you should attempt to use the fastest exposure time allowable to still produce that high-quality image.

Using distance for protection

Distance is an effective means to reduce exposure. Since radiation intensity decreases as the distance from the source increases, you can greatly reduce your own exposure by staying as far from the source as possible. This rule is particularly important to remember when you are taking portable radiographs or assisting in the exposure room with a fluoroscopy case.

Using protective barriers to shield

The third concept is to use *shielding*. The first example of a protective barrier is the control booth. Control booths are designed so that the technologist is not exposed to any radiation that has been scattered. Use the lead impregnated glass window to observe the patient. Do not defeat the purpose of the control booth by leaning out from behind the barrier during the exposure. Protective barriers also come in the form of rolling shields. Rolling shields are seen used in fluoroscopy rooms, interventional radiography suites, and especially operating room (OR) suites. The concept is again fairly simple; when a rolling shield is available, position it between you and the source of radiation.

Radiation protection during portable radiography

Portable radiography tends to present another set of challenges when trying to reduce ones exposure to radiation. To lower your exposure dose when performing portable radiography, always wear a lead gown and use the distance concept by making sure you stand at least six feet behind the radiation source. If you must be in the immediate area of the radiation source, stand at right angles (90°) to the patient and the central ray because X-rays in the diagnostic range have a minimum intensity at a scatter angle of 90°.

Radiation protection during fluoroscopy

During fluoroscopy, if you are not needed to assist the radiologist, remain behind the control booth protective barrier. When you are needed, always wear a lead apron, thyroid shield, and make sure to keep your front facing the fluoroscopy unit at all times. Stay facing the fluoroscopic unit at all times because if you have on a lead gown that only covers your front, when you turn around, your back is exposed and unprotected from the radiation source. Also, whenever you're in the exposure suite, position yourself so that the radiologist is between you and the radiation source. The radiologist must stand in relatively close proximity to the patient and the radiation source to accomplish the exam. The only time you have to be close to the radiation source is when you are needed to assist the radiologist with some task related to the examination. Therefore, if you are not needed, then use distance to your advantage and step back at least two steps.

When available, leaded glasses can be worn to reduce the exposure to the lens of the eye. Leaded glasses are especially useful during interventional radiology procedures. Another consideration is to wear a wrap-around lead gown to afford the technologist 360 degrees of radiation protection coverage. Specifically, wear a wrap-around lead gown when you must constantly turn your back on the fluoro unit while assisting the radiologist. It should be noted that these gowns are specifically designed for technologists since the radiologist should never be turned around while the fluoro is actively on.

Personnel dosimeters

A personnel dosimeter doesn't protect you from radiation exposure; however, it does provide information that indicates how well you keep your radiation exposures to a minimum. The purpose of a personnel dosimeter is to monitor occupational radiation exposure of radiation workers. There are two types of monitoring devices in use today, *film badges* and *thermoluminescent dosimeters* (TLDs). Although both types have similar outward appearances, their internal features are quite different.

Film badges

Film badges began being used in the 1940's and are still in use today. Film badges use a small piece of sealed radiation dosimetry film (similar to dental radiographic film) sandwiched between metal filters within a plastic holder to record exposures. Film badges cannot accurately measure low exposures of less than 10 mR but are very accurate in measuring higher exposures. The advantages in using film badges are their low cost in addition to being relatively easy to handle and process. The disadvantages are they are not reusable and can only be worn for 1 month at a time.

Thermoluminescent dosimeters

TLDs use a special thermoluminescent material, such as lithium fluoride, in either powder or crystal form, to record exposure. Thermoluminescent crystals contain defects in their lattice or crystalline structure caused either naturally or by the addition of an impurity. These defects permit electrons to be released from their orbits as a result of energy acquired during exposure to ionizing radiation. The freed electrons, which now possess the energy absorbed from the incident radiation, become trapped in areas outside normal electron shells of the atom. When the thermoluminescent material is heated, the trapped electrons release their stored excess energy as visible light and then return to their normal position. A photomultiplier tube is used to measure the intensity of this light. If various parameters are held constant, the amount of light released is proportionate to the intensity of radiation that exposed the TLD. Tables of data are consulted to convert a light intensity measurement to a dose received.

TLDs have certain advantages over film badges, such as:

- They are more accurate at both high and low exposure levels.
- They are more sensitive to exposure.
- They can be reused.

Cost is the main disadvantage in using TLDs. On average, TLD service is twice as much as monitoring services for film badges.

