Linear Accelerators in Radiotherapy

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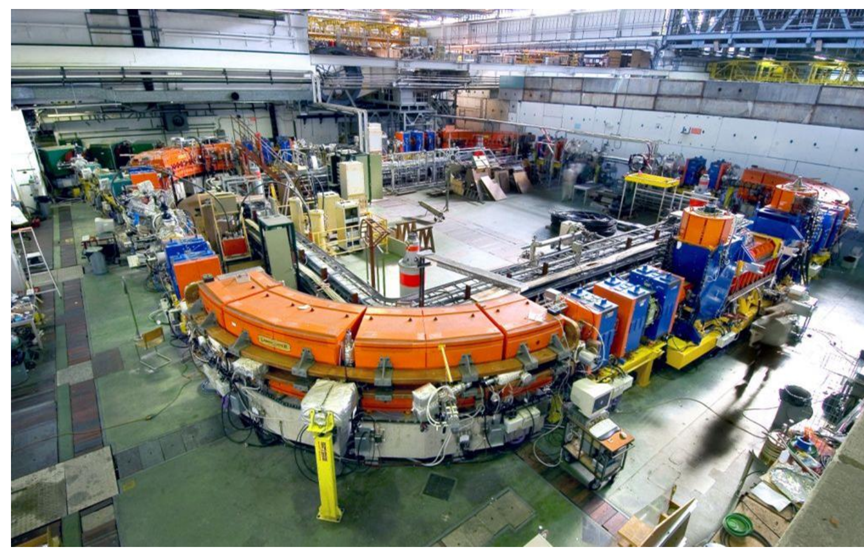
Augusta Victoria Hospital
مستشفى الأوغستا فكتوريا-المُطّلع


University of Coimbra


Al-Quds University


Birzeit University

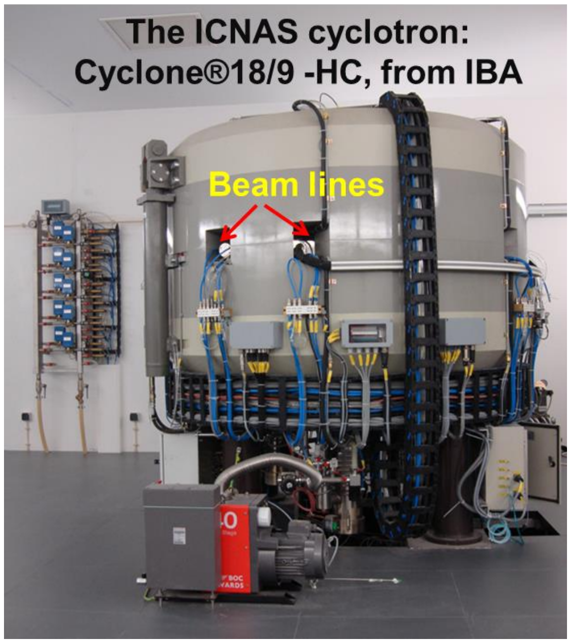


CERN

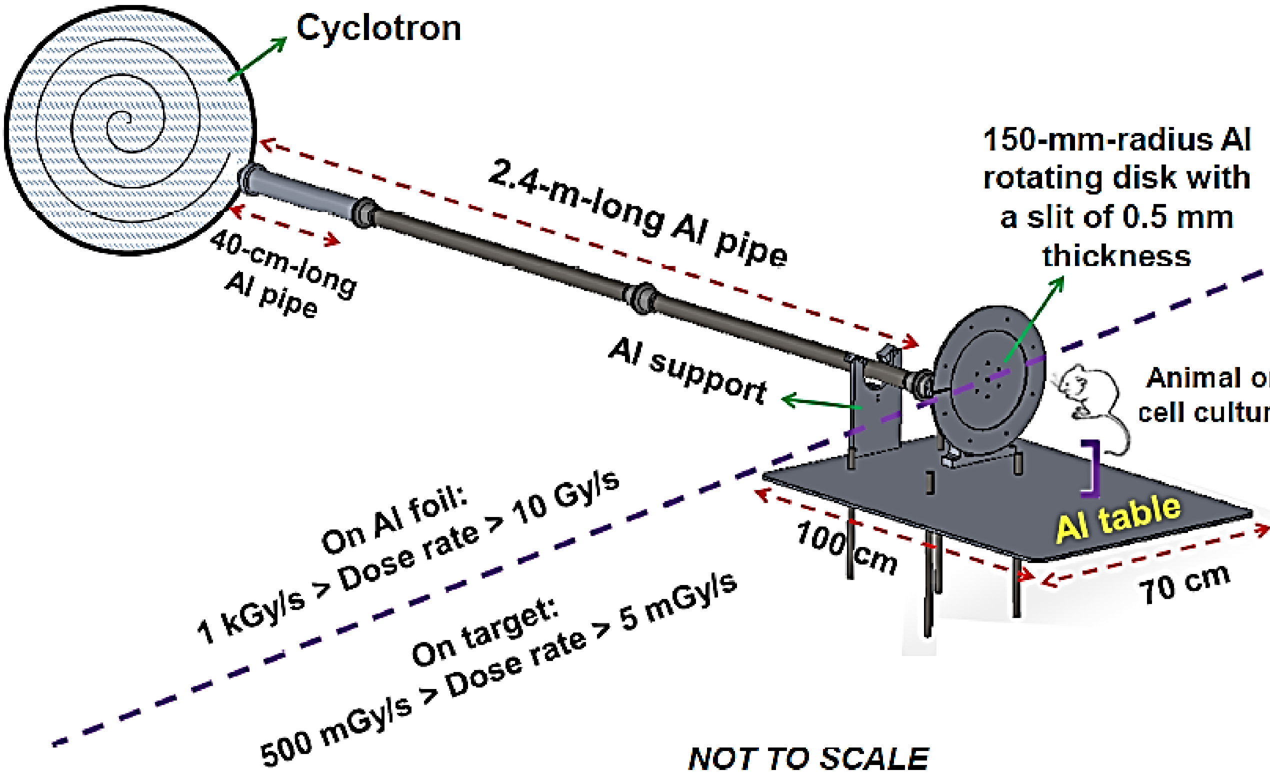
Augusta Victoria Hospital Jerusalem

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



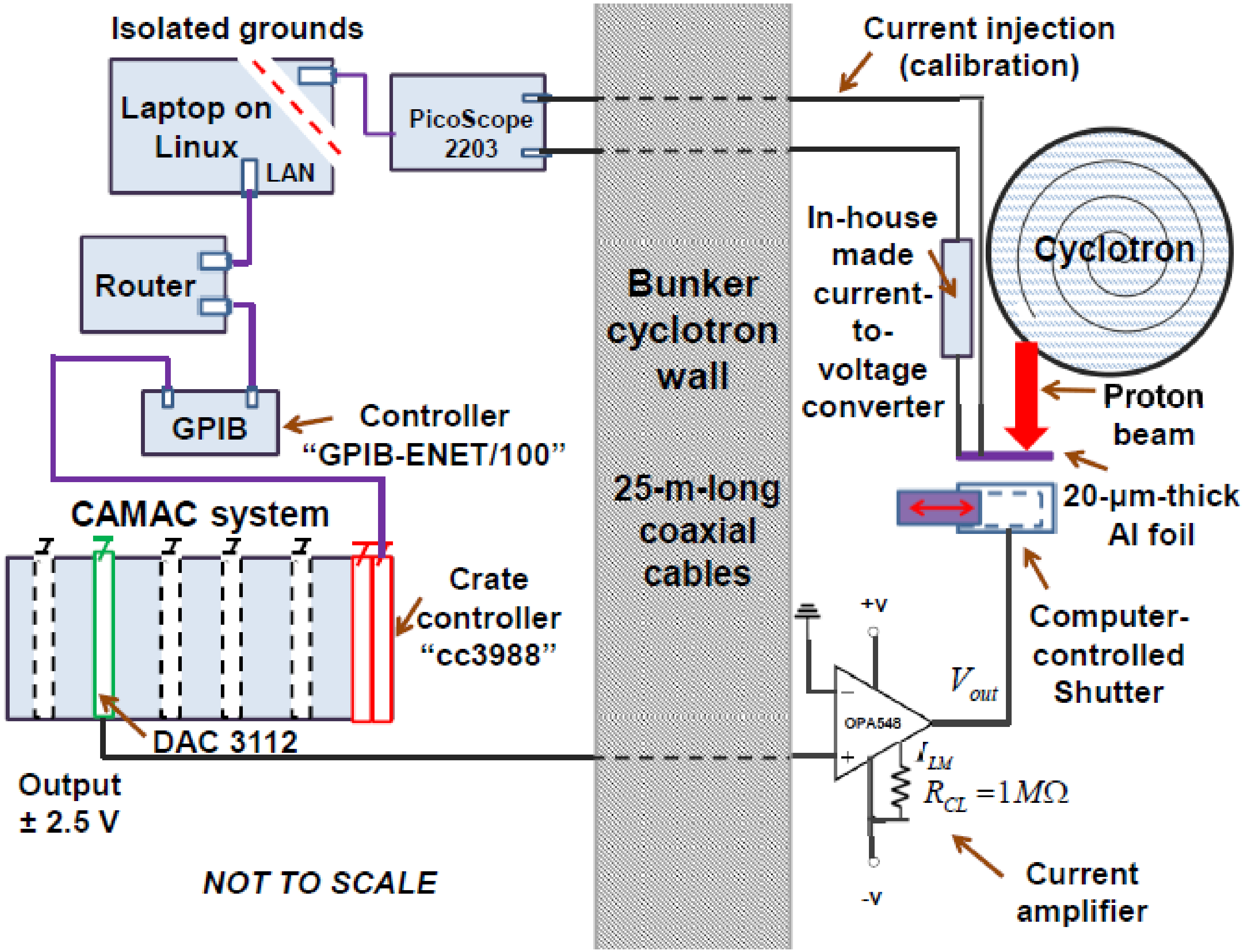
University of Coimbra



(Ghithan et al. 2013 JINST)

(Ghithan et al. 2015 JINST)

