Physical and biological basis of radiation oncology

Radioactivity is a part of our earth - it has existed as long. Naturally occurring radioactive materials are present in its crust; the floors and walls of our homes, schools, and offices; and in the food we eat and drink. There are radioactive gases in the air we breathe. Our own bodies -muscles, bones, and tissue - contain naturally occurring radioactive elements.

Man all along has been exposed to natural radiation arising from the earth as well as from outside the earth. The radiation we receive from outer space is called cosmic radiation or cosmic rays.

We also receive exposure from man-made radiation, such as X-rays, radiation used to diagnose diseases, and for cancer therapy. Radioactivity is the term used to describe disintegration of atoms. The atom can be characterized by the number of protons in the nucleus. Some natural elements are unstable. Therefore, their nuclei disintegrate or decay, thus releasing energy in the form of radiation. This physical phenomenon is called radioactivity, and the radioactive atoms are called nuclei. The radioactive decay is expressed in units called becquerels. One Becquerel (Bq) equals one disintegration per second.

The radionuclides decay at a characteristic rate that remains constant regardless of external influences, such as temperature or pressure. The time that it takes for half the radionuclides to disintegrate or decay is called half-life. This half-life differs for each radioelement, ranging from fractions of a second to billions of years. For example, the half-life of Ftor 18 (^{18}F) is 110 min., Technetium 99m (^{99m}Tc) is 6 hours, Iodine 131 (^{131}I) is eight days, but for Uranium 238 (^{238}U), which is present in varying amounts all over the world, it is 4.5 billion years. Potassium 40 (^{40}P), the main source of radioactivity in our bodies, has a half-life of 1.42 billion years.

Types of radiation

The term "radiation" is very broad, and includes such things as light and radio waves. In our context it refers to "ionizing" radiation: which means that as such radiation passes through matter, it can cause them to become electrically charged or ionized. In living tissues, the electrical ions produced by radiation can affect biological processes.

These are various types of radiation, each having different characteristics. The common ionizing radiations generally talked about are:

• **Alpha radiation** consists of heavy positively-charged particles emitted by atoms of elements such as uranium and radium. Alpha radiation can be stopped completely by a sheet of paper or by the thin surface layer of our skin (epidermis). However, if alpha-emitting materials are taken into the body by breathing, eating, or drinking, they can expose internal tissues directly and may therefore, cause more biological damage. Alpha radiation high energy for radiation oncology has production by cyclotrotron.

• **Beta radiation** consists of electrons. They are more penetrating than alpha particles and can pass through 1-2 centimeters of water. In general, a sheet of aluminum a few millimeters thick will stop beta radiation. Beta radiation high energy for radiation oncology has production by linear accelerator.

• **Gamma rays** are electromagnetic radiation similar to X-rays, light, and radio waves. In general, gamma rays, depending on their energy, can pass right through the human body, but can be stopped by thick walls of concrete or lead.

• **Neutrons** are uncharged particles. Therefore, they do not produce ionization directly. But, their interactions with the atoms of matter can give rise to alpha, beta, gamma, or X-rays which then produce ionization. Neutrons are penetrating and only can be stopped by thick masses of concrete, water, or paraffin.

Although we cannot see or feel the presence of radiation, it can be detected and measured in the most minute quantities with quite simple radiation measuring instruments.

Radiation dose

Sunlight feels warm because our body absorbs the infra-red rays it contains. But, infra-red rays do not produce ionization in body tissue. In contrast, ionizing radiation can impair the normal functioning of the cells or even kill them The amount of energy necessary to cause significant biological effects through ionization is so small that our bodies cannot feel this energy as in the case of infra-red rays which produce heat.

The biological effects of ionizing radiation vary with the type of energy. A measure of the risk of biological harm is the dose of radiation that the tissues receive. The unit of absorbed radiation dose is the sievert (Sv) Since one sievert is a large quantity, radiation doses normally encountered are expressed in millisievert (mSv) or microsievert (uSv) which are one-thousandth or one millionth of a sievert For example, one chest X-ray will give 0.2 mSv of radiation dose (0.2 mSv = 20 mrem).

On average, our radiation exposure due to all natural sources amounts to about 2.4 mSv (2.4 mSv = 240 mrem) a year - though this figure can vary, depending on the geographical location in which we live, by several hundred percent In our homes and buildings, we have radioactive elements in the air we breathe These radioactive elements are radon (Radon 222), thoron (Thoron 220) and both their daughter products, formed by the decay of radium (Radium 226) and thorium present in many sorts of rocks, other building materials, and in the soil. By far the largest source of natural radiation exposure comes from varying amounts of uranium and thorium in the soil around the world.

Additionally, we are exposed to varying amounts of radiation from sources such as medical X-rays, in radiation oncology γ-rays etc., industrial uses of nuclear techniques, and other consumer products such as luminized wrist watches, ionization smoke detectors. We also are exposed to radiation from radioactive elements contained in fallout from nuclear explosives testing, and routine normal discharges from nuclear and coal power stations.

BIOLOGICAL EFFECTS OF RADIATION

The following discussions only consider the effects of radiation at the cellular level. How the effects created in different cells and tissues combine to affect the whole organism is not discussed (effects on the whole organism are considered acute or delayed according to the length of the latent period i.e. the time between the exposure and the manifestation of the effect.). Radiosensitivity of malignant tumor tissues don’t have very big difference with normal tissues.

It is important to note that none of the effects discussed here are unique to ionizing radiation - they may also be brought about by exposure to chemicals or non ionizing radiation such as UV or infrared.

I. CELL STRUCTURE AND FUNCTION

1. Cell Membrane (plasma membrane). Thin bilayer of phospholipids surround the cell and forming a passive barrier impenetrable to most polar molecules. Proteins distributed throughout the bilayer actively control the movement of many ions and molecules into and out of the cell.

2. Nucleus. The nucleus contains the chromosomal material and serves as the site of RNA synthesis (transcription). Usually the largest "organelle" in the cell, it is dense granular in appearance, and surrounded by a double membrane (envelope).

3. DNA (Deoxyribonucleic acid). DNA is the most important material making up the chromosomes and serves as the master blueprint for the cell. It determines what types of RNA are produced which, in turn, determine the types of protein that are produced. The DNA molecule takes the form of a twisted ladder or double helix. The sides of the ladder are strands of alternating sugar and phosphate groups. Branching off from each sugar group is one of four nitrogenous bases: cytosine, thymine, adenine and guanine. The rungs of the ladder consist of two nitrogenous bases, one from each strand, linked by hydrogen bonds. Cytosine is always paired with guanine, and thymine is always paired with adenine. A section of DNA that codes for one protein is referred to as a gene although the "message" from several genes can be carried by a single piece of RNA.

4. Chromosomes. Chromosomes consist of highly convoluted supercoils of DNA and associated protein. Each chromosome possesses a single centromere, a short specialized section of the chromosome that serves as a type of attachment point. The centromere must be present for the appropriate movement of the chromosomes during cell division. To ensure its survival, each new cell must possess all the required DNA, i.e., a complete chromosome complement.

