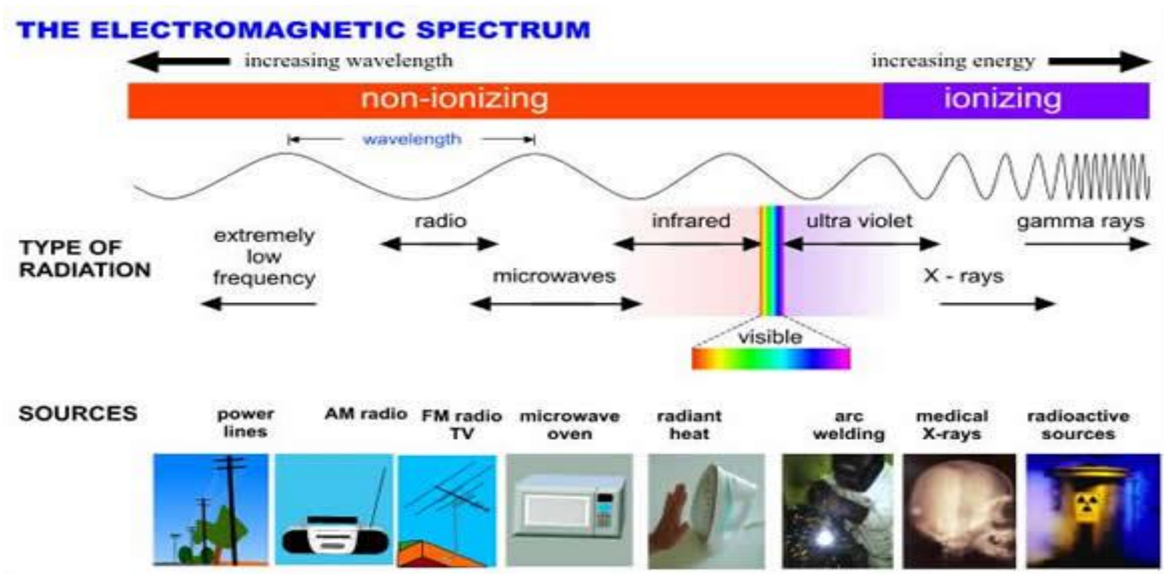
Chapter 3

Radiation Biology and Radiation Protection

Radiation Biology

Radiation Biology is the branch of biological sciences concerned with the effects of ionizing radiation on living organisms.

First we need to identify exactly what x-ray is. **An x-ray** is energy that travels through the air in waves. In this way it is similar to radio waves, microwaves and rays of light. The major difference is the length of the waves that travels through the air. The shorter the wave length of the radiation, the greater the energy. For example, radio waves have very long wavelengths and very little energy. X-rays have very short wavelengths and very high energy.



Ionization is what makes x-ray potentially harmful. X-rays have the ability to remove an electron from the orbital shell of an atom within our body, this is called ionization. Atoms are identified by the number of protons, neutrons and electrons within them. When that number is changed the atom is changed and so is the molecule that contains the atom.

There are two types of ionizing radiation:

- Electromagnetic.
- Particulate

Electromagnetic radiation includes gamma rays, which originate from a nucleus of radioactive atoms. Gamma rays travel through the air in waves instead of particles and x-rays which originate from x-ray tube production. Both x-rays and gamma rays travel through the air at the speed of light and have no mass or electrical charge.

Particulate radiation originates from the nucleus of radioactive atoms. Particulate radiation includes alpha radiation which has no medical use and beta radiation. Beta radiation, among other things, is used in nuclear medicine and positron emission tomography also known as “PET” studies.

Because we are unable to conduct controlled studies, most of what we know about the harmful effects of ionizing radiation has been gathered from health consequences resulting from its uses and in historical events.

Following the discovery of X-rays in 1895, **Clarence Dally** assisted Thomas Edison on the development of the “**Edison x-ray focus tube”**. At the time, the levels of X-rays produced were not believed to be dangerous; however Edison noted how "*the x-ray had affected poisonously my assistant, Mr. Dally*”.

By 1900 Clarence Dally was suffering radiation damage to his hands and face. This damage was sufficient to require time off work. In 1902, one lesion on his left wrist was treated unsuccessfully with multiple skin grafts and eventually his left hand was amputated. Ulceration on his right hand necessitated the amputation of four fingers.

These procedures failed to halt the progression of his carcinoma, and despite the amputation of his arms at the elbow and shoulder, he died from mediastinal cancer. Following this, Thomas Edison abandoned his research on X-rays.

Radium Dial Painters The radium dial painting industry began in the United States in the early 1900’s when it was found that objects painted with radio-luminous material were visible in the dark. Several dial painting plants were established to capitalize on this discovery, including the “*U.S. Radium Corporation*” in Orange, New Jersey and the “*Radium Dial Company*” in Ottawa, Illinois. These plants employed several hundred women to paint watch dials and military instruments with radium paint. Many of these women ingested Ra-226 and Ra-228 as they '*tipped*' brushes between their lips to obtain a finer point.

A New York dentist, Theodore Blum, was one of the first to note the biological effects of radium when he observed what he termed “*radium jaw*” in a woman who had worked at a New Jersey dial painting plant. Such early cases exhibited “*acute necrosis of the jaw, usually involving infection and severe leukopenia and anemia”*. Within a few years osteogenic sarcomas began to appear. The practice of tipping brushes was prohibited in the late 1920s.

Shoe Fitters The shoe fitting fluoroscope was a common fixture in shoe stores during the 1930s, 1940s and 1950s. A typical unit, like the Adrian machine shown in our presentation, consisted of a vertical wooden cabinet with an opening near the bottom into which the feet were placed. When you looked through one of the three viewing ports on the top of the cabinet (e.g., one for the child being fitted, one for the child's parent, and the third for the shoe salesman or saleswoman), you would see a fluorescent image of the bones of the feet and the outline of the shoes.

