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Maryland Proton Treatment Center

Introduction to Pencil Beam Scanning Proton Therapy

Beam Commissioning and Routine QA

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Disclosure

None

Outline

Introduction

- AAPM TG-224
- Beam Delivery Technology
  - Pencil Beam Scanning
- Beam Characteristics
  - Bragg Peak parameters
  - Spot Profile

Part 1: Commissioning & Annual QA

- Dosimetry
  - Beam Scanning
  - Output Calibration
  - Spot Profile & Position
  - Other Beam Quality parameters
- Imaging
- Mechanical
- Safety

Part 2: Monthly QA

- Dosimetry
  - Dose per MU
  - Range (Energy)
  - Flatness and Symmetry
  - Spot Profile & Position
  - Radiation Isocenter
- Imaging
- Mechanical
- Safety

Part 3: Weekly QA & Daily QA

- Weekly
  - Gantry angle vs indicators
  - Snout or applicator extensions
  - Imaging Systems
- Daily
  - Dosimetric Parameters
  - Patient Setup Verification
  - Data Communication
  - Safety

Outline

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Introduction

Quality Assurance in Radiation Therapy

ICRU recommendation: Deliver dose accurately within 5%

References for proton QA:

ICRU 59 and 78 have limited discussion

TG 224: Comprehensive QA for proton therapy machine quality assurance

Quality Assurance in Proton Radiotherapy

Three key branches

- Patient-specific QA
- Treatment Planning System (TPS) QA
- General equipment functionality [discussed in TG 224]
    - Dosimetric
    - Mechanical
    - Imaging
    - Safety

Introduction

AAPM task group 224: Comprehensive proton therapy machine quality assurance

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- Identifies a comprehensive set of QA procedures for three proton therapy delivery systems
- Identifies parameters that affect precision of beam delivery and the frequency of various checks
- Recommends tolerance limits

Introduction

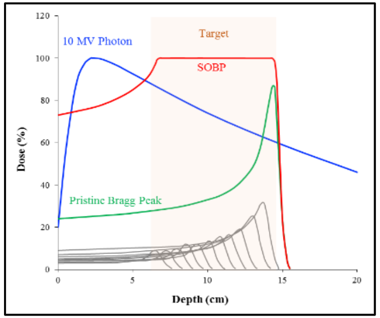
Proton Radiotherapy Overview

Due to the finite range of the proton beam (Bragg Peak)

→ Better normal tissue sparing

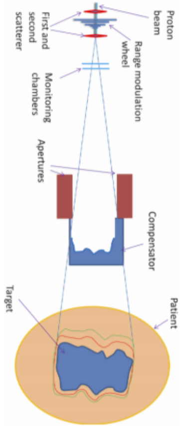
Spread-out Bragg Peak (SOBP):

Created by adding Bragg peaks with different energy and intensity

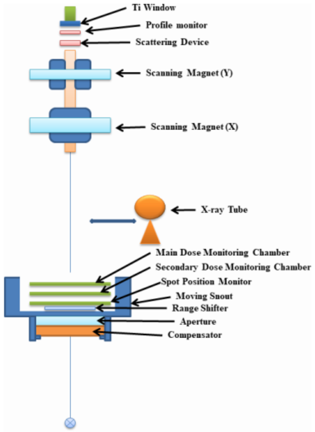


Beam Delivery Technology

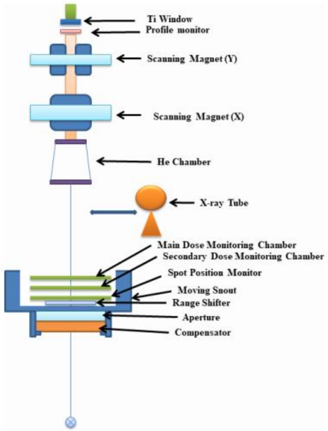
- Double Scattering
- Uniform Scanning
- **Pencil Beam Scanning**



Double Scattering



Uniform Scanning



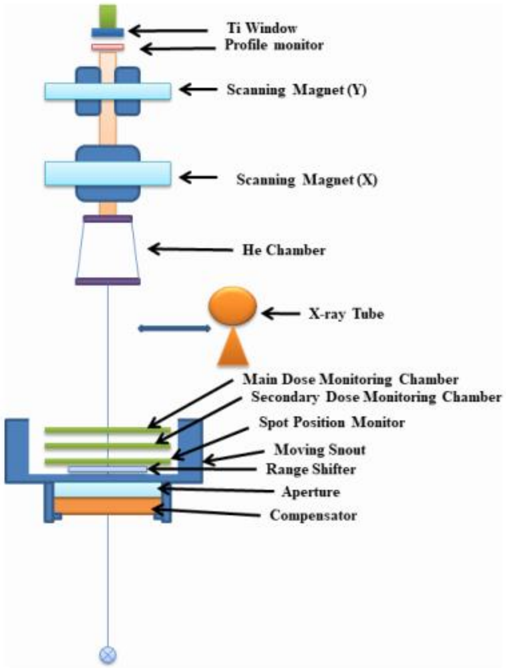
Pencil Beam Scanning

** AAPM-TG-224*

Introduction

Pencil Beam Scanning (PBS) Proton Therapy

- Delivery with pencil beam (spot)
- Can optimize spot position, weight and energy
  - Magnets direct beam off CAX
  - Degraders (and range shifters) can be used to reduce range
- Offers both distal and proximal dose conformity
- Scattered radiation from primary and neutron beam is minimal



Pencil Beam Scanning

** AAPM-TG-224*

Introduction

Pencil Beam Scanning Proton Therapy

SOBP is less relevant, especially for Multi-Field Optimization (MFO) plans

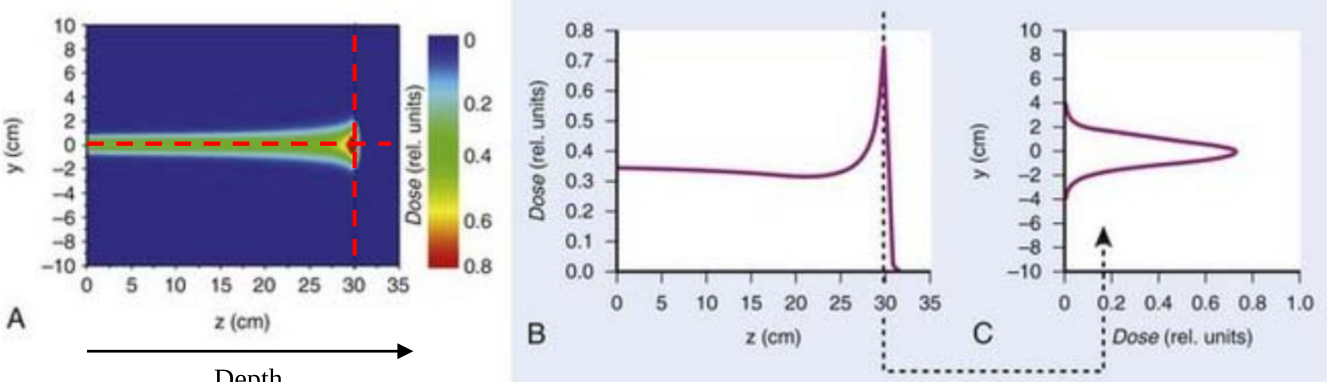
- Field intensity can be extremely non-uniform
- Proximal and distal conformity with each spot

Dose Profile

Bragg Peak

Spot Profile

Proton Beam



Depth

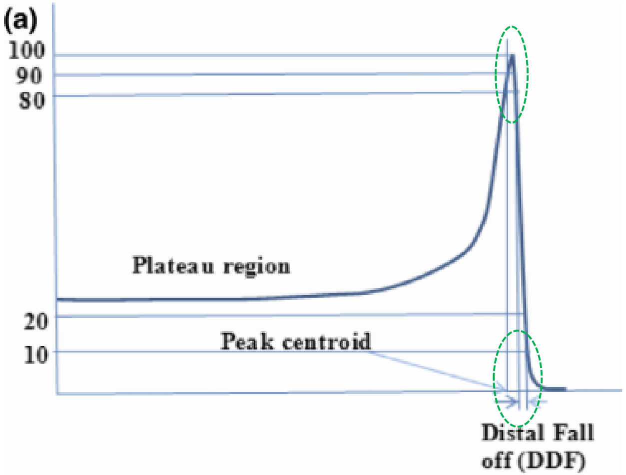
*https://oncohemakey.com/proton-therapy/

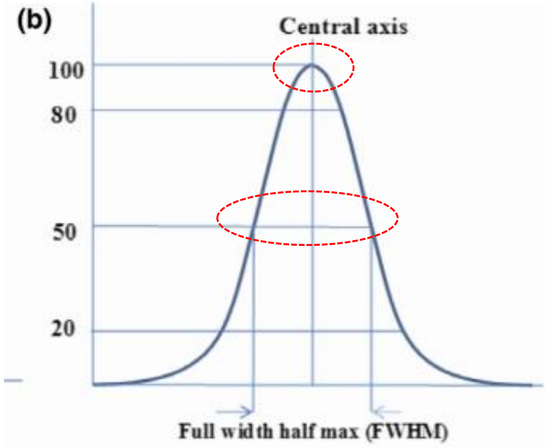
Introduction

Beam parameters

- Range of the pristine Bragg peak
- Distal dose falloff of the Bragg peak

- Centroid of beam profile
- FWHM or sigma (FWHM = 2.355×σ)
- Shape of beam spot
- Dependence of spot size on gantry angle