Where to wear a personnel dosimeter

Depending upon the reference you may be consulting, dosimeter wear recommendations will vary a little here and there. In the performance of routine radiography duties when a lead apron is not donned, a *single* dosimeter is worn on the outside of the clothing at the level of the collar. Wearing the dosimeter at the level of the collar allows for an accurate dose reading for the head, neck, and thyroid areas. When a lead gown is worn for fluoroscopy, for C-arm cases in the OR, or during portable radiography and only a *single* dosimeter is worn; the dosimeter is again worn at the level of the collar, outside of the clothing, and outside of the lead gown. In past years, some guidance instructed technologists to wear their single dosimeter underneath the lead gown. But if worn in this manner, the dosimeter will then record an incorrectly low exposure reading which will not truly tell how much radiation was received by the unprotected body parts.

Some departments issue *two* dosimeters to the technologist for wear during fluoroscopy cases; one for the collar (labeled for the collar) and one for the body (labeled for the body). If this is the case, wear the collar dosimeter at the level of the collar outside of the clothing, outside of the lead gown/thyroid shield. Secondly, wear the body dosimeter on the front of the body outside of the clothing but *under* a wrap-around lead gown at the level of the waist. For accurate exposure readings, it is important to always wear the correct dosimeter in the correct body region.

When to wear your dosimeter

Dosimeters (TLD or film badge) should be worn whenever you are at work and in the radiology department. Make certain to wear your single dosimeter consistently in the same location on your body (the collar area) each and every time. This ensures a consistent reading of exposure to the head, neck, and thyroid area. If you leave the radiology department to go perform portable radiographs (or a C-arm case in the OR) anywhere in the military treatment facility (MTF), keep your dosimeter on. If you leave the department to go on a personal appointment within the MTF, go to lunch inside or outside the facility, go on a break inside or outside the facility, or leave because it is the end of your duty day, take your dosimeter off and hang it on the storage board.

Once declared, female technologists that are pregnant get issued two dosimeters. One is labeled for the collar and is worn at the collar outside of the clothing. The other is labeled for the body region and is worn on the front of the body at the waist level outside of any clothing to measure any dose received to that region. Obviously, the body dosimeter is the badge recording any dose to the embryo/fetus.

Localized exposure dosimeters

You may wear additional dosimeters in certain situations, like special procedures, to assess localized exposures, such as an extremity dosimeter when the hands are consistently exposure to the primary beam in performance of your daily duties. When wearing these additional dosimeters, be sure to wear the other required *normal* dosimeters as well.

To reiterate this point, always wear body region specific dosimeters in the correct body region. Never interchange the wear of collar, body, or extremity dosimeters in body regions other than their assigned body region.

Dosimeter storage area

While dosimeters are not being worn, keep them in a storage area designated by the radiation safety officer (RSO) of the facility. The storage area should be near to, but outside of, the radiation area. Radiation area, in this case, refers to the exposure/therapy rooms. For convenience, it is advisable to locate the storage area near the entrance of the department, thereby encouraging technologists to put on or take off the dosimeter as they enter or leave the department.

The designated storage area also has a *control dosimeter* that should not be removed from the storage area. The purpose of the control dosimeter is to measure any background radiation inherent to the storage area. This background radiation is then subtracted from the readings on the personnel dosimeters to obtain a more accurate occupational dose.

In most AF facilities, bioenvironmental engineering personnel usually collect the dosimeters monthly and send them to a lab for processing. The lab sends the results of the monthly readings to the designated facility RSO through bioenvironmental services. The RSO will investigate any abnormally high readings (even those that do not necessarily exceed the dose-limit standards) to evaluate for potentially unsafe radiation working habits.

NOTE: Any deliberate overexposure of dosimeters is considered a criminal offense and is punishable under federal law.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

