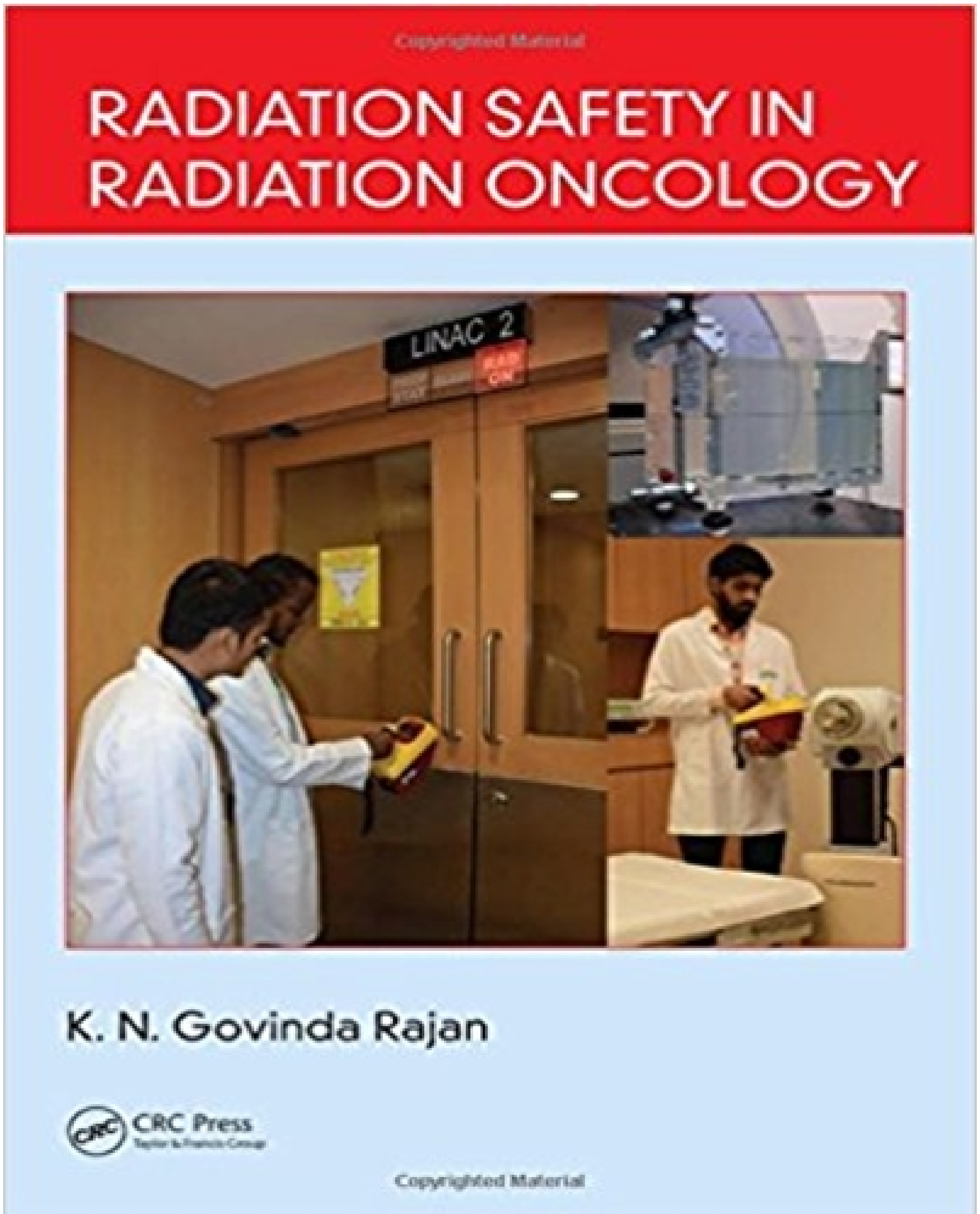
Solutions for Radiation Safety in Radiation Oncology 1st Edition by Rajan