** AAPM-TG-224*

Introduction

Beam Characteristics

Type of measurement for QA

- *Direct* measurement of beam parameter

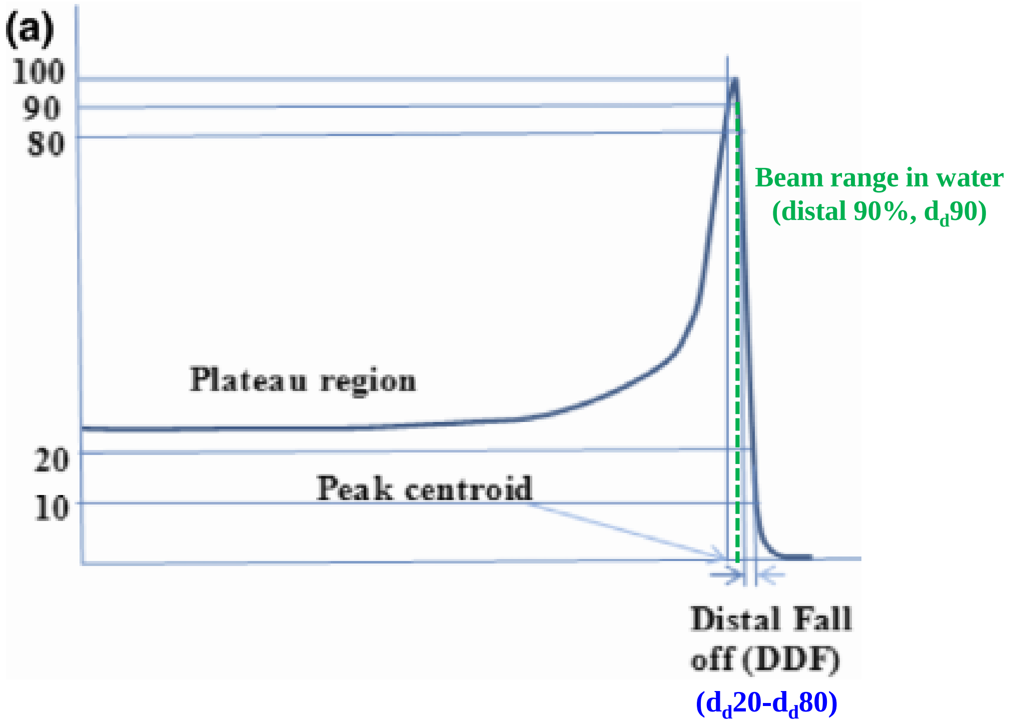
or

- *Measurement of parameters associated* to beam parameter

Relevant beam parameters (ICRU 78):

Bragg Peak

- Beam range (d_d90) in water
- Distal dose fall off (DDF) (d_d20-d_d80)



* AAPM-TG-224

Introduction

Beam Characteristics

Type of measurement for QA

- *Direct* measurement of beam parameter

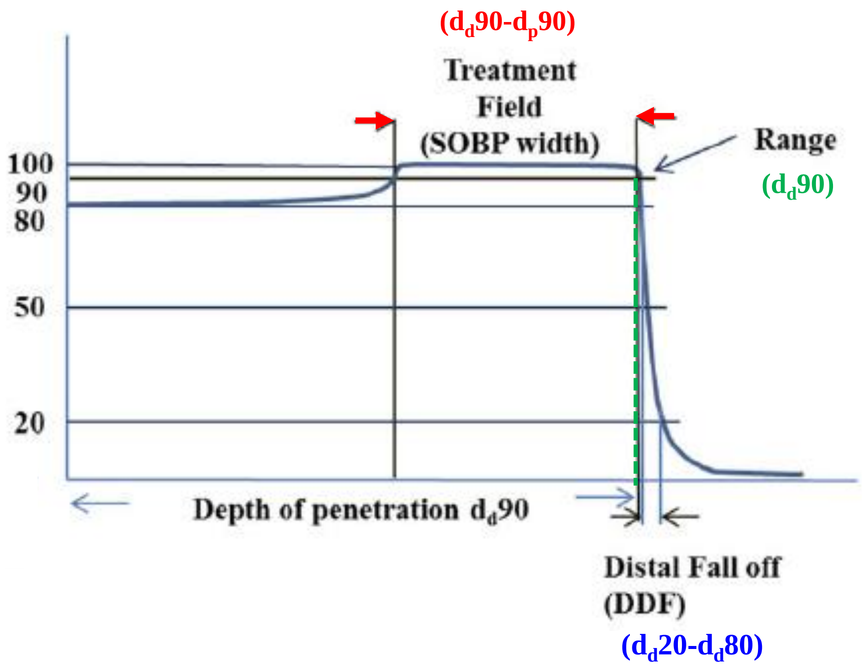
or

- *Measurement of parameters associated* to beam parameter

Relevant beam parameters (ICRU 78):

SOBP

- Beam range ($d_d 90$) in water
- Distal dose fall off (DDF) ($d_d 20$-$d_d 80$)
- SOBP width ($d_p 90$-$d_d 90$)



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Introduction

Beam Characteristics

Type of measurement for QA

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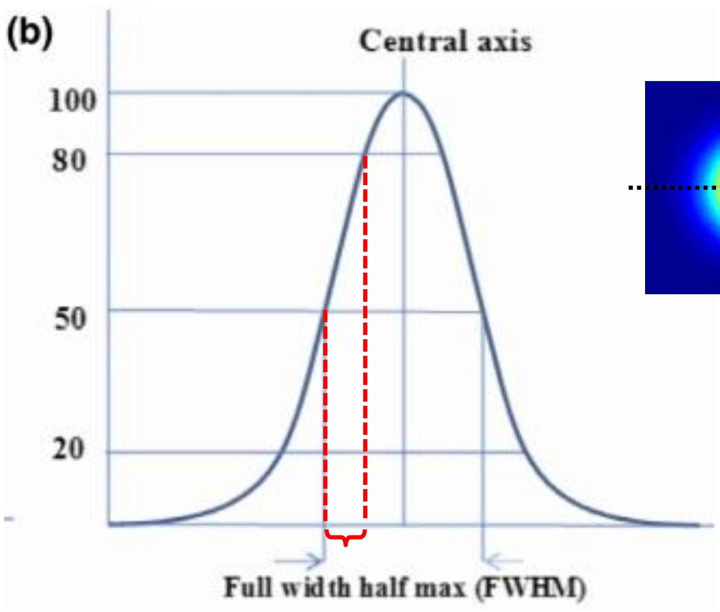
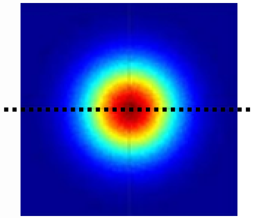
Relevant beam parameters (ICRU 78):

Spot Profile

- FWHM or Sigma (FWHM = 2.355×σ)
- Lateral penumbra of spot (80-20%, d_l80-d_l20)
- Position





* AAPM-TG-224

Introduction

Beam Characteristics

Type of measurement for QA

- *Direct* measurement of beam parameter

or

- *Measurement of parameters associated* to beam parameter

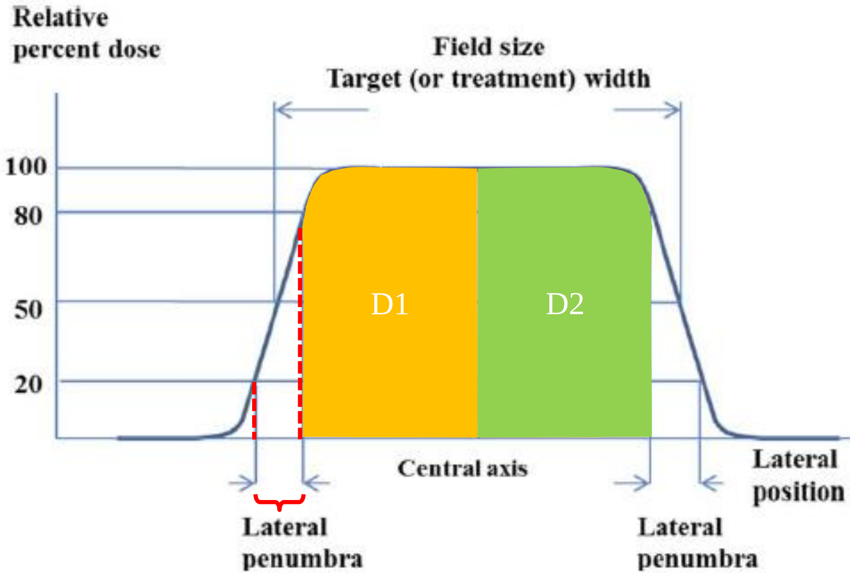
Relevant beam parameters (ICRU 78):

Broad Beam Profile

- Lateral Uniformity (flatness and symmetry)

$$F_{lp} = \left(\frac{d_{lp\,\max} - d_{lp\,\min}}{d_{lp\,\max} + d_{lp\,\min}}\right) \qquad S_{lp} = \left(\frac{D_1 - D_2}{D_1 + D_2}\right)100.$$

- Lateral penumbra width (80-20%, d_l80-d_l20)



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Introduction

Imaging in Proton Therapy (TG-224)

Imaging

- Planar kV
- Volumetric imaging (CBCT, portable, CT on rails)
- Similar to photon: Follow TG 142, TG 179

TG-224 is NOT a recipe and you must consider your system

E.g. "… recommends tolerance limits and ranges for parameters …"

"… should be used only as guidelines and implemented as supported by a facility's risk analysis, based on equipment-specific characteristics and limitations."

