



SRT-100™

Cutaneous Lesion Clinical Handbook



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Chapter 1: Radiation Physics



What is “Radiation”?

Radiation comes from the root word “radiate.” Radiate is defined as “to proceed in a direct line from or toward a center.”

Radiation is energy that is radiated in the form of waves or particles. Radiation can be thought of as the transmission of energy through space. The two major forms of radiation are:

- Electromagnetic (EM) radiation
- Particulate radiation

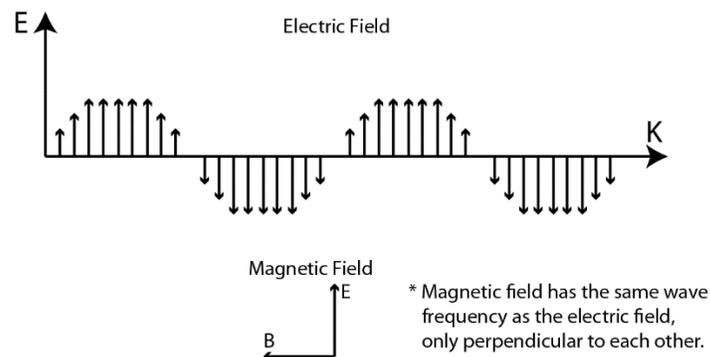
Both forms can interact with matter, and transfer their energy to the matter.

Electromagnetic Radiation

Visible light, radio waves, and UV-rays are all forms of radiation propagated as waves. These are all examples of a more general classification of radiation known as electromagnetic. Electromagnetic (EM) waves transport energy and momentum from one source to a receiver. As the frequency of the EM wave increases, so does the photon’s energy. Also, as frequency increases, wavelength decreases. Electromagnetic radiation has no mass, and moves through space at the speed of light (3.0×10^8 meters per second). An electromagnetic wave is characterized by its intensity and the frequency of the time variation of the electric and magnetic fields.

Electromagnetic radiation can be described by two models:

- Wave Model
- Photon Model



EM Radiation: Wave Model

The distance between maxima of the EM fields is the wavelength (λ). The frequency (ν) of the wave is given by:

$$\nu = c / \lambda$$

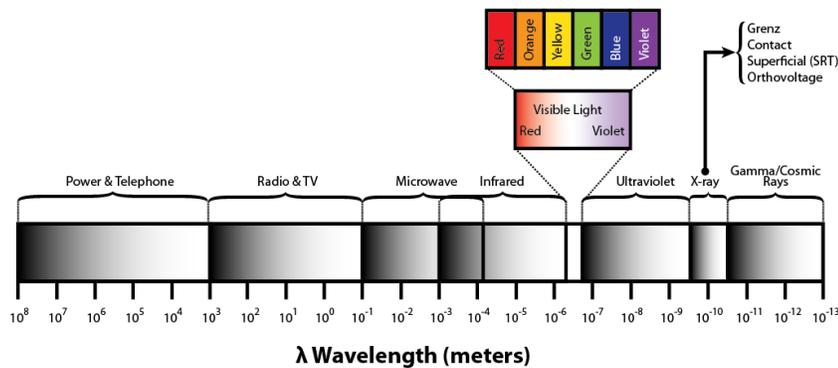
EM Radiation: Photon Model

Electromagnetic radiation can also be described as discrete packets of energy called photons. The energy (E) is related to the wavelength (λ) in the wave model through Planck's constant (h) and the speed of light (c).

$$E = h c / \lambda$$

Electromagnetic Spectrum

Electromagnetic spectrum is defined as the entire range of frequencies or wavelengths of electromagnetic radiation, from gamma rays to radio waves, including visible light. Electromagnetic spectrum comprises electromagnetic waves. Electromagnetic waves constitute similar kind of disturbances repeating at certain wavelengths.



Electromagnetic Spectrum

There are a number of different types of waves that constitute the electromagnetic spectrum. Radio waves are used for radio and television broadcasts, mobile phones, and government and non-government services like aeronautical beacons. The FM stations require 200 KHz of frequencies for a maximum of hundred stations. The 25 KHz frequency range is known as guard bands which are used to minimize interference. Televisions require 5 MHz separation. Microwave waves are used in telephone satellites which are used to transmit the human voice in microwave code. It has a very short wavelength that, it is easily absorbed by water. The microwave radiation generates molecular rotation and torsion which produces heat. For this purpose, it is used in microwave ovens. It is also used in electron spectroscopy. Infrared waves form the lower end of the visible spectrum, with a frequency ranging from 10^{10} - 10^{14} Hertz. They generate heat formed by the vibration of molecules and are used in infrared detectors, television remote controls, etc.

Visible light is the narrow band of electromagnetic spectrum which is detected by the human eye. It has the frequency of 10^{14} Hertz and wavelength of 10^{-6} m. Visible light waves are produced by the ionization of electrons, and retina of the eyes can sense only this range of wavelength. When white light is passed through a prism it splits to form seven different colors, a process known as dispersion. Ultraviolet rays have a very high energy with frequency ranging from 10^{14} - 10^{16} Hertz. These rays are highly carcinogenic due to ionizing radiation, but they do have some therapeutic features. The sun is the source of UV rays; therefore, sunburns and damage to the eyes can occur with long exposure.

X-rays are penetrating rays formed when fast-moving high energy electrons are stopped by a metal; the frequency range is from 10^{16} - 10^{19} Hertz and wavelength of 10^{-8} to 10^{-10} m. X-rays are used to determine molecular structures and are commonly used in the medical field as they can penetrate through flesh. They can be produced in parcels of energy called photons, just like light. X-rays are produced as the result of changes in the positions of the electrons orbiting the nucleus, as the electrons shift to different energy levels. X-rays were first observed and documented in 1895 by Wilhelm Conrad Roentgen, a German scientist who found them by accident when experimenting with vacuum tubes. Treatment of diseases with X-rays began within months of Roentgen's discovery, and within four years, X-rays were being used successfully for the treatment of skin cancers.

Particulate Radiation

Particle radiation is a stream of atomic or subatomic particles that may be charged positively (e.g. alpha particles), or negatively (e.g. beta particles), or not at all (e.g. neutrons). Alpha particles and beta particles are considered directly ionizing because they carry a charge and can, therefore, interact directly with atomic electrons through coulombic forces (i.e. like charges repel each other; opposite charges attract each other). The neutron is an indirectly ionizing particle. It is indirectly ionizing because it does not carry an electrical charge. Ionization is caused by charged particles, which are produced during collisions with atomic nuclei.

Ionizing and Non-Ionizing Radiation

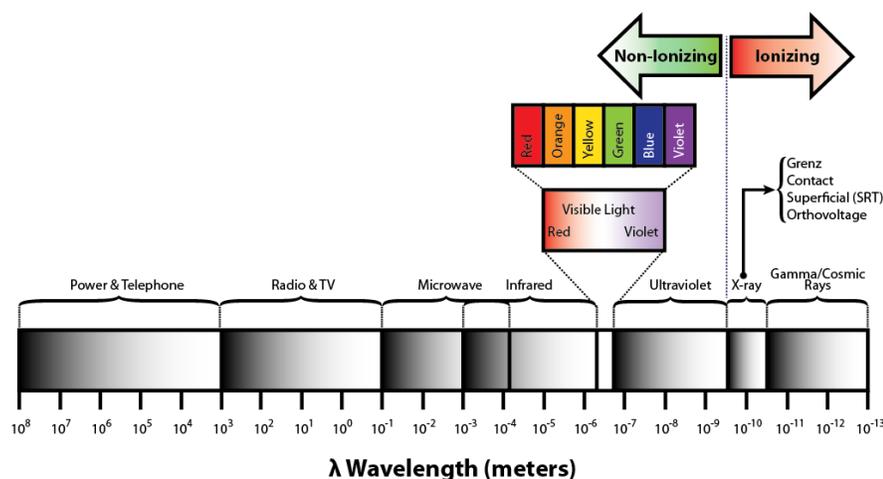
Radiation is categorized as either ionizing or non-ionizing. From the standpoint of radiation protection, this categorization denotes the level of danger posed to humans.

Ionizing Radiation

Ionizing is the process of removing electrons from atoms, leaving two electrically charged particles (an electron and a positively charged ion) behind. The negatively charged electrons and positively charged ions created by ionizing radiation may cause damage in living tissue. Basically, a particle is ionizing if its energy is higher than the ionization energy of a typical substance, and interacts with electrons significantly. Photons (electromagnetic) and particles with energies above about 10 electron volts (eV) are ionizing. Not all electromagnetic radiation (EMR) is ionizing. Only the high-frequency portion of the electromagnetic spectrum, which includes X-rays and gamma rays, is ionizing. Alpha particles, beta particles, cosmic rays, gamma rays, and X-ray radiation all carry energy high enough to ionize atoms. In addition, free neutrons are also ionizing, since their interactions with matter are inevitably more energetic than this threshold.

Non-ionizing Radiation

Non-ionizing radiation is the term given to radiation in the part of the electromagnetic spectrum where there is insufficient energy to cause ionization. It includes electric and magnetic fields, radio waves, microwaves, infrared, ultraviolet, and visible radiation. Longer wave lengths/lower frequency waves (electric and radio waves) have less energy than shorter wave length/higher frequency waves (X-ray and gamma rays). Non-ionizing radiation is harmful to organisms only in proportion to the thermal energy deposited, and is conventionally considered harmless at low powers which do not produce significant temperature rise.



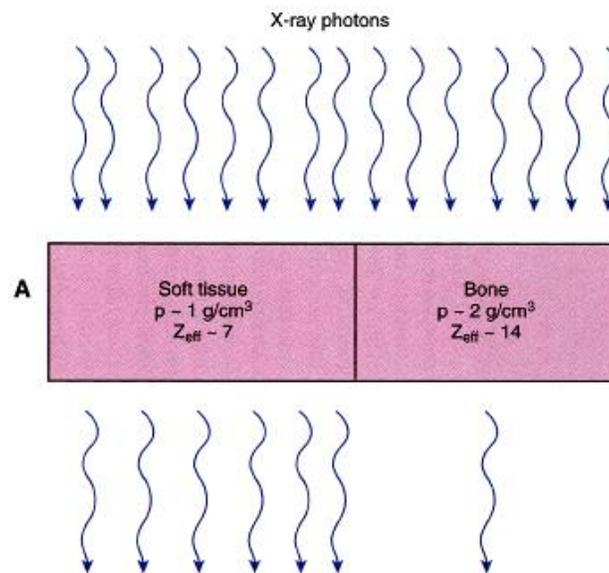
Ionizing vs. Non-Ionizing Radiation

Interactions of Radiation and Matter

Understanding how radiation interacts with matter leads to an understanding of why different types of radiation have greater penetrating power and how to protect against each type of radiation. To develop a means to estimate radiation dose (i.e., the energy absorbed by tissue), one needs to understand the processes by which radiation interacts with tissue.

Photon (X-ray) Radiation

Photon beams interact with the matter through which they pass and consequently, the beam intensity (the number of photons per area) is attenuated. The degree to which photon beams are attenuated, and the degree to which each interaction type contribute to the tissue dose, can be calculated using the incident energy. There are a variety of types of interactions for photons; however, the main interaction that occurs with Superficial Radiation Therapy energies is photoelectric absorption.



The likelihood of a photon interaction in bone is several times greater at energies typical of Superficial Therapy procedures, but the differences decrease at higher energies typical of orthovoltage therapies.

Particle Interactions

Particles, unlike photons, have mass, and some have charge. Hence, the processes that govern what happens to particles differ from those that govern what happens to photons. Understanding particle interactions in matter (e.g., tissue) is the last major requirement to understanding the phenomenon that contribute to radiation dose.

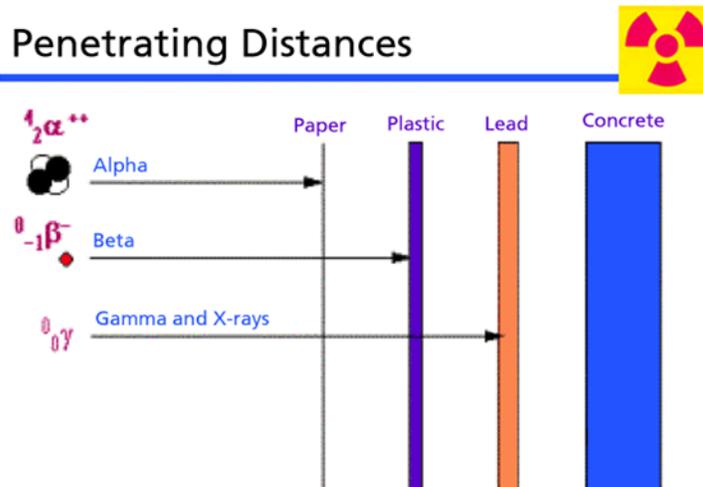
Particles (except for neutrons) are charged and cause atomic ionization or excitation as they move through matter as a result of coulomb forces (repulsion of like electric charges). The electrons released by photon interactions will eventually stop because each coulomb interaction results in a transfer of energy to atomic electrons of the material irradiated. The processes that slow down the incident particles are of importance to the theory of radiation dosimetry because those processes impart energy to the material irradiated.

Beta Particles

Beta particles can travel several hundred times the distance of alpha particles in air, penetrate skin and tissue, and require a few millimeters of aluminum to stop them. Thus, beta particles can be both an external and internal hazard.

Gamma Rays

Gamma rays are the most penetrating type of radiation and can travel many meters in air and many centimeters in tissue. Because gamma rays can travel through the body, they are sometimes referred to simply as “penetrating radiation”. Like beta particles, gamma rays constitute both an internal and external hazard.



Alpha Particles

Alpha particles are relatively heavy (~7300x that of electron) and have 2 units of charge; therefore, they have much shorter range, because each Coloumb interaction is greater. The

typical range of alpha particles in tissue is 40 μm . This explains why alpha particles are normally only a hazard of “internal emitters.”

Neutrons

The processes for slowing of neutrons in matter is the reverse of that of charged particles.

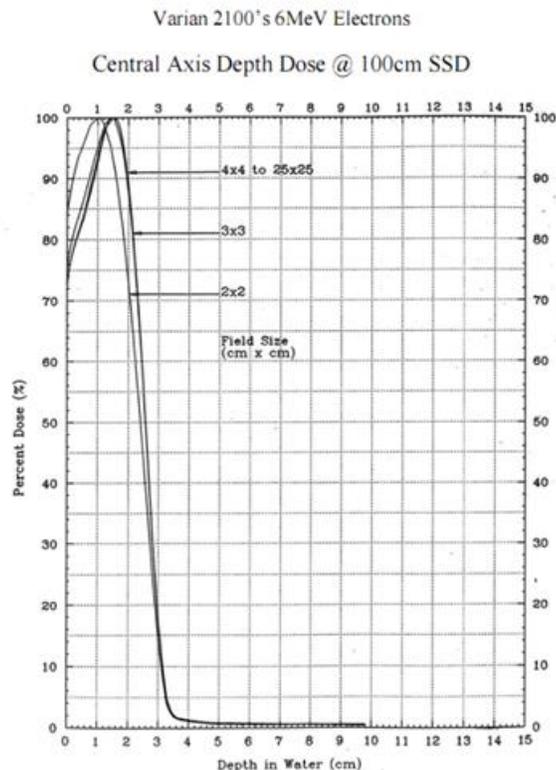
Because neutrons are of neutral charge, there is no Coulomb interaction. Neutrons are primarily slowed as a result of ‘collisions’ and scattering from nuclei and are eventually absorbed in by the nuclei in neutron-capture reactions. In elastic scattering (this is where the kinetic energy is conserved through the collision), the maximum energy (Q_{max}) that a particle of mass M and energy E can transfer to a free particle of mass m is $Q_{\text{max}} = 4mM/(M+m)^2$. Since neutrons and protons have near equal mass, large energy transfers are possible in proton rich material, e.g., water or tissue. Less energy is transferred (per collision) to ^{12}C or heavier atoms (because their mass m is larger).

Electrons

The lowest stable electron beam used for very superficial lesions is around 6MeV, which only deposits 85% of its energy at the surface with large field sizes. The graph below shows that electron surface dose is field size dependent, and as the field size shrinks, so does the surface dose. The average field size for a very superficial skin lesion is from the 3x3 to 1.5x1.5 (80% skin lesions are head and neck); this lowers the surface dose even more to 77% and 73% respectively. To raise the surface dose, bolus material is applied. The bolus must be of a certain thickness to raise the desired therapeutic dose to the surface. Changing field sizes without changing the thickness of the bolus can lead to some lesions being under-dosed at the surface.

It is also important to note that at the depth of the dermis, high significant dose is being deposited.

Electron beams are produced in the MeV range, which means the beams have to travel to a depth in tissue before the maximum energy is achieved. This lack of saturation at the surface renders less than 100% of the dose to where the lesion lies, but this can be remedied by placing bolus material (which acts as a tissue equivalent) over the patient’s skin. As already mentioned, however, bolus thickness must be adjusted according to field size, making it difficult to provide correct dosage to very superficial lesions that are only a couple of millimeters thick.



Electron surface dose. Note the change in surface dose with different field sizes

Electrons lose energy constantly as they pass through a medium, and their rate of energy loss and amount of scattering is dependent on their energy. For lower energy electrons, lateral scattering happens shortly after entering the tissue. This leads to a relatively rapid loss of energy, with a significant 'peak' of energy loss at Z_{max} relative to the surface dose. Higher energy electron beams tend to undergo minimal scattering near the surface and continue onwards, losing their energy over a greater distance. This leads to a significantly broader region of dose distribution, and Z_{max} is not significantly greater than the surface dose. The final outcome of these interactions is that high energy electrons have a high surface dose relative to low energy electrons.

Comparing Interactions of Photon and Electron Beams

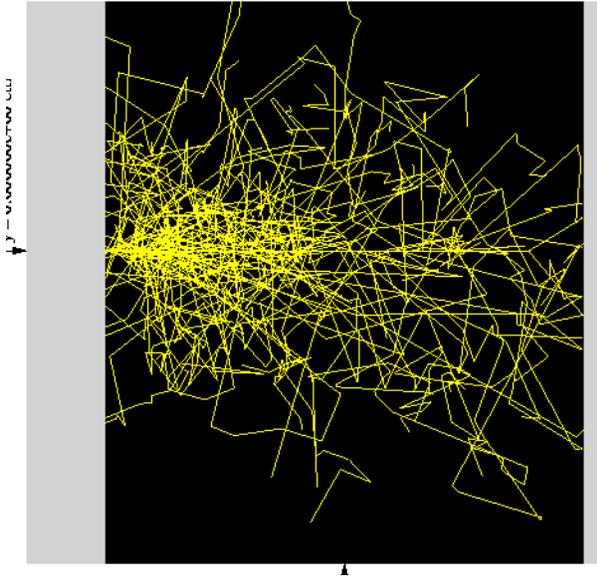
Photons

- Not charged
- Zero rest mass
- $V = C$ (speed of light)
- No Coulomb force
- Random and rare interactions
- Infinite range (in theory)

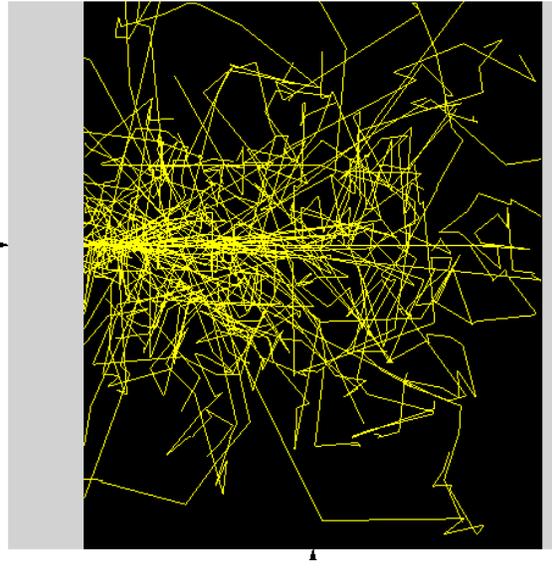
Electrons

- Charged
- Finite mass
- $V < C$
- Coulomb force
- Continuous interactions
- Finite range

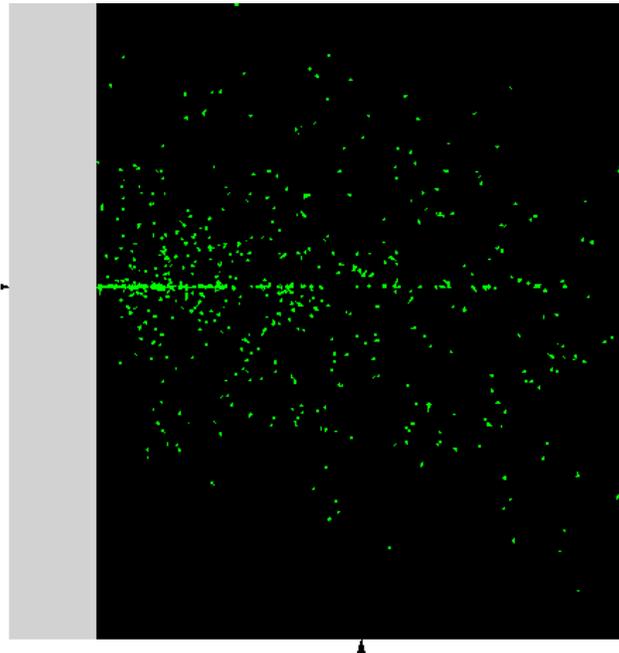
Interactions are random on a micro-scale but result in a predictable average ionization.



1st 100 photons



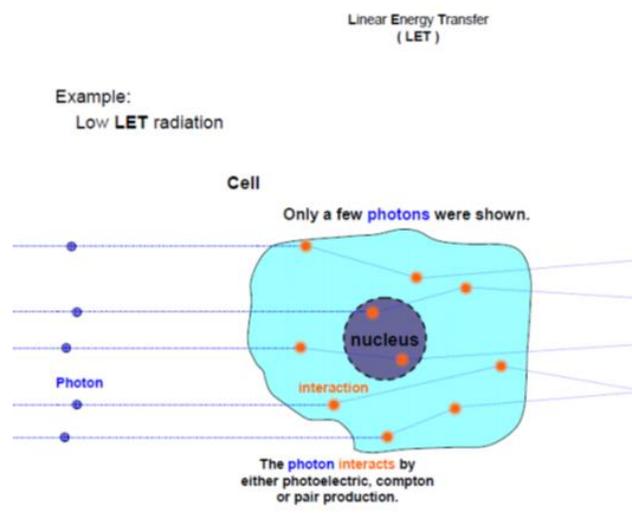
2nd 100 photons



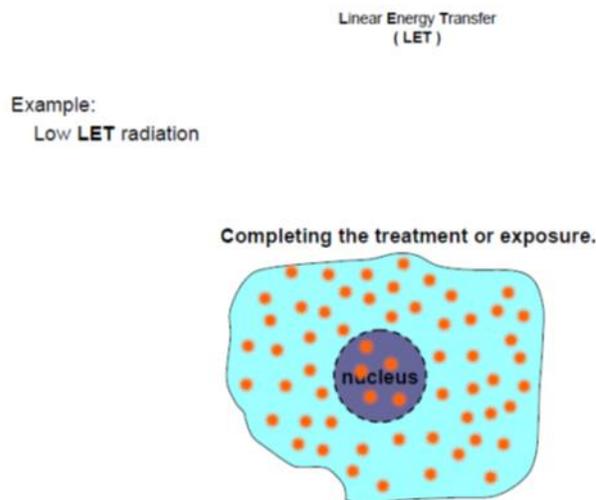
*Electrons produced
(Note the under-ionization pattern)*

Superficial Radiation Modalities

Superficial kilovoltage modalities deposit energy in a more uniform distribution than electron beams. This is accomplished because of the forms of waves that first interact with the tissue. With low Linear Energy Transfer (LET) radiation, the interactions produced are relatively far apart from each other. Therefore, they will be spread throughout the cell, making for a more uniform dose distribution throughout the cell.



During Superficial Radiotherapy treatment fractions, an accumulation of ionizations take place across the cell, evenly distributing the energy and not leaving areas of under-ionization present. The areas of under-ionization in electron beam therapy are the reason why dosages are much higher than the range of Superficial.





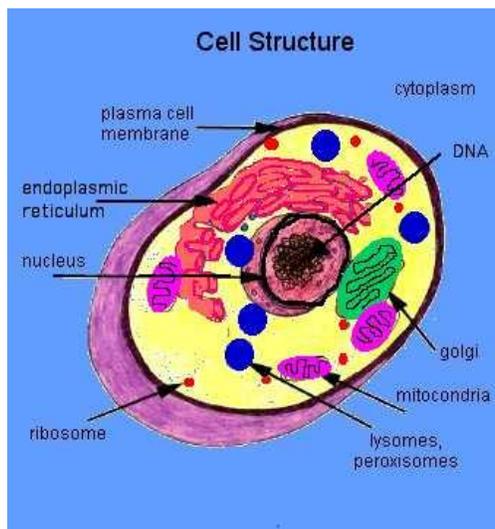
Chapter 2: Radiobiology



Radiobiology, the branch of science concerned with the action of ionizing radiation on biological tissues and living organisms, is a combination of two disciplines: radiation physics and biology. Ionization of the tissue and excitation of orbital electrons results in the disposition of energy in tissues. This produces ions and radicals within the cell (mostly from water molecules). When these radicals and ions interact with other cell materials, damage can result. Certain levels of cellular damage can be repaired by the cell, while further levels can result in cell death. This chapter deals with the interactions of X-rays—the energy used when delivering treatment with the SRT-100™ superficial radiotherapy unit.

Within a year after Roentgen's discovery of X-rays in 1895, scientists learned that exposure to ionizing radiation could lead to biological damage. Since that time, a tremendous amount of research has been performed attempting to interpret the reactions which take place from the moment that radiation enters a living cell until some permanent damage is produced. From beginning to end, these initial reactions are probably completed in a millionth of a second, making them very difficult to study. For this reason, it is still not known which of the many chemical or biochemical reactions brought about by ionizing radiation are responsible for initiating biological damage.

Since the primary site of radiation damage is in the cell, the logical place to start a study of the biological effects of radiation is with the structure of this basic unit of all living material. Cells are the building blocks of which man and his living environment are composed; they are the fundamental unit of which all living organisms are made. Although there is no such thing as a typical cell, all cells have several features in common. Most cells are composed of protoplasm: a mixture of carbohydrates, lipids, proteins, nucleic acids, inorganic salts, gases, and between 70 and 80% water. Cells can be subdivided into three major parts: the cell membrane, the cytoplasm, and the nucleus.



Cell Membrane

The cell membrane is only a millionth of a centimeter thick, and is a living functional part of the cell. It helps to regulate the concentration of water, salts, and organic matter which form the interior environment of the cell. In red blood cells and nerve cells, the membrane distinguishes between sodium and potassium ions even though these ions are alike in size and electrical charge. The membrane actively transports potassium ions into the cell and opposes the entrance of sodium ions. The membrane is thus capable of "active transport." In addition, all food entering the cell and all waste products or secretions leaving it must pass through this membrane.

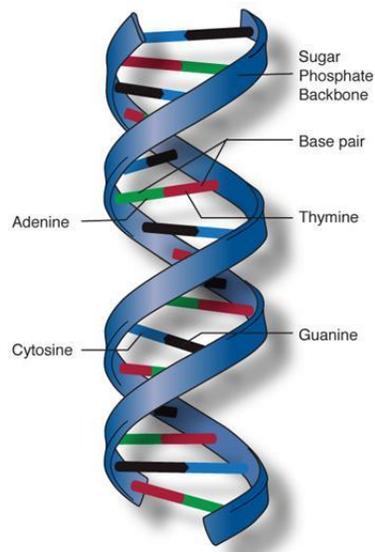
Cytoplasm

The cytoplasm is a jelly-like substance in which the nucleus is suspended; it is encased within the cell membrane. This material is an aqueous solution of soluble proteins and salts which constitutes the interior environment of the cell. Many small functional units called organelles are contained in the cytoplasm. Principal among these is the mitochondria, which are the "power plants" of both plant and animal cells. It is here that oxygen is used for the oxidation of essential foodstuffs and the formation of carbon dioxide. The metabolic energy released is captured in the chemical bonds of a special energy-storing molecule known as ATP (adenosine triphosphate). This molecule supplies the energy for all the activities of the cell, including reproduction. The lysosomes contain the digestive enzymes that break down large molecules, such as those of fats, proteins, and nucleic acids, into smaller constituents that can be oxidized by the oxidative enzymes of the mitochondria. The lysosomal membrane isolates the digestive enzymes from the rest of the cytoplasm. Rupture of the membrane and release of the enzymes leads to the dissolution of the cell.

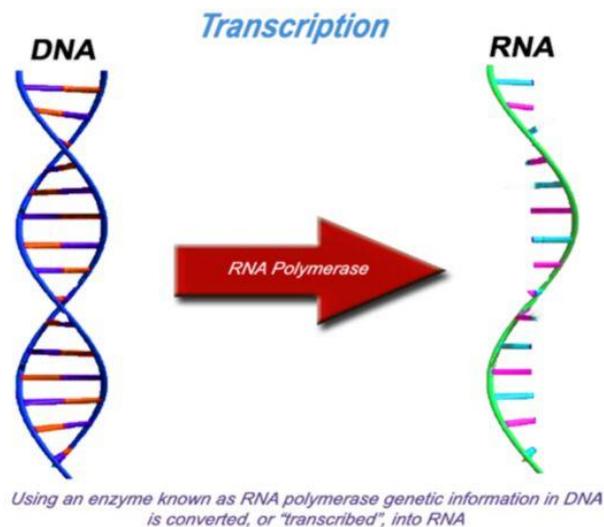
Nucleus

Each cell contains a small, usually oval, body known as the nucleus. In some cells this has a relatively fixed position and is found near the center; in others it may move around freely and be found almost anywhere in the cell. The nucleus is an important center of control of the cell, directing cellular activity and containing the hereditary factors (genes) responsible for the traits of the animal or plant. The membrane surrounding the nucleus and separating it from the adjacent cytoplasm is called the nuclear membrane. It is a double membrane with annuli, or holes, in the outer layer, open to the cytoplasm. This suggests that the cytoplasm of the cell is in direct communication with the protoplasm of the cell nucleus (the nucleoplasm). The function of this nuclear membrane is to regulate the constant flow of materials into and out of the nucleus. The nucleoli are spherical bodies which are found within the cell nucleus. These cell constituents are packed with tiny granules similar to the ribosomes of the cytoplasm. The nucleoli are rich in RNA and appear to be active centers of protein and RNA synthesis.

DNA (Deoxyribonucleic Acid) 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. It is generally assumed to take the form of a twisted ladder or double helix.

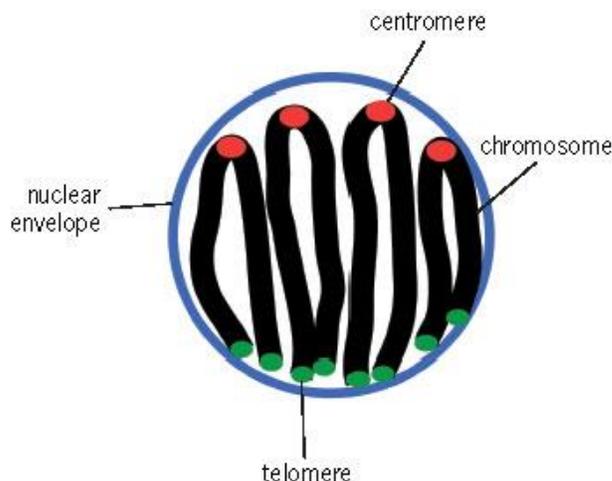


The sides of the ladder are strands of alternating sugar and phosphate groups. Branching off from each sugar group is one of four nitrogenous bases: cytosine, thymine, adenine and guanine. The rungs of the ladder consist of two nitrogenous bases, one from each strand, linked by hydrogen bonds. Cytosine 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 single piece of RNA.



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 the entire required DNA (a complete chromosome complement).



Effects of Radiation on Cells

A great deal of work has been performed on examining the effects of radiation on various organelles. It has been established that it takes about 3,000 to 5,000 rad of absorbed dose to rupture a human cell membrane. This major injury to the cell allows the extracellular fluids to enter into the cell. Inversely, it also allows leakage out of ions and nutrients which the cell brought inside. Membrane rupture may result in the death of a cell; in this case, death would be compared to drowning. Large doses below 3,000 rad increase the permeability of the cell membrane and some leakage occurs.

Radiation effects on cytoplasm are negligible compared to observed effects on structures which are suspended within it. The first involve the mitochondria. It requires a few thousand rad to disrupt their function. This results in the immediate interruption of the cell's food supply (ATP). If the cell has a large reserve of ATP it can repair the damage to the mitochondria and then continue to produce ATP. The greater the radiation dose received, the longer the repair time will be. If the stored food supply is not adequate to nourish the cell during repair, then the cell will die from starvation.

Another organelle within the cytoplasm that is affected by radiation is the lysosome. The lysosome will rupture at dose levels between 500 and 1,000 rad. When this occurs, the enzymes are released within the cell and begin digesting structures of the cell. This cell death can be compared with suicide. At much larger doses the digestive enzymes are rendered inactive.

The most radiologically sensitive part of the cell is the nucleus. Because there is a wide band of sensitivity for cell nuclei, quantifying a dose range is difficult. The major effect of radiation on the cell nucleus is the inhibition of DNA replication. This means that the cell is unable to prepare for division. Before a cell divides, it produces a complete duplicate set of chromosomes which carry all the information needed to reproduce the organism. With damaged DNA, duplicate

chromosomes cannot be manufactured. If this process is delayed long enough, the cell dies and the death of the cell can be compared to death in childbirth. At lower doses, DNA production is delayed only a short time. As the dose is increased, the delay period gets longer until death occurs.

Law of Bergonie and Tribondeau

As early as 1906 an attempt was made to correlate the differences in sensitivity of various cells with differences in cellular physiology. These differences in sensitivity are stated in the Law of Bergonie and Tribondeau: "*The radiosensitivity of a tissue is directly proportional to its reproductive capacity and inversely proportional to its degree of differentiation.*" In other words, cells most active in reproducing themselves and cells not fully mature will be most harmed by radiation. This law is considered to be a rule of thumb, with some cells and tissues showing exceptions.

Since the time that the Law of Bergonie and Tribondeau was formulated, it is generally accepted that cells tend to be radiosensitive if they are:

- Cells that have a *high division rate*
- Cells that have a *high metabolic rate*
- Cells that are of a *non-specialized type*
- Cells that are *well nourished*

Even though all subsequent biological effects can be traced back to the interaction of radiation with atoms, there are two mechanisms by which radiation ultimately affects cells. These two mechanisms are commonly called *direct effects* and *indirect effects*.

Direct Effects

In direct action, radiation interacts directly with the critical target in the cell. The atoms of the target itself may be ionized or excited, leading to the chain of physical and chemical events that eventually produce the biological damage. Direct action is the dominant process in the interaction of high LET particles with biological material. Alpha particles and beta particles are considered directly ionizing because they carry a charge and can, therefore, interact directly with atomic electrons through coulombic forces (i.e. like charges repel each other; opposite charges attract each other).

Indirect Effect

In indirect action, the radiation interacts with other molecules and atoms (mainly water, since about 80% of a cell is composed of water) within the cell to produce free radicals, which can, through diffusion in the cell, damage the critical target within the cell. In interactions of radiation with water, short-lived yet extremely reactive free radicals such as H_2O^+ (water ions) and OH (hydroxyl radicals) are produced. These free radicals can break the chemical bonds and produce chemical changes that lead to biological damage; they are highly reactive molecules

because they have an unpaired valence electron. About two thirds of the biological damage by low LET radiation, such as X-rays, is due to indirect action.

The steps involved in producing biological damage by the indirect action of X-rays are:

Step 1: Primary photon interaction (photoelectric effect, Compton Effect and pair production) produces a high energy electron.

Step 2: The high energy electron moving through tissue produces free radicals in water.

Step 3: The free radicals may produce changes in DNA from breakage of chemical bonds.

Step 4: The changes in chemical bonds result in biological effects.

Step 1 is in the realm of physics; Step 2 is in chemistry; Steps 3 and 4 are in radiobiology.

Linear Energy Transfer (LET)

For use in radiobiology and radiation protection, the physical quantity that is useful for defining the quality of an ionizing radiation beam is the linear energy transfer (LET). The LET focuses attention on the linear rate of energy absorption by the absorbing medium as the charged particle traverses the medium.

In contrast to the stopping power, which has a typical unit of MeV/cm, the unit usually used for the LET is keV/ μ m. The energy average is obtained by dividing the particle track into equal energy increments and averaging the length of track over which these energy increments are deposited. Typical LET values for commonly used radiations are:

- 250 kVp X-rays: 2 keV/ μ m.
- Cobalt-60 γ rays: 0.3 keV/ μ m
- 3 MeV X-rays: 0.3 keV/ μ m.
- 1 MeV electrons: 0.25 keV/ μ m

X-rays are considered low LET (sparsely ionizing) radiations, while energetic neutrons, protons and heavy charged particles are high LET (densely ionizing) radiations. The demarcation value between low and high LET is at approximately 10 keV/ μ m.

The cell proliferation cycle is defined by two well defined time periods:

- Mitosis (*M*), where division takes place
- The period of DNA synthesis (*S*)

The *M* and *S* portions of the cell cycle are separated by two periods (gaps)—G1 and G2—when, respectively, DNA has not yet been synthesized or has been synthesized but other metabolic processes are taking place. The time between successive divisions (mitoses) is called the *cell cycle time*. For mammalian cells growing in culture, the *S* phase is usually in the range of 6–8 h, the *M* phase less than an hour, G2 is in the range of 2-4 h, and G1 is 1-8 h, making the total cell cycle between 10-20 hours. In contrast, the cell cycle for stem cells in certain tissues is up to about 10 days. In general, cells are most radiosensitive in the *M* and G2 phases, and most resistant in the late *S* phase.