Despite these relatively high exposures, there were no reported injuries to shoe store customers. Unfortunately, the same cannot be said for the operators of these machines. Many shoe salespersons put their hands into the x-ray beam to squeeze the shoe during the fitting. As a result, one saleswoman who had operated a shoe fitting fluoroscope 10 to 20 times each day over a ten year period developed dermatitis of the hands. One of the more serious injuries linked to the operation of these machines involved a shoe model who received such a serious radiation burn that her leg had to be amputated (Bavley 1950).

Excerpts from Installation Directions:

> *"Before putting the tube in the X-ray Machine, place the machine in the most desirable location. . . . We would suggest that you center the machine in the store so that it will be equally accessible from any point. Of course, it should face the ladies' and children's departments by virtue of the heavier sales in these departments."*
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> *"At some time or other a customer may request an examination of the foot without the shoe for diagnosing a bone condition. We suggest that you refer this work to the professional man, and advise your customer to have an X-ray laboratory or doctor whose office is equipped with X-ray, make this inspection."*

Three Mile Island "Three Mile Island Nuclear Generating Station" (TMI) is a civilian nuclear power plant (NPP) located on Three Mile Island in the Susquehanna River, south of Harrisburg, Pennsylvania. It has two separate units, known as "*TMI-1*" and "*TMI-2*". The plant is widely known for having been the site of the most significant accident in United States commercial nuclear energy, on March 28, 1979, when TMI-2 suffered a partial meltdown. According to the US Nuclear Regulatory Commission, the accident resulted in no deaths or injuries to plant workers or members of nearby communities. The reactor core of TMI-2 has since been removed from the site, but the site has not been decommissioned.

Chernobyl. The Chernobyl disaster was a nuclear accident that occurred on April 26, 1986 at the Chernobyl Nuclear Power Plant in Ukraine which at the time was part of the Soviet Union, and was under the direct jurisdiction of the central authorities in Moscow. An explosion and fire released large quantities of radioactive contamination into the atmosphere, which spread over much of Western USSR and Europe.

It is widely considered to have been the worst nuclear power plant accident in history, and is one of only two classified as a level 7 event on the "*International Nuclear Event Scale*" (the other being the Fukushima nuclear disaster recently in Japan). The battle to contain the contamination and avert a greater catastrophe ultimately involved over 500,000 workers and cost an estimated 18 billion rubles, crippling the Soviet economy. Initially the Chernobyl accident caused the deaths of 32 people. Dozens more contracted serious radiation sickness; some of these people later died. Between 50 and 185 million curies of radionuclides escaped into the atmosphere. This is several times more radioactivity than that created by the atomic bombs dropped on Hiroshima and Nagasaki, Japan. This radioactivity was spread by the wind over Belarus, Russia, and Ukraine and soon reached as far west as France and Italy. Millions of acres of forest and farmland were contaminated; and although many thousands of people were evacuated, hundreds of thousands more remained in contaminated areas. In addition, in subsequent years many livestock were born deformed, and among humans several thousand radiation-induced illnesses and cancer deaths are expected in the long term.

Nevada Test Site Formerly the Nevada Proving Grounds, the Nevada Test Site is located in Nye County Nevada, about sixty-five miles northwest of Las Vegas, and covers approximately 1,375 square miles.

Between 1951 and 1992, nine hundred and twenty-eight documented atmospheric and underground nuclear tests occurred at the Test Site. A three-year moratorium on nuclear testing occurred between 1958 and 1961.

On August 5, 1963, the United States, Russia, and the United Kingdom ratified the "*Partial Test Ban Treaty*" (PTBT), prohibiting further atmospheric tests. The last atmospheric test occurred at the Test Site on July 17, 1962.

President Truman approved the use of the Nevada site at the end of a three-year study called "*Project Nutmeg*", which investigated possible test site locations within the continental United States. The location in Nevada was preferred for a number of reasons:

- The facilities at the existing bombing range within which it would remain (landing strips, housing, etc.,) .
- Its proximity to Highway 95 for personnel access.
- The predictable weather.
- The mountainous terrain surrounding the site provided security against spying and limited public access.
- The support of the small local population and state political leaders also weighed favorably in the decision.

During the decision-making process, the health hazard of radioactive fallout to the downwind population was a minor concern. The government established a guideline for safety as a 125-mile radius from the test to populated areas. Although Las Vegas fell within this area, the government was confident that meteorologists could predict the wind patterns for the day of the test to ensure the fallout cloud drifted away from populated areas. But unclassified documents and studies in recent years show the fallout from tests, in fact, drifted across most of the United States.

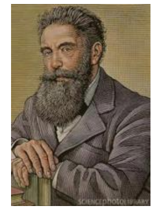
Pressured by international concern over radioactive fallout, the government began to move tests underground. Once the Limited Test Ban Treaty was ratified, the mushroom clouds disappeared from the Horizon Satellite photographs of Yucca Flat clearly show the craters caused by these tests. Occasionally, there would be leaks of radiation from the craters known as "*venting*".

The last underground test took place on September 23, 1992, after a moratorium beginning in October 1992 temporarily ended all nuclear testing. Underground tests scheduled for 1993 were left uncompleted. The U.S. Senate, however, has not ratified the "*Test Ban Treaty*" negotiated by President Clinton and signed by 108 other nations.

Visitors to the site can see two examples of the towers built above the shafts prepared for underground tests: one for a test called "Icecap", the other "Gabbs". Although no further tests have taken place, the Nevada Test Site remains ready in case testing resumes. In 2001, the government indicated periodic testing might resume, ensuring the nation's nuclear stockpile is still functional. As of 2007, there is a two-year readiness period before testing could resume should the president lift the moratorium.

