

Linear Accelerators in Radiotherapy

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LIP Summer Internships

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Augusta Victoria Hospital
مستشفى الأوغستا فكتوريا-المطلع

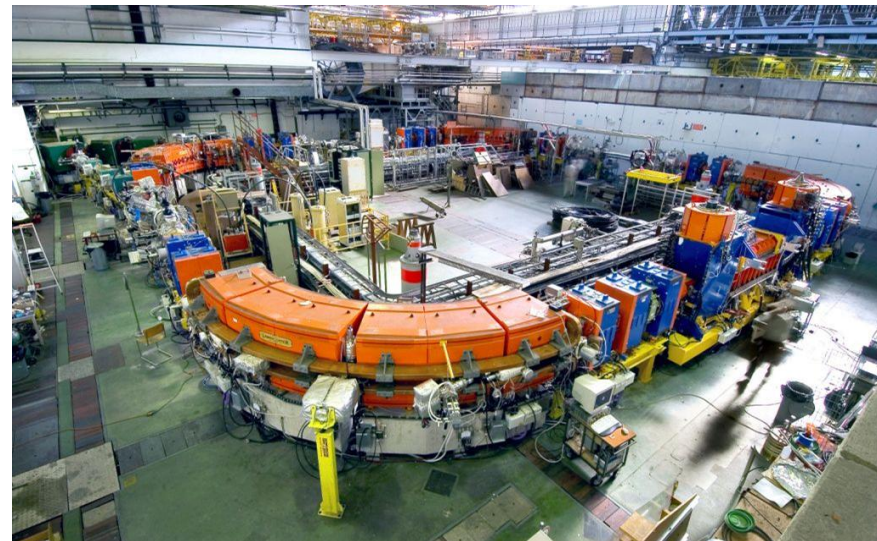
University of Coimbra



Al-Quds University



Birzeit University



CERN

Augusta Victoria Hospital Jerusalem



Augusta Victoria Hospital is named after **Empress Augusta Victoria**, wife of German Kaiser Wilhelm II, because she supported its founding during their 1898 visit to Jerusalem as part of a German imperial project.

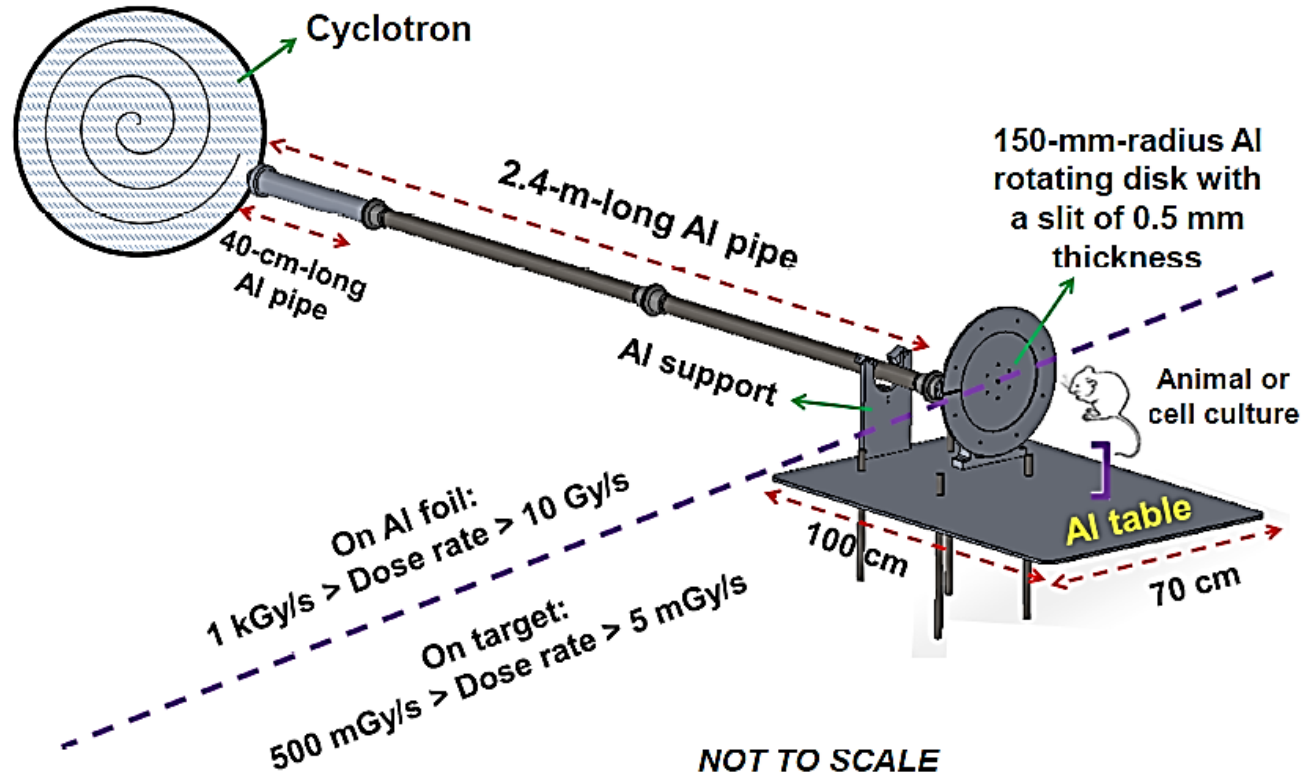


(1) Development of a PET cyclotron based irradiation setup for proton radiobiology

The ICNAS cyclotron:
Cyclone®18/9 -HC, from IBA

Beam lines

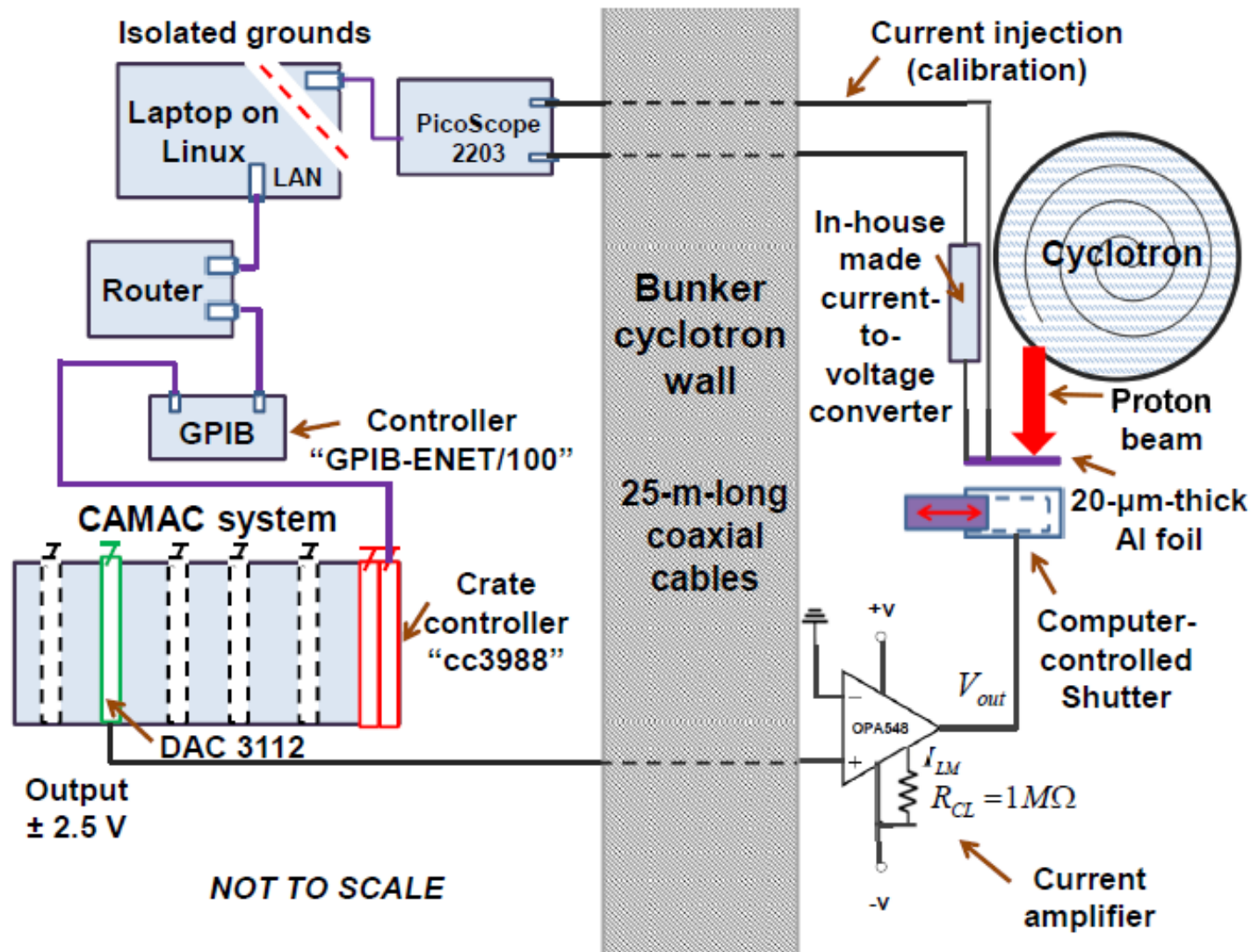
University of Coimbra



(Ghithan et al. 2013 JINST)

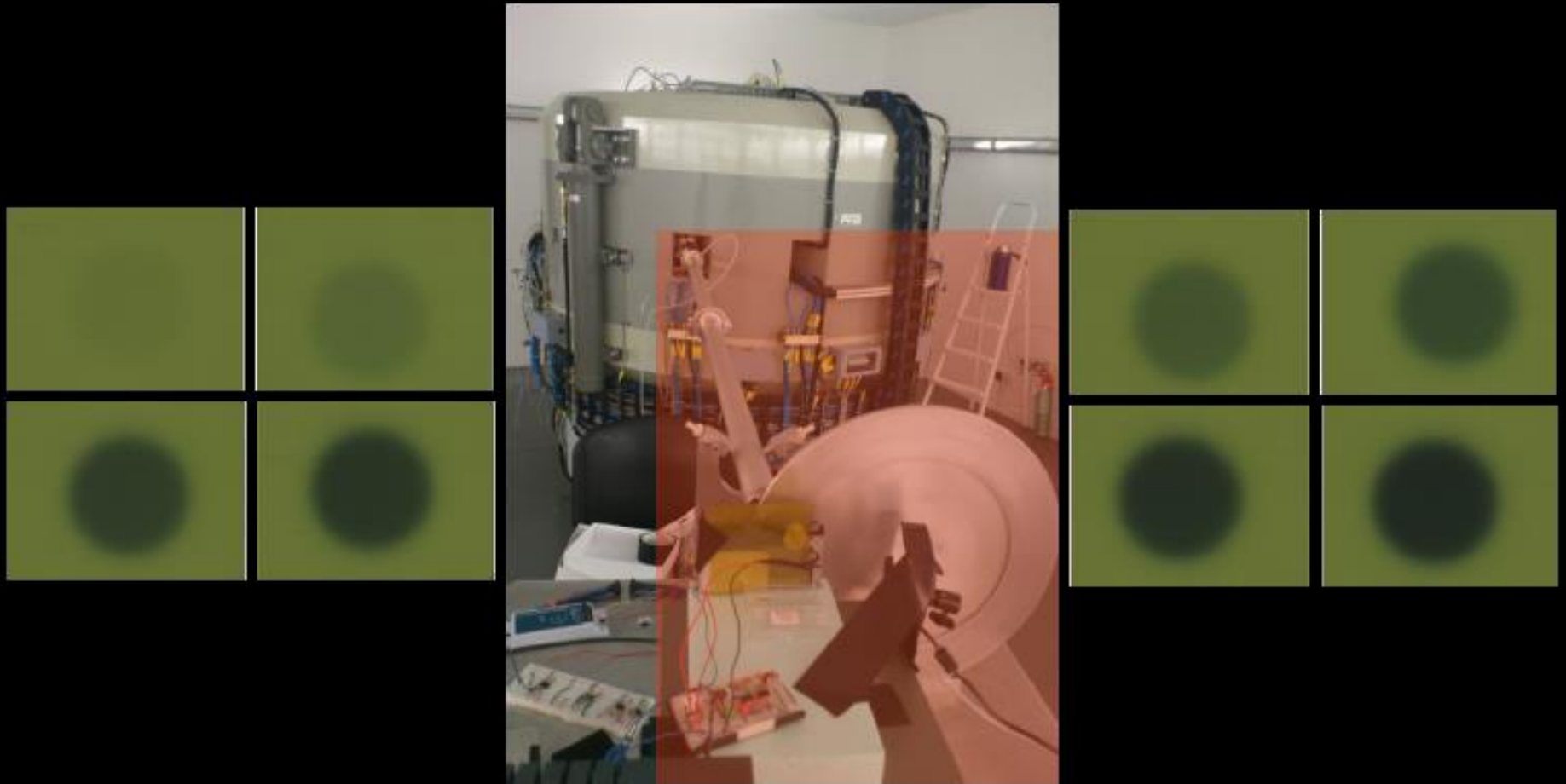
(Ghithan et al. 2015 JINST)