Development of a PET cyclotron based irradiation setup for proton radiobiology



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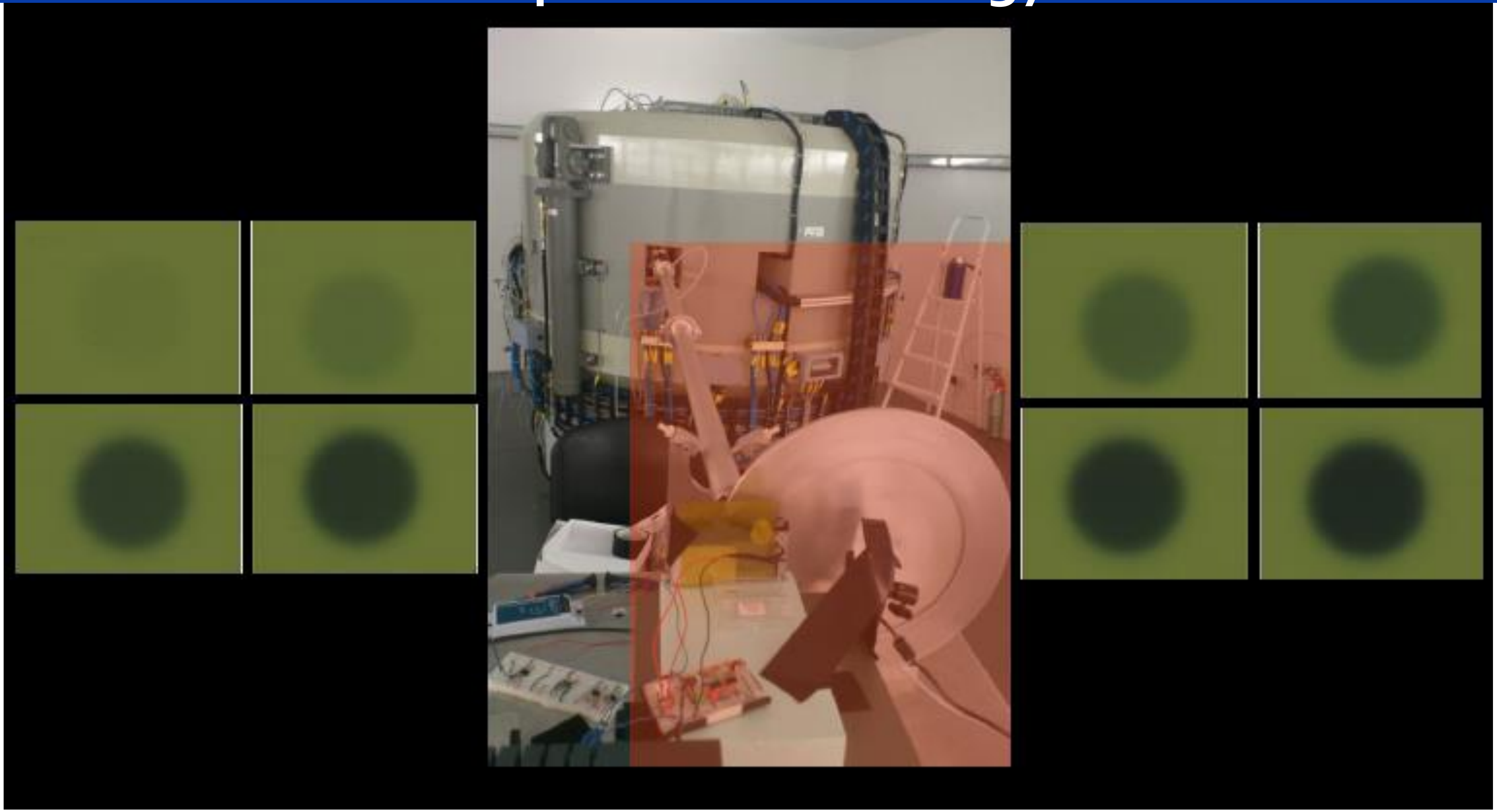
Development of a PET cyclotron based irradiation setup for proton radiobiology

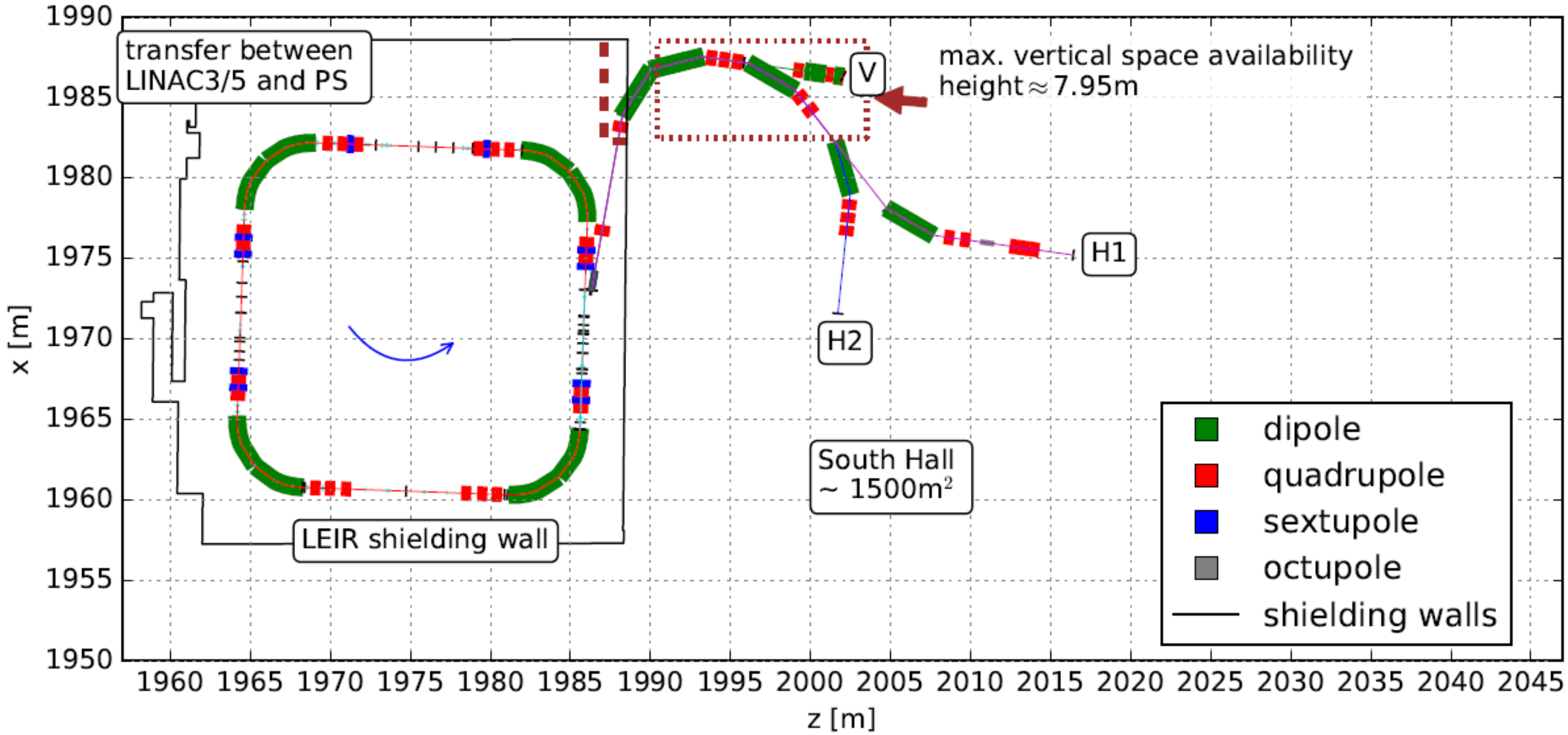


- Geant4 simulation toolkit
- 2D automatically controlled positioning system

(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 40x40 mm² (H1), field uniformity > 90% across irradiation field
- Pencil beam with multispot scanning (V, H1, H2)