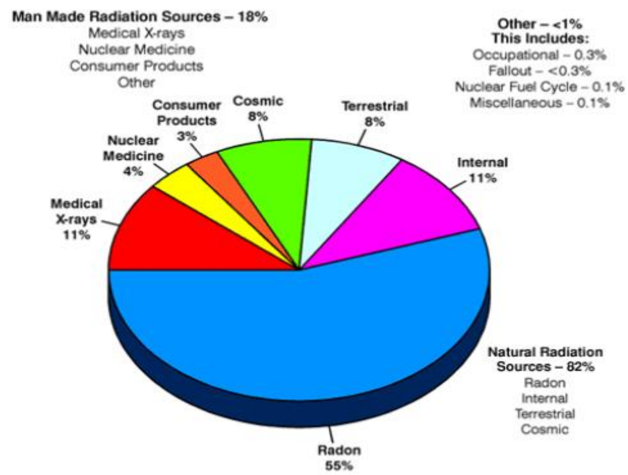
Today the United States Department of Justice over sees the "*Radiation exposure compensation act*". It provides payment of between $50,000 and $100,000 to people who were negatively affected by nuclear testing at the Nevada test site.

Physical Properties



X-rays are a form of electromagnetic radiation. They are similar to visible light but are of shorter wavelength. X-rays have no mass or charge but behave as both waves and particles depending on how they are viewed. When we talk about x-rays, we either talk about the wavelength and energy, which are aspects of waves, or we talk about photons, which are particle like packets of energy.

Human Exposure to Radiation



Human beings are continuously exposed to sources of ionizing radiation. Some people are exposed to a wide variety whereas others are exposed to a limited number. Sources may be natural or man-made. Natural sources of ionizing radiation have always been part of human life. Ionizing radiation from environmental sources is called natural background radiation it has three components:

- **Terrestrial radiation** from radioactive materials in the earth
- **Cosmic radiation** from the sun and beyond the solar system
- **Biologic radiation** from radio nuclides deposited in the human body through natural processes.

Ionizing radiation created by humans for various uses is classified as manmade or artificial radiation. Sources of artificial radiation include: consumer products, air travel, nuclear fuel for generation of power, atmospheric fallout from nuclear weapons, accidents in nuclear power plants and medical radiation.

Only about one third of 1% of the total exposure to ionizing radiation you will receive in your lifetime will come from exposure received while performing your duties as a radiographer.

X-ray Interaction with Matter

When x-ray comes into contact with matter there are five different things that can happen. The first thing that can happen is nothing. The x-ray may just pass right through and not have any interaction at all. The other four things that can happen are all either **absorption** or **scatter**. When photons are absorbed or scattered this is referred to as attenuation and reduces the number of photons in the primary beam.

Coherent scattering also called classic scattering occurs primarily with low-energy x-rays. The photon stimulates the atom and increases its overall energy. This excess energy is given off as scatter radiation in the form of an x-ray photon.

For **pair production** to occur the energy of the x-ray photon must be so high that we are unable to produce this interaction with standard x-ray equipment.

Photodisintegration occurs at even higher energy levels than pair production.

The two interactions that we are most concerned with are **photoelectric** and **Compton** interactions.

With the **photoelectric effect**, all of the energy of the incoming photon is totally transferred to an atom of the irradiated matter. The incoming photon interacts with an orbital electron and all of the photon's energy is transferred to the orbital electron which causes an orbital electron to be ejected from the atom. The photon ceases to exist**. In other words all of the energy from the x-ray photon is absorbed by the patient**.

Compton scattering is a process in which a photon is partially a absorbed by an outer shell electron. The electron absorbs enough energy to break the binding energy bond and is ejected while the remaining photon energy exits the atom. The photon, now less energetic continues on a different direction as scatter radiation.

The **photoelectric interaction** is responsible for the radiation exposure to our patients. The **Compton interaction** is responsible for exposure to radiographers and the general public.

It is very important to remember that this means that the source of exposure to our patients is the primary beam coming from the x-ray tube. The source of exposure to the radiographer is scatter radiation coming from the patient.

Law of Bergonie and Tribondeau

In 1906 two French radiobiologists made one of radiology's most important discoveries by exposing rabbit testicles to ionizing radiation and observing its effects, Bergonie and Tribondeau studied the relationship between metabolic state and radiosensitivity. The law of Bergonie and Tribondeau specifically states that:

1) **Stem cells are radiosensitive.**
2) **Immature or young cells and tissues are more radiosensitive; resistance to radiation increases with increased cell maturity.**
3) **Low metabolic rate decreases radiosensitivity and high metabolic rate increases radiosensitivity.**
4) **High proliferation (reproductive) rate for cells and fast growth rate increases the radiosensitivity of those cells.**

Absorbed Dose

The human body consists of many different types of tissue each having their own atomic structure. If it were not for these differences production of a diagnostic radiograph would not be possible. The anatomic structural differences seen on a radiograph result from x-ray interaction with various tissues within the anatomic part. As x-rays pass through the tissue within our body they may interact with the atoms or they may exit the body without interacting. During this travel through the tissue some or all of the x-ray energy may be transferred to the tissue.

This transfer of energy is called **absorption**. The amount of x-ray absorption per unit mass is called **absorbed dose**. Biologic damage is directly related to absorbed dose.

As the atomic number of the irradiated tissue increases, the absorbed dose increases.

The tissue in our body with the highest atomic number is bone, next is muscle then fat, then fluid, and finally air. This is why bone appears white on an x-ray and air appears very dark.

As the x-ray energy decreases more of the x-ray is absorbed by the body so the absorbed dose to the tissue increases.

LET and RBE

LET, "*Linear Energy Transfer*", is a unit of measurement that relates to the quantity absorbed dose and is an important concept in radiation biology. The amount of ionization that occurs in tissue is directly related to how much energy it receives. The biologic damage to tissue coincides with the amount of ionization that occurs. The degree of ionization resulting from various types of ionizing radiation is not equal. For example particulate radiation, such as alpha particles, lose energy quickly as they interact with tissue. This quick loss of energy causes much ionization in the tissue. Alpha and some of the other particulate radiation are said to be high LET radiation since they have the potential to cause many ionizations as they interact with tissue.

