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Dosimetry and Treatment Planning for Basic and Advanced Applications
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Treatment machines

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Outline – 1st part

- ✓ **BASIC INFO ABOUT**

CONVENTIONAL TREATMENT UNITS

COBALT UNITS

LINEAR ACCELERATORS

Outline – 2nd part

- ✓ **BEAM MODIFIER (<u>PHOTONS</u>, ELECTRONS) IN CONVENTIONAL TREATMENT UNITS**

  BLOCKS

  SPOILER

  BOLUS

  COMPENSATOR

  WEDGE

  MLC

- ✓ PATIENT SUPPORT

  TREATMENT COUCH

Introduction

RT alone or, more frequently, given in association with surgery and medical treatments has been a major means of fighting cancer since the discovery of X-rays by Röntgen in 1895

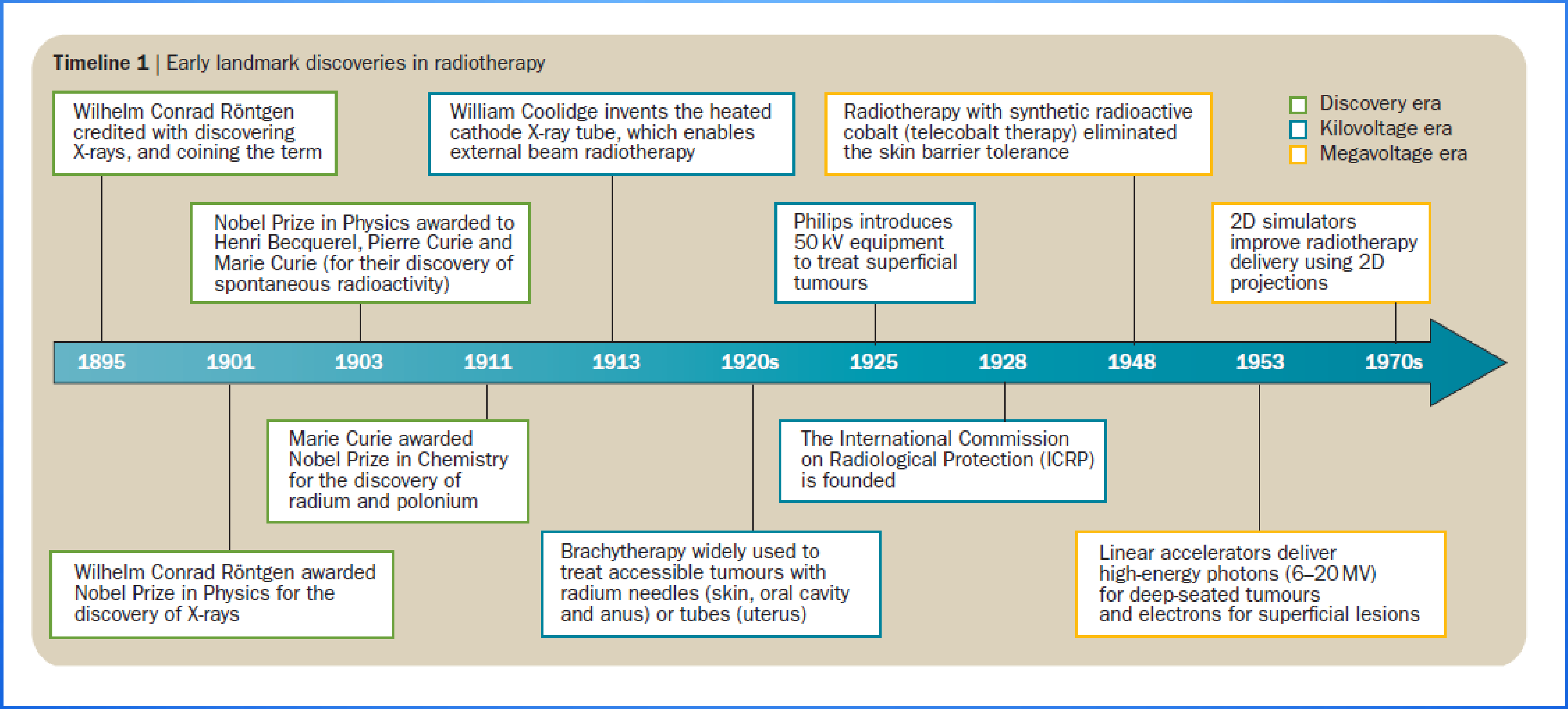
RT developed over four major eras:

1. **DISCOVERY ERA**, from Rontgen's discovery to about the late 1920s
2. **ORTHOVOLTAGE ERA**, from the late 1920s throughWorld War II
3. **MEGAVOLTAGE ERA**, which began with higher-energy linacs for therapy in the 1950s and, with refinements such as intensity-modulated X-ray therapy (IMXT), is still ongoing (with introduction of special machine such as Tomotherapy and Cyberkife)
4. The last phase of **PARTICLE THERAPY** (proton and ion beams): actually, the roots of PT fall into the third or MV phas, with the first treatment of humans in 1954; only in the mid 1980s did a firts hospital-based proton facility become feasible

Introduction

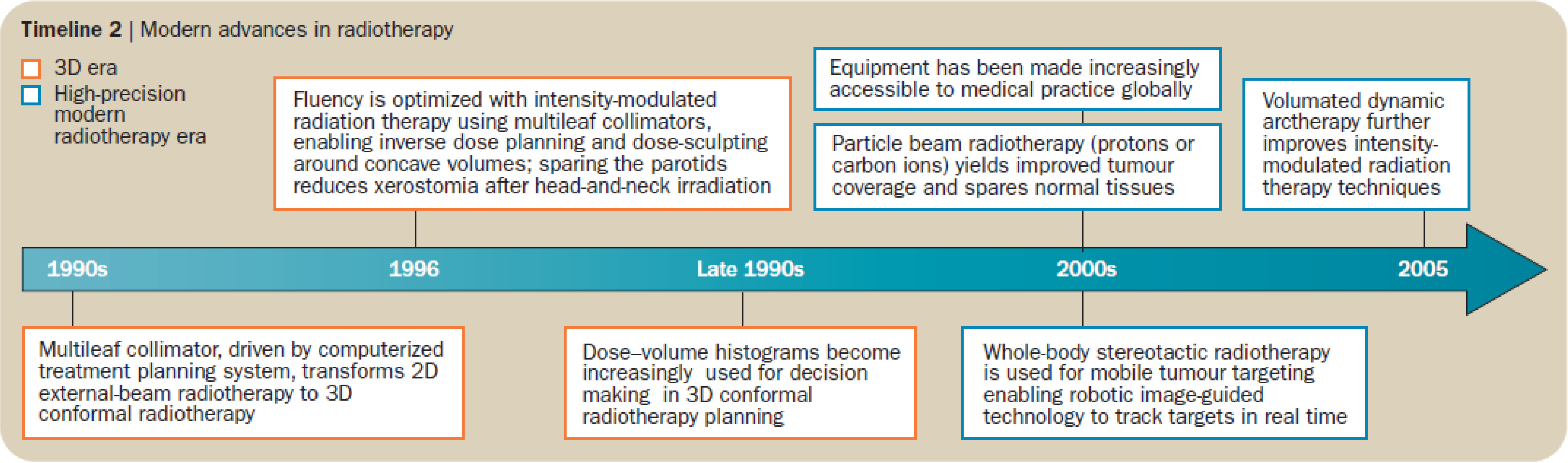
- Since the beginning of RT the technology of radiation production has been aimed towards ever higher photon and electron beam energies and intensities; since 1980's towards computerization and intensity modulated beam delivery
- 1900-1950: technological progress relatively slow and mainly based on X-ray tubes, van de Graaff generators, betatrons; most of external beam radiotherapy carried out with x-ray generated at voltages up to 300 kVp
- 1950: introduction of 60Co-teletherapy, providing a first answer in the quest of higher energy, placed the cobalt unit at the forefront of radiotherapy for several years
- Concurrently devoleped medical LINACS (US and UK) soon eclipsed Cobalt Units: Linacs offered a major versatility in RT (providing either photons and electrons with a wide range of energies)
- However, even in the present era of MV beams, conventional kV machines have not completely disappeared (expecially for superficial skin lesions)
- Moreover, the RT-technology scenario includes special machines Co-based (**Gamma knife** and the most recent ViewRay)

Timeline/1



Thariat, J. *et al. Nat. Rev. Clin. Oncol.* **10**, 52–60 (2013); published online 27 November 2012; doi:10.1038/nrclinonc.2012.203

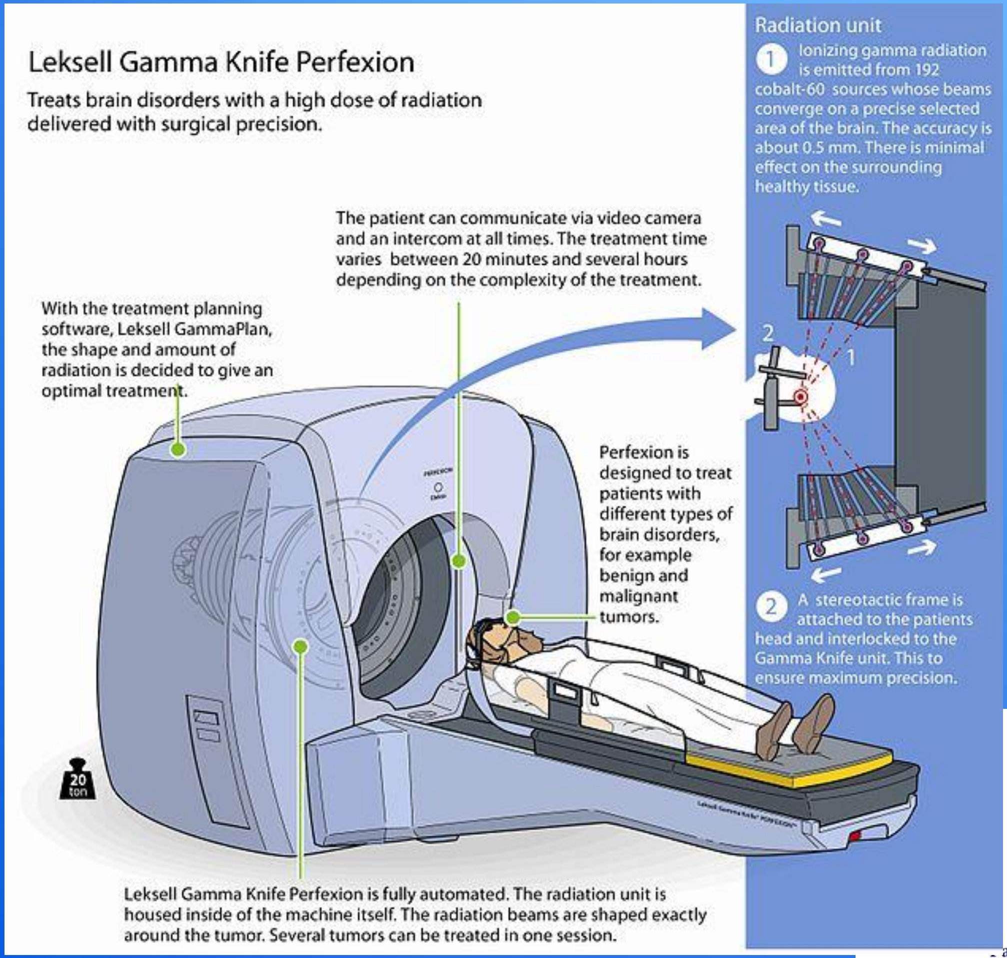
Timeline/2



Thariat, J. *et al. Nat. Rev. Clin. Oncol.* **10**, 52–60 (2013); published online 27 November 2012; doi:10.1038/nrclinonc.2012.203

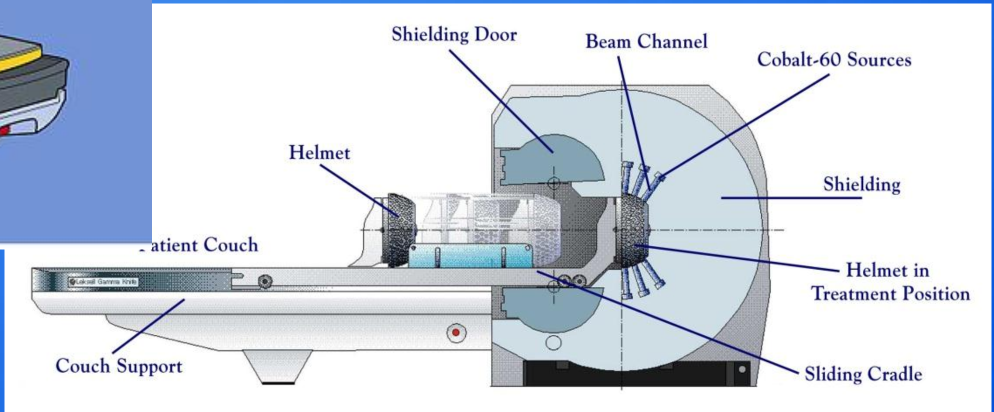
Cobalt-therapy is not dead

Gamma knife surgery (Elekta)



In the 1950s, Swedish professors Borje Larsson of the Gustaf Werner Institute, University of Uppsala, and Lars Leksell at the Karolinska Institute in Stockholm, Sweden, began to investigate combining proton beams with stereotactic (guiding) devices capable of pinpointing targets within the brain. This approach was eventually abandoned because it was complex and costly.

Instead, in 1967, the researchers arranged for construction of the first Gamma Knife device using cobalt-60 as the energy source. Leksell termed this new surgical technique "stereotactic radiosurgery"

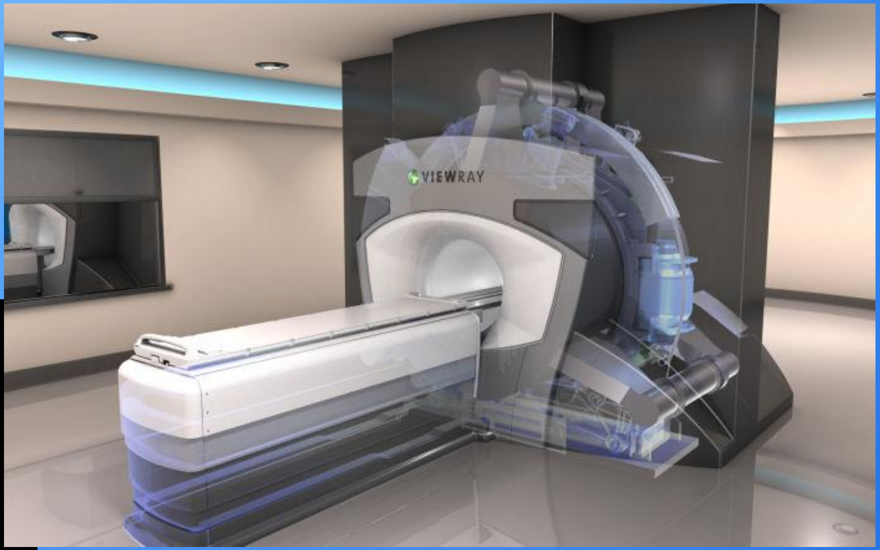


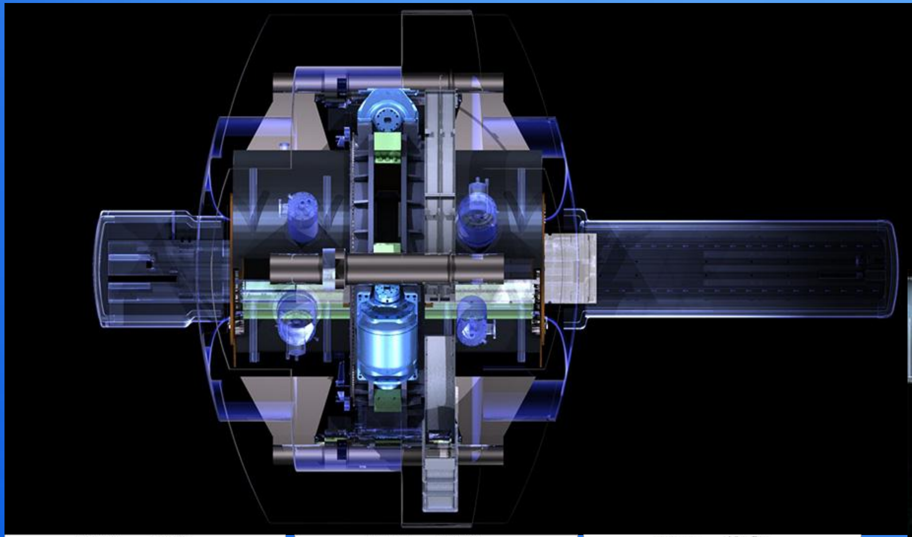
Cobalt Therapy is not dead

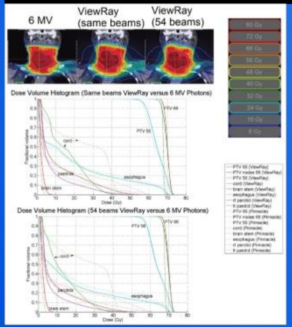
ViewRay

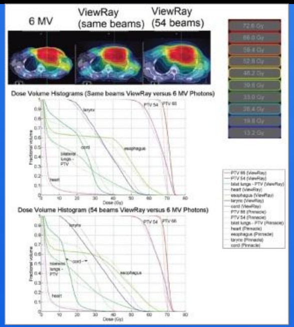
ViewRay provides soft-tissue imaging during RT. Its design is the combination of Co-60 with 0.35 Tesla MRI and allows for MR-guided IMRT delivery with multiple beams

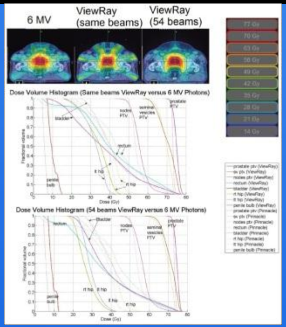
Benchmark: 2014











Physics of X-rays production

- Clinical X-rays machines can be classified in
  1) kV Units: 10÷500 kV (and above)
  2) MV Units: 1÷50 MV (60-Co included; although γ-emitter)
- Clinical X-rays are produced when electrons (with kinetic energies between 10 keV to 50 meV) are decelerated in metallic targets
- **Mechanism of production**: **Bremsstrhalung process**, a radiative collision between a high-speed incident electron and the nuclei of the target material; since produced photons may have any energy, from zero up to the initial kinetic energy of the electron, the process results in a **continuous** Bremsstrahlung spectrum
- The direction of emission of Bremsstrahlung photons depends on the electron energy, with a nearly isotropic emission at energies below about 100 keV, becoming extremely peaked in the forward direction as the electron energy is above several MeV

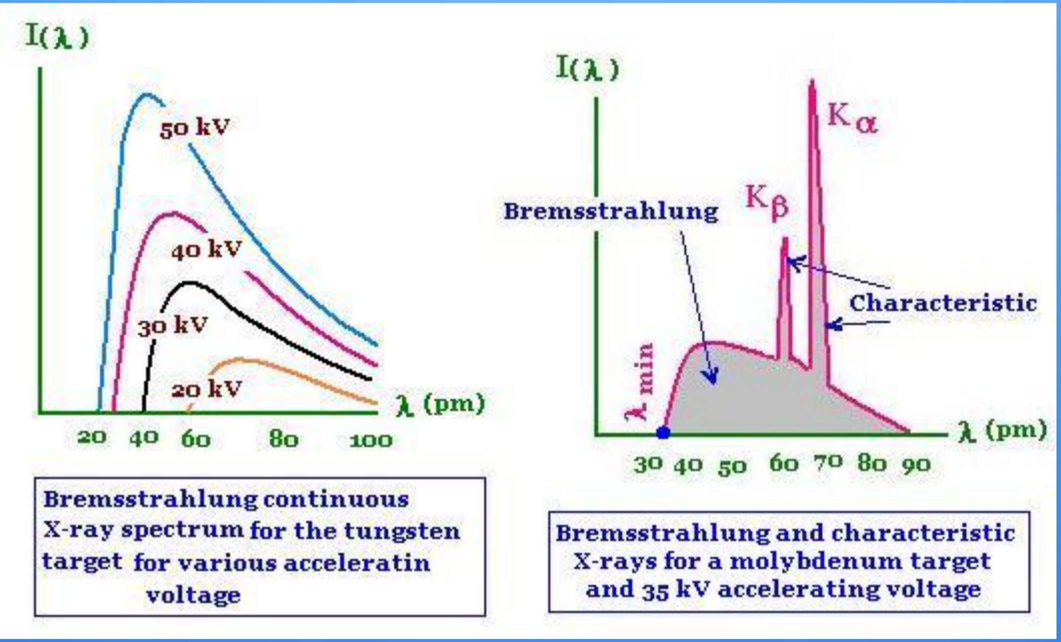
Physics of X-rays production

- **Transmission-type targets** are used in MV X-rays tubes, while in low-voltage is adavantageous to obtain the X-rays on the same side of the target (at 90° with respect to the direction of the electron beam)
- The probability of Bremsstrahlung production varies with Z^2 of target materail, so high-Z materials are preferred
- **The efficiency of production** (ratio of x-rays emitted energy to electron kinetic energy deposited) varies linearly with Z and the kinetic energy of incident electron: for energies of ~100 keV, in a tungsten target, the efficiency is only ~1%,with the rest of deposited energy appearing as heat
- Electrons incident on the target also produce **Charateristic X-rays** resulting from the EM interaction with orbital electrons of the target material; the incident electron ejects an orbital electron from an inner shell (K, L) so creating an orbital vacancy, filled soon after by an eletrcon from outer shell (L, M; N); the energy difference between the two shells is generally radiated in the form of Characteristic X-Rays
- The Characteristic X-Rays have **discrete energies** (that are typical of the atom and the shells involved in that transition)

X-rays SPECTRA

- The relative contribute of characteristic photons tototal spectrum decrease with energy:in W-target is ~ 20%,at electron energy ~100 keV,but becomes negligible in the MV range
- X-ray beams prouduced by X-ray machines are heterogeneous in energy (and their energy is designated in terms of kV or MV unlike that of the electrons)
- A typical energy spectrum shows
  - a continuous distribution of energies (Bremsstrahlung photons) superimposed by
  - characteristic radiation spectra of discrete energies: the (theoretical) spectrum ranges from zero to Emax (i.e. kinetic energy of incident electron)

X-rays SPECTRA



The Bremsstrahlung spectrum originates in the x-ray target, while the characteristic line spectra in the target and in any attenuator placed into the beam

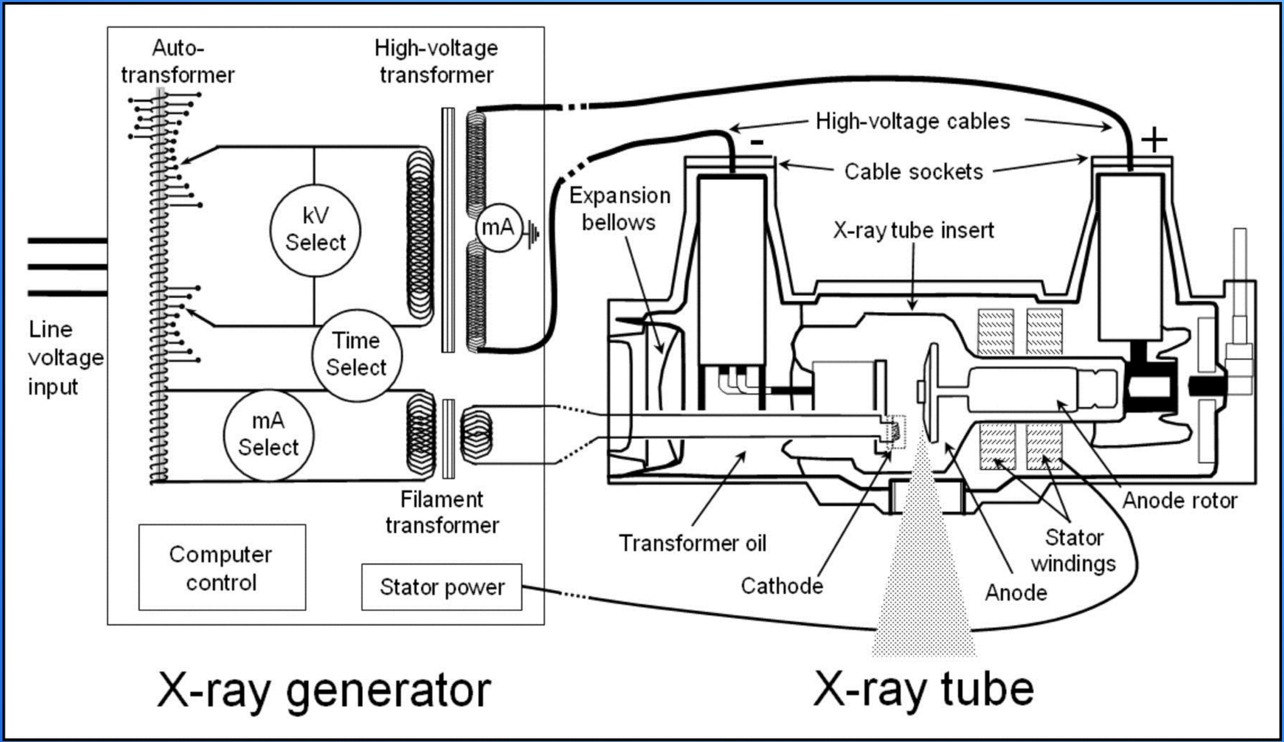
Inherent and added filtrations modify significantly the energy spectrum, removing the low-energy component of the beam

Kilovoltage Units

Grenz Ray Therapy	(< 20 kV)
Contact Therapy	(40÷ 50 kV)
Superficial Therapy	(50÷ 150 kV)
Orthovoltage (Deep) Therapy	(150 ÷ 500 kV)
Supervoltage Therapy	(500-1000 kV)

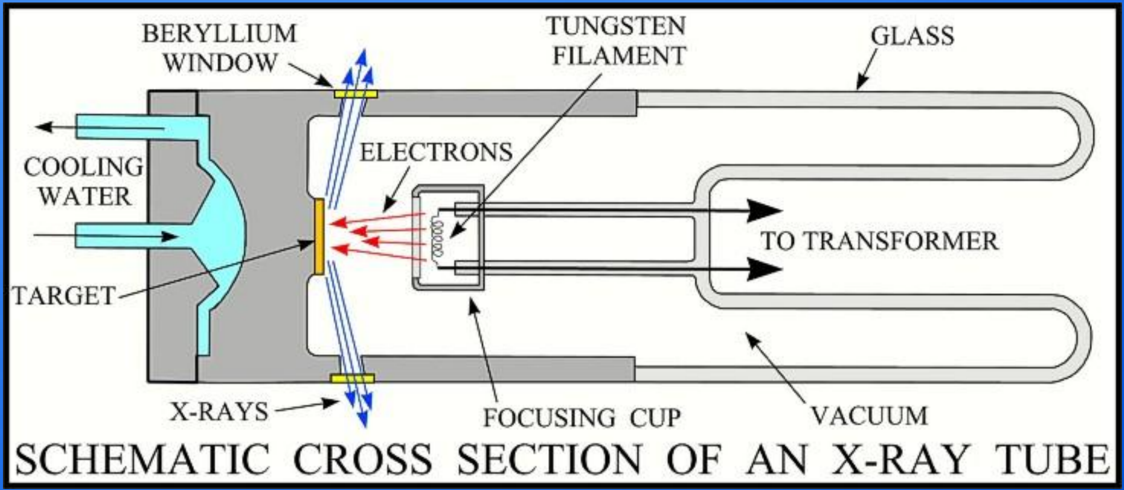
According NCRP, National Council on radiation Protection & Measurements, Report #34

Orthovoltage Units



Main components
X-rays tube (Coolidge tube)
A ceiling or floor mount for the tube
A target cooling system
A control console
An X-ray power generator

<u>X-rays production efficiency</u>: ~1% (99% of electron kinetic energy transformed in heat)
<u>Target material</u>: high Z and high melting point (W)



X-ray produce
150÷500 kV (wit
kV)

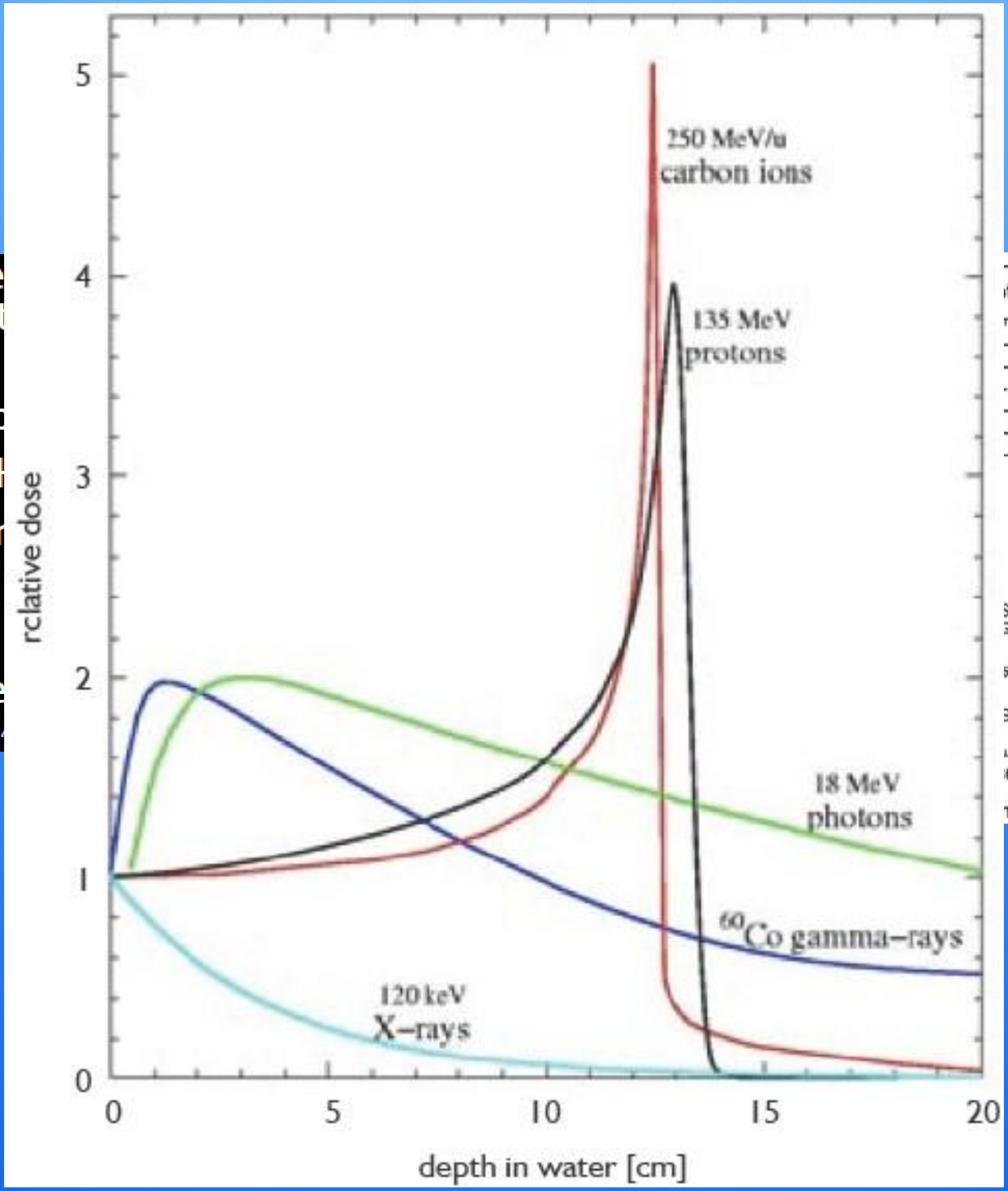
Tube current: 1c

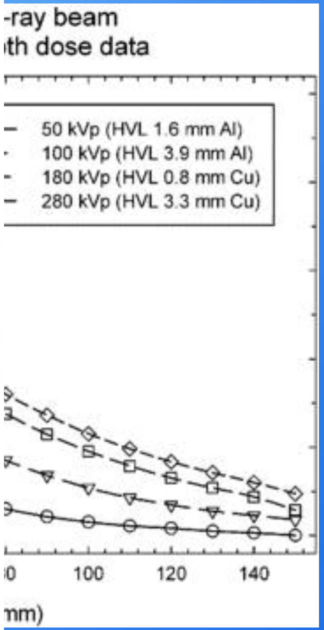
Beam Quality: H

Field size: cor
diaphragm)

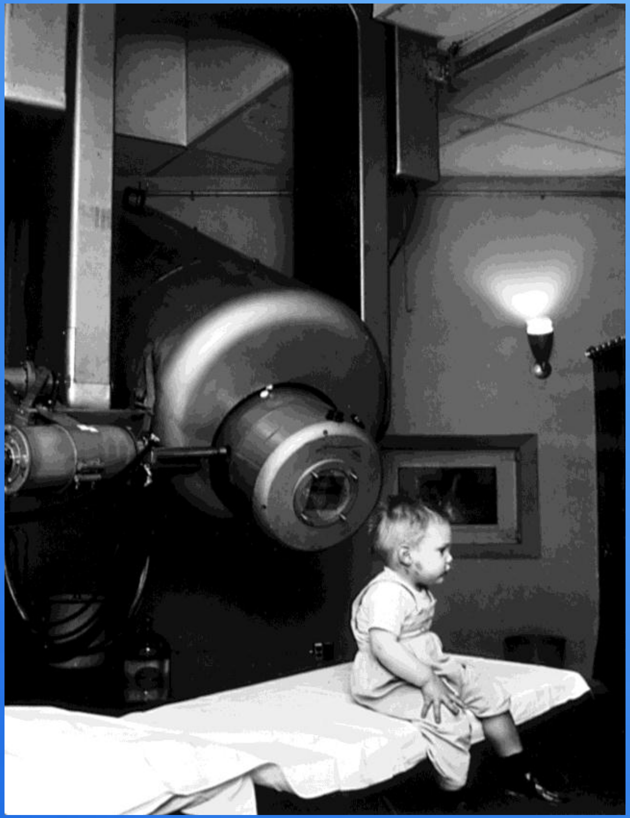
SSD: usually 50

Maximum dose
90% at a depth

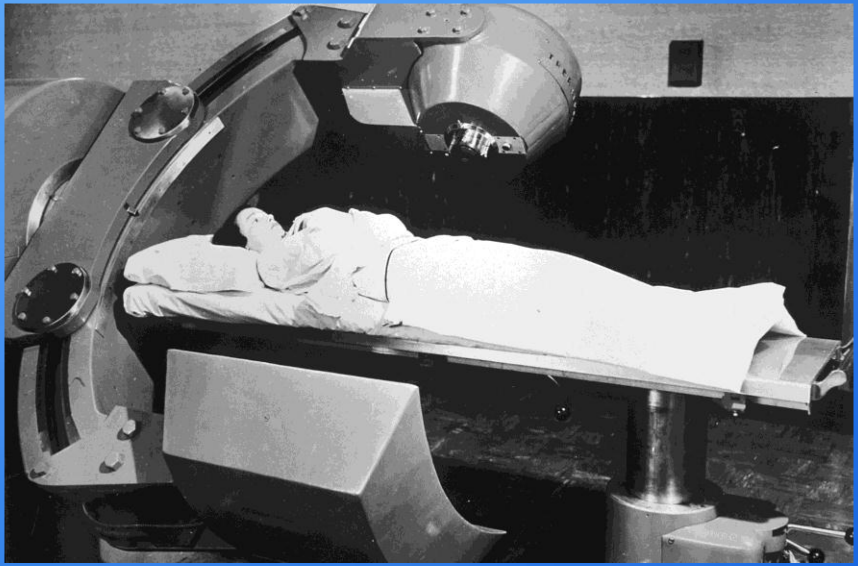




MV UNITS



The first patient to be treated with Cobalt-60 radiation was treated on October 27, 1951 at Victoria Hospital in London, Ontario



Historical image showing Gordon Isaacs, the first patient treated with linac (electron beam) for retinoblastoma in 1957. Gordon's right eye was removed January 11, 1957, because the cancer had spread. His left eye, however, had only a localized tumor that prompted. Henry Kaplan to try to treat it with the electron beam

GAMMA RAY UNITS or TELETHERAPY UNITS

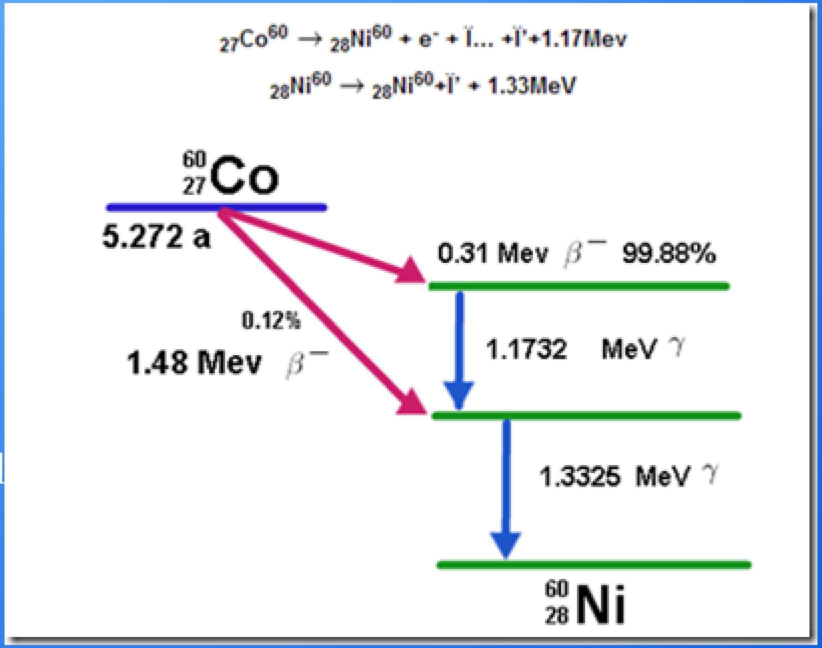
Of all the other radionuclides used for teletherapy (^{137}Cs, ^{226}Ra) Cobalt-60 resulted the most suitable for external beam theraphy because could offer extremely useful features:

- High energy γ-ray emission (1.17 and 1.33 MeV)
- High specific γ rate constant (1.30 Rm^2h^{-1} / Ci)
- Long half-life (5.26 years)
- High specific activity (~250 Ci/g)
- Simple means of production ($^{59}Co(n,\gamma)\,^{60}Co$)

Main components: a radioactive source, a source housing including beam collimators and a source movement device, gantry and stand, a patient support assembly and a machine console

The cobalt source

- Emission of β particle (Emax = 0.32 MeV) and 2 photons per disintegration of energy 1.17 and 1.44 MeV
- The emitted photons are clinically useful, while the particles are absorbed in cobalt metal or stainless-steel capsule resulting in negligible Bremstrahlung and characteristics X-rays
- Lower-energy photons produced by primary component scattering in the source itself, surrounding capsule, source house and collimator contribute significantly (10%) to total intensity of the beam.
- Electron contamination is also present in the beam
- Typical source activities: 185 ÷370TBq providing at 80 cm from the source (SAD) a dose rate of ~ 100÷200 cGy/min



The collimator system consists of 2 pair of heavy metal blocks that can be move independently to obtain rectangular and square fields from 5x5 to 35x35 cm^2 at 80 cm from the source

The ***transmission penumbra***, due to oblique radiation passing through the edge of the blocks, can be minimized but not completely removed for all field sizes even with appropriate block shaping design

The ***geometrical penumbra***, resulting from finite source diameter, is independent from field sizes, increase with source diameter, SSD, but decrease with the source-collimator distance, so it can be reduced using extendable *penumbra trimmers*

In teletherapy machines the prescribed dose is delivered in terms of time of exposure (minutes and seconds) with the use of 2 independent timers

The primary timer controls the treatment time, the secondary serving as *back up timer* in case of failure of the primary one

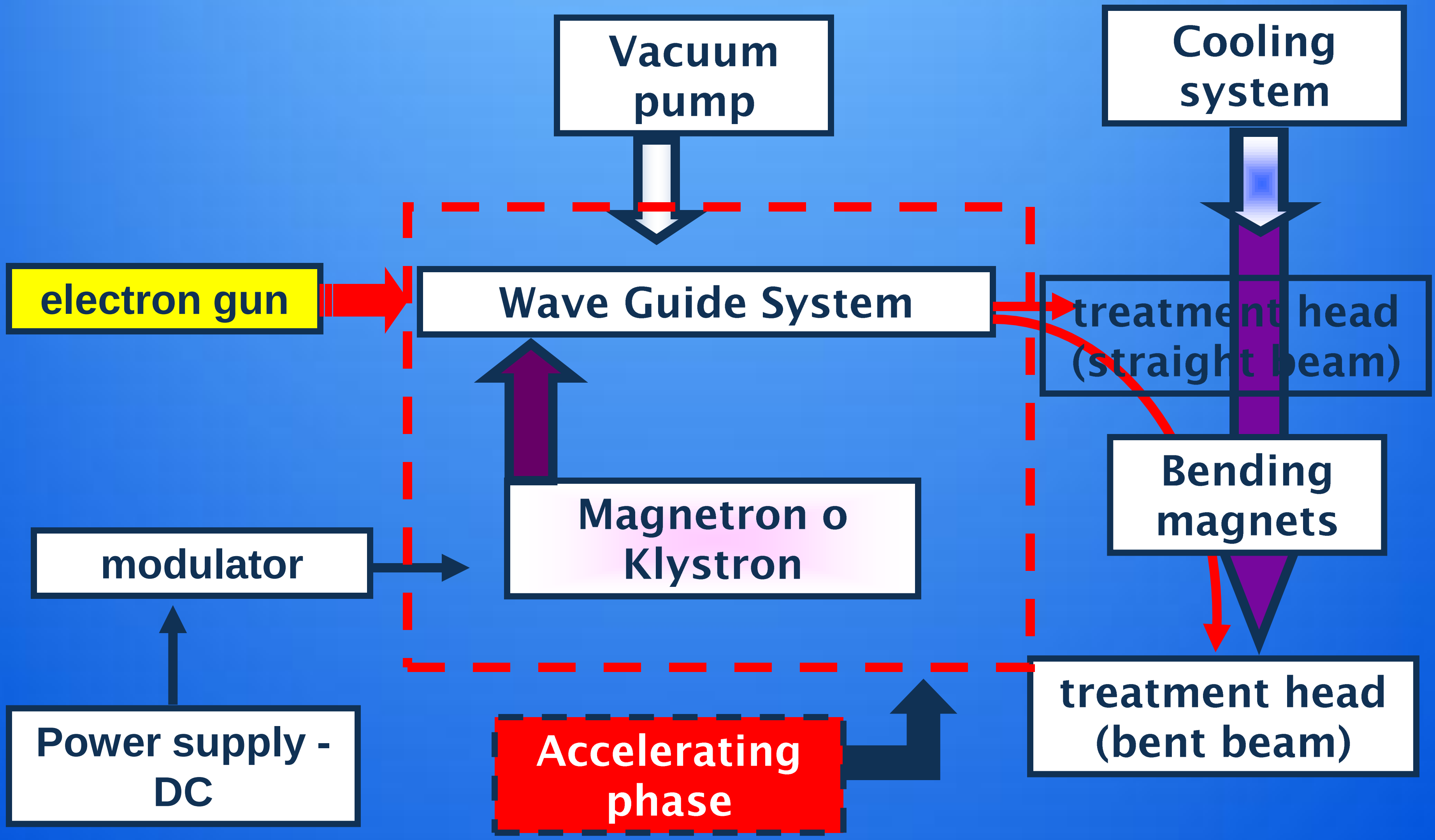
As for Orthovoltage Units, the set treatment time includes the shutter correction time to account, here, for the travel time spent by the source moving between the OFF and ON positions at the start and the end of irradiation

Linear accelerators

- **Medical linacs are devices that accelerate electrons to high kinetic energies from 4 to 25 MeV through special evacuated linear structures(accelerating waveguide) using microwave RF fields at frequencies of about 3000 MHz**

- Various types of linac available for clinical use: some provide X-rays only, in low mega-voltage range (**4 or 6MV**),others provide both X-rays and electrons at various energies.
- Typical modern high energy linacs provide two photon energies (e.g. 6-18) and several electron energies from 4 to 22/25MeV.

LINAC – BLOCK DIAGRAM



LINAC: how does it work

- A Power supply provides AC power to the Modulator, consisting essentially of a PFN (Pulse Forming Network)and a tube switch (HydrogenThyratron)
- HV DC pulses from the Modulator are delivered to Magnetron or Klystron and simultaneously to the ElectronGun
- Pulsed MWs produced in Magnetron/Klystron are injected into the accelerating structure through a waveguide system
- At the proper instant electrons produced by the electron gun (thermionic emission) are also pulse injected into the accelerating structure (evacuated to high vacuum)
- The injected electrons (initial energy of 50 keV) interact with the EM field of the MWs nd gain energy from the sinusoidal electric field by an acceleration process similar to that of a surf rider
- Electrons emerging from the exit window of the accelerating waveguide are in form of a pencil beam of about 3 mm in diameter
- In low energy linacs, with relatively short accelerating structure,they proceed straight on striking a target for X-rayproduction
- In higher energy linacs(long and horizontal accelerating waveguide)they are bent through a suitable angle (90°or270°) before reaching the target,by the beam transport system consisting of bending magnets, focussing coils and other components

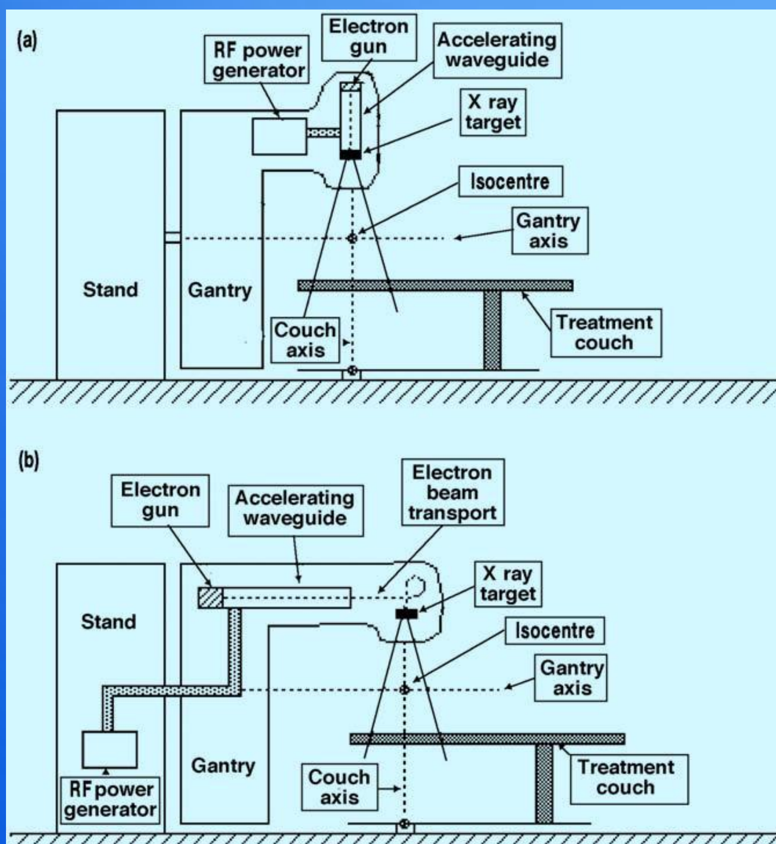
LINAC: components

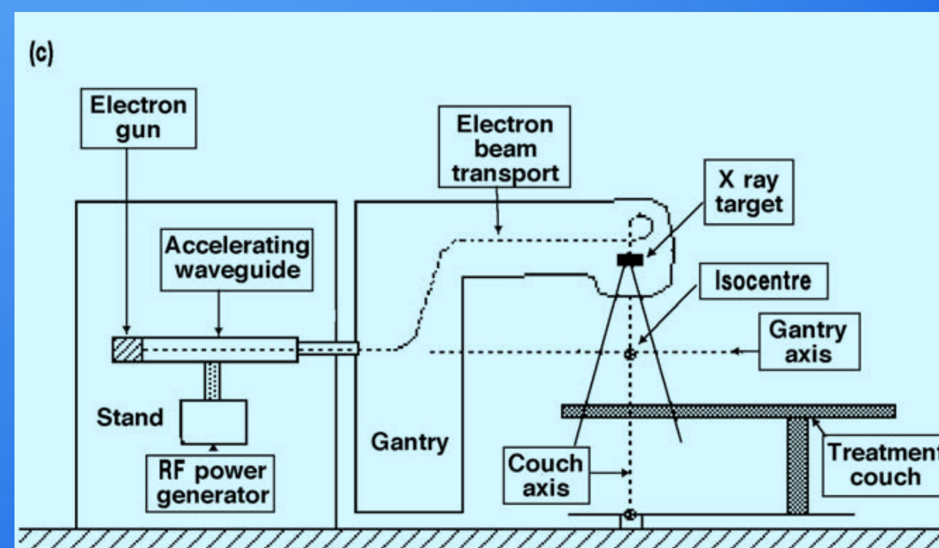
- They are mounted isocentrically the 5 major sections

  1) GANTRY
  2) GANTRY STAND OR SUPPORT
  3) MODULATOR CABINET
  4) PATIENT SUPPORT ASSEMBLY (TREATMENT TABLE)
  5) CONTROL CONSOLE

Design configurations

- Significant variations in design from one commercial model to another depending on final electron kinetic energy





DRIVE STAND

The gantry rotates on horizontal axis bearings located inside the Drive Stand, a large rectangular cabinet that is firmly secured to the treatment room floor.

Major components located in the Drive Stand:

1. Klystron or Magnetron
2. RF Waveguide
3. Circulator (connects item 1 and 2 above)
4. Cooling water system.

Modulator component

This is the noisiest of the linac system components and is located inside the treatment room.

Contains 3 subcomponents:

Fan Control, cooling the power distribution system.

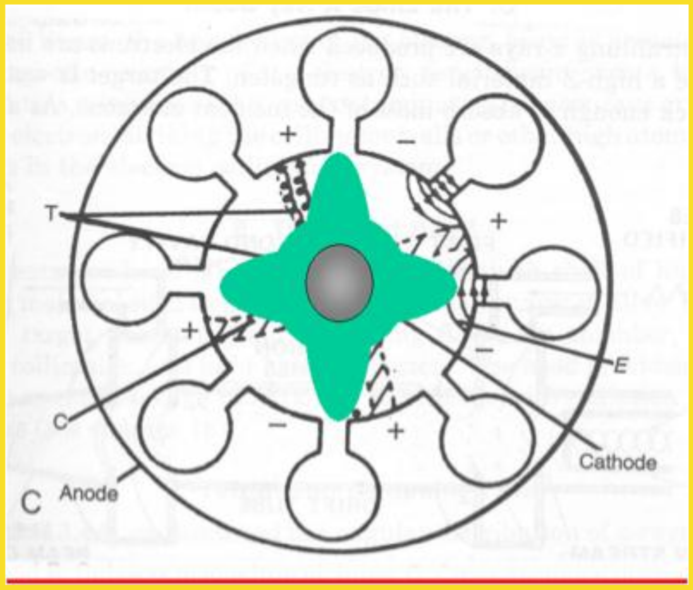
The auxiliary power distribution system, contains the emergency off button that shuts the power to the linac.

Primary power distribution system.

RF POWER: MAGNETRON

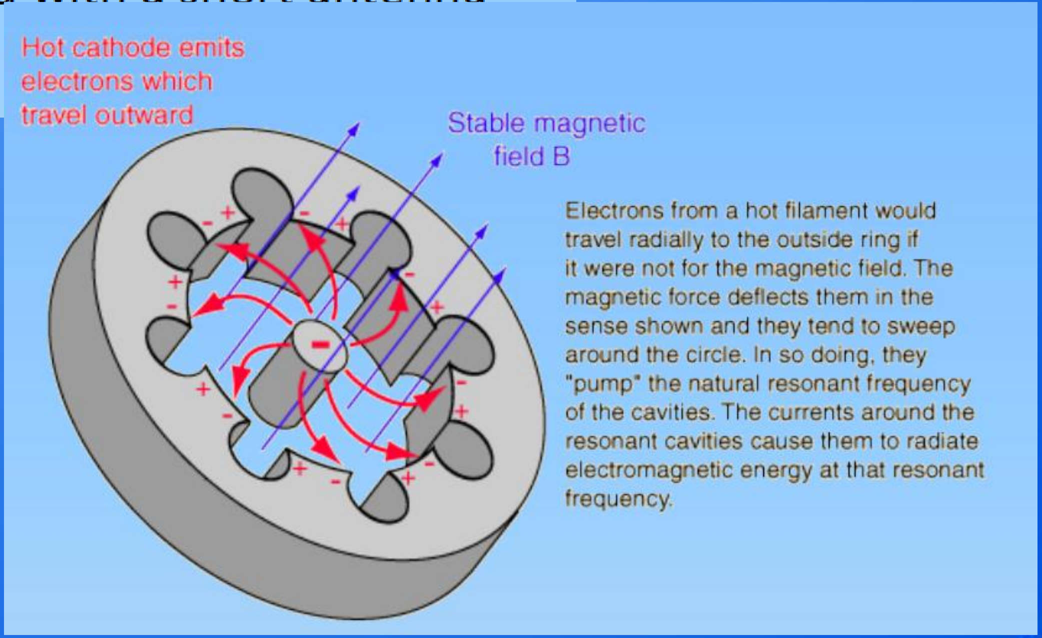
High-power oscillator, generating MW pulses (several μs duration) and with **a repetion rate or pulse repetiton frequency** of several hundred pulses per second.
The frequency of the MW within each pulse is≈**3000 MHz (3 gHz)**.

Has a cylindrical construction: a central cathode C and an outer anode A with resonant cavities machined out of a solid piece of Cu. Space between A & C are evacuated C is heated by an inner filament and the electrons are generated by thermoionic emission
A static MF is applied perpend. to the plane of the cross-section of the cavities and a pulsed DC EF is applied between A & C
Electrons emitted from C are accelerated toward A by the action of the DC-EF. Under the simultaneous influence of MF, electrons move in complex spirals toward the resonant cavities, radiating energy in the form of MW.
The generated MW **pulses** (typically 2 MW peak power) are led to the accelerator structure via the waveguide



RF POWER: MAGNETRON

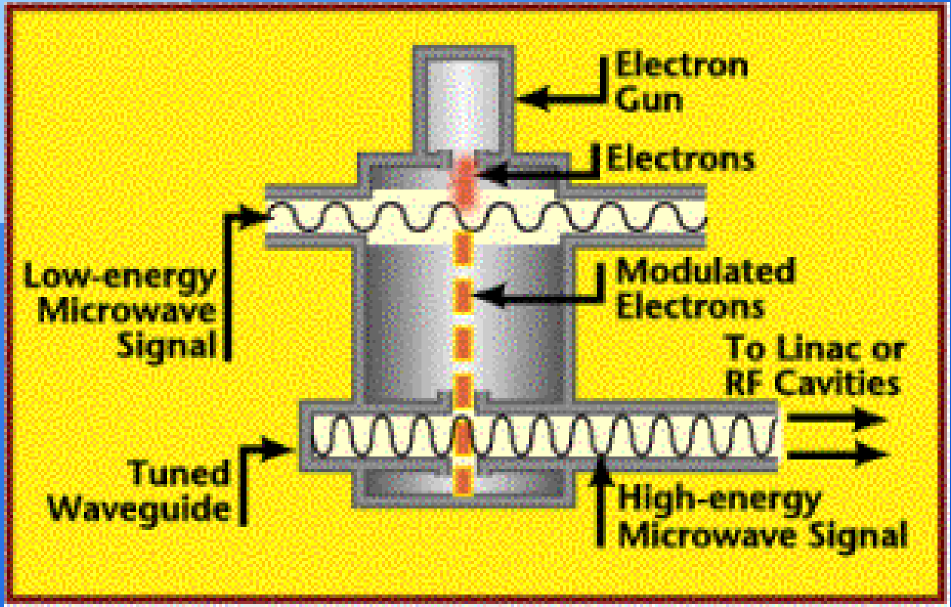
– As seen in your microwave oven!
– Operation
  - Central cathode that also serves as filament
  - Magnetic field causes electrons to spiral outward
  - As the electrons pass the cavity they induce a resonant, RF field in the cavity through the oscillation of charges around the cavity
  - The RF field can then be extracted with a short antenna attached to one of the spokes



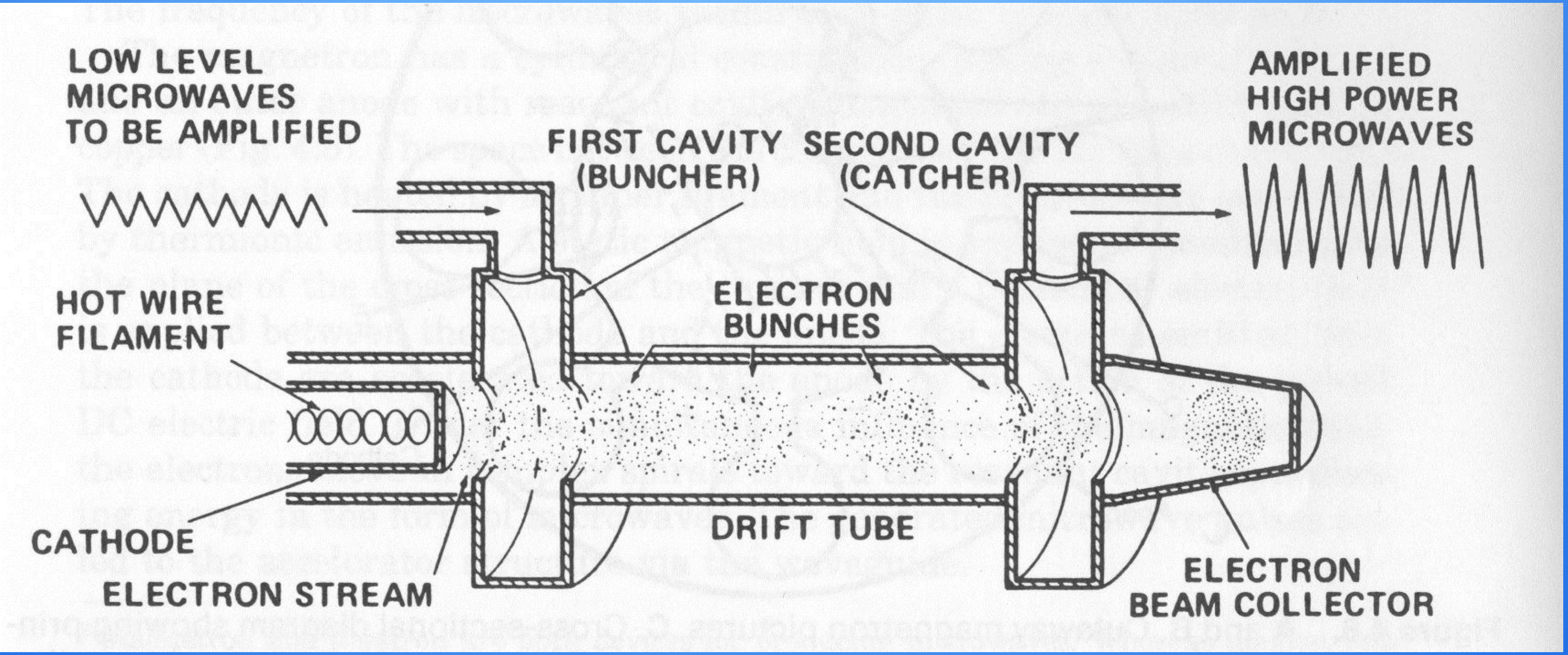
RF POWER: KLYSTRON

- Used in High Energy Physics (HEP) and > 6 MeV medical linacs
- Operation – effectively an RF amplifier
  - DC beam produced at high voltage
  - Low power RF excites input cavity
  - Electrons are accelerated or deaccelerated in the input cavity
  - Velocity modulation becomes time modulation during drift
  - Bunched beam excites output cavity
  - Spent beam is stopped

The Klystron is not a microwave generator but rather a microwave amplifier that amplifies low power RF generated by an RF oscillator (RF driver).



RF POWER: KLYSTRON



Klystron consists of 3 separate sections: the electron gun (cathode, anode and grid), the RF section and the collector section

The RF section has a drift tube and 2 or more cavities: the first is the 'buncher' cavity (with RF input) and the last is the 'catcher' cavity (with RF output)

RF POWER: KLYSTRON

The electrons produced by the cathode are accelerated toward the first cavity which is energized by low power microwaves to be amplified.

The oscillating electric field from microwaves modulates the electron beam velocity, so the electrons arrive to the catcher cavity sorted in compact bunches.

In the catcher cavity the electron bunches are decelerated by retarding electric field, induced by them in the cavity, and part of their kinetic energy is converted into high-power microwaves, which have the same frequency as the input signal. 5-30 MW power can be reached with this unit

Transmission Waveguides

The microwave power transmission from Magnetron or Klystron to accelerating waveguide is accomplished by RF power transmission waveguides, gas filled (SF_6) metallic structures of rectangular cross-section.

A component called ***circulator*** must be inserted in RF power transmission system to protect RF source from reflected power

Accelerating wave guide

The central component of a linac is the **accelerating waveguide,** a metallic structure of circular cross-section consisting of a linear array of microwave cavities

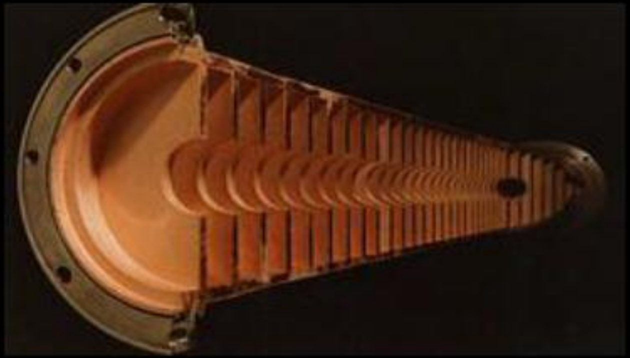
The simplest accelerating waveguide is obtained from an evacuated cylindrical uniform waveguide by adding a series of ireses (disks), with circular holes at the center, placed at certain distances along the guide.

These ireses, dividing the waveguide in a series of cylindrical cavities, make the guide non uniform, with a microwave phase velocity <u>no more exceeding that of light</u> in vacuum (as it happens in uniform waveguide) allowing electron acceleration

Accelerating wave guide

- The cavities of the accelerating waveguide are arranged to serve two purposes:

1. to couple and distribute microwave power between adjacent cavities (and hence along the length of the structure)
2. to provide an *E* field with suitable axial distribution for accelerating electrons



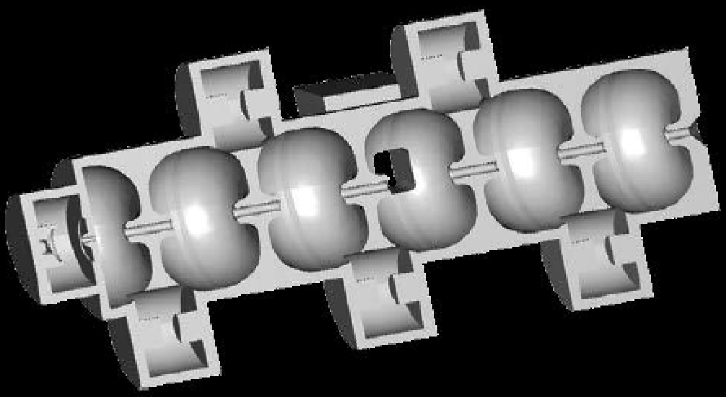
- Two types of accelerating waveguide have been developed:

- **Travelling Wave Structure**
- **Standing Wave Structure**

Accelerating wave guide

- The initial portion of the structure is called the ***buncher***: its cavities are non uniform varying in inner diameter, aperture diameter and axial spacing in order to concentrate the continuum of injected electrons in discrete bunches and to start their acceleration

- Early buncher designs contained many cavities, later, only several cavities were used: today in general the buncher consists of only a single half cavity



Accelerating wave guide

- In the **TRAVELLING WAVE** structure the microwaves enter the accelerating waveguide and propagate toward the end of the waveguide where they are absorbed without any reflection or exit the waveguide to be absorbed in a resistive load; in this configuration ONLY ONE IN FOUR CAVITIES, at any given moment, IS SUITABLE FOR ELECTRON ACCELERATION providing an electric field in the direction of propagation

- In the **STANDING WAVE** structure each end of the waveguide is terminated with a conducting disc to **reflect** the microwave power, so that the combination of forward and reverse travelling waves results in a buildup of stationary waves in the waveguide; in this configuration, at all times, EVERY SECOND CAVITIES CARRIES NO ELECTRIC FIELD, producing no energy gain. These cavities, serving only as coupling cavities, can be moved off-axis, thus shortening the accelerating waveguide by 50% and making easier the optimization of the waveguide

Beam Transport Systems

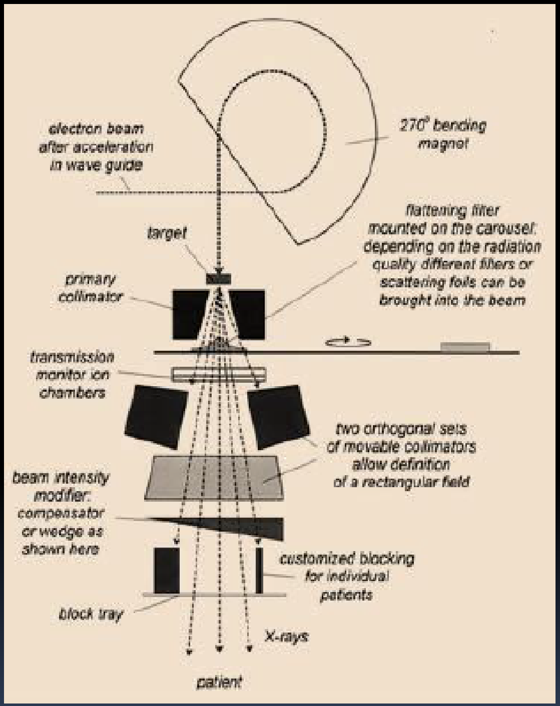
The Beam Transport System includes solenoids and steering coils **OVER** accelerator structure, together focussing quadrupoles and bending magnets **AFTER** the accelerator structure.

The system confines, steers, and guides the electron beam from the injection to x-ray target or electron scatterer.

If low energy units, with short SW structures and straight-through beam design require no bending magnet (and solenoid need not to be used to confine the beam) higher energy (isocentric) machines necessitate bending magnets so that the correspondly longer structure can lie horizontally

Beam Transport Systems

- The electron beam entering a beam transport system contains particles differing in energy, with some degree of angular divergence and lateral displacement from central axis
- The task of the transport system is to bring this diversity of particles to a small and coaxially directed beam on the central axis of the x-ray target or the scattering foil.
- Most isocentric treatment units employ a nominal 90° or 270° beam bending magnets
- The 270° magnet systems are usually achromatic (electrons of different energy brought to the a single focal point) and the resulting isocenter height is acceptably low



Auxilliary Systems

(Services not directly involved with electron acceleration, yet important for the functionality of the machine)

A vacuum pumping system producing a vacuum pressure of $\sim 10^{-6}$ torr in the accelerating guide and RF generator

A water cooling system for cooling the accelerating guide, target, circulator and RF generator

An optional air pressure system for pneumatic movement of the target and other beam shaping components

Shielding against leakage radiation

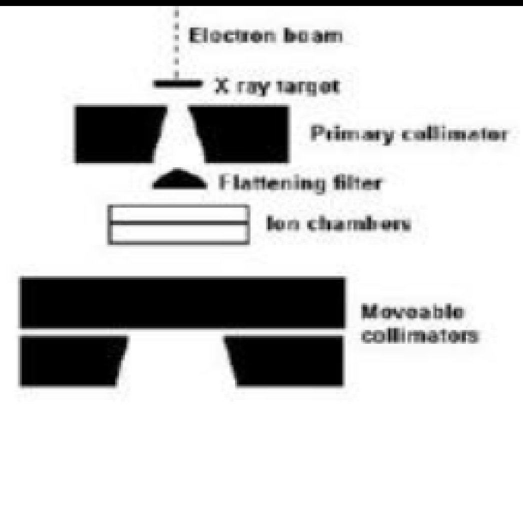
Treatment Head

- The linac treatment head consists of a thick shell of high density shielding material (U (<6 MV), Pb, W, Pb-W alloy)

- The head contains several components that influence the production, shaping, localizing and monitoring of <u>clinical</u> photon and electron beams

- A typical treatment head include:

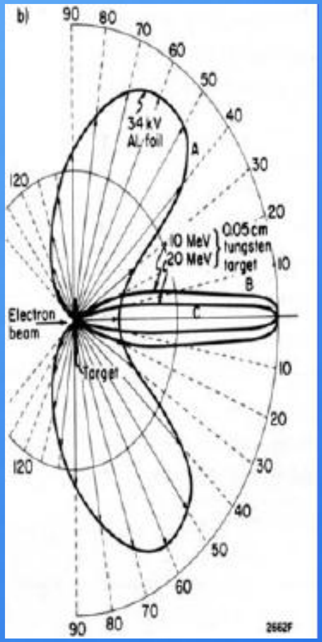
  - Retractable X-ray target(s)
  - Flattening filters and scattering foils
  - Primary and adjustable secondary collimators
  - Dual transmission ionization chambers
  - Field defining light and range finder
  - Optional retractable wedges
  - Optional Multi Leaf Collimator (MLC)

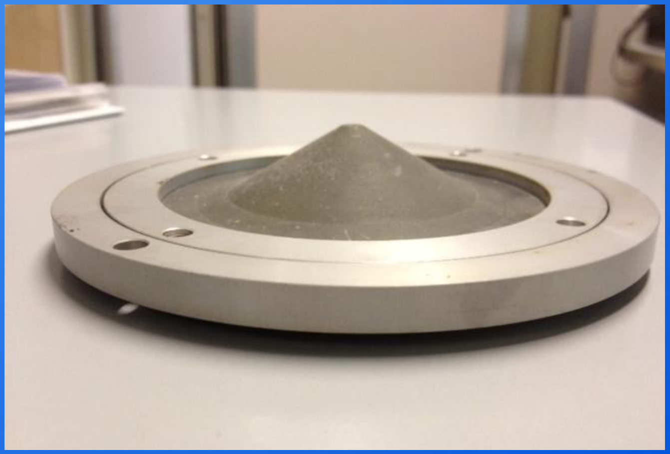


Treatment head configured for photons

Clinical photon beams

- Clinical photon beams are produced with an X-ray movable target and **flattened** with a **flattening filter** (<u>one filter for each energy</u>) since the x-ray production is peaked in the forward direction
- At electron energy below 15MeV optimal targets have high atomic number Z (low Z at greater energies) while optimal flattening filters have low Z irrespective of beam energy
- The flattening filters (and the scattering foils for the clinical electron beams) are usually mounted on a rotating carousel just below the primary collimator





FFF beams are not a new idea . . .

