CHAPTER 1

Therapeutic Use of Radiation

1-1. Introduction

Radiation therapy, surgery, and chemotherapy are the three principal modalities currently used in the management of cancer. There are more than 200 types of cancers, all of which involve the rapid growth of abnormal cells that form tumors, which may compress, invade or destroy normal cells.

Radiation therapy also called radiotherapy, x-ray therapy, or teletherapy uses different forms of radiation like superficial photon beam, megavoltage photon beam, electron beam, and implant to cause biological damage at the atomic level leading to cell death. Fractionated schedules of treatment are used to differentially kill cancerous cells since they are more sensitive to radiation compared to normal cells. Careful treatment planning can precisely direct the radiation to the cancer while minimizing radiation damage to normal surrounding tissues. Since radiation therapy is not a surgical procedure, it is better tolerated, does not need hospitalization and there are no life-threatening complications. However it requires daily visits to the treatment center for several weeks.

Surgery involves the removal of tumors and its surrounding normal tissues and hence is a very localized form of treatment.

Chemotherapy uses drug taken either orally, intramuscularly or intravenously. Since the drug used travels throughout the body, cancer cells in remote location can be eradicated using this mode of treatment. The management of cancer is a multidisciplinary care requiring a combination of these methods of treatment. Radiation therapy is used with chemotherapy or when surgery is not an effective means of treatment. For other cases, radiation therapy is used to shrink cancer before surgery or after surgery to destroy any remaining cancer cells from growing again.

Besides cancer, radiation therapy has found other applications such as the treatment of benign tumors, relieving pain, reduce bleeding, immuno-suppessor in total body irradiation, to inhibit keliods formation, to inhibit atopic bone growth, and to ablate of arterio-venous malformation.

The goal of radiotherapy can be classified as either "curative" or "palliative". With **curative radiotherapy**, the aim is to deliver sufficient radiation to the tumor to eradicate every malignant cell while keeping the dose to non-useful and potentially harmful radiation to adjacent normal tissues to an absolute minimum. A change of ± 10% in dose can significantly alter the probability of local tumor control and/or normal tissue injury as illustrated in Figure 1-1.

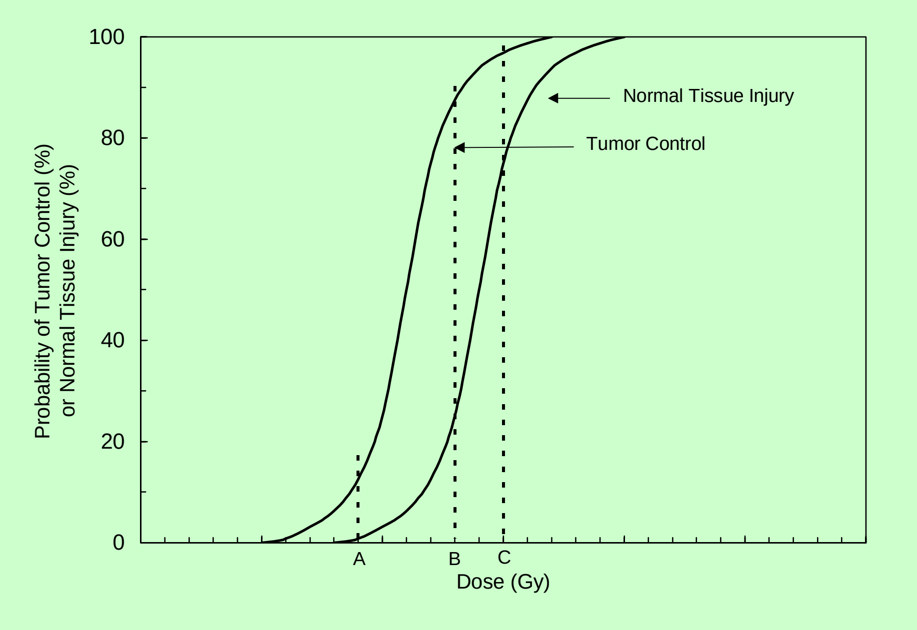


Figure 1-1. Relationship of radiation dose to tumor control and tissue injury.

Shown in the figure is three prescribed doses at A, B, and C. The probability of tumor control increases as well as the normal tissue injury as the doses increases. The objective in radiotherapy is to search for a dose that has a good tumor control with acceptable level of complications. With **palliative radiotherapy**, the aim is to relieve distressing symptoms. Cancer distressing symptoms can be pain due to bone invasion, headaches due to brain metastasis, paralysis due to spinal cord compression, or bleeding due to involvement of the skin, bladder, or bowels. The area of treatment is typically localized and the dose prescribed is lower with fewer fractions of treatment. Besides curative and palliative intent, there are circumstances when the family demands that all possible effort be done to the patient. This goal can be called "**radiation psychotherapy**".

1-2. Radiation Quantities and Units

Various means of quantifying the effect of radiation has been introduced since its discovery. The earliest method has been the observed effects of radiation on skin. Since this method is not precise, a more rigorous unit, the roentgen was later proposed. The roentgen was defined in terms of exposure in air. As defined it is not directly related to the energy deposition or biological effects of radiation. A newer term called **rad** which is an acronym of **radiation absorbed dose** was used. This unit is being replaced with the SI unit, the gray (Gy). Likewise, the concept of exposure and unit of roentgen is currently being replaced with gray and air kerma.

Like other physical quantities, there exist four basic units for radiation measurements as listed in Table 1-1.

Table 1-1. Radiological Units

Radiation Quantities	Conventional Unit	SI Unit
Exposure	Roentgen	C/kg
Absorbed Dose	rad	Gy
Dose Equivalent	rem	Sv
Radioactivity	Ci	Bq

The exposure quantity is used to define the amount of ionization of air by radiation. On the other hand, the absorbed dose quantity defines the amount of deposition of energy in a medium. The dose equivalent quantity is used to correlate the amount of deposition of energy and also the destructiveness of radiation towards biological system. The radioactivity quantity merely described the decay characteristics of a radioactive substance. All these quantities will be discussed in details.

The **exposure, X** defined by ICRU Report No. 33[1] as the quotient dQ by dm,

$$X = \frac{dQ}{dm} \tag{1-13}$$

where the value of dQ is the absolute value of the total charges of the ions of one sign produced in air when all the electrons (negatrons and positrons) liberated by photons in air mass dm are completely stopped in air. Note that the roentgen is only defined for radiation exposure for photons only and in the air medium. The roentgen is related to the System International (SI) unit as

$$1\ R = 2.58 \times 10^{-4}\ C/kg \tag{1-14}$$

***EXERCISE 1-1**. From equation (1-14), show that 1 R is equal to the production of 1 esu of charges in 1 cc of air.

As defined, a valid measurement of exposure is only possible if all the electrons produced in a known volume of air remain along their entire path length and collected in air. These conditions can only be satisfied only in the “standard air ionization chambers” which are few and available in only large standard laboratories. For photons greater than 3 MeV, the electron range exceeds the size of the chamber and as such, it is impractical to measure and hence the exposure is undefined. Even for lower energies, it is general not feasible to have an air buffer zone surrounding the volume of interest. Field radiation measurement such as the thimble ionization chamber used plastic wall in the shape of a thimble to define the ion collection volume. The plastic wall must be air equivalent that is absorbing the same amount of energy per gram as absorbed by air. Since most plastic absorbed less than air, the equivalence concept is achieved by using aluminum as the central electrode of the ionization chamber.