Solutions

$$[-(dN/N)/dt]_{eff} = [-(dN/N)/dt]_p + [-(dN/N)/dt]_b \quad \text{or}$$

$$\lambda_{eff} = \lambda_p + \lambda_b$$

Since $\lambda = \ln 2 / T_{1/2}$, $\ln 2 / T_{1/2,eff} = \ln 2 / T_{1/2,p} + \ln 2 / T_{1/2,b}$

Or $T_{1/2,eff} = (T_{1/2,p} \times T_{1/2,b}) / (T_{1/2,p} + T_{1/2,b})$

$T_{1/2,eff}$ can be measured in a nuclaer medicine department if some radioactivity is administered to a patient for the purposes of dignosis or treatment. Using a counter, the emitted gamam can be measured w.r.t. time. Since the patient will also be discreting the radiopahrmaceutical through urine, what one measures is te effective half life.

39. According to the formula derived above, (1/24) + (1/8) = (1/6) or $T_{1/2,eff}$ = 6 days.

40. (1/1) – (1/6) = (5/6) hr or $T_{1/2,p}$ = 6/5 = 1.2 hr.

41. For secular equilibrium, $T_{1/2,P} >> T_{1/2,D}$ (say 100 or 1000 times). So, this is a case of secular equilibrium. We have seen in the text that secular equilibrium is reached in 6 to 7 half lives. So, the maximum activity would occur after say 7 x 1.25 or 8 to 9 minutes approximately.

42. For transient equilibrium (TE), $T_{1/2,P} > T_{1/2,D}$. So, this is a case of TE. TE is achieved after about 4 to 5 half lives. So, one can extract maximum activity of ^{99m}Tc practically every day for imaging or for other purposes.

Chapter 2

Answers

1. Mega voltage X-ray beams and MeV range electron beams are the most common beams used these days for cancer treatment. Particle beams like the protons or heavy charged particle beams (e.g. alphas or carbon ions) are also in use but to a lesser extent due to their cost. Fast neutron beams produced by cyclotrons are also in use in some centers. Thermal neutrons are used to treat brain tumors but a reactor is necessary as a source of thermal neutrons.

2. Differentiate between DIP and IDIPs in their energy deposition mechanisms.

   Energy deposition is because of charged particles mainly losing energy in the medium due to columbic interactions with electrons of the atoms of the medium. So they are called DIP. X-rays and neutrons eject electrons or charged particles (depending on the incident energy) which in turn lose energy in the medium.
   So IDIP ⟶ DIP ⟶ energy deposition.

3. Photoelectric effect, Compton effect and pair production. In the photon energy range of interest in radiation oncology the majority of interactions are through Compton effect which produces scattered electrons which is often a nuisance in photon therapy. It increases patient skin dose and leads to the loss of skin sparing effect of photon beams.

4. Particle fluence is the number incident per unit area and energy fluence is the energy incident per unit area. In case of monoenergetic beam one can get the energy fluence by multiplying the particle fluence by the energy of each particle. In the case of a spectrum, we can get the energy fluence by multiplying particle differential fluence by the energy value at each bin.

5. Kerma = Energy fluence x mass energy transfer coefficient of the medium. For a spectrum, one has to do this for an arbitrary energy bin and integrate over the energy spectrum.

6. For photons of energy > 8 MeV, generally neutron ejection from the nuclei of atoms is possible since 8 MeV is the average binding energy of nucleons in the nucleus. Proton ejection becomes more difficult due to the coulomb barrier. The exact photon energy for neutron ejection, however, depends on the actual binding energies of the atoms. Very low energy nuclides have lower neutron binding energies. So for a typical 10 MV beam, neutrons are produced in a linac facility by the interactions of the photons with the target, collimator and other components of the linac head, room air and the room walls, floor and ceiling.