244. Dose limits for radiation exposure

1. Why are occupational exposure dose limits set?

2. What are the assumptions under which dose limits are set?

3. What is the annual whole body occupational dose limit for radiation workers?

4. What is the occupational dose limit for pregnant radiation workers?

5. How is the cumulative dose limit calculated for occupational radiation workers?

6. What is the cumulative whole body exposure limit for a 25-year old X-ray tech?

7. What is the dose limit for the general population receiving occupational radiation exposure?

245. Minimizing patient exposure

1. What is the best way to reduce your patients’ exposure to radiation?

2. How does filtration reduce patient exposure?

3. How is the mean energy of the useful beam increased? What is the resultant LET value?

4. Should your collimation ever exceed the size of the image receptor? Explain what happens if you do.

5. What is PBL?

6. When should you use gonadal shielding?

7. What should you do whenever there is the possibility that a patient is pregnant?

246. Minimizing radiation exposure to technologists

1. If you need someone to help hold a patient for an exposure, who should you ask first?

2. What actions should be taken when someone must hold a patient during an examination?

3. What are the three main concepts of radiation protection?

4. What are two things that can be employed to lower your exposure dose when performing portable radiography?

5. During fluoroscopy, if you are not needed to assist the radiologist, where should you stand?

6. When should the wrap-around lead gown be worn?

7. What is the purpose of a personnel dosimeter?

8. Where is a single dosimeter worn in performance of routine radiography duties when a lead apron is not donned?

9. If you leave the radiology department to go perform a portable radiograph, what should you do with your dosimeter?

10. If you leave the radiology department, what are some examples in which you should take your dosimeter off?

11. Where are dosimeters maintained when not in use?

12. What is the purpose of the control dosimeter?

6–3. Radiology Safety Program

The Air Force supplies its people with the best quality equipment, supplies, and weapons systems needed to accomplish the mission. However, these are all useless without people to maintain and operate them. Since people are our most important resource, it is imperative that we keep them healthy, injury free, and able to perform their assigned duties. The Air Force Occupational Safety and Health (AFOSH) program is designed to do just that.

Most of our concern about occupational safety deals with radiation protection, an area we just presented. In addition, we will discuss some unique safety concerns in other parts of the diagnostic imaging department that you must be aware of for your own safety and for the safety of other staff members, patients, and visitors alike.

247. The Air Force Occupational Safety and Health program and radiology services

The AFOSH program is an intensive program designed to protect all personnel from work-related injuries, occupational illnesses, and death. AFI 91–203, *Air Force Consolidated Occupational Safety Instruction* is the governing instruction that guides USAF leaders at all levels.

AFI 91–203

AFI 91–203 includes all safety, fire protection, and health activities that affect the health and safety of all Air Force military and civilian personnel while on duty. The responsibility to provide an environment free from unsafe acts or unsafe conditions requires that all levels of the hospital staff be vigilant in the performance of their duties to eliminate practices or conditions that could result in patient, visitor, and employee injury.

It incorporates the safety principles of the Occupational Safety and Health Administration (OSHA) to administer a safety program compatible with Air Force directives, National Fire Protection Association (NFPA) codes, Joint Commission standards, pertinent Federal regulations, and national consensus standards. To view the full AFI, sign in to the AF Portal to access the AF e-Publishing website at http://www.e-publishing.af.mil/.

As future supervisors and NCOICs in diagnostic imaging, you should be familiar with the various instructions that pertain to radiology safety. The following is a short list of pertinent reading material:

- DoDI 6055.08, Occupational Ionizing Radiation Protection Program
- AFI 40–201, Radioactive Materials Management
- AFI 48–148, Ionizing Radiation Protection
- AFMAN 48–125, Personnel Ionizing Radiation Dosimetry

The following are general safety points all radiology technologists should be aware of:

- Collimate the useful beam to the smallest size necessary for the diagnostic procedure. Check collimators for accurate beam size control and alignment during routine safety inspections. X-ray technologists can accomplish this check easily by exposing a single film with the beam size limited to less than the film size and centered. A simple comparison of the image produced against that which was desired will indicate accuracy. Facilities using collimators with beam-defining lights should have the capability to dim the overhead lighting to allow accurate alignment of the light field.
- Be sure leaded aprons and gloves are in good condition. To maintain the integrity of the lead, always hang aprons when not in use. Do not fold aprons because sharp creases result in cracks.
- Make certain personnel dosimeters are worn by all physicians and technologists (including medical maintenance and bioenvironmental engineering personnel) when working with X-ray equipment.
- Maintain positioning locks and motion limiters for X-ray equipment in good working condition. Report malfunctioning locks and limiters to medical maintenance immediately.
- Ensure counter balance systems (weights, pulleys, cables, springs, locks, and brakes) are checked on a semiannual basis (through BMET).
- Position overhead movable X-ray equipment and cables out of the way when not in use.
- Label doors leading to X-ray exposure rooms “X-ray exposure room, knock before entering.” Keep doors closed during exposures.
- Maintain leaded drapes and the bucky slot shield on fluoroscopy units in good condition. Leaded drapes should be easily positioned and the bucky shield should effectively cover the entire slot.
- Maintain good housekeeping because a considerable amount of work is done under low levels of illumination.
- Store portable X-ray equipment to prevent unauthorized use. Keep a leaded apron with the portable machine for the operator to use. When the machine is transported, the tube head should be in a lowered position.
- Keep in mind that the use of radioactive materials must be in accordance with Nuclear Regulatory Commission (NRC) license and/or USAF permit conditions. The RSO specified on the license/permit must monitor this program.