The cell cycle time of malignant cells is shorter than that of some normal tissue cells, but during regeneration after injury, normal cells can proliferate faster. Cell death of non-proliferating (static) cells is defined as the loss of a specific function, while for stem cells and other cells capable of many divisions it is defined as the loss of reproductive integrity (reproductive death). A surviving cell that maintains its reproductive integrity and proliferates almost indefinitely is said to be clonogenic.

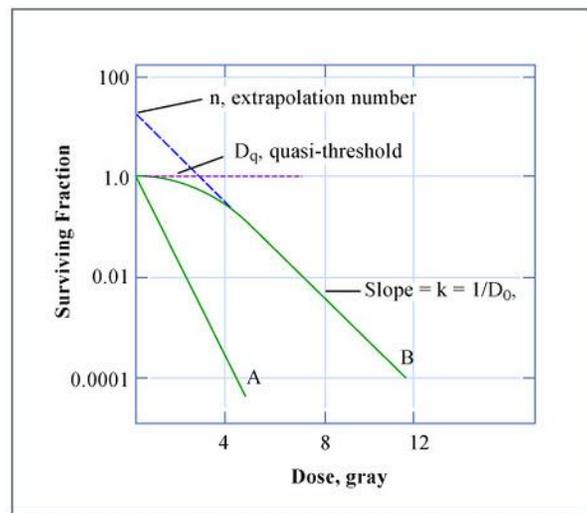
Classification of Radiation Damage

Radiation damage to mammalian cells is divided into three categories:

- *Lethal damage*, which is irreversible, irreparable and leads to cell death.
- *Sublethal damage*, which can be repaired in hours unless additional sublethal damage is added that eventually leads to lethal damage.
- *Potentially lethal damage*, which can be manipulated by repair when cells are allowed to remain in a non-dividing state.

Cell Survival Curve

A cell survival curve describes the relationship between the surviving fraction of cells [i.e. the fraction of irradiated cells that maintain their reproductive integrity (clonogenic cells)] and the absorbed dose. Cell survival as a function of radiation dose is graphically represented by plotting the surviving fraction on a logarithmic scale on the ordinate against dose on a linear scale on the abscissa.



The type of radiation influences the shape of the cell survival curve. Densely ionizing radiations exhibit a cell survival curve that is almost an exponential function of dose, shown by an almost straight line on the log–linear plot. For sparsely ionizing radiation, however, the curves show an initial slope followed by a shoulder region and then become nearly straight at higher doses. Factors that make cells less radiosensitive are: removal of oxygen to create a hypoxic state, the addition of chemical radical scavengers, the use of low dose rates or fractionated irradiation, and cells synchronized in the late S phase of the cell cycle.

Several mathematical methods of varying degrees of complexity have been developed to define the shape of cell survival curves, all based on the concept of the random nature of energy deposition by radiation. The linear quadratic model is now most often used to describe the cell survival curve, assuming that there are two components to cell kill by radiation:

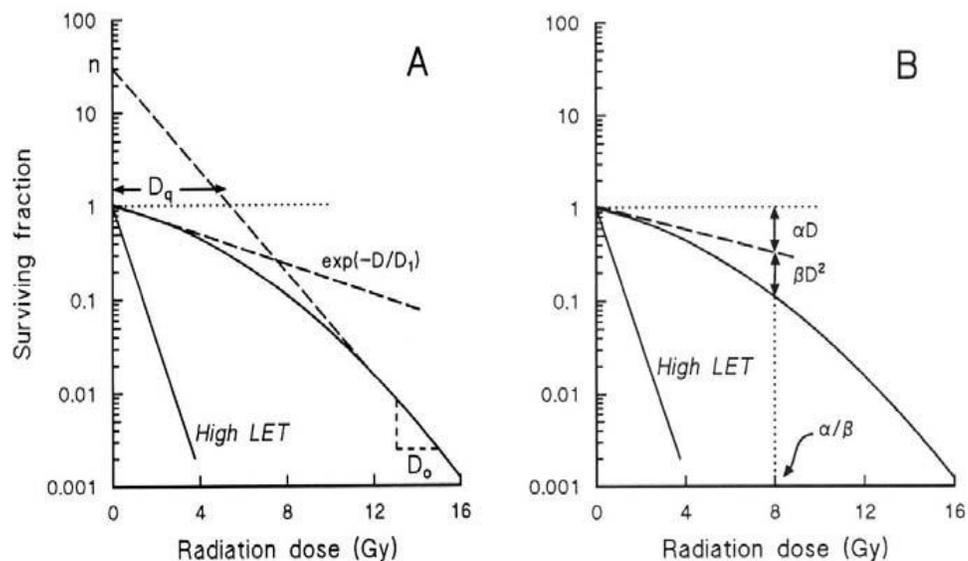
$$-aD-bD^2$$

$$S(D) = e$$

- Where:
- S(D)** is the fraction of cells surviving a dose *D*;
 - a** is a constant describing the initial slope of the cell survival curve;
 - b** is a smaller constant describing the quadratic component of cell killing.

The ratio *a/b* gives the dose at which the linear and quadratic components of cell killing are equal [8 Gy in the example shown in figure below (b)].

The ratio *a/b* gives the dose at which the linear and quadratic components of cell killing are equal [8 Gy in the example shown in figure below (b)].



Typical cell survival curves for high LET (densely ionizing) radiation and low LET (sparsely ionizing) radiation. (a) The earlier multitarget single hit model; (b) the current linear quadratic model.

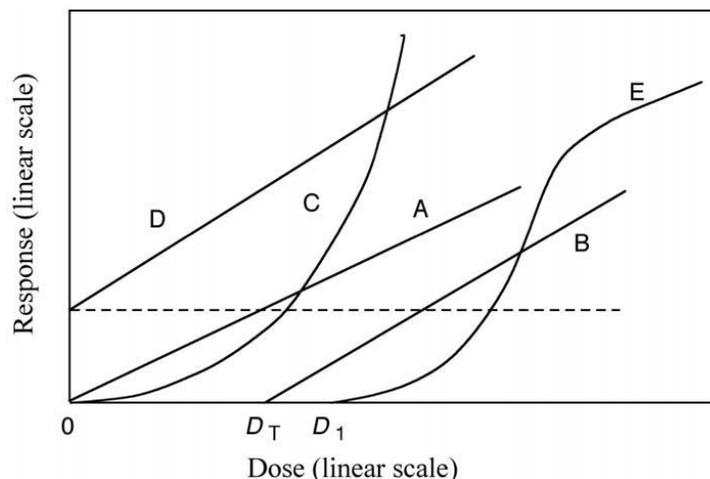
A plot of a biological effect observed (e.g. tumor induction or tissue response) against the dose given is called a *dose response curve*. Generally, as dose increases, so does the effect.

Three types of dose response relationships are known:

- Linear
- Linear quadratic
- Sigmoid

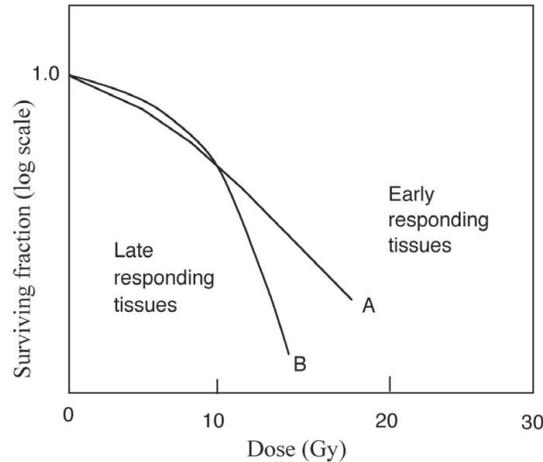
Dose response curves may or may not have a threshold. A threshold dose is the largest dose for a particular effect studied below which no effect will be observed. Various dose response curves are shown in figure below with:

- A linear relationship with no threshold
- A linear relationship with a threshold
- A linear quadratic relationship with no threshold



Typical dose response curves for cancer induction (curves A, B, C and D) and for tissue response (curve E). Curve A represents a linear relationship with no threshold; curve B represents a linear relationship with threshold D_T ; curve C represents a linear quadratic relationship with no threshold (assumed for stochastic effects, for example carcinogenesis); curve D represents a linear relationship with no threshold (the area below the dashed line represents the natural incidence of the effect, for example carcinogenesis); and curve E represents a sigmoid relationship with threshold D_1 , as is common for deterministic effects in tissues, for example tumor control or treatment morbidity. The curves are diagrammatic only and are separated for clarity (in practice the dashed line would be lower).

The response of different tissues or organs to radiation varies markedly, depending primarily on two factors: the inherent sensitivity of the individual cells and the kinetics of the population. There is a clear distinction in radiation response between tissues that are early responding (skin, mucosa and intestinal epithelium) and those that are late responding (spinal cord), as shown schematically in the figure below for the surviving fraction against the dose.

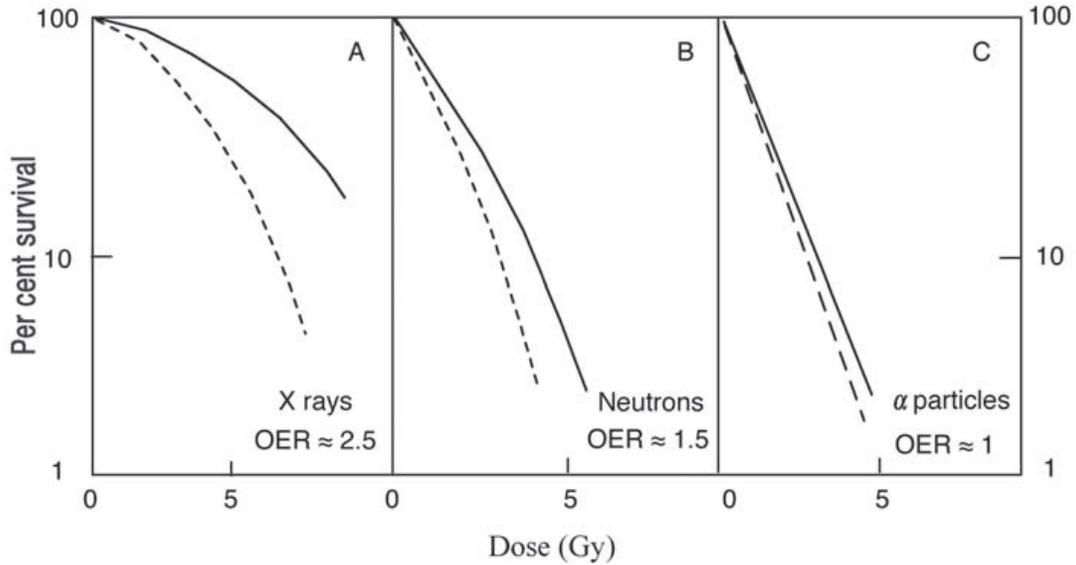


Hypothetical target cell survival curves for (curve A) early responding tissues and (curve B) late responding tissues.

The cell survival curves for late responding tissues are more curved than those for early responding tissues. For early effects, the ratio a/b is large and a dominates at low doses. For late effects, a/b is small and b has an influence at doses lower than for early responding tissues. The a and b components of mammalian cell killing are equal at approximately $a/b = 10$ Gy and $a/b = 3$ Gy for early and late effects, respectively.

Oxygen Enhancement Ratio (OER)

The presence or absence of molecular oxygen within a cell influences the biological effect of ionizing radiation: the larger the cell oxygenation above anoxia, the larger is the biological effect of ionizing radiation. Especially for low LET radiations, the larger the cell oxygenation above anoxia, the larger the biological effect until saturation of the effect of oxygen occurs. As shown in the figure below, the effect is quite dramatic for low LET (sparsely ionizing) radiations, while for high LET (densely ionizing) radiations it is much less pronounced. The ratio of doses without and with oxygen (hypoxic versus well oxygenated cells) to produce the same biological effect is called the *oxygen enhancement ratio* (OER).



Typical cell surviving fractions for X- rays, neutrons and α particles: dashed curves are for well oxygenated cells, solid curves for hypoxic cells.

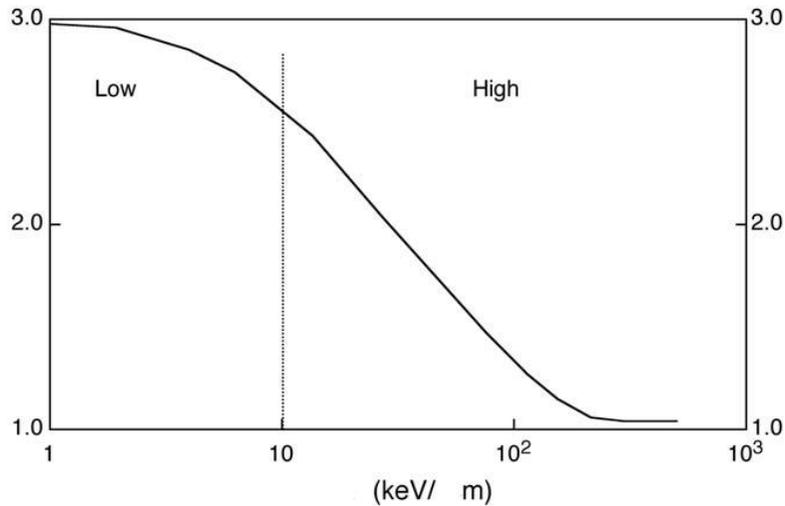
Dose to produce a given effect without oxygen

$$\text{OER} = \frac{\text{Dose to produce a given effect without oxygen}}{\text{Dose to produce the same effect with oxygen}}$$

Dose to produce the same effect with oxygen

The OER for X-rays and electrons is about three (3) at high doses and falls to about two (2) for doses of 1–2 Gy. The OER decreases as the LET increases and approaches OER = 1 at about LET = 150 keV/mm, as shown in the figure below. Cells at the periphery of tumor cords growing around blood vessels become chronically hypoxic because of the consumption of most of the oxygen near the blood vessel. The transient closing of blood vessels can also make the whole tumor cord hypoxic for a few minutes at a time.

Reoxygenation—the process by which cells that are hypoxic become oxygenated after irradiation, through the killing and removal of oxically radiosensitive cells from the tumor—can occur.



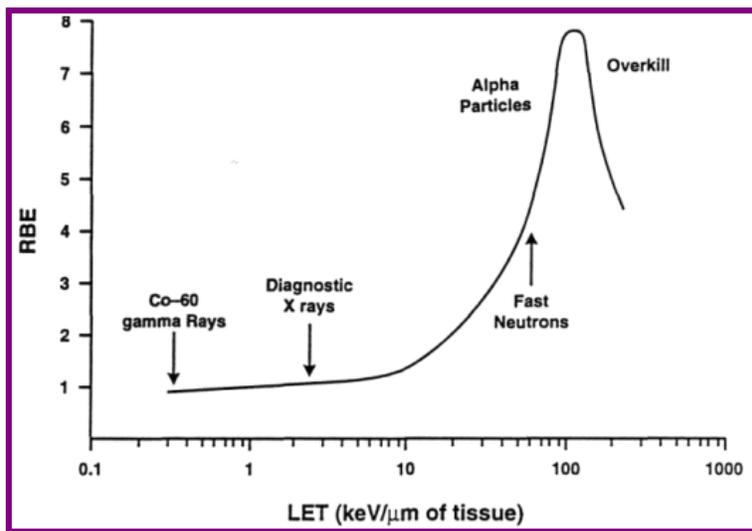
OER plotted against LET. The vertical dashed line separates the low LET region, where LET < 10 keV/mm, from the high LET region, where LET > 10 keV/mm.

Relative Biological Effectiveness (RBE)

As the LET of radiation increases, the ability of the radiation to produce biological damage also increases. The relative biological effectiveness (RBE) compares the dose of test radiation to the dose of standard radiation to produce the same biological effect. The standard radiation has been taken as 250 kVp X-rays for historical reasons, but is now recommended to be Cobalt 60 gamma rays. The RBE is defined by the following ratio:

$$\text{RBE} = \frac{\text{Dose from standard radiation to produce a given biological effect}}{\text{Dose from test radiation to produce the same biological effect}}$$

The RBE varies not only with the type of radiation but also with the type of cell or tissue, biologic effect under investigation, dose, dose rate and fractionation. In general, the RBE increases with the LET to reach a maximum RBE of 3-8 (depending on the level of cell death) at LET ^a 200 keV/m, and then decreases because of energy overkill, as shown in the figure below.



RBE against LET. The vertical dashed line separates the low LET region, where $RBE \approx 1$, from the high LET region, where the RBE first rises with the LET, reaches a peak of about 8 for $LET \approx 200$ keV/mm, and then drops with a further increase in the LET.

There are four stages in action of indirect ionizing radiation on biological structures:

- Physical
- Physical-chemical
- Chemical
- Biological

Physical

The transfer of kinetic energy from ionizing radiation to atoms or molecules leads to excitation and ionization of these atoms or molecules.

Physical-Chemical

The placement of absorbed energy from ionizing radiation into molecules and between them. The formation of free radicals takes place.

Chemical

The reactions between free radicals and intact molecules take place. Formation of molecules with abnormal structure and function realize.

Biological

The formation of injuries on all levels – from cellular structures to organism and population. Development of processes of biological damage and reparative processes occur on biological stage. As discussed previously, the two mechanisms by which radiation affects cells are through *direct effects* and *indirect effects*.

Effects of Oxygen on Free Radical Formation

The presence of dissolved oxygen can modify the reaction by enabling the creation of other free radical species with greater stability and longer lifetimes.

- $H\cdot + O_2 = HO_2$ (hydroperoxy free radical)
- $R\cdot + O_2 = RO_2$ (organic peroxy free radical)

The transfer of the free radical to a biological molecule can be sufficiently damaging to cause bond breakage or inactivation of key functions. In addition, the organic peroxy free radical can transfer the radical from molecule to molecule causing damage at each encounter. Thus, a cumulative effect can occur, greater than a single ionization or broken bond. Free radicals readily recombine to electronic and orbital neutrality. However, when many exist, as in high radiation fluence, orbital neutrality can be achieved by hydrogen radical dimerization (H_2) and the formation of toxic hydrogen peroxide (H_2O_2). The radical can also be transferred to an organic molecule in the cell.

The lifetimes of simple free radicals ($H\cdot$ or $OH\cdot$) are very short, with a typical lifetime of less than 0.1 second. While generally highly reactive, they do not exist long enough to migrate from the site of formation to the cell nucleus. However, the oxygen-derived species such as hydroperoxy free radical does not readily recombine into neutral forms. These more stable forms have a lifetime long enough to migrate to the nucleus, where serious damage can occur.

Radiation-Induced Membrane Damage

Biological membranes serve as highly specific mediators between the cell, organelles, and the environment. Radiation changes within the lipid bilayers of the membrane may alter ionic pumps. This may be due to changes in the viscosity of intracellular fluids associated with disruptions in the ratio of bound to unbound water. Such changes would result in an impairment of the ability of the cell to maintain metabolic equilibrium and could be very damaging, even if the shift in equilibrium were quite small.

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. Ionizing radiation has been suggested as playing a role in plasma membrane damage, which may be an important factor in cell death. New fractionation schemes, outlined in Chapter 8, have been arranged to keep the total dose low so minimal (and no long term) damage is accumulated to the cell membrane.



Chapter 3: Principles of Radiation Safety



Within a decade of the discovery of X-rays in 1895 and radioactivity in 1896, scientists had developed uses for radiation, primarily in the area of medical diagnosis and treatment. This scientific endeavor has continued to the present, resulting in the current use of radiation for the improvement of human life. The research, development, and use of radiation necessarily results in the researchers and users of this technology being exposed to radiation in the course of their work. Although early scientists were unaware of the potential dangers of occupational radiation exposure, it wasn't long before the scientific and medical communities realized that occupational radiation exposure needed to be controlled for the safety of radiation workers.

In the 1920s, the first formal recommendations for radiation protection were promulgated by the International X-ray and Radium Protection Commission (established by the Second International Congress of Radiology in 1928) and the United States Advisory Committee on X-ray and Radium protection. These recommendations were based on the concept of a "Tolerance Dose." This concept was intended to set limits that prevented the occurrence of clinically observable radiation effects (like reddening of the skin). The recommended "Tolerance Dose" was gradually reduced in subsequent decades in recognition of the growing use of radiation and the growing realization that chronic effects such as cancer or genetic abnormalities may also be induced by radiation.

By the mid-1950s, with the realization of the potential expansion of the radiation industry and the number of workers that may be exposed, the "Tolerance Dose" levels were reduced again, and the concept of maintaining exposures as low as practical was adopted. This formed the guiding principles of the radiation-protection system still in use today by the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP), the international and national scientific committees charged with development of radiation-protection recommendations. These guiding principles are those of *justification*, *dose limitation*, and *optimization of dose at levels that are as low as reasonably achievable* (the ALARA principle).

Justification of the use of a source of radiation or radioactivity is accomplished through regulatory reviews, licensing processes, political will (such as national security uses), etc. The principles of the system that are directly applicable to a radiation-safety program protecting workers are those of *dose limitation* and the ALARA philosophy. Since the inception of the current system for radiation-safety standards in the mid-1950s, the *dose limitation* principle has been included to meet "the need to apply individual dose limits to ensure that the procedures of justification and ALARA do not result in individuals or groups of individuals exceeding levels of acceptable risk" (NCRP 1993). Therefore, the dose limits represent an acceptable level of potential occupational risk and do not represent a level that will necessarily be unsafe if they are exceeded. Similarly, optimization of actual dose levels through the inclusion of the ALARA principle has been to meet "the need to ensure that the total societal detriment from such justifiable activities or practices is maintained ALARA, economic and social factors being taken into account" (NCRP 1993).

X-ray Radiation Safety

X-ray Radiation Safety training is mandatory for radiation workers to comply with State Regulatory requirements and policies. Individuals requiring this training include Physicians, PAs, Nurses, Technical Support Staff, Technicians, Medical Assistants, and medical students.

The goal of the Radiation Safety Program is to provide guidance for the safe use of radiation-producing equipment in clinical areas and for the safety of all personnel involved.

Prohibited Use of X-ray Equipment

It is unlawful to operate any X-ray equipment unless it is operated in compliance with all local, state, and federal regulations.

The use of X-ray radiation on humans is strictly regulated and is only permitted with authorization from a licensed practitioner for healing arts purposes.

Individuals must not be exposed to X-ray radiation for training or demonstration purposes.

Occupational Exposure

Occupational exposure is the radiation exposure potentially received working with and around X-ray systems.

Local, state, and federal regulations limit the amount of radiation dose allowed for occupational radiation workers, members of the public, and the fetus of a declared pregnant radiation worker.

Occupational Dose Limits

All personnel who work with any form of radiation are considered radiation workers and are subject to occupational dose limits. These limits do not include background radiation or radiation received for personal medical reasons.

Maximum Permissible Dose – Adults

Whole Body – Head, Neck, Torso, Upper arms & legs	50.0 mSv
Lens of the Eye	150.0 mSv
Extremities, Skin, and Internal Organs	500.0 mSv

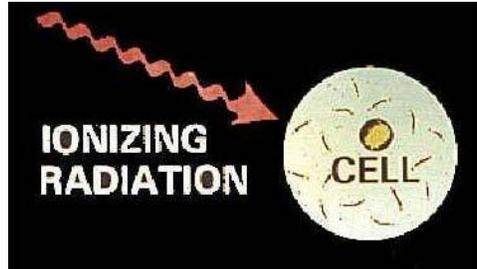
Doses received within these limits are not expected to cause adverse health effects, even if the maximum is received each year for a total of fifty years.

Prenatal Radiation Exposure

A “Declared Pregnant” radiation worker is a woman who has voluntarily chosen to declare her pregnancy *in writing* to the Radiation Safety Officer. The maximum permissible dose limit to an embryo/fetus of a declared pregnant radiation worker is 5.0 mSv for the entire pregnancy.

Why is Radiation Harmful?

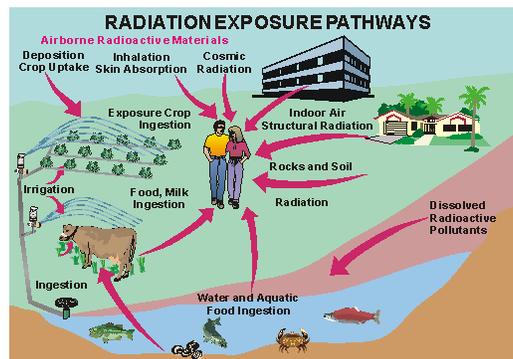
Radiation can cause changes in human cells and tissues by interfering with the way a cell functions.



Radiation Exposure

Current radiation safety practices are focused on keeping occupational exposure to radiation as low as reasonably achievable. However, the radiation exposure received while working with X-ray equipment is only a fraction of a person's total radiation exposure.

Radiation is everywhere, and exposure to ionizing radiation can come from many sources. Typically, the greatest source of radiation exposure comes from nature itself. This is called background radiation.



Sources of Background Radiation

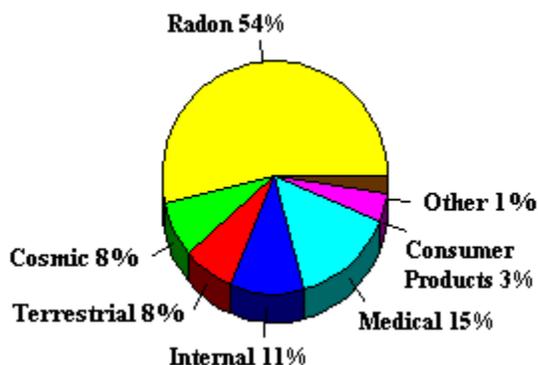
Natural = 3.0 mSv

- Radon – basements and water supplies
- Cosmic – outer space
- Terrestrial – soil, rocks and plants

Human-produced = .6 mSv

- Medical and dental X-rays
 - 200 million medical X-rays performed each year
- Nuclear medicine and cancer therapy
 - 15 million cancer therapy treatments each year
- Consumer products
 - TV's, smoke detectors, tobacco products, natural gas, etc.

The average person receives 3.60 mSv per year



ALARA

ALARA stands for as low as reasonably achievable. Regulations require that employers and staff make “every reasonable effort to maintain radiation exposure as far below the maximum allowable permissible dose limits as practical taking into consideration the purpose for which sources of radiation are used.”

The radiation exposure for occupational workers is far less than the annual radiation exposure limits because personnel follow ALARA guidelines. The basic guidelines are:

- Minimize **time** near radiation sources.
- Maximize **distance** from radiation sources.
- Use **shielding** devices when applicable.

Time

Radiation dose is directly proportional to the time an individual is exposed to a source of ionizing radiation.

Distance

The more distance between the body and a radiation source, the less exposure received. This is called the inverse square law.

Shielding

The application of shielding (such as a lead apron) provides a barrier between the body and the source of radiation.

Patient Radiation Exposure

Patient radiation exposure must also be ALARA; this includes:

- Using appropriate applicator with the primary radiation beam.
- Understanding the controls of the equipment to administer the prescribed patient dose.

Dosimetry Badges

Dosimetry badges are intended to measure your external occupational radiation exposure received while working at a clinic. A new badge is issued each quarter. An individual's dosimetry history is available from the RSO by written request.



Dosimetry Badge Guidelines

When issued a dosimetry badge, follow the guidelines below. An individual's badge is his/her own responsibility, and all readings are permanently recorded in the dosimetry history.

- Wear only the badge assigned to you.
- Do not wear your badge while participating in personal medical /dental procedures.
- Never intentionally expose your badge or anyone else's badge to radiation.
- Never take your badge home. Store your badge in the designated area.
- If your badge is lost or damaged, call the RSO immediately for a replacement.

Wearing Your Dosimeter

- Always make sure your dosimeter is worn on the collar external to your clothing.
- Wearing your dosimeter incorrectly can result in false dose measurements.

Dosimetry Reports

On dosimeter reports (such as the one below from Landauer), individuals are identified by their participant number (found on the back of the dosimeter). Dosimeter reports are sent to the site/department each quarter. If you are unable to locate any report, contact the RSO.

Radiation Dosimetry Report LANDAUER®
Landauer, Inc. 2 Science Road, Glenwood, IL 60425-1596
Telephone: (708)755-7000 Facsimile: (708)755-7016
www.landauerinc.com

Electronic Representation 

SOUTHERN ILLINOIS UNIV
ALVIN JAMES KANE
SCHOOL OF MEDICINE
P.O. BOX 19612
SPRINGFIELD IL 62794

Account: 010998 Series: 0610080624 Analytical Work Order: 04172006 Report Date: 04/10/2006 Dosimeter Received: Report Time in Work Days: 5

Part #	Name	Sex	DOB	Use	Dose Equivalent (MREM) For Periods Shown Below	Quarterly Accumulated Dose Equivalent (MREM)			Year to Date Dose Equivalent (MREM)			Lifetime Dose Equivalent (MREM)			Records For Year	Expiration Date			
						Deep Dose	Eye LDE	Shallow SDE	Deep Dose	Eye LDE	Shallow SDE	Deep Dose	Eye LDE	Shallow SDE			Deep Dose	Eye LDE	Shallow SDE
00000	Pa CNTRL				SL	SL	SL								3	08/1994			
	U CNTRL							M								08/1994			
00003	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	40	50	3	08/1994	
00007	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	10	10	10	3	08/1994
00008	U RFINGR							M							40	3	08/1994		
00011	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	10/1997
00015	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	20	30	30	3	08/1994
00020	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	30	30	40	3	08/1994
00030	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	280	340	420	3	08/1994
	U RFINGR							M							850			08/1994	
00031	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	10	10	70	3	08/1994
00039	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	130	130	130	3	08/1994
00092	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	03/1997
00138	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	11/2000
00400	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	10	10	10	3	10/2002
00465	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	09/2003
00472	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	10/2003
00475	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	20	20	20	3	03/2004
00477	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	07/2004
00478	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	11/2004
00479	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	02/2005
00480	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	04/2005
00481	Pa WHBODY				SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	07/2005
00482	Pa CHEST							SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	3	09/2005

NOTE: ABSENT

SL: SELECTED MINIMAL REPORTING LIMIT OF 10 MREM
ELECTRONIC MEDIA TO FOLLOW THIS REPORT

Quality Control Release: RCH

1 PR 8472 RPT130 N1 3206
Accredited by the National Institute of Standards and Technology through NVLAP for the scope of accreditation under NVLAP Lab Code 100516-07
Page 1

“SL” - Selected Minimum Reporting Limit

Whole body doses equivalent to less than 0.10 mSv (10 mrem) will be noted as “SL” for minimal on the dosimeter report. For ring dosimeters, “M” indicates less than 0.30 mSv (30 mrem).



Taking New Aim At Skin Cancer™

ALARA Action Levels

If any dose equivalent exceeds a pre-established ALARA action level, the RSO should contact the participant and his/her supervisor to determine if future exposure can be reduced.

What Do “Deep,” “Eye,” and “Shallow” Indicate on Dosimeter Reports?

- Deep: Dose equivalents in the “Deep” column heading mean penetrating radiation dose to internal organs.
- Eye: Dose equivalents in the “Eye” column heading indicate dose to the lens of the eye.
- Shallow: Dose equivalents in the “Shallow” column heading means dose to the skin for whole body dosimeters.

Shielding for Patients Receiving Superficial Radiation Therapy

Protective apparel can reduce exposure to the thyroid, extremities, and eyes. Lead aprons, thyroid shields, and lead lined glasses should be available to ALL patients involved with receiving Superficial Radiation Therapy, when appropriate.

- Lead aprons cover about 75%-80% of a person’s active bone marrow
- The use of thyroid shields, leaded safety glasses, and lead aprons are strongly recommended during Superficial Radiation Therapy for the patient, as appropriate.

Holding Patients

- No occupational radiation worker should ever hold a patient during a Superficial Radiation Therapy procedure.
- An individual (patient’s family member, etc.) who volunteers to hold a patient, if needed, should wear 0.25 mm lead equivalent protective apparel (i.e. apron, glasses) for exposure to scatter radiation.
- An individual holding a patient should never be in alignment with the primary beam.
- Pregnant women should not hold patients during a Superficial Radiation Therapy procedure.

Caution Signs

Highly visible signs assure unnecessary exposure to staff and patients, and should be posted wherever applicable.



Unsafe and Emergency Conditions

If an unsafe condition arises with a Superficial Radiation Therapy unit:

- Report any unusual or unsafe conditions involving sources of radiation to the Radiation Safety Officer.
- If an emergency occurs:
 - Turn power OFF to the Superficial Radiation Therapy Unit.
 - Remove patient from the room.
 - Notify your Supervisor and contact the RSO.



Chapter 4: Principles of X-ray Production



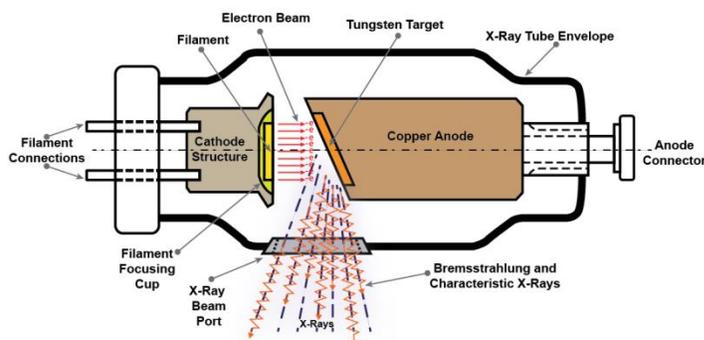
How Are Superficial Radiation Therapy X-rays Produced?

X-rays are created by taking energy from electrons and converting it into photons with appropriate energies. This energy conversion takes place within the system's X-ray tube.

X-ray Tube

The quantity (exposure) and quality (spectrum) of the X-ray radiation produced can be controlled by adjusting the electrical quantities (kV, mA) applied to the tube. An X-ray tube is an energy converter. It receives electrical energy and converts it into two other forms: X-radiation and heat. The heat is an undesirable byproduct. X-ray tubes are designed and constructed to maximize X-ray production and to dissipate heat as rapidly as possible. The X-ray tube is a relatively simple electrical device typically containing two principle elements: a cathode and an anode. As the electrical current flows through the tube from cathode to anode, the electrons undergo an energy loss, which results in the generation of X-radiation. A cross-sectional view of a typical X-ray tube is shown below.

Cathode



Outline of an X-Ray Tube

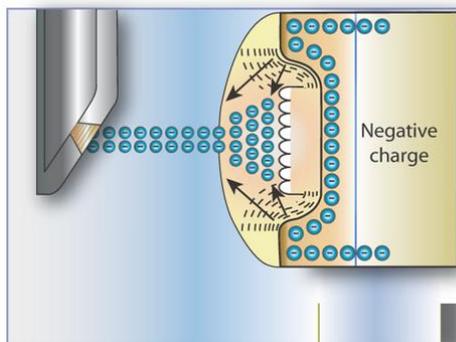
The purpose of the cathode is to:

- Serve as the source of electrons for the X-ray tube.
- Direct their flow toward the anode.

The typical cathode consists of a small coil of wire (a filament) recessed within a cup-shaped region, as shown above. Tungsten is used in construction of the cathode filament because of its high melting point (3370° C) and a vapor pressure that prevents the wire from vaporizing at the high temperatures imposed. In a process known as thermionic emission, thermal energy (or heat) is used to expel the electrons from the cathode. The filament of the cathode is heated in the same way as a light bulb filament by passing a current through it. This heating current is not the same as the current flowing through the X-ray tube (the mA) that produces the X-radiation.

Filament

The filament sits in a separate metallic focusing cup. Because of the tendency for particles of equal charge to repel each other, it would be possible for the electron beam to spread as it crossed the tube and bombard an undesirably large target area on the anode. By maintaining the focusing cup at the same negative potential as is the heated filament, the repulsive charge from the focusing cup tends to direct the electrons toward a relatively small area on the target.

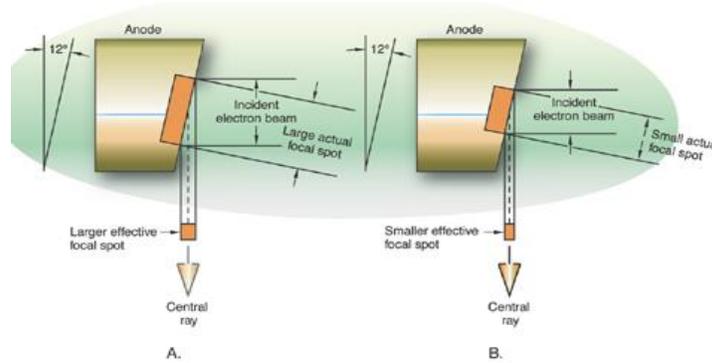


Anode

The anode consists of a target material placed on the surface of a larger cylinder. It is estimated that more than 99% of the energy in the electron beam is converted to heat energy at the time of its interaction with the target. The ability of the target material to withstand high temperatures and the speed with which heat can be dissipated by the anode are therefore of great importance. If the atomic number of the target material is sufficiently high, it will favorably influence the efficiency of production of X-rays. Because tungsten satisfies these requirements, it has long served as a target material of choice. Tungsten has:

- A high melting point (3370° C)
- A high atomic number (74)
- A low tendency to vaporize
- Good heat conductivity

Tungsten is embedded in the end of a copper cylinder. Despite the high melting point of tungsten, a copper cylinder is still needed to dissipate the great amount of heat generated during an exposure. Copper is a better conductor of heat and has a relatively high melting point (1070° C). The tungsten block sits on the end of the copper cylinder with the surface of the tungsten plate at a predetermined angle (usually from 15 to 22.5 degrees).



Focal Spot

The size of the tungsten plate exceeds the size of the electron beam. This is necessary to avoid the electron beam striking the surface of the cylinder and causing melting of the copper, since it has a relatively lower melting point.

The area of the surface of the target that is bombarded by electrons during an exposure is called the focal spot. When viewed perpendicularly to the surface of the target, the size of the focal spot is referred to as the "projected focal spot" or "effective focal spot". The actual focal spot tends to be rectangular in shape while the projected focal spot is more nearly square in shape. In addition to a different shape of the projected versus the actual focal spot, there is also an important difference in area.