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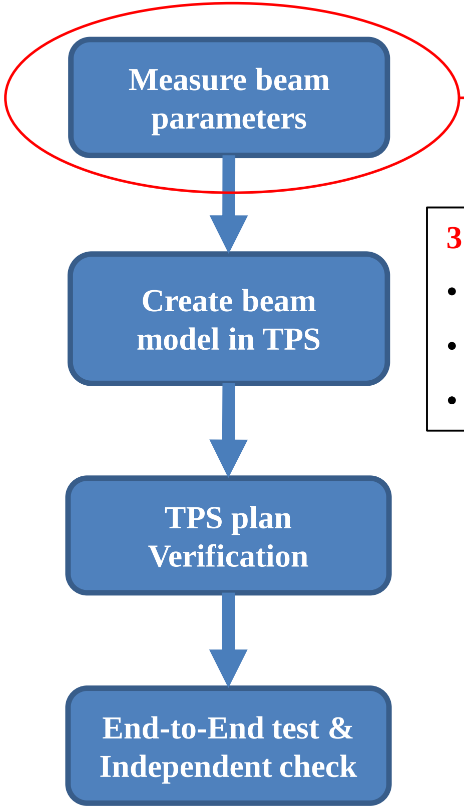
Commissioning



Must be checked routinely to ensure consistent dose delivery - QA

3 main parameters for each energy:

- Integrated depth dose (IDD)
- Absolute dose
- Spot profile

Commissioning Process:

- Plan Preparation: Use a beam model close to yours
  - Dosimetry
  - Imaging
  - Mechanical
  - Safety
- Create beam model
- TPS plan verification
- End-to-End test & Independent Check

(1) Beam Scanning

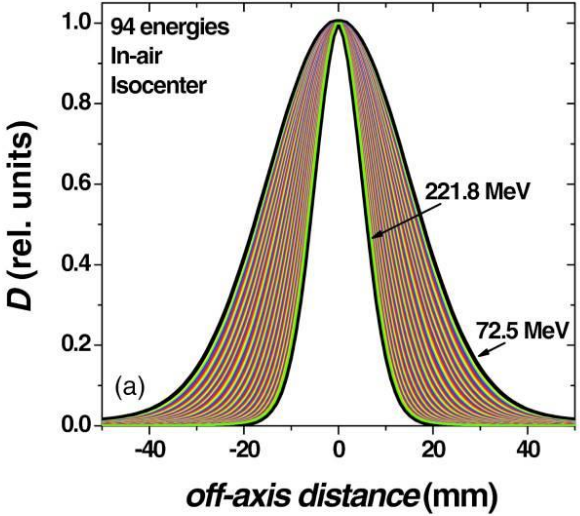
Beam Scanning: IDDs in water

Range measurements and Integrated Depth dose curves (IDDs)

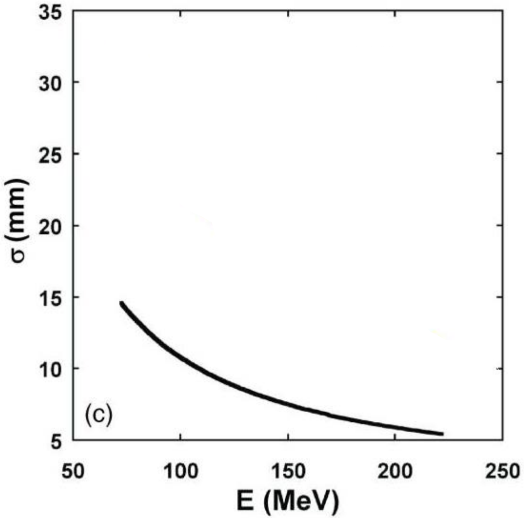
For PBS we need to measure IDD, because

- We have spots which can be wide based on energy

Spot size is a function energy



Spot size gets bigger as energy decreases



*Zhu et al, Med Phys, 40(4), 2013

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Beam Scanning: IDDs in water

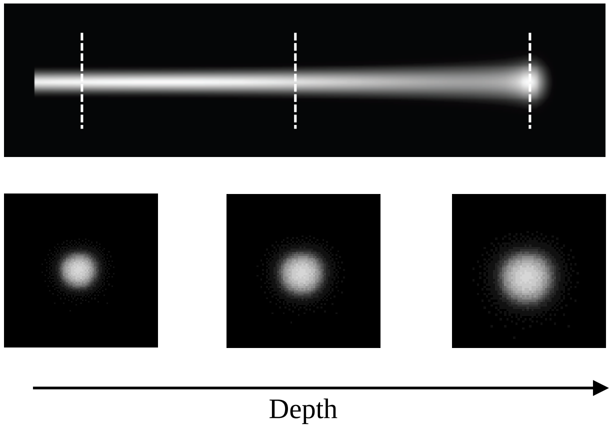
Range measurements and Integrated Depth dose curves (IDDs)

For PBS we need to measure IDD, because

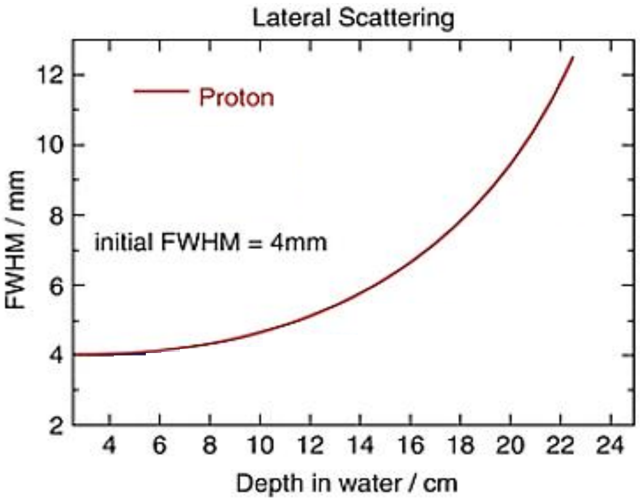
- We have spots which can be wide based on energy and depth

Spot size gets bigger in depth

Proton Beam



FWHM increases in depth



*Heidelberg, PTCOG 2009

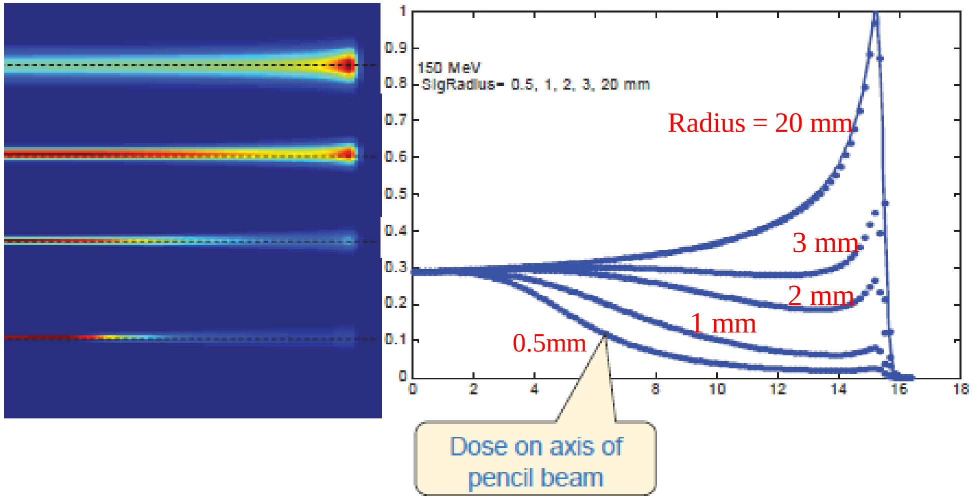
Beam Scanning: IDDs in water

Range measurements and Integrated Depth dose curves (IDDs)

For PBS we need to measure IDD, because

- We have spots which can be wide based on <u>energy</u> and <u>depth</u>
- We need to measure the whole dose from the spot → Need integrate over the whole spot's profile

- You need a **large chamber**



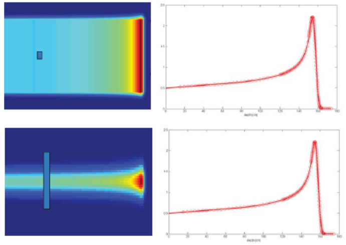
Beam Scanning: IDDs in water

Range measurements and Integrated Depth dose curves (IDDs)

Bragg peaks need to be measured from the ***highest energy (~250 MeV) down to lowest energy (70 MeV) in 10 MeV intervals***

Small chamber *vs.* ***large chamber***

- A large uniform field using a small chamber (like photon, not practical for proton-PBS)
- A small field (spot) using a large chamber to capture all primary protons, secondary charges



Scanning chambers

- Bragg Peak Chamber (PTW)

  8.4 cm diameter

- Stingray Chamber (IBA Dosimetry)

  12 cm diameter

Reference chamber

- Monitor Ionization Chamber (PTW)

Beam Scanning: IDDs in water

Using:

- 3D water tank with thin side-window (scanning range ~ 35 – 45 cm)
- Scanning chamber (large parallel-plate chamber)
- Reference chamber