Development of a PET cyclotron based irradiation setup for proton radiobiology



(Ghithan et al. 2015 JINST)

Development of a PET cyclotron based irradiation setup for proton radiobiology

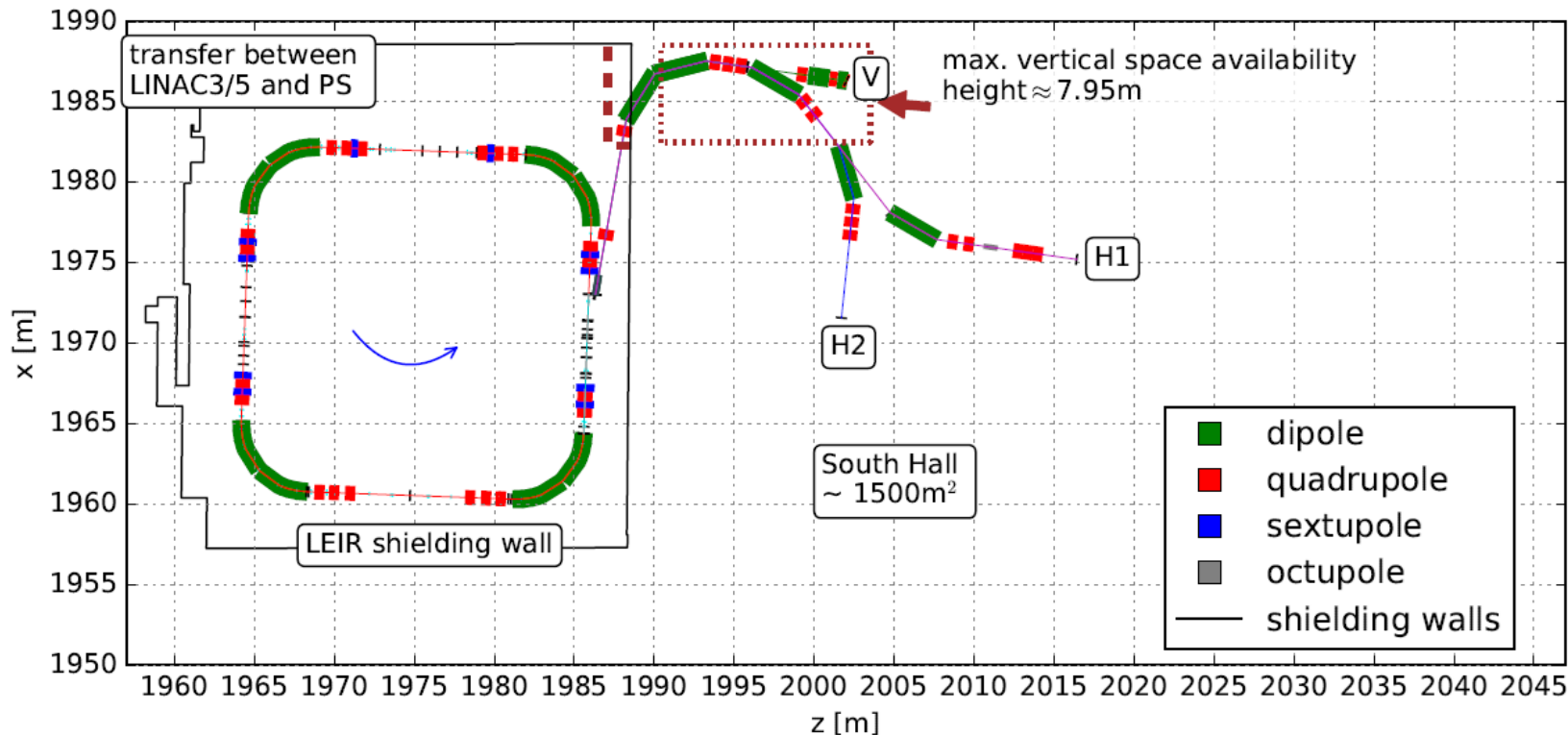


- **Geant4** simulation toolkit
- 2D automatically controlled positioning system

(Ghithan et al. 2015 JINST)

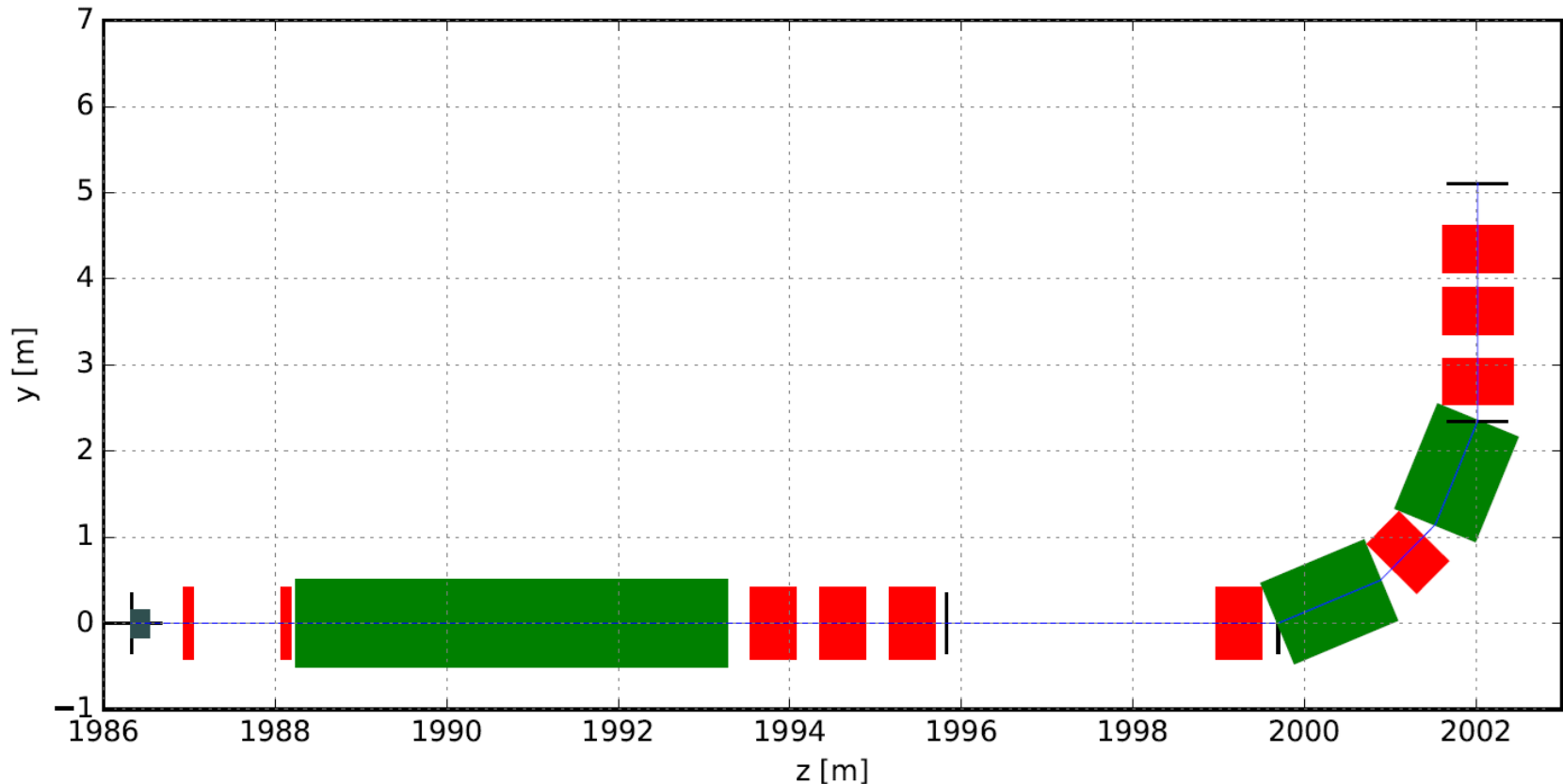
(2) Design study of beam transport lines for BioLEIR facility at CERN

- ❑ Vertical beam line: going upwards, <75 MeV/u, limited to 10^8 ions/s
- ❑ 2 horizontal beam lines: 440 MeV/u, $10^8/10^9$ ions/s + $10^8/10^{10}$ p/s
- ❑ Broad beam 40×40 mm² (H1), field uniformity $> 90\%$ across irradiation field
- ❑ Pencil beam with multispot scanning (V, H1, H2)

