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Prepared by: Carolyn J. Frigmanski, M.A., B.S.R.T. ®
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Conversion Table for the Units of Radiation Measurement

Traditional Name	Current Name	Measurement
Roentgen	Coulomb/kilogram	In air exposure
Rad	Gray	Radiation absorbed dose
REM	Sievert	Dose equivalent
Curie	Becquerel	Radioactivity

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UNIT NUMBER 8

CELLULAR AND MOLECULAR BIOLOGY

PREPARED BY: CAROLYN J. FRIGMANSKI, M.A., B.S.R.T. (R)

INTRODUCTION

In this unit we will start out with the very elementary component of our bodies, the cell, and discuss the category of macromolecules found within the human body. We will also discuss the theories relative to cellular and molecular damage from radiation in both somatic or general body cells and reproductive or sex cells.

CELL PROLIFERATION

As we all know, cells form tissues; tissues form organs; organs form systems; and systems form bodies. This process requires the proliferation of cells. Cell proliferation is the act of a single cell or a group of cells reproducing and multiplying in number. There are two categories of cell proliferation in the human body.[1(p457)] Mitosis involves cell division for somatic cells. Somatic cells are general body cells such as skin, muscle, hair, etc. The second category is meiosis. Meiosis involves the process of cell division for genetic cells. The genetic cells are the oogonium in females and spermatogonium in males.

MITOSIS

Mitosis is commonly described as a multiplication division of general body cells. It has been well established that cells go through five stages in mitosis. The first stage is interphase. It involves the growth period of the cell between its divisions.[1(p458)] It is in this stage that DNA takes the form of a chromosome. Prophase involves the swelling of the nucleus and DNA becomes more prominent. Metaphase involves chromosomes lining up at the equator or mid portion of the cell. Since the chromosomes are concentrated at the equator, it is very easy to microscopically examine the chromosomes when evaluating radiation-induced damage.

Anaphase involves each chromosome splitting at the centromere so that the centromere and two chromatids are connected by spindle fibers to the poles of the nucleus.[1(p458)] The chromatids begin their migration to the respective halves of the cytoplasmic filled shared cell membrane. Telophase involves the disappearance of the chromosomes as individual identities and a mass of DNA is seen. The nuclear membrane invaginates or closes off with half the cytoplasm and cell organelles moving into each of the daughter cells.

The average time from one mitosis to another in human cells is approximately 10-20 hours. This time period is referred to as a cell cycle or generation time. Cells that are undergoing mitosis are more sensitive to radiation damage than cells not in mitotic stages.

MEIOSIS

Meiosis is generally considered and described as a reduction division. The primary germ sex cell has 46 chromosomes or 23 pairs just like the somatic cell.[1(p458)] These germ cells go through the various stages of mitosis and produce two daughter cells, each containing 46 chromosomes. However, unlike mitosis, a second cell division occurs in which the two daughter cells divide and produce four granddaughter cells that now have 23 chromosomes each. The reduction from 46 to 23 chromosomes is important because the other compliment of 23 chromosomes must be completed by the opposite sex cell when fertilization occurs.

COMPONENTS OF THE CELL

The nucleus is a specialized structure composed of karyoplasm that contains the chromosomes that controls biochemical reactions that occur within the cell and reproduction (mitosis) of the cell.[1(p456)] Within the nucleus is found one or more masses; nucleoli made of loosely bound granules of RNA that are not enclosed by a membrane. The nucleus is enclosed by an envelope composed of two membranes that contain small pores and serve as a barrier to most molecules, but RNA passes to the cytoplasm through these pores. The mammalian cell nucleus is more sensitive to ionizing radiation than is the cytoplasm.

Cytoplasm surrounds the nucleus and makes up the bulk of the protoplasm of the cell.[1(p456)] Suspended within the cytoplasm are membrane bound structures. These structures called organelles include the endoplasmic reticulum, Golgi apparatus, mitochondria, ribosomes and lysosomes.

(1) Endoplasmic reticulum consists of a network of tubules or channels that interconnects with the nuclear envelope and the cytoplasmic or plasma membrane.[1(p456)] There are two types of endoplasmic reticulum, granular and smooth. Granular type has ribosome particles bound to the membrane for the synthesis of proteins that are to be secreted from the cell. Smooth type membrane has no ribosomes attached; however, fatty acids and steroid synthesis takes place. Calcium ion storage that is released in muscle cells during contractions occurs in this type.

(2) Golgi apparatus is believed to originate from the endoplasmic reticulum and consists of a series of flattened sacs or vesicles in close proximity to the nucleus. The contents of the vesicles are concentrated and a sugar may be added to the protein in the vesicle forming a secretory granule. These granules migrate from the Golgi area to the cytoplasmic membrane where they are released from the cell by a process of exocytosis.

(3) Ribosomes are concentrated aggregations of RNA and proteins.[1(p456)] Protein synthesis takes place here as the ribosomes are attached to a membrane of the rough endoplasmic reticulum and are transported to the Golgi apparatus for processing.

(4) Mitochondria are the real "power houses" of the cell.[1(p456)] We find oxidative enzymes for the breakdown of fatty acids and glucose and also enzyme systems for the production of adenosine triphosphate (ATP). Mitochondria exhibit a double membrane. The outer portion is smooth and surrounds the mitochondrion itself. The inner membrane folds at intervals into a central portion forming partial partitions known as cristae. It is the major site for ATP production, oxygen utilization and also enzymes of Krebs cycle and oxidative phosphorlation.

(5) Lysosomes are membrane bodies containing digestive enzymes.[1(p456)] These enzymes are hydrolytic in nature and can breakdown organic compounds. They play an active role in phagocytosis in White Blood Cells. "Autolysis" occurs in dying worn-out cells when the membrane ruptures and the enzymes destroy the cellular material.

Please refer to the diagram at the conclusion of the unit.

FOUR PHASES OF A CELL CYCLE

There are three additional phases in the life cycle of a cell. The first is called G1 that represents gap-1 or a pre-DNA synthesis phase.[1(p458)] The S phase means that DNA has been synthesized or replicated in two identical DNA molecules. The last phase is called G2 or gap-2 that indicates the post-DNA synthesis period. We know that cells in mitosis are very radiosensitive. The G1-S phase is the next most radiosensitive. In the late S phase the cell is most resistant to radiation injury.

FIVE PRINCIPAL TYPES OF MACROMOLECULES

Macromolecules are made of hundreds of thousands of atoms that form the most complex proteins and carbohydrates to the simplest and most abundant macromolecule, water. Proteins, lipids and carbohydrates are organic molecules that are necessary for life and contain carbon. The rarest of the macromolecules is DNA.[1(p471)] DNA is found in the nucleus. It is the most critical and radiosensitive of the five macromolecules. Water, which is found in 80% of our bodies, contributes to radiation effects by delivering energy to the essential target molecules. This process is referred to as radiolysis and will be discussed in a later heading.

PROTEINS

All proteins contain carbon, hydrogen, oxygen and nitrogen bound together by covalent bonds and most proteins contain some sulfur.[1(p453)] Certain proteins contain small amounts of phosphorous. The basic building blocks for proteins are the 22 amino acid molecules. The covalent bonds formed between amino acid molecules during protein synthesis are called peptide bonds. An amino acid contains a carboxyl group (-COOH) which gives it acidic properties; an amino group (-NH2) which gives it basic properties, a hydrogen atom, and a group of atoms designated the R-group. All are bonded to a central carbon atom. The atoms in the R-group distinguish one amino acid from another and give it specific characteristics.

The generalized formula for amino acids is

$$\begin{array}{c} R \\ | \\ H_2N - C - COOH \\ | \\ H \end{array}$$

Amino acids are combined by dehydration synthesis to form polypeptide or protein chains. Proteins are composed of at least 100 amino acids and a different number of polypeptide chains. Polypeptides and proteins are broken down to smaller peptide chains and to amino acids in the reverse reaction of hydrolysis.

The primary structure of a protein molecule is determined by the sequence of amino acids in the polypeptide chain.[1(p453)] Hydrogen bonding in the polypeptide chain provides the secondary structure of the molecule.

The ability of the proteins to perform their functions depends on their shape.[1(p454)] If the hydrogen bonds that maintain the protein's shape are broken, the protein becomes nonfunctional. Denaturation of protein molecules is due to the change in its shape. Since many protein functions depend on surface interactions, any change in protein structure will change the specificity of the protein; i.e. the chemicals with which it can interact.

PROTEIN SYNTHESIS

Normal cell structure and function (anatomy and physiology) would not be possible without proteins. Proteins form the cytoskeleton and other structural components of the cell and function as transport molecules, receptors, antibodies, and enzymes.

Since enzymes control the metabolic processes that enable cells to survive, the cells must possess information for producing specialized proteins. This information is held in DNA molecules in the form of a genetic code.[1(p457)] This coded information instructs cells how to synthesize specific protein molecules. The part of a DNA molecule that contains the genetic information for making one kind of protein is called a "gene". The genes instruct the cells to synthesize the particular enzymes needed to control metabolic pathways.

The DNA molecules are located in the chromatin within the cell's nucleus. Protein synthesis occurs in the cytoplasm. This transfer of information is the function of certain RNA molecules.

One kind of RNA is called a messenger RNA and its function is the transfer of information from the nucleus to the cytoplasm where ribosomes can use this information in the copy to construct a protein.[1(p457)] The substances need amino acids.

Ribosomes are the sites at which proteins are synthesized.[1(p456)] Protein is a large molecule that performs a multitude of structured and functional roles in living organisms. When the ribosomes are attached to the endoplasmic reticulum, the synthesized protein is released into the lumen between the reticular membranes. From this point the protein is eventually released to its exterior of the cell in the process of protein secretion.

CARBOHYDRATES/SACCHARIDES

Carbohydrates supply much of the energy needed by the cells.[1(p454)] Simple sugar molecules serve as the building blocks for carbohydrates and certain cell structures.

Carbohydrate molecules contain atoms of carbon, hydrogen and oxygen.[1(p454)] These molecules usually have twice as many hydrogen as oxygen atoms. The ratio of the number of H atoms to the number of O atoms is usually 2:1 (like water = hydrate). The monosaccharides are the basic building blocks of other carbohydrates. The carbon atoms of carbohydrate molecules are joined in chains whose lengths vary with the kind of carbohydrate. The short length chains are called sugars. A simple sugar (monosaccharide, glucose, fructose, galactose) combine by dehydration synthesis to form disaccharides (maltose, sucrose, lactose) and polysaccharides (starch in plants, glycogen in animals).

Polysaccharides are digested to disaccharides and monosaccharides by hydrolysis.

The basic function of carbohydrates is to provide fuel for cellular metabolism.[1(p454)] Glucose is the molecule that supplies the body with energy. Fats and proteins must be catabolized into glucose before they can be used as fuels for cellular metabolism.

LIPIDS

Lipids are organic molecules that are insoluble in water. These molecules contain a smaller proportion of oxygen than in carbohydrates. The lipids are insoluble in water because their chemical structure contains few polar chemical bonds that can interact with polar water molecules. Lipids supply energy for cellular activities, serve as thermal insulators to the environment and fuel for the body by providing energy stores.[1(p454)]

The lipids include triglycerides, made of fatty acids and glycerol, phospholipids, steroids and fat-soluble vitamins.[1(p454)]

Triglycerides can have one, two or three fatty acids attached to the glycerol molecule. Fatty acids are straight chains of carbon molecules of varying lengths which may be saturated (only single covalent bond between carbon atoms) or unsaturated (one or more double covalent bond between the carbon atoms). Fatty acids contain a carboxyl group (-COOH) which is a characteristic of organic acids. In dehydration synthesis the hydrogen atom from a hydroxyl group on the glycerol combine with the hydroxyl group of a fatty acid to form a molecule of water. This reaction forms a monoglyceride (monocylglycerol).

The diglycerides and triglycerides are a combination of two or three fatty acids and glycerol.

Phospholipids are lipids in which a fatty acid is replaced by a phosphate- containing molecule. Phospholipids are a major structural component of cell membranes and present in all tissues.

Steroids are lipids composed of four interconnected rings of carbon atoms that are fused together, giving the molecule a rigid structure. Attached to this ring are chemical groups or short hydrocarbon chains. Very few polar groups are present, hence insoluble in water.

Cholesterol is a steroid and is a precursor of steroid hormones, estrogen and testosterone, the sex hormones.

Adrenal hormones-cortical and aldosterone are adrenal cortical hormones.

DNA

Nucleic acids are complex molecules that serve as building blocks called nucleotides that are responsible for the storage of genetic information in DNA.[1(pp454-455)] There are two types of nucleic acids: DNA-deoxyribonucleic acid and RNA-ribonucleic acid.

DNA nucleotides contain a monsaccharide with an attached phosphate group and organic base.[1(p455)] The DNA (deoxyribonucleic acid) contains the monosaccharide deoxyribose and a ring of carbon and nitrogen atoms known as a base. Four different nucleotides are present in DNA, corresponding to the four different bases that may be attached to the deoxyribose. The four bases are classified (1) purine bases, adenine and guanine which have two rings of nitrogen and carbon atoms and (2) the pyrimidine bases, cytosine and thymine which have only one ring of nitrogen and carbon. The phosphate group of one nucleotide is linked to the sugar of the adjacent nucleotide to form a chain with the bases attached to the outside of the sugar-phosphate backbone.

A DNA molecule consists of two chains of nucleotides coiled around each other to form a double helix.[1(p456)] The two chains of nucleotides are joined by weak hydrogen bonds that form between the purine base on one chain and the primidine base of the other chain. It is the sequence of bases in the DNA molecules that the coded information for all protein synthesis is located.

Each chain of the DNA molecule may serve as a template for the formation of a new DNA molecule. The replication is possible when the two chains become untwisted and separate, as the weak hydrogen bonds are broken. DNA nucleotides become attached to the nucleotides on the DNA chain by complementary base pairing. The DNA nucleotides are linked together by enzymatic action (DNA polymerase) to form a new chain. Bases on the new chain are linked to complimentary bases on the old chain by hydrogen bonds. A new DNA molecule is thus formed as a duplicate of the original.

DNA controls cell function and all the hereditary information representing the cell or the whole individual, RNA is essential for protein synthesis. There are several differences between DNA and RNA. The DNA sugar is deoxyrobose and RNA is Ribose. DNA is found in the nucleus and RNA is found in the nucleus and the cytoplasm. DNA is double spiral and RNA is a single spiral with uracil replacing thymine.

WATER

Water forms the medium in which all living processes occur and life as we know it would be inconceivable in the absence of this molecule (H_2O). The chemical reactions that occur continuously within the body involve chemical reactants that are in aqueous solutions.

Water is an ideal solvent. Water is the most abundant molecule in our body: 99 out of every 100 molecules are water molecules. The primary role of water in the body is to provide a fluid medium in which chemical reactions can occur. Water also directly participates in many chemical reactions.

A dehydration reaction is a synthesis reaction as water is produced; a hydrolysis reaction is a decomposition reaction as water molecules are depleted.[1(p453)]

Water can mix with other substances to form solutions, suspensions and colloids. A solution is any liquid that contains non-dissolved substances that will settle out of the liquid; a colloid is a liquid that contains non-dissolved substances that do not settle out. In all living organisms the intracellular and extracellular fluids are very complex consisting of solutions, suspensions and colloids. Water molecules exist in the free state or disassociated state and/or bound to other molecules forming a structural relationship.

Water plays a vital role in maintaining the homeostatic state. Without water "stasis" would result and a diseased state would ensue and ultimately death would be the end result.

RADIOBIOLOGY

Radiobiology involves studying the effects of ionizing radiation on biologic tissues.[1(p463)] Over the last century, since the discovery of x-rays, biological effects of radiation have been observed, documented, recorded and verified for most of the human body systems. Radiation effects can be identified as early or immediate. The effects will occur within minutes and/or days after the initial exposure. A classic example of an immediate effect of radiation would be a sunburn when you have subjected yourself to cosmic radiation for a prolonged period of time. The second type of radiation effect is referred to as late or delayed. The radiation effect is not observed for many months and/or years. We sometimes refer to this delay in manifestation of symptoms as a "latent" period because it is invisible until it manifests later. An example of a late or delayed effect of radiation would be the development of leukemia in the Atomic bomb survivors 20 years later.

TARGET THEORY

Since we have observed and documented the effects of radiation on tissue, it was essential for us to provide some rational and scientific explanation on how this occurs. The target theory states that cell death occurs when a target molecule that is essential for normal function of the cell is inactivated.[1(p474)] The most critical of all the target molecules in the cells' activity and growth is DNA in the nucleus. A direct effect occurs when the initial ionizing event occurs in the target molecule itself. Cytoplasm has a great deal of molecules contained it. Radiation or an ionizing event can occur in one of these molecules. The non-critical molecule may transfer the energy to the target molecule. When this process occurs, it is considered an indirect effect because the target molecule was not inactivated by the initial ionizing event.

TWO TARGET THEORY MODELS

In the single-target, single-hit model the cell has one vital target which is injured by an ionizing event and inactivated.[1(p476)] There is a statistical law, called the Poisson Distribution, which explains the random interaction of radiation photons in comparison to the number of targets that are available in the cell. This law provides a quantifying explanation that 63% will be killed and 37% will survive.

In the multi-target, single-hit model the cell has various targets but only one target is hit by the ionizing event.[1(477)] Because there are more targets, more of them will survive at low radiation doses; however, less will survive at high radiation doses since the opportunity for more targets to be hit at least once will occur.

RADIATION EFFECTS ON MACROMOLECULES

We know that DNA, proteins, carbohydrates, and lipids are formed by the connection of smaller units in long chains. An ionizing radiation event may break the thread or backbone of a long chain of molecules. This is an example of main-chain scission. Some radiation events will produce small spur-like molecules. These spurs will extend up the main chain and connect in a pattern that no longer replicates the parent molecule. This process is called cross-linking.[1(p470)] The last and most important effect of radiation on macromolecules is termed a point lesion. A point lesion is the breakage of a single chemical bond which, at low radiation doses, is considered to be the cellular radiation damage that results in late effects.

RADIATION EFFECTS ON DNA

As we all know, DNA is a double-helix structure made of sugar and phosphates along its strand with nitrogenous bases partnered together as the rungs of the ladder. When radiation or ionizing events occur, one or both sides of the DNA molecule may be severed.[1(p472)] This is main-chain scission just as it was in the other macromolecules.

Cross-linking and rung breakage causing separation of the nitrogenous bases can also be produced by ionizing events that occur on the internal structure of the DNA molecule. The previous radiation insults can be reversed.

The last of these effects from radiation is most critical because it is not reversible. In a point mutation there is a change or loss of a nitrogenous base in the DNA.[1(p473)] Since DNA replicates identical daughter DNA molecules, the changed or altered DNA will replicate the alteration as well. We call it a mutation. Some mutations do not result in any harm to the individual. However, point mutations can cause genetic mutation in future generations.

Some of the observable effects of radiation on DNA include cell death, induction of malignant disease and genetic damage.

RADIOLYSIS OF WATER

Because our body is predominantly water, we have many water targets available for radiation insult.[1(p473)] It becomes the primary radiation interaction in the body. As we all know, water is comprised of two hydrogen atoms each containing one electron and one oxygen atom which contains eight electrons. When a water molecule is subjected to an ionizing event, it is altered by the production of a free radical. A free radical is an uncharged molecule that contains a single unpaired electron in the outermost shell. This free radical is highly reactive and unstable. It can diffuse through the cell and transfer its excess energy to other surrounding molecules by disrupting their bonds and producing point lesions. One of the major free radical combinations includes Hydrogen Peroxide that is poisonous to the cell. Many scientists believe it produces the commonly identified symptoms of "radiation sickness". Another free radical combination includes the production of hydroperoxol. Both of these chemical interactions produce the principal damaging products in our cells and jeopardize cell viability.

Water is the most abundant substance in our cellular composition. Water is located both intracellularly and extracellularly. Water as found in our body contains large amounts of free and unbound molecules. Ionizing radiation passing through our cellular composition can interact with the water molecules and eject electrons producing an ionized state.

$$H_2O$$

The ejected electron could react or combine with a neutral molecule of water:[1(p473)]

$$H_2O + e-$$

The water molecules (ionized) dissociates:[1(p473)]

$$H_2O + H_2O -$$

These water molecules (ionized) are unstable and dissociate very rapidly forming other ions (H+ and OH -) and free radicals (H° + OH°) which are electrically neutral, but are very reactive.[1(p474)]

Free radicals can react with water molecules, organic molecules and oxygen molecules. Some reactions produce toxic products i.e. hydrogen peroxide (H_2O_2) which can be lethal to certain cells.