The **absorbed dose, D** defined by ICRU Report No. 51[2] as the quotient of dE by dm,

$$D = \frac{dE}{dm} \tag{1-15}$$

---

[1] ICRU Report No 33. Radiation Quantities and Units. International Commission on Radiation Units and Measurements. 7910 Woodmont Ave, Washington, DC, 1980.

[2] ICRU Report No 51. Quantities and Units in Radiation Protection Dosimetry. International Commission on Radiation Units and Measurements. 7910 Woodmont Ave, Bethesda, MD, 1993.

where dE is the mean energy imparted by ionizing radiation to matter and dm is the mass of the matter in that volume element. As defined, absorbed dose can be applied to any form of ionizing radiation and any type of medium. The unit of absorbed dose is the rad. The rad is defined as 100 ergs of radiation energy absorbed in a gram of matter. The rad is related to the SI unit as

$$1 \text{ rad} = 100 \text{ erg/gm} = 0.01 \text{ J/kg}$$

The joule, J is a unit of energy and equals to 10^7 erg. The special name of gray (Gy) is used to represent Joule per kilogram. In general, direct measurement of absorbed dose is difficult and impractical. Instead, ionization in air is measured in a medium and converted into absorbed dose in the medium using the ratio of absorption coefficients called f-factor or through Bragg-Gray formalism.

EXAMPLE 1-1. If 200 rads are delivered to 10 grams of tissue, what is the total energy absorbed. Express your answer in gram-rad

SOLUTION:

$$\begin{aligned} E &= 200 \text{ rad x } 10 \text{ gm} \\ &= 2000 \text{ gram} - \text{rad} \end{aligned}$$

***EXERCISE 1-2**. Show that gram-rad is equivalent to unit of energy.

The absorbed dose can be related to the exposure. The average energy needed to produce an ion pair in the gas over a wide range of varying conditions of temperature and pressure is 33.97 eV. This value is denoted as

$$\frac{\overline{W}}{e} = 33.97 \frac{\text{eV}}{\text{ion pair}} = 33.97 \frac{\text{J}}{\text{C}}$$

EXAMPLE 1-2. How much charged in Coulomb would be liberated in air by a 10 MeV electron?

SOLUTION:

$$\begin{aligned} Q &= (1\text{x}10^7 \text{ eV}) \text{ x } \frac{1 \text{ ion}}{33.97 \text{ eV}} \text{ x } \frac{1.6\text{x}10^{-19}\text{ C}}{1 \text{ ion}} \\ &= 4.71 \text{ x } 10^{-14} \text{ C} \end{aligned}$$

***EXERCISE 1-3**. Show that w/e is equal to 33.97 J/C from 33.97 eV per ion pair.

The equivalent of absorbed dose in air from 1 roentgen is 0.876 cGy as illustrated in the EXAMPLE below.

EXAMPLE 1-3. Show that 1 R of ionization in air is equivalent to 0.876 cGy of absorbed dose in air.

SOLUTION:

$$1\,R = 2.58\text{x}10^{-4}\,\frac{C}{kg}\,\text{x}33.97\,\frac{J}{C} = 8.76\text{x}10^{-3}\,\frac{J}{kg}$$

$$= 8.76\text{x}10^{-3}\ Gy = 0.876\ cGy$$

Another term that is coming to use is the **kinetic energy released per unit mass (KERMA)**. It is the unit of dose describing the initial kinetic energy of indirectly ionizing radiations (x-rays and γ-rays) transferred to directly ionizing radiation. One KERMA is equal to 1 Gy.

The **dose equivalent, H** defined by ICRU Report No. 51 as the product of Q and D at a point,

$$H = Q \text{ x } D \tag{1-16}$$

where Q is the quality factor and D is the absorbed dose at that point. The quality factors are different for different types of radiation as listed in Table 1-2.

Table 1-2. Radiation weighting factors[3]

Radiation Types	Weighting factor (w_R)
X-rays, γ-rays, electrons, positron, muons	1
Neutrons $<$ 10 keV	5
10 keV to 100 keV	10
$>$ 100 keV to 2 MeV	20
$>$ 2 MeV to 20 MeV	10
$>$ 20 MeV	5
Protons $>$ 2 MeV	2
α-particles, fission fragments nonrelavistic heavy nuclei	20

The old unit of dose equivalent is the rem acronym of rad equivalent man.

EXAMPLE 1-4. Find the equivalent dose of 100 cGy of alpha-particles and 100 cGy of photons.

---

[3] Data from NCRP Report No. 116 (1993). Compared to data from NCRP Report No. 91 (1987), the quality factor for neutrons (other than thermal neutrons), α-particles, and multiple-charged particles of unknown energy is 20.

SOLUTION:

$$
\begin{aligned}
H &= D_1 x\, Q_1 + D_2 x\, Q_2 \\
&= 1x\,20 + 1x\,1 \\
&= 20 + 1 = 21\,\mathrm{Sv}
\end{aligned}
$$

For the SI unit, the unit of dose equivalent has a special name called Sievert (Sv). The two units are related as

$$1\ \mathrm{Sv} = 100\ \mathrm{rem}$$

Like absorbed dose, the based unit of dose equivalent is Joule per kilogram (J/kg).

The radioactivity of a sample represents the number of disintegration per second. The old unit of activity is the Curie. One Curie represents the number of disintegration per second (dps) from a gram of Radium. It is equal to 3.7 x 10^{10} dps.

EXAMPLE 1-5: How many mCi of a radioactive isotope ($\tau = 60$ days) are required at the date of shipment if the receiving amount is 15 mCi after 3 days

SOLUTION:

$$
\begin{aligned}
A_o &= \frac{A}{e^{-\frac{.693}{\tau}t}} \\
&= \frac{15\ \mathrm{mCi}}{e^{-\frac{.693}{60d}x3d}} \\
&= \frac{15\ \mathrm{mCi}}{0.9659} = 15.5\ \mathrm{mCi}
\end{aligned}
$$

For intracavitary treatment, the radioactivity is typically quantified as equivalence to the activity of radium as **milligram radium equivalent** amount. For SI unit, the unit of radioactivity has a special name called Becquerel (Bq). It is defined to be 1 dps.

1-3. Radiotherapy Beams

Several types of radiation beams have been used in radiotherapy. These include, x-rays, gamma-rays, electron, neutron, protons and heavy ion beams. By far, the most accessible radiation beams are x-ray beam, gamma-ray, and electron beam. X-ray beam and electron beam is primarily from linear accelerator and gamma-ray beam from cobalt-60 machine. X-ray beams are from the kilovoltage generators and megavoltage (MV) linear accelerators and betatron upto 45 MV.

