Treatment Machines for External Beam Radiotherapy

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Lecture_3

Contents

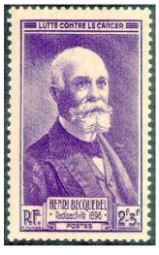
- Introduction – Discovery of x-rays
- How x-ray machine works
- Types of teletherapy machines
- How does Cobalt-60 teletherapy machine works
  - Radioactive sources used
  - The head and the source housing
  - Dose delivery mechanism

Objective

- To understand the basic principles of equipment used for external beam radiotherapy.

Introduction

- The study and use of ionizing radiation in medicine started with three important discoveries:
  - X rays by Wilhelm Roentgen in 1895.
  - Natural radioactivity by Henri Becquerel in 1896.
  - Radium-226 by Pierre and Marie Curie in 1898.



Introduction

- During the first 50 years of radiation medicine the technological progress was aimed mainly towards:
  - Development of analogue imaging techniques.
  - Optimization of image quality with concurrent minimization of dose.
  - Ever increasing energies and beam intensities.
- During the last 2 decades most developments in radiation medicine were related to:
  - Integration of computers in imaging
  - Development of digital imaging techniques
  - Incorporation of computers into therapeutic dose delivery with high energy linear accelerators (linacs).

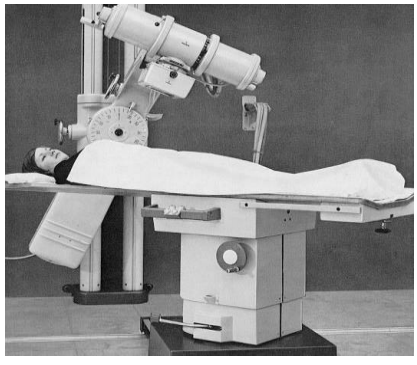
Treatment machines used for EBRT

- X- ray machine:
  - Superficial x-ray machine: 10 - 100 kVp
  - Orthovoltage x-ray machine: 100 - 500 kVp
- Cobalt-60 teletherapy machine (Megavoltage)
- Linear accelerator (linac):
  - Megavoltage x rays: 6 - 25 MV
  - Electrons: 6 - 30 MeV

X-ray Machine

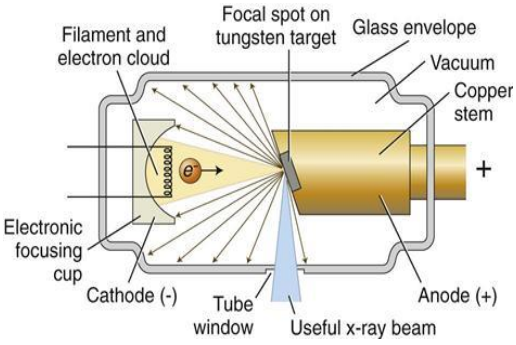
X-ray Machine

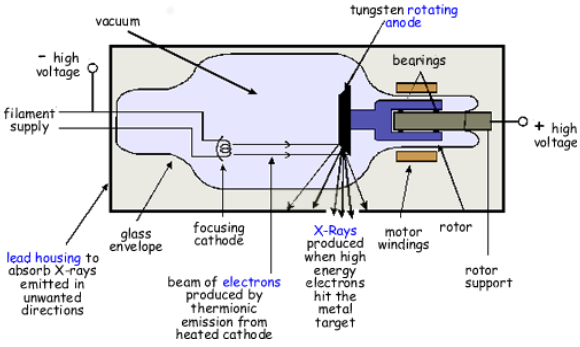
- Superficial and orthovoltage beams used in radiotherapy are produced by x-ray machines. The main components of a radiotherapy x-ray machine are:
  1) X-ray tube
  2) Target cooling system
  3) Ceiling or floor mount for the x-ray tube
  4) Patient support assembly
  5) Control console
  6) X-ray power generator



X-ray Machine

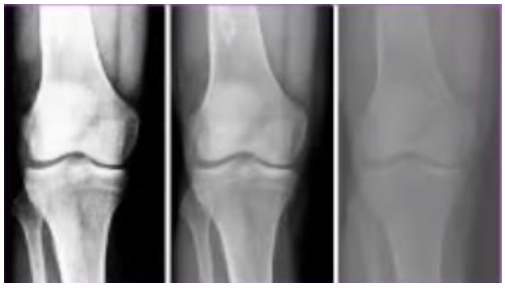
- The main components of a typical therapy x-ray tube are:
  - Heated filament (cathode)
  - Water or oil cooled target (anode)





Kvp & mAs

Increasing Kvp



Lower contrast = More gray colour

Increasing mAs

Less darker image = higher contrast

Superficial x-ray machine

Superficial x-ray machine

- The energy is between 10 Kvp to 100 Kvp
- Treats small skin lesions to the depth of up to 5 mm
- The size of the applicator varies
- Typical SSD is < 30 cm
- Beam quality (HVL) is between 0.5 mm to 8 mm of AL
- Filter are used in the machine to absorb low energy photons which may unnecessarily increase the skin dose.
- The photon beam sometime contaminated with electrons scattered from the applicator.

