Authorization and Inspection of Linear Accelerators (LINACS) Used in Radiotherapy
Day 1

IAEA
International Atomic Energy Agency

Introductions and Familiarization with Facility

- Instructor Introduction
- Student Introductions
- Potential Hazards and Rally Points
- Restrooms

IAEA

Agenda

- Day 1
  - Biology of Cancer Treatment
  - Introduction to Linear Accelerators
  - Important Facility Construction and Safety Features
  - Calibration, Quality Control, and Quality Assurance

Biology of Cancer Treatment

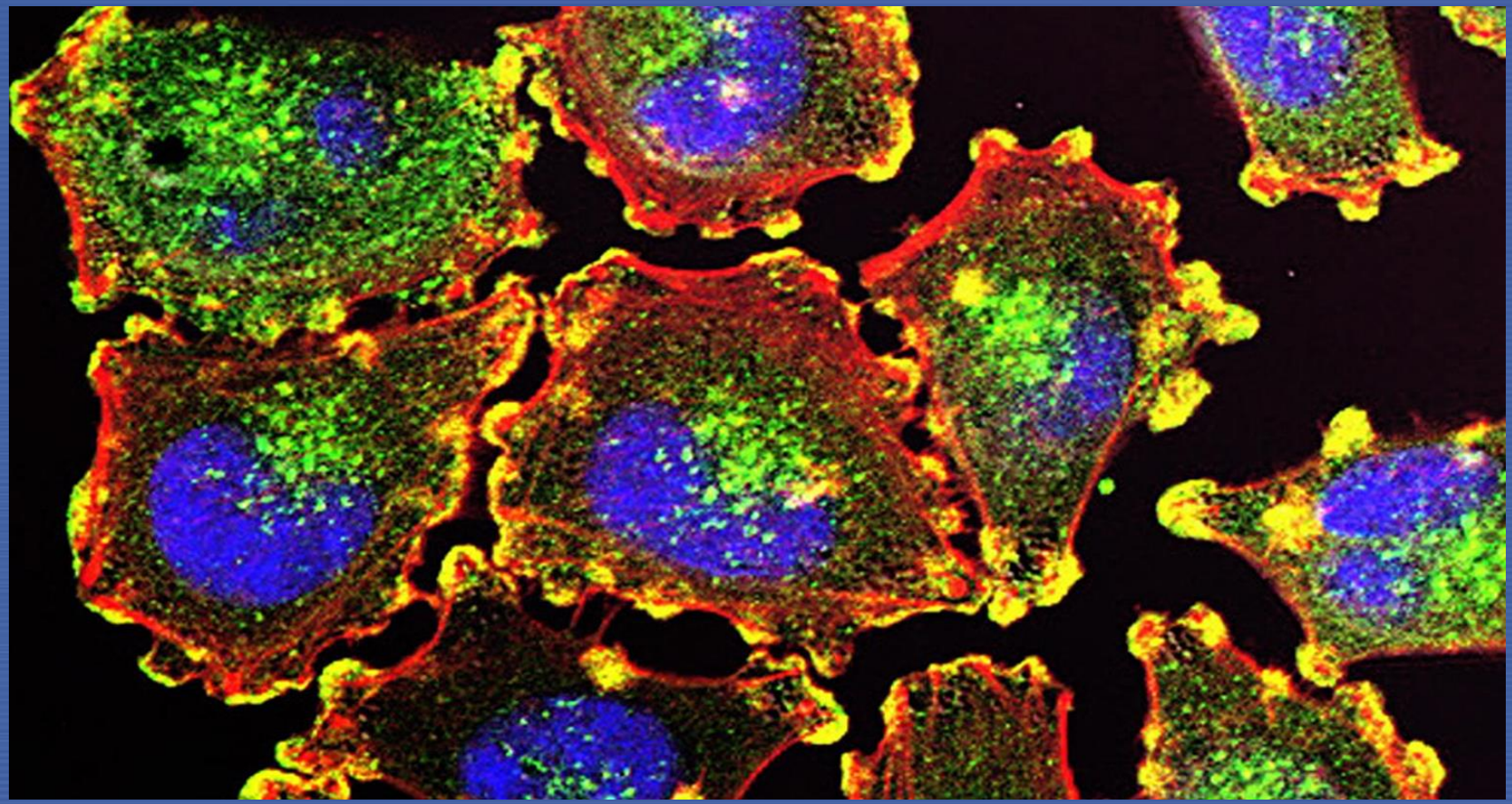
Biology of Cancer and Treatment

- Learning Objective

  After this section the students should know the hallmarks of cancer and the mechanism of cell damage from radiation. They should understand the concept of therapeutic window in radiation and the role in fractionation and normal tissue tolerances in treatment plan design.

This section should take 60 minutes

Biology of Cancer and Treatment



Biology of Cancer and Treatment

- Overview
- How Much is an MeV?
- Mechanism of Cell destruction
- Cell Survival
- Therapeutic Window
- Fractionation
- Serial vs Parallel organs
- Dose Escalation

Overview

- Cancer describes an enormous spectrum of diseases that all originate from uncontrolled cellular growth.
- Benign tumors can be symptomatic
- Malignant tumors (cancers) are further defined and classified by their cell type, tissue, or organ of origin.

Overview

Radiation therapy uses targeted energy (e.g., X-rays, radioactive substances) to destroy cancer cells, shrink tumors, and/or alleviate certain cancer-related symptoms. It may be used:

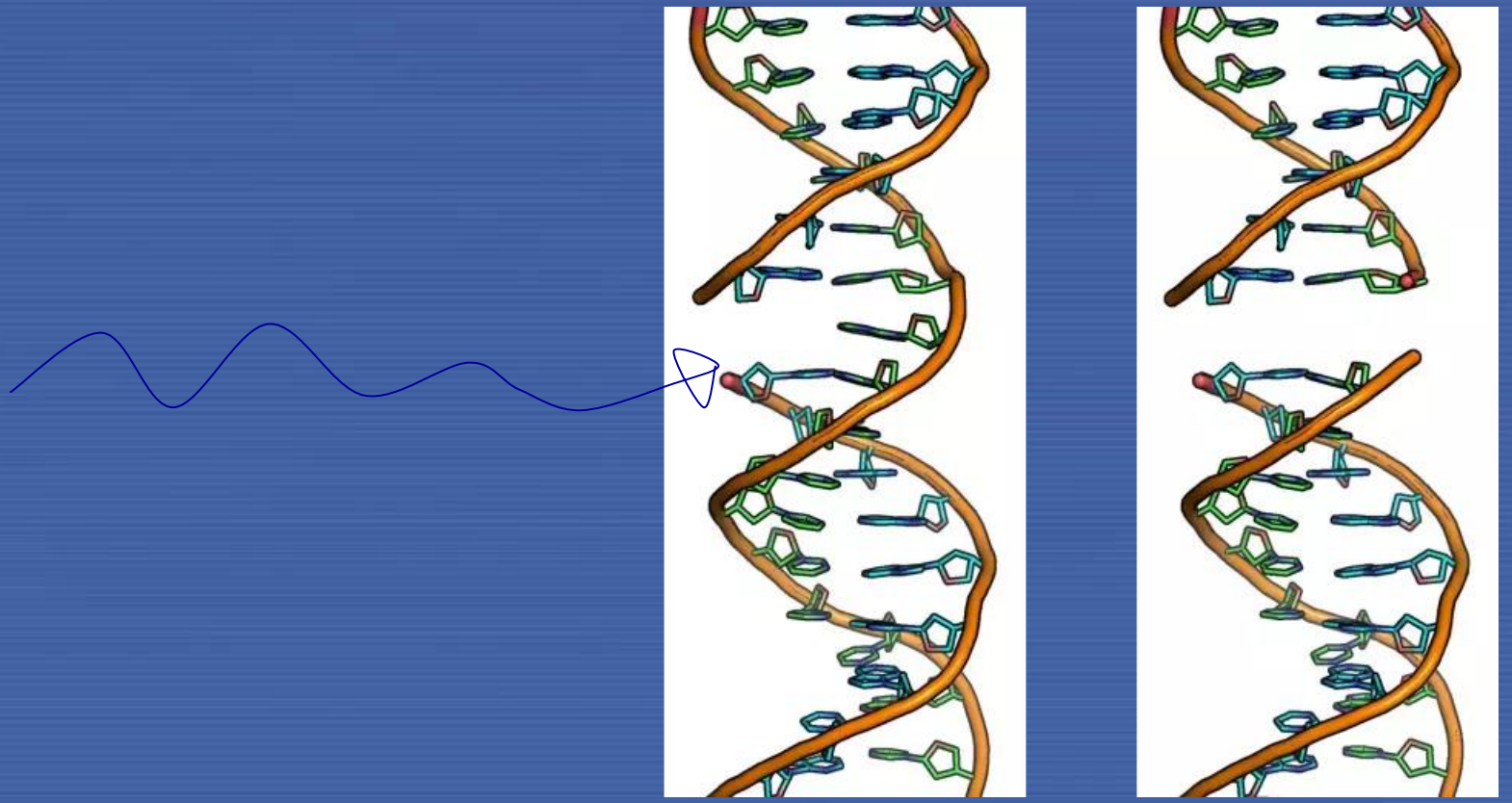
- As a primary treatment to destroy cancer cells
- In combination with other treatments to stop the growth of cancer cells
- Before another treatment to shrink a tumor
- After another treatment to stop the growth of any remaining cancer cells
- To relieve symptoms of advanced cancer

Radiation therapy is an important part of treatment for many patients. Because each cancer type requires a different approach, each patient's treatment plan is customized to their unique needs and treatment goals.

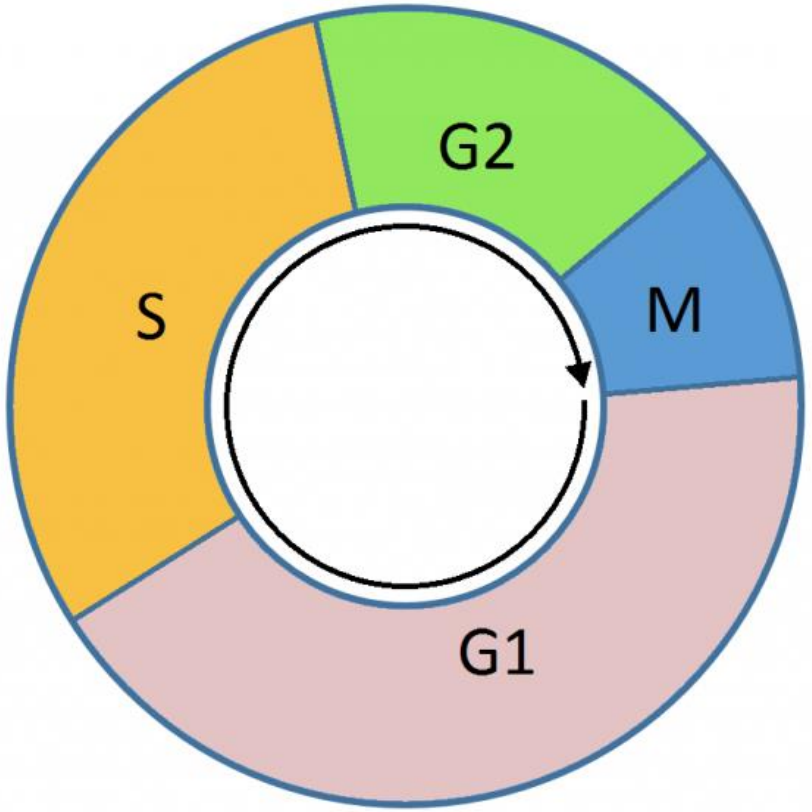
How Much is an MeV?

- 1MeV=1.602e-13J
- Specific heat of water = 4200 J/kg C
- 1 Gy = 1 J/kg
- Typical prescribed dose = 30-80Gy