5. Cell Cycle. The cell cycle is a cyclical sequence of four stages that a cell passes through: G_1 S, G_2 and M. In G_1 each chromosome consists of a single molecule of DNA. In the next stage, S, each

molecule (chromosome) is duplicated so that the newly synthesized molecule is attached to the original at the centromere. In G_2 therefore, each chromosome consists of two identical halves (sister chromatids). In M the cell undergoes mitosis or meiosis during which the two halves are separated. If the process is successful, each of the new cells produced will get a complete complement of chromosomes. G_1, S, and G_2 are collectively referred to as interphase.

6. Cell Division. There are two types of cell division: mitosis and meiosis. The latter is restricted to the reproductive tissues whereas mitosis takes place throughout the somatic tissues of the body. As such, the present discussion is limited to mitosis. During the early stages of mitosis the chromosomes align themselves along the equator (middle) of the cell, each chromosome consisting of two identical chromatids joined at the centromere. By one means or another a series of microtubules "attach" to each centromere and pull the chromosome apart: one chromatid goes to one side of the cell, the other chromatid goes to the other side of the cell. When all the chromosomal material has been segregated (telophase), the cell divides down the middle to produce two daughter cells each of which will be in G_1. It is very important that the chromosomes (i.e. DNA) be evenly divided; if a daughter cell gets too much or too little, it will probably die.

7. RNA (ribonucleic acid). For all practical purposes RNA is single stranded DNA, i.e., a sugar-phosphate chain with one of four nitrogenous bases attached to each sugar group. It is produced in the nucleus by a process (transcription) in which certain sections of the DNA molecule split. One side of the opened DNA molecule serves as a template for the production of RNA. The RNA then migrates out of the nucleus into the cytoplasm where it is involved in protein production (translation). The sequence of bases on the RNA molecule determines which types of proteins are produced by specifying the order in which the amino acids are joined. There are three types of RNA: messenger, transfer, and ribosomal RNA.

8. Ribosomes. Ribosomes are small particles found scattered throughout the cytoplasm. In some cases they are also found on the surface of endoplasmic reticulum. They consist of ribosomal RNA (arranged to form two subunits) and are used to organize the transfer and messenger RNA into the proper geometry for the production of protein.

9. Proteins. Proteins are large molecules composed of thousands of amino acids arranged in a specific sequence and three dimensional structure. Some serve a structural role while others are active metabolically as enzymes. The latter types of proteins are catalysts which regulate cell metabolism. It is by determining which proteins are produced, at what time, and in what quantities, that the chromosomes exert their control over the cell.

10. Lysosomes. Lysosomes are small vesicles in the cytoplasm bounded by a single membrane and lacking a discernible internal structure. Their function is unclear but they are often considered a storage site for destructive enzymes. Sometimes referred to as "suicide bags", a rupturing of their membrane can lead to cell death.

11. Mitochondria. Double membrane bound organelles with a high degree of internal organization and containing their own complement of DNA. They are involved in respiration, an oxygen fueled process by which energy is obtained from the breakdown of organic molecules into water and carbon dioxide.

12. Golgi Complex. Stacks of flattened membrane bound sacs involved in carbohydrate metabolism.

13. Endoplasmic Reti'culum. Convoluted system of membranous passages in cytoplasm.

14. Water . Almost 95% of the cell consists of water.

II. MOLECULAR AND SUBCELLULAR EFFECTS

1. Interactions of Radiation with Cellular Constituents. Charged particles (such as beta or alpha particles) transfer energy to the molecules they pass near. These molecules are excited, ionized or broken in such a way as to produce free radicals.

Gamma rays or x-rays must first interact with some atom in the cell by the photoelectric effect, compton scattering or pair production (compton scattering is the most important for the gamma ray energies commonly encountered). In these processes the gamma ray or x-ray transfers energy to an electron which then travels through the cell ionizing or exciting the molecules it comes close to.

2. Radiolvsis of Water. As the name suggests, this is the splitting apart of water by radiation. Water is the major constituent of the cell. As such, the majority of the interactions of radiation in cells will be with water. The following reactions are brought about by the transfer of energy from betas, alphas, or electrons to the water molecule (excitation of the water molecule is of little importance and will not be considered).

The water may be ionized:

$$\text{radiation} + H_2O \bullet\!\!— \quad —> H_2O^+ + e^-$$
$$—> H^+ + OH^-$$

or free radicals may be produced:

$$\text{radiation} + H_2O — \quad —> H° + OH°$$

Free radicals are neutral (uncharged) atoms or molecules with unpaired electrons. They are extremely reactive. Within a microsecond of their formation they may react with some molecule (the target) and damage it, or they may react with the molecule to produce a new radical species which then proceeds to damage other molecules.

$$RH + OH° \text{ ----- } > R°\ H_2O$$

Another radiolytic product of interest is hydrogen peroxide:

$$OH° + OH° \; > \; H_2O_2$$
$$\text{or} \quad O_2 + e^- \quad > O_2-$$
$$0_2- + H^* \quad > H0_2$$
$$HO_2 + H° \text{-----------------------------------} > H_2O_2$$

Hydrogen peroxide has the potential to be highly damaging to cellular constituents. It is much longer lived than free radicals and can travel substantial distances in the cell, even across membranes, to attack its target.

Nevertheless, it is readily broken down by a variety of enzymes present in most healthy cells. As such, damage produced by hydrogen peroxide is of limited consequence.

3. Types of Subcellular Effects

a. Direct Effects. These are effects produced when the initial interaction of radiation (e.g. alpha particle, beta particle or electron) is with the target molecule.

b. Indirect Effects. These are effects mediated by free radicals. The primary interaction of radiation is with water. It is the resulting free radicals that damage the target molecule(s). Of the various free radicals formed, the hydroxyl (OH°) free radical is believed to mediate the most damage.

Both direct and indirect effects are probably important although the latter are generally believed to be most important. One current line of thought believes that indirect effects predominate for low LET radiation (eg. x-rays, gamma-rays and betas) while direct effects are more important with high LET radiation (eg. alphas and neutrons).