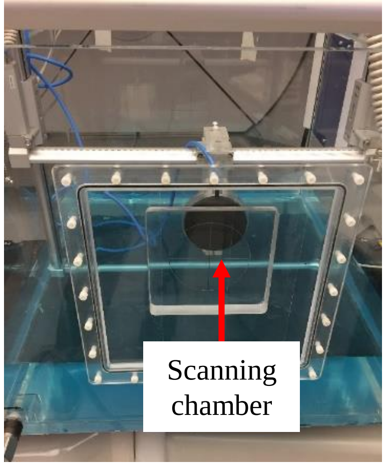
You need to know

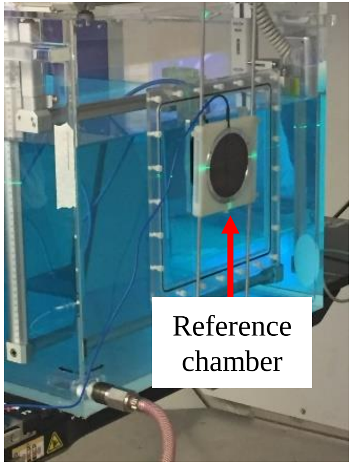
-WET of scanning and reference chambers
-WET of thin window of the 3D tank

Scanning volume
48 × 48 × 41cm


Scanning range
38cm vertically & 35cm horizontally

- ➢ Why 90˚ :
  - ❑ **Limited range of chamber and couch motion in 0˚**
- ➢ Why 0˚ :
  - ❑ **Limited range of chamber motion in 90˚**





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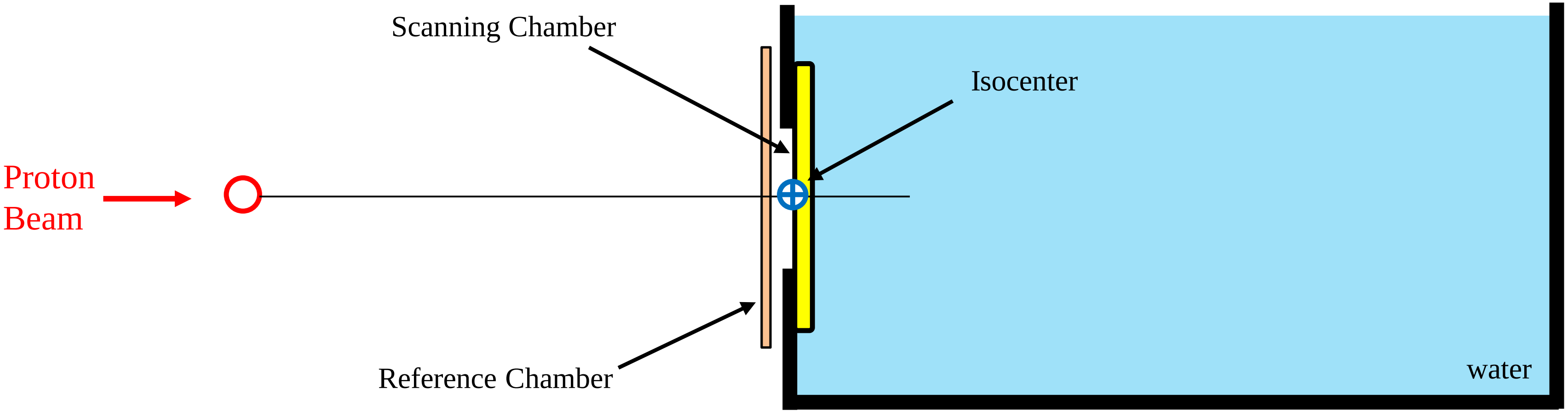
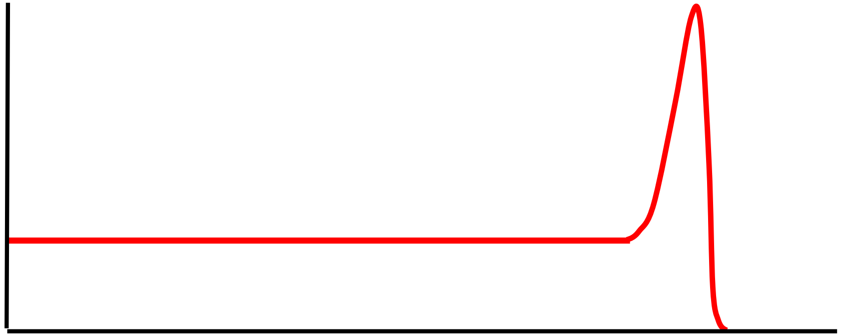
Beam Scanning: IDDs in water



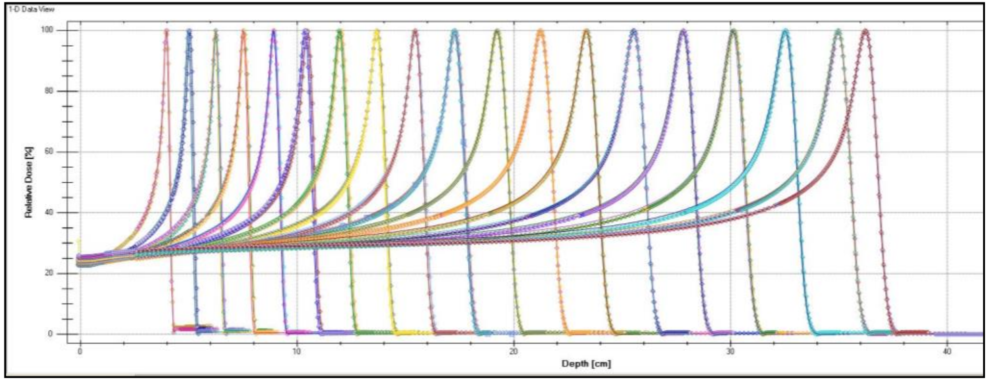


Note: *Water gets activated and needs to cool down.*

Beam Scanning: IDDs in water

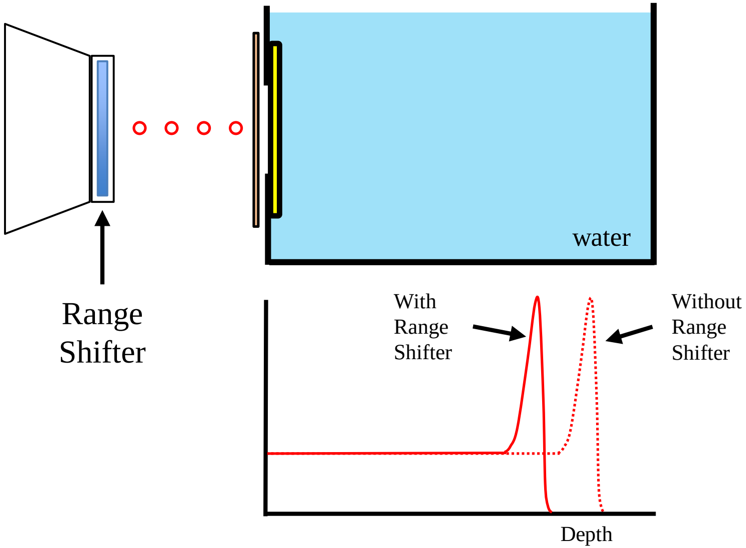
Range measurements and Integrated Depth dose curves (IDDs) [TG-224 Tolerance (Annual): Range: ±1mm, Depth Dose: ±2%]

Measure from the **highest energy (~250 MeV) down to lowest energy (70 MeV) in 10 MeV intervals**



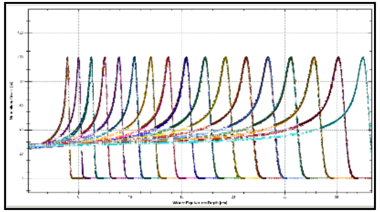
IDDs measured at 10 MeV intervals, starting from 70 MeV to 245 MeV

IDD measurements in water with range shifter

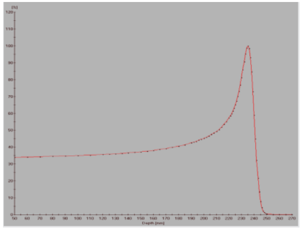


Proton Range (Bragg Peak) Verification

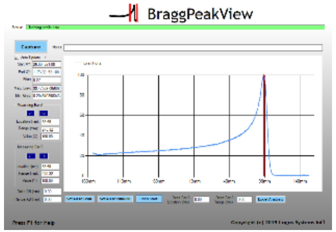
- **Range Verification** [TG-224 Tolerance (Annual): ±1mm]
- **Monthly QA**
  - ***Giraffe or Zebra*** *(IBA)*
    - *Multi-layer ion chambers (180 chambers)*

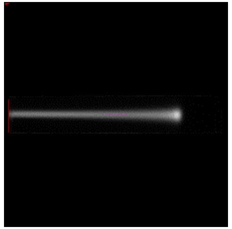



  - ***PEAKFINDER*** *(PTW)*
    - *Beam scanning system (2 chambers)*




  - ***Ranger*** *(Logos)*
    - *Scintillator*



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Measure WETs of couches, range shifters, etc.