General safety practices

To make the hospital facility as safe as possible, here are some common safety practices for employees to follow while on duty:

- Report any unsafe act or condition observed to their supervisor.
- Remove or wipe up any foreign material or liquid observed on floors.

- Know relevant work procedures and safe work practices.
- Do not use any damaged or defective equipment.
- Learn correct lifting and handling procedures, especially to prevent back, muscle, or hernia-type injuries which frequently result from incorrect lifting techniques.
- Do not participate in horseplay or practical jokes, which often result in injuries.
- Report all injuries, however slight, to your supervisor and get immediate first aid.
- Ensure used needles, syringes, and sharp instruments are properly disposed of in approved containers and never in wastebaskets, trash bags, or linen carts.
- Wear appropriate protective clothing and equipment when using cleaning solutions, solvents, caustics, etc., or whenever the job requires it, such as in laboratories, shops, etc.

These general safety practices apply to everyone who works in the MTF. For more detailed information and guidance about the AFOSH program; talk to your supervisor, NCOIC, unit safety representative (USR), or reference AFI 91–203.

248. Unique safety concerns for magnetic resonance imaging and nuclear medicine

There are hazards in every part of the diagnostic imaging department and in larger military treatment facilities (MTF) where magnetic resonance imaging (MRI) and nuclear medicine (NM) are present, unique challenges arise in the realm of staff and patient safety. This lesson discusses these two specialty (shred) areas to help you understand their unique safety concerns.

Magnetic resonance imaging safety

MRI utilizes electro-magnets and radio waves to create diagnostic images. The electro-magnets used in MRI are extremely powerful and are *constantly on* which produce a strong magnetic field throughout the immediate scanner area. Clinical MRI magnets can produce a magnetic field approximately 60,000 times the earth's normal magnetic pull. Ferrous materials (items with magnetic properties) within range of the magnetic field can cause a serious safety risk to both patient and technologist alike. Certain medically implanted devices are not MRI compatible or MRI safe; therefore, all non-MRI personnel and patients must be properly screened and monitored when entering the MRI area.

In order to promote safe practices, MRI operates using four safety zones. Zone one is an area that is accessible to the general public, and individuals in this zone are not typically supervised by MRI personnel. Zone two is an area in which non-MRI personnel movement is still authorized; however, it becomes supervised by a MRI tech. Zone three is the area that leads to the MRI scanner room (the immediate area outside the suite) and is the area where non-MRI personnel access is not authorized. Safety mistakes with ferrous materials in this zone could cause serious harm to both individuals and equipment. All personnel should be screened by MRI staff prior to entering zone three. Zone four is the MRI scan room. Like zone three, zone four is only accessible by MRI staff members. Anybody entering zone four must be escorted by MRI personnel.

It is important to understand that metal objects on your person or in your pockets can become dangerous projectiles when in a MRI suite. Numerous incidents around the world have been documented about desk chairs, gurneys, wheelchairs, and code carts being drawn into the MRI scanner causing thousands of dollars of damage to the MRI unit, bodily harm, and even death in extreme instances. Personal awareness and good safety habits are paramount when working around a MRI scanner.

The following individual is acknowledged for his assistance in the technical input for the MRI content: TSgt Michael S. Griffin, USAF, RT (R) (CT).

Nuclear medicine safety

Nuclear medicine (NM) varies from typical X-ray in how the radiation is produced. In X-ray, the source of ionizing radiation originates from the tube of the X-ray imaging system. In NM, a radiopharmaceutical is injected into the patient's blood stream which makes the patient become the source of radiation. An imaging system called a gamma scintillation camera (or scanner) is used to create diagnostic images of the specific organ structure that is the area of interest. A variety of radionuclides are used for patient dosing in nuclear medicine. The radionuclide used most commonly is Technetium 99 metastable (^{99m}Tc) and it is made readily available from a Molybdenum Technetium 99 ($^{99}Mo/^{99m}Tc$) generator. The material produced has a monoenergetic gamma emission of 140 keV, a half-life of 6 hours, and is easily tagged to a chemical compound that allows the radioactive material to collect in the bodily area of interest being imaged or watched for a physiological function. As you should remember from previous lessons, a half-life is determined by the time it takes for an irradiated item—in this case, a radiopharmaceutical (radionuclide)—to decay down to half of its original strength.

NOTE: All doses and radioactive material coming into the clinic or hospital must be coordinated through the RSO or the NM clinic.

NM techs employ the ALARA concept when handling radioactive materials. In order to use or handle radioactive material, the NM technologist must be on the radioactive handlers permit; if they are not, they cannot use or handle radioactive material. NM techs utilize the same three basic principles of radiation protection as regular radiographers do: (1) time, (2) distance, and (3) shielding.

