MODERN EQUIPMENTS & ITS ROLE IN HYPO-FRACTIONATION

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Hypofractionation

- ‘‘Because the greatest part of the time used to treat a patient is spent on the set-up, the actual treatment time being only a fraction of the total time, it was logical to use fewer large fractions to decrease machine time.’’ – **Gilbert Fletcher**

- Hypofractionated radiation therapy treatment in which the total dose of radiation is divided into large doses and treatments are given over a shorter period of time (fewer days or weeks) than standard radiation therapy

TELETHERAPY EQUIPMENTS

- Telecobalt units
- Linear accelerator
- Gamma Knife
- View Ray
- MRI Guided LINAC
- Tomotherapy
- Cyber knife
- Proton Accelerator
- HDR machines
- Electronic Brachytherapy

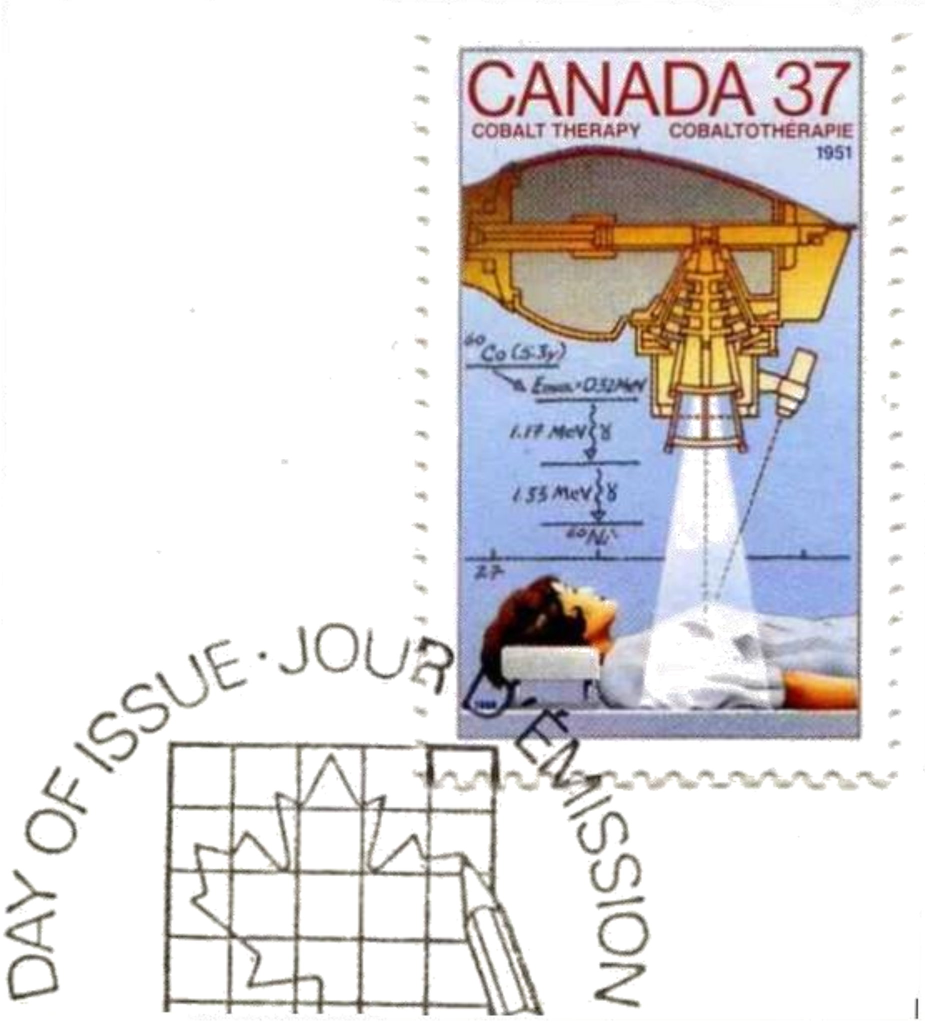
TELECOBALT UNITS

- Most often mounted isocentrically with SAD of 80 cm or 100 cm
- The main components of a teletherapy machine are:
  - Radioactive source
  - Source housing, including beam collimator and source movement mechanism
  - Gantry and stand
  - Patient support assembly
  - Machine control console

TELE COBALT UNIT

Cobalt-60 teletherapy machine, Theratron-780, AECL (now MDS Nordion), Ottawa, Canada

Telecobalt machines



- Cobalt-60 teletherapy machine depicted on a postage stamp issued by Canada Post in 1988
  - In honor of Harold E. Johns, who invented the cobalt-60 machine in the 1950s.

Telecobalt sources

- Telecobalt sources are cylinders with height of 2.5 cm and diameter of 1, 1.5, or 2 cm
  - The smaller is the source diameter, the smaller is the physical beam penumbra and the more expensive is the source.
  - Often a diameter of 2.0 cm is chosen as a compromise between the cost and penumbra.
- Typical source activity: of the order of 5 000 – 10 000 Ci (185 – 370 TBq).
- Typical dose rates at 80 cm from source: of the order of 100 – 200 cGy/min

Teletherapy source housing

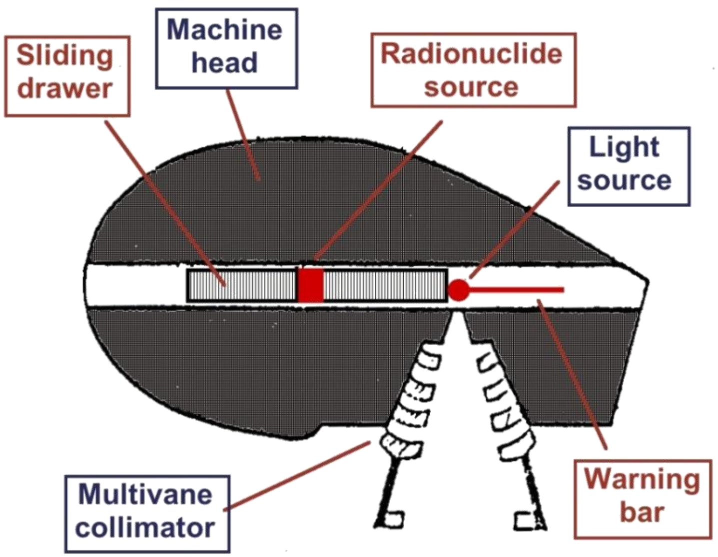
- The source head consists of:
  - Steel shell with lead for shielding purposes
  - Mechanism for bringing the source in front of the collimator opening to produce the clinical gamma ray beam.

- Currently, two methods are used for moving the Tele-therapy source from the BEAM-OFF into the BEAM-ON position and back:
  - Source on a sliding drawer
  - Source on a rotating cylinder

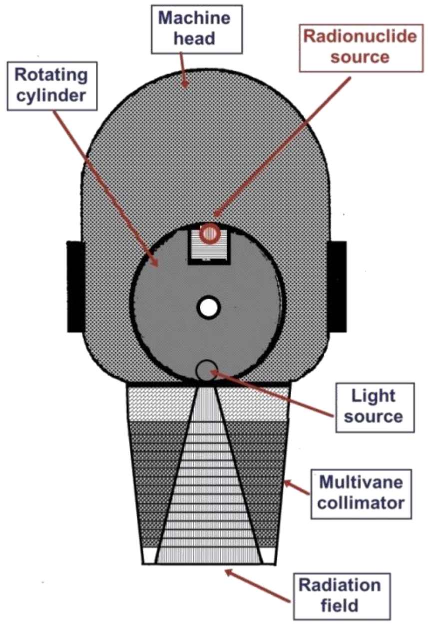
Teletherapy source housing

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

Source on a sliding drawer



Source on a rotating cylinder



Teletherapy source housing

- Some radiation (leakage radiation) will escape from the teletherapy machine even when the source is in the BEAM-OFF position.

- Head leakage typically amounts to less than 2 mR/h (0.02 mSv/h) at 1 m from the source.

- International regulations require that the average leakage of a teletherapy machine head be less than 20 mR/h (0.2 mSv/h).

Dose delivery with teletherapy machines

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

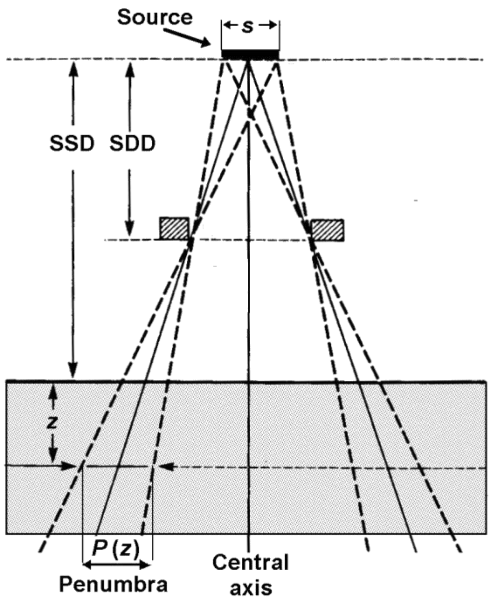
- The set treatment time should incorporate the shutter correction time to account for the travel time of the source from the BEAM-OFF to the BEAM-ON position at the start of the irradiation and for the reverse travel at the end of irradiation.

Collimator and penumbra

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

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

$$\frac{P(z)}{s} = \frac{(SSD + z - SDD)}{SDD}$$



Linear Accelerator

- Unlike in x-ray tube it is not possible to apply high voltage of a few MV for acceleration due to insulation considerations
- In linear accelerator a high electric field is established in the accelerator tube by applying radiofrequency (RF) power and this helps in accelerating electrons in a linear path

RF power

- To produce high electric field of the order of 75-150 KV/cm in an accelerator tube, a radiofrequency (RF) source of power from microwave cavities is used from magnetron or klystron
- A magnetron is an oscillator cum power amplifier in the frequency range 3000MHz.
- The RF power can also be produced by a klystron which is a power amplifier.
- This requires a RF generator for low power input.
- The output power from the RF source is transported to accelerator tube by special waveguides.
- The RF power is produced in pulses.

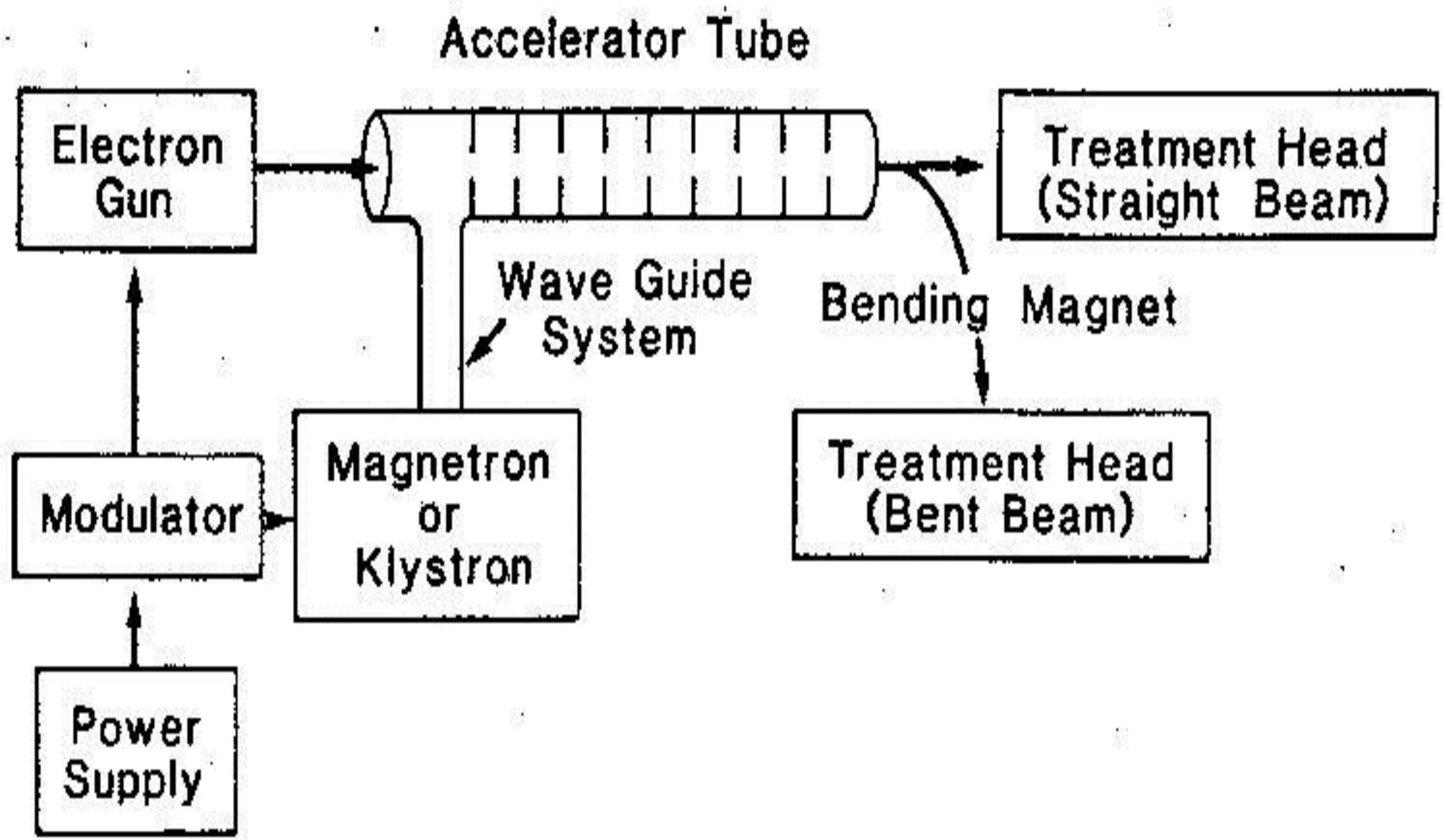
Accelerator structure

- Accelerator tube consists of a long series of evacuated microwave cavities
- In the travelling wave type of structures, the RF power establishes a travelling wave using the adjacent coupling cavities
- In the standing wave structure the adjacent disks are coupled by a side coupling cavity
- For a given input power the standing wave structure produces double the electric field compare to TW tube
- The length of the tube is about 35cm for low energy LINAC of about 6MV with standing wave structure and about 100 cm for a high energy accelerator in the energy range 10-18MV

Energy

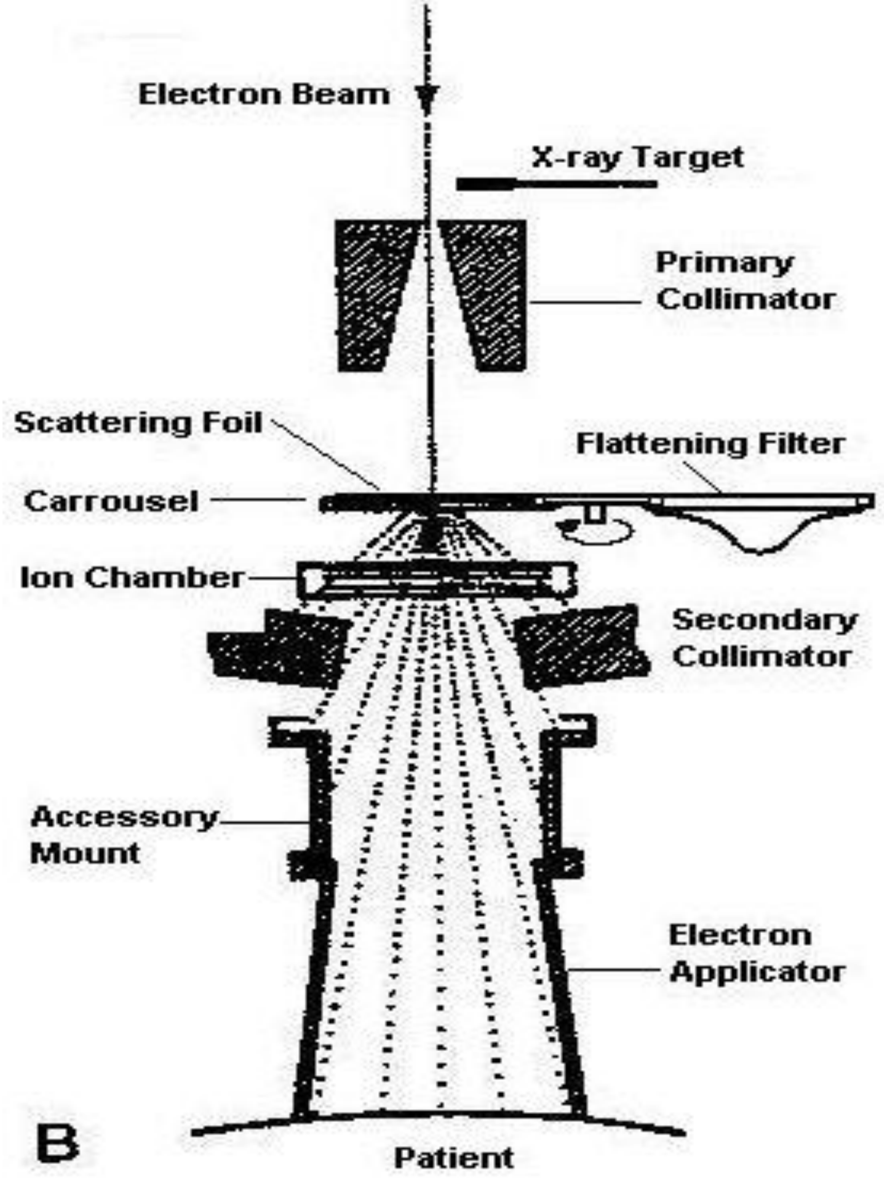
- The electrons injected by the electron gun are accelerated and passes through a thin low Z window as electron beam.
- The energy of the electrons can be increased by increasing the applied microwave power or the length of the tube or by careful design and fabrication of the tube