X-rays and rays actually produce more interactions in the tissue; however, when compared to some particulate radiation, such as alpha particles, produce less ionization in tissue and are considered to be low LET radiation.

In radiology, the **relative biological effectiveness** (often abbreviated as **RBE**) is the ratio of biological effectiveness of one type of ionizing radiation relative to another, given the same amount of absorbed energy. Biologic damage resulting from radiation interaction with tissue increases as the LET of radiation increases. Many scientists have attempted to quantify different types of radiation as to their biological effectiveness in relation to absorbed dose quantities. This however has proven difficult; therefore, the RBE is not practical for delineating radiation protection dose levels. The quality factor, basically a measure of RBE, is used for calculation of the absorbed dose equivalents.

Absorbed Dose Equivalent

The biologic effect of radiation exposure varies according to the type of radiation involved and its energy. Equal doses of various types of radiation will not necessarily result in equal biologic effects. Some radiation workers may be exposed to several types of radiation with unequal levels of biological effect. The **rem** which stands for "*radiation equivalent man"* is the unit of dose equivalent. To simplify the process of measuring occupational dose a radiation weighting factor is assigned to each type of radiation based on a variation in biologic damage that is produced when an individual receives exposure from different types of radiation. The unit of dose equivalent, otherwise known as rem is the unit commonly used to report occupational dose to radiation workers in the United States.

When we talk about the exposure to a radiographer we use rem as the unit of measure for exposure. This is the unit that your personnel monitoring badges are reported in.

Dose Fractionation

If the quantity of radiation is delivered over a long period of time, the biological effect of the same dose will be less than if it were delivered quickly. As the time of delivery and the quantity of radiation is increased, a higher dose will be required to produce the same biological effect. Lengthening the time of the delivery of radiation may be accomplished in two ways, **fractionated** or **protracted**.

A **protracted** dose is one that is delivered continuously, but at a lower dose rate. A **fractionated** dose is one that is delivered at the same dose rate, but divided into equal fractional quantities of radiation. Dose fractionation is used in radiation therapy because it allows time for tissue repair and recovery between doses.

Dose Response Curve

A **dose response curve** is a graphic representation of the relationship between the amount of radiation absorbed by a cell or organism and the amount of damage seen. Dose response curves vary in two basic ways.

First, response curves are either **linear** or **nonlinear**.

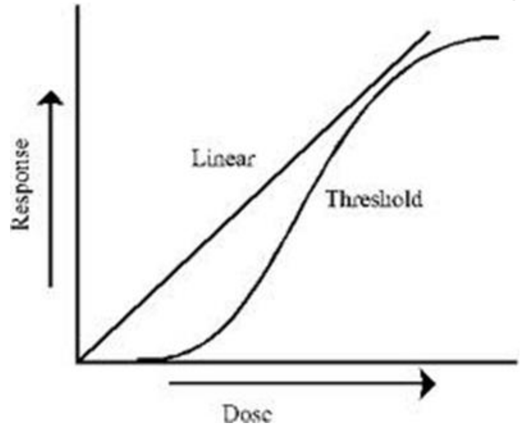
In **linear** responses there is a proportional relationship between the dose and response, and the curve forms a straight line. In other words, twice as much exposure will result in twice as much damage.

In **nonlinear** responses are those in which there is no fixed proportional relationship between dose and response. They form a curved line when graphed.

Second, response curves are either **threshold** or **non-threshold**.

A response that has a **threshold** is one in which a level is reached below which no damage is observed. An example of a threshold response is sunburn. If a person were to stay in the sun long enough then they will experience sunburn. However, they must be exposed to the sun for a certain period of time for that to happen. There is no chance that exposure to a single ray of sunshine can cause a person to experience sunburn.

A **non-threshold** response is one in which theoretically even the smallest dose could cause an effect. The odds of serious damage from non-threshold effects caused by x-rays are very remote. Just as the odds of winning the lottery by purchasing a single lottery ticket are very remote. That being said, it is our responsibility to limit the amount of exposure to our patients to the smallest amount possible. We want to get our patients the lowest number of dose response "*lottery tickets*" possible while still performing quality exams and gathering all of the information that the physician needs in order to provide a diagnosis.



Cell Radiosensitivity

Several biological factors must be considered when discussing cell radiosensitivity these variables are based on biological variations in the individual organisms. These factors include:

- Age
- Gender
- Oxygenation

Age. Radiosensitivity is highest before birth and until maturity. During early stages and human development there are a great number of immature, nonspecialized cells, which are more susceptible to radiation damage when compared to the adult stage of the human lifecycle. The use of radiation protection measures is very important for protection of the developing embryo and fetus, all children and women may have a likelihood of reproducing.

Gender. Scientific research indicates that females are approximately 5% to 10% more radiation resistant than males. This is due to the fact that female reproductive organs are internal and protected, while male reproductive organs are external and exposed.

Oxygenation. Oxygen enhances the effect of ionizing radiation on living organisms by increasing cell radiosensitivity. Cells that *are* highly oxygenated are at a higher risk from the damage caused by ionizing radiation than cells that *are not* highly oxygenated.

Direct effect versus indirect effect

In the 1920's a variety of researchers found that biologic effects were due primarily to ionization processes in tissues. Two different processes were identified.

The **direct** affect refers to radiation interaction with a photon directly interacts with a target or critical DNA molecule.

In the **indirect** effect, a photon strikes a noncritical molecule, usually water, but the noncritical molecule transfers the ionization energy to the critical DNA molecule creating an indirect effect.

Because the human body is composed of approximately 80% water, it is believed that the greatest percentage of ionizations will occur as interactions between photons and water molecules. When a water molecule is ionized, it separates into free radicals. **Free radicals** are very chemically reactive forms of ions. A free radical can react quickly with no molecules because it has an electron in the outer energy shell that is not having partner. Since free radicals have an unpaired electron, they are very reactive and can impart some of their excess energy to other molecules. It is this transfer of energy by free radicals that causes biological damage. Free radicals are capable of traveling through the cell and causing biological damage at distances away from their origin.