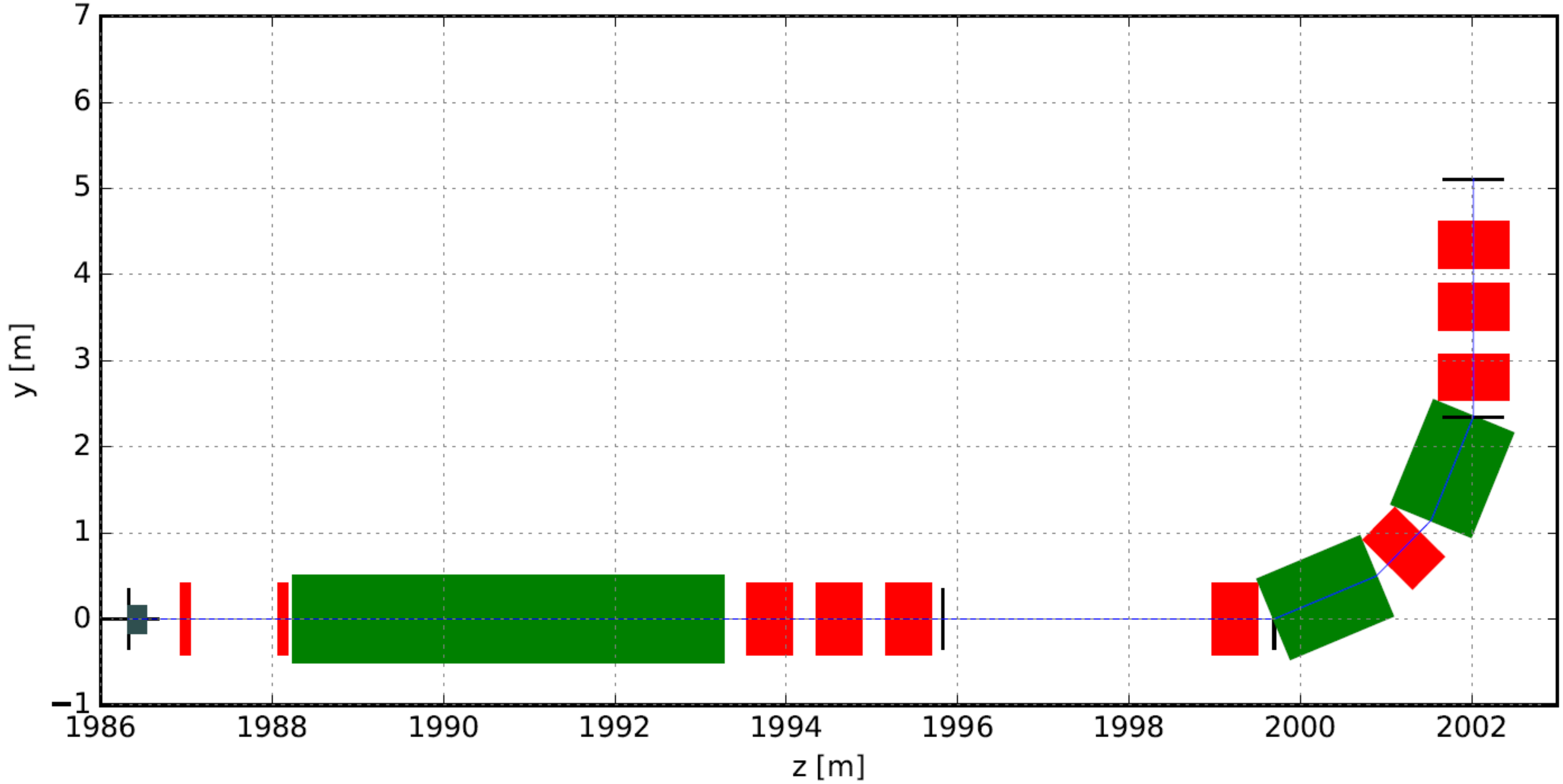


MAD-X / MAD - Methodical Accelerator Design

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

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



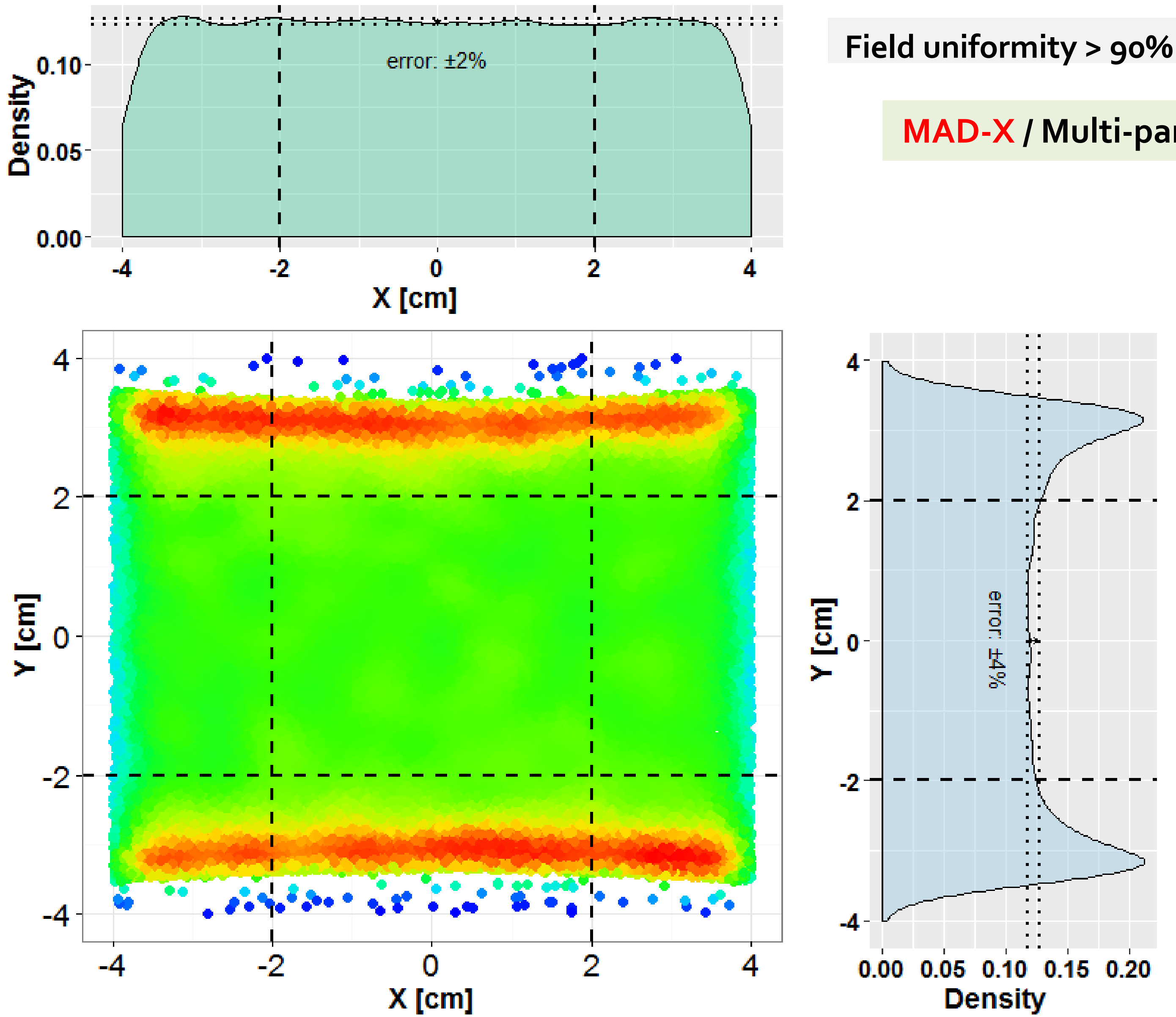
MAD-X / MAD - Methodical Accelerator Design