The size of the electron beam is determined by the:

- Size of the cathode filament
- Structure of the focusing cup
- Position of the filament within the focusing cup

The anode and cathode are contained in an airtight enclosure, or envelope. The primary functions of the envelope are to provide support and electrical insulation for the anode and cathode assemblies and to maintain a vacuum in the tube.

X-ray Tube Housing

The X-ray tube housing provides support for the envelope, within which a vacuum is maintained. The vacuum permits independent control of both the number of electrons that constitutes an electron beam, and the speed of flow of the electrons. The vacuum eliminates the possibility of collisions between molecules of air and accelerated electrons. In addition, removal of air prevents deterioration of the filament by oxidation.

The tube housing provides:

- A mechanical support for the tube.
- Electrical insulation for high voltage cables that feed into the tube.
- Radiation shielding.

Heat is produced in the focal spot area by the bombarding electrons from the cathode. Since only a small fraction of the electronic energy is converted in X-radiation, circulation of water is needed to dissipate the heat created.

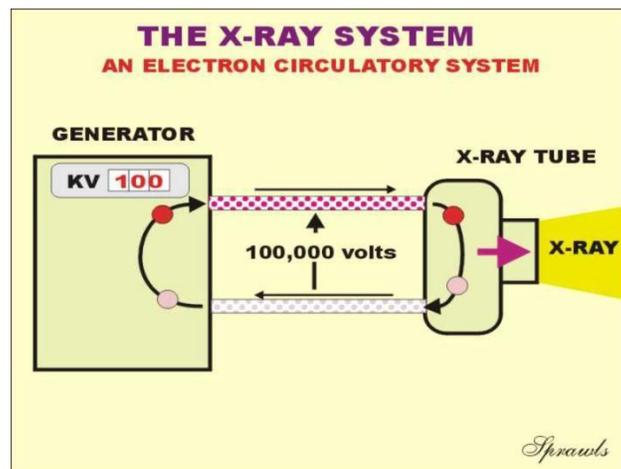
Electrical Circuit

The energy used by the X-ray tube to produce X-radiation is supplied by an electrical circuit, as illustrated below. The circuit connects the tube to the source of electrical energy, often referred to as the generator. The generator receives the electrical energy from the electrical power system and converts it into the appropriate form to apply to the X-ray tube. The generator also provides the ability to adjust certain electrical quantities that control the X-ray production process.

The three principle electrical quantities are:

- kV (the voltage or electrical potential applied to the tube)
- mA (the electrical current that flows through the tube)
- Treatment Time (duration of the treatment time, generally in increments, not seconds, due to incorporation of tube current ramp-up time)

The circuit is actually a circulatory system for electrons; they pick up energy as they pass through the generator and transfer their energy to the X-ray tube anode.





Chapter 5: Classifications of X-rays



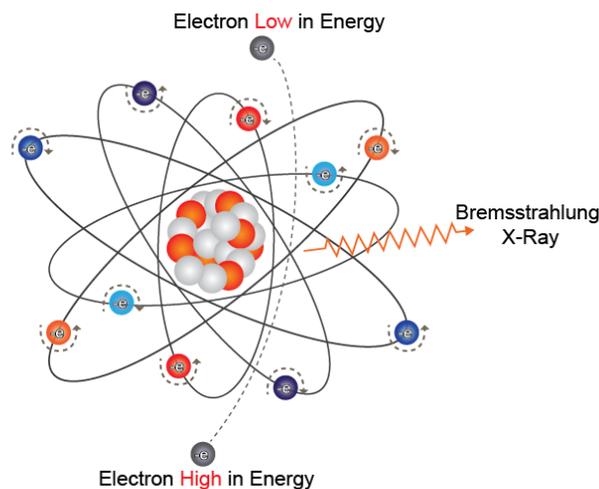
Electrons traveling from the filament (cathode) to the target (anode) convert a small percentage (1%) of their kinetic energy into X-ray photons by the formation of **bremstrahlung** and **characteristic** radiation.

Bremstrahlung Interactions

Bremstrahlung interactions, the primary source of X-ray photons from an X-ray tube, are produced by the sudden stopping, breaking, or slowing of high-speed electrons at the target.

When the electrons from the filament strike the tungsten target, X-ray photons are created if they either hit a target nucleus directly (which is rare), or their path takes them close to the nucleus. If a high-speed electron hits the nucleus of a target atom, all its kinetic energy is transformed into a single X-ray photon. (Total absorption has occurred). Thus, the energy of the resultant photon (keV) is numerically equal to the energy of the electron. This in turn is equal to the kilovoltage applied across the X-ray tube at the instant of its passage. This happens rarely.

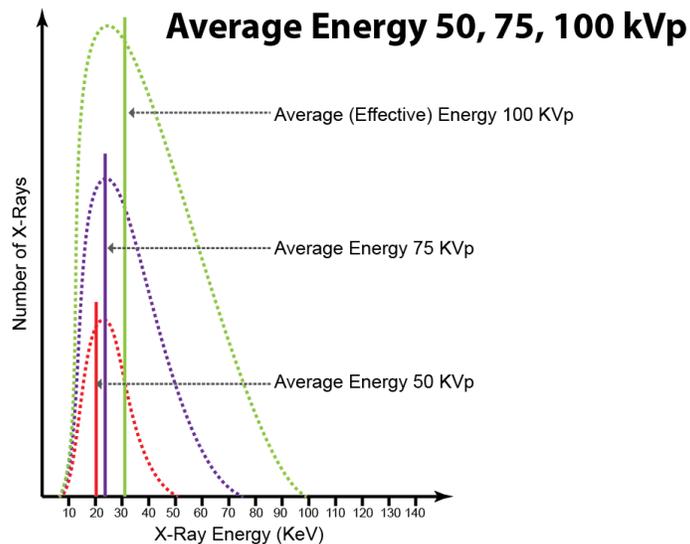
Most high-speed electrons have near or wide misses with the nuclei. In these interactions, a negatively-charged high-speed electron is attracted to the positively-charged nucleus and loses some of its velocity. This deceleration causes the electron to lose some kinetic energy, which is given off in the form of a photon. The closer the high-speed electron approaches the nuclei, the greater the electrostatic attraction on the electron, the braking effect, and the greater the energy of the resulting Bremstrahlung photon.



Bremstrahlung X-Rays

Bremsstrahlung interactions generate X-ray photons with a continuous spectrum of energy. The energy of an X-ray beam may be described by identifying the peak operating voltage (in kVp). The SRT-100™ Superficial Radiation Therapy unit operates at peak voltages of 50, 70, and 100 kVp. The spectrum of energies can be explained by the fluctuating voltage across the tube. The reasons for these continuous spectrums are:

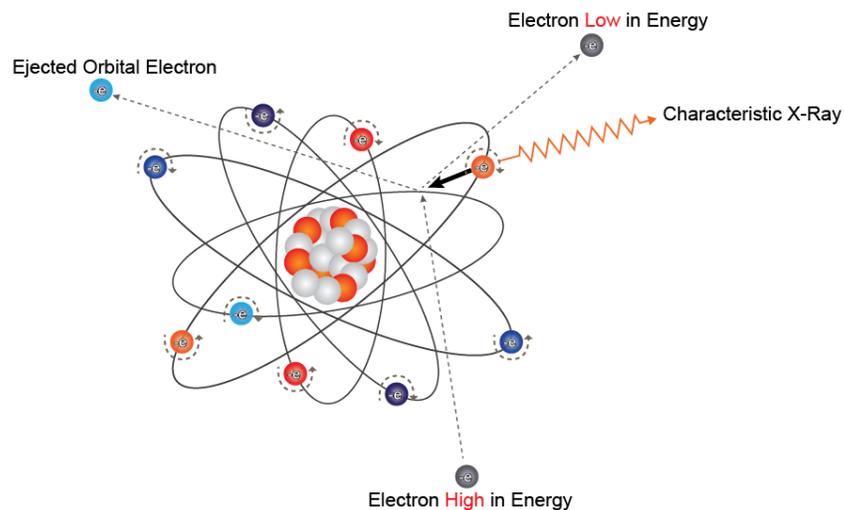
- The continuously varying voltage difference between the target and the filament, which is characteristic of half wave rectification, causes the electrons striking the target to have varying levels of kinetic energy.
- Depth of generation of photons in the target.
- Most electrons participate in many interactions before all their kinetic energy is expended. Therefore, an electron carries differing amounts of energy at the time of each interaction with a tungsten atom that results in the generation of an X-ray photon.
- The bombarding electrons pass at varying distances around tungsten nuclei and are thus deflected to varying extents. As a result, they give up varying amounts of energy in the form of Bremsstrahlung photons.



Characteristic Radiation

Characteristic radiation occurs when an electron from the filament displaces an electron from an inner-shell of the tungsten target atom, thereby ionizing the atom. When this happens, another electron in an outer-shell of the tungsten atom is quickly attracted into the void in the deficient inner-shell. When the displaced electron is replaced by the outer-shell electron, a photon is emitted with an energy equivalent to the difference in the two orbital binding energies.

Characteristic radiation from the K-shell occurs only above 70 kVp with a tungsten target and occurs as discrete increments compared with Bremsstrahlung radiation. The energies of characteristic photons are a function of the energy levels of various electron orbital levels and therefore are characteristic of the target atoms. Characteristic radiation has a higher intensity, but is only a minor source of radiation from an X-ray tube.



Characteristic X-Rays



Chapter 6: Controlling Factors for X-rays



The X-ray beam emitted from an X-ray tube may be modified to suit the needs of the application by altering the beam treatment time (timer), exposure rate (mA), beam energy (kV and filtration), beam shape (applicator and surface cutout), and target-to-patient distance (long or short applicator/cone).

Treatment Time

This factor affects the changes in the X-ray spectrum that result when the exposure time is increased, while the tube current (mA) and voltage (kVp) remain constant. When the treatment time is doubled, the number of photons generated is doubled, but the range intensity of photon energies is unchanged. Therefore, changing the time simply controls the “quantity” of the treatment.

The amount of radiation that a patient receives is determined in cGy. Treatment times are derived automatically when dose in cGy is dialed up on the SRT-100™.

Tube Current (mA)

This illustrates the changes in the spectrum of photons that result from increasing tube current (mA) while maintaining constant tube voltage (kVp) and exposure time. As the mA setting is increased, more power is applied to the filament, which heats up and releases more electrons that collide with the target to produce X-rays. A linear relationship exists between mA and radiation output. The SRT-100 has set mA for all three therapeutic energies.

Tube Voltage (kVp)

Increasing kVp increases the potential difference between the cathode and anode, thereby increasing the energy of each electron when it strikes the target. The greater the potential difference, the faster the electrons travel from the cathode to the anode. This results in an increased efficiency of conversion of electron energy into X-ray photons, and thus an increase in:

- The number of photons generated.
- Their mean energy.
- Their maximal energy.

The increased number of high-energy photons produced per unit time by use of higher kVp results from the greater efficiency in the production of Bremsstrahlung photons that occurs when increased numbers of higher-energy electrons interact with the target. The ability of X-ray photons to penetrate matter depends on their energy. High-energy X-ray photons have a greater probability of penetrating deeper in matter, whereas relatively low energy photons have a greater probability of being absorbed at a shallower depth.

The SRT-100™ has three set therapeutic kVp energies – 50 kV, 70 kV, and 100 kV.

Half Value Layer

A useful way to characterize the penetrating quality of an X-ray beam is by its half value layer (HVL). The HVL is the thickness of an absorber, such as aluminum, required to reduce the number of X-ray photons passing through it by one half. As the average energy of X-ray beam increases, so does its HVL. The term “quality” refers to the mean energy of an X-ray beam. Half value layer measures the intensity of a beam.

Filtration

An X-ray beam consists of a spectrum of X-ray photons of different energies, but only photons with sufficient energy to penetrate to a certain therapeutic depth are useful for Superficial Radiation Therapy. Photons that are of low energy (long wavelength) can't contribute to a patient's therapeutic depth, only to surface acute reactions. Consequently, to reduce acute reactions to the patient's skin surface, the less-penetrating photons should be removed. This can be accomplished by placing an aluminum filter in the path of the beam. The aluminum removes many of the lower-energy photons, with lesser effect on the higher energy photons that are able to penetrate to the appropriate therapeutic depth.

The SRT-100™ has automatic filtration placement. Upon selection of the appropriate therapeutic energy, the filter automatically positions itself and registers on the control console.

Inherent Filtration

In determination of the amount of filtration required for a particular X-ray machine, kVp and inherent filtration of the tube and its housing must be considered. Inherent filtration consists of the materials that X-ray photons encounter as they travel from the focal spot of the target to form the usable beam outside the tube enclosure. These materials include the glass wall of the X-ray tube, the insulation that surrounds the tube, and the barrier material that prevents the air from escaping through the X-ray port.

Total Filtration

The total filtration of the beam includes the inherent filtration (composed of part of the X-ray tube and tube housing) and the added filtration (thin sheets of a metal inserted in the X-ray beam).

Total filtration = inherent filtration plus external filtration (aluminum disks).

Applicators

An applicator is a metallic barrier with an aperture in the middle used to reduce the size and shape of the X-ray beam, and therefore the volume of irradiated tissue within the patient. Typically, round applicators are built as open-ended aiming cylinders which attach to the X-ray tube aperture.

Many of the absorbed photons generate scattered radiation within the exposed tissues by a process called Compton scattering. These scattered photons travel in all directions. The detrimental effect of scattered radiation can be minimized by using the correct applicator to fit the appropriate margin around the lesion being treated.

The SRT-100™ has applicators available in the following sizes: 1.0 cm, 1.5 cm, 2.0 cm, 2.5 cm, 3.0 cm, 4.0 cm, 5.0 cm, 7.3 cm, 10 cm, 12.7 cm, and 18x8 cm.



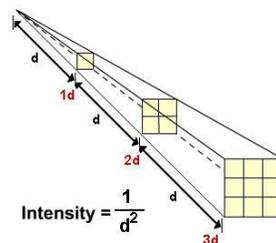
Connected to the end of each applicator is a clear polycarbonate replaceable safety contact shield, which provides:

- Treated area visibility
- Margin clearance
- Clinical safety

The contact shields (also known as applicator tips) must maintain contact with the patient's skin surface in order for the correct therapeutic treatment dose to be administered. If contact is not maintained during treatment, dose may fall below an acceptable therapeutic dose due to the inverse square law.

Inverse Square Law

The intensity of an X-ray beam at a given point (number of photons per cross-sectional area per unit exposure time) depends on the distance of the measuring device from the focal spot. For a given beam, the intensity is inversely proportional to the square of the distance from the source. The reason for this decrease in intensity is that the X-ray beam spreads out as it moves from the source of X-rays.

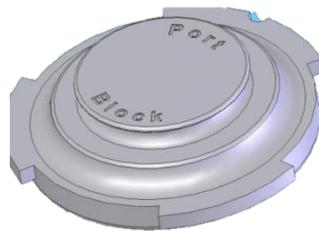


Inverse Square Law

As the above diagram depicts, I is intensity and D is distance. Therefore, if a dose of 100 centigray (cGy) is measured at a distance of 2 m, a dose of 400 cGy will be found at 1 m, and 25 cGy at 4 m. Therefore, changing the treatment distance between the treatment applicator and the patient's skin distance would affect the beam intensity. Be careful when setting a patient up for treatment by assuring the applicator and skin are in constant contact across the treatment volume.

X-ray Port Block

The SRT-100™ system initiates an automatic Warm-Up when the unit is turned on; this extends the life of the X-ray tube and the efficiency of the output of therapeutic energy. In order for the automatic Warm-Up procedure to take place, the X-ray Port Block, which blocks the X-ray beam, must be in place to minimize any scatter in the room.



SRT-100™ Port Block

RAD Check™

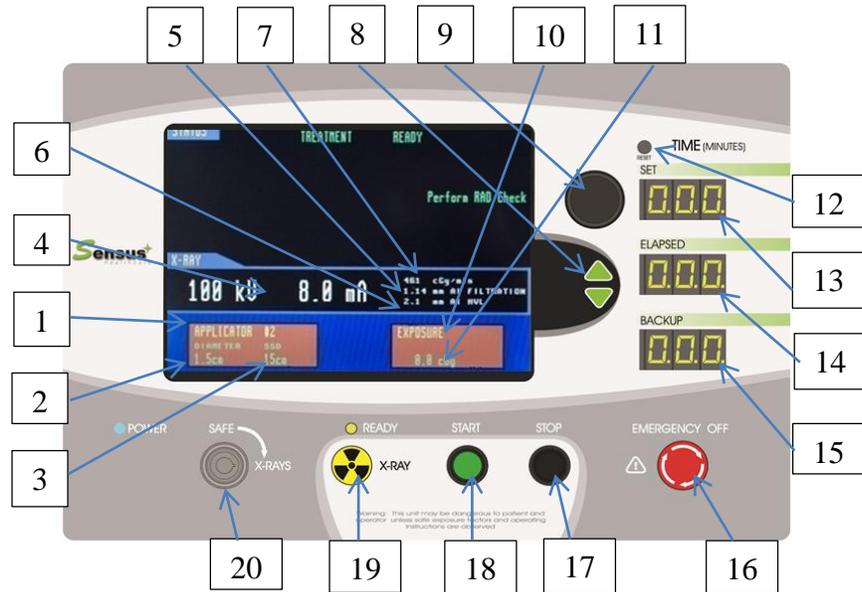
The SRT-100 is equipped with a patented Physics Daily Constancy Check (“RAD Check”) feature. The RAD Check is a pre-treatment X-ray output verification which ensures accurate X-ray dose delivery to the patient. The constancy check is performed daily (per state regulations) and is logged in a quality assurance binder.



SRT-100™ RAD Check Applicator

Operating Console

One of the many technical advantages found on the SRT-100™ is the ability to easily enter the dose in cGy by just turning a dial. This step alone does away with calculations and dial adjustment necessary with less modern systems.



The SRT-100™ console displays:

1. Applicator # in use
2. Diameter of applicator
3. Treatment SSD
4. Selected therapeutic energy (kV and mA)
5. Total filtration
6. HVL
7. cGy per minute
8. UP and DOWN arrows to select therapeutic energy
9. Knob to dial up treatment time
10. cGy is illustrated as treatment time is dialed in
11. Real-time cGy being delivered during treatment
12. Reset Button (pushed after delivery of dose and documentation in treatment log)
13. Set treatment time
14. Elapsing of treatment time during actual treatment
15. Backup timer so treatment time will terminate appropriately
16. Emergency OFF
17. STOP Button
18. START Button
19. X-ray illuminated light (activated when X-rays are being produced)
20. X-ray activation key (turn the key from SAFE to X-RAYS, then push START button)



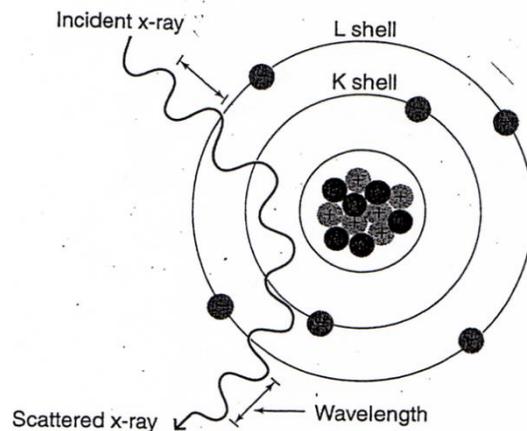
Chapter 7: Interactions of X-rays with Matter



The intensity of an X-ray beam is reduced by interaction with the matter it encounters. This attenuation results from interactions of individual photons in the beam with atoms at the patient's skin surface. The X-ray photons are absorbed and scattered upon the interaction at the skin surface. In scattering, photons are ejected out of the primary beam as a result of interactions with the orbital electrons of absorber atoms. In the case of Superficial Radiation Therapy, three mechanisms exist where these interactions take place: Coherent scattering, Compton scattering, and photoelectric absorption.

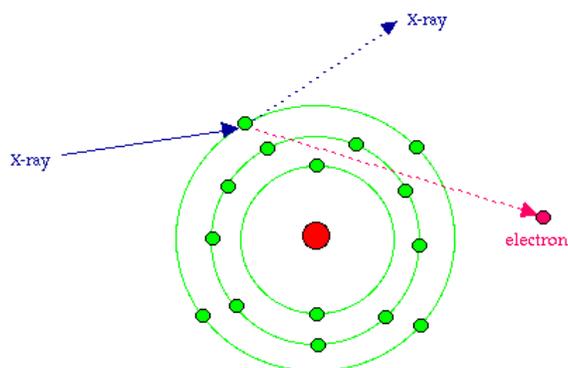
Coherent Scattering

Coherent Scattering (also known as *classical scattering* and *Thompson Scattering*) may occur when a low-energy incident photon passes near an outer electron of an atom (which has a low binding energy). The incident photon interacts with the electron in the outer-shell by causing it to vibrate momentarily at the same frequency as the incoming photon. The incident photon then ceases to exist. The vibration causes the electron to radiate energy in the form of another X-ray photon with the same frequency and energy as in the incident photon. In effect, the direction of the incident X-ray photon is altered. This interaction accounts for low percentage of the total number of interactions.



Compton Scattering

Compton scattering occurs when a photon interacts with an outer orbital electron, which receives kinetic energy and recoils from the point of impact. The incident photon is then deflected by its interaction and is scattered from the site of the collision. The energy of the scattered photon equals the energy of the incident photon minus the kinetic energy gained by the recoil electron plus its bonding energy. As with photoelectric absorption, Compton scattering results in the loss of an electron and ionization of the absorbing atom.



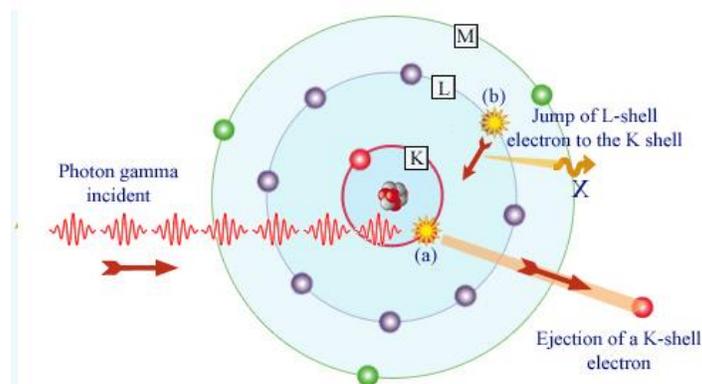
Scattered photons travel in all directions. The higher the energy of the incident photon, however, the greater the probability that the angle of scatter of the secondary photon will be small and its direction will be forward.

The probability of Compton scattering is directly proportional to the electron density. The number of electrons in bone is greater than in water; therefore, the probability of Compton scattering is correspondingly greater in bone than in tissue. The importance of photoelectric absorption and Compton scattering in Superficial Radiation Therapy relates to differences in the way photons are absorbed by various anatomic structures, since the number of photoelectric and Compton interactions are greater in hard tissues than in soft tissues.

Photoelectric Absorption

Photoelectric absorption occurs when an incident photon collides with an inner-shell electron in an atom of the absorbing medium resulting in total absorption and the incident photon ceases to exist. The electron is ejected from its shell, resulting in ionization and becomes a recoil electron (photoelectron). The kinetic energy imparted to the recoil electron is equal to the energy of the incident photon minus that used to overcome the binding energy of the electron. In the case of atoms with low atomic numbers (e.g. those in most biologic energy of the incident photon), most Photoelectric interactions occur in the K shell because the density of the electron cloud is greater in this region and a higher probability of interaction exists.

An atom that has participated in photoelectric interaction is ionized. This electron deficiency (usually in the K shell) is instantly filled, usually by an L- or M- shell electron, with the release of characteristic radiation. Whatever the orbit of the replacement electron, the characteristic photons generated is of such low-energy that they are absorbed within the patient.



The recoil electrons ejected during photoelectric absorptions travel only a short distance in the absorber before they give up their energy. As a consequence, all the energy of incident photons that undergo photoelectric interaction is deposited in the patient. This is beneficial in producing evenly spaced ionizations throughout the cancer cells.

The frequency of photoelectric interaction varies directly with the third power of the atomic number of the absorber. For example, because the effective atomic number of compact bone ($Z = 7,4$), the probability that a photon will be absorbed by a photoelectric interaction in bone is approximately 6.5 times greater than in an equal distance of water.

Secondary Electrons

In both photoelectric absorption and Compton scattering, electrons are ejected from their orbits in the absorbing material after interaction with X-ray photons. These secondary electrons give up their energy in the absorber by either of two processes: collisional interaction with other electrons, resulting in ionization or excitation of the affected atom, and irradiative interactions. Secondary electrons eventually dissipate all their energy, mostly as heat by collisional interaction, and come to rest.

Beam Attenuation

The reduction of beam intensity is predictable because it depends on physical characteristics of the beam and absorber. A monochromatic beam of photons, a beam in which all the photons have the same energy, provides a good example. When just the primary (not scattered) photons are considered, a constant fraction of the beam is attenuated as the beam moves through each unit thickness of an absorber. Therefore, 1.5 cm of water may reduce beam intensity by 50%, the next 1.5 cm by another 50% (to 25% of the original intensity), and so on. This HVL is a measure of beam energy describing the amount of an absorber that reduces the beam intensity by half; in the preceding example, the HVL is 1.5 cm. The absorption of the beam depends primarily on the thickness and mass of the absorber and the energy of the beam.

The Mean Energy

The spectrum of photon energies (as illustrated by the kVp setting) in an X-ray beam is wide. In such a heterogeneous beam the probability of absorption of individual photons depends on their energy. Low-energy photons are much more likely than high-energy photons to be absorbed. As a consequence the superficial layers of an absorber tend to remove the low energy photons and transmit the higher energy photons. Therefore as an X-ray beam passes through matter, the intensity of the beam decreases but the mean energy of the resultant beam increases. In contrast to the absorption of a monochromatic beam, an X-ray beam is absorbed less and less by each succeeding unit of absorber thickness. For example, the first .5 cm of water might absorb about 50% of the photons in an X-ray beam with a mean energy of 35 kVp. The mean energy of the remnant beam might increase 20% as a result of the loss of lower energy photons. The next .5 cm of water removes only about 30 of the photons as the average energy of the beam increases another 10%. If the water test object is thick enough, the mean energy of the remnant beam approaches the peak voltage applied across the tube and absorption becomes similar to that of a monochromatic beam.

K-edge Absorption

As the energy of the beam increases, so does the transmission of the beam through the absorber. When the energy of the incident photon is raised to the binding energy of the k-shell electrons of the absorber, however, the probability of photoelectric absorption increases sharply and the number of transmitted photons is greatly decreased. This is called k-edge absorption. (The probability that a photon will interact with an orbital electron is greatest when the energy of the photon equals the binding energy of the electron; it decreases as the photon energy increases.)

Photons with energy less than the binding energy of K shell electrons interact photoelectrically only with electrons in the L shell, and in shells even farther from the nucleus.



Chapter 8: Fractionation



Fractionation is a method of treating cancer utilizing ionizing radiation therapy, where the total dose is divided into several smaller doses over a period of time. An optimal fractionation scheme will maximize the effects of radiation on cancer and minimize the negative side effects. Experiments in radiobiology have found that as the absorbed dose of radiation increases, the number of cells which survive decreases. If the radiation is fractionated into smaller doses, with one or more rest periods in between, fewer cells die. These rest periods give self-repair mechanisms time to repair the damage of DNA and other biomolecules such as proteins.

There are 4 biologic factors that influence fractionation responses:

- Repair of sublethal damage
- Redistribution
- Reoxygenation
- Re-assortment of cells

Repair

Repair is the one of the primary reasons to fractionate radiotherapy. As discussed in Chapter 2, there are three types of damage that ionizing radiation can cause to cells:

- Lethal Damage - damage which is fatal to the cell
- Sublethal Damage - damage which can be repaired before the next fraction of radiation is delivered
- Potentially Lethal Damage - damage which can be repaired under certain circumstances (usually when the cell is paused in the cell cycle due to external factors)

By splitting radiation dose into small parts, cells are allowed to repair sublethal damage. The amount of damage that is repaired depends on the ability of the cell to recognize the damage and activate:

- Repair pathways
- Repair cell cycle arrest

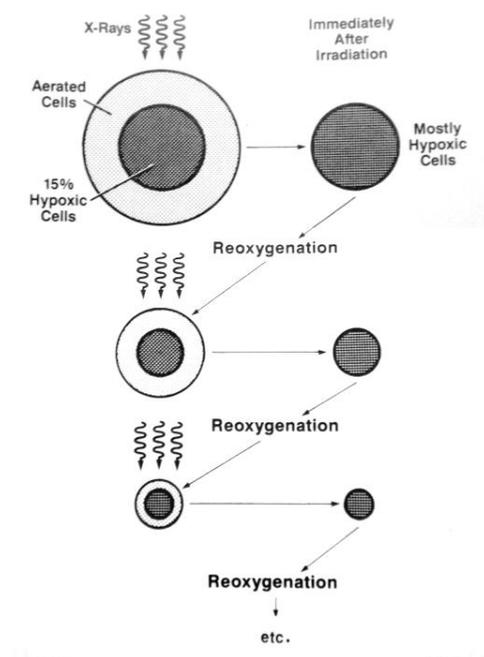
Malignant cells frequently suppress these pathways, often through mutation or inhibition of TP53, preventing them from undergoing efficient repair. Normal tissue cells with intact repair pathways are able to repair the sublethal damage by the time the next fraction is delivered.

Redistribution

When radiotherapy is given to a population of cells, they may be in different parts of the cell cycle. Cells in S phase are typically radioresistant, whereas those in late G2 and M phases are relatively sensitive. A small dose of radiation delivered over a short time period (via external beam or high dose brachytherapy) will kill a lot of the sensitive cells and less of the resistant cells. Over time, the surviving cells will continue to cycle. If a second dose of radiation is delivered some time later, some of these cells will have left the resistant phase and be in a more sensitive phase, allowing them to be killed more easily.

Reoxygenation

Tumors may be acutely or chronically hypoxic. This oxygenation status may change during treatment. Acute hypoxia is due to transient closure of capillaries or arterioles servicing parts of the tumor. While this vessel is closed, the tumor cells become hypoxic and resistant to the indirect action of radiation. These vessels are usually only closed for short times but may occur during a fractionated dose of radiation. Splitting the dose into fractions raises the possibility of the closed vessel being open the next time around, and therefore allowing the tumor cells to be killed.



Chronic hypoxia is due to the poor vasculature of tumors and the distance oxygen must travel to reach cells that are far from the capillaries. These chronically hypoxic cells are also resistant to radiation. Fractionated radiotherapy kills cells that lie close to the capillary more effectively. As these cells are removed, the chronically hypoxic cells are able to move closer to their nutrient source, and therefore become relatively oxalic. Oxalic cells can be killed.

Reoxygenation: Summary

- Hypoxic cells are much less radiosensitive than well-oxygenated cells
- Tumor hypoxia is a cause of failure in R/T, especially with a small number of large fractions
- Reoxygenation has been shown in animal tumors, but with widely varying time courses
- The evidence for reoxygenation in human tumors is less direct

Repopulation

Repopulation is the increase in cell division that is seen in normal cells at some point after radiation is delivered. Repopulation occurs in different speeds depending on the tissue. In general, early responding tissues begin repopulation at about 4 weeks. By increasing treatment time over this amount, it is possible to reduce early toxicity in that tissue. Late responding tissues only begin repopulation after a conventional course of radiation has been completed, and therefore repopulation has minimal effect on these effects (the repair 'R' is more important for late tissues). In normal tissues, a homeostatic response following radiation injury may involve a reduction of cell cycle time, an increase in growth fraction (e.g., recruitment of resting cells), and/or a decrease in cell loss factor.

In tumors, the rate of cell production exceeds the rate of cell loss. Repopulation may involve any of above three mechanisms.

Repopulation: Summary

- Delayed repopulation in normal tissues and tumors
- Delay is longer for late than for early normal tissue damage
- Accelerated repopulation may occur in some tumors
- Prolonging treatment time can spare early NT (normal tissue) damage, but is likely to decrease TCP (tumor control probability) with rapidly proliferating tumors

Fractionation Schemes

Choice of dose and fractionation schemes depends upon the following factors:

- Radiosensitivity of the tumor
- Size of the treatment volume
- Proximity of dose-limiting structures
- Vascularity of the area

Altering fractionation schedules where treatment margin cells are in a stressful environment has proven to increase the therapeutic index. Altering the fractionation scheme may consist of:

- Reduced fraction size
- Raise of overall total dose (with extended overall treatment days)
- Skip Fractionation schemes (break between overall treatment fractions)
- Expanded overall treatment time from the first to last fraction

Reactions

Two types of reactions may occur during the treatment of skin lesions:

- Latent reactions
- Acute reactions

Latent Reactions

Latent reactions are defined as reactions occurring at least 90 days from the first fraction to the present time. Latent reactions can be controlled by monitoring dose per fraction and the overall total dose.

Examples of latent reactions:

- Skin atrophy (causing the skin to appear thin and pale)
- Telangiectasia (small, visible, spidery blood vessels)
- Increased hypo- or hyper-pigmentation (color change)

Latent radiation reactions to skin lesion treatment have mainly been related to Electron Beam Therapy, where energy deposit patterns are far inferior to Superficial Radiation Therapy's electromagnetic radiation. With EBT, the under-ionization in quadrants of cancer cells proved insufficient to eradicate lesions at lower doses (in the mid-4000s cGy); instead, the total dose required to irradiate SCC and BCC lesions using EBT requires doses in the mid-6000 cGy range. This higher total dose required for Electron Beam Therapy—which in turn can spur latent reactions—forces clinicians using EBT to limit the areas of treatment on the body.

Clinicians should therefore be aware that exceeding 500 cGy per fraction in areas of low vascularity could lead to perforation of the lysosome membrane and the deposit of enzymes into the cytoplasm, resulting in cell death. This is a particular concern on lower limbs, where slow healing process is evident due to dermal shutdown. Lower limbs can be successfully treated using SRT by limiting the maximum total dose to the mid 5500 cGy, which lowers the overall damage to the cell membranes and expands longevity of the cells.

Acute Reactions

Acute reactions are those which can occur from the first fraction until 90 days afterward. Acute radiation side effects are caused by damage to rapidly dividing normal cells in the area being treated without having sufficient time to repair. Delivery of a therapeutic dose within the timeframe of 2 weeks will often present acute reactions. How fast a fractionation scheme is delivered controls the severity of acute reactions.

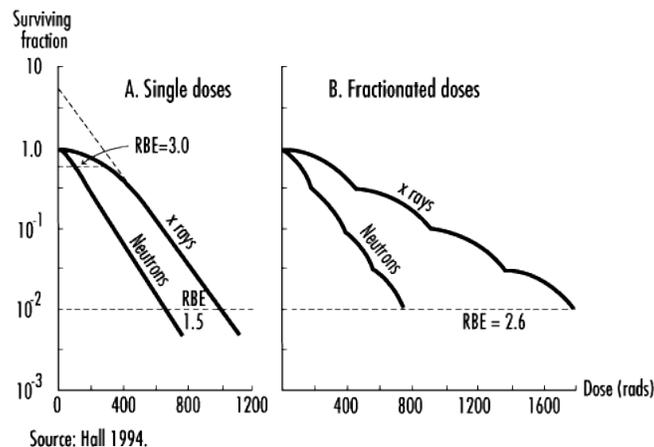
Examples of acute reactions:

- Erythema (skin turns red and warm, similar to sunburn)
- Skin may peel and become moist and oozy.
- Skin may ulcerate, especially when mucous surfaces are affected

Therapeutic Index

Fractionation is used to improve the therapeutic index of radiotherapy. Choice of dose and fractionation depend upon the following factors:

- Radiosensitivity of the tumor
- Size of the treatment volume
- Proximity of dose-limiting structures
- Vascularity of the area



Fractionation: Summary

- Effective fractionation spares normal tissue, allowing for repair of sublethal damage and repopulation
- Fractionation increases tumor damage because of reoxygenation and reassortment

Fractionation for Superficial Radiation Therapy

Optimal fractionation for Superficial Radiation Therapy can be achieved by utilizing the “Shrinking Technique”; this technique has three major steps to eradicate a lesion: the physical entry of the energy, the chemical change in the water molecules to create radicals, and the biological concept that starts slow and picks up steam like a train during the fractionation scheme.

The process begins when a patient receives the first fraction; the physical entry of dose is received by the lesion and the surrounding margin. At a cellular level, the first chemical reaction has occurred—free electrons broke the water molecules and created radicals that traveled to the extent of the lives and hit targets of the cells. The targets encompass many of the cell organelles, most importantly the DNA in the nucleus. Cells in a normal healthy environment would repair the hits (damage) caused by the radiation in around six hours; however, cancer cells’ daily function is not the same as normal cells. Cancer cells are continuously going through mitosis and metabolic changes. As fractions are continued, the accumulated hits on the targets

of the cells begin to take a toll, and cancer cells start to die off at a much faster rate than the surrounding normal cells in the outer margin of the lesion.

Cancer cells, due to their high rate of mitosis, neglect to store reserve energy in their mitochondria; therefore, at the time of repair between fractionations, not all damage is completed. As an accumulation of hits mount in number, the cancer cell has trouble with everyday function and will enter mitosis and fail to complete the process, eventually dying. During the fractionation scheme, the physical and chemical reactions maintain constant, and the biological reaction increases as cancer cells accumulate damage. Over the course of the fractionation process, the cancerous lesion starts to shrink in size due to atrophy of the peripheral cells of the lesion dying off.

Lesions that are above 4mm in size tend to have a hypoxic or anoxic core to them (about 15%). The lack of oxygen makes these cells less sensitive to X-rays. Since water molecules are used to create the radicals, the lack of oxygen in the center prevents the creation of radicals needed to kill the cancer cells. Fractionation helps by delivering dose to the peripheral cells of the lesion, creating radicals that eventually travel further into the lesion. As fractions accumulate, cancer cells die off and the core of the lesion starts to receive oxygen, making the cells more sensitive to radiation.

At first, the biological response by the lesion is slow. After three to four fractions, erythema (redness due to increased blood flow) starts to show, and the biological effect begins to take effect with the accumulation of hits and the death of cancer cells. Around fraction eight or nine, one can start to see the return of vascularity to the center of the lesion with the presence of blood. After completion of the last fractionation, the biological effect will continue for about 12 to 14 days, so the usual follow-up for a skin lesion should be around six weeks.