The biological effects of ionizing radiation can be traced to the alteration of chemical bonds. The most critical site of damage occurs within the cell's DNA molecules.[1(p474)]

The chemical combinations or products of the radiolysis of water can be summarized as:

OH• = hydroxyl radical
e- (aqueous)
H+ (H_3O+)
H_2O_2 = hydrogen peroxide
H•
H_2
$O•_2$- = superoxide radical
$HO•_2$ = hydroperoxy radical

EFFECTS OF X-RAYS IN TISSUE

When we expose the patient to radiation, we are in effect ionizing and depositing energy in their tissue. This deposited energy can result in molecular changes such as the main-change scissions we had discussed earlier or the relocation of an atom in the molecule. This abnormal molecule may function inappropriately or cease to function totally. If significant changes occur, the consequences may be measurable and observable. The results of the interactions of radiation in living tissue occur at an atomic level. This process may be reversible with mechanisms for recovery and repair by enzymes. When atoms become ionized, they will have a tendency to become electrically neutral again.

LAW OF BERGONIE AND TRIBONDEAU

In 1906, two French scientists named Bergonie and Tribondeau postulated the law of radiosensitivity of living tissue that holds true today. The law states that stem cells are more radiosensitive than mature cells.[1(p463)] The younger the tissues and organs are, the more radiosensitive they are. When the level of metabolic activity is high, radiosensitivity is high and as the proliferation and growth rate increases in cells, their radiosensitivity correspondingly increases. These fundamental concepts explain why it is so critical for radiographers to use extreme caution and apply protective measures for pregnant women, in addition to, radiation exposures to children. Radiosensitivity is influenced by the function of the organ in the body, the rate at which the cells mature in an organ, and the inherent radiosensitivity of the cell type. A chart has been included for your reference that lists cell types from most radiosensitive to those least radiosensitive. A brief description of the cells is also provided. Please refer to the chart at the conclusion of the unit.

PHYSICAL FACTORS

We know that different types of radiation have exposed different body tissues. There are two major physical factors that influence the degree of radiation effect on these tissues. The first is described as linear energy transfer or LET.[1(p463)] It is a measurement of the rate at which energy is transferred from ionizing radiation to soft tissue. Increasing LET increases biologic damage. An example would be an alpha particle that is a helium nucleus and a very large particle. It can transfer a large amount of energy in soft tissue. A beta particle is much smaller in size and transfers less energy to surrounding soft tissue.

The second factor is called relative biological effectiveness or RBE.[1(p463)] It is simply a formula that is used to compare the effects from various types of radiation on biological tissue.

$$\text{RBE} = \frac{\text{dose of standard radiation to produce a given effect}}{\text{dose of test radiation necessary to produce the same effect}}$$

An example of utilizing relative biological effectiveness is taking two types of radiation and exposing the same biological tissue or organism to produce death. Let's say we took two-week-old white mice and exposed them to 500 Rads of x-radiation and they all died. We could take another type of radiation, for example, alpha particles, and expose them to varying amounts of alpha particle radiation. We then measure the number of Rads that produce death in these mice. A simple comparison would be made as shown below.

RBE example (This is a hypothetical example)

$$\frac{\text{500 Rads of x-radiation}}{\text{250 Rads of alpha particles}} = 2.0 \text{ RBE}$$

BIOLOGICAL FACTORS

Tissues will respond differently to the different types of radiation. One of the factors is called the oxygen enhancement ratio or the OER.[1(p464)] It has been proven that biologic tissues are much more sensitive to radiation when irradiated in an oxygen state than in an anoxic (without oxygen) condition. It is interesting to note that some radiotherapy departments are placing their patients in a hyperbaric chamber that provides an oxygen-enriched environment. After they are in the hyperbaric chamber for a period of time, they are placed on the radiation therapy table for their radiation dose. They are trying to optimize the effects of oxygen enhancement and increased radiosensitivity in efforts to kill or damage more of the cancerous tissue.

The second factor is age.[1(p465)] Human beings are most radiosensitive before birth than at any period in their life cycle. However, it is interesting to note that as we become senior citizens or experience older age, our biological tissues become more radiosensitive than when we were mature adults.

Gender is also a factor. Females are able to sustain an estimated 5-10% more radiation than males.

DOSE-RESPONSE RELATIONSHIPS

Dose response relationship is a mathematical relationship that provides information about different radiation doses and the magnitude of the observed response.[1(p466)] This information is displayed on the graph. When looking at a dose response graph, it is important to identify two characteristics. The first is deciding whether it is a linear or nonlinear response. For example, if the graph provides a straight line, it indicates that the response to radiation is directly proportional to the dose. A nonlinear relationship to response may show a line which is curved and in a non-proportional relationship.

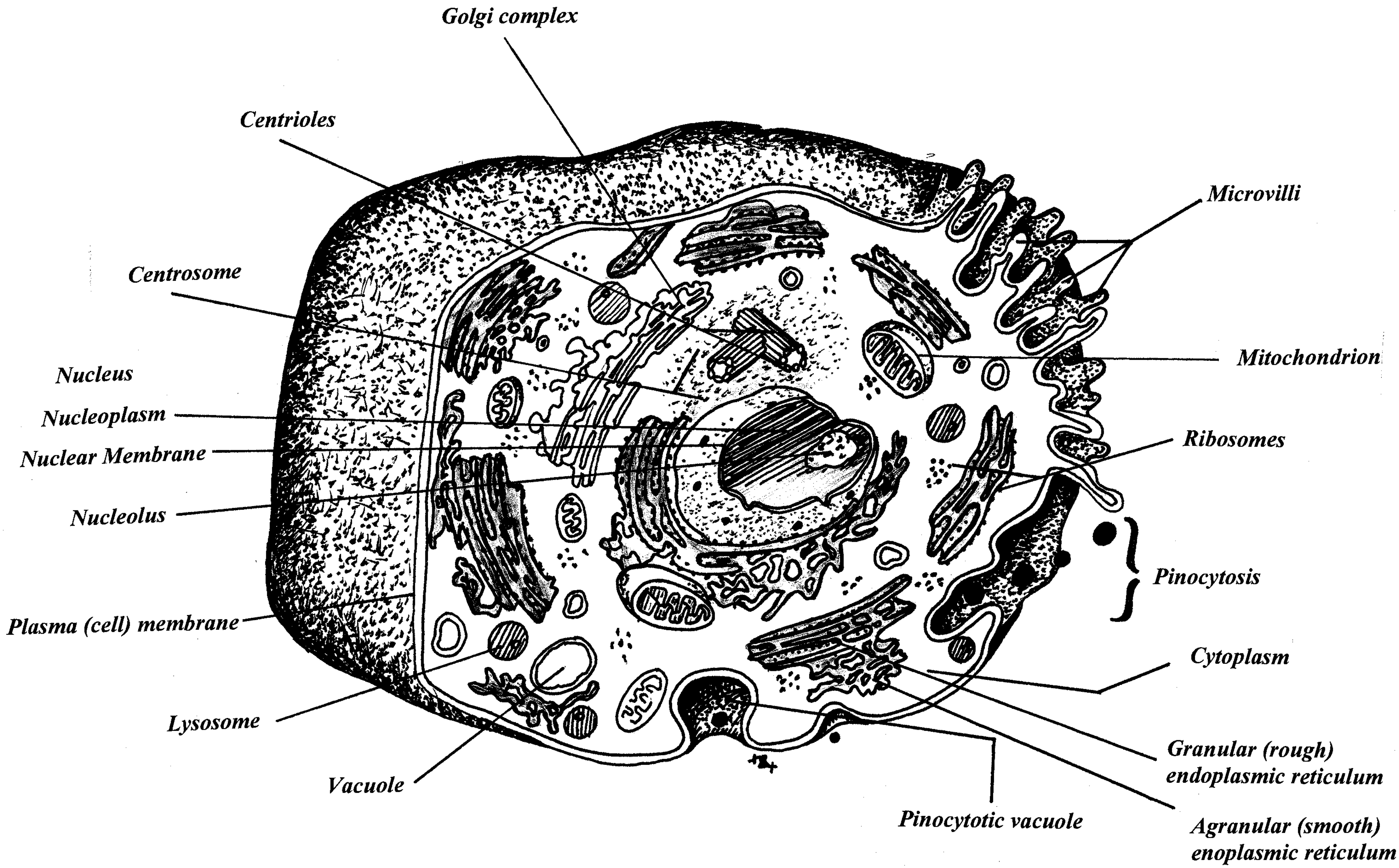
The second characteristic is to decide whether the dose is threshold or non-threshold in producing a biological response.[1(p467)] For example, the horizontal axis usually displays dose in Rads and the vertical axis usually describes response. If the line appears at the zero intersection, it indicates that any amount of radiation will produce a response in biological tissue (non-threshold dose). If the line begins at a certain number of Rads on the horizontal axis, it indicates that it is a threshold dose. A threshold dose means that the biological tissue can sustain a certain amount of radiation dose without manifesting a significant response that can be charted. Please refer to the charts at the conclusion of this unit.

In 1990, the Biological Effects of Ionizing Radiations (Beir) of the National Academy of Sciences determined that a linear, non-threshold model be utilized in establishing radiation protection guidelines. In other words, the effects of radiation doses are directly proportional to the responses in biological tissue and that any amount of radiation may produce a response.

This concludes Unit 8. Please proceed to the unit questions and complete the required personal data.

Atom	Estimated % in Body
Hydrogen	***60***
Oxygen	***25.7***
Carbon	***10.7***
Nitrogen	***2.4***
Calcium	***2.4***
Phosphorus	***0.1***
Sulfur	***0.1***
Trace atoms	***0.8***

Molecule	Estimated % in Body[1(pp452-453)]
Water	***80***
Protein	***15***
Lipid	***2***
Carbohydrate	***1***
Nucleic acid	***1***
Other misc.	***1***



Generalized Animal Cell based on Microscopic Study

(diagram courtesy of Mr. Ryan Landis, R.T. (R))

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The indirect effects of radiation on a macromolecule (**including water**) may be diagrammed as follows:

incident photon of radiation

↓

ionization of an atom with electron emission

↓

ion radical

↓

free radical that is very unstable

↓

interaction with macromolecule and the disruption of chemical bonds

↓

biological effects may manifest in hours, days, months or years depending on the critical nature of its function in the cell i.e.

if the cell dies, the biological effect will result when the cell attempts to divide;

if the radiation damage is carcinogenic, the biological effect may be delayed for many years; and

if the cell is genetic, a mutation, particularly a recessive type, may not be expressed for many generations.

indirect/a/word

Synopsized Listing of Cell Sensitivity and Function

Level of Sensitivity	Cell Type	Primary Function(s)
Highest	Lymphocytes	These white blood cells are the main means for providing the body with immune capability. There are 2 categories: "B" cells produce humoral immunity & "T" cells produce cell mediated immunity.
High	Spermatogonia	These spermatic cells are undifferentiated and contain 46 chromosomes in their nuclei. This cell is the first cell in the process of spermatogenesis. These cells divide mitotically to form several cell generations. At puberty, some hormones cause these cells to form primary spermatocytes which contain 46 chromosomes.
	Erythroblasts	These cells are derived from hemocytoblasts located in the red bone marrow. The erythroblasts have the ability to synthesize hemoglobin in their cytoplasm. The nucleus shrinks and is extruded from the cytoplasmic membrane and the cell is then called an erythrocyte (red blood cell).
	Intestinal Crypt	These cells are found between the bases of the small intestine villi. These are intestinal tubular glands that reach downward into the intestinal mucous membrane.
Intermediate	Endothelial	A tissue that lines the lymphatic vessels and the blood circulatory system. The circulatory system is lined with a thin layer of these cells of the squamous type which continues throughout the heart, arteries, capillaries and veins.
	Osteoblasts	These bone forming cells have the ability to secrete the organic matrix components as a precursor to fibrous protein collagen.
	Spermatids	These cells are formed from secondary spermatocytes that have undergone meiotic division producing cells that have 23 chromosomes. The spermatids gradually become transformed into spermatozoa (sperm).
	Fibroblasts	These cells are small, flattened and somewhat irregularly shaped with a large nucleus and little cytoplasm. These cells have the ability to produce/form fibrils.
Low	Muscle	Shortly after birth, these primary cells loose their ability to undergo mitosis after cellular differentiation. These cells can contract to produce motion or movement.
	Nerve	Shortly after birth, these primary cells loose their ability to undergo mitosis after cellular differentiation. These primary cells are highly specialized and found in the brain, spinal cord and nerves for conduction of impulses.
Lowest	Chondrocytes	These cells make up the cellular portion of cartilage. These cells put down the extracellular materials and then are enclosed in spaces called "lacunae".

Some Important Terms and/or Concepts in Unit 8

Cells form tissues; tissues form organs; organs for systems; and systems form bodies.

Cell proliferation is the act of a single cell or a group of cells reproducing and multiplying in number.

There are 2 categories of proliferation in the human body:

a. Mitosis involves cell division for somatic cells (general body cells). Mitosis is commonly described as a multiplication division of general body cells.

b. Meiosis involves the process of cell division for genetic cells (the oogonium in females and spermatogonium in males). Meiosis is generally considered and described as a reduction division.

The nucleus is a specialized structure composed of karyoplasm that contains the chromosomes that controls biological reactions and reproduction that occur within the cell.

Cytoplasm surrounds the nucleus and makes up the bulk of the protoplasm of the cell.

Dose response relationship is a mathematical relationship that provides information about different radiation doses and the magnitude of the observed responses.

Genes instruct the cells to synthesize particular enzymes needed to control metabolic pathways.

Carbohydrates supply much of the energy needed by the cells.

Lipids supply energy for cellular activities, serve as thermal insulators to the environment and fuel for the body by providing energy stores.

Nucleic acids are complex molecules that are responsible for the storage of genetic information in DNA.

Water forms the medium in which all living processes occur. The primary role of water in the body is to provide a fluid medium in which chemical reactions can occur.

Radiobiology involves studying the effects of ionizing radiation on biologic tissues.

Early or immediate effects radiation will occur within minutes and/or days after the initial exposure.

Late or delayed effects if radiation will not be observed for many months and/or years.

The target theory states that cell death occurs when a target molecule that is essential for normal function of the cell is inactivated.

A direct effect occurs when the initial ionizing event occurs in the target molecule itself.

An indirect effect occurs when a non-critical molecule transfers the energy to the target molecule.

In the single-target, single-hit model, the cell has one vital target which is injured by an ionizing event and inactivated.

In the multi-target, single-hit model, the cell has various targets but only one target is hit by the ionizing event.

A point lesion is the breakage of a single chemical bond which, at low radiation doses, is considered to be the cellular radiation damage that results in late effects.

Water becomes the primary radiation interaction in the body.

Free radicals can react with water molecules, organic molecules and oxygen molecules. Some reactions produce toxic products i.e. hydrogen peroxide (H2O2) which can be lethal to certain cells.

The most critical site of damage occurs within the cell's DNA molecules.

The results of the interactions of radiation in living tissue occur at an atomic level.

Bergonie and Tribondeau postulated the law of radiosensitivity of living tissue.

Linear energy transfer or LET is a measurement of the rate at which energy is transferred from ionizing radiation to soft tissue.

Relative biologic effectiveness or RBE is simply a formula that is used to compare the effects from various types of radiation on biological tissue.

Biologic tissues are much more sensitive to radiation when irradiated in an oxygen state than in an anoxic (without oxygen) condition.

Females are able to sustain an estimated 5-10% more radiation than males.

A linear, non-threshold model be utilized in establishing radiation protection guidelines. i.e. the effects of radiation doses are directly proportional to the responses in biological tissue and that any amount of radiation may produce a response.

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.

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UNIT NUMBER 9

BIOLOGICAL EFFECTS OF RADIATION EXPOSURE - ACUTE

PREPARED BY: Carolyn J. Frigmanski, M.A., B.S.R.T. (R)

INTRODUCTION

This unit is going to discuss the acute effects of radiation. Acute radiation exposure involves a large dose of radiation absorbed by the human being in a short period of time. Examples of this situation have occurred in nuclear power plant accidents, nuclear weapons testing, and in the atomic bombings of Hiroshima and Nagasaki over 53 years ago.

Single large doses of radiation to the whole body may result in serious radiation injuries. Massive exposures of 100 to 1000 rads may occur accidentally in atomic energy installations or deliberately in the treatment of some forms of cancer, particularly leukemia. Following whole body irradiation, leukemia patients are followed by compatible bone marrow transplants and chemotherapy.

We have gathered information about acute radiation lethality from the victims of the Atomic bombings on Hiroshima and Nagasaki in 1945.

Some accidental exposures of persons in nuclear weapons and nuclear energy fields have resulted in death. In 1979, the United States nuclear power plant at Three Mile Island had an accident that resulted in no deaths or serious exposure. In April 1986, the nuclear power plant at Chernobyl in the Ukraine had a serious accident that resulted in the death of 30-32 people from acute radiation syndrome with a significant number of other people who have experienced the later effects from radiation.

THE DEVELOPMENT OF THE ATOMIC BOMB

In 1938, a German chemist named Otto Hahn discovered nuclear fission, or atom-splitting process. During the first third of this century, Germany was pre-eminent in physics and was recognized universally as advanced in the applications of nuclear physics. The top German physicists in 1939 organized themselves into a group called the "Uranium Club" to develop an atomic bomb. Dr. Otto Hahn, Werner Heisenberg who won the 1932 Nobel prize in physics and Max Von Laue, another Nobel laureate in physics were among the elite members. An atomic bomb can be created by the sudden release of energy upon splitting of the nuclei of such heavy elements, such as plutonium or uranium. When a neutron strikes the nucleus of an atom of uranium-235 or plutonium-239, it causes the nucleus to split into fragments. Each fragment is a nucleus with about half the protons and neutrons of the original nucleus. In the process of splitting the original nucleus, thermal energy, as well as gamma radiation, are emitted in great intensity. This process is called fission. Under certain conditions, escaping neutrons strike and cause fission in more of the surrounding fragmented uranium nuclei. This situation creates an ongoing chain reaction of thermal energy and gamma radiation.

Enrico Fermi and a group of other scientists at The University of Chicago produced the first chain reaction on December 2, 1942. The efforts of United States scientists and physicists in the field of theoretical physics were escalated as World War II continued for several years with great numbers of casualties. The first atomic bombs were built in the United States at a site called Los Alamos in New Mexico during World War II under a program referred to as the "Manhattan Project". The U.S. military feared that Germany was developing its own atomic bomb to be dropped on London or Paris to give the Nazis a quick victory. J. Robert Oppenheimer, Enrico Fermi, and seven other theoretical physicists met in Los Alamos with the order to build the atomic bomb. In May of 1942, J. Robert Oppenheimer was delegated the sole person in charge of the project. The project expanded from a small group of physicists to 1,500 employees, 4,000 civilians, and 2,000 military personnel who lived in 500 apartments, dorms, and trailers. The Manhattan Project labs and scientific facilities consisted of 250 buildings.

In May 1945, the Alos mission took custody of nine members of the "Uranium Club" and brought them to Farm Hill, a large country house near Cambridge, England used by British Intelligence units. Alos was assigned the urgent task of determining the status of Nazi efforts to build an atomic bomb. Hidden microphones in every room and hallway recorded the scientists' conversations. British intelligence agencies refused to release the tapes for almost 50 years. Many believe superior attitude and vanity blinded the German scientists from placing more emphasis and urgency in the weapons development program.

The first Atomic Bomb was successfully tested on July 16, 1945 at a site 193 kilometers (120 miles) south of Albuquerque, New Mexico. This bomb used a plutonium nucleus. The first Atomic Bomb to be used in warfare was dropped by the United States on Hiroshima, Japan on August 6, 1945. This Atomic Bomb, nicknamed the "Little Boy", used Uranium -235. The force of the explosion was equivalent to more than 15,000 tons of TNT. The bomb completely devastated 10 square kilometers (4 square miles) of the heart of Hiroshima which was occupied by 343,000 inhabitants. Of this number, it is estimated that 66,000 were killed immediately and

69,000 were injured. There are estimates that more than 67% of the city's structures were destroyed or damaged.