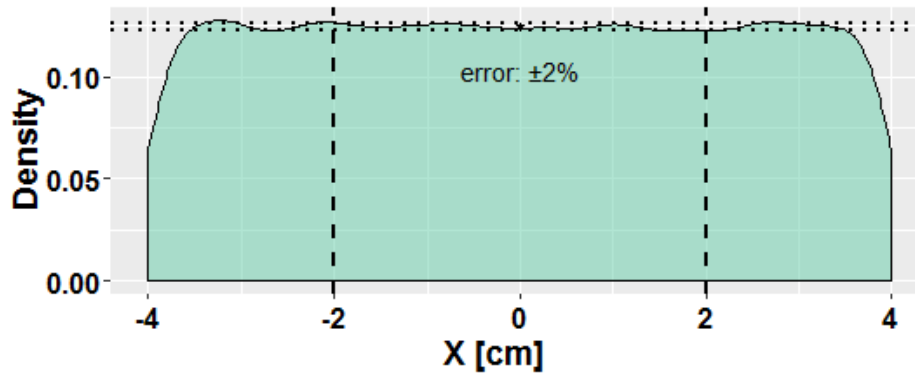


Survey plot of the vertical beamline in z-y plane

The vertical target plane is located about 6.5 m above the LEIR floor level

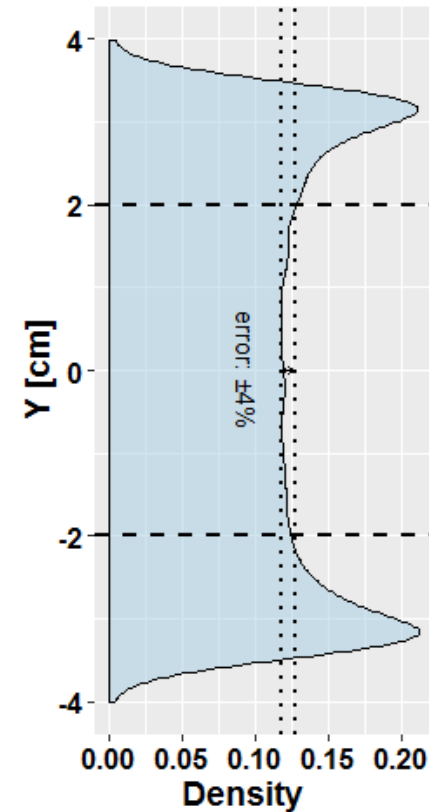
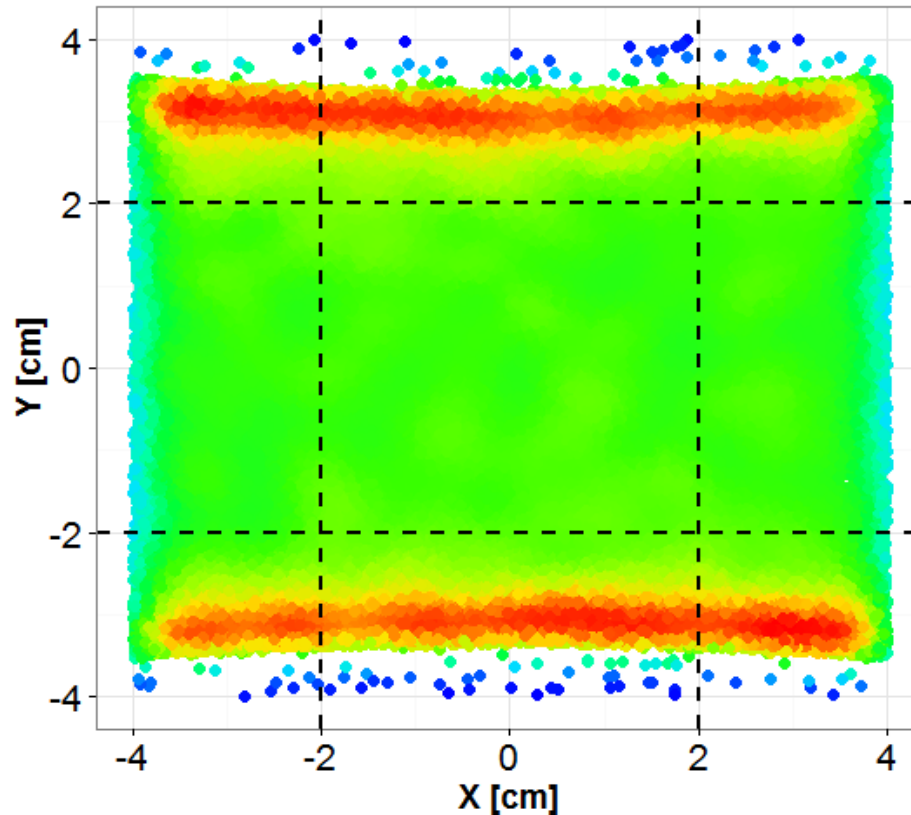


First horizontal extension / broad beam

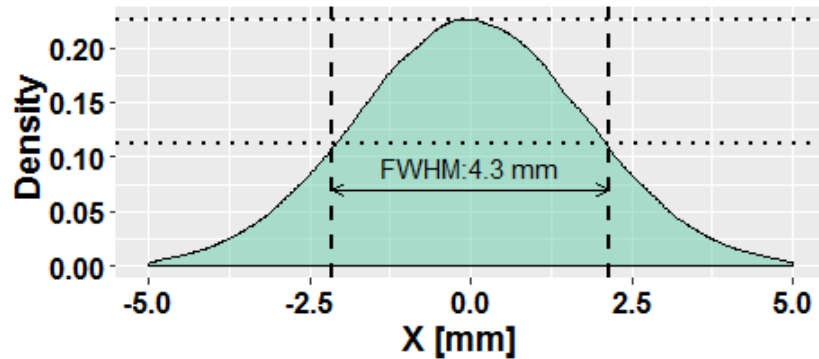


Field uniformity > 90% across irradiation field

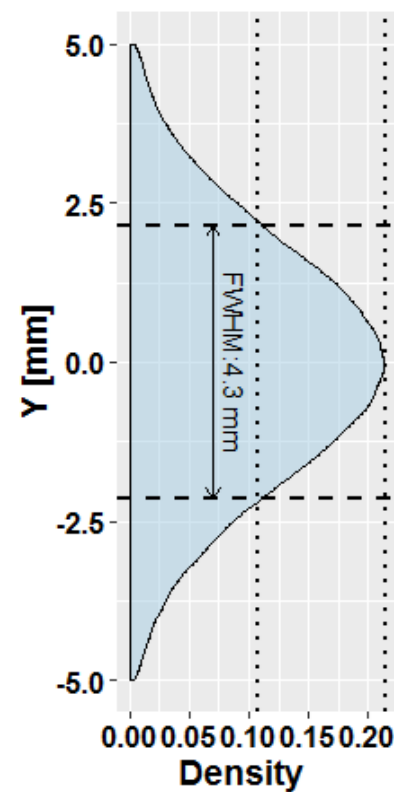
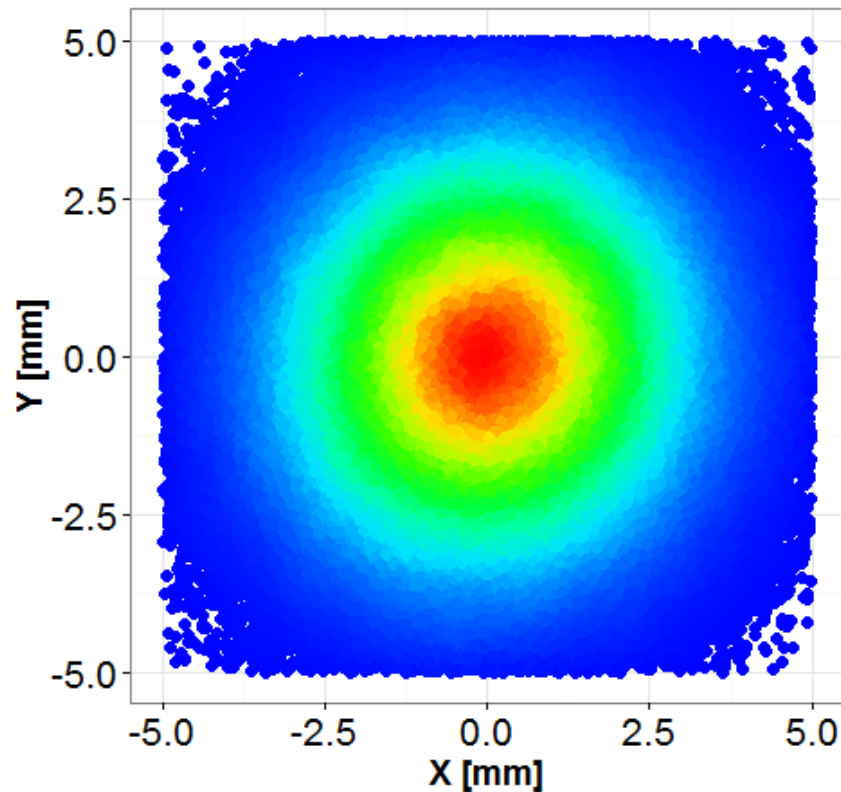
MAD-X / Multi-particle tracking code



First horizontal extension / pencil beam

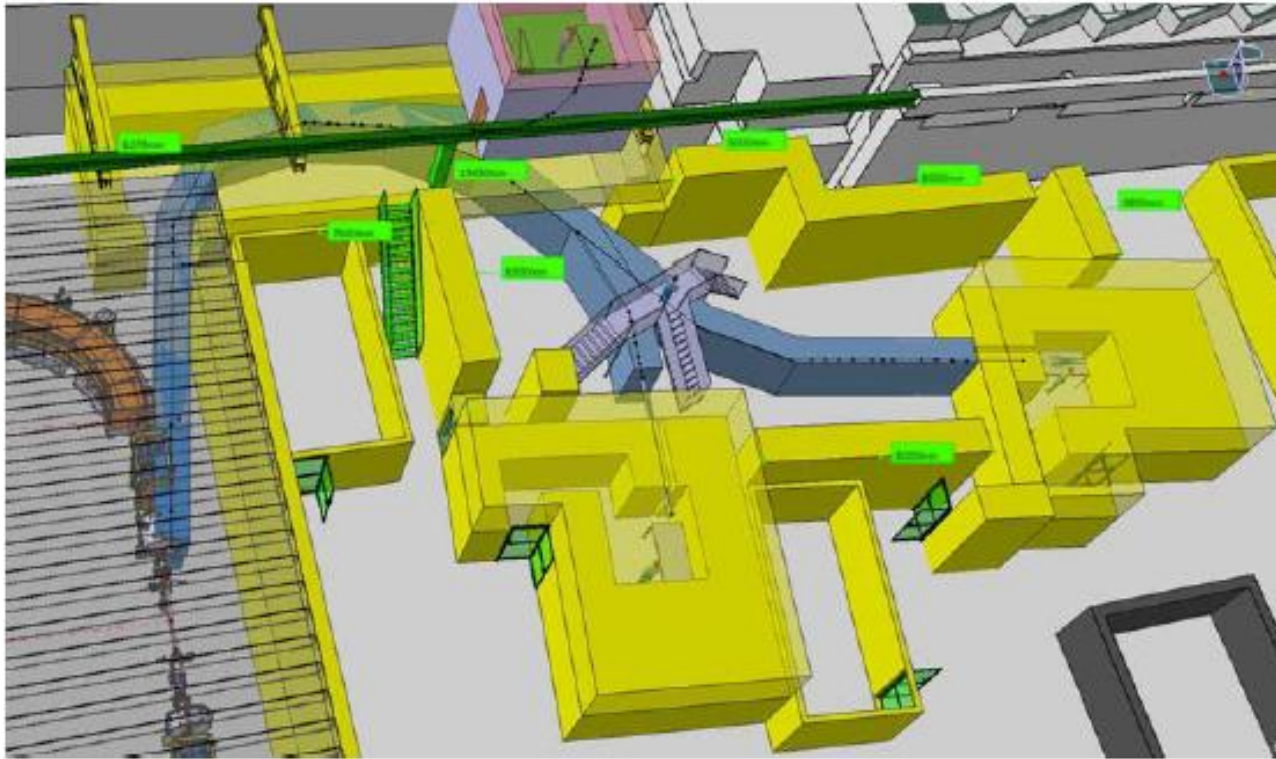


MAD-X / Multi-particle tracking code



Biomedical experimental area

Design of the biomedical experimental area providing common instrumentation & sample/detector mounts, access & area control.