The past 30 years have seen varying fractionation approaches towards treating areas of low vascularity. Much of the previous data dealt with Electron Therapy, and has no resemblance to present superficial schemes. Superficial Radiation Therapy should not be compared to Electron Therapy, since there are several dissimilarities. Electron and Superficial Therapy have different energy characteristics and different biological effects upon the cells (RBE). Electrons have mass, whereas Superficial is electromagnetic; these two energies relate differently at a cellular level, and thus give a different biological response to the same cells.

The 1990s saw great strides made in the field of radiobiology, and many of the “rules of thumb” that had been used with relation to cellular response have changed. When reviewing the fundamentals of radiobiology, there are three areas of concern that must be noted: Linear Energy Transfer (LET), Relative Biological Effectiveness (RBE), and Oxygen Enhancement Ratio (OER).



Chapter 9: Medical Dosimetry



Dosimetry is simply applied physics. The primary goal of radiation dosimetry is a quantitative estimation of the absorption of energy in tissue. To make estimates of radiation dose (i.e., the energy absorbed by tissue), one needs to understand the processes by which radiation interacts with tissue as it those interactions that result in the transfer of energy to the tissue. The term *dose* is used to describe the amount of energy absorbed per unit mass at a site of interest, while *exposure* is a measure of radiation based on its ability to produce ionization in air under standard conditions of temperature and pressure.

Radiation Dose Quantities and Units

Three physical quantities are basic to radiation dosimetry of photon beams:

- Exposure
- Kerma
- Absorbed Dose

The conventional units for these quantities are:

- Roentgen (R) for exposure
 - The amount of ionizing X-ray exposure that would liberate 1 electrostatic unit of negative or positive charge per cm^3 of air
- Rad for kerma and absorbed dose
 - Where $100 \text{ erg/g} = 1 \text{ rad}$

The International System of Units (SI) uses:

- Coulomb per kilogram (C/kg) for exposure ($2.58 \times 10^{-4} \text{ C/kg} = 1 \text{ R}$)
- Joule per kilogram for kerma and absorbed dose ($1 \text{ Gy} = 1 \text{ J/kg}$)

The special name for the joule per kilogram is the Gray. The SI system has no special name for units of exposure.

Exposure

Exposure is a measure of radiation quantity, the capacity of radiation to ionize air. The roentgen is the traditional unit of radiation exposure measured in air; 1 R is the amount of ionizing radiation (i.e. X- and gamma radiation) that produces 2.08×10^9 ion pairs in 1 cc of air (STP). Roentgen measures the intensity of radiation to which an object is exposed.

No specific SI unit is equivalent to the R (as mentioned above), but in terms of other SI units it is equal to coulombs per kilogram (C/kg); $1 \text{ R} = 2.58 \times 10^4 \text{ C/kg}$ equals $3.88 \times 10^3 \text{ R}$.

The roentgen applies only for X-rays and gamma rays. In recent years the roentgen has been replaced by air kerma, an acronym for kinetic energy released in matter.

Kerma

Kerma (K)—kinetic energy released in medium—is defined as the sum of the initial kinetic energies of the charged particles liberated by indirectly ionizing radiation (photons) in a volume element of a material divided by the mass of the volume element. In other words, Kerma measures the kinetic energy transferred from photons to electrons.

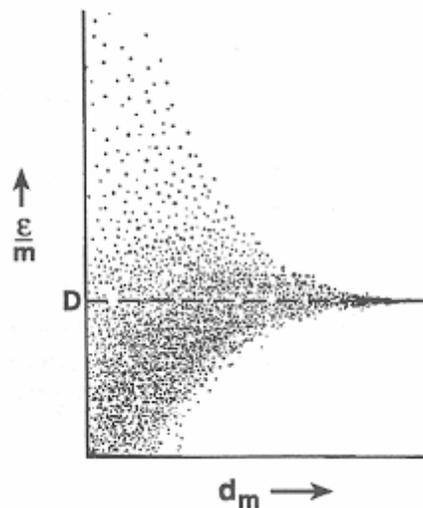
The unit for kerma is joule per kilogram [gray (Gy)], which is the same unit as for absorbed dose. (Kerma is closely related to—but not exactly the same as—absorbed dose.)

Absorbed Dose

Absorbed dose is a measure of the energy absorbed by any type of ionizing radiation per unit mass of any type of matter.

The SI unit is the gray (Gy); as with kerma, 1 Gy equals 1 joule/kg. The traditional unit of absorbed dose is the Rad (radiation absorbed dose), where 1 rad is equivalent to 100 ergs/g of absorber.

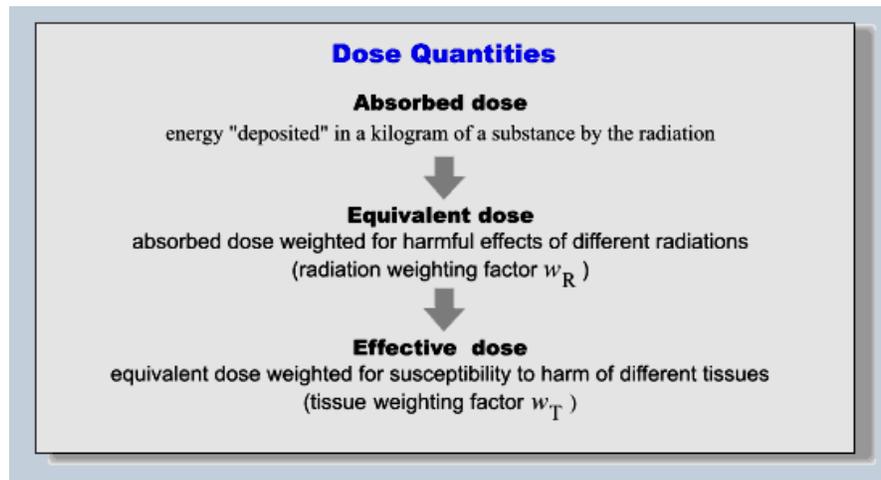
For small volumes, there is statistical variation of the absorbed dose since the likelihood of interaction per unit distance is characterized by a probability. The stochastic (random) variation of absorbed dose as a function of volume is shown here:



When averaged over the mass of an organ, the absorbed dose is probably the most useful measure of radiation dose for epidemiologic studies. Absorbed dose is defined by the energy absorbed per gram and is generally viewed, particularly in epidemiology, as a macroscopic quantity. The damage to living tissues, on a microscopic level, can vary depending on a number of physical and biological parameters.

Equivalent Dose

The equivalent dose (H_T) is used to compare the biologic effects of different types of radiation on a tissue or organ. It is expressed as a sum to allow for the time possibility that the tissue or organ has been exposed to more than one type of radiation. The radiation weighting factor is chosen for the type and energy of the radiation involved. Therefore, high LET radiations (which are more damaging to tissue than low LET radiations) have a correspondingly higher WR. The unit of equivalent dose is the Sievert (Sv). For diagnostic X-ray examinations, 1 Sv equals 1 Gy. The traditional unit of equivalent dose is the rem (roentgen equivalent man). One Sievert equals 100 rems.



Absorbed dose: rad or Gray (1 Gy = 100 rad, for photons)

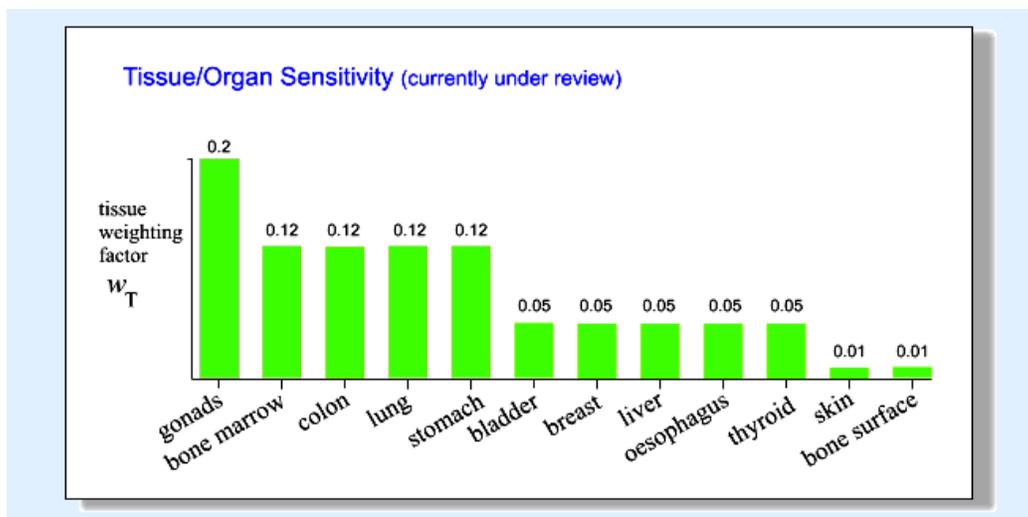
Equivalent dose: rem or Sievert (1 Sv = 100 rem for photons)

Effective dose: rem or Sievert (1 Sv = 100 rem for photons)

Effective Dose

Effective Dose a measure of the stochastic effect that a radiation dose to part of the body will have on the whole organism; it is used to estimate the risk in humans, and is a "radiation protection" quantity.

The unit of effective dose is the Sievert (Sv). The tissue weighting factors include gonads, 0.20; red bone marrow, 0.12; esophagus, 0.5; thyroid, 0.05; thyroid, 0.05; skin, 0.01; and bone surface, 0.01.



ICRP Publication 60		2006 Draft ICRP Report	
Gonads	0.20	Gonads	0.08
Bone marrow	0.12	Bone marrow	0.12
Colon	0.12	Colon	0.12
Lung	0.12	Lung	0.12
Stomach	0.12	Stomach	0.12
Bladder	0.05	Bladder	0.04
Breast	0.05	Breast	0.12
Liver	0.05	Liver	0.04
Oesophagus	0.05	Oesophagus	0.04
Thyroid	0.05	Thyroid	0.04
Skin	0.01	Skin	0.01
Bone surface	0.01	Bone surface	0.01
		Brain	0.01
		Salivary glands	0.01
Remainder	0.05	Remainder	0.12

Radioactivity

The measurement of radioactivity (A) describes the decay rate of a sample of radioactive material. The SI unit is the Becquerel (Bq). 1 Bq equals 1 disintegration/second. The traditional unit is the curie (Ci), which corresponds to the activity of 1 g of radium.



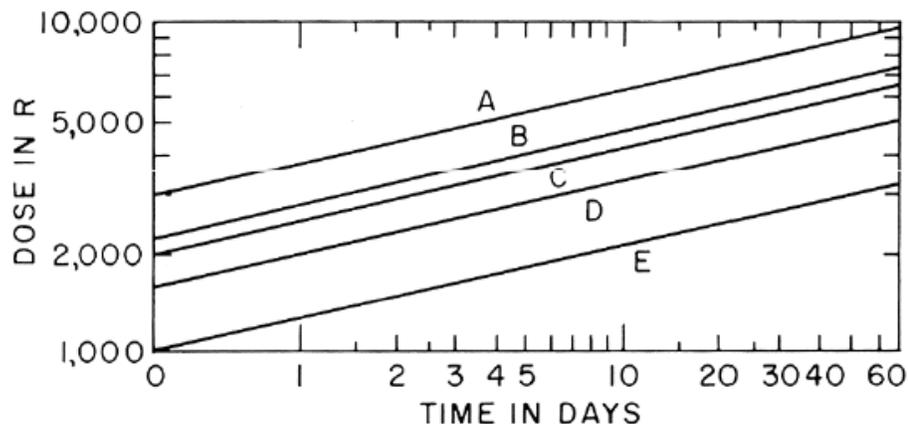
Chapter 10:
TDF Tables: Time, Dose,
& Fractionation
For BCC and SCC



In 1944, Strandquist was the first to present the importance of fractionation based on acquired data and observation of the effects of tumor and normal surrounding skin over dosage and time. The observations were based on a 250 kV X-ray machine which was used to deliver 2.0Gy/day, three to five times a week, to 280 carcinomas of the skin and lip. The resulting Strandquist Plot was based upon overall time in relation to a single total dose and represents the iso-effective total dose, D , against the log of overall treatment time, T .

$$D \propto T^{0.33}$$

There were three to five fractions a week, so overall time in the plot would imply the number of fractions needed. The plot demonstrated the iso-effect curve for skin was about 0.33. In the plot below, the y axis is total Dose in Rad (R) and the x axis is Time in Days. The "B" curve represents dose at which cure was achieved, while overdose would occur if the dose lay above the "B" curve and skin necrosis (A curve) would occur. Similarly, should the dose lie below the "B" curve, cure may not be achieved, although other milder skin reactions such as moist desquamation (C), dry desquamation (D), and erythema (E) would be seen at subsequently lower doses. Strandquist's results indicated that 2000 rad in one day was equivalent to 3000 rad in 4 days, 4000 rad in 11 days, 5000 rad in 25 days, and 6000 rad in 45 days. Strandquist's research found that total dose is most meaningful when the overall treatment time is known.



The Strandquist Plot led Dr. Ellis and colleagues to develop the Nominal Standard Dose (NSD) system in 1967; the NSD system takes into account both time and number of fractions. Total dose = where T is the overall time in days and N is the number of fractions. Ellis proposed that fractionation is twice as important as time according to clinical observations. The formula projected that the tolerance dose for normal tissue (D cGy) could be related to the overall treatment time (T days) and the number of fractions (N). The formula became known as the Ellis NSD equation, and was based on the iso-effect curve for skin, the slope of which is 0.33.

$$TDF = 10^{-3} \times NSD^{1.538} = Nd^{1.538} (T/N)^{-0.17} \times 10^{-3}$$

(N = Number of fractions, d = dose per fraction, T =overall treatment time in days)

The disadvantage of the Ellis Equation was it produced a number which described a complete course of fractionated radiotherapy, which results in full connective tissue tolerance. If the

values of D , T , and N were substituted with numbers of less than full tolerance, then the NSD number would be meaningless.

In 1973, Orton and Ellis developed the concept of Time Dose Factor (TDF), which takes into account time, fractions, and interval between fractions. The NSD concept has thus become simplified by the introduction of time, dose, and fractionation factors, which are proportional to partial tolerance but not dependent upon any specific NSD value. Partial tolerance is related to NSD by a factor which is a function of overall time, the dose per fraction, and the fraction pattern. This factor is called the time, dose, and fractionation (TDF) factor.

The TDF numbers were evaluated for treatment schedules of 1, 2, 3, 4, and 5 fractions per week and corresponding tables containing TDF factors for various treatment regimens were presented. Orton and Ellis consolidated these numbers into corresponding tables based on the number of fractions per week. By using these TDF tables in treatment planning, it is possible to predict treatment outcome for cure, skin necrosis, and other effects. The cure for epithelial skin cancers requires a TDF number between 90 and 110; thus, the therapeutic index when treating with the SRT-100™ lies between these two numbers. The TDF tables presented by Orton and Ellis offer a pre-calculated standardized optimal range for effective delivery of desired dose. Following the TDF tables allows an increased number of fractions with improved cosmesis yet no compromise in efficacy. The importance and utility of these tables in planning curative treatment regimens that are precise and predictable cannot be overstated.

TDF Tables: Where to Start?

The tables are based upon radiobiological responses to Basal Cell and Squamous Cell skin lesions. The TDF tables have a horizontal green row that gives total fractions and a vertical red row assigning dose per fraction in cGy. The cells between the two rows give a TDF number. The tables state how many fractions per week along the top. When a desired fractionation scheme is selected, it is important that the joining of the horizontal fractionation and the vertical dose per fraction converge to a number within the therapeutic index (highlighted in gold with blue number).

In reference to Goldschmidt, *Journal of the American Academy of Dermatology* (February 1994), cure of epithelial skin cancers requires a TDF number between 90 and 110. The TDF numbers in blue with gold background are the therapeutic index number.

When selecting a fractionation scheme, select a therapeutic treatment number at 100 TDF. Selection of a number in the middle of the Therapeutic Index advantages:

- Breaks of less than 5 days will have little decay effect on courses.
- Irregularities in setups (contour inconsistencies)
- Large treatment areas

An example would be to look at the table for 3 fractions per week, go over to 12 fractions and then down to where it is level with 200 rad on the left column, note the TDF number is 36. The TDF numbers we are looking for to cure skin lesions should lie “between” 90 to 110; this TDF number will give the correct biological response. Select the 4-fraction per week table, go along

the top to 22 fractions, follow it down the table until your finger is horizontal with the 250 rad line, and note the TDF number of 99, this falls in the therapeutic index. There will be different courses that can be selected, just remember that more fractionation will render less issues.

Some of the more common fractionation scheme used for all parts of the body:

- 380 cGy per fraction/ 3 times a week / 12 total fractions/ total dose of 4560 cGy/
TDF=98
- 380 cGy per fraction/ 2 times a week / 13 total fractions/ total dose of 4940 cGy/
TDF=100
- 320 cGy per fraction/ 3 times a week / 16 total fractions/ total dose of 5120 cGy/
TDF=100

The following tables have a horizontal green row that gives total fractions and a vertical red row assigning dose per fraction in cGy. The cells between the two rows give a TDF number. The tables state how many fractions per week along the top. When a desired fractionation scheme is selected, it is important that the joining of the horizontal fractionation and the vertical dose per fraction converge to a number within the therapeutic index (highlighted in gold with blue number).

1 Fraction per Week Schedule

Dose / Fraction (cGy)	TDF Table Time Dose Fractionation Factors for One Fraction Per Week																			
	TDF # Between 90 and 110 for NSMC Skin Lesions - No. OF FRACTIONS																			
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
20	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
40	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4			
60	2	2	2	3	3	4	4	4	5	5	6	6	6	7	7	8	8			
80	3	3	4	4	5	6	6	7	8	8	9	9	10	11	11	12	13			
100	4	4	5	6	7	8	9	10	11	12	12	13	14	15	16	17	18			
110	4	5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21			
120	5	6	7	8	9	11	12	13	14	15	16	18	19	20	21	22	24			
130	5	7	8	9	11	12	13	15	16	17	19	20	21	23	24	25	27			
140	6	7	9	10	12	13	15	16	18	19	21	22	24	25	27	28	30			
150	7	8	10	12	13	15	17	18	20	22	23	25	27	28	30	32	33			
160	7	9	11	13	15	17	18	20	22	24	26	28	29	31	33	35	37			
170	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40			
180	9	11	13	15	18	20	22	24	26	29	31	33	35	37	40	42	44			
190	10	12	14	17	19	22	24	26	29	31	33	36	38	41	43	45	48			
200	10	13	16	18	21	23	26	28	31	34	36	39	41	44	47	49	52			
210	11	14	17	20	22	25	28	31	33	36	39	42	45	47	50	53	56			
220	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60			
230	13	16	19	22	26	29	32	35	38	42	45	48	51	54	58	61	64			
240	14	17	21	24	27	31	34	38	41	44	48	51	55	58	62	65	68			
250	15	18	22	26	29	33	36	40	44	47	51	55	58	62	66	69	73			
260	15	19	23	27	31	35	39	43	46	50	54	58	62	66	70	74	77			
270	16	21	25	29	33	37	41	45	49	53	57	62	66	70	74	78	82			
280	17	22	26	30	35	39	43	48	52	56	61	65	69	74	78	82	87			
290	18	23	27	32	37	41	46	50	55	60	64	69	73	78	82	87	92			
300	19	24	29	34	39	43	48	53	58	63	68	72	77	82	87	92	96			
320	21	27	32	37	43	48	53	59	64	69	75	80	85	91	96	101	107			
340	23	29	35	41	47	53	58	64	70	76	82	88	94	99	105	111	117			
360	26	32	38	45	51	57	64	70	77	83	89	96	102	109	115	121	128			
380	28	35	42	49	56	62	69	76	83	90	97	104	111	118	125	132	139			
400	30	38	45	53	60	68	75	83	90	98	105	113	120	128	135	143	150			
420	32	40	49	57	65	73	81	89	97	105	113	121	129	138	146	154				
440	35	43	52	61	70	78	87	96	104	113	122	130	139	148	156					
460	37	47	56	65	74	84	93	102	112	121	130	140	149	158						
480	40	50	60	70	80	89	99	109	119	129	139	149	159							
500	42	53	63	74	85	95	106	116	127	138	148	159								
520	45	56	67	79	90	101	112	124	135	146	157									
540	48	60	71	83	95	107	119	131	143	155										
560	50	63	76	88	101	113	126	139	151											
580	53	66	80	93	106	120	133	146	160											
600	56	70	84	98	112	126	140	154												
700	71	89	107	124	142	160	178													
800	87	109	131	153	174															
900	105	131	157																	
1000	123	154																		

2 Fractions per Week Schedule

Dose / Fraction (cGy)	TDF Table Time Dose Fractionation Factors for Two Fractions Per Week TDF # Between 90 and 110 for NMSC Skin Lesions - NUMBER OF FRACTIONS																								
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25			
20	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2			
40	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6			
60	2	2	3	3	4	4	4	5	5	6	6	7	7	8	8	9	9	9	10	10	11	11			
80	3	4	4	5	6	6	7	8	8	9	10	10	11	12	13	13	14	15	15	16	17	17			
100	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25			
110	5	6	7	8	9	10	11	13	14	15	16	17	18	19	21	22	23	24	25	26	27	29			
120	5	7	8	9	10	12	13	14	16	17	18	20	21	22	23	25	26	27	29	30	31	33			
130	6	7	9	10	12	13	15	16	18	19	21	22	24	25	27	28	30	31	32	34	35	37			
140	7	8	10	12	13	15	17	18	20	21	23	25	26	28	30	31	33	35	36	38	40	41			
150	7	9	11	13	15	17	18	20	22	24	26	28	29	31	33	35	37	39	40	42	44	46			
160	8	10	12	14	16	18	20	22	24	26	28	30	32	35	37	39	41	43	45	47	49	51			
170	9	11	13	16	18	20	22	25	27	29	31	33	36	38	40	42	45	47	49	51	53	56			
180	10	12	15	17	19	22	24	27	29	32	34	37	39	41	44	46	49	51	54	56	58	61			
190	11	13	16	19	21	24	26	29	32	34	37	40	42	45	48	50	53	56	58	61	63	66			
200	11	14	17	20	23	26	29	31	34	37	40	43	46	49	52	54	57	60	63	66	69	72			
210	12	15	19	22	25	28	31	34	37	40	43	46	49	52	56	59	62	65	68	71	74	77			
220	13	17	20	23	27	30	33	36	40	43	46	50	53	56	60	63	66	70	73	76	80	83			
230	14	18	21	25	28	32	35	39	43	46	50	53	57	60	64	67	71	75	78	82	85	89			
240	15	19	23	27	30	34	38	42	45	49	53	57	61	64	68	72	76	80	83	87	91	95			
250	16	20	24	28	32	36	40	44	48	52	56	61	65	69	73	77	81	85	89	93	97	101			
260	17	21	26	30	34	39	43	47	51	56	60	64	69	73	77	81	86	90	94	99	103	107			
270	18	23	27	32	36	41	45	50	54	59	64	68	73	77	82	86	91	95	100	104	109	114			
280	19	24	29	34	38	43	48	53	58	62	67	72	77	82	86	91	96	101	106	110	115	120			
290	20	25	30	35	41	46	51	56	61	66	71	76	81	86	91	96	101	106	111	117	122	127			
300	21	27	32	37	43	48	53	59	64	69	75	80	85	91	96	101	107	112	117	123	128	133			
320	24	29	35	41	47	53	59	65	71	77	83	88	94	100	106	112	118	124	130	136	142	147			
340	26	32	39	45	52	58	65	71	78	84	91	97	104	110	117	123	129	136	142	149	155	162			
360	28	35	42	49	57	64	71	78	85	92	99	106	113	120	127	134	141	148	155	163					
380	31	38	46	54	61	69	77	84	92	100	108	115	123	131	138	146	154	161							
400	33	42	50	58	66	75	83	91	100	108	116	125	133	141	150	158									
420	36	45	54	63	72	81	90	99	107	116	125	134	143	152											
440	38	48	58	67	77	87	96	106	115	125	135	144	154												
460	41	52	62	72	82	93	103	113	124	134	144	155													
480	44	55	66	77	88	99	110	121	132	143	154														
500	47	59	70	82	94	105	117	129	141	152															
520	50	62	75	87	100	112	124	137	149	162															
540	53	66	79	92	105	119	132	145	158																
560	56	70	84	98	112	125	139	153																	
580	59	74	88	103	118	132	147	162																	
600	62	78	93	109	124	140	155																		
700	79	98	118	138	157	177																			
800	97	121	145	169																					
900	116	145	174																						
1000	136	170																							

3 Fractions per Week Schedule

Dose / Fraction (cGy)	TDF Table Time Dose Fractionation Factors for Three Fractions per Week TDF # Between 90 and 110 for NSMC Skin Lesions - NUMBER OF FRACTIONS																					
	4	5	6	8	10	12	14	15	16	18	20	22	24	25	26	28	30	32	34	35	36	40
20	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4
40	1	1	2	2	3	3	4	4	4	5	5	6	6	6	7	7	8	8	9	9	9	10
60	2	2	3	4	5	6	7	7	8	9	10	10	11	12	12	13	14	15	16	17	17	19
80	3	4	4	6	7	9	10	11	12	13	15	16	18	19	19	21	22	24	25	26	27	30
100	4	5	6	8	10	13	15	16	17	19	21	23	25	26	27	29	31	33	36	37	38	42
110	5	6	7	10	12	15	17	18	19	22	24	27	29	30	32	34	36	39	41	42	44	48
120	6	7	8	11	14	17	19	21	22	25	28	30	33	35	36	39	42	44	47	48	50	55
130	6	8	9	13	16	19	22	24	25	28	31	34	38	39	41	44	47	50	53	55	56	63
140	7	9	11	14	18	21	25	26	28	32	35	39	42	44	46	49	53	56	60	61	63	70
150	8	10	12	16	20	23	27	29	31	35	39	43	47	49	51	55	59	62	66	68	70	78
160	9	11	13	17	22	26	30	32	35	39	43	47	52	54	56	60	65	69	73	75	78	86
170	9	12	14	19	24	28	33	36	38	43	47	52	57	59	62	66	71	76	80	83	85	95
180	10	13	16	21	26	31	36	39	41	47	52	57	62	65	67	72	78	83	88	90	93	103
190	11	14	17	22	28	34	39	42	45	51	56	62	67	70	73	79	84	90	96	98	101	112
200	12	15	18	24	30	36	43	46	49	55	61	67	73	76	79	85	91	97	103	106	109	122
210	13	16	20	26	33	39	46	49	52	59	66	72	79	82	85	92	98	105	111	115	118	131
220	14	18	21	28	35	42	49	53	56	63	70	77	84	88	92	99	106	113	120	123	127	141
230	15	19	23	30	38	45	53	57	60	68	75	83	90	94	98	106	113	121	128	132	136	151
240	16	20	24	32	40	48	56	60	64	72	80	89	97	101	105	113	121	129	137	141	145	161
250	17	21	26	34	43	51	60	64	69	77	86	94	103	107	111	120	129	137	146	150	154	
260	18	23	27	36	46	55	64	68	73	82	91	100	109	114	118	127	137	146	155			
270	19	24	29	39	48	58	68	72	77	87	96	106	116	121	125	135	145	154				
280	20	25	31	41	51	61	71	76	82	92	102	112	122	127	133	143	153					
290	22	27	32	43	54	65	75	81	86	97	108	118	129	135	140	151						
300	23	28	34	45	57	68	79	85	91	102	113	125	136	142	147	159						
320	25	31	38	50	63	75	88	94	100	113	125	138	150	157	163							
340	27	34	41	55	69	82	96	103	110	124	137	151										
360	30	38	45	60	75	90	105	113	120	135	150	165										
380	33	41	49	65	82	98	114	122	131	147	163											
400	35	44	53	71	88	106	124	132	141	159												
420	38	48	57	76	95	114	133	143	152													
440	41	51	61	82	102	123	143	153														
460	44	55	66	88	109	131	153															
480	47	58	70	93	117	140	164															
500	50	62	75	100	124	149	174															
520	53	66	79	106	132	159																
540	56	70	84	112	140	168																
560	59	74	89	118	148	178																
580	63	78	94	125	156																	
600	66	82	99	132	165																	
700	83	104	125	167																		
800	103	128	154																			
900	123	154																				
1000	145	181																				

4 Fractions per Week Schedule

Dose / Fraction (cGy)	TDF Table Time Dose Fractionation Factors for Four Fractions per Week TDF # Between 90 and 110 for NSMC Skin Lesions - NUMBER OF FRACTIONS																					
	4	5	6	8	10	12	14	15	16	18	20	22	24	25	26	28	30	32	34	35	36	40
20	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4
40	1	1	2	2	3	3	4	4	4	5	5	6	6	7	7	8	8	9	9	9	10	11
60	2	3	3	4	5	6	7	8	8	9	10	11	12	13	13	14	15	16	17	18	18	20
80	3	4	5	6	8	9	11	12	13	14	16	17	19	20	20	22	23	25	27	27	28	31
100	4	6	7	9	11	13	15	17	18	20	22	24	26	28	29	31	33	35	37	39	40	44
110	5	6	8	10	13	15	18	19	20	23	26	28	31	32	33	36	38	41	43	45	46	51
120	6	7	9	12	15	18	20	22	23	26	29	32	35	36	38	41	44	47	50	51	53	58
130	7	8	10	13	16	20	23	25	26	30	33	36	40	41	43	46	49	53	56	58	59	66
140	7	9	11	15	18	22	26	28	30	33	37	41	44	46	48	52	55	59	63	65	67	74
150	8	10	12	16	21	25	29	31	33	37	41	45	49	51	53	58	62	66	70	72	74	82
160	9	11	14	18	23	27	32	34	36	41	45	50	54	57	59	64	68	73	77	79	82	91
170	10	12	15	20	25	30	35	37	40	45	50	55	60	62	65	70	75	80	85	87	90	100
180	11	14	16	22	27	33	38	41	44	49	54	60	65	68	71	76	82	87	93	95	98	109
190	12	15	18	24	30	35	41	44	47	53	59	65	71	74	77	83	89	95	101	103	106	118
200	13	16	19	26	32	38	45	48	51	58	64	70	77	80	83	90	96	102	109	112	115	128
210	14	17	21	28	34	41	48	52	55	62	69	76	83	86	90	97	103	110	117	121	124	138
220	15	19	22	30	37	44	52	56	59	67	74	82	89	93	96	104	111	119	126	130	133	148
230	16	20	24	32	40	48	56	60	63	71	79	87	95	99	103	111	119	127	135	139	143	159
240	17	21	25	34	42	51	59	64	68	76	85	93	102	106	110	119	127	136	144	148	152	
250	18	23	27	36	45	54	63	68	72	81	90	99	108	113	117	126	135	144	153	158		
260	19	24	29	38	48	57	67	72	77	86	96	105	115	120	125	134	144	153				
270	20	25	30	41	51	61	71	76	81	91	102	112	122	127	132	142	152					
280	21	27	32	43	54	64	75	81	86	97	107	118	129	134	140	150	161					
290	23	28	34	45	57	68	79	85	91	102	113	125	136	142	147	159						
300	24	30	36	48	60	72	84	90	96	107	119	131	143	149	155							
320	26	33	40	53	66	79	92	99	105	119	132	145	158	165								
340	29	36	43	58	72	87	101	109	116	130	145	159										
360	32	40	47	63	79	95	111	119	126	142	158											
380	34	43	52	69	86	103	120	129	137	155												
400	37	46	56	74	93	112	130	139	149	167												
420	40	50	60	80	100	120	140	150	160													
440	43	54	65	86	108	129	151															
460	46	58	69	92	115	138	161															
480	49	61	74	98	123	148	172															
500	52	65	79	105	131	157																
520	56	70	83	111	139	167																
540	59	74	88	118	147	177																
560	62	78	94	125	156																	
580	66	82	99	132	165																	
600	69	87	104	139	173																	
700	88	110	132	176																		
800	108	135	162																			
900	129	162																				
1000	152																					

5 Fractions per Week Schedule

Dose / Fraction (cGy)	TDF Table Time Dose Fractionation Factors for Five Fractions Per Week TDF # Between 90 and 110 for NSMC Skin Lesions - NUMBER OF FRACTIONS																					
	4	5	6	8	10	12	14	15	16	18	20	22	24	25	26	28	30	32	34	35	36	40
20	0	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	3	3	4
40	1	1	2	2	3	3	4	4	4	5	6	6	7	7	7	8	8	9	9	10	10	11
60	2	3	3	4	5	6	7	8	8	9	10	11	12	13	13	15	16	17	18	18	19	21
80	3	4	5	6	8	10	11	12	13	15	16	18	19	20	21	23	24	26	27	28	29	32
100	5	6	7	9	11	14	16	17	18	20	23	25	27	28	30	32	34	36	39	40	41	45
110	5	7	8	11	13	16	18	20	21	24	26	29	32	33	34	37	39	42	45	46	47	53
120	6	8	9	12	15	18	21	23	24	27	30	33	36	38	39	42	45	48	51	53	54	60
130	7	9	10	14	17	20	24	26	27	31	34	37	41	43	44	48	51	54	58	60	61	68
140	8	10	11	15	19	23	27	29	31	34	38	42	46	48	50	53	57	61	65	67	69	76
150	9	11	13	17	21	25	30	32	34	38	42	47	51	53	55	59	64	68	72	74	76	85
160	9	12	14	19	23	28	33	35	37	42	47	51	56	58	61	66	70	75	80	82	84	94
170	10	13	15	21	26	31	36	39	41	46	51	57	62	64	67	72	77	82	87	90	92	103
180	11	14	17	22	28	34	39	42	45	50	56	62	67	70	73	79	84	90	95	98	101	112
190	12	15	18	24	31	37	43	46	49	55	61	67	73	76	79	85	91	97	104	107	110	122
200	13	17	20	26	33	40	46	49	53	59	66	73	79	82	86	92	99	105	112	115	119	132
210	14	18	21	28	36	43	50	53	57	64	71	78	85	89	92	99	107	114	121	124	128	142
220	15	19	23	31	38	46	53	57	61	69	76	84	92	95	99	107	115	122	130	134	137	153
230	16	20	25	33	41	49	57	61	65	74	82	90	98	102	106	114	123	131	139	143	147	163
240	17	22	26	35	44	52	61	65	70	79	87	96	105	109	113	122	131	140	148	153	157	
250	19	23	28	37	46	56	65	70	74	84	93	102	112	116	121	130	139	149	158			
260	20	25	30	40	49	59	69	74	79	89	99	109	118	123	128	138	148	158				
270	21	26	31	42	52	63	73	78	84	94	105	115	126	131	136	146	157					
280	22	28	33	44	55	66	77	83	89	100	111	122	133	138	144	155						
290	23	29	35	47	58	70	82	88	93	105	117	128	140	146	152							
300	25	31	37	49	62	74	86	92	98	111	123	135	148	154								
320	27	34	41	54	68	82	95	102	109	122	136	149	163									
340	30	37	45	60	75	89	104	114	119	134	149	164										
360	33	41	49	65	81	98	114	122	130	147	163											
380	35	44	53	71	88	106	124	133	142	159												
400	38	48	57	77	96	115	134	144	153													
420	41	52	62	83	103	124	144	155														
440	44	55	67	89	111	133	155															
460	48	59	71	95	119	142	166															
480	51	63	76	101	127	152																
500	54	67	81	108	135	162																
520	57	72	86	115	143	172																
540	61	76	91	121	152																	
560	64	80	96	128	161																	
580	68	85	102	136	169																	
600	71	89	107	143	179																	
700	91	113	136	181																		
800	111	139	167																			
900	133	167																				
1000	157																					

Although the TDF tables can look intimidating at first, they provide physicians with many options for delivery of dose. The best approach is to select a fractionation scheme that has been used as a standard. One fractionation scheme that is very successful in the treatment of all areas of the body delivers 380cGy per fraction, 12 fractions, 3 times a week, with a TDF number of 98. During the treatment of your first four to five patients, clinicians will get a feel for the reactions patients will experience; these observations are helpful when determining the energy and the area of future treatments.

It is important to never push dose. During treatment, especially to limbs, monitor the reaction to the lesion. If brisk reactions develop before the 3rd or 4th fraction (not just the erythema that is expected, but a reaction that cause discomfort or swelling), there are several things to check.

First, skin should be completely free of ointment or makeup during treatment. These items can lead to a refraction of the energy at the surface, causing an earlier than expected dose reaction. This is especially true for topical products containing metal. The metal refracts the energy and does not let it penetrate to the expected treatment depth. Always ensure skin is clean is product-free prior to treatment.

Another possible cause of brisk reactions may be the medications that the patient is taking. Vitamin K has been known to sensitize the reaction of radiation to the skin. The body habitats of the patients can be challenging sometimes, particularly in areas with paper skin and low vascularity.

The majority of patients will experience only the standard reactions to the fractionation scheme. However, if a patient does have a brisk reaction, give the patient a week's break, then re-evaluate to continue treatment. Have the patient come back in a week, and then continue.

TDF Decay Table

A disruption in the treatment course could possibly decay whatever portion of the TDF factor had been delivered to that point. Since the course of treatments in the elderly are sometimes interrupted, clinicians will need to refer to a decay table with “decay factors”. The table is based upon radiobiological responses to cancer cells. In order to use a decay table, physicians must know the total days under treatment and the total days of rest. The table is based upon total days under treatment until the interruption, and the total days of rest before the treatment resumes.