Superficial x-ray machine

Superficial x-ray machine

Orthovoltage x-ray machine

Orthovoltage x-ray machine

- The energy is between 100 Kvp to 500 Kvp
- Treats small skin lesions and bone metastasis (Ribs) to the depth of up to 20 mm
- Typical SSD is from 30 to 60 cm
- Beam quality (HVL) is between 0.2 mm to 5 mm of Cu
- Sometimes replaces megavoltage machine for palliative treatments

Orthovoltage x-ray machine

Cobalt 60 teletherapy unit

Cobalt-60 production

- Co-59 bombarded by neutrons in nuclear reactors:

$$^{59}_{27}\mathrm{Co} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{60}_{27}\mathrm{Co} + \gamma$$

Cobalt-60 teletherapy machine

- Cobalt-60 teletherapy unit, developed in Canada in 1950s, was the first truly practical megavoltage therapy machine.

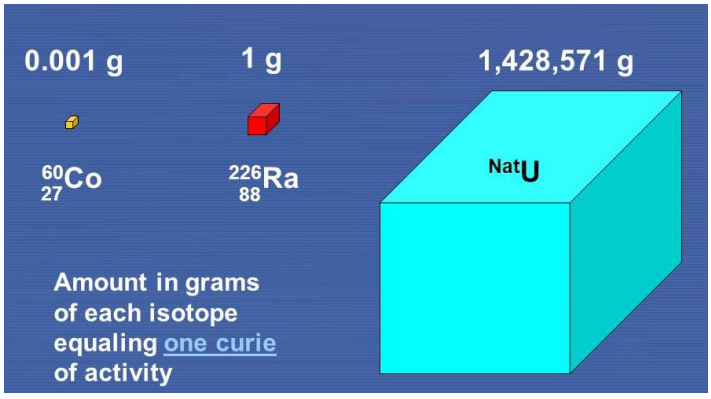
- **The important features of a teletherapy source are:**
  1) Relatively high energy gamma ray emission (about 1 MV)
  2) Relatively long half-life (about several years)
  3) Relatively high specific activity (of the order of 100 Ci/g)
  4) Relatively simple means of production

Radionuclides

- Of the close to 300 natural nuclides and over 3000 artificially produced radionuclides:
  - Only four of them meet the teletherapy source requirements (Co-60, Cs-137, Eu-152, and Ra-226) and only cobalt-60 is actually used in practice.

Radionuclide	Co-60	Cs-137	Eu-152	Ra-226
Half-life (y)	5.26	30	13.4	1600
Energy (MeV)	1.25, 1.33	0.660	0.6-1.4	0.18-2.2
Specific activity (Ci/g)	1130	80	180	0.988
Means of production	^{59}Co+n *in reactor*	*Fission by-product*	^{151}Eu+n *in reactor*	*Natural* ^{238}U *series*