(Ghithan et al. 2017, CERN-2017-001-M)

Biomedical laboratory
~200m²

Robotic placement system

Provision for cell imaging

Independent user access to
irradiation areas

Provision for an X-ray
irradiation control: ideally
6MeV Linac close by

Local experimental control
(counting rooms)

Augusta Victoria Hospital

Versa EVO



Versa HD



Synergy



Augusta Victoria Hospital / Key Number

Year	No. Pt
2017	991
2018	1369
2019	1514
2020	1516
2021	1796
2022	2097
2023	2010
2024	1581
2025	1166
2026	562

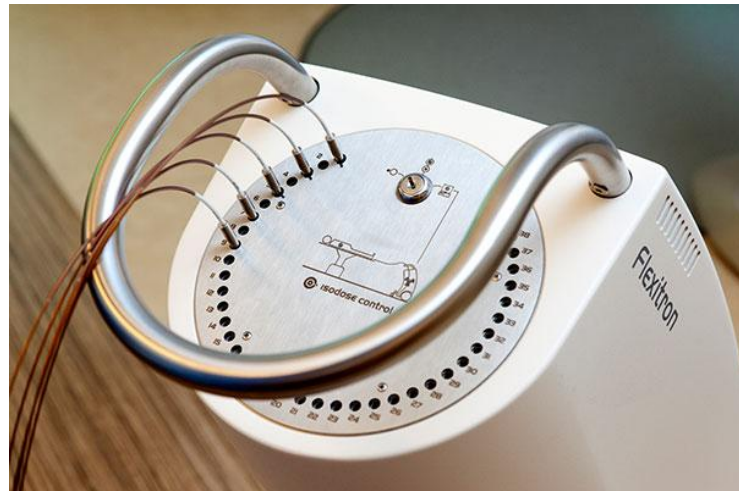
Brachytherapy

- **Brachytherapy** is defined as a short distance treatment of malignant disease with radiation emanating from small sealed sources.
- The sources are placed directly into the treatment volume or near the treatment volume.
- The radiation dose is delivered directly to the cancerous tissue with minimal effect on surrounding healthy tissues.

22 Patients since October 2025



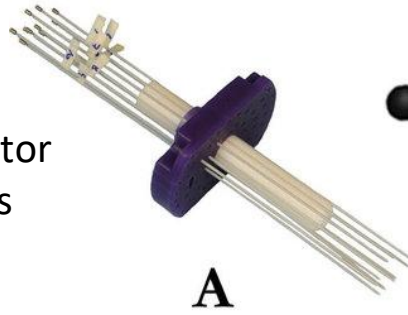
Iridium-192
Gamma rays (380 keV)



HDR Remote afterloader

Intracavitary Applicators

Vaginal cylinder applicator
with 8 parallel catheters

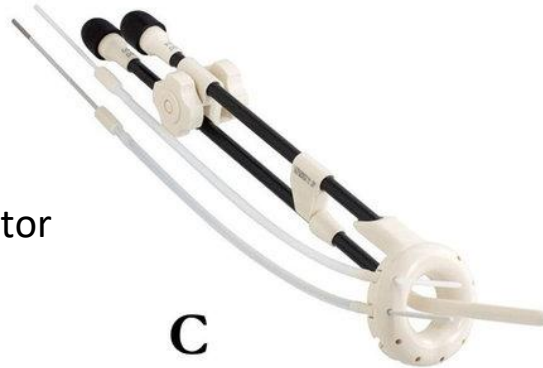


A



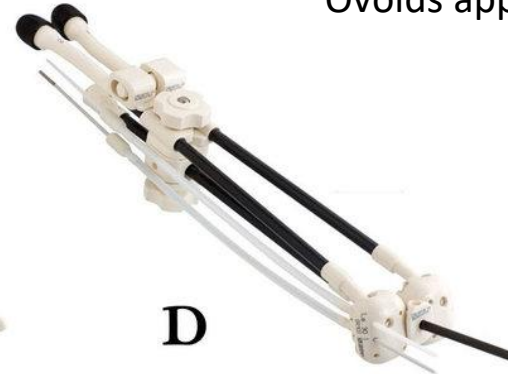
B

Ovoids applicator



C

Ring applicator



D

Four standardized applicators for gynecological brachytherapy:

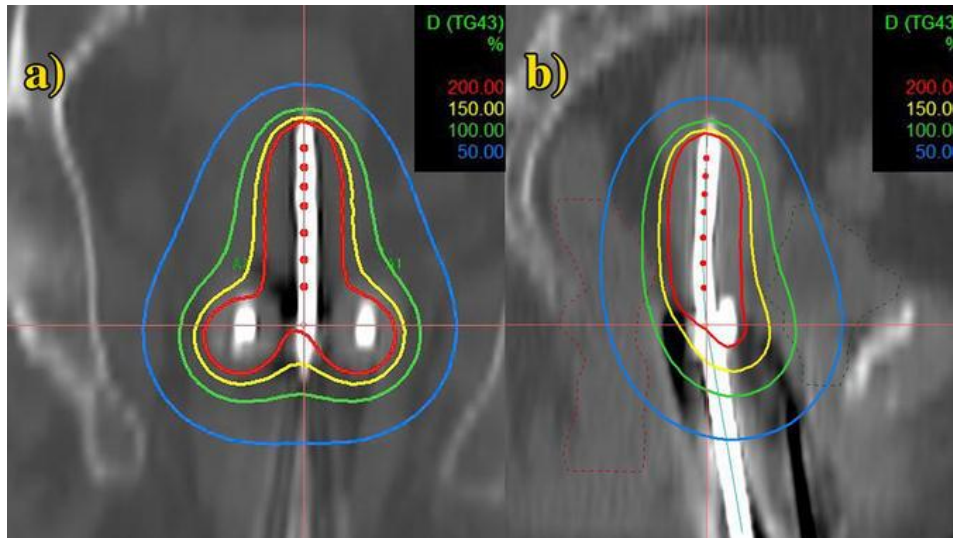
- B,C&D also have a uterine tandem and allow for interstitial catheters.
- The uterine tandem provides a channel for dwell positions inside the uterine canal.
- The ring(C) and ovoids(B & D) act as guides for inserting catheters into the tissue surrounding the cervix.

Dwell Time & Dwell Position in Brachytherapy

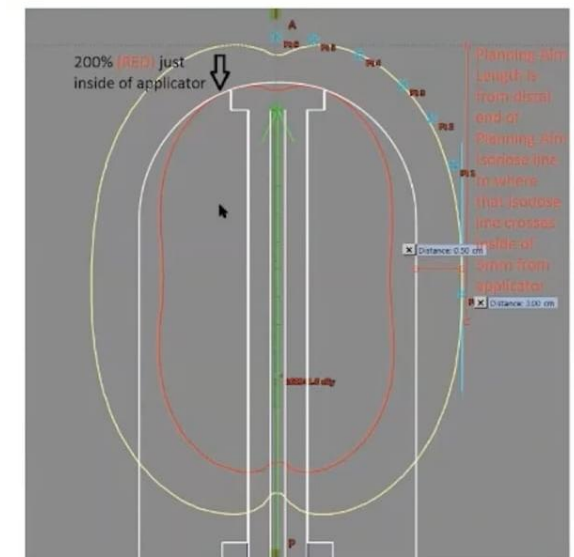
Dwell Position: a specific point along the applicator or catheter where the radiation source can stop.

Dwell Time: the amount of time the source stays at a dwell position to deliver radiation.

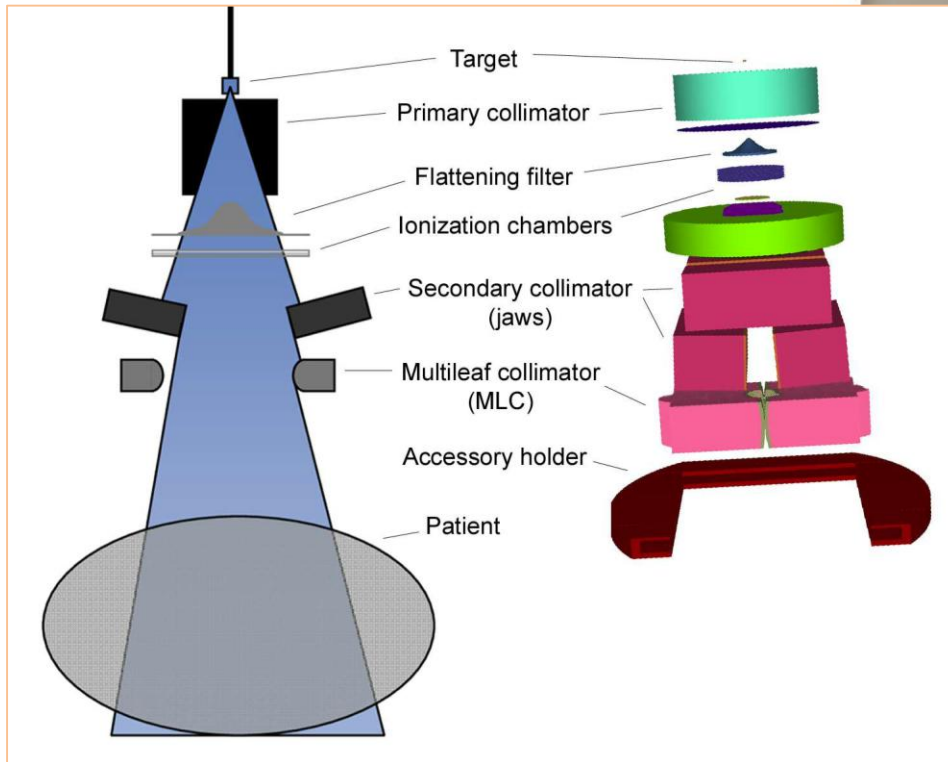
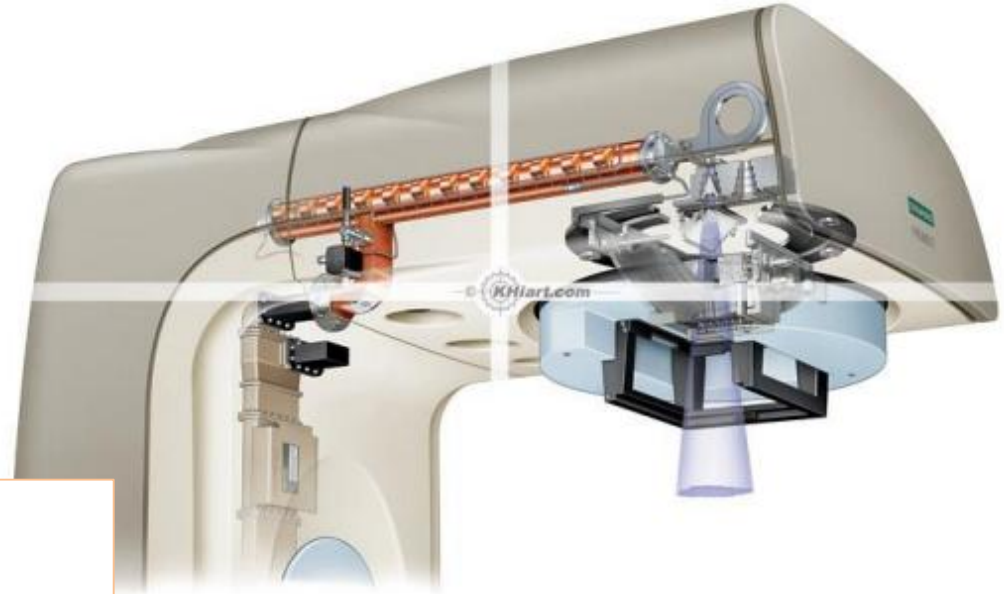
- ✓ By varying **dwell times** and **positions**, medical physicist can **shape the dose distribution** around the tumor while sparing healthy tissue.
 - Multiple dwell positions and variable dwell times allow **precise dose shaping**.
 - Optimizes tumor coverage while sparing healthy tissues.