"Decay Factors" for Split-Course Radiotherapy												
T (Days)	Rest Period R (Days)											
	5	10	15	20	25	30	35	40	50	60	80	100
5	0.93	0.89	0.86	0.84	0.82	0.81	0.80	0.79	0.77	0.75	0.73	0.72
10	0.96	0.93	0.90	0.89	0.87	0.86	0.85	0.84	0.82	0.81	0.79	0.77
15	0.97	0.95	0.93	0.91	0.9	0.89	0.88	0.87	0.85	0.84	0.82	0.8
20	0.98	0.96	0.94	0.93	0.91	0.9	0.89	0.89	0.87	0.86	0.84	0.82
25	0.98	0.96	0.95	0.94	0.93	0.92	0.91	0.9	0.89	0.87	0.85	0.84
30	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.9	0.89	0.87	0.85
35	0.99	0.97	0.96	0.95	0.94	0.93	0.93	0.92	0.91	0.9	0.88	0.86
40	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.93	0.91	0.9	0.89	0.87
45	0.99	0.98	0.97	0.96	0.95	0.95	0.94	0.93	0.92	0.91	0.89	0.88
50	0.99	0.98	0.97	0.96	0.96	0.95	0.94	0.94	0.93	0.92	0.9	0.89

T = Total Days of TX before Break

R = Total Days of Rest

TDF X = “Decay Factor” = Adjusted TDF for TX after Break



Chapter 11: Therapeutic Index For BCC and SCC

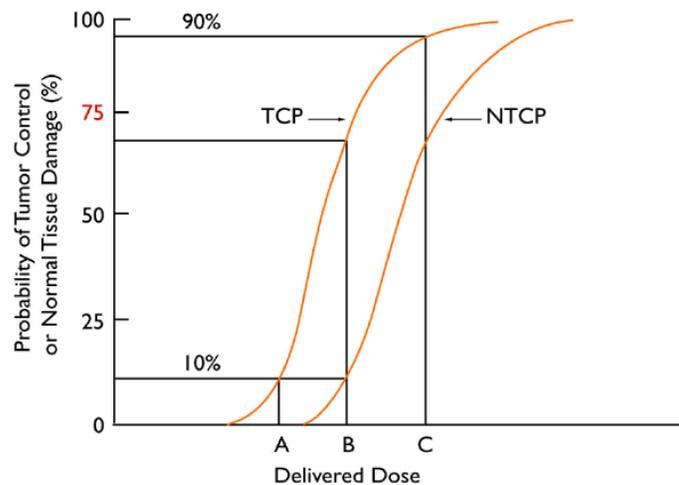


The aim of radiotherapy is to deliver enough radiation to the tumor to destroy it without irradiating normal tissue to a dose that will lead to serious complications. Every dose of radiation delivered to a patient, with the aim of cure of a tumor, is limited by the possibility of serious damage to normal tissues. This risk is of course inherent in all forms of medical therapy, including drug therapy and surgery and radiotherapy. The balance between the probability of tumor control (TCP) and the risk of normal tissue complications (NTCP) is a measure of the therapeutic ratio of the treatment.

TCP – Tumor Control Probability – the likelihood of controlling tumor growth

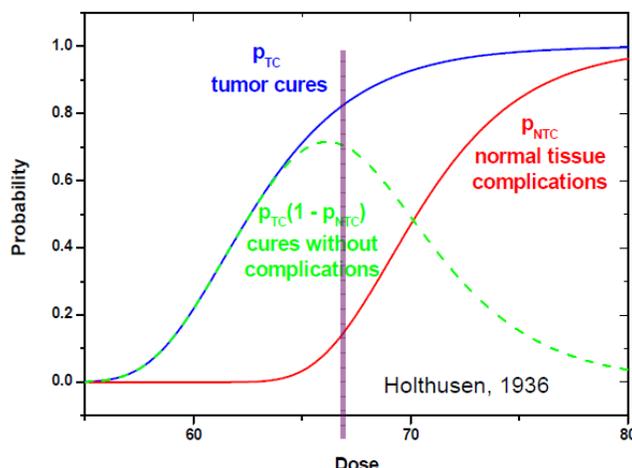
NTCP – Normal Tissue Complication Probability – the likelihood of normal tissue complications

As shown in the Figure below, the principle is usually illustrated by plotting two sigmoid curves, one for the tumor control probability (TCP) (curve A) and the other for the normal tissue complication probability (NTCP) (curve B).



The optimum choice of radiation dose fractionation scheme in the treatment of a given tumor maximizes the TCP and simultaneously minimizes the NTCP.

The further curve B (NTCP) is to the right of curve A (TCP) the easier it is to achieve the radiotherapeutic goal, the larger is the therapeutic ratio and the less likely will it be that the treatment causes complications. The therapeutic ratio generally refers to the ratio of the TCP and NTCP at a specified level of response (usually 0.05) for normal tissue.



The optimal dosage range lies along the vertical purple line, where the probability of cure is high while normal tissue reactions are minimal. The therapeutic index lies within the area denoted by the dotted line. The therapeutic index for skin lies between 3500cGy and 7000cGy to eradicate Basal cell and Squamous cell lesions. This margin does not take into account latent and acute reactions, which are related to the environment of the cells under treatment.

Lower Limbs

In the past, clinicians have not been successful in treating low vascular regions of the body, such as lower limbs. The main reasons for this were the types of energy being used and the standard fractionation schemes of the time. Today there are new approaches that are based more upon a biological response than merely trying to achieve a dose that falls within the aforementioned range, resulting in far superior outcomes.

As stated earlier, past treatments of lower limbs was typically performed with Electron therapy; since vascularity is low, and skin on lower limbs can be thin, lower limbs were not an optimal site for treatment. Furthermore, using Electron therapy meant performing treatments at almost 20% above therapeutic margin, due to the lack of sufficient deposit of energy in the cancers cells based upon the low LET and clumping of interactants. The 7000cGy is the upper limit for dose that can be delivered to this cell structure of the skin. Since most Electron therapy achieves a dose in the mid 6000cGy range, and the rules that apply to latent reactions suggest the closer you get within the tolerance of the cells, the quicker the onset of adverse reactions, Electron therapy treatments are more likely to lead to an onset of such reactions. Additionally, there are some fractionation schemes that are used with kV energy around the 3500cGy dosage. These are the schemes that lead to acute and latent reaction, and are limited to areas of high vascularity only.

On the opposite end of the therapeutic spectrum, several European studies have shown that a fraction of dose over 500cGy would render certain organelles in the cell nonfunctional. One example would be the lysosome; above this dose per fraction, the membrane perforates, dumping the enzymes which it holds into the cytoplasm, causing cell death. Since this cell death can affect cells that are in the margin around the lesion, this would explain the lack of healing. When it comes to limbs, new rules are in place to lower reactions and minimize latent effects. Fractionation schemes should come from the 2 or 3 fraction a week TDF tables. Areas that look

healthy can be treated at 380cGy, while areas of lower and less healthy body habitat should drop down to 320cGy. Total doses should not exceed the mid 5500cGy. These rules will help in the treatment of areas of low vascularity.

Radiation-sensitive targets are located in the nucleus and the cytoplasm of the cell. Cell death may occur if key macromolecules (e.g., DNA) are damaged or destroyed. Considerable evidence has proven that damage to DNA is the primary cause of radiation-induced cell death. The concept of key or critical targets has led to a model of radiation-induced cellular damage termed target theory in which critical targets may be inactivated by one or more ionization events (hits). The physical and chemical factors that affect Cellular Radiosensitivity are Dose Rate, LET, Fractionation, and the presence of oxygen. Inherent and biologic factors of the cell are Mitotic Rate, Degree of Differentiation, and Cell Cycle Phase.

Fractionation of the radiation dose typically produces better tumor control for a given level of normal-tissue toxicity than a single large dose. There are a number of radiobiological justifications for fractionations: the repair of sublethal damage in normal tissues; the reassortment of cells within the cell cycle moving tumor cells to more sensitive phase; and the repopulation of normal tissue cells. However, over-extending treatment time can lead to cancer cell proliferation, and reoxygenation of tumor cells as the tumor shrinks. To eradicate a tumor in radiation therapy while staying within the desired therapeutic index, several factors play an important role: total dose of radiation, time of dose delivery, and fractionation of dose. Dose is a physical quantity of radiation. Dose refers to the amount of energy absorbed from a beam of radiation at a given point in a medium. The two SI units of dose are in Gray (Gy) or Centigray (cGy). Gray and Centigray can be used for any type of radiation. The prescription used to setup your selected fractionation schemes will have dose in cGy. Usual dose range will fall between 4500 cGy to the mid 5500 cGy.



Chapter 12: Cutaneous lesions: Energy Margins & Fractionation Guidelines



Three step procedure to optimize dose delivery to a specific lesion subtype:

Treatment margins, energy, and fractionation schemes are selected based upon certain parameters to insure optimal dosage is delivered across the tumor and marginal volume. Factors influencing prognosis of NMSC:

- Tumor size (increasing size confers higher risk of recurrence)
- Tumor site (lesions on the central face, especially around the eyes, nose, lips and ears, are at higher risk of recurrence)
- Definition of clinical margins (poorly defined lesions are at higher risk of recurrence)
- Histological subtype (certain subtypes confer higher risk of recurrence)
- Histological features of aggression (perineural and/or perivascular involvement confers higher risk of recurrence)
- Failure of previous treatment (recurrent lesions are at higher risk of further recurrence)
- Immunosuppression (possibly confers increased risk of recurrence)

Tumor Margins for Basal Cell Carcinoma

BCC – Histological Type	Recurrence Risk /Aggressiveness	Margins
Nodular (Classic Basal-Cell Carcinoma)	Low Risk	8mm
Nodulocystic	Low Risk	8mm
Adenoid	Low Risk	8mm
Keratotic	Low Risk	8mm
BCC with Adnexal Differentiation	Low Risk	8mm
Superficial (Multicentric)	Low Risk	8mm
Pleomorphic	Low Risk	8mm
Clear Cell	Low Risk	8mm
Signet Ring	Low Risk	8mm
Cystic Cell Carcinoma	Low Risk	8mm
Pigmented Basal-Cell Carcinoma	Low Risk	8mm
Rodent Ulcer (Jacobi Ulcer)	Low Risk	8mm
Fibroepithelioma of Pinkus	Low Risk	8mm
Polypoid Basal-Cell Carcinoma	Low Risk	8mm
Pore-like Basal-Cell Carcinoma	Low Risk	8mm
Aberrant Basal-Cell Carcinoma	Low Risk	8mm
Basosquamous (Metatypical)	High Risk	10mm
Micro Nodular	High Risk	10mm
Infiltrative	High Risk	10mm
Morphoeic or Sclerosing	High Risk	10mm
BCC with Squamous Differentiation	High Risk	10mm

Tumor Margins for Squamous Cell Carcinoma

SCC – Histological Type	Recurrence Risk /Aggressiveness	Margins
In-situ	Low Risk	10mm
• Bowen’s disease; Erythroplasia of Queyrat		
Keratoacanthoma	Low Risk	10mm
Erythroplasia	Low Risk	10mm
Metaplasia	Low Risk	10mm
Papillary Carcinoma	Low Risk	10mm
Verrucous Squamous Cell Carcinoma	Low Risk	10mm
Papillary Squamous Cell Carcinoma	Low Risk	10mm
Squamous Cell Carcinoma	Low Risk	10mm
Large Cell Keratinizing Squamous Cell Carcinoma	Low Risk	10mm
Large Cell Non-Keratinizing Squamous Cell Carcinoma	Low Risk	10mm
Small Cell Keratinizing Squamous Cell Carcinoma	Low Risk	10mm
Adenoid/Pseudoglandular Squamous Cell Carcinoma	Low Risk	10mm
Intraepidermal Squamous Cell Carcinoma	Low Risk	10mm
Spindle Cell Squamous Cell Carcinoma	High Risk	10mm
Invasive SCC	High Risk	10mm

Tumor Margins for Other Variants of Squamous Cell Carcinoma

SCC – Histological Type	Recurrence Risk /Aggressiveness	Margins
Clear-cell squamous-cell carcinoma	Low Risk	10mm
Keratoacanthoma	Low Risk	10mm
Signet-ring-cell squamous-cell carcinoma	Low Risk	10mm
Basaloid squamous cell carcinoma	High Risk	10mm

Energy Selection (BCC and SCC)

Energy selection is based upon:

Lesion Thickness

- Lesion maximum lesion thickness
 - Topographical height of lesion
 - Punch biopsy depth of lesion

Histology Type

- Reassurance risk, aggressiveness
 - High Risk
 - Consistency of Histology report

Age of lesion and Density Pattern

- Age of lesion with reference to tissue density
 - Hypoxic and anoxic portion of lesion
 - Thickness of dead tissue overlying the lesion

- *Lesion Thickness*

The highest topographical point of a lesion, plus the depth of a punch biopsy will give the overall thickness of a lesion.

When possible, de-bulk lesions.

Surface + biopsy depth = overall lesion thickness

- 0.1mm to 3mm = 50kV
- 4mm to 9mm = 70kV
- 10mm up = 100Kv

- *Histology Type*

High Risk lesions call for higher energy penetration due to the fact biopsy reports can yield insufficient depth data.

- 0.1mm to 3mm = 70kV
- 4mm up = 100kV

- *Age of lesion and Density Pattern*

Lesions that a patient has had for several years can yield an area where a lack of oxygen exist, hypoxic and anoxic tissue. Lesions that have hard scabs may consist of an area with a higher density than water. kV energies are Z dependent and penetration through such areas of lesions can be hindered by this higher density.

When possible, de-bulk lesions.

- 0.1mm to 3mm = 70kV
- 3mm up = 100kV

Fractionation Schemes (BCC and SCC)

Selection is based upon:

- Skin thickness

- Vascularity
- Recurrence risk, aggressiveness
- Underlying bone and cartilage
- Patient medical condition (diabetic, lupus, etc.)

The TDF tables supply many fractionations schemes which can be used in the treatment of superficial skin lesions. The fractionation schemes that yield a better control with reference to acute and latent reactions are listed below:

- A. 380cGy, 12 fractions, 3 times a week, TDF= 98
- B. 380cGy, 13 fractions, 2 times a week, TDF= 100
- C. 320cGy, 16 fractions, 3 times a week, TDF= 100*
- D. 320cGy, 17 fractions, 2 times a week, TDF= 100*
- E. 380cGy, 13 fractions, 3 times a week, TDF= 106*
- F. 380cGy, 14 fractions, 2 times a week, TDF= 108*

- Skin thickness

Patients that have thin skin will have acute reaction within a shorter time frame. Fractionation schemes B and D with dose delivered 2 times a week give better control from acute reactions.

- Vascularity

Patients that have poor vascularity issue have better control of acute reactions with fractionation schemes B and D where dose is delivered 2 times a week.

- Recurrent risk, aggressiveness

High risk and aggressive lesions should be taken to a dose of at least 5000cGy*. Fractionation schemes C, D, E and F can be used in order to obtain a total dose in the upper therapeutic index.

- Underlying bone and cartilage

All 4 fractionation schemes, A, B, C, and D, can be used when underlying bone and cartilage is present. The monitoring of the patient's progress is the main issue through the fractionation scheme.

- Patient medical condition

Some medical conditions such as the patient being a diabetic or having lupus have been linked to sensitizing the effect of radiation on the patient's skin surface. Fractionation schemes that have 2 fractions per week, B and D, are optimal for such conditions.

Lesions of other Etiologies

<i>Histological type</i>	<i>Tumor Margins Recurrence risk, aggressiveness</i>	<i>Margins</i>
Kaposi Sarcoma (T-Cell)	Low Risk	10mm
Lymphoma Cutis	Low Risk	10mm
Mycosis Fungoides (Cutaneous T- Cell Lymphoma)	Low Risk	10mm
Merkel Cell Carcinoma	Palliative	20mm
<ul style="list-style-type: none"> ➤ Trabecular ➤ Intermediate ➤ Small Cell 		
Primary Cutaneous B- Cell Lymphoma (PCBCL)	Low Risk	10mm
<ul style="list-style-type: none"> ➤ Diffuse large B-cell lymphoma ➤ Primary cutaneous follicular lymphoma ➤ Primary cutaneous marginal zone lymphoma ➤ Intravascular large B-cell lymphoma ➤ Plasmacytoma ➤ Plasmacytosis 		
Paget's Disease (EMPD)	Low Risk	10mm
Peyronie's Disease	Low Risk	10mm

Energy Selection

Kaposi Sarcoma (T-Cell)	100kV
Lymphoma Cutis	100kV
Mycosis Fungoides (Cutaneous T- Cell Lymphoma)	100kV
Merkel Cell Carcinoma	100kV

Primary Cutaneous B- Cell Lymphoma (PCBCL)	100kV
Paget's disease (EMPD)	50kV
Peyronie's Disease	70kV

Fractionation Schemes

Kaposi Sarcoma (T-Cell)	400cGy in 5 fractions, 5 times a week	Total Dose of 2000cGy
Lymphoma Cutis	400cGy in 5 fractions, 5 times a week	Total Dose of 2000cGy
Mycosis Fungoides (Cutaneous T- Cell Lymphoma)	400cGy in 5 fractions, 5 times a week	Total Dose of 2000cGy
<ul style="list-style-type: none"> • MF Alternative Fractionation Scheme 	300cGy in 10 fractions, 5 times a week	Total Dose of 3000cGy
Merkel Cell Carcinoma	400cGy in 5 fractions, 5 times a week	Total Dose of 2000cGy

Primary Cutaneous B- Cell Lymphoma (PCBCL)	400cGy in 5 fractions, 5 times a week	Total Dose of 2000cGy
Paget's Disease (EMPD)	325cGy in 16 fractions, 3 times a week	Total Dose of 5200cGy

*First 8 fractions, Break of 2 weeks, last 8 Fractions
*Decay factor built-in to total Dose

Peyronie's Disease	300cGy in 10 fractions, 3 times a week	Total Dose of 3000cGy
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*First 5 fractions, Break of 6 weeks, last 5 Fractions
*Decay factor built-in to total Dose



Chapter 13: Indications For Cutaneous Lesion SRT-100™



Basal Cell Carcinoma

Comprising 60 percent of primary skin cancers, the basal cell carcinoma is a slow-growing lesion that invades tissue but rarely metastasizes. Most metastatic basal cell carcinomas arise from large tumors. Basal cell carcinomas that have recurred after excision may be at greater risk of metastasis. Basal cell carcinoma is common on the face and on other exposed skin surfaces but may occur anywhere. The common form first appears as a small round or oval area of skin thickening. Usually there is no itching, pain or change in skin color. The area very slowly extends circumferentially, creating a slightly raised edge, which may have a shiny, pearly or slightly translucent appearance.



Classification

Basal-cell carcinomas may be divided into the following types:

- Nodular basal-cell carcinoma (Classic basal-cell carcinoma)
- Cystic basal-cell carcinoma
- Cicatricial basal-cell carcinoma (Morpheaform basal-cell carcinoma, Morphoeic basal-cell carcinoma)
- Infiltrative basal-cell carcinoma
- Micronodular basal-cell carcinoma
- Superficial basal-cell carcinoma (Superficial Multicentric basal-cell carcinoma)
- Pigmented basal-cell carcinoma
- Rodent ulcer (Jacobi ulcer)
- Fibroepithelioma of Pinkus
- Polypoid basal-cell carcinoma
- Pore-like basal-cell carcinoma
- Aberrant basal-cell carcinoma

Etiology

Basal-cell carcinoma is a common skin cancer, but when solar (actinic) keratoses are also considered, basal cell carcinomas are second in prevalence. Basal cell carcinoma occurs mainly in fair-skinned patients with a family history of this cancer. Sunlight is a factor in about two-thirds of these cancers; therefore, doctors recommend sun screens with at least SPF 30. One-third occurs in non-sun-exposed areas; thus, the pathogenesis is more complex than UV exposure as the cause.



Signs and Symptoms

Patients present with a shiny, pearly nodule. However, superficial basal-cell cancer can present as a red patch like eczema. Infiltrative or Morpheaform basal-cell cancers can present as a skin thickening or scar tissue – making diagnosis difficult without using tactile sensation and a skin biopsy. It is often difficult to distinguish basal-cell cancer from acne scar, actinic elastosis, and recent cryodestruction inflammation.

Histology

Basal cell carcinoma is a malignant epithelial tumor arising only in skin, from the basal layer of the epidermis or of the pilosebaceous adnexa. Tumor is represented by compact areas, well delineated and invading the dermis, apparent with no connection with the epidermis. Tumor cells resemble normal basal cells (small, monomorphous) are disposed in palisade at the periphery of the tumor nests, but are spindle-shaped and irregular in the middle. Tumor clusters are separated by a reduced stroma with inflammatory infiltrate.

As the lesion continues to grow, the central area becomes atrophic, leaving a hollow that is covered by thin skin, often with visible vessels, which eventually ulcerates. The growing edges become more irregular, and the shape becomes uneven. The base is also invasive and gradually erodes the underlying tissue, making it difficult to excise the lesion completely.



Less common forms include a superficial basal cell carcinoma that resembles a patch of dermatitis, a pigmented basal cell carcinoma that resembles a nodular malignant melanoma and an aggressive-growth basal cell carcinoma. Aggressive-growth basal cell carcinoma is an infiltrating Sclerosing lesion that may appear similar to a scar with a firm or hard base. In patients younger than 35 years, basal cell carcinoma tends to adopt the more aggressive forms.

No pre-malignant conditions precede basal cell carcinoma. Basal cell carcinoma and lesions of similar appearance are compared in the table illustration below.

Features of Basal Cell Carcinoma and Lesions of Similar Appearance

Lesion	Location	Surface	Color	Outline	Other features
Basal cell carcinoma	Most common on face, but can occur anywhere	Raised, pearly, firm	Normal skin color	Round at first, irregular later	May ulcerate
Superficial basal cell carcinoma	Any location	Roughened	Skin-colored or pink	Round or irregular	Resembles dermatitis
Pigmented basal cell carcinoma	Most commonly occurs on the face	Nodule	Growing area is dark brown or black	Becomes irregular as growth progresses	Looks like a nodular malignant melanoma
Infiltrating basal cell carcinoma	Any location	Smooth	Skin-colored	Various	Looks like a firm scar that grows aggressively
Tricoepithelioma	Any location	Raised, pearly	Normal skin color	Round	Does not become malignant
Keloid after	Site of previous injury	Raised, rounded, smooth	Usually pink, may be skin-colored	Varies, often linear	Often large, but no growth one year
Molluscum contagiosum	Face and hands of children, areas of sexual contact	Raised, rounded central hollow Soft, fleshy	Skin-colored	Round	Usually multiple, in clusters or scattered; contagious
Dermatofibroma	Often occurs on limbs, rarely on face	Flat or slightly raised, edge not thickened or pearly	Skin-colored, firm under the surface but not on the surface	Usually round or oval	Usually >5 mm diameter when first noticed

Basal Cell Carcinoma Treatment Fractionation and Doses

- **Use of Standard TDF Fractionation Tables:**
 - TDF number between 90 and 110. Optimal TDF is 100
- **Baseline fractionation scheme:**
 - 380cGy in 12 fractions, 3 times a week, total Dose of 4560cGy with a 98TDF (Baseline fractionation scheme refers to a minimization of acute reactions)
- **Selection of treatment kV (50kV, 70kV, 100kV):**
 - Based upon the Tumor Margin, Energy, and Fractionation Guidelines.
- **Treatment Margin:**
 - 8-10mm with standard setup, clinical setups on the auricular or nasal area will optimize when flash becomes present.

Common Fractionation Schemes:

- 380 cGy per fraction/ 3 times a week / 12 total fractions/ total dose of 4560 cGy/ TDF=98
- 380 cGy per fraction/ 2 times a week / 13 total fractions/ total dose of 4940 cGy/ TDF=100
- 320 cGy per fraction/ 3 times a week / 16 total fractions/ total dose of 5120 cGy/ TDF=100

Squamous Cell Carcinoma

Squamous cell carcinoma comprises 20 percent of all cases of skin cancer. It typically occurs on areas of the skin that have been exposed to sunlight for many years.

Classification

Cancer can be considered a very large and exceptionally heterogeneous family of malignant diseases, with squamous cell carcinomas comprising one of the largest subsets.

The International Classification of Diseases for Oncology (ICD-O) system lists a number of morphological subtypes and variants of malignant squamous cell neoplasms, including:

- Papillary carcinoma
- Verrucous squamous cell carcinoma
- Papillary squamous cell carcinoma
- Squamous cell carcinoma
- Large cell keratinizing squamous cell carcinoma
- Large cell nonkeratinizing squamous cell carcinoma
- Small cell keratinizing squamous cell carcinoma
- Spindle cell squamous cell carcinoma
- Adenoid/Pseudoglandular squamous cell carcinoma
- Intraepidermal squamous cell carcinoma
- Lymphoepithelial carcinoma

Other variants of squamous cell carcinoma are recognized under other systems, such as:

- Basaloid squamous cell carcinoma]
- Clear-cell squamous-cell carcinoma
- Keratoacanthoma
- Signet-ring-cell squamous-cell carcinoma

Etiology

It may also appear in areas that have been subjected to ionizing irradiation or in other locations in patients who have undergone treatment with immunosuppressive drugs or have been exposed to organic trivalent arsenic compounds or tars. Squamous cell carcinoma of the lip may be related to pipe smoking, as well as to sunlight exposure.



Human papillomavirus infection may be a precursor of Keratoacanthoma and periungual, genital and other squamous cell carcinomas, especially in immunosuppressed patients. The affected area develops a slight redness, scaling, fissuring and an uneven surface. Superficial dilated vessels may be visible. The lesion often appears very dry and may bleed when stretched or abraded. It spreads laterally from the edges and may heap up irregularly. New lesions often appear near old ones. Clusters of lesions may occur as fleshy masses. The centers may become atrophic and develop raw patches or frank ulceration.

Two other skin lesions are considered part of the squamous cell carcinoma spectrum. The first type, Keratoacanthoma, is closely related to squamous cell carcinoma. Like squamous cell carcinoma, it appears on skin damaged by sunlight or chemicals. It often occurs at the site of trauma, especially in immunosuppressed patients. It is sometimes associated with human papillomavirus infection. Keratoacanthoma appears as a skin-colored or pink smooth lesion, which becomes dome-shaped during a period of very rapid growth. When mature, it is volcano-shaped, with protruding masses of keratin resembling lava. Classic Keratoacanthoma is not malignant and regresses spontaneously, but atypical lesions may actually be squamous cell carcinoma. Many dermatopathologists include Keratoacanthoma in the spectrum of squamous cell carcinoma.



The second type is Verrucous carcinoma, a variant of squamous cell carcinoma that features an irregular warty surface.



Sign and Symptoms

Symptoms are highly variable depending on the involved organs. SCC of the skin begins as a small nodule and as it enlarges the center becomes necrotic and sloughs and the nodule turns into an ulcer.

- The lesion caused by SCC is often asymptomatic
- Ulcer or reddish skin plaque that is slow growing
- Intermittent bleeding from the tumor, especially on the lip
- The clinical appearance is highly variable
- Usually the tumor presents as an ulcerated lesion with hard, raised edges

- The tumor may be in the form of a hard plaque or a papule, often with an opalescent quality, with tiny blood vessels
- The tumor can lie below the level of the surrounding skin, and eventually ulcerates and invades the underlying tissue
- The tumor commonly presents on sun-exposed areas (e.g. back of the hand, scalp, lip, and superior surface of pinna)
- On the lip, the tumor forms a small ulcer, which fails to heal and bleeds intermittently
- Evidence of chronic skin photo damage, such as multiple actinic keratoses (solar keratoses)
- The tumor grows relatively slowly
- Unlike basal cell carcinoma (BCC), squamous cell carcinoma (SCC) has a substantial risk of metastasis
- Risk of metastasis is higher in SCC arising in scars, on the lower lips or mucosa, and occurring in immunosuppressed patients.

About one-third of lingual and mucosal tumors metastasize before diagnosis (these are often related to tobacco and alcohol use)

Histology

Squamous cell carcinoma is a malignant epithelial tumor which originates in epidermis, squamous mucosa or areas of squamous metaplasia. In skin, tumor cells destroy the basement membrane and form sheets or compact masses which invade the subjacent connective tissue (dermis). In well differentiated carcinomas, tumor cells are pleomorphic/atypical, but resembling normal keratinocytes from prickle layer (large, polygonal, with abundant eosinophilic (pink) cytoplasm and central nucleus). Their disposal tends to be similar to that of normal epidermis: immature/basal cells at the periphery, becoming more mature to the center of the tumor masses. Tumor cells transform into keratinized squamous and form round nodules with concentric, laminated layers, called "cell nests" or "epithelial/keratinous pearls". The surrounding stroma is reduced and contains inflammatory infiltrate (lymphocytes). Poorly differentiated squamous carcinomas contain more pleomorphic cells and no keratinization. Tumor cells transformed into keratinized squamous form round nodules with concentric, laminated layers, called "cell nests" or "epithelial/keratinous pearls".

Features of Squamous Cell Carcinoma and Lesions of Similar Appearance

Lesion	Location	Surface	Color	Outline	Other features
Squamous cell carcinoma	Areas exposed to sunlight, radiation or arsenicals	Rough, irregular, sometimes scaly, sometimes has visible vessels, sometimes warty or with fleshy masses	Skin-colored at first, sometimes reddened later	Vague	New lesions may appear near old ones Does not clear with corticosteroid therapy
Keratoacanthoma (a variant of squamous cell carcinoma)	Exposed areas, especially face and hands	Smooth dome, becoming volcano-shaped	Skin-colored or slightly reddened	Well-defined	Goes through a period of very rapid growth, often regresses
Eczema and atopic dermatitis	Atopic dermatitis behind ears, on flexure areas	Reddened, slightly scaly, sometimes with vesicles	Dry at first, fissured, may weep	Indefinite	Common in atopic persons and those exposed to irritants
Contact dermatitis	Wherever skin comes in contact with an irritant	Reddened, slightly scaly, sometimes with vesicles	Dry at first, fissured, may weep	Circumscribed	Dermatitis clears with corticosteroid therapy
Psoriasis	Elbows, knees, scalp, sacral cleft, nails	Scaly with underlying reddened base	White dry scales, smooth pink or red where scales are removed; may bleed	Well-demarcated; round, irregular or confluent	Often widespread, sometimes itchy; varies with season
Seborrheic dermatitis)	Scalp, forehead, nasolabial fold, midline trunk	Raised, with scales	Yellow or brown	Well-demarcated	Some lesions can be easily removed

Squamous Cell Carcinoma Treatment Fractionation and Doses

- **Use of Standard TDF Fractionation Tables:**
 - TDF number between 90 and 110. Optimal TDF is 100
- **Baseline fractionation scheme:**
 - 380cGy in 12 fractions, 3 times a week, total Dose of 4560cGy with a 98TDF (Baseline fractionation scheme refers to a minimization of acute reactions)
- **Selection of treatment kV (50kV, 70kV, 100kV):**
 - Based upon the Tumor Margin, Energy, and Fractionation Guidelines.
- **Treatment margin:**
 - 10mm with standard setup, clinical setups on the auricular or nasal area will optimize when flash becomes present.

Common Fractionation Schemes:

- 380 cGy per fraction/ 3 times a week / 12 total fractions/ total dose of 4560 cGy/ TDF=98
- 380 cGy per fraction/ 2 times a week / 13 total fractions/ total dose of 4940 cGy/ TDF=100
- 320 cGy per fraction/ 3 times a week / 16 total fractions/ total dose of 5120 cGy/ TDF=100

Bowen's Disease

Bowen's disease (BD) (also known as "squamous cell carcinoma in situ") is a neoplastic skin disease, it can be considered as an early stage or intraepidermal form of squamous cell carcinoma. It was named after John T. Bowen. Erythroplasia of Queyrat is a form of squamous cell carcinoma in situ arising on the glans or prepuce, possibly induced by HPV.

Etiology

Causes of BD include solar damage, arsenic, immunosuppression (including AIDS), viral infection (human papillomavirus or HPV) and chronic skin injury and dermatoses.



Signs and symptoms

Bowen's disease typically presents as a gradually enlarging, well demarcated erythematous plaque with an irregular border and surface crusting or scaling. BD may occur at any age in adults but is rare before the age of 30 years - most patients are aged over 60. Any site may be affected, although involvement of palms or soles is uncommon. BD occurs predominantly in women (70-85% of cases). About 60-85% of patients have lesions on the lower leg, usually in previously or presently sun exposed areas of skin. This is a persistent progressive non-elevated red scaly or crusted plaque which is due to an intraepidermal carcinoma and is potentially malignant. The lesions may occur anywhere on the skin surface or on mucosal surfaces.



Histology

Bowen's disease is essentially equivalent to squamous cell carcinoma in situ. Atypical squamous cells proliferate through the whole thickness of the epidermis. The entire tumor is confined to the epidermis and does not invade into the dermis. The cells in Bowen's are often highly atypical under the microscope, and may in fact look more unusual than the cells of some invasive squamous cell carcinomas.



Bowen's Disease Treatment Fractionation and Doses

- **Use of Standard TDF Fractionation Tables:**
 - TDF number between 90 and 110. Optimal TDF is 100
- **Baseline fractionation scheme:**
 - 380cGy in 12 fractions, 3 times a week, total Dose of 4560cGy with a 98TDF (Baseline fractionation scheme refers to a minimization of acute reactions)
- **Selection of treatment kV (50kV, 70kV, 100kV):**
 - Based upon Tumor Margin, Energy, and Fractionation Guidelines.
- **Treatment margin:**
 - 10mm with standard setup, clinical setups on the auricular or nasal area will optimize when flash becomes present.

Common Fractionation Schemes:

- 380 cGy per fraction/ 3 times a week / 12 total fractions/ total dose of 4560 cGy/
TDF=98
- 380 cGy per fraction/ 2 times a week / 13 total fractions/ total dose of 4940 cGy/
TDF=100
- 320 cGy per fraction/ 3 times a week / 16 total fractions/ total dose of 5120 cGy/
TDF=100

Mycosis Fungoides (Cutaneous T- Cell Lymphoma)

Mycosis Fungoides (also known as Alibert-Bazin syndrome or granuloma Fungoides), is the most common form of cutaneous T-cell lymphoma. It generally affects the skin, but may progress internally over time.

Etiology

The cause of mycosis Fungoides is unknown, but it is not believed to be hereditary or genetic in the vast majority of cases. One incident has been reported of a possible genetic link. It is not contagious. The disease is an unusual expression of CD4 T cells, a part of the immune system. These T cells are skin-associated, meaning that they biochemically and biologically are most related to the skin, in a dynamic manner. Mycosis Fungoides is the most common type of 'Cutaneous T-cell Lymphoma' (CTCL), but there are many other types of CTCL that have nothing to do with mycosis Fungoides and these disorders are treated differently.



Signs and Symptoms

The signs and symptoms of mycosis Fungoides include:

- Itchy, scaly rash
- Flat, red patches
- Rash or patches that occur on the buttocks, groin, under the arms, and on the chest or breast
- Very light or very dark patches
- Hardened, raised patches called plaques
- Round, red nodules that are shaped like a mushroom and may be ulcerated
- Large areas of the skin that are thickened, scaly and itchy
- Thickened skin folds
- Inflamed lymph nodes

Most patients initially present with a scaly red rash or plaques. A few individuals, however, present with the nodules. Mycosis Fungoides is rarely seen before age twenty, but it does occasionally occur in children. The average age of onset is between age forty-five and fifty-five for those presenting with the rash or plaques, and age sixty for those presenting with the nodules.



Histology

Mycosis Fungoides (MF) represents the most common variant of CTCL and is characterized by a monoclonal proliferation of epidermotropic CD4+/CD45RO+ T-cells often with aberrant expression of mature T-cell antigens. MF (Alibert-Bazin type) is characterized by the presence of polymorphic patches, plaques, and tumors. Sézary syndrome (SS) is a rare CTCL variant closely related to MF and has classically been described as a triad of erythroderma, generalized lymphadenopathy and Sézary cells (atypical neoplastic T lymphocytes with hyper convoluted cerebriform nuclei) in the skin, blood, and lymph nodes. The WHO-EORTC system currently distinguishes SS as a separate entity from MF, but rare cases of SS preceded by typical MF have been described.

Mycosis Fungoides (MF) Treatment Fractionation and Doses

- **Use of Standard Fractionation:**
 - 400cGy in 5 fractions, 5 times a week, total Dose of 2000cGy
- **Baseline fractionation scheme:**
 - Same as above
- **Selection of treatment kV (50kV, 70kV, 100kV):**
 - 100kV for tumor coverage.
- **Treatment margin:**
 - 10mm with standard setup
- **Alternative Fractionation Scheme:**
 - 300cGy in 10 fractions, 5 times a week, total Dose of 3000cGy total of 2 weeks.

Kaposi Sarcoma (T-Cell)

Kaposi sarcoma (KS) is a tumor caused by Human herpes virus 8 (HHV8), also known as Kaposi sarcoma-associated herpes virus (KSHV). It was originally described by Moritz Kaposi (KA-pə-shi), a Hungarian dermatologist practicing at the University of Vienna in 1872.



Etiology

It became more widely known as one of the AIDS-defining illnesses in the 1980s. The viral cause for this cancer was discovered in 1994. Although KS is now well-established to be caused by a viral infection, there is widespread lack of awareness of this even among persons at risk for KSHV/HHV-8 infection.

Kaposi's sarcoma (KS) is a systemic disease that can present with cutaneous lesions with or without internal involvement. Four subtypes have been described: Classic KS, affecting middle aged men of Mediterranean descent; African endemic KS; KS in iatrogenically immunosuppressed patients; and AIDS-related KS. The erythematous to violaceous cutaneous lesions seen in KS have several morphologies: macular, patch, plaque, nodular, and exophytic. The cutaneous lesions can be solitary, localized or disseminated. KS can involve the oral cavity, lymph nodes, and viscera. Classic KS tends to be indolent, presenting with erythematous or violaceous patches on the lower extremities. African endemic KS and AIDS-related KS tend to be more aggressive. The AIDS-related KS lesions often rapidly progress to plaques and nodules affecting the upper trunk, face, and oral mucosa. The diagnosis can be made with a tissue biopsy and, if clinically indicated, internal imaging should be done.

Signs and Symptoms

KS lesions are nodules or blotches that may be red, purple, brown, or black, and are usually papular (in other words, palpable or raised). They are typically found on the skin, but spread elsewhere is common, especially the mouth, gastrointestinal tract and respiratory tract. Growth can range from very slow to explosively fast, and is associated with significant mortality and morbidity.