Block diagram- Accelerator



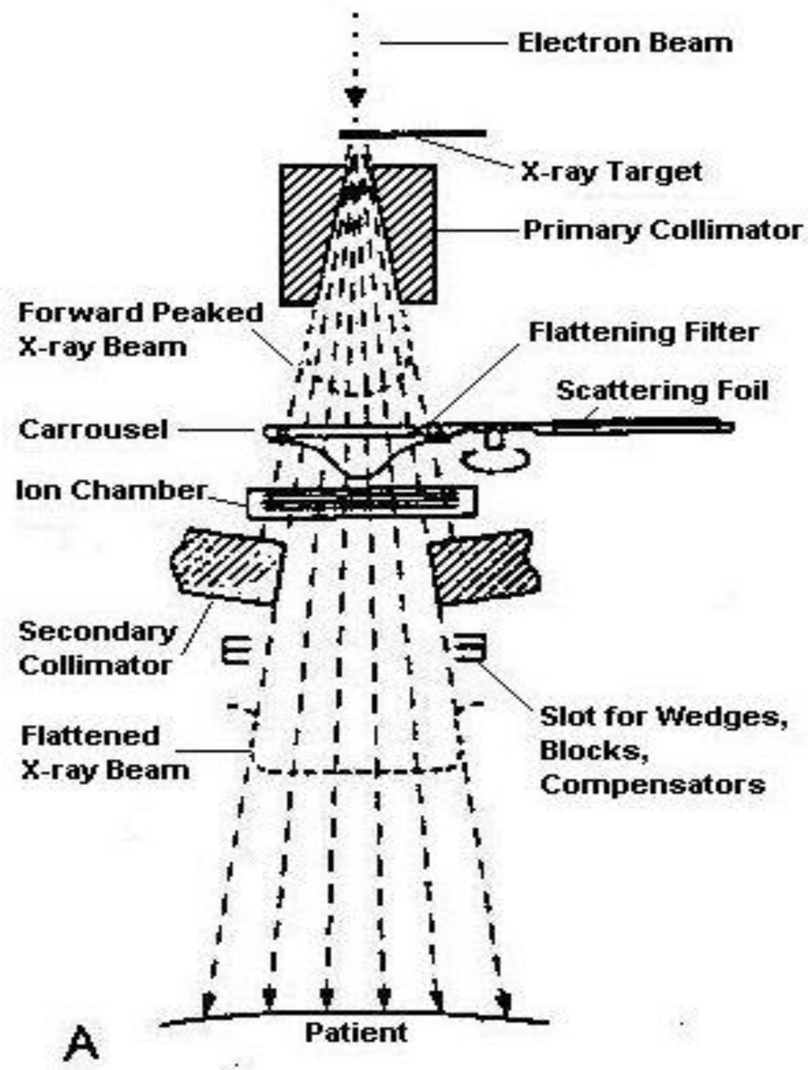
Treatment head- Electron Beam

- The head contains a number of components like bending magnet to turn the electron beam for useful direction by bending through 90 degree (or) 270 degree
- The smaller diameter (3mm) electron beam is made to pass through a high Z scattering foil to broaden the electron beam and comes out as electron beam for treatment
- This beam passes through a pair of transmission type ion chamber to monitor the beam in terms of symmetry, uniformity and dose output



Treatment head- Photon Beam

- For X-rays the narrow electron beam is made to impinge on a transmission high Z target to produce X-rays.
- These X-rays passes through a flattening filter before entering the monitor chambers.
- The beam is then collimated by a primary and secondary collimator to achieve rectangular or square field for treatment.
- An accessory mount at the bottom of the head is provided to place beam modifiers like wedge filters, beam shaping blocks and electron applicators in some units



Various systems-Modulator

- The modulator cabinet or region contains high voltage components coils, capacitors etc.., charging and discharging circuits, main and DQ thyratrons etc.. sometimes these are located in the stand of the unit
- The high voltage is applied to the anode of the RF sources like magnetrons and klystrons
- The RF produced is transported through special wave guides
- Usually the RF is a pulsed power with a pulse duration of few micro seconds and a pulse repetition rate of multiples of power supply frequency

Vaccum pump

- A high efficiency ion pump is used to maintain Vaccum in accelerator tube
- The pressure inside the tube is about 10 -70 Torr.
- A display system gives the pressure at a given time

SF-6 gas system

- The RF source of power before entering into accelerator structure is filled in wave guide and this may produce arcing in this volume and cause damage due to high electric field and to prevent this, it is filled with dry SF-6 gas

Cooling system

- The main components like ion pump, bending magnets, RF sources, wave guides, target etc produce heat during their operations
- In order to prevent from damage to these components due to excessive heat and to improve the performance of various systems the temperature is maintained by circulating demineralised good quality of water at the desired pressure and fluoride by pumping demineralised water stored in a tank
- This demineralized water is also cooled by a secondary cooling system by water cooler.
- The temperature is monitored and controlled

Target or scattering foil

- The X-ray target is usually a high Z material like tungsten of about a mm thick to stop the high energy electrons and produce X-rays by bremsstrahlung

- The forward distribution of beam of X-rays is flattened by accurately positioned conical suitably designed flattening filters made out of heavy materials like stainless steel etc. the target is surrounded by a flowing water jacket to remove the heat produced

- The scattering foils of a few mm thick and of a high Z material like gold etc is used to broaden the narrow electron beam into a broad beam by scattering that is required for treatment. Foils of different thicknesses may be used for different electron energy ranges

Dosimetry system

- Both X-rays and electron beams are made to pass through to two sets of pair of specially designed ion chambers known as monitor chambers to monitor the beam flatness and symmetry and take corrective action for deviation from functional design

- Further these also serve as dosimeters and as monitor chambers to measure dose rate and integrated doses

- The beam outputs are usually in the range 200-500cGy/min at isocentre

Collimators

- The X-rays produced is passed through a long primary collimator and required fields can be set by using secondary collimator which are usually two pairs of movable tungsten blocks located in two planes and movable in perpendicular direction to beam
- The fields are visualized by an optical system
- In modern accelerators one of the jaws are replaced by MLC or added as a territory collimator

Control console

- The control console has facilities to select and set many parameters for treatment like type of radiation whether X-rays or electron mode, the energy of the beam, type of technique like fixed, arc etc.. arc angles, dose , time of treatment etc. it also displace various functional and safety interlocks

Interlocks

- A number of safety and functional related interlocks are provided to know the status or safety related problems faced in the machine leading to stopping of the beam production the interlocks help in identifying problem areas for taking remedial measures

- Some examples of interlocks are door interlock, water flow, power supply, modulator, dose rate, temperature, RF arcing, energy, bending magnet etc

Patient couch

- The patient couch is of a robust low density and high precisions system commensurate with treatment machine
- This has longitudinal movements in three directions and rotation facility
- Mechanical and electrical scales are provided
- Couch rotation axis pass through isocentre
- Thin window for posterior port is also available
- Modern units are provided 6D couch (yolk, pitch & roll)

Networking

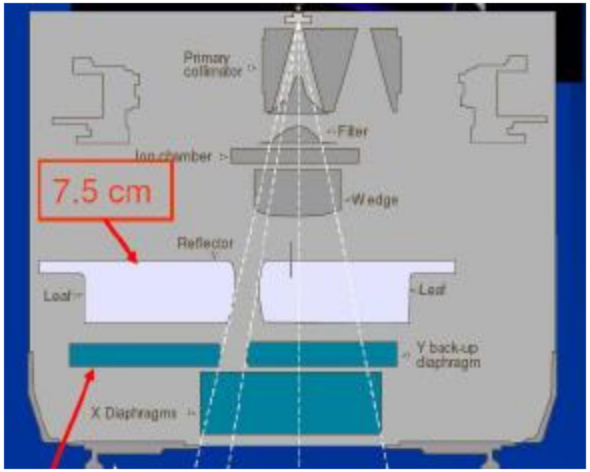
- In view of the digital electronics and communication systems available now, it is possible to interconnect work stations like CT scanner, MRI, simulators or CT simulator, nuclear imaging systems, treatment planning systems, electronic treatment charts, record and verify systems including portal imaging systems, scheduling, billing and hospital administrative system

Recent developments

- Digital electronics technology made possible to design and incorporate dynamic wedges replacing the physical wedges
- An important development is the introduction intensity modulated radiation therapy (IMRT) for achieving conformal radiation therapy
- Advanced systems can perform dynamic conformal therapy
- Portal imaging for verification of reproducibility of field are also possible
- There are special machines for dedicated treatments like stereotactic radio surgery or therapy
- Some are provided with high dose rate mode which will be useful for total skin electron therapy or total body irradiation

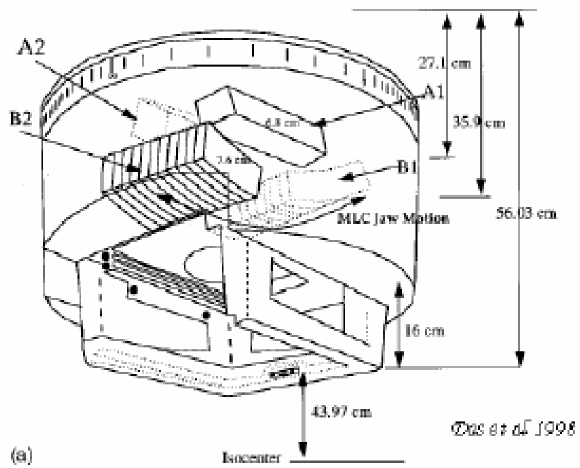
MLC DESIGN IN ACCELERATORS

Elekta



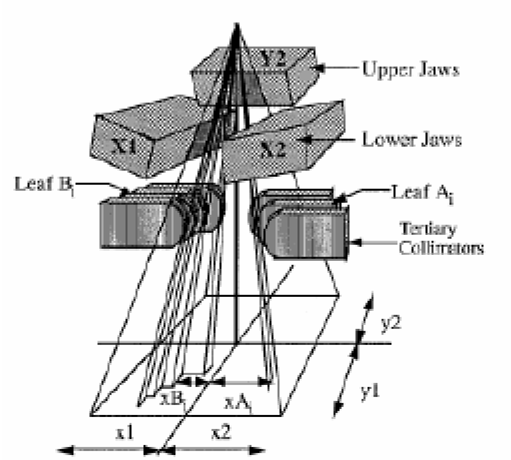
- MLC-Upper jaw replacement
- 40 x 40 cm Field size
- 12.5 cm Leaf over travel
- opposing leaves do not touch
- Rounded leaf MLC
- Step & shoot Delivery

Siemens



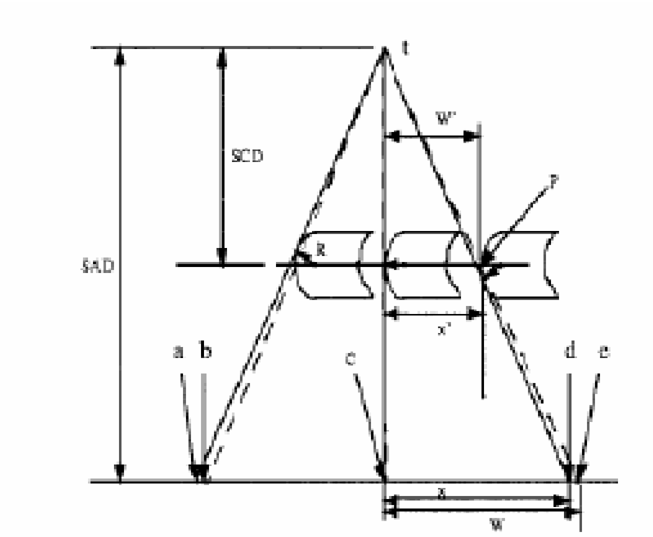
- MLC-Lower jaw replacement
- 58 Leaves (54x10mm;4 x 65 mm)
- 82 leaves (78 x10 mm; 4 x 5 mm)
- 160 leaves (160x5 mm)
- Step & Shoot Delivery
- 10 cm over travel
- 40 x 40 cm field size
- Double focused

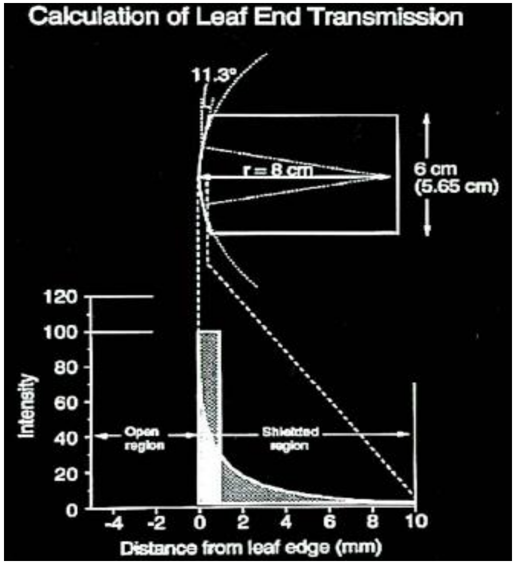
Varian

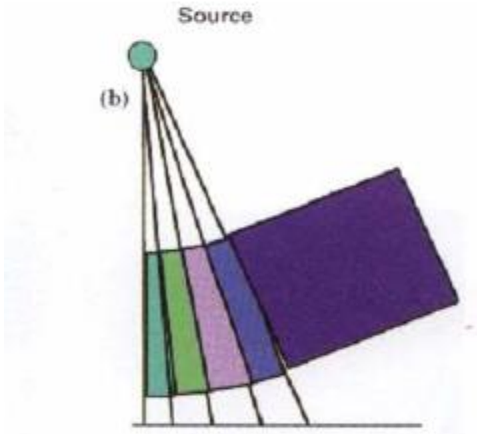


- MLC- Tertiary collimator
- Tip is rounded to produce constant penumbra for different displacements
- 80 leaves (80x10 mm)
- 120leaves(80x5mm;40x10mm)
- 15 cm Leaf Over travel
- Step & shoot , Dynamic IMRT

EFFECT OF LEAF EDGE ON PENUMBRA

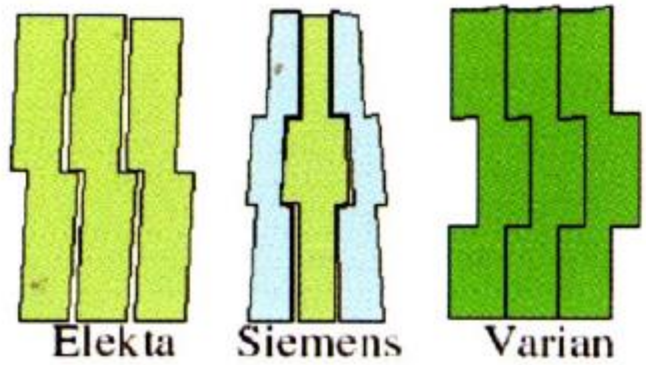




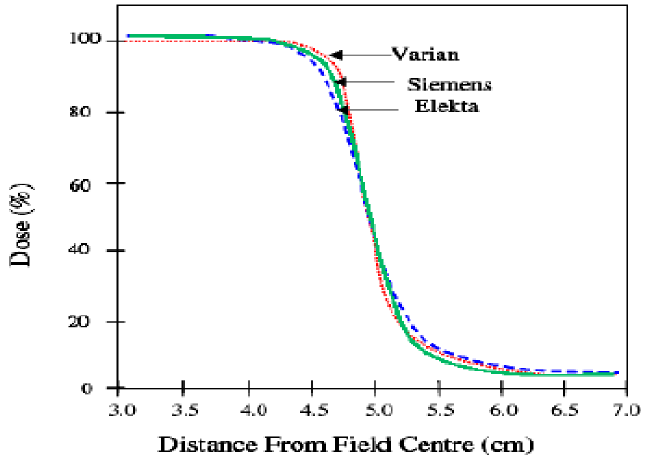


Round Edge- Varian & Elekta

Flat diverging edge- Siemens

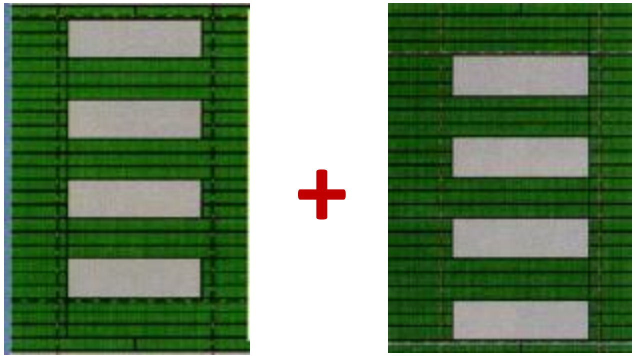


Leaf Design with Tongue & Groove

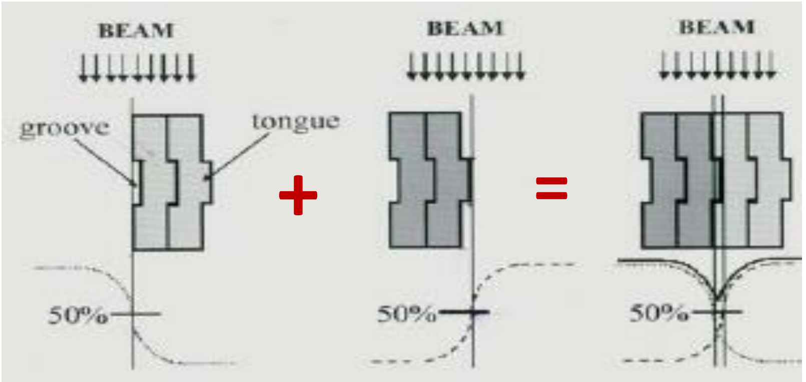


Penumbra with leaf design

Tongue & Groove Effect

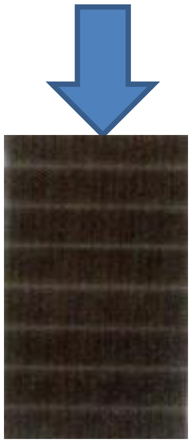


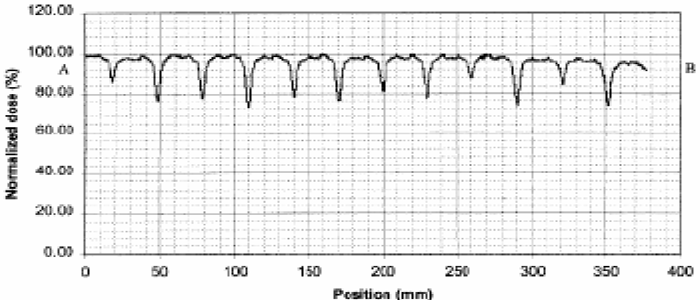
Film exposed with matching fields



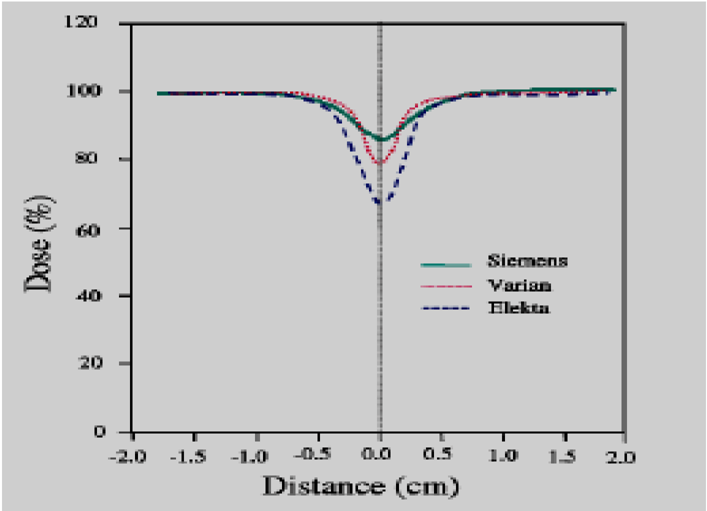
Intensity variation due to Tongue & Groove