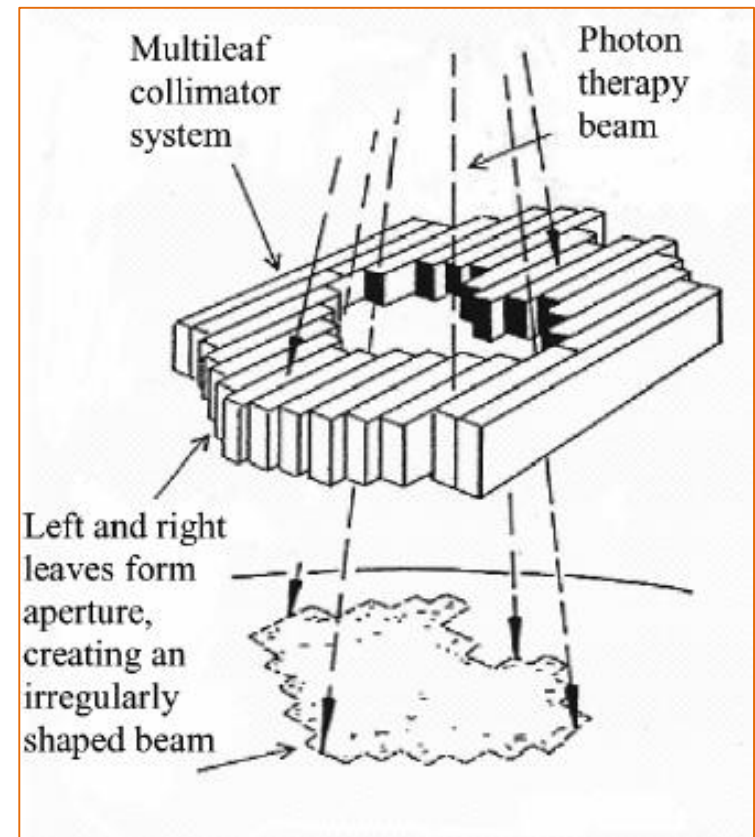
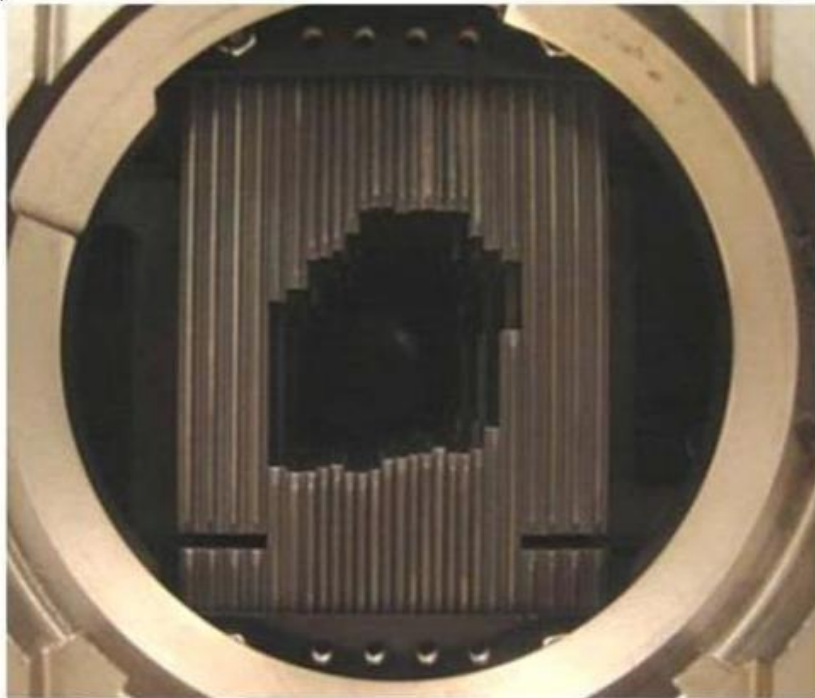
Isodose distribution of a patient in (a) coronal view (b) sagittal view



Linear Accelerator

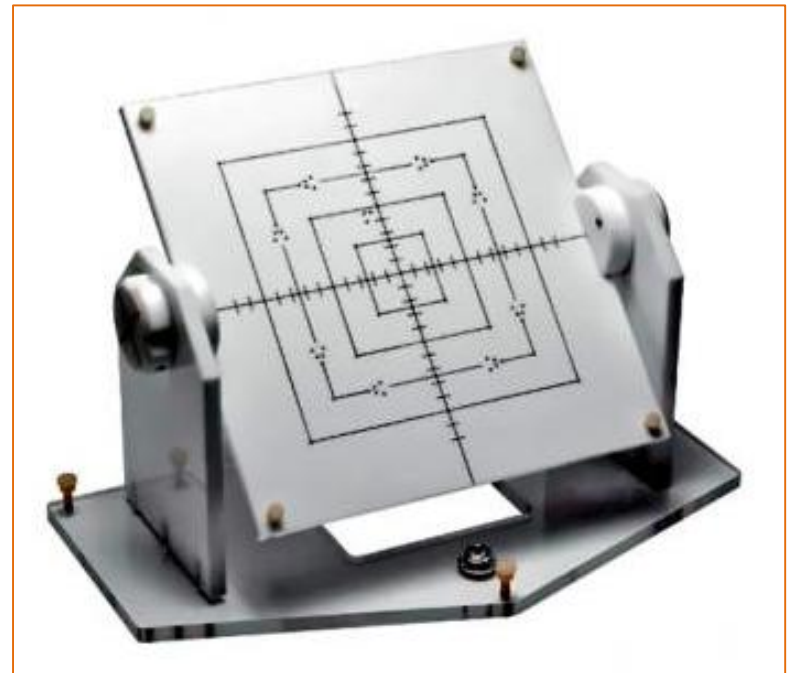
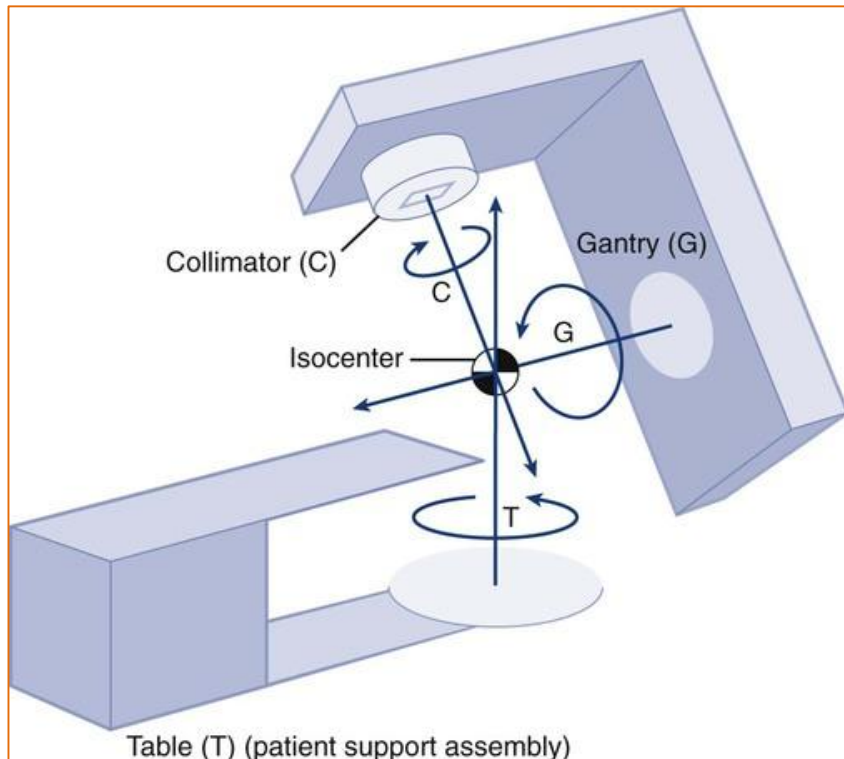


MLC - Multi Leaf Collimator

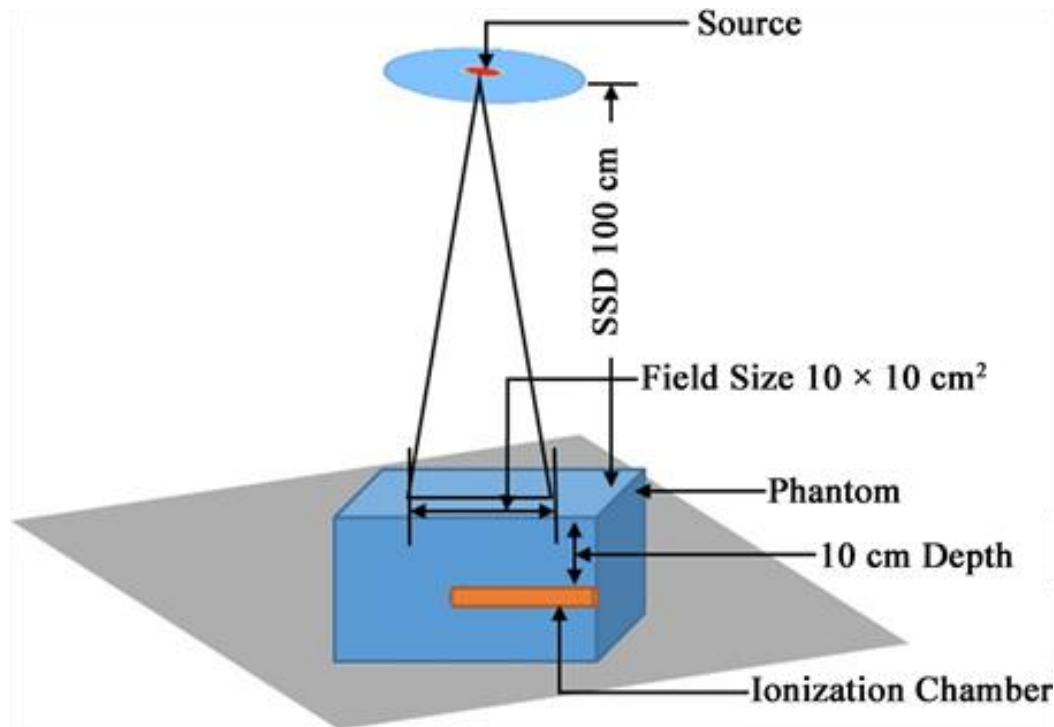


Commissioning and acceptance of LINAC

- Commissioning is the process of testing and acquiring data that would be used in **treatment planning system (TPS)**.
- Ensuring all manufacturers parameters are correct as stated in the manual.
- Ensuring interlocks are working properly; machine safety, patient safety and dose interlocks, etc.
- Performance of **mechanical checks**.