Mechanism Of Cell Destruction



Mechanism Of Cell Destruction



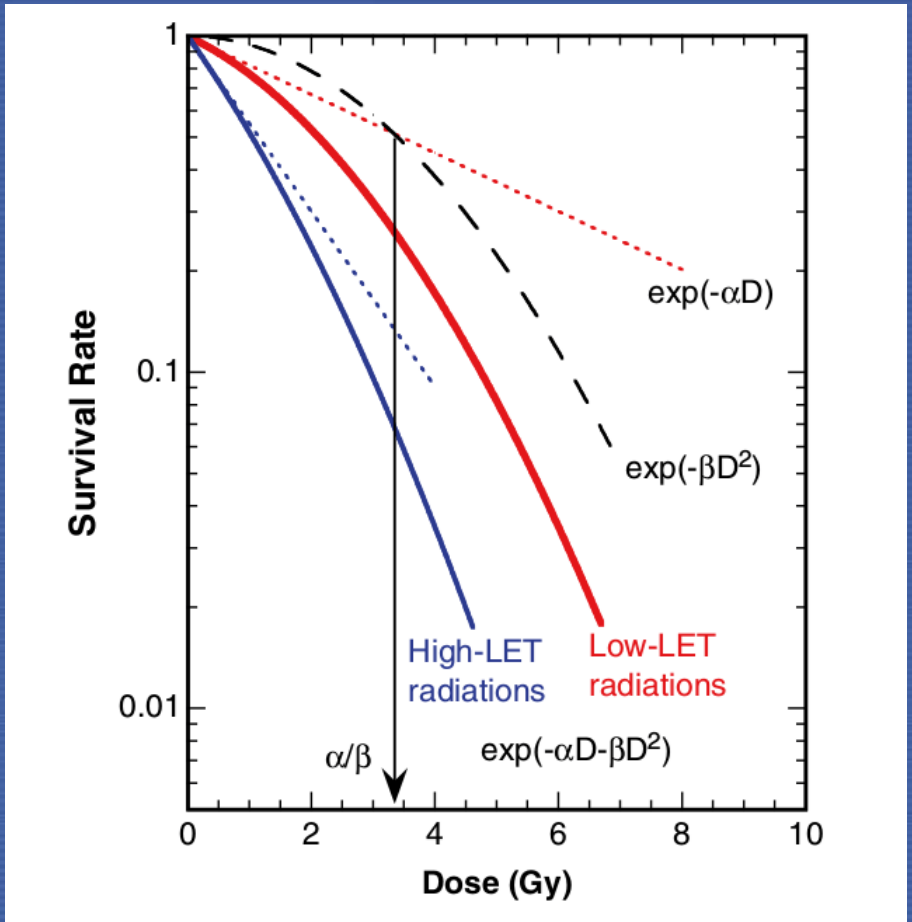
G1 - Growth

S - DNA synthesis

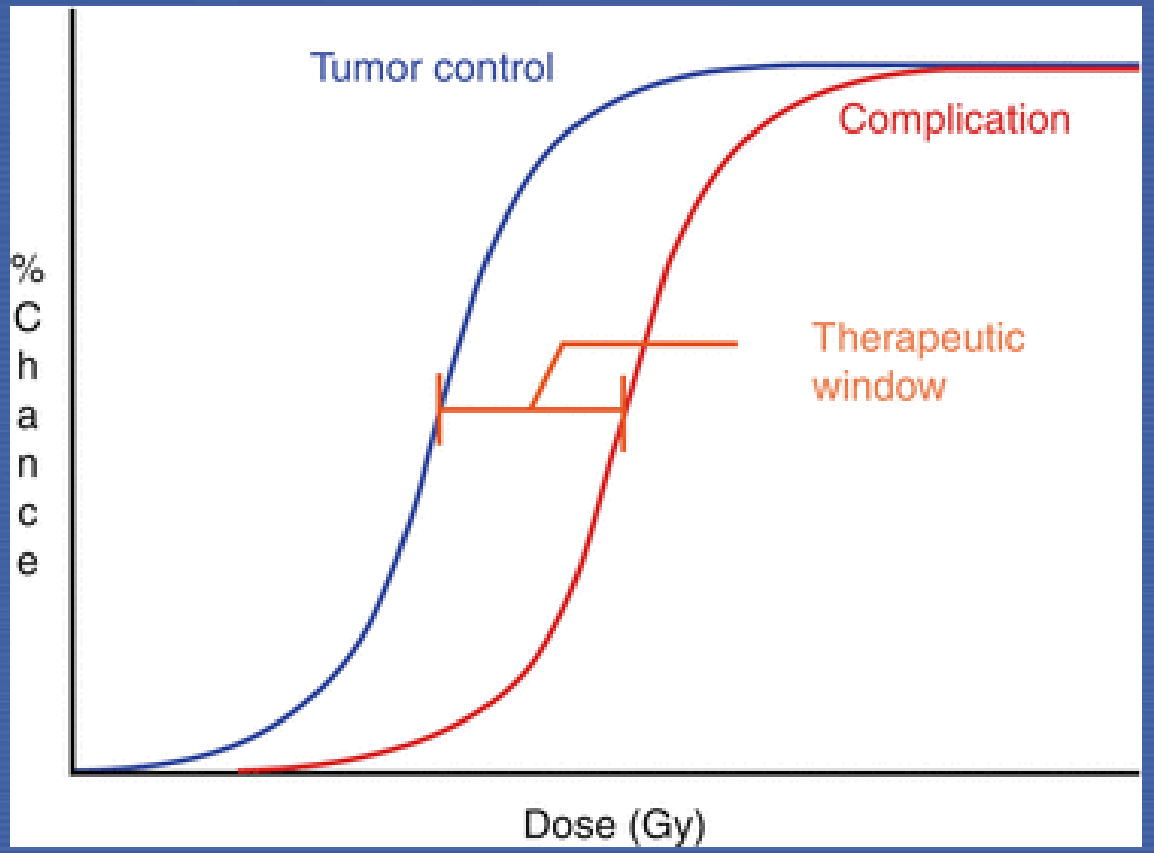
G2 - Growth and preparation for mitosis

M - Mitosis (cell division)

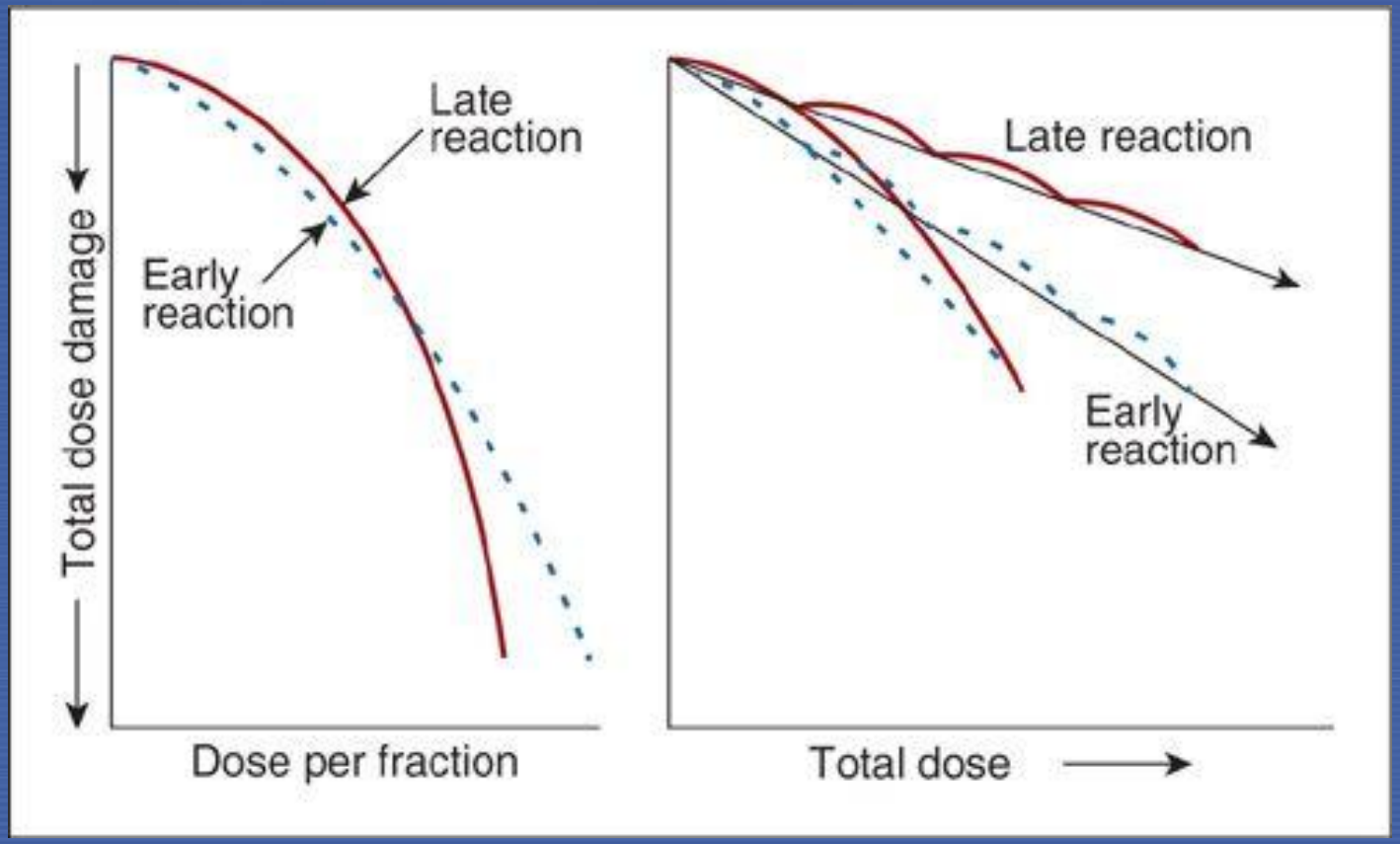
Cell Survival Curve



Therapeutic Window



Fractionation



Serial vs Parallel Organs

- A serial organ: damage to a part prevents function of the whole
  - Spinal cord
- A parallel organ: function can be retained even with damage
  - Lung, kidney, liver
- Some have qualities of both
  - Heart

Dose Escalation

- Improvements allow for higher dose
  - More accurate dosimetry
  - Advancements in treatment planning
  - Higher precision delivery
  - More accurate imaging and positioning
  - Higher dose improves cure rates

Quiz- Questions

1. What is the current theory of how Radiation kills cancer cells?
2. What is the limiting factor for the dose we can deliver to a tumor?
3. What is the role of fractionation in radiation therapy?
4. The spinal cord is an example of a serial or parallel organ? What dose metric is most important in the evaluation of spinal cord dose?

Quiz- Answers

1. What is the current theory of how Radiation kills cancer cells?
   DNA double strand breaks

2. What is the limiting factor for the dose we can deliver to a tumor?
   Organ toxicity

3. What is the role of fractionation in radiation therapy?
   Healthy tissue recovery

4. The spinal cord is an example of a serial or parallel organ? What dose metric is most important in the evaluation of spinal cord dose?
   Serial. Max dose.

Introduction to Linear Accelerators

Introduction to Linear Accelerators

- Learning Objectives

  After this section the students should understand the role of radiotherapy in cancer treatment. They should be able to name and identify the basic components of a linear accelerator from beam generation to beam shaping, as well as their purpose and the general physics behind them.

- This section should take 120 minutes
  - Two 10 minute breaks will be provided

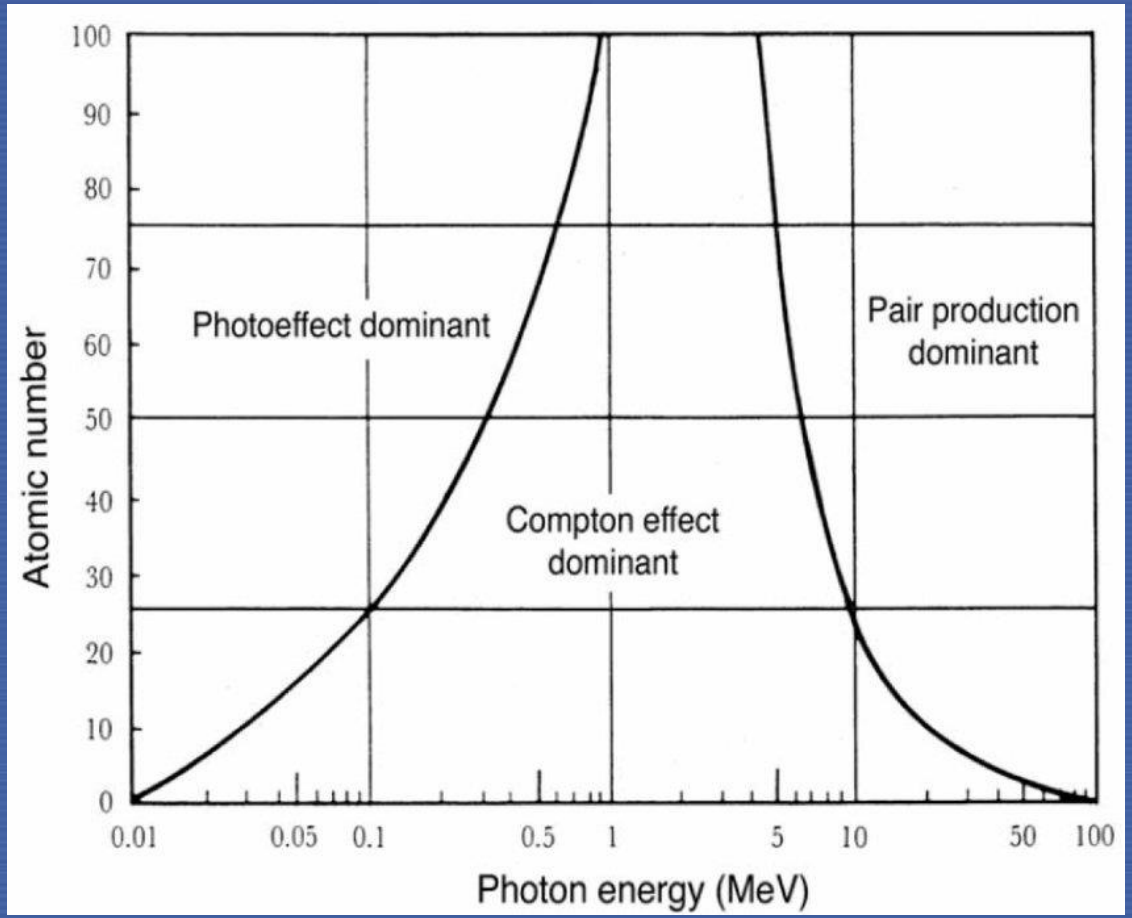
Introduction to Linear Accelerators

- Physics Primer
- Medical Treatment of Cancer
- Brachytherapy Treatment
- Linear Accelerator Overview
- Beam Generating Components
- Beam Controlling Components

Quick Physics Primer

- Quick Physics Primer
- Linear Accelerators (LINACS) use photons and electrons to treat humans
- A photon or x-ray interacts with matter through three mechanisms.

Quick Physics Primer



Quick Physics Primer

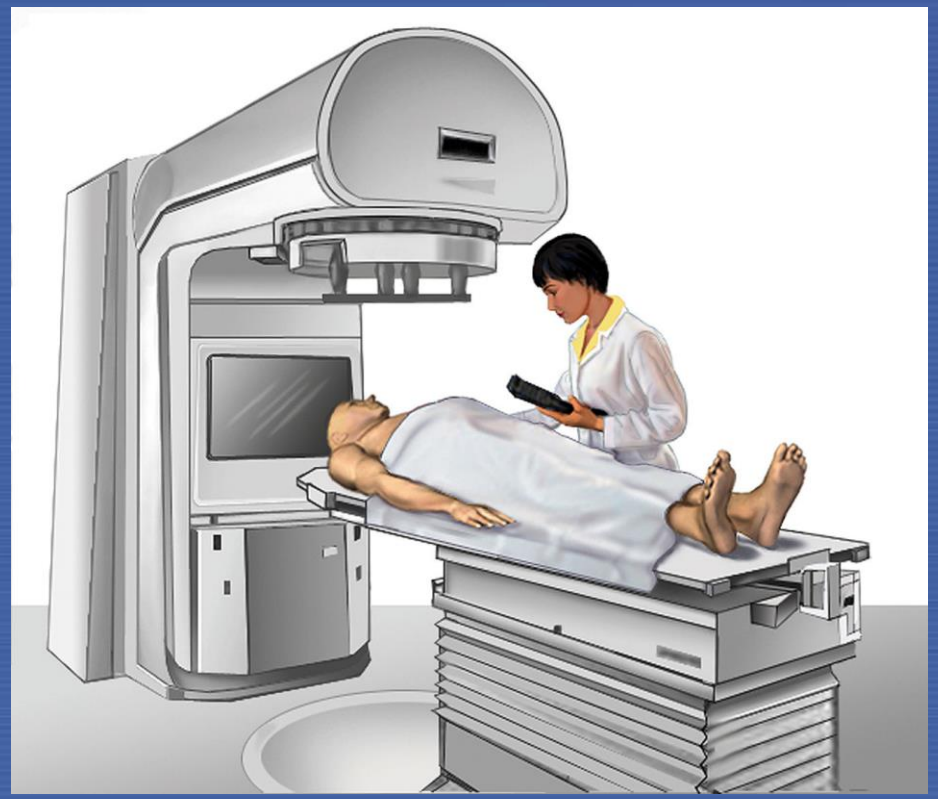
Photoneutron interactions:

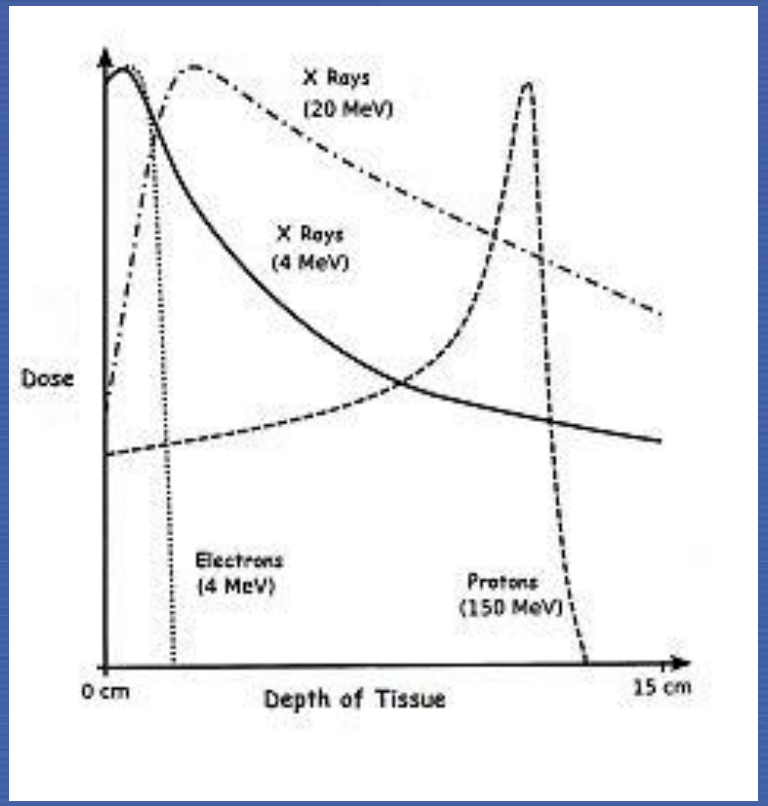
- Little concern at 10 MeV
- Must be considered for 15 or 18 MeV photon beams

- High Z materials – LINAC head
- Can make the LINAC radioactive!