The second Atomic Bomb was dropped on Nagasaki on August 9, 1945 and used Plutonium-239. The force of this blast equaled 21,000 tons of TNT. The smaller size of Nagasaki reduced destruction to approximately 39,000 persons killed and 25,000 injured. It is estimated that 40% of the city's structures were destroyed or seriously damaged. The consequences and devastation of these two atomic bombs prompted the Japanese to begin surrender negotiations the following day.

In the late 1940's and in the 1950's, the United States continued to conduct dozens of test explosions of atomic bombs in the Pacific and in Nevada. By January of 1950, the President of the United States announced the start of hydrogen bomb production.

HIROSHIMA

Hiroshima is the capital of southwestern Honshu, Japan, on Hiroshima Bay on the Inland Sea. It was originally founded as a castle town in the 16th Century. From 1868 through the period of the World War II, it became a military center. It was the first city to be struck by an atomic bomb. The city had previously been spared earlier in the war because it was viewed as a religious city with many Buddhist believers. The American military could accurately calculate the full effects of the Atomic bomb since it had not been previously damaged by earlier bombings. It was strategically a major military city. The Aioi Bridge was an unusual T-type bridge and the target for the first Atomic Bomb. In addition to the natives of Hiroshima, there were several thousand Koreans working as forced-laborers in the armament factories, foreign students from southeast Asia and some American POW army pilots who had been shot down earlier in the war years.

The Atomic Bomb, nicknamed the "Little Boy", weighed 9,000 pounds and used all the uranium produced in the Manhattan Project. It was the only bomb to be used without appropriate testing. It was dropped from a B-29 aircraft named the Enola Gay. The Enola Gay was escorted by two additional B-29 bombers, one carrying cameras and the other blast measuring instruments. It took approximately 43 seconds for the "Little Boy" to descend on Hiroshima. The explosion occurred 570 meters above the ground with a light blue flash. The diameter of the fireball was 100 meters with a central temperature of 300,000° Celsius. Black and white smoke covered the whole city and rose thousands of kilometers high into the clouds. The pressure of the blast has been estimated to be 4.5-6.7 tons per square meter. The fires continued for two days with large black drops of rain containing mud, ash, and other radioactive fallout materials. As previously mentioned, most of the city was destroyed. Estimates of the number killed ranged from 70 to 100,000. Deaths from radiation poisoning have mounted through the years. In 1947, the Atomic Bomb Casualty Commission was established to conduct medical and biological research on the effects of radiation. This Commission established five public hospitals and 40 private clinics to give free treatment to victims of the bombing.

Hiroshima has become a spiritual center for the peace movement to band atomic weapons. Peace Memorial Park contains a museum and monuments dedicated to those killed. The cenotaph for victims of the bombing is shaped as an enormous saddle, resembling the small clay saddles placed in ancient Japanese tombs. It contains a stone chest with a scroll listing the names of those killed. Atomic Bomb Memorial Dome is the remains of the only building to survive the blast.

NAGASAKI

Nagasaki is in the northwestern portion of Kyuhu, Japan, facing the East China Sea. It is dominated by mountains, has limited agriculture, a fishing industry, ship building, and a naval base at Sasebo. It is Japan's second oldest port that was opened to foreign trade. On August 9, 1945, the second Atomic Bomb, named the "Fat Man", weighed 10,000 pounds and was dropped on the city. The "Fat Man" used the plutonium nucleus since it was made chemically with the more plentiful uranium-235. The B-29 aircraft that carried this bomb was called "Bock's Car". At 1:02 a.m., the bomb was dropped from 27,000 feet and landed on the Urakami district that was occupied by approximately 15,000 Japanese Catholics. The Nagasaki Medical College, in addition to other schools and public buildings, was located in the district. This district also served as a site for munitions and other factories. About 40% of the city was destroyed. The estimate of the casualties was between 37-39,000 persons killed instantly with approximately 25,000 injured.

On August 15, at noon, the Emperor of Japan signed a formal surrender aboard the battleship U.S.S. Missouri. Deaths by the end of 1945 were 70,000 and deaths by 1950 recorded 140,000 people.

Since World War II, the city has been rebuilt and is significant as a spiritual center for movements to band nuclear weapons very much like Hiroshima. Peace Park, on the Urakami-Gawa, was established under the point of detonation of the bomb.

THE AFTERMATH OF THE ATOMIC BOMBINGS

On the first anniversary of the conclusion of World War II, a "Peace Revival Festival" was organized by the citizens of Hiroshima. On August 6, 1947, the Mayor of Hiroshima read the first "Peace Declaration". In September of 1949, the Soviet Union proclaimed possession of an A-bomb as well.

In January of 1950, the United States began the development of hydrogen bomb production. By May of 1950, the Korean War had broken out. In August 1966, scientists at the Research Institute for Nuclear Medicine and Biology of Hiroshima University recovered information and reproduced a scale model of the city with the location of the residents at the hypocenter area so that they could establish more scientific data on the tragedy of the inhabitants of the city. This organization reported its findings in 1975 to the United Nations as an appeal to ban nuclear weapons in the world.

THREE-MILE ISLAND

Three Mile Island is a nuclear power station situated on the Susquehanna River near Harrisburg, Pennsylvania. At 4 a.m. on March 28, 1979, an automatically operated valve in the Unit 2 reactor mistakenly closed, shutting off the water supply to the main feed water system. This caused the reactor core to shut down automatically. A series of equipment and instruments malfunctions, human errors in operating procedures, and mistaken decisions in the ensuing hours led to a serious loss in the water coolant from the reactor core. As a result, the core was partially exposed. The zirconium cladding of its fuel reacted with the surrounding superheated steam to form a large accumulation of hydrogen gas. Some of the hydrogen gas escaped from the core into the containment vessel of the reactor building. In the following days, adequate coolant water circulation in the core was restored.

This is considered the most serious nuclear power accident in U.S. history. There was very little radioactive gases actually escaping into the atmosphere during those several days. There was no threat to the surrounding population from radiation injury. Cleanup continued until 1990. Fifty-two per cent (52%) of the core melted down and has remained unusable.

The results of this incident prompted the immediate and temporary closing of seven operating reactors like Three-Mile Island. A moratorium on licensing of all new reactors was temporarily imposed. The whole process of approval for new plants by the Nuclear Regulatory Commission was significantly slowed down for years. No new reactors were ordered by utility companies from 1979 through the 1980's. It increased public fear about safety of nuclear power plants and it strengthened public opposition to new power plant construction.

CHERNOBYL

Chernobyl is considered the worse accident in the history of nuclear power generation in the world. The Chernobyl Station is situated at the settlement of Pryp'Yat which is located 10 miles northwest of the city of Chernobyl and 65 miles north of Kiev in the Ukraine. The station consisted of six reactors, two of which were never completed. The design of the reactor is the outdated RBMK type, which are considered unstable at low power. Each reactor was capable of producing 1,000 megavolts of electric power. The station came on line in the years 1977 through 1983. On April 25 and 26, 1986, a technologist at reactor Unit 4 attempted a poorly designed experiment. Workers shut down the reactor's power regulating system and its emergency safety system. They withdrew most of the control rods from the core that allows the reactor to continue running at 7% power. Most Western reactors use water to moderate the amount of atom splitting within the reactor. When the water flow is increased, nuclear activity speeds up whereas when water flow is decreased, the nuclear activity slows down. The reason RBMK types are unstable at low power is that the graphite moderator surrounds vertical tubes that hold the nuclear fuel and water that will be boiled into steam. The designers of Chernobyl did not realize that when the amount of water in the reactor is dramatically decreased, the graphite control rods have almost no impact on the nuclear activity. Also, they did not encase the reactors in massive concrete and steel containment domes to minimize any radiation spills.

At 1:23 a.m. on April 26, a chain reaction in the core went out of control. Several explosions triggered a large fireball and blew off the heavy 1,000-ton concrete lid of the reactor. This, and the ensuing fire, released 180 tons of radioactive iodine gas into the atmosphere where it was carried great distances. A partial meltdown occurred. On April 27, 30,000 inhabitants of Pryp'Yat were evacuated.

A cover-up was attempted. On April 28, a Swedish monitoring system reported high levels of wind-transported radioactivity and the world was finally informed of the accident. On May 4, heat and radioactivity leaking from the core were finally contained at a great expense to the workers. Radioactive debris was buried at approximately 800 temporary sites. Later that year, the highly radioactive reactor core was enclosed in a concrete and steel sarcophagus, which is currently deemed structurally unsound, and under daily monitoring for possible radiation leaks in addition to its explosive capability.

There were 32 immediate deaths, mostly firefighters, with dozens contaminated from radioactive fallout. Others contracted radiation sickness and died later. Between 50-185 million Curies of radionuclide escaped into the atmosphere. It was estimated to be several times more radioactivity than the Atomic Bombs delivered at Hiroshima and Nagasaki combined. The radioactive fallout exposed five million people and spread over Belarus, Russia, the Ukraine, and as far west as France and Italy. Millions of acres of forests and farmland were contaminated while hundreds of thousands of people remained in the contaminated areas. In subsequent years, livestock have borne deformed offspring. Several thousand radiation-induced illnesses and cancers in humans have been discovered and documented as a result of this nuclear power disaster.

Others who helped in the cleanup at Chernobyl have had an increased incidence of cardiovascular and gastrointestinal disease and cancers of the stomach and lungs. Dr. Alex Nikiforov, director of the Russian Centre of Ecological Medicine stated, "It is as if they are suffering from accelerated aging. They have roughly the same diseases as anybody else, but the diseases occur with higher frequency and in a more acute manner."

The most noted illness as a result of Chernobyl disaster is an increase in thyroid cancer, especially in children. Researchers have been screening residents of regions with the most fall-out radiation. This radiation was passed onto people mainly through the milk of cows who ate foliage contaminated with radioactive iodine and through vegetation grown in contaminated soil. The rates of thyroid cancer has climbed from approximately 0.7 per million children in 1986 through 1988 to 3.7 per million in 1993. Rates increased most in regions closer to Chernobyl; over 200% in Belarus, a country just north of the Ukraine. The number of thyroid cancer cases in Belarus and the Ukraine has exceeded the total number of all cases in Europe.

Of the 200,000 people who were cleanup workers in the two years following the accident, the Atomic Energy Agency estimates about 20,000 received about thirty percent more radiation than most people absorb in a lifetime. As many as 10,000 others received more than three times the lifetime dosage. Several dozen received doses that could kill them in a few years.

Here the certainty ends. In addition to the radiation-related illnesses, there is a growing phobia concerning other illnesses. Almost every hospitalized patient in Ukraine, doctors say, attributes his or her illness to the Chernobyl fallout. The phobia is most high among the cleanup workers.

However, the concern is greatest for children with serious diseases. Leukemia in the Ukraine is up about twenty percent in the past few years, but most of it comes from southern Ukraine where there was little radiation. Many doctors attribute it to industrial pollution in the state, but it is very difficult to convince parents of young victims that it is not Chernobyl related.

CHERNOBYL TODAY

Two remaining reactors are still in operation today. Workers are bussed in from outside the plant. They work shifts no longer than two hours to reduce radiation risks.

No people live within a six-mile radius of the plant. This area is called the Dead Zone because it is considered unfit for human life. Beyond the Dead Zone is an area where a few hundred elderly people have returned to live out their lives. Those who have returned to the evacuated areas literally had to start over. Their animals were slaughtered and their gardens ruined by the government. The gardens they grow now are in irradiated soil, their animals eat irradiated feed, and the water they drink is irradiated. There are no children in this area because they are not allowed past the checkpoints. When these people die, nothing will be left of their village.

Other hazards have recently appeared at Chernobyl. Almost eight years after the explosion, scientists have announced a new health hazard, Americium-241. Valerie Kopikin, a Russian geochemist, said that in the summer of 1989 plutonium, which is made in large quantities in nuclear reactors, was found in the underground waters of the Red Forest. As plutonium decays to Americium-241, it becomes even more medically dangerous and more likely to migrate into water. Americium-241 also has a longer half-life (433 years). By the year 2060 A.D., the alpha-particle emission rate of Americium-241 will be twice that of plutonium.

Scientists now report permanent genetic damage related to the Chernobyl accident passing from one generation to another near the site of the plant. Yuri Dubrova of the Navilov Institute of General Genetics reports that mutations occur twice as often in children of families exposed to the radioactive fallout when compared to other families.

DRAWINGS

Unforgettable Fire is a collection of drawings about the Atomic Bomb experience as drawn by survivors in 1975. The collection was started by Nippon Hoso Kyo Kai (NHK), a Japan Broadcasting Corporation. The pictures are a vivid documentary of the horrific tragedy experienced by the citizens of Hiroshima and Nagasaki. It is amazing to see the graphic illustrations by the Japanese who were on the ground in the city of Hiroshima when the Atomic Bomb was dropped. You may want to review this book's contents as a library loan.

THE STAGES OF ACUTE RADIATION LETHALITY

As acute whole body radiation exposure increases, the human body experiences three stages. The first stage is called the prodromal stage in which patients or victims manifest symptoms identified with radiation sickness.[1(p485)] The second stage is the latent period in which the patient or victim has a sense of well-being and recovery. The third stage is the manifest illness stage in which three body systems are predominantly and progressively vulnerable. The first is the hematologic or hemopoetic system; the second is the gastrointestinal system; and the last is the central nervous system. We will be discussing each of these syndromes in the following paragraphs.

PRODROMAL SYNDROME

The prodromal syndrome occurs with acute radiation doses of 100 Rads or less and may produce nausea, vomiting and diarrhea.[1(p485)] We classically describe these clinical symptoms as "immediate radiation sickness". These clinical symptoms may occur within hours of the exposure and continue for a period of one to two days. The severity of the symptoms is dose related. The higher the doses of radiation received by the patient or victim, the shorter the prodromal time will result. Because it is often associated with nausea, vomiting and diarrhea, it is also called NVD syndrome.

LATENT PERIOD

The latent period may be produced with radiation doses from 100 to 10,000 Rads.[1(p485)] The latent period may last from hours or weeks dependent on the size of the dose encountered by the patient or victim. Usually, the latent period is identified with a period of well being in which the patient or victim mistakenly believes he or she has recovered. At very low radiation doses, the prodromal period and the associated latent period may be eliminated.

MANIFEST ILLNESSES

The first system to be affected by acute radiation doses of 200 to 1,000 Rads is the hematologic or hemopoetic system.[1(p485)] The latent period may extend as long as four weeks with the number of circulating blood cells declining over time. The patient or victim experiences episodes of vomiting, diarrhea, general malaise and fever. Petechial hemorrhages on the skin and ulcers in the mouth may occur. As the dose of radiation increases, the reduction in red and white blood cells, in addition to platelets, drops considerably. If the patient or victim receives a sublethal dose, recovery begins in two to four weeks with six months for a full recovery. During this time period, the circulating blood cells are reproducing to accommodate the recovery process. However, if the patient or victim sustains a lethal dose of radiation, he will die from hemorrhage, dehydration and infection. Infection becomes very prevalent because the number of platelets is not being reproduced quick enough to defend the body from infectious agents.

A sublethal exposure of 100 to 300 rads will produce feelings of nausea, vomiting, and malaise for 12 to 24 hours. After the latent period of three to five weeks, alopecia may occur, but hair usually regrows. Blood cell counts will drop. Many patients or victims will develop cataracts in two to six years. Most of the patients or victims receiving this dose will recover. Some will enter a chronic stage of anemia for months. These patients or victims will statistically have an increased incidence of leukemia. In the midlethal exposure range of approximately 450 rads, about one-half of the exposed patients or victims will die within 30 days from pancytopenia. Pancytopenia represents the increased and rapid loss of all three blood cells and platelets. This particular group of symptoms is sometimes referred to as the bone marrow syndrome.

The second system to be affected by acute radiation doses of 1,000 to 5,000 rads is the gastrointestinal.[1(p485)] The patient or victim will experience the first wave of symptoms that include vomiting and diarrhea persisting for hours and up to one day. The symptoms progress to nausea, ongoing vomiting, anorexia and bloody stools. Hemorrhages occur in the skin and intestines. Treatment includes blood transfusions, I.V. fluids, antibiotics and bone marrow transplants from compatible donors. The patient or victim undergoes the complications from the hematologic system since this dose exceeds the dose to promote hematologic injury. The patient or victim ultimately dies four to ten days after exposure. This group of symptoms is classified as gastrointestinal in nature because the stem cells in the intestinal lining do not mature quickly enough to replace those that have been damaged by radiation insult. Stem cells need approximately three to five days to mature.

The last system to be affected by acute radiation doses greater than 5,000 rads is the central nervous system.[1(p486)] The latent period may last as long as 12 hours. The patient or victim has a severe onset of diarrhea and vomiting within minutes. The symptoms continue with irritation, confusion, and loss of vision and consciousness within one hour. More severe symptoms include loss of motor control, convulsions, ataxia, lethargy, and coma. Death usually results within hours or up to three days. The most common cause of death is due to increased intracerebral fluids and the associated inflammation of the blood vessels and meninges of the brain and spinal cord.

LETHAL DOSE CHART

A chart can be constructed that reflects the amount of radiation dose to the whole body that will result in death within 60 days to 50% of the exposed population.[1(pp486-487)] We refer to this as the LD 50/60. 50 represents the percentage of population and 60 represents the length of time in days. The LD 50/60 for human beings is approximately 300 rads of radiation in an acute situation. Death from radiation exposure is a nonlinear, threshold dose-response relationship. It should be noted that as the radiation dose increases, the average time between exposure and death decreases. This is referred to as the mean survival time. Please refer to the chart provided at the conclusion of this unit.

It should be stressed again to all medical radiographers and other individuals using radiation for diagnostic medical purposes that death cannot occur because of the lower energy of radiation used to produce our finished radiographs and the smaller volume of patient tissues that are subjected to radiation exposure.

This concludes unit 9. Please proceed to the unit questions and complete the required personal data.

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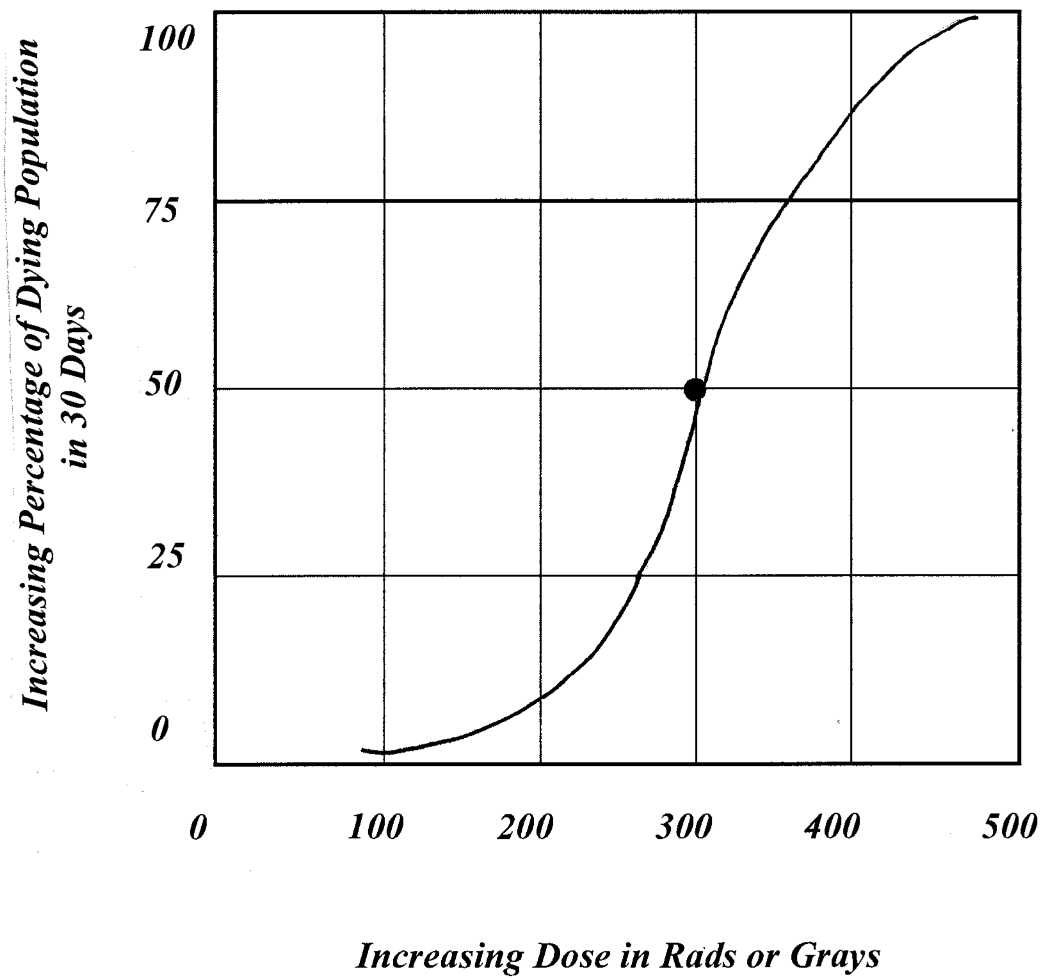
Lethal Dose Chart Identification

Locate the 50% population and draw a line to the dose curve. Drop a perpendicular line to the dose axis and you can determine the dose required to kill 50% of the population.