Radiosurgery with unflattened 6-MV photon beams

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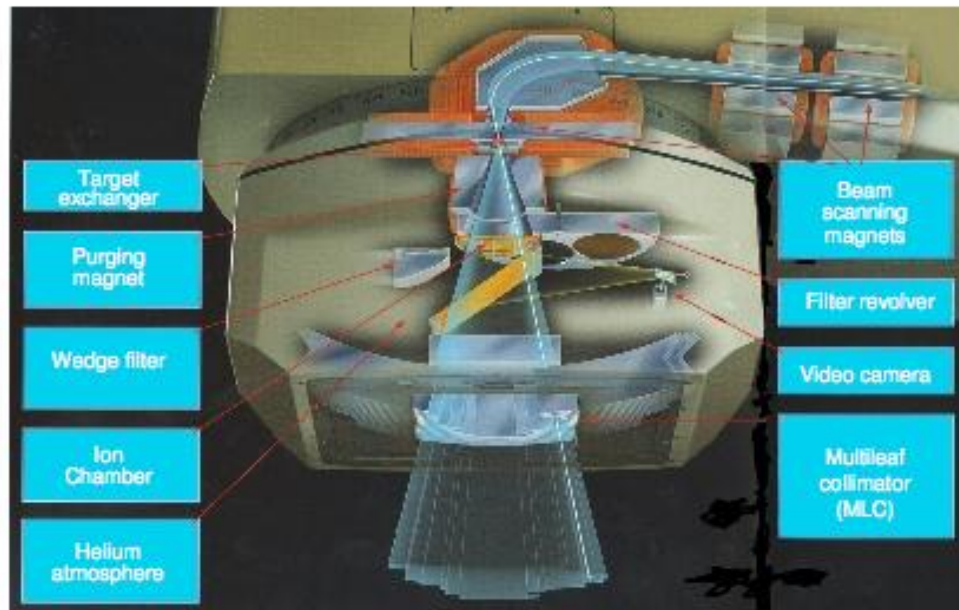
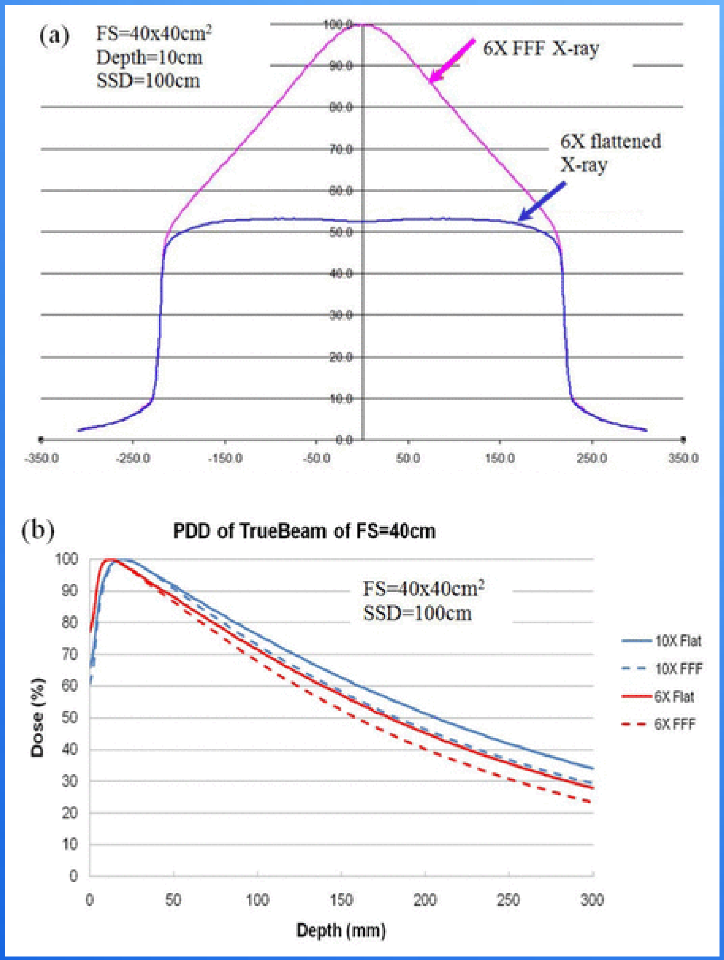
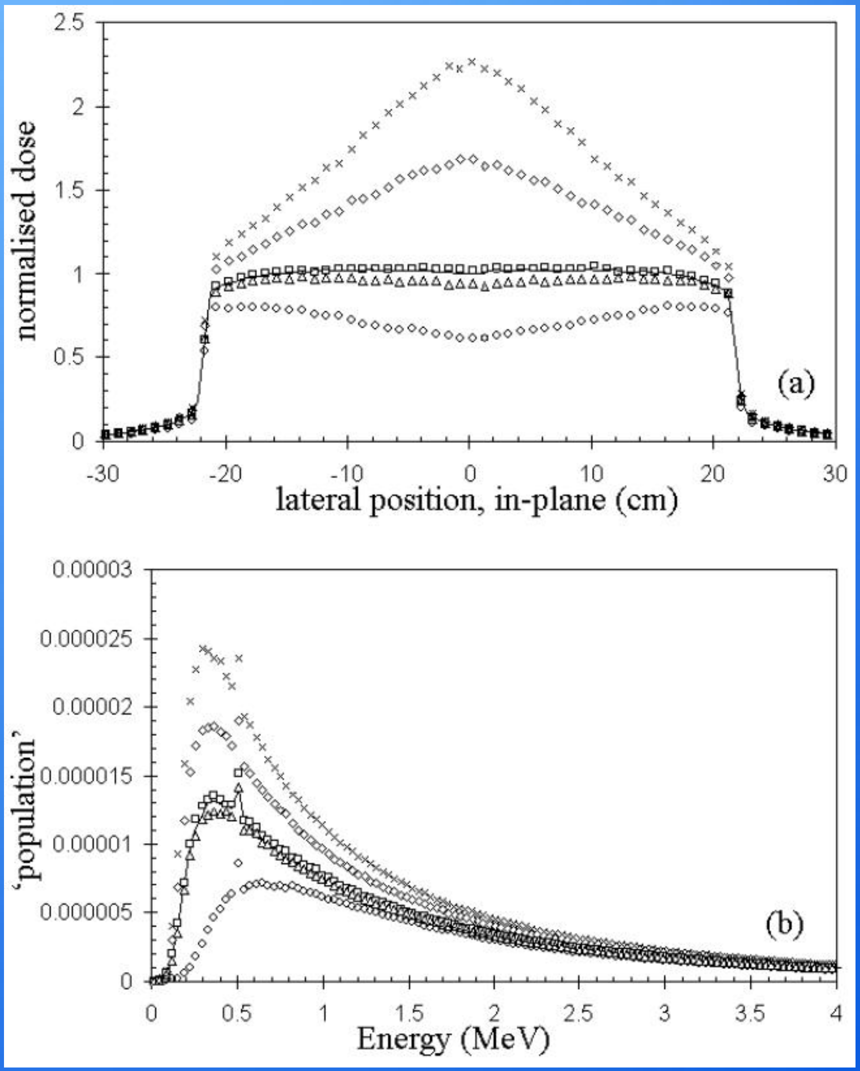
Med Phys. 1991 (18) 519-521

Treatment head of the Scanditronix MM50 racetrack microtron



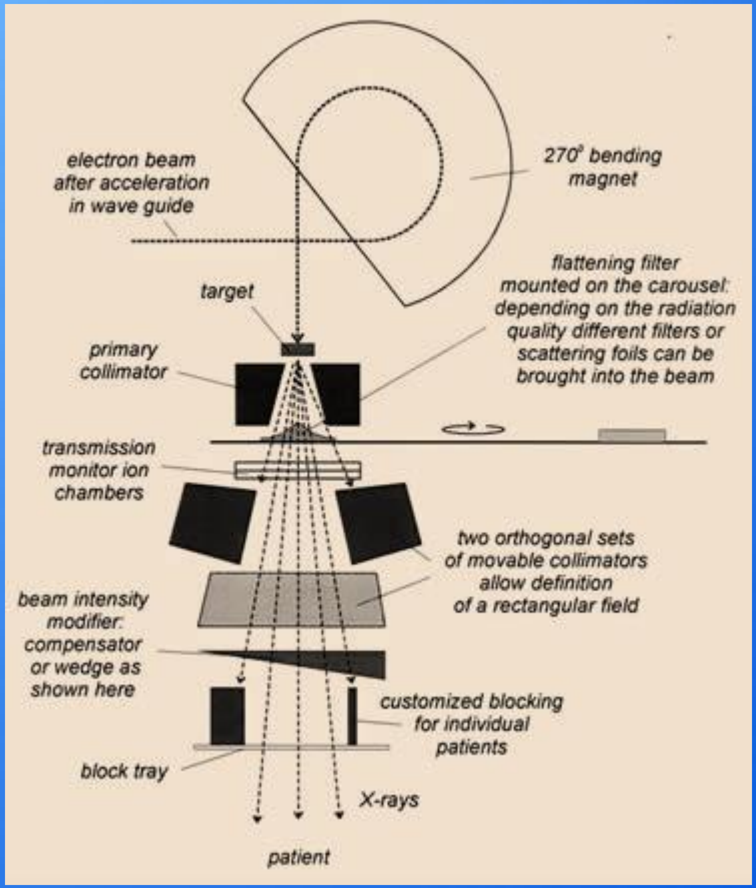
Clinical photon beams: FF vs FFF

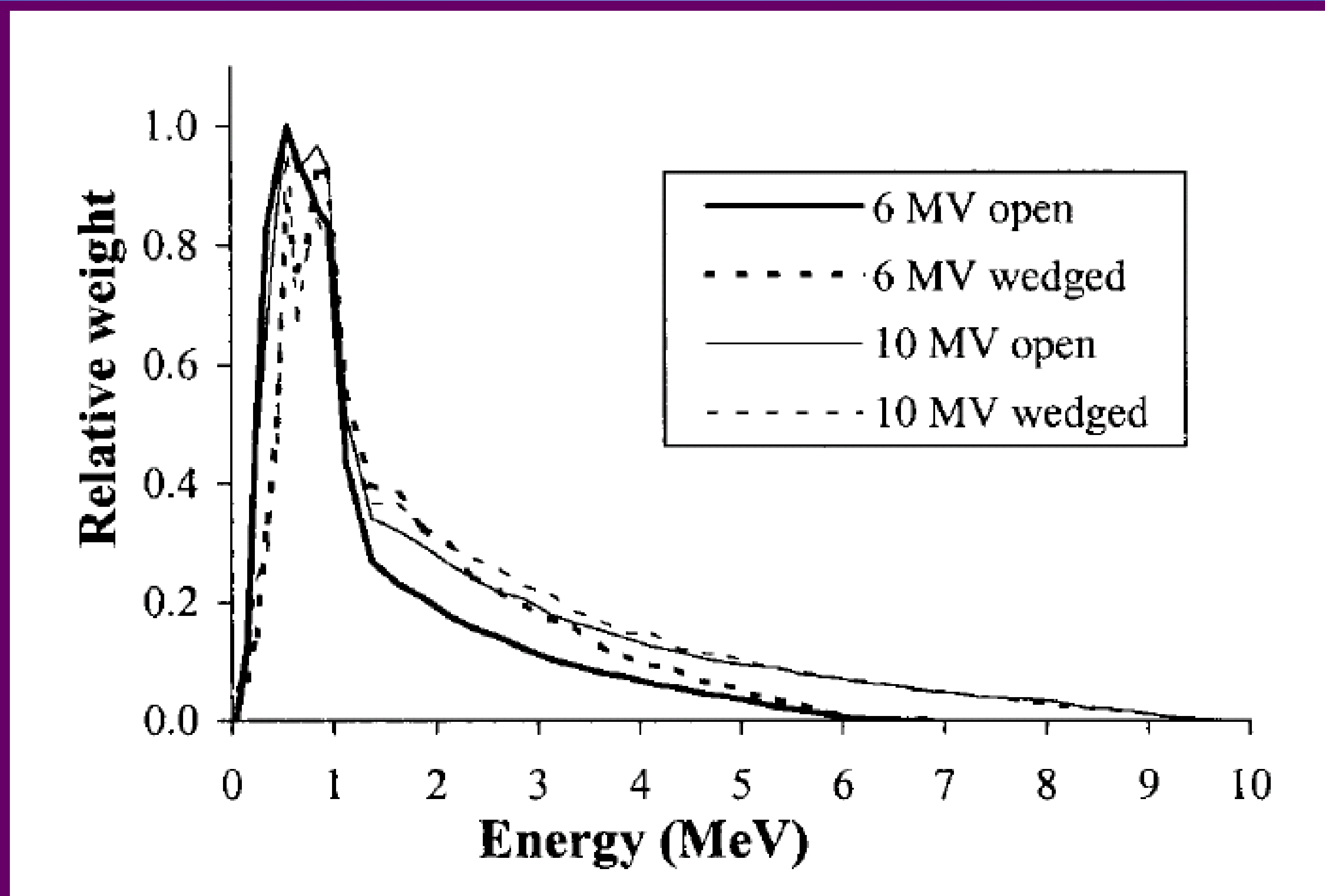




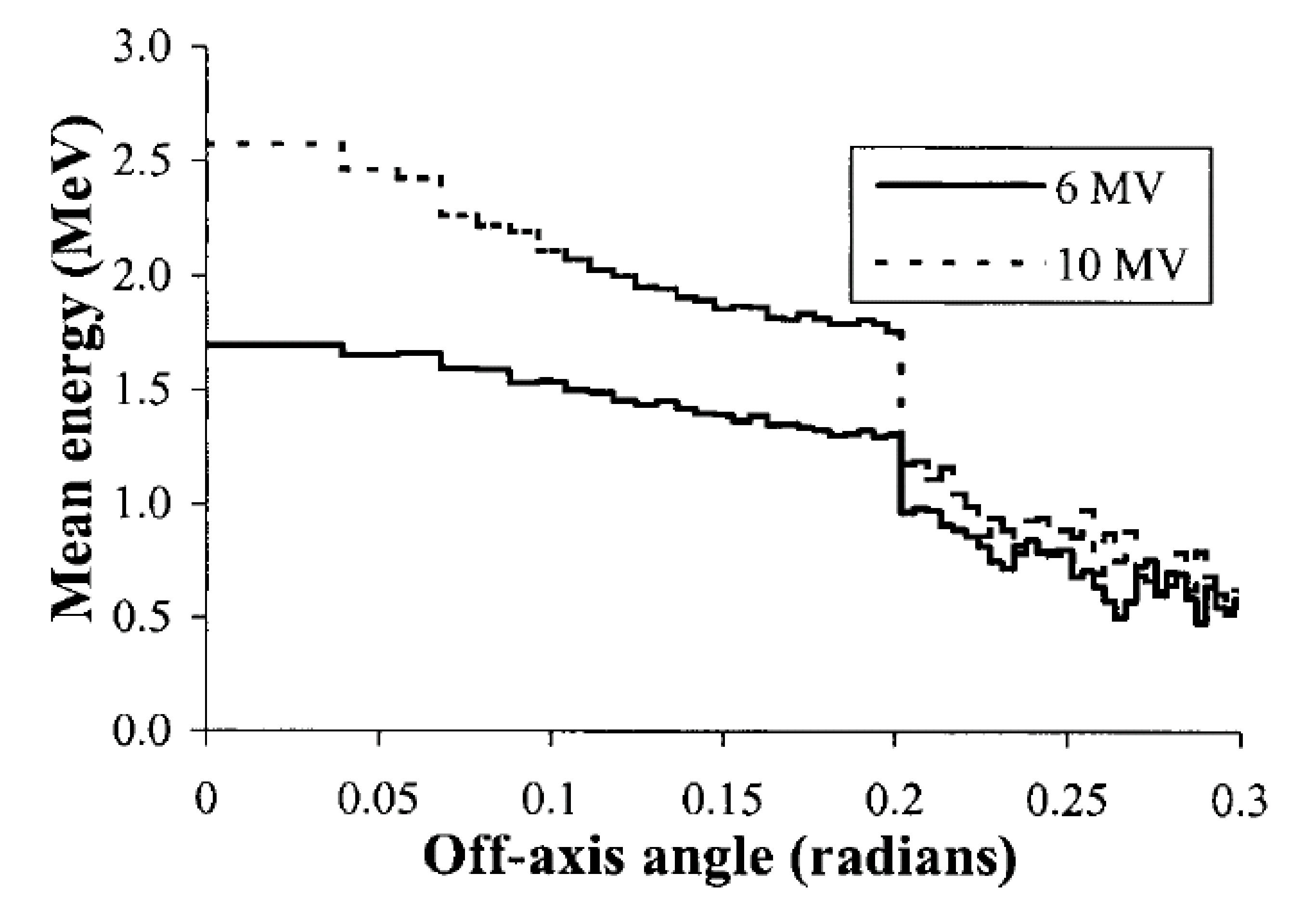
Clinical photon beams

- Collimation is obtained with 2 or 3 collimation devices: primary collimator, secondary collimator, MLC (see below)
- The primary collimator defines the largest available circular field: it consists in a conical opening shaped inside a tungsten shielding block, facing to the target on one end and to the flattening filter on the other end
- The **secondary beam defining collimators** usually consist of 4 (independent) blocks, 2 forming the **upper and 2 the lower jaws of the collimator system**, providing (asymmetric) rectangular or square fields with sides from few mm up to 40cm





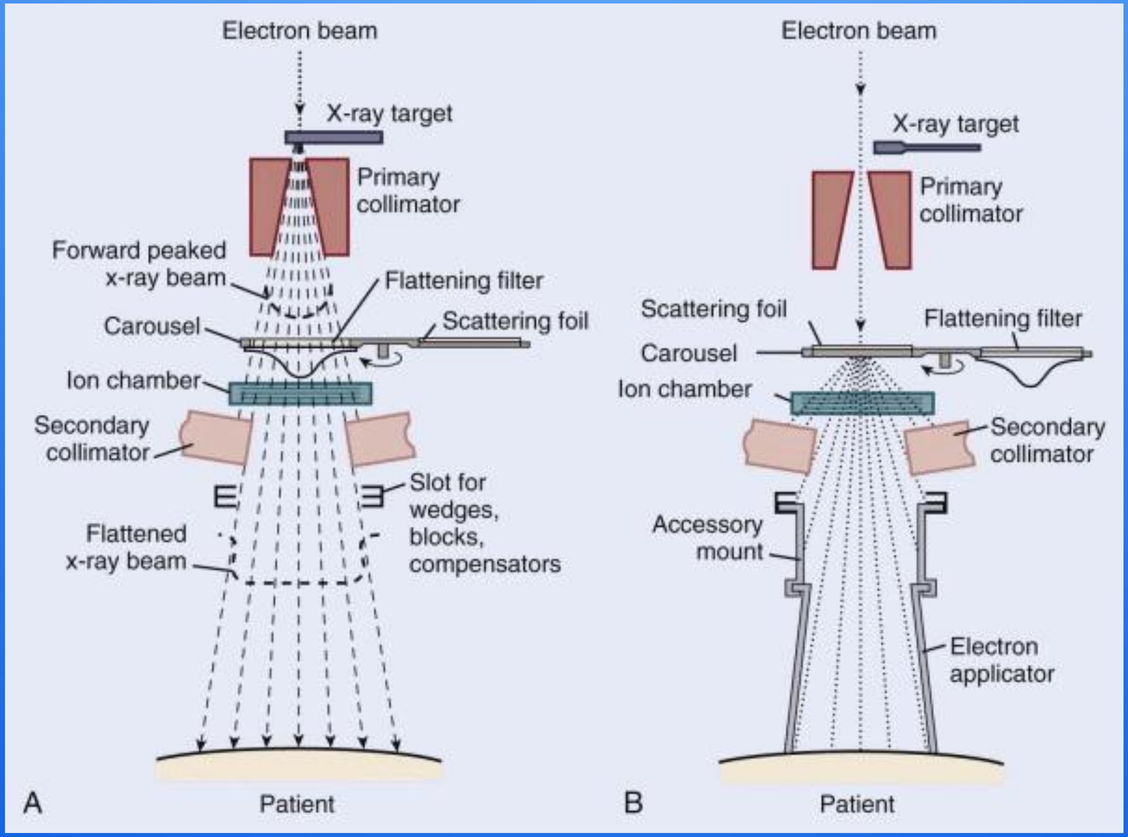
The energy spectra of the 6 MV and 10 MV beams of an Elekta SL15 linear accelerator



Mean photon energy as a function of off-axis distance

Clinical electron beams

Electron mode operation: the x-ray target and the flattening filter are removed
The electron beam currents required for the electron therapy are several hundreds lower than for clinical photon beams
The electron **pencil beam** exiting the beam transport system is made to strike a single or dual **scattering foil** in order to spread the beam and get a uniform electron fluence across the field



Clinical electron beams

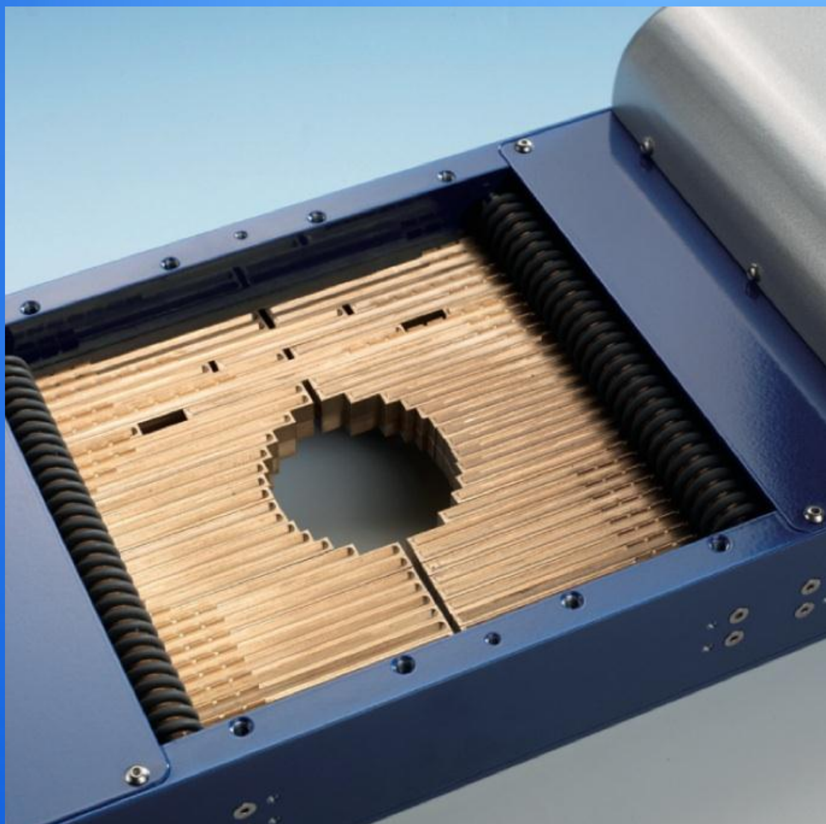
Whereas the x-ray beam collimation systems of most linacs are similar, the electron beam collimation systems vary widely

Since the electrons scatter quickly in air, the beam collimation must be attained close to skin surface of the patient

Due to the considerable scattering from the movable jaws, **the output critically depends** on opening of the jaws

Usually electron applicator cones (of various sizes) or auxilliary trimmers (continuously variable beam collimator), extending down to the skin surface, are attached to the treatment head with x-ray collimator jaws set to provide fields a few centimeters wider (depending on energy)

Beam monitoring system



Electron MLC
similar design of the conventional photon MLC

Collimators
for e-IORT

Beam monitoring system

The beam monitor system in linacs consists of several ion chambers or a single chamber with multiple plates (electrodes)

The chambers are usually transmission type (flat parallel plate) chambers to cover and monitor the entire beam continuously during patient treatment

For patient safety the system usually consists of two separately sealed ionization chambers with completely independent biasing power supplies and readout electrometers

Monitor chambers are usually sealed so that their response is independent of ambient temperature and pressure. They must have a minimal effect on clinical photon and electron beams and should operate under saturation condition

Beam monitoring system

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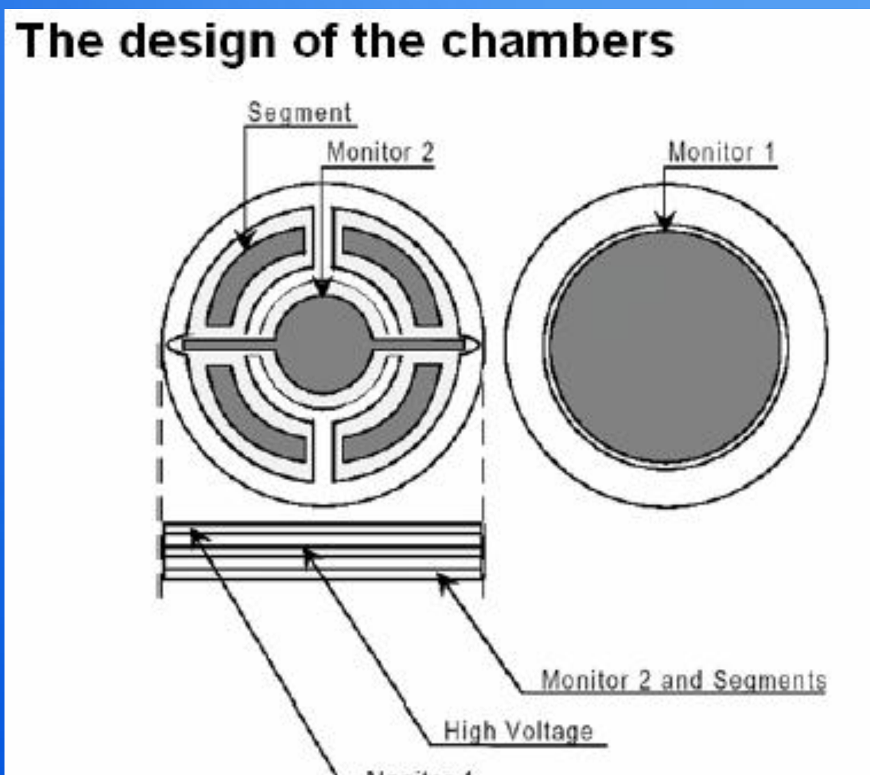
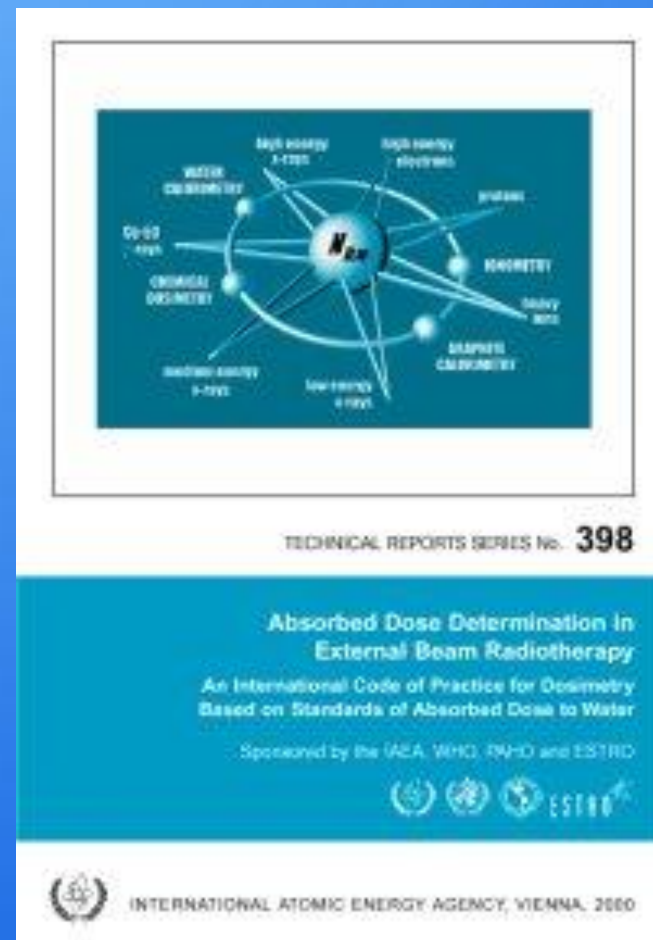
Beam monitoring system

- The monitor chambers have 2 main monitoring aims are:
  - dosimetry of the clinical beams (integrated dose and dose rate)
  - field uniformity and symmetry
- They are located just below the FF or SF and ABOVE the secondary collimators
- They can be sealed or not sealed
- They can be used both for photons and electrons or not (depend on the design)

- Their collecting plates are divided in several collecting sectors providing signals related to delivered dose and uniformity (radial and transverse) of the beam
- The latter signals are used in automatic feedback circuits to steer the electron beam through the accelerating waveguide,beam transport system and on to the target or scattering foils in order to ensure beam flatness and symmetry
- The 2 dose channels are completely independent, either can terminate the preset exposure,with the second lagging the first by a costant number (or percent) of MU; in the event of simultaneous failure a timer will turn off the beam with minimal additional dose


Ionizations chambers
Photon chamber
Electron chamber


The design of the chambers
Segment
Monitor 2
Monitor 1
Monitor 2 and Segments
High Voltage
Monitor 1


TECHNICAL REPORTS SERIES No. 398
Absorbed Dose Determination in External Beam Radiotherapy
An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water
Sponsored by the IAEA, WHO, PAHO and ESTRO
INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2000

The new era of linac: the digital generation

- Digital linacs equipped with high dose rate FFF beams have been clinically implemented in a number of hospitals.

- Pitfalls of current conventional practice:

  Dose delivery and imaging are 2 disconnected events.

  Fast delivery on digital linacs still takes minutes.

  We are blind to patient anatomy during dose delivery

  → One solution: On-board imaging during dose delivery

  Different names have been used: beam level imaging, on-treatment imaging, intrafraction imaging…(GATED VMAT)

- Features:

  High dose rate FFF beams

  HD-MLC with 2.5 mm leaf width

  Digital control systems: streamlined delivery

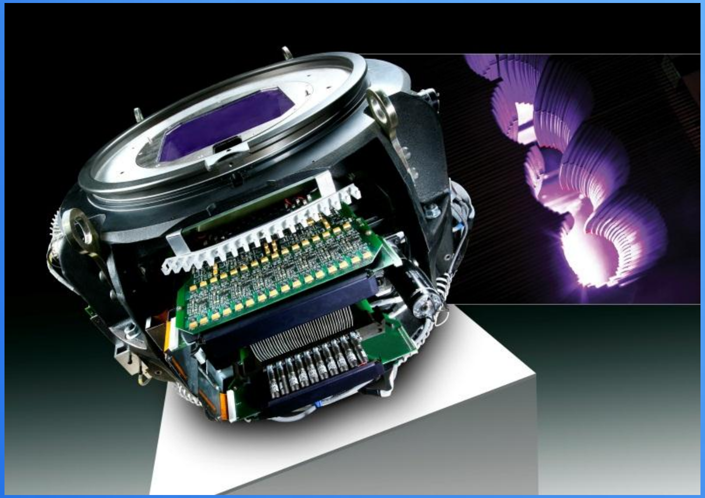
  Allows for *fast* delivery of radiation treatment

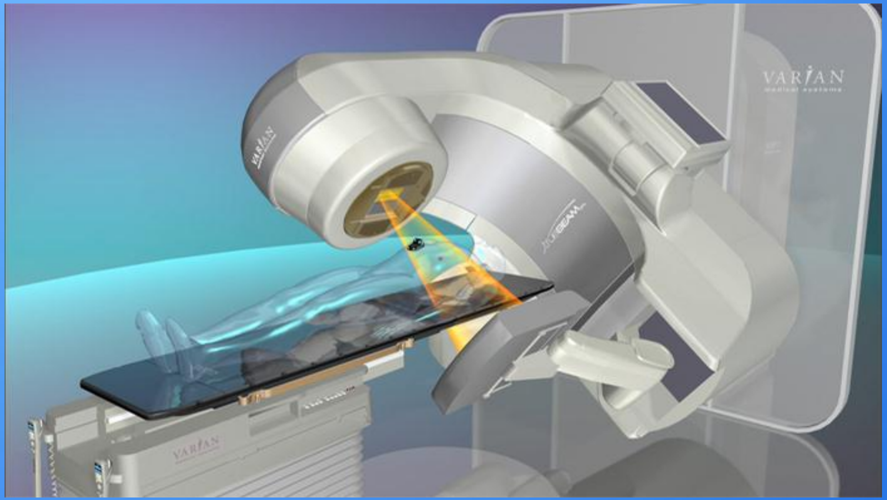
  IGRT

The new era of linac: the digital generation

Versa HD (Elekta)

True Beam 2.0, True Beam STX





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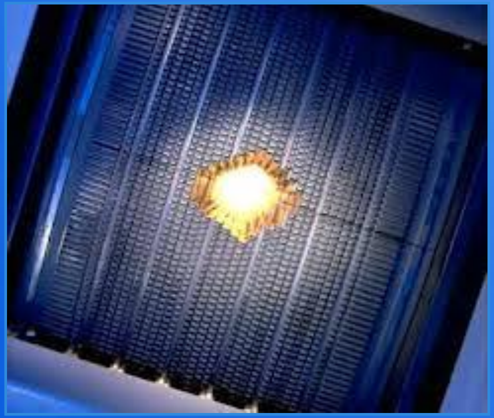
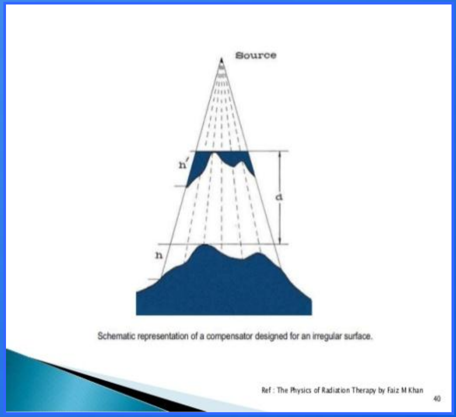
Beam Modifiers in Radiation Therapy

Beam modifiers produce a desirable change of the spatial distribution of radiation by insertion of any material in the beam path



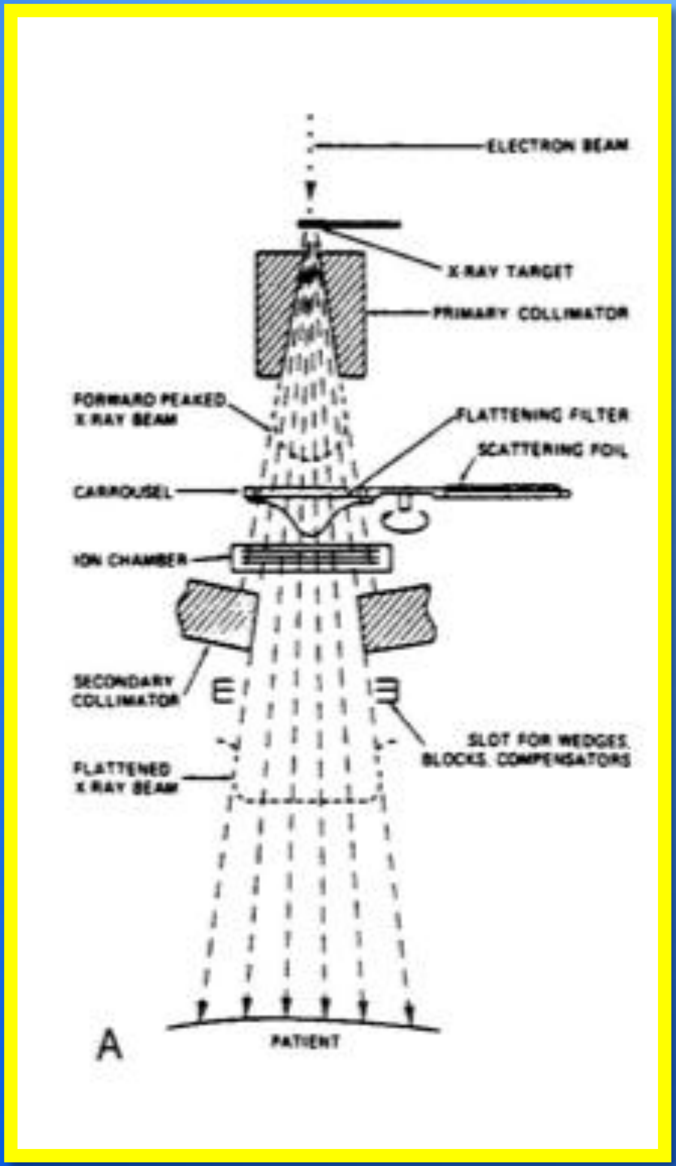


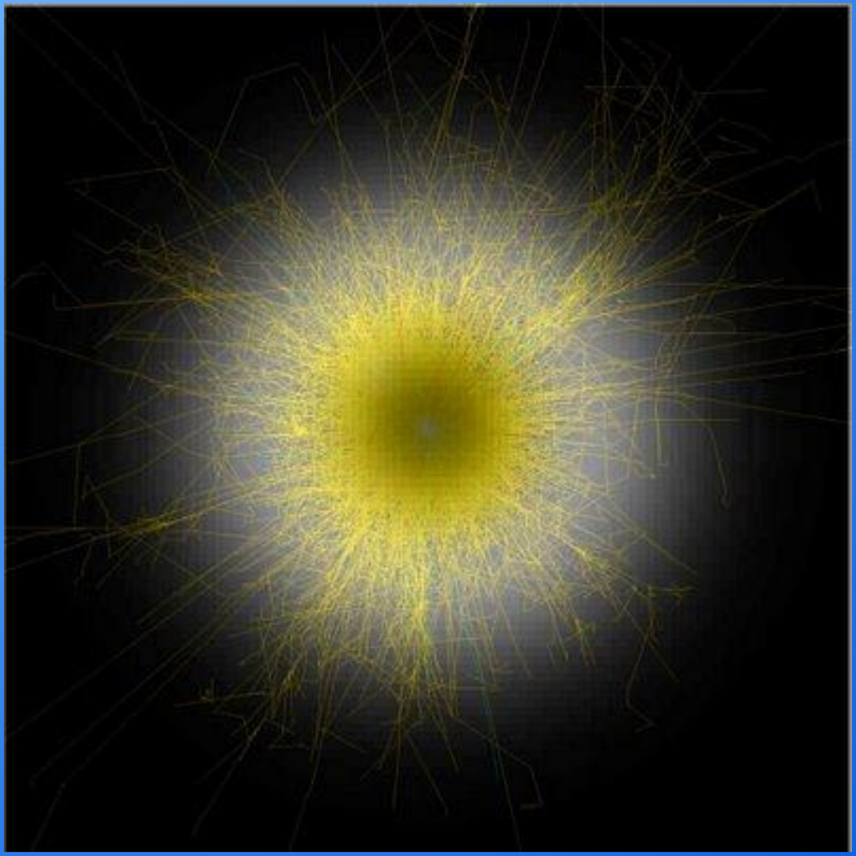
Why beam modification?

Beam modification increases the conformity allowing a higher dose delivery to the target while sparing more of normal tissue simultaneously

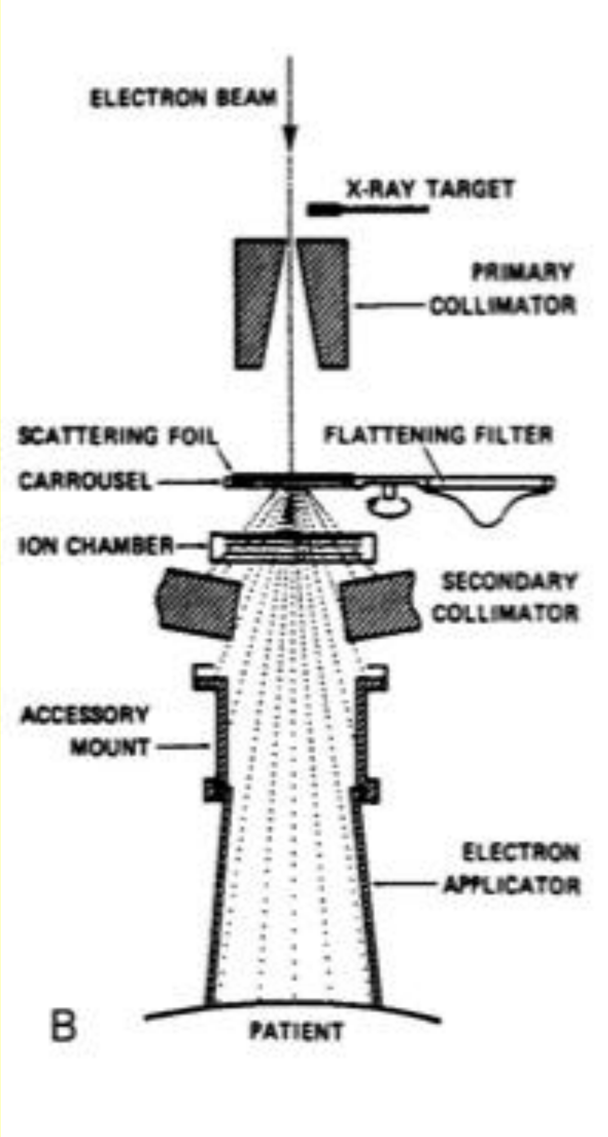
→ It thus fulfils the basic aim of radiotherapy

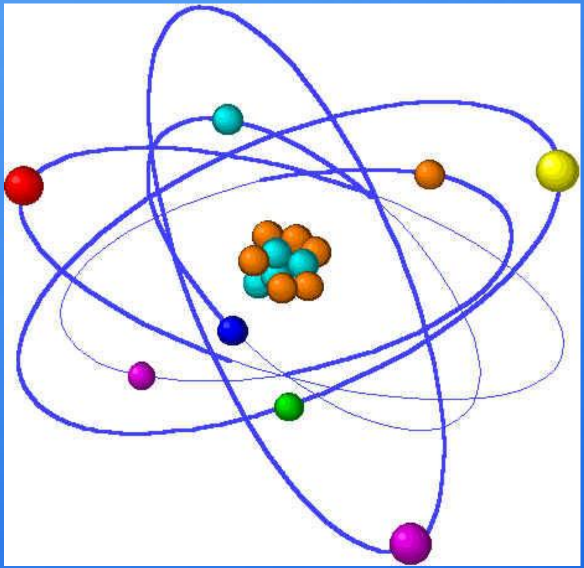
Beam modification devices: photon beams





Beam modification devices: electron beams





4 main types of beam modification

Shielding to eliminate radiation dose to some special parts of the zone at which the beam is directed

Compensation to allow normal dose distribution to be applied to the target zone, when the beam enters obliquely through the body or where the contour of the body is not flat or where different types of tissues are present

Wedge filtration where a special tilt in isodose curves is useful for covering certain target volumes

Flattening filter where the spatial distribution of the original photon beam is altered by reducing the central exposure rate relative to the peripheral (see lecture by Dr Foti)

Outline

- ✓ BEAM MODIFIER (PHOTONS, ELECTRONS) IN CONVENTIONAL TREATMENT UNITS

BLOCKS

Field blocking and shaping devices

- Shielding blocks
- Custom blocks
- Asymmetrical jaws
- Multileaf collimators

Shielding

- The aims of shielding are:

  - to protect critical organs

  - avoid unnecessary irradiation to surrounding normal tissue

  - *matching adjacent fields*

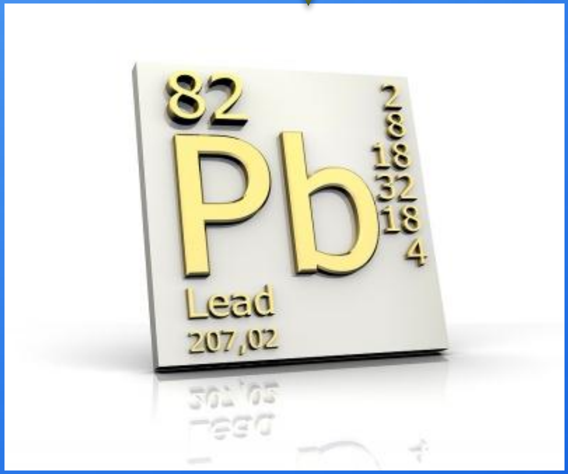
- Since radiation attenuation is exponential and because of scattering, complete shielding can never be achieved.