1. Possible Suhcellular Targets

a) Enzymes (proteins). Alterations in their three-dimensional structure can affect their function and therefore the cell's metabolism. Probably not an important target since hundreds to thousands of rads are required for appreciable inactivation of enzymes. This is due to the large number of molecules of each enzyme present in the cell. For every enzyme molecule damaged there will be thousands of undamaged molecules still active. Furthermore, they can be quickly replaced.

b. Membranes. Alterations in the proteins that form part of a membrane's structure can cause changes in its permeability to various molecules, i.e., electrolytes. In the case of nerve cells, this would affect their ability to conduct electrical impulses. In the case of lysosomes, the unregulated release of its catabolic enzymes into the cell could be disastrous. Damage to the nuclear membrane (envelope) could affect the manner in which the cells divide and thus their viability.

c. Chromosomes. The consensus seems to be that radiation affects cells primarily by damage to the chromosomal DNA. Studies wherein the nucleus and cytoplasm are irradiated separately indicate that the nucleus is up to 100 times more sensitive than the cytoplasm. Since most cells possess only one or two copies of each DNA molecule, damage here will have a greater effect than damage to a molecule for which thousands of copies exist e.g., enzymes. There are three major types of damage to the chromosomes: base damage, single strand breaks and double strand breaks.

i. DNA Base Damage. The most common effect of radiation on DNA. Primarily due to interactions of free radicals with the nitrogenous bases. For example, the free radical might induce the deamination of the nitrogenous base cytosine converting it to uracil. In most cases this damage is easily repaired. The "classical" (rather slow) repair mechanism operates in the following manner: First the damaged section is excised by an endonuclease. Next the excised segment is resynthesized by a polymerase using the undamaged strand as a template. Finally ligases attach the newly synthesized segment in place. Faster, less accurate repair mechanisms also exist. If the damage remains unrepaired, the cell may survive and reproduce although its function may be impaired. Or, the effect on the cell metabolism may be severe enough to lead to cell death.

Repair becomes most difficult when multiple damage sites occur locally -especially where damage occurs on both stands of the DNA molecule. This is the case because the repair of one side (strand) of DNA requires the use of the other side as a template. If the template is also damaged, repair may be impossible. Other related damage can involve the production of cross links across the DNA molecule, deletions of pieces of the DNA molecule and inversion of sections of the DNA.

DNA base damage is often (although not always) what is meant by the term mutation. It is also often referred to as a genetic (vs chromosomal) mutation. Base damage is less likely than chromosomal mutations to result in cell death.

ii. Single Strand Breaks (SSBs). One strand of the DNA breaks but not the other. Requires approximately 10-20 eV per break. Breakage of carbon bonds in sugar molecules readily produced by OH° radicals. Quickly repaired by a mechanism similar to that previously discussed. SSBs are not considered to be as important as either of the other two types of damage.

Double Strand Breaks (DSBs). Both strands of the DNA may be broken by a single event or by two separate events. The relationship between the dose and the number of double strand breaks appears to be linear-quadratic. At low doses, the number of DSBs increases linearly with dose due to the increased number of cases where both strands are broken at once by a single event. At high doses the number of DSBs increases quadratically due to the increased frequency of DSBs caused by two discrete events where opposite strands of the DNA molecule are broken separately but close together in space and time. Repair mechanisms for DSBs have not been identified. The problem is that the two portions of the broken DNA molecule may separate before repair can occur. One possible role of the chromosomal protein (histones) is to hold the broken ends together so that repair may occur. Double strand breaks, if unrepaired, result in broken chromosomes. The ends of the chromosomes at the site of the break are said to be "sticky" and tend to attach to other broken or unbroken chromosomes. The results depend on the stage of the cell cycle at which the exposure occurred, i.e., in G_2 each chromosome consists of two DNA molecules (chromatids) whereas in G_1 each chromosome consists of only one DNA molecule. The result of breaks in G_1 are called chromosomal aberrations. The result of breaks in G_2 are chromatid aberrations.

Chromosomal and chromatid aberrations: rings, fragments, dicentrics, etc.

The following photograph is of a cell in the late stages of division (anaphase). It contains a chromosome which has formed a bridge (see arrow), one centromere has been pulled to the left and the other has been pulled to the right. The cell will attempt to divide vertically down the middle unsuccessfully. Dicentric chromosomes, the chromosomal aberration most uniquely identified as being caused by radiation, can be quantitatively related to radiation dose. In fact, the dose from an acute exposure can be estimated by counting the number of dicentrics produced and comparing this with the number known to be produced by the particular type of radiation involved. For example, following an acute exposure to radiation, a blood sample is taken and the peripheral blood lymphocytes cultured in vitro (because these cells are relatively long-lived, this can be done up to several weeks after the exposure without the cells entering mitosis and the aberrations being "lost"). The lymphocytes are stopped in mitosis.

III. CONSEQUENCES OF RADIATION DAMAGE TO CHROMOSOMES

Unrepaired damage to the DNA has one of two possible outcomes: the cell survives but with an impaired (malfunctioning) metabolism, or the cell dies.

1. Cell Survives but with Impaired Metabolism

The nature of the "malfunction" may inconsequential or more severe. It may delay or alter cell differentiation and division, even resulting in cancer (needless to say, dead cells don't become cancerous). It is well known that cells with faulty DNA repair mechanisms are prone to becoming cancerous. It is also known that cancerous tissues possess increased numbers of chromosomal aberrations (rings, etc.).

2. Cell Death

High doses of radiation can result in the immediate death of the cell (interphase death) while lower doses may slow down the cell cycle. The latter is due to a lengthening of G_2 brought about by some unknown mechanism. If the exposed cell passes through G_2 and attempts to divide, the survival of the daughter cells requires that each receive a complete complement of chromosomes. Chromosomal aberrations of the sort discussed earlier can prevent a proper distribution of the chromosomes and result in the death of the cell during division (reproductive death). For a chromosome to divide properly it must have a single centromere; acentric fragments have none while dicentrics have two. The assumed involvement of double stranded breaks in the formation of chromosome aberrations and the absence of any known repair mechanisms for double stranded breaks has led many to conclude that they are the single most important contributor to cell death. However, other possibilities exist and considerable uncertainty still remains about the role of DSBs in cell death (refer to the discussion of the "Molecular Theory" in the following consideration of cell survival curves). Unrepaired single strand breaks or base damage could cause an incomplete duplication of the DNA in S. This in turn could lead to an unequal distribution of the DNA at mitosis and hence, cell death. Alternatively, radiation damage to the nuclear membrane is known to play a role in the behavior of chromosomes at mitosis.

For low LET radiation the most sensitive stages of the cell cycle, with respect to cell death, are mitosis and late G_l (at the G,-S border) although individual cell types show some variation in this regard. During mitosis the chromosomes are condensed and the repair mechanisms have poor access to the DNA molecule. During transcription of RNA the cell appears to be least sensitive to radiation damage because the uncoiled "open" nature of the DNA makes the repair mechanisms especially effective. All phases of the cell cycle appear equally sensitive to high LET radiation.

The shapes of such survival curves can be interpreted in a number of ways:

1. Repair. Perhaps the most widely accepted explanation for the shoulder on the survival curve is that it indicates the presence of a DNA repair mechanism.

2. Target Theory fmultiterget/multihit processes). In target theory the shape of the survival curve is explained in terms of the number of targets in a cell that must be hit or in terms of the number of hits that an individual target in the cell must receive for cell death to occur. At the center of such theories are equations that attempt to describe the observed relationship between cell survival and dose, and, at the same time, to appear biologically justifiable. Unfortunately, in relating these theories to the real world, highly unrealistic limitations must often be placed on the biological processes assumed responsible for cell death.