Some Important Terms and/or Concepts in Unit 9

Acute radiation exposure involves a large dose of radiation absorbed by a human being in a short period of time.

Massive exposures of 100 to 1,000 rads may occur accidentally in atomic energy installations or deliberately in the treatment of some forms of cancer, particularly leukemia.

We have gathered information about acute radiation lethality from the victims of the Atomic bombings on Hiroshima and Nagasaki in 1945.

An atomic bomb can be created by the sudden release of energy upon splitting of the nuclei of such heavy elements as plutonium or uranium.

The first atomic bombs were built in the United States at a site called Los Alamos in New Mexico during World War II under a program referred to as the "Manhattan Project".

J. Robert Oppenheimer, Enrico Fermi, and seven other theoretical physicists met in Los Alamos with the order to build the Atomic Bomb. The first Atomic Bomb was successfully tested on July 16, 1945 at a site 193 kilometers (120 miles) south of Albuquerque, New Mexico.

The first Atomic Bomb to be used in warfare was dropped by the United States on Hiroshima, Japan on August 6, 1945.

The second Atomic Bomb was dropped by the United States on Nagasaki on August 9, 1945.

Three Mile Island is a nuclear power station situated on the Susquehanna River near Harrisburg, Pennsylvania.

Chernobyl is considered the worse accident in the history of nuclear power generation in the world.

The Prodromal stage is when patients or victims manifest symptoms identified with radiation sickness. Prodromal syndrome occurs with acute radiation doses of 100 Rads or less and may produce nausea, vomiting and diarrhea and is also called NVD syndrome.

The latent period is when the patient or victim receives acute radiation doses, but has a sense of well being and recovery.

The manifest illness stage occurs when three body systems are predominantly and progressively vulnerable.

1. Hematologic or hemopoetic system occurs with 200-1,000 Rads
2. Gastrointestinal system occurs with 1,000-5,000 Rads.
3. Central nervous system occurs with doses greater than 5,000 Rads.

If the patient or victim receives a sublethal dose, recovery begins in two to four weeks with six months for full recovery.

LD 50/60 is a chart that can be constructed to reflect the amount of radiation dose to the whole body that will result in death within 60 days to 50% of the exposed population.

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.

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UNIT NUMBER 10

BIOLOGICAL EFFECTS OF RADIATION EXPOSURE - CHRONIC

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INTRODUCTION

One of the most fascinating topics in radiation biology is the effect radiation has had on actual human beings since the discovery of x-ray in 1895. This unit will discuss many of the documented situations that have occurred over time. The serious consequences to our early investigators will be discussed, in addition to, some unwilling or unknowing victims at the time when our level of scientific knowledge was limited on the biological effects of radiation.

In 1994, President Bill Clinton formed an Advisory Committee on the Ethics of Human Radiation Experiments that were conducted in the United States from the years 1944-1974. Due to the consequences of radiation experienced by these individuals, the ethical and moral implications of the experiments that were conducted and the relative benefit from those experiments have created an even more sensitized population to the risk of radiation exposure.

LOCAL TISSUE DAMAGE

If we relate back to the target theory, it is easy to understand that a higher dose of radiation is necessary to produce a response to a small portion of the body when compared to the entire body. Obviously, when the entire body is exposed to radiation, the possibilities and statistical probability that more targets will be struck increases, thereby causing a greater biological effect. Some of the effects to local tissue include necrosis (cell death), atrophy of a tissue that interacted with the radiation and the corresponding death of an organ if a greater dose of radiation has occurred. Obviously, if death does not occur with a minimal dose, there may be some limited or total non-function of the tissue or the organs it composes. The last consequence of radiation to local tissue involves the simple process of recovery without any evident physiologic loss.

RADIATION EFFECTS ON SKIN

I am sure that most of us have sustained sunburn in our lifetime and realized that one of the first reactions the skin has to cosmic radiation is erythema (skin reddening). We also have witnessed in our personal bodies that after erythema occurs, we go through a period of skin peeling that relates to the cell death of epithelial tissue. We also experienced the process of tanning and realized that our tan fades over time. These situations are directly related on the physiologic processes of skin replacement. Skin cells are replaced at a rate of approximately 2% per day.[1(p488)] The skin is composed of three layers, the ectoderm, or the outer layer, the mesoderm, in the middle, and the endoderm, on the inside closest to additional soft tissues, muscles, etc. As skin cells mature, they migrate to the upper level, or ectoderm. This process allows us the opportunity to replace skin in a timely manner and assists us as one of our first and greatest lines of defense against disease. In addition to the skin replacement and erythema, some people receiving a significant dose to the skin may have epilation in the body part exposed to radiation. Epilation or alopecia is the term used for loss of hair.

EARLY INVESTIGATORS AND CASUALTIES OVER SEAS

On November 8, 1895, Dr. Wilhelm Konrad Roentgen was working at his laboratory at the University of Wurzburg in Germany. He was utilizing a Crooke's tube or in some instances a reference is made to a Hittdorf tube. This tube was an uncovered glass envelope containing two terminals in his lab. One terminal was referred to as the cathode (-) and the other as the anode (+), just as we have in modern day x-ray tubes. In addition to this uncovered glass envelope he had barium platinocyanide crystals. He noticed that the barium platinocyanide crystals would fluoresce when the tube was energized even after he enclosed the tube in black shielding. Some authorities consider this discovery of x-ray somewhat accidental since this was not his primary research goal. He did not know the origin of mysterious rays. He termed the name "x-rays" for the x that is an unknown variable in mathematics. He published a paper in 1896 to the scientific community. He also realized that there might be medical applications using this mysterious ray. He consequently brought his wife Bertha into this laboratory and performed the first PA hand film in the world. Mrs. Roentgen's original hand film is on display in the Smithsonian Institute in Washington D.C. In 1901 he won the first Nobel Prize in Physics. In 1921 he died from cancer of the colon.

At the same time, Marie and Pierre Curie were working in a laboratory near the Sorbonne in Paris. They conducted many experiments together until Pierre's tragic death. Pierre was crossing the street in Paris when a thunderstorm spooked some horses pulling a cart and he was trampled to death. Needless to say, Marie continued the research without him. She received two Nobel Prizes, one shared with Pierre and one on her own achievements.

Marie went on the battlefields in World War I with the precursor to the ambulance service in a wooden wagon that was later identified as a "Curie Wagon" because she took x-rays of soldiers on the battlefield to locate shrapnel and bullets. She and Pierre are considered the discoverers of radioactivity even though a contemporary of theirs, named Henry Becquerel, was also working on the principles of radioactivity too. In 1934, Marie died from aplastic anemia.

EARLY INVESTIGATORS AND CASUALTIES IN THE UNITED STATES

The first x-ray image was produced in a Physics Lab at Dartmouth College in Hanover, New Hampshire in February of 1896, less than six months from the original discovery date of x-rays. In the same year Michael Pupin was working with fluorescent screens and glass photographic plates. Thomas Edison was involved with the development of the fluoroscope. He also investigated several types of fluorescent crystals for utilization in intensifying screens. His research was conducted from 1894 to 1904. The invention of the fluoroscope required the ongoing application of fluoroscopy for the refinements of the invention. His assistant, Clarence Dally, died after numerous exposures from fluoroscopy to his arms and hands. The bilateral amputation of his arms was considered the direct result of overexposure to x-rays. He unfortunately has the distinction of being the first fatality from man-made radiation in the United States. His death caused a great deal of distress to Thomas Edison. In fact, he completely abandoned his research, published notifications in scientific magazines, and alerted the general public by way of newspapers about the hazards of radiation and that it should no longer be promoted or developed for future medical applications.

Since Thomas Edison was causing a great deal of concern about the biological hazards of radiation, it was important for radiology investigators to develop methods in which to reduce the dose of radiation exposure. In 1904, Charles Leonard utilized the concept of having two glass plates with emulsion. In this manner he could reduce the exposure and also produce an improved image. However, the voltage capabilities at that time were very limited so a big advance occurred when Snook designed a transformer in 1907 to produce a higher voltage power source.

The x-ray tubes used by Roentgen and others were considered "cold". In other words, the electricity was supplied to a filament that was not pre-warmed. This created a great deal of stress on the filaments of these glass tubes. It was considered a tremendous advantage and breakthrough in the development of x-ray tubes when W. D. Coolidge announced the development of a hot cathode x-ray tube in 1913 while employed at the General Electric Company Laboratories. Approximately eight years later, Hollis Potter and Gustav Bucky developed the first crosshatch grid. All of these developments helped us to improve our technical ability to optimize radiation production while minimizing harmful radiation exposures and improving diagnostic information to physicians.

LATE/CHRONIC EFFECTS OF RADIATION

Radiation that has been delivered in low doses over long periods of time is considered chronic and generates such biological effects as radiation-induced malignancy and genetic effects. As our scientific body of knowledge grew relative to the biological effects of radiation, it was necessary to develop radiation protection guidelines. The guidelines were based on the suspected or observed effects of radiation that had occurred in the first 50 years of radiation producing equipment and exposure to human beings.

DOSE-RESPONSE RELATIONSHIP CHARTS

A dose-response relationship chart reflects the amount of radiation required to produce a biological effect on the organism. Dose response relationship charts have two characteristics. The first characteristic is to determine whether it is linear or nonlinear.[1(pp466-467)] If the information is portrayed as a straight line on the chart, it is considered linear. If the information is portrayed in a non-straight line, it is considered nonlinear. Linear relationships are directly proportional and nonlinear relationships are not directly proportional. The second characteristic of a dose-response chart is to determine whether the dose that provides a response is threshold or non-threshold. A threshold dose means the organism can receive a certain amount of radiation before an effect is observed. A non-threshold dose means that any amount of radiation will produce a response. Therefore, the chart is constructed with the dose on the horizontal axis and degree of response on the vertical axis. The graphic representation of the radiation amounts and the biological responses are then plotted. Please refer to the chart at the conclusion of this unit.

CATARACT FORMATION

In 1932, the first cyclotron was developed in the United States. The cyclotron is a linear accelerator.[1(p499)] The function of the cyclotron is to accelerate charged particles to high energies. There was a long corridor connecting the linear accelerator with the target material at the opposite end of the corridor. There were windows in the corridor with mirrors so that the first cyclotron inventors and experimenters could watch outside the corridor.

In 1949, the first paper was published reporting an increased incidence of cataracts among the cyclotron workers. By1960, several hundred cases of cataracts were documented on physicists working in the cyclotron industry. Due to the advanced technical refinements of the cyclotron industry today, the doses are too low to reach threshold and cataracts are no longer an occupational risk.

RADIATION INDUCED MALIGNANCY

LEUKEMIA

In the 1920's, radiologists were concerned about the effects of radiation on the hematologic system. Radiologists did a comparison study with other physicians and documented the fact that they experienced increased rates for pernicious anemia and leukemia.

After the Atomic Bomb in Hiroshima and Nagasaki in 1945, many survivors developed leukemia after a latent period of four to seven years and were placed at risk at 20 years. Other populations who exhibited elevated incidences of leukemia included radiation therapy patients and children irradiated in utero.

CANCER INDUCING CONTRAST MEDIUM

A contrast medium was developed in 1925 for application in angiography. This commercially prepared contrast medium called Thoratrast consisted of Thorium Dioxide. This contrast medium was on the market for approximately 20 years. In that 20-year period, many patients had documented liver cancers after angiographic studies had been performed with Thoratrast. By 1945, Thoratrast had been removed from the market for commercial sale.

RADIUM-INDUCED BONE CANCER

Some of you may be old enough to remember or may have a grandparent or older relative who was excited to have a wristwatch with a face that glowed in the dark. This watch face was painted by young women using a paintbrush and dipping it into radium sulfate paint. Women would make a fine point on the paintbrush by inserting it into their mouth so that the numbers on the face of the watch were very fine in detail. Seventy-two (72) bone cancers were documented in approximately 800 watch painters. Unfortunately, some of the bone cancers occurred in the mandible and resulted in disfiguring and psychologically traumatizing radical surgeries in women in their prime life period.

In addition to watch painting, radium salts were used to treat arthritis and tuberculosis. After we gained a greater understanding of radioactivity, the radium salts were eliminated as a treatment for these two disease entities in 1950.

CHILDREN AND THYROID CANCER

In the 1940's and 1950's, there were two studies performed in the United States relative to children. One study was conducted in Ann Arbor, Michigan that involved several thousand children. Children were treated with radiation therapy techniques of 20-30 Rads with beam collimation. The purpose of the radiotherapy was to shrink the thymus gland that is located in the anterior neck proximal to the thyroid gland. Children who experienced psychological stress or malnutrition manifested this situation with an enlarged thymus. The enlarged thymus gland suppressed the trachea and made it difficult for them to breathe. One of the attributes of radiation is to shrink or atrophy tissue. Therefore, it was quite reasonable at that time to treat these children's thymus glands with the anticipated outcome of improving their airways.

A smaller group of children were exposed to larger radiation fields in Rochester, New York. Both of these populations of children experienced a significant number of thyroid cancer nodules 20 years later.

A third population of children received a significant dose of radiation estimated to be 1,200 Rads in the Rongelap Atoll in the Pacific Ocean. These 21 children received their radiation doses based on some atomic bomb blast fallout in 1954. These children also developed thyroid carcinomas in later life.

MINERS AND LUNG CANCER

Early in this century, it has been documented that pitchblende mineworkers in Germany had experienced an increased incidence of lung cancers. It has been documented that approximately 50% of these mineworkers died from radon gas inhalation while working in the mines.

In the 1950's and 1960's, uranium mineworkers in Colorado also developed an elevated incidence of lung cancer. Many of these uranium mineworkers had been employed in locating uranium for the atomic bomb industry. Their lung cancer incidence was eight times higher than the general population and resulted in a 20 times greater incidence if they had smoked cigarettes. You may remember that it was quite fashionable to smoke cigarettes during these two decades of American lifestyles.

WOMEN AND BREAST CANCER

By the mid 1960's, many of the young women who were treated for tuberculosis by multiple fluoroscopic exams and radium salts developed breast cancer. It has been documented as ten times higher than the general population and four times higher than the breast cancer incidence of the Atomic Bomb survivors.

IRRADIATION OF THE HEMOPOIETIC SYSTEM

The hemopoietic system is composed of bone marrow, circulating blood cells and lymphoid tissue structures, such as the spleen, lymph nodes and thymus gland.[1(p491)] One of the principal effects of radiation is the decreased number of blood cells in the body. In comparing the various types of cells, it has been determined that lymphocytes are the most radiosensitive cell in the body. As you may remember, lymphocytes are essential for our immune system. It is easy to determine a decrease in the number of circulatory blood cells by simple laboratory methods after radiation exposure has occurred.

CHROMOSOMES AND RADIATION

In the 1950's, human chromosomes were analyzed by culturing human cells in the laboratory, exposing them to various levels of radiation and taking photomicrographs of the cells.[1(p492)] Chromosomal aberrations have not been proven to occur after diagnostic radiographic examination with 5 Rads.[1(p493)] However, chromosomal aberrations have definitely been demonstrated when high dose fluoroscopy has been administered.

Some of the chromosomal aberrations include chromatid deletion where a portion of the DNA code is removed by the incident radiation photon. Some chromosomes form a ring-like shape when DNA sequences are eliminated at both ends of the chromosome and the ring deformity replicates in the cell cycle.[1(p495)] The third chromosomal aberration that has been demonstrated photomicrographically is called reciprocal translocation. The fragment of DNA from one chromosome is relocated on the end of a chromosome adjacent to it.

RADIATION EFFECTS ON THE GONADS

The process of gametogenesis is the progression of stem cells or the precursors to the mature cells.[1(p490)] The stem cells of the ovary are called oogonia and go through a process of spontaneous degeneration during our in utero first half of fetal life. In the second portion of our in utero fetal life, the oogonia become oocytes that stay in suspended growth until the years of puberty.

At puberty, the follicles rupture and eject a mature germ cell called the ovum. Therefore, from puberty to menopause, women have approximately 400-500 ova available for fertilization.[1(p490)]

The male stem cells are called spermatogonia that mature to spermatocytes and multiply into spermatids that eventually mature to functional spermatozoa (sperm) in a three to five week process. Their sperm count is constantly replenished within this time period.

Unfortunately for women, the number of ova we have at puberty are the only sex cells available for fertilization. Because the sex cells develop in a different manner for males and females, the response to radiation of these sex cells is different. In the cycle of sperm development, the spermatogonia are the most sensitive to radiation. Radiation does of 10 Rad will reduce the number of sperm.[1(p490)] Two hundred (200) Rad of radiation will produce temporary sterility and radiation doses of 500 Rads or greater will produce permanent sterility.

In the female, the oocyte is the most radiosensitive cell in the ovary. With 10 Rad of radiation, the female will experience the suspension of menses.[1(p490)] At 200 Rad of radiation, temporary sterility will occur and radiation exposure of 500 Rads or greater will produce permanent sterility. In the 25-50 Rad range, there is a measurable increase in genetic mutations!

RADIATION AND PREGNANCY

The biologic effects of radiation before, during, and after pregnancy have been demonstrated in animals and observed in humans. There is a concern for interrupted fertility when radiation is administered before pregnancy. Concern for congenital defects in the newborn can result from radiation during pregnancy and suspected genetic defects can occur in the child after pregnancy.

It is a well-documented fact that the first two weeks of the first trimester of a pregnancy is considered the most radiosensitive period for the fetus. The biological effects of radiation exposure in utero are time and dose related. Prenatal death, congenital abnormalities, malignant induction, and mental retardation are all feasible consequences of radiation exposure in utero.

The genetic effects of radiation during pregnancy for human beings have not been substantiated. However, a tremendous amount of research has been conducted on flies and mice. They have very short gestational periods and many generations can be studied in a short period of time. Some of the research indicated that radiation-induced mutations are usually harmful and that the frequency of mutation is directly proportional to the dose. The greater the dose, the greater is the frequency of mutation. When any radiation dose is provided to a germ cell, the results include some genetic risk. Most radiation-induced mutations are recessive in nature. The frequency of radiation-induced genetic mutation is considered extremely low, but it does not allow us to disregard conscientious radiation protection measures for pregnant women.

LIFE-SPAN SHORTENING

It has been postulated by medical physicists and radiation biologists that life span can be reduced ten days for every Rad of radiation exposure.[1(p500)] Many experiments have been conducted on animals and the findings have been extrapolated to human beings.

There have been some studies conducted on life span shortening. One investigator evaluated 7,000 death records of field x-ray equipment operators during World War II.[1(p500)] The death records of these operators indicated no life span shortening based on their radiation exposures during the war. No life span shortening has been observed in the Atomic Bomb victims.

In the 1930's through the 1960's, American radiologists were studied in comparison to other physicians. It was published that American radiologists were dying approximately five years earlier than the general population. When the study was published, the radiologists in Great Britain were concerned and conducted a study of their own. The British investigators found no such effects on life span shortening due to occupational radiation risks. Since one of the criteria for valid scientific study is the reproducibility of the results, the validity of the American study is controversial and nonsupportive by other studies.