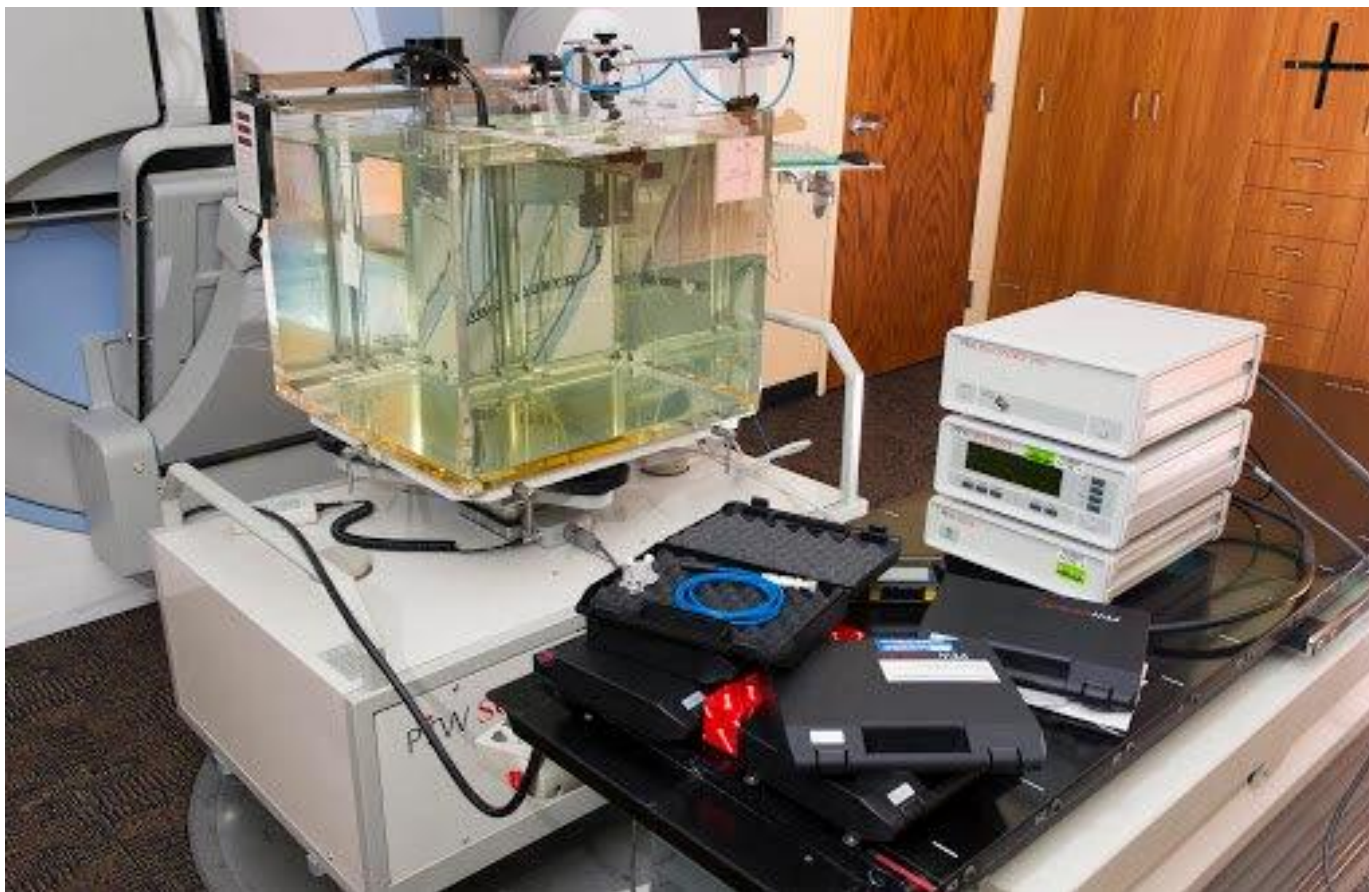
Commissioning and acceptance of LINAC



Dose monitor is generally calibrated in terms of the ratio of monitor units to the absorbed dose on the central axis at the depth of dose maximum D_{max} , for a 10cm x 10cm field and for the standard SSD, generally 100cm.

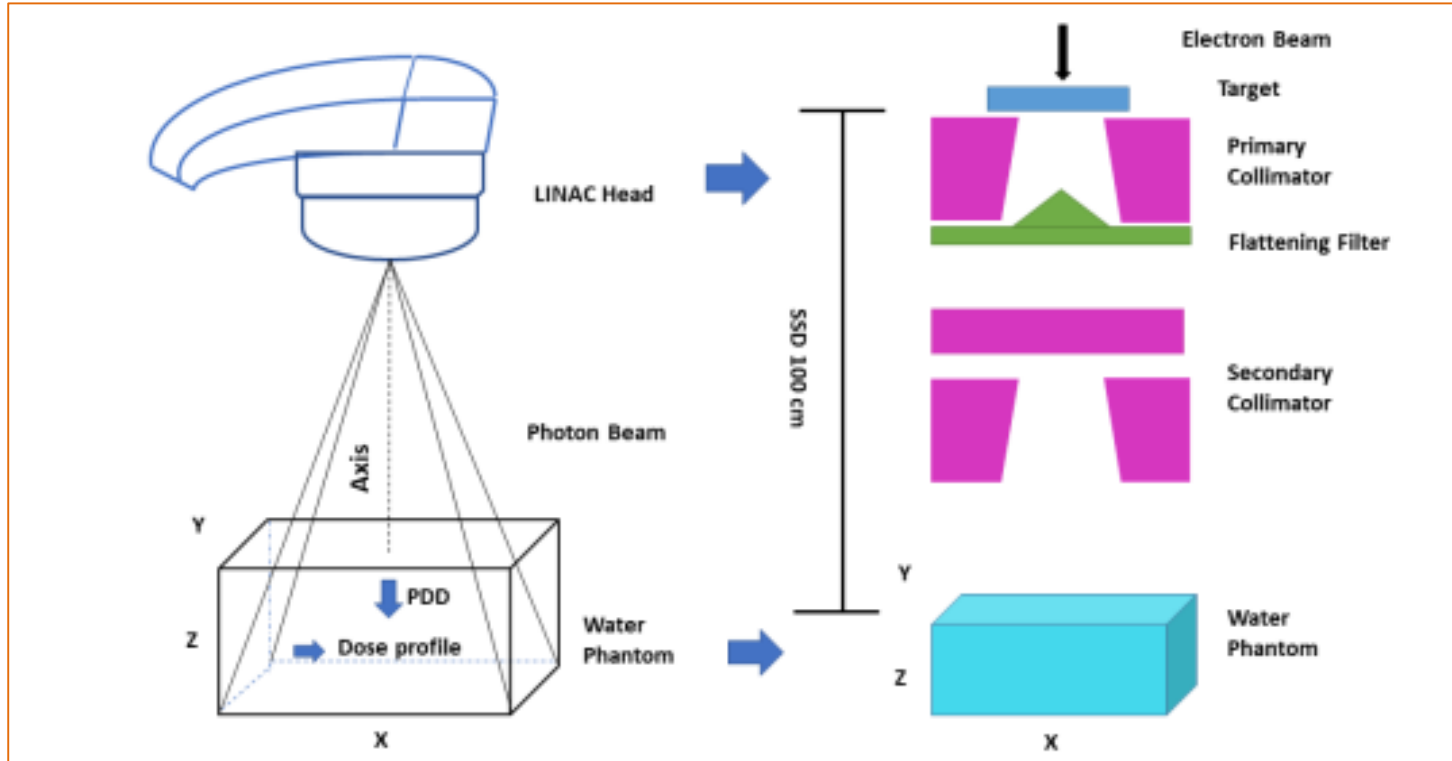
QA protocols according to TRS-398

Water phantom used for commissioning

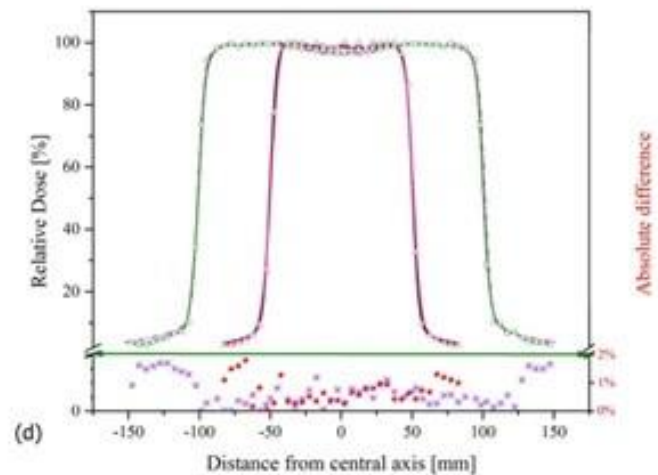
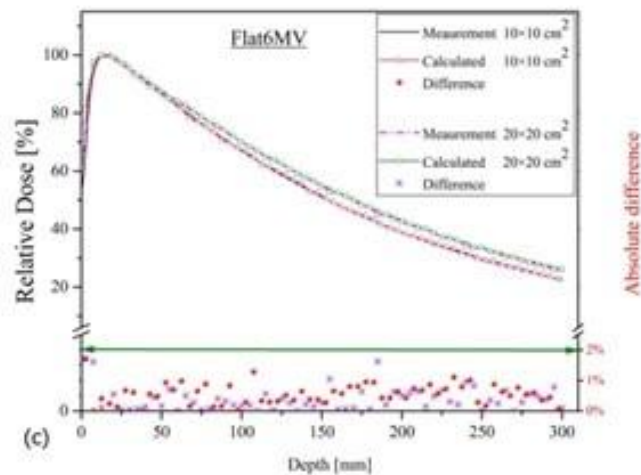
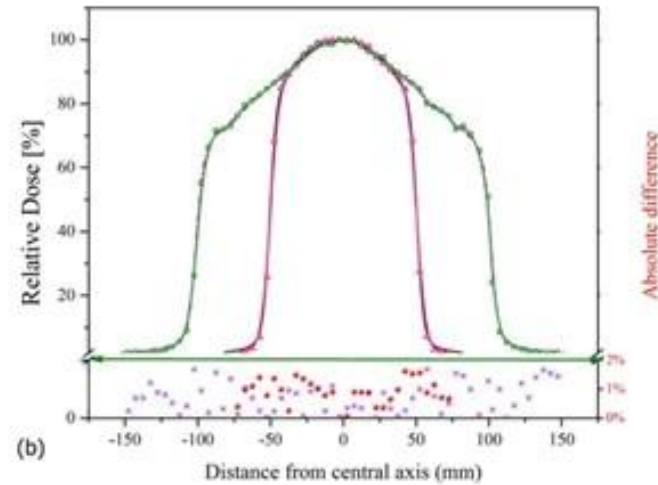
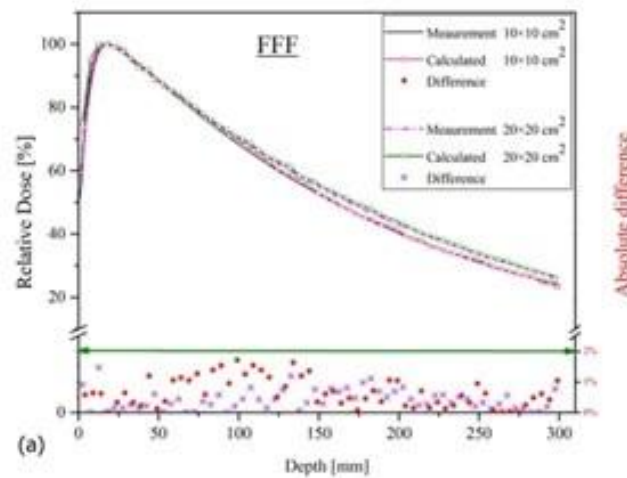


Getting percentage depth doses, beam profiles, relative output factors, wedge factors, and Tray factors. All this factors will affect the dose to be delivered and hence should be introduced into the calculation of the dose.