Histology

Despite its name, in general it is not considered a true sarcoma, which is a tumor arising from mesenchymal tissue. KS, in fact, arises as a cancer of lymphatic endothelium and forms vascular channels that fill with blood cells, giving the tumor its characteristic bruise-like appearance. KSHV proteins are uniformly detected in KS cancer cells.

KS lesions contain tumor cells with a characteristic abnormal elongated shape, called spindle cells. The tumor is highly vascular, containing abnormally dense and irregular blood vessels, which leak red blood cells into the surrounding tissue and give the tumor its dark color. Inflammation around the tumor may produce swelling and pain.

Although KS may be suspected from the appearance of lesions and the patient's risk factors, definite diagnosis can be made only by biopsy and microscopic examination, which will show the presence of spindle cells. Detection of the KSHV protein LANA in tumor cells confirms the diagnosis

Kaposi's sarcoma (KS) Treatment Fractionation and Doses

- **Use of Standard Fractionation:**
 - 400cGy in 5 fractions, 5 times a week, total Dose of 2000cGy
- **Baseline fractionation scheme:**
 - Same as above
- **Selection of treatment kV (50kV, 70kV, 100kV):**
 - 100kV for tumor coverage.
- **Treatment margin:**
 - 10mm with standard setup

Primary Cutaneous B- Cell Lymphoma (PCBCL)

Lymphoma is the most common blood cancer. The two main forms of lymphoma are Hodgkin lymphoma (HL) and non-Hodgkin lymphoma (NHL). Lymphoma occurs when lymphocytes, a type of white blood cell, grow abnormally. The body has two main types of lymphocytes that can develop into lymphomas: B-lymphocytes (B-cells) and T-lymphocytes (T-cells). Cancerous lymphocytes can travel to many parts of the body, including the lymph nodes, spleen, bone marrow, blood or other organs, and can accumulate to form tumors.



B-cell lymphomas, which occur when B-lymphocyte cells become cancerous, account for 85 percent of all NHL cases in the United States. There are many different forms of B-cell lymphoma.

Cutaneous B-cell lymphomas constitute a group of diseases that occur less commonly than cutaneous T-cell lymphoma, and are characterized histologically by B-cells that appear similar to those normally found in germinal centers of lymph nodes. Conditions included in this group are:

- Diffuse large B-cell lymphoma
- Primary cutaneous follicular lymphoma
- Primary cutaneous marginal zone lymphoma
- Intravascular large B-cell lymphoma
- Plasmacytoma
- Plasmacytosis

Etiology

Although there is continuing research, at this time no single factor has been proven to cause this disease. There is no supportive research indicating that this is a genetic or hereditary disease. Past studies do not show connections between chemical exposure, environment, pesticides, radiation, allergies and occupations. Exposure to Agent Orange may be a risk factor for developing cutaneous lymphoma for veterans of the Vietnam War, but no direct cause-effect relationship has been established.

While the disease is not contagious or directly inherited, epidemiologists – the scientists who study patterns of disease in populations – have identified factors in the distribution of cutaneous lymphoma that may eventually help determine what causes the disease. These factors include age, gender, immune system genes, geography and ethnic background.



Signs and Symptoms

The lumps formed beneath the skin cutaneous lymphoma are due to a collection of the malignant cells in the skin. In an attempt to purge the system of the mutated cells, the body pushes the clustered malignant cells towards the surface of the skin.

Histology

Cutaneous B-cell lymphomas (CBCL) are less common than cutaneous T-cell lymphomas (CTCL). Like CTCL, they are antigen driven processes. It appears that heavy chain genes (VH) of the B cells show significant mutations. Once this occurs, a neoplastic clone develops. There are definitely some environmental factors associated with this such as *Borrelia burgdorferi* infection (agent of Lyme disease). The term SALT (Skin Associated Lymphoid Tissue) has been applied to some of these B cell lymphomas, citing the similarity of CBCL with other B cell lymphomas arising within mucosa such as the salivary gland and gastrointestinal tract.

Cutaneous B-cell lymphomas (CBCL) Treatment Fractionation and Doses

- **Use of Standard Fractionation:**
 - 400cGy in 5 fractions, 5 times a week, total Dose of 2000cGy
- **Baseline fractionation scheme:**
 - Same as above
- **Selection of treatment kV (50kV, 70kV, 100kV):**
 - 100kV for tumor coverage.
- **Treatment Margin:**
 - 10mm with standard setup

Paget's disease (EMPD)

Extramammary Paget disease (EMPD) is a rare cutaneous adenocarcinoma described as an apocrine gland tumor occurring in both a benign and a malignant form, with metastatic potential. The areas of the body affected—vulva, perianal region, penis, scrotum, perineum, and axilla—generally contain large concentrations of apocrine glands.



A rare cutaneous neoplasm that occurs in the elderly. It develops more frequently in women and predominantly involves apocrine gland-bearing areas, especially the vulva, scrotum, and perianal areas. The lesions develop as erythematous scaly patches that progress to crusted, pruritic, erythematous plaques. The clinical differential diagnosis includes squamous cell carcinoma in situ and superficial fungal infection. It is generally thought to be an adenocarcinoma of the epidermis, from which it extends into the contiguous epithelium of hair follicles and eccrine sweat ducts.

Etiology

The histogenesis of EPD is not uniform. Paget cells in the epidermis may occur as an in situ upward extension of an in situ adenocarcinoma in deeper glands (25%). Alternatively, EPD may have a multifocal primary origin in the epidermis and its related appendages. The primary tumor and Paget cells are usually mucus-secreting. Primary tumors in the anorectum can arise within the rectal mucosa or intramuscular glands.

Signs and symptoms

Skin lesions, often mistaken as eczema that may be itchy or painful. A biopsy will establish the diagnosis. The histology of the lesion is the same as for Paget's disease of the breast.



Histology

High-molecular-weight cytokeratins (34betaE12) were uncharacteristically expressed in the cytoplasm of the Paget cells with equal or greater strength than in the surrounding keratinocytes, suggesting some degree of squamous differentiation. Very few publications have reported the coexistence of EMPD with squamous cell carcinoma in situ, occurring mostly in the vulva. To our knowledge, our case is the first report of scrotal EMPD with features of Bowen disease. Our findings support the theory that primary EMPD arises multifocally from multipotential epidermal cells.

Extramammary Paget disease (EMPD) Treatment Fractionation and Doses

- **Skip Fractionation:**
 - 325cGy in 16 fractions, 3 times a week, total Dose of 5200cGy
 - (First 8 fractions, Break of 2 weeks, last 8 Fractions)
 - (Decay factor built-in to total Dose)
- **Baseline fractionation scheme:**
 - Same as above
- **Selection of treatment kV (50kV, 70kV, 100kV):**
 - 50kV for tumor coverage.
- **Treatment margin:**
 - 10mm with standard setup

Peyronie's Disease

Peyronie's disease is characterized by a plaque, or hard lump, that forms within the penis. The plaque, a flat plate of scar tissue, develops on the top or bottom side of the penis inside a thick membrane called the tunica albuginea, which envelopes the erectile tissues. The plaque begins as a localized inflammation and develops into a hardened scar. This plaque has no relationship to the plaque that can develop in arteries.

Cases of Peyronie's disease range from mild to severe. Symptoms may develop slowly or appear overnight. In severe cases, the hardened plaque reduces flexibility, causing pain and forcing the penis to bend or arc during erection. In many cases, the pain decreases over time, but the bend in the penis may remain a problem, making sexual intercourse difficult. The sexual problems that result can disrupt a couple's physical and emotional relationship and can lower a man's self-esteem. In a small percentage of men with the milder form of the disease, inflammation may resolve without causing significant pain or permanent bending.

The plaque itself is benign, or noncancerous. It is not a tumor. Peyronie's disease is not contagious and is not known to be caused by any transmittable disease.

Etiology

Many researchers believe the plaque of Peyronie's disease develops following trauma, such as hitting or bending that causes localized bleeding inside the penis. Two chambers known as the corpora cavernosa run the length of the penis. A connecting tissue, called a septum, runs between the two chambers and attaches at the top and bottom of the tunica albuginea.

If the penis is bumped or bent, an area where the septum attaches to the tunica albuginea may stretch beyond a limit, injuring the tunica albuginea and rupturing small blood vessels. As a result of aging, diminished elasticity near the point of attachment of the septum might increase the chances of injury. In addition, the septum can also be damaged and form tough, fibrous tissue, called fibrosis.

The tunica albuginea has many layers, and little blood flows through those layers. Therefore, the inflammation can be trapped between the layers for many months. During that time, the inflammatory cells may release substances that cause excessive fibrosis and reduce elasticity. This chronic process eventually forms a plaque with excessive amounts of scar tissue and causes calcification, loss of elasticity in spots, and penile deformity.

While trauma might explain some cases of Peyronie's disease, it does not explain why most cases develop slowly and with no apparent traumatic event. It also does not explain why some cases resolve or why similar conditions such as Dupuytren's contracture do not seem to result from severe trauma.

Some researchers theorize that Peyronie's disease may be an autoimmune disorder

Histology

Peyronie's disease is an inflammatory condition characterized by the formation of fibrous, noncompliant nodules in the tunica albuginea which can impede tunical expansion during penile erection, leading to deformity and bending. While the cause of this disease is thought to be due

to microvascular trauma and abnormal wound healing, other hypotheses include genetic predisposition. In this review the pathophysiology of Peyronie's disease is discussed as well as current hypotheses regarding its origin.

Peyronie's Disease Treatment Fractionation and Doses

- **Use of Standard Fractionation:**
 - 150 cGy per fraction/ 3 times a week/ 9 total fractions/ total dose 1350 cGy
- **Baseline fractionation scheme:**
 - Same as above
- **Selection of treatment kV (50kV, 70kV, 100kV):**
 - 70kV for tumor coverage.
- **Treatment Margin:**
 - 10mm with standard setup

Skip Fractionation Schemes:

- 300cGy in 10 fractions, 3 times a week, total Dose of 3000cGy
- (First 5 fractions, Break of 6 weeks, last 5 Fractions)
- (Decay factor built-in to total Dose)

Merkel Cell Carcinoma

Merkel cell carcinoma is a rare and highly aggressive skin cancer, which, in most cases, is caused by a virus (Merkel cell polyomavirus) discovered by scientists at the University of Pittsburgh in 2008. It is also known as cutaneous APUDoma, primary neuroendocrine carcinoma of the skin, primary small cell carcinoma of the skin, and trabecular carcinoma of the skin.



Approximately 80% of Merkel cell carcinomas are caused by Merkel cell polyomavirus (MCV). The virus is clonally integrated into the cancer cells. In addition, the virus has a particular mutation only when found in cancer cells, but not when it is detected in healthy skin cells. Direct evidence for this oncogenetic mechanism comes from research showing that inhibition of production of MCV proteins causes MCV-infected Merkel carcinoma cells to die but has no effect on malignant Merkel cells that are not infected with this virus. MCV-uninfected tumors, which account for approximately 20% of Merkel cell carcinomas, appear to have a separate and as-yet unknown cause. No other cancers have been confirmed so far to be caused by this virus. Because of the viral origin for this cancer, immunotherapies are a promising avenue for research to treat virus-positive Merkel cell carcinoma.

This cancer is considered to be a form of neuroendocrine tumor. While patients with a small tumor (less than 2 cm) that has not yet metastasized to regional lymph nodes have an expected 5-year survival rate of more than 80 percent, once a lesion has metastasized regionally, the rate drops to about 50 percent. Up to half of patients that have been seemingly treated successfully (i.e. that initially appear cancer-free) subsequently suffer a recurrence of their disease. Recent reviews cite an overall 5-year survival rate of about 60% for all MCC combined.

Merkel cell carcinoma (MCC) occurs most often on the sun-exposed face, head, and neck.

Etiology

A newly discovered virus called Merkel cell polyomavirus (MCV) likely contributes to the development of the majority of MCC. Approximately 80% of MCC have this virus integrated in a monoclonal pattern, indicating that the infection was present in a precursor cell before it became cancerous. At least 20% of MCC tumors are not infected with MCV, suggesting that MCC may have other causes as well.

Polyomavirus have been known to be oncogenic (cancer-causing) viruses in animals since the 1950s, but MCV is the first polyomavirus strongly suspected to cause tumors in humans. Like other tumor viruses, most people who are infected with MCV probably do not develop

MCC. It is currently unknown what other steps or co-factors are required for MCC-type cancers to develop. Exposure to ultraviolet (UV) light, which is found in natural sunlight and in the artificial light generated by tanning beds, probably contributes to MCC development in a high percentage of cases. MCC can also occur together with other sun exposure-related skin cancers that are not infected with MCV (i.e. basal cell carcinoma, squamous cell carcinoma, and melanoma). Intriguingly, most MCV viruses obtained so far from tumors have specific mutations that render the virus uninfecious. It is unknown whether these particular mutations result from sun exposure. MCC also occurs more frequently than would otherwise be expected among immunosuppressed patients, such as transplant patients, AIDS patients, and the elderly persons, suggesting that the initiation and progression of the disease is modulated by the immune system.

While infection with MCV is common in humans, MCC patients whose tumors contain MCV have higher antibody levels against the virus than similarly infected healthy adults. A recent study of a large patient registry from Finland suggests that individuals with MCV-positive MCC's have better prognoses than do MCC patients without MCV infection. While MCV-positive MCC may be a less aggressive form of the disease, the results of the aforementioned study may instead be due to significant differences in other confounding factors, including tumor stage at the time of diagnosis, the age of the patient, or the location of the tumor rather than any intrinsic difference in disease aggressiveness or response to therapy.

Signs and Symptoms

MCC usually presents as a firm, painless, nodule (up to 2 cm diameter) or mass (>2 cm diameter). These flesh-colored, red, or blue tumors typically vary in size from 0.5 cm (less than one-quarter of an inch) to more than 5 cm (2 inches) in diameter, and usually enlarge rapidly. Although MCC's may arise almost anywhere on the body, about half originate on sun-exposed areas of the head and neck, one-third on the legs, and about one-sixth on the arms. In about 12% of cases, no obvious anatomical site of origin ("primary site") can be identified.

Merkel cell cancers tend to invade locally, infiltrating the underlying subcutaneous fat, fascia, and muscle, and typically metastasize early in their natural history, most often to the regional lymph nodes. MCC's also spread aggressively through the blood vessels, particularly to liver, lung, brain, and bone.

Histology

Merkel Cell Carcinoma is a microscopically small cell carcinoma, poorly differentiated, consists of small cells (slightly larger than lymphocytes), with a scanty cytoplasm, round nuclei with fine chromatin. Numerous figures are division's mitotic cells, apoptotic and bonfires necrosis. The stroma consists of numerous capillaries. In preparations stained with hematoxylin and eosin staining, conglomerates are intermediate filaments in the form of spheres near the poles of the cell nucleus (called IF Bodies), diagnostic for this type of cancer. Histologically, there are three types of MCC:

- Trabecular
- Intermediate
- Small cell

Merkel Cell Carcinoma (MCC) Treatment Fractionation and Doses

- **Use of Standard Fractionation:**
 - 400cGy in 5 fractions, 5 times a week, total Dose of 2000cGy (palliative)
- **Baseline fractionation scheme:**
 - Same as above
- **Selection of treatment kV (50kV, 70kV, 100kV):**
 - 100kV for tumor coverage.
- **Treatment Margin:**
 - 20mm with standard setup



Chapter 14: Clinical Radiation Oncology



Radiotherapy is a clinical treatment modality where ionizing radiation is used to treat patients with malignant neoplasms. The goal of radiation therapy is to deliver a measured dose of radiation to a defined volume with minimal damage to surrounding normal tissue, resulting in eradication of the tumor. Radiotherapy is generally given in divided doses or fractionated. Radiotherapy is useful in the treatment of localized tumors and can provide long-term local control with preservation of regional function. There are several principles that dictate the prescription of irradiation and therefore the management of cancer patients, with the goal of delivering a precise dose of radiation to a defined tumor volume with as minimal damage as possible to surrounding normal tissues.

Principles of Radiotherapy

- Eradication of the tumor
- Improvement of quality of life
- Prolongation of life span

Process of Radiotherapy

- Tumor staging. Complete evaluation of the full extent of the tumor.
- The knowledge of the biologic behavior of specific tumor types. This includes potential areas of metastasis.
- Defining the goal of Superficial Radiation Therapy: Curative versus palliative treatment.
 - Curative: It is projected that the patient has the probability for long-term survival.
 - Palliative: Patient survival for an extended period is not projected. However, irradiation of the tumor will improve the patient's quality of life.
- When selecting an appropriate treatment course, clinicians may utilize irradiation alone or in combination with surgery.
- Determination of the irradiation dose and volume to be treated. This depends upon the anatomic location, histological type, tumor stage, potential lymph node involvement, other tumor characteristics and normal structures present in the area to be irradiated.
- Evaluation of the patient's general condition.

Clinical Evaluation

- Pathology
- Staging work-up
- Patterns of spread and failure
- Biologic mechanisms
- Microenvironment conditions
 - Oxygen tension (necessary for production of free radicals and the resultant tumor damage)
- “Inherent “cellular radioresistance
 - Repair sublethal and potential lethal damage
- Tumor cell repopulation

Therapeutic Decision: Goal of Therapy

- Curative: definitive

Periodic Evaluation (During Treatment) and Follow-Up

- Careful assessment of acute and late toxicity



Chapter 15: Patient Selection For Cutaneous Lesion Treatment



The main objective in radiation oncology for skin lesions is to eradicate the lesion while maintaining the patient's present and future quality of life. Delivering precisely measured dose of radiation to a defined tumor volume with minimal damage to surrounding tissue is the main goal. The success of eradicating a tumor depends on the radiosensitivity of the tumor as well as tolerance of surrounding normal tissue. Normal tissue toxicity factors that should be considered in selecting a dose scheme should depend on the size or volume of the area, vascularity, and the underlying and supporting tissues. The tissues of the body have individual variation of absorption and tolerance to ionizing radiation. Therapeutic indexes (also known as therapeutic ratio) are a good tool for dose selection.

When the soft X-rays from the SRT beam hits a cell that is dividing, the cell will be damaged. Cancer cells are much less able than normal cells to repair themselves, causing the cancer cell to be destroyed. As the damaged cells die, healthy cells begin to replace them. Superficial radiation therapy works by optimizing damage to cancer cells while minimizing the effects to normal cells in the margins. SRT is specifically engineered to deliver 100% of the energy at the skin surface. Energy selection is based upon the deepest portion of the lesion. SRT-100 has 3 therapeutic energies that cover all depths of lesions that a Dermatologist would want to treat.

The average outpatient treatment can take place 1 to 5 times per week. The number of sessions required will vary based on the tumor size, depth, and location.

During treatment, a small lead cutout with a treatment applicator is placed on the skin thru which soft X-rays are delivered for less than a minute. The therapy is non-invasive and painless. Upon completion, the lead cutout and applicator are removed.

The patients are able to drive themselves home and immediately return to normal activities. Superficial radiation therapy skin treatments are localized to the skin cancer and margin; all other areas of the body are protected with treatment devices which are placed prior to treatment. There is no exposure to other areas of your body.

As treatments progress, patients will develop some inflammation which may result in some soreness around the area being treated. Many patients equate the sensation to minor sunburn. Patient selection for training:

1. Patient etiologies should be kept to SCC and BCC
2. Lesion size, 3cm or less
3. Optimal lesion selection should cover any part of the body
4. Lesions covering upper eye lid, lower eye lid, outer canthus, or inner canthus need purchase of an internal eye shield. Instructions provided by Sensus healthcare

General outline of a patient treatment: the procedure consists of 5 documents which justify the CPT codes used with superficial radiation therapy. The documents consist of: Eligibility, Simulation, Prescription, Second Calculation, and Management.

- a. A day or so prior to the start of treatment, the physician will perform a "simulation". Using the information from the biopsy, the doctor will outline the treatment area with a marking pen and prescribe a dose. Generally this dose is divided up into 8-16 equal treatments called "fractions". This method allows for the marginal tissue to recover from targeted hits made by the soft X-rays. A custom shield is cut from a piece of lead to minimize the area exposed by the SRT beam. The Eligibility,

- simulation, Prescription, and second Calculation documents are completed at this time, post Simulation.
- b. Based upon the selected fractionation scheme, the patient will usually be treated 2 to 3 times a week. These fractions are equally spaced apart to optimize the recovery with cells in the treatment margins. Total treatment time from setup to end of treatment us usually around 10 to 15 minutes.
 - c. Every fifth fraction, an evaluation of the lesions reaction will be documented on the Management form.
 - d. Around the 3 to 4 fraction (treatment), redness to the skin will start to appear.
 - e. Fractions 7, 8, 9, most lesions become more sensitive to the radiation due to the core of the lesion becoming less hypoxic or anoxic. If the patient has a little more reaction than anticipated, a break may be warranted. Patient body habitat, paper skin, underlying cartilage or bone, maybe overall bad circulation can warrant such breaks. The break will slow down the biological response and enable the completion of treatments.
 - f. Upon completion of the fractionation scheme the patient will experience 2 more weeks of a continued biological reaction.
 - g. A six week follow-up is the standard to give time for the lesions to be fully irradiated and for marginal tissue respond back to normal.



Chapter 16: Cutaneous Lesion Clinical Treatment Planning



Tumor Depth

Once the decision has been made to proceed with Superficial Radiation Therapy, several logistical issues need to be addressed prior the beginning of therapy. The first consideration is the penetration depth of the beam needed to adequately treat the skin cancer. Slide review is essential as a means of appreciating the histologic characteristics and depth of the tumor. A simple micrometer can be used in conjunction with most standard microscopes. Our standard microscopes have a built-in program that can measure depth and assist in estimating tumor volume. Once the depth of the tumor has been determined, the penetrating quality of the beam can be selected to adequately treat the deepest portions of the tumor.

Beam Quality

The heterogeneous beam produced by superficial dermatologic X-ray units consists of X-rays of varying wavelengths. The distribution and proportion of short wavelengths (hard X-rays) versus longer wavelengths (soft X-rays) determines the penetrating effect, or quality, of the radiation. The penetration of superficial quality X-rays is determined by three variables: the voltage (kV), the filtration, and the target skin distance (TSD). The combined effect of these variables has been traditionally expressed as the "half-value layer" (HVL). The half value layer is the thickness of a given material (typically aluminum) that reduces the intensity of the photon beam to 50% of the original exposure (Goldschmidt, 1991). The greater the HVL, the more penetrating the resulting beam.

The range in which most dermatologic X-ray machines operate within is 50 to 100 kV, which relates to an HVL range of 0.4mm Al to 2.0mm Al. As the kilovoltage increases, the potential difference between the cathode and the anode increases, resulting in a higher speed and energy of the electrons aimed at the tungsten target. The increase in kV results in a higher intensity photon beam with greater penetrating power.

Beam quality is also affected by the degree of filtration. An aluminum filter is typically employed to filter out the lower intensity portions of the heterogeneous beam, resulting in an emerging beam of less intensity but of greater average penetration.

Umbra Selection

In a similar fashion, once the beam depth has been selected, the beam width must be considered. The umbra of the treatment field is directly proportional to the *clinical* margins of the lesion. Careful clinical inspection by an experienced clinician with proper illumination is the gold standard of margin delineation. If there is any question as to the borders or if it is ill-defined, scouting 10 biopsies may be warranted. Once the clinical lesion border has been identified, it should be delineated and recorded in some fashion. Various marking techniques are available of varying degrees of permanence and visibility. One commonly employed method is to delineate the clinical lesion with a gentian violet marker or Castellani paint. A treatment margin is then selected beyond the clinically evident tumor. 8-10mm margins are common for BCC, while 10mm is used for SCC. Ill-defined and more aggressive tumors may warrant a wider margin. Lead shields are typically utilized to limit the beam to a desired treatment area. Occasionally, in some situations where a lead shield is not employed, the applicator itself may serve as the desired treatment diameter, such as on the auricular areas where many folds are present. Because there is an inherent drop-off in the beam along the edges, it is preferable to use a shield diameter smaller or equal to the applicator size to minimize the lateral edge drop-off effect.

If more than one tumor is being treated concomitantly or the treatment site is near a previous radiation treatment site, care must be taken to prevent overlap of the treatment fields.



Chapter 17: Cutaneous Lesion Clinical Treatment Documentation



Intentionally blank. The Clinical Treatment Documentation will be placed in this handbook by the Sensus Clinical Applications Team during training.



Chapter 18: Clinical Applications Definitions



A

Absorbed Dose: The energy imparted to matter by ionizing radiation per unit mass of irradiated material. The unit of radiation absorbed dose is the rad. One rad equals 100 ergs or energy per gram of matter.

Acute Exposure: Radiation exposure of short duration.

Alpha Particle: A charged particle having a mass and charge equal in magnitude to a helium nucleus (a cluster of two protons and two neutrons) that is emitted from the nucleus of an atom.

Anemia: Deficiency of blood as a whole, or deficiency in hemoglobin or in the number of the red blood cells.

Area Monitoring: Routine monitoring of the radiation level or contamination in a particular area, building, room, or piece of equipment. Some laboratories or operations distinguish between routine monitoring and survey activities.

Atom: Smallest unit of an element which is capable of entering into a chemical reaction.

Atomic Mass: The mass of a neutral atom of a nuclide, usually expressed in terms of "atomic mass units". An "atomic mass unit" is one-twelfth the mass of one neutral atom of ^{12}C ; equivalent to 1.6604×10^{-24} grams. (Symbol: A).

Atomic Number: The number of protons in the nucleus of an atom of a nuclide. The "effective atomic number" is calculated from the composition and atomic numbers of a compound or mixture of atoms with different atomic numbers. An element of this atomic number would interact with photons in the same way as the compound or mixture. (Symbol: Z).

Attenuation: The process by which a beam of radiation is reduced in intensity when passing through some material. It is the combination of absorption and scattering processes and leads to a decrease in flux density of the beam when projected through matter.

Autoradiograph: Record of radiation from radioactive material in an object, made by placing the object in close proximity to a photographic emulsion.

B

Beam: A unidirectional or approximately unidirectional flow of electromagnetic radiation or particles.

Beta Particle: Charged particle emitted from the nucleus of an atom, with a mass and charge equal in magnitude to that of the electron.

Bone Marrow: Soft material which fills the cavity in most bones; it manufactures most of the formed elements of the blood (white and red blood cells).

Bone Seeker: Any compound or ion that migrates into a bone in the body.

Bremsstrahlung: Secondary photon radiation produced by deceleration of charged particles passing through matter.

C

Carcinogenic: Capable of producing cancer.

Chronic Exposure: Radiation exposure of long duration by fractionation or protraction. (See Dose, Fractionation and Dose, Protraction.)

Contamination, Radioactive: Deposition of radioactive material anywhere where it is not desired, particularly where its presence may be harmful. The harm may be in interfering with an experiment or a procedure, or in actually being a source of danger to personnel.

Counter, Geiger-Mueller: Highly sensitive, gas-filled radiation-detecting device. It operates at voltages sufficiently high to produce avalanche ionization.

Counter, Proportional: Gas-filled radiation detection device; the electronic pulse produced is proportional to the number of ions formed in the gas by the primary ionizing particle.

Counter, Scintillation: The combination of phosphor, photomultiplier tube, and associated circuitry for measuring light emissions produced by ionization in the phosphors.

Cumulative Dose (Radiation): The total dose resulting from repeated exposures to radiation.

Curie: The special unit of activity. One curie equals 3.700×10^{10} nuclear disintegrations per second. (Abbreviated Ci.) Several fractions of the curie are in common usage.

D

Decay, Radioactive: Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles and/or photons.

Detector, Radiation: Any device for converting radiant energy to a form more suitable for observation. An instrument used to determine the presence, and sometimes the amount, of radiation.

Dose Equivalent (DE): A quantity frequently used in radiation protection. It expresses all radiation on a common scale for calculating the effective absorbed dose. It is defined as the product of the absorbed dose in Grey or rad and certain modifying factors. (The unit of dose equivalent is the Sievert or rem.)

Dose, Fractionation: A method of administering radiation, in which relatively small doses are given daily or at longer intervals.

Dose, Protraction: A method of administering radiation by delivering it continuously over a relatively long period at a reduced dose rate.

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

Dosimeter: Instrument to detect and measure accumulated radiation dose. See Film Badge and TLD.

E

Effective half-life = Biological half-life x Radioactive half-life / (Biological half-life + Radioactive half-life)

Electron Volt: A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt. Larger multiple units of the electron volt are frequently used: keV for one thousand (or kilo) electron volts; MeV for one million (or mega) electron volts. (Abbreviated: eV, $1 \text{ eV} = 1.6 \times 10^{-12} \text{ erg.}$)

Electron: A stable elementary particle having an electric charge equal to $\pm 1.60210 \times 10^{-19}$ coulomb and a rest mass equal to $9.1091 \times 10^{-31} \text{ kg.}$

Exposure: A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume of air are completely stopped in air, divided by the mass of the air in the volume. The special unit of radiation exposure is the roentgen (R).

F

Film Badge: A pack of photographic film which measures radiation exposure for personnel monitoring. The badge may contain two or three films of differing sensitivity and filters to shield parts of the film from certain types of radiation.

Fissile: A nuclide capable of undergoing fission by interaction with slow neutrons.

Fission, Nuclear: A nuclear transformation characterized by the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy in the form of heat and nuclear radiations.

G

Gamma Ray: Short wavelength electromagnetic radiation (range of energy from 10 keV to 9 MeV) emitted from the nucleus of an atom during radioactive decay.

Gas Amplification: As applied to gas ionization radiation detecting instruments, the ratio of the charge collected to the charge produced by the initial ionizing event.

Geiger Region: In an ionization radiation detector, the operating voltage interval in which the charge collected per ionizing event is essentially independent of the number of primary ions produced in the initial ionizing event.

Geiger Threshold: The lowest voltage applied to a counter tube for which the number of pulse produced in the counter tube is essentially the same, regardless of a limited voltage increase.

Grenz rays: (10–20kv - kilovolts.) These are still used in some centers, particularly in Germany. Contact therapy using 40–50kv and short source to surface distance (SSD). Grenz rays are used for treatment depths of 1–2mm, as they provide very rapid falling depth-doses.

H

Half Value Layer (Half Thickness) (HVL): The thickness of a specified substance which, when introduced into the path of given beam of radiation, reduces the exposure rate by one-half.

Half-Life, Biological: The time required for the body to eliminate one-half of an administered dosage of any substance by regular biological processes of elimination. It is approximately the same for both stable and radioactive isotopes of a particular element.

Half-Life, Effective: Time required for a radioactive element deposited in a human or animal to be diminished by 50 percent as a result of the combined action of radioactive decay and biological elimination.

Half-Life, Radioactive: Time required for a radioactive substance to lose 50 percent of its radioactivity by decay. Each radionuclide has a unique half-life.

I

Interlock: A device, usually electrical and/or mechanical, to prevent activation of a device until a preliminary condition has been met, or to prevent hazardous operations. Its purpose usually is safety.

Ion Pair: Two particles of opposite charge, usually referring to the electron and positively charged atomic or molecular residue resulting from the interaction of ionizing radiation with the orbital electrons of atoms.

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

Ionization Chamber: An instrument designed to measure a quantity of ionizing radiation in terms of the electric charge associated with ions produced within a defined volume.

Ionization: The process by which a neutral atom or molecule acquires a positive or negative charge.

Irradiation: Exposure to radiation.

Isotopes: Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons, and therefore differing in the mass number. Almost identical chemical properties exist between isotopes of a particular element.

K

Kerma: The sum of the initial kinetic energies of all charged particles liberated by indirectly ionizing particles in a volume, divided by the mass of matter in that volume.

L

Linear Energy Transfer (LET): The amount of energy transferred to matter as radiation interacts with it. Often expressed in units of keV per micron of path length.

M

Maximum Permissible Dose Equivalent (MPD): The greatest dose equivalent that a person or specified body part shall be allowed to receive in a given period of time.

Microcurie: One-millionth of a curie (3.7×10^4 disintegrations per second). Abbreviated μCi .

Millicurie: One-thousandth of a curie (3.7×10^7 disintegrations per second). Abbreviated mCi .

Monitoring: Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region.

O

Orthovoltage therapy: ('Deep therapy' with 150–300kv.) Most clinical units operate at 200–300kv. The treatment distance is about 50cm SSD. Ninety percent of the dose is delivered within approximately 2cm of the surface.

P

Personnel Monitoring: Monitoring of any part of an individual, his breath or excretions, or any part of his clothing.

Photon: A quantity of electromagnetic energy (E) whose value in joules is the product of its frequency (ν) in hertz and Planck's constant (h). The equation is $E = h\nu$.

Picocurie: One-millionth of a microcurie (3.7×10^{-2} disintegrations per second or 2.22 disintegrations per minute). Abbreviated pCi .

Proton: Elementary nuclear particle with a positive electric charge equal numerically to the charge of the electron and a mass of 1.007277 mass units.

Q

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 for all ionizing radiations) the effectiveness of the absorbed dose of radiation.

R

Rad: The unit of absorbed dose in rads is equal to 0.01 J/kg in any medium. (See Absorbed Dose.)

Radiation or Ionizing Radiation: Gamma rays and X-rays, alpha and beta particles, neutrons, protons, high-speed electrons and other nuclear particles, but not visible light, sound, radio waves, laser radiation, or microwaves.

Radiation-Producing Machine: Any device capable of producing radiation when the associated control devices are operated or electrical circuits are energized.

Radioactive Material: Any material which emits radiation spontaneously.

Rem: A special unit of radiation dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor QF.

Roentgen (R): The unit of radiation exposure. One roentgen equals 2.58×10^{-4} coulomb per kilogram or air. (See Exposure.)

S

Scattering: Change of direction of subatomic particles or photons as a result of a collision or interaction.

Sealed Source: Any radioactive material permanently encapsulated in such a manner that it will not be released under the most severe conditions likely to be encountered in normal use. This encapsulation must meet rigid specifications.

Secondary Electron: An electron ejected from an atom, molecule, or surface as a result of an interaction with a charged particle or photon.

Source Material: Uranium or Thorium, or any combination thereof, in any physical or chemical form except SNM, and ores which contain less than one-twentieth of one percent (0.05%) of Uranium or Thorium.

Special Nuclear Material (SNM): Plutonium or Uranium-235, or material enriched in U-233, U-235, or Plutonium.

Specific Ionization: Number of ion pairs per unit length of path of ionizing radiation in a medium; e.g., per cm of air, or per micrometer of tissue.

Superficial therapy: (50–150kv) with typical filtration, beams with half-value layers (HVLs) in the range of 1–8mm Al. The SSD is normally 10–30cm. Beam characteristics are suitable for treatment of lesions up to 5mm deep, delivering 90% of the dose to the surface.

T

TLD (Thermo luminescent Dosimeter): A crystalline material (e.g., lithium fluoride) which is used to measure accumulated radiation dose. When exposed to radiation at ambient temperatures, electrons migrate to crystal lattice defects. When heated, the crystal releases this energy as light which can be detected by a photomultiplier tube and correlated to the amount of radiation dose received.

Total Ionization: The total electric charge of one sign on the ions produced by radiation in the process of losing its kinetic energy. For a given gas, the total ionization is closely proportional to the initial ionization and is nearly independent of the nature of the ionizing radiation. It is frequently used as a measure of radiation energy.

U

Useful Beam (Radiology): Radiation that passes through the aperture, cone, or other collimating device of the source housing, “Sometimes called the “primary beam””.

V

Valence Electron: Electron that is gained, lost, or shared in a chemical reaction.

X

X-rays: Penetrating electromagnetic radiation whose wavelengths are shorter than those of visible light and ultraviolet radiation. X-rays are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions, it is customary to refer to photons originating in the nucleus as gamma rays, and those originating in the extra-nuclear part of the atom as X-rays. These rays are sometimes called roentgen rays after their discoverer, W.C. Roentgen.



Chapter 19: Cutaneous Lesion Clinical Applications Procedures



Chapter 19: Clinical Applications Procedures

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P1: Clinical Treatment Procedures



Patient Positioning

There are several factors that must be taken into account when positioning a patient for superficial radiation therapy; these include the patient's ability to lie flat, or on their side, the mobility of the patient's head and neck, and the patient's ability to remain still. Patients with good mobility can lie in the supine position and turn their head either way, allowing access to the lesion. The only blocking required for this type of patient is a pillow under the head and downward pressure from the SRT-100™. It is helpful in these patients to place a pillow under the knees to alleviate any pressure on the lower back and to minimize the chance of movement during the treatment. The more comfortable the patient is, the less they are apt to move during treatment.

Patients with a lesion on the vertex of the scalp, or on the posterior aspect of the scalp, may need to lie in the prone position for adequate treatment to be achieved. This is most easily accomplished with a prone pillow with a face cutout. With the prone pillow on the bed, the patient can use a pushup like motion to lay prone with their face in the cutout area. They can then place their hands either by their side or in front of their face.

Patients confined to a wheelchair require both blocking and immobilization to achieve a reliable and effective means of treatment. These patients usually require immobilization of the neck to stabilize the head, which is best achieved with the use of foam blocks applied to the neck in the same fashion as a c-collar would be in a trauma situation. After the head and neck are stabilized, apply the external eye shields and thyroid shield, then place the lead shield/cutout over the lesion for treatment. The use of an elastic bandage material to anchor the arm of the SRT-100™ is helpful in this setting, since it keeps the SRT-100™ applicator tight against the treatment area, and also helps the patient remember to be still.

Shielding

Lead cutouts are used to define the edge of the treatment field and stop radiation to normal tissue outside the selected margin. The kV energy which is used has very small penumbra regions when it comes to the beam profiles of the treatment applicator. The lead cutouts which help define the borders on the skin are usually smaller in size than the applicator diameter. The lead inside the applicator will actually limit the penumbra because it is not the natural border of the applicator. Again, the lead cutouts should always be smaller or equal to the area of the applicator.