- Time—NM techs minimize the amount of time they are exposed to radioactive sources.
- Distance—NM techs maximize their distance from radioactive sources.
- Shielding—NM techs utilize lead shielding to reduce direct exposure to radioactive sources.

Because the patient doses are often in liquid form, NM technologists must also guard against radioactive spills that can increase exposure. They wear gloves and lab coats when handling patient doses and routinely survey clinical areas with a Geiger-Mueller detector to see if any radioactive contamination is present. Then perform decontamination procedures as needed.

Radiation protection is a primary concern for those who work in a NM clinic. Understandably, those who visit the clinic (e.g., other hospital staff, patient's family, etc.) or are imaged by NM professionals may be somewhat apprehensive and not know what to expect concerning their radiation exposure. After all, medical ionizing radiation exposure to patients is one of the largest sources of radiation exposure equaling nearly the same exposure from all other background sources. Today, NM is the second largest source of medical radiation exposure behind computed tomography (CT). The benefits of NM procedures are immense and certainly exceed the risks when exams are ordered appropriately and studies are optimized to obtain the best image quality with the lowest radiation dose.

Whether you work in a NM clinic, are a patient, or are visiting a fellow staff member in NM, it is important to be aware of the hazards that are present as well as how to reduce your radiation exposure from those hazards.

The following individual is acknowledged for his assistance in the technical input for the NM content: MSgt Thomas W. Roomsburg II, USAF, RT (R) (N).

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

247. The Air Force Occupational Safety and Health program and radiology services

1. What sort of information is contained in AFI 91–203, *Air Force Consolidated Occupational Safety Instruction*?

2. How should lead gowns be stored when not in use?

3. List three considerations for portable units.

248. Unique safety concerns for magnetic resonance imaging and nuclear medicine

1. What does MRI utilize to create diagnostic images?
2. Are the extremely powerful electro-magnets used in MRI ever turned off?
3. How many safety zones does MRI use to promote safe practices?
4. What or who is the source of radiation in NM?
5. NM techs employ the ALARA concept and utilize what three basic principles of radiation protection?
6. What is used to survey NM clinical areas to see if radioactive contamination is present?

Answers to Self-Test Questions

239

1. When a photon from the primary beam has an ionizing event with an atom or molecule of a cell, the radiation has a *direct* effect on that cell.
2. When an ejected electron and the secondary photons that are created as a result of the ionizing event can go on to have other interactions with neighboring molecules or cells.
3. When water is irradiated, a portion of it breaks down into other, simpler molecular products.
4. Indirectly.
5. If direct or indirect radiation damage is significant enough to prevent key molecules of a cell from performing their function, the cell may die.
6. Deoxyribonucleic acid (DNA).

240

1. Immature and rapidly dividing simple cells are more radiosensitive than mature, complex ones and those of stable tissues.
2. Most sensitive: blood, and gonadal.
   Least sensitive: nerve, brain, and muscle.
3. Gray (Gy_t) and Sievert (Sv).
4. 1 Gy_t = 100 rad; 1 Sv=100 rem.
5. A measurement of the amount of energy imparted to an absorbing material by ionizing radiation.
6. A number that expresses a beam of radiation’s ability to produce a biological response.
7. As LET increases, RBE increases.

8. Total dose is the entire amount of radiation received with no indication of the time over which it was received. Dose rate is the amount of radiation received per unit of time.
9. Age, gender, metabolic rate, and aerobic state.

241

1. The relationship between the amount of radiation received and the type of response it produces in an organism.
2. The effect being measured increases in direct proportion to the dose of radiation.
3. The effect being measured is not observed below a certain dose.
4. Linear, nonthreshold relationship.
5. As Low As Reasonably Achievable.
6. Any exposure to ionizing radiation, no matter how small, has the ability to produce negative effects to human tissue which may include an increased risk of genetic mutations and/or cancer.
7. (1) Time—minimize exposure time whenever possible.
   (2) Distance—when possible, double the distance between you and the source of radiation.
   (3) Shielding—use an absorber material (lead) to shield the patient or yourself from unnecessary radiation exposure.