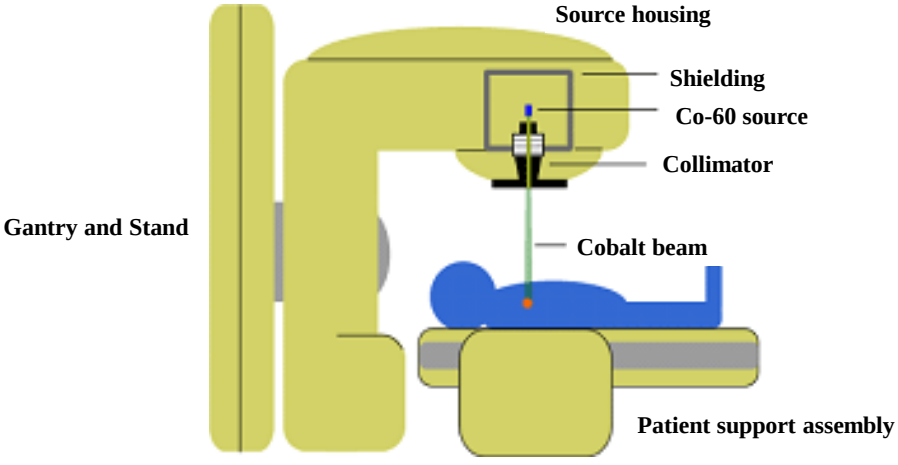
Specific activity comparison



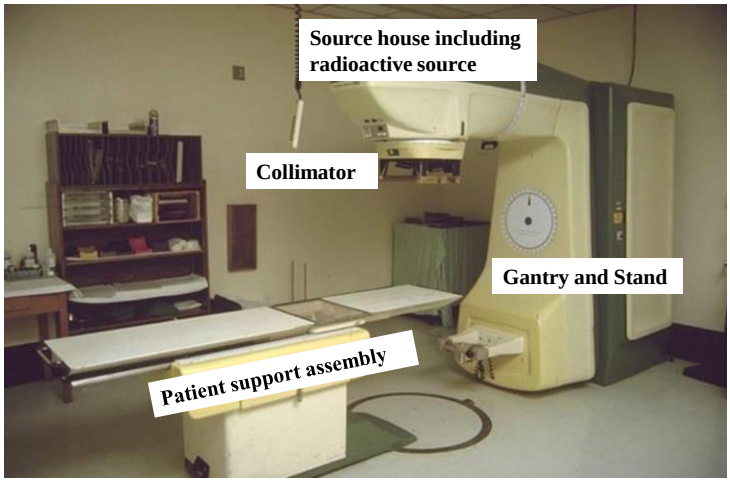
Teletherapy machines

- Treatment machines used for external beam radiotherapy with gamma ray sources are called teletherapy machines.
- They are most often mounted isocentrically with source to axis distance (SAD) of 80 cm or 100 cm.
- **The main components of a teletherapy machine are:**
  1) Radioactive source
  2) Source housing, including beam collimator and source movement mechanism.
  3) Gantry and stand.
  4) Patient support assembly.
  5) Machine control console

Co-60 Teletherapy machines



Cobalt-60 teletherapy machine



Cobalt 60 teletherapy machine, Canada

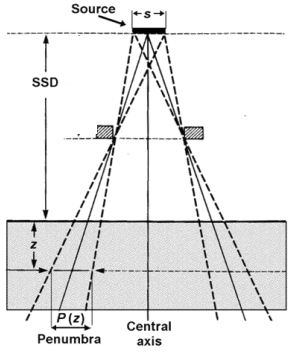
Teletherapy sources – Co-60

- Teletherapy sources are cylinders with height of 2.5 cm and diameter of 1, 1.5, or 2 cm.
  - The smaller is the source diameter, the smaller is the physical beam penumbra and the more expensive is the source.
  - Often a diameter of 1.5 cm is chosen as a compromise between the cost and penumbra.
- Typical source activity: of the order of 5,000 – 10,000 Ci (185 - 370 TBq).
- Typical dose rates at 80 cm from source: of the order of 100 - 200 cGy/min
- Teletherapy source is usually replaced within one half-life after it is installed. Financial considerations often result in longer source usage.

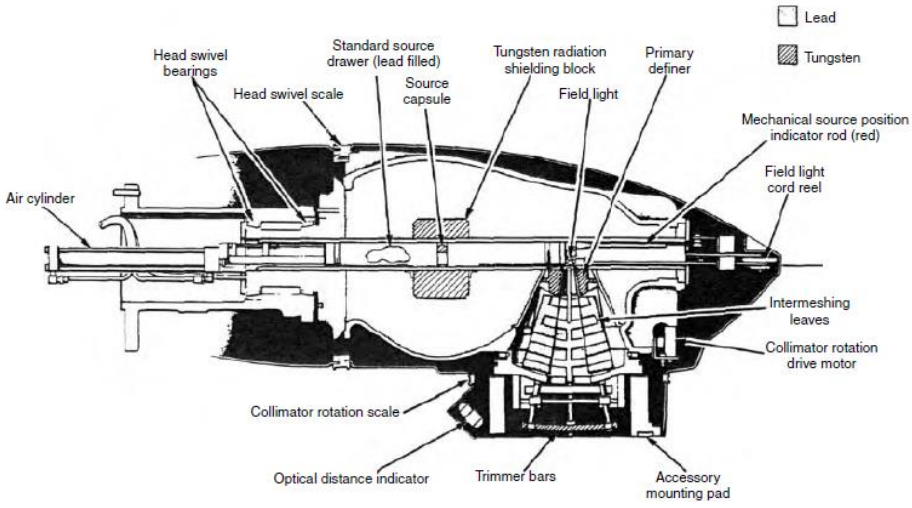
Collimator and penumbra

- Collimators of teletherapy machines provide square and rectangular radiation fields typically ranging from 5 x 5 to 35 x 35 cm^2 at 80 cm from the source.