X-ray beam comprises of characteristic radiation superimposed onto the bremstrahlung radiation background. For kilovoltage photon beam, the characteristic radiation is from the tungsten target around 88 keV. For megavoltage beam, the energy spectrum comprises principally from bremstrahlung radiation. Which type of photon beam should be used will depend on the clinical applications. Superficial lesion is typically treated using kilovoltage unit. Megavoltage beams are used to treat deep-seated tumors because of its high penetrability and low dose to the skin and subcutaneous tissues. In general, low-energy megavoltage photon beam such as cobalt-60 or 4-8 MV x-rays are adequate for treatment of cancers that are located at moderate depth as in the head & neck region or breast. High-energy megavoltage beams are preferable for the management of the deep-seated cancers such as uterus, bladder, prostate, colorectal, esophagus, pancreas, and some lung and brain cancers.

The next clinically useful teletherapy beam is the **electron beam** produced by betatrons and high-energy linear accelerators. Although electron beam of any energy above 4 MeV can be produced, a linear accelerator typically comes with five electron beam energies from 5 MeV to 22 MeV. The advantage of electron beam is its finite depth of penetration, which is different from the photon beam. Electron beam is primarily used for appositional field treatment.

Radiation for brachytherapy is the **γ-rays** from radioactive sources. Radioactive sources that are currently in use are Iridium-192, Iodine-125, and Palladium-103. Iodine-125 and Palladium-103 are currently used to treat prostate. These sources may produce both γ-rays and β-rays the latter radiation is typically absorbed by the encapsulation and hence is not clinically useful.

Disease such as Pyterium is treated using **β-rays** from Strontium-90. Because of the limited penetration to a few mm from the source, β-ray is only effective in the treatment of thin layers of tissues. Phosphorus-32 with β-ray maximum energies of 1.7 MeV is used in the treatment of cyst and pleural cavity in internally administered radionuclide therapy.

Other forms of radiation that have been used in radiotherapy are protons[4], neutrons[5], and heavy ions (helium, neon, and carbon)[6] sponsored by NCI[7]. The properties of the radiotherapy beams are indicated in Table 1-2.

Table 1-2. Radiation types used in radiotherapy

Radiation Types	mass	charge

---

[4] Massachusetts General Hospital, Boston, MA.

[5] University of Pennsylvania (d-T), Philadelphia, PA and MD Anderson (cyclotron produced), Houston, TX.

[6] Lawrence Berkeley Laboratory, Berkeley, CA

[7] Report of the working group on the evaluation of treatment planning for particle beam radiotherapy. National Cancer Institute Report, 1987.

x-rays	0	0
γ-rays	0	0
β	m_e	-1, +1
p	m_p	+1
n	m_n	0
heavy ions	$x\,m_p + y\,m_n$	+

There is also a growing interest in the use of high linear energy transfer (LET) radiations, in order to take advantage of the different biological and physical effects of low and high LET radiation, thus improving the therapeutic ratio. A few neutrons and protons facilities are available around the United States. Radiation treatment using neutrons are limited to a few sites in the United States. **Neutrons** are derived from cyclotron and 'D-T' generators. The advantage of the neutron therapy is its high linear energy transfer (LET) capability.

Pi-minus meson (π^-) also simply called **pion** has also been used in radiation treatment at the Los Alamos Meson Physics Facility, Lost Alamos, NM[8]. The π^- mesons up to 800 MeV can be produced using high-energy proton linear accelerators and up to 600 MeV using synchrocyclotrons. The pion is produced by the proton-proton or proton-neutron collision with a negative Q-value of 140 MeV. The pion was predicted by Yukawa and finally discovered in cosmic rays by C.F. Powell and G. Ochhialini in 1947. The pion comes in three states: +, - or 0. The π^+ and π^- each has a rest mass of 139.6 MeV or approximately 273 times the mass of the electron. On the other hand, π^0 has a rest mass of 135.0 MeV.

EXAMPLE 1-6: Compute the mass equivalence of the rest mass of π^0 and expressed in kilogram

SOLUTION:

$$135.0\text{ MeV} = 135.0\text{ MeV x } \frac{1.6605\text{x}10^{-27}\text{ kg}}{931.5\text{ MeV}}$$

$$= 2.41\text{x}10^{-28}\text{ kg}$$

A π^- has short half-life of 2.6 x 10^{-8} sec decaying into muon, which subsequently decays into an electron with a half-life of 2.2 x 10^{-6} sec. The pion is thought to characterized nuclear force in the same way as photons characterizing electrical forces. But pion is only produced at very high energies about 300 MeV.

---

[8] Zink SR et al. Pion treatment procedures and verification techniques. Int J Radiat Oncol Biol Phys 10: 723-735; 1984.

1-4. Simulation

To successfully treat a patient, the radiation oncologist must seek ways to maximize the delivery of absorbed dose to the tumor and minimize the absorbed dose to the normal surrounding tissue. Since most tumors are deep seated and can be close to sensitive structures, individualized planning of the radiation treatment is required. This may involve directing the radiation beam from different angles into the body or using different type of radiation. To achieve this objective, a simulation or planning session must be initiated prior to actual treatment.

During simulation the patient will be positioned in such a way that the setup is comfortable for the patient and can be easily reproduced daily for treatment. Various immobilization devices are used to assist in the patient setup. Patient simulation is typically performed using specialized equipment called **simulator**. The simulator is a machine that has the same capabilities of a treatment machine except producing diagnostic quality x-ray beam. As such the simulator has the advantage of producing high quality radiograph compared to linear accelerator.

Many variables must be decided during simulation. These include treatment field size, number of portals, beam directions aiming at the target, and beam modifiers. After evaluating diagnostic x-rays or other tests, the size and location of the tumors are determined. The number of portals and intended beam directions are implemented at the time of simulation. The field size of each portal is determined at this time using fluoroscopy of the simulator. After the target area is defined radiographs are taken. Based on the radiographs, special custom blocks are fabricated to block the beam from irradiating normal tissue.

After the radiographs are taken essential markings are drawn on the patients for consistent reproducibility during daily treatment setup. Lines or tattoo marks of field sizes, laser alignment position, and other relevant marking. In selective cases, markings are also made on immobilization devices.

Before completing the simulation session, patient contour must be acquired for computerized treatment planning. Patient contour can be acquired manually or using CT scanned image. Manual contour are taken using simple tools like solder wire and calipers and transferred to a paper and digitized into the treatment planning computers.

1-5. Treatment Planning

Treatment planning has evolved from manual treatment planning to sophisticate computerized inverse treatment planning. In the past, the planning of a treatment was based on the superposition of isodose charts of a radiation beam onto the patient contour. The radiation beam was collected on flat surface phantom. During implementation, the isodose distribution was corrected for the curvature of the patient and the beams were summed to generate a treatment plan. This planning was also limited to the central beam axis and hence is referred to 2D treatment planning. Manual planning was tedious and time consuming.

Treatment planning was computerized when computers became available. Patient contours taken were digitized into treatment planning computer. Beams with weighting were directed onto the contours and summed. The resulting isodose distributions were evaluated for acceptability. Should the isodose distributions were found to be unacceptable the process was repeated with different beam directions and/or weightings. The evaluation process was repeated until an acceptable isodose distribution was generated. At this time, the computer algorithm was also account from tissue inhomogeneity

Computerized treatment planning was further improved with algorithms that can perform **three-dimensional (3D) treatment planning**. Three-dimensional conformal treatment planning is currently the best treatment planning system available. The planning system requires CT scanned images for the identification of patient contours, anatomy, and tissue heterogeneity. The planning resulted in the presentation of beam eye view and dose volume histograms, which are used for evaluation and comparison of treatment plans.