242

1. When a very large whole-body dose of radiation exposure is received which leads to death within days or weeks.
2. Hematologic (blood), gastrointestinal (GI), and central nervous systems (CNS).
3. 200 rad (2 Gy_t) to 1,000 rad (10 Gy_t).
4. Overwhelming damage to the intestinal cell lining.
5. Increased intracranial pressure and swelling of the brain due to fluid accumulation associated with vascular and membrane damage.
6. The lethal dose of whole-body exposure sufficient to cause death to 50 percent of the subjects irradiated within 60 days.
7. Skin erythema (redness and swelling) and ulceration, temporary or permanent sterility, and depression of the immune system.
8. (1) 10 rad (100 mGy_t) causes the least observable response.
   (2) 200 rad (2 Gy_t) causes temporary infertility.
   (3) 500 rad (5 Gy_t) causes sterility.

243

1. There is no minimum amount of radiation correlated to the production of long-term effects because long-term effects are considered nonthreshold which means we assume any radiation exposure *may* produce some long-term (or late) effects long after the initial exposure.
2. Carcinogenesis, embryological effect, cataractogenesis, and life-span shortening.
3. Because many women do not even realize they are pregnant for much of the first trimester.
4. Radiation does not produce unique diseases to cause life-span shortening. Instead, the irradiated person develops the same diseases as anyone else would—only sooner.
5. No.

244

1. To restrict the total amount of radiation a person may receive while doing their medical diagnostic radiology job.
2. All radiation exposure is harmful and therefore all unnecessary radiation exposure should be avoided.
3. 50 mSv per year (5000 mrem/yr).
4. 5 mSv (500 mrem) for the entire gestation with the stipulation that no monthly exposure can be greater than 0.5 mSv (50 mrem).
5. By multiplying 10 mSv (1000 mrem) and the radiation workers age (in years).

6. 250 mSv (25 rem).
7. 1 mSv per year (100 mrem/yr).

245

1. Get it right the first time, in other words, by minimizing your repeats.
2. By absorbing the low energy photons thereby reducing the patient's skin dose.
3. By using higher kVp values which results in the beam having a lower LET value.
4. No. You would be only adding to the patient's radiation exposure and adding nothing to the diagnostic quality of the exam itself.
5. A function of the collimator that automatically adjusts the X-ray field size to correspond with the size of the IR when the cassette is placed in the bucky.
6. If the gonads lie within the primary X-ray field or within 5 cm of the beam despite proper beam limitation, if the clinical objectives of the examination will not be compromised by shielding, and if the patient has a reasonable reproductive potential.
7. Consult a radiologist.

246

1. Nonpregnant relatives or friends accompanying the patient.
2. The "holder" must wear a leaded apron, thyroid shield, and if appropriate, leaded gloves in addition to positioning themselves as far as practical from the primary beam.
3. Time, distance, and shielding.
4. Always wear a lead gown and use the distance concept by making sure you stand at least six feet behind the radiation source.
5. Remain behind the control booth protective barrier.
6. When you must constantly turn your back on the fluoro unit while assisting the radiologist.
7. To monitor occupational radiation exposure of radiation workers.
8. On the outside of the clothing at the level of the collar.
9. Keep your dosimeter on.
10. If you go on a personal appointment within the MTF, go to lunch inside or outside the facility, go on a break inside or outside the facility, or leave because it is the end of your duty day.
11. In a storage area designated by the radiation safety office.
12. To measure any background radiation inherent to the storage area.

247

1. It includes all safety, fire protection, and health activities that affect the health and safety of all military and civilian personnel while on duty.
2. Hung on a rack.
3. Store portable X-ray equipment to prevent unauthorized use. Keep a leaded apron with the portable machine for the operator to use. When the machine is transported, the tube head should be in a lowered position.

248

1. Electro-magnets and radio waves.
2. No, the electro-magnets are constantly on.
3. Four.
4. The patient.
5. Time, distance, and shielding.
6. A Geiger-Mueller detector.

Complete the unit review exercise before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

77. (239) When irradiated water is transformed into hydrogen peroxide and kills surrounding cells, it is an example of
    a. the target theory.
    b. direct effects of radiation.
    c. indirect effects of radiation.
    d. the Law of Bergonié and Tribondeau.

78. (239) The greatest amount of radiation damage in vivo occurs as a result of
    a. target theory.
    b. direct effects.
    c. indirect effects.
    d. radiolysis of water.

79. (240) The Law of Bergonié and Tribondeau states
    a. all radiation damage will result in a mutation.
    b. all radiation damage occurs as a result of direct effects.
    c. immature and rapidly dividing cells are more radiosensitive.
    d. if certain key molecules within a cell are damaged by radiation, the cell may die.

80. (240) Which radiation beam has the highest linear energy transfer (LET)?
    a. 50 mAs; 115 kVp.
    b. 100 mAs; 100 kVp.
    c. 200 mAs; 85 kVp.
    d. 400 mAs; 72 kVp.