Ideal shielding material

Principal characteristics:

- high atomic number
- high density
- easily available
- inexpensive
- the choice of the material also depends upon the type of the radiation beam

The most commonly used shielding material for photons is **lead**



Custom blocks (patient-specific)

- Material used for custom blocking is known as the **Lipowitz's alloy** or by using brand names as **Cerrobend, Bendalloy, Pewtalloy, MCP 152**

50% Bi 26.7% Pb 13.3% Sn 10% Cd	Melting point 70°C Density 9.4 g cm^{-3} at 20°C

- The main advantage over lead is that <u>its melting point</u> is lower (for Pb: 327 °C); it is harder at room temperature

Custom blocks

- Blocks can be classified as:
  - *positive blocks*, where the central area is blocked
  - *negative blocks*, where the peripheral area is blocked

- The thickness used depends on the energy of the radiation

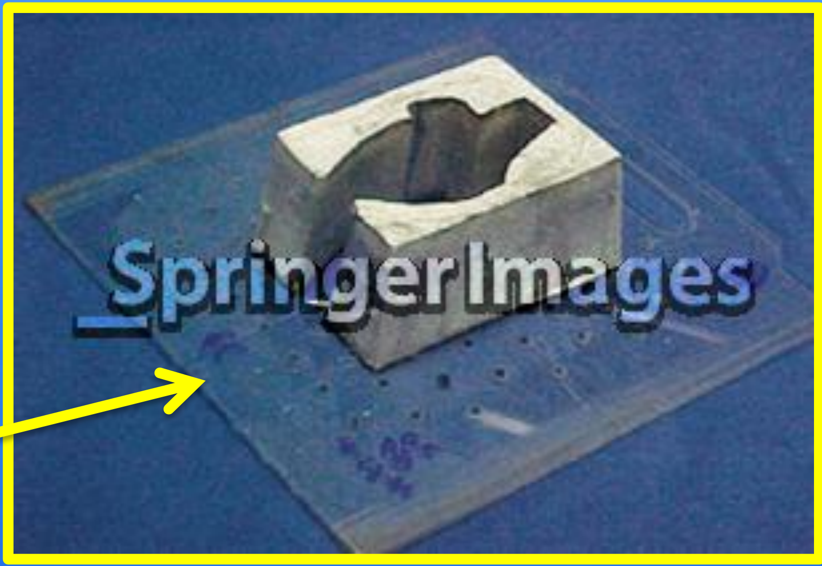
- The thickness which reduces beam transmission to 5% of its original is considered acceptable

- The optimal position of blocks is obtained making them "**focusing**" or "**divergent**" i.e. the surfaces follow the geometric divergence of the beam. This minimises the block transmission penumbra

Custom blocks

- The plastic transparent tray (**SHADOW TRAY**) where the blocks are placed attenuates the primary beam (≈ 10 % for 6 MV, 8% for 10 MV, 6.5% for 15 MV)

- It is necessary to consider it in the calculation of dose (TPS)



tray

Blocks: effects (1)

- The use of blocks changes the scatter component of the beam:
  1. From the interaction with the tray, there is the production of secondary radiation (other electrons and photons)

     the electrons created in the tray increment the superficial dose to the patient

     this effect strongly depends upon the distance between tray and surface patient

Blocks: effects (2)

Schematic representation of contamination electron scatter produced in a polycarbonate accessory tray

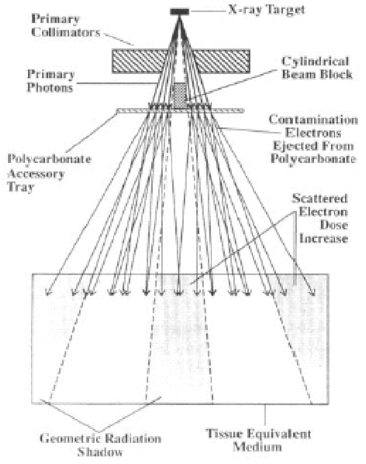
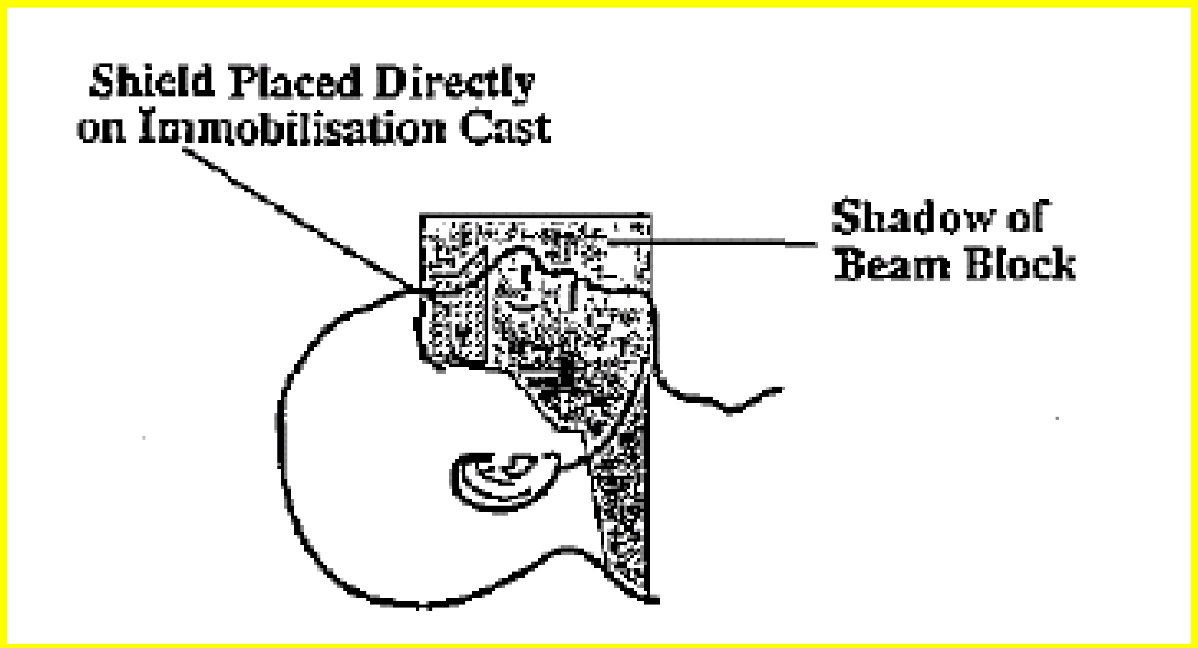


Figure 1. Schematic representation of contamination electron scatter produced in a polycarbonate accessory tray.

Blocks: effects (3)

Example of clinical use of the shielding technique to protect from the tray scatter radiation in the cranio-cervical irradiation



Blocks: effects (4)

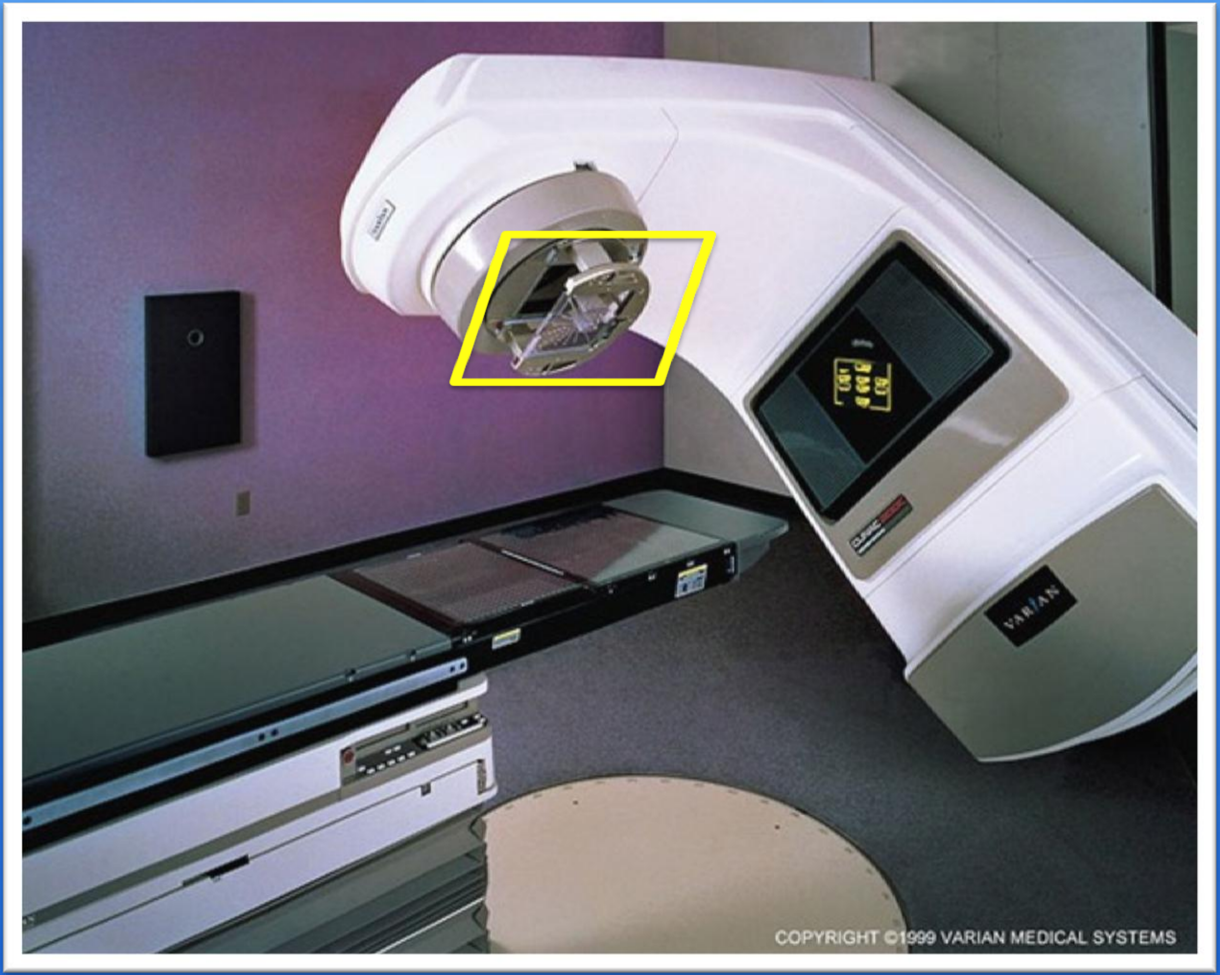
- The use of blocks changes the scatter component of the beam:

2. Reducing the patient volume in which the scatter photons are generated

   this effect changes the central axis dose

3. Shielding partly the head scatter

Blocks set-up

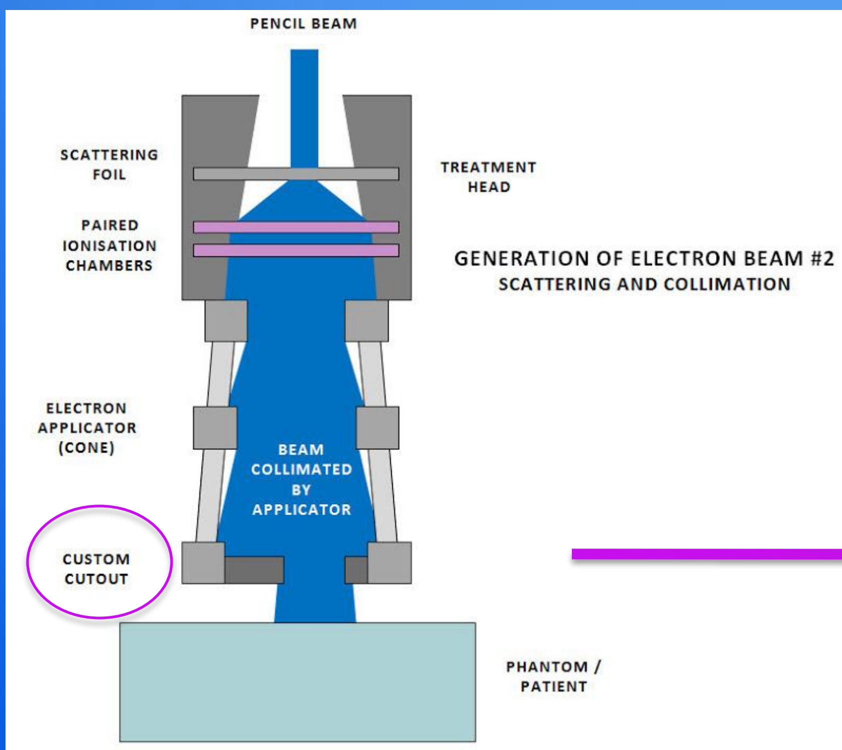


Shielding with electron beams (1)

- Electron field shaping can be done using lead alloy cut-outs
- For a low-energy electrons (<10 MeV), sheets of lead, less than 6 mm thickness are used
- The lead sheet can be placed directly on the skin where shielding of structures against backscatter electrons is required
- Design is easier, because the size is same as that of the field on the patients skin surface (a tissue equivalent material is coated over the lead shield like wax/ dental acrylic/aluminum)

Shielding with electron beams (2)

- Cut-outs in Cerrobend are more frequently supported at the end of the treatment electron applicator
- The required shielding thickness of the cut-outs should be approximately equal to the maximum range of the highest electron energy beam available in this alloy



Independent jaws (1)

- The x-rays collimators can be moved independently to allow **asymmetric fields** with fields centres positioned away from the true central axis
- Used when we want to block off part of the field along the central axis without changing the position of the isocenter
- Independently movable jaws, allowing us to shield a part of the field, perform "beam splitting"
- Beam is blocked off at the central axis to remove the divergence
- This feature is useful for matching adjacent fields
- Of course this modality has many advantages (compared to secondary blocking, beam splitters): reducing the setup time, sparing the technologist from handling heavy blocks (**safety**)

Independent jaws (2)

- Use of independent jaws and other beam blocking devices results in the **shift of the isodose curves**; this is due to the attenuation of photons and electrons scatter from the blocked part of the field
- When a field is collimated asymmetrically, one needs to take into account changes in the collimator scatter, phantom scatter and off-axis beam quality
- This latter effect arises as a consequence of using flattening filter which results in greater beam hardening close to the central axis compared with the periphery of the beam
- Independent jaws can be used to produce **dynamic wedges** also generated electronically by creating wedged beam profiles through the dynamic motion of an independent jaw within the treatment field

Outline

✓ **BEAM MODIFIER (PHOTONS, ELECTRON) IN CONVENTIONAL TREATMENT UNITS**

SPOILER

- S ys made
fr kin

- Ba ases
wh

- Firs head
and

Fig. 1. Lucite spoiler for lateral beam arrangement for head and neck treatments.

Use of spoiler in the TBI* technique

material: PMMA

thickness: 1 cm

energy: 6 MV

Superficial dose increments: ≈ 95%

* Total body irradiation (TBI) is a form of radiotherapy used primarily as part of the preparative regimen for haematopoietic stem cell (or bone marrow) transplantation. It serves to destroy or suppress the recipient's immune system, preventing immunologic rejection of transplanted donor bone marrow or blood stem cells.

The concept of compensation

- A radiation beam incident on an irregular or sloping surface produces skewing of the isodose curves

- In certain treatment situation, the surface irregularities give rise to unacceptable non uniformity of dose within the target volume or causes excessive irradiation of sensitive structures such as spinal cord.

- Many techniques have been devised to overcome this problem, including the use of **wedge fields** or **multiple fields**, the addition of **bolus** material or **tissue compensator**

The concept of compensation

- The idea is to compensate for "missing tissue", due to changes in anatomical outline of the patient and internal tissue inhomogeneities ["The Physics of Conformal Radiotherapy - Advances in Technology" S. Webb, IOP, 1997]

- They are no more than blocks of metal alloy in which the local thickness varies with the position to achieve differential attenuation of the beam

- They are field/patient-specific (time consuming process)

- They represented the <u>only method to obtain </u>this **before** the computer-controlled linac jaws and in particular **before MLC**

Outline

- ✓ **BEAM MODIFIER (<u>PHOTONS</u>, ELECTRONS) IN CONVENTIONAL TREATMENT UNITS**

BOLUS

Bolus

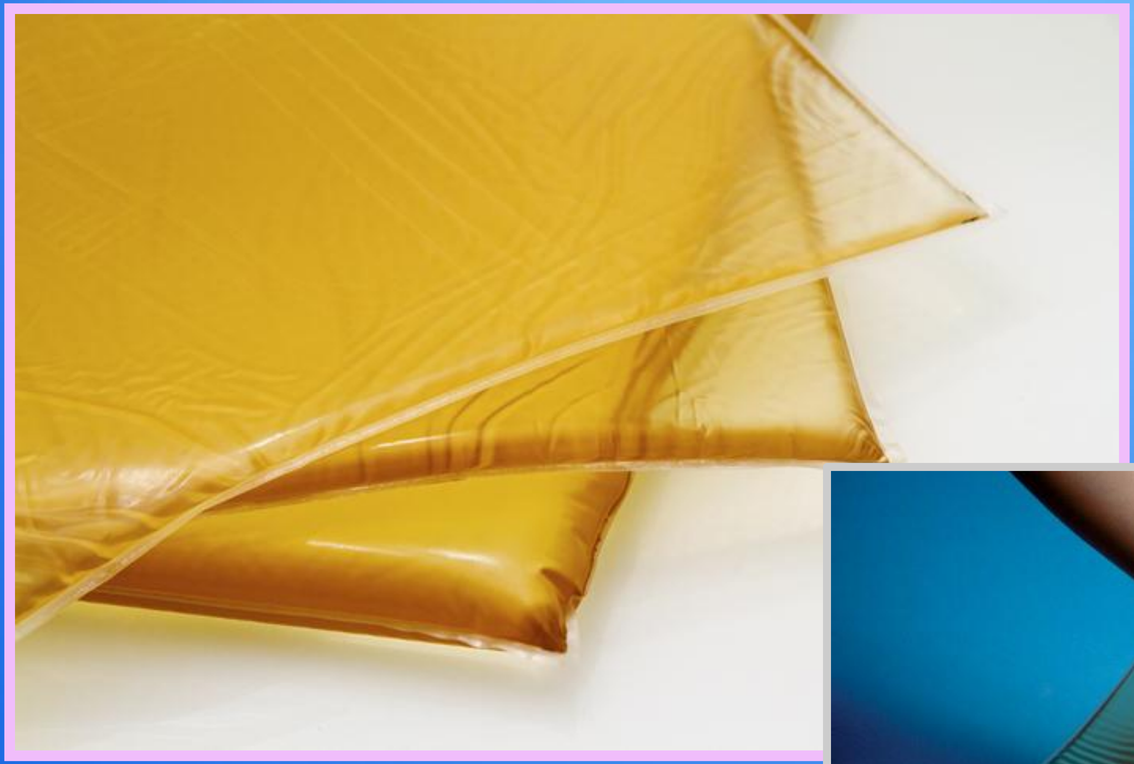
- Bolus is a **tissue-equivalent material** that is placed directly onto the skin of patient to even out the irregular contours of a patient to present a flat surface normal to the beam

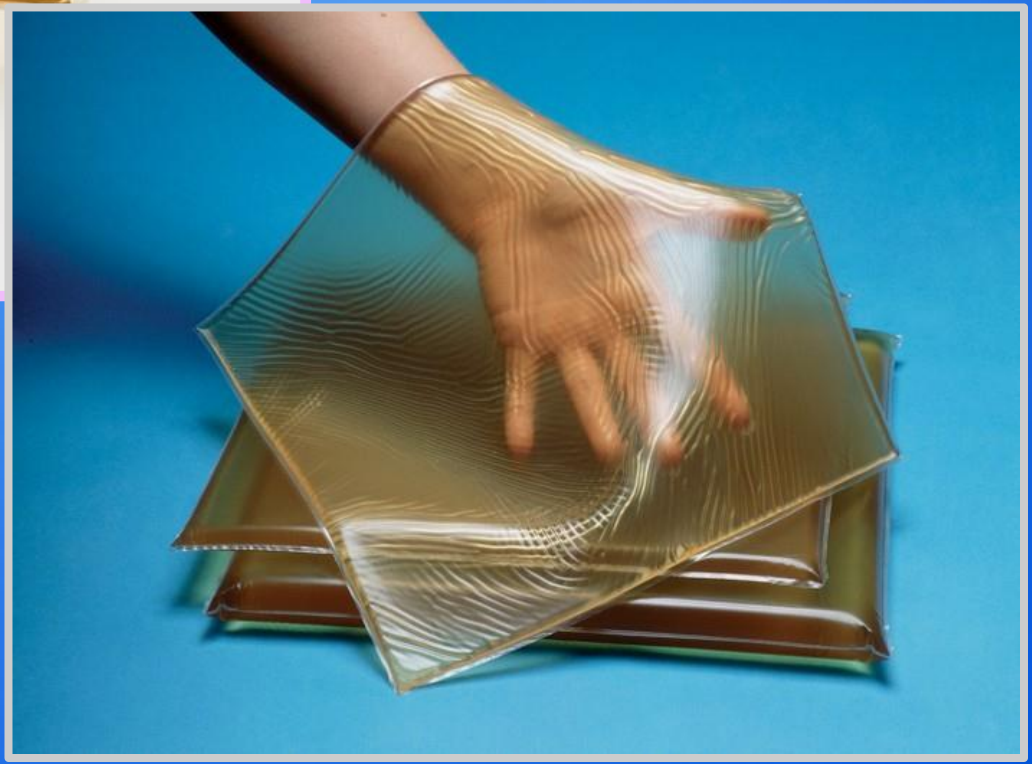
- This use of bolus should be distinguished from that of a **bolus layer**, which is thick enough to provide adequate dose build-up over the skin surface (**build-up bolus**)

- The use of bolus brings the isodose lines closer to the surface of the patient that means: to **increment surface dose** <u>reducing the skin sparing effect (for linac photons beams)</u>

- In the calculation of dose, bolus is part of the patient

Bolus layer

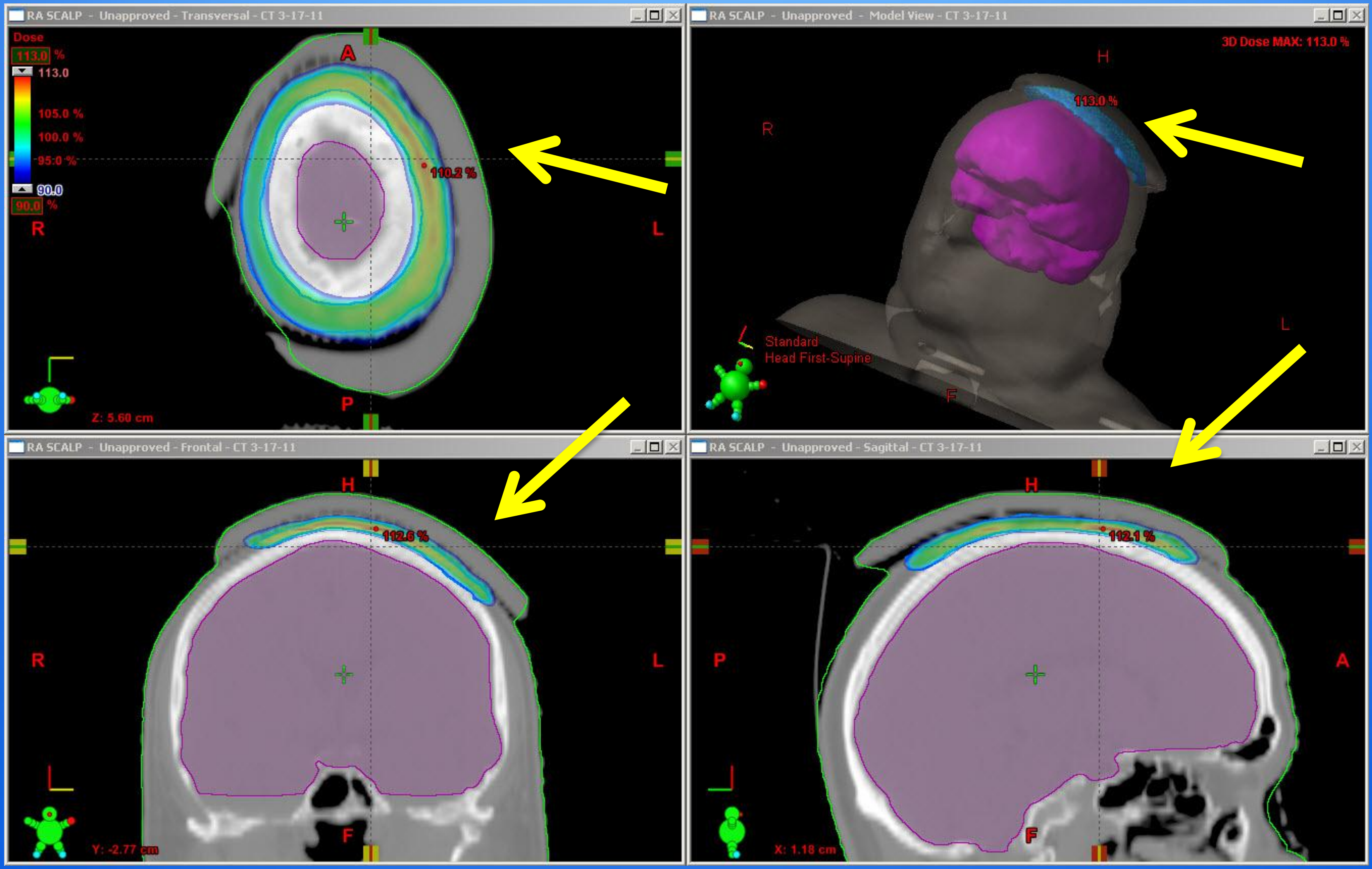




Thickness
Co^{60} : 2 - 3 mm
6 MV : 5 -10 mm
10 MV : 10 - 15 mm

Bolus

Bolus incorporated in TPS (CT-simulation)



Bolus with electron beams

According to the Hogstrom definition

“a specifically shaped material, which is usually tissue equivalent, that is normally placed either in direct contact with the patient’ s skin surface, close to the patient’ s skin surface, or inside a body cavity

This material is designed to provide extra scattering or energy degradation of the electron beam

Its purpose is usually to shape the dose distribution to conform to the target volume and/or to provide a more uniform dose inside the target volume”

Bolus with electron beams

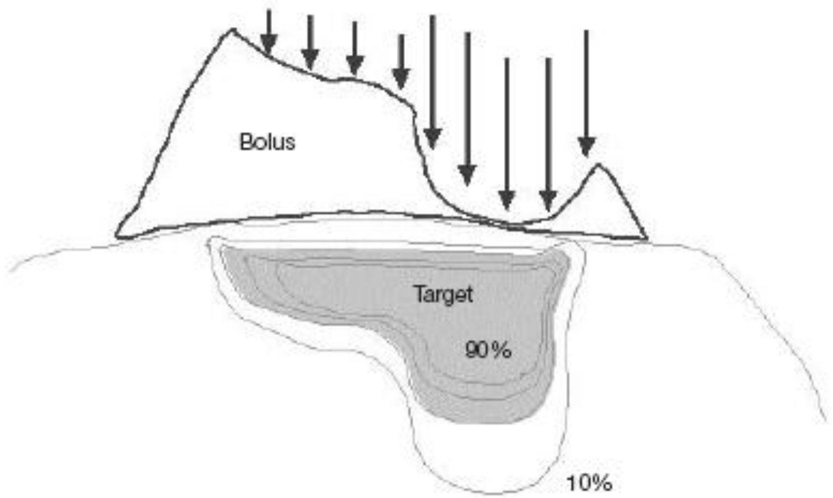


FIG. 8.8. Construction of a custom bolus to conform isodose lines to the shape of the target.

Shaped bolus, which varies the penetration of the electrons across the incident beam so that the 90% isodose surface conforms to the distal surface of the PTV

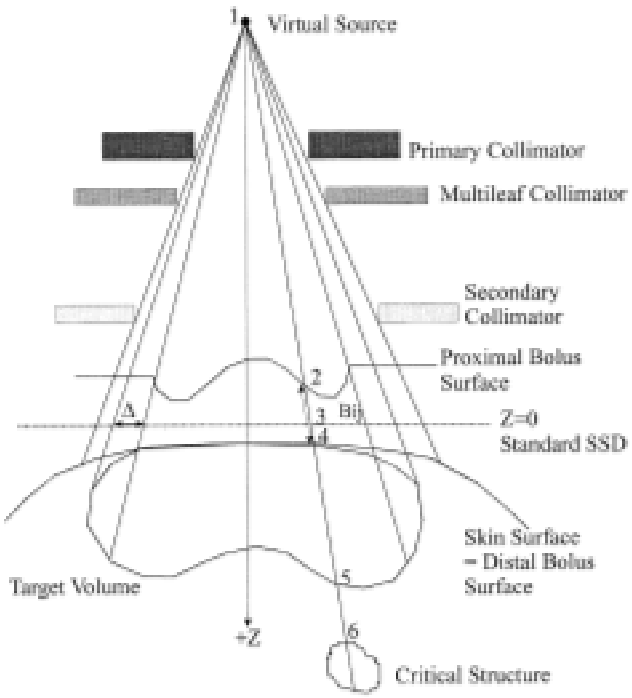


Fig. 1. Sketch illustrating the fan geometry and design elements of the bolus design system.

Outline

- ✓ **BEAM MODIFIER (<u>PHOTONS</u>, ELECTRONS) IN CONVENTIONAL TREATMENT UNITS**

COMPENSATOR

Compensator

- Placing bolus directly on the skin surface implies - for **high energy beams (MV)** – **the loss of skin sparing feature**

- It can an advantage if the target is superficial (in this case we can employ **electrons**)

- In the case of the **MV photon beams**, a **compensator filter** was introduced to approximate the bolus function and, at the same time, to preserve the skin-sparing effect

- The compensator is placed at a suitable distance away from the patient's skin (15-20 cm)

Bolus vs compensator

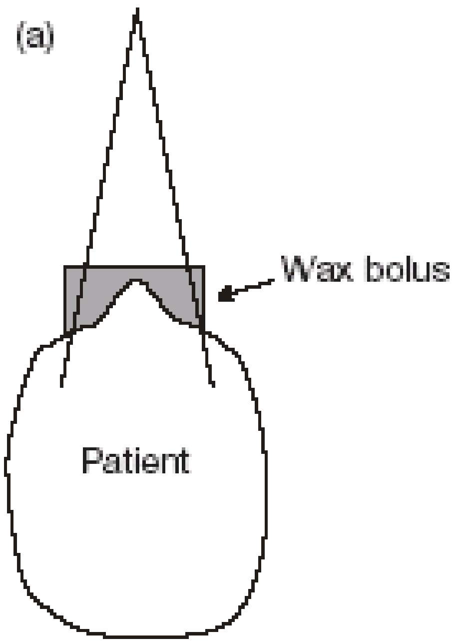


FIG. 7.18. Difference between a bolus and a compensating filter. In (a) a wax bolus is placed on the skin, producing a flat radiation distribution. Skin sparing is lost with bolus. In (b) a compensator achieving the same dose distribution as in (a) is constructed and attached to the treatment unit. Due to the large air gap, skin sparing is maintained.

Compensator

The dimension and shape of a compensator must be adjusted to account for:

- beam divergence
- attenuation properties of the filter material and soft tissue
- reduction in scatter at various depths due to the compensating filters, when it is placed at the distance away from the skin

to compensate for these factors a <u>tissue compensator</u> always has an attenuation less than that required for primary radiation.

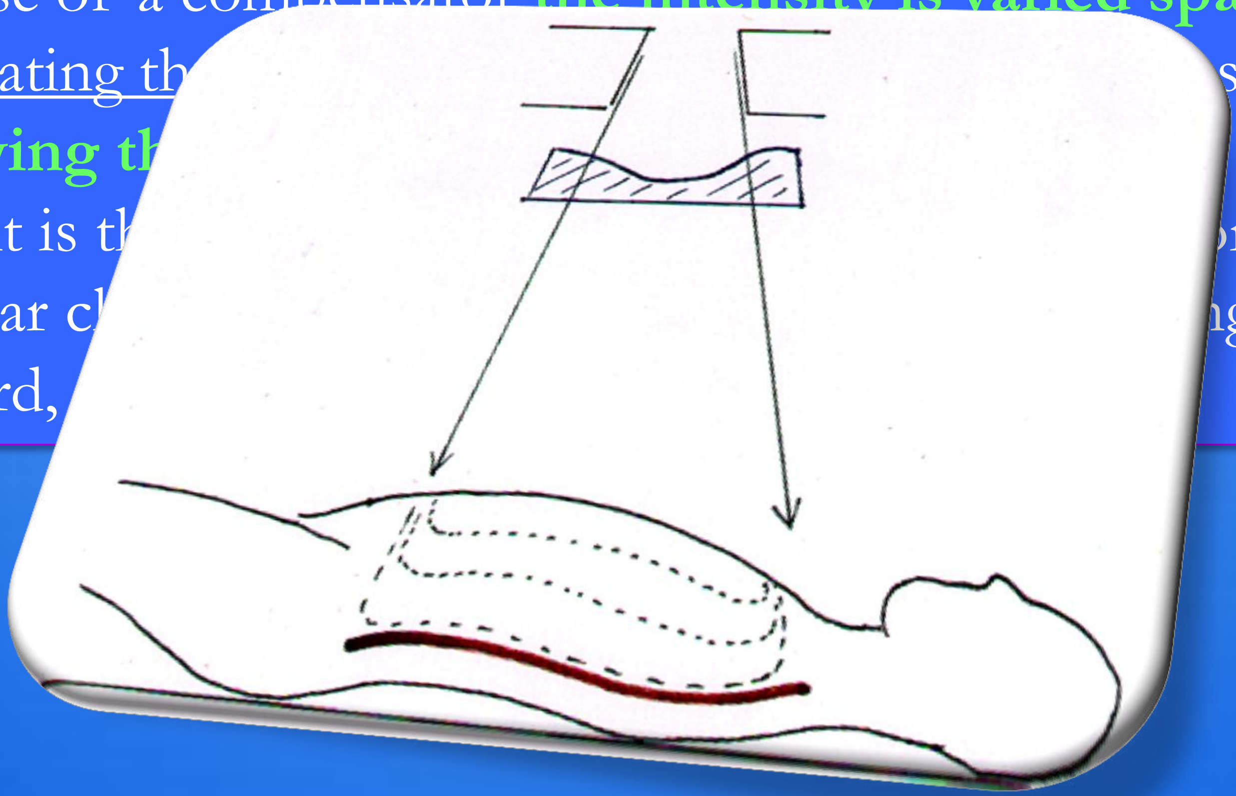
Compensator

The concep[t is mainly that] **we can change the beam intensity i**[...]

2D Modulation of Beam Intensity

In the case of a com[pensator] **the intensity is varied spatially by attenuating th**[...] [compen]sator with **varying th**[...]

The result is th[...] [conf]orm to a particular c[...] [...]ng the spinal cord, [...]



2D vs 3D Compensator

2D compensator	3D compensator
Thickness varies along a single dimension only	Designed to compensate tissue deficit for both transverse and longitudinal body cross sections
Can be constructed using thin sheets of lead, lucite or aluminum	Various devices are used to drive a pantographic cutting unit
This results in production of a laminated filter	Cavity is produced in the Styrofoam; blocks are then used to cast compensator filters.