3. The Molecular Theory (double strand breaks and cell death). In this interpretation, double strand breaks in chromosomes are responsible for cell death. Such breaks can be produced by a single event when both strands are broken at once or by two separate events when each strand is broken individually but close together in space and time.

V. EFFECTS OF RADIATION IN TISSUE

A tissue is a group of similar cells organized to perform a common function.

1. The Law of Bergonie and Tribondeau

The "law", formulated in 1906, characterizes those tissues which are most radiosensitive. Like all laws in biology it is a generalization and will have its exceptions. Radiobiologists tend to dismiss this law as either being wrong or misleading. Despite this, it does have its uses.

According to the law, the most radiosensitive tissues possess cells which:

a. are dividing at the time of exposure
b. in the normal course of their lifetime undergo numerous divisions
c. are of an undifferentiated type, i.e., unspecialized in structure and function

The law is not really describing which cells/tissues are most radiosensitive. Instead it is describing those cells/tissues where the effects are first observed, i.e. it is describing the rate at which the effect occurs, not its magnitude.

Nevertheless, at low doses rapidly dividing cells do indeed appear to be more sensitive than slowly dividing cells. At high doses the reverse appears to be true.

2. <u>Radiosensitive Tissues</u>

a) germinal (reproductive) cells of the ovary and testis, i.e., spermatogonia
b) hematopoietic (bloodforming) tissues: red bone marrow spleen lymph nodes thymus
c) epithelium of skin
d) epithelium of gastrointestinal tract (interstitial crypt cells)

Lymphocytes and oocytes are exceptions to the law because they are radiosensitive even though they are neither dividing nor unspecialized.

3. <u>Radioresistant Tissues</u>

a. bone	d. cartilage
b. liver	e. muscle
c. kidney	f. nervous tissue

VI. MODIFYING FACTORS

1. Radiation Quality

Different types of radiation produce the same types of effects. However, the magnitudes of the effects can be quite different even though the doses (rads) are identical. The extent of the biological damage inflicted by a given type of radiation increases with the linear energy transfer (LET) of the radiation. Linear energy transfer, similar to stopping power, is a measure of the amount of energy transferred per unit distance travelled by charged particles. The more energy lost per unit distance, the higher the LET, and the greater the density of ions and free radicals in the charged particle tracks. The latter phenomenon is the most probable reason for the greater biological effects of high LET radiation.

In radiation protection the difference in the effects of different types of radiation is indicated by a quality factor (Q). The quality factor is multiplied by the dose (rad) to obtain the dose equivalent (rem). The latter is intended to reflect the biological damage (cancer and genetic effects) produced by a given dose from a specific type of radiation.

In radiation biology these differences are indicated by the relative biological effectiveness (RBE), the ratio of the doses from two different types of radiation required to produce the same effect. Conventionally the dose required from 250 kVp x-rays is used as the standard for comparison:

$$\text{RBE} = \frac{\text{dose of 250 kVP x-rays needed to produce a given magnitude of a certain effect}}{\text{dose of another radiation needed to produce the same magnitude of the same effect.}}$$

Although the RBE is a more precise estimate of a radiation's biological effect than the quality factor, its use is restricted to radiation biology.

2. <u>Oxygen Tension</u>

Cells containing normal levels of oxygen (40+ mm Hg) tend to be 2-3 times as sensitive to low LET radiation as cells low in oxygen (hypoxic). For a given effect this difference is referred to as the oxygen enhancement ratio (OER). The relationship between oxygen and radiosensitivity is most pronounced below 20 mm Hg. Above this, an increase in oxygen concentration does little to increase the radiosensitivity of a tissue. It should be noted that the levels referred to are the oxygen concentrations in the cells themselves (the oxygen tension) not the concentrations in the environment. Poorly vascularized tissue, i.e., tumors, tend to be hypoxic; tissues well supplied with blood tend to have normal oxygen tensions.

This effect of oxygen might be due to a resulting increase in the production of hydrogen peroxide (refer to the section entitled "Radiolysis of Water" under MOLECULAR AND SUBCELLULAR EFFECTS). Another explanation involves the affinity of oxygen for electrons. By acquiring the electrons produced during the radiolysis of water, oxygen might slow down the recombination of certain other radiolytic products. This could increase the capacity for damage by extending their effective lifespan. Why oxygen tension appears to have no effect with high LET radiation is uncertain. Perhaps the maximally effective concentrations of oxygen are already produced in the dense track of ionization and excitation formed by high LET particles.

3. Dose Rate

The manner in which the dose is delivered can be classified as follows:

a. Chronic Exposure. The dose is accumulated continuously with time, i.e., 1rad/hr for 100 hours (total dose 100 rad).

b. Fractionated Exposure. The dose is received in discrete quantities.

e. Acute Exposure. The dose is received instantaneously or at least in a very short time with respect to the lifespan of the organism (total dose: 100 rads).

CHRONIC FRACTIONATED ACUTE

For low LET radiation, the greatest effect per unit dose is seen with acute exposures and the smallest effect with chronic exposures (especially with slowly dividing cells/tissues). This is true if the dose rate lies between 10 and 5,000 rad/hr. Lowering the dose rate below 10 rad/hr does not appear to reduce the magnitude of the effect. At 5,000 rad/hr, the maximum damage is done and increasing the dose rate further has no additional effect. For high LET radiation the "dose rate effect" is either less pronounced or absent. In fact, there is some evidence that chronic exposures with high LET radiation may be more carcinogenic than acute exposures. The usual explanation for the dose rate effect involves the cell's repair mechanisms: below 10 rad/hr these repair mechanisms are maximally effective; from 10 to 5,000 rad/hr the repair rate falls behind the rate of damage; above 5,000 rad/hr any repair is superfluous. Similarly, the number of chromosomal double strand breaks will increase with dose rate since the number of two event DSBs increases. For two separate single strand breaks to produce a DSB, they must occur close together on the DNA molecule and close together in time; the higher the dose rate the greater the probability that two SSBs will be sufficiently close in time.

4. Chemical Protective Agents

Certain chemicals administered immediately before exposure (within 30 minutes or so) can reduce the effective dose of radiation by a factor of 1.5 to 2.0, the dose reduction factor (DRF). The DRF is often defined as the ratio of the UVs for unprotected and protected animals. Such agents are usually administered intravenously prior to the exposure. Postirradiation or oral administrations are rarely effective. Examples of radioprotective drugs include cysteine, cystamine, and glutathione, (common to many of these agents is the presence of a sulphydryl group). Various proposals have been made to explain their effect: they might scavenge free radicals, they might donate hydrogen atoms to the free radical groups formed on damaged molecules, they might attach to sensitive portions of the target molecules thus protecting them, or they might induce hypoxia in the cells. A severe drawback with most of these agents is their toxicity and the fact they have to be used at near-lethal levels. One category of agents has been discovered that is effective at substantially lower doses, however. These complex compounds have been found to reduce the radiosensitivity of all tissues with the exception of the nervous system which is normally radioresistant. Of these, the most widely investigated has been WR-2721, S-2 (3-aminopropylamino) ethylphosphorothioic acid. A similar agent, WR-3689, is of particular interest since it appears to work better with healthy (well oxygenated) tissue than neoplastic (hypoxic) tissue. Furthermore, it is slightly less toxic than WR-2721 and may be effective when administered orally.