81. (241) What dose-response relationship curve do genetic effects appear to follow?
    a. Linear, threshold.
    b. Linear, nonthreshold.
    c. Nonlinear, threshold.
    d. Nonlinear, nonthreshold.

82. (241) On what dose-response relationship are radiation protection guidelines based upon?
    a. Linear, threshold.
    b. Linear, nonthreshold.
    c. Nonlinear, threshold.
    d. Nonlinear, nonthreshold.

83. (242) A nuclear accident victim exposed to 60 gray (Gy_t) would probably die from
    a. internal bleeding.
    b. intracranial pressure.
    c. electrolyte imbalance.
    d. overwhelming infection.

84. (242) If the gonads (male or female) are exposed to 2 gray (Gy_t), what is the expected radiation induced response on the reproduction organs?
    a. Sterility.
    b. Organ death.
    c. Temporary infertility.
    d. No observable response.

85. (243) During what phase of gestation can radiation exposure potentially cause congenital abnormalities (birth defects) and neonatal death?
    a. The third trimester.
    b. The first two weeks.
    c. Weeks 2 through 10.
    d. Weeks 11 through 24.

86. (243) Radiation induced cataractogenesis is considered to be
    a. acute radiation damage.
    b. a long-term genetic effect.
    c. a long-term somatic effect.
    d. of no concern at diagnostic levels.

87. (243) What is the average life-span shortening for radiation workers?
    a. Zero (0) days.
    b. Twelve (12) days.
    c. Fifty days (50) days.
    d. One hundred and twenty (120) days.

88. (244) What is the annual whole body dose limit for radiation workers in millisieverts (mSv)?
    a. 5.
    b. 50.
    c. 150.
    d. 500.

89. (244) Why are individuals under the age of 18 not permitted the full occupational exposure dose allowed for a radiation worker?
    a. Because their cells are more radiosensitive.
    b. Because it would require consent from their parents.
    c. Because we are not sure how radiation affects minors.
    d. Because they are not mature enough to practice safe radiation protection.

90. (244) Under the international system for dose equivalent limits, what is the maximum cumulative dose for a 30 year old X-ray technologist?
    a. 0.6 rem.
    b. 60 rem.
    c. 30 mSv.
    d. 300 mSv.

91. (244) Why are radiation workers allowed a higher occupational exposure than the general public?
    a. Because we become more resistant to radiation over time.
    b. Because we only represent a small portion of the gene pool.
    c. Because we have been issued thermoluminescent dosimeters.
    d. Because we have received special training in radiation safety.

92. (245) What methods do technologists use to reduce radiation exposure to patients?
    a. Filtration, collimation, and shielding.
    b. Frequency of examination, filtration, and shielding.
    c. Filtration, collimation, and number of views requested.
    d. Number of views requested, frequency of examination, and filtration.

93. (245) When would it be appropriate to *not* use gonadal shielding?
    a. If the patient says it is unnecessary.
    b. If shielding obscures important anatomy.
    c. If the gonads are not in the primary beam.
    d. If the use of shielding increases exam time.

94. (246) If you should need assistance in holding a patient during a radiographic procedure, whom should you ask first?
    a. Radiologic technologists.
    b. Medical personnel accompanying the patient.
    c. Nonpregnant relatives and friends accompanying the patient.
    d. Administrative-support personnel within the X-ray department.

95. (246) What is *not* true of a thermoluminescent dosimeter (TLD)?
    a. They are low cost.
    b. They can be reused.
    c. They are more sensitive to exposures.
    d. They are accurate at high and low exposure levels.

96. (246) The purpose of the control dosimeter is to
    a. measure therapeutic radiation inherent to the storage area.
    b. measure background radiation inherent to the storage area.
    c. measure fluoroscopic radiation exposure of radiation workers.
    d. measure occupational radiation exposure of radiation workers.

97. (247) Who is responsible for ensuring the hospital environment is free from unsafe acts or conditions?
    a. Patients.
    b. Managers.
    c. Supervisors.
    d. All hospital personnel.

98. (248) When compared to the normal magnetic pull of earth, approximately how strong are clinical magnetic resonance imaging (MRI) magnets?
    a. They are equal.
    b. 10,000 times stronger.
    c. 60,000 times stronger.
    d. 100,000 times stronger.

99. (248) In what magnetic resonance imaging (MRI) safety zone do non-MRI personnel begin to be supervised by MRI technicians?
    a. Zone 1.
    b. Zone 2.
    c. Zone 3.
    d. Zone 4.

100. (248) While nuclear medicine is the second largest source of medical radiation exposure, what is the first largest source?
   a. Radiography.
   b. Computed tomography.
   c. Interventional radiology.
   d. Cardiac catheterization lab.