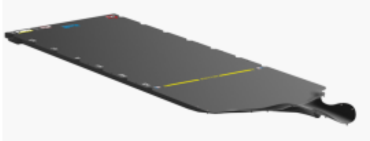
Range shifters

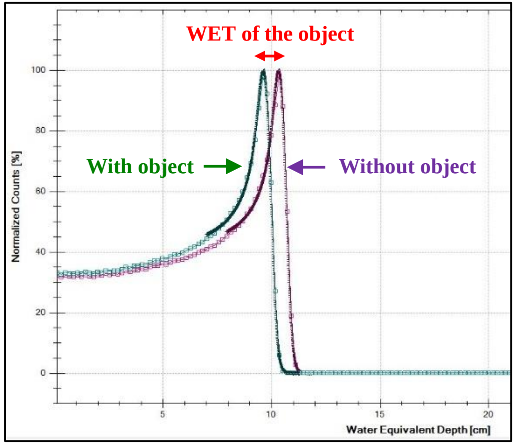
[TG-224 Tolerance (Annual): ±2%]

- Measure water equivalent thicknesses (WET)
  - Compare to the values from manufacturer
- Check homogeneity (CT scan)

Treatment couch, QA devices (solid water, …) and commonly used implants

Measure water equivalent thicknesses (WET)





(2) Output Calibration

Output Calibration (TRS-398)

Using **IAEA-TRS 398 report** for the determination of absorbed dose from a proton beam. [TG-224 recommended]

IAEA TRS-398: Reference Dosimetry for 50-250 MeV Proton Beams [TG-224 Tolerance (Annual): ±2%]

- *Calibration factor in terms of absorbed dose to water* $N_{D,W}$
- *Recommended chambers:*
  - **Cylindrical chambers**
  - **Plane-parallel chambers** must be used for proton beams with qualities at the reference depth $R_{res} < 0.5$ g/cm^2.

STEPS:

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Output Calibration (TRS-398)

STEP 1: Measure Bragg peak curves (IDD) for each energy ✓

STEP 2: Calculating k_Q values for each energy

Residual range, R_{res} (in g/cm²), is the beam quality index

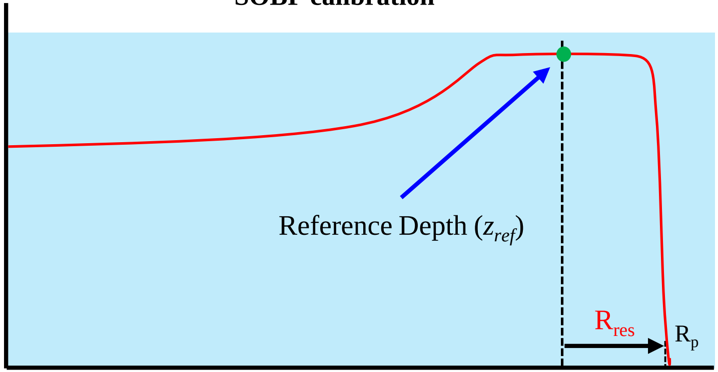
Practical Range

$$R_{res} = R_p - z_{ref}$$

Measurement (Reference) Depth

➢ There are two ways of doing TRS-398 calibration

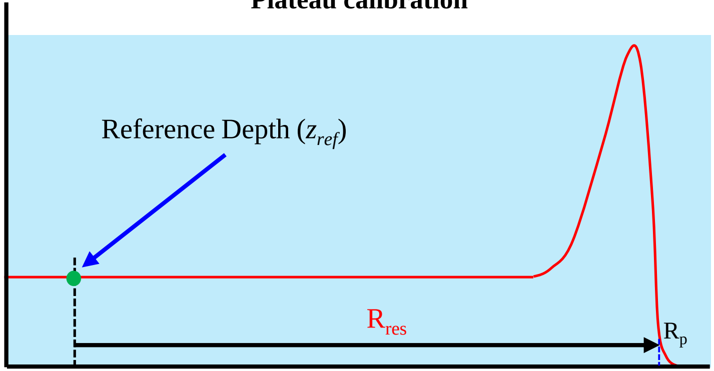
SOBP calibration



Higher uncertainties with SOBP methods

Used for verification

Plateau calibration



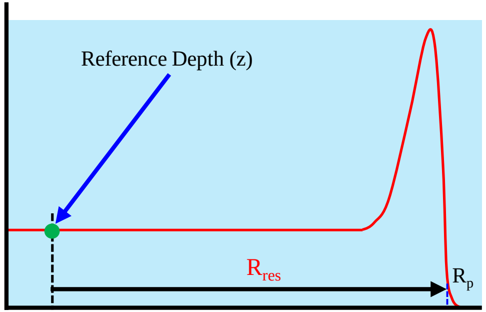
More commonly used

Output Calibration (TRS-398)

STEP 2: Calculating k_Q values for each energy

Beam Quality Determination:

- *Use depth dose distribution to find Practical Range (R_p)*
- *Based on Reference Depth (z_{ref}) find Residual Range (R_{res})*
- *TRS-398 table gives k_Q based on R_{res}*



Ionization chamber type [a]	Beam quality R_{res} (g cm^{-2})															
	0.25	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	7.5	10	15	20	30
Attix RMI 449	0.995	0.992	0.990	0.989	0.989	0.989	0.989	0.989	0.989	0.989	0.989	0.988	0.988	0.988	0.988	0.987
Capintec PS-033	1.029	1.026	1.024	1.024	1.023	1.023	1.023	1.023	1.023	1.023	1.023	1.022	1.022	1.022	1.022	1.021
Exradin P11	1.000	0.997	0.995	0.994	0.994	0.994	0.994	0.994	0.994	0.994	0.993	0.993	0.993	0.993	0.993	0.992
Holt (Memorial)	1.014	1.010	1.009	1.008	1.008	1.008	1.008	1.008	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.006
NACP / Calcam	0.994	0.991	0.989	0.989	0.988	0.988	0.988	0.988	0.988	0.988	0.988	0.987	0.987	0.987	0.987	0.986
Markus	1.009	1.005	1.004	1.003	1.003	1.003	1.003	1.003	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.001
Roos	1.008	1.004	1.003	1.002	1.002	1.002	1.002	1.002	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.000

** IAEA TRS-398*

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Output Calibration (TRS-398)

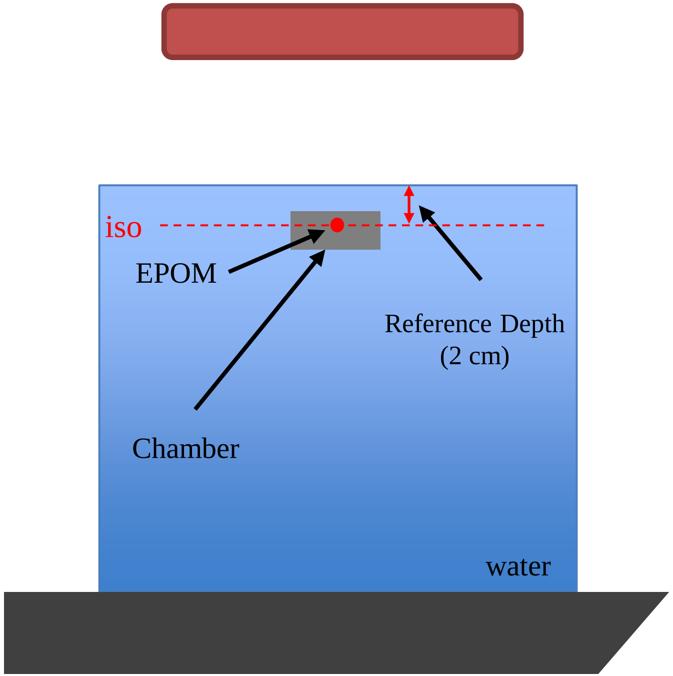
STEP 3: Perform measurement at reference depth for each energy

Use 3D (or 1D) water tank and follow TRS-398 (IAEA) protocol

- *Reference dosimetry → Large field is measured with a small chamber*

Absolute Dose for Protons

- *Use ADCL calibrated cylindrical/parallel plate chamber ($N_{D,w}$)*
- *Position chamber at reference depth*
- *Deliver uniform and monoenergetic 10 ×10 cm^2 field size beam*
  - Uniformity should be verified ahead of time



Output Calibration (TRS-398)

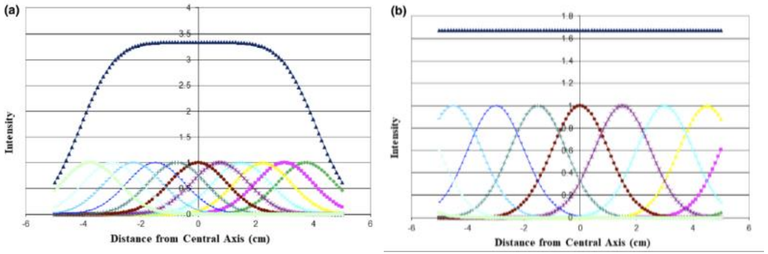
Corrected chamber reading

Chamber calibration factor

Absorbed dose to water at the reference depth → $D_w = M_{corrected} \times N_{D,w} \times k_Q$ ← Beam quality factor

(Gy)

Uniform fields can be created with different spot spacing and MU



Measured dose depends on

- **MU of the central spots** (MU per spot)
- **Contribution from surrounding spots** (depends on spot spacing)

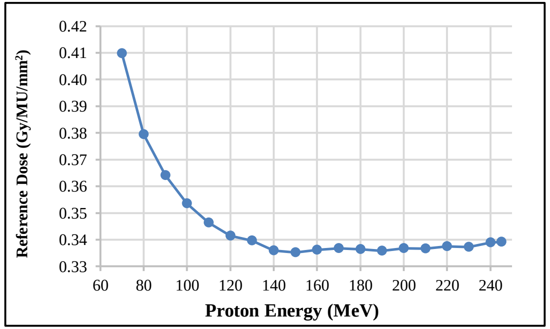
Consider the **spot MU and density**

$$\text{Dose to water at iso} = \frac{D_w}{(\text{MU per spot}) \times (\text{spot per mm}^2)}$$