Recently, there is the introduction of **inverse treatment planning system**. This system is different from the 3D treatment planning system. In inverse planning, the treatment goal is defined and the computer algorithm would search for the best beam orientation and weighting that would satisfy the treatment goals as requested by the operator.

Current radiotherapy practices with emphasis on high-dose delivery using carefully planned irradiation techniques require that dosimetry be accurate and reliable. It is now widely accepted that dosimetry is an important link in the planning and delivery of a course of radiation treatment. There is some evidence that at least for some tumors, a variation of ±5% could make a difference between local control and failure.[9] Also, normal tissue responses are sharply dependent on dose although the curve tends to be less steep than those of tumor control responses.

1-6. Radiation Treatment

There are two basic methods of delivering radiation dosage depending on the relative location of the radiation source to the patient. If the radiation source is outside and at some distance from the patient, the

---

[9] Herring DR and Compton DM. Br J Radiol Special Report 5:51; 1971.

treatment is called **external beam therapy** or teletherapy. Teletherapy is derived from the Greek word “tele” to mean “far”. Radiation producing generators used to perform external beam therapy includes kilovoltage units, cobalt-60 units, betatrons, and linear accelerators. If the radiation source is placed near or implanted directly into the tumors, the treatment is called **brachytherapy** or radioactive implant. Brachytherapy is most often performed using sealed radioactive sources in the form of seeds, tube, or needles. The sources must be sealed to avoid radioactive contamination. It is not unusual for a patient to receive a combination of external beam followed by brachytherapy.

In external beam therapy, the radiation dosage is usually delivered in fractions. Fractionation takes advantage of the fact than cancer cells proliferate more rapidly compared to normal tissue cells. There is more cell kill because cells at the stage of dividing are more sensitive to radiation. The actual number of fractions during a course of treatment will depend on the total dose to be delivered for a particular type of malignancy. In general, five fractions are given per week. While the treatment session maybe about 15 minutes, the actual treatment or beam on time is about a minute. During treatment, the patient will be alone in the treatment room but will be continuously monitored by therapists through closed-circuit television and two-way intercom system. The patient should experience no pain or discomfort during treatment. The therapy machine which is very larger and making various noises can be intimidating to the patient for the first time. A course of radiation treatment takes on average about 4 to 5 weeks. Most patients are treated using this form of therapy.

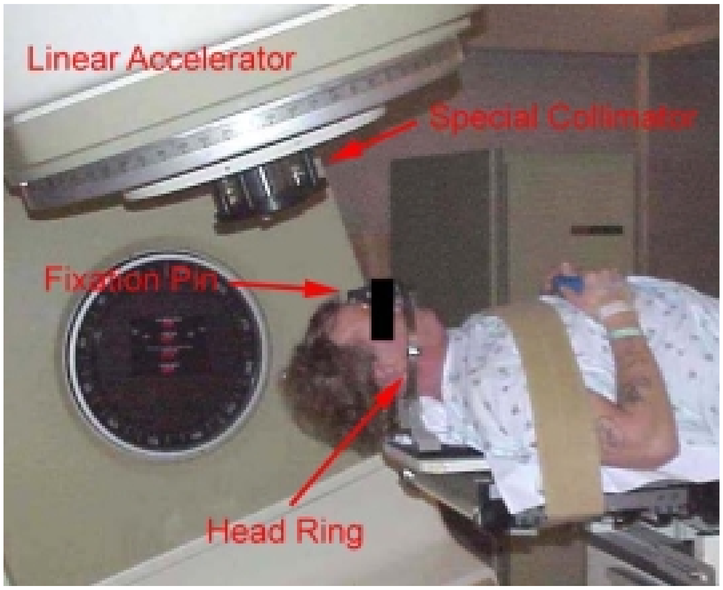
Brachytherapy is often used to treat well-localized cancers because a greater dose of radiation can be given to the tumor and less dose to the surrounding normal tissues. Implants are often performed for treating cancers of the eyes, cervix, uterus, vagina, prostate, or head and neck. Radioactive implants are usually performed in the operating room. Following the procedure, the patient is taken to the Radiation Oncology Clinic for x-rays radiograph for dose computation. In some cases, the radioactive sources may be left inside the patient permanently with radioactivity decaying on its own. In other cases, the radioactive sources are removed after a few days. Most patients are required to stay in the hospital while the implant is in place and their contact with visitors are limited during this time period.

***EXERCISE 1-4**. Under what circumstance can a patient be allowed to move or temporary leave the hospital while receiving temporary implants.

Beside external beam therapy and brachytherapy, there is another form of radiation treatment called **internally administered radionuclide**

therapy. In internally administered radionuclide therapy the sources used are not sealed and hence circulation of radionuclide to normal functioning organs may occur. Examples of this form of treatment are the use of iodine-131 for the treatment of thyroid cancer and the use of phosphorus-32 for the treatment of brain cyst.

Special treatment techniques for a variety of malignancies can be performed through some modification of the treatment machines and hence are only in a few radiation oncology facilities. **Total body irradiation (TBI)** is used to prepare for bone marrow transplants in the treatment of patients with leukemias and lymphomas. To perform this procedure the treatment room must be large so that the patient is about 2-4 m away from the radiation source. In addition, the dose rate has to be lowered to deliver about 10 to 20 cGy per minute. Likewise, larger treatment room is required for **total skin electron therapy (TSET)** for the treatment of skin diseases such as mycosis fungiodes. **Stereotactic radiosurgery** is used to treat arteriovenous malformation (AVM) and small brain tumors. In this procedure, the location of the lesion is determined relative to the stereotactic ring fixed to the patient's head. This geometrical information is used to direct a finely collimated beam of x-rays into the lesion from many directions as illustrated in Figure 1-2.



[redacted]

Figure 1-2. Stereotactic Radiosurgery

This alternative is an excellent alternative to surgery in many clinical situations. **Intraoperative radiotherapy (IORT)** is a procedure where electron beam therapy is used to treat the lesion through surgical open wound. This procedure requires a surgical room. This advantage of this procedure is that surrounding normal organs can be completely spare from irradiation.

1-7. Side Effects of Radiation Treatment

Although radiation is a powerful tool in management of cancers, it can cause a variety of side effects. The side effects do not show in all patients and their severity will depend on the type of cancer, the amount of radiation delivered, and the size and region of the body being treated. The side effects are usually presented in the later stage of radiation treatment and are temporary. However they should be reported to the radiation oncologists so that medication can be given for temporary relieve. Side effects may sometimes continue for a few weeks after completion of radiation treatment.

An obvious side effect is fatigue due to the need of energy to fight cancer cells and repair injured cells. Blood counts and body weight may decrease and periodic assessments are required. The skin at the treatment area may look reddened, irritated, tanned or sunburned. This effect is expected to clear up after completion of treatment. Upset stomach or diarrhea is expected in the radiation treatment in the lower abdominal area. For prostate treatment, there are risks of impotence and to a lesser extent incontinence. Other side effects include frequent and painful urination and rectal irritation or bleeding. Nausea or vomiting may also occur in the treatment of upper abdominal area. For patients with treatment to the head and neck region, there is the possibility of sores in the mouth, decrease saliva leading to dry mouth and difficulty in swallowing. It is also possible for the patient to loose or change of taste called taste blindness. Temporary hair loss called alopecia can also occur in the treatment of the scalp or head. The hair will grow again after completion of treatment.