Quick Physics Primer

- Electrons are charged particles
- Constantly depositing energy and scattering through the medium they are traversing
- Their range is:
  - Significantly shorter than photons
  - Dependent on their energy and the density of the material they're passing through





External Beam Image Source: National Cancer Institute (NCI) Creator: NIH Medical Arts ; Depth Dose Graph: Wikipedia

Medical Treatment of Cancer

- Approximately 50% of cancer patients are treated with radiation therapy.
- Cancer treatment can include other treatment like chemotherapy and hormonal therapy.
- Patients can be treated with chemotherapy and radiation therapy at the same time.

Medical Treatment of Cancer

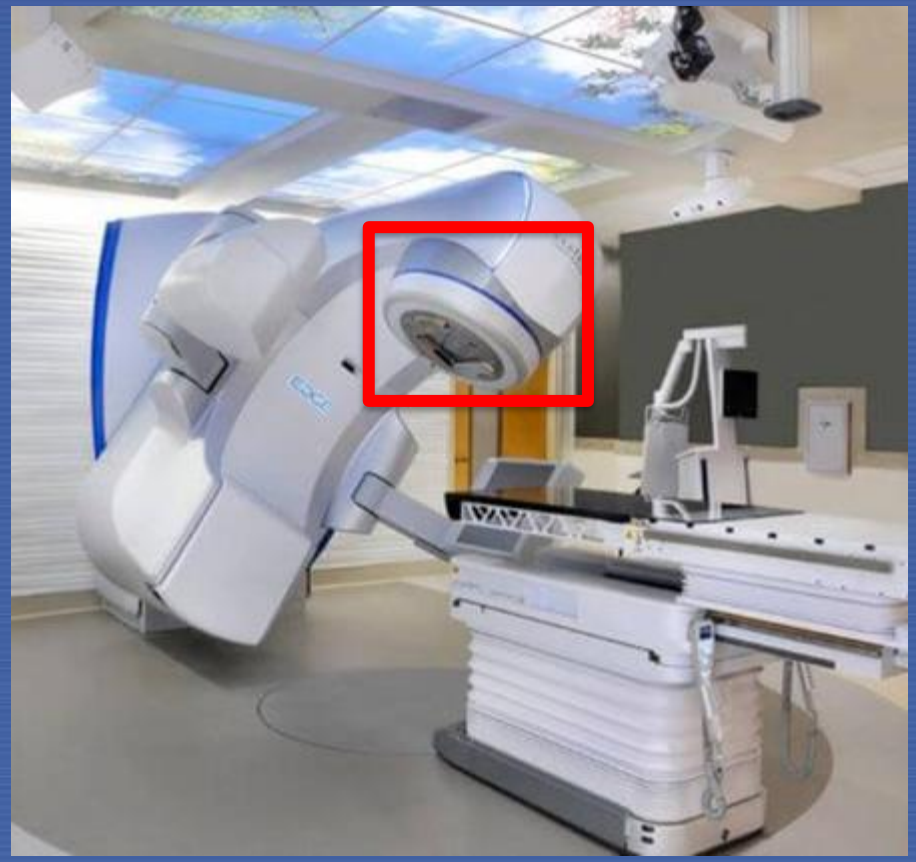
- The most common form of radiation therapy is external beam radiation therapy.
- External Beam radiation therapy is typically provided by a Medical Linear Accelerator (LINAC).
- Other types of radiation treatment include manual brachytherapy and high dose rate remote afterloaders.

Brachytherapy Treatment

- High-Dose-Rate (HDR) Remote Afterloader
  - Ir-192, ~74 day half life, ~5-15 minute treatments
- Low-Dose-Rate (LDR)
  - Cs-137, ~30 year half life, 1-7 day treatments
- Permanent Implant
  - Radioactive seeds implanted into the body
  - Complete radioactive decay within the body
  - ~10-60 day half-life

Linear Accelerator Machine





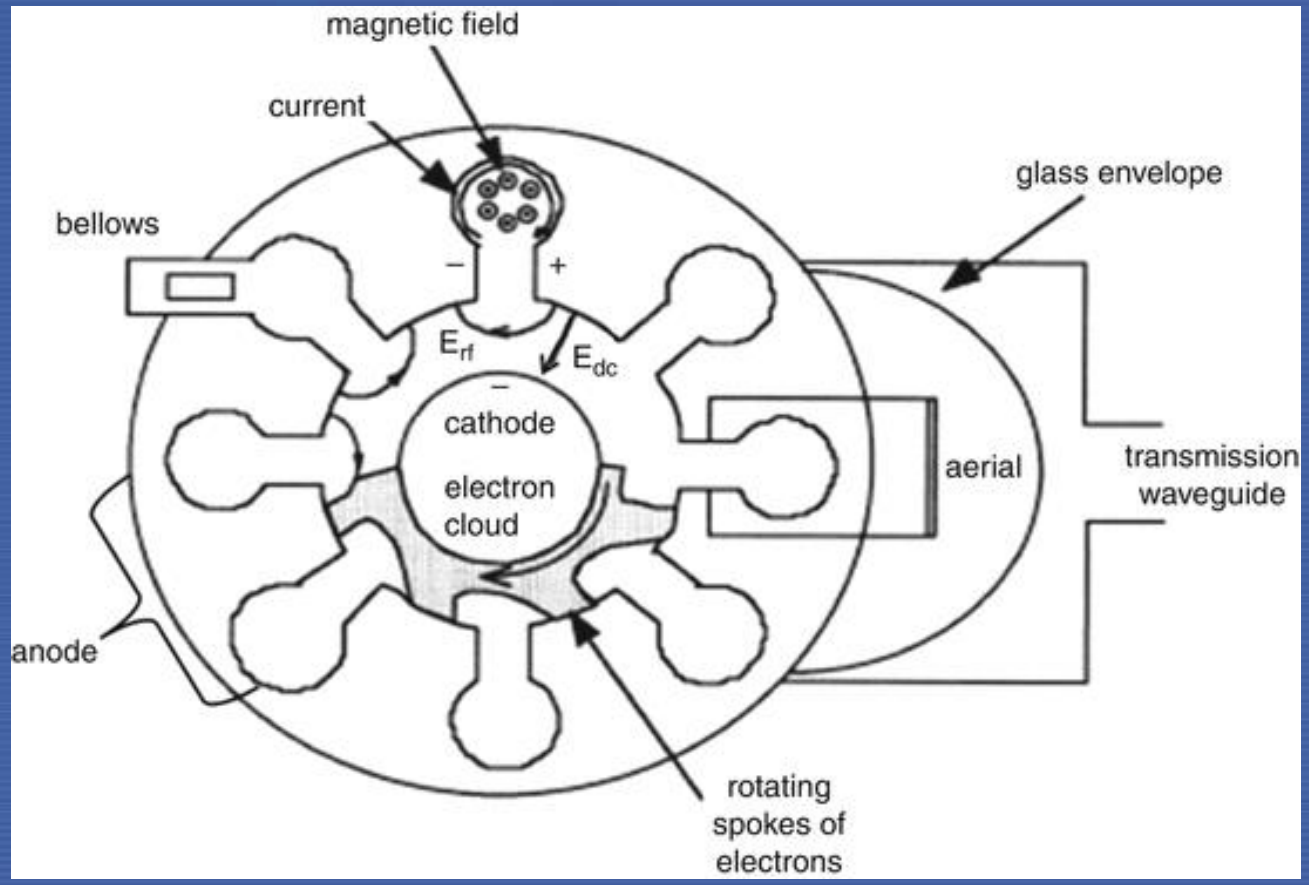
Introduction to Linear Accelerators

- A Linear Accelerator is a machine that produces high energy electrons and/or x-rays.
- This high energy radiation directed to the diseased area to destroy the cancer cells
- The energy of the electrons and/or x-rays produced can be selected by the user and changed for each treatment.

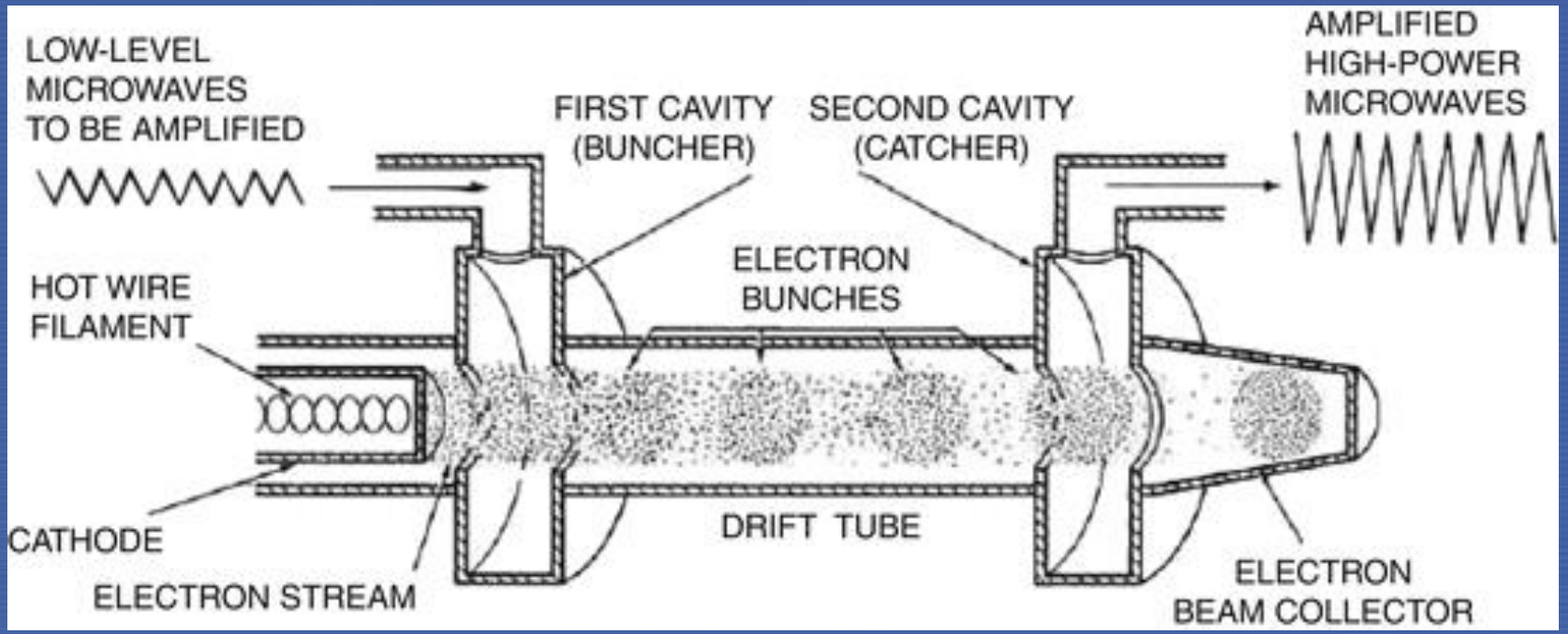
Introduction to Linear Accelerators

- The LINAC uses microwave technology (like that used for radar) to accelerate electrons in the LINAC "wave guide," then these electrons either collide with a heavy metal target to produce high-energy x-rays or a scattering foil to create a therapeutic electron field.