5. Temperature

In many experiments a dramatic increase in radioresistance has been produced by lowering an animal's body temperature. For example, in mice the lethal dose can be doubled by reducing the body temperature to 5°C. However, in some cases the lowered temperature merely serves to delay the effect, not reduce it. The increase in radioresistance is apparently due to a reduction in oxygen tension that accompanies a lower body temperature. If the effect is simply delayed it may be due to a reduced mitotic rate; once the animal warms up and mitosis resumes, reproductive cell death can occur.

6. Sex

In many species females tend to be slightly more radioresistant than males That this is related to differences in hormonal levels is suggested by the fact that castrated males reverse this tendency. Differences in sensitivity depend on the effect being looked for. In humans, for example, males are more susceptible to leukemia but females are more susceptible to thyroid cancer.

7. Species

For animals the more primitive the species the more radioresistant the organism: protozoans are highly radioresistant, insects less so, and mammals are the most radiosensitive. With plant species, the larger the interphase chromosome volume (ICV) the greater the radiosensitivity. The ICV is defined as the average volume of the nuclei divided by the number of chromosome characteristic of the species. A useful way to compare the radiosensitivities of different species is by comparing their LD50. The LD50 is the dose from an acute exposure that will kill off 50% of the population (with the exposed organisms left untreated). Since all organisms die if you observe them long enough, we usually specify that the deaths must occur within a certain time after the exposure. For example the LD50 is the lethal dose that will kill 50% of the population within 30 days.

There is probably no single reason as to why various species show such a wide range of sensitivities. Some possible explanations include differences in the effectiveness of their repair mechanisms, differences in mitotic rates, differences in oxygen tension, differences in the number and size of their chromosomes, etc. The high sensitivity of mammals to radiation (i.e. the low LD50 s) is likely related to their complexity. The more complex the system and the wider the range of tissue types the greater the liklihood certain essential tissues will be radiosensitive.

RADIATION PROTECTION PRINCIPLES

There are four basic radiation protection principles that can be employed to reduce exposure to ionizing radiation These principles are based on consideration of four radiation protection factors that alter radiation dose, time, distance, shielding, and quantity

Time

Time is an important factor in radiation protection. This principle states that the shorter the time spent in a radiation field, the less radiation will be accumulated. Depending on the activity present, radioactive material will emit a known amount of radiation per unit time. Many radiation monitoring devices measure exposure in milliroentgens (mR) per hour. An exposure rate of 60 mR/hr means that for each minute spent in a radiation field, a person will receive a 1-mR exposure (60 mR/hr -5- 60 min/hr = 1 mR/min) Obviously, the longer a person remains in a radiation field, the more radiation that person will accumulate.

A rotating team approach can be used to keep individual radiation exposures to a minimum as long as patient care is not compromised and if personnel are available

Distance

The second radiation protection factor is distance, and the principle is the farther a person is from a source of radiation, the lower the radiation dose This principle is known as the inverse square law. By measuring the radiation exposure rate at a given distance from a source of radiation and then doubling the distance from the source, the intensity of the radiation is decreased by a factor of four For example, a source of radiation that measures 8 mR/hr at 2 feet from a source would measure only 2 mR/hr at 4 feet Conversely, when the distance from the source of radiation is reduced by half, for example, from 2 feet to 1 foot, the exposure rate increases from 8 mR/hr to 32 mR/hr, a factor of four.

Shielding

The third radiation protection factor is shielding The principle follows that the denser a material, the greater is its ability to stop the passage of radiation. In most cases, high-density materials such as lead are used as shields against radiation. Portable lead or concrete shields are sometimes used when responding to accidents where contamination levels are very high. In addition, some specialty centers for radiation accident management have constructed shielded surgical tables for protection. Such measures are, however, not recommended in the community hospital.

In emergency management of the contaminated patient, shielding is limited to standard surgical clothing with slight modifications. Surgical clothing will protect the individual against contamination, and also will stop the passage of all alpha and some beta radiation. However, it does not stop penetrating gamma radiation In the hospital emergency department shielding is actually limited to anti-contamination measures, and the principles of time and distance are used to reduce radiation exposure.

IONIZING RADIATION: GLOSSARY OF SELECTED TERMS

Absorbed Dose: Quantity of energy imparted by ionizing radiation to unit mass of matter such as tissue. The units of absorbed dose are rad (rad, conventional unit) and gray (Gy, SI unit): See Rad.

Activity: Attribute of an amount of a radionuclide. Describes the rate at which transformations occur in it. The units of activity are curie (Ci, conventional unit) and becquerel (Bq, SI unit): see Curie.

Acute Radiation Syndrome: A term for the collective response of the hematopoietic, gastrointestinal, cardiovascular, and central nervous system to exposure from radiation.

ALARA: From Federal Register (1975) 10CFR20.1 (c): "Persons engaged in activities under licenses issued by the Nuclear Regulatory Commission.. should make every reasonable effort to maintain radiation exposures, and releases of radioactive materials in effluent to unrestricted areas as low as is reasonably achievable." The term "as low as is reasonably achievable" means as low as is reasonably achievable taking into account the state of technology and the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to the utilization of atomic energy in the public interest.

Alpha Particle, Alpha Radiation: Alpha particles are ejected spontaneously from the nuclei of some radioactive elements. The alpha particle is identical to a helium-4 nucleus (^4He), which has an atomic mass number of 4 and an electrostatic charge of+2. It has low penetrating power and short range, such that even the most energetic alpha particle generally does not penetrate the skin to the depth of the germinal layer. The major hazard occurs when matter containing alpha-emitting nuclide is introduced into the body. Symbol – α.

Atom: The smallest particle of an element that cannot be divided or broken up by chemical means and still retains the properties and characteristics of that element.

Background Radiation: natural radiation arising from several sources. These are: (1) radioactive materials in rocks and soils of the earth; (2) radioactive materials in a person's body; (3) cosmic radiation, or radiation emanating from outer space and penetrating the atmosphere. The background radiation has always been with us, being higher in early years of the earth's history. It will vary from place to place depending upon altitude and quantities of natural radioactive materials present; and (4) average to US resident = 0.36 rem (3.6 millisieverts) of which 0.30 rem (3.0 millisieverts) is from naturally occurring sources, primarily radon (0.20 rem; 2.0 millisieverts).