1-8. Radiation Oncology Facilities

Because cancer can occur anywhere in the body, a wide range of equipment is needed for optimum management. The equipment should provide a wide spectrum of photon beams from 50 kV to 25 MV and a range of electron beams from 6 MeV to 24 MeV. These machines should be isocentrically mounted to allow radiation to be aimed from all directions around the patient. Today, modern linear accelerator is computerized, and has added capabilities to perform **conformal radiation therapy**. The machine is equipped with **multileaf collimation** that can be used to shape treatment field or modulate the radiation beam. Conventional shaping of treatment field is done using fabricated cerrobend blocks. The technique of therapy using beam modulation is called **intensity modulated radiation therapy (IMRT)**. The advantage of IMRT is the reduced dose to organ-at-risk and a means of escalating dose to target. Because of the modulation capability, IMRT can also be used to increase dose at selected region within the target referred to as dose painting or treating multiple targets at a time and therefore shortening the treatment course time. In addition there record verification that facilitated patient setup and validate daily treatment. There also **portal imaging system** that is used for port verification. Not all radiation oncology facilities have the different equipment because of the cost of the equipment. The basic equipment of a radiation oncology facility is a medium energy linear accelerator or a cobalt-60 unit.

Low energy x-rays and electron beams are used for treating superficial tumors such as skin cancers or surgical bed. Medium energy x-rays are used for treating tumors located at intermediate depth such as head and neck tumors or breast cancers. High energy x-rays are well suited for treating tumors located deep within the body such as cancer of lung, prostate, or uterine cervix. Medium-energy and high-energy x-rays beam have the advantage of the skin sparing effect. Skin sparing refers to the ability of the radiation to deliver higher dose to deep- seated tumors relative to the dose to the skin.

A treatment planning system is required to produce individualized treatment plan appropriate for each patient. For planning of a radiation treatment, some means of obtaining patient contour for the planning system, which is usually carried out in a simulation room.

A variety of radioactive sources should be available to perform brachytherapy. Commonly used sources are Iridium-192, Cesium-137, Iodine-125, and Palladium-103. Iridium-192 and Cesium-137 sources are used for temporary implants while Iodine-125 and Palladium-103 for permanent implants. The above sources are manually loaded into the patient for treatment. Another procedure called remote afterloading technique uses a computer-controlled microprocessor to insert and remove source automatically.

1-9. Radiation Oncology Team

An expert team of medical specialists that includes radiation oncologists, medical physicists, medical dosimetrists, radiation therapists, oncology nurses, and others is needed to properly deliver radiotherapy to the patients. A physician called radiation oncologist leads the team. The size of the team will depend on the size of the radiation oncology facility and the number of patients being treated and the type of procedures performed.

Radiation oncologists participate with the surgeons and the medical oncologists in deciding the overall treatment plan. They decide whether radiation therapy is indicated, the region to be treated, and the dose of radiation to be delivered. They supervise the plan of treatment and carefully monitor the course of radiotherapy.

Medical physicists work closely with the radiation oncologists and supervise the work of the medical dosimetrists in planning the treatment of each patient. They conduct quality control program for equipment and procedures and calibrate the machines at regular intervals.

Medical dosimetrists perform calculations to ensure that patient's tumor receives the dose prescribed by the radiation oncologist. They determine how the radiation beams should be arranged to best destroy the tumor and spare the normal tissues surrounding the tumor.

Radiation therapists are the persons who actually do patient setup and deliver the radiation treatments. They monitor the patient during the course of treatment and maintain the daily treatment records.

Oncology nurses help to educate each patient and family about the radiation treatment, and they provide emotional support to the patients. They also help with the initial examination of the patient, the weekly clinic evaluation, and follow-up visits.

Other members of the radiation oncology team that provide care of a patient undergoing radiotherapy include **social workers**, **dietitians**, and clerical members.

1-10. Biological Basis of Radiotherapy

The body cells normally grow, divide, and replace themselves. Sometimes, these cells may lose its ability to regulate its growth and they divide rapidly and grow into masses of tissue known as tumors without any order or regard for their function. Tumors can be either benign or malignant. Benign tumors are not cancer. They usually grow slowly, and generally do not spread to other part of the body. Benign tumors can generally be removed surgically without any further problems. On the other hand, malignant tumors are cancerous. They are usually capable of invading adjacent tissue or metastasizing to other parts of the body. The most common methods for cancer to spread are through the lymphatics to regional nodes or through the blood circulation system to distant organs. Because cancer can spread, it is important to detect it early as possible so treatment can be initiated while the cancer is limited. Cancers are most curable if they are localized.

Ionizing radiation destroys the ability of all cells cancerous and normal to grow and reproduce. However cancerous cells are more sensitive to radiation than normal cells. If the radiation is given just as the cell is about to reproduce, i.e. divide into two cells, the radiation will prevent the cell from dividing and it will die. Since cancer cells grow rapidly, more cancer cells are in the process of dividing and are more susceptible to radiation than normal cells. The destruction of cancerous cells leads to the effective treatment while the destruction of normal cells leads to the production of side effects.

The biological response of tumors and normal tissues to ionizing radiation is governed by several factors.

The physical deposition of energy in living tissue through ionization initiates a chain of chemical reactions those results in cellular damage and ultimately in the observed clinical effect. Ionizing radiation deposits its energy along its path and hence setting electron in motion. The density of ionization energy along the path of these particles is the linear energy transfer (LET). It represents the amount of energy deposited in tissue per unit track length (keV/μm). This LET accounts for the different biological effectiveness of different type of radiation. However, it is unimportant clinically since only x-rays and γ-rays are used in conventional radiotherapy.

The energy absorbed per gram of tissue is relatively small and relative few molecules are ionized. For example for a radiation dosage of 400 cGy, only 1 out of 5 x 10^7 molecules is ionized. Although it may appear as sparely ionizing, of the 10^{22} molecules in a gram of tissue, 10^{15} molecules will acquire sufficient energy to be ionized.

The effect of radiation at the cellular level is the loss of function and loss of reproductive ability. The tissue response based on the cellular response to radiation on the parenchymal cells and vascular stromal cells. Subsequently shows the overall organ response to radiation.

Repair, repopulation, reoxygenation, and reassortment known as the four R's of radiobiology play important role to tumor response to radiation. In addition, other factors like tumor growth factor and cell loss factor are also important.

The ability of eradicate a tumor is highly dependent on the size and radiosensitivity of the tumor. Generally, lesser dose is required for small size and radiosensitive tumors. Radiosensitive tumors include leukemias, lymphomas, seminomas, and dysgerminomas while radioresistant tumors are melanomas and sarcomas. Reoxygenation is the only "4 R's" that occurs in tumors but not in normal tissues. Tumor cells contains about 5-20% of hypoxic cells due to the limited diffusion distance of oxygen from inadequate tumor vascular supply. Normal tissue contains no or fewer hypoxic cells. The extent to which tumor reoxygenate during a course of radiation may determine whether it can be eradicate by radiotherapy.