Radiolysis occurs when a water molecule is ionized, resulting in three ions capable of recombining with other free radicals to form new molecules. The free radicals resulting from radiolysis of the breakdown of the molecules have the potential to recombine to form a new water molecule or to combine with other radicals to form new molecules. It is believed that most of the effects of radiation on living organisms are a result of radiolysis or the indirect action cosmic photon interacts with a noncritical molecule.

Short and Long Term Effects

Biological effects may be classified as either **short-term** effects, or **long-term** effects. Biological effects from radiation fit into one of the other classification depending on the length of time it takes for the effect of become evident or demonstrable. As previously discussed several factors such as total radiation, amount of absorbed dose, and body area receiving the exposure determine the type and intensity of the effect. This type of radiation effect is typical of the risk to a patient undergoing a diagnostic x-ray examination.

Short Term effects are found in acute radiation syndrome, which includes, but is not limited to:

- Gonadal dysfunctions
- Epilation
- Depression of white blood cells
- Death.

Clinical signs and symptoms of short-term effects include:

- Nausea
- Vomiting
- Diarrhea
- Anemia
- Leukopenia
- Hemorrhage
- Fever
- Infection
- Shock

Short-term effects are typically threshold effects.

Long-term or "*late effects*" of radiation may result from small doses of radiation received over a number of years. Long term effects may also be demonstrated in individuals who have been exposed to a single dose of radiation and have been in a long latent period. *These are typically the effects associated with the exposure to an x-ray patient.*

Examples of long-term effects that have been demonstrated through epidemiologic studies of survivors of radiation exposures include the following:

Local tissue effects. An example of this affect is when the skin undergoes changes in its texture elasticity and appearance. It appears dry, chapped, and prematurely aged. Exposed skin they also exhibit an increase in skin lesions, both benign and malignant. These changes are both dose and time related.

Chromosomal changes. Chromosomal damage may be exhibited as abnormal pairings, translocation, and other phenomenon that can result in cell damage and dysfunction.

Cataracts. Radiation-induced cataracts were reported as early as the 1940s. The radiosensitivity of the lens of the eye has been demonstrated to be age-dependent. This means that the older the individual, the more susceptible one is to radiation-induced cataracts.

Lifespans shortening. It is suggested that as a result of chromosomal mutations affect us and lifespan of an individual acutely exposed will be compromised, and / or shortened. For this reason, the amount of radiation delivered in radiographic procedures should always be as low as reasonably possible to obtain the necessary to obtain the necessary diagnostic information, and radiation protection measures should always be used.

Somatic versus Genetic Effects

The effects of radiation on living organisms are further classified as **somatic**, or **genetic**. Somatic effects occur to the individual who has been exposed to ionizing radiation, whereas genetic effects may not be apparent in the exposed individual but passed on to future generations through genetically damaged chromosomes.

Somatic effects occurring to living organisms may be classified as either early, or late somatic effects, depending on the length of time from the moment of radiation exposure to the first appearance of symptoms.

Early or acute somatic effects are those that appear within minutes, hours, days, or weeks after the initial radiation exposure. Examples of early or acute effects are:

- Loss of bone marrow function
- Gastrointestinal syndrome
- Central nervous system syndrome

Late somatic effects are those that appear after a period of months or years after the initial exposure. Late somatic effects may result from an initial dose of radiation that caused early acute symptoms, and ultimately repair and recovery, or chronic low-level doses of radiation received over a long period of time. Carcinogenesis is the most important late somatic affect it is difficult to verify statistically because it cannot be distinguished from cancers normally expected in populations.

10 Physical properties of X-ray

1. X-rays are the most penetrating electromagnetic waves. This is one of the aspects of x-rays first noted, its ability to pass through matter. This is the reason x-rays are useful for seeing “inside” the body.

2. X-rays are heterogeneous and polyenergetic. This means that x-rays have more than one origin and many different energies. Along with varying thicknesses of anatomic structures and atomic number of tissues this is the basis for differential absorption of x-rays, as some x-rays will be absorbed and others will not.
3. X-rays travel in a straight line at the speed of light. X-rays diverge from the source and are admitted isotropically in the same way that light usually travels in a straight line and diverges in all directions from a light bulb. The fact that x-rays are emitted in all directions makes it necessary to use lead shielding in the x-ray tube to permit x-rays to only exit the window.
4. X-rays cannot be focused by a lens or reflected off of a surface. This characteristic makes it necessary to use various other means to control the x-ray beam, including collimation and filtration.
5. X-rays are electrically neutral. An x-ray is electromagnetic in nature, which means that it is pure energy and therefore does not have any mass or particle associated with it. Because an x-ray photon is not made up of particles an x-ray has no electrical charge.
6. X-ray photons produced both scatter and secondary radiation when interacting with matter. Scattered and secondary radiation are responsible for most of the exposure to operators of x-ray equipment.
7. X-rays cause some crystals to fluoresce or give off light. This is the pieces of operation for intensifying and fluoroscopic screens.
8. X-rays affect photographic film. This is the basis of medical imaging and the basis of operation for film badges.
9. X-rays ionize all matter including gases. This is the basis of operation of ionization chambers used to detect radiation. Some automatic exposure controls also use this principle.
10. X-rays cause some biologic changes. These potential changes must be understood by the radiologic technologist to effectively practice radiation protection both for themselves and for their patients.