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

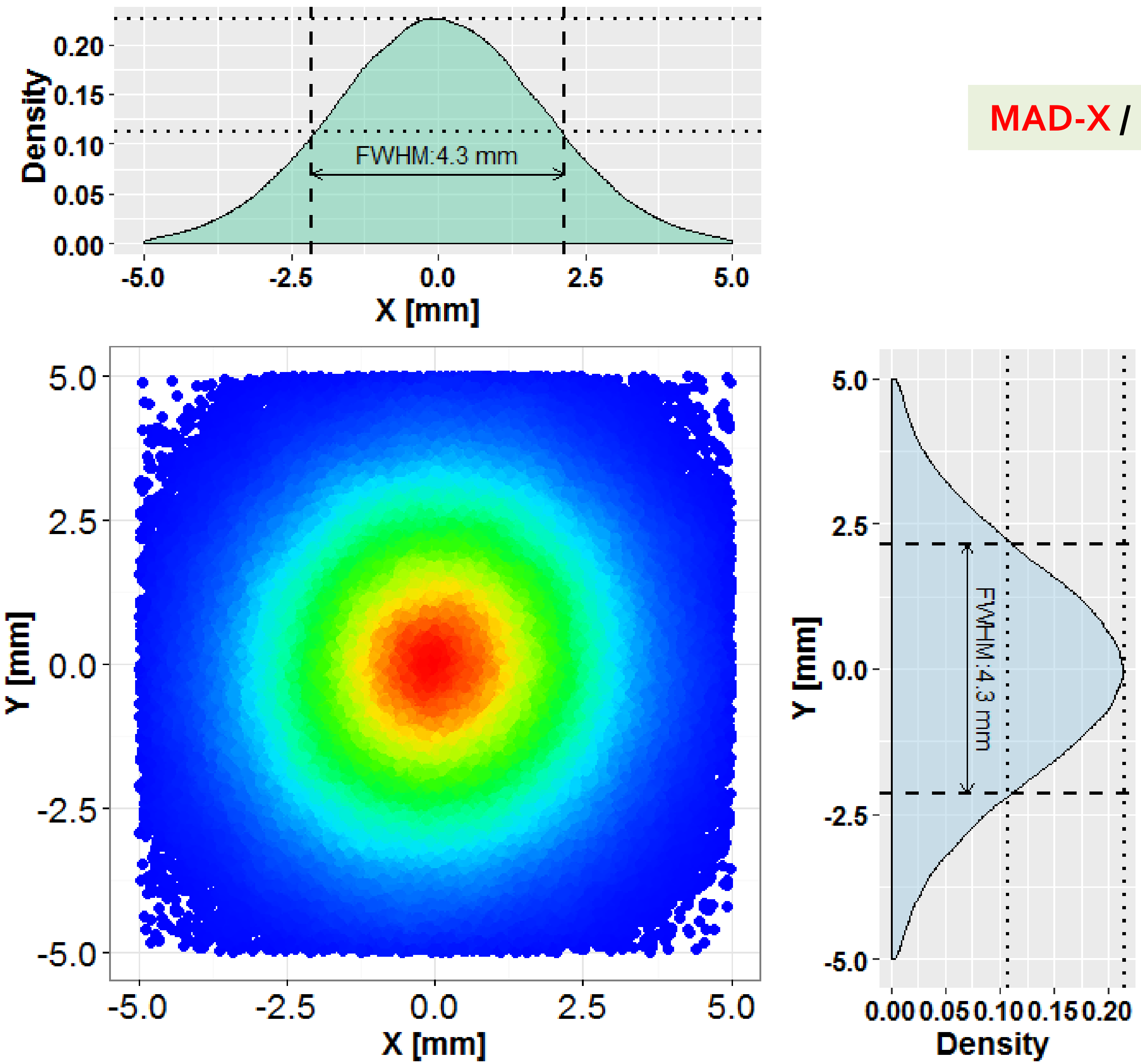
First horizontal extension / broad beam

Field uniformity > 90% across irradiation field

MAD-X / Multi-particle tracking code



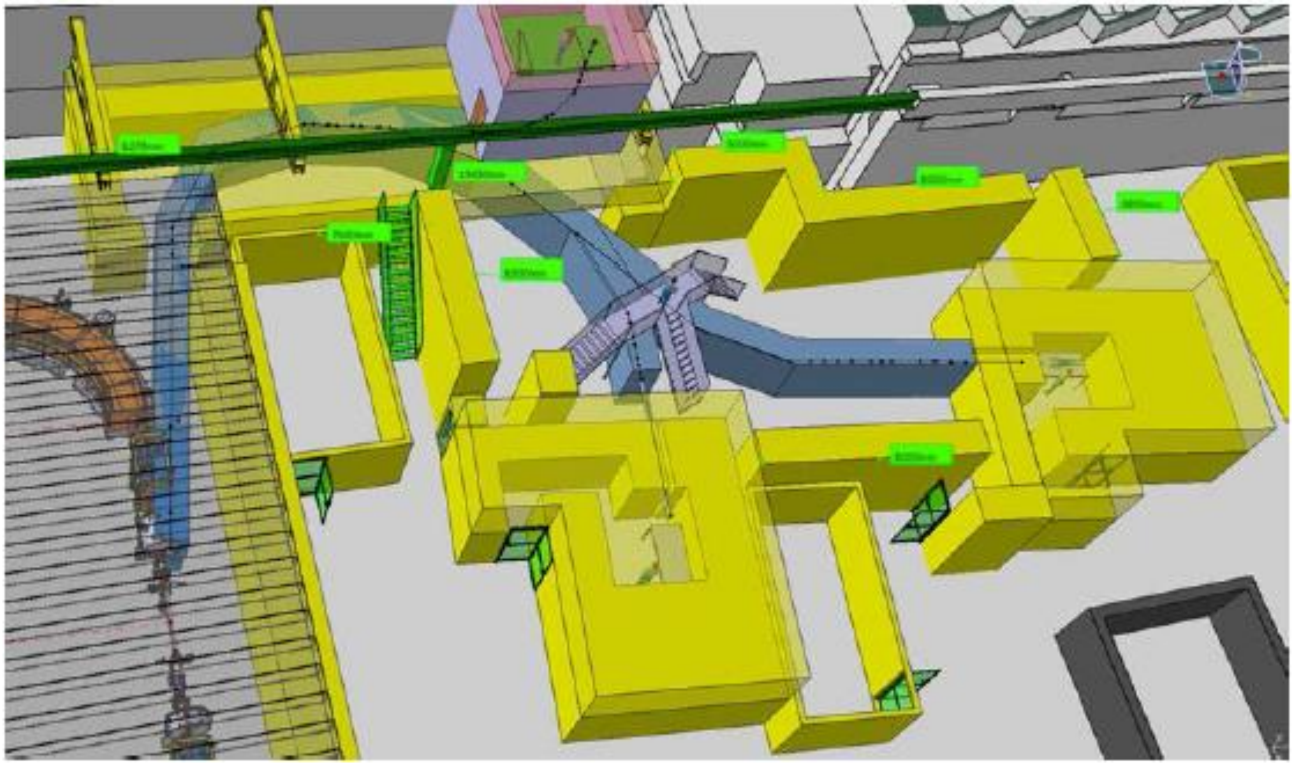
First horizontal extension / pencil beam



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

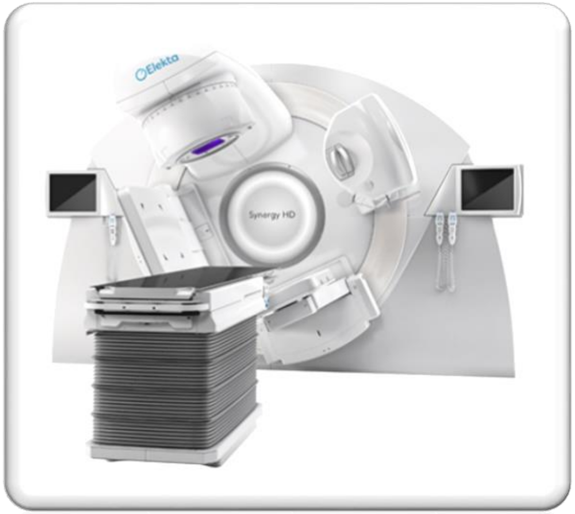
Local experimental control (counting rooms)

Augusta Victoria Hospital

Versa EVO

Versa HD

Synergy

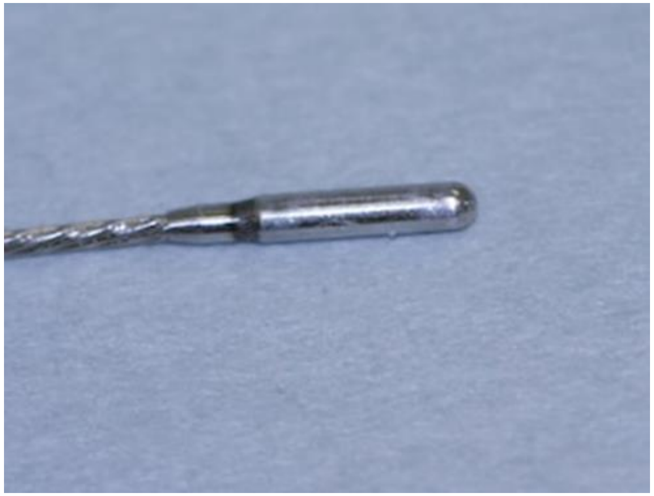


Augusta Victoria Hospital / Key Number

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

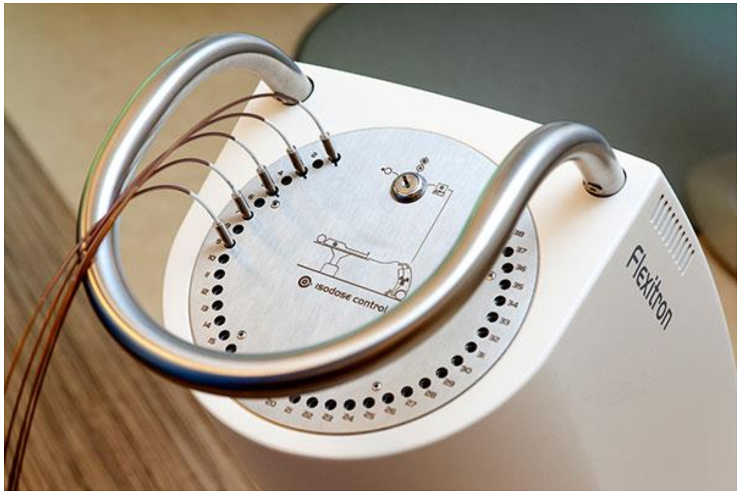
Ongoinig - Brachytherapy

- **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.



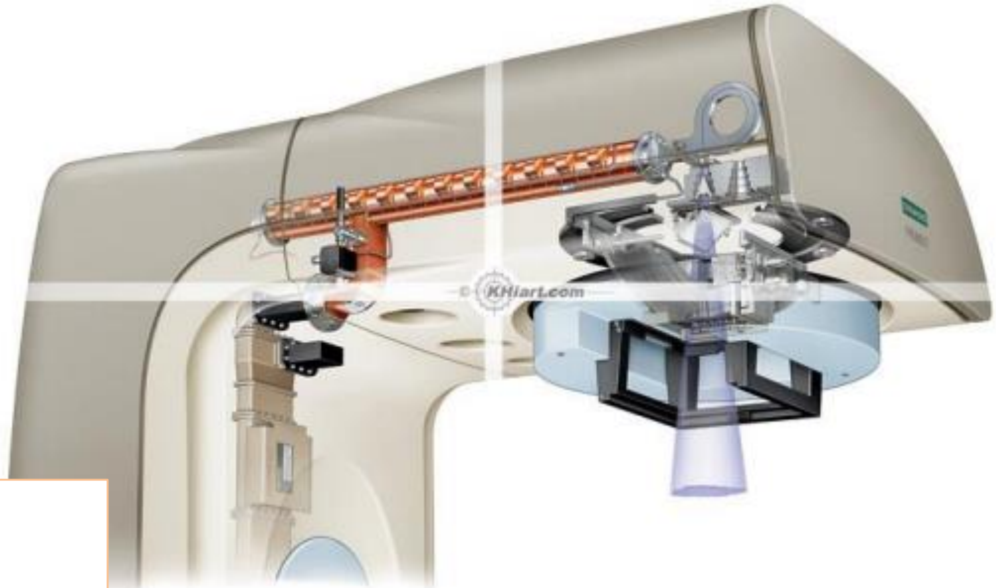
Iridium-192

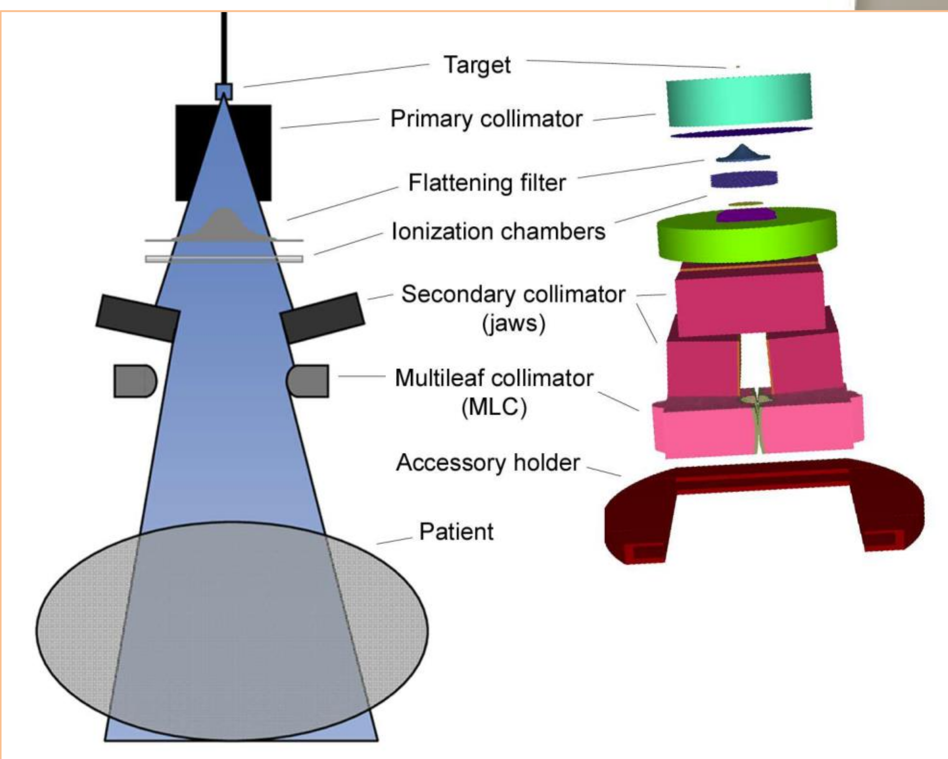
Gamma rays (380 keV)