Becquerel: The SI unit of activity designating the quantity of a radionuclide resulting in 1 disintegration per second.

Beta Particle, Beta Radiation: Charged particle emitted from the nucleus of an atom, with a mass and charge equal in magnitude to that of the electron. Beta radiation has medium to intermediate penetrating power; its range in air is from a few inches to several feet. The most energetic beta particles will penetrate skin and a fraction of an inch of tissue. Symbol –β.

Biological Half-Life: The time required for the body to eliminate one-half of an internally deposited radioactive substance by normal processes of elimination. This time is the same for both stable and radioactive isotopes of a particular element. See Half-Life: Physical, Effective.

Biological Recovery: In the context of radiation induced cellular damage, biological recovery is promoted by the combination of DNA repair mechanisms and repopulation of affected cell systems. This process occurs over a period ranging from a day to several days after a specific exposure, depending on the type and extent of the damage, and the proliferation rate of the cell systems involved. See Biological Repair.

Biological Repair: In the context of radiation induced cellular DNA damage, refers to repair of such damage by error-free or, in some circumstances, error-prone mechanisms. Most repair processes are completed in about 2 minutes, others, particularly when double strand DNA breaks exist, may take several hours, but all will be completed within 24 hours after a specific exposure. See Biological Recovery.

Centromere: The constricted portion of the chromosome at which the chromatids are joined and by which the chromosome is attached to the spindle during cell division.

Charged Particle: An elementary particle that carries a positive or negative electrical charge.

Chromosome: In animal cells, a structure in the nucleus containing a linear thread of DNA, which transmits genetic information and is associated with RNA and histories; during cell division, the material (chromatin) composing the chromosome is compactly coiled, making it visible with appropriate staining and permitting its movement in the cell with minimal entanglement.

Combined Injury: A tissue trauma or disease state resulting from more than one cause.

Contamination, Radioactive Contamination (Personal): Deposition of radioactive nuclide on the skin (external contamination) or in body systems (internal contamination). If not excreted, internally deposited radioactive nuclides may be incorporated into cellular systems.

Controlled Area: An area where entry, activities, and exit are controlled to assure radiation protection and prevent the spread of contamination.

Cosmic Rays: High-energy particulate and electromagnetic radiations that originate outside the earth's atmosphere.

Criticality: A term used in reactor physics to describe the state when the number of neutrons released by fission is exactly balanced by the neutrons being absorbed (by the fuel and poisons) and escaping the reactor core. A reactor is said to be "critical" when it achieves a self-sustaining nuclear chain reaction.

Cumulative Dose: Total dose accumulated by an individual or population over time from exposure to radiation. The conventional unit is the rem (rem; for an individual) or person-rem (p rem; for a population); SI unit is the sievert (Sv) or person-sievert (pSv). See Rem.

Curie (Ci): Quantity of any radioactive nuclide such that 37 billion (37 x 1010) disintegrations occur per second. 1 curie equals 3.7 x 1010 becquerels; 1 becquerel equals 2.7 x 10~n curies or 27 pico curies (pCi).

Cytogenetics: The branch of genetics devoted to the study of chromosomes.

Decay (Radioactive): The process of spontaneous disintegration (transformation) of a radionuclide. The decrease in the activity of a radioactive substance.

Decay Product: A nuclide or radionuclide produced by decay. It may be formed directly from a radionuclide or as a result of a series of successive decays through several radionuclides.

Decontamination: The reduction or removal of contaminating radioactive material from a structure, area, object, or person.

Deposition: An accumulation or collection of energy or inorganic material in tissue.

Detector: A material or device that is sensitive to radiation and can produce a response signal suitable for measurement or analysis. A radiation detection instrument.

Deterministic (Non-Stochastic) Effect: Associated with immediate or delayed cell death (lethal damage). Describes biological effects whose severity is a function of dose; for these effects, a threshold dose may exist; examples of radiation induced somatic effects are cataract, nonmalignant damage to skin, hematologic deficiencies, and impairment of fertility.

DNA: A nucleic acid that is the carrier of genetic information.

Dose: A general term denoting the quantity of radiation or energy absorbed. For special purposes, dose must be qualified; if unqualified, refers to absorbed dose.

Absorbed Dose: The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the point of interest; unit of absorbed dose has been the rad and now in the System International (SI) units is the gray (Gy), 100 rad = 1 gray.

Cumulative Dose: Total dose resulting from repeated exposure to radiation.

Dose Equivalent (DE): The absorbed dose multiplied by weighing factors, such as the quality factor so that doses received from different radiations (alpha, beta, gamma, neutrons) can be summed to provide an effective total dose to an individual. The dose equivalent, H, at a point in tissue is given by the equation: H = DQN where D is the absorbed dose, Q is the quality factor, and N is the product of all other modifying factors. Such factors might take into account, for example, absorbed dose rate and fractionation. The conventional unit of dose equivalent has been the rem and now in the System International (SI) units, is the sievert (Sv), 100 rem = 1 sievert.

Dose Rate: Absorbed dose delivered per unit time.

Dose Ranges: Arbitrarily designated ranges of dose-response curves.

Low Dose: For many biological end points, the low dose range is roughly 0 to 20 rads. (For mutations in the plant Tradescantia, and for life shortening in mice, 20 rads is the dose above which significant deviations from the linear term can be detected.) For occupational exposures, low dose is generally considered to be less than 1 rem/year of committed whole-body equivalent of radiation, although levels up to 5 rem/year are permissible.

Intermediate Dose: Ranges from about 20 to 250 rads, depending on the biological system.

High Dose: Ranges from about 250-400 rads, depending on the biological system Very High Dose: The remaining curve beyond the high dose region.

Dose Rate Effectiveness Factor (DREF): Factor by which linear interpolation from data obtained at high doses and high dose rates overestimate the risk per unit observed dose of radiation delivered at very low doses and/or low dose rates.

Dosimeter: A device that measures radiation dose.

Effective Half-Life: The effective half-life of a given isotope is the time in which the quantity in the body will decrease by half as a result of both radioactive decay and biological elimination. See Biological, Physical Half-Life.

Electromagnetic Radiation: Energy emitted in the form of a wave and resulting from changing electric or magnetic fields. Ionizing electromagnetic radiations have short wavelengths (x-rays, gamma rays). Ultraviolet, visible and infrared radiations are non-ionizing components of the electromagnetic spectrum of intermediate wavelength. Radar and radiowaves have long wavelengths and also are non-ionizing.

Electron: An elementary particle with either a unit positive or negative electric charge and with low mass, 1/1836 that of a proton. Positively charged electrons, are called positrons. See Beta Particle.

Electron Volt: A measure of the energy of a radiation. Technically, one electron-volt is the energy received by an electron in passing through a potential of one volt. It is a very small unit being only about 400 billion billionths of a calorie. Note that this unit is a unit of energy, not electrical potential. More common uses of this unit are the KeV or 1000 electron volts, or the MeV, one million electron volts.