- The geometric penumbra resulting from the finite source diameter, may be minimized by using:
  - Small source diameter
  - Penumbra trimmers as close as possible to the patient's skin (z = 0)



Teletherapy source housing



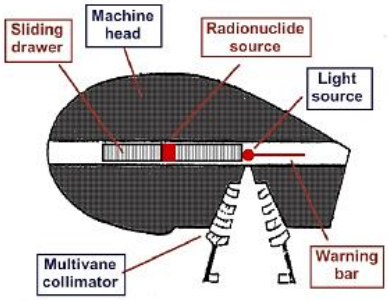
Teletherapy source housing

- **The source head consists of:**
  - Steel shell with lead for shielding purposes
  - Mechanism for bringing the source in front of the collimator opening to produce the clinical gamma ray beam.
- Currently, two methods are used for moving the tele-therapy source from the BEAM-OFF into the BEAM-ON position and back:
  1. Source on a sliding drawer
  2. Source on a rotating cylinder

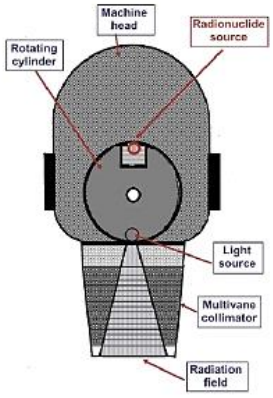
Teletherapy source housing

- Methods for moving the teletherapy source from the BEAM-OFF into the BEAM-ON position and back:

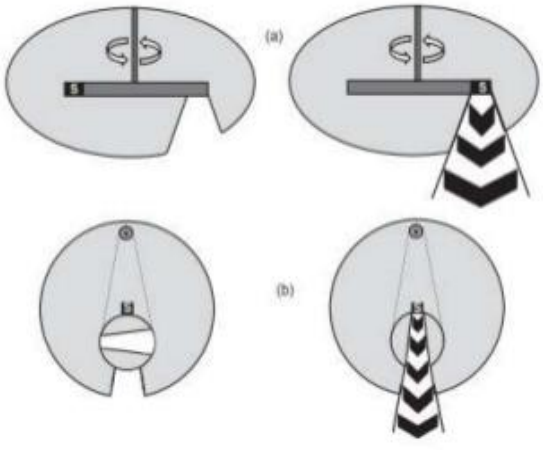
Source on a sliding drawer

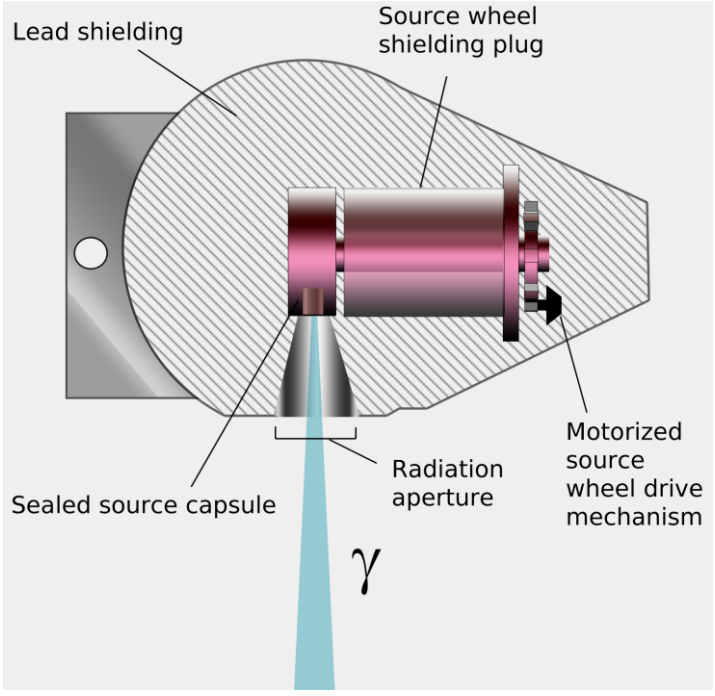


Source on a rotating cylinder



Teletherapy source housing





Teletherapy source housing

- Both methods (source-on-drawer and source-on-cylinder) incorporate a safety feature in which the beam is terminated automatically in the event of power failure or emergency.

- When the source is in the BEAM-OFF position, a light source appears in the BEAM-ON position above the collimator opening, allowing an optical visualization of the radiation field, as defined by the machine collimator.

Dose delivery mechanism

- The prescribed dose is delivered to the patient with the help of two treatment timers: primary and secondary.
  - The primary timer actually controls the treatment time and turns the beam off upon reaching the prescribed beam-on time.
  - The secondary timer serves as a backup timer in case of the primary timer's failure to turn the beam off.

- The set treatment time should incorporate the shutter correction time to account for the travel time of the source from the BEAM-OFF to the BEAM-ON position at the start of the irradiation and for the reverse travel at the end of irradiation.

Modern Cobalt-60 Unit

Reference

- Radiation Oncology Physics: A Handbook for Teachers and Students by: EB. Podgorsak (Chapter 5, p.123)
- Discovery of x-rays, YouTube link: https://www.youtube.com/watch?v=vYztZlLJ3ds

Any Questions ?

Thank you!