Processed Film



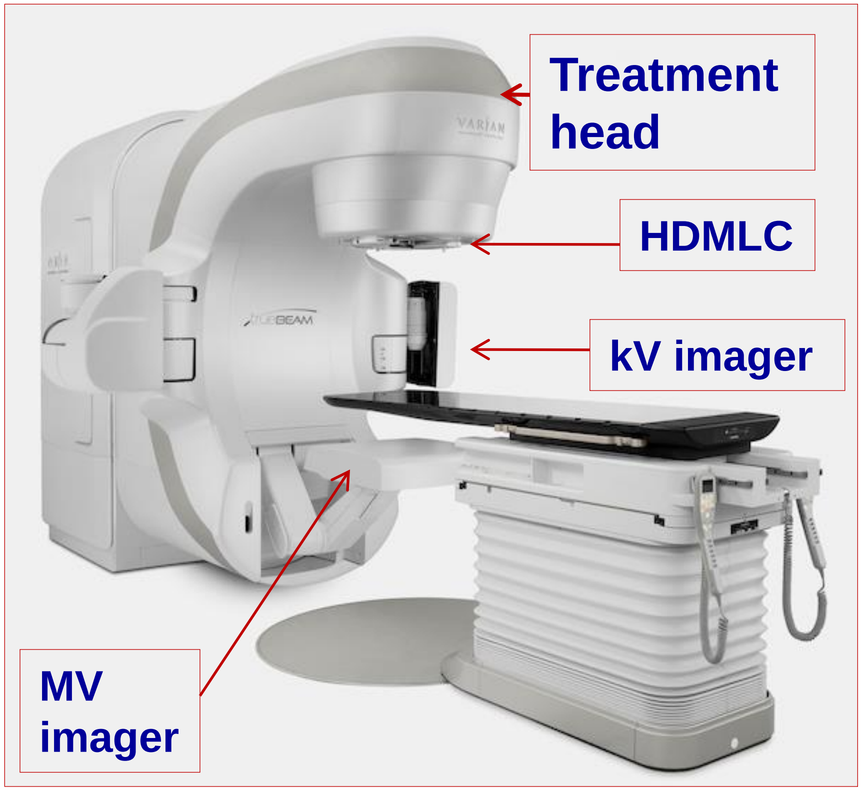


Profile showing Tongue & Groove Effect



Dose Variation due to Tongue & Groove Effect

Commercial Accelerators



Varian

Elekta

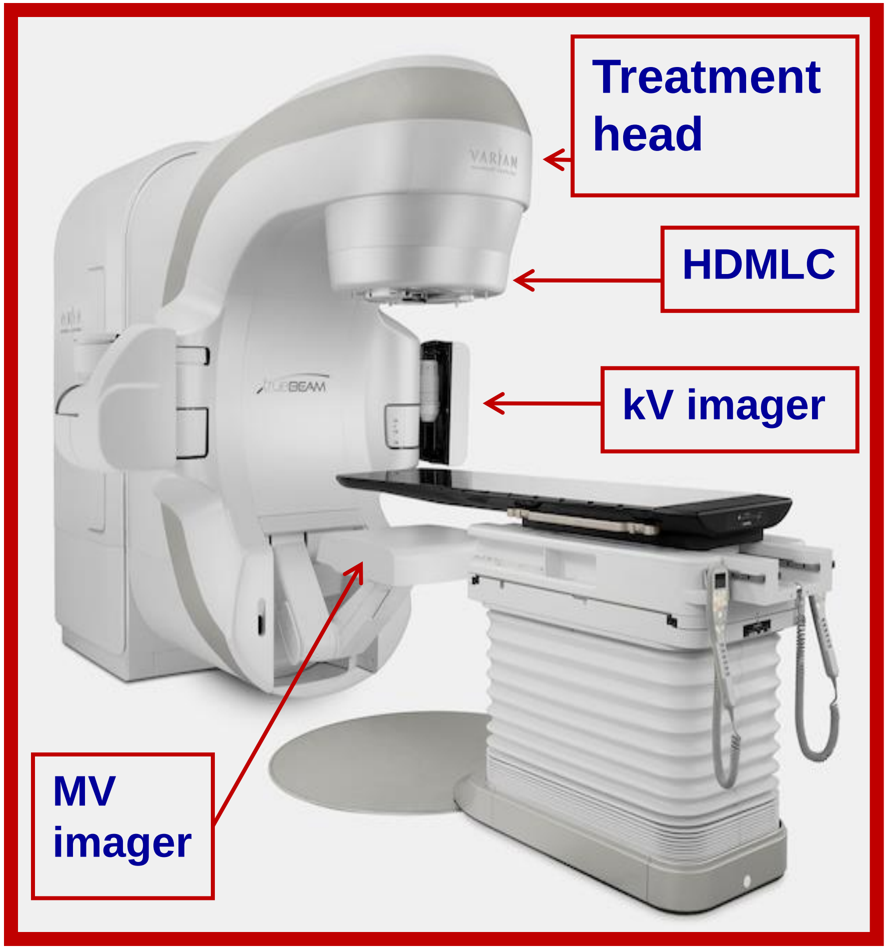
FFF Photon Beam LINAC

- Contains waveguide system, carousel assembly, beam generation, and monitoring control system which differs from the precedingaccelerators

- Photon energies: X6, X6FFF, X10, X10FFF

- Dose rates:
- 100 to 600 MU/min - X6 & X10
- 400 to 1400 MU/min - X6FFF
- 400 to 2400 MU/min - X10FFF

- 120 leaves HDMLC:
- Central 32 pairs – 2.5 mm
- Peripheral 28 pairs – 5.0 mm
- Total length across MLC = 22 cm



FFF beam

Distinct characteristics

- different beam profile
- higher dose rate
- different photon energy spectrum
- different head-scatter properties

Unique features to FFF beams

- sharper penumbra
- less head scatter
- less out-of-field dose
- increased ion recombination in dosimeter

Characteristics of commercially available FFF beams

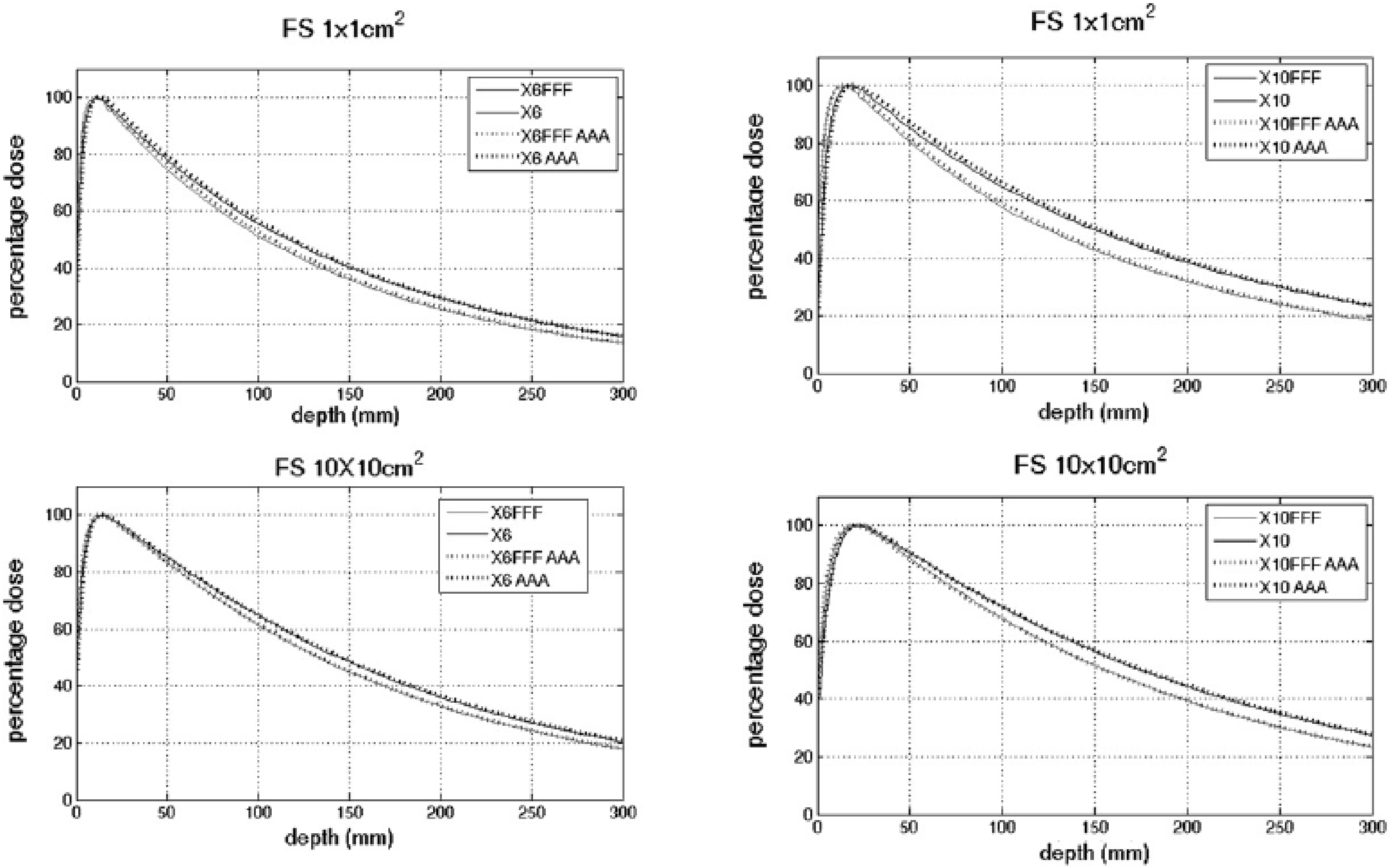
TABLE 1. Characteristics of commercially available FFF beams. All dosimetric quantities are given for a 10×10 cm^2 field at 100 cm SSD unless otherwise noted and were provided by the manufacturers.

	Varian		*Elekta*		*Siemens*			
Nominal energy (MV)	6 FFF	10 FFF	6 FFF	10 FFF	7 UF	11 UF	14 UF	17 UF
Bremsstrahlung target material	Tungsten		Tungsten		Tungsten			
Approximate mean electron energy on target (MeV)	6.2	10.5	7	10.5	8.9	14.4	16.4	18.3
Filtration	0.8 mm Brass		2mm Stainless steel		1.27 mm Al			
d_{max} (cm)	1.5	2.3	1.7	2.4	1.9	2.7	3.0	3.3
Dose at 10 cm depth (%)	64.2	71.7	67.5	73.0	68.5	74.5	76.5	78.0
Dose 10 cm from central axis (40×40 cm^2 field), at d_{max} (%)	77	60	70[a]	59[a]	68	57	-	-
Maximum dose rate on beam axis at d_{max} (cGy/min)	1400	2400	1400	2200	2000	2000	2000	2000
Dose per pulse on beam axis at d_{max} (cGy/pulse)	0.08	0.13	0.06	0.09/0.14[b]	0.13	0.13	0.13	0.13

[a] Defined at 90 cm SSD, 10 cm depth
[b] Feedback/nonfeedback machine.

FFF: Depth Dose

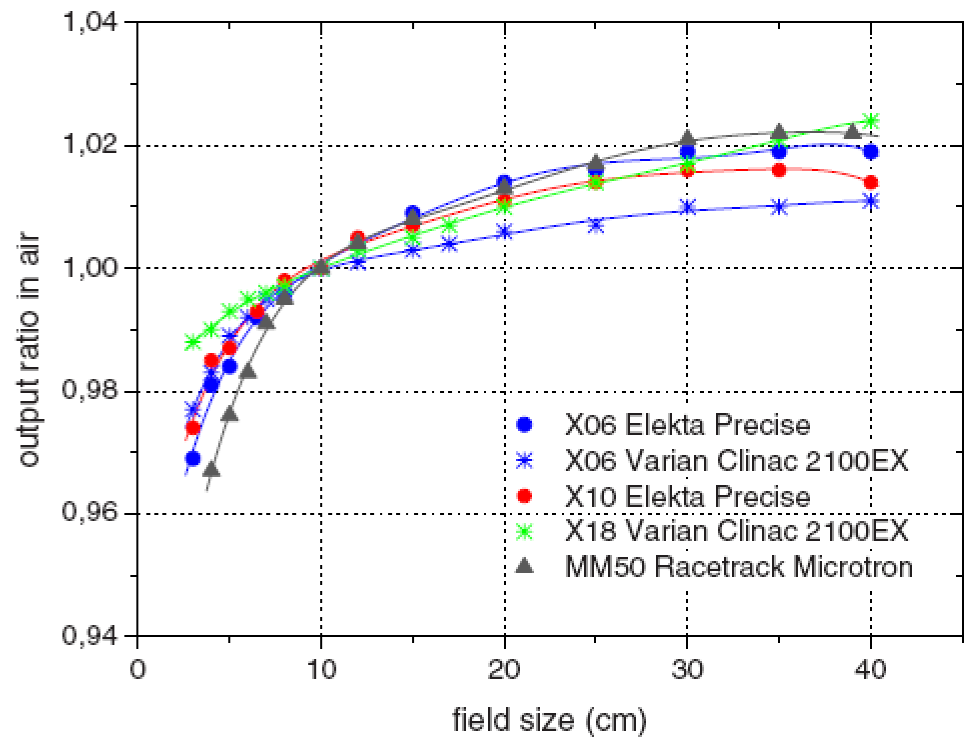
6 MV FFF corresponds to 5 MV FF
18 MV FFF corresponds to 15 MV FF



d_m: nearly insensitive to FS variation **Steeper dose fall off in exponential region**

Head Scatter Factor (Sc) for FFF LINAC

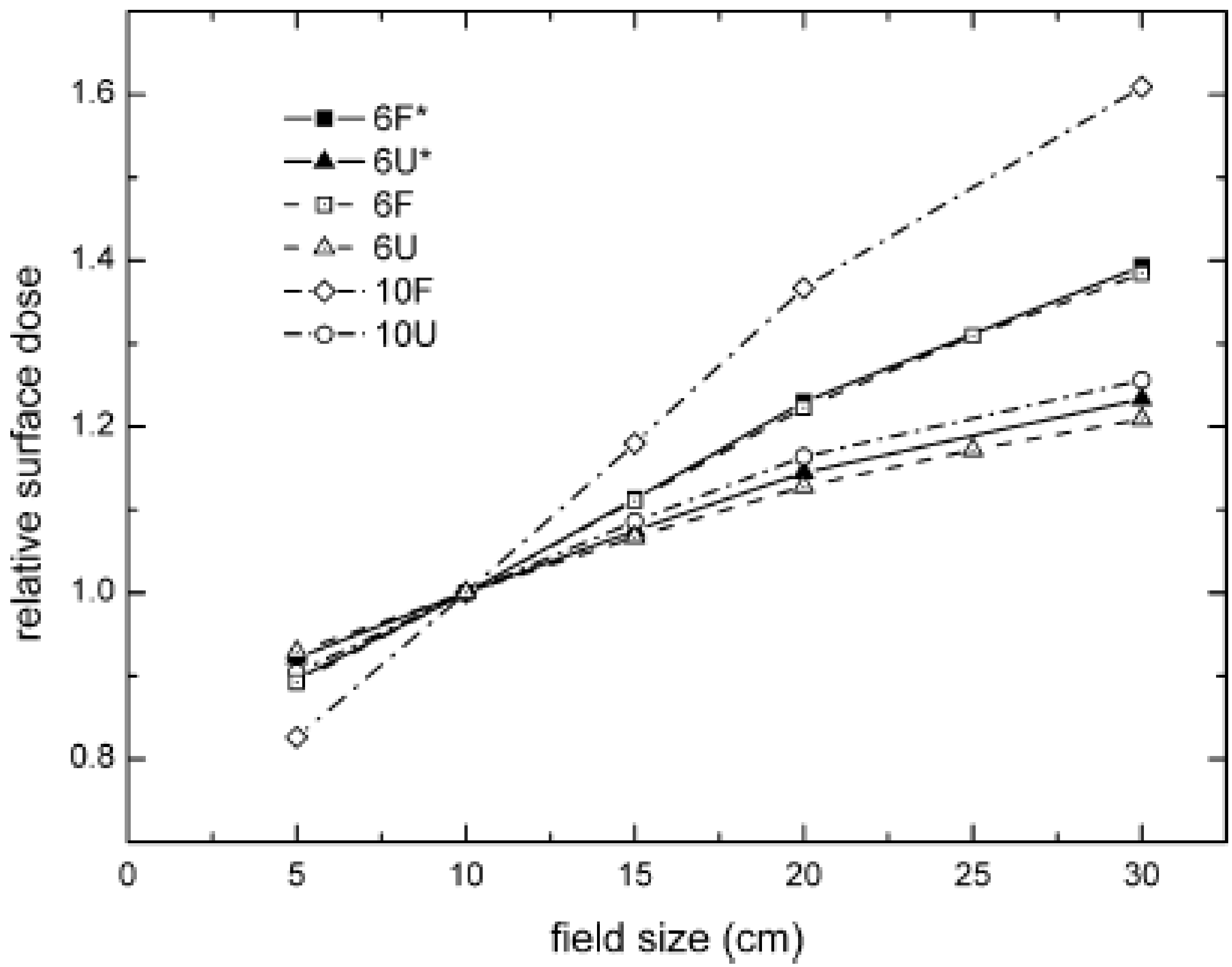
- X6FFF: 1.5% for field sizes 5x5 to 20x20 cm^2
- X6FF: about 6% for field sizes 5x5 to 20x20 cm^2
- Simplistic model for irregular field dose calculation



FFF: Relative Surface Dose

Smaller variation with field size for FFF beams in comparison to FF beams

For small fields - higher surface dose by FFF than FF



Lekshell Gamma Knife- LGK 4B/4C

Source to UCP Distance = 40 cm

- LGK is a standard SRS device specifically designed for intracranial radiosurgery,
- Contains 201 ^{60}Co sources, distributed along five parallel cycles in a hemispherical surface of radius 40 cm
- Each source of nominal activity 30 ci contains 12 - 20 ^{60}Co cylindrical pellets.
- Radiation emitted by each source is collimated by three different collimators: first two are permanently installed in the central body and final collimation is achieved by one of the four interchangeable collimator helmets which define a beam dia of 4, 8, 14 or 18 mm at the focus or unit centre point (UCP).
- Patient couch- sliding cradle - helmet attached
- Collimator system is designed to produce a precise overlap of 201 individual beams at the UCP (x=y=z= 100 mm) - mechanical centre.
- Superimposition of 201 beams produces approx. spherical dose distribution at UCP

LGK Perfexion

- Collimator system consists of 192 ^{60}Co sources, divided into 8 sectors that can be individually positioned to any of 4 states: 4 mm, 8 mm, 16 mm or OFF.