(Gy/MU/mm²)

(MU per spot): Total MU / # of spots

(spot per mm²): Spot spacing



* AAPM-TG-224

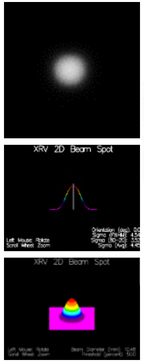
(3) Spot Profile & Position

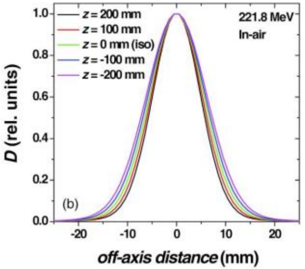
Spot Profiles

Spot profiles in air at iso and different distances from iso

- Measure spot profiles for each energy <u>using scintillator</u> (with and without range shifter)
    - *At isocenter and multiple distance from isocenter (±10, ±20 from iso)*
    - *Perform at different gantry angles* [TG-224 Tolerance (Annual): ±10%]

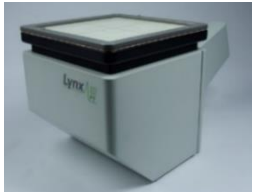
- Determine sigma (σ) and lateral penumbra [TG-224 Tolerance (Annual): Lat. penumbra±2mm]
    - ❑ *May need <u>spot profile measurements in water</u> (depends on TPS and algorithm)*





➢ *Device:*

- ○ ***Lynx2D*** *(IBA)*



- ○ ***XRV-3000 Eagle (320 ×320 mm) or XRV-4000 Hawk (420 ×320 mm)*** *(Logos System)*

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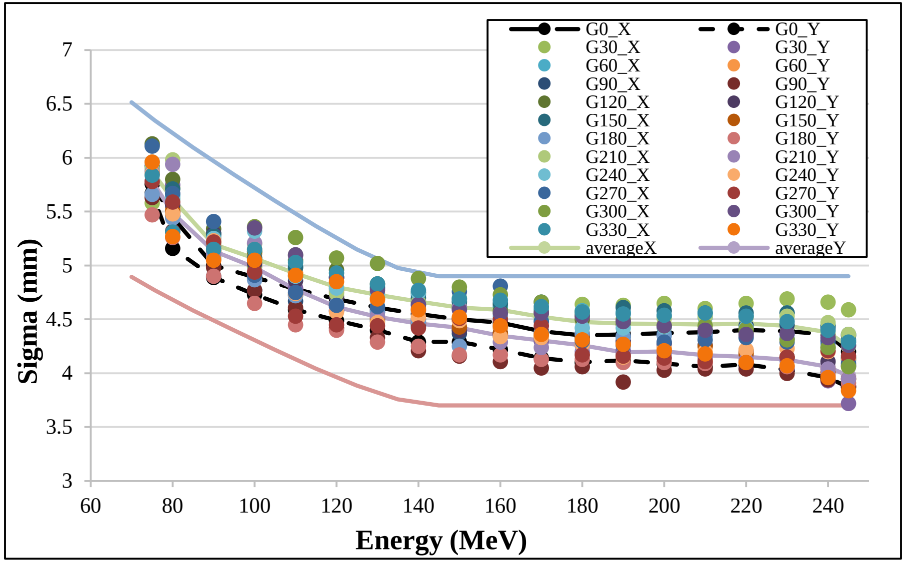
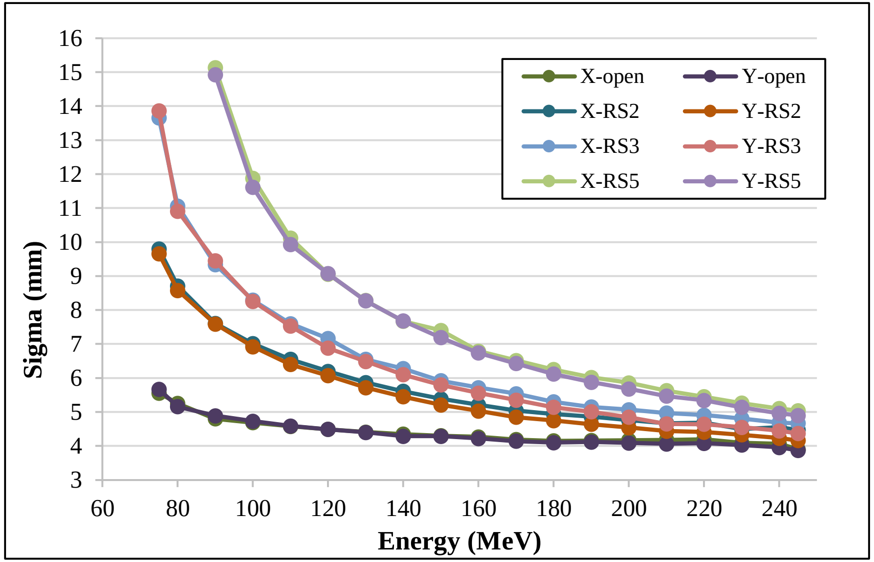
Spot Profiles

Distribution of σ over gantry angle as function of energy



[TG-224 Tolerance (Annual): ±10%]

Distribution of σ of range shifters angle as function of energy



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Spot Position and Symmetry

Spot Symmetry [TG-224 Tolerance (Annual): ±1%]

Symmetry between the x and y profiles.

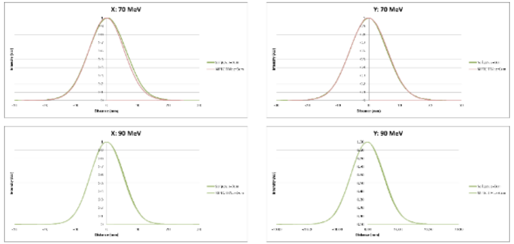
$$\text{Symmetry} = (\sigma_x - \sigma_y)/(\sigma_x + \sigma_y)\times 100$$

With and without range shifter for all energies

No Range Shifter

70 MeV

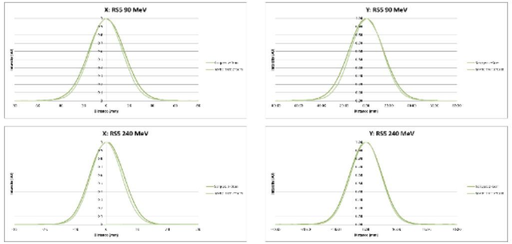
90 MeV



5cm Range Shifter

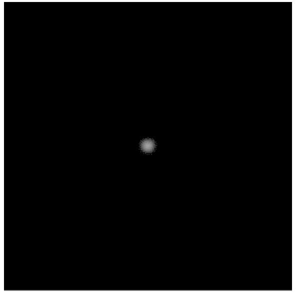
70 MeV

90 MeV

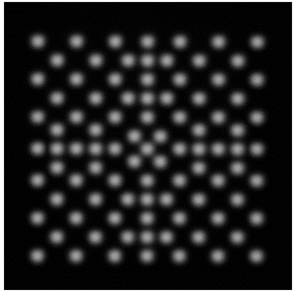


Spot Position Accuracy [TG-224 Tolerance (Annual): ±1mm]

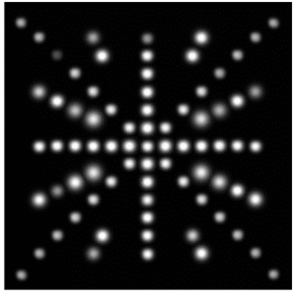
Perform for multiple gantry angles and compare to 0°



Single Spot - Single Energy (245 MeV)



Multiple Spots - Single Energy (160 MeV)



Multiple Spots - Multiple Energies (70-245 MeV)

(4) Other Beam Quality Parameters

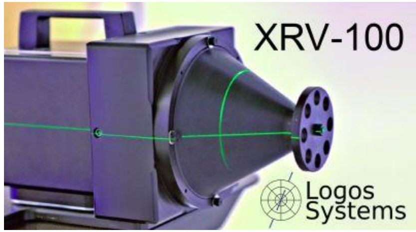
Radiation Isocenter

Radiation isocenter [TG-224 Tolerance (Annual): ±1mm]

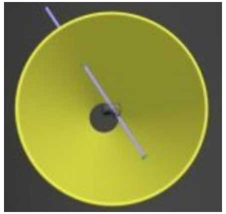
- Verification of radiation isocenter with imaging isocenter and lasers
- Single spots are delivered at multiple gantry angles and over a range of energies

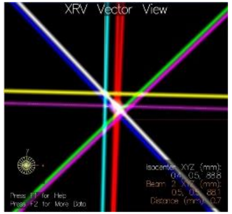
➢ *Device:*

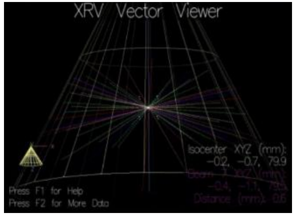
- ***XRV-100 or XRV-124*** *(Logos System)*



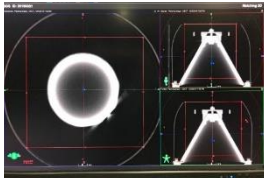
Proton beam creates entry and exit beam spots on the surface of a scintillator cone