Power Source: Magnetron



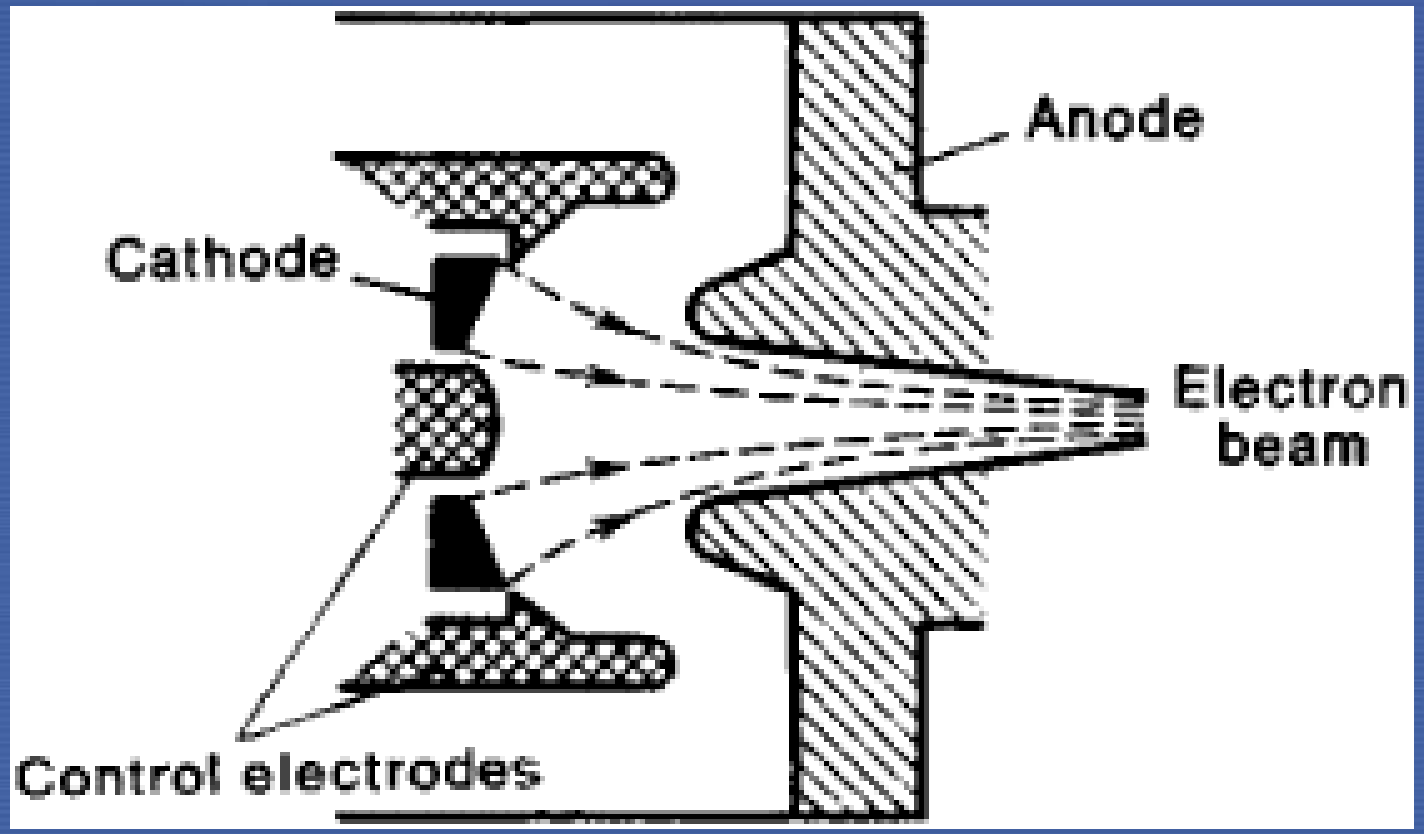
Power Source: Klystron



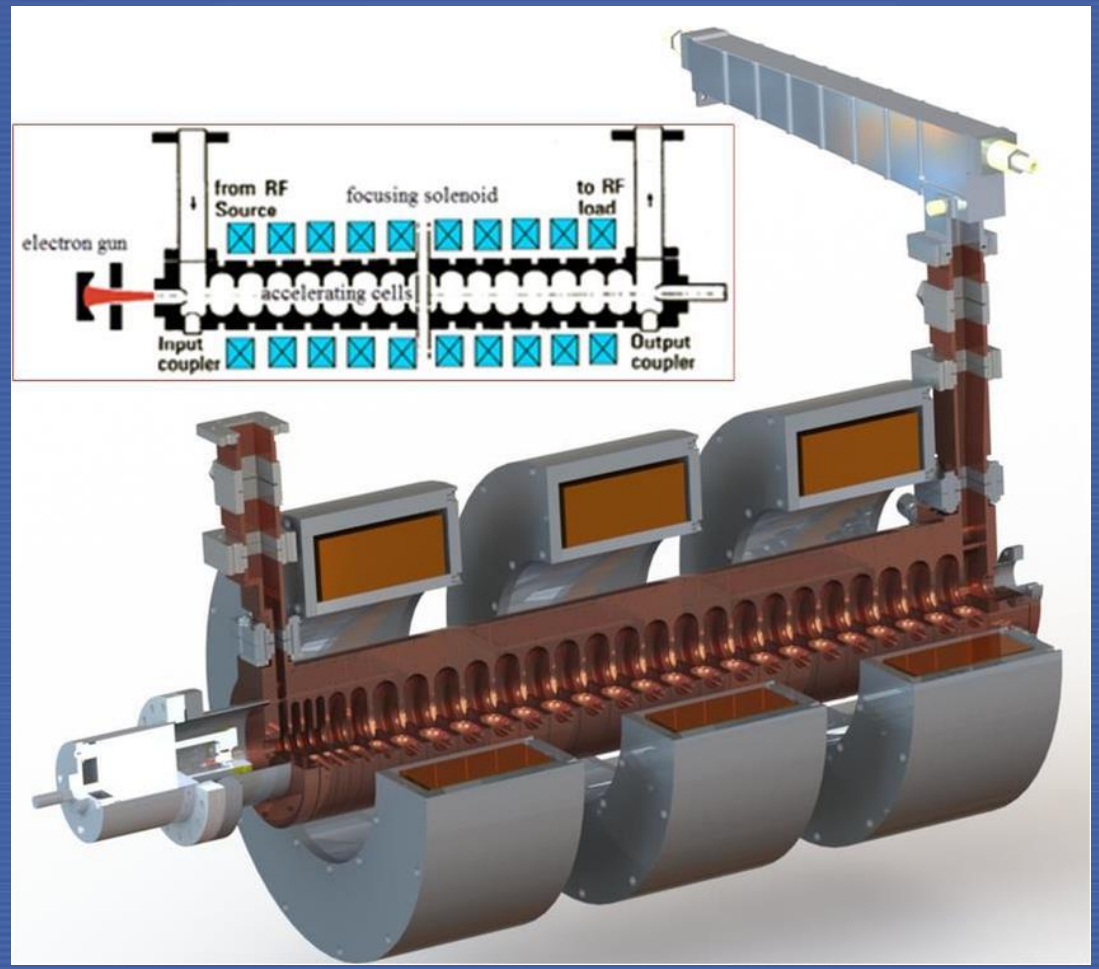
Beam Generating Components

- Electron Gun
- Waveguide
- Bending Magnet

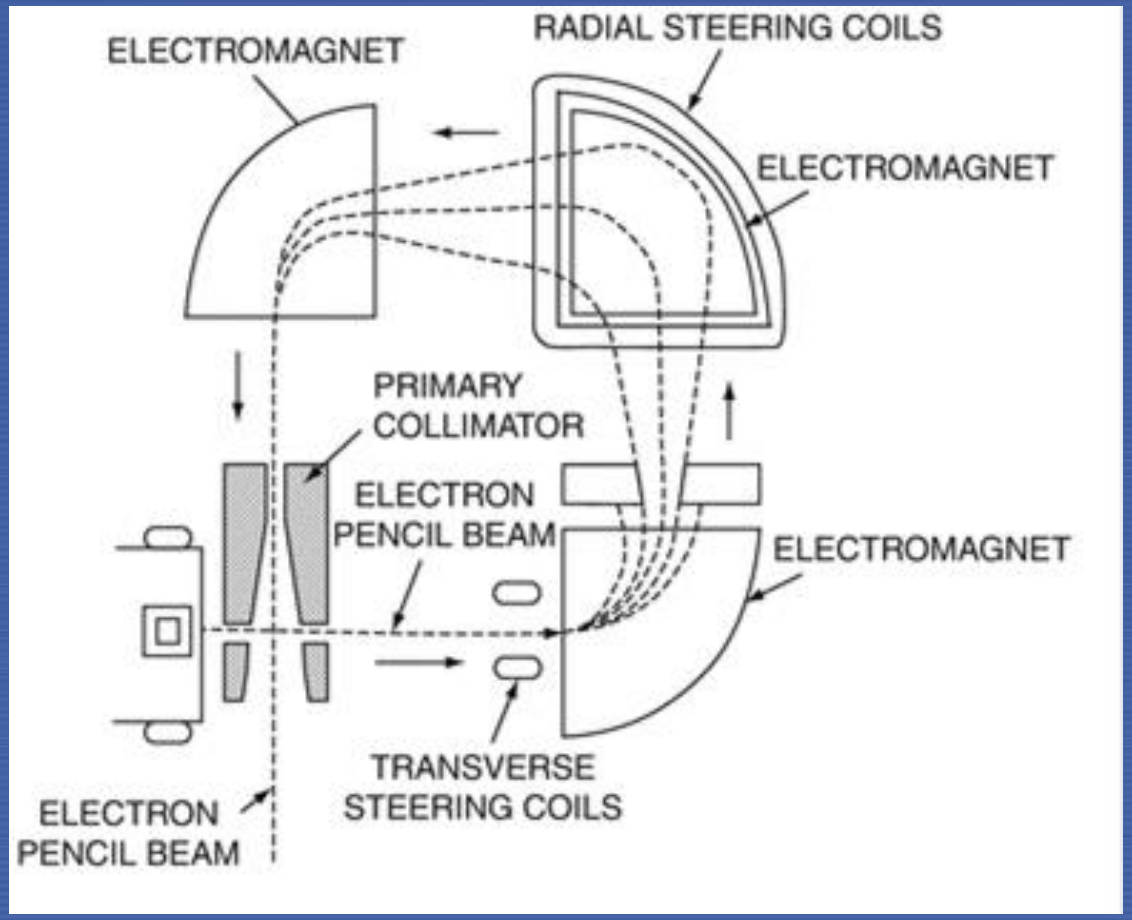
Electron Gun



Waveguide

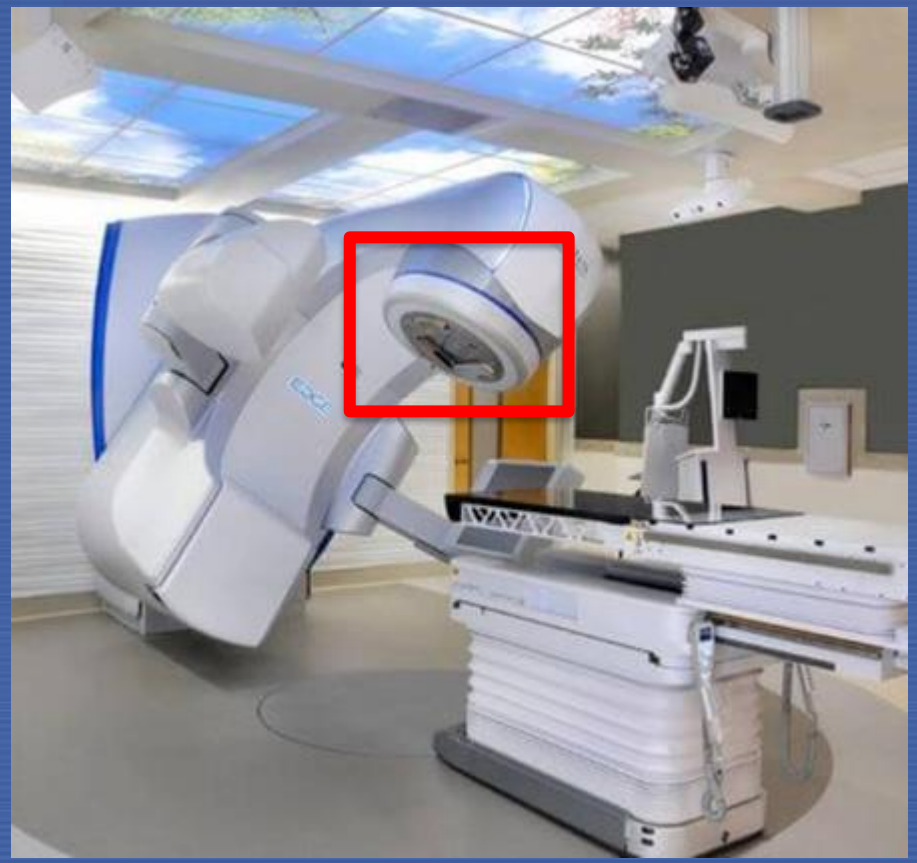

from RF Source
focusing solenoid
to RF load
electron gun
accelerating cells
Input coupler
Output coupler

Bending Magnet

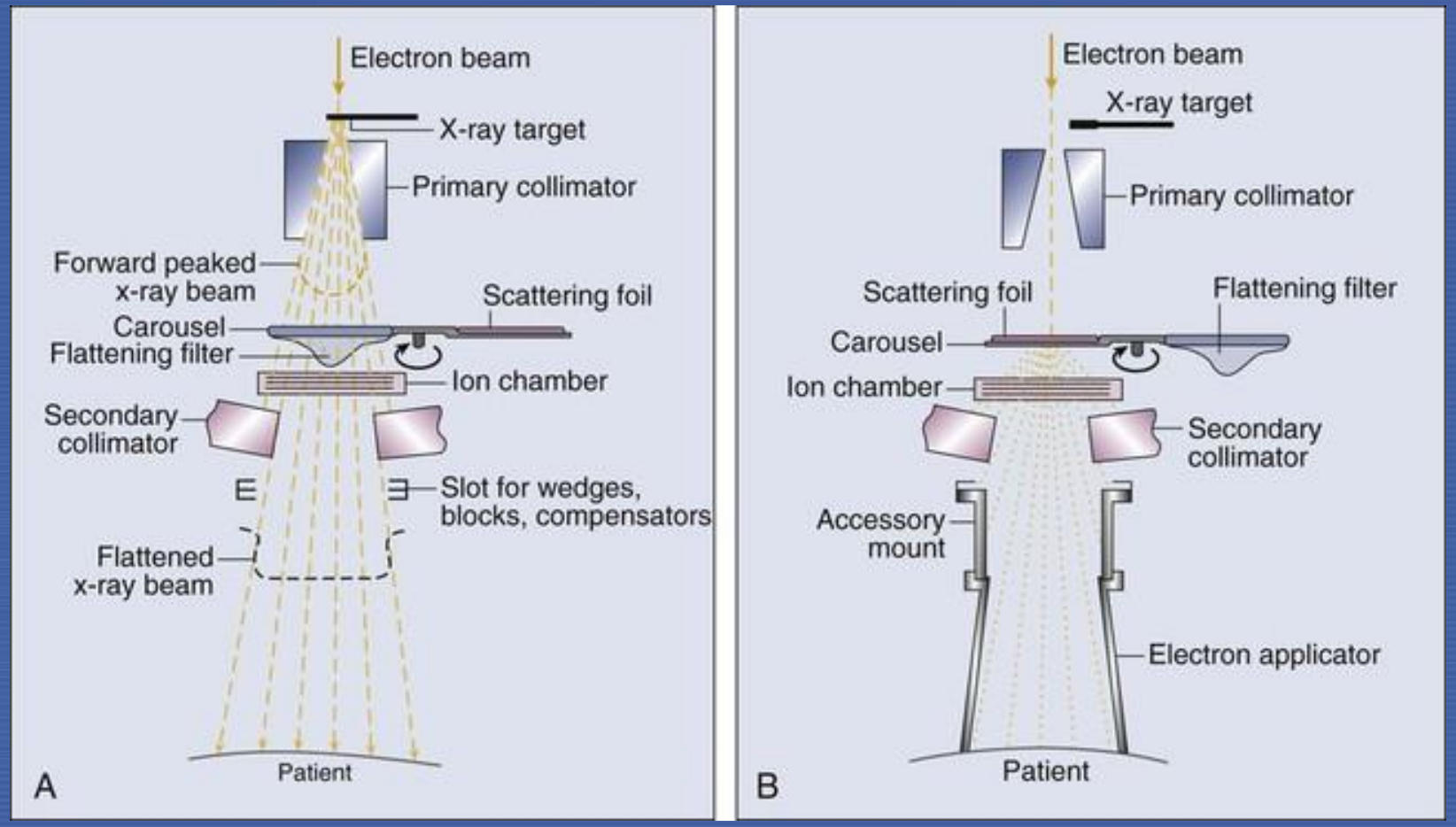


Introduction to Linear Accelerators

- The beam of electors and/or x-rays can be manipulated by putting objects (beam modifiers) into the beam path.
- Beam modifiers can be inside the linear accelerator head, or attached to it.