The tumor radiocurability of a tumors depends on the radiosensitivity of the tumor and normal tissue tolerance. The **therapeutic ratio** defined as the ratio of normal tissue tolerance dose to tumor lethal dose is used as a measure of radiocurability. Of course, the tissue tolerance dose and the tumor lethal dose must be specified to the condition of interest. The goal of curative intent is to produce local tumor control without exceeding unacceptable complications.

1-11. Quality Assurance

Although a certain standard of quality must be established and maintained in any task, it is particularly important in radiation oncology. The importance is emphasized because of the delivery of tumorcidal dose to the patient. Unintended delivery of radiation dose to normal tissue would lead to radiation injury and would not accomplish the intended goal of radiotherapy. A quality assurance (QA) program, which is essentially a set of policies and procedures, must be established to maintain the quality of patient care. The general QA program has been set and recommended by professional organization such as American Association of Physicists in Medicine (AAPM), American College of Radiology (ACR), and American College of Medical Physics (ABMP). Mandatory QA program is required by the Nuclear Regulatory Commission and individual states for the use of radiation as healing arts. The Joint Commission for Accreditation of Health Care Organizations (JCAHO) has also a QA program that is required of hospital seeking their accreditation.

The purpose of the QA program is to objectively monitor the quality and appropriateness of patient care in a systematic fashion to achieve the desired goals of radiotherapy. This QA program therefore addresses all activities in radiation oncology that includes administrative, clinical, physical, and technical aspects of radiation oncology. As described, there are no single personnel that have expertise in all these areas. A team of personnel consisting of **radiation oncologists, radiation oncology nurses, radiation oncology physicists, medical dosimetrists, therapists**, and administrators are needed. All the staff providing radiation oncology service must be well coordinated and committed for the QA program to be effective.

The physics component of the QA program in radiation oncology is the responsibilities of the radiation oncology physicist. Many clinical physics tasks such as routine treatment planning and source preparation traditionally performed by a radiation oncology physicist have been delegated to medical dosimetrist or physics assistant. The qualification of the radiation oncology physicist should have a minimum of a master's degree in physics or related field and certified by either the American Board of Radiology (ABR) or American Board of Medical Physics (ABMP). The qualification for medical dosimetrist should have a minimum of a high school diploma and certified by American Association of Medical Dosimetrists. Medical physicist has the role of establishing the procedures, directing the activities and ensuring the compliance of these activities. Medical physicist must be available for consulting in clinically difficult cases and for appropriate for further action when unintended deviation occurs such as machine breakdown and incorrect dose. Medical physicist must also provide extended support in acceptance testing and commission of newly acquired equipment and maintenance of equipment performance. The role and responsibilities of physics team have been described in literature.[10]

1-12. Historical Perspectives - External beam

External beam therapy especially treatment of skin cancer started immediately after the discovery of x-rays by Roentgen in 1895. The treatment of deep-seated malignancies started around 1920s with the advent of x-ray units that produced radiation beam with energies in the kilovoltage range. Until the middle of 1950s, radiotherapy was performed using superficial and orthovoltage x-ray beams produced from machines operating in the 50-300 kV range. These machines have limited application since the maximum dose was delivered to the skin surface and these photon beams have limited penetration. The depth at which the dose from these beams dropped to 50% of maximum dose range from a few millimeters to a few centimeters, and these were low dose rate, short treatment distance machines.

Around the 1950s, there was a dramatic change in the practice of radiotherapy with the introduction of Co-60 units and megavoltage machines such as the betatrons and linear accelerators. The motivation for the improvement and upgrades of machines was the desire to raise the survival rate by increasing our ability to destroy the local tumor. Radiation oncologists around the world agreed that many types of cancers could be better controlled because of the unique radiation characteristics offered by these high-energy machines. An important radiation characteristic of these machines is that it allows the delivery of high radiation doses deeper into the tissues and highly penetrating. For example, cobalt-60 unit delivers the maximum dose 0.5 cm below the skin. Next, these high-energy machines produce adequate dose rates at large treatment distances. Overall, **megavoltage therapy offers deeper penetration into tissues, better skin sparing, and the absorption of the beam by the tissue is relatively independent of the absorbing tissue since Compton interaction is the dominant process**.

The use of megavoltage (MV) beams started with the Van de Graaff generators in 1930s. During this period betatrons and linear accelerators were also beginning to make their impact. The first betatron was built by DW Kerst at the University of Illinois, Chicago in 1940 and the first patient was treated in 1948. In around 1950s, there was the clinical introduction of cobalt-60 unit and high-energy machines. The first high-activity cobalt-60 source was produced in Canada in 1951. Later in the 1960s, there was the introduction of electron beams for the treatment of superficial lesion. As the

---

[10] Khan, F. Residency training for medical physicists. Int J Radiat Oncol Biol Phys. 24: 853; 1992.

Cobalt-60 teletherapy unit introduced in the late 1950s continue to be useful and dependable treatment machines. Most of these high-energy machines were transformed into mounted isocentric units and offer the capability of moving beam irradiation in addition to fixed beam treatment from any angular orientation. With further technical developments, the betatron, which produces more penetrating radiation, which is more appealing gradually, replaced isotope teletherapy units. However, betatrons because of their low output are now replaced with high-energy linear accelerators.

Modern linear accelerator grew out of pioneering work of scientists in UK and USA who developed magnetron and klystron, respectively. The growth of linear accelerators started replacing Co-60 teletherapy machines in the 1980s. Mean time cyclic accelerator called Microtrons were also developed and a 10 MeV therapy machine installed in Stockholm was put into clinical use in 1976, followed by installation of 20 MeV microtron at the Umea University Hospital, Umea, Sweden.

Modern radiation therapy requires the use of highly sophisticated equipment to improve survival rate, reduce morbidity, and improve quality of life for patients undergoing radiation treatment. As the survival rate progressively improved, attention is now shifted to morbidity and quality of life as an important aspect of treatment in addition to survival.

With more sophisticated machines, additional beam selection and a better understanding of the radiobiology, modern day radiation therapy has assumed an increasingly important role in the treatment of various types of diseases. Specialized procedures are being implemented to increase the benefit of radiotherapy.

Conformation therapy was introduced by S Takahashi[11] in 1960. The technique used changing field size during treatment in rotational therapy to create a high dose volume that conforms closely to the target volume resulting in excluding more normal tissue in the field compared to conventional therapy. Consequently, it is possible to increase the target dose without parallel increase in toxicity. The changing of field size to conform to the tumor was conceptually achieved using multi-leaf collimator. At that time, this technique was not practical and hence was not popular. With improvement in computer technology it is now possible to automate field shaping. Today linear accelerators are equipped with multi-leaf collimators that project 0.5 or 1.0 cm width at isocenter.

1-13. Historical Perspectives - Brachytherapy

---

[11] Takahashi S, Kitabataka T, Morita K, Okajima S, Ilda H. Methoden zur besseren Anpassung der Dosisverteiluing an tiefliegende Krankheitsherde bei Bewegungsbestrahlung. Strahlenther 1960: 115; 478-488. Takahashi S. Conformation radiotherapy. Acta Radio Suppl 1965: 242; 1142.