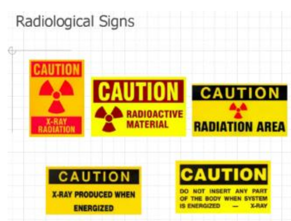
NOTES

Radiation Safety

Each time a radiographic examination is indicated, the licensed medical practitioner must consider the potential diagnostic benefits to be gained from the radiographic examination, versus the potential biological harm to the patient resulting from radiation exposure. The decision is often called the "benefit versus risk principle" and must be considered each time a radiologic examination is requested. Once the decision to perform a radiographic procedure has been made by the doctor, it is the radiographer's responsibility to perform the examination and to follow all recognized radiation protection guidelines. These guidelines consist of cardinal principles and procedures intended to reduce unnecessary radiation exposure to the patient and radiation operator.

The main goal of all radiation protection activities is to keep all radiation exposure as low as reasonably achievable. We will discuss current radiation protection philosophy, the ALARA concept, effective absorbed dose equivalent guidelines, and radiation protection procedures for the patient and the radiographer.

Guidelines limiting the amount of radiation received by the general public and those individuals who use radiation at work have been established by several international and government agencies. Traditionally, radiation exposure limits have been expressed as the maximum permissible dose (MPD), to which the radiation occupation worker or the general public can be exposed. Over the years, as knowledge of the harmful effects of radiation has increased, the maximum permissible dose has been decreased. However the MPD is no longer used as a criterion of radiation exposure in radiation protection.



In 1987 the National Council on Radiation Protection issued new guidelines for limits on exposure to ionizing radiation based on the "dose equivalent", the name for the unit of effective absorbed dose equivalent limits is REM, which stands for "radiation equivalent man". The recommendations on effective absorbed dose equivalent limits for individuals are based on the general ALARA concept and the "negligible individual risk level".

Effective absorb dose equivalent limits differ for radiation workers and the general population. There further modified by reference to specific organ or tissue exposures and embryo fetus exposures. For occupational exposure, the annual effective absorb dose equipment is five REM. The age of the radiation worker is also a factor in exposure limitations. Previously, no one under 18 years of age was allowed to work with ionizing radiation. The NCRP has stated that for educational and training purposes, radiation workers less than 18 years old being limited to an annual affective absorbed dose equivalent of 0.1rem. In addition to annual dose limitations, a cumulative for lifetime dose limitations must be observed. This limit is determined by the age of the radiation worker. The total allowable cumulative exposure is the age in years of the worker times 1 rem. For example a 30-year-old radiographer is allowed a cumulative exposure of 30 x 1 rem or 30 rem.

Guidelines for exposure limitations for the general public are less than those for radiation workers. With regard to a pregnant radiographer embryo fetal exposures are also considered separately. The total dose equivalent for the fetus of a pregnant radiographer is 0.5rem for the entire term of pregnancy and not more than .05rem in a single month.

Reducing unnecessary radiation exposure is the responsibility of everyone involved in the examination including the doctor the radiographer and even the support staff.

It's the **doctor's responsibility** to explain why the radiologic examination is necessary, to answer patient questions, and to respond to any concerns about the nature of the examination. Poor communication may result in a repeat examination, or even in the rock patient being radiographed. Effective communication becomes an important factor in reducing unnecessary or excessive radiation exposure. Patients have the right to know about the examination and if inadequately informed, they may have questions or fears regarding the nature purpose or even the value of the exam. Patients who do not understand what is going to happen or what is expected may even be reluctant to cooperate.

It is the **radiographer's responsibility** to give the patient clear, concise instructions and to communicate in such a way that patients understand what is expected of them in order to complete the examination. If at any time the patient refuses to undergo the examination, the radiographer should seek supervisory assistance and never insist that the patient submit to any procedure against his or her will. Make sure that you take the time to explain the procedure so that the patient understands, answer any patient questions within ethical limitations, and have asked a question that cannot be answered; the radiographer should seek supervisory assistance. Remember, patients have the right to be completely informed about the medical care and to have their questions answered.

Many repeat examinations can result from inadequate patient preparation. It is important to ask the patient to remove all radiopaque objects from the area to be Radiograph, such as necklaces, zippers, piercings, etc. A repeat examination results in a repeat or "double" radiation exposure to the patient.

Proper instructions regarding breathing and motion control are another important step in patient preparation. Careful attention to radiographic positioning also helps reduce the number of repeat radiographs and thus reduces unnecessary radiation exposure. Radiographers should never attempt the radiographic procedure if they are uncertain as to the correct procedure. If in doubt or just inexperienced, the radiographers should stop and ask for help.

Primary beam limitation

Primary beam limitation refers to the use of a device (such as an aperture diaphragm, Cohen, or collimator), to limit the useful or primary radiation beam to the area of clinical interest, thereby decreasing the area of the body tissue being exposed to radiation. This in turn reduces the amount of secondary scattered radiation and also limits unnecessary exposure to nearby tissue. A beam restrictor however is only as effective as the operator uses the device.

A collimator, often referred to as a "variable collimator", is an efficient **beam limitation device**. Attached to the radiographic to housing, the collimator looks like a square box with a clear plastic window. It contains two sets of adjustable lead shutters mounted at different levels, a light source, and a mirror to deflect the light source. It has given the radiographer the ability to limit the primary radiation beam to the area of clinical interest. Proper coloration of the primary radiation beam will result in an unexposed margin around the edge of the radiographic. Never allow the primary radiation beam to expose an area beyond the area of clinical interest. The collimator is equipped with a light source that simulates the radiation exposure area. The collimator like is used as a guide in positioning, alignment, central ray replacement, and collimation. **Making the x-ray beam smaller is referred to as *increasing collimation.***

The efficiency of any beam restricting device depends upon its regular and proper use by the radiographer. Positive beam limitation, “PBL”, system was designed in response to the concern about the operator forgetting to limit the primary beam. The PBL system actually restricts the primary beam to the film size used in the Bucky tray. An additional benefit of restricting the primary being is improved radiographic quality. It properly collimated primary radiation being produces less secondary scatter radiation, thus reducing possible film fog or increasing film darkening.