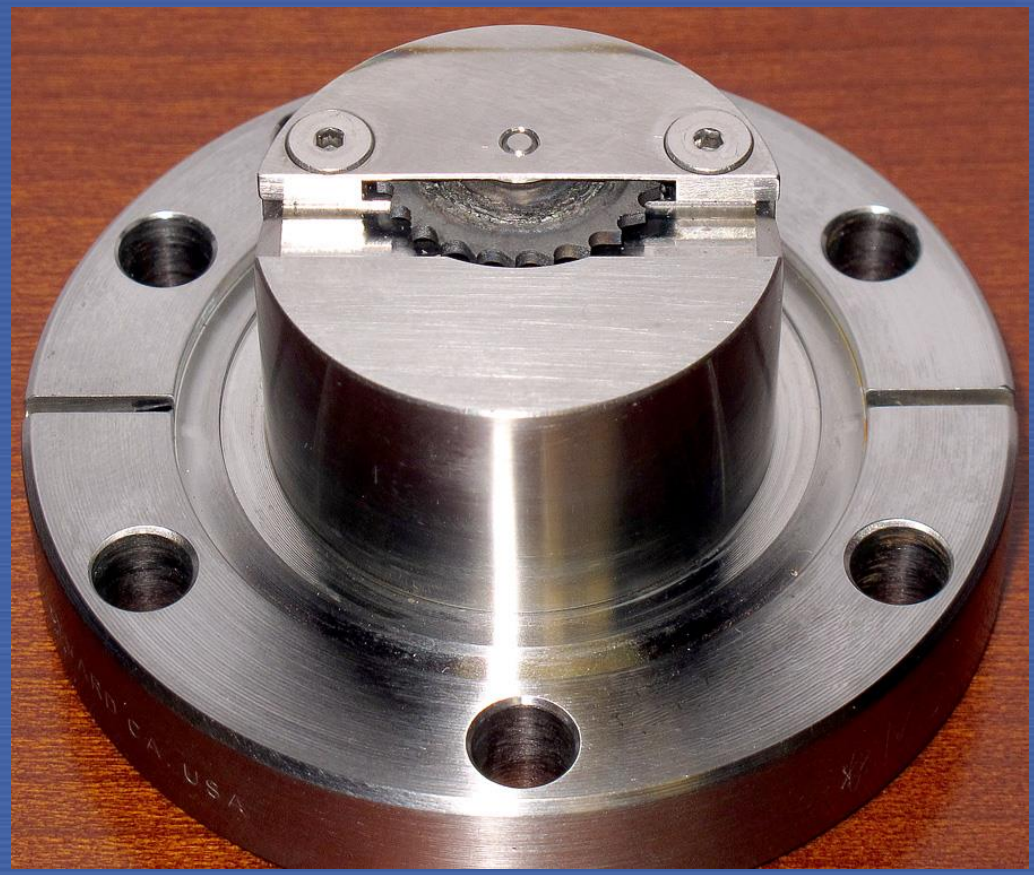
Beam Modifying Component



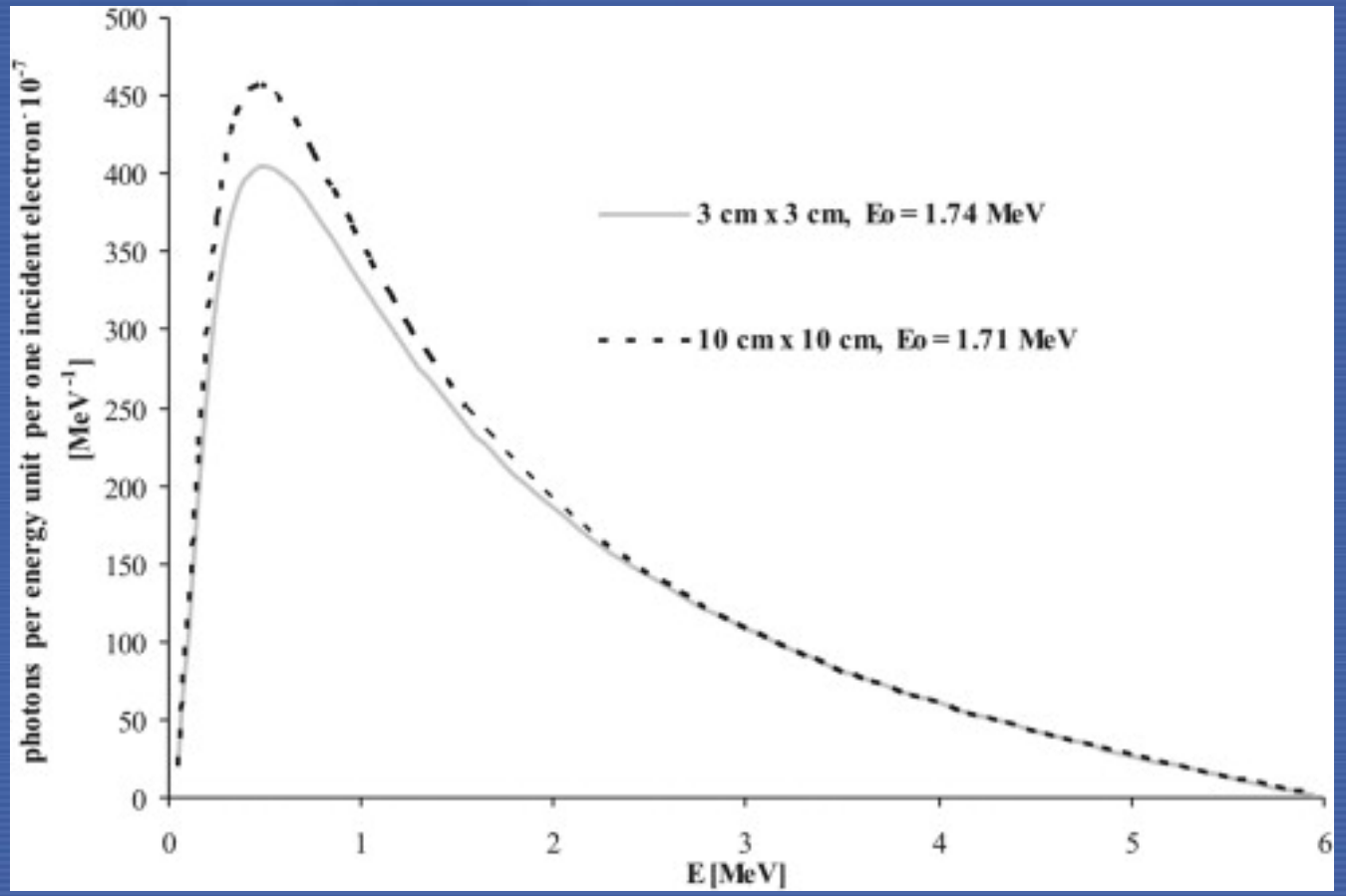
Beam Modifying Components

- X-ray Target
- Primary Collimator
- Carousel: Flattening Filter
- Ion Chamber
- Jaws (Secondary Collimator)
- Multileaf Collimator (MLC)
- Accessory Tray
- Patient

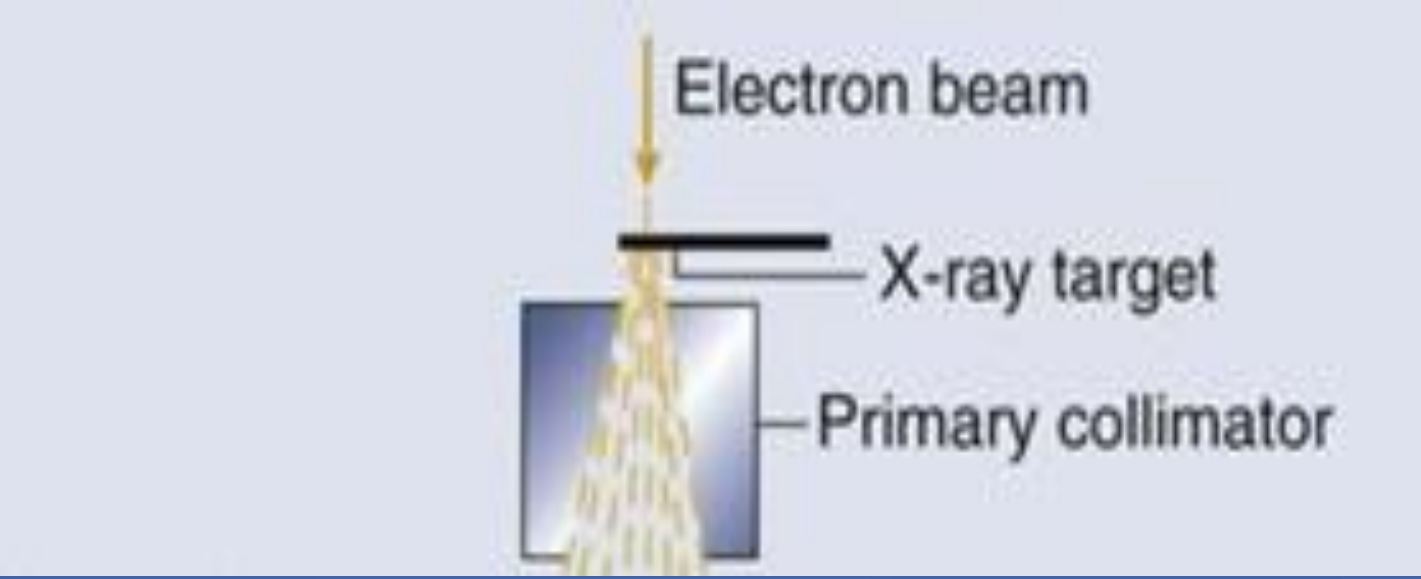
X-ray Target



X-ray Target


photons per energy unit per one incident electron·10⁻⁷ [MeV⁻¹]
500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
E [MeV]
3 cm x 3 cm, Eo = 1.74 MeV
10 cm x 10 cm, Eo = 1.71 MeV