A study of the chronic affects of radiation on medical radiographers is presently underway at the University of Minnesota. Approximately 150,000 American radiographers completed two questionnaires relative to their clinical practice, personal life styles and other demographic information.[1(p500)] So far, the study has shown that radiation exposures experienced by technologists today are not associated with an increased risk of cancer.[2]

RISK ESTIMATES

It is important for medical radiographers to have a basic understanding of statistical risk calculations so that information that is available through multiple media can be evaluated in an intelligent manner. There are approximately three types of risk estimates. The first is called relative risk.[1(p502)] It involves estimating effects of radiation over a long period of time in a large population without knowing the precise details of their dose. The formula is:

$$\text{Relative Risk} = \frac{\text{Observed cases}}{\text{Expected cases}}$$

The second category of risk estimate is called excess risk in which the risk of a spontaneously occurring effect based on a radiation-induced population is estimated.[1(pp502-503)] When the observed cases are greater than the expected cases, an excess risk has been established. The formula is:

Excess Risk = Observed cases>Expected cases

The last risk estimate called absolute is the most difficult and most strenuous to calculate. It involves the knowledge of at least two different dose levels. Risk is then calculated in units of numbers of cases per 10,000,000 persons/per Rad/per year.[1(p503)] Since calculating risk estimates are not in the realm of medical radiographer responsibilities, it will not be necessary to elaborate on these to any great degree.

This concludes Unit 10. Please proceed to the unit questions and complete the required personal data.

Dose-Response Relationship Chart Identification

Radiation Protection Guidelines are based on a non-threshold, linear relationship!

Table 1 Linear versus Non-Linear

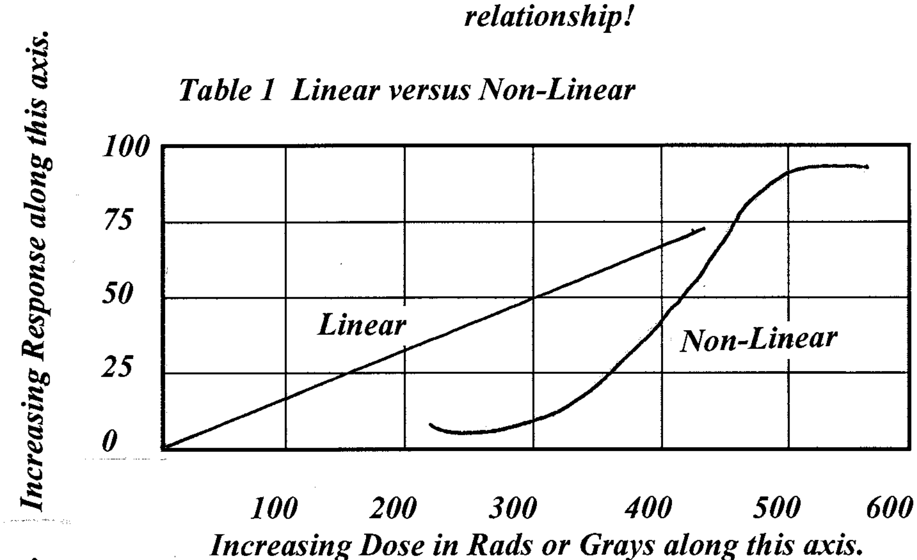


Table 2 Threshold versus Non-Threshold

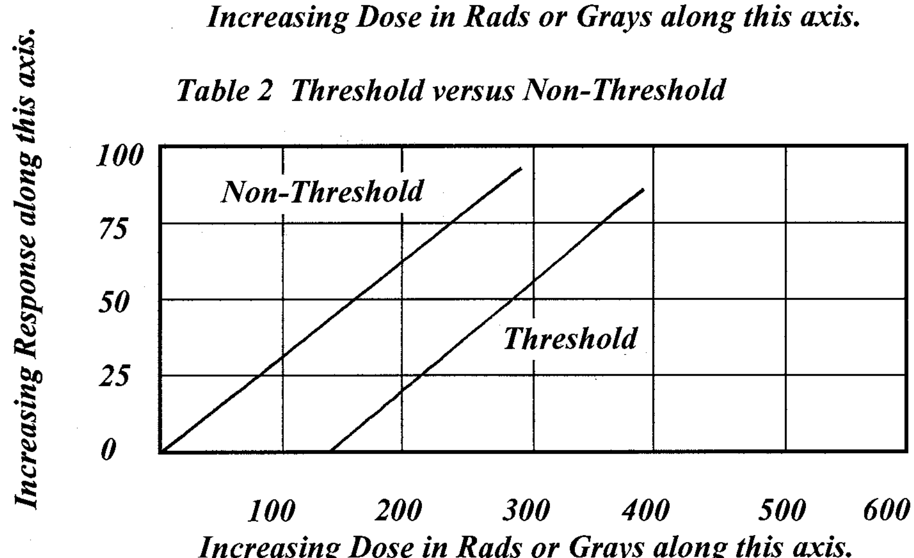
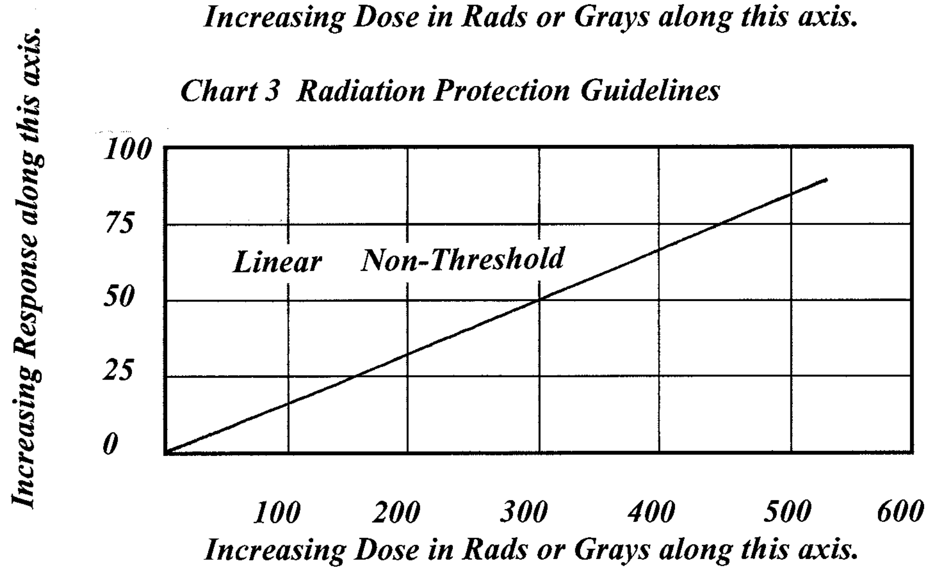


Chart 3 Radiation Protection Guidelines



It is assumed that any amount of radiation, regardless of how small, will produce a directly porportional response in biological tissue.

Some Important Terms and/or Concepts in Unit 10

A higher dose of radiation is necessary to produce a response to a small portion of the body when compared to the entire body.

The effects to local tissue include necrosis (cell death), atrophy of a tissue that interacted with the radiation and the corresponding death of an organ if a greater dose of radiation has occurred.

The last consequence of radiation to local tissue involves the simple process of recovery without any evident physiologic loss.

Erythema describes skin reddening.

Epilation or alopecia is the term used for loss of hair.

Cathode (-)   Anode (+)

The first x-ray image was produced in a Physics Lab at Dartmouth College in Hanover, New Hampshire in February of 1896.

Michael Pupin worked with fluorescent screens and glass photographic plates.

Thomas Edison developed of the fluoroscope.

Clarence Dally was the first fatality from man-made radiation in the United States.

Charles Leonard utilized the concept of having two glass plates with emulsion.

Snook designed a transformer to produce a higher voltage power source.

W. D. Coolidge developed the first hot cathode x-ray tube in 1913.

Hollis Potter and Gustav Bucky developed the first crosshatch grid and moving mechanism.

Radiation that has been delivered in low doses over long periods of time is considered chronic and generates such biological effects as radiation-induced malignancy and genetic effects.

A dose-response relationship chart reflects the amount of radiation required to produce a biological effect on the organism.

Linear relationships are directly proportional and nonlinear relationships are not directly proportional.

A threshold dose means the organism can receive a certain amount of radiation before an effect is observed.

A non-threshold dose means that any amount of radiation will produce a response.

The cyclotron is a linear accelerator.

One of the principal effects of radiation is the decreased number of blood cells in the body.

Lymphocytes are the most radiosensitive cell in the body.

Chromatid deletion occurs when a portion of the DNA code is removed by the incident radiation photon.

Some chromosomes form a ring-like shape when DNA sequences are eliminated at both ends of the chromosome and the ring deformity replicates in the cell cycle.

Reciprocal translocation occurs when a fragment of DNA from one chromosome is relocated on the end of a chromosome adjacent to it.

Spermatogonia are the most radiosensitive cells in males.

Oocyte is the most radiosensitive cell in females.

It is a well-documented fact that the first two weeks of the first trimester of a pregnancy is considered the most radiosensitive period for the fetus.

Relative risk involves estimating effects of radiation over a long period of time in a large population without knowing the precise details of their dose.

Excess risk involves the reality of observed cases being greater than the expected cases.

Absolute risk involves the knowledge of at least two different dose levels. Risk is then calculated in units of numbers of cases per 10,000,000 persons/per Rad/per year.

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.

[2] 2007 Update: Radiologic Technologists Health Study. *ARRT.* 2007: 33-34.

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UNIT NUMBER 11

COMMON METHODS USED TO CONTROL RADIATION EXPOSURE TO THE PATIENT

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INTRODUCTION

In this unit we will discuss common methods used to control radiation exposure to patients. It is important to realize that this issue is becoming more prominent and of greater concern to public health officials and medical physicists. One of the two primary issues related to increasing patient dose is the increased frequency of x-ray examinations among all age groups in the United States. The annual increase is between 6-10%. It is higher than many other countries in the world. One explanation for this increase is the physicians' reliance on x-ray for diagnosis and the physicians' opportunity to use newer imaging modalities to confirm the diagnosis. There are also the implications that the American people have become a litigious society. Physicians are more concerned about protecting themselves from legal ramifications. The second cause for increased patient doses in this country is relative to the prolonged fluoro time with our current angio-interventional exams. It has been documented that patients have recently experienced fluoroscopic burns. The FDA issued alerts and warnings to physicians a couple of years ago relative to this situation.

Radiation protection guidelines stem from the concern for the late effects of radiation on human beings.

QUALITY ASSURANCE AND CONTROL

The terms Quality Assurance and Quality Control are not synonymous. There is distinction between them. Quality Assurance refers to the overall assessment and evaluation of patient care and Quality Control refers to the measurement, testing, and evaluation of radiographic equipment.[1(p428)] The traditional methods of quality control with radiographic equipment involves acceptance testing when equipment is purchased, installed and prepared for patient use; the routine performance evaluations that are usually conducted on an annual basis; and the immediate correction of fluctuations or errors in the equipment when recognized by the medical radiographers and brought to the attention of the appropriate personnel. Some of the components of the quality control program must be conducted by a medical physicist, such as acceptance testing and annual calibration of equipment, but other portions of a good quality control program can be implemented by medical radiographers on a routine basis.

HOSPITAL ACCREDITATION

Medical radiographers employed in hospital environments are fully cognizant of the Joint Commission on Accreditation of Hospital Organizations, which is commonly referred to as the Joint Commission. The function of the Joint Commission is to inspect hospitals and assure that quality patient care is being maintained. Inspections are provided periodically and hospitals are given accreditation status based on their performance. The Joint Commission inspection is linked to Medicare/Medicaid funding so that it is mandatory for facilities utilizing these funds to have the inspection. If institutions fail to meet the requirements published by the Joint Commission, the funding can be withdrawn.

The Joint Commission organization has developed a "10-step" program to assist administrators across the country in the monitoring and evaluation process.[1(p428)] This 10-step program involves the following process. When a particular item has been determined for monitoring and evaluation, the administrative personnel must assign responsibility to the appropriate individual. For example, a certain medical radiographer in the department may be assigned processor QC as part of their daily activities in assuring good quality radiographs for patient examinations. The scope of care must be delineated in the responsibility with various aspects identified. For example, the objective was to have all mammography patient studies completed within 30 minutes. The scope of patient care would have to include the prompt processing of registration materials, the completion of a diagnostic examination in a courteous and professional manner and a prompt departure of the patient from the facility. Outcomes and limits have been established. The next step in the situation would be to collect and organize the data for every mammography patient that was scheduled in a 30-day period. The data should be evaluated to determine whether the quality of care was reached and if the outcomes were satisfactory to the medical radiographer, the patient, and the department operations. Actions should be implemented to improve care if the results were not satisfactory or to maintain the objective if the process was successful. This objective should be assessed on an ongoing basis and documentation should be provided relative to the successful incorporation of this standard. Most hospitals have an organization-wide Quality Assurance program. It would be important for individual departments to communicate their standards and information relative to the performance of the department or its interrelationship with other departments in the facility.

The Joint Commission now requires the monitoring of doses in every x-ray tube in the country in facilities it accredits. Physicists must monitor the dose in every room and compare it to the national average. Actual output measurements are required, and the data should be posted in every room.[1(p429)] The Joint Commission does not require that it be within limits, but it requires the monitoring of actual output measurements.

ROUTINE QUALITY CONTROL ACTIVITIES FOR RADIOGRAPHERS

Medical radiographers can take an active role in quality control in their facilities. Some basic quality control activities include maintaining a clean and well-stocked darkroom. Close monitoring of the film inventory should be conducted so that the oldest film will be used first and the risk of out-dated film would be minimized. The processors can have a daily temperature check, sensitometry strip performed and daily cross over roller cleaning. When the processor lid is off, the chemistry color and levels should be checked visually. Replenishment should be monitored for the appropriate solution in the respective tanks.

It is important to realize that when radiographers are involved in QC activities with the processing solutions, protective apparel such as chemically resistant gloves, apron and a face shield should be utilized as an OSHA standard. OSHA is the Occupational Safety and Health Act.

In addition to protective apparel, the material safety data sheets that are commonly referred to as MSDS sheets should be immediately available at or near the processing sites. It is important to realize that processing solutions are considered bio-hazardous materials and care should be stressed when performing activities relative to the processor solutions.

Radiographers should clean the inside and outside of the screens and cassettes regularly. If there is a possibility of a cassette being damaged, a wire mesh test should be conducted to evaluate film screen contact, and damaged screens or cassettes should be replaced as soon as possible.

Another is the collimator. Since medical radiographers use the collimators frequently throughout the day, it is important to check the field size accuracy. In other words, if you collimate to an 8" x 10" field at 40 inches, the respective field of radiation exposure to the patient should not exceed these parameters. It is easy to check by simply pulling the Bucky tray out with the 8 x 10 locked in place, bring the tube over the film at its recommended S.I.D. and see if the field light corresponds to the respective dimensions of the film.[1(p430)] If there is a discrepancy, it should be reported as soon as possible to prevent unnecessary exposure to the patient to anatomic areas not needed in the examination. A second collimator parameter that can be easily checked is the centering of the x-ray tube to the table. When the center lock has been activated, the tube should center to the midline of the table. If this does not occur, it should be reported as quickly as possible to the appropriate individuals so that the tube head can be aligned appropriately.

These are just a few examples of some quality control activities. Individual departments can develop other parameters that are used on a daily basis.

GONAD SHIELDING AND USES

All medical radiographers know that gonad shielding should be utilized on patients to minimize radiation dose to the reproductive organs whenever possible. However, radiographers may not apply this standard principle for several reasons. One of the reasons is that the gonad shields may not be readily available or clinically acceptable at the time the examination is performed.[1(p563)]

A second reason commonly provided is the fact that radiographers say they do not understand when and how to use them appropriately. The last situation involves the physician who supports the concept of utilizing gonad shields, but does not insist on their use in clinical practice. The next several paragraphs will clarify these particular issues.

Gonad shields should be used when a particularly sensitive tissue or organ, such as the lens of the eye, breast and gonads, is in or near the useful beam.[1(p563)] Gonad shielding should be used if inappropriately placed gonad shields will not compromise the clinical objectives of the examination. Gonad shielding should be used on all patients who have a reasonably reproductive potential. Some facilities will provide a specific age category in which a gonad shield must be used. Gonad shields should be used if the gonads lie within the primary x-ray field, or within close proximity (about 5 cms) despite proper beam collimation. When gonad shields are utilized on males, the radiation dose can be reduced as great as 95%, and as great as 50% on females. Gonad shields should be used in addition to proper beam limitation and not as a substitute for it.

Gonad shielding is important for adults of reproductive age and also for children because they have their reproductive lives ahead of them.

The types of gonad shields to be utilized may be dependent on the examination involved. For example, it is most common to use a contact or shaped shield that is placed directly on the patient's body relative to the location of the reproductive organs.[1(p562)] Any lead impregnated device can be utilized such as the commercially prepared gonad shields, a lead apron, lead glove, etc. Knowing that all these devices can be utilized as a gonad shield should minimize the problems of not having readily available shields.

The second type of shield is called a shadow shield that attaches to the tube housing.[1(p562)] The shadow outline is then displayed on the patient's body and positioned appropriately in respect to their reproductive organ area. Shadow shields are frequently used in scoliosis filming. Scoliosis is much more prevalent in young girls than in young boys. It is imperative for us to protect the breasts and reproductive organs since these young patients will have multiple studies perform in the assessment and medical management of their scoliosis.

In conclusion, gonadal shields should be used on all patients, especially children and those adults who are potentially reproductive.[1(p563)] Gonad shielding should be utilized when the gonads lie in or near the useful beam without compromising or jeopardizing diagnostic information. Proper collimation and positioning should not be relaxed when gonad shields are utilized.

COMMUNICATION SKILLS

Medical radiographers should take the time to assess patient comprehension level to determine their ability to follow instructions. It may be necessary to adjust your vocabulary based on the patient's age and mental status. It is important to take time to practice your instructions with the patient to solicit cooperation and better diagnostic images without repeats. It is important for radiographers to be empathetic to patient's needs. Radiographers should explain the procedure to the patient and encourage their participation whenever possible. It is always helpful to thank the patient at the conclusion of the examination for their cooperation. Since there is a level of anxiety on the patient's part for their diagnosis, it is helpful for radiographers to explain to the patient the process of radiologist interpretation and report preparation so that they know when to contact their personal physician for the results of the diagnostic exam.

RESPIRATORY ACTIVITY

It is important for radiographers to assess the patient's ability to comply with directions relative to their respiratory activity. Radiographers should watch the patient's chest and/or abdomen to evaluate inspiration and expiration sequence. It is important of correlate exposure time to the appropriate respiratory sequence required, i.e. inspiration versus expiration. The medical radiographer must select the appropriate exposure time relative to the patient's capability level. Radiographers should consider rotor delays particularly when filming pediatric patients. It may be necessary to stimulate crying in pediatric patients so that appropriate respiratory activity can be obtained.

IMMOBILIZATION DEVICES

Radiographers should have various immobilization devices available for their use to assist them in minimizing patient motion so that additional exposures by repeats are not necessary.[1(p272)] It is important to realize that patient motion is considered to be the biggest detriment to detail. It is important to realize that we, as human beings, have two types of motion. Voluntary motion can be controlled by the patient consciously, such as taking in a deep breath and holding it. Involuntary motion occurs when the patient cannot consciously control it, such as peristalsis, tremors, etc.

Some of the commonly utilized immobilization devices include tape, retention bands and other positioning aides (previously known as "restraints"), which are radiolucent sponges, sandbags, mummification, respiration phase, short exposure time and Pb devices. Mummification involves the process predominantly used in pediatrics when a sheet is utilized to immobilize the extremities and torso of infants and children. When the sheet is wrapped appropriately around the patient, the infant or child can be moved as a "unit".

TYPES OF TECHNIQUE CHARTS

There are several choices for technique charts available for medical radiographers to use.

A variable kVp, fixed mAs chart involves mAs that stays the same and kVp is altered depending on patient thickness.[1(p288)] A fixed kVp, variable mAs chart means the kVp stays the same and various mAs combinations are used for various body habitus. In certain instances, high kVp should be used for dedicated examinations, such as chest and barium studies. It is essential for radiographers to realize that a minimum 30% increase in mAs is required to produce a perceptible difference in optical density.