Treating Over a Cavity

Should the lesion exist over a cavity, such as the nasal, ear, or oral cavity, internal shielding needs to be applied? Look at the entry of the beam, does it exit into a cavity or close to it. If it does, take a surgical glove and cut one of the fingers off. Put one of the lead sinkers provided in the starter kit, this will provide a barrier between the lead and the patient. Try and select a sinker that will fit snug into the cavity. For the oral cavity, just take a flat piece of lead and place it into the figure tip. Make sure to align the shield in the direction the beam will exit behind the lesion. The purpose for blocking the cavity is to absorb the remaining low energies that can exit into the cavity, thus bouncing around causing mucosal breakdown.

When any part of the head is treated, external eyes should be shielded. The thyroid gland area should also be protected with a thyroid shield. When the eyelids, internal canthus, and external

canthus are irradiated, internal eye shields should be placed between the eyelid and the properly anesthetized eye. A lead apron should be placed over the patient's pelvis and neck area (thyroid), before such sections of the body are treated. Anytime an area is treated and a cavity is present in the underlining area, fill the cavity with lead to reduce reactions (place lead in a barrier in order to stop the leads contact to the patient's skin).

When treating the head and neck or upper thoracic region, blocking of the thyroid is required. The thyroid shield comes with the starter kit. They have a Velcro closure for use on sitting patients. It is simply placed over the thyroid during the treatment. One can use a larger lead apron if one is treating non facial lesions.

When radiating around the eyelids, internal canthus, or external canthus are irradiated, silver-plated lead internal eye shields (not provided) should be placed between the eyelid and the properly anesthetized eye. Internal eye shields have tabs on the top which can be grasped with a hemostat; a curved hemostat enables a better angle of insertion. Insert the intraocular eye shields using the following procedure: Instill one drop of tetracaine ophthalmic solution into the eye. Ensure that the shield is lubricated with a sterile eye lubricant. Lift up the superior eyelid and place the shield between the upper eyelid and the globe, then slide the shield under the lower eyelid. After the shield is placed, treatment of the lesion on or around the eyelid can commence. Typically, a custom lead shield is used, but in some cases (such as at a medial canthal concave location) a treatment cone of the exact desired port can be used without a shield. The removal of the intraocular shield is the exact opposite of the insertion.



Clinical Setups

Setups in areas which take a little effort to get a flat entry or a consistent margin are referenced as clinical setups. The ears, nose, appendages that have a curvature to their surface often require documentation and photos to help with consistent recreation of applicator contact with the lesion and surrounding margin. These setups tend to have areas of "flash" within the cutout of the lead shield on the surface of the patient. Flash is simply the lack of tissue in the way of the beam, air. In these instances, block down with a separate piece of lead, without violating the margin or lesion. Should the flash simply go off into air in the direction away from the patient's skin, no blocking is needed.

Air Gaps

The human body is not flat, so every setup will have its mounds and valleys. Despite these challenges, it is important to maintain consistency in these irregularities. Although 1 to 2

mm will not push a lesion's dose outside the therapeutic index, 3 to 5mm could have an impact in clearing the backside of the lesion or pushing a section into an acute reaction scenario.

Inverse Square Law

Certain situations, such as lesions with a bulky top, or where a large air gap remains after setup, are subject to the inverse square law and may be more prone to reactions. The inverse square law says that an object that is twice the distance from the source of the radiation will receive a quarter of the radiation. The beam of radiation affects intensity of energy, and not a direct proportion. On an average, 6-8% of dose can be lost for every 1 mm of air gap (depending upon the applicator size with relation to scatter). Inversely, dose is gained for every 1 mm of tissue that rises up through the applicator from the set SSD of treatment. The inverse square law is one of the main reasons to select a TDF number of 100 when selecting a fractionation scheme for treatment. This therapeutic number mitigates reactions and assures index compliance, even if there are small irregularities in the setup.

Starter Kit

The Starter Kit included with the SRT-100™ system comes with items helpful when beginning to treat using Superficial Radiation Therapy.

The most important items included in the kit are prefabricated lead foil cutouts (precut to 8cm by 8cm, with circular cuts of 1.0 cm, 1.5 cm, 2.0 cm, 2.5 cm, 3.0 cm, 3.5 cm, 4.0 cm, 4.5 cm, 5.0 cm, plus 4 blanks with no cutouts), along with tools to help make additional lead cutouts.

Additional lead shielding items in the kit include four intra-nasal weights (elongated Barrel weights which will fit snugly in the nose), and four oval weights for the ear canal (sized to fit snugly in the ear).

The kit also contains important blocking and radiation protection items, such as lead goggles, a thyroid collar, an X-ray apron, and a coated head and neck support.



P2: Administrative Procedures for Superficial Radiation Therapy



The Sensus Healthcare SRT-100™ program is administratively controlled by several procedures. These procedures include radiation safety, training requirements, operator qualifications, as well as mandatory records, postings, and reporting. These are required by state and federal regulatory codes for ionizing radiation therapy devices with X-ray energies of 100 kV and less.

1. Radiation Safety

General safety procedures for Superficial Radiation Therapy:

- All individuals must wear their assigned dosimeters as required.
- Individuals whose presence during an exam is not required should not stay as an observer unless required as a part of the clinical learning process.
- All individuals shall exit the room while a patient receives a treatment.
- A patient shall not be held by another individual during a treatment.
- Immobilization devices should be used whenever possible to insure accuracy of treatments.
- Patients shall wear external eye shields or goggles during treatments.
- Patients shall have lead shields placed on the skin to define the treatment area (minimal of .762mm lead thickness).
- Patients shall wear lead aprons (minimal of .25mm lead thickness) over unaffected areas of the body that are close to the treatment site.
- Patients shall wear thyroids shield when treatment areas are in the proximity of the head and neck region (minimal of .25mm lead thickness).
- Only individuals who meet the state-mandated qualifications for an operator of Superficial Radiation Therapy may operate the SRT-100™ unit.

Exposure limits:

- Annual radiation exposure limits for Superficial Radiation Therapy workers are:
 - Whole body effective dose – 50.0 mSv
 - Any individual organ or tissue, other than the lens of the eye – 500.0 mSv
 - Lens of the eye – 150.0 mSv
 - Skin – 500.0 mSv
 - Extremity – 500.0 mSv

2. ALARA

ALARA stands for: “As Low As Reasonably Achievable”; radiation workers are encouraged, empowered, and required to keep their radiation exposures ALARA for themselves as well as that of their co-workers, visitors, and patients (excluding therapeutic radiation doses).

- Methods include time, distance, and shielding.
- Be cognizant of where radiation exposures might be highest and minimize time in those areas.
- Place shielding apron(s) on patients as appropriate.

3. Personnel Radiation Monitoring

General dosimeter requirements:

- Dosimeter shall, at a minimum, be worn by all personnel who may receive greater than 10% of the regulatory annual occupational dose limit.
- Dosimeters are required for individuals involved in the therapeutic treatment procedures of patients.
- Dosimeters used for individuals shall be able to detect photon radiation.
- Dosimeters shall be provided by and applied for through the Radiation Safety Officer.
- The dosimeter is worn at the collar.
- Declared pregnant workers who frequent a restricted area shall be assigned two dosimeters.
 - One dosimeter worn at the collar (labeled “neck” or “collar”)
 - Second dosimeter worn at waist level (labeled “waist” or “chest”)

Care of dosimeters:

- Personal radiation dosimeters are for use by a single individual and shall not be shared, reassigned or discarded.
- Radiation dosimeters do not provide protection from radiation; they only provide an "after the fact" assessment of radiation to which it (and presumably the wearer) was exposed.
- Radiation dosimeters shall be worn at the position appropriate for the work being performed.
- Radiation dosimeters are very sensitive to environmental conditions such as heat, light and moisture. Dosimeters should be used properly, should not be taken home or stored in cars or on windowsills.
- Radiation dosimeters shall be stored in low background areas (e.g., offices) when not being worn.
- Radiation dosimeters are for occupational exposure only and are NOT to be worn during personal medical or dental procedures.

Dosimetry analysis and reports:

- Personal dosimeters must be returned in a timely fashion to the Radiation Safety Officer for analysis.
- Quarterly dosimeter analysis reports are sent by the vendor to the Radiation Safety Officer.
- Quarterly analysis reports shall be placed in the document binder for review.
- Monitored personnel shall be provided copies of individual dosimeter reports upon request.
- Requests must be made to the Radiation Safety Officer. Reports will be provided within 30 days after the request is made or within 30 days after receipt of the data for the last dosimeter, whichever is later.

Dosimeter exchange procedure:

- To prevent unmonitored exposure, before used dosimeters are returned, new dosimeters are picked up.
- All dosimeters shall be picked up in the Radiation Safety Officer during the first 3 working days of each quarterly series.
- All dosimeters shall be returned to the Radiation Safety Officer during the first 10 days of the quarterly series.
- All late returned and non-returned dosimeters require completion of a radiation dosimetry follow-up form.
- The Radiation Safety Officer shall issue the form upon receipt of a report indicating a dosimeter was not returned as required.

Lost, late return, or damaged dosimeters:

- Lost or damaged dosimeters shall be reported immediately to the Radiation Safety Officer.
- Temporary replacement dosimeters will be issued if dosimeters are lost or damaged prior to the return exchange.
- A radiation dosimeter follow-up is required to be completed for all lost, late return and damaged dosimeters.

4. Pregnant Worker Radiation Safety

- Pregnant individuals are not considered declared pregnant workers until they declare the pregnancy in writing to the Radiation Safety Officer.
- The declaration must include:
 - The name of the individual
 - The date of declaration
 - The type of radiation exposed to in the workplace
 - The estimated date of conception
- The radiation dose limit to the fetus/embryo of a declared pregnant worker is 5.0 mSv total effective dose equivalent over the term of the pregnancy.
- The RSO will review the individual's exposure record. If the record indicates that an exposure to the embryo/fetus of greater than 5.0 mSv may occur, the RSO will initiate steps to move the individual to a position of lower radiation exposure and one that the exposure can be maintained less than 5.0 mSv.
- Pregnant individuals may continue to operate and work around Superficial Radiation Therapy unless deemed otherwise by the RSO.
- Pregnant individuals should review NRC Regulatory Guide 8.13. This guide covers the effects of radiation to the embryo and fetus.

5. Radiation Survey Requirements

- Radiation surveys should be performed at Commissioning and Annual QA.
- Performed to verify shielding adequacy.
- They determine worst-case exposure to any individual outside of treatment room per criteria of mSv or mRem per hour, week, and year.
- They help inform staff of radiation exposure rates during treatment to assist in maintaining radiation exposures ALARA.

6. Operator Requirements

- All operators of the SRT-100™ Superficial Radiation Therapy unit shall be licensed in accordance with state regulations.
- A radiation therapy technologist may utilize the SRT-100™ Superficial Radiation Therapy unit for therapeutic purposes on a patient.
- A radiation therapy technologist must work under the general supervision of a licensed practitioner.
- In order to provide general supervision, the licensed practitioner must be readily available for consulting with and directing the procedures.
- Each department that utilizes the SRT-100™ Superficial Radiation Therapy unit must maintain copies of current licensure for all personnel who operate the unit.
- Before operating any SRT-100™ Superficial Radiation Therapy unit, the operator shall ensure they are familiar with the unit's operating characteristics, as well as the purpose and function of protective devices.
- Any operator who has questions concerning or doubts regarding the operation of a unit shall immediately seek guidance from their RSO or other appropriate individual.
- Operators shall report promptly to their RSO any condition they know or suspect may constitute, lead to or cause a violation of regulations, or unnecessary exposure to radiation.

7. Training Requirements

SRT-100™ Superficial Radiation Therapy Radiation Worker:

- Only individuals who meet the qualifications for an operator of Superficial Radiation Therapy unit may operate in a clinical (human-use) setting.
- Prior to allowing an individual to operate a Superficial Radiation Therapy unit, ensure the individual is licensed in accordance with the state.
- Ensure the individual has obtained SRT-100™ Superficial Radiation Therapy training. Generally this training includes:
 - Radiation
 - Generating X-rays
 - Types of X-rays Produced
 - Controlling X-rays
 - Fundamental Principles of Radiobiology
 - Principles of Radiation Oncology

- Therapeutic Index
- Fractionation
- TDF Tables
- Clinical Treatment Planning
- SRT Documentation for Clinical Treatment
- Radiation Safety
- SRT-100™ Operations and Procedures
- Instructions for promptly reporting any condition that may constitute, or lead to, or cause a violation of radiation protection or QA procedures, policies, rules or regulations

Ancillary Radiation Worker

- All employees shall receive general radiation protection training.
- The minimum training shall include:
 - Health protection problems associated with exposure to radiation and procedures to minimize the exposure
 - Instruction to report promptly any condition that they know or suspect may constitute or lead to or cause a violation of radiation protection or QA procedures, policies, rules or regulations.
 - Applicable warning signage
 - The location of the restricted area

Patients

- Departments that perform procedures involving SRT shall maintain informational material on procedures routinely performed.
- Informational material shall be provided upon request or as considered necessary by the prescribing physician

8. Intervals for Quality Assurance & Routine Maintenance of the SRT-100™ Unit

- Daily QA: Each day any patients are being treated.
At least three times per week if patients are not being treated.
- Monthly QA: Encompassed by Daily QA. Certain states may require Physicists to review Daily QA records at least once per week/per month.
- Annual QA: Once per calendar year. Interval between Annual QA should be 'reasonably' spaced to accommodate the annual definition (e.g., not less than nine months and not more than fifteen months between performances of Annual QA's). State regulations may dictate a more restrictive interval.

SRT-100™ PM: Unit Preventive Maintenance should be performed annually.

9. Equipment Logs

- Owners of an SRT-100™ Superficial Radiation Therapy unit should maintain a separate maintenance log, which should include:
 - Unit serial number
 - Incidents and actions
 - Maintenance performed
 - Repair information
- The SRT-100™ Superficial Radiation Therapy system includes a User Manual, which is readily available as a reference to operators.
- SRT-100™ Superficial Radiation Therapy logs and manuals shall be maintained in or accessible from (e.g., computer terminal) the area (e.g., room) where the SRT-100™ is housed.
- SRT-100™ Superficial Radiation Therapy logs and manuals shall be readily available for use by the operator and inspection by the RSO or state inspector.

10. Posting and Signage

- Each site/department where SRT is used shall post in conspicuous locations:
 - State Notice to Employees
 - Location where this manual, applicable audit(s) and applicable inspection report(s) are maintained
 - Location where applicable rules and regulations are maintained
 - Method for contacting the RSO
 - A caution sign on the treatment room door: "CAUTION – RADIATION," or "CAUTION-This equipment produces radiation when energized," or equivalent.
 - A sign reminding patients to inform the staff prior to having Superficial Radiation Therapy treatment if there is a possibility of pregnancy.

11. Incident and Overexposure Notification Action

ALARA investigations and notifications:

- ALARA investigations shall be performed when individuals exceed 10% and 30% of the applicable regulatory limits for general radiation workers.
- The RSO will provide a written report of the exposure to the individual.
- Request the individual submit an explanation of radiation exposure during the time period in question.
- The RSO will investigate the cause(s) of the exposure and implement corrective action as deemed necessary.
- The RSO will notify the state Department of Radiation Protection within 30 days, or per state requirements.
- The notification shall include:
 - An estimation of the individual's dose
 - The levels of radiation involved
 - The cause of the exposure

- Any corrective action taken or planned to assure against recurrence
- Written notification to the individual
 - The written notification shall include nature and extent of the exposure

QA Recordable Incidents

- QA "recordable" incidents are include those that may or may not be reportable to the state:
 - Any problems with the operation of SRT-100™ Superficial Radiation Therapy unit shall be reported immediately to the RSO and documented.
 - Any problems with the operation of SRT-100™ Superficial Radiation Therapy unit that could result (but has not yet resulted) in an overexposure to personnel shall be reported immediately to the RSO (i.e., exposure greater than allow limits).

QA Reportable Incidents

- QA "reportable" incidents are ones, by rule, which require a written report to the state.
- Examples of reportable incidents:
 - Superficial Radiation Therapy to the wrong patient.
 - Superficial Radiation Therapy to the wrong treatment site.
 - Superficial Radiation Therapy dose involving the wrong energy of treatment.
 - Superficial Radiation Therapy treatment consisting of three or fewer fractions and the calculated total administered dose differs from the total prescribed dose by more than ten percent of the total prescribed dose.
 - Superficial Radiation therapy treatment consisting of more than three fractions and the calculated total administered dose differs from the total prescribed dose by more than twenty percent of the total prescribed dose.
- The RSO shall investigate the overexposure and submit required reports to the appropriate state department.
- Reportable incidents shall be reported to the appropriate state department by letter within 15 days after the incident occurred. The letter shall include:
 - The name and address of the facility
 - A brief description of the event
 - Why the event occurred
 - The effect on the patient
 - What improvements are need to prevent recurrence
 - Actions taken to prevent recurrence

Other Reportable Incidences

- "Overexposures" to personnel ("overexposure" means greater than the limit(s) allowed by regulatory requirements for personnel) shall be reported by the RSO to:
 - Appropriate state department
 - Immediately by phone if personnel exposures of 250.0 mSv or more to the whole body; 1500.0 mSv or more to the skin, and/or 3,750.0 mSv or more to an extremity (note: this must be followed by the written report listed below.)

- Within 24 hours by phone if personnel exposures of 50.0 mSv or more to the whole body, 300.0 mSv or more to the skin, and/or 750.0 mSv or more to an extremity (note: this must be followed by the written report listed below.)
- Within 30 days, in writing if personnel exposure is greater allowable limits.
- Written reports to the appropriate state department shall include:
 - Extent of the exposure
 - The cause of the exposure
 - Corrective steps take or planned to be taken to prevent recurrence
 - The individual receiving the overexposure.

12. Records

Training

- Training records shall be maintained in a readily accessible file(s).
- Training records shall be current and made available upon request to the inspectors.
- All training records associated with a Superficial Radiation Therapy Radiation Worker shall be maintained for three years after deactivation of the individual.
- Copies of records documenting completion of initial training shall be provided to the Radiation Safety Officer upon application for dosimetry and shall be maintained by the Radiation Safety Officer with the individual's SRT Radiation Worker records.

QA

- QA records shall be maintained in a readily accessible file(s).
- QA records shall be current and made available upon request to the inspectors.
- QA records shall be maintained at least since the last regulatory inspection (though it is recommended to keep records for at least seven years, as storage space allows).

Badge Reports

- Badge Reports shall be maintained in a readily accessible file(s).
- Badge Reports shall be current and made available upon request to the inspectors.
- Badge Reports shall be made available to radiation workers at their request and actively provided for their review at least once per year. It is recommended they be located in a known and easily accessible location.

Patient Records

- Patient records to be maintained for at least seven years and maintained per requirements of HIPAA.

Inspection Reports

- All inspection reports should be maintained on site in a file associated with the SRT-100™ unit

- Any inspection with a finding must be posted in a location frequented and easily observable by Radiation Workers. Follow-up and final resolution of findings must also be posted for Radiation Workers to easily observe.



P3: Operating Procedures For Superficial Radiation Therapy



Safety Features

- **Normal X-ray Beam termination:** After the programmed Beam On time is reached during normal treatments the X-ray beam terminates
- **“Stop” beam:** The SRT-100™ has a “Start” and “Stop” button on the Control Console. To stop the X-ray beam before the end of a normal treatment, simply press the Stop button.
- **“Emergency Stop” beam:** If the normal Stop button fails to terminate the X-ray beam, press the Emergency Off button. This will de-energize the treatment unit and control console.
- The unit may have a door interlock. If so, then opening the door during periods of ‘X-ray beam ON’ will terminate the beam.

Power Up and Down the SRT- 100™

- To turn power on, place the circuit breaker, located at the rear of the Base Unit, to the “ON” Position (1=ON). This circuit breaker applies power to both the Base Unit and the Control Console.
- To turn the power OFF, return the circuit breaker on the Base Unit to the “0” position.



Warm-Up Modes

- The SRT-100™ X-ray tube must be gradually brought up to operating temperature by delivering short intervals of X-ray beam at increasing kilovoltage levels. This is Warm-Up.
- The SRT-100™ unit has two Warm-Up modes: Automatic and Manual.
- Normally, each day before treatments begin, the unit is warmed up using the automatic Warm-Up sequence. The unit will be interlocked and not allow X-ray beam production until a Warm-Up is completed each treatment day.
- Warm-Up also is necessary if the SRT-100™ has been idle for more than eight hours (i.e., has not produced an X-ray beam). However, if the unit has not been powered down and more than eight hours have elapsed since the last Warm-Up, a manual Warm-Up may be completed. This manual Warm-Up requires less time

than the automatic Warm-Up and is used to accommodate patient scheduling to avoid the time required for a normal Warm-Up (approximately 6.5 minutes for normal Warm-Up vs. approximately 1.25 minutes for manual Warm-Up).

- Automatic Warm-Up
 - When a Warm-Up is necessary, “Warm-Up” mode is displayed at the top of the LCD screen.
 - Warm-Up mode can only occur if the Port Block applicator is installed on the X-ray port.
 - The Warm-Up cycle will start at 50 kV with X-rays produced for 60 seconds. The unit then automatically increases by 10 kV and runs another 60 seconds. The unit will continue to increment up by 10 kV with 60 second beam-on times until the 100 kV beam is completed. At that point, the Port Block can be removed, and the RAD Check or a normal treatment applicator cone can be installed on the X-ray Port.
- Manual Warm-Up
 - Manual Warm-Up mode is used if Warm-Up is needed, yet a full Warm-Up was completed since the unit has been energized, and a full Warm-Up will conflict with a soon-to-be performed treatment.
 - Enter the Manual Warm-Up mode by pressing the Beam Energy arrow down past 50 kV. “Manual Warm-Up” will appear on the Control Console screen.
 - In Manual Warm-Up mode the beam -on period is only 20 seconds (as opposed to 60 seconds for Automatic Warm-Up mode).
 - Press the Start button to initiate each Warm-Up mode beam on.

Daily Safety Check for Door Interlocks and X-RAY ON Light

- The daily safety checks of the door interlocks and the X-RAY ON light should be done AFTER a Warm-Up is completed. It can be done before or after Rad Check
- To perform a daily interlock and light check:
 1. Press the Clear button, then press the green toggle switch to “Warm-Up” mode.
 2. Press the Start button. When beam is on, look at the X-RAY ON light to verify it is lit.
 3. While the beam is still on, open the treatment door; the beam should stop.
 4. Close the door. Press the Clear button and toggle the green switch back to Warm-Up mode.
 5. Press the Start button and wait for beam on to start. Press the Stop button. Beam should stop.
 6. Press the Clear button and continue with RAD Check mode.

RAD Check

- Prior to patients' therapy sessions, the operator should perform a RAD check procedure to confirm accurate radiation output of the SRT-100™ system. RAD Check should be performed after the morning Warm-Up
- To perform a RAD check procedure:
 1. Attach RAD check Sensor to applicator mount.
 2. Set time to 0.2 minutes.
 3. Press START. Let exposure run to termination.
 4. After the exposure, the LCD shows a number indicating the percentage of Baseline reference.

97%-103%:

- If the percentage is between 97% and 103% it is **OK to treat**.
- Please note that the 100% \pm 3% variation is perfectly normal and that the unit is functioning within an acceptable range.
- Please note that a percentage between 97%-103% does not change dose output!

\leq 96% or \geq 104%

- If the percentage is \leq 96% or \geq 104% **DO NOT TREAT**.
- Notify management and physics. The unit needs recalibration and/or repair.

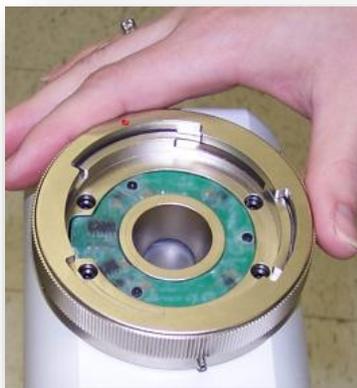
Upon completion of RAD Check, patient treatment can commence.

Treatment Procedure

After the treatment applicator cone size, beam energy, and treatment time is determined the patient and treatment unit can be setup for patient treatment.

- Installation of Applicator Cone
 - An applicator must be installed before exposures are enabled. The applicator must have a clear tip installed on the distal end.
 - The proximal end of the clear tip must be fully seated against the shoulder of the applicator cone to maintain the correct Source to Skin Distance.
- Applicator Installation:
 - Rotate the spring-loaded outer collar of the X-ray housing port counterclockwise so that the "slot" in the collar is over the "slot" inside the applicator mount.
 - While holding the rotated collar, place the Applicator Cone into the mount, and seat the applicator "tab" into the "slot" of the inner mount.

- Slowly release the collar to its normal position. Do not allow it to snap back into place (this may damage the collar spring assembly)
- If the outer does not fully return to its normal position, the Applicator Cone is not positioned properly in the applicator mount. Rotate the collar again, and reseat the applicator tab into the inner applicator mount.



Applicator Cone Removal

- Rotate the spring-loaded collar counterclockwise to line up the collar with the Applicator Cone tab.
- Lift the Applicator straight out of the X-ray tube port.
- Slowly release the collar to its normal position. Do not allow it to snap back into place.

X-ray Tube Head Positioning

- Prior to positioning the X-ray Tube Assembly for treatment, mount prescribed sized Applicator in the tube port. Ensure that the Applicator tip is clean for contact with the patient.
- Use the Up/Down Lift buttons on the Base Unit control panel to roughly adjust the vertical height for the patient's position and anatomical treatment site.
- Release the Arm Locks as needed and extend the arms to the appropriate position near the patient's treatment site.
- Loosen the X-ray Tube Head assembly Rotation Lock by turning it counterclockwise and rotate the X-ray Tube Head into the appropriate position.
- Use all three of the positioning controls as needed to position the Applicator to be in proper contact and angle with the patient's skin for the prescribed treatment. These controls include the Up/Down Lift buttons, Arm Locks, and Tube Rotation Lock. Applicator Cone positioning is often an iterative process.

- When the desired positioning has been achieved, ensure the two Arm Locks are locked and the Rotation Lock is firmly set.

Input and Verify Treatment Parameters

- Treatment Parameters include:
 1. Beam Energy
 2. Treatment Time
 3. Applicator Cone size
 4. Fractional Dose
- Note that:
 - Treatments are given in fractionated doses, with each fraction generally given each treatment day.
 - A patient will receive several fractions that will deliver an overall total prescribed dose.
 - The total dose, fractional dose, and number of fractions are specified on a patient's prescription chart that a physician fills out.
 - The fractional dose will generally stay consistent throughout the patient's treatment scheme, unless otherwise changed by the physician.

1. Beam Energy (kV setting)

- Move the key switch to the X-RAYS position.
- Use the Up/Down Arrows to select the kV treatment setting. These beam energies are displayed in the X-ray Parameter Field as 50 kV, 70 kV or 100 kV. [It is noted that the SRT-100™ can be configured to have only two or even one energy available. If configured for less than three energies, the disabled kV treatment settings do not display on the LCD.]
- The SRT-100™ automatically selects and displays the mA setting corresponding to the kV value shown in the X-ray Parameter Field.
- The SRT-100™ automatically determines the appropriate filter for the selected kV value and moves it into place in the X-ray Tube Port. When the filter is in place, it is identified by its thickness and material on the display, to the right of the mA indication. These are in mm Al. Until the filter is in place, the Exposure Display and Status Display will indicate STANDBY.
- When the kV is selected, the calibrated values for Half Value Layer (HVL) and Dose Rate (cGy/min) are also displayed to the right of the mA value.
 - NOTE: The HVL and Dose Rate values displayed are based on calibration factors entered into the SRT-100™ by the Medical Physicist during commissioning and routine system calibration.

2. Treatment Time (set in 0.00 minutes)
 - Rotate the black Rotary Knob (Exposure Time Control) to display the desired exposure time on the SET display. Pressing the knob inward while turning it moves the display in increments of 0.1 of a minute. Turning the knob without pressing it inward moves the display in increments of 0.01 of a minute. Rotating the knob clockwise increases the setting. Rotating the knob counterclockwise decreases the setting.
 - When the SET display indicates the desired setting, the exposure time is selected, and will be in effect for the next exposure.
3. Applicator Cone Size
 - The Applicator size is automatically set and displayed when an Applicator is installed in the X-ray Tube Port. Each Applicator has small magnets positioned in special patterns in the Applicator flange; the pattern is sensed by the X-ray Tube Port housing so the unit 'knows' what Applicator is installed.
 - As part of the control console parameter setting process, however, verify the intended Applicator was indeed installed.
4. Fractional Dose (cGy for each treatment)
 - The fractional dose will be displayed to the right of the Applicator size on the control console.
 - A fractional dose is a function of the Beam Energy, Treatment Time, and Applicator Size.
 - The displayed fractional dose should be approximately the same as the physician's prescribed fractional dose.
5. Verify:
 - Beam Energy
 - Treatment Time
 - Applicator Cone Size
 - Prescribed Fractional Dose

Confirm READY Mode

- To enable an exposure, the system must be in READY mode, which will be indicated by the following conditions:
 - No Faults or Errors displayed.
 - Status Display indicates TREATMENT and READY.
 - Exposure Display indicates READY.
 - Green Ready Lamp above X-ray Indicator is ON.

Initiate Treatment

- Press and hold the START pushbutton for approximately 1 second until READY on Status Display changes to PREHEAT to begin the X-ray exposure.
- When PREHEAT appears, the system is preparing for the exposure (cooling pump starts, high voltage power supply begins charging, etc.).
- The status changes to X-RAY ON when the system starts emitting X-rays.
- The SRT-100™ will emit a brief tone and then short intermittent tones for the duration of the exposure. The X-ray lamp on the control console will also light up during X-ray production.
- The absorbed radiation dose to the skin surface will be displayed in cGy on the control console as the exposure progresses. This is the calculated dose based on the treatment parameters set above, as well as the calibration dose factors measured by the Medical Physicist and programmed into the control console.
- As the exposure progresses, the Elapsed and Backup Timers count UP to the time on the SET display.

Normal Treatment Termination

- When the Elapsed Time equals the Set Time the exposure ends. An approximate 1-second tone will sound. The following indications will be displayed:
 - COMPLETE will be displayed in the Status and Exposure areas.
 - The calculation of total absorbed dose to the skin surface in cGy will be displayed as Actual Dose.
 - A backup safety timer will continue with the remainder of a 192 second countdown that began with commencement of X-ray exposure. If allowed to fully count down, the system will return to READY. If it is necessary to make another exposure before the countdown is finished press the STOP button and the rest of the countdown will be cancelled.
 - To prepare the system for another exposure, the RESET button must be pressed to return all the TIME displays to 0.00. After a short STANDBY period, the system will return to Ready Mode.
- When completed, return the key switch to the “SAFE” position.

Abnormal Exposure Termination

- Exposures can be terminated at any time prior to reaching the SET time by any one of the following:
 - Pressing the STOP button
 - Pressing either of the two Emergency OFF switches.
 - Activation of any Facility Interlock (e.g., door interlock)
 - Loss of power

- Activation of hardware backup timer
- Key switch moved to the SAFE position

NOTE:

- If the exposure is terminated before the prescribed fractional dose is completely delivered, the remaining dose will be delivered via two methods depending on the mode of termination. If the beam was terminated using the STOP button, then simply pressing the START button without pressing the RESET button. The unit will 'remember' how much time was delivered and continue with the remainder. This also applies to beam termination via door interlock, etc.
- If the beam was terminated with either of the Emergency OFF methods, the remainder of the delivery time must be entered as Treatment Time and Beam On started as if a new treatment (i.e., the operator must know how much time was delivered before the Emergency OFF; subtract that from the prescribed delivery time to determine the remaining time to be delivered). This also applies to termination via power failure.



P4: Quality Assurance Procedures for Superficial Radiation Therapy



The Quality Assurance Program for the Sensus Healthcare SRT-100™ is comprised of several procedures. These procedures encompass regulatory requirements for ionizing radiation therapy devices for X-ray energies of 100 kV and less, as well as standards of quality practices delineated in AAPM Task Group 61 “AAPM protocol for 40–300 kV X-ray beam dosimetry in radiotherapy and radiobiology.”

Commissioning

- Perform after unit’s initial arrival on-site
- Perform before first patient treatment
- Conduct ‘Area Radiation Survey’ to determine safety and adequacy of treatment room shielding
- Test and verify functionality of safety systems
- Determine for each beam:
 - Beam Energy Half Value Layer (HVL)
 - Absolute Output for 5 cm and 10 cm Applicator Cones
 - Relative output for remaining 15 cm SSD Applicator Cones
 - Output for remaining 15 cm SSD Applicator Cones
 - Input calibration values into machine and establish daily QA Baseline (RAD Check)
 - Verify Flatness and Symmetry of each beam is within $\pm 3\%$
- Create report of all findings
- Report to be maintained on site with SRT-100™
- Provide report to State Regulatory Authorities if required

SRT-100™ Superficial Radiation Therapy testing and Commissioning Equipment

- Superficial Radiation Therapy testing and commissioning equipment (i.e. pancake chambers, ion chambers) that will be used to test or commission a SRT-100™ shall be calibrated at least every two years or as recommended by the manufacturer.
- Copies of the equipment calibration are typically included in/with the commissioning report, and shall be maintained along with the report in the document binder.
- Equipment outside limiting criteria must be removed from service by Physicist until repaired. Equipment must be rechecked prior to returning to service.

Daily QA

- Warm-up (Automatic Sequence if greater than 8 hrs. since last beam on)
- Check of Safety Systems (Door Interlocks and X-RAY ON light)
- RAD Check
 - **97% to 103% = OK to Treat**
 - A variation of $100\% \pm 3\%$ perfectly normal within an acceptable range.
 - A variation of $100\% \pm 3\%$ does not change dose output.
 - **$\leq 96\%$ or $\geq 104\%$ = DO NOT TREAT**
 - Notify physics and RSO and/or authorized user (Physician)
- Record findings
- Perform each day patients are being treated, but at least three times per week if patients are not being treated

Monthly QA

- Normal testing required on a monthly basis is adequately performed during the Daily QA
- In certain states, monthly spot checks may be State mandated
 - If required, forward to physics for review

Annual QA

- Do before first patient treatment
- Conduct 'Area Radiation Survey' to determine safety and adequacy of treatment room shielding
- Test and verify functionality of safety systems
- Determine for each beam:
 - Beam Energy Half Value Layer (HVL)
 - Absolute Output for 5cm and 10cm Applicators
 - Relative output for remaining 15cm SSD Applicators
 - Output for remaining 15cm SSD Applicators
 - Input calibration values into machine and establish daily QA Baseline (RAD Check)
 - Verify Flatness and Symmetry of each beam is within $\pm 3\%$
- Create report of all findings
- Report to be maintained on site with SRT-100™ documentation
- Perform on an approximate annual basis (or less than 365 days since last Annual, if dictated by State requirements)

Area Radiation Survey

- Use Ion Chamber-type area radiation survey instrument.
- Instrument must be calibrated at least once each twelve months.
- Simulate Beam down geometry: Use 10cm applicator cone directed down towards container of approximately 10cm or more of water (simulating treatment of patient anatomy with cone directed downward on patient or anatomical part > 5cm thickness). End of cone in contact with water. Survey each potentially occupied space directly outside each treatment room wall for each energy beam. This verifies adequate shielding to protect non-controlled areas from the worst case radiation scatter.
- Simulate Beam horizontal geometry: Use 2.5cm applicator cone with approximately 0.5cm wax in contact with cone end (simulating treatment of patient appendage e.g., ear or nose). Beam directed horizontally toward nearest treatment room wall. Survey each potentially occupied space outside the treatment room using each beam of energy. This verifies adequate shielding to protect non-controlled areas from the worst-case primary beam.

SRT-100™ QA Review

- The SRT-100™ Superficial Radiation Therapy unit shall routinely be evaluated for compliance to applicable state and federal regulations.
- The SRT-100™ Superficial Radiation Therapy unit shall be commissioned upon receipt and annually thereafter. The commissioning shall be performed by a certified physicist that meets the compliances warranted by state and federal regulations.
- The SRT-100™ Superficial Radiation Therapy unit shall be evaluated as recommended by the AAPM in Task Group 61 report.
- Copies of the commissioning shall be maintained in the document binder.
- The SRT-100™ Superficial Radiation Therapy Unit shall have a Daily QA procedure performed to check the constancy of each therapeutic energy, prior to patient treatments.
- The Daily QA procedure is performed with the RAD Check sensor/applicator.
 - If more than 3% different from the reference value, service/re-calibration is required and the system should not be operable until service is completed.
- The QA results from the daily RAD Check are documented daily on a Quality Assurance log.
- Be sure to review:
 - Radiation Monitoring Requirements
 - ALARA and overexposure notification procedures
 - Radiation safety procedures
 - SRT-100™ Superficial Radiation Therapy unit operator requirements
 - Training requirements
 - Quality Control and Commissioning Tests
 - SRT-100™ Superficial Radiation Therapy Maintenance Logs and Operation Manuals
 - Posting and signage
 - Incident actions



P5: Emergency Procedures



Emergency Procedures

- The SRT-100™ produces radiation only when energized (i.e., beam is turned on).
- Radiation ceases to be emitted when the beam is turned off, power switch is turned off, or power plug is pulled.
- Emergency procedures, which contain as a minimum the phone numbers of persons to call in an emergency, should be located near the control console and known by all workers in the area.
- Follow this procedure in case of an emergency:

1. Turn OFF equipment at Control Console.

- Press the Stop Button or the Emergency Stop Button

2. Turn OFF SRT-100™'s main power switch in back of Base Unit.

3. Remove patient from treatment room, if present.

4. Post a sign on the equipment to prevent its use during incident investigation.

5. Call one of the individuals listed below immediately.

6. Call Sensus Healthcare if unit needs repair: 1-800-324-9890.

7. Safeguard radiation badges to prevent loss.

Emergency Contact Numbers

Dr. (Dermatologist)

xxx-xxx-xxxx

Dr. (Physicist)

yyy-yyy-yyyy



P6: Morning QA Procedure



Intentionally blank. The Morning QA Procedure will be placed in this handbook by the Sensus Clinical Applications Team during training.



P7: Quality Management Program



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P8: Administrative Clinical Controls Procedure



Intentionally blank. The Administrative Clinical Controls Procedure will be placed in this handbook by the Sensus Clinical Applications Team during training.