The practice of brachytherapy started after the discovery of radioactivity by Becquerel in 1896 and radium by Marie S. Curie in 1898. In 1901, Danlos inserted radium tubes into tumor. In 1912, Hirsh reported the insertion of a probe containing radium through the nasal cavity into the sella tursica of a patient with acromegaly following transphenoidal resection. In 1914, Stevenson and Joly improved the practice of brachytherapy with the introduction of radium needles made of steel or platinum. In 1914, Frazier began implanting radium sources at craniotom for primary brain tumors. Regaud and Debierne of Paris in 1915 used radon gas collected in capillary glass tubes and placed into platinum sheath for interstitial implantation. In 1926 Gioacchino Failla collecting radon gas in gold tubes instead of glass. The gold tubes filtered β-ray radiation that caused intense necrosis treated with radon collected in glass tubes. B.H. Colmery introduced radioactive gold seeds for permanent interstitial implantation in 1951.

The practice of brachytherapy declined when x-rays machines with higher energies around 130 kV to 200 kV were introduced in 1930s, and in the 1950s. In late 1960s, and particularly during the 1970s, there was a rebirth in the use of brachytherapy. This rebirth was due in part to the introduction of 1) artificially produced radioisotopes, 2) computerized dosimetry systems, 3) afterloading techniques, and 4) remote afterloading systems. These artificially produced radioisotopes serve as substitutes for radium sources as well as allowing the selection of an isotope appropriate for the particular tumor treatment. Since the artificially produced radioisotopes typically emit lower energy photons, they are easier to shield and less hazardous than radium sources. Some of the radioactive sources that have been used in the past are given in Table 1-2.

Table 1-2. Brachytherapy source that have been used in the past.

Radionuclide	Physical Form	Application
Cobalt-60	seed	eye plaque, intracavitary, interstitial
Tantalum-182	wire	interstitial implant
Radon-222	seed	permanent interstitial implant
Radium-226	needles	interstitial, intracavitary
Ruthenium		eye plaque

There is also the development of radiation dosimetry systems that provided a set implantation rules of radioactive sources that will achieve a particular dose distribution. In early 1930s, Paterson and Parker in Manchester developed a system of rules to distribute radium sources in a tumor that yielded a uniform dose to within 10% within the implanted region. These rules soon became popular throughout the world and set the basis for the well-known "Manchester" system of source and dose distribution used in major cancer centers. Concurrently, Edith Quimby in the United States developed a set of rules and tables for the use of uniform needles of radium spaced uniformly in an implant. Her system provides the minimum dose to the surface of the implant instead of the "average dose ± 10%" of the Manchester system. Today, computer dosimetry systems that are more powerful and sophisticated that can perform optimization, immediate dosimetry and generating valuable parameters such as dose-volume histograms and isodose distribution are standard practice.

Afterloading techniques and remote afterloading machines have reduced and virtually eliminate radiation exposure to personnel compared to the **pre-loading** technique where radioactive sources are directly placed into the patient at the time of surgery. **Afterloading techniques entail two fundamental steps: the insertion of an empty applicator or catheters into the patient in the operating room and the manual loading radioactive sources in the patient's room**. The afterloading catheters are closed end plastic tubes and applicators such as the Fletcher-Suit-Delclos system provide pathways for the insertion of encapsulated radioactive sources into the patient. Since the radioactive sources are always maintained inside the catheters or applicators, they do not come into contact with the patient. A wide variety of applicators and afterloading catheters are available to assist the implantation of radioactive sources into almost any anatomical part of a body. As such, most brachytherapy procedure are performed using **afterloading technique** today. Since the sources can be loaded in the patient's room, exposure to personnel occurs only when visiting the patient room instead of from the time of surgery. Further reduction or eliminate of exposure to personnel is possible with the use of remote afterloading machines where the machines load the radioactive sources into the patient and remove them after the dose delivery.

1-14. Safe Use of Therapeutic Equipment

High dosage and highly penetrating radiation beam is required in radiotherapy to destroy cancers. On the other hand, if the radiation beam is directed at unintended area, it can also cause significant harm to humans. As such radiation safety must be practiced diligently in radiation oncology. There are federal and state regulatory guidelines that have been established to minimize radiation accident involves in the operation of therapeutic equipment. These include the control of radiation sources, radiation environment, and accurate delivery of the stated dose to the patient.

The management of the radiation environment started at the time when there is an interest in acquiring radiation-producing machines. This includes the construction of treatment room to house the equipment and shielding requirements must satisfy regulatory requirements. Most treatment room has maze to reduce scatter dose to the treatment. The thickness of the treatment room wall will depend on the energy of the radiation machine and other intercepting barrier. For example, the primary wall thickness can be decreased if a beam stopper as shown in Figure 1-3.

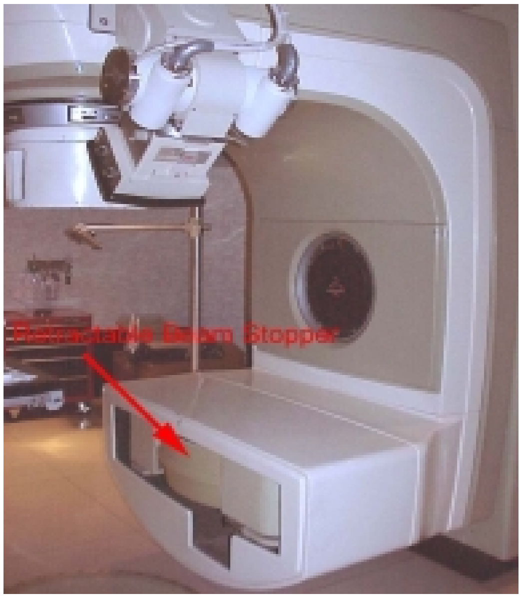


Figure 1-3. A beam stopper incorporated in a linear accelerator[12].

Neutron contamination should be considered when dealing with high-energy photon beam greater than 10 MV. This includes neutron shielding, neutron dosage to personnel and patient as well. At the initial time of energizing the machine, radiation survey must be performed to ensure that it is safe and also conform to regulatory requirements.

In addition, the machine must also be shielded to satisfy regulatory requirements. **For cobalt-60 teletherapy unit, the radiation leakage through the treatment head in the "OFF" position should not exceed 2 mR per hour at 1 m away and 0.1% of the useful beam in the "ON" position.** For x-ray producing machines such as the linear accelerator, the radiation leakage at 1 m away along the electron beam path should exceed 0.5% of the useful beam measured at the treatment distance. In addition, the leakage at any point outside the maximum field size but within a circle of radius 2 m centered at the beam axis in the perpendicular plane at treatment distance should not exceed 0.2% of the useful beam at treatment distance. The transmission through **adjustable collimator** should not exceed 1% and **multileaf collimator** should not exceed 2%. This transmission is lower compared 5% allowed by the **7 cm cerrobend block** typically used to create beam shaping.

Aside of radiation leakage, radiation safety features must be checked on daily basis. These include door interlock, visual communications with patients, audio communication with the patients. Other than safety features, tools used to assist in patient treatment should be checked to ensure its performance. These include machine output, laser, field size, and optical distance indicator. In short, there is a quality assurance program in radiation

---

[12] Model 6/100 Varian linear accelerator

oncology that monitors the performance of the equipment and daily operation for safety delivery of radiation dose to the patient.