Some of our radiographic equipment has automatic exposure control (AEC) or phototiming that minimizes the need for the calculation of manual exposures.[1(p291)] However, automatic exposure control charts must identify the chambers to be selected and must be calibrated periodically so that consistent radiographic exposures can be maintained. The radiographer utilizing automatic exposure control or phototiming must become very conscientious of the position of the central ray so that the exposure can be measured appropriately. Positioning skills are critical when utilizing automatic exposure or phototimed equipment.

USE OF TECHNIQUE CHARTS

When a manual technique chart has been established, it is important for the medial radiographer to read the chart accurately. Most charts will require the measurement of patient body tissues. Measure tissue through the path of the central ray. Measuring actual tissue and do NOT have an air gap. Use technique charts located in each x-ray room.

Check the request for clinical history and adjust for normal versus abnormal tissue densities. Radiographers must consider the age and body habitus of the patient when adjusting techniques. Be sure to read the scale in centimeters versus inches on the body tissue caliper.

When performing x-rays on patients in a cast, compensation should be calculated for wet versus dry, full versus partial, etc. Fiberglass casts warrant a 0-2 kVp change from non-cast techniques. The master envelope of the patient should be pulled and previous requests checked for location of previous injury and previous cast techniques.

Radiographers should be able to alter the recommended technique when compensating for additive versus destructive disease processes that may be inherent within the patient based on their clinical history.[1(p278)] When automatic exposure control is utilized, it is important for the correct chamber and to center appropriately. As changes occur in the department, such as film, screen or chemistry, it may be necessary to change the data on the technique chart so that it accurately reflects the conditions presently implemented in the department. Technique charts should be kept up-to-date.

EXPOSURE TIME SELECTION

Medical radiographers should realize that it is important to use the shortest time possible to minimize risks of motion.[1(p248)] The exposure time should be correctly selected and double-checked on the control panel if another technologist is working collectively. If corrections are needed, they should be carefully calculated. The degree of patient cooperation should be evaluated.

MINIMIZE POSITIONING ERRORS

It is a professional obligation for all medical radiographers to be careful and conscientious in performing radiographic examinations. Enough time and assistance should be allocated to minimize the risk of repeat examinations. If repeat views are commonly occurring, it may be necessary to review positioning concepts or adjusting the technique charts to correct this problem as soon as possible. It is important for medical radiographers to become "expert" in performing examinations so that they can teach others in an appropriate manner.

PROTECTING THE PREGNANT PATIENT

Medical radiographers should always be conscientious of basic radiation protection considerations particularly relative to pregnant patients. A medical radiographer should never knowingly perform a radiographic examination on a pregnant patient unless a documented decision has been made to do so. If a radiographic examination must be performed on a pregnant patient, the medical radiographer should make every attempt to minimize radiation dose by using precise collimation, carefully positioning protective shields, utilizing high kVp techniques, and minimizing the number of views required to secure an adequate diagnosis.[1(p528)]

Elective booking can also be an option for the pregnant patient.[1(p528)] It is important for medical radiographers or physicians to determine the time of the patient's last menstrual period relative to scheduling an elective examination. If there is a risk of pregnancy, the physician should discuss the benefit versus risk option with the patient of having the examination performed or delayed.

The development and use of a patient questionnaire is helpful in determining the possibilities of pregnancy. It is a fundamental requirement that signs should be posted in waiting rooms requesting the patient to inform the radiographers if there is a risk of pregnancy.

If multiple radiographic examinations are performed on a patient who discovers a pregnancy at the time, an estimate of fetal dose can be calculated by a medical physicist.[1(p529)] For the medical physicist to calculate the dose appropriately, it is important to know the techniques used, the number of films, the patient's measurement at the time of filming, etc. The state of gestation must be determined when the exposures occurred. Based on this information, the pregnant person will be informed of the alternatives. She may choose to continue her pregnancy to term or may decide to terminate the pregnancy. The patient needs to be educated about the radiation measurement and dose involved based on her particular situation. If the medical physicist has calculated a fetal dose below 10 Rads, a therapeutic abortion not indicated. If the fetal dose is calculated between 11-24 Rads, careful consideration must be made by the patient. When the fetal dose is calculated above 25 Rads, a therapeutic abortion is justified.

REDUCTION OF UNNECESSARY PATIENT DOSES

It is important for medical radiographers to eliminate unnecessary examinations by correlating the clinical histories of the patient with the examination ordered. If a discrepancy occurs, the medical radiographer should inform the ordering physician or consult with the radiologist so that the radiographic examination can be justified. Medical radiographers should eliminate or minimize the number of repeat films taken on patients. Whenever possible, using high kilovoltage techniques will reduce patient doses. However, the scale of contrast must be evaluated so that diagnostic information may not be lost. Converting the facility to a rare earth film-screen combinations will reduce the patient dose 50-75% when compared to utilizing older conventional calcium tungstate screens and film combinations. Gonadal shields should be available in radiographic installations where medical radiographers will be working. Using the specific shield for the body part under examination is important. If all of the above listed practices are maintained, the possibilities and risks of unnecessary patient doses can be minimized.

Please refer to the chart provided at the conclusion of this unit for a synopsized listing of common methods to reduce radiation exposure to the patient.

This concludes Unit 11. Please proceed to the unit questions and complete the required personal data.

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Synopsis of Radiation Protection Measures for the Patient

based on Radiographer Performance, Knowledge & Facility Operation

Name of Measure	*How to Utilize Measure Effectively*
elimination of unnecessary examinations	*educate physicians & patients; correlate patient clinical history with ordered examination*
minimization of repeat exposures #1 reason for repeats is under or over exposure!	*carefully position & take appropriate time; review positioning data as needed for specific views*
selection of appropriate exposure factors	*read operator console & technique charts appropriately; doublecheck; fixed kVp, variable mAs techniques have been demonstrated to reduce repeats*
selection of appropriate imaging receptor	*use correct film-screen combinations for examination; convert to rare-earth system*
solicitation of patient co-operation	*explain procedure & use appropriate vocabulary; practice instructions with the patient*
proper collimation	*keep the x-ray beam the same size as the correctly selected film size or collimate closely without jeopardizing diagnostic information*
application of gonad shielding	*use correct shield type and in correct anatomic location without compromising the examination*
implementation of daily q.c. on processor	*check temperature, solutions, crossovers & sensitometry strip*
minimization of risk to pregnant patient	*consult ordering physician, check L.M.P., elective booking option, post signs and/or use patient questionnaire*
report equipment malfunctions	*contact medical physicist, biomedical engineer or supervisor immediately without subjecting the patient to any risk*
use immobilization devices when necessary	*keep an appropriate variety and sizes immediately available*
follow manufacturer's recommendations	*learn to operate all radiographic equipment and accessories appropriately before using on patient*
maintenance of continuing education	*keep up on new developments, review essential concepts and maintain professional ARRT status*

patprot/a/word

Organizations involved in Radiation Protection for Radiation Workers and the General Public

Primary Common Goal: to minimize radiation exposure to patients and personnel!

Abbreviation	*Official Name*	*Purpose(s) of Organization*
ICRP	***International Commission on Radiological Protection***	***international system of dose limitations; founded on 3 basic tenets:*** ***a. no practice shall be adopted unless its introduction produces a net positive benefit;*** ***b. all exposures should be kept as low as reasonably achievable (ALARA), economic & social factors being taken into account (this means that equipment and other operational factors must be designed so that workers do not exceed the operational dose limit);*** ***c. the dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.***
BEIR	***Biological Effects of Ionizing Radiation***	***advisory committee that publishes reports on the effects of ionizing radiation on biologic systems***
NCRP	***National Council on Radiation Protection and Measurement***	***agency that collects & analyzes data; makes recommendations in the form of reports; the reports listed below may be of interest or helpful:***
		NCRP #91 replaced with NCRP #116: covers topics such as exposure limits; dose equivalents; deterministic vs stocastic effects; fetal protection; occupational vs non-occupational exposure; emergency exposure
		NCRP # 102: covers topics such as equipment design & use; diagnostic equipment including fluoro., mobile & tomography; warning signs & shielding
		NCRP # 105: covers topics such as radiation protection for medical & allied health professionals; radiation quantities; background radiation;biological effects; acute radiation effects; carcinogenic dose limits; time-distance-shielding concepts; dose monitoring
NCR	***U.S. Nuclear Regulatory Commission***	***federal agency that regulates the use of radioactive substances and has the power to enforce the regulations; it does not regulate the use of radiation producing equipment; "agreement states" are states that have agreed to adopt & comply with the NCR radiation safety program***
FDA	***U.S. Food and Drug Administration***	***federal agency that regulates the design and manufacture of radiation producing equipment under the auspices of the Radiation Control for Health and Safety Act of 1968; regulations include specific standards for beam quality, beam reproducibility, timer mechanisms, mA linearity; beam collimation & alignment; light field intensity; requirements for fluoroscopic equipment***

The World Health Organization (WHO) is an international epidemiological organization involved in major research of the Atomic Bomb survivors & Chernobyl victim follow-up; promotes aspects of radiological health.

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Addendum, 2010: Radiation protection principles have common and/or specific applications based on the type of imaging modality you are utilizing. Some practices have already converted from conventional film-screen technology to digital imaging equipment. Many practices will be converting from conventional film-screen technology to digital imaging technologies in the upcoming years. Please feel free to consider utilizing the following self-learning units to expand your knowledge base and technical skills with computed radiography or digital imaging equipment in providing radiation protection principles for your patients, co-workers and yourself.	Number of A.S.R.T. Category A CE credits
Set 17: Unit 36: ***Radiographic Imaging & Exposure*** by Terri L. Fauber	11
Set 25: Unit 44: ***RadiationPprotection in Medical Radiography*** by Mary Alice Statkiewicz, et. al.	15
Set: 45: Unit 45: ***Digital Radiography and PACS*** by Christi Carter & Beth Veale	9
Please check the S.T.A.R.S. web site www.xrayhomestudies.com for current expiration dates and availability of these and new offerings in the future for your educational needs.	

Some Important Terms and/or Concepts in Unit 11

Increasing patient dose is the increased frequency of x-ray examinations among all age groups in the United States.

Increased patient doses in this country are relative to the prolonged fluoro time with our current angio-interventional exams.

Quality Assurance refers to the overall assessment and evaluation of patient care.

Quality Control refers to the measurement, testing, and evaluation of radiographic equipment.

The Joint Commission has developed a "10-step" program to assist administrators across the country in the monitoring and evaluation process.

Medical radiographers can take an active role in quality control in their facilities.

OSHA is the Occupational Safety and Health Act.

Radiographers should clean the inside and outside of the screens and cassettes regularly.

Film screen contact and damaged screens or cassettes should be replaced as soon as possible.

Gonad shields should be used when a particularly sensitive tissue or organ, such as the lens of the eye, breast and gonads, is in or near the useful beam. Gonad shielding should be used if inappropriately placed gonad shields will not compromise the clinical objectives of the examination. Gonad shielding should be used on all patients who have a reasonably reproductive potential.

When gonad shields are utilized on males, the radiation dose can be reduced as great as 95%, and as great as 50% on females.

Gonadal shields should be available in radiographic installations where medical radiographers will be working.

A contact or shaped shield is placed directly on the patient's body relative to the location of the reproductive organs.

A shadow shield attaches to the tube housing. The shadow outline is then displayed on the patient's body and positioned appropriately in respect to their reproductive organ area.

Medical radiographers should take the time to assess patient comprehension level to determine their ability to follow instructions. It may be necessary to adjust your vocabulary based on the patient's age and mental status. It is important to take time to practice your instructions with the patient to solicit cooperation and better diagnostic images without repeats. It is important for radiographers to be empathetic to patient's needs.

Radiographers need to assess the patient's ability to comply with directions relative to their respiratory activity. Radiographers should watch the patient's chest and/or abdomen to evaluate inspiration and expiration sequence. It is important of correlate exposure time to the appropriate respiratory sequence required.

Radiographers should consider rotor delays particularly when filming pediatric patients.

Radiographers should have various immobilization devices available for their use to assist them in minimizing patient motion so that additional exposures by repeats are not necessary.

Voluntary motion can be controlled by the patient.

Involuntary motion occurs when the patient cannot consciously control it, such as peristalsis, tremors, etc.

A variable kVp, fixed mAs chart involves mAs that stays the same and kVp is altered depending on patient thickness.

A fixed kVp, variable mAs chart means the kVp stays the same and various mAs combinations are used for various body habitus.

Radiographers to realize that a minimum 30% increase in mAs is required to produce a perceptible difference in optical density.

Radiographers should check the request for clinical history and adjust for normal versus abnormal tissue densities.

Radiographers should be able to alter the recommended technique when compensating for additive versus destructive disease processes that may be inherent within the patient based on their clinical history.

When automatic exposure control is utilized, it is important for the correct chamber and to center appropriately.

Technique charts should be kept up-to-date.

Medical radiographers should realize that it is important to use the shortest time possible to minimize risks of motion.

Medical radiographers should always be conscientious of basic radiation protection considerations particularly relative to pregnant patients.

A medical radiographer should never knowingly perform a radiographic examination on a pregnant patient unless a documented decision has been made to do so.

If a radiographic examination must be performed on a pregnant patient, the medical radiographer should make every attempt to minimize radiation dose by using precise collimation, carefully positioning protective shields, utilizing high kVp techniques, and minimizing the number of views required to secure an adequate diagnosis.

It is important for medical radiographers or physicians to determine the time of the patient's last menstrual period relative to scheduling an elective examination.

It is a fundamental requirement that signs should be posted in waiting rooms requesting the patient to inform the radiographers if there is a risk of pregnancy.

Medical radiographers to eliminate unnecessary examinations by correlating the clinical histories of the patient with the examination ordered.

Using high kilovoltage techniques will reduce patient doses.

Converting the facility to a rare earth film-screen combinations will reduce the patient dose 50-75% when compared to utilizing older conventional calcium tungstate screens and film combinations.

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.

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Unit Number 12

Common Methods Used to Control Radiation Exposure to the Operator

Prepared by: Carolyn J. Frigmanski, M.A., B.S.R.T. (R)

INTRODUCTION

It is in the best interest of all individuals operating diagnostic medical radiographic equipment to develop conscientious habits and a thorough understanding of methods that can be utilized to reduce personal radiation exposure. This unit will discuss common methods utilized in minimizing occupational radiation exposure risk. A summary of these common practices will be provided for quick and easy reference at the conclusion of the unit.

Occupational hazards for radiologic technologists include the following:

- Radiation
- Electricity
- Mechanical hazards
- Chemical hazards
- Patient handling
- Infections

We will only discuss radiation risks in this unit.

RADIOLOGICAL HEALTH PHYSICS

There are many state and federal organizations or agencies involved with the primary concern and issues related to providing radiation protection for the general public and for persons working in radiation industries. These organizations or agencies are strong proponents of the ALARA concept. ALARA represent the acronym for 'As Low As Reasonably Achievable'.[1(p547)] There are three cardinal principles in the ALARA Concept that minimizes the risks for occupational dose. The first principle requires that the time of exposure be as short as possible. The second principle relates to the fundamental concepts of the Inverse Square Law. Radiography personnel should maintain as large a distance as possible from the source of radiation exposure. The third principle involves the utilization of a shield between the source of radiation and the person at risk for exposure. A shield may be any barrier that prevents radiation from reaching the operator.[1(p555)] Common barrier include lead shields, walls, the portable machine, and a physician wearing an apron when you place yourself behind the physician. The key words in the ALARA Concept are time, distance and shielding.

RADIATION PROTECTION GUIDELINES

Since the inception of radiation protection guidelines, there have been significant changes in the last forty years. The ALARA Concept was originally introduced by the International Council of Radiation Protection in 1966. The ICRP recommended that radiation exposure must have a specific benefit to outweigh the risk. All exposures should be kept as low as reasonably achievable (ALARA). The dose to individuals shall not exceed limits for appropriate circumstances.

In 1987, the National Council on Radiation Protection and Measurement (N.C.R.P.) established limits on radiation exposure for radiation workers and the general public. There were two effects of radiation that provided major concern.[1(p521)] Early effects of radiation occur immediately after the overdose and can be diagnosed by decreased circulating blood cells and sperm count. The late effect develops after a long time from the initial exposure and can cause cancer and genetic defects to offspring.

In previous years, radiography personnel were familiar with the initials MPD.[1(p520)] MPD represented the maximum permissible dose that we now call the dose limit. The maximum permissible dose was defined as the maximum amount of radiation that would be expected to produce no significant radiation effects based on a linear, non-threshold dose response relationship in light of our current knowledge. We calculated our MPD with a simple formula.

N - 18(5) = ____ Rads. The N represented your age. Let's use this example.

A 24-year-old medical radiographer wanted to calculate the MPD. 24 - 18 = 6. 6 x 5 was 30. The MPD for this employee was 30 Rads.

In 1993, the ICRP (International Commission on Radiation Protection) made changes in the calculation of the cumulative whole-body dose limit. The present formula is 10 mSv x your age. The annual dose limit is 50 mSv and the dose limit during pregnancy is reduced to 5 mSv. A chart with the dose limit recommendations is provided at the conclusion of this unit for your reference. In diagnostic imaging, the appropriate dose level seldom exceeds 1/10 of the published amount or 5 mSv (500 millirem) per year. I must remind you that the occupational exposures for imaging personnel is highest in fluoroscopic examinations and radiographic procedures that must be performed a portable study.

THE PREGNANT RADIATION WORKER

There are some specific guidelines for radiation workers who become pregnant. It is important for the radiation worker to notify her supervisor as soon as possible. The pregnancy is then considered declared and the dose limit becomes 0.5 mSv per month.[1(p525)] The supervisor or medical physicist should review the pregnant radiation worker's previous radiation records to aid in determining what measures are necessary to minimize radiation risk. If the pregnant radiation worker is in an area requiring fluoroscopy, the proper weight and length of a wraparound lead apron should be provided. It is reasonable for the pregnant radiation worker to request two personnel monitoring devices. One device would be worn at the collar and the other device would be worn at the waist. The pregnant radiation worker should be re-sensitized to the cardinal principles of radiation protection. When normal protective radiation measures are taken, it is nearly impossible for a radiation worker to approach fetal dose.

MANAGEMENT PRINCIPLES

When new employees are added to the staff, it is important for the supervisory personnel to provide training. The orientation process should include the principles and policies on radiation protection that are utilized in the facility. Existing employees should have in-service training on an annual basis devoted to radiation protection principles to keep everyone conscientious and sensitized. All radiation workers should learn how to read the posted personnel monitoring reports on a monthly basis. Supervisory personnel should provide some counseling or refer the employee to the appropriate individual for counseling during pregnancy.

PERSONNEL MONITORING DEVICES

Personnel monitoring refers to procedures instituted to estimate the amount of radiation received by individuals who work around radiation.[1(p555)] The personnel monitor offers no protection against radiation exposure. It simply measures the quantity of radiation to which it was exposed and therefore is used as an indication of the exposure of the water.

There are three personnel monitoring devices available on the market. The most commonly used personnel monitoring device is the film badge. The film badge came on the market in the 1940's.

Previous to the film badge, blood tests were a method used to detect biological effects of occupational exposure. Periodic blood tests were not accurate since other factors could influence the blood cell count such as the development of an infectious process.

The film incorporated into a film badge is special radiation-dosimetry film that is particularly sensitive to ionizing radiation.[1(p556)] The density on the exposed and process film is proportional to the exposure received by the film badge. Carefully controlled calibration, processing, and analyzing conditions are necessary for the film badge to accurately measure occupational exposure.

The metal filters along with the window in the plastic film holder allow estimation of the radiation energy.[1(p556)] The usual filters are made of aluminum and copper. If the radiation exposure is due to penetrating radiation, the image of the filters on the processed film will be faint and there may be no image at all of the window in the plastic holder. If the badge is exposed to soft radiation, the filters will be well imaged and the densities under the filters will allow estimation of the x-ray energy. Often the filters to the front of the badge and the filters to the back of the badge have different shapes to allow the film-badge vendor to determine if the radiation detected by the badge entered through the front or back of the badge. Radiation that had entered through the back would normally indicate that the person wearing the badge was exposed to considerably higher levels of radiation than indicated, since the radiation would have penetrated through the body before interacting with the film badge. For this reason, film badges must be worn with the proper side to the front.