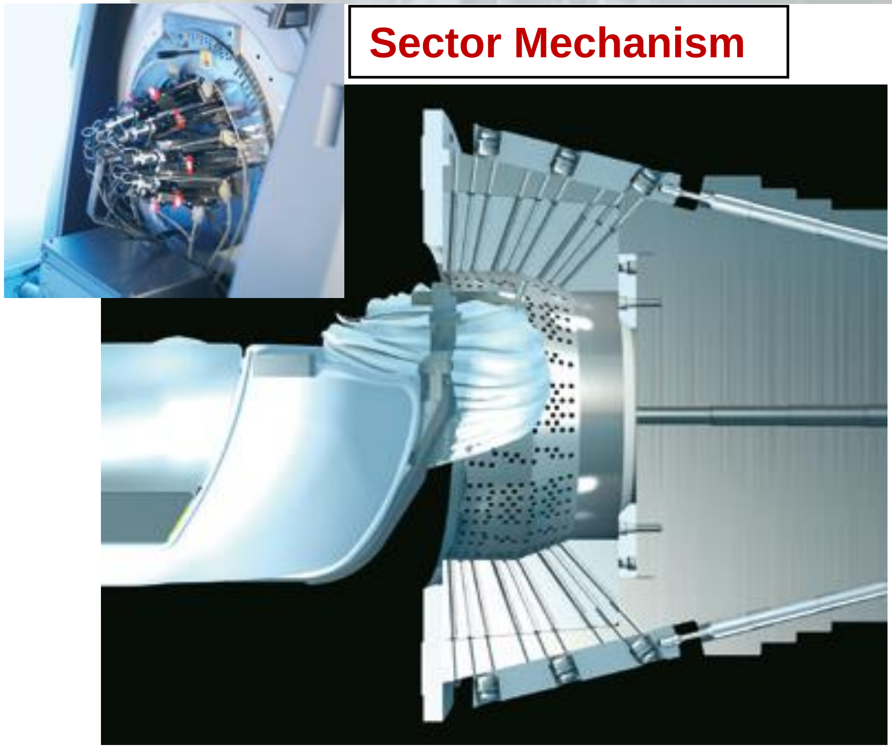
- During treatment these sources are positioned via the sector mechanism to generate the desired radiation beam and enable treatment of highly complex structures.

- Beam size can be changed dynamically by the sector.

- Individual sectors can be blocked for further shaping of each radiation shot.

- Larger collimator bore

- Main advantages: Increased throughput, increased patient comfort and extended anatomical reach.



Sector Mechanism

Evolution of LGK

1968
Model S

Prototype for clinical research

1986
Model U

Computer dose planning

1987
Model B

Improved collimator design

1999
Model C

Semi-robotic patient positioning

Improved dose conformity

2004
Model 4C

Improved software

Merger/fusion capability

2006
Perfexion

Improved conformity

Large cavity

Very low body dose

Rapid treatment

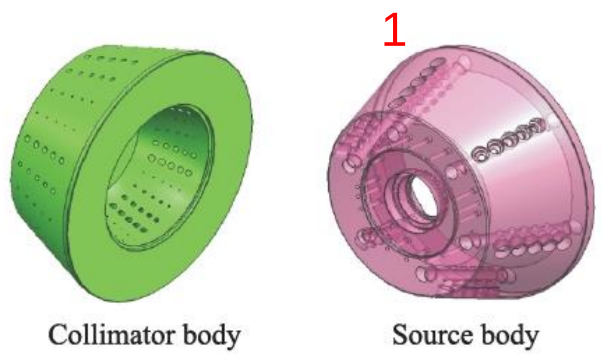
Full automation

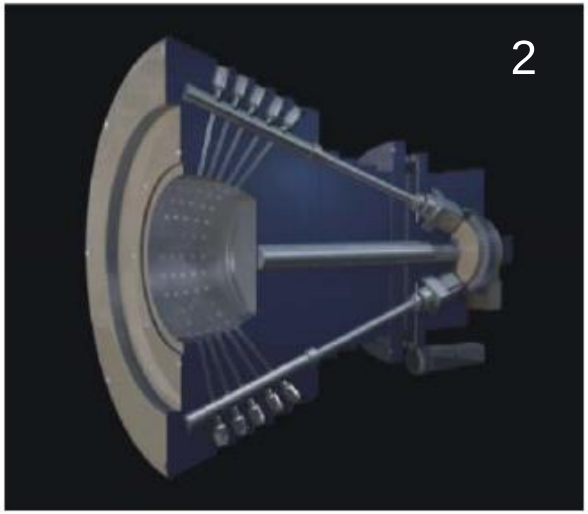
Expert panel

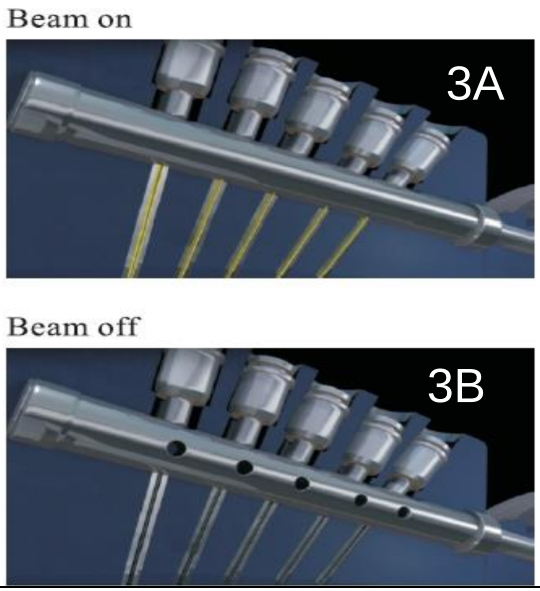
Rotating Gamma knife- INFINI

- Contains 30 Co-60 Sources
- 30 beams are focused on the focal point by collimators
- The distance from focal point to each source is different i.e. non-isometric
- The purpose of non-isometric design is to increase the treatment space.

Gantry Components of INFINI







Beam ON:

- The Source Body turns to a position such that all Cobalt source align with Collimator holes
- Beam Switch turned ON (Fig. 3A)
- Gantry door open

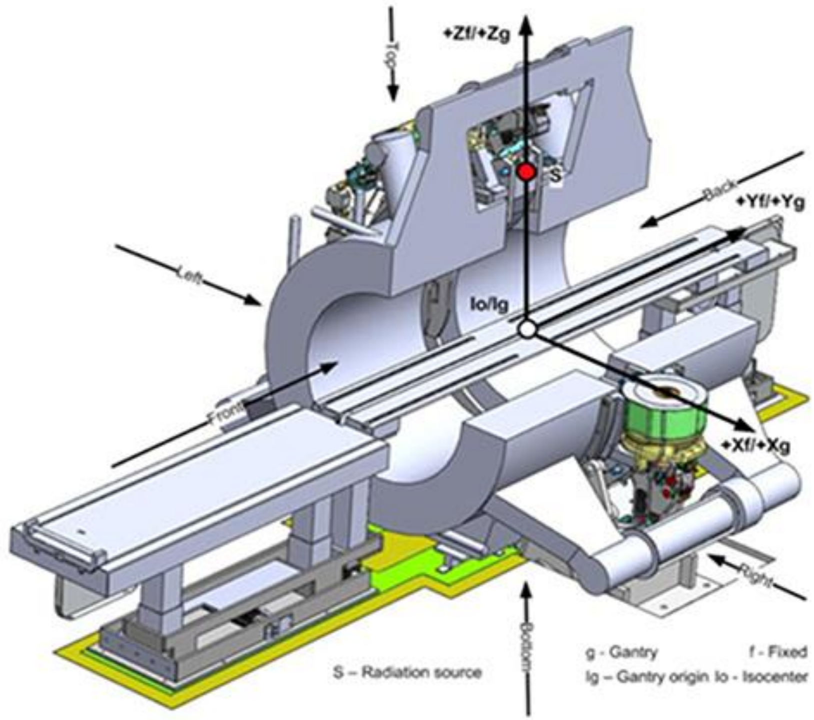
Beam OFF:

- The Source Body turns to a position that no Cobalt source aligns with any Collimator hole – all radiations blocked by collimator Body
- Beam Switch turned OFF (Fig.3B)
- Gantry door closed

Cobalt-60 – MR IGRT System (ViewRay)

- 0.35 T MRI, 70 cm bore, 50 cm FOV
- 3 ^{60}Co heads 120 degrees apart with divergent MLCs
- Conventional (3D), IMRT, and SBRT delivery
- Monte Carlo based dose calculation only
- Ability to track tissues at 4 frames per second

ViewRay (Co-60 based Tx Equipment)

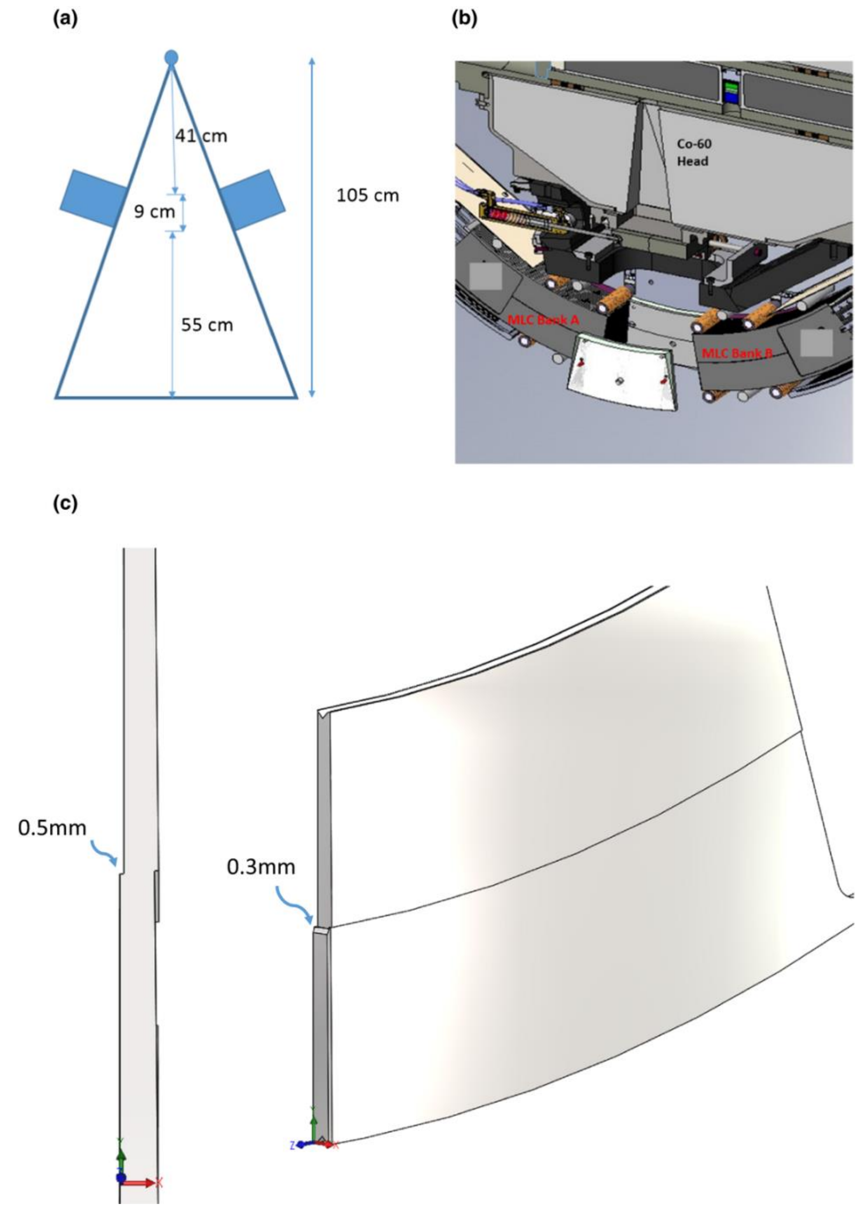


Being used as

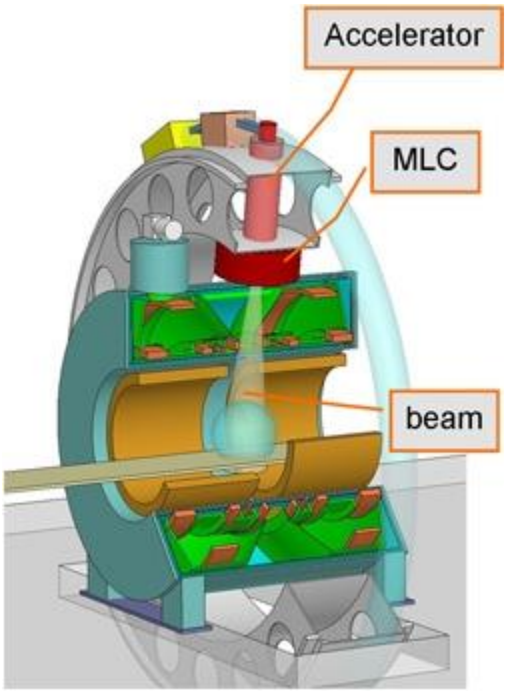
- MR-IGRT System
- On couch Adaptive Radiation (image, contour, optimize, dose calculate, QA, treat)
- MR Treatment Control (i.e. MR Gating)

Recent Upgradation of ViewRay: Addition of MLC

- Source to isocentre distance = 105 cm
- 60 doubly focused leaves mounted on two opposed leaf banks (30 pairs)
- Projected leaf width at isocentre = 1.05 cm
- 0.3 mm tongue and groove on the leading edge of each leaf and 0.5 mm on the adjacent sides
- Maximum field size = 27.3 × 27.3 cm^2
- Provision of inter-digitation
- Over-travel from isocentre = 13.65 cm



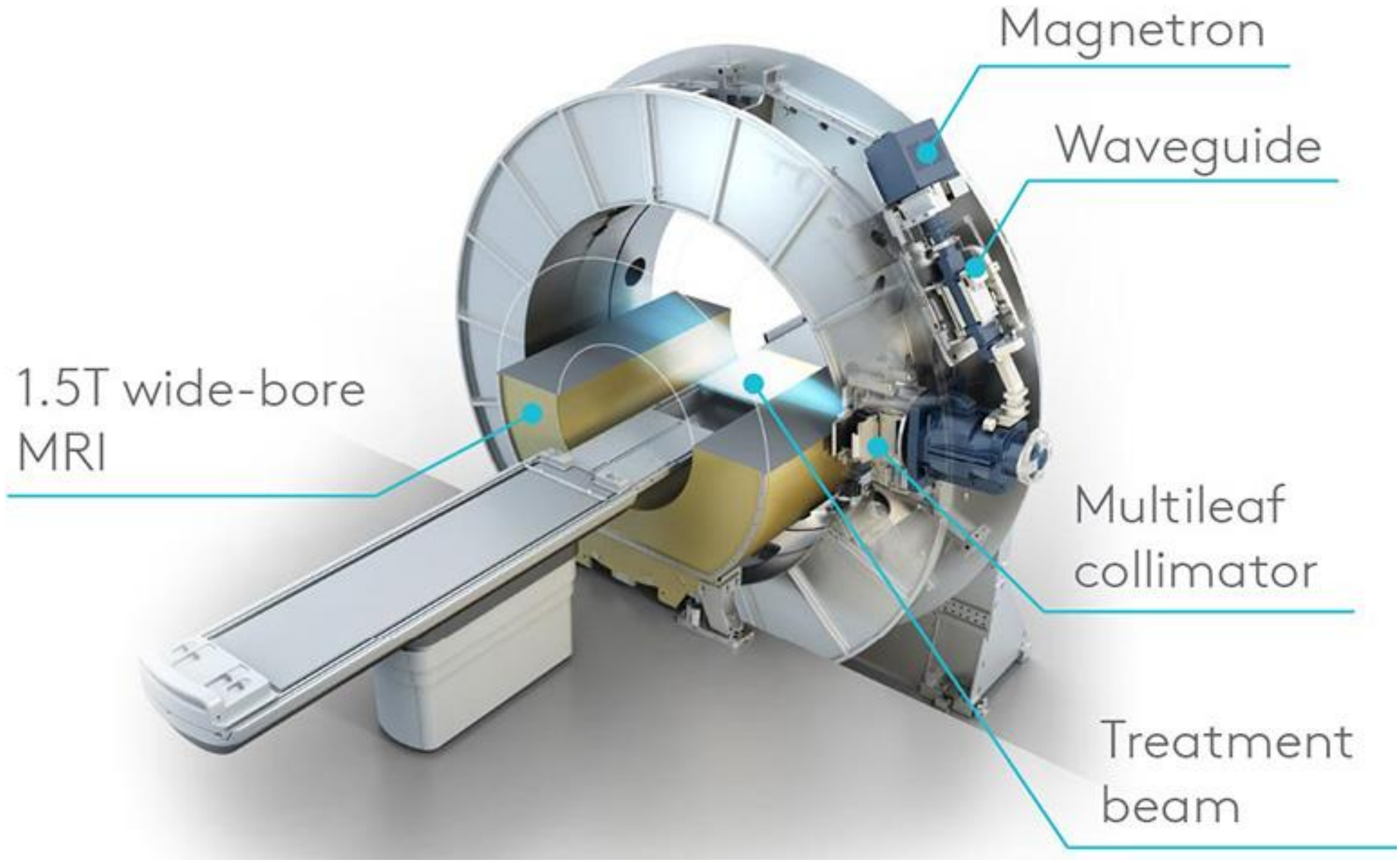
MR - LINAC



Cut-away view of the MR-LINAC. The LINAC gantry and its peripherals are around the MRI. The light blue toroid indicates the low magnetic field zone outside the MRI created by adapting the active shielding to decouple the MRI and the accelerator.