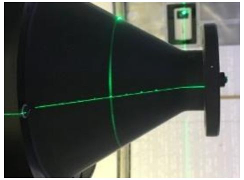






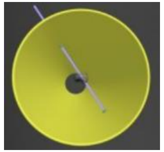
Radiation Isocenter

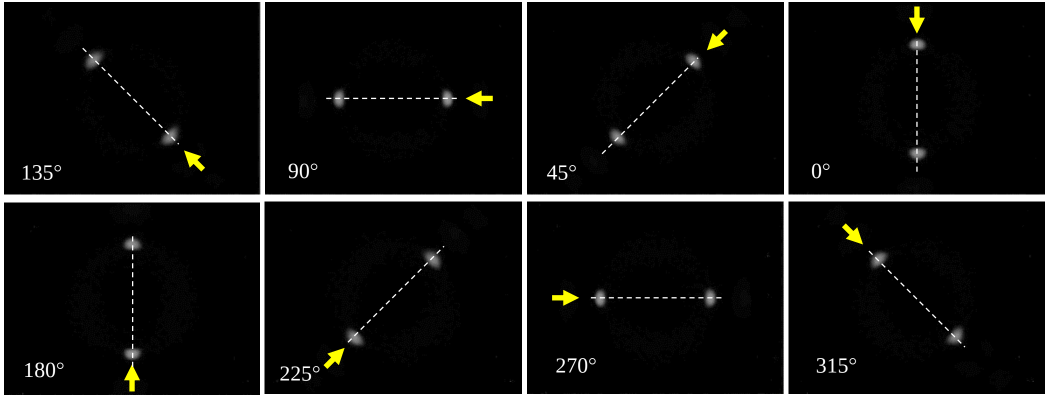




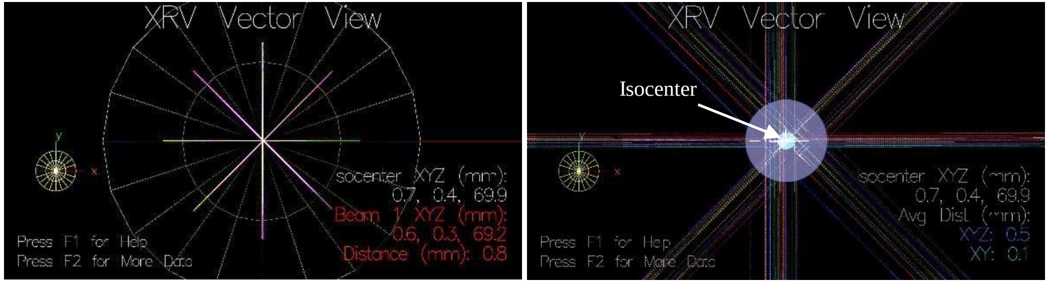
Radiation isocenter vs Imaging isocenter

- Setup the device at isocenter using imaging system
- Deliver a single spot at multiple gantry angles to the isocenter
- Get entrance and exit spots on the scintillator cone





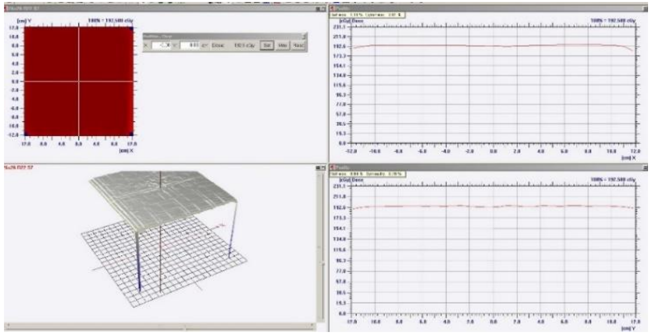
- Software
    - Connects the entrance and exit spots
    - Gives the location of Radiation Isocenter



Uniformity *(Similar to photon)*

Flatness and Symmetry

[TG-224 Tolerance (Annual): ±2% & ±1%]

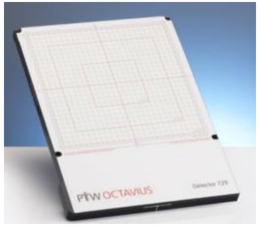


- Deliver multiple single energies and also SOBP plans using the largest field
- Perform the same test at multiple gantry angles (0° and at least every 90°)

Perform uniformity check using an array detector or a scintillator device

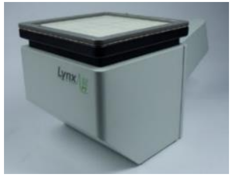
➢ **Array detector**

- MatriXX-PT (IBA)
- OCTAVIUS (PTW)



➢ **Scintillator**

- Lynx2D (IBA)
- *XRV-3000 Eagle or XRV-4000 Hawk* *(Logos System)*



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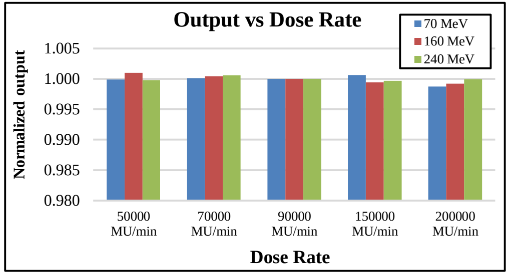
Beam Quality *(Similar to photon)*

Variation of output with dose rate

[TG-224 Tolerance (Annual): ±2%]

Deliver a fixed MU with multiple dose rates for multiple energies (Example: 70, 160, 240 MeV)

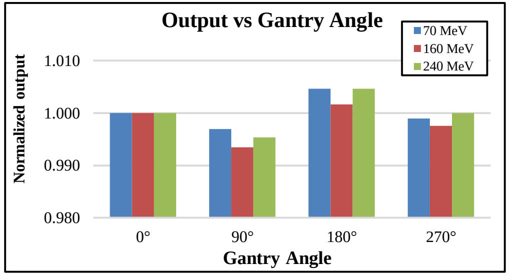


Variation of output with gantry angle

[Tolerance (Annual): ±1%]

Deliver mono-energetic plane multiple energies (Example: 70, 160, 240 MeV)

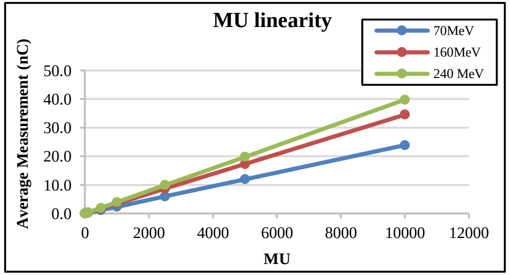
Compare to 0° gantry angle



Monitor Unit Linearity

[TG-224 Tolerance (Annual): ±1%]

Deliver several MU settings for multiple energies (Example: 70, 160, 240 MeV)



Beam Quality *(Similar to photon)*

Monitor End Effect [TG-224 Tolerance (Annual): 1 MU/minimum deliverable MU]

Deliver a range of energies (Example: 70, 160, 240MeV)

$$\text{End Effect} = \left(\frac{I_n - I_1}{nI_1 - I_n}\right) MU$$

I_n : ionization after n-1 interruptions
I_1 : ionization after no interruptions
MU : total MU

Reproducibility [TG-224 Tolerance (Annual): ±2%]

Delivered multiple plans to array/scintillator or ion chamber

Secondary MU chamber [TG-224 (Annual): Functional]

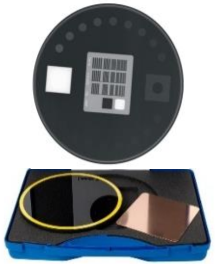
Override the primary chamber and evaluate the function of secondary MU chamber

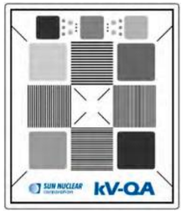
Imaging *(Similar to photon)*

Follow TG-142, TG-179

kV Image Quality

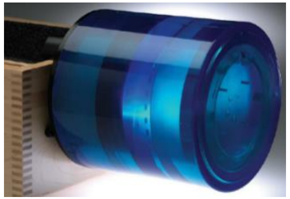
- kV Quality check phantom

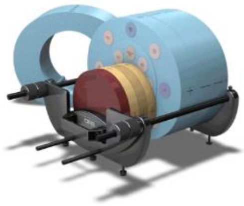




CBCT Image Quality

- CBCT Quality check phantom





Imaging iso as a function of gantry angle

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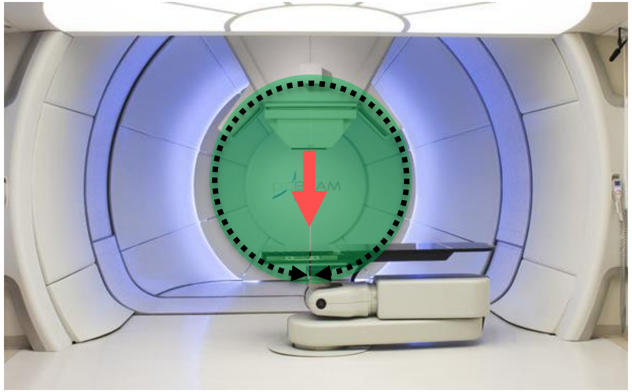
Mechanical *(Similar to photon)*

Gantry Angle Accuracy [TG-224 Tolerance (Annual): ±1°]



Snout Position Accuracy [TG-224 Tolerance (Annual): ±1cm/±1°]

- The snout should exhibit parallel motion at ±90 degrees.