A patient undergoing radiotherapy is typically not radioactive except for implant. While the patient is undergoing radioactive implant, the patient is hospitalized until the sources are removed or pose no hazard to family or friends. On the other hand, patients receiving permanent implants are always radioactive. As such, the patient is given instructions and advice on how to handle radioactive sources and radiation safety to the public.

Summary

1-1. Radiotherapy has found application in the treatment of malignancies but also treatments of benign tumors relieves pains, reduces bleeding, and prevents growth.

1-2. The two modes of delivering radiation doses are external beam therapy and brachytherapy.

1-3. The SI radiological units are Gray for absorbed dose, Coulomb per kilogram for exposure, Sievert for dose equivalent and Becquerel for radioactivity.

1-4. Different types of radiation are being used for radiotherapy. The commonly used radiation are photon beam and electron beam. Other types of radiation beam being used are neutrons and protons. For brachytherapy, Iridium-192, Palladium-103, Cesium-137, and Iodine-125 are used nowadays.

1-5. A patient must undergo a simulation or planning session prior to actual treatment. The purpose of the planning session is prepare the patient for treatment with consistent, comfortable, and reproducible setup.

1-6. The intent of treatment planning is to design individualized radiation delivery method that would optimized dosage to the tumor and minimize irradiation of normal tissues.

1-7. The goal of radiotherapy can be classified as either “curative” or “palliative”. For curative, the aim is to deliver sufficient radiation dose to eradicate the tumors while minimizing complications. On the other hand, for palliative intent, the aim is to relief symptoms requiring less dosage.

1-8. The obvious side effect of radiation treatment is fatigue and skin response at entry portal. Other side effects will depend on the treatment areas. For abdominal region, nauseating and vomiting may occur. For head and neck treatment, sore mouth, difficulty in swallowing and loss of taste may occur. Generally the side effects are temporary.

1-9. The basic equipment of a radiation oncology facility is a high-energy photon beam unit. Other equipment may be tools for taking contours and treatment planning system. Radioactive sources are needed to perform brachytherapy.

1-10. A quality assurance program is needed to maintain a standard quality of patient care. The team that leads the quality assurance program should include radiation oncologists, radiation oncology nurses, medical physicists, medical dosimetrists, and therapists.

1-11. Because of the involved high radiation dosage, safety procedure must be followed and radiotherapy must be practice with extreme care.

Study Guide

1-1. Define in your own words the following terms:

- (a) radiation therapy
- (b) chemotherapy
- (c) curative therapy
- (d) palliative therapy
- (e) radiation psychotherapy
- (f) radiation absorbed dose
- (g) exposure
- (h) radioactivity
- (i) KERMA
- (j) dose equivalent
- (k) pi-minus meson
- (l) simulation
- (m) 3D treatment planning system
- (n) inverse planning system
- (o) brachytherapy
- (p) external beam therapy
- (q) internal administered radionuclide therapy
- (r) total body irradiation
- (s) total skin electron therapy
- (t) stereotactic radiosurgery
- (u) intraoperative radiotherapy
- (v) conformal radiation therapy
- (w) multileaf collimation
- (x) portal imaging system
- (y) LET
- (z) therapeutic ratio

1-2. List three primary modalities used to manage cancers.

1-3. Identify three applications of radiotherapy.

1-4. List two goals of radiotherapy.

1-5. What is the difference between curative and palliative intent of treatment.

1-6. What is the difference between the absorbed dose of 100 cGy from γ-rays in bone and 100 cGy from β-rays in tissue?

1-7. List three types of radiation beams used in radiotherapy.

1-8. List three advantages of megavoltage photon beam.

1-9. List the advantage of electron beam.

1-10. How is neutron produced for use in neutron therapy?

1-11. What are the typical process done during simulation?

1-12. What is the function of treatment planning?

1-13. What is the difference between 2D and 3D treatment planning system

1-14. What is the difference between forward and inverse planning system

1-15. Identify the three modes of delivering radiation dosage to lesions.

1-16. List three possible side effects of radiotherapy.

1-17. What are the type of equipment available in a radiation oncology facility

1-18. What are the four Rs in radiobiology?

1-19. What is the purpose of quality assurance in radiation oncology

1-20. Identify the reasons for the rebirth of brachytherapy in 1960s

1-21. What is the function of the applicator or catheters in afterloading techniques?

1-22. Distinguish the difference between manual loading, preloading, afterloading, and remote afterloading techniques in brachytherapy.

1-23. List three basic safety features than must be check on a daily basis before the operation of a linear accelerator.

1-24. What is the leakage requirement of cobalt-60 source used in teletherapy.

Problems

1-1. How much charged in Coulomb would be liberated in air by a 6 MeV electron?

1-2. The output of a kilovoltage unit is calibrated and found to produce 3000R/min in air. Convert this exposure to absorbed dose in air and expressed in Gy.

1-3. A radiation worker is exposed to 50 cGy of 50 keV neutrons and 80 cGy of photons. Compute its equivalent dose and express it in Sv.

1-4. Compute the activity of Palladium-103 (half-life = 17 days) after 3 days of shipment if the initial activity is 40 mCi.

1-5. The muon has a rest mass energy of 105.7 MeV. Approximately how many times muons is more massive than an electron?

1-6. The pi-minus meson has a rest mass energy of 139.6 MeV. Express this rest mass in kilogram.

*1-7. An erg is defined as the amount of energy needed to move one gram of mass through a distance of 1 cm with a force of 1 dyne. Show that 1 Joule is equal to 1 x 10^7 ergs.

Multiple Choice Questions

Choose one correct answer.

1-1. Comparing curative and palliative radiotherapy, palliative intent prescribed
a) same dosage
b) lesser dosage
c) more dosage
d) more fractions
e) same fractions

1-2. The choice of radiation dose to a tumor depends on
I. histology of the tumor
II. curative or palliative consideration
III. tolerance of normal structures surrounding the tumor

a) I
b) I and II
c) II and III
d) I and III
e) I, II, and III

1-3. The exposure rate is usually measured in
a) tissue
b) bone
c) air
d) water
e) polystyrene

1-4. Which is not true of the roentgen
a) it is not defined for other form of radiation except photons
b) it is not defined for ionization of other medium except air
c) it is not a unit of dose
d) it represent the amount of either positive or negative charge collected
e) none of the above

1-5. The difference between exposure and dose is
a) the difference between rad and gray
b) the difference between ionization in air and absorption in medium
c) the difference between ionizing and non-ionization radiation
d) the difference between roentgen and rem
e) none of the above

1-6. The average value of W/e has been determined experimentally to be 33.97 eV per ion pair. This value is
a) independent of incident radiation energy
b) a constant for all materials
c) a specific value for a given mass of air
d) a specific path length of air
e) a constant in water

1-7. The primary advantage of brachytherapy over teletherapy is
a) there is no repair of sublethal damage
b) the dose distribution is more homogeneous
c) the normal tissue irradiated is minimized
d) it is less hazardous to staff personnel
e) it has polyenergetic radiation

1-8. Safety door interlock spot check should be performed
a) annually
b) monthly
c) weekly
d) daily
e) as required

1-9. Under what circumstances would a patient be considered "hot" or radioactive
a) after a single treatment using a linear accelerator
b) after a temporary implant
c) after a permanent implant

d) after a superficial treatment
e) after an electron beam treatment