- To improve delineation accuracy - better differentiation between target tissue (tumour) and non-target tissue (normal tissue/OAR) is required
- MRI offer superior soft-tissue contrast over CT
- Thus, clinicians can see tumour tissue more clearly and adapt the radiation dose while a patient is being treated.
- Escalated dose delivery to tumour, high precision and effective than ever before.
- It could also reduce the number of treatment sessions, providing more convenience for patients.
- Treatment for all types of cancer and specially suitable for moving tumour e.g. lung, pancreatic, liver, tumours of upper abdomen.

MR LINAC: Components (Elekta Unity)



Tomotherapy

- Helical tomotherapy is IMRT delivery technique.
- Resembles Helical CT scanning
- 6 MV LINAC mounted on a slip ring gantry
- The beam passes through a primary collimator which is further collimated into a fan-beam shape by an adjustable jaw.
- A binary 64 leaf MLC is used to divide the fan beam in X-direction. MLC leaves travels in Y-direction
- During treatment, ring gantry continuously rotates while the patient is continuously translated through the rotating beam plane
- Dose is thus delivered in a helical fashion
- Ring gantry contain a detector system mounted opposite the accelerator which is used for MVCT data acquisition.
- Beam stopper – reduced shielding requirement

Imaging: 3 MVCT
Treatment: 6 MV (IMRT)

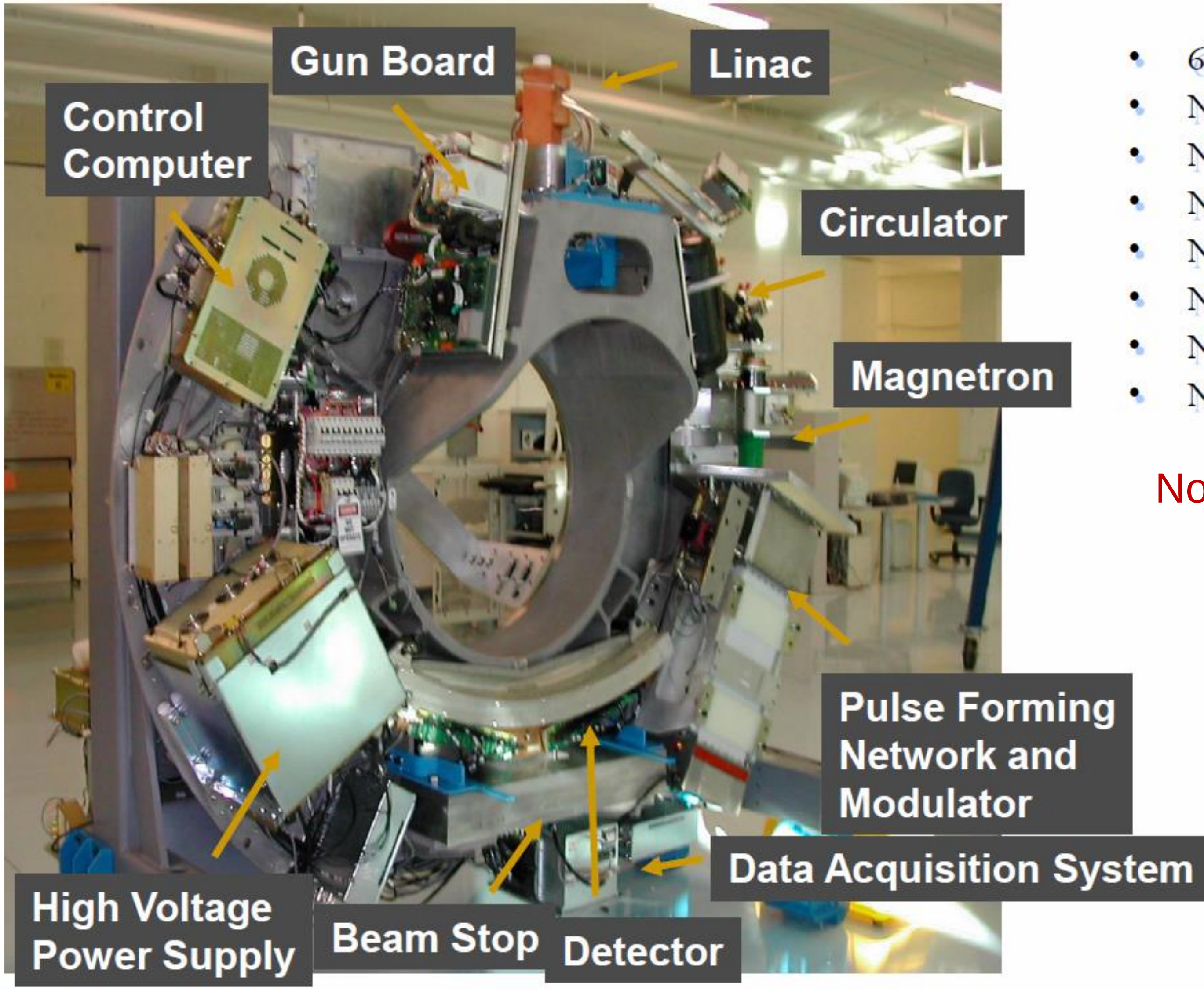
Source to rotation centre distance = 85 cm

Source to detector distance = 145 cm

FS: 40 cm x 5 cm (max)

Components of Tomotherapy Machine

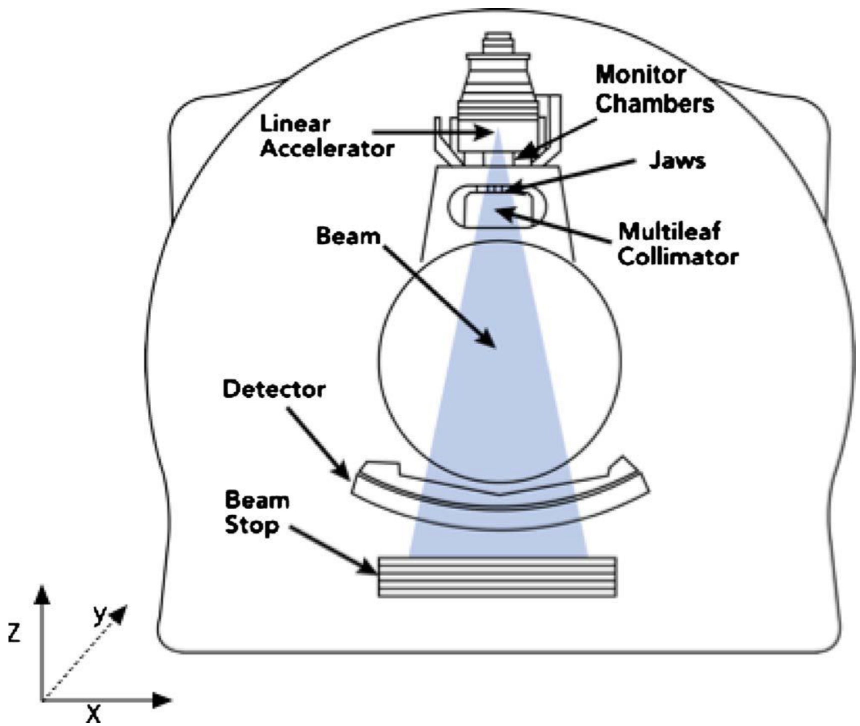
HI-ART Tomotherapy Unit



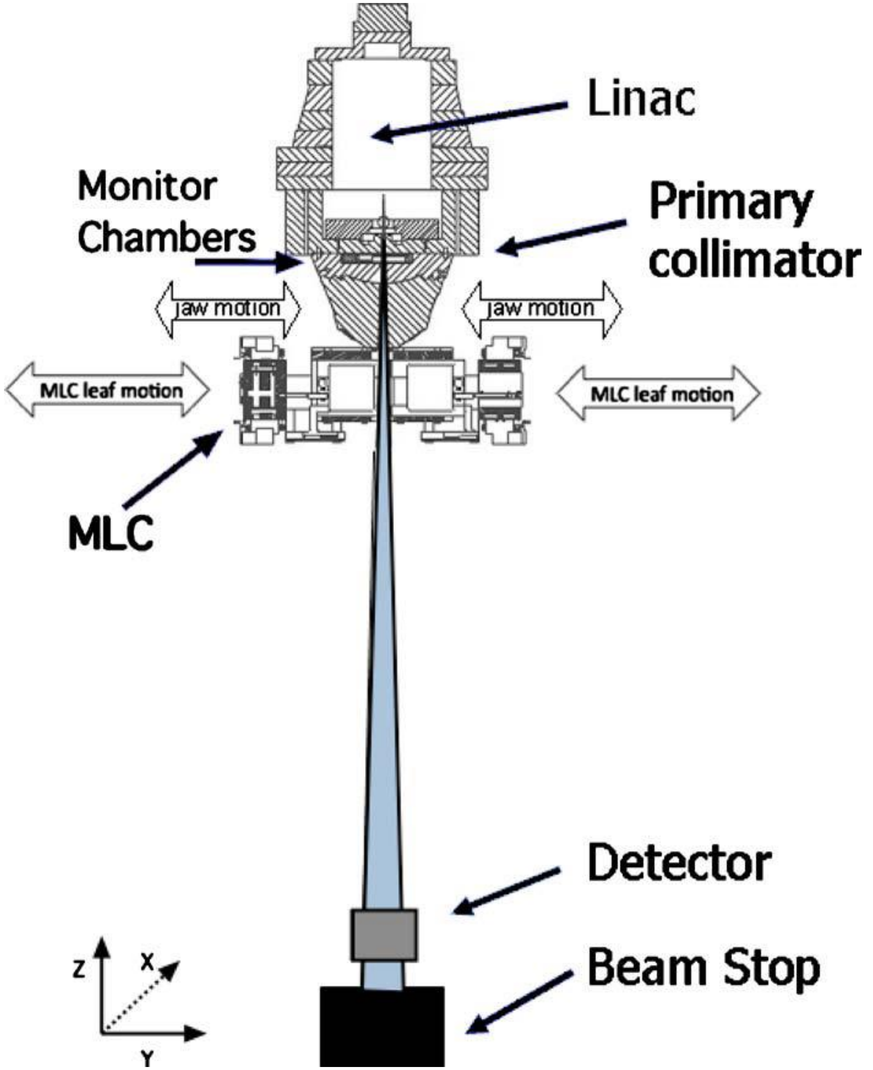
- 6 MV photon beam
- No electrons
- No wedges
- No gantry angles
- No collimator angles
- No table angles
- No field size
- No field light

No flattening Filter

Main components of Tomotherapy

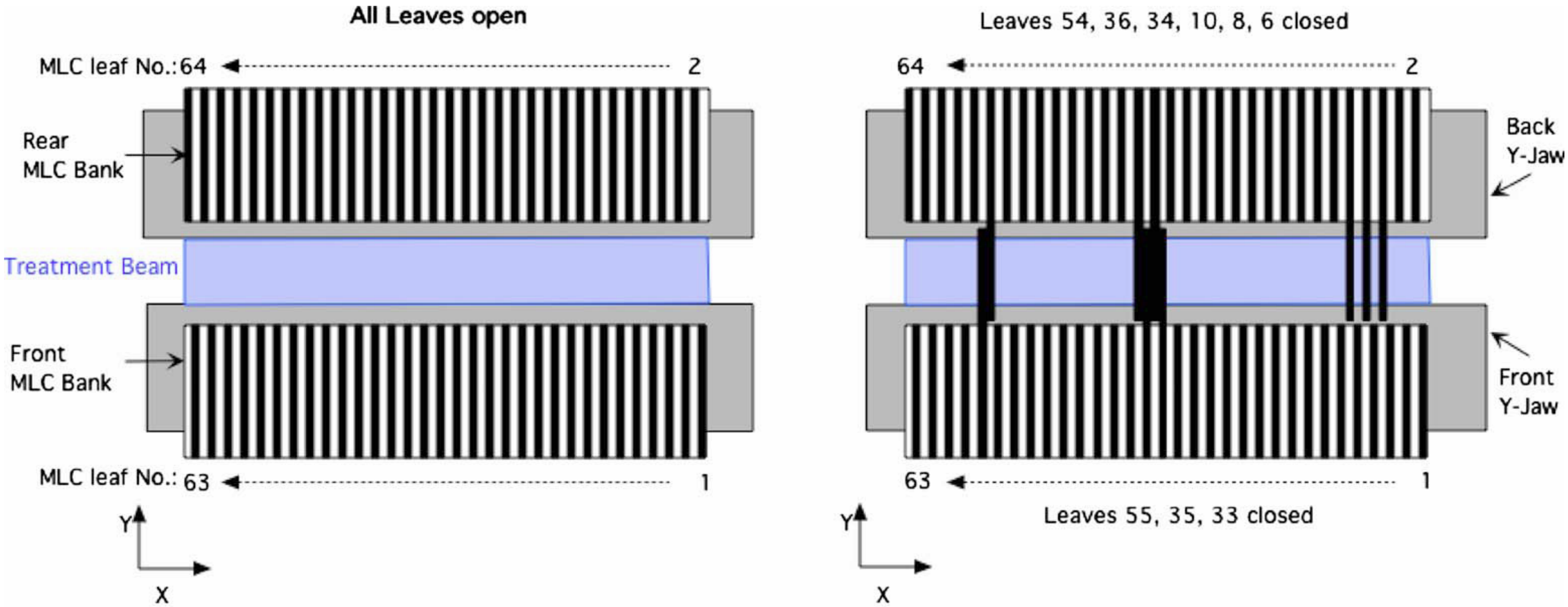


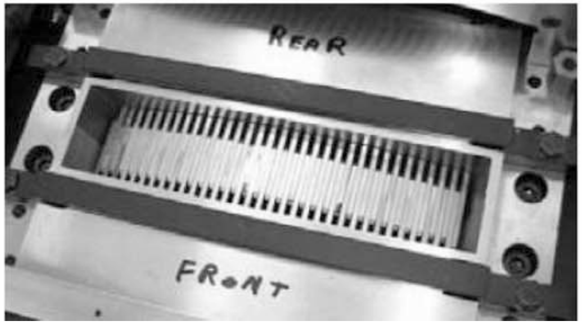
Frontal view



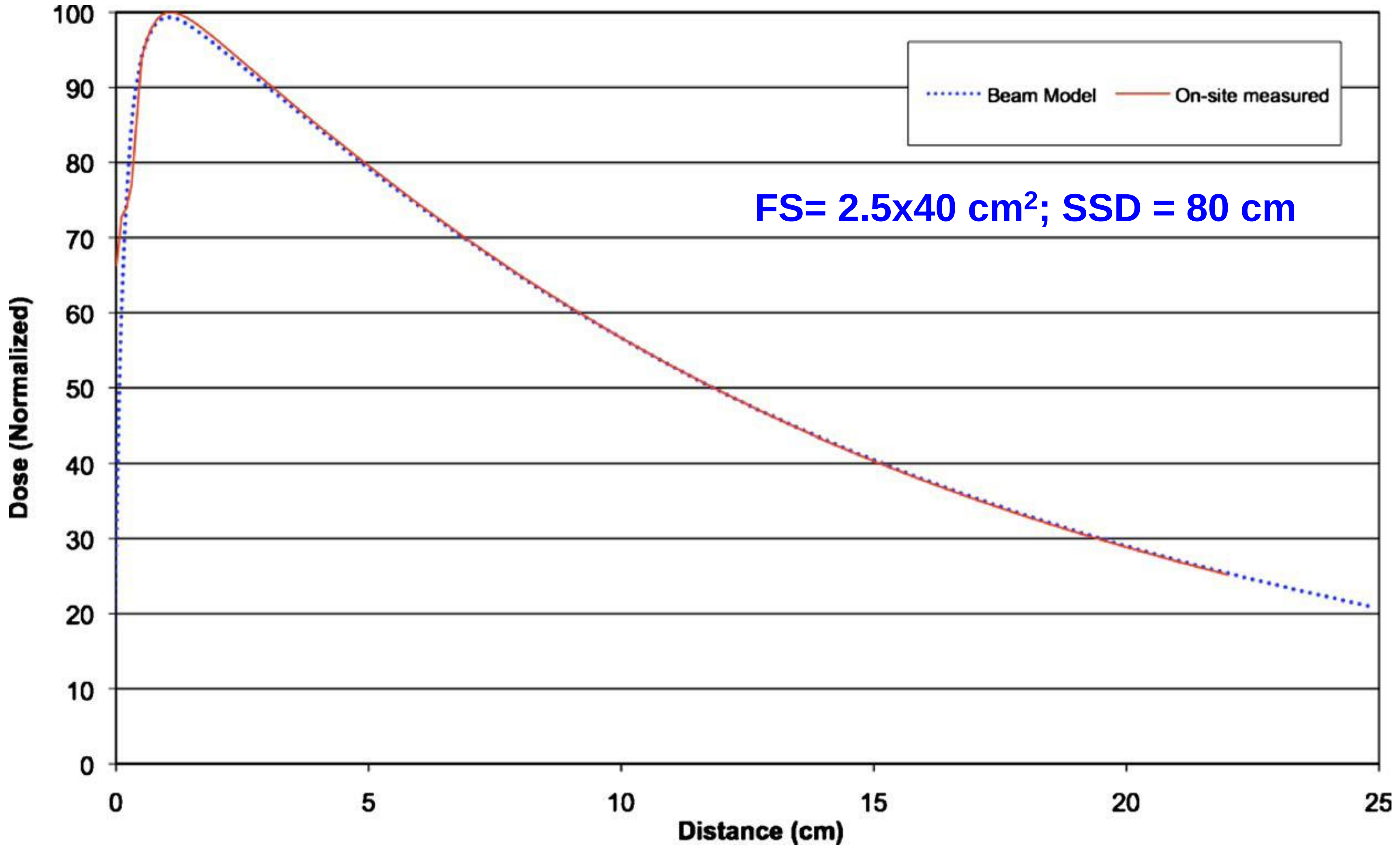
Lateral View of beam collimation components