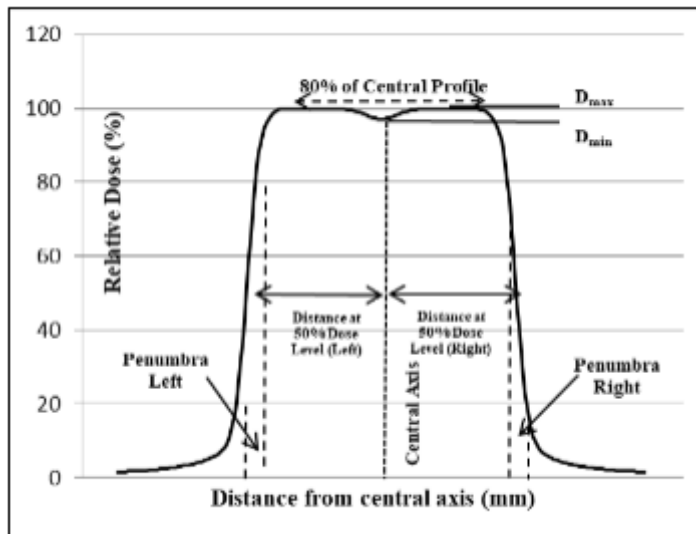
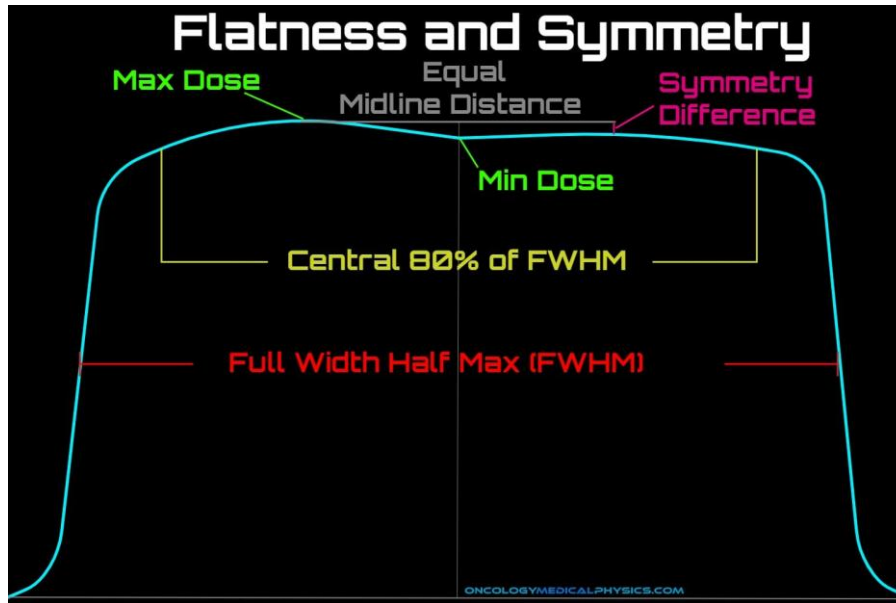
Water phantom used for commissioning



PDD and beam profile of 6MV and 6FFF energies



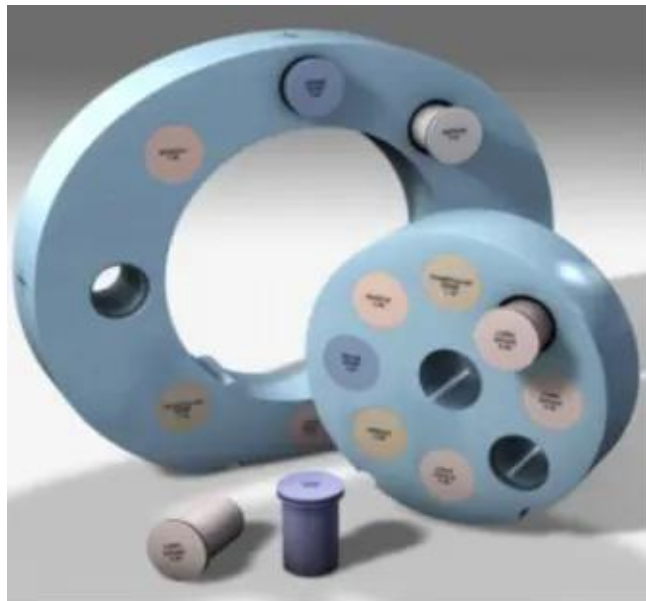
Flatness & Symmetry



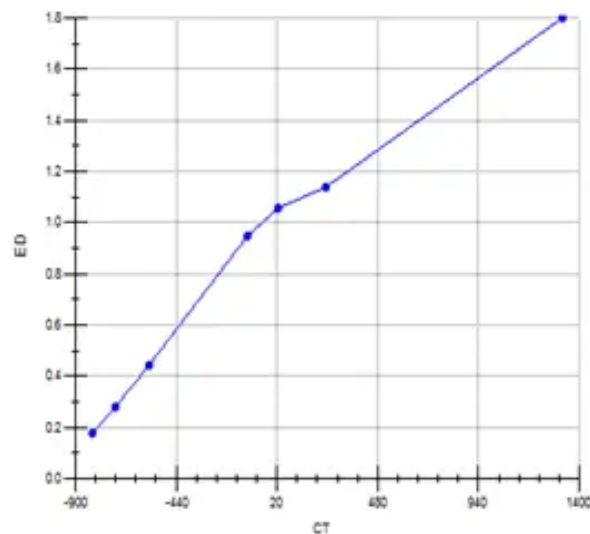
$$\text{Flatness} = \frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}} \times 100\%$$

$$\text{Symmetry} = \frac{\text{Distance}_{\text{Left}} - \text{Distance}_{\text{Right}}}{\text{Distance}_{\text{Left}} + \text{Distance}_{\text{Right}}} \times 100\%$$

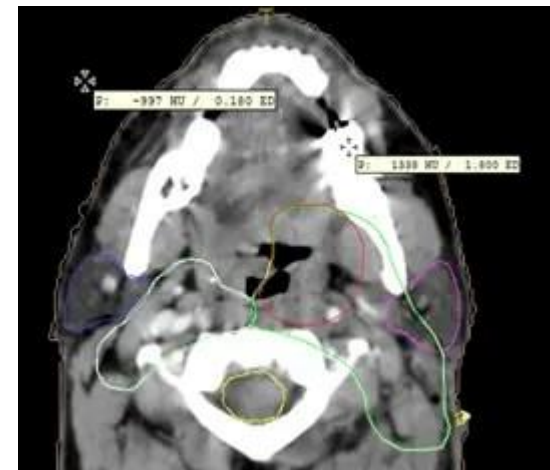
Phantom for HU calculation



CT to ED curve



ED in different mediums



Hounsfield Unit formula

$$HU = \left(\frac{\mu_{\text{material}} - \mu_{\text{water}}}{\mu_{\text{water}}} \right) \times 1000$$

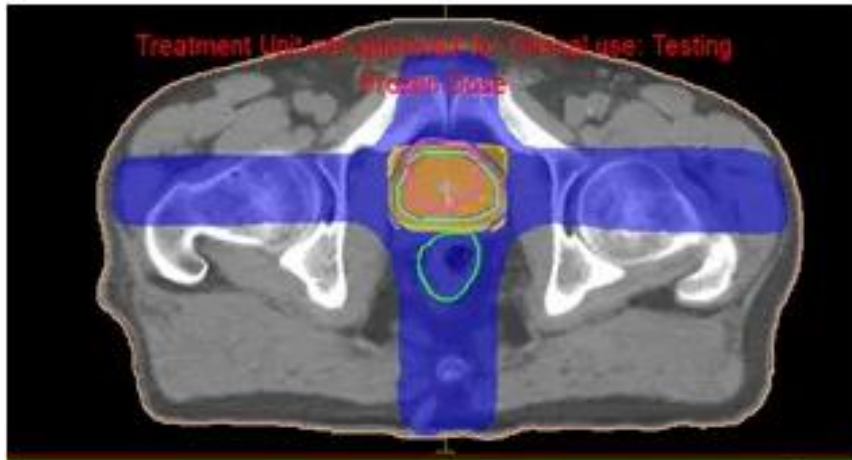
μ = CT linear attenuation coefficient

Hounsfield Units for human body

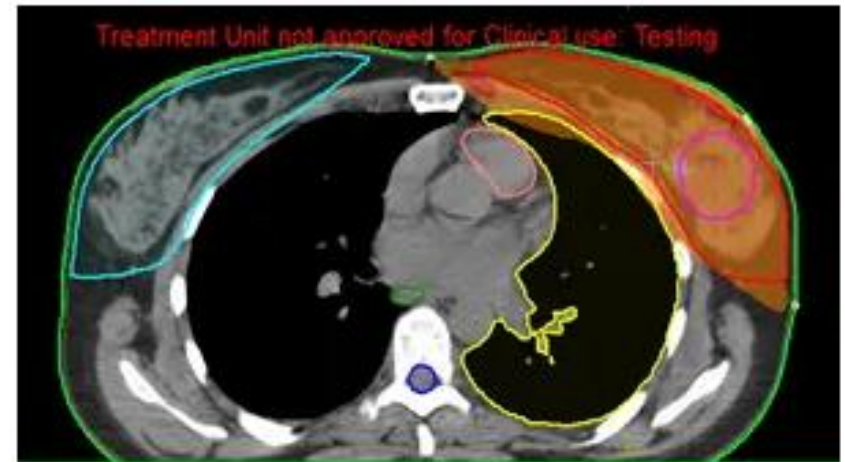
<i>Bone</i>	1000
<i>Liver</i>	40 to 60
<i>White Matter</i>	46
<i>Grey Matter</i>	43
<i>Blood</i>	40
<i>Muscle</i>	10 to 40
<i>Kidney</i>	30
<i>Cerebrospinal Fluid</i>	15
<i>Water</i>	0
<i>Fat</i>	-50 to -100
<i>Air</i>	-1000