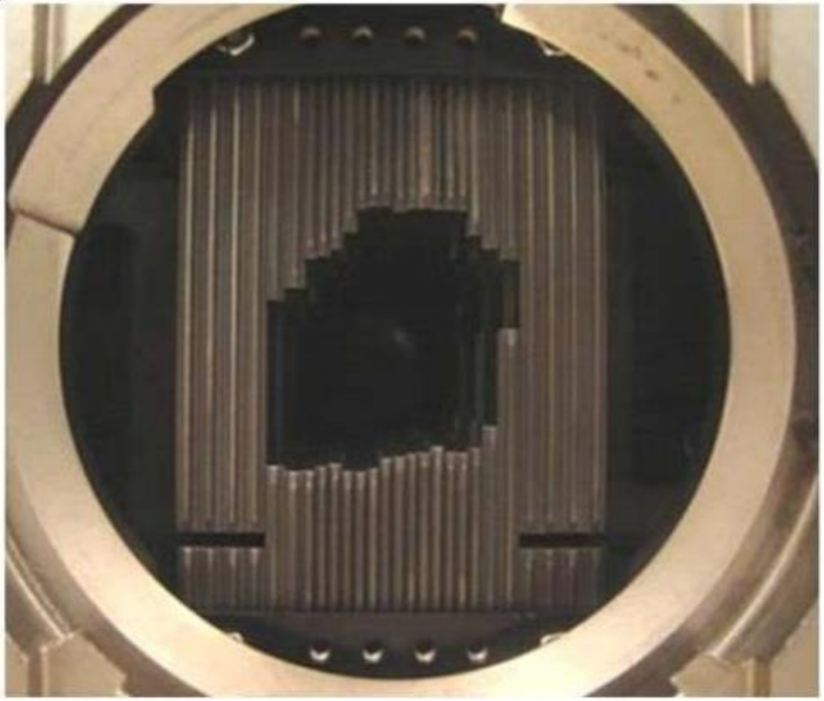
HDR Remote afterloader

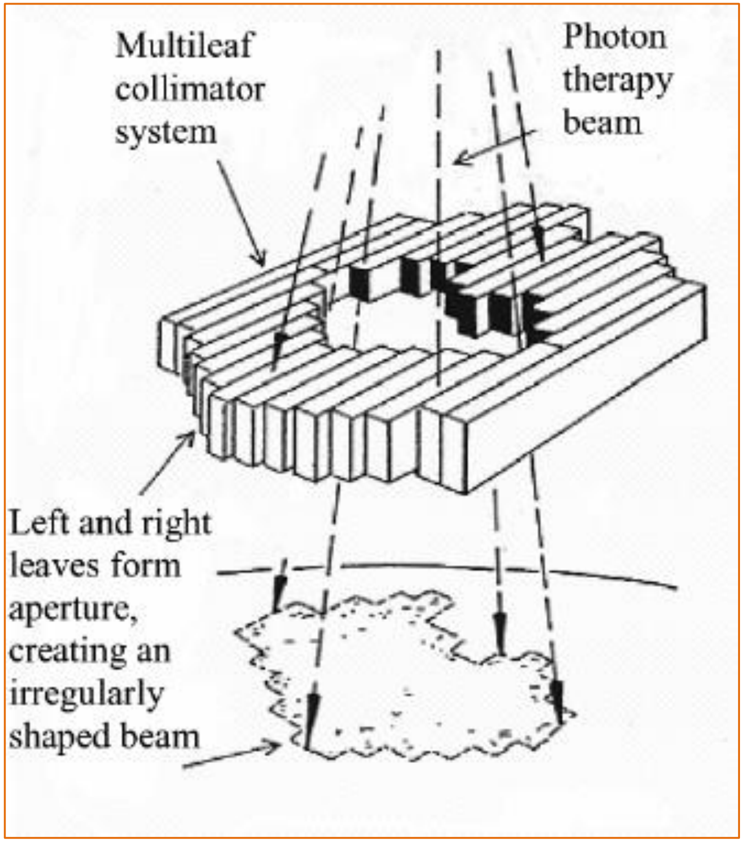
Linear Accelerator





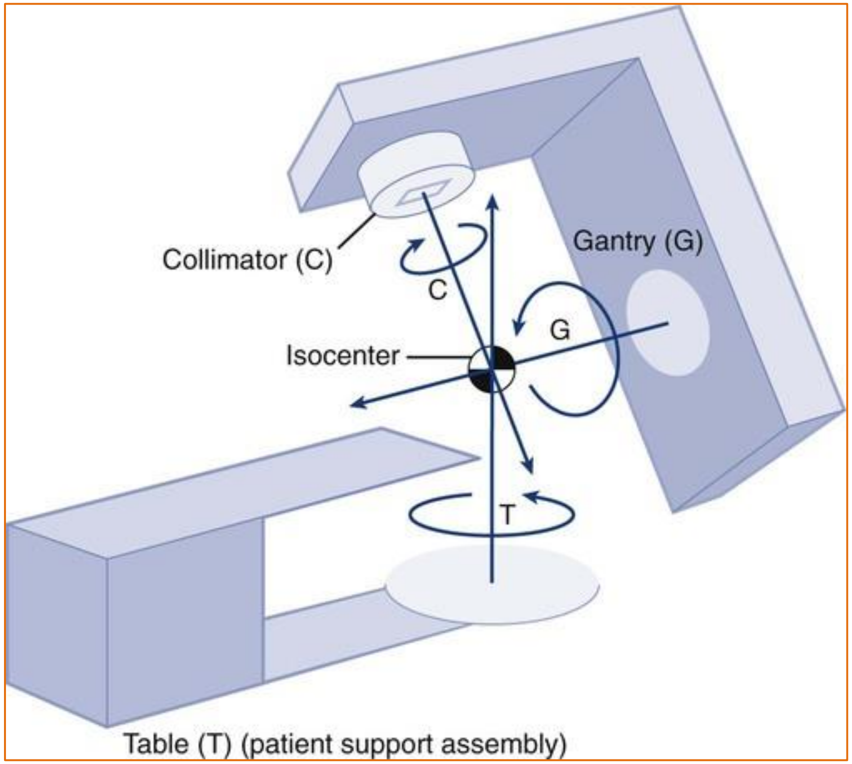
MLC - Multi Leaf Collimator

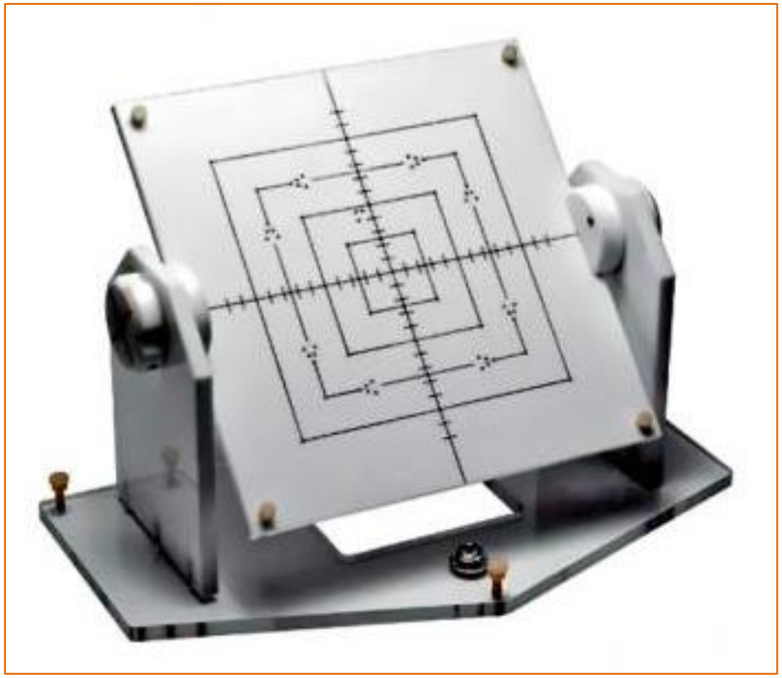




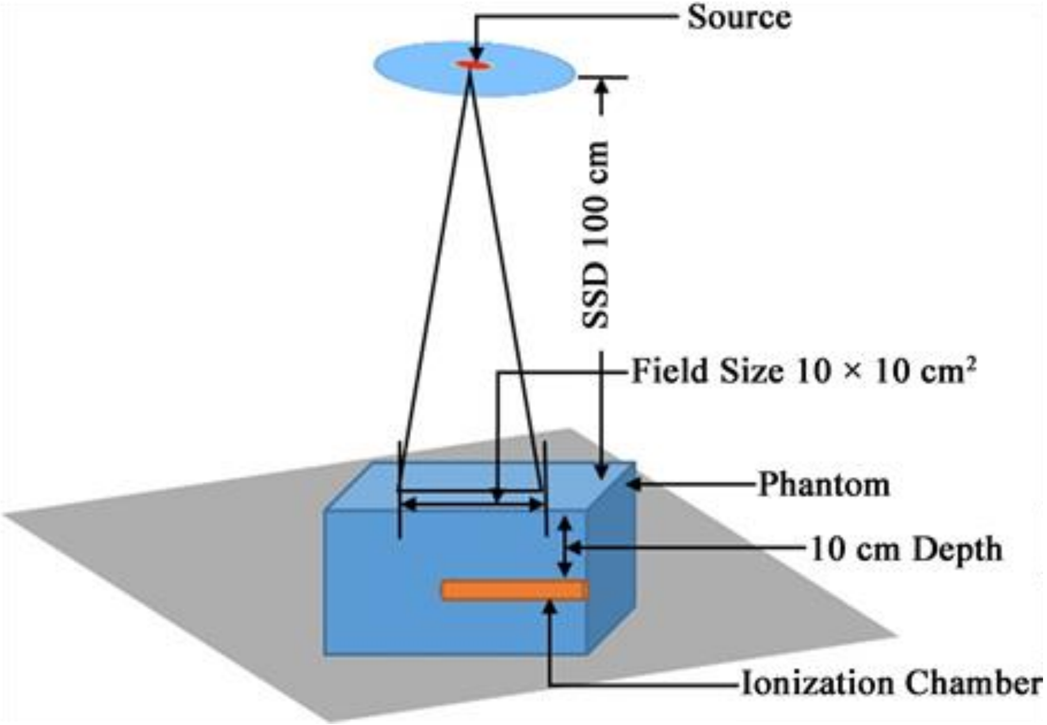
Commissioning and acceptance of LINAC

- 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 probably; machine safety, patient safety and dose interlocks, etc.
- Performance of mechanical checks.