Outline

- ✓ **BEAM MODIFIER (<u>PHOTONS</u>, ELECTRONS) IN CONVENTIONAL TREATMENT UNITS**

WEDGE

Wedge

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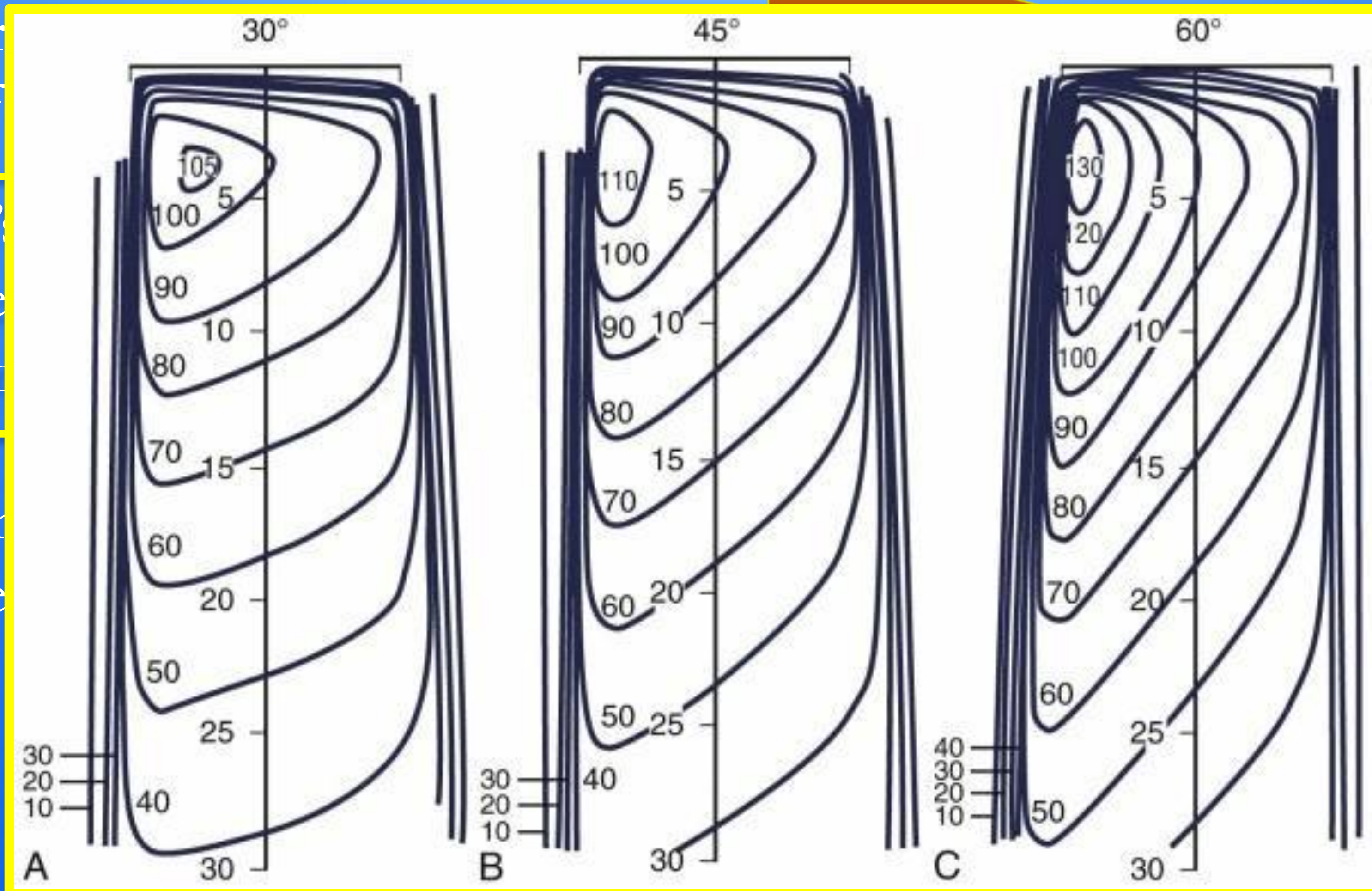
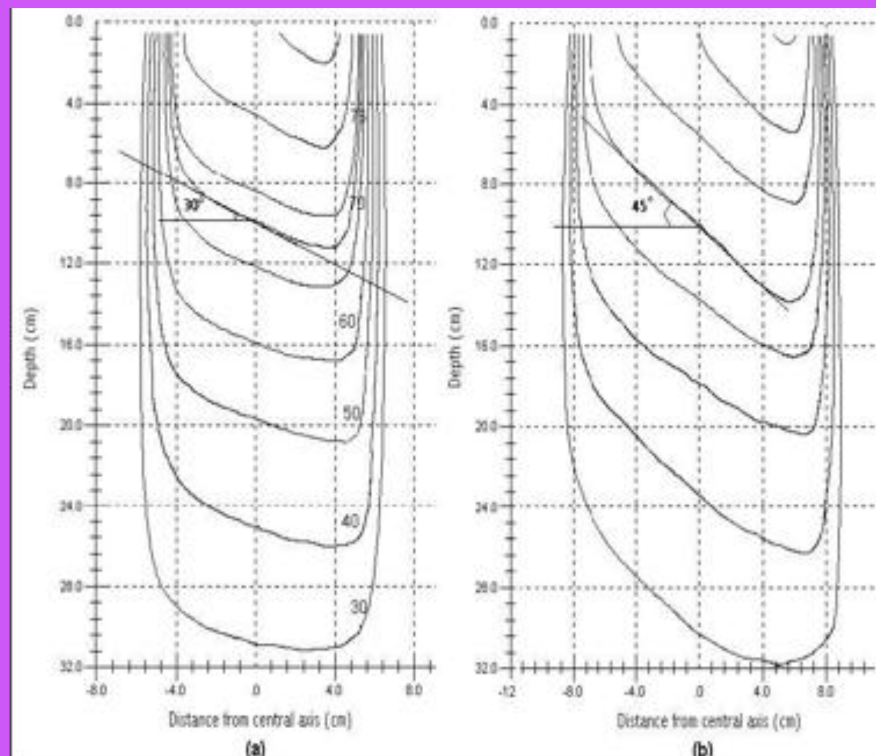


Wedge (isodose) angle

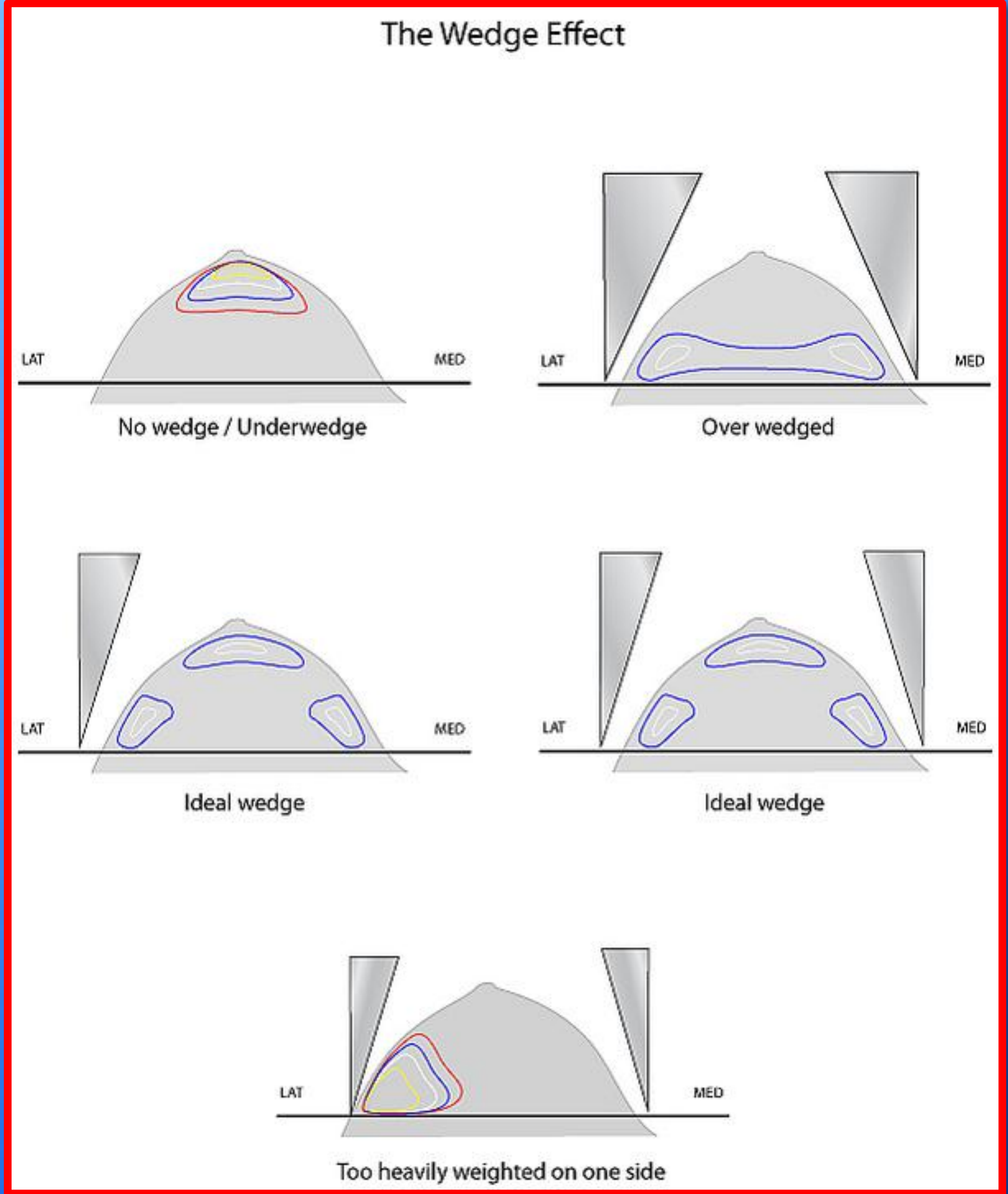
The angle through which an isodose curve is tilted at the central ray of a beam at a specified (reference) depth



The angle between the isodose curve and the normal to the central axis, at a specified (reference) depth

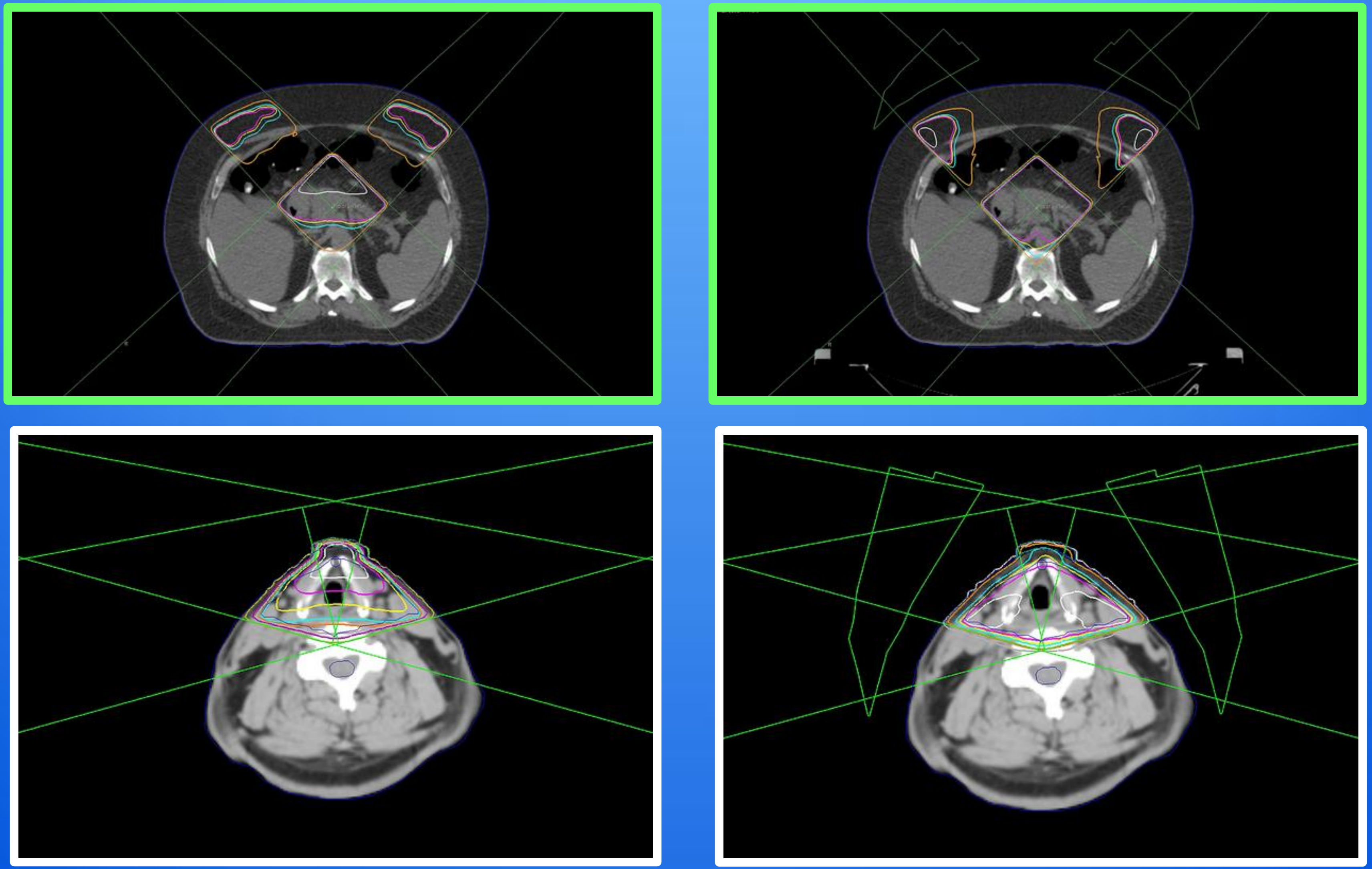
As a consequence of the scatter the angle decreases with increasing the depth in the phantom

A classical clinical application of the wedge filter: the breast planning



Wedge: other typical clinical sites

The choice of the wedge angle also depends on
the angle between the central rays of the two beams ("hinge angle")



Wedges systems

- Physical or manual or external wedges
- Universal or motorized or internal wedges
- Dynamic or virtual wedges

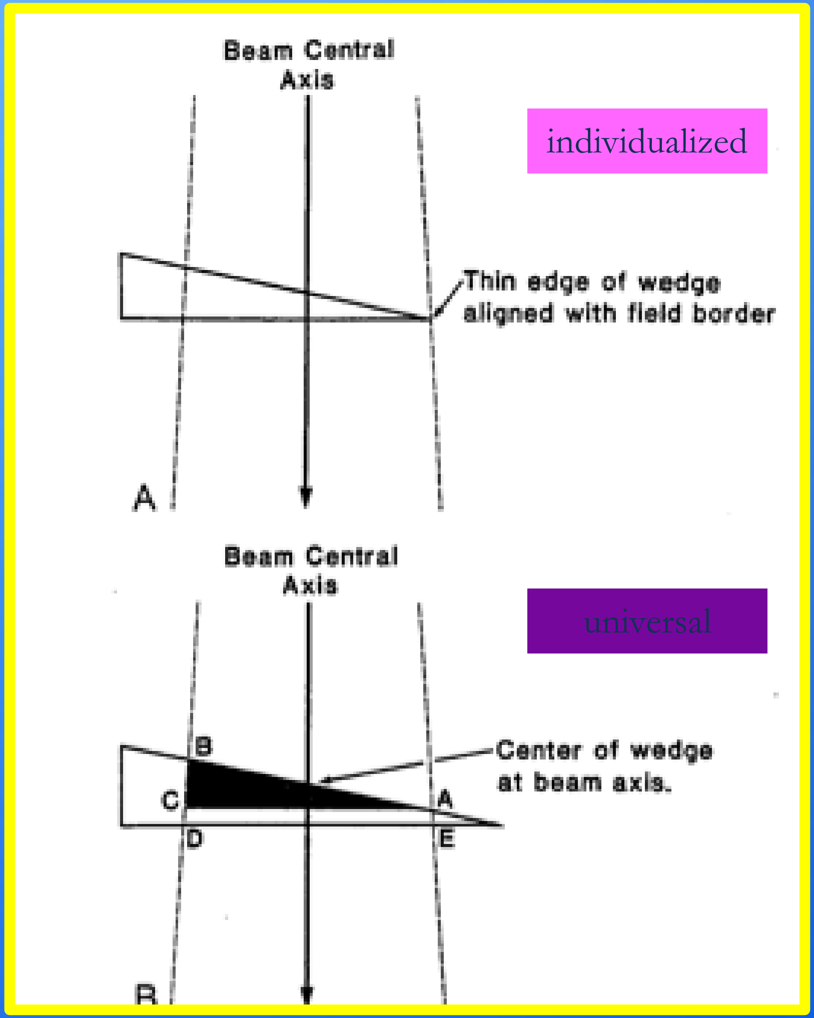
Physical (manual or external) wedges

- It is an angled piece of lead or steel or copper or tungsten that is placed in the beam to produce a gradient in radiation intensity (at a distance of at least 15 cm from the skin)
- Manual intervention is required to mount physical wedges on the gantry head's collimator assembly (VARIAN, SIEMENS)

Physical (manual or external) wedges

Individualized Physical wedges

- This technique (**Cobalt units**) requires a separate wedge for each beam width, in order to minimize the loss of output beam
- It is designed to align the thin end of the wedge with the border of the light field



Universal (motorized or internal) wedges

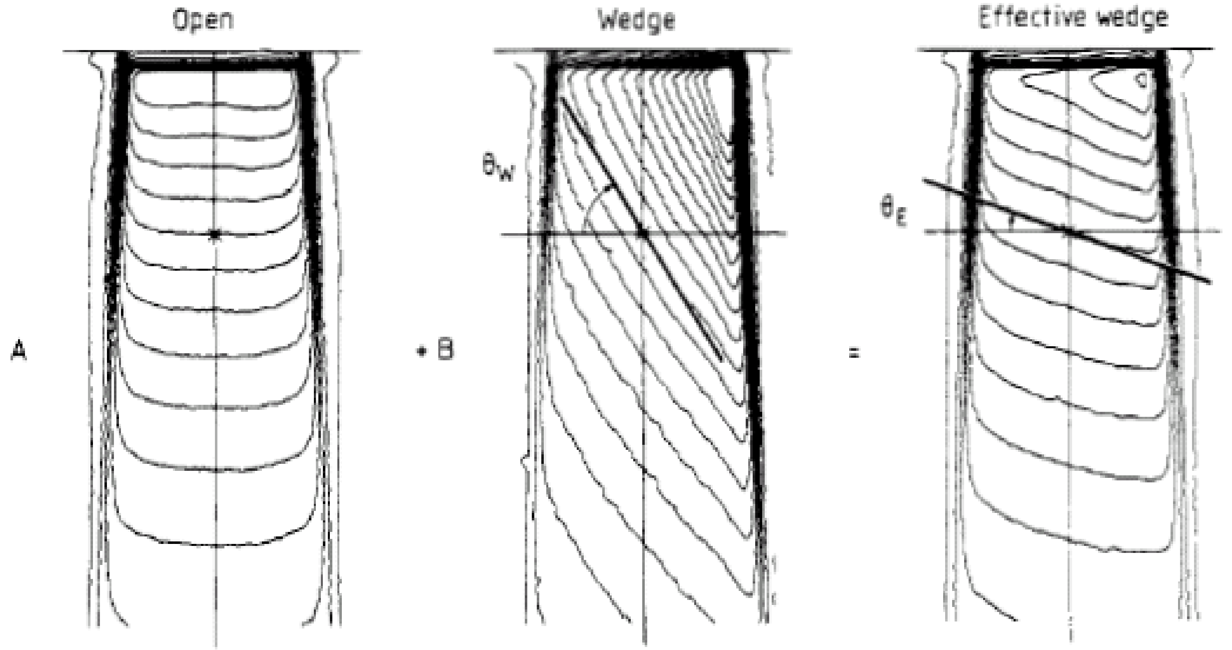
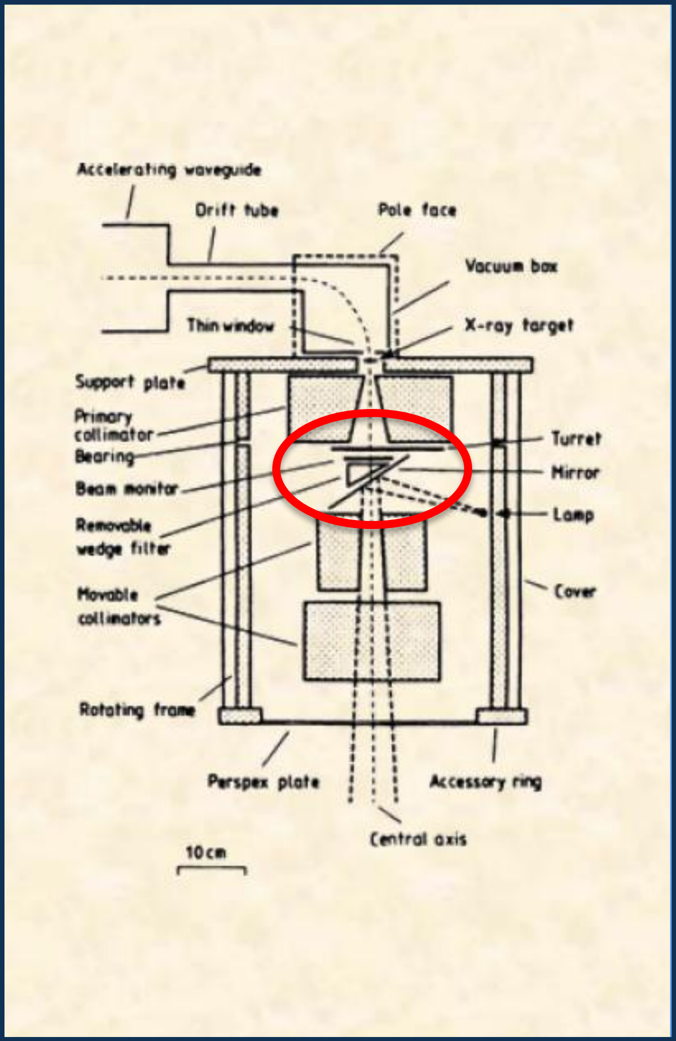


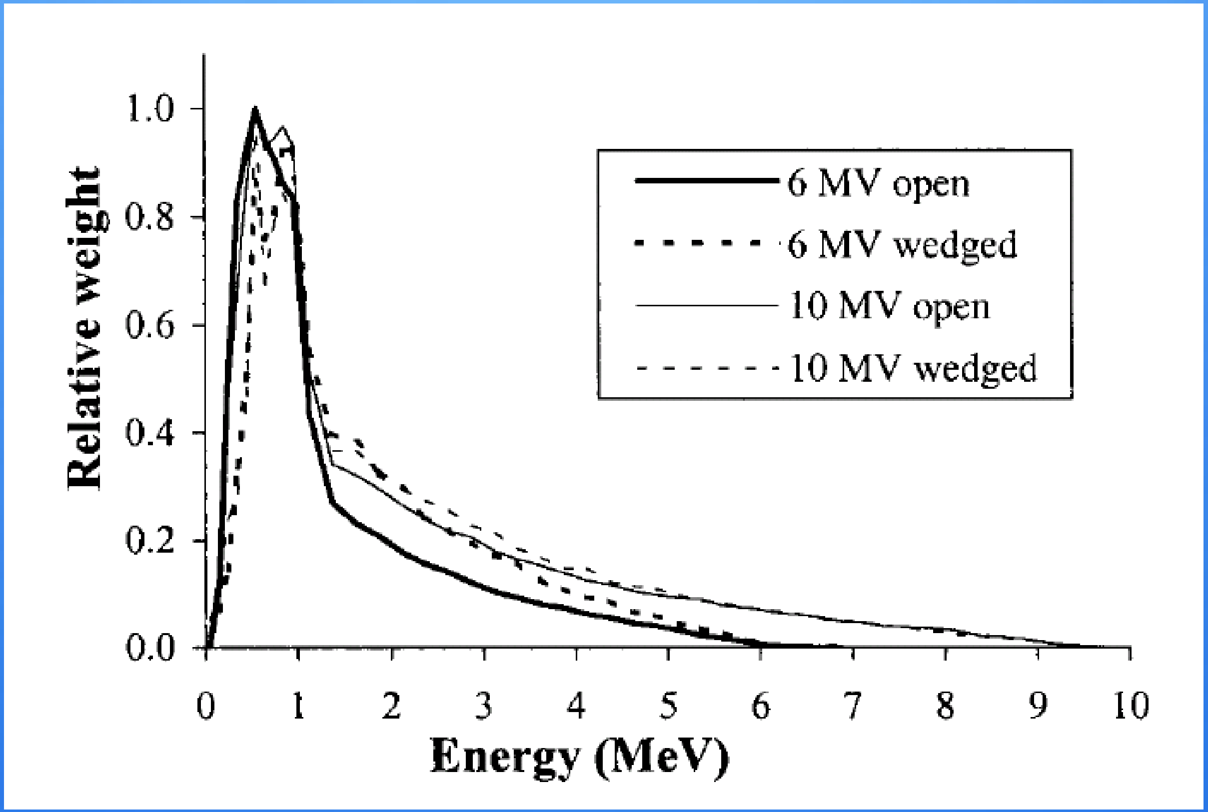
Figure 1. The effective wedge distribution D is given by the combination of the open D_O and wedged D_W fields in the proportions A and B respectively, where $A + B = 1$. The example shown is for a 10 cm × 10 cm field.

Universal wedges by ELEKTA



Beam quality and physical (external or internal) wedges

Elekta linac



It changes the beam quality by preferably attenuating the lower-energy photons (**BEAM HARDENING**) and, to a lesser extent, by Compton scattering, which produces energy degradation (**BEAM SOFTENING**)

More advanced wedge systems

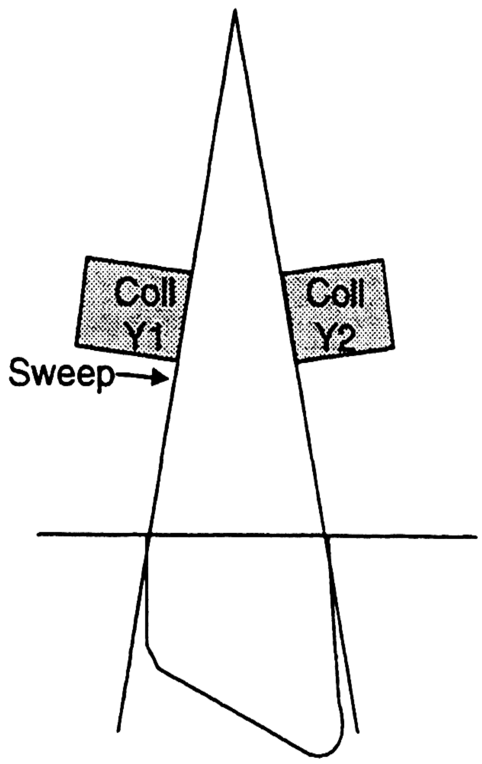
- Physical wedge has some inherent undesirable features

DYNAMIC OR VIRTUAL WEDGE

- The wedge shape is generated by moving one jaw (hot jaw) while the beam is on (the other is static: cold jaw)
- The resultant wedged beam is clean, more flexible in terms of field size and wedge angle, and does not require manual loading/unloading

'dynamic' (VARIAN) or **'virtual' wedge (SIEMENS)**

The Varian solution: Enhanced Dynamic Wedge, EDW™



Collimator Sweeping Action

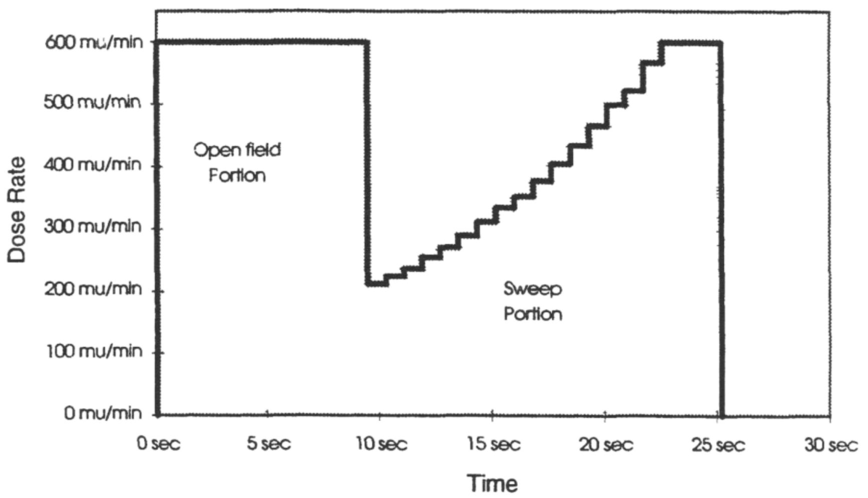


Figure 4-1 Dose Rate Progression

The Varian solution: Enhanced Dynamic Wedge, EDW™

- ED
- Seg … on vs MU

DYNAMIC TREATMENT SUMMARY DATA
TREATMENT SCREEN INDEX : 8

TREATMENT PARAMETER SETTINGS :

TYPE	ENERGY	MU	ORIG MU	TIME	DOSE RATE	ORNT	Y1	Y2	WEDGE ANGLE
E DWEDGE	6X	150	-	1.00	400	Y1-IN	9.0	9.0	60

STATISTICS SUMMARY

DOSE STD DEV	(MU) :	0.03
POSITION STD DEV	(cm) :	0.018
DOSE-WEIGHTED POSITION STD DEV	(cm) :	0.018
NUMBER OF SAMPLES	:	528

STT SUMMARY

	SETTINGS			ACTUALS		
INSTANCE	DOSE (MU)	Y1(cm)	Y2(cm)	DOSE (MU)	Y1(cm)	Y2(cm)
1	0.00	9.00	9.00	0.00	9.00	9.00
2	28.22	9.00	9.00	28.24	9.00	9.00
3	30.96	8.08	9.00	30.98	8.10	9.00
4	33.95	7.15	9.00	33.96	7.18	9.00
5	37.21	6.23	9.00	37.24	6.25	9.00
6	40.66	5.33	9.00	40.69	5.35	9.00
7	44.51	4.40	9.00	44.52	4.43	9.00
8	48.69	3.48	9.00	48.69	3.50	9.00
9	53.25	2.55	9.00	53.28	2.55	9.00
10	58.20	1.63	9.00	58.21	1.63	9.00
11	63.57	0.70	9.00	63.60	0.73	9.00
12	69.25	-0.20	9.00	69.29	-0.20	9.00
13	75.57	-1.13	9.00	75.61	-1.13	9.00
14	82.44	-2.05	9.00	82.48	-2.03	9.00
15	89.91	-2.98	9.00	89.93	-2.95	9.00
16	98.05	-3.90	9.00	98.06	-3.88	9.00
17	106.89	-4.83	9.00	106.93	-4.80	9.00
18	116.21	-5.73	9.00	116.23	-5.70	9.00
19	126.58	-6.65	9.00	126.62	-6.63	9.00
20	137.82	-7.58	9.00	137.85	-7.55	9.00
21	150.00	-8.50	9.00	150.06	-8.50	9.00

EDW™ (Varian) vs Virtual Wedge™ (Siemens)

Feature	Enhanced Dynamic Wedge	Virtual Wedge
Jaw Position vs MU	Determined using segmented treatment table (STT)	Determined using analytic equation
Method of delivery	Variation of dose rate and moving jaw speed	Variation of dose rate only
Initial/Final Jaw Positions	Initially open; final position 0.5 cm from fixed jaw	[illegible] jaw; final position fully opened.
Wedge direction option	EDW for Y (upper) jaws only. Treatment prohibited if fixed jaw >0.5cm beyond moving jaw limits	VW for X or Y jaws. Treatment allowed if fixed jaw >1cm beyond moving jaw limits
Jaw travel limitations		
Gradient direction	10 cm pass CAX.	upper jaw: 2 cm pass CAX. lower jaw: 10 cm pass CAX.
Non-gradient direction	No limit.	No limit.
Monitor Unit Input	MUs = Total MUs delivered during treatment	Programmed MUs = MUs delivered with CAX in the field. Total MUs termed MU_{max}.
Wedge Angle Selection	7 wedge angles (10°, 15°, 20°, 25°, 30°, 45°, 60°)	Continuous to 60°; Larger angles available with reduced field sizes.
Wedge Factors	Strong function of both wedge angle and field size; Weak function of off-axis distance.	Approximately unity (Ⅱ5%) for symmetric fields; Strong function of off-axis distance.
Machine-independence	STTs same for all Varian machines	VW equation may vary with user-adjustable calibration factor c.

Complex delivery

(The Elekta solution: Omni Wedge™)

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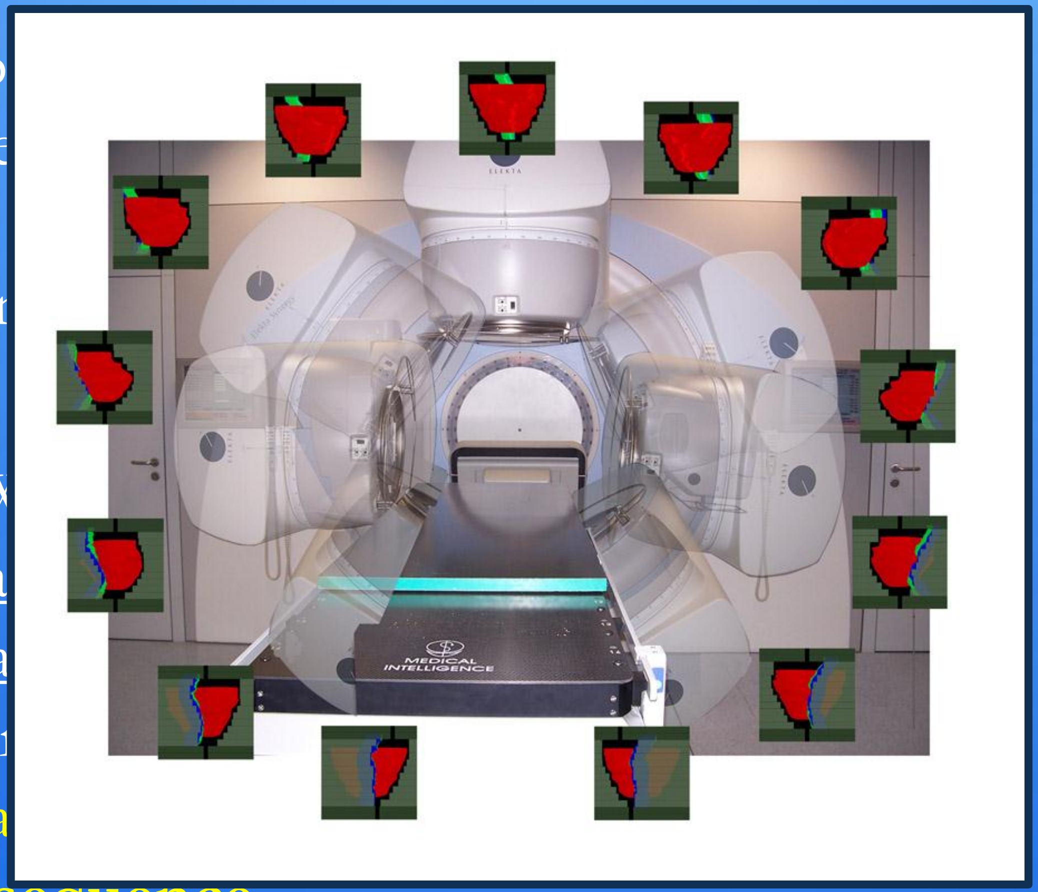
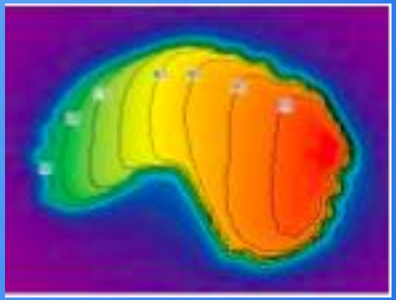
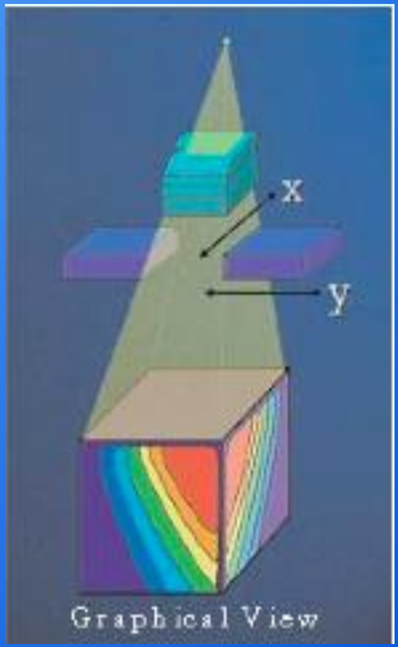






With **VMAT** …OMNIWEDGE™ actually disappears

Outline

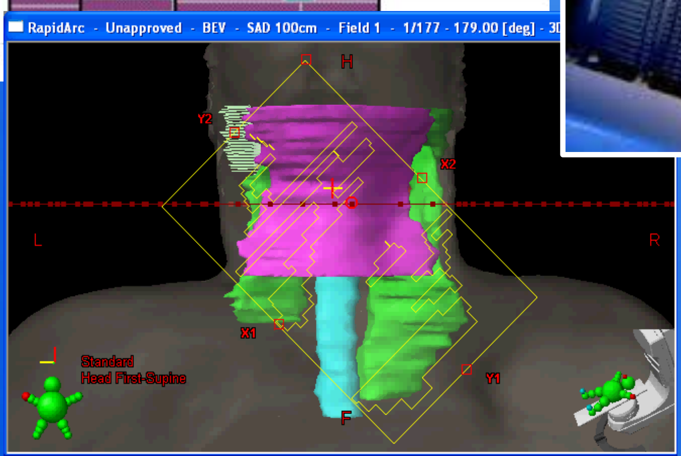
✓ **BEAM MODIFIER (<u>PHOTONS</u>, ELECTRONS) IN CONVENTIONAL TREATMENT UNITS**