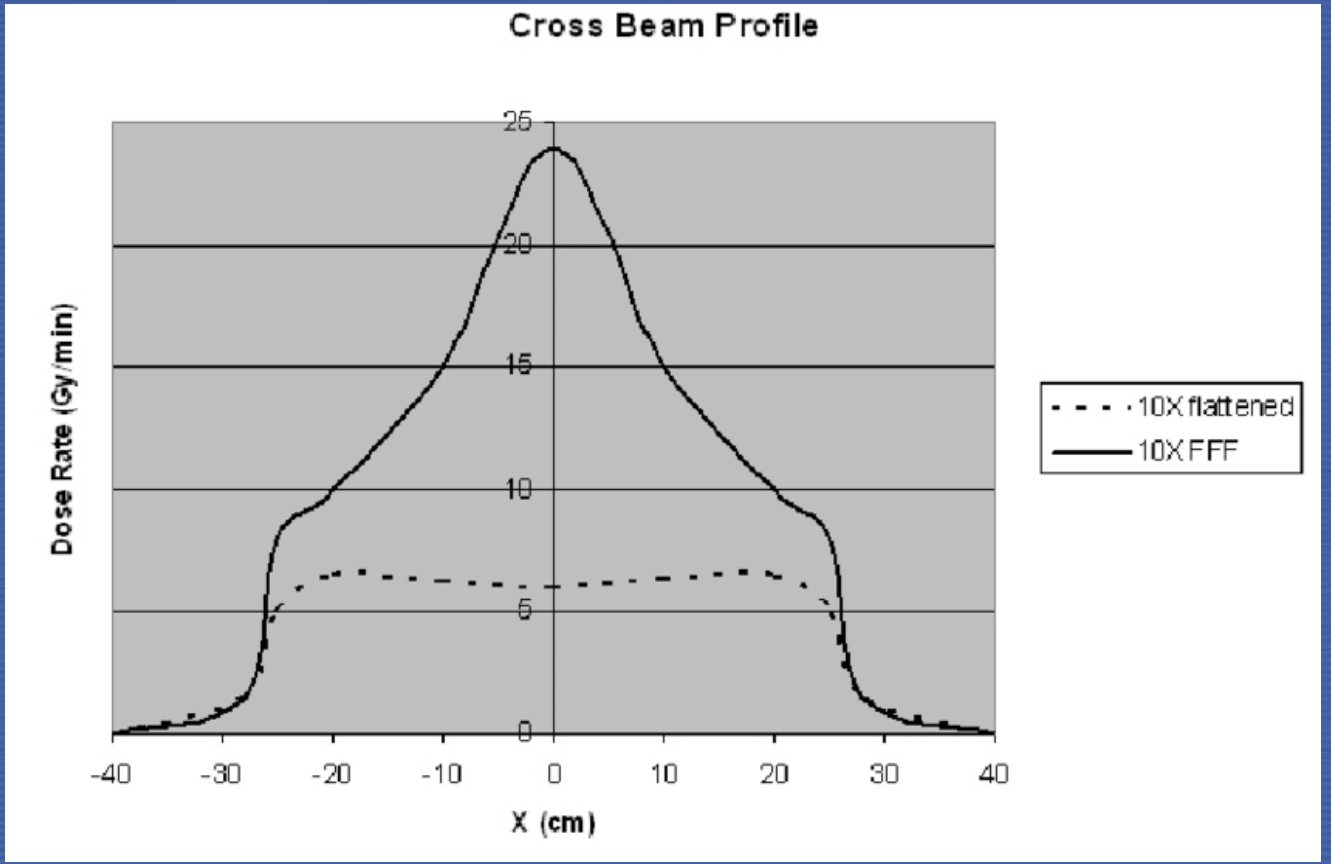
Primary Collimator



Carousel: Flattening Filter



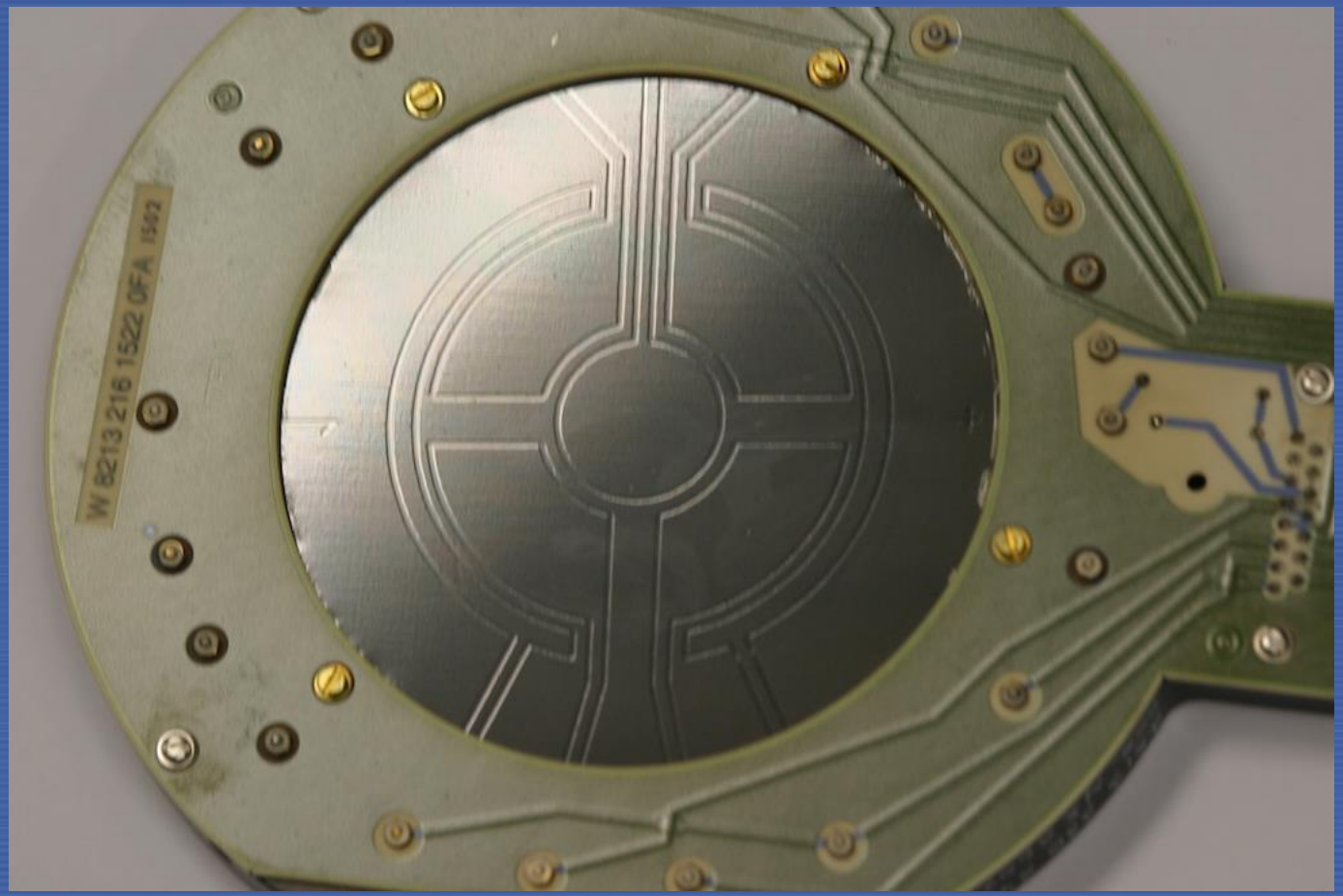
Flattening Filter



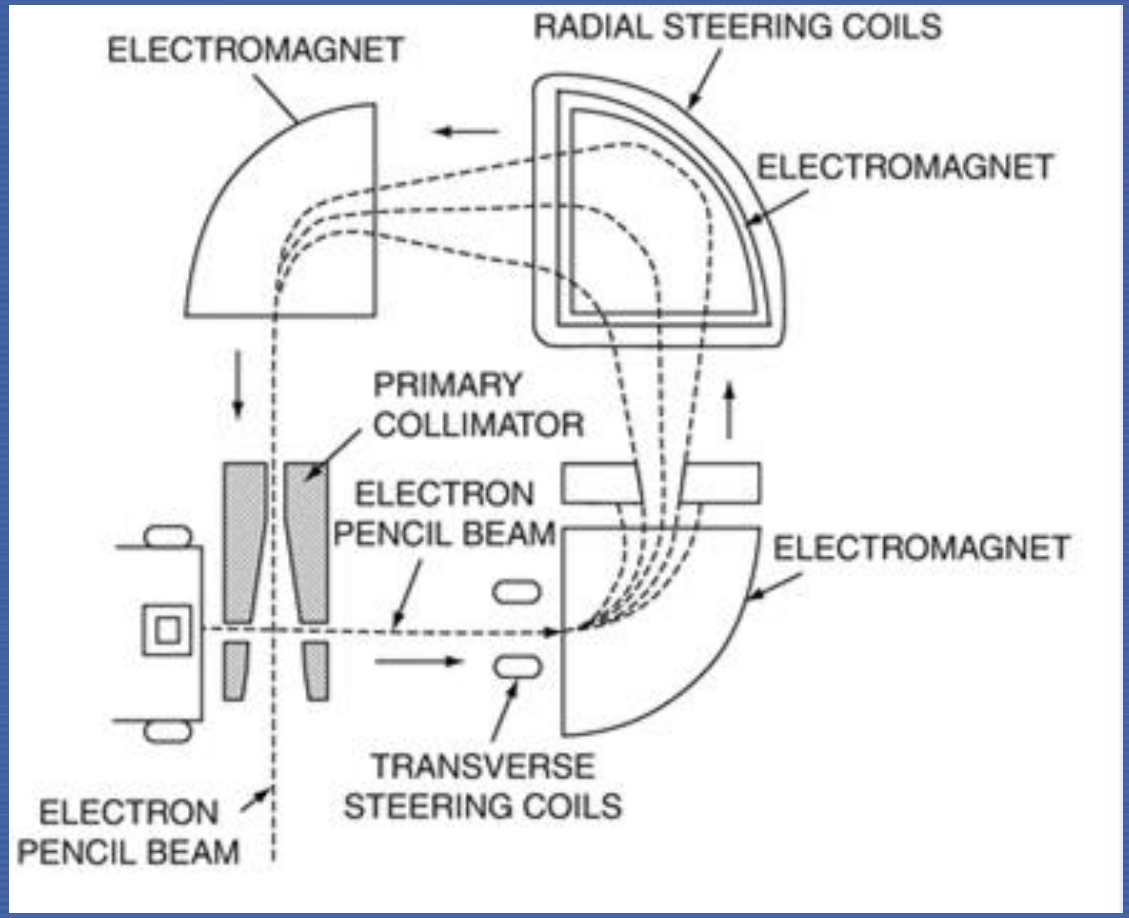
Ion Chamber



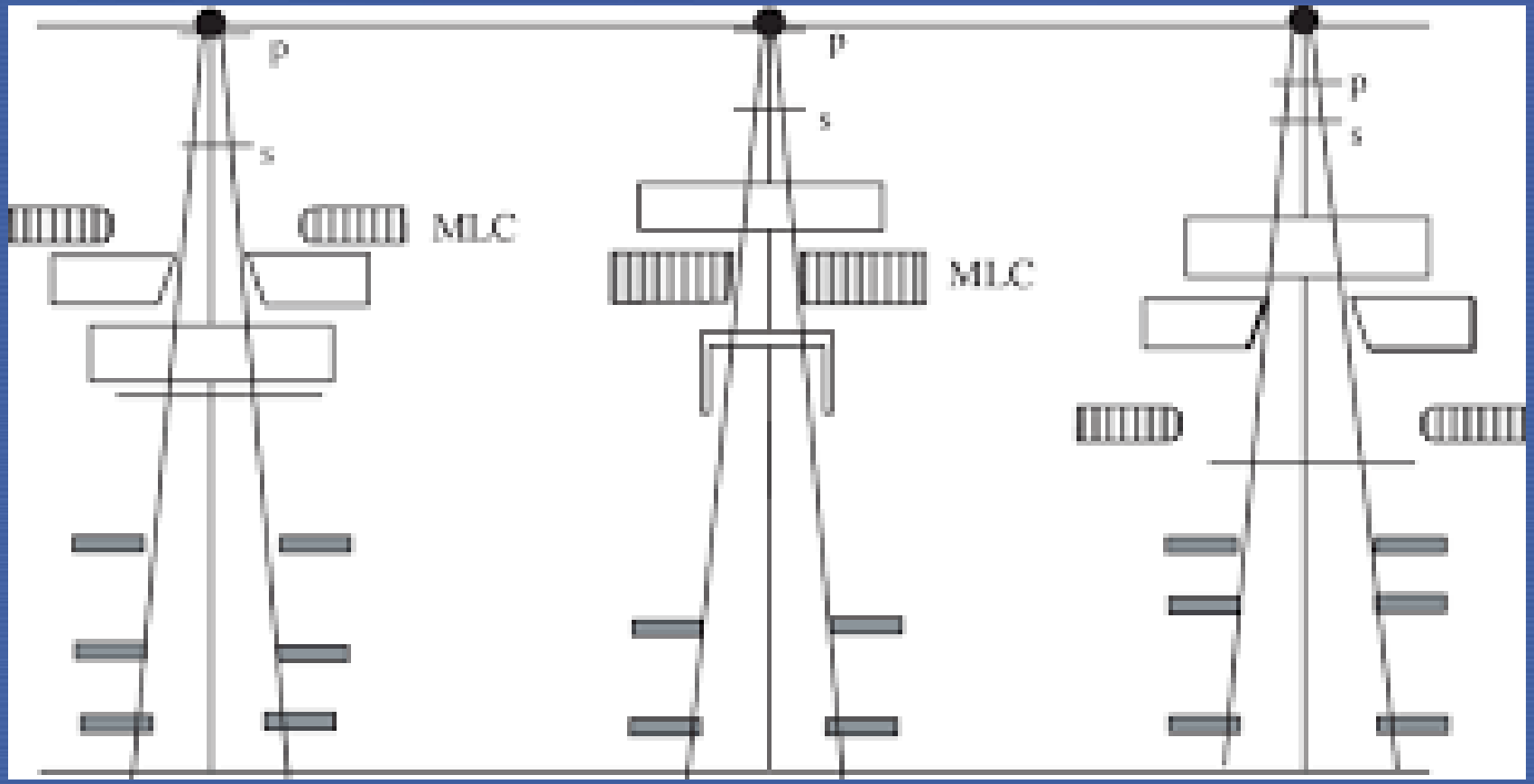
Ion Chamber



Bending Magnet



Jaws



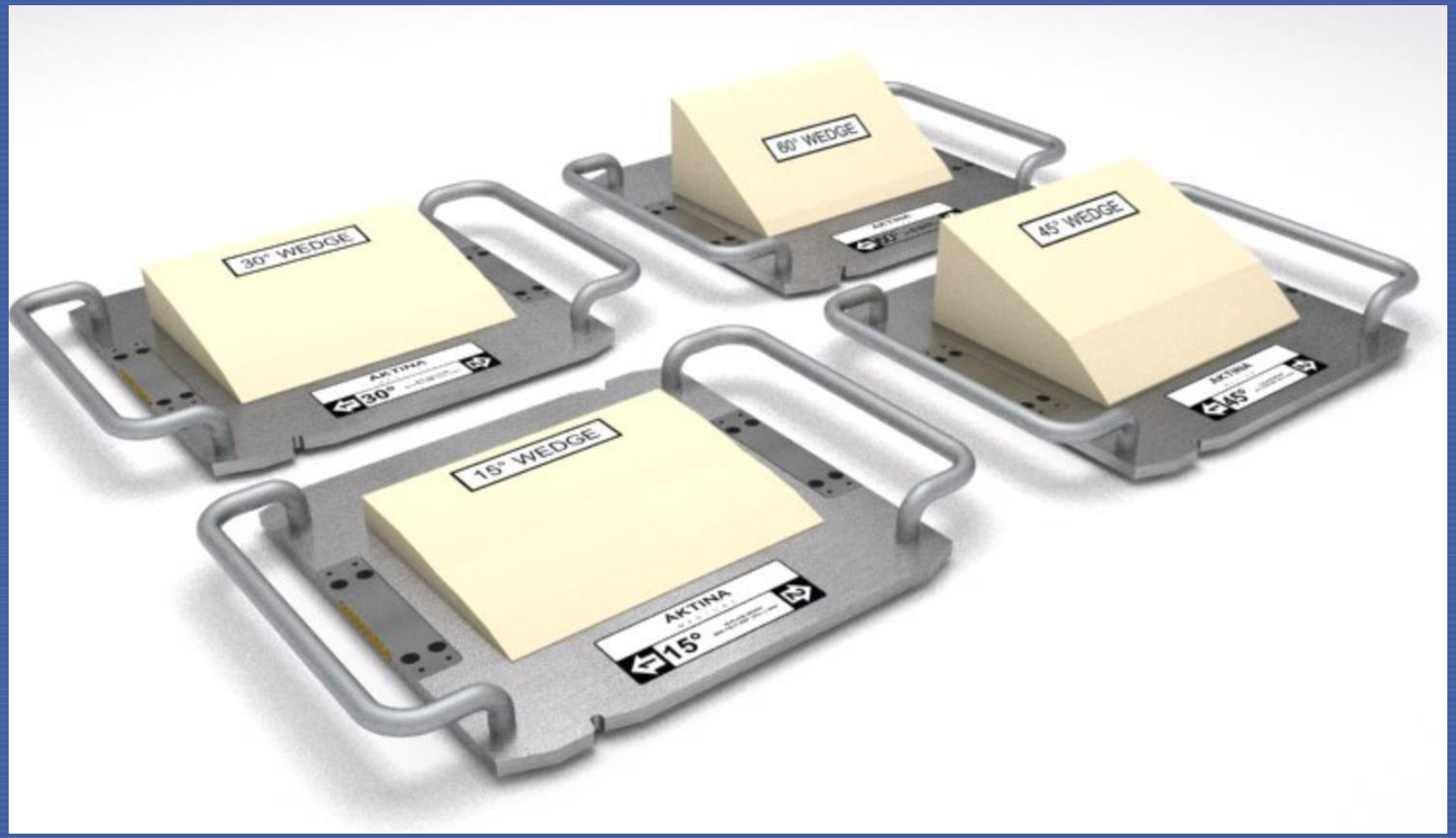
Multileaf Collimator



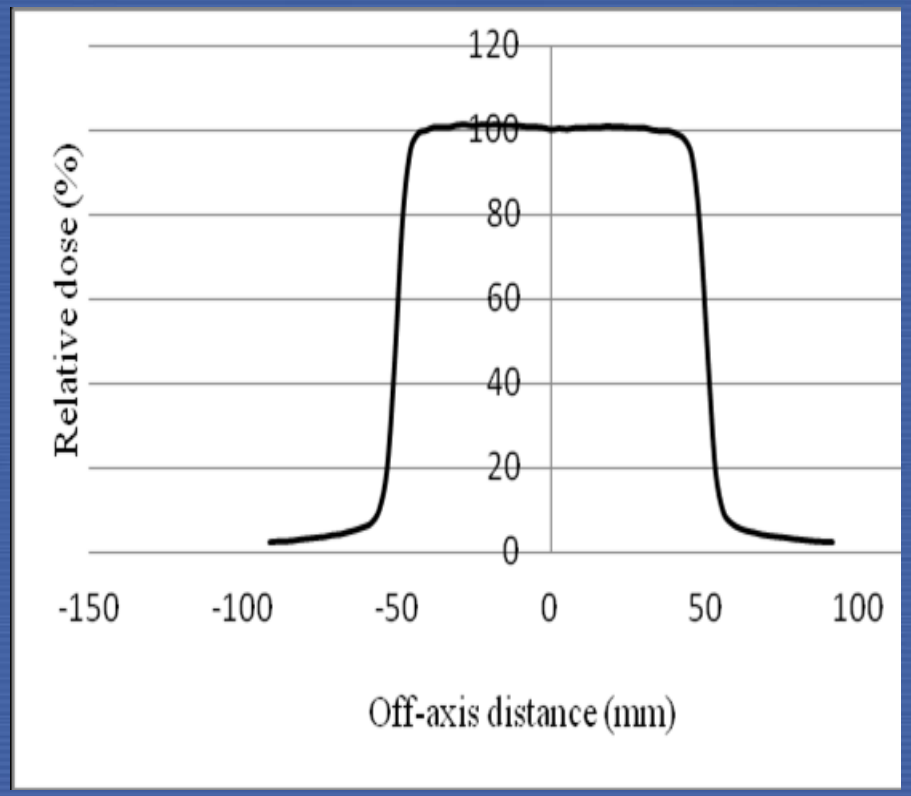
Accessory Tray

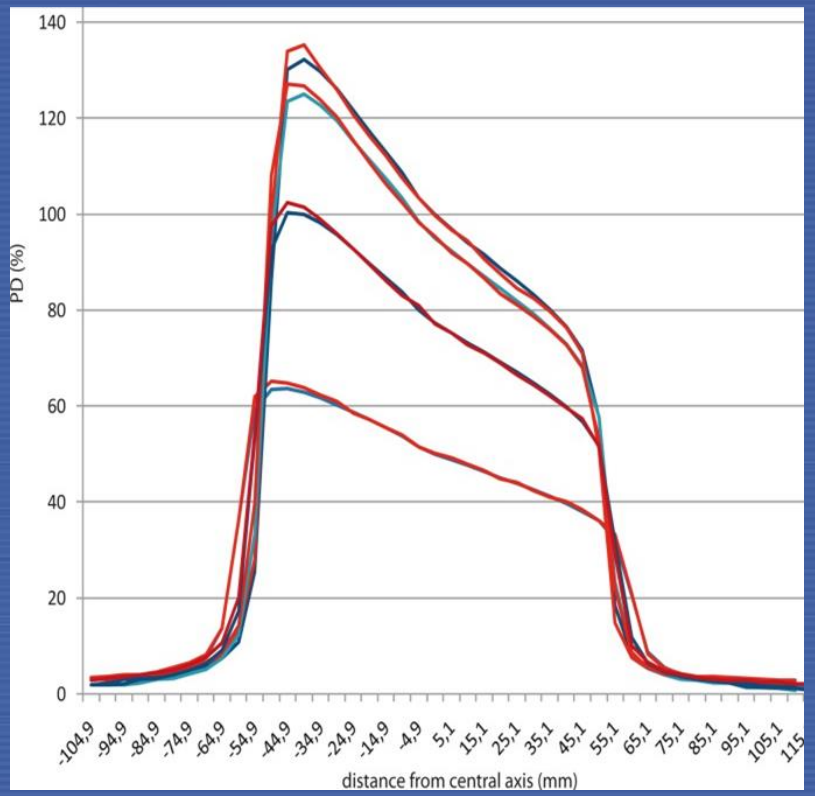
The accessory tray is an attachment point for many different components, some for treatment and some for quality assurance or calibration purposes.