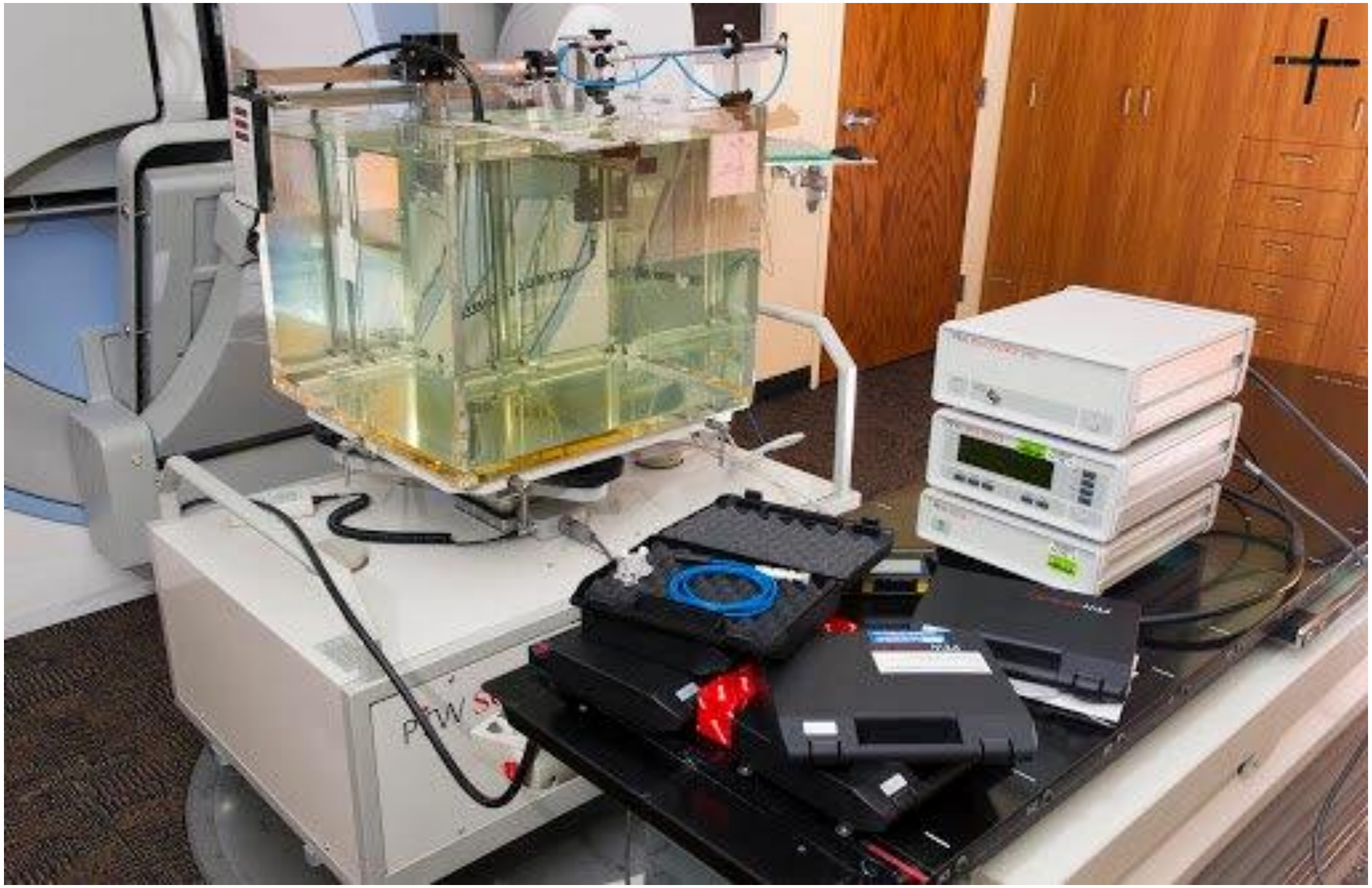
Commissioning and acceptance of LINAC



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 Dmax, for a 10cm x 10cm field and for the standard SSD, generally 100cm.

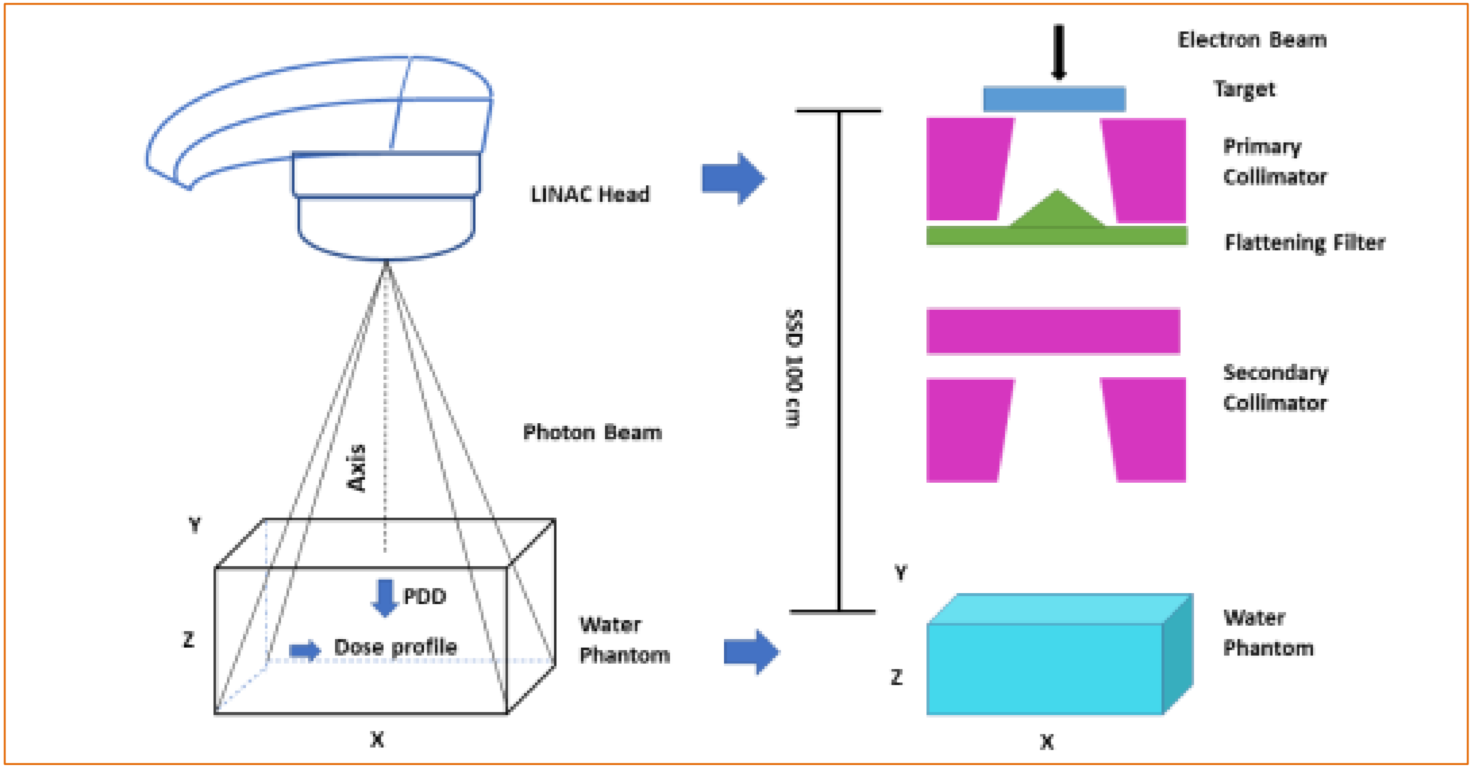
QA protocols according to TRS-398

Water phantom used for commissioning

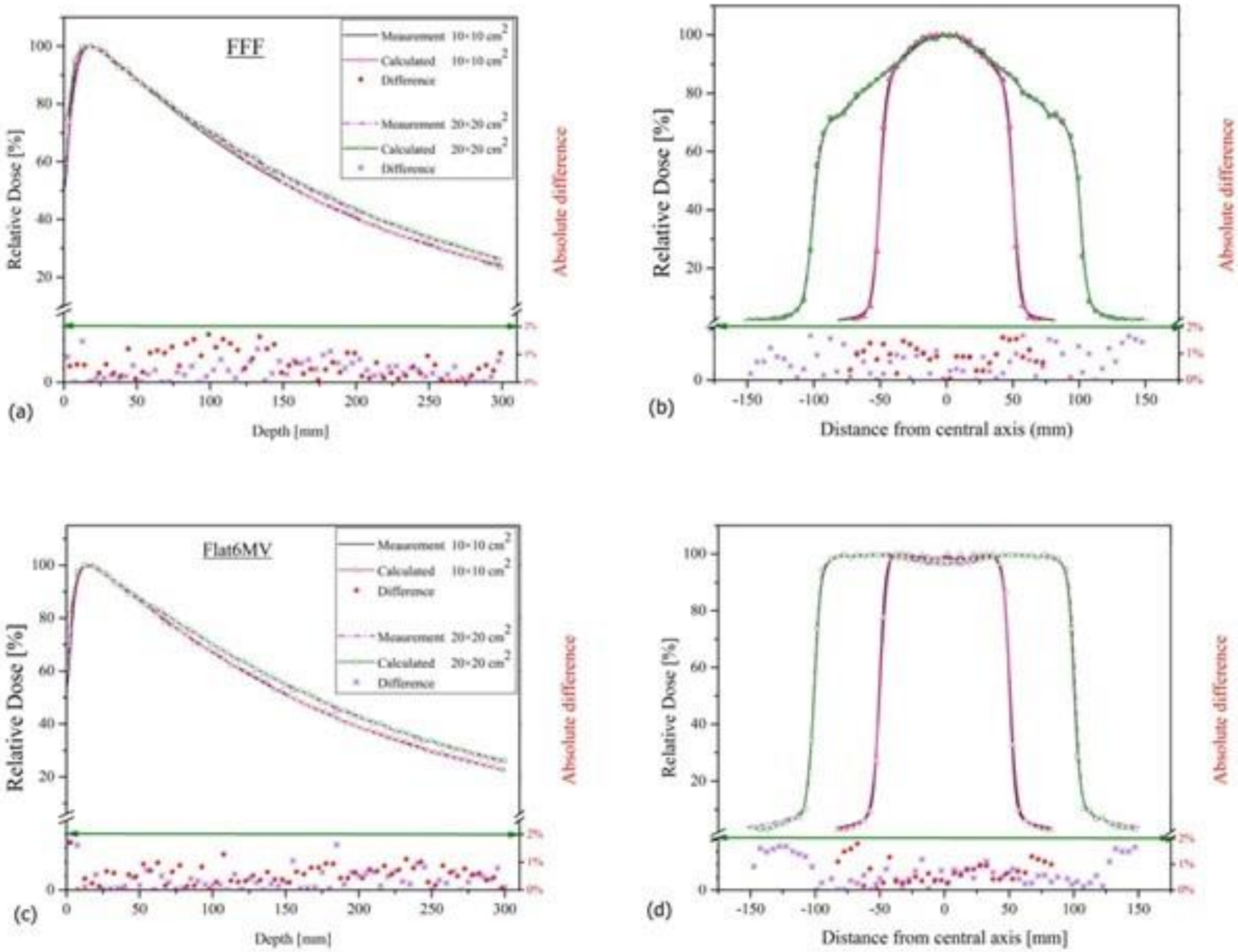


Getting percentage depth doses, beam profiles, relative output factors, wedge factors, and Tray factors. All this factors will affect the dose to be delivered and hence should be introduced into the calculation of the dose.