Film badges cannot detect exposures of 10 mR or less. Since these minimal doses are not measurable, the personnel monitoring report will register the reading with a big 'M' or minimum. This minimum does not mean no exposure has occurred to the radiation worker. Film badges are inexpensive, easy to handle, not difficult to process and are reasonably accurate. They have become a preferred personnel-monitoring device.

Film-badge monitors also have disadvantages. Since they incorporate film as the sensing device, they cannot be worn for long periods of time because of fogging due to temperatures and humidity.[1(p557)] The fogging produced by elevated temperatures and humidity will result in a falsely high evaluation of exposure.

The second type of personnel monitoring is the thermoluminescent dosimeter or TLD.[1(p557)] It consists of a lithium fluoride (LIF) chip approximately 3 mm square and 1 mm thick or powder placed in a wearable container. The containers are usually in the style of a wristwatch or ring badge. When the TLD is exposed to x-ray, the energy is absorbed in the crystal lattice. When the TLDs are returned to the commercial company, the crystals are heated. The crystal gives off measurable light that corresponds to the amount of radiation dose received by the radiation worker. TLDs are very sensitive, accurate and expensive to utilize on a regular basis.

Properly calibrated TLD monitors can measure exposures as low as 5 mR.[1(p557)] TLD monitors do not suffer from loss of information following exposure to excessive heat or humidity. Consequently, they can be worn for intervals up to three months at a time. The price of a typical

TLD monitoring service is perhaps twice that of film-badge monitoring. TLD monitoring is improving constantly and is slowly replacing film-badge monitoring.

TLD badges have the added advantage of also being able to discriminate between different types of radiation through the use of the filters, for example neutron versus x-ray radiation of electron versus x-ray radiation.

The last personnel monitoring device is the pocket dosimeter.[1(p558)] It looks like a writing pen that contains a charged chamber in a metal cylinder approximately 2 cm in diameter by 10 cm long. As the chamber becomes exposed to radiation, the charge becomes neutralized and the voltage is measured by simply holding the pocket dosimeter to the eye and looking into a light source. The pocket dosimeter gives immediate results to the radiation worker. A pocket dosimeter is a fairly expensive, easily damaged device that has a limited reading volume. Pocket ionization chambers are available in several different ranges, but the are usually employed in diagnostic radiography has a range of 0 to 200 mR.

It is sometimes controversial about where to wear your personnel-monitoring device. Please follow the recommended policy of your employment facility. Nearly all state radiation control programs recommend/require the personnel radiation monitors be worn at collar level.[1(p559)] It is not out of the ordinary to request a second personnel monitor during pregnancy.

If the technologist participates in fluoroscopy and wears a protective apron, as recommended, then the personnel monitor should be positioned on the collar above the protective apron. The maximum permissible dose values refer not only to whole-body exposure but also to partial-body exposure of the head, neck, trunk, lens of the eye, gonads, and bone marrow. The head and neck regions are restricted to the same maximum permissible dose as the entire body. It has been shown that during fluoroscopy, when a protective apron is worn, the exposure to the collar region is 10 to 20 times greater than that to the trunk of the body beneath the protective lead apron. Consequently, if the personnel monitor is worn beneath the protective apron, it will record a falsely low exposure and will not indicate what could be a hazardous exposure to unprotected parts of the body.

Two exceptions are monitoring the abdomen during pregnancy and monitoring the extremities during special-procedures in which the technologist's hands are in close proximity to the useful beam.[1(p559)] Radiologists often should wear extremity monitors during fluoroscopy, as should nuclear medicine technologists when handling radioactive material.

FIELD SURVEY DEVICES

Ion chambers are devices used to measure a dose rate from radiation producing machines and materials by collecting the ions produced.[1(p539)] They operate in the range of 100 to 300 volts. The most familiar of these is the "cutie pie", a portable instrument used for area surveys. It has a wide range (1mR/hr to several thousand R/hr), and it is accurate. A Victoreen R Meter is another type of ion chamber used by physicists to measure fluoro and X-ray equipment output.

Proportional Counters are devices operated at higher voltages than do ion chambers and are very sensitive.[1(p540)] They depend on secondary ionizations to take place within the chamber, resulting in a higher reading of ions collected than that produced by the action of the radiation within the gas-filled chamber. They have the ability to distinguish between alpha and beta particles and find their primary application in laboratories rather than in radiology departments.

Geiger-Muller counters employ a gas filled tube with a sufficiently high voltage across it so that a single ionization event causes the entire tube to discharge.[1(p541)] Because it takes a brief amount of time for the tube to be restored to its original condition (the resolution time), GM counters can become saturated and are then not able to detect ionizations occurring shortly afterwards. For this reason, they are not very useful as dosimeters. They are, however, particularly useful at detecting single ionizing events, finding lost radioactive sources, detecting contamination, and determining if a leak exists in room shielding.

PERSONNEL MONITORING REPORT

The results of the personnel monitoring report must be recorded in a precise fashion and maintained for review as stipulated by state and federal regulations. The personnel monitoring report should include items such as:

employee name and type of monitor;
identification number of radiation worker and monitor;
current exposure;
cumulative quarterly and annual exposure; and
additional data such as birth date, gender, social security number, etc.

The social security number is becoming an issue at this time and may deleted from future personnel monitoring reports since this personal data may be publicly displayed at your place of employment.

It is important to remember when changing employment that your total radiation exposure history should be transferred to the new employer location.[1(p559)] It is also important to report a lost personnel-monitoring device as quickly as possible so that a replacement can be obtained from the commercial vendor. Most commercial vendors will replace the personnel-monitoring device within a 24-hour period. The company that processes the personnel monitoring report will average the last six months of readings and print the corresponding number on the current month's report. It should be remembered that the control monitor is not to be used as a replacement film badge. The control monitor is used to measure background exposure during transportation, handling and storage of the film badges. The control monitor should not be stored in or adjacent to any radiation areas. It is also important to know that personnel radiation monitors should not be worn during personnel medical examination. The personnel radiation monitor is provided to measure occupational dose.

EQUIPMENT DESIGN FOR RADIATION PROTECTION

Physicist, biomedical engineers, and other manufacturing specialists are interested in providing appropriate equipment design to minimize radiation risk to the users. The x-ray tube housing must reduce leakage to a specific amount. The control panel must have lights to indicate when the x-ray tube is energized. Some control panels will have an audible signal in addition to the visual light. The source image distance (S.I.D.) indicator should be easily read and accurate. Collimation and beam alignment should be checked on a regular basis. The exposure switch should be fixed to operator console to prevent radiography personnel from leaving the protective barrier of the control booth.

DESIGN OF PROTECTIVE BARRIERS AND WORK AREAS

Medical physicist is consulted for assistance in designing proper radiation shielding of new or renovating x-ray room facilities. There are two types of protective barriers. A primary protective barrier is any wall to which the useful beam can be directed.[1(p535)] The rule of thumb requires 1/16" of lead or 4"of masonry. A secondary protective barrier is designed to shield areas from secondary radiation, such as scatter and leakage from the x-ray tube. The rule of thumb is four thicknesses of 5/8" gypsum board or 1/2" plate glass or lead acrylic. The control booth is considered a secondary protective barrier since the primary beam should never be directed to toward it. The controlled area is any area that is occupied primarily by imaging personnel.

For fixed shielding:

1. Secondary barriers: those struck by stray radiation (the sum of leakage and scatter), 1/32 inch Pb equivalent.[1(p535)]
2. Minimum barrier height: 7 feet
3. Overlapping surfaces: 1/2 inch of the secondary barrier over the primary where they meet.
4. The exposure switch must be positioned at least 30 inches from any open edge of the booth.
5. Rooms must be constructed so that radiation must scatter at least twice before reaching the operator.

Shielding of the X-ray tube itself must be such that exposure from leakage radiation is no more than 100 mR per hour at a distance of one meter.

Work Area Definitions

In settings where ionizing radiation is utilized, there exist biologic exposure limits in mrem for the designation of work areas.[1(p536)]

An "*unrestricted area*" is one where radiation levels are essentially the same as background radiation. The dose in any unrestricted area cannot exceed 2 mrem in any one-hour period and cannot exceed 100 mrem annually.

A "*radiation area*" is one where an individual's exposure could be more than 5 mrem but less than 100 mrem per hour at 30 cm from the radiation emitter. These areas are required to have controlled access, and be designated with the purple, magenta, or black on yellow trefoil sign reading "Caution - Radiation Area."

A "*high radiation area*" is one where an individual's exposure is more than 100 mrem per hour. These areas must display a "High Radiation Area" warning sign and have controlled access features such as door interlocks.

A "very high radiation area" exists when an individual's absorbed dose could exceed 500 Rad in one hour. These areas are found more commonly in radiation therapy departments and research laboratories.

The amount of shielding required for an area or room to be considered "safe" or as an unrestricted area will depend on the workload of that room, calculated in mA-minutes/week.[1(p537)]

OPERATOR SAFETY ACTIVITIES

It is important for radiography personnel to become familiar with the operation of the equipment. It is important to report equipment malfunctions immediately. Report fluctuations in exposure as soon as possible. Watch the ballistics mAs meter during the exposure to see if the selected mA has been maintained and that the selected time occurred for the length of exposure.

It is important to report any inappropriate orders for x-ray examinations to the supervisor or physician. Most facilities feel physician orders should be dealt with by another physician rather than at the radiation worker level. It is important to be efficient and accurate when positioning all patient examinations to minimize repeats. Remember to follow the safe operating procedures for your equipment and report any unsafe conditions immediately to supervisor, physician or radiation safety officer.

PROTECTIVE APPAREL

Lead aprons and gloves should have a layer of tin or lead-impregnated vinyl with a thickness of 0.25, 0.5 and / or 1.0mm of lead equivalent. [1(p560)] There are other materials on the market today that are being used in the construction of protective apparel such as Xenolite which is 30% lighter than commonly used lead aprons. Protective apparel can be purchased in many sizes and shapes to accommodate appropriate shielding of radiosensitive anatomic areas. It is important to store all protective apparel appropriately to minimize cracks and pinholes in the continuity of the lead lining. The lead aprons and gloves should be checked on a regular basis to assure continuity of the lead lining.

PATIENT HOLDING

Diagnostic imaging personnel should never be used to hold a patient during a radiographic examination.[1(pp560-561)] Alternatives should be implemented. Positioning devices may be effective. The patient's relative or friend may be recruited to assist in the radiologic examination when protective apparel has been provided to them. If the patient does not have a relative or friend available at the time of examination, a non-radiation working employee should be recruited.

IMPORTANT ASPECTS OF RADIATION PROTECTION

All medical radiography personnel should understand and apply the three cardinal principles of radiation control.

Time = reduce or limit the time spent near a radiation source.
Distance = move away or keep as much distance as possible from the radiation source.
Shielding = use barriers between the source and the individual.

Medical radiography personnel should not allow the familiarity of the equipment and procedure to result in poor radiation protection methods.

Diagnostic medical radiography personnel never stand in the primary beam. They should always wear protective apparel or stand behind a protective barrier of some type. Personnel radiation monitoring devices should be worn at all times and positioned outside the lead apron.

Diagnostic medical radiography personnel should never hold a patient during an exposure.

Diagnostic medical radiography personnel should always collimate to the smallest field size appropriate for the examination.

Equipment considerations involve using gonadal shielding on all persons of childbearing age and breast shielding when it does not interfere with the area of interest. Gonadal shields should be positioned appropriately so that the anatomic area under investigation is not interfered with by the shielding device.

Appropriate filtration should be used to minimize the low energy x-rays that have little value in producing the x-ray image.

Intensifying screens should be used whenever possible since they reduce exposure to the patient by more than 95% when compared to examinations performed without screens.

Medical radiographers must always take time to ascertain the possibilities of pregnancy on female patients. Whenever possible, radiographic examination of the pelvis and abdomen of a pregnant woman should be avoided, especially during the first trimester, unless medically advised as having a substantial benefit for the pregnant woman's medical care.

OPERATION SAFETY

Remember:

The BEST exposure is NO exposure!!

RADIATION DOSES AND RADIATION WORKERS

Over half of all radiation workers monitored in the United States receive no measurable doses.[1(p547)] Medical radiography workers fall into this category.

The other half average approximately 300 mrem per year. Industrial radiographers, manufacturers, radioactive waste processors, etc. fall into this category.[1(p547)]

Radiation and Cancer

The risk of occupational levels of radiation exposure causing cancer is unknown and is estimated from data for very high levels of radiation exposure. However, the safe estimate is that some risk may exist.

Approximately **one in five adults normally will die from cancer** from all possible causes such as smoking, food, alcohol, drugs, air pollutants, natural background radiation, and inherited traits.[1(p506)]

There is a risk of 4 in 1000 (.4%) that a 1000 mrem (.01Sv) dose will cause a fatal cancer.[1(p508)]

Therefore, in a group of 10,000 workers:

-2,000 would die of cancer from all causes other than occupational exposure to radiation;
-approximately 4 more would die from occupational exposure to 1000 mrem of radiation;
-this means that 1000 mrem of radiation would increase a worker's chances of dying from cancer from 20% natural occurrence to 20.04%.

Is it in the cards?

-The additional chance of developing a cancer from an occupational exposure of 10,000 mrem (0.1Sv) is about the same as the chances of drawing an ace from a full deck of cards three times in a row.

-The additional chance of dying from a cancer from an occupational exposure of 10,000 mrem is equal to the chance of drawing two aces successively on the first two draws from a full deck of cards.

It is helpful to compare the risks from occupational exposure to radiation to other health risks.

-being 15% overweight reduces our life expectancy by 2 years
-receiving 300 mrem per year from 18 to 65 reduces our life expectancy by 15 days

This concludes Unit 12. Please proceed to the unit question and complete the required personal data.

Summary of Dose-Limiting Recommendations from NCRP Report #116, page 56 Table 19.1

Limitation of Exposure to Ionizing Radiation
(issued March, 1993 with copyright by the NCRP)

A. Occupational Exposures*	
1. Effective dose limits	
a) Annual	***50 mSv***
b) Cumulative	***10 mSv x age***
2. Equivalent dose annual limits for tissues and organs	
a) Llens of eye	***150 mSv***
b) Skin, hands and feet	***500 mSv***
B. Guidance for emergency occupational exposure*	***(see Section 14)***
C. Public exposures (annual)	
1. Effective dose limit, continuous or frequent exposure*	***1 mSv***
2. Effective dose limit, infrequent exposure*	***5 mSv***
3. Equivalent dose limits for tissues and organs*	
a. Lens of eye	***15 mSv***
b. Skin, hands and feet	***50 mSv***
4. Remedial action for natural sources:	
a. Effective dose (excluding radon)	***>5 mSv***
b. Exposure to radon decay products	***>7 x 10^{-3} Jh m^{-3}***
D. Education and training exposures (annual)*	
1. Effective dose limit	***1 mSv***
2. Equivalent dose limit for tissues and organs	
a. Lens of eye	***15 mSv***
b. Skin, hands and feet	***50 mSv***
E. Embryo-fetus exposures (monthly)*	
1. Equivalent dose limit	***0.5 mSv***
F. Negligible individual dose (annual)*	***0.01 mSv***

****Sum of external and internal exposures but excluding doses from natural sources.***

Synopsis of Radiation Protection Measures for the Radiographer/Operator

Occupational radiation doses may originate from a variety of sources such as:

-accidental exposure to the primary beam;
-scatter from the patient;
-leakage from the x-ray tube; and/or
-scatter from other sources.

Name of Measure	*How to Utilize Measure Effectively*
time	*less time, less exposure; employees should be rotated in OR or GI fluoroscopic rooms to minimize risk*
distance	*most important factor based on the Inverse Square Law due to attenuation by the intervening air molecules; at a distance of 1 meter, the intensity of scatter radiation emitted from a patient is 0.1% of the original intensity; standing at 90 degrees from the patient will result in the lowest exposure to the operator.*
shielding *moveable included*	*the greater the amount of attenuating material between the source & the radiographer, the less the dose. NCRP recommendations for moveable shielding is 0.25 mm, but 0.5 mm Pb preferred for fluoro drapes and the Bucky slot cover; fixed shielding is listed in the unit.*
protective aprons, gloves, thyroid shields, glasses	*0.5 mm. Pb required*
type of x-ray generation	*3 phase produces a higher average kVp which makes lower mAs settings possible when compared to single phase*
immobilization	*use correct size & style; properly position devices*
exposure control cord length	*must be fixed to operator console and not long enough for operator to extend past the open edge of the control booth*
protective tube housing	*leakagecan not be more than 100 mR per hour at a distance of 1 meter*
use of personnel monitoring devices	*see unit for details of advantages & disadvantages of each type*
holding patients	*radiologic personnel should never hold a patient during an exposure! seek appropriate positioning devices or non-radiation individuals*
fluoro time & cumulative timer	*intermittent fluoro should be used; pay attention to the 5 minute audible signal; rotate personnel*
minimization of portable examinations	*rotate personnel*
malfunctioning equipment	*report it immediately to the appropriate individuals as soon as possible*

familiarity of examinations	*do not grow careless or disinterested by the repetitiveness of certain examinations that could warrant repeat exposures to the patient and consequently scatter*
pregnancy	*follow additional precautions during the pregnancy by declaring it to the appropriate supervisory individuals*
radiation protection education	*attend regularly scheduled annual inservices at your place of employment or attend other conferences on the subject*
continuing education	*keep up on new developments; review essential concepts; maintain your active A.R.R.T. status by satisfying the national requirements*

perprot/a/word

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Addendum, 2010: Radiation protection principles have common and/or specific applications based on the type of imaging modality you are utilizing. Some practices have already converted from conventional film-screen technology to digital imaging equipment. Many practices will be converting from conventional film-screen technology to digital imaging technologies in the upcoming years. Please feel free to consider utilizing the following self-learning units to expand your knowledge base and technical skills with computed radiography or digital imaging equipment in providing radiation protection principles for your patients, co-workers and yourself.	Number of A.S.R.T. Category A CE credits
Set 17: Unit 36: ***Radiographic Imaging & Exposure*** by Terri L. Fauber	11
Set 25: Unit 44: ***RadiationPprotection in Medical Radiography*** by Mary Alice Statkiewicz, et. al.	15
Set: 45: Unit 45: ***Digital Radiography and PACS*** by Christi Carter & Beth Veale	9
Please check the S.T.A.R.S. web site www.xrayhomestudies.com for current expiration dates and availability of these and new offerings in the future for your educational needs.	

SOME IMPORTANT TERMS AND/OR CONCENTS IN UNIT 12

It is in the best interest of all individuals operating diagnostic medical radiographic equipment to develop conscientious habits and a thorough understanding of methods that can be utilized to reduce personal radiation exposure.

ALARA represent the acronym for 'As Low As Reasonably Achievable'.

The key words in the ALARA Concept are time, distance and shielding.

The ICRP recommended that radiation exposure must have a specific benefit to outweigh the risk.

The dose to individuals shall not exceed limits for appropriate circumstances.

Early effects of radiation occur immediately after the overdose and can be diagnosed by decreased circulating blood cells and sperm count. The late effect develops after a long time from the initial exposure and can cause cancer and genetic defects to offspring.

The maximize permissible dose was defined as the maximum amount of radiation that would be expected to produce no significant radiation effects based on a linear, non-threshold dose response relationship in light of our current knowledge. We calculated our MPD with a simple formula. This term has been changed to Dose Limit.

The cumulative whole-body dose limit uses the formula = 10 mSv x your age. The annual dose limit is 50 mSv and the dose limit during pregnancy is reduced to 5 mSv.

It is important for the radiation worker to notify her supervisor as soon as possible. The pregnancy is then considered declared and the dose limit becomes 0.5 mSv per month.

If the pregnant radiation worker is in an area requiring fluoroscopy, the proper weight and length of a wraparound lead apron should be provided. It is reasonable for the pregnant radiation worker to request two personnel monitoring devices. One device would be worn at the collar and the other device would be worn at the waist. The pregnant radiation worker should be re-sensitized to the cardinal principles of radiation protection. When normal protective radiation measures are taken, it is nearly impossible for a radiation worker to approach fetal dose.

The orientation process for new employees should include the principles and policies on radiation protection that are utilized in the facility.