Student Notes

Glossary

Terms

Actual focal spot—The rectangular area on the target which is actually bombarded by electrons.

Anode—The positive electrode of an X-ray tube.

Binding energy—The energy required to remove an electron from its shell to a point just outside the atom.

Bremsstrahlung radiation—Radiation that has been deflected due to the attractive forces of a nucleus.

Cathode—The negative electrode of an X-ray tube.

Compton effect or Compton scatter—The result of a partial transfer of energy from an incident photon to an electron, thereby ejecting the electron from its shell.

Contrast—A relative measure of the difference between densities on a radiograph.

Effective focal spot—The focal spot as it appears from the center of the X-ray field perpendicular to the long axis of the tube.

Ionization—Any process that results in the removal or addition of an orbital electron from or to an atom or molecule.

Isotopes—Atoms of the same element having the same atomic number, but different mass numbers.

Latent image—The information deposited in the emulsion of a film after exposure and before processing.

Linear energy transfer—A measurement of the amount of energy imparted to an absorbing material by ionizing radiation.

Photoelectric effect—Occurs when an incident photon imparts all of its energy to an electron, after which the photon no longer exists.

Radiobiology—The branch of biological sciences concerned with the effects of radiation on living tissue.

Relative biological effectiveness—The ability of radiation to produce a biological response expressed numerically.

Thermonic emission—To give off ions (electrons) when subjected to heat.

Abbreviations and Acronyms

AC	alternating current
AEC	automatic exposure control
AED	automated external defibrillator
AFI	Air Force instruction
AFMAN	Air Force manual
AFOSH	Air Force Occupational Safety and Health
Al	aluminum
ALARA	as low as reasonably achievable
amps	amperes
AP	anterior-posterior (projection)
ARS	acute radiation syndrome

B + F	base plus fog
BMET	biomedical equipment technician
C	Celsius
cc	cubic centimeter
C/kg	coulombs per kilogram
cm	centimeter
cm^2	centimeter squared
CNS	central nervous system
CR	central ray
CS	Compton scattering
CT	computed tomography
D	distance; density
DI	diagnostic imaging
DC	direct current
DL	dose limit
D-max	density maximum
D-min	density minimum
DNA	deoxyribonucleic acid
DoDI	Department of Defense instruction
EMF	electromotive force
EPA	Environmental Protection Agency
eV	electron volt
F	Fahrenheit
GI	gastrointestinal
Gy	gray
Gy_a	International System of radiation measurement for air kerma
Gy_t	International System of radiation measurement for a gray
H	hydrogen
H and D	Hurter and Driffield
H_2O	water
H_2O_2	hydrogen peroxide
hr	Hour
HVL	half-value layer
Hz	Hertz
I	intensity (measured in amperes)
IR	image receptor
keV	kiloelectron volt
kg	kilogram
kilo	one thousand of the units
KUB	kidney ureters and bladder
kV	kilovoltage
kVp	kilovoltage peak
kW	kilowatts

$LD_{50/60}$	Lethal radiation dose equivalent to cause 50 percent fatalities of those persons exposed within 60 days
LET	linear energy transfer
LRE	log relative exposure
mA	milliampere
mAs	milliampere-seconds
mega	one million of the units
MeV	million electron volts
mGy	milligray
min	minute
mm	millimeter
Mo	Molybdenum
MPD	maximum permissable dose
mR	milliroentgens
mrem	millirem
MRI	magnetic resonance imaging
mR/s	milliroentgens per second
mSv	millisievert
MTF	military treatment facility
NCOIC	noncommissioned officer in charge
NCRP	National Council on Radiation Protection and Measurement
NFPA	National Fire Protection Association
NM	nuclear medicine
O	Oxygen
OD	optical density
OH	hydroxyl molecules
OID	object-to-image distance
OR	operating room
OSHA	Occupational Safety and Health Administration
PA	posterior-anterior (projection)
Pb	lead
PBL	positive beam limitation
PE	photoelectric effect
PET	positron emission tomography
PMRP	Precious Metals Recovery Program
R	Roentgen
rad	radiation absorbed dose
RBE	relative biological effectiveness
rem	radiation equivalent to man
RSO	radiation safety officer
RT	registered technologist
sec	second
SI	International System of radiation measurement

SID	source-to-image distance
SR	scatter radiation
Sv	sievert
Tc	Technetium
TLD	thermoluminescent dosimeters
T-spine	thoracic spine
TV	television
USR	unit safety representative
V	volts
W	watts
X-ray	X-radiation
yr	year

Student Notes

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