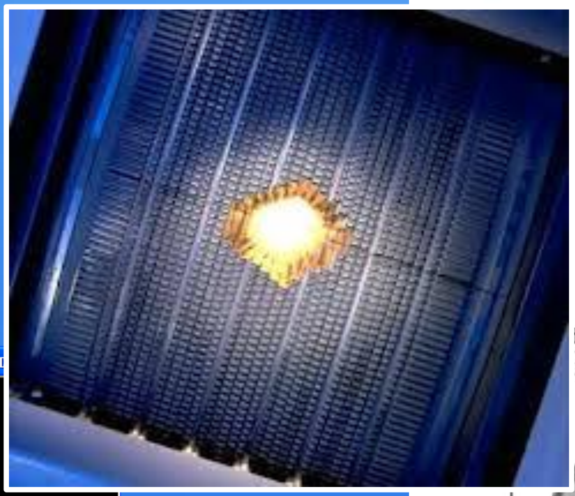
MLC

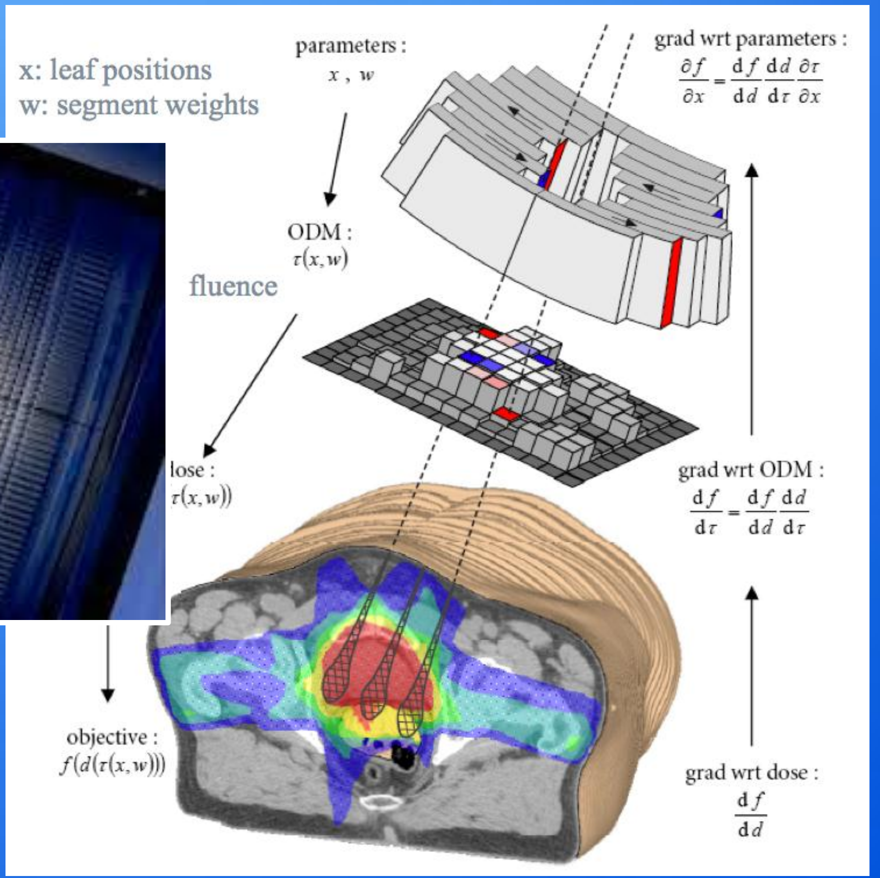
MLC

MLC is THE protagonist of the modern RT

3DCRT, IMRT, IMAT, VMAT





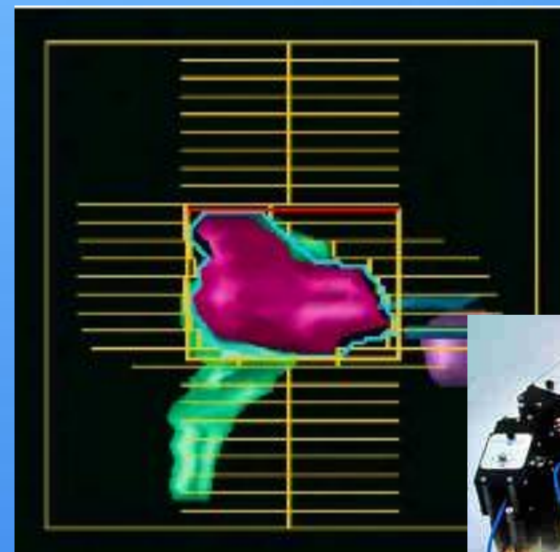


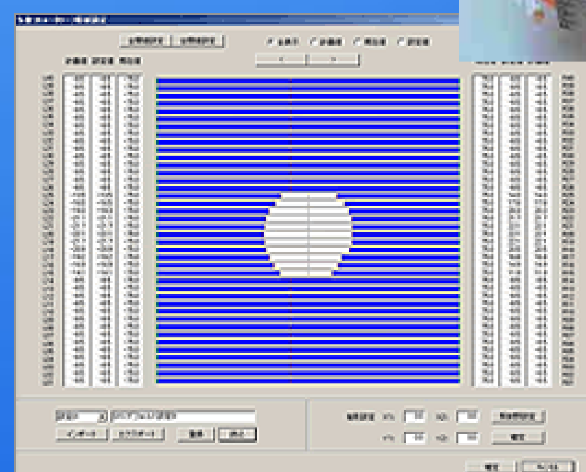
MLC – MULTILEAVES COLLIMATOR

- Individually shaped irregular fields made by Cerrobend blocking turned out to be time-consuming and expensive

- Great progress in CRT was achieved by the development of **MLC technology**

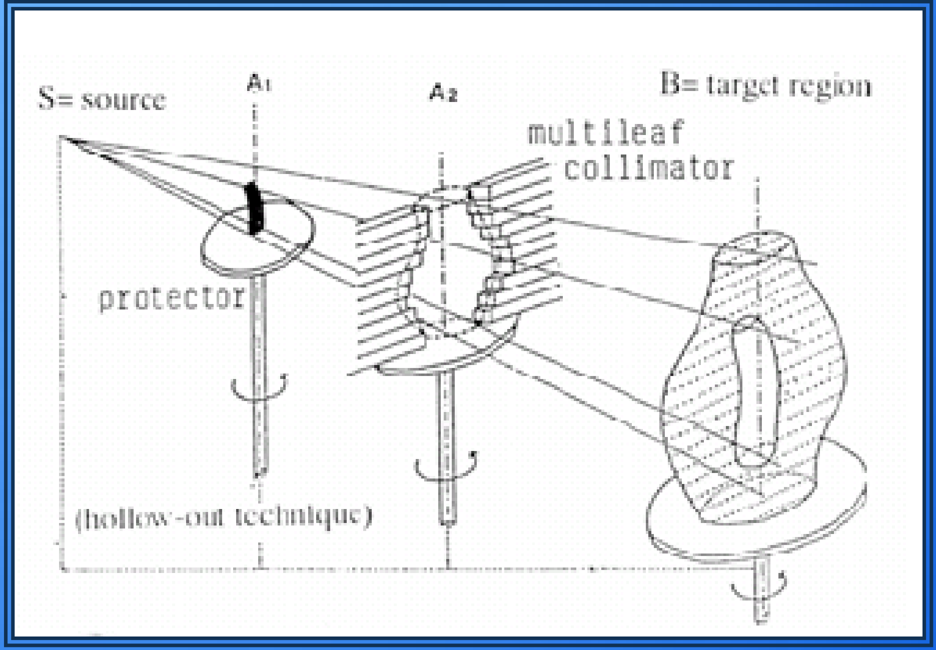
- The dose distributions obtained with MLCs resulted to be equivalent to blocks with enhanced flexibility





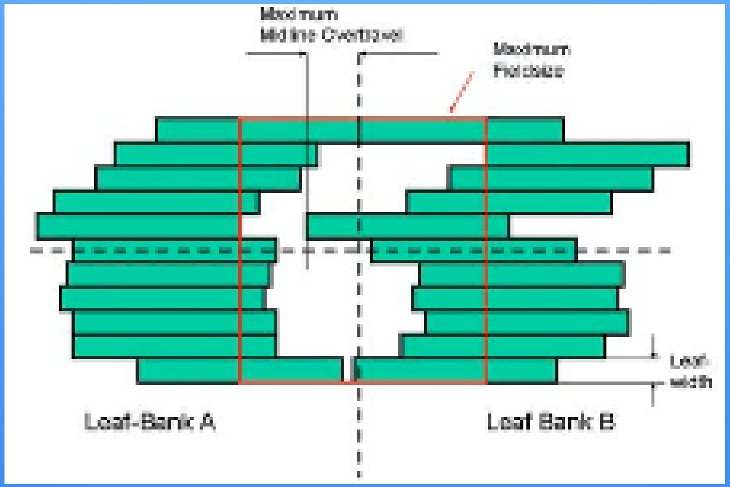
MLC

CRT was introduced in the early 1960s by radiation oncologist Takahashi, who had the idea to concentrate the dose to the target volume using various forms of axial transverse tomography and rotating multi-leaf collimators (Takahashi 1965)



The **founding ideas**: the "birth" of MLC, the "birth" of CRT in its more complex form (VMAT)

MLC = Multileaves Collimator



The MLCs are beam-shaping devices that consist of two opposing banks of attenuating leaves, each of which can be positioned independently

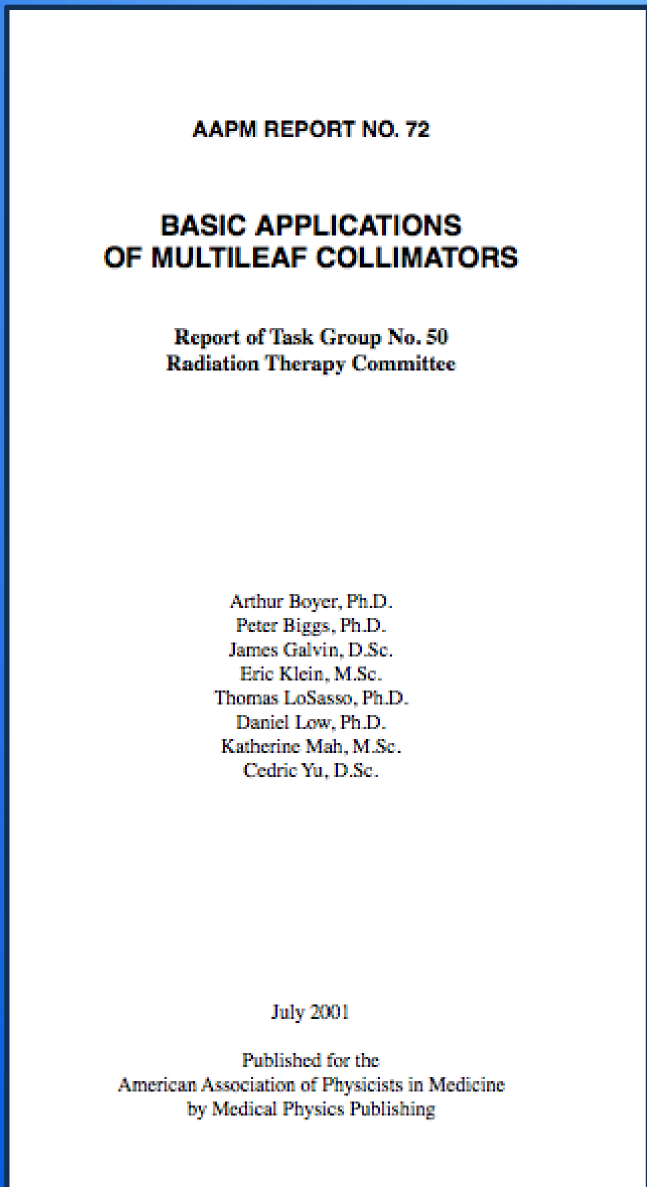
MLC

- The leaves can be driven by motors to such positions that, seen from the "BEV" of the source, the collimator corresponds to the shape of the tumor (**fitting the target**)
- Though already proposed by Takahashi in 1960, it took about 25 years before the first commercial computer controlled MLCs appeared on the market
- The fact is that MLCs are mechanical devices with high mechanical complexity, and they have to fulfill very rigid technical, dosimetric, and safety constraints

MLC design - Manufactured model may differ in

- **Architecture head**: number of collimators and MLC position relative to other collimator(s)
- **Material**
- **Number of leaves**
- **Leaf width**
- **Leaf thickness**
- **Leaf-end design**
- **Leaf-side design**
- **Single-focused & double focused**
- **Restriction on position and motion**
- **Leaf speed**
- **Field size**
- **Isocenter clearance**
- **MLC control feature (driving and verification mechanisms)**

MLC: basic information


AAPM REPORT NO. 72

BASIC APPLICATIONS
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Report of Task Group No. 50
Radiation Therapy Committee

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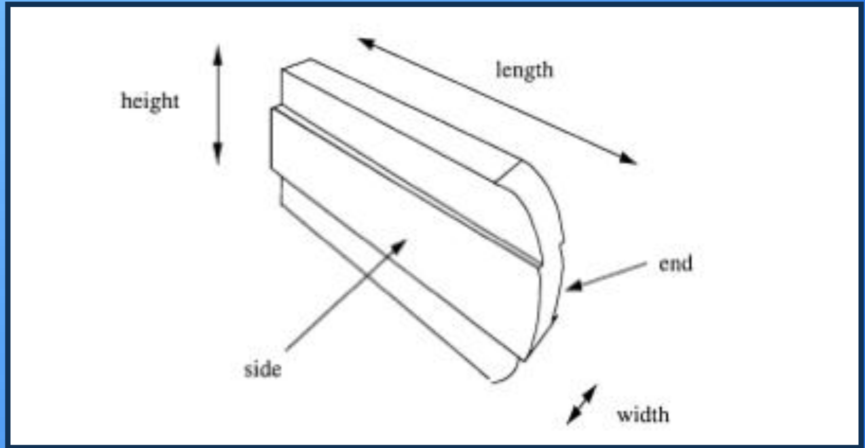

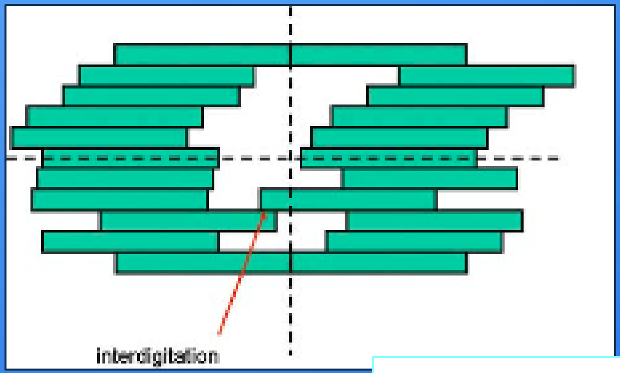

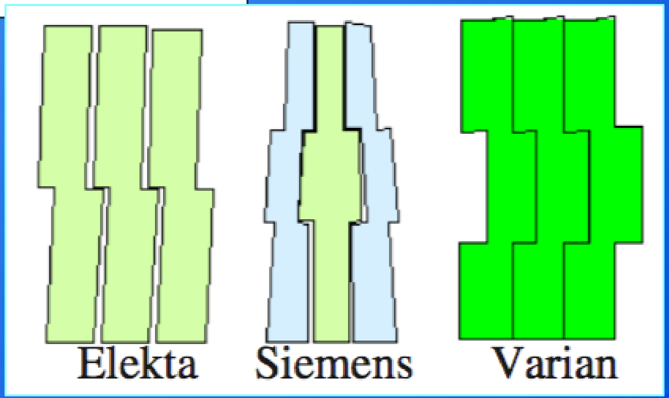

RPT_72 AAPM TG50

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RPT_72 AAPM TG50: terminology

Leaf width: small leaf dimension perpendicular to the motion direction (and to propagation direction)

Leaf length: leaf dimension parallel to the motion direction (and to propagation direction)

Leaf end: the surface of the leaf inserted into the field along this dimension

Leaf side: the surfaces in contact with adjacent leaves

Height of the leaf: the dimension of the leaf along the direction of propagation of the primary x-ray beam (from the top of the leaf near the x-ray source to the bottom of the leaf nearest the isocenter (attenuation properties)

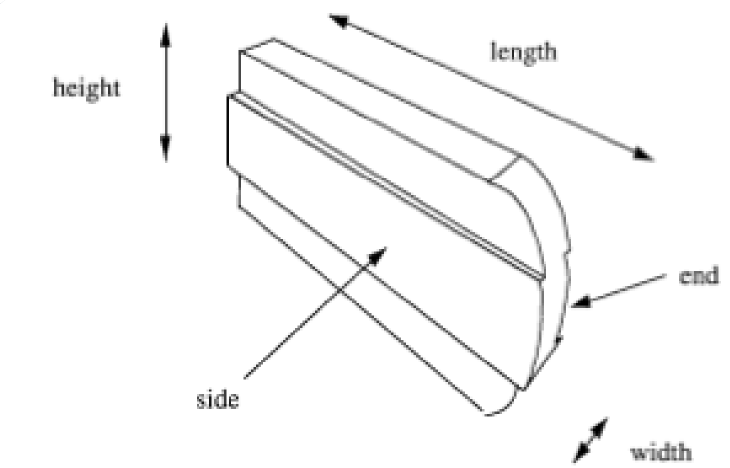
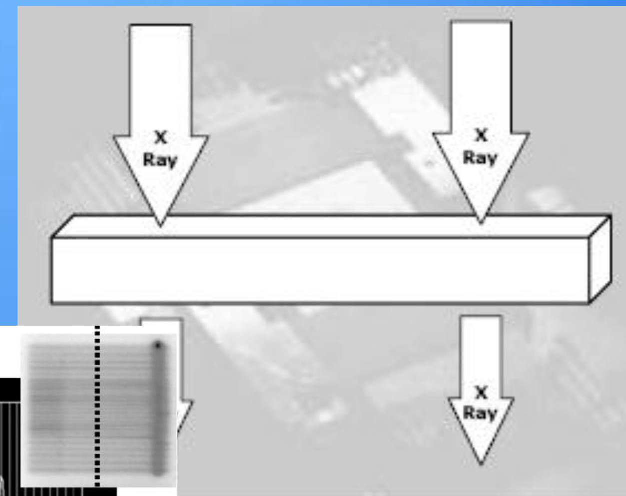


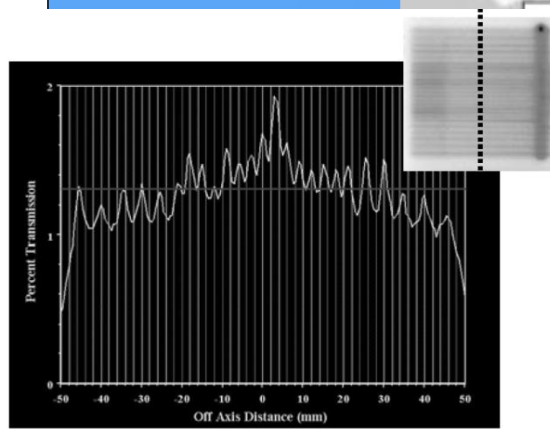
Figure 1. Schematic of generic MLC leaf illustrating leaf terminology. An example of a curved end and a stepped side.

RPT_72 AAPM TG50: transmission



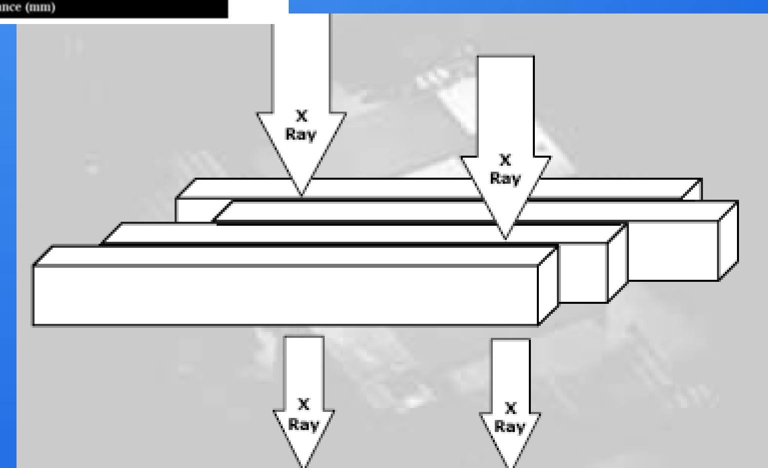
Leaf transmission: the reduction of dose through the full height of the leaf

Interleaf transmission: the reduction of dose measured along a line passing between leaf sides

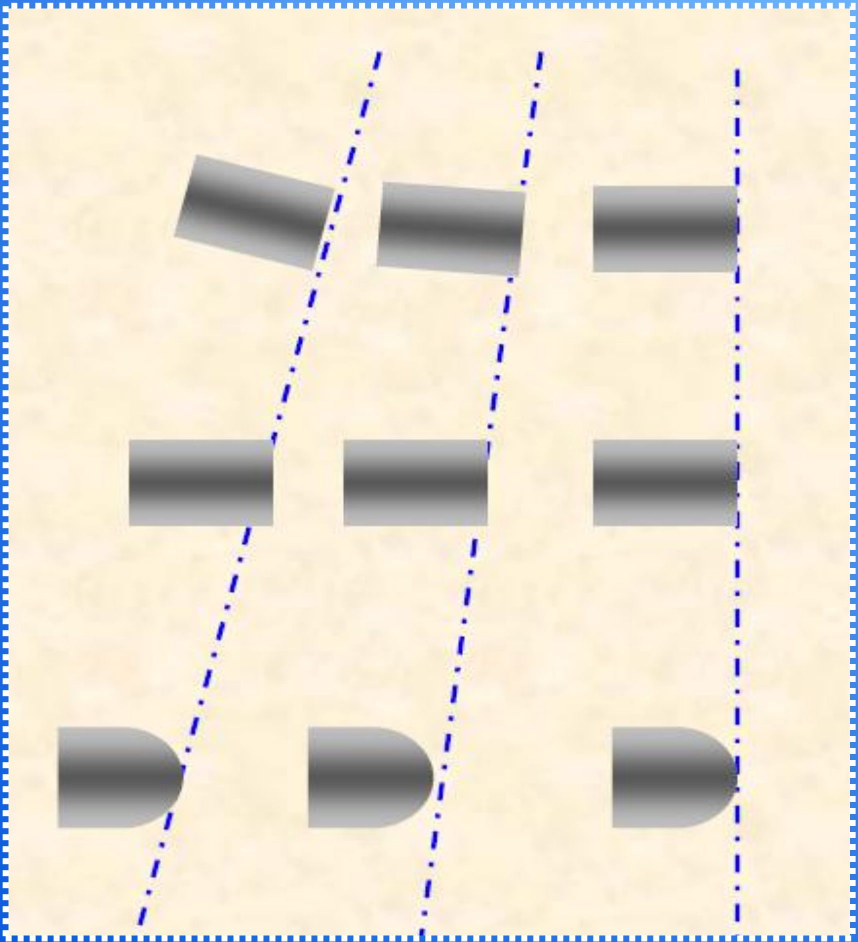


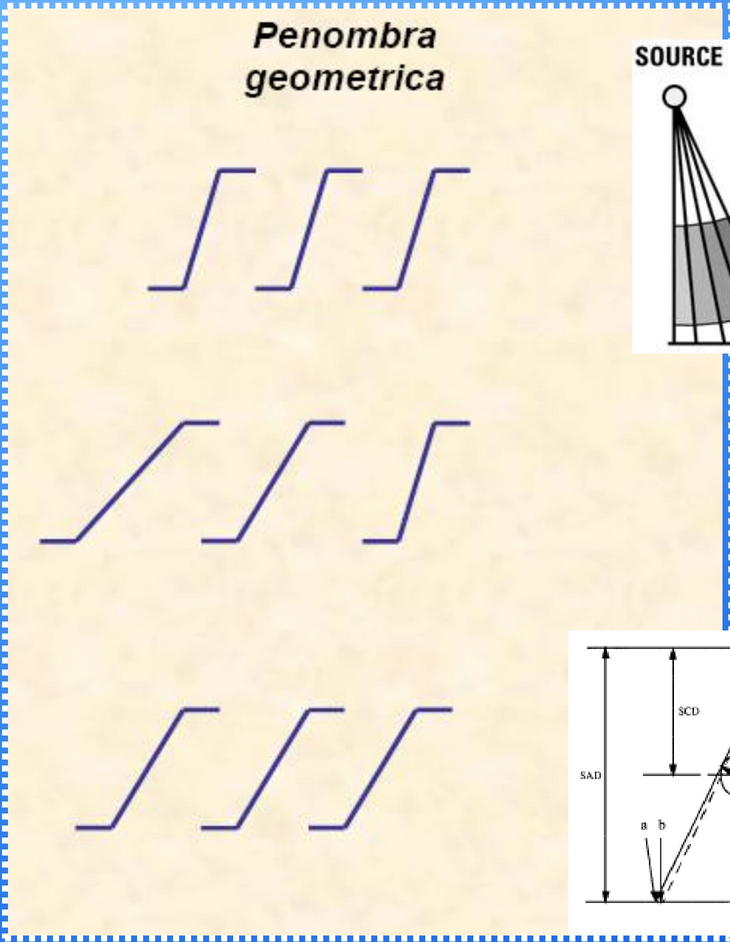
End transmission: the reduction of dose measured along a ray passing between the ends of opposed leaves in their most closed position

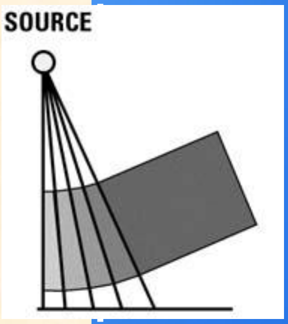
MLC transmission: the average of leaf and interleaf transmissions (should be less than 2%)➔ TPS parameter

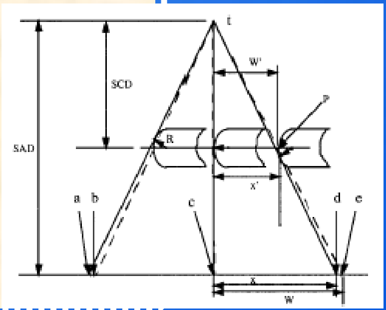


MLC - leaf end shape



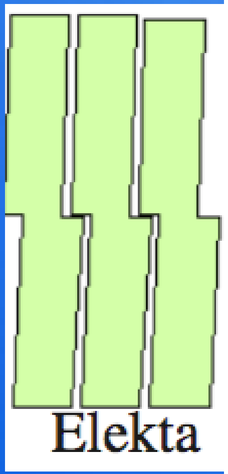


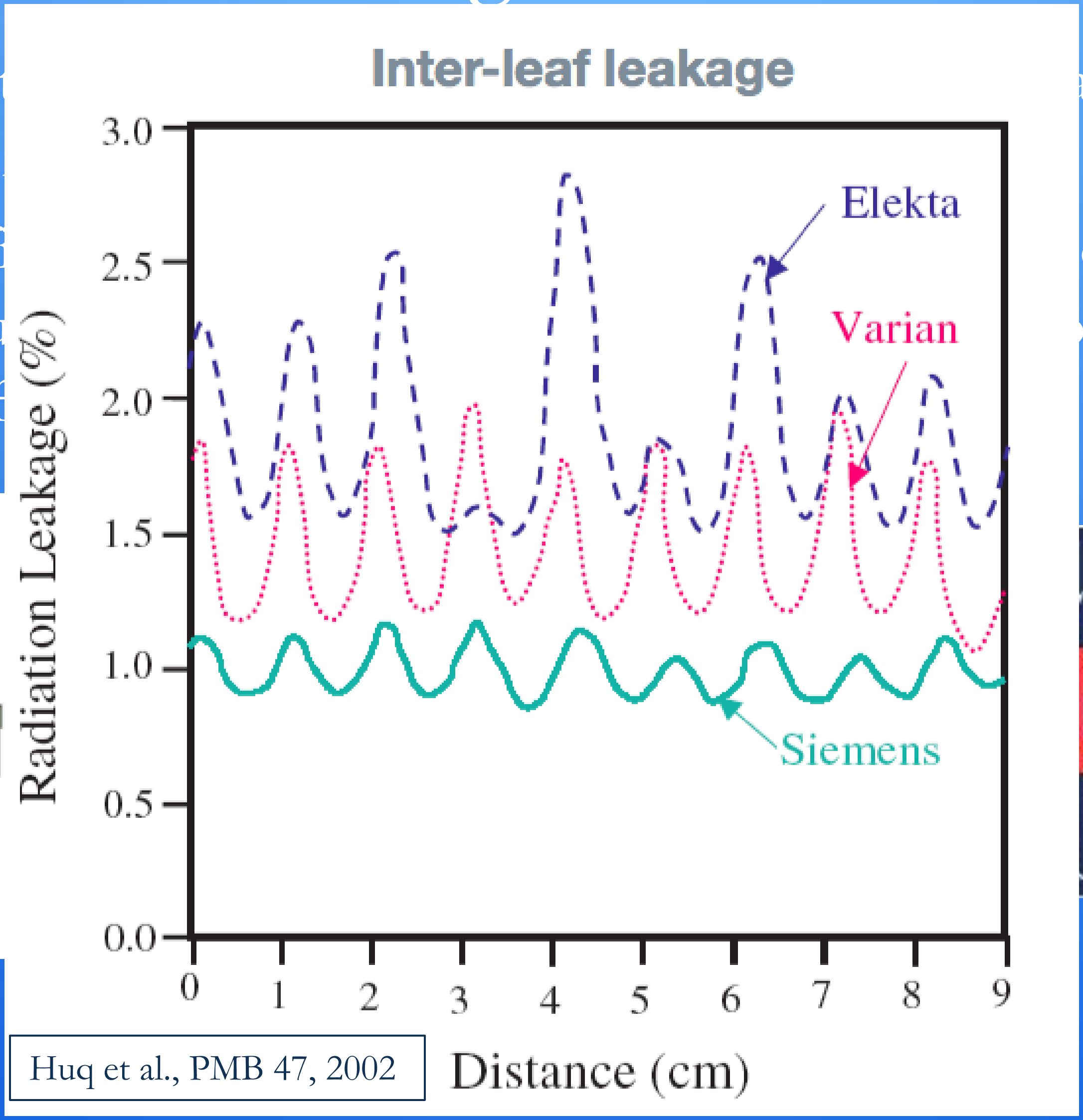


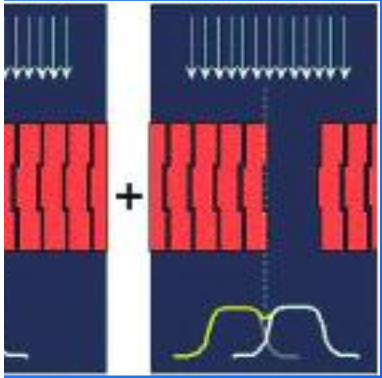


MLC – leaf side
The Tongue and Groove

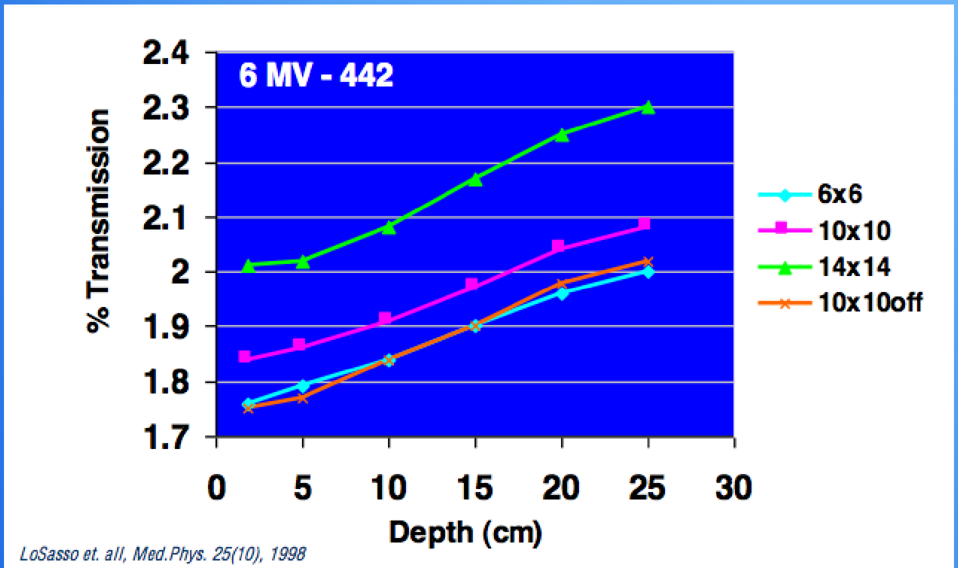
- To reduce t … a tongue-and-groove des…
- If a large fi … on is divided into two su … f the two treatment f…



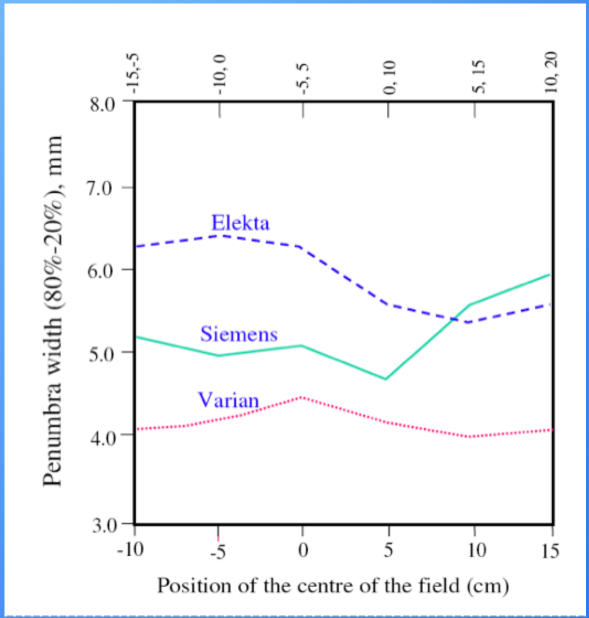




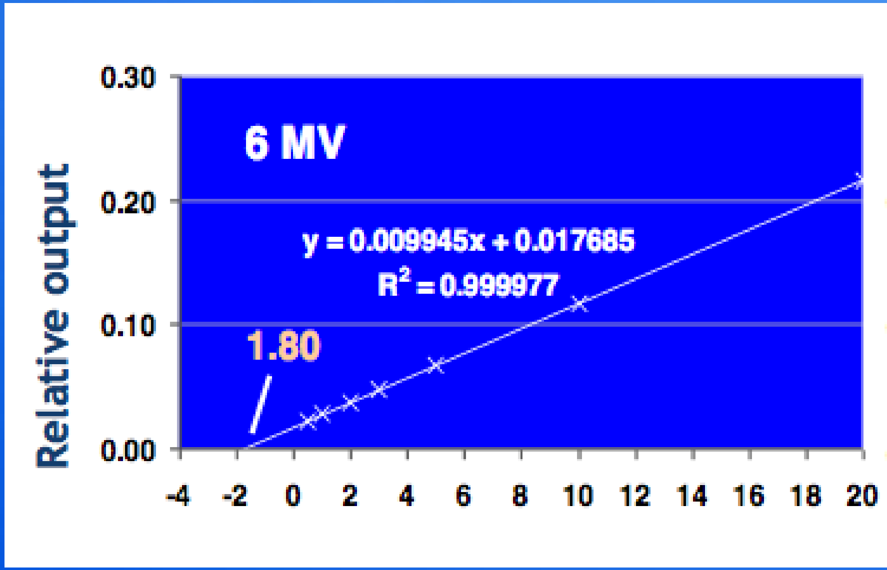
MLC - dosimetric characterization

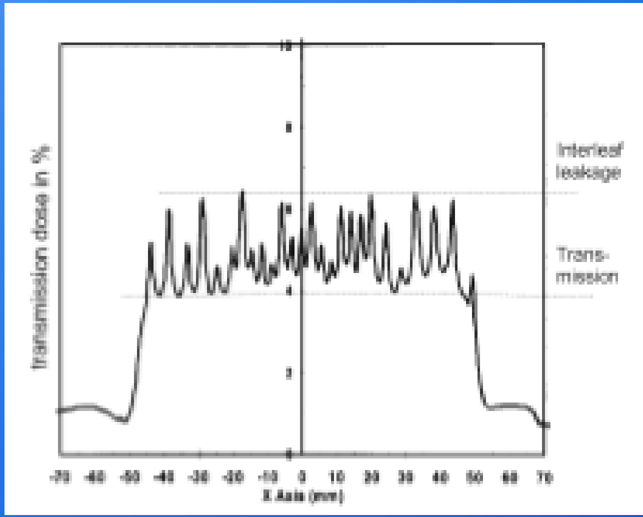


LoSasso et. all, Med.Phys. 25(10), 1998



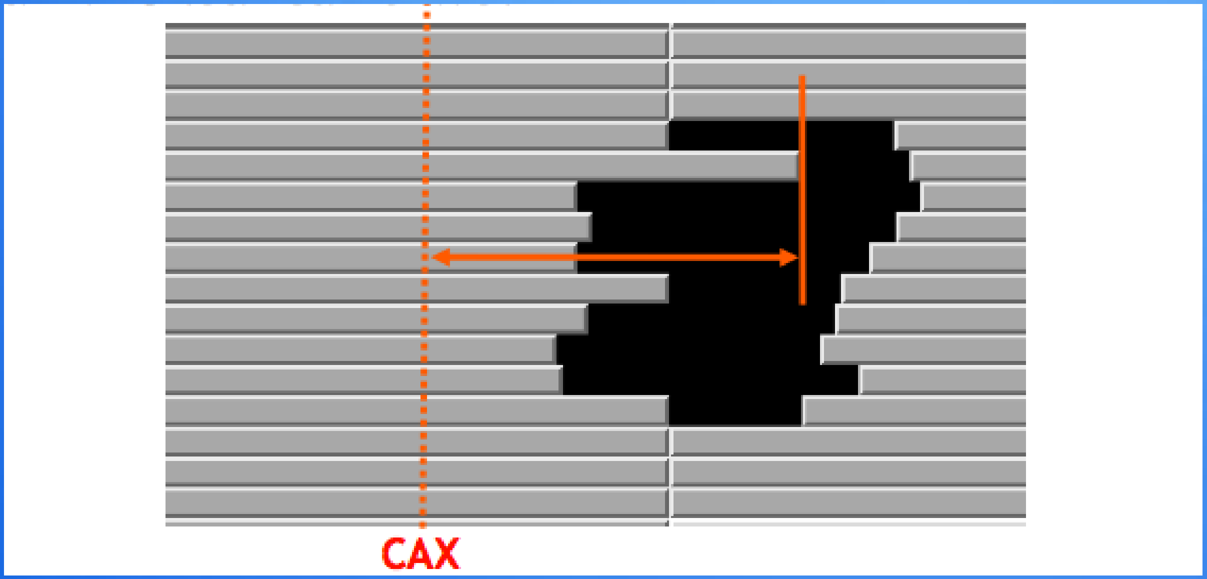
Hu et al. PMB 47 2002



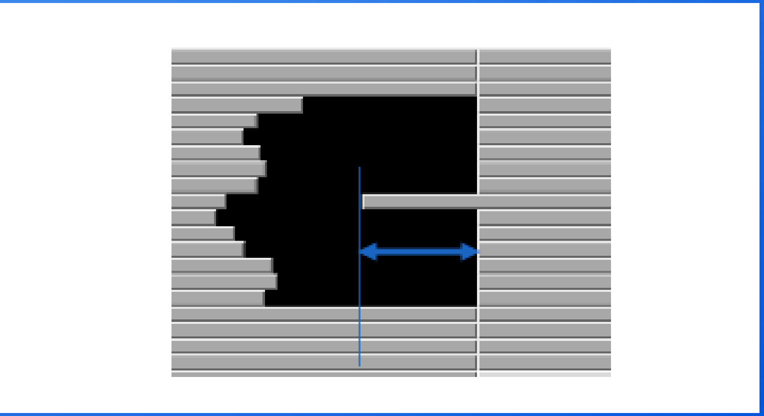


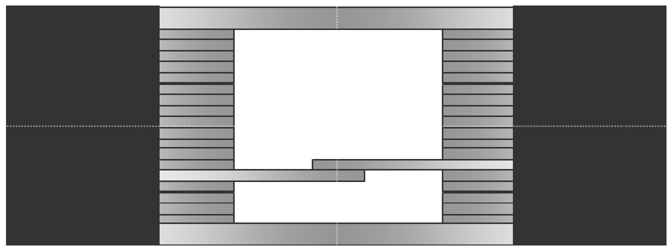
MLC – motion constraints

Leaf over-travel: the maximum distance over the beam CAX to which an MLC leaf can travel