7. Under charged particle equilibrium conditions, collision kerma and absorbed dose are equal. Due to the finite attenuation of photons over the ranges of electrons they produce, exact equilibrium is not attained and so a correction needs to be applied to derive collision kerma from the equilibrium dose. This is 1 for kV X-rays and around 0.5 % for Co-60 beams and increases with increasing photon energies and more difficult to evaluate. This is the reason for measuring local absorbed dose instead of collision kerma of photon beams. It is less problematic in the case of neutron beams since the charged particles produced by neutrons have much smaller ranges compared to the X-ray beam situation. So, CPE exists for much higher energies and collision kerma and kerma can be measured for higher energy neutrons as well.

8. Two important interaction mechanisms are (i) columbic interactions with electrons of the atoms of the medium and (ii) nuclear interactions in the coulomb field of the nucleus (not the nuclear force interactions). If there is no loss of energy the interactions are known as elastic (collisions). If it entails energy loss it is known as inelastic. If the charged particle does not lose energy there can be no biological effects in a biological system. Inelastic columbic interactions (with electrons) result in the ionization of atoms causing loss of energy and slowing down of the charged particles. When the charged particle is not having enough energy to ionize the atoms it cannot cause ionization and the electron can only be elastically scattered. The interactions of CPs in the coulomb field of the nucleus are known as non-radiative and radiative collisions. In a radiative collision, the CP loses a small fraction of its energy as a bremstrahlung photon (inelastic). Only a small fraction of

the collisions are radiative. Remaining collisions are just elastic scattering or deflection of charged particle without losing energy.

9. When an electron traverses matter it goes past the atoms of the medium. The strength of an interaction depends on the distance of approach (known as the impact parameter) of the electron from the interacting atom. The minimum impact parameter leads to head on collision (with maximum energy transfer). The maximum impact parameter (distances much larger than the dimensions of the atoms) corresponds to the electron just going past the without interacting (with no energy transfer). Large impact parameters give rise to very small energy transfers (and correspond to soft collisions). For smaller impact parameters (say of the order of atomic dimensions) the collisions are much harder causing ionization/excitations of atoms. For still smaller impact parameters (much less than the dimensions of the atoms) the interactions are with the coulomb field of the nucleus.

10. Since the charged particle interactions are very large the energy loss of a charged particle is usually characterized by the concept of stopping power which just gives the energy loss of the charged particle per unit path length traversed in the medium. Part of the electron interactions results in radiative collisions and the rest in ionizing collisions, as seen in the previous question. So, the stopping power is also correspondingly apportioned into radiative stopping power and collision stopping power.

11. Bremstrahlung efficiency.

12. Stopping power relates to the energy loss of charged particle (per unit path length) which is not exactly the same as energy locally transferred by the charged particle to the medium (known as Linear Energy Transfer or LET). The bremstrahlung energy usually escapes from the local region. (So, LET excludes the radiated part). The biological effect is because of the energy absorbed in the biological medium and so it depends on the LET. High LET corresponds to ionizing events occurring very close to one another compared to low LET where ionizing events are further apart. X-rays and electrons are examples of low LET and protons, neutrons, alphas etc. are examples of high LET radiations. (LET refers to CPs. So, LET of X-rays and neutrons imply the LET of the charged particles produced by these radiations).

13. Range corresponds to the depth of penetration. Path length corresponds to the length of the path of the charged particles. Since elastic scatterings can deviate the path of the charged particles path length is larger than the range. This difference is large for electrons since they are easily scattered because of their small mass.

14. Energy fluence x mass energy absorption coefficient gives collision kerma and charged particle fluence x collision stopping power gives the absorbed dose.

15. Because of the smaller velocities the LET increases and hence the dose profile.

16. Bragg Curve is a graph of LET vs depth of the charged particle traversing a medium. The Let reaches a maximum at the end of the range and so the Brag curve peaks. This is known as the Bragg peak. Since range increases with the charged particle energy, the depth of Bragg Peak also increases with CP energy. This is the ideal position for treating a tumor for maximum energy deposition (or biological damage). However, the tumor has a finite crosssection. So, to use CPs for cancer therapy, the peak has to be spread to accommodate the tumor. A spread in the energy of the CP beam can result in a spread of the peak to give a spread out peak. The CP treatment beams have a device called ridge filter which can differentially attenuate the CP beam to produce a spread out peak.