Couch Localization Accuracy [Tolerance (Annual): ±1mm]

6D Treatment Couch

- Translational [TG-224 Tolerance (Annual): ±1mm]
- Rotational [TG-224 Tolerance (Annual): ±1°]
- Couch sag [TG-224 Tolerance (Annual): ±1mm]

Lasers [Tolerance (Annual): ±1mm]

Safety *(Similar to photon)*

Gantry [TG-224 Tolerance (Annual): Functional]

- Motion Enable/Stop
- Laser guard
- Emergency stop buttons

Warning Lights [TG-224 Tolerance (Annual): Functional]

Interlocks [TG-224 Tolerance (Annual): Functional]

- Room secure (last man button)
- Door interlock (for radiation and imaging)
- Beam hold and stop buttons
- Collision interlock
- Range Shifter

Annual QA

Annual QA

Should evaluate and modify QA **based on specific needs and technologies**

- QMP is responsible for all Annual QA
- **Subset of commissioning**

- Checking all mechanical functionality
- Evaluating quality and accuracy of imaging devices
- Safety procedures and interlocks
- Verify a subset of dosimetric data collected during commission
- Calibration of proton beam dose output

TG-224 (Table IV)

TABLE IV. Annual QA procedures for proton therapy.

	Tolerances
	DS/PS
Dosimetry	
Standard output calibration	±2%
Range verification	±1 mm
SOBP width	±2%/±2 mm
Depth doses verification	±2%
Lateral profile penumbra	±2 mm
Range uniformity	±0.5 mm
Field symmetry	±1%
Field flatness	±2%
Spot position	
Spot size	
Uniformity of spot shapes[c]	
Inverse square correction	±1%
Monitor chambers:	
Linearity	±1%
Reproducibility	±2%
Minimum/Maximum dose/spot	Functional
End effect	1 MU
SOBP factors	±2%
Range shifter factors	±2%
Relative output factors	±2%
Verification of daily QA equipment	±1% and/or ± 1
Cross calibration of field chambers	±2%
MLC leakage	
Interleaf	
Leaf-end	
Shielding support	

TABLE IV. Annual QA procedures for proton therapy.

	Tolerances			
	Method of delivery			
	DS/PS	US	PBS	Comments
Mechanical (all delivery systems)				
Coincidence of proton and x-ray field		±1 mm		
Coincidence of proton and light field		±1 mm		If light field is used for setup
Gantry angle accuracy		1°		
Gantry isocentricity		≤2 mm		Diameter of a circle
Gantry x-ray isocentricty		≤2 mm		Diameter of a circle
Couch sag		≤1 mm		Weight limit and position as specified by manufacturer
Snout extension accuracy		±10 mm		
Snout rotational accuracy		1°		
CBCT isocentricity		2 mm		Diameter of a circle
Imaging System functionality				
Image system permormance and dose				TG-179 and TG-142
CBCT				TG-179, TG-142, and MPPG-2a
Standard annual x-ray system checks				State regulations
Safety checks				
MLC activation test		<0.02 mSv/h		Exposure from short-term activation
Collision protection interlock tests		Functional		
Dead man switch		Functional		On the pendant
Radiation warning sign		Functional		Inside and outside treatment room
Door interlock		Functional		
Beam pause		Functional		
Room beam stop		Functional		Inside and outside treatment room
Facility beam stop		Functional		Inside and outside treatment room
Beam delivery indicator		Functional		Inside and outside treatment room
Radiation monitors		Functional		
Audio and visual monitoring		Functional		
Gantry rotation sensor		Functional		
Room clearance push button		Functional		
Room sensor		Functional		For detection of motion
Visual inspections				
Modulation wheels		Functional		Visually check removable modulation wheels
Block and compensator doors		Functional		Check for wear/tear and cracks

DS/PS, Double Scattering/Passive Scattering; US, Uniform Scanning; PBS, Pencil Beam Scanning; CBCT, Cone beam computed tomography; TG, Task group; MPPG, Medical Physics Practice Guideline.
[a]Some centers may define distal and proximal depth dose at 95% or 98%.
[b]Depending on the US delivery vendor, 1% symmetry consistency may not be achievable due to random beam start times of layer's wobble pattern.
[c]See text for discussion of effects of spot shapes. Note also that penumbra and spot size may be viewed as interchangeable for some distributions.

** AAPM-TG-224*

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Outline

Introduction

- AAPM TG-224
- Beam Delivery Technology
  - Pencil Beam Scanning
- Beam Characteristics
  - Bragg Peak parameters
  - Spot Profile

Part 1: Commissioning & Annual QA

- Dosimetry
  - Beam Scanning
  - Output Calibration
  - Spot Profile & Position
  - Other Beam Quality parameters
- Imaging
- Mechanical
- Safety

Part 2: Monthly QA

- Dosimetry
  - Dose per MU
  - Range (Energy)
  - Flatness and Symmetry
  - Spot Profile & Position
  - Radiation Isocenter
- Imaging
- Mechanical
- Safety

Part 3: Weekly QA & Daily QA

- Weekly
  - Gantry angle vs indicators
  - Snout or applicator extensions
  - Imaging Systems
- Daily
  - Dosimetric Parameters
  - Patient Setup Verification
  - Data Communication
  - Safety

Monthly QA

QMP is responsible for all monthly checks

- **Dosimetry**
  - Output
  - Range (Energy)
  - Spot profile and position
  - Flatness/Symmetry of broad fields
- **Mechanical**
  - Gantry and couch isocentricity
  - Couch rotational, translational, and vertical axis accuracy
  - Snout accuracy and trueness
- **Safety**
  - Emergency stop
  - Interlock functionality
- **Imaging**
  - Image Quality (TG-142, TG-179)
- **Respiratory Gating Equipment** (SDX, …)
  - Functional (TG-76, TG-142)

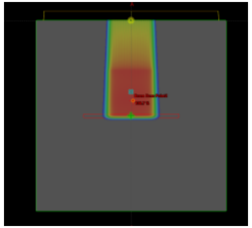
TABLE III. Monthly QA procedures for proton therapy.

	Tolerances			
	Method of delivery			
	DS/PS	US	PBS	Comments
Dosimetry				
Output constancy	±2%	±2%	±2%	Measured at different gantry angles (relative to baseline)
Field symmetry	±1%	±2%[a]	±1%	Measured at different gantry angles (relative to baseline)
Field flatness	±2%	±2%	±2%	Measured at different gantry angles (relative to baseline)
Range	±1 mm	±1 mm	±1 mm	For several clinically relevant energies
Spot size			±10%	At different gantry angles
Mechanical (all delivery systems)				
Gantry isocentricity		≤2 mm		Diameter of a circle
Couch isocentricity		≤2 mm		Diameter of a circle
Couch translational accuracy		≤1 mm		All axes
Couch rotational accuracy		1°		
Couch trueness		≤1 mm		Vertical axis
Snout trueness		≤1 mm		
MLC:				
Light/radiation field coincidence (symmetric)		2 mm or 1%		On a side (if light field is used for clinical setup)-Similar to TG-142
Light/radiation field coincidence (asymmetric)		1 mm or 1%		On a side (if light field is used for clinical setup)-Similar to TG-142
Collimator angle indicator		±1°		Four cardinal angles-Similar to TG-142
Leaf position accuracy (2 designated patterns)		±2 mm		1 mm if MLC is used for field matching/patching-Similar to TG-142
Compensator placement accuracy		±2 mm		
Imaging and treatment coordinate coincidence		±2 mm		Four cardinal angles
Congruence of proton and x-ray field		±2 mm		
Safety (all delivery systems)				
Emergency motion buttons		Functional		Inside and outside of the treatment room
Exposure from long-term activation		<0.02 mSv/h @ surface		Should be checked more frequently if the radiation is higher.
Imaging (if applicable)				
Image quality				TG-179 and TG-142
Respiratory gating		Functional		Refer to TG-76, TG-142 and MPPG-2a

DS/PS, Double Scattering/Passive Scattering; US, Uniform Scanning; PBS, Pencil Beam Scanning; TG, Task group; MPPG, Medical Physics Practice Guidelines.
[a]Depending on the US delivery vendor, 1% symmetry consistency may not be achievable due to random beam start times of a layer's wobble pattern

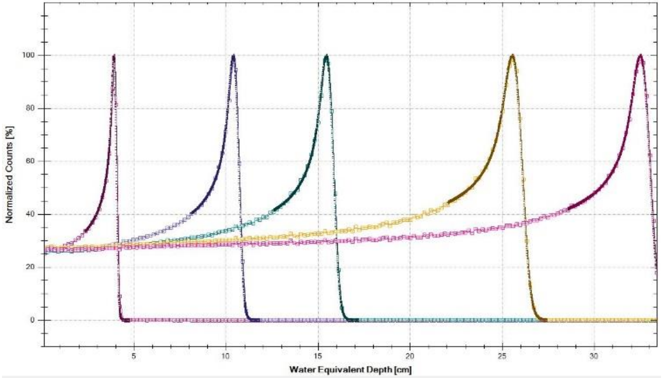
Monthly QA

- **Dosimetry**
  - Output [TG-224 Tolerance (Monthly): ±2%]
    - Different chamber than daily check
    - Single energy and SOBP plans
    - Recommended at several gantry angles




  - Range (Energy) [TG-224 Tolerance (Monthly): ±1mm]
    - Several energies spanning full range

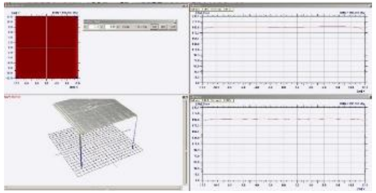
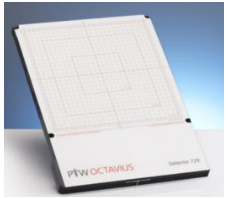