Leaf span: the maximum distance from the tip of the most retracted leaf to the tip of the most extended leaf

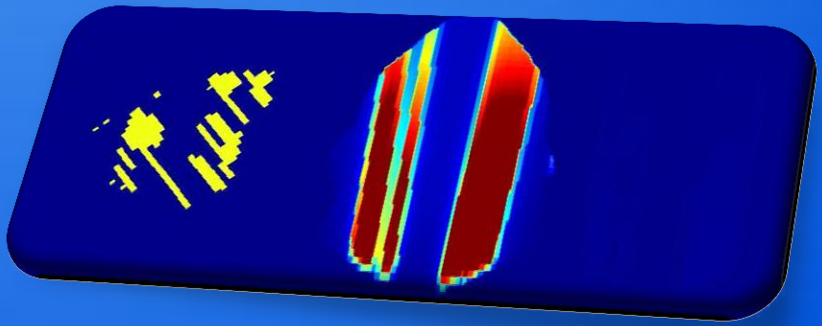




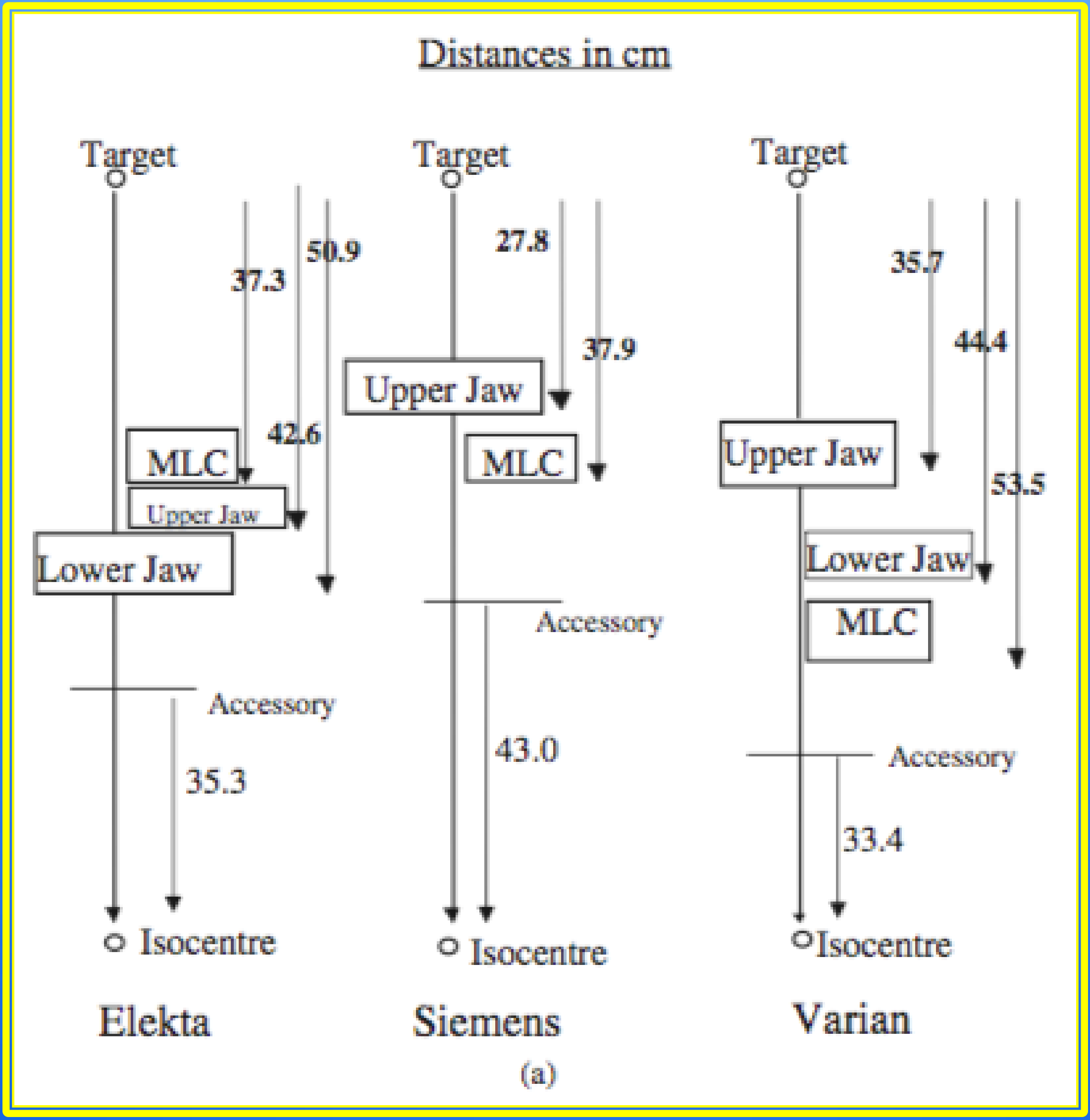
MLC - The Interdigitation

- It is the ability of leaves on one side of a field to interdigitate with neighboring leaves on the opposing leaf bank
- The ends of odd-numbered leaves from the right-hand bank are driven past the ends of even- numbered leaves from the left-hand bank
- The Varian collimator was the first commercial system that could perform it

It can be used to create **island blocks** by using two exposures of the same field: very important for **modulation** intensity (IMRT, VMAT)



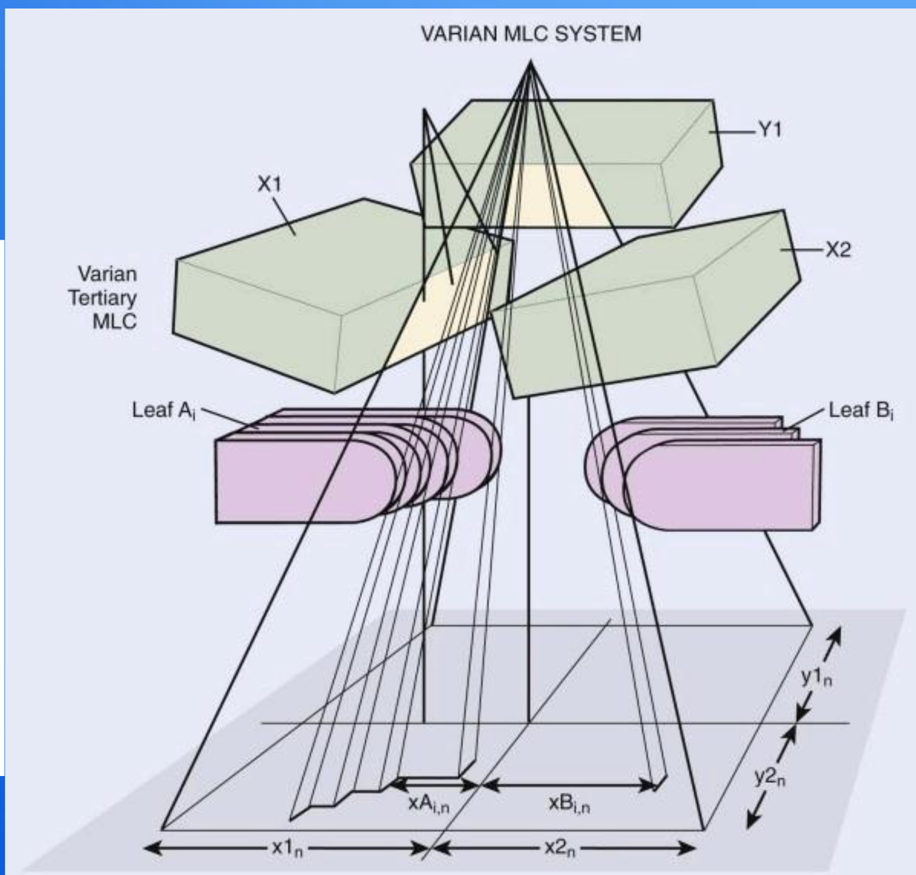
MLC configuration in the Treatment Head

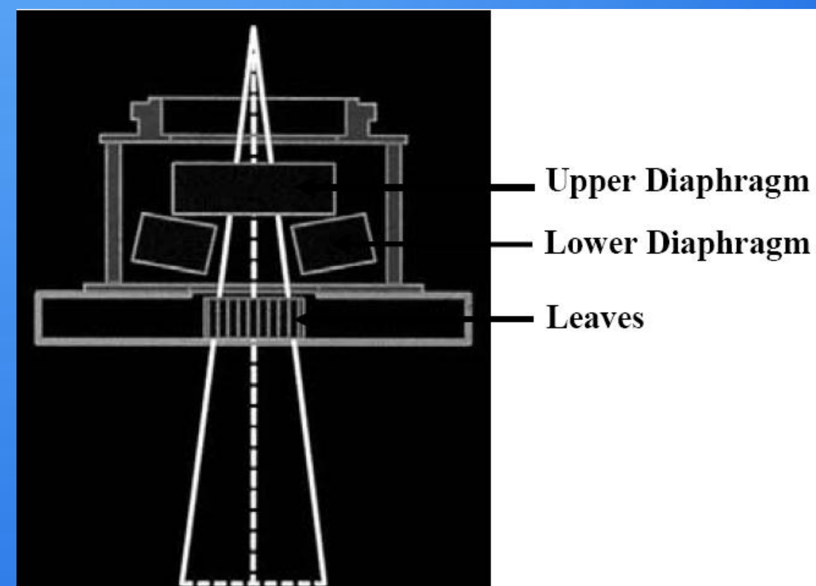


MLC – Varian configuration

Terziary, 3rd level (or Add-on) Collimator

The Y1 jaw has been omitted for clarity





MLC – Varian configuration

- It is positioned just below the level of the standard upper and lower jaws
- This is "ok" for maintenance actions
- Disadvantage: the added bulk and the minor clearance to the mechanical isocenter
- Moving the MLC farther from the x-ray target requires an increase in the size of the leaves and a longer travel distance to move from one side of the field to the other
- The result is that such a tertiary system decreases the collision free zone
- In **IMRT**, **to cover large fields**, it can become necessary **to split the field in 2 or 3 sub-fields** (different carriage positions)

Clearance head

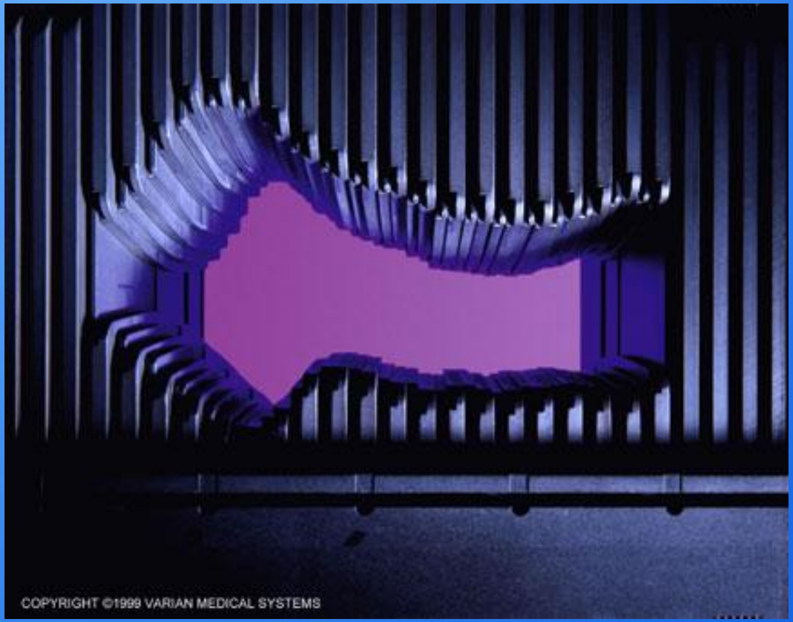
MLC	Largest	Block tray	Wedge
Elekta	45 cm	35.3 cm	35.3 cm
Siemens	43 cm	43 cm	43 cm
Varian	42 cm	35 cm	35 cm

MLC – Varian design

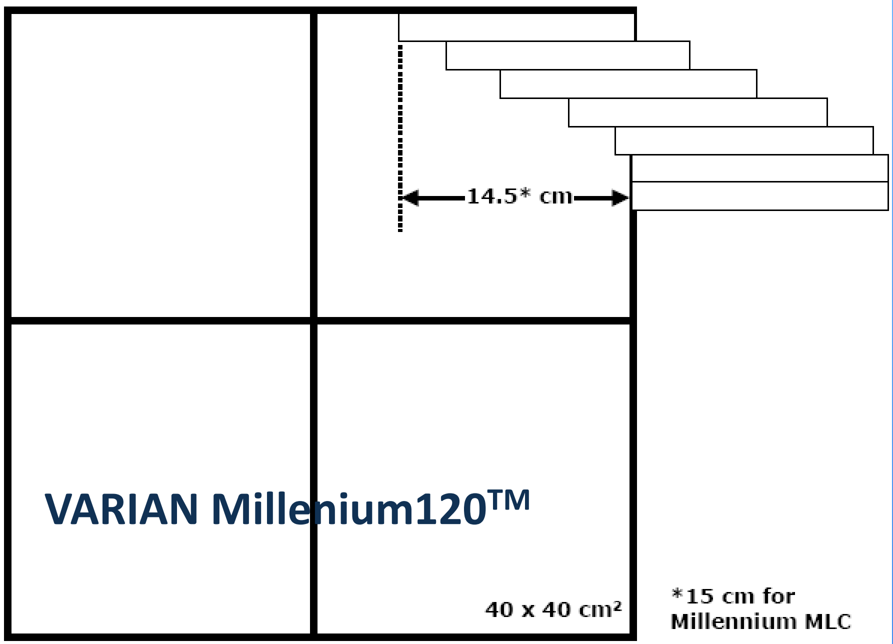
- Rounded leaf-end
- Single focused
- No backup jaw moving with MLCs (not properly true: JAW TRACKING with TRUE BEAM^{TM})

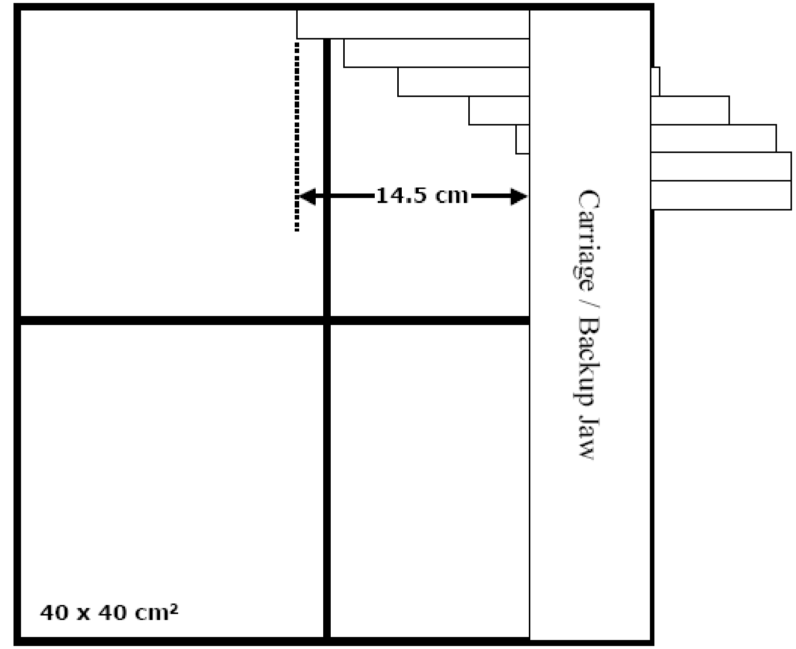
MLC – Varian Millenium120™

- The leaves travel on a carriage to extend their movement across the field
- Leaf interdigitation: yes
- The distance between the most extended leaf and the most retracted leaf on the same side (carriage) can be up to 15 cm
- Max field length X-direction: 40 cm
- Max leaf retract position (from CAX): 20.1 cm
- Max leaf extend position (over CAX): -20 cm
- Leaf width in the central 20 cm of field: 5 mm
- Leaf width in outer 20 cm of field: 10 mm
- Maximum speed: 2.5 cm/s
- Leaf height: 60 mm
- Leaf end radius: 80 mm
- Leaf tongue and groove offsets: 0.4 mm
- W-alloy

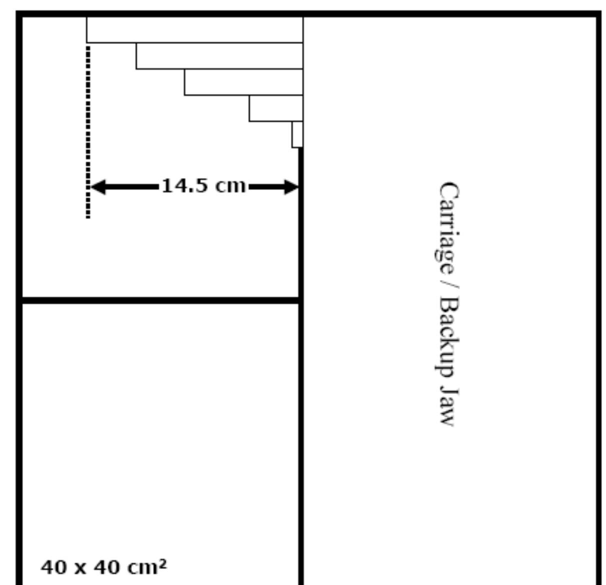


Leaf motion constraints



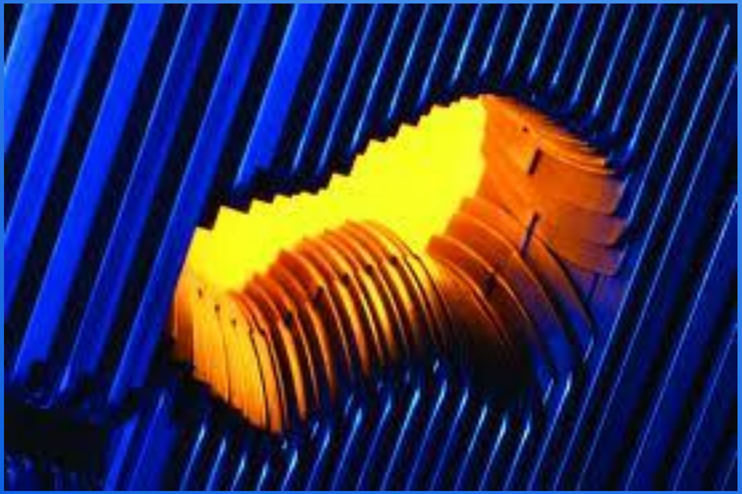


Extending the leaves out to the field center is not possible when large fields are used. This can be illustrated by a medium field size of 20-cm width that is symmetric relative to the field center. Here, the entire carriage can be moved so that the leaves can extend 5 cm (the 15 cm limit minus the 10 cm half field width) over the field center



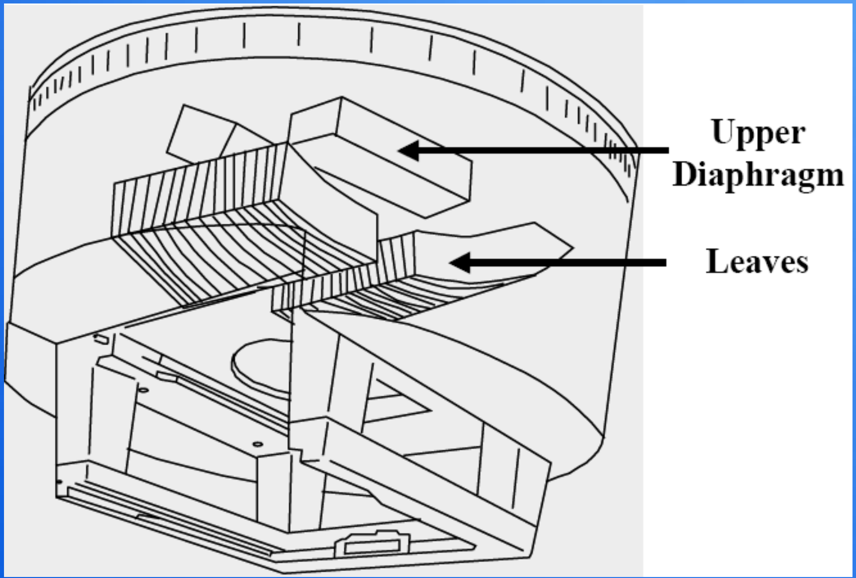
MLC – Varian 2.5 mm HD120™

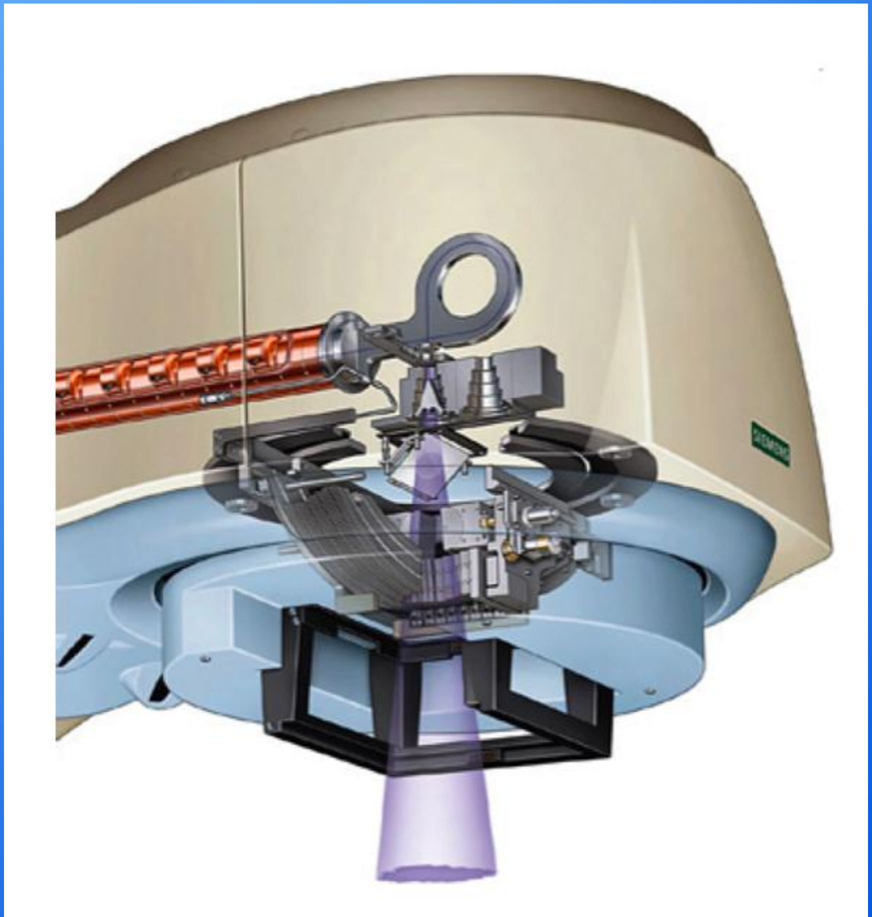
- The width of the central leaves is 2.5 mm
- Each side of the Varian collimator is configured with 60 leaves distributed in an 8 cm wide central region with 32x2.5 mm leaves, flanked by two 7 cm wide outer regions with 14x5.0 mm leaves, for a total width of 22 cm
- Maximum static field size: 40 x 22 cm^2
- MLC mounted on Varian True Beam™ True Beam$_{STx}$™



MLC – Siemens configuration

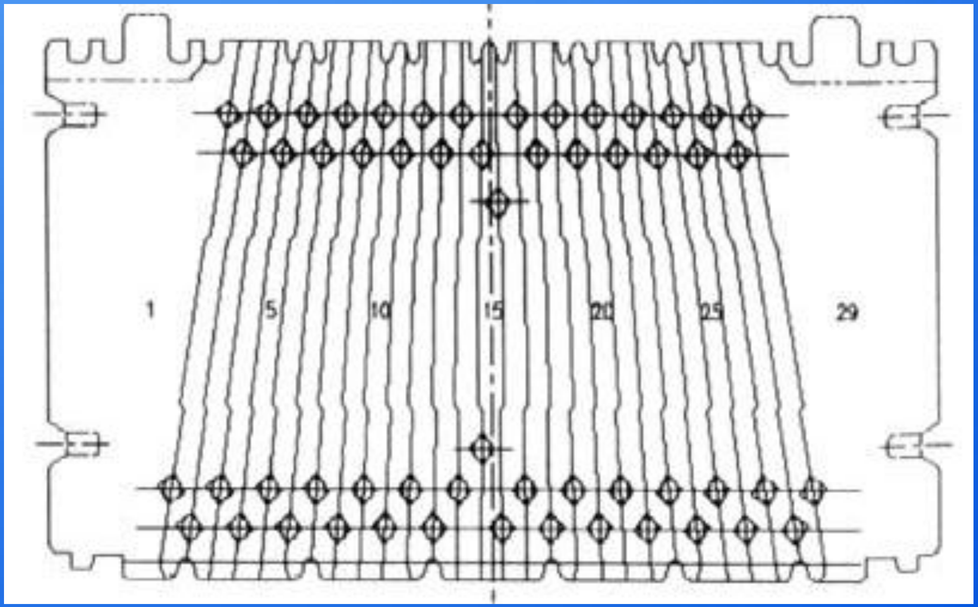
Lower Jaw replacement



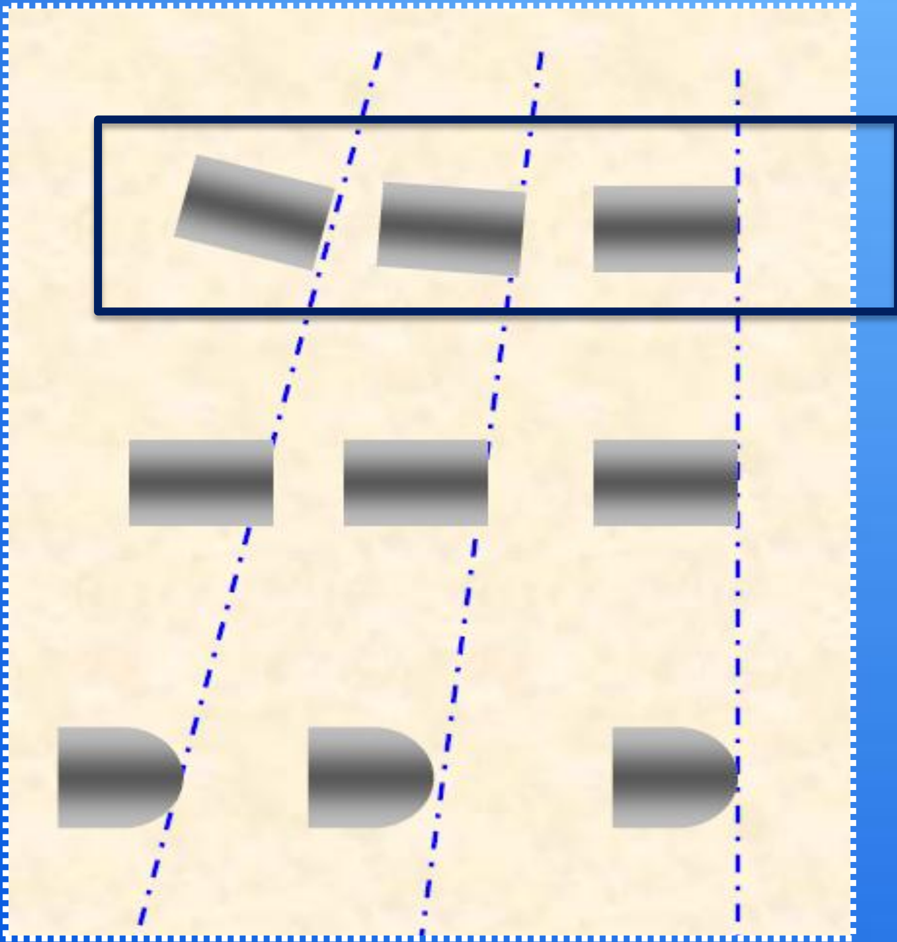


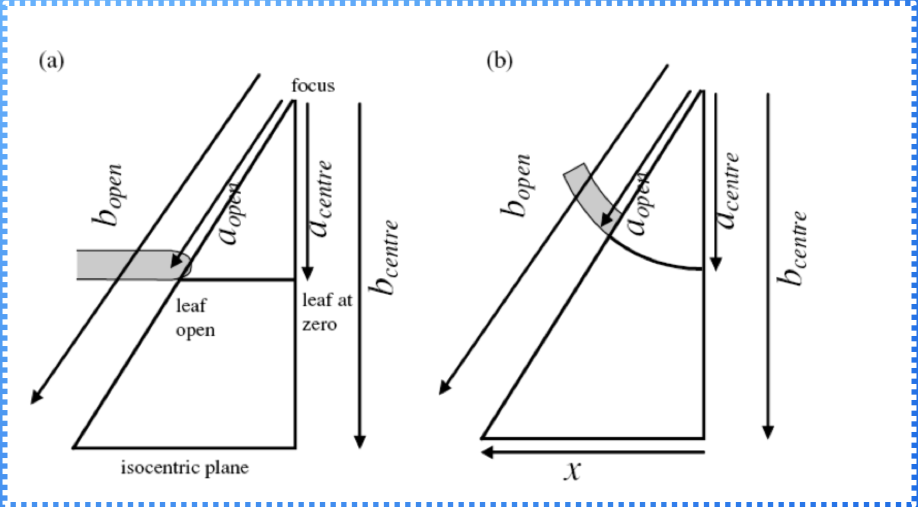
MLC – Siemens design

- MLC replaces **completely** secondary collimator
- The leaf ends are straight and are focused on the x-ray source
- The leaf ends as well as the leaf sides match the beam divergence, making the configuration **double-focused**
- Y-jaw backups each MLC segment



Siemens MLC leaf ends





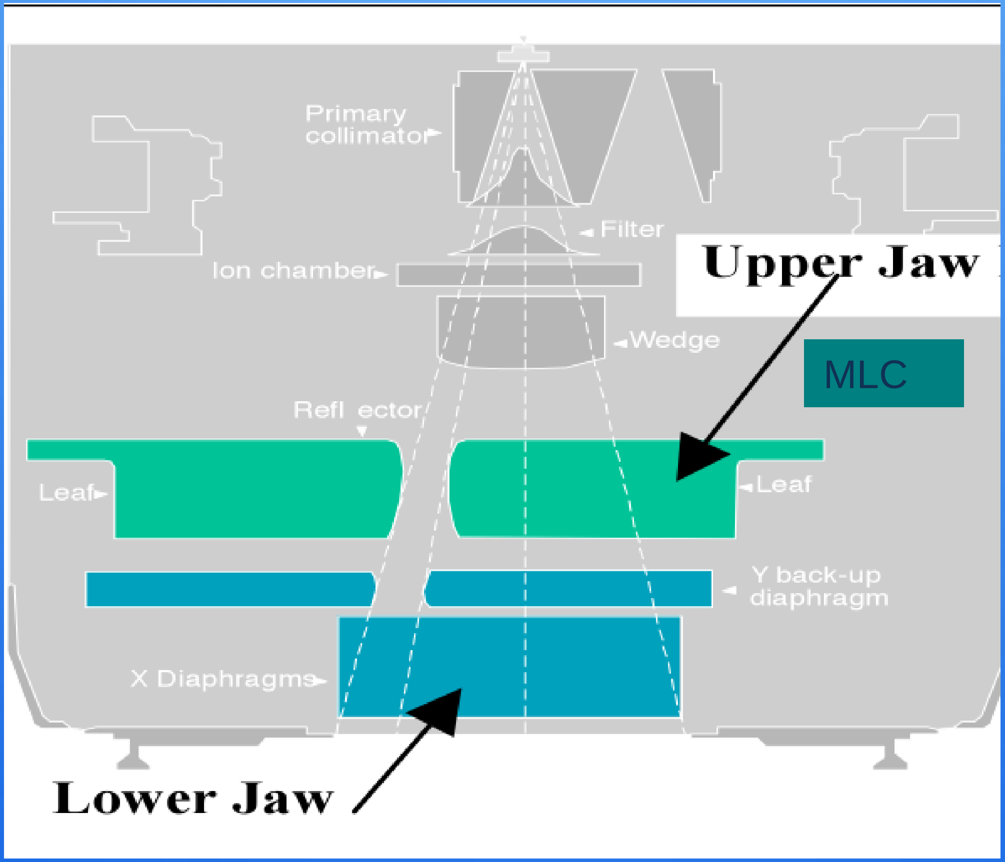
Siemens linacs use MLCs that move <u>in an arc</u> such that the flat faces of the leaf ends are always in the same plane as the radiation focus

Siemens 160 MLC™

160 MLC	
Number of leaves	160
Absolute leaf positioning accuracy at isocenter (mm)	±0.5
Leaf positioning reproducibility at isocenter (mm)	±0.3
Maximum circular field diameter (cm)	40
Leaf resolution at isocenter (mm)	5
Variance of leaf resolution at isocenter (µm)	200
Interdigitation	Yes
Maximum leaf speed (cm / s)	4
Servo-control speed	Yes
Reticule	Built in
Maximum field size (cm)	40 x 40
Minimum field size (cm)	0 x 0
Maximum leaf movement of a single leaf (cm)	20
Overtravel of leaves (cm)	20
Leaf material	Tungsten
Leaf height (mm)	95
Individual leaf guide to ensure reliable leaf distance and friction minimization	Yes
Jaw height (mm)	77
Jaw positioning accuracy Field sizes of 5 cm x 5 cm	Non-overtravel region: ±1 mm or ±1% Overtravel region: ±1.25 mm
Overtravel of jaws (cm)	2
Jaw speed (mm / sec)	20
Jaw end design	Pivoting

MLC – Elekta configuration

Upper Jaw replacement



MLC – Elekta design (1)

- MLC closest to source
- Rounded leaf-end Single focused
- The MLC leaves move in the y-direction

……………………………………………………………

- Backup collimator moving with MLCs
- A “back-up” collimator, located beneath the leaves and above the lower jaws, augments the attenuation provided by the individual leaves
- The back-up is essentially a thin upper jaw that can be set to follow the leaves if they are being ganged together to form a straight edge or else set to the position of the outermost leaf if the leaves are forming a shape

MLC – Elekta design (2)

- The primary advantage of the upper jaw replacement design is that the range of motion of the leaves required to traverse the collimated field width is smaller, allowing for a shorter leaf length and therefore a more compact treatment head diameter

…………………………………………………………………………………

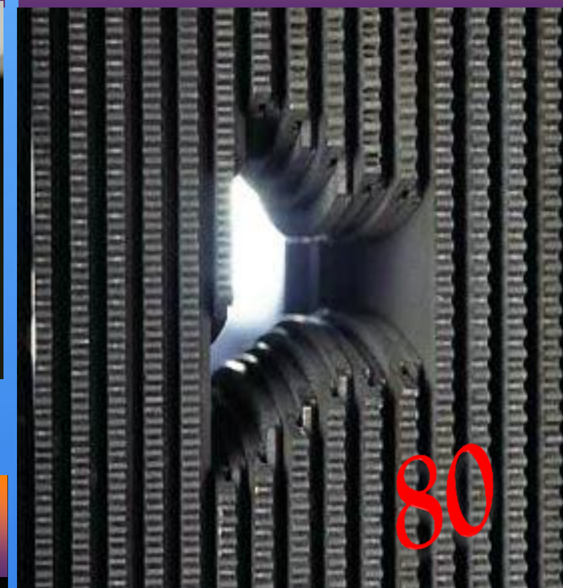
- The disadvantage of having the MLC leaves so far from the accelerator isocenter is that the leaf width must be somewhat smaller and the tolerances on the dimensions of the leaves as well as the leaf travel must be tighter than for other configurations.