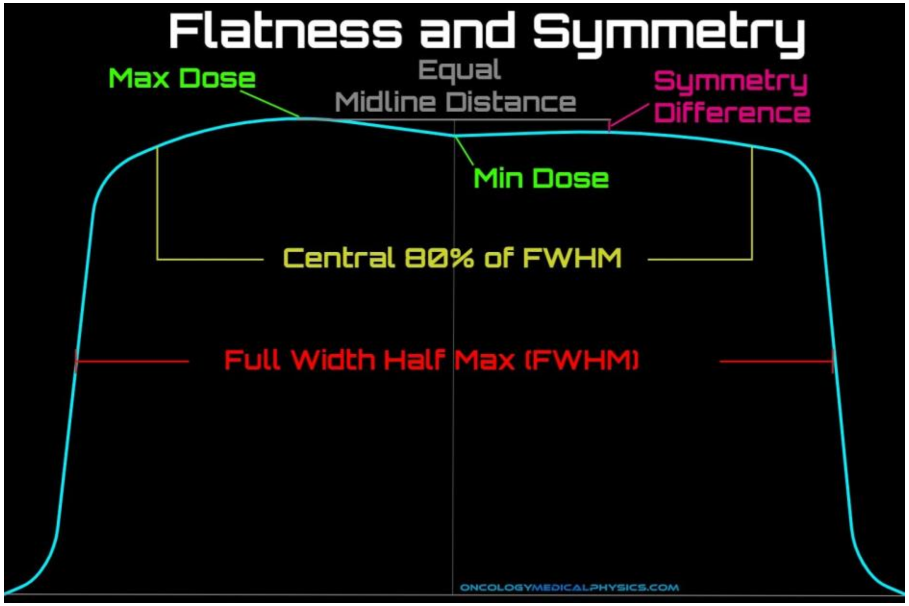
Water phantom used for commissioning

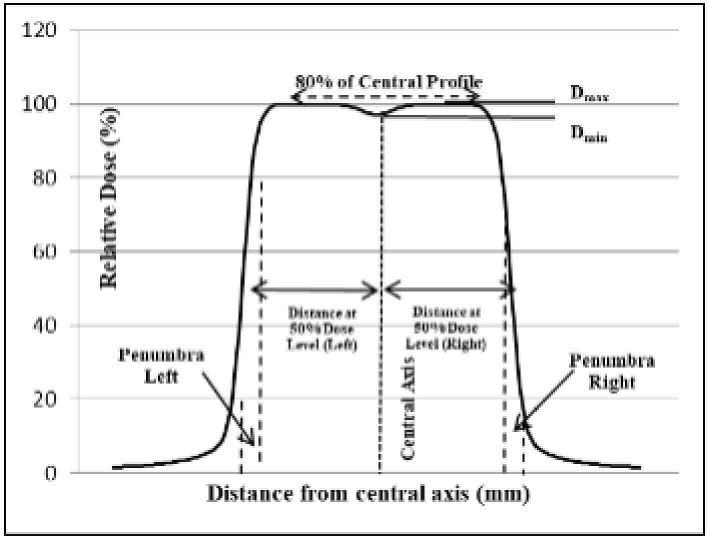


PDD and beam profile of 6MV and 6FFF energies



Flatness & Symmetry

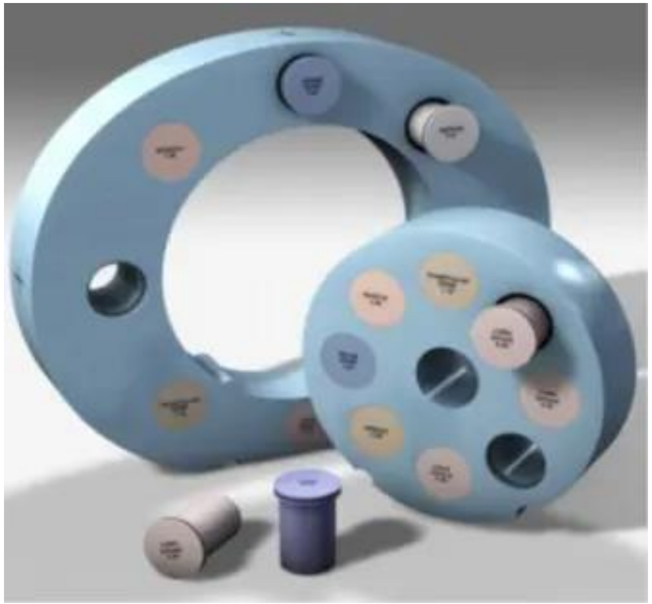




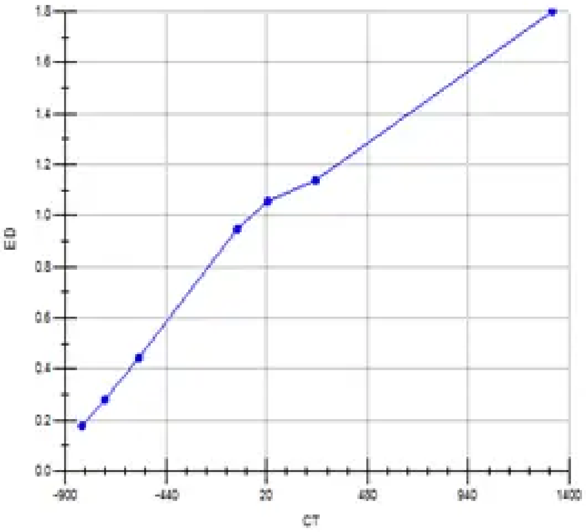
$$\text{Flatness} = \frac{D_{max} - D_{min}}{D_{max} + D_{min}} \times 100\%$$

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

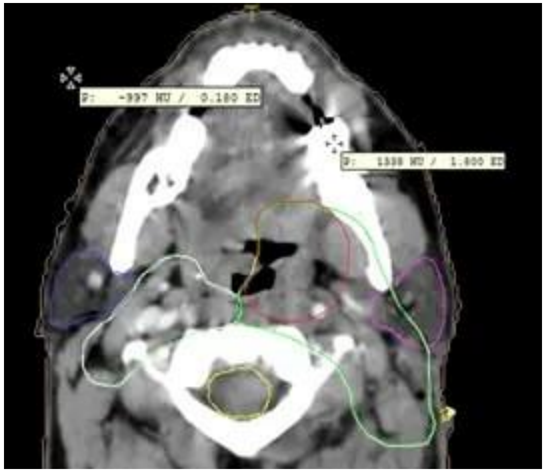
Phantom for HU calculation



CT to ED curve



ED in different mediums



Hounsfield Unit formula

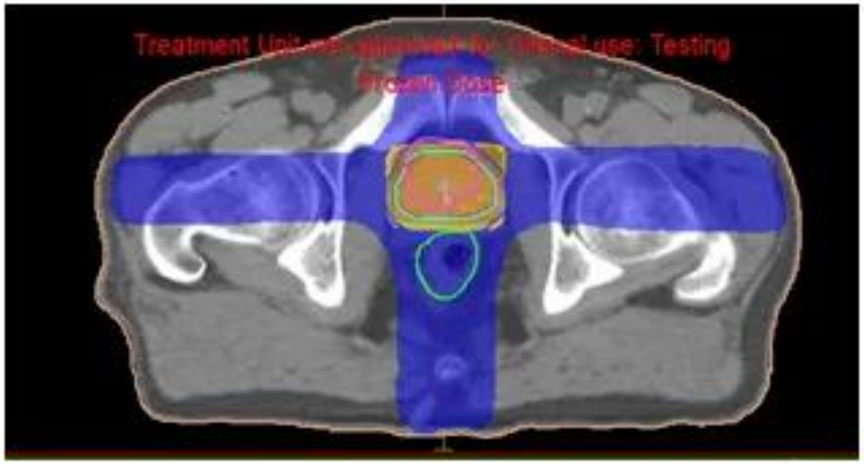
$$HU = \left(\frac{\mu_{\text{material}} - \mu_{\text{water}}}{\mu_{\text{water}}} \right) \times 1000$$

μ = CT linear attenuation coefficient

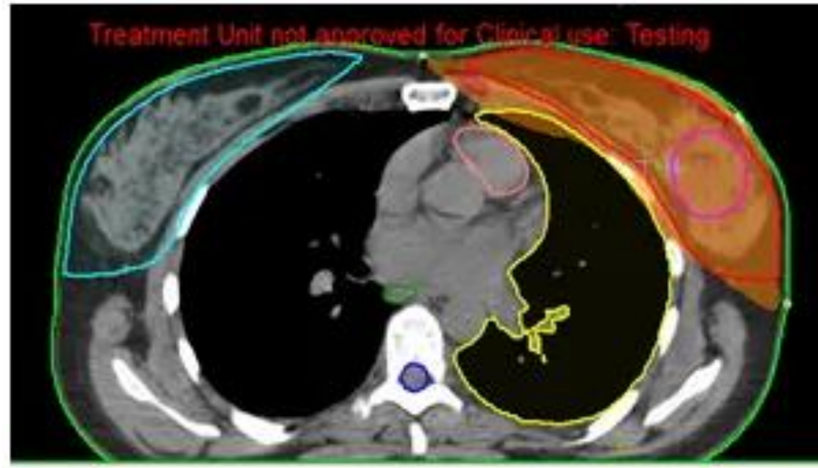
Hounsfield Units for human body	
Bone	*1000*
Liver	*40 to 60*
White Matter	*46*
Grey Matter	*43*
Blood	*40*
Muscle	*10 to 40*
Kidney	*30*
Cerebrospinal Fluid	*15*
Water	*0*
Fat	*-50 to -100*
Air	*-1000*