Encapsulated Source: A radionuclide sealed in a container, such as a tube or needle. Also called a sealed source.

Epidemiology: The study of the relationships of the various factors determining the frequency and distribution of diseases in a human community.

Epilation: The removal of hair by roots.

Erythema: A name applied to redness of the skin produced by congestion of the capillaries, which may result from a variety of causes, the etiology or a specific type of lesion often being indicated by a modifying term.

Exposure: A quantity used to indicate the amount of ionization in air produced by X or gamma radiation. The conventional unit is the roentgen (R). One roentgen is approximately equal to one rad and/or one rem for X and gamma radiation.

Fibrosis: The formation of fibrous tissue; fibroid or fibrous degeneration.

Fractionation: The delivery of a given total dose of radiation as several smaller doses, separated by intervals of time.

Free Radical: A neutral, highly reactive atom or grouping of atoms that has an unpaired electron.

Gamma Rays: High energy radiation of short wavelength emitted during radioactive decay of many radioactive elements. Similar in properties to x-rays, but gamma rays are of nuclear origin, while x-rays are formed by the excitation of orbital electrons. Gamma rays are the most penetrating of ionizing radiations and can be a major external hazard. Symbol – γ.

Geiger-Mueller (GM) Counter: A radiation measuring device in which a single ionizing event will produce a complete arc discharge between two electrodes. The Geiger counter produces a large, easily measured pulse for each radiation event but cannot distinguish between pulse sizes and is relatively slow in action.

Genetic Effect: An effect of ionizing radiation on genes of somatic (diploid) or reproductive (haploid) cells that is passed on to their progeny. The effect may be expressed clinically in exposed populations (somatic effects) or the descendants of the exposed population (inherited genetic effects).

Gray: SI unit of absorbed dose; 1 Gy = 100 rads. See Rad.

Half-Life (Physical): The time required for the activity of a given radioactive element to decrease to half of its initial value through radioactive decay. The half-life is a characteristic property of each radioactive element and is independent of its amount or condition. See Biological, Effective Half-Life.

Half-Value Layer (HVL): The thickness of a slab of matter required to reduce the intensity (or exposure rate) of an x- or y-ray beam to one half.

Hematopoietic: Pertaining to or effecting the formation of blood cells.

Ion: Subatomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

lonization: The process by which a neutral atom or molecule acquires or looses an electric charge. The production of ions.

Ionizing Radiation: Electromagnetic radiation (x-ray and gamma ray photons) or particulate radiation (alpha particles, beta particles, electrons, positrons, protons, neutrons, and heavy particles) capable of producing ions by direct or secondary processes.

Isotopes: Atoms with the same number of protons but differing in their atomic masses (due to different numbers of neutrons in their respective nuclei) and in their nuclear properties (radioactivity, fission, etc.).

Latent Period: Period of apparent biological/clinical inactivity between time of exposure of tissue to an injurious agent and observed response.

LD50 (Lethal Dose50): Dose of ionizing radiation that would kill 50% of a group of individuals receiving that dose. Usually related to a specified time period that typically for humans is 60 days. Thus the LD50/6o is the dose that would result in the deaths within 60 days of 50% of a group of individuals each receiving that dose; this is approximately 450 R (360 rad to bone marrow) for humans in the absence of medical treatment; this now can be raised to 800-900 rad with appropriate clinical treatment.

Leukocyte: Any colorless, ameboid cell mass. White blood cell or corpuscle.

Linear Energy Transfer (LET): The average energy lost by ionizing radiation per unit distance of its travel through a medium. High LET (HLET) is generally associated with protons, alpha particles, and neutrons, while low LET (LLET) is associated with x-rays, electrons, and gamma rays.

Linear Non-Threshold Hypothesis: An assumption that within the range of exposure conditions usually encountered in radiation work, there is a linear relationship without threshold between dose and the probability of effect. This implies that low-dose effects can be estimated by extrapolation from high dose data. Relates to the risk of stochastic effects. See Stochastic Effect.

Linear-Quadratic (LQ) Model: Also, linear-quadratic dose-effect relationship; expresses the effect (e.g. mutation or cancer) as partly directly proportional to the dose (linear term) and partly proportional to the square of the dose (quadratic term). The linear term will predominate at lower doses, the quadratic term of higher doses (See Crossover Dose.)

Lymphocyte: A mononuclear leukocyte 7u. to 20u, in diameter, with a deeply staining nucleus containing dense chromatin, and a pale-blue-staining cytoplasm. Lymphocytes participate in humoral and cell-mediated immunity.

Mass Number: The sum of the neutrons and protons in a nucleus, the mass number is the nearest whole number to an atom's atomic weight in atomic mass units. For instance, the mass number for uranium-235 is 235.

Metaphase: A stage of cell division when the chromosomes are located along the center of the cell prior to separation.

Mitosis: A method of indirect division of a cell, consisting of a complex of various processes, by means of which the two daughter nuclei normally receive identical complements of the number of chromosomes characteristic of the somatic cells of the species.

Monitoring: Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present for purposes of health protection. Also referred to as "surveying."

Mutation: A physical or chemical change in the DNA in a gene or genes comprising the chromosomes in the cell nucleus. Radiation induced mutations in reproductive cells or their precursors may lead to inherited effects in the progeny of individuals in an exposed population. Radiation induced mutations in somatic cells may lead to effects in exposed individuals.

Necrosis: The sum of the morphological changes indicative of cell death and caused by the progressive degradative action of enzymes; it may affect groups of cells or part of a structure or an organ.

Neoplasia: The formation of a neoplasm, i.e., the progressive multiplication of cells characterized by abnormal growth process, such as a tumor.

Non-Stochastic Effect: See Deterministic Effect.

Nucleus: In an atom, the nucleus is the central portion which contains nearly all of the mass of the atom and serves as the body around which the orbital electrons revolve. The nucleus is made up of positively charged particles, protons, that provide the electric charge to attract the orbital electrons which are electrically neutral and serve to balance the nuclear forces.

Nuclide: A general term applicable to all atomic forms of the elements, including stable and radioactive isotopes.

Pathogen: Any disease-producing microorganism or material.

Personnel Monitor: A device for measuring a person's exposure to a physical or chemical agent in the environment, such as radiation. Information on the dose-equivalent of ionizing radiation to biological tissue is derived from exposures recorded by film badges, ionization chambers, and thermoluminescent devices; from determinations based on whole-body counting and analysis of biological specimens; and from area monitoring and special surveys.

Person-Rein (Man-Rein): Conventional unit of collective population dose. Maybe calculated by summing the doses (in rems) to individuals in a population, or multiplying the average individual dose (in rems) by the number of individuals in the population. The equivalent SI unit is the person-sievert (pSv).

Phenotype: The entire makeup of an individual as determined both genetically and environmentally. A type distinguished by visible characteristics rather than by hereditary traits.