MLC of Tomotherapy Unit

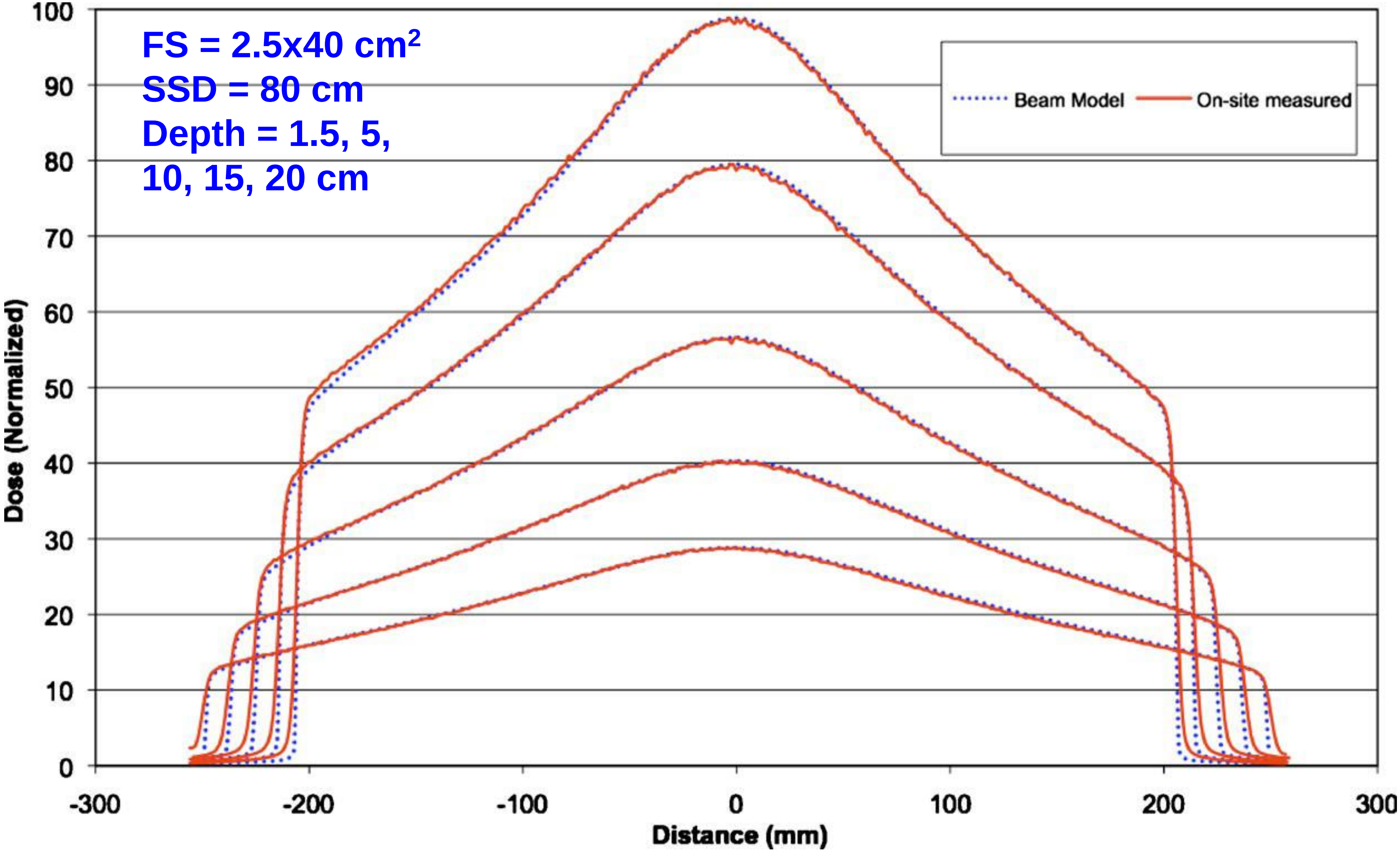




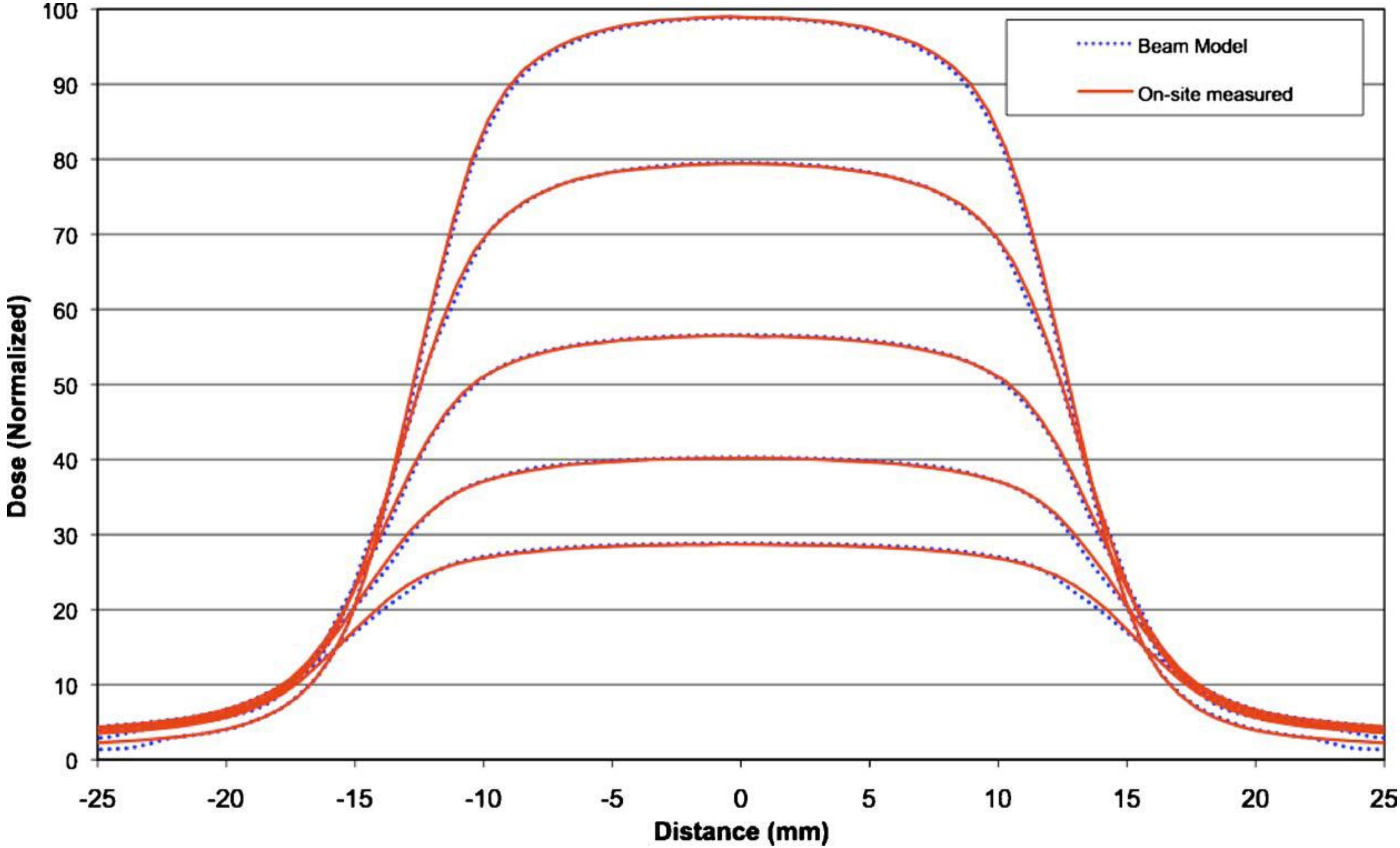
Tomotherapy : PDD



Tomotherapy: Transverse Beam Profiles



Tomotherapy: Longitudinal Beam Profiles



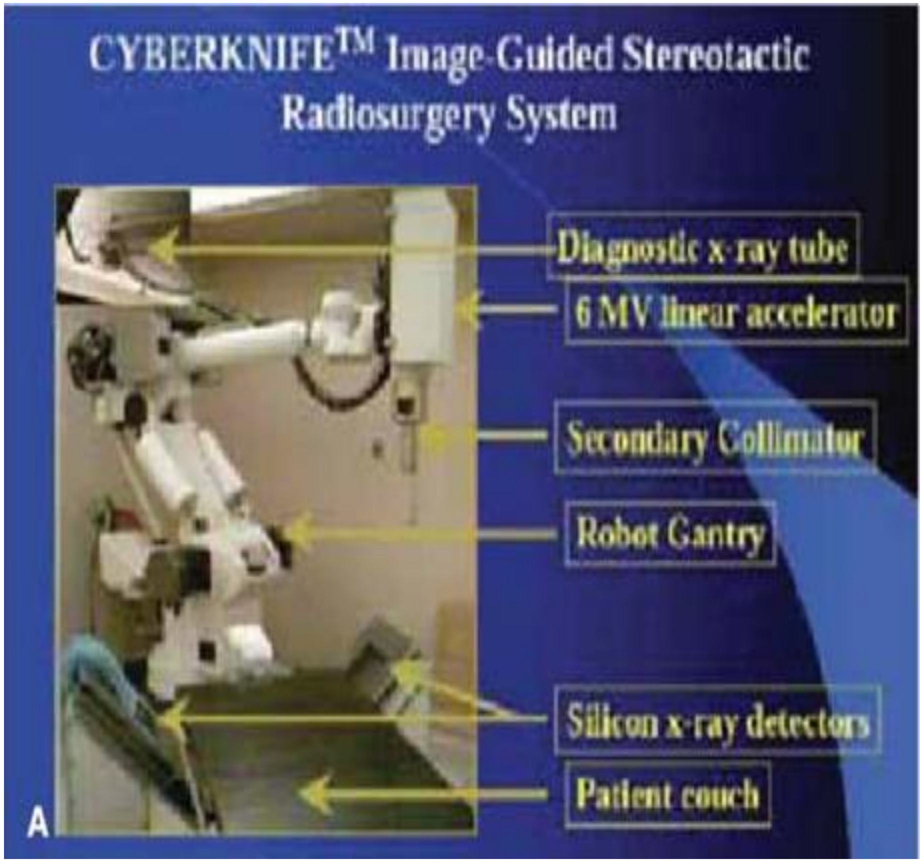
Cyber Knife (CK M6)

- Cyber Knife is a robotic stereotactic radiosurgery system
- LINAC attached to the end of robotic arm is free to rotate and translate with 6 degrees of freedom
- LINAC is capable of producing 6 MV photon beam

Cyber Knife – contd.

- Distance between target to isocentre can be varied anywhere between 60-120 cm
- Pseudo isocentre is defined for the purpose of definition of field sizes, output measurement and shielding calculation
- Distance between pseudo isocentre and target is taken at 80 cm
- Available treatment field sizes are circular in shape with diameters varies from 5 mm to 60 mm at pseudo isocentre

Cyber knife : Operational aspects

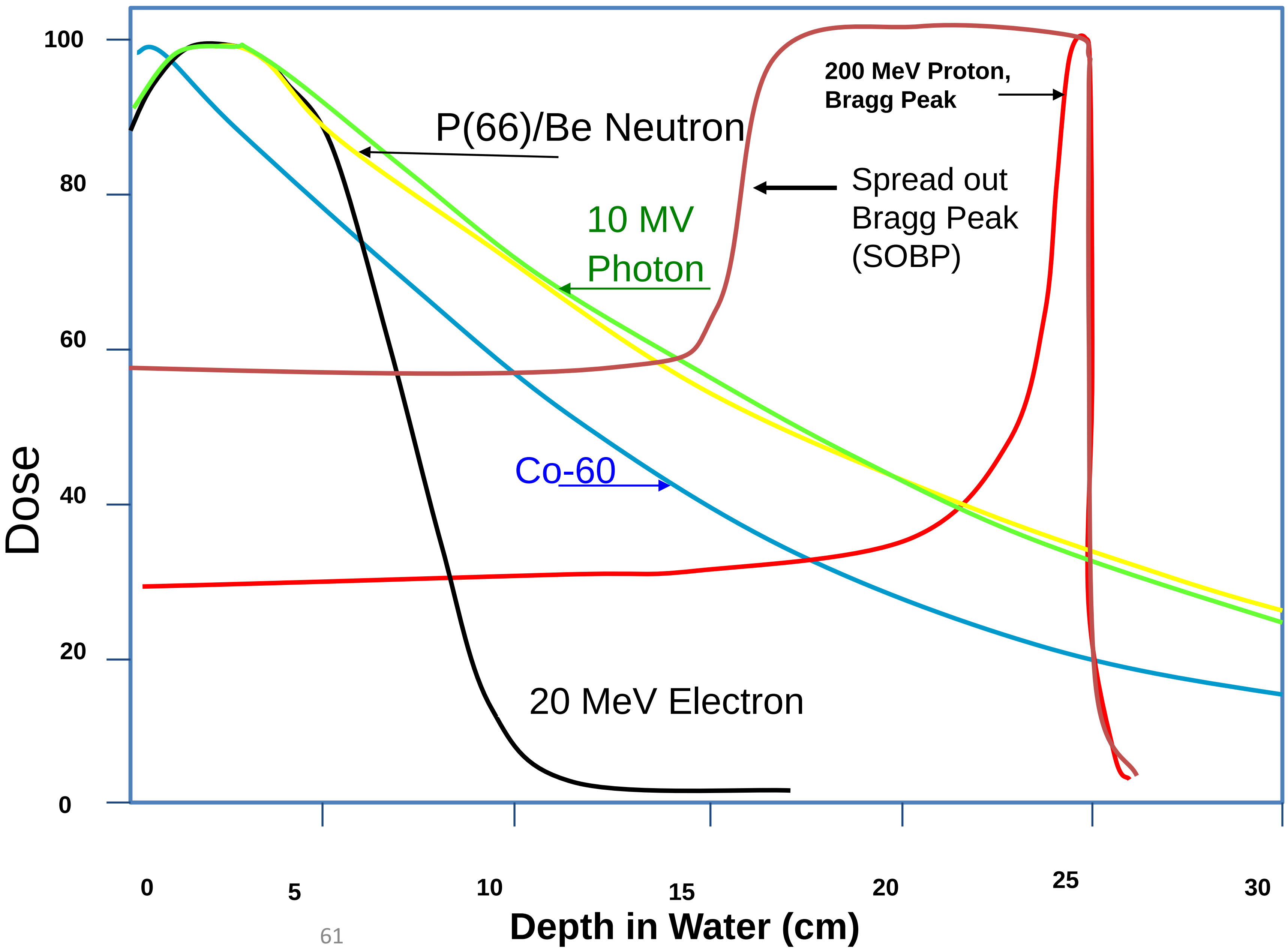


Ceiling mounted x-ray tube & floor mounted flat panel detector provides continuous imaging and adjust robatic arm

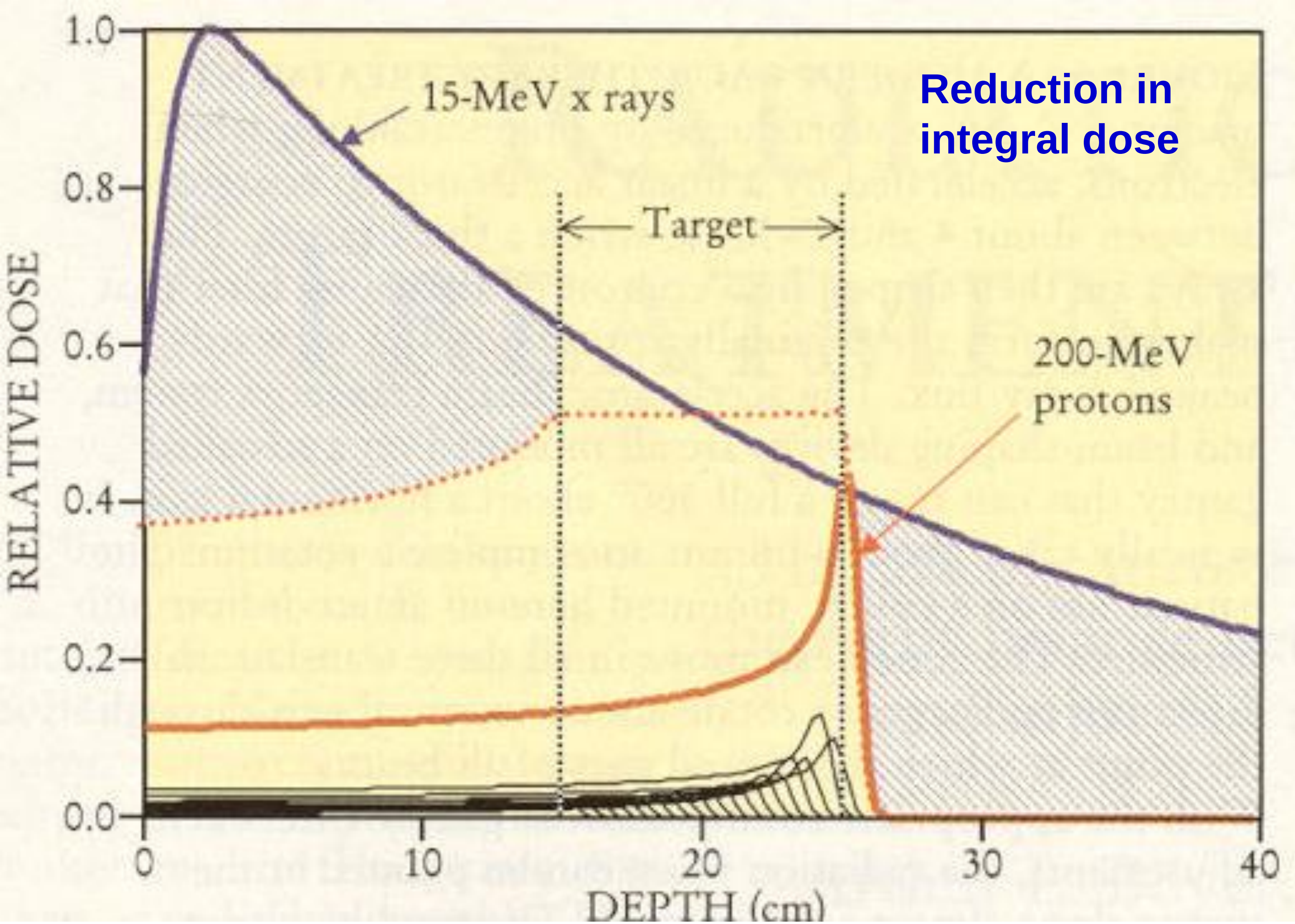
Cyber knife & Accessories: CK M6

Fixed circular cone collimator: 12 circular collimators (5 to 60 mm), can select up to three for a treatment.