17. Because the electrons are easily scattered compared to heavy CP beams and hard collisions can impart significant energy transfer to electrons, the electrons are lost from the beam easily resulting is a drastic fall of the electron fluence (and hence the dose) with depth. Thus electron beams do not have a finite range and do not produce a Bragg curve and a Bragg Peak. Another important difference is the bremstrahlung production and the crosssection for this varies as ($1/m^2$). So, bremstrahlung is important only for electrons and the tail of the electron depth dose profile clearly shows the bremstrahlung background appears as a tail of the electron depth dose profile.

18. The comparison of dose profiles in the book explains the advantages namely, low dose to normal tissues, very high dose to the tumor target and very little dose beyond the target and a higher biological defectiveness.

19. Thermal neutrons have a very high capture crosssection for thermal neutrons. If a tumor can preferentially absorb boron compounds they can be targeted by directing a thermal neutron beam to the tumor. The thermal neutron capture results in the release of high LET particles that kill tumor cells. It has been used in brain cancers and in other body sites as well.

20. Neutrons can be produced in (D,D) and (D,T) and (p, Be) reactions. Cyclotron and (D,T) generators are used as sources of fast neutrons for cancer therapy. Here an accelerated deuterons or protons bombard a D,T or Be targets producing fast neutrons.

21. The neutron production mainly arises from the interaction of X-rays with linac primary and secondary collimators (about 54 to 55 % from primary collimator, 26 to 27 % from MLCs and jaws and 5 to 6% from target for a Siemens linac referred to in the text). Other components in the liac too make a very small contribution.

22. The average BE of neutron is about 8 MeV though it can be lower or higher than this depending on the nature of the target nuclei. Since the photon must deliver around this energy to the nucleus to emit a neutron from the X-ray target or other linac components, there is a threshold energy for neutron production. So, below 10 MV, neutron is not an issue for a medical linac.

23. (γ, n) reactions (also known as photodisintegration). Neutrons are also produced through $(\gamma, 2n)$ and (γ, pn) reactions but the yield is lower than for the (γ, n) reactions.

24. Two mechanisms operate in the ejection of neutrons from the target nuclides. (i) In the case of direct collision of neutrons with surface nucleons – this is known as direct interaction – photons transfer all its energies to the ejected neutrons. (ii) In the case of compound nucleus formation, the photon is absorbed and its energy is shared by all nucleons and one or more neutrons that manage to gain more energy escape from the nucleus. This is like evaporation of neutrons.

25. Like photodisintegration electrodisintegration, emitting neutron is also possible, but the crosssection is smaller by a factor of 100 and so can be neglected.

26. Through photonuclear reactions. The residual nuclide, following a nuclear reaction, is generally not ending up in a stable element configuration leaving it in a radioactive state. For > 10 MV beams, the linac head gets activated and most of the radioactive nuclides produce are short lived positron isotopes (half life in minutes). The gamma exposure from these radioisotopes gives rise to dose to technologists who approach the linac immediately after the treatment session. Studies have shown that the technologist may typically receive an annual dose of around few mSv due the head activation. If the technologist enters the room after a gap of about 10 minutes, the activity significantly reduces and so is the technologist dose.

27. Air activation produces ozone which is a health hazard. Adequate ventilation must be provided to reduce ozone concentration to acceptable levels.

28. They are classified as fast, slow, epithermal and thermal as explained in the text.

29. Scattering by hydrogen atom. Hydrogen atom. Heavier the mass smaller is the recoil and more energy is retained by the neutron.

30. Neutrons are moderated by the room walls and energy degraded to reach thermal and epithermal energies. These neutrons are also and attenuated in intensity by the room dimensions before reaching the door. The door uses a hydrogenous material impregnated with boron (e.g. borated polyethylene) for capturing thermal neutrons. The capture gamma is having energy in the MeV range and must be attenuated by a lead backing in the door to acceptable levels before entering the control room.