Beam Modifiers - Wedges



Beam Modifiers - Wedges

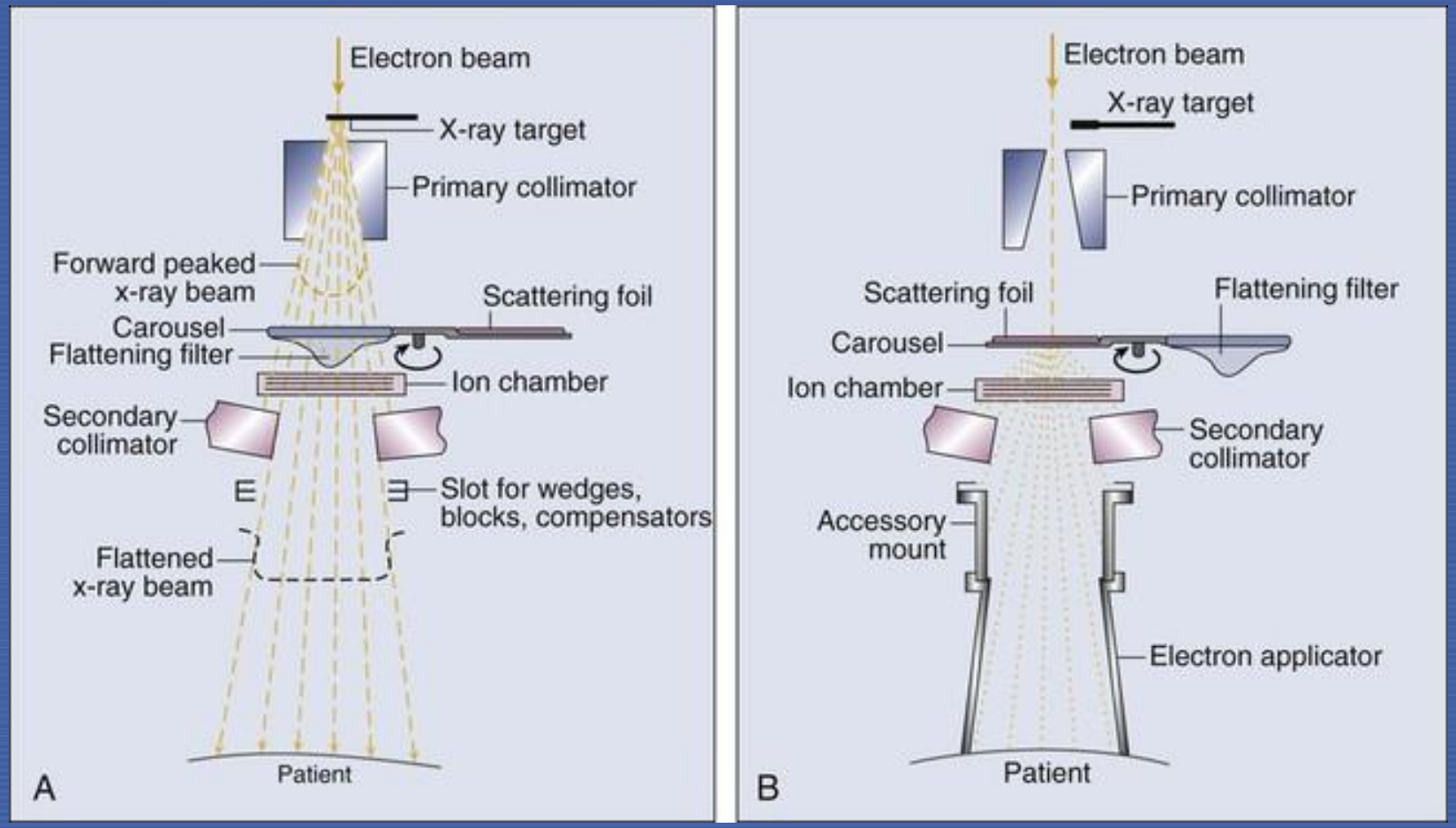




Patient



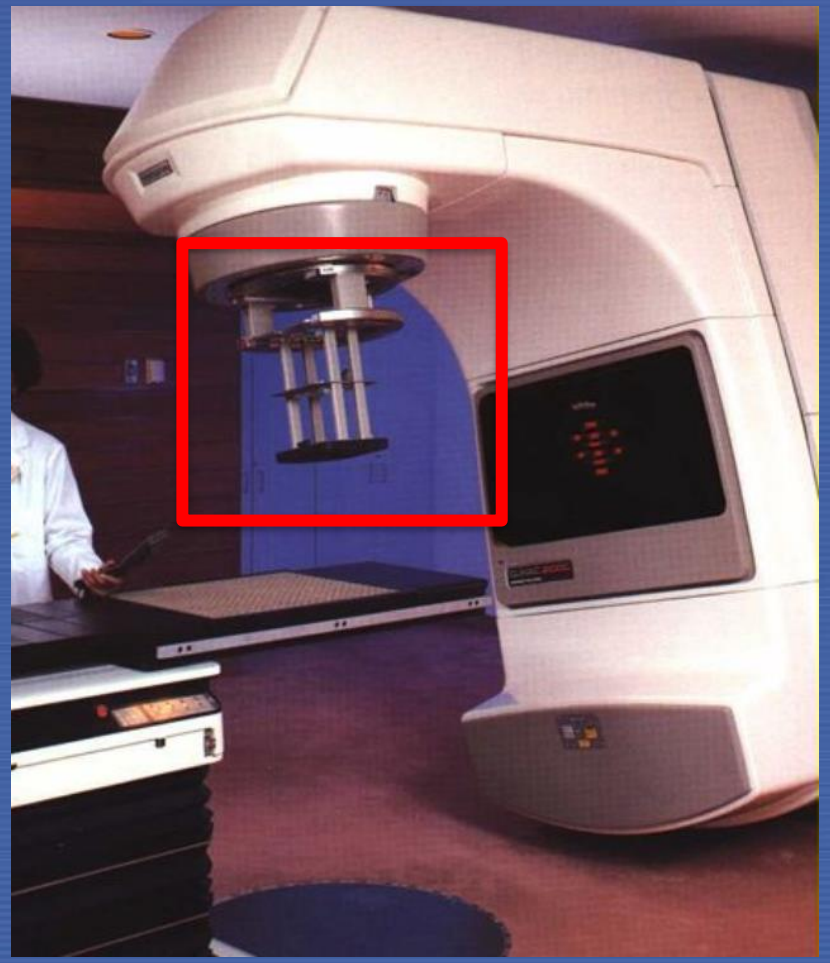
Linear Accelerator Head



Carousel: Scattering Foil



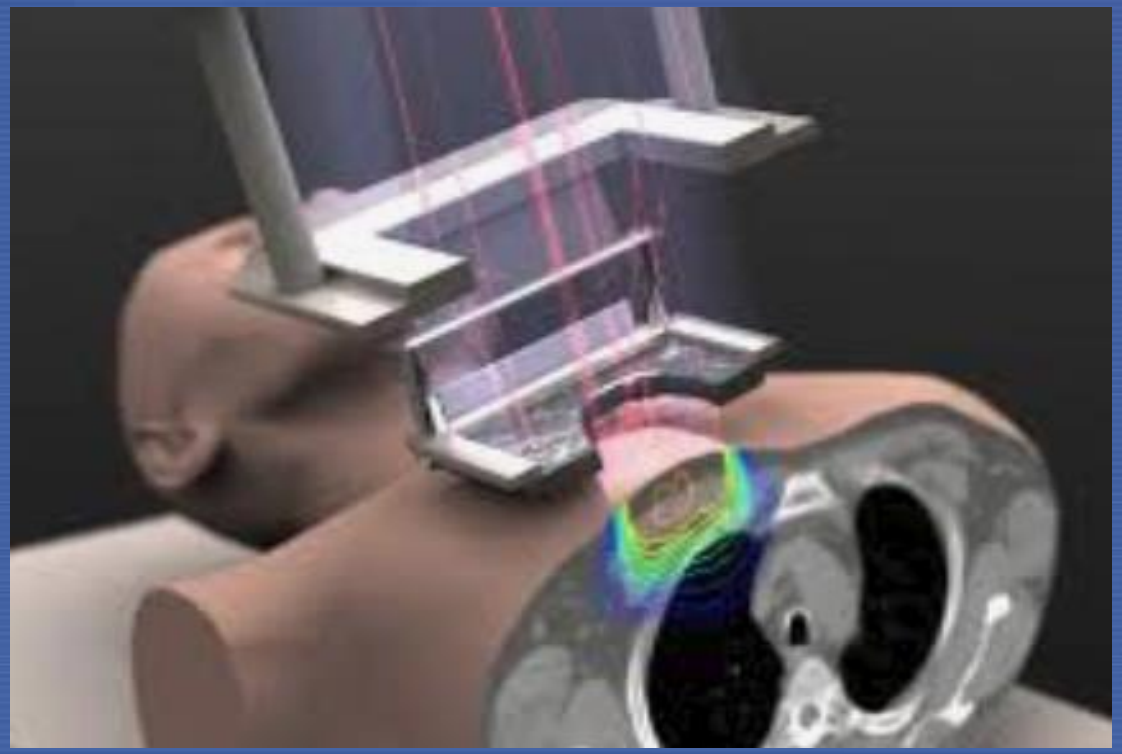
Electron Applicator



Beam Modifiers – Block



Beam Modifier - Block



Field Light



Quiz - Questions

1. What is the dominant photon interaction in radiotherapy?
2. Which is more penetrating, photons or electrons?
3. At what energy do neutrons become a consideration?
4. What is the purpose of the flattening filter?
5. What two important functions are served by the ion chamber measurement?
6. Why aren't MLC used for electrons?
7. What components of the LINAC can move during treatment?

Quiz- Answers

1. What is the dominant photon interaction in radiotherapy?
   Compton Scattering

2. Which is more penetrating, photons or electrons?
   Photons

3. At what energy do neutrons become a consideration?
   Greater than 10MV (15/18MV)

4. What is the purpose of the flattening filter?
   To create an even dose profile at a given depth (10cm)

Quiz- Answers

5. What two important functions are served by the ion chamber measurement?
   Beam steering and termination

6. Why aren't MLC used for electrons?
   Shaping needs to occur near the patient

7. What components of the LINAC can move during treatment?
   The gantry, jaws, and MLC

Important Facility Construction and Safety Features

Important Facility Construction and Safety Features

- Learning Objective
  After this section the students should be able to describe the main safety features of construction and equipment. They should understand how these features operate and why they are important.
- This section should take 30 minutes

Important facility construction and safety features

- All doors, gates, photoelectric beams and motion detectors must be interlocked to the treatment unit to prevent an exposure if a door is open. The interlock must also ensure that when the door is opened the irradiation will be terminated.
- The radiation output of the device should not be resumed automatically after the door is closed again.
- The interlock should be fail-safe so that safety is not jeopardized in the event of failure of any one component of the system.

Important facility construction and safety features

- Radiotherapy departments are usually located on the periphery of the hospital or clinic complex to avoid radiation protection problems arising from therapy rooms being adjacent to high occupancy areas.
- The amount of shielding required in each of the barriers of the treatment bunker will depend to some extent on the use of the surrounding areas. Areas with high occupancy levels will require greater shielding.
- In order to reduce the radiation dose near the entrance, a restricted access passageway leading to the room may be incorporated in the design. This passageway is termed the maze.

Important facility construction and safety features

- Signage should be present to identify the radiation hazard
- An indicator near the door should clearly identify when the beam is on.
- An emergency stop button should be easily accessible the operators at the console, on the treatment table, and on the LINAC itself.
- Safety switches to detect collision with the patient and stop motion of the gantry or table.





Treatment Room Door



Audio-Visual Monitoring



LINAC Control Console



Quiz - Questions

1. What mechanism is recommended to prevent accidental exposure or injury from moving components?
2. To reduce the shielding burden the areas adjacent to the vault should be?
3. How can patient safety be monitored during treatment?
4. What are two security features to prevent unauthorized operation of the LINAC?

Quiz - Answers

1. What mechanism is recommended to prevent accidental exposure or injury from moving components?

   Interlocks and safety switches

2. To reduce the shielding burden the areas adjacent to the vault should be?

   Low Occupancy

3. How can patient safety be monitored during treatment?

   Audio and visual monitoring

4. What are two security features to prevent unauthorized operation of the LINAC?

   Key and login security

Lunch

Quality Assurance of Linear Accelerators

Quality Assurance of Linear Accelerators

- Learning Objective

  After this section the students should understand the structure of Quality Assurance programs as well as common policies, equipment, and procedures that make up these programs.

This section should take 90 minutes, a 10 minute break may be provided

Introduction to Linear Accelerators

- The Linear Accelerator features several built-in safety measures to ensure that it will deliver the dose as prescribed.
- These safety features are routinely checked to ensure they are working properly.

Calibration, Quality Control and Assurance Components

- QA program structure and management.
- Equipment acceptance and commissioning records.
- QC program content.
- Tolerances and frequencies
- Results and actions.
- Preventive maintenance program records and actions.