Existing employees should have in-service training on an annual basis devoted to radiation protection principles to keep everyone conscientious and sensitized.

All radiation workers should learn how to read the posted personnel monitoring reports on a monthly basis.

The most commonly used personnel monitoring device is the film badge.

Film badges cannot detect exposures of 10 mR or less.

The thermoluminescent dosimeter or TLD consists of a lithium fluoride chip or powder placed in a wearable container.

The pocket dosimeter contains a charged chamber in a metal cylinder.

Personnel monitoring refers to procedures instituted to estimate the amount of radiation received by individuals who work around radiation.

Ion chambers are devices used to measure dose rate from radiation producing machines and material by collecting the ions produced.

Geiger-Muller counters are particularly useful at detecting single ionizing events, finding lost radioactive sources, detecting contamination, and determining if a leas exits in room shielding.

The results of the personnel monitoring report must be recorded in a precise fashion and maintained for review as stipulated by state and federal regulations.

It is important to remember when changing employment that your total radiation exposure history should be transferred to the new employer location.

It should be remembered that the control monitor is not to be used as a replacement film badge. The control monitor is used to measure background exposure during transportation, handling and storage of the film badges

It is also important to know that personnel radiation monitors should not be worn during personnel medical examination

Physicists, biomedical engineers and other manufacturing specialists are interested in providing appropriate equipment design to minimize radiation risk to the users.

The exposure switch must be positioned at least 30 inches from any open edge of the booth.

Medical physicist is consulted for assistance in designing proper radiation shielding of new or renovating x-ray room facilities.

There are two types of protective barriers. A primary protective barrier is any wall to which the useful beam can be directed. A secondary protective barrier is designed to shield areas from secondary radiation, such as scatter and leakage from the x-ray tube.

The controlled area is any area that is occupied primarily by imaging personnel.

A "*radiation area*" is required to have controlled access, and be designated with the purple, magenta, or black on yellow trefoil sign reading "Caution - Radiation Area."

The amount of shielding required for an area or room to be considered "safe" or as an unrestricted area will depend on the <u>workload</u> of that room, calculated in <u>mA-minutes/week</u>.

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Medical radiographers must always take time to ascertain the possibilities of pregnancy on female patients.

Over half of all radiation workers monitored in the United States receive no measurable doses.

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.

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Conversion Table for the Units of Radiation Measurement

Traditional Name	Current Name	Measurement
Roentgen	Coulomb/kilogram	In air exposure
Rad	Gray	Radiation absorbed dose
REM	Sievert	Dose equivalent
Curie	Becquerel	Radioactivity

Units 8 – 12

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Unit 8
Title: Cellular and Molecular Biology

1. The portion of the cell that contains DNA is called the
   a. cytoplasm
   b. nucleus
   c. nucleolus
   d. macromolecule

2. The organelle which digests macromolecules for energy production is called the
   a. ribosome
   b. nucleolus
   c. mitochondria
   d. lysosome

3. The process of cellular division for genetic cells in both sexes is called
   a. meiosis
   b. mitosis
   c. cell cycle
   d. cell generation

4. The pre-DNA synthesis stage in a cell cycle is identified as
   a. M phase
   b. G_1
   c. G_2
   d. S

5. The phase of mitosis in which the chromosomes line up at the equator of the parent cell is
   a. anaphase
   b. prophase
   c. telophase
   d. metaphase

6. The most abundant macromolecule in the human body is
   a. saccharides
   b. lipids
   c. water
   d. protein

7. The macromolecule that controls cell function and heredity is
   a. DNA
   b. lipids
   c. RNA
   d. carbohydrates

8. Radiation biologists have determined that ionizing radiation can produce
   a. no effects in living tissue
   b. observable effects in dead tissue
   c. no change in chromosomes
   d. genetic change

9. The physical factor which uses a formula to compare biologic effects of various forms of radiation is called
   a. OER
   b. RBE
   c. LET
   d. REM

10. The biological factor which indicates cell radiosensitivity increases with oxygen saturation is called
    a. LET
    b. RBE
    c. OER
    d. REM

11. In the target theory, one initial ionizing event may "hit" a critical target and the cell will
a. die
b. recover
c. multiply
d. sustain no effect

12. The radiolysis of water is considered to be a (an)
a. critical target
b. direct effect
c. indirect effect
d. minimal effect

13. The term "radiation sickness" refers to the conversion of water into a toxic compound called
a. tritium
b. hydrogen peroxide
c. carbon monoxide
d. hydrochloric acid

14. Dose-response relationships are graphic mathematical displays of
a. how radiation affects radiation workers
b. how the percentage of death is calculated to an exposed group
c. how different doses of radiation affect mice and flies
d. how different cells are affected by radiation exposure

15. The law which describes the fundamental principles of cell radiosensitivity was developed by
a. Marie and Pierre Curie
b. Bergonie and Tribondeau
c. Albert Einstein
d. Wilhelm Roentgen

16. One explanation for high fetal radiosensitivity is
a. the small number of reproducing cells
b. the dependence on maternal blood flow
c. the type and rate at which cells mature
d. the amount of amniotic fluid

17. The human cell type ***most*** sensitive to radiation insult is
a. brain and spinal cord
b. lymphocytes
c. bone
d. erythroblasts

18. The human cell type ***least*** sensitive to radiation insult is
a. brain and spinal cord
b. lymphocytes
c. bone
d. erythroblasts

19. The term used to identify the loss or change in the sequence of nitrogenous bases in DNA is
a. point lesion
b. cross-linking
c. point mutation
d. main-chain scission

20. The ***most*** radiosensitive period in the aging process of human beings occurs during
a. childhood
b. adolescence
c. adulthood
d. fetal development in utero

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Unit 9
Title: Biological Effects of Radiation Exposure - Acute

1. In diagnostic radiographic installations, the probability of an accident involving acute radiation lethality is
   a. 80%
   b. less than 50%
   c. 60%
   d. impossible

2. Thirty people died from acute radiation exposure at
   a. Three Mile Island
   b. Chernobyl
   c. Davis Besse
   d. Nagasaki

3. "Immediate radiation sickness" occurs in the
   a. prodromal stage
   b. latent stage
   c. G.I. stage
   d. CNS stage

4. Manifest illnesses occur in a specific order based on increasing dose as
   a. prodromal, GI and hematologic
   b. CNS, G.I. hematologic
   c. hematologic, G.I., CNS
   d. latent, hematologic, CNS

5. The stage of acute radiation lethality in which the victim feels he is "recovering" is
   a. prodromal
   b. latent
   c. hematologic
   d. G.I.

6. The manifest illness that is produced by radiation doses of 200-1,000 Grays is
   a. G.I.
   b. prodromal
   c. CNS
   d. hematologic

7. The manifest illness, which occurs within 4 to 10 days after a radiation dose of 5000 Grays, is
   a. G.I.
   b. hematologic
   c. CNS
   d. G.U.

8. The chart containing information about the percent of deaths in a certain time frame is
   a. acuity chart
   b. survival curve
   c. latent dose
   d. lethal dose chart

9. The unit of radiation measured for acute radiation lethality is
   a. Roentgen
   b. Rads
   c. REM
   d. Becqueral

10. The shortest survival period for victims of radiation doses in excess of 5,000 Grays is
   a. CNS
   b. G.I.
   c. hematologic
   d. G. U.

11. The most notorious nuclear power plant accident in the United States was
   a. Davis Besse
   b. Enrico Fermi
   c. Three Mile Island
   d. San Francisco

12. The city of Hiroshima was selected for the first atomic bombing because it
   a. had no military armament factories
   b. was the home of all military officials
   c. was located in the mountains
   d. had not been previously bombed

13. The temperature at the central core of the atomic bomb's fireball was
   a. 100,000 ^{o}F
   b. 300,000 ^{o}C
   c. 1 million ^{o}C
   d. less than 100,000 ^{o}C

14. The rationale in dropping the Atomic Bomb was to
   a. spare further American lives
   b. gain another Presidential term for H. Truman
   c. maintain confidence with U.S. allies
   d. demonstrate Albert Einstein's research

15. The atomic bomb is often described and pictured as a
   a. red fireball
   b. black fireball
   c. "mushroom" cloud
   d. cumulus cloud

16. The second Japanese city to be bombed on August 9, 1945 was
   a. Hiroshima
   b. Tokyo
   c. Nagano
   d. Nagasaki

17. The manifest illness in which a full recovery can occur within six months is
   a. CNS
   b. hematologic
   c. G.I.
   d. G.U.

18. The element(s) first used for fission in the atomic bomb production was
   a. uranium
   b. radium and uranium
   c. radon and plutonium
   d. plutonium and uranium

19. The most notorious nuclear power plant accident in the World was
   a. Davis Besse
   b. Enrico Fermi
   c. Three Mile Island
   d. Chernobyl

20. Cities that began the world wide ban of nuclear weapons after World War II were
   a. Hiroshima and Nagasaki
   b. Washington, D.C. and Tokyo
   c. Hiroshima and Washington, D.C.
   d. Berlin and Tokyo

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Unit 10
Title: Biological Effects of Radiation Exposure — Chronic

1. The consequence of local tissue damage to high doses of radiation is
   a. no recovery
   b. cell proliferation
   c. sterility
   d. total non-function of the tissue or organ

2. Radiation effects on the skin include
   a. erythema & birth marks
   b. premature aging
   c. excessive wrinkles & creases
   d. desquamation & erythemia

3. Wilhelm Konrad Roentgen died in 1921 from
   a. colon cancer
   b. melanoma
   c. leukemia
   d. pernicious anemia

4. The only woman to have won two Nobel prizes in the entire history of the award is
   a. Amelia Earhart
   b. Florence Nightingale
   c. Marie Curie
   d. Sarah Bernhart

5. The individual who is considered the first fatality from the effects of prolonged exposure to man-made radiation is
   a. Pierre Curie
   b. Clarence Dally
   c. Bertha Roentgen
   d. Thomas Edison

6. The dose-response relationship characteristic that demonstrates a directly proportional effect to dose is
   a. linear
   b. semi-log
   c. non-linear
   d. quadratic

7. The dose-response relationship characteristic that demonstrates any amount of radiation will produce an effect is
   a. threshold
   b. non-linear
   c. non-threshold
   d. linear

8. Current radiation protection guidelines support the dose-response relationship identified as
   a. threshold, non-linear
   b. non-threshold, linear
   c. non-linear, non-threshold
   d. linear, threshold

9. The population of scientists who experienced and reported Cataracts were
   a. cyclotron physicists
   b. Atomic Bomb survivors
   c. German mine workers
   d. radium watch painters

10. Elevated incidence of radiation-induced leukemia was demonstrated in
    a. nuclear power plant accident survivors
    b. British radiologists
    c. pregnant women
    d. children irradiated in utero

11. Liver cancer was induced by a contrast medium used in angiography called
    a. Pantopaque
    b. Dionosil oily
    c. Thoratrast
    d. Ethiodol

12. Radium salts were used in the early half of this century to treat patients with
  a. TB and arthritis
  b. pneumonia and meningitis
  c. black lung disease and polio
  d. smallpox and TB

13. In the U.S., we historically treated children with enlarged thymus glands who later manifested
  a. bone cancer
  b. thyroid cancer
  c. brain cancer
  d. melanoma

14. Historically occupationally-induced malignancies have been documented in the
  a. brain and kidney
  b. skin and bowel
  c. liver and lymph
  d. bone and lung

15. After prolonged high-dose fluoroscopic procedures, chromosomal alterations have been identified such as
  a. rung addition
  b. chromatid addition
  c. reciprocal relocation
  d. ring formation

16. Irradiation to the gonads in adults of 200 Rads (2 Gy) produces
  a. suspension of menses
  b. permanent sterility
  c. temporary sterility
  d. impotence

17. The <u>most</u> sensitive period for fetal radiation is
  a. 1^{st} 2 weeks of 1^{st} trimester
  b. 1^{st} 2 weeks of 2^{nd} trimester
  c. 1^{st} 2 weeks of last trimester
  d. anytime

18. Life-span shortening based on chronic doses of low level radiation is
  a. considerable
  b. controversial
  c. well-documented
  d. definitely well established

19. The most difficult risk estimate to calculate is
  a. relative
  b. statistical
  c. excess
  d. absolute

20. A current study involving thousands of U.S. Medical Radiographers who have been employed under low level radiation risks indicates
  a. an excess risk for leukemia
  b. an excess risk for all cancers
  c. no effects have been identified at this time
  d. an absolute risk for melanoma

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Specialized Topics in Areas of Radiologic Sciences
P.O. Box 2931 Toledo, Ohio 43606 419-471-1973
E-mail: info@xrayhomestudies.com
www.xrayhomestudies.com

Unit 11
Title: Common Methods used to Control Radiation Exposure to the Patient

1. United States medical physicists and radiation biologists are concerned about radiation amounts received by the general public because
   a. the frequency of x-ray examinations is decreasing
   b. the frequency of erythema is increasing from diagnostic procedures
   c. multiple modalities are not available for diagnosis confirmation
   d. physicians order more x-rays to protect themselves from litigation

2. With the increasing sophistication of angio-interventional procedures, the radiation exposures during fluoroscopy is
   a. increasing
   b. remaining the same
   c. decreasing
   d. insignificant

3. Quality control is different than quality assurance because it involves
   a. only the x ray film processors
   b. only the x ray generating equipment
   c. only physicists and biomedical engineers
   d. acceptance and performance evaluation radiographic equipment

4. The national program of accreditation utilized by hospital facilities receiving Medicare/ Medicaid funding is known as
   a. IRS and NRCP
   b. IRS and FDA
   c. JRCRT and ACS
   d. The Joint Commission

5. The reason commonly used by radiographers for <u>not</u> using a gonad shield is
   a. placing it incorrectly on the body
   b. not important for use
   c. diagnostic x rays have little dose
   d. the radiologist/physician doesn't insist on it

6. A gonad shield that attaches to the collimator is called
   a. shadow
   b. contact
   c. shaped
   d. portable

7. Appropriate gonad shielding can reduce dose as great as ___% in males and ___% in females
   a. 60:40
   b. 95:50
   c. 75:25
   d. 50:95

8. The population(s) who need gonadal shielding include
   a. children only
   b. women in childbearing age
   c. children and adults with reproductive potential
   d. males up to age 65

9. To enhance communication with the patient, radiographers should always
   a. hurry the procedure without explanation
   b. disregard patient comprehension
   c. be sympathetic
   d. be empathetic

10. To minimize repeats due to respiratory activity, radiographers should always
    a. consider sedation
    b. select any exposure time
    c. use the same time
    d. watch the patient carefully

11. The movement of the stomach, small bowel and colon after ingesting a big lunch is a type of
   a. involuntary motion
   b. voluntary motion
   c. self-conscious motion
   d. automatic motion

12. The type of technique chart which reduces patient dose the best is called a
   a. variable kVp, fixed mAs
   b. high kVp
   c. variable mAs, fixed kVp
   d. phototiming chart

13. The biggest detriment to detail on a finished radiograph is created by
   a. long S.I.D.
   b. short O.I.D.
   c. patient motion
   d. slow film-screen combination

14. A radiographer interested in minimizing positioning errors will develop conscientious habits involving
   a. fast positioning skills regardless of patient's physical challenges
   b. allowance of just enough time regardless of patient comprehension or capabilities
   c. student practice without supervision
   d. periodically review of personal film quality and patient skills

15. If a x-ray examination is absolutely necessary on a pregnant patient, the radiographer should always
   a. precisely collimate & carefully position protective shields
   b. use longer times of exposure
   c. do the routine number of views
   d. take repeats as needed

16. When a fetal dose of 30 Rads (300 mGy) has been calculated by a medical physicist, the recommendation for a pregnant woman is to
   a. continue the pregnancy
   b. terminate the pregnancy.
   c. not have additional pregnancies in the future
   d. continue the pregnancy without any concern

17. — 20. Identify four technical choices in the list below to minimize patient dose:

____ a. use high kVp

____ b. skip gonad shielding

____ c. hurry patients so you can go home on time

____ d. use shortest time possible

e. use long S.I.D.

f. be careful while positioning

g. take as many views as you can throw out repeats

h. use ALARA concept

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P.O. Box 2931 Toledo, Ohio 43606
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Website: www.xrayhomestudies.com

Unit 12
Title: Common Methods Used to Control Radiation Exposure to the Operator

1. Time, distance and shielding are considered the
   a. ACR recommendations
   b. cardinal principles of radiation protection
   c. IRS guidelines
   d. NCRP recommendations

2. The ALARA concept includes stipulation(s) such as
   a. risks of radiation exposure must outweigh the benefits
   b. specific dose limits can be exceeded
   c. repeats are justified to get a good examination
   d. all exposures should be kept as low as reasonably achievable

3. The maximum permissible dose is now called the
   a. ALARA unit
   b. maximum limit
   c. dose limit
   d. maximum dose limit

4. A 30 year old radiation worker could have a cumulative whole body dose limit of
   a. 300 mSv
   b. 30 Sv
   c. 150 mSv
   d. 15 Sv

5. A 26 year old radiation worker could have a dose limit of ___ or less during her pregnancy.
   a. 26 mSv
   b. 2.6 mSv
   c. 5 mSv
   d. 10 Sv

6. Declaring a pregnancy to your supervisor is important because
   a. your dose limit becomes 1.5 mSv/month
   b. it will determine the need to change your scheduled rotations in fluoroscopy
   c. it requires the use of two personal monitoring devices
   d. your supervisor should review your previous radiation records with you

7. Managers following good radiation protection principles for their personnel should
   a. provide annual in-services on radiation protection
   b. provide counseling opportunities during pregnancy
   c. provide new employees with policies and procedures about radiation protection
   d. all of the above

8. The most practical and inexpensive personnel monitoring device in existence today is a
   a. TLD
   b. Film badge
   c. pocket dosimeter
   d. Geiger counter

9. Lithium fluoride chips/powders are found in the
   a. TLD
   b. pocket dosimeter
   c. film badge
   d. Geiger counter

10. The personnel monitoring device that provides immediate results is the
    a. film badge
    b. TLD
    c. pocket dosimeter
    d. Geiger counter

11. Personnel monitoring device reports should contain
    a. current exposure only
    b. cumulative monthly exposure
    c. last year's exposure results
    d. year-to-date exposure

12. If you lose your film badge, you should
    a. use the control badge
    b. report it immediately and get a replacement from the commercial vendor
    c. wait for the next shipment
    d. use someone else's during their absence

13. Since the film badge is your "personal" monitor, you may
    a. not wear it during personal medical exams
    b. wear it to the beach
    c. wear it during your dental x-rays
    d. share it with others who lose theirs

14. Exposure switches on the operator console should be
    a. 6 feet or longer for mobility
    b. located within a secondary barrier
    c. fixed permanently to the console
    d. removable

15. When an x-ray tube is replaced, the medical physicist should check for
    a. accurate billing
    b. leakage radiation
    c. delivery date
    d. remnant radiation

16. A protective barrier which requires 1/16" Pb or 4" of masonry is called
    a. secondary
    b. tertiary
    c. control booth
    d. primary

17. The control booth is considered a
    a. primary barrier
    b. tertiary barrier
    c. secondary barrier
    d. controlled work space

18. — 20. Match 3 of the following items that will <u>reduce</u> your risk of radiation exposure

_____ a. stay as close as possible to the patient or volunteer to hold patients
b. collimate the beam to the anatomy under investigation
_____ c. use ALARA concepts all the time
d. give your Pb apron and gloves to the physician
_____ e. use intensifying screens at all times

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Answer Sheet for: Units 8-12 Radiation Protection & Physics Series

Please place your lettered selection for each question in the respective box and return *ONLY this post test sheet to* S.T.A.R.S. office P.O. Box 2931 Toledo, Ohio 43606

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Unit 8	Unit 9	Unit 10	Unit 11	Unit 12
1.	1.	1.	1.	1.
2.	2.	2.	2.	2.
3.	3.	3.	3.	3.
4.	4.	4.	4.	4.
5.	5.	5.	5.	5.
6.	6.	6.	6.	6.
7.	7.	7.	7.	7.
8.	8.	8.	8.	8.
9.	9.	9.	9.	9.
10.	10.	10.	10.	10.
11.	11.	11.	11.	11.
12.	12.	12.	12.	12.
13.	13.	13.	13.	13.
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