Planning

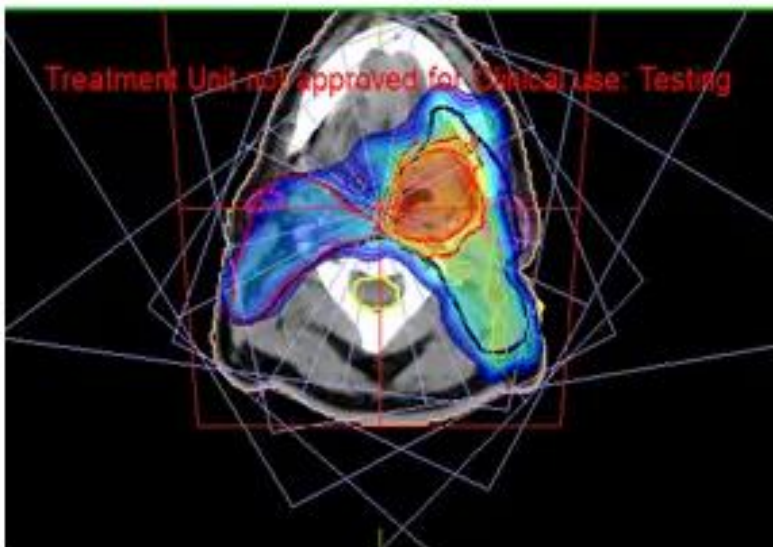
Dose distribution of a prostate 3D plan



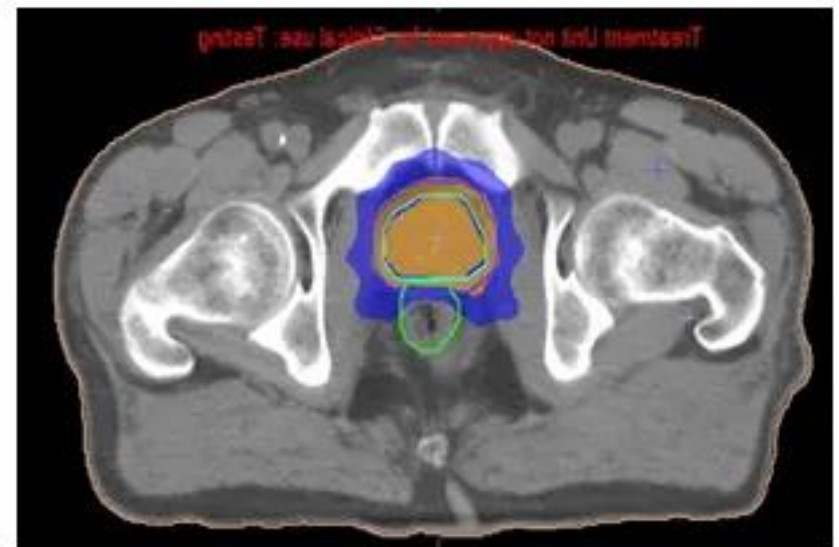
Dose distribution of a breast 3D plan



Dose distribution of a IMRT neck plan



Dose distribution of a VMAT prostate case



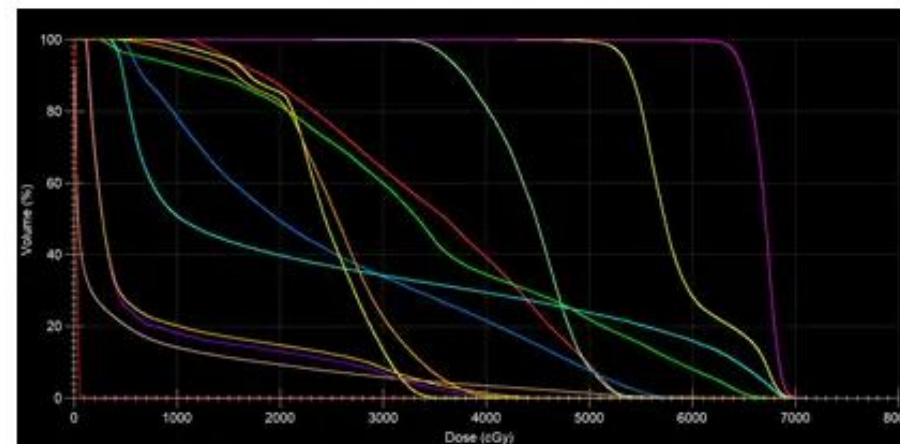
Plan evaluation

Statistics of different organs

DVH Statistics								
Dosimetric Criteria	Statistics	Display						
Structure	Volume (cm³)	Min. Dose (Gy)	Max. Dose (Gy)	Mean Dose (Gy)	Ref. Vol. (cm³)	Ref. Vol. (%)	Ref. Dose (Gy)	
Brainstem	29.435	35.082	54.752	52.578	1.000	3.40	53.769	
PTV	105.194	50.817	59.061	54.435	105.171	99.98	51.300	
OpticChiasm	1.181	25.616	49.093	36.669				
Spinal Cord	10.614	0.266	28.893	3.069				
OpticNrv_R	0.608	12.972	27.582	17.953				
OpticNrv_L	0.576	12.202	24.953	16.493				
Lens_L	0.107	7.055	8.707	7.811				
Lens_R	0.156	6.965	9.106	7.982				
Eye_R	7.984	5.603	16.665	11.046				
Eye_L	7.323	5.890	16.070	11.416				
Cochlea_L	0.032	39.374	46.123	42.790				
Cochlea_R	0.029	42.267	45.517	43.618				
Body+Mask(Unsp.Tiss.)	3316.898	0.000	56.604	5.427				

DVH of the contoured structures

Organs at risk	Constraints	Secondary criteria
Optic chiasma	Dmax<54 Gy	Dmax<60 Gy
Optic nerve	Dmax<54 Gy	Dmax<55 Gy
Cochlea	Dmean<45 Gy	
Brainstem	Dmax<54 Gy	Dmax<60 Gy,
D59 Gy<10 cc		
Pituitary gland	Dmax<50 Gy	Dmax<60 Gy
Eye	Dmax<45 Gy	
Lacrimal gland	Dmax<40 Gy	
Lens	Dmax<6 Gy	Dmax<10 Gy



Plan Quality assurance - Delta4 Phantom



Patient-Specific QA involves verifying that the radiation dose calculated by the treatment planning system (TPS) can be accurately delivered by the treatment machine for each individual patient.

The **Gamma Index** is a **quantitative metric** used in **radiation therapy** to compare two dose distributions:

- **Planned dose** (from TPS)
- **Measured dose** (from QA measurements)

Gamma index combines two criteria:

1. **Dose difference (DD)** – e.g., within **3%**
2. **Distance to agreement (DTA)** – e.g., within **3 mm**

A point passes the gamma test if **both criteria** are met.



What is Annual QA?

- ✓ Comprehensive quality check of LINAC components.
- ✓ Based on AAPM TG-142 Protocols.
- ☐ Daily QA: Basic checks
- ☐ Monthly QA: Intermediate checks
- ☐ Annual QA: Full system review

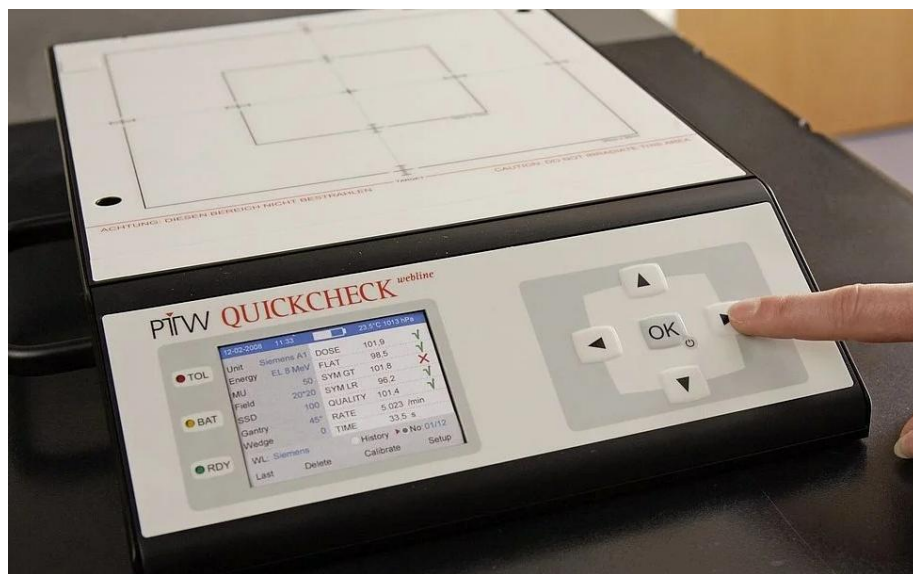
Ensuring Long Term Stability and Clinical Reliability

Why Annual QA Matters?

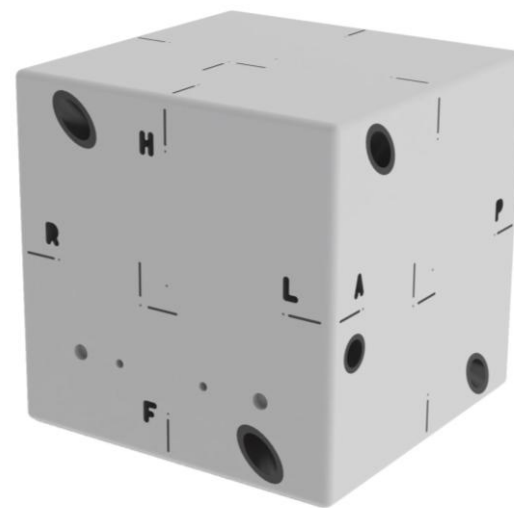
- ✓ Ensures clinical integrity and accuracy.
- ✓ Detects long-term drifts or degradation.
- ✓ Improves patient safety and treatment precision.

Quality assurance

- Morning checks are done to confirm that data is still reliable for treatment.
- Beam quality (Beam flatness and symmetry)
- Dose rate is still 1cGy to 1 MU.
- Laser alignment is reliable.
- Imaging: kV/MV/CBCT geometry.



PTW QUICKCHECK webline



MIMI Phantom: Multiple Imaging Modality Isocentricity Phantom

Data Analysis & Tolerances

TG-142 tolerances:

- ✓ Output: $\pm 1\%$,
- ✓ X-ray flatness/symmetry: $\pm 1\%$
- ✓ Beam quality (PDD_{10}): $\pm 1\%$ for photons
- ✓ MLC: $\pm 1\text{mm}$,
- ✓ Imaging: $\pm 1\text{mm}$

Received: 9 February 2021 | Revised: 16 March 2021 | Accepted: 28 April 2021

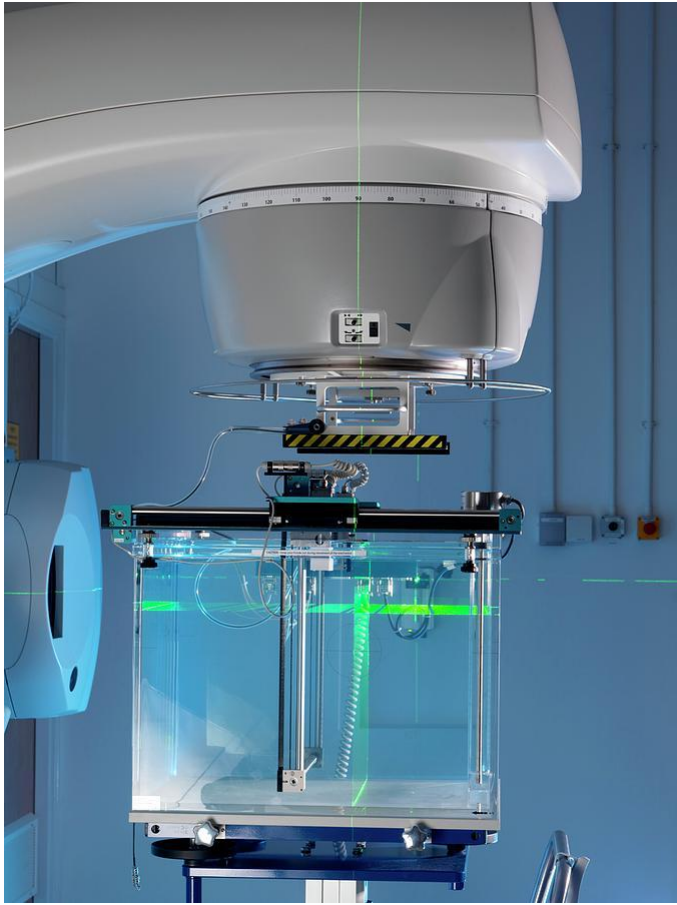
DOI: 10.1002/mp.14992

AAPM SCIENTIFIC REPORT

MEDICAL PHYSICS

AAPM Task Group 198 Report: An implementation guide for TG 142 quality assurance of medical accelerators

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Thank you!

**Scientists have a duty to use their knowledge
for the good of society.**