Depth Dose Characteristics of Tx Beams



Superiority of P-Beam over HEX



Available Proton Accelerators

Cyclotron

- Consists of dipole magnets to produce uniform magnetic fields (straight sides are parallel but slightly separated),
- Particles injected into it move in a semi-circular path & acquire energy at the gaps,
- Isochronous or Synchrocyclotron and Semiconducting cyclotron
- Single frequency RF; fixed energy continuous beam

Synchrotron

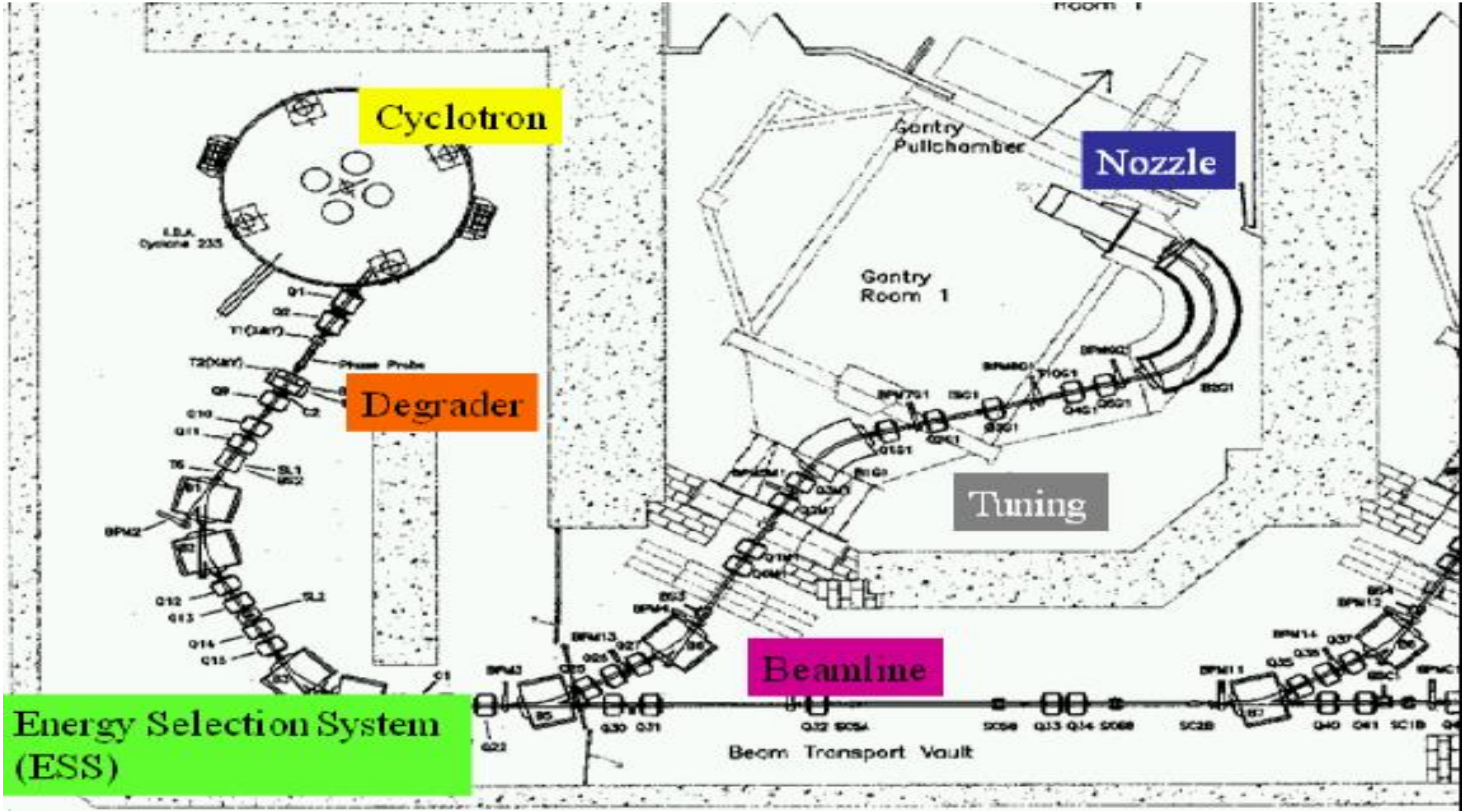
- Circular accelerating ring
- EM resonant cavities around the ring accelerate the particles which moves in the same radius
- H field strength is increased with increase in particle energy – are in synchronization

Cyclotron

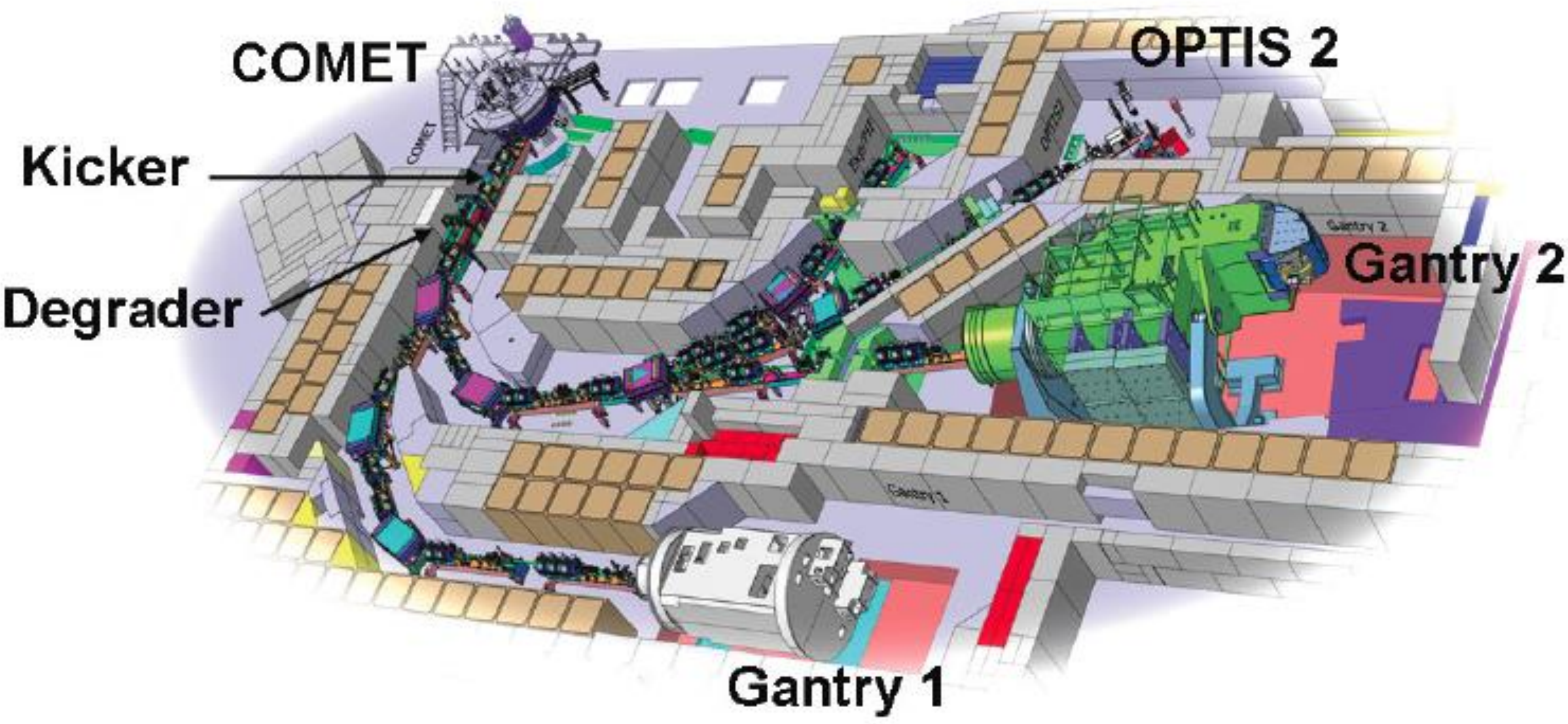
Through electrolysis, protons are taken from water and injected into the cyclotron (cylindrical structure at center) which accelerates protons to nearly the speed of light.

The protons travel through the beam line, guided by electromagnets, into treatment rooms.

Proton Beam Production & Transport

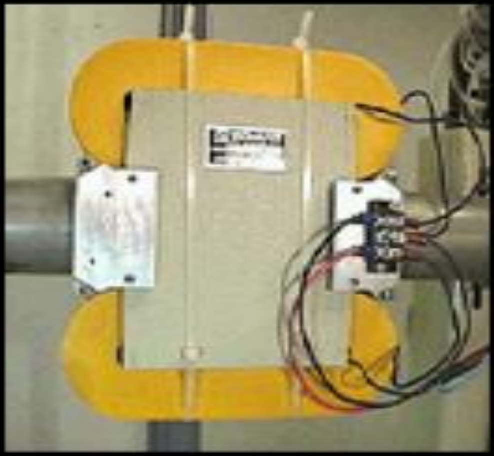


Proton Beam Production & Transport

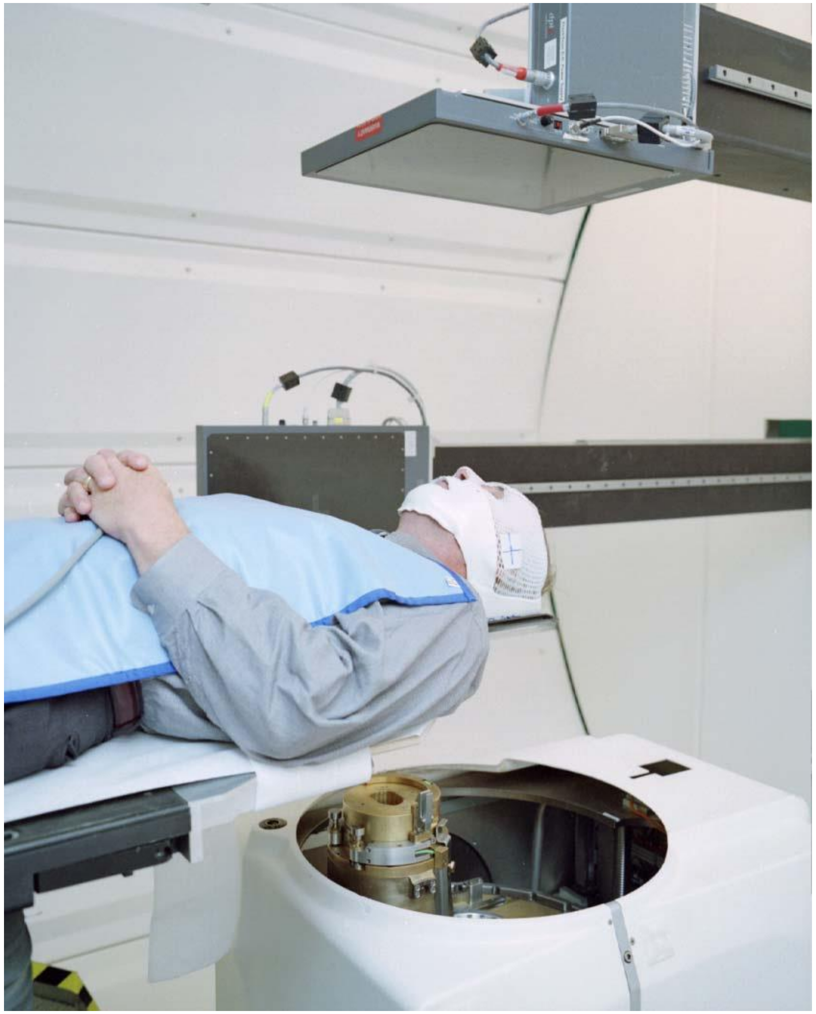


Cyclotron: Proton Beam Transport

- Dipoles – Bend, guide the proton beam
- Quadrupoles – Focus the proton beam
- Steering Coils – Fine-tune direction of beam
- Beam Profile Monitors with beam stops – providing input to magnets

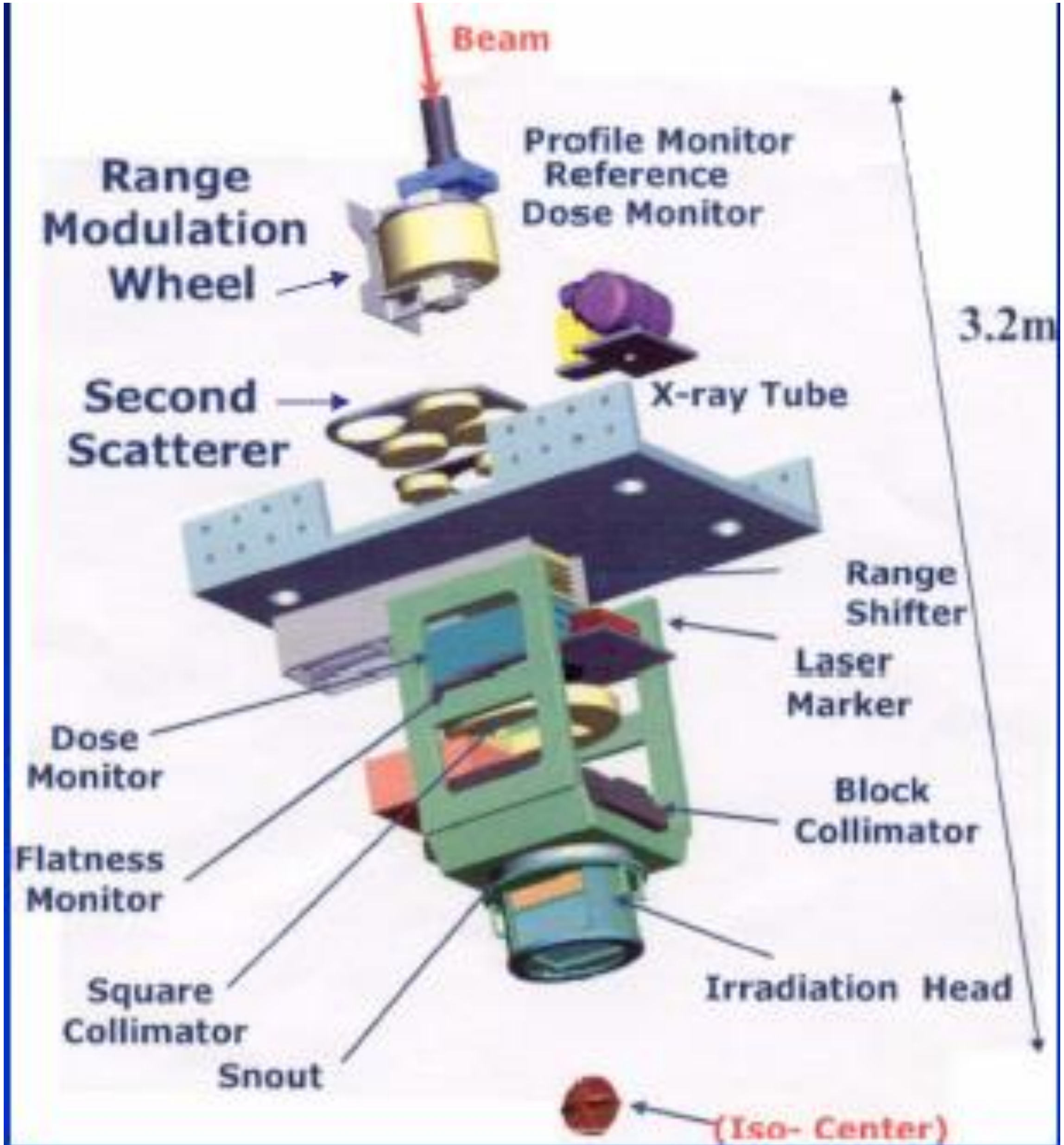


Proton Beam Gantry & Tx Nozzle



Proton therapy is delivered while the patient lie on the treatment table. The gantry rotates to deliver the treatment precisely to the tumor site.

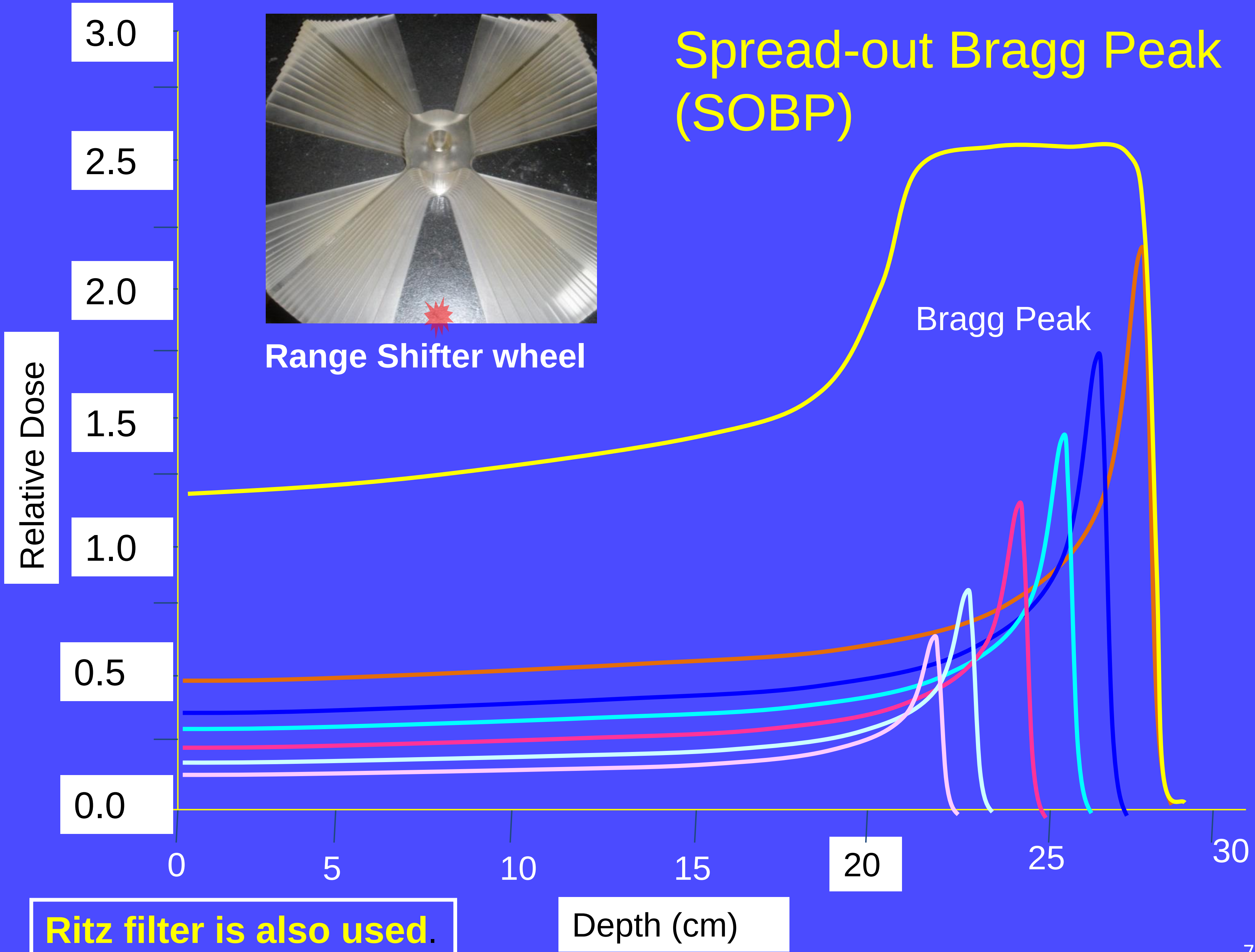
Schematic Diagram of Nozzle



Nozzle of Proton beam accelerator is nothing but the treatment head,

Contains various components for beam shaping and beam monitoring.