P9: Radiation Safety Operations Manual



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Clinical Applications Appendices





Appendix A: TDF Tables for Patient Treatment Planning for BCC and SCC



1 Fraction per Week Schedule

Dose / Fraction (cGy)	TDF Table Time Dose Fractionation Factors for One Fraction Per Week																			
	TDF # Between 90 and 110 for NSMC Skin Lesions - No. OF FRACTIONS																			
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
20	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
40	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4			
60	2	2	2	3	3	4	4	4	5	5	6	6	6	7	7	8	8			
80	3	3	4	4	5	6	6	7	8	8	9	9	10	11	11	12	13			
100	4	4	5	6	7	8	9	10	11	12	12	13	14	15	16	17	18			
110	4	5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21			
120	5	6	7	8	9	11	12	13	14	15	16	18	19	20	21	22	24			
130	5	7	8	9	11	12	13	15	16	17	19	20	21	23	24	25	27			
140	6	7	9	10	12	13	15	16	18	19	21	22	24	25	27	28	30			
150	7	8	10	12	13	15	17	18	20	22	23	25	27	28	30	32	33			
160	7	9	11	13	15	17	18	20	22	24	26	28	29	31	33	35	37			
170	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40			
180	9	11	13	15	18	20	22	24	26	29	31	33	35	37	40	42	44			
190	10	12	14	17	19	22	24	26	29	31	33	36	38	41	43	45	48			
200	10	13	16	18	21	23	26	28	31	34	36	39	41	44	47	49	52			
210	11	14	17	20	22	25	28	31	33	36	39	42	45	47	50	53	56			
220	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60			
230	13	16	19	22	26	29	32	35	38	42	45	48	51	54	58	61	64			
240	14	17	21	24	27	31	34	38	41	44	48	51	55	58	62	65	68			
250	15	18	22	26	29	33	36	40	44	47	51	55	58	62	66	69	73			
260	15	19	23	27	31	35	39	43	46	50	54	58	62	66	70	74	77			
270	16	21	25	29	33	37	41	45	49	53	57	62	66	70	74	78	82			
280	17	22	26	30	35	39	43	48	52	56	61	65	69	74	78	82	87			
290	18	23	27	32	37	41	46	50	55	60	64	69	73	78	82	87	92			
300	19	24	29	34	39	43	48	53	58	63	68	72	77	82	87	92	96			
320	21	27	32	37	43	48	53	59	64	69	75	80	85	91	96	101	107			
340	23	29	35	41	47	53	58	64	70	76	82	88	94	99	105	111	117			
360	26	32	38	45	51	57	64	70	77	83	89	96	102	109	115	121	128			
380	28	35	42	49	56	62	69	76	83	90	97	104	111	118	125	132	139			
400	30	38	45	53	60	68	75	83	90	98	105	113	120	128	135	143	150			
420	32	40	49	57	65	73	81	89	97	105	113	121	129	138	146	154				
440	35	43	52	61	70	78	87	96	104	113	122	130	139	148	156					
460	37	47	56	65	74	84	93	102	112	121	130	140	149	158						
480	40	50	60	70	80	89	99	109	119	129	139	149	159							
500	42	53	63	74	85	95	106	116	127	138	148	159								
520	45	56	67	79	90	101	112	124	135	146	157									
540	48	60	71	83	95	107	119	131	143	155										
560	50	63	76	88	101	113	126	139	151											
580	53	66	80	93	106	120	133	146	160											
600	56	70	84	98	112	126	140	154												
700	71	89	107	124	142	160	178													
800	87	109	131	153	174															
900	105	131	157																	
1000	123	154																		

2 Fractions per Week Schedule

Dose / Fraction (cGy)	TDF Table Time Dose Fractionation Factors for Two Fractions Per Week																								
	TDF # Between 90 and 110 for NMSC Skin Lesions - NUMBER OF FRACTIONS																								
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25			
20	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2			
40	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6			
60	2	2	3	3	4	4	4	5	5	6	6	7	7	8	8	9	9	9	10	10	11	11			
80	3	4	4	5	6	6	7	8	8	9	10	10	11	12	13	13	14	15	15	16	17	17			
100	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25			
110	5	6	7	8	9	10	11	13	14	15	16	17	18	19	21	22	23	24	25	26	27	29			
120	5	7	8	9	10	12	13	14	16	17	18	20	21	22	23	25	26	27	29	30	31	33			
130	6	7	9	10	12	13	15	16	18	19	21	22	24	25	27	28	30	31	32	34	35	37			
140	7	8	10	12	13	15	17	18	20	21	23	25	26	28	30	31	33	35	36	38	40	41			
150	7	9	11	13	15	17	18	20	22	24	26	28	29	31	33	35	37	39	40	42	44	46			
160	8	10	12	14	16	18	20	22	24	26	28	30	32	35	37	39	41	43	45	47	49	51			
170	9	11	13	16	18	20	22	25	27	29	31	33	36	38	40	42	45	47	49	51	53	56			
180	10	12	15	17	19	22	24	27	29	32	34	37	39	41	44	46	49	51	54	56	58	61			
190	11	13	16	19	21	24	26	29	32	34	37	40	42	45	48	50	53	56	58	61	63	66			
200	11	14	17	20	23	26	29	31	34	37	40	43	46	49	52	54	57	60	63	66	69	72			
210	12	15	19	22	25	28	31	34	37	40	43	46	49	52	56	59	62	65	68	71	74	77			
220	13	17	20	23	27	30	33	36	40	43	46	50	53	56	60	63	66	70	73	76	80	83			
230	14	18	21	25	28	32	35	39	43	46	50	53	57	60	64	67	71	75	78	82	85	89			
240	15	19	23	27	30	34	38	42	45	49	53	57	61	64	68	72	76	80	83	87	91	95			
250	16	20	24	28	32	36	40	44	48	52	56	61	65	69	73	77	81	85	89	93	97	101			
260	17	21	26	30	34	39	43	47	51	56	60	64	69	73	77	81	86	90	94	99	103	107			
270	18	23	27	32	36	41	45	50	54	59	64	68	73	77	82	86	91	95	100	104	109	114			
280	19	24	29	34	38	43	48	53	58	62	67	72	77	82	86	91	96	101	106	110	115	120			
290	20	25	30	35	41	46	51	56	61	66	71	76	81	86	91	96	101	106	111	117	122	127			
300	21	27	32	37	43	48	53	59	64	69	75	80	85	91	96	101	107	112	117	123	128	133			
320	24	29	35	41	47	53	59	65	71	77	83	88	94	100	106	112	118	124	130	136	142	147			
340	26	32	39	45	52	58	65	71	78	84	91	97	104	110	117	123	129	136	142	149	155	162			
360	28	35	42	49	57	64	71	78	85	92	99	106	113	120	127	134	141	148	155	163					
380	31	38	46	54	61	69	77	84	92	100	108	115	123	131	138	146	154	161							
400	33	42	50	58	66	75	83	91	100	108	116	125	133	141	150	158									
420	36	45	54	63	72	81	90	99	107	116	125	134	143	152											
440	38	48	58	67	77	87	96	106	115	125	135	144	154												
460	41	52	62	72	82	93	103	113	124	134	144	155													
480	44	55	66	77	88	99	110	121	132	143	154														
500	47	59	70	82	94	105	117	129	141	152															
520	50	62	75	87	100	112	124	137	149	162															
540	53	66	79	92	105	119	132	145	158																
560	56	70	84	98	112	125	139	153																	
580	59	74	88	103	118	132	147	162																	
600	62	78	93	109	124	140	155																		
700	79	98	118	138	157	177																			
800	97	121	145	169																					
900	116	145	174																						
1000	136	170																							

3 Fractions per Week Schedule

Dose / Fraction (cGy)	TDF Table Time Dose Fractionation Factors for Three Fractions per Week																					
	TDF # Between 90 and 110 for NSMC Skin Lesions - NUMBER OF FRACTIONS																					
	4	5	6	8	10	12	14	15	16	18	20	22	24	25	26	28	30	32	34	35	36	40
20	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4
40	1	1	2	2	3	3	4	4	4	5	5	6	6	6	7	7	8	8	9	9	9	10
60	2	2	3	4	5	6	7	7	8	9	10	10	11	12	12	13	14	15	16	17	17	19
80	3	4	4	6	7	9	10	11	12	13	15	16	18	19	19	21	22	24	25	26	27	30
100	4	5	6	8	10	13	15	16	17	19	21	23	25	26	27	29	31	33	36	37	38	42
110	5	6	7	10	12	15	17	18	19	22	24	27	29	30	32	34	36	39	41	42	44	48
120	6	7	8	11	14	17	19	21	22	25	28	30	33	35	36	39	42	44	47	48	50	55
130	6	8	9	13	16	19	22	24	25	28	31	34	38	39	41	44	47	50	53	55	56	63
140	7	9	11	14	18	21	25	26	28	32	35	39	42	44	46	49	53	56	60	61	63	70
150	8	10	12	16	20	23	27	29	31	35	39	43	47	49	51	55	59	62	66	68	70	78
160	9	11	13	17	22	26	30	32	35	39	43	47	52	54	56	60	65	69	73	75	78	86
170	9	12	14	19	24	28	33	36	38	43	47	52	57	59	62	66	71	76	80	83	85	95
180	10	13	16	21	26	31	36	39	41	47	52	57	62	65	67	72	78	83	88	90	93	103
190	11	14	17	22	28	34	39	42	45	51	56	62	67	70	73	79	84	90	96	98	101	112
200	12	15	18	24	30	36	43	46	49	55	61	67	73	76	79	85	91	97	103	106	109	122
210	13	16	20	26	33	39	46	49	52	59	66	72	79	82	85	92	98	105	111	115	118	131
220	14	18	21	28	35	42	49	53	56	63	70	77	84	88	92	99	106	113	120	123	127	141
230	15	19	23	30	38	45	53	57	60	68	75	83	90	94	98	106	113	121	128	132	136	151
240	16	20	24	32	40	48	56	60	64	72	80	89	97	101	105	113	121	129	137	141	145	161
250	17	21	26	34	43	51	60	64	69	77	86	94	103	107	111	120	129	137	146	150	154	
260	18	23	27	36	46	55	64	68	73	82	91	100	109	114	118	127	137	146	155			
270	19	24	29	39	48	58	68	72	77	87	96	106	116	121	125	135	145	154				
280	20	25	31	41	51	61	71	76	82	92	102	112	122	127	133	143	153					
290	22	27	32	43	54	65	75	81	86	97	108	118	129	135	140	151						
300	23	28	34	45	57	68	79	85	91	102	113	125	136	142	147	159						
320	25	31	38	50	63	75	88	94	100	113	125	138	150	157	163							
340	27	34	41	55	69	82	96	103	110	124	137	151										
360	30	38	45	60	75	90	105	113	120	135	150	165										
380	33	41	49	65	82	98	114	122	131	147	163											
400	35	44	53	71	88	106	124	132	141	159												
420	38	48	57	76	95	114	133	143	152													
440	41	51	61	82	102	123	143	153														
460	44	55	66	88	109	131	153															
480	47	58	70	93	117	140	164															
500	50	62	75	100	124	149	174															
520	53	66	79	106	132	159																
540	56	70	84	112	140	168																
560	59	74	89	118	148	178																
580	63	78	94	125	156																	
600	66	82	99	132	165																	
700	83	104	125	167																		
800	103	128	154																			
900	123	154																				
1000	145	181																				

4 Fractions per Week Schedule

Dose / Fraction (cGy)	TDF Table Time Dose Fractionation Factors for Four Fractions per Week TDF # Between 90 and 110 for NSMC Skin Lesions - NUMBER OF FRACTIONS																					
	4	5	6	8	10	12	14	15	16	18	20	22	24	25	26	28	30	32	34	35	36	40
20	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	4
40	1	1	2	2	3	3	4	4	4	5	5	6	6	7	7	8	8	9	9	9	10	11
60	2	3	3	4	5	6	7	8	8	9	10	11	12	13	13	14	15	16	17	18	18	20
80	3	4	5	6	8	9	11	12	13	14	16	17	19	20	20	22	23	25	27	27	28	31
100	4	6	7	9	11	13	15	17	18	20	22	24	26	28	29	31	33	35	37	39	40	44
110	5	6	8	10	13	15	18	19	20	23	26	28	31	32	33	36	38	41	43	45	46	51
120	6	7	9	12	15	18	20	22	23	26	29	32	35	36	38	41	44	47	50	51	53	58
130	7	8	10	13	16	20	23	25	26	30	33	36	40	41	43	46	49	53	56	58	59	66
140	7	9	11	15	18	22	26	28	30	33	37	41	44	46	48	52	55	59	63	65	67	74
150	8	10	12	16	21	25	29	31	33	37	41	45	49	51	53	58	62	66	70	72	74	82
160	9	11	14	18	23	27	32	34	36	41	45	50	54	57	59	64	68	73	77	79	82	91
170	10	12	15	20	25	30	35	37	40	45	50	55	60	62	65	70	75	80	85	87	90	100
180	11	14	16	22	27	33	38	41	44	49	54	60	65	68	71	76	82	87	93	95	98	109
190	12	15	18	24	30	35	41	44	47	53	59	65	71	74	77	83	89	95	101	103	106	118
200	13	16	19	26	32	38	45	48	51	58	64	70	77	80	83	90	96	102	109	112	115	128
210	14	17	21	28	34	41	48	52	55	62	69	76	83	86	90	97	103	110	117	121	124	138
220	15	19	22	30	37	44	52	56	59	67	74	82	89	93	96	104	111	119	126	130	133	148
230	16	20	24	32	40	48	56	60	63	71	79	87	95	99	103	111	119	127	135	139	143	159
240	17	21	25	34	42	51	59	64	68	76	85	93	102	106	110	119	127	136	144	148	152	
250	18	23	27	36	45	54	63	68	72	81	90	99	108	113	117	126	135	144	153	158		
260	19	24	29	38	48	57	67	72	77	86	96	105	115	120	125	134	144	153				
270	20	25	30	41	51	61	71	76	81	91	102	112	122	127	132	142	152					
280	21	27	32	43	54	64	75	81	86	97	107	118	129	134	140	150	161					
290	23	28	34	45	57	68	79	85	91	102	113	125	136	142	147	159						
300	24	30	36	48	60	72	84	90	96	107	119	131	143	149	155							
320	26	33	40	53	66	79	92	99	105	119	132	145	158	165								
340	29	36	43	58	72	87	101	109	116	130	145	159										
360	32	40	47	63	79	95	111	119	126	142	158											
380	34	43	52	69	86	103	120	129	137	155												
400	37	46	56	74	93	112	130	139	149	167												
420	40	50	60	80	100	120	140	150	160													
440	43	54	65	86	108	129	151															
460	46	58	69	92	115	138	161															
480	49	61	74	98	123	148	172															
500	52	65	79	105	131	157																
520	56	70	83	111	139	167																
540	59	74	88	118	147	177																
560	62	78	94	125	156																	
580	66	82	99	132	165																	
600	69	87	104	139	173																	
700	88	110	132	176																		
800	108	135	162																			
900	129	162																				
1000	152																					

5 Fractions per Week Schedule

Dose / Fraction (cGy)	TDF Table Time Dose Fractionation Factors for Five Fractions Per Week TDF # Between 90 and 110 for NSMC Skin Lesions - NUMBER OF FRACTIONS																																			
	4	5	6	8	10	12	14	15	16	18	20	22	24	25	26	28	30	32	34	35	36	40														
20	0	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	3	3	4														
40	1	1	2	2	3	3	4	4	4	5	6	6	7	7	7	8	8	9	9	10	10	11														
60	2	3	3	4	5	6	7	8	8	9	10	11	12	13	13	15	16	17	18	18	19	21														
80	3	4	5	6	8	10	11	12	13	15	16	18	19	20	21	23	24	26	27	28	29	32														
100	5	6	7	9	11	14	16	17	18	20	23	25	27	28	30	32	34	36	39	40	41	45														
110	5	7	8	11	13	16	18	20	21	24	26	29	32	33	34	37	39	42	45	46	47	53														
120	6	8	9	12	15	18	21	23	24	27	30	33	36	38	39	42	45	48	51	53	54	60														
130	7	9	10	14	17	20	24	26	27	31	34	37	41	43	44	48	51	54	58	60	61	68														
140	8	10	11	15	19	23	27	29	31	34	38	42	46	48	50	53	57	61	65	67	69	76														
150	9	11	13	17	21	25	30	32	34	38	42	47	51	53	55	59	64	68	72	74	76	85														
160	9	12	14	19	23	28	33	35	37	42	47	51	56	58	61	66	70	75	80	82	84	94														
170	10	13	15	21	26	31	36	39	41	46	51	57	62	64	67	72	77	82	87	90	92	103														
180	11	14	17	22	28	34	39	42	45	50	56	62	67	70	73	79	84	90	95	98	101	112														
190	12	15	18	24	31	37	43	46	49	55	61	67	73	76	79	85	91	97	104	107	110	122														
200	13	17	20	26	33	40	46	49	53	59	66	73	79	82	86	92	99	105	112	115	119	132														
210	14	18	21	28	36	43	50	53	57	64	71	78	85	89	92	99	107	114	121	124	128	142														
220	15	19	23	31	38	46	53	57	61	69	76	84	92	95	99	107	115	122	130	134	137	153														
230	16	20	25	33	41	49	57	61	65	74	82	90	98	102	106	114	123	131	139	143	147	163														
240	17	22	26	35	44	52	61	65	70	79	87	96	105	109	113	122	131	140	148	153	157															
250	19	23	28	37	46	56	65	70	74	84	93	102	112	116	121	130	139	149	158																	
260	20	25	30	40	49	59	69	74	79	89	99	109	118	123	128	138	148	158																		
270	21	26	31	42	52	63	73	78	84	94	105	115	126	131	136	146	157																			
280	22	28	33	44	55	66	77	83	89	100	111	122	133	138	144	155																				
290	23	29	35	47	58	70	82	88	93	105	117	128	140	146	152																					
300	25	31	37	49	62	74	86	92	98	111	123	135	148	154																						
320	27	34	41	54	68	82	95	102	109	122	136	149	163																							
340	30	37	45	60	75	89	104	114	119	134	149	164																								
360	33	41	49	65	81	98	114	122	130	147	163																									
380	35	44	53	71	88	106	124	133	142	159																										
400	38	48	57	77	96	115	134	144	153																											
420	41	52	62	83	103	124	144	155																												
440	44	55	67	89	111	133	155																													
460	48	59	71	95	119	142	166																													
480	51	63	76	101	127	152																														
500	54	67	81	108	135	162																														
520	57	72	86	115	143	172																														
540	61	76	91	121	152																															
560	64	80	96	128	161																															
580	68	85	102	136	169																															
600	71	89	107	143	179																															
700	91	113	136	181																																
800	111	139	167																																	
900	133	167																																		
1000	157																																			

Decay Factors for Disrupted Treatment Protocols

"Decay Factors" for Split-Course Radiotherapy												
T (Days)	Rest Period R (Days)											
	5	10	15	20	25	30	35	40	50	60	80	100
5	0.93	0.89	0.86	0.84	0.82	0.81	0.80	0.79	0.77	0.75	0.73	0.72
10	0.96	0.93	0.90	0.89	0.87	0.86	0.85	0.84	0.82	0.81	0.79	0.77
15	0.97	0.95	0.93	0.91	0.9	0.89	0.88	0.87	0.85	0.84	0.82	0.8
20	0.98	0.96	0.94	0.93	0.91	0.9	0.89	0.89	0.87	0.86	0.84	0.82
25	0.98	0.96	0.95	0.94	0.93	0.92	0.91	0.9	0.89	0.87	0.85	0.84
30	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.9	0.89	0.87	0.85
35	0.99	0.97	0.96	0.95	0.94	0.93	0.93	0.92	0.91	0.9	0.88	0.86
40	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.93	0.91	0.9	0.89	0.87
45	0.99	0.98	0.97	0.96	0.95	0.95	0.94	0.93	0.92	0.91	0.89	0.88
50	0.99	0.98	0.97	0.96	0.96	0.95	0.94	0.94	0.93	0.92	0.9	0.89

- **T** = Total Days of TX Before Break
- **R** = Total Days of Rest
- **TDF X** = "Decay Factor" = Adjusted TDF for TX After Break



Appendix B: SRT-100™ System Troubleshooting



Fault Messages and Detection & Recovery

When system or interlock faults are detected by the system, Error Messages are displayed on the LCD screen. When the problem is cleared, the Error Message on the LCD will disappear. The following table describes each Error Message, its cause, the corrective action that the operator can take to resolve it and the steps necessary to resume a treatment if it has been interrupted by an Error Message.

Error Message	Cause	Corrective Action	How to Resume Treatment
Comm. Error	Communication between the Control Console and the Base Unit has failed.	Check the data cable connections. If problem persists, contact SERVICE personnel.	Turn the circuit breaker off and restart the system.
Interlock 1 Open	A door or other protective enclosure device connected to Interlock Circuit 1 is not in the correct position.	Remove key from front panel keyswitch, check the corresponding door/enclosure to make sure it's in the right position.	The Resume Exposure function allows restarting of the exposure. Press START to continue the treatment exposure.
Interlock 2 Open	A door or other protective enclosure device connected to Interlock Circuit 1 is not in the correct position.	Remove key from front panel keyswitch, check the corresponding door/enclosure to make sure it's in the right position.	The Resume Exposure function allows restarting of the exposure. Press START to continue the treatment exposure.
kV/mA Accuracy	Either the kilovoltage or the tube current deviate from their nominal values by 3% or more.	If problem persists, contact SERVICE personnel.	Resume only after Service Attention.

Error Message	Cause	Corrective Action	How to Resume Treatment
Low Filament Current	The system has detected low filament current, preventing exposure if the high voltage cable has become disconnected from the X-ray tube head.	If problem persists, contact SERVICE personnel.	Resume only after Service Attention.
Low Filament	HV cable disconnected or X-ray tube failure	Contact SERVICE personnel	Resume only after Service Attention.
No Applicator	The applicator sensor has detected that no applicator is in place, or that applicator is installed incorrectly.	Remove applicator. Inspect mounting area of X-ray Tube Head to identify and remove any foreign objects. Reinstall applicator.	If this error is displayed during the period of an exposure, contact SERVICE personnel.
Over-Current	Internal circuitry has determined that there is a current regulation problem	Contact SERVICE personnel	Record the elapsed time of the treatment and consult with medical direction for retreatment.
Over-Voltage	Internal circuitry has determined that there is a voltage regulation problem KV has exceeded set value by 10%.	Contact SERVICE personnel.	Record the elapsed time of the treatment and consult with medical direction for retreatment.
Port-Block Applicator Required	Warm-up selected or required and Port Block Applicator not installed	Install Beam Block Applicator.	Operation (Warm-up) resumed with Start pushbutton.

Error Message	Cause	Corrective Action	How to Resume Treatment
Power Failure	The power to the system was interrupted during an exposure. The displayed Elapsed exposure time indicates the exposure time completed when the power failure occurred.	Restart the system and continue treatment with the remaining time.	Restart the system and continue treatment with the remaining time.
RAD Check Error	The RAD check system has detected a 3% difference in output rate.	Contact SERVICE personnel	Resume only after Service Attention.
Remote X-ray Switch	A door or other protective enclosure device connected to Interlock Circuit 1 is not in the correct position.	Remove key from front panel keyswitch, check the corresponding door/enclosure to make sure it's in the right position.	The Resume Exposure function allows restarting of the exposure. Press START to continue the treatment exposure.
Service Required Extended Idle	X-ray tube has been unused for a longer time than can be conditioned by Auto-Warm-up feature	Contact SERVICE personnel to perform a manual warm-up.	Resume normal operation after service attention.
Tube Arc	The internal circuitry has detected a momentary interruption in the high voltage potential The system has detected arcing internally within the X-ray tube head.	Perform manual warm-up procedure, then repeat treatment. If problem reoccurs, contact SERVICE personnel.	After performing a manual warm-up, restart the treatment. If it occurs later in the exposure, contact service.

Error Message	Cause	Corrective Action	How to Resume Treatment
Water Flow Low	Flow Sensor in the coolant path detects insufficient flow (less than 4.2 LPM).	Check hose connections at tube head for leaks. Reseat connections.	Record the remaining time (difference between the Set time and the Elapsed Time). Reset unit and set the remaining treatment time on the unit. Press START to continue the treatment exposure.
Water Over Temp	Internal coolant water temperature sensor indicates that coolant temperature is at maximum (42° C. or higher).	Check that Base Unit louvers are unobstructed, to allow free movement of air through the system.	Record the remaining time (difference between the Set time and the Elapsed Time). Reset unit and set the remaining treatment time on the unit. Press START to continue the treatment exposure.
Water Level Low	There is insufficient coolant in reservoir to ensure X-ray tube cooling	Follow procedure in the Technical Manual to add coolant to the coolant reservoir in the Base Unit.	Reattempt exposure after adding coolant.

Error Message	Cause	Corrective Action	How to Resume Treatment
X-ray Filter	<p>The X-ray Filter Changer Assembly has detected an invalid filter/kV combination. The X-ray filter positioned in the tube head port does not match the selected kV setting.</p> <p>NOTE: The LEDS on the case control panel blink on and then off at power up until the automatic filter changer cycles through a self-test.</p>	<p>Turn system OFF, wait 1 minute, and then turn back on.</p> <p>If problem persists, contact SERVICE personnel.</p> <p>NOTE: There is a method to manually position the filter assembly by removing the screw in the endcap of the X-ray tube head, inserting a 7/64 hex key and turning the filter carriage until the proper indication is visible on the Base Control Panel.</p>	<p>Record the remaining time (difference between the Set time and the Elapsed Time).</p> <p>Reset unit and set the remaining treatment time on the unit.</p> <p>Press START to continue the treatment exposure.</p>

Troubleshooting

Most problems that occur before or during an exposure are detected by the system. Messages are placed on the LCD screen notifying the operator of the condition. Incorrect operation or incompatible settings are also indicated this way. However, in several cases, the system may not be able to display an error message. In these few cases, use the chart below to isolate and resolve the problem.

Problem	Possible Causes	Corrective Action
Arm lift inoperative	Arm extended out of safe (closed) position.	Return arm to safe (closed) position and retry.
Arm will not balance in raised position.	Internal spring in arm detached or broken.	Do not use system, contact service personnel.
Liquid leaking from X-ray Tube Head	Coolant hoses not seated properly.	Re-connect coolant hoses.
Unit circuit breaker trips OFF at the beginning of or during exposure.	Power source not supplying adequate current.	Recheck specification of power source.
Unit will not turn on when Power Switch is pressed to ON.	System not connected to power source.	Check that system is properly connected to power source and that power source has power applied to it.
	Emergency OFF switch disengaged.	Check that both Emergency OFF switches are "armed" (rotate in the direction of arrows to "arm" the switch).
	LCD blank.	Check whether individual power and status lamps are lit. If they are, a problem with the system operation is likely.



Appendix C: Patient Consent Form



Consent for Superficial Radiation

I hereby request, authorize, and give my consent to _____, M.D./D.O., and/or his/her associates or assistants, to perform Superficial Radiation and/or any other treatment(s) or technical procedure(s) deemed necessary or advisable in the diagnosis or treatment of my case including, but not limited to the pathology, radiology, and laboratory services.

I understand that early side effects of radiation include irritation, redness, and ulceration of the skin as well as possible skin infection.

I understand that late effects of radiation can include skin atrophy (thinning of the skin), telangiectasia (visible, small blood vessels in the skin), increased skin pigmentation (darkening of the skin), hair loss in the area treated, non-healing ulcer (rare), and/or a different type of skin cancer can develop in the area treated (very rare).

I acknowledge that no guarantee or assurance has been given by anyone as to the results that may be obtained, that there is no 100% cure rate for skin cancers, and that the practice of medicine and surgery is not an exact science for which assurances regarding cure rate can be made.

I consent to photographing the treatment, including appropriate portions of my body, for medical, scientific or educational purposes.

I understand that it is my responsibility to undergo regular and periodic check-ups (at least yearly) to detect recurrent or new skin cancers, and agree to follow instructions regarding treatment sites(s).

The possible risks and complications of Superficial Radiation and the possible risks and complications of failing to undergo or delay treatment have been explained to me and any questions that I may have had have been answered to my satisfaction

Printed name of patient or person authorized to consent for Patient: _____

Signed: _____

Date: _____



Appendix D: General Skin Care Recommendations



General Skin Care Recommendations

Washing: Patients should be encouraged to wash the irradiated skin daily using warm water and non-perfumed soap. The use of wash cloths may cause friction and are therefore discouraged. The use of a soft towel to pat dry is recommended.

Use of Deodorants: Patients may continue to use deodorants (excluding antiperspirants containing aluminum) during radiation therapy.

Other Skin Products: Patients are discouraged from using any perfumed products which may possess chemical irritants and induce discomfort. Products such as gels or creams should not be applied. Patients should be encouraged to use products advocated by the radiation department.

Hair Removal: The use of an electric shaver is recommended and wax or other depilatory creams are discouraged. Patients are asked not to shave the axilla if it is within the treatment field.

Swimming: Patients may continue to swim in chlorinated pools but should rinse afterwards. Patients experiencing a radiation skin reaction which has progressed beyond dry desquamation should avoid swimming.

Heat and Cold: Patients are encouraged to avoid direct application of heat or cold to the irradiated area i.e. ice or electric heating pads.

Band-Aids, Tape and Clothing: Rubbing, scratching and massaging the skin within the treatment area causes friction and should be discouraged. The use of Band-Aids or tape on the skin should also be avoided. Wearing loose fitting cotton clothing may avoid traumatic shearing and friction injuries. The use of a mild detergent to wash clothing is also recommended.

Post Treatment Skin Care Recommendations

Sun Exposure: Patients should be instructed to avoid direct sun exposure and cover the irradiated skin. The use of sunscreen products with at least SPF 30 are recommended for at least one year following treatment.



Appendix E: Clinical Presentations & Care



Appendix E: Clinical Presentation & Care

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Non-Urgent Clinical Presentation & Care

Clinical Presentation

Erythema:

- Pink to dusky coloration
- May be accompanied by mild edema
- Burning, itching and mild discomfort

Dry desquamation:

- Partial loss of the epidermal basal cells
- Dryness, itching, scaling, flaking and peeling
- Hyperpigmentation

Reaction Assessment

Assessment to include:

- Location
- Size of area
- Color
- Discomfort (burning, itching, pulling, tenderness) – erythema
- Discomfort (dryness, itching, scaling, flaking, peeling) – dry desquamation

Promote Cleanliness

- Use non-perfumed soap. Bathe using warm water and palm of hand to gently wash affected skin. Rinse well and pat dry with a soft towel
- Wash hair using warm water and mild, non-medicated shampoo such as baby shampoo

Promote Comfort

- Avoid petroleum jelly based products
- Avoid irritant products containing alcohol, perfumes, or additives and products containing Alpha Hydroxyl Acids (AHA)

Post Treatment/Reduce Inflammation

- Alleviate pruritus and inflammation. Corticosteroid creams may be used sparingly as ordered by the physician

Urgent Clinical Presentation: Requires medical attention within 24 hours

Clinical Presentation

Moist Desquamation:

- Sloughing of the epidermis and exposure of the dermal layer
- Blister or vesicle formation
- Serous drainage
- Pain

Reaction Assessment

Assessment to include:

- Location
- Moist areas
- Dry areas
- Size of area
- Wound base: granular tissue, eschar or necrotic tissue
- Exudate
- Type
- Amount
- Odor
- Discomfort (burning, itching, pulling, tenderness)
- Signs of clinical infection
- Fever
- Foul odor
- Purulent drainage
- Pain and swelling extending outside of radiation area

Promote Cleanliness

- Cleanse with warm or room temperature normal saline

Manage Pain (During Treatment Break)

- Assess pain at each appointment
- Administer analgesics as ordered by the physician (clean area upon restart of treatments)

Prevention of Infection

- Regularly assess for signs of infection
- Culture wound if infection suspected
- Apply antibacterial/antifungal products as ordered by the physician



Appendix F: Declaration of Pregnancy



Form Letter for Declaring Pregnancy

This form letter is provided for your convenience. To make your written declaration of pregnancy, you may fill in the blanks in this form letter, or you may write your own letter.

Declaration of Pregnancy

To: _____

In accordance with the NRC's regulations in 10CFR20.1208, "Dose to an Embryo/Fetus," I am declaring that I am pregnant. I believe I became pregnant in the Month and Year indicated below:

Month & Year of Conception

I understand the radiation dose to my embryo/fetus during my entire pregnancy will not be allowed to exceed 0.5 rem (5 millisievert) {*unless the dose has already been exceeded between the time of conception and submitting this letter*}. I also understand that meeting the lower dose limit may require a change in job or job responsibilities during my pregnancy.

Signature of Person Declaring Pregnancy

Name (PRINTED) of Person Declaring Pregnancy

Date



Appendix G: Cutaneous Lesion SRT-100 Documentation for Clinical Treatment



Intentionally blank. The Documentation for Clinical Treatment will be placed in this handbook by the Sensus Clinical Applications Team during training.



Appendix H: Morning QA Form





Appendix I: Annual ALARA Review of Radiation Safety Program



Annual ALARA Review of the Radiation Safety Program

Year: _____

Date of Review: _____

Licensee: _____

License Number: _____

Date of Expiration: _____

Radiation Safety Officer: _____

The ALARA Review evaluates the methods and implementation of the Radiation Safety Program. The following is a list of items that were examined during this review:

Posting of Notices and Signs

Rooms or Areas are properly posted with a CAUTION – RADIATION AREA sign to indicate the presence of a Radiation Area.

Yes _____ No _____ N/A _____

A copy of the NOTICE TO EMPLOYEES is posted for use by individuals participating in the licensed activities.

Yes _____ No _____ N/A _____

A copy of the State Regulations is available for use by those individuals participating in the licensed activities.

Yes _____ No _____ N/A _____

Annual ALARA Review of the Radiation Safety Program

Copies of the Amendment Letters are incorporated into the current license and are available for use by those individuals participating in the licensed activities.

Yes _____ No _____ N/A _____

A copy of the Emergency Operating Procedures applicable to licensed activities is properly posted.

Yes _____ No _____ N/A _____

Personnel Monitoring Records

Records of current occupational radiation exposures to individuals are being maintained in accordance with State Regulations.

Yes _____ No _____ N/A _____

Records of cumulative occupational radiation dose are maintained for each radiation worker in accordance with State Regulations.

Yes _____ No _____ N/A _____

Personnel monitoring records are reviewed at least on a quarterly basis in accordance with ALARA Level I & II guidelines.

Yes _____ No _____ N/A _____

Operating Procedures and Manuals

The facilities' Radiation Safety In-Service program for all radiation workers is being conducted at the time of orientation and at least on an annual basis.

Yes _____ No _____ N/A _____

A Radiation Safety Procedures Manual is written and copies are made available for the use of all radiation workers.

Yes _____ No _____ N/A _____

The Radiation Safety Officer reviews and signs radiation documents at least on a quarterly basis.

Yes _____ No _____ N/A _____

Misadministration

Was a misadministration reported to the DRH during the calendar year involving the administration of a diagnostic X-ray radiation machine exposure to a patient?

Yes _____ No _____ N/A _____

Administrative Actions

At the time of this ALARA Review, this facility was found to substantially comply with State and NRC Regulations.

Radiation Safety Officer

Date



Appendix J: Radiation Safety Training Sign-In Sheet





Appendix K: Cutaneous Lesion SRT-100™ Training Sign-In Sheet





Appendix L: X-ray Sign



Intentionally blank. The X-ray sign will be placed in this handbook by the Sensus Clinical Applications Team during training.



Appendix M: Badge Reports



Intentionally blank. Badge Reports should be supplied to you on a quarterly basis by your radiation monitoring company.



Appendix N: Commissioning Report



Intentionally blank. The Commissioning Report will be placed in this handbook by the Sensus Clinical Applications Team during training.



Appendix O: Final Survey Report



Intentionally blank. The Final Survey Report will be placed in this handbook by the Sensus Clinical Applications Team during training.



Appendix P: Commissioning Output Sheet



Intentionally blank. The Commissioning Output Sheet will be placed in this handbook by the Sensus Clinical Applications Team during training.



Appendix Q:
Cutaneous Lesion
Fx Time Tables: 50kV, 70kV,
& 100kV



Set Time per Dose

50kV 380 cGy Fx			
applicator size	cGy per minute	Calc time	FX Dose
1.5 cm			
2.0 cm			
2.5 cm			
3.0cm			
4.0 cm			
5.0 cm			
10.0 cm			

50kV 320 cGy			
applicator size	cGy per minute	Calc time	FX Dose
1.5cm			
2.0 cm			
2.5 cm			
3.0 cm			
4.0 cm			
5.0 cm			
10.0 cm			

Set Time per Dose

70kV 380 cGy Fx			
applicator size	cGy per minute	Calc time	FX Dose
1.5 cm			
2.0 cm			
2.5 cm			
3.0cm			
4.0 cm			
5.0 cm			
10.0 cm			

70kV 320 cGy			
applicator size	cGy per minute	Calc time	FX Dose
1.5cm			
2.0 cm			
2.5 cm			
3.0 cm			
4.0 cm			
5.0 cm			
10.0 cm			

Set Time per Dose

100kV 380 cGy Fx			
applicator size	cGy per minute	Calc time	FX Dose
1.5 cm			
2.0 cm			
2.5 cm			
3.0cm			
4.0 cm			
5.0 cm			
10.0 cm			

100kV 320 cGy			
applicator size	cGy per minute	Calc time	FX Dose
1.5cm			
2.0 cm			
2.5 cm			
3.0 cm			
4.0 cm			
5.0 cm			
10.0 cm			



Appendix R: Notice to Employees



Intentionally blank. The Notice to Employees will be placed in this handbook by the Sensus Clinical Applications Team during training.



Appendix S: State Regulations



Intentionally blank. The State Regulations will be placed in this handbook by the Sensus Clinical Applications Team during training.



Appendix T: Authorized User Form





Appendix U: Authorized Physician Form



Authorized Physician

The Authorized Physician must be registered with the state in order to give physics support.

Facility Name: _____

Authorized Physician: _____

Date: _____



Appendix V: Citations



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