Filtration

The **filtration** of the primary radiation is another method used to protect the patient from unnecessary radiation exposure. Radiographic filters serve two major functions by removing low-energy, long wavelength photons from the primary beam. These functions are designed to protect the patient’s skin and superficial tissue, and improve the quality of the radiation beam.

There are two types of radiographic filtration:

- Inherent filtration
- Added filtration

Inherent filtration consists of the tubes glass envelope, insulating oil, and the glass window. Inherent filtration is expressed in equivalent aluminum thickness and should be at least 0.5 mm of aluminum. Aluminum is the metal of choice because it is effectively removes low-energy x-rays, is inexpensive, and it’s sturdy.

Added filtration is any filtration added to the existing inherent filtration. These filters usually consisting of aluminum sheets, maybe added outside the tube housing. The inherent filtration plus added filtration represents the required amount of total filtration. The total amount of radiographic tube filtration is dependent upon the kilo-voltage ranges of the equipment. Any x-ray machine operating above70kVp is required to have the equivalent of 2.5 millimeter aluminum filtration.

Film Screen Speed

Most of the image that is created on an x-ray film is a result of light emitted from an intensify screen located inside the cassette, rather than from direct exposure to X-rays. It would take a very long exposure to create an image from x-rays only. Traditionally calcium tungstate was the phosphor used to emit light in the film screen combination. The development of rare earth prospers allowed radiographers to create images using far less exposure. Film screens speed rating is a way to quantify how much radiation is required to create an image. For example a 400 screen speed system would require half as much radiation as a 200 screens the system to create an image with the same density. However that same 400 screen speed system would require twice as much radiation as an 800 screen speed system. Therefore the faster the screen speed the last radiation required to create the image. However, a faster screen speed produces an image with less recorded detail.

Gonadal Shielding

The decision to use gonadal shielding must be considered with each individual patient situation and the radiographic request. However, the following criteria provide guidelines for deciding when gonadal shielding should be used.

1. Use gonadal shielding on all patients who have a reasonable likelihood of reproducing.
2. Use gonadal shielding on all children.
3. Use gonadal shielding if the gonads lie within the primary beam or within 5 cm of the primary beam's edge.
4. Use gonadal shielding if the shielding will not obscure necessary diagnostic information on the radiograph.

Gonadal shields can develop cracks and pin point holes with consistent use or when not properly stored. Gonadal shields should be stored flat without folds when not in use, and should be regularly checked for cracks or pinpoint holes which can allow radiation leaks to the patient.

Pregnant Patients

Observing all radiation protection guidelines is extremely important if the patient is pregnant or pregnancy is suspected. It is important to remember that it is the doctor's possibility to evaluate the patient and to determine if the diagnostic benefits outweigh the risks associated with radiation exposure. The radiographer's responsibility is to avoid unnecessary radiation exposure and to produce diagnostic quality radiographs while providing for the patient comfort and safety. This can be accomplished by forming all recommended radiation protection procedures and by providing the pregnant patient with a lead apron or shield placed over the units or totally surrounding the pelvis. It is not that it is more important to practice radiation safety when you're patients pregnant it is always important. It is just that if you're patients pregnant now there are more reasons to be concerned. If you practice these skills as if each patient were pregnant then when you actually do have a pregnant patient there won't be any problems.

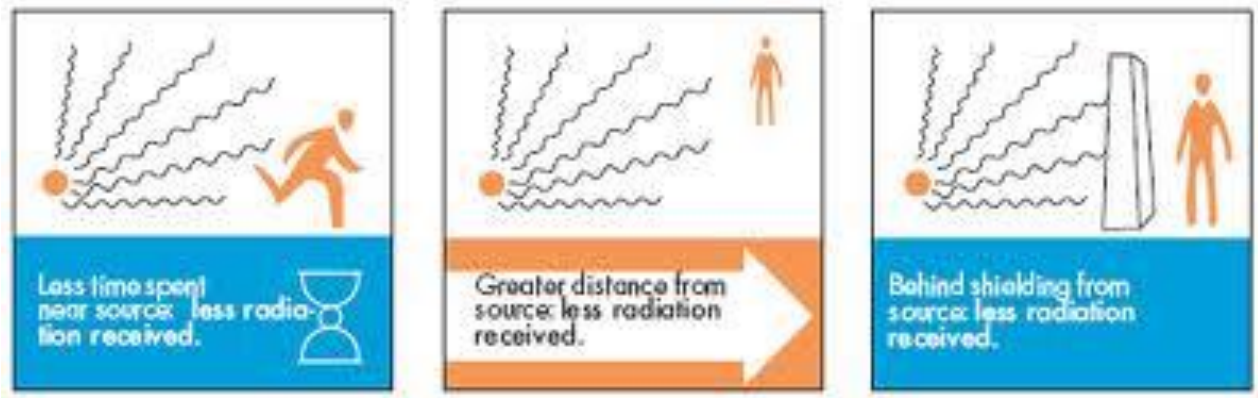
When determining the pregnancy status of the patient the first 10 days following the onset of menstruation is considered the safe period. During this time a patient is unlikely to be pregnant.

Radiation protection procedures for the potentially pregnant patient conform to the ALARA concept. The use of the "10 day rule", which states that pelvic or abdominal x-rays of women of childbearing age are done only in the first 10 days following the onset of menstruation, is no longer used. The guideline to follow is that all radiographic procedures being performed in a manner taking the radiation procedure as low as reasonably achievable.

Protecting the Radiographer

There are three cardinal principles of radiation protection:

- **Time**
- **Distance**
- **Shielding**



If used together, the principles of time, distance and shielding can minimize radiation exposure to the patient and to the radiographer. These three cardinal principles were developed for nuclear energy employees who have the potential to be exposed to high levels of radiation in the workplace. The radiographer, of course, is not expected to be employed in a high-level radiation area, such as a nuclear energy, but the cardinal principles have practical application to medical radiography.