The ELEKTA MLCs

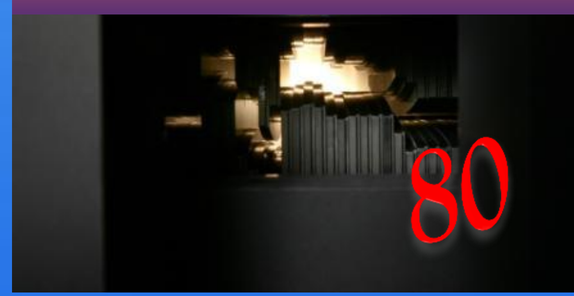
Agility™

Apex™

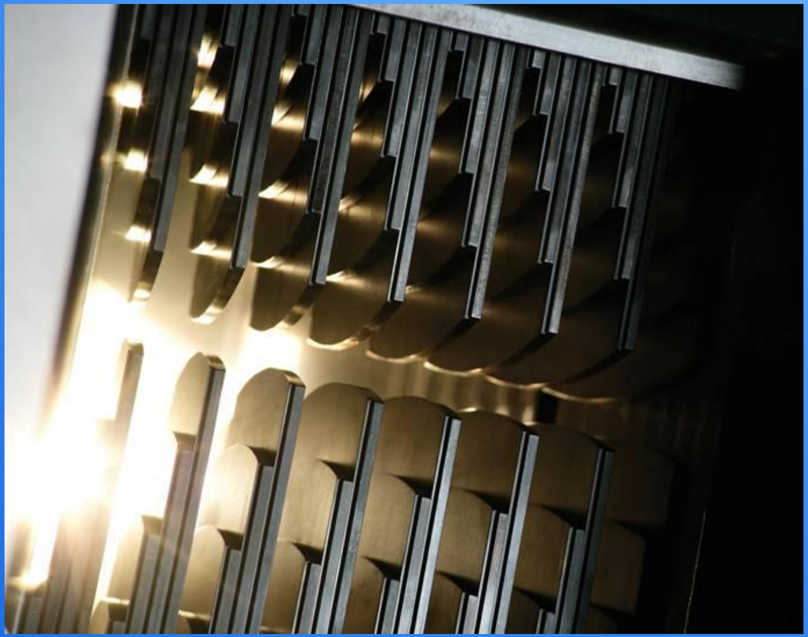
Beam Modulator™



MLCi2™

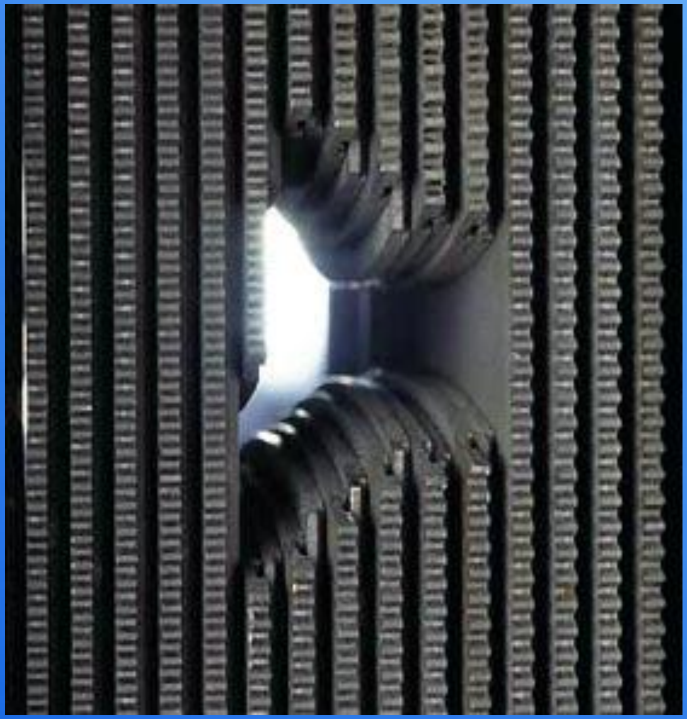


MLci2™



	MLCi2™
Width leaf (@iso)	10 mm
Number of leaves	80 (40 pairs)
Max field size (@iso)	40 cm x 40 cm
Over-travel	12.5 cm
Focalized	single
Thickness	8.2 cm
Interdigitation	yes
Penumbra	< 7 mm (5 cm x 5 cm to 15 cm x 15 cm) < 8 mm (> 15 cm x 15 cm)
RT delivery	3DCRT-IMRT-VMAT

MLC Elekta Beam Modulator™

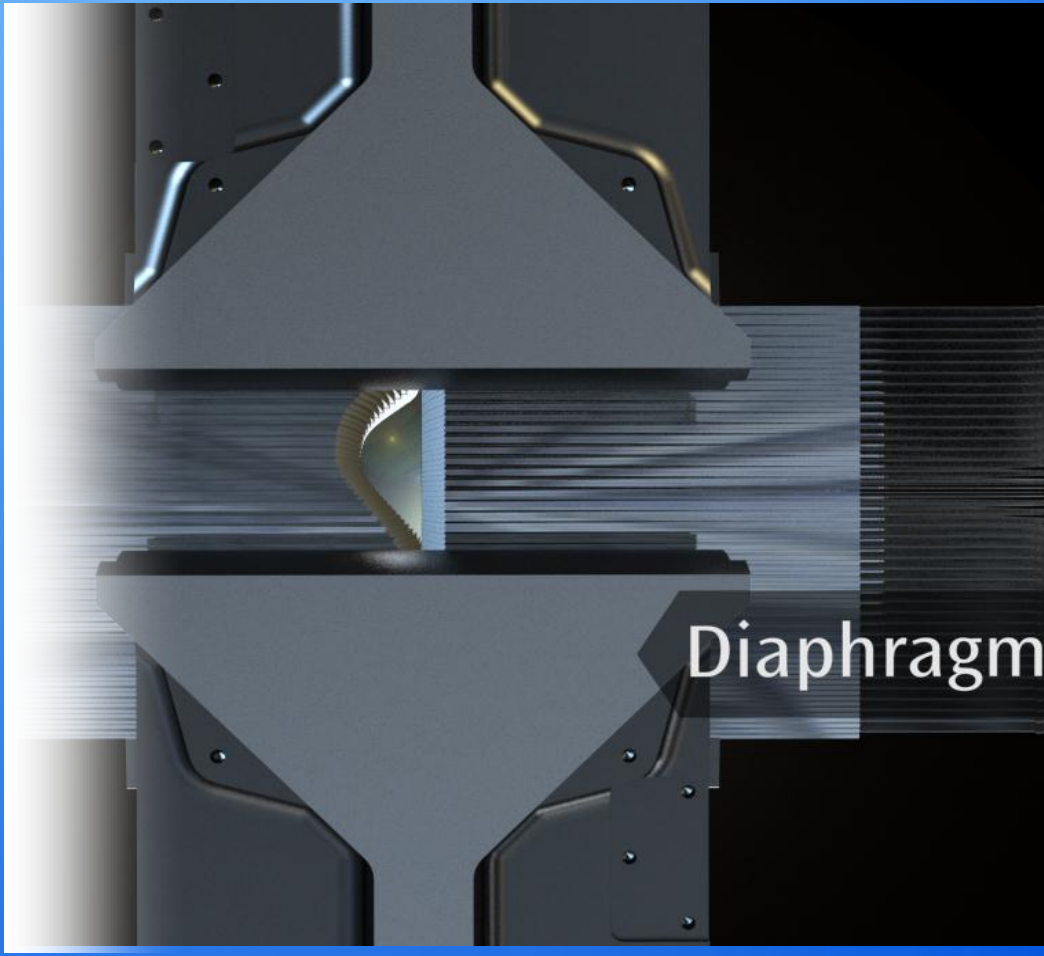


	Beam Modulator™
Width leaf (@iso)	4 mm
Number of leaves	80 (40 pairs)
Max field size (@iso)	16 cm x 21 cm
Over-travel	full
Focalized	single
Thickness	7.5 cm
Interdigitation	yes
Back-up collimator	no
Penumbra	< 4 mm (up to 5 cm x 5 cm) < 5 mm (up to 10 cm x 10 cm) < 6 mm (> 10 cm x 10 cm)
RT delivery	3DCRT-IMRT-VMAT

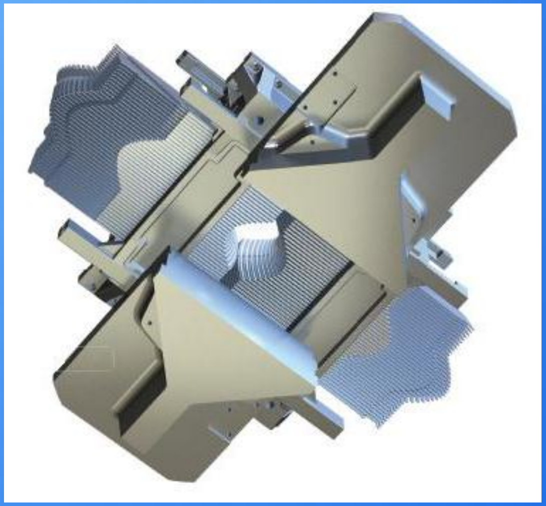
μMLC Elekta Apex™

	Apex™ (add-on)
Width leaf (@iso)	2.5 mm
Number of leaves	112 (56 pairs)
Max field size (@iso)	12 cm x 14 cm
Over-travel	¾ field size
Focalized	double
Thickness	8 cm
Interdigitation	yes
Junction	Tongue and groove
Penumbra	< 3.5 mm
RT delivery	3DCRT-IMRT-S&S no VMAT

MLC – the new Elekta configuration: complete upper replacement (opposite of Siemens design)



The Elekta MLC Agility^{TM}

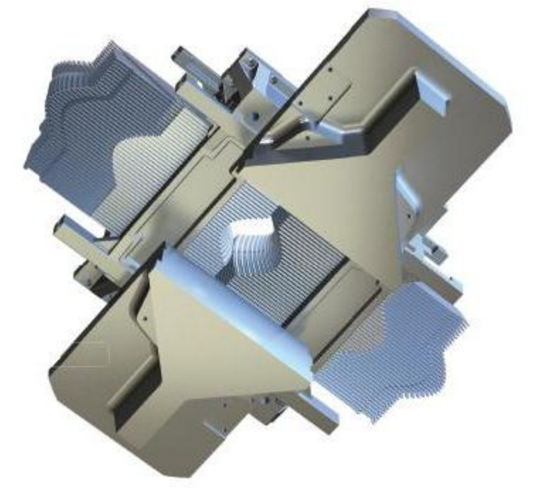


- Number of leaves: 160
- Interdigitation: yes
- Material: W-alloy leaves
- Width (@ isocentre): 5 mm
- The leaves are mounted on dynamic leaf guides that can move up to 15 cm; relative to the guide the leaves can extend up to 20 cm
- Leaf sides: flat
- The gaps between the leaves: tilted to reduce overall transmission
- The single pair of diaphragms are a novel, sculpted design to reduce their thickness where leaves will always provide additional shielding They move perpendicular to the MLC and can over-travel the central axis by up to 12 cm; both the leaf and diaphragm ends are rounded.

Agility™

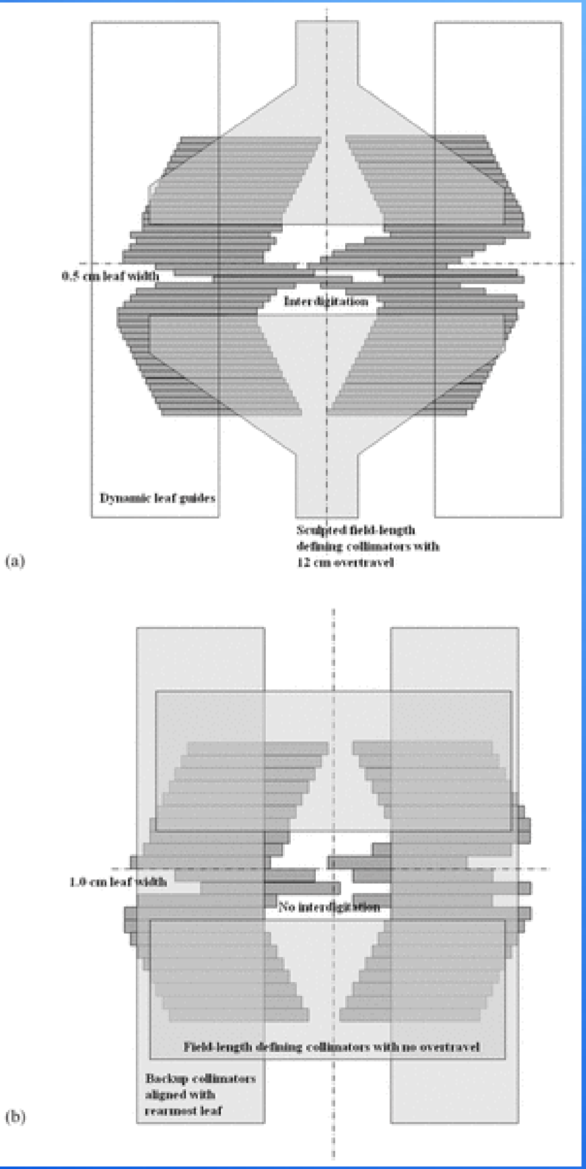
Attributes: Mechanical

Interdigitation capable	yes
Number of leaves	160
Nominal leaf width projection at iso-center	5 mm
Maximum field size	40 x 40 cm
Minimum recommended field size	0.5 x 0.5 cm
Maximum distance between leaves on same leaf guide	20 cm
Leaf travel over central axis	15 cm
Leaf nominal height	9 cm
Leaf positioning resolution	0.1 mm
Leaf positioning verification method	Optical
Diaphragm overtravel	12 cm



Head rotation	365°
Head weight	420 kg
Radiation head diameter	81.5 cm*
Head to isocenter clearance	45 cm
Head rotation speed for set-up	12°/ s maximum
Head rotation speed for dynamic delivery techniques	6°/s maximum
Leaf speed	Up to 3.5 cm/s Combined with leaf guide up to 6.5 cm/s
Diaphragm speed	Up to 9 cm/s
Maximum swept diameter	

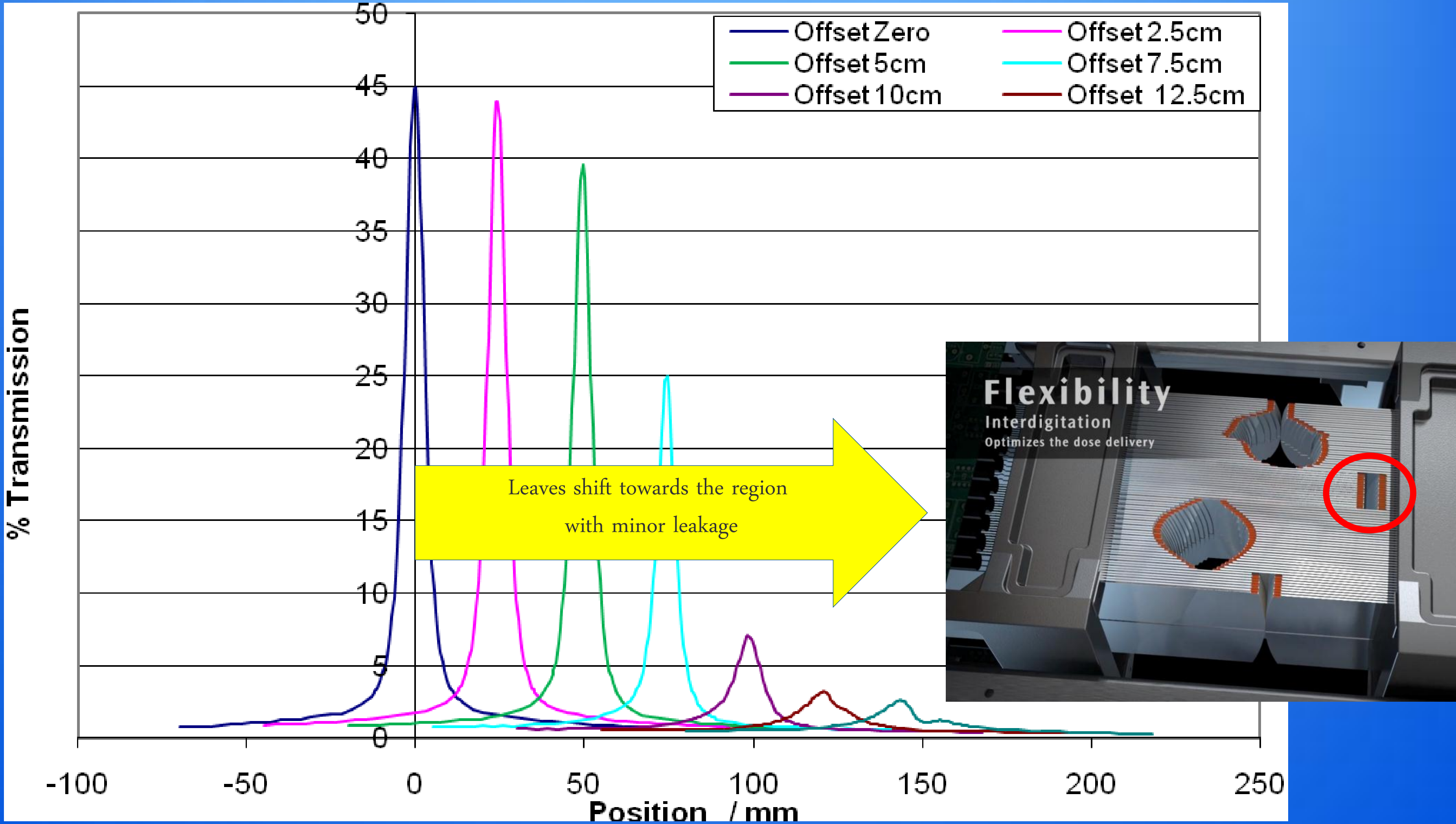
Elekta MLCs comparison



Characteristic	*Agility Head*	*MLCi Head*
Maximum field size (cm)	40 × 40	40 × 40
Leaf pitch (cm)	0.5	1.0
X[a] collimator range with respect to central axis (cm)	Not applicable	-12.5 to 20
Leaf guide range with respect to central axis (cm)	5 to 20	Not applicable
MLC leaf range with respect to guide (cm)	-20 to 0	Not applicable
MLC range with respect to central axis (cm)	-15 to 20	-12.5 to 20
Y[a] collimator range with respect to central axis (cm)	-12 to 20	0 to 20
Focus – MLC distance (cm)	31.8	29.8
MLC thickness (cm)	9.0	7.5
Maximum MLC leaf speed (cms^{-1})	3.5	2.0
Maximum X[a] collimator / leaf guide speed (cms^{-1})	3.0	2.0
Maximum Y[a] collimator speed (cms^{-1})	9.0	1.5

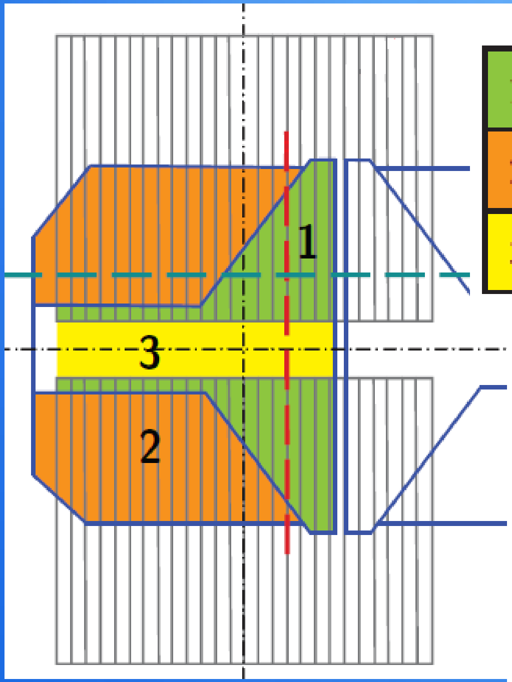
[a]IEC61217 convention.

Agility™

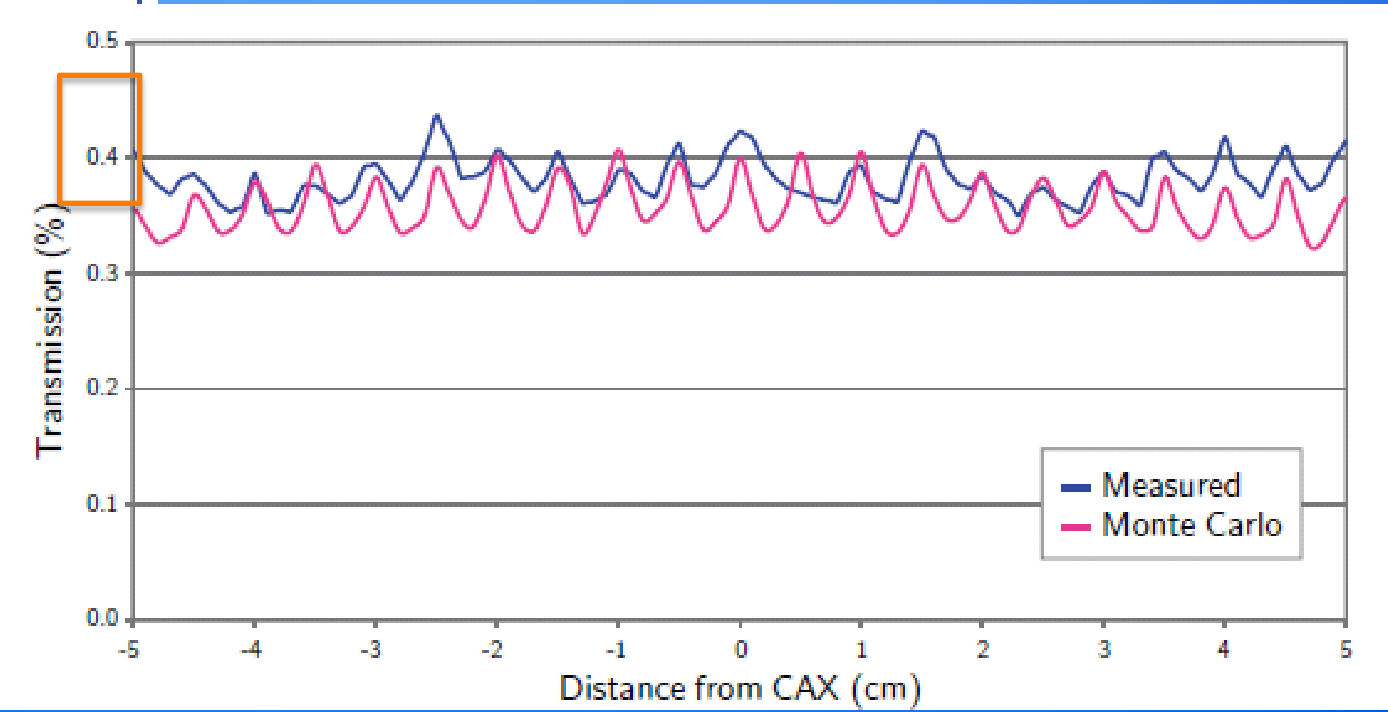


% Transmission
Position / mm
Offset Zero
Offset 2.5cm
Offset 5cm
Offset 7.5cm
Offset 10cm
Offset 12.5cm
Leaves shift towards the region
with minor leakage
Flexibility
Interdigitation
Optimizes the dose delivery

Agility™

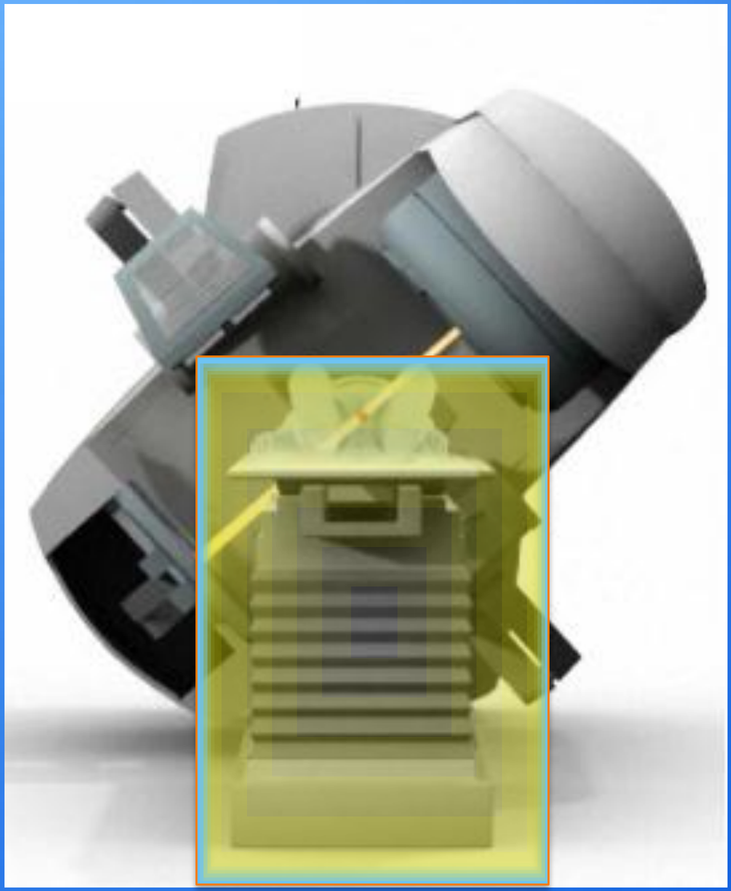


1	Leaves + $\text{Diaphragms}_{\text{Thick}}$	<0.07%
2	Leaves + $\text{Diaphragms}_{\text{Thin}}$	<0.13%
3	$\text{Diaphragms}_{\text{Thick}}$ alone	<0.35%



Outline

✓ **PATIENT SUPPORT TREATMENT COUCH**



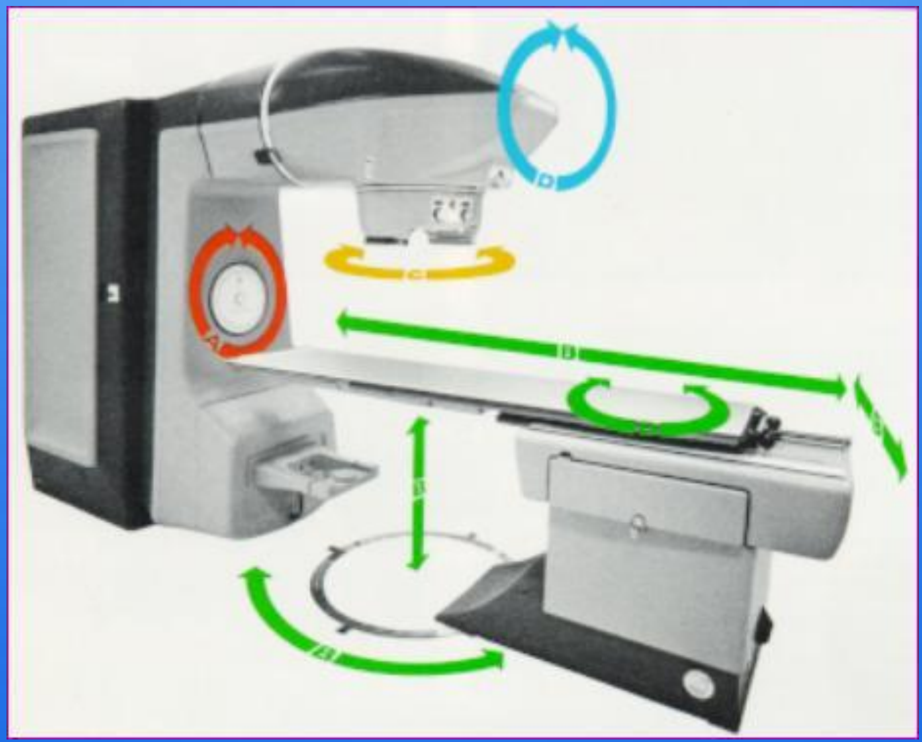
Patient-support

- Patient support and positioning devices are designed to implement a given treatment technique
- Important criteria include patient comfort, stability, and reproducibility of set-up and treatment geometry that allows accurate calculation and delivery of dose

Treatment couch - movements

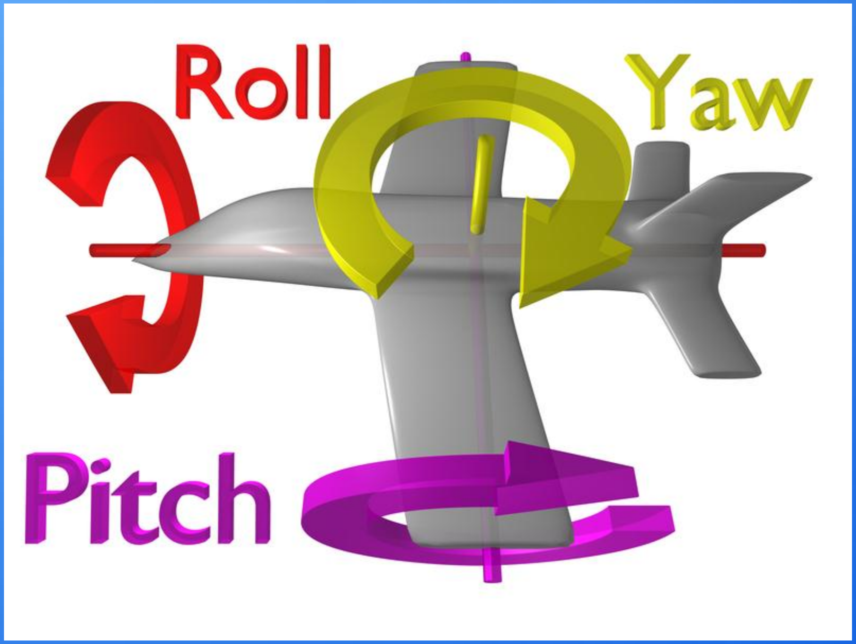
4 degrees of movements: vertical, transversal, longitudinal, yaw

6 degrees movements: vertical, transversal, longitudinal, yaw, **pitch, roll** (with remote robotic control capability)



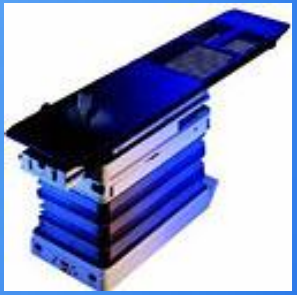
Treatment couch - rotations

- PITCH: rotation around the X-axis
- ROLL: rotation around the Y-axis
- YAW: rotation around the Z-axis



Treatment couch - tabletop

- Current linac couch has special top consisting in a carbon fiber table
- The carbon fiber plates sandwiched with a plastic foam core
- The carbon fiber construction ensures that no metal parts are used in the entire treatment area



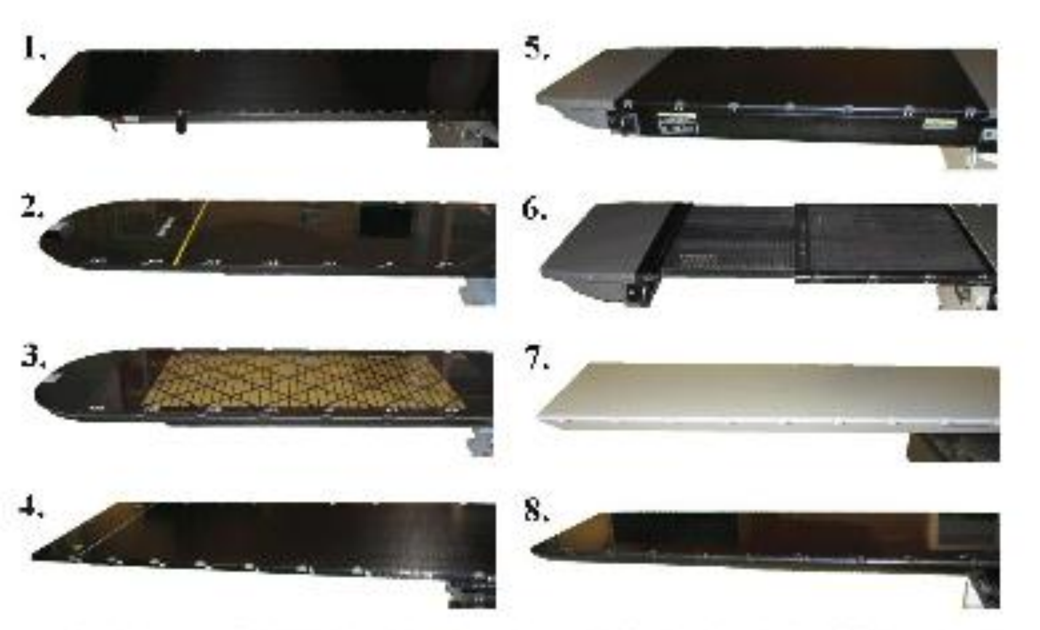


FIG. 1. Couch inserts studied: 1) BrainLAB imaging couch top, 2) Qfix kVue Standard, 3) Qfix kVue DoseMax, 4) MEDTEC model MT-IL 3303, 5) universal sandwich panel, 6) Varian grid insert, 7) DIGNITY AirPlate, 8) Varian Exact IGRT couchtop.

Seppala, Kulmala, J App Cl Med Phys 12(4), Fall 2011

Elekta HexaPOD™ evo (6 DOF)

baseboard

IGRT module

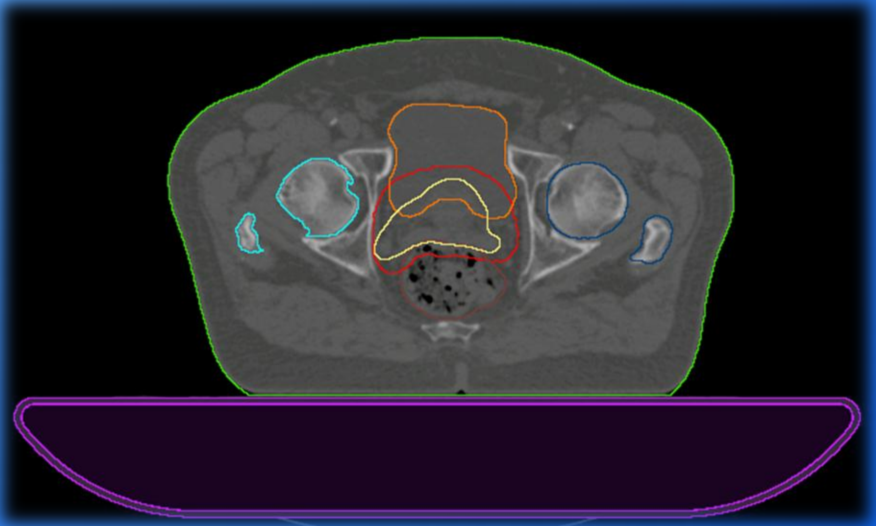
Connexion Short Indexing Bar

Varian Exact™ IGRT (4 DOF)

Varian PerfectPitch™ (6 DOF)

The impact of treatment couch on the calculation of dose

- Many papers in literature recommend that the <u>couch be included in the treatment planning</u> for all treatments that involve posteriors beams (**6 MV**)
- **VMAT**!
- **Modeling the couch in the TPS**
- There is also a loss of skin sparing (increase in skin dose), the degree depending on the dose prescription, the amount of the beam passing through the couch and the angle of incidence



IOP Publishing Physics in Medicine and Biology

Phys. Med. Biol. 54 (2009) N157–N166 doi:10.1088/0031-9155/54/9/N03

NOTE

The impact of treatment couch modelling on RapidArc

Eugenio Vanetti, Giorgia Nicolini, Alessandro Clivio, Antonella Fogliata and Luca Cozzi[1]

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Online at stacks.iop.org/PMB/54/N157

Abstract

A planning and dosimetric study was carried out on a cohort of six CT datasets from patients treated for prostate cancer to assess the impact of couch modelling on the accuracy of dose calculation for the volumetric modulated arc technique RapidArc. For each patient, RapidArc plans were optimized using the couch while final dose calculation was performed with different conditions (thin, medium, thick and no couch). Analysis was performed in terms of dose volume histograms, dose difference histograms and 3D-γ tests. Pre-treatment verification measurements were performed using the PTW-729 array in conjunction with the Octavius phantom (PTW, Freiburg); similarly, HU characterization of couch was performed with the same phantom and ion chamber measurements comparing calculations and experimental data. A set of Hounsfield Units (HU) valid for low and high energy and the entire couch length was found as internal structure HU = −960, surface shell HU = −700. Analysis of dose plans showed that differences larger than 1.5 Gy for a 70 Gy prescription might be observed on significant fractions of PTVs. Smaller differences are visible in the medium low-dose regions. Pre-treatment verification on composite delivery confirmed these observations and, at the same time, showed good accuracy of dose calculations in the presence of couch modelling compared to delivery in the same conditions (GAI ranging from 95% to 100%). Results confirmed the reliability of the geometrical model build in the planning system Eclipse, and (i) there is no measurable effect if the wrong segment of the couch is used in the calculations; (ii) there are significant discrepancies of potential clinical impact at the level of the target volumes if calculations are performed without couch and delivery is performed with couch, and (iii) the effect is particularly relevant at low energy (6 MV in this

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Phys. Med. Biol. 56 (2011) 7435–7447 doi:10.1088/0031-9155/56/23/007

The clinical impact of the couch top and rails on IMRT and arc therapy

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Abstract

The clinical impact of the Varian Exact Couch on dose, volume coverage to targets and critical structures, and tumor control probability (TCP) has not been described. Thus, we examined their effects on IMRT and arc therapy. Five clinical prostate patients were planned with both 6 MV eight-field IMRT and 6 MV two-arc RapidArc techniques using the Eclipse treatment planning system. These plans neglected treatment couch attenuation, as is a common clinical practice. Dose distributions were then recalculated in Eclipse with the inclusion of the Varian Exact Couch (imaging couch top) and the rails in varying configurations. The changes in dose and coverage were evaluated using the dose-volume histograms from each plan iteration. We used a TCP model to calculate losses in tumor control resulting from not accounting for the couch top and rails. We also verified dose measurements in a phantom. Failure to account for the treatment couch and rails resulted in clinically unacceptable dose and volume coverage losses to the targets for both IMRT and RapidArc. The couch caused average prescription dose losses (relative to plans that ignored the couch) to the prostate of 4.2% and 2.0% for IMRT with the rails out and in, respectively, and 3.2% and 2.9% for RapidArc with the rails out and in, respectively. On average, the percentage of the target covered by the prescribed dose dropped to 35% and 84% for IMRT (rails out and in, respectively) and to 18% and 17% for RapidArc (rails out and in, respectively). The TCP was also reduced by as much as 10.5% (6.3% on average). Dose and volume coverage losses for IMRT plans were primarily due to the rails, while the imaging couch top contributed most to losses for RapidArc. Both the couch top and rails contribute to dose and coverage losses that can render plans clinically unacceptable. A follow-up

GRAZIE!...
And …sorry for my "englishitalian"