Planning

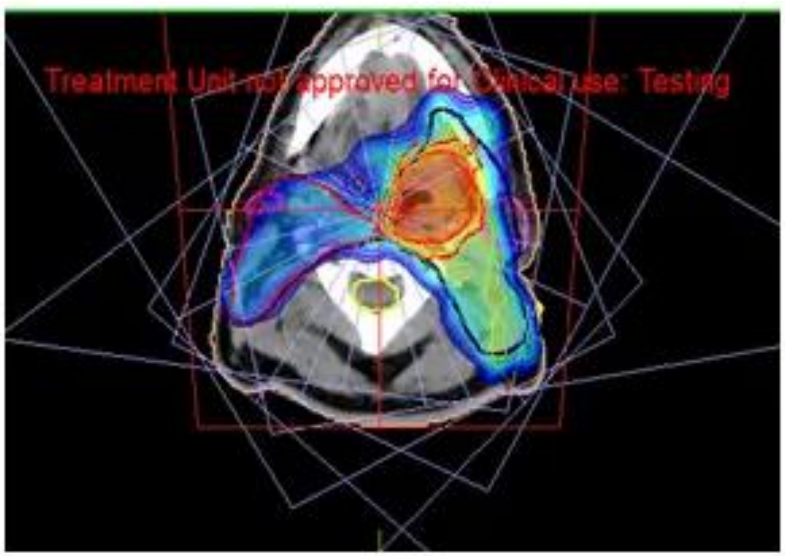
Dose distribution of a prostate 3D plan



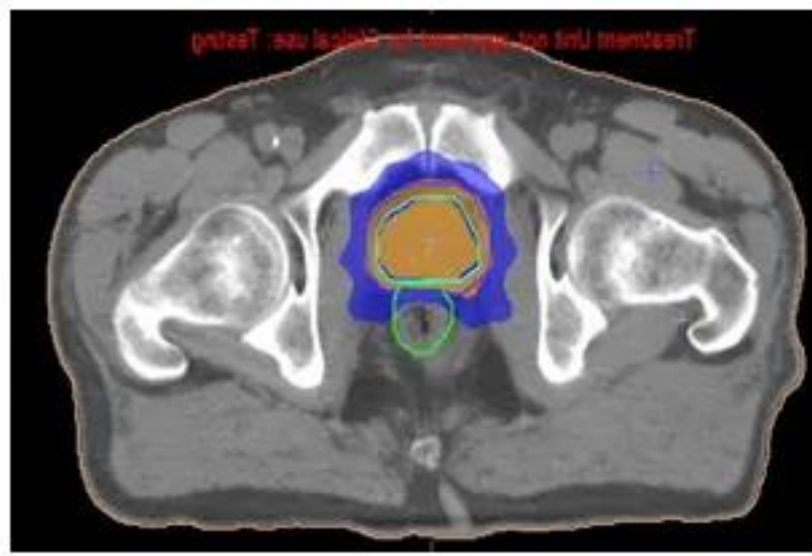
Dose distribution of a breast 3D plan



Dose distribution of a IMRT neck plan



Dose distribution of a VMAT prostate case



Plan evaluation

Statistics of different organs

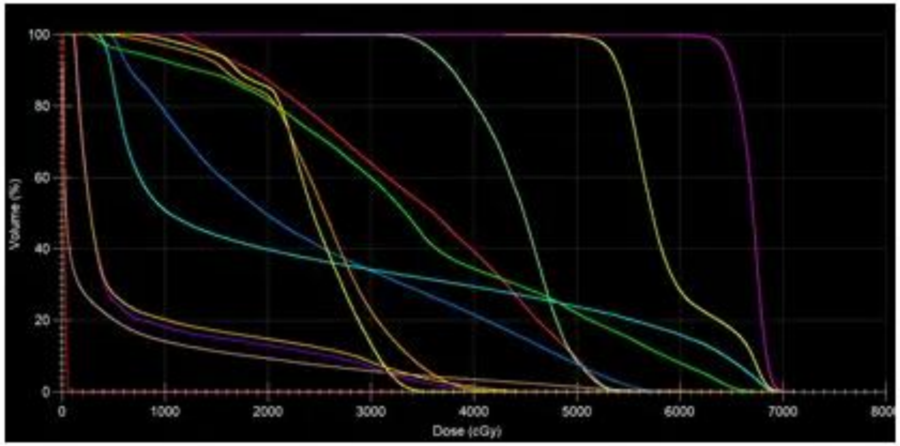
DVH Statistics

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			

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

DVH of the contoured structures



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?

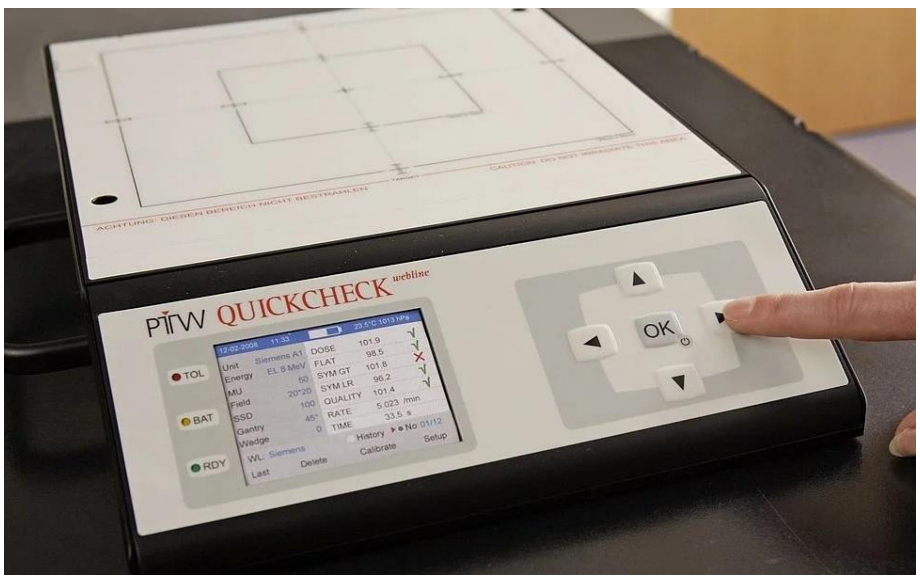
✓Ensures clinical integrity and accuracy.

✓Detects long-term drifts or degradation.

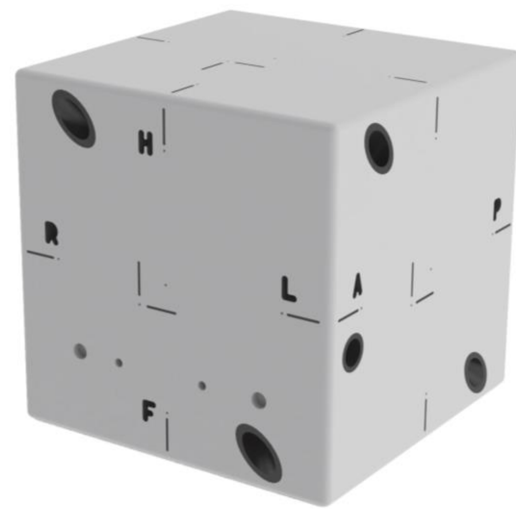
✓Improves patient safety and treatment precision.

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: ±1%,

✓ X-ray flatness/symmetry: ±1%

✓ Beam quality (PDD_{10}): ±1 % for photons

✓MLC: ±1mm,

✓Imaging: ±1mm

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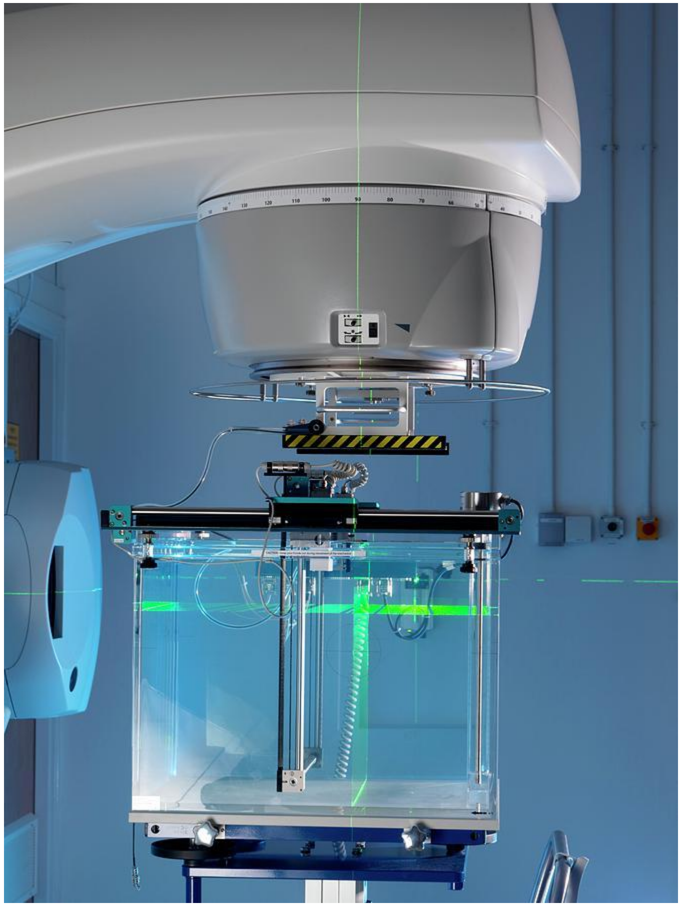
AAPM SCIENTIFIC REPORT

MEDICAL PHYSICS

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

Joseph Hanley[1] | Sean Dresser[2] | William Simon[3] | Ryan Flynn[4] | Eric E. Klein[5] | Daniel Letourneau[6] | Chihray Liu[7] | Fang-Fang Yin[8] | Bijan Arjomandy[9] | Lijun Ma[10] | Francisco Aguirre[11] | Jimmy Jones[12] | John Bayouth[13] | Todd Holmes[14]



Thank you!

Scientists have a moral responsibility to society. We must all strive to make the world a better place to live!