Quality Management Program

- Written Directive Procedure
  - Written Directive signed
  - Source/Beam Location Verification
  - Computer Calculations verified
    - Input
    - Output
    - Transfer
    - Manual confirmation
  - Acceptance Testing by Qualified Individual
  - QC Testing reviewed by Qualified Individual
  - Review Written Directives (Patient Chart)
  - Report Medical Events

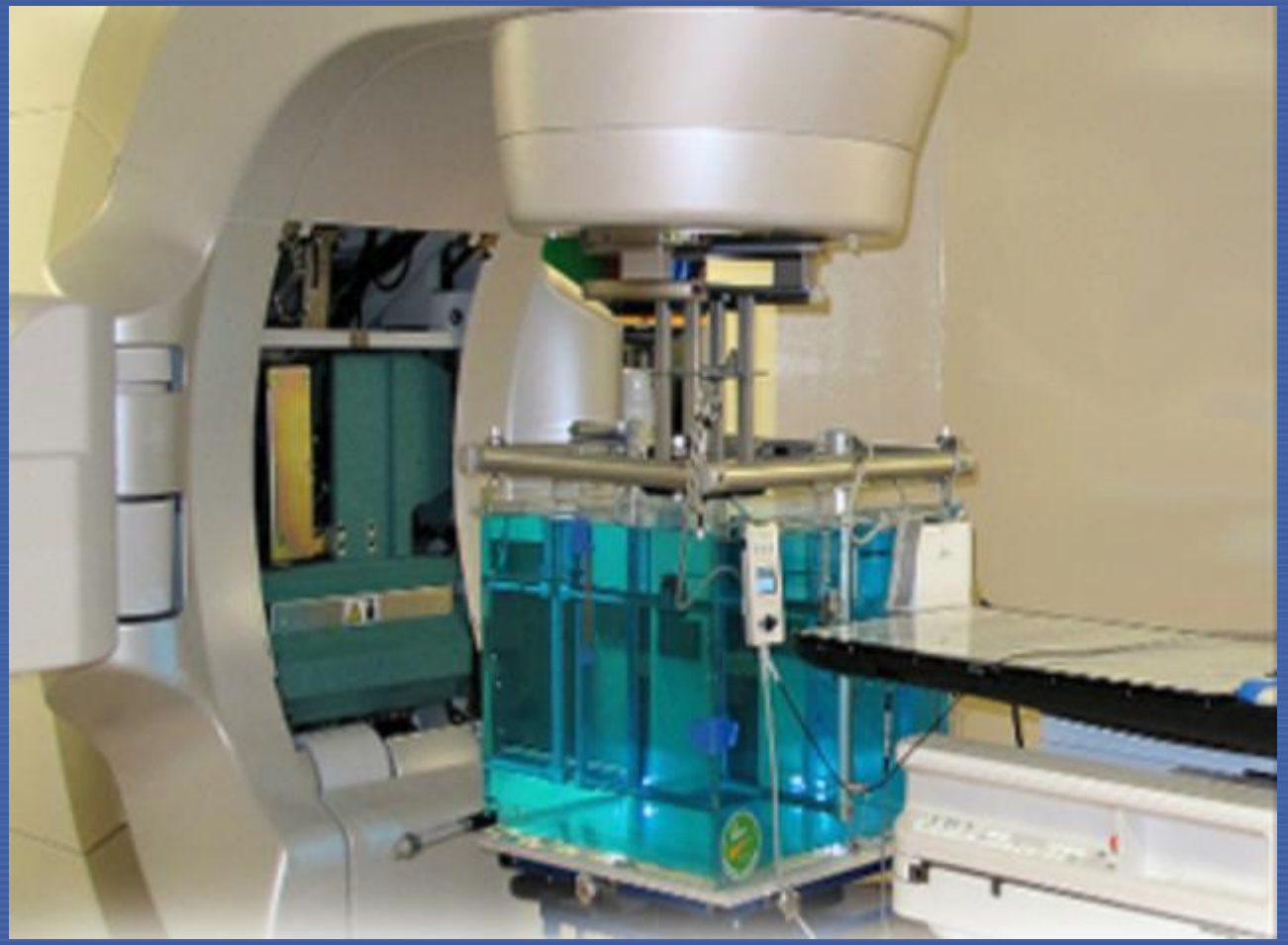
Equipment



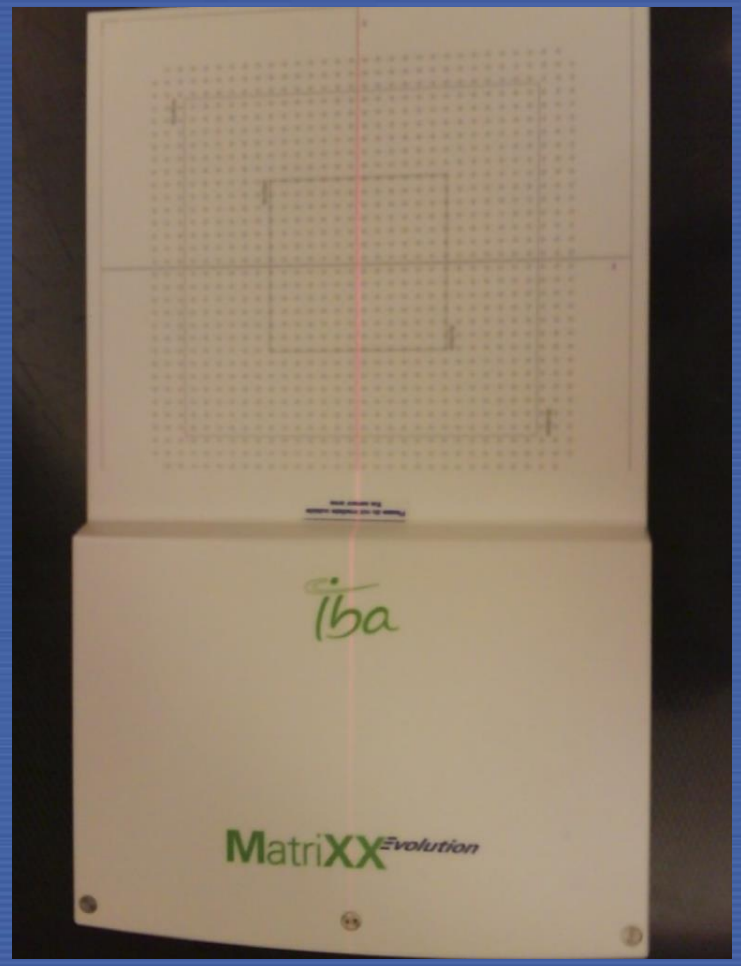
Equipment



Equipment

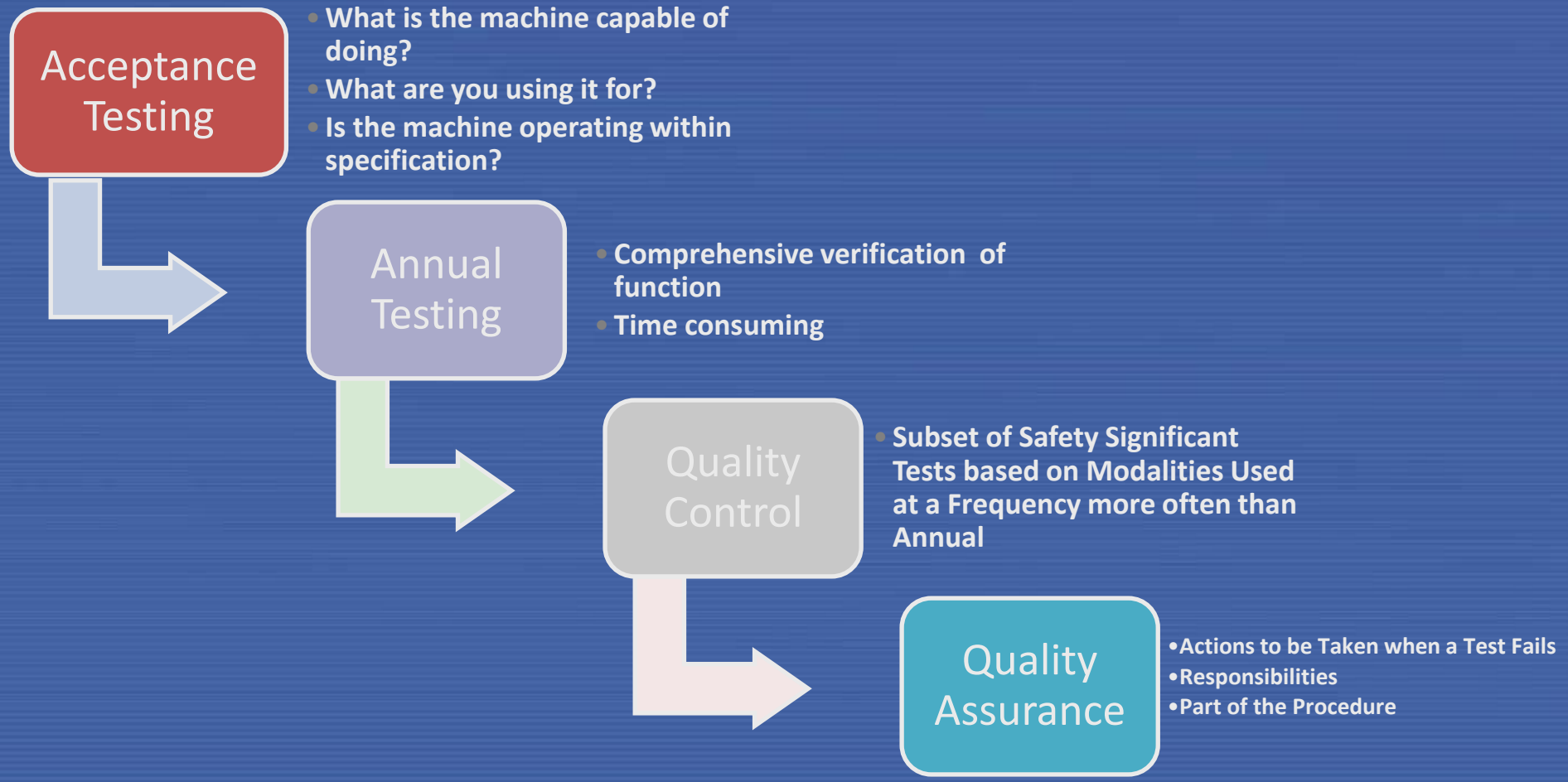


Equipment



Quality Assurance

- AAPM/IAEA recommendations for device performance verification
  - Task Group – 46 *Comprehensive QA for radiation oncology*
  - Task Group -142 *Quality Assurance of Medical Accelerators*
  - IAEA Technical Document 989 *Quality Assurance in Radiotherapy*
  - IAEA Review of Radiation Oncology Physics: A Handbook for Teachers and Students Chapter 12 - *QA in Radiation Therapy*


Acceptance Testing
What is the machine capable of doing?
What are you using it for?
Is the machine operating within specification?
Annual Testing
Comprehensive verification of function
Time consuming
Quality Control
Subset of Safety Significant Tests based on Modalities Used at a Frequency more often than Annual
Quality Assurance
Actions to be Taken when a Test Fails
Responsibilities
Part of the Procedure

Quality Assurance

- Actions to be defined/committed to by the licensee:
  - Tolerance level, no action is required.
    - A typical tolerance level might be 3% for a daily machine output check
  - Action level, immediate investigation and correction is necessary, and the equipment must not be clinically used.
    - A typical action level might be 5% for a daily machine output check; a typical action might be that no treatment be given until the discrepancy is resolved.

TG-40

TABLE II. QA of medical accelerators.

Frequency	Procedure	Tolerance[a]
Daily	Dosimetry	
	X-ray output constancy	3%
	Electron output constancy[b]	3%
	Mechanical	
	Localizing lasers	2 mm
	Distance indicator (ODI)	2 mm
	Safety	
	Door interlock	Functional
	Audiovisual monitor	Functional
Monthly	Dosimetry	
	x-ray output constancy[c]	2%
	Electron output constancy[c]	2%
	Backup monitor constancy	2%
	x-ray central axis dosimetry parameter (PDD, TAR) constancy	2%
	Electron central axis dosimetry parameter constancy (PDD)	2 mm @ therapeutic depth
	x-ray beam flatness constancy	2%
	Electron beam flatness constancy	3%
	x-ray and electron symmetry	3%
	Safety Interlocks	
	Emergency off switches	Functional

Daily Output and Distance Checks

12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.4 QA program for linear accelerators

Daily tests

Procedure or item to be tested	Action level
X ray output constancy	3 %
Electron output constancy	3 %



Daily output checks and verification of flatness and symmetry can be done using different multi-detector devices.

IAEA

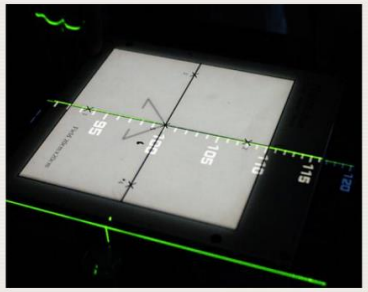
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12.3 QUALITY ASSURANCE PROGRAMME FOR EQUIPMENT

12.3.3 QA program for cobalt-60 teletherapy machines

Daily tests

Procedure or item to be tested	Action level
Lasers	2 mm
Distance indicator	2 mm



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Quiz- Questions

1. What are the different frequencies for checking output and their associated tolerances?
2. What is the required calibration frequency of ion chambers? Electrometers?
3. What is the difference between a tolerance level and an action level?

Quiz- Answers

1. What are the different frequencies for checking output and their associated tolerances?

   3% daily, 2% monthly

2. What is the required calibration frequency of ion chambers? Electrometers?

   2 years

3. What is the difference between a tolerance level and an action level?

   Tolerance = notification, Action = no treatment

Exercise 1: Beam Calibration Exercise

This exercise should take 60 minutes

Summary : Questions and Answers

Introduction to Linear Accelerators - Questions

1. What is the dominant photon interaction in radiotherapy?
2. Which is more penetrating, photons or electrons?
3. At what energy do neutrons become a consideration?
4. What is the purpose of the flattening filter?
5. What two important functions are served by the ion chamber measurement?
6. Why aren't MLC used for electrons?
7. What components of the LINAC can move during treatment?

Quiz- Answers

1. What is the dominant photon interaction in radiotherapy?
   Compton Scattering

2. Which is more penetrating, photons or electrons?
   Photons

3. At what energy do neutrons become a consideration?
   Greater than 10MV (15/18MV)

4. What is the purpose of the flattening filter?
   To create an even dose profile at a given depth (10cm)

Quiz- Answers

5. What two important functions are served by the ion chamber measurement?
   Beam steering and termination

6. Why aren't MLC used for electrons?
   Shaping needs to occur near the patient

7. What components of the LINAC can move during treatment?
   The gantry, jaws, and MLC

Facility Construction Features - Questions

1. What mechanism is recommended to prevent accidental exposure or injury from moving components?
2. To reduce the shielding burden the areas adjacent to the vault should be?
3. How can patient safety be monitored during treatment?
4. What are two security features to prevent unauthorized operation of the LINAC?

Quiz - Answers

1. What mechanism is recommended to prevent accidental exposure or injury from moving components?

   Interlocks and safety switches

2. To reduce the shielding burden the areas adjacent to the vault should be?

   Low Occupancy

3. How can patient safety be monitored during treatment?

   Audio and visual monitoring

4. What are two security features to prevent unauthorized operation of the LINAC?

   Key and login security

Biology of Cancer Treatment Questions

1. What is the current theory of how Radiation kills cancer cells?
2. What is the limiting factor for the dose we can deliver to a tumor?
3. What is the role of fractionation in radiation therapy?
4. The spinal cord is an example of a serial or parallel organ? What dose metric is most important in the evaluation of spinal cord dose?

Quiz- Answers

1. What is the current theory of how Radiation kills cancer cells?
   DNA double strand breaks

2. What is the limiting factor for the dose we can deliver to a tumor?
   Organ toxicity

3. What is the role of fractionation in radiation therapy?
   Healthy tissue recovery

4. The spinal cord is an example of a serial or parallel organ? What dose metric is most important in the evaluation of spinal cord dose?
   Serial. Max dose.

Quality Assurance- Questions

1. What are the different frequencies for checking output and their associated tolerances?
2. What is the required calibration frequency of ion chambers? Electrometers?
3. What is the difference between a tolerance level and an action level?

Quiz- Answers

1. What are the different frequencies for checking output and their associated tolerances?

   3% daily, 2% monthly

2. What is the required calibration frequency of ion chambers? Electrometers?

   2 years

3. What is the difference between a tolerance level and an action level?

   Tolerance = notification, Action = no treatment