Time Radiation exposure is proportional to the amount of time spent in the radiation. A five-minute exposure to radiation would result in irradiation dose five times as great as a 1 min. exposure to radiation. This has several implications that can be related to the radiographer and the patient. The radiographer has a responsibility to:

• Not stay in the radiography room during the exposure unless standing behind a protective barrier.

• Reduce the amount of time that the patient is exposed to radiation. Reduce repeat radiographs and subsequently reduce time and radiation exposure.

• Use of fast exposure time factor whenever possible as fast exposure time can reduce radiographic motion unsharpness due to patient movement.

Distance between the radiographer and the radiation source is the most effective way to reduce patient exposure and the most easily applied principal radiation protection the inverse square law which applies to point sources of radiation can be used to demonstrate the effect of distance on radiation intensity. Radiation from an x-ray to is considered to be a point source of radiation. **The distance from the x-ray source of radiation (the x-ray tube) to the image receptor is termed source to image receptor distance (S.I.D.).**

X-rays are similar to light in that the further you move away from the source, the dimmer light becomes or the last intensely x-rays become.

The law of physics that govern this principle is known as the inverse square law. The inverse square law states that radiation intensity is inversely proportional to the square of the distance from the source.

In English that means that as we move twice as far from the source the radiation intensity is cut to merely one fourth. If a person were standing 3 feet from a source of radiation and was exposed to 10 mrem of radiation then moved one step further away and was now 6 feet from the source of radiation, the exposure would now be 2.5 mrem of radiation.

Shielding is the third cardinal principle of radiation protection. As x-ray photons travel through the air or through tissue, the quantity and energy of the x-ray photons decrease. The degree to which the quantity and energy of the x-ray photons is decreased depends upon several factors: the original quantity and energy of the x-ray beam; type of absorber material; and thickness of material. If x-ray photons travel through not absorbing material eventually their energy will be lost to the material and no x-rays will emerge through the other side. Protective shields are usually constructed of lead or a concrete wall.. This serves as an absorber of the radiation should be situated so that it intercepts the primary radiation and any radiation that has scattered. The radiographer should stand behind a lead shield or wall barrier when making the radiographic exposure. The radiographer should not peek around the shield or wall, but should watch the patient through the protective glass window installed in the shield or wall. There are two types of lead shielding: primary and secondary.

A primary barrier is any protective barrier that the primary beam may be directed toward. A primary barrier should consist of the equivalent of 1/16 of an inch of lead and should be as high as 7 feet from the x-ray room floor. Primary protective shielding is located perpendicular to the primary x-ray beam.

Secondary shielding is any protective barrier that the primary beam cannot be directed toward. Secondary shielding provides radiation protection only from scatter or secondary radiation. It must contain the equivalent of 1/32 of an inch of lead and be a length as high as 7 feet off the x-ray room floor. Secondary protective shielding barriers (such as the control console shield, or structural barrier) often containing window through which the operator can observe the patient. The window is required to contain a 1.5 mm lead equivalent.

Protective apparel is used for the patient and radiographer whenever additional protection is desired or necessary. Handle aprons, gloves, and gonadal shields with care. Protective apparel should be properly stored when not in use to prevent cracks from developing which could result from the bending of the protective layer insert, cracks could permit radiation to leek through.

Protective apparel is a secondary barrier only, and it should not be used in the primary beam.

The radiographer who becomes pregnant while employed in that capacity should discuss her pregnancy with her supervisor and attending physician. If a pregnant radiographer performs the usual recommended radiation safety procedures during all radiography examinations and uses the optional protective measures outlined, it is nearly impossible for the radiographer to be exposed fetal dose equivalent. Pregnancy does not justify layoff or termination.

Accurate radiation detection and measurement is necessary if occupational exposure levels are to be kept below the maximum permissible dose levels. Personnel and area monitoring are the most commonly used procedures used to determine occupational exposure. Film badges are the most frequently used type of personal monitoring device, they are economical and considered relatively accurate recording low doses of radiation, if instructions regarding care, and use, are followed. A film badge consists of three parts: a film packet, metal filters, and a plastic holder with a clip for attachment. After processing, the degree of film darkening beneath the filters provided basis for estimating the radiation exposure.

NOTES

Chapter 3 Quiz

Radiation Biology and Radiation Protection

1. The unit commonly used to report occupational dose to radiation workers in the United States is:
   - A. mR.
   - B. mrad.
   - C. rem.
   - D. mGy.

2. According to the Laws of Bergonie and Tribondeau, which of the following types of cell is most radiosensitive?
   - A. Cells with little oxygen
   - B. Mature cells
   - C. Stem cells
   - D. Cells with a low metabolic rate

3 When an electron is removed from an atom, the atom is said to be:
   - A. radioactive.
   - B. a nuclide.
   - C. unstable.
   - D. ionized.

4. Which of the following types of radiation effect is typical of the risk to a patient undergoing a diagnostic x-ray examination?
   - A. Short-term effects
   - B. Genetic effects
   - C. Threshold effects
   - D. Nonthreshold effects

5. What is the guiding philosophy of radiation protection?
   - A. ALARMA—as long as radiographs are made accessible
   - B. ALARA—as low as reasonably achievable
   - C. ALAIS—as long as ionizations are small
   - D. ALAP—as low as possible

6. Which of the following changes decrease patient dose?
   1. Using faster screens
   2. Increasing collimation
   3. Using a shorter exposure time

   A. 1 and 2 only
   B. 1 and 3 only
   C. 2 and 3 only
   D. 1, 2, and 3

7. Males are 5% to 10% more sensitive to the harmfull effects of radiation than females.
   A. True
   B. False

8. The relationship between SID and beam intensity is expressed in the:
   A. proportional square law.
   B. inverse square law.
   C. reciprocity law.
   D. target-distance law.

9. A device for removing long wavelength radiation from the primary x-ray beam is a:
   A. collimator.
   B. rheostat.
   C. rectifier.
   D. filter.