Photon: X- or gamma radiations are normally considered as continuous wave motions (electromagnetic waves). However, in certain reactions with matter they can behave as individual particles. (See Compton Effect.) The energy of these particles is related to the frequency or wavelength of the radiation with the apparent particle known as a photon.

Physiological: Pertaining to the living organism and its parts and the physical and chemical factors involved.

Probability: The mathematical chance that a given event will occur.

Probability of Causation (PC): The probability calculated from the increase in the probability that a particular disease outcome, C, (e.g. lung cancer) due to a possible cause, D, (e.g. radiation dose) as a proportion of the possibility of C given D, everything conditional on certain characteristics of the individual (e.g. age, sex, smoker, etc.)

Protraction: The spreading out of a radiation close over time by continuous delivery at a lower dose rate.

Proton: An elementary nuclear particle with a positive electric charge equal numerically to the charge of the electron and having a mass about equal to that of a hydrogen atom.

Quality Factor (QF): The linear energy-transfer-dependent factor by which absorbed doses are multiplied to obtain, for radiation protection purposes, a quantity that expresses on a common scale the effectiveness of the absorbed dose derived from various radiation sources. For low linear energy transfer radiations (x-rays, gamma and beta radiation) the QF is approximately 1; for high linear energy transfer radiations such as alpha a QF of 20 is recommended. The QF for neutrons varies with energy from 2 to 11. The QF for high energy proton or neutron of unknown energy is 10.

Rad: The conventional unit of absorbed dose. The rad is a measure of the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. A dose of 1 rad corresponds to the absorption of 100 ergs of radiation energy per gram of absorbing material or tissue. The equivalent SI unit is the gray (Gy); 1 Gy = l00 rads.

Radiation: The energy propagated through space or through matter as waves; "radiation," or "radiation energy," when unqualified, usually refers to electromagnetic radiation; commonly classified by frequency: Hertzian, infrared, visible, ultraviolet, x, and gamma rays.

Radiation Sickness: The prodromal manifestations of acute radiation injury, varying in severity, scope and cause, depending on the conditions of exposure to ionizing radiation. (See Acute Radiation Syndrome.)

Radioactivity: The properly characterized by spontaneous disintegrations of nuclei, emitting radiation.

Radionuclide: A radioactive nuclide.

Radiopharmaceutical: A chemical compound labeled with radioactivity used in medicine for diagnosis or therapy.

Rem: Radiation Equivalent in Man; the conventional unit of radiation dose to the whole body or a specified organ or tissue that takes into account the radiation quality, such that the rem dose is equal to the absorbed dose in rads multiplied by the quality factor (QF) of the type of radiation involved. The equivalent SI unit is the sievert (Sv); 1 Sv = 100 rems. See Quality Factor.

Risk: The probability of injury, harm or damage. Expressed in epidemiological terms as the absolute or relative risk.

Risk-Absolute: Relates to the number of disease cases or deaths induced. The excess absolute risk is expressed as the numerical difference between the risk in the exposed and the non-exposed population.

Risk Relative: The ratio of the number of cases of disease or deaths observed in the exposed population and the number observed in the non-exposed population.

Risk-Radiation Induced Effect: The probability of cancer and leukemia or hereditary genetic damage per unit dose equivalent.

Roentgen (R): Unit of radiation exposure. It is a measure of radiation intensity relating to ionization of air. When the exposure is 1 R, the surface dose is about 1 rad. One roentgen is approximately 2.1 billion (2.1 x 109) ion pairs per cubic centimeter of air from x or gamma radiations. See Exposure.

Sealed Source: A radioactive source, sealed in an impervious container that has sufficient mechanical strength to prevent contact with and dispersion of the radioactive material under the conditions of use and wear for which it was designed. Generally used for radiography or radiation therapy.

SI Units: Systeme International d'Unites (SI). Conversion factors between SI and
conventional units are: conventional —> multiply by -> SI unit
<— divided by <—
rad 0.01 Gy
rem 0.01 Sv
Ci 3.7 x 1010 Bq

Sievert (Sv): The international system unit (SI unit) of radiation dose equivalent-100 rems.

Somatic Effect: A (radiation induced) effect that may be expressed clinically in an. individual.

Stochastic Effect: Describes random, biological or clinical effects (e.g. tumorigenesis, inherited genetic effects) whose probability of occurrence in an irradiated (exposed) population is a direct function of dose. There is no relationship between dose and the severity of the effect. No threshold doses are assumed for stochastic effects. See Deterministic Effects.

Subclinical: Describing situations, problems, or groups of individuals with problems of less magnitude than those that mandate clinical attention but may nevertheless be quite bothersome for the individual.

Symptom: Any subjective evidence of disease or change in a patient's condition.

Syndrome: The sum of signs or symptoms that occur together and indicate a deviation from normal.

Teratogenic Effect: An effect on the fetus caused by exposure to a harmful agent. The deformities caused by thalidomide were in this category. For radiation, the first trimester of the pregnancy is the most sensitive period.

Thermoluminescent Dosimeter (TLD): A crystalline material in which radiation causes storage of part of its energy. Upon hearing, this energy is released in the form of light. The amount of light indicates the amount of radiation. This device is used for monitoring of radiation received by a worker by placing it in a badge that he wears.

Tumorigenesis: The production of tumors.

Whole Body Counter: An instrument used to measure the amount of x- or gamma radiation emitted from a human body. For ultimate sensitivity it requires shielding from background radiation. It is used to estimate the quantities of certain radioactive materials in the body.

Whole Body Exposure: An exposure of the body to external radiation where the entire body rather than an isolated part is irradiated. When a radioactive material is uniformly distributed throughout the body tissues rather than being concentrated in certain organs, the irradiation can be considered whole-body exposure.

RADIATION UNIT CONVERSION GUIDE

Radiation Measurements

	Radioactivity	Absorbed Dose	Dose Equivalent	Exposure
Common Units	curie (Ci)	rad	rem	Roentgen (R)
SI Units	becquerel (Bq)	gray (Gy)	sievert (Sv)	coulomb/kilogram (C/kg)

Conversion Equivalence

1 curie = 3. 7 x 10^{10} disintegrations per second		1 becquerel = 1 disintegration per second
1 millicurie (mCi)	=	37 megabecquerels (MBq)
1 rad	=	0.01 gray(Gy)
rem	=	0.01 sievert (Sv)
roentgen (R)	=	0.000258 coulomb/kilogram (C/kg)
megabecquerel (MBci)	—	0.027 millicuries (mCi)
gray (Gy)	=	100 rad
sievert (Sv)	=	100 rem
1 coulomb/kilogram (C/kg)	=	3,880 roentgens

STANDARD PREFIXES FOR UNITS OF MEASUREMENTS

Multiple	**Prefix '**	**Symbol**
10^{18}	exa	E

10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	M
10^{-6}	micro	M
10-9	nano	n
$l0^{-12}$	pico	h
10^{-15}	femto	f
10^{-18}	atto	a