Spread-out Bragg Peak (SOBP)



Ritz filter is also used.

Helium Ion Therapy

- The beam penumbra of protons at larger depths is comparable to that of high energy photon beams.

- Helium ion possess sharper beam penumbra at all depths, a more pronounced Bragg-peak, and a steeper dose falloff beyond the Bragg-peak.

- The higher atomic number of helium ions compared to protons can result in break-up of primary beam particles, resulting in a fragmentation tail.

- Due to the lower atomic number of helium compared to carbon ions only a small percentage of the total dose is deposited beyond the Bragg-peak.

- It is reported that the use of helium ions results in further reduction of dose to surrounding normal tissues and organs at risk in comparison to proton beams.

Carbon Ion Therapy

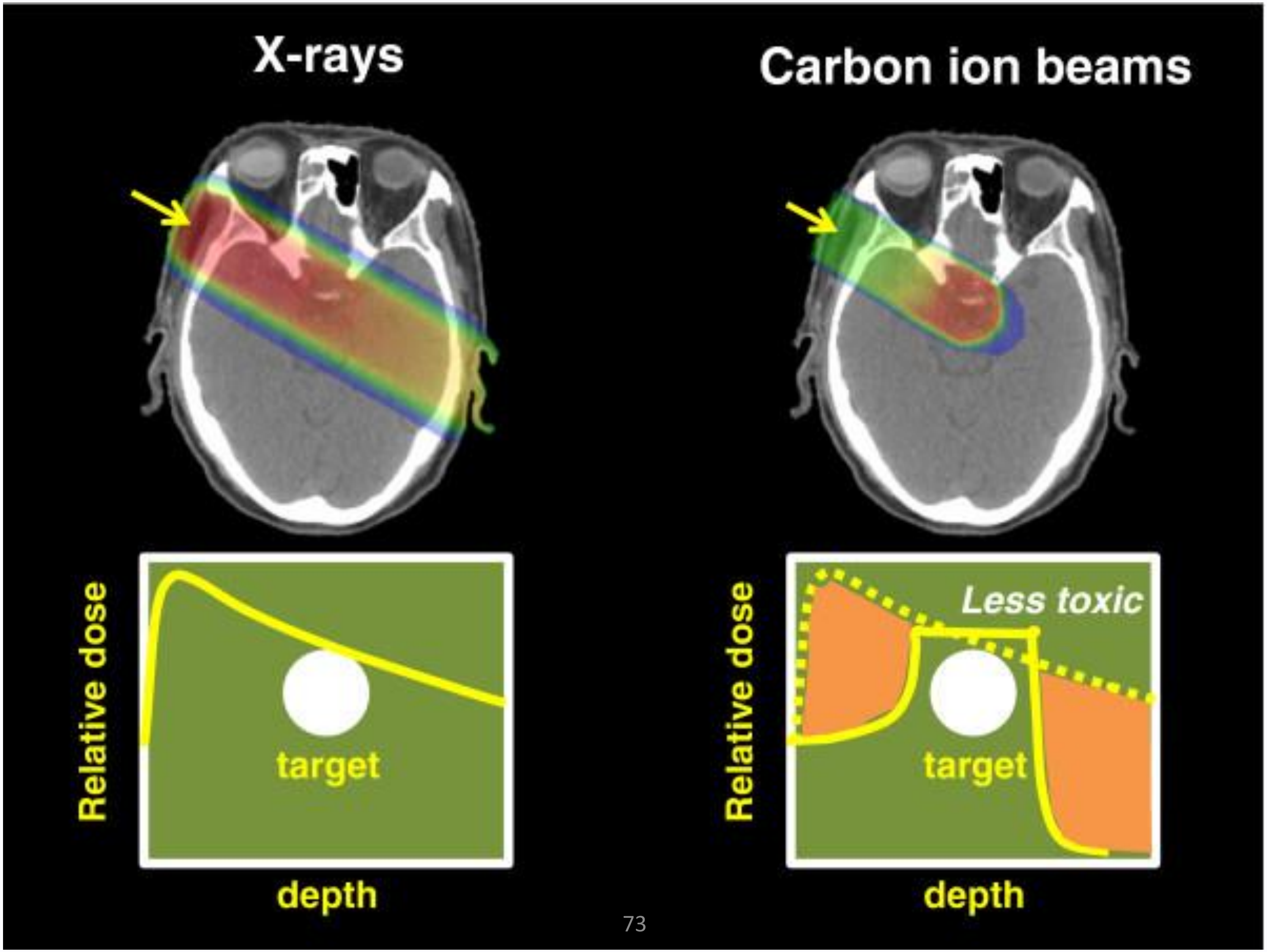
- Carbon (^{12}C) ion beam is now-a-days thought to be a better choice among proton and heavy ions due to higher LET and better dose localization.

- ^{12}C ions are heavier than protons and have been shown to be effective in the treatment of so-called radioresistant tumours.

- It has been shown that the differential radiosensitivity between poorly-oxygenated (radioresistant) and well-oxygenated (radiosensitive) cells is reduced with high LET radiation.

- Tumour sites that are prone to hypoxia might benefit most from high LET radiations (e.g. squamous cell head and neck cancer and non-small cell lung cancer).

Carbon Ion Therapy



Comparison: C-ion & Proton Beam

Statements	Proton Beam Therapy	Carbon Ion Therapy
Proton's Advantages over Carbon	• Lower cost • Able to be delivered via gantry, allowing multiple beam angles •More narrow range of RBE (1-1.1) and greater certainty leading to smaller variations in actual delivered dose. • Decreased risk of late normal tissue damage due to lower RBE.	•Higher cost (2-3 x proton therapy) •Usually delivered via a fixed beam, not permitting multiple angles •There are uncertainties in the RBE (1.5-3.4) which may cause large variations in the actual delivered dose. • Potential for increased risk of late normal tissue damage due to higher/variable RBE.
Carbon's Advantages over Proton	•RBE is similar to photon radiation and increased tumor control would not be expected. •Larger lateral penumbra which can cause greater dose to normal tissue structures than carbon ion.	•Higher RBE particularly at distal edge of Bragg peak which may permit greater tumor control. •Smaller lateral penumbra which may permit a more conformal dose laterally and limit normal tissue damage.
Similarities of Proton and Carbon ion beams	•Both proton and carbon ion limit the integral dose and therefore are predicted to reduce the risk of secondary malignancies over photon therapy, particularly in the pediatric population. •Both proton and carbon ion research is limited, largely consisting of small series of patients where definitive conclusions are difficult to make.	

MODERN HDR TREATMENT UNITS

MicroSelectron HDR unit (Courtesy Elekta)

Ir-192

GammaMed Plus system. (Varian)

Ir-192

Varisource system. Courtesy Varian)

Ir-192

Multisource HDR unit (Courtesy BEBIG)

Ir-192 & Co-60

Flexitron HDR unit (Courtesy Elekta)

Ir-192 & Co-60

Electronic Brachytherapy

- Electronic brachytherapy utilizes x-rays produced by miniature x-ray tubes using an externally applied electric potential to accelerate electrons and produce bremsstrahlung photons from a high-atomic number target
- Commercially available electronic brachytherapy sources operate at peak voltages below 100 kVp, with the most common devices operating at ≤50 kVp
- Advantages
  - adjustable dose rate, capacity to adjust dwell times and dose rate dynamically to provide more flexibility in optimization of dose distributions
  - variable photon spectra through variable kVp
  - Comparatively less shielding (Ir^{192})

Electronic Brachytherapy

- Disadvantages:
  - lack of constancy of output compared to radionuclide decay
  - variations in source-to-source dose rate and dose distributions
  - increased source size, limited dose rate at depth in tissue
  - limited source lifespan
  - The need to measure the output of a tube preceding each clinical use
  - the potential for risk of electrical shock to the patient and for blood clotting due to heat production in nearby blood vessels
  - there is limited evidence of treatment efficacy and healthy tissue toxicities

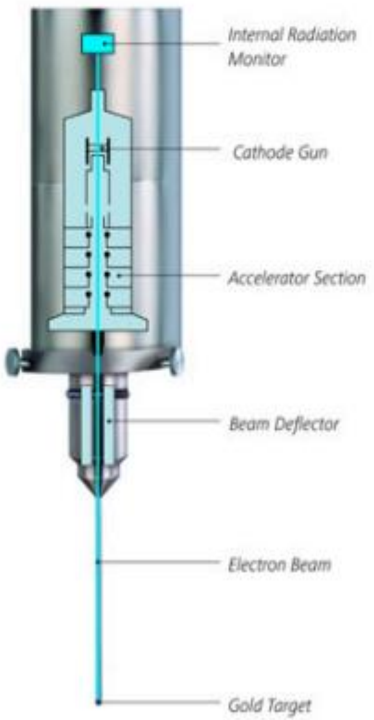
Commercial Electronic brachytherapy devices

Zeiss INTRABEAM

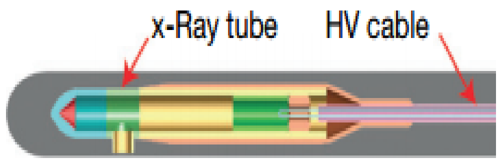
Xoft Axxent

INTRABEAM

- Miniature electron gun to direct electrons onto a target located within a treatment probe that can be placed directly in tissue or at the center of an applicator
- The electrons are generated outside of the treatment probe and directed into a 100-mm-long, 3.2-mm-diameter drift tube
- 1-µm-thick gold target
- The INTRABEAM operates at 30, 40, and 50 kVp at selected currents from 5 to 40 µA
- Approximate treatment times are 25 and 38 min for a 3.5- and 5.0-cm-diameter spherical applicator
- x-ray target has a lifespan of approximately 100 h before it needs to be replaced
- Intracavitary treatment following breast lumpectomy, a dose of 5 to 7 Gy at 1-cm

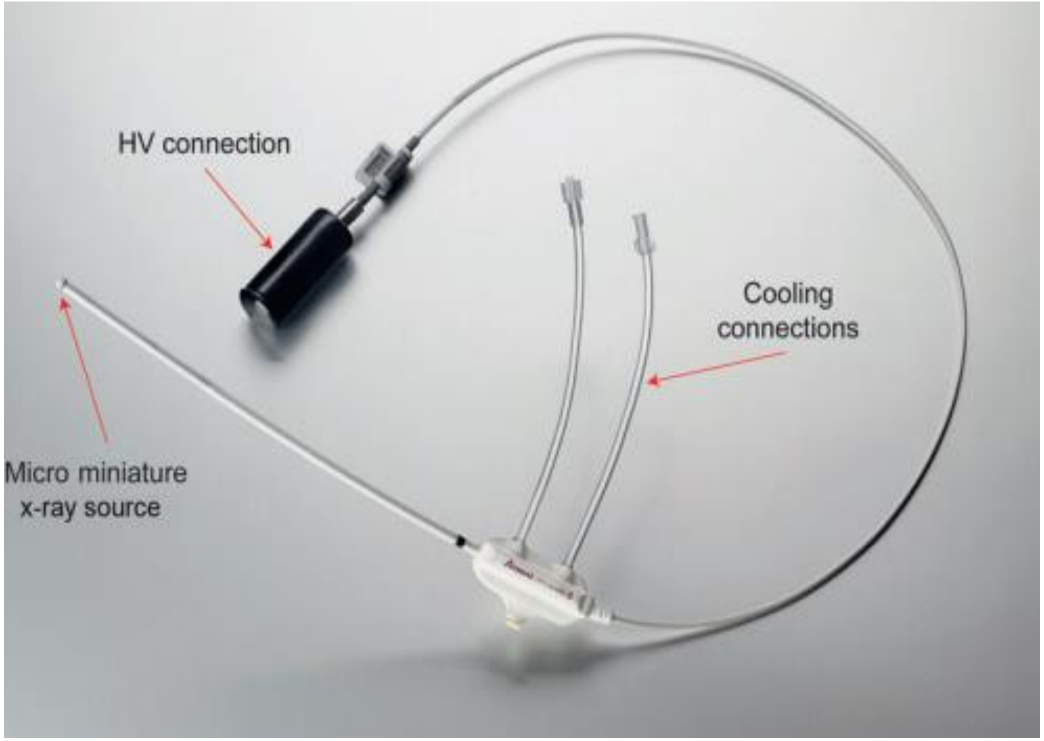


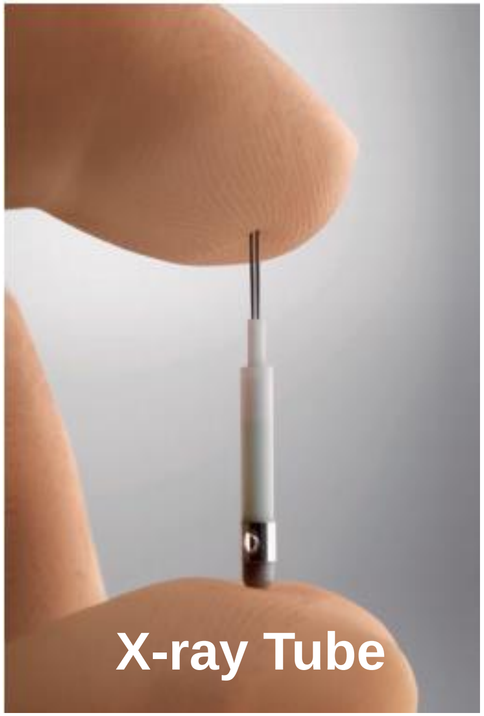
AXXENT (Xoft)



- Composed of an electronic controller, a disposable miniaturized electronic x-ray source contained a flexible probe, and a variety of applicators utilized to treat sites such as breast, gynecological organs, and skin
- The tube can be operated between 20 and 50 kVp
- Operating voltage of 50 kV and tube current of 300 μA
- Dose rate is approximately 0.6 Gy /min at 3 cm as measured in water

AXXENT (XOFT)





- Given Prescription for post surgical breast brachytherapy (RTOG-0143) is 3400cGy in 10# delivered twice daily
- After lumpectomy 20Gy (IORT) prescribed at the applicator surface

Operating parameters and usage of current clinical system

Machine name	Manufacturer	Approximate number of units worldwide (UK and Europe/ USA)[a]	Clinical applications	Approximate treatment time	Accelerating potential (kV), tube current (mA)	Half-value layer (mmAl)	Geometry	Applicator or cone size	Focus-to-surface distance	Study
INTRABEAM®	Carl Zeiss Surgical (Oberkochen, Germany)	250 (160/60)	Skin, breast,[b] intracranial, kyphoplasty, other	25–40 min (spheres) 5–30 min (surface applicator)	50, 0.04	0.1 (bare source) 0.8–1.3 (spherical applicators) 1.6–2.1 (sphere and 1–2 cm water)	Point source (probe tip, steered)	15- to 50-mm spheres, 10- to 60-mm surface applicators, 20- to 35-mm cylinders	10–26 mm (surface)	Eaton[11] and Schneider et al[12]
Xoft®	iCAD Inc. (Nashua, NH)	>150 (10/140)	Skin,[b] breast,[b] vaginal	10–25 min (balloon) 5–10 min (surface) 10–15 min (endocavitary)	50, 0.3	0.5 (bare source), 1.6 (endocavitary)	Point source (catheter, stepped)	30- to 60-mm balloons, 10- to 50-mm cones, 20- to 35-mm cylinders	20–30 mm (cones)	Liu et al,[13] Richardson et al,[14] Bhatnagar[15] and Dickler et al[16]
Papillon	Ariane Medical Systems Ltd (Derby, UK)	11 (11/0)	Rectum,[b] skin, breast	2 min	50, 2.7	0.6 (cone)	Collimated source	22- to 30-mm cones	29–38 mm	Gerard et al[17]
Esteya®	Elekta AB-Nucletron (Stockholm, Sweden)	10 (2/8)	Skin[b]	2 min	70, 0.5–1.6	1.9 (surface applicator)	Collimated source	10- to 30-mm surface applicators	60 mm	Garcia-Martinez et al[18]
Photoelectric therapy	Xstrahl Ltd (Camberley, UK)	1 (1/0)	Skin[b]	1–2 min	80, 1.3	2.9 (surface applicator)	Collimated source	10- to 50-mm surface applicators	50 mm	M Robinson, 2014, personal communication
SRT-100™	Sensus Healthcare (Boca Raton, FL)	150 (7/130)	Skin[b]	1–2 min	50–100, 8–10	0.5–2.1 (cone)	Collimated source	10- to 50-mm (100 mm) cones	150 mm (250 mm)	User manual

Conclusions

- Hypo fractionated radiotherapy can be delivered with all the modern radiotherapy equipments
- The advanced technology has provided options for enhancing accuracy and precision of dose delivery in hypo fractionated radiotherapy
- The safe and effective implementation of advanced technology in hypo fractionated treatment requires good understanding of the capabilities and limitations of the equipment concerned
- The use of ultra modern facility in terms of improved clinical outcome need to be made sure before implementing for routine use

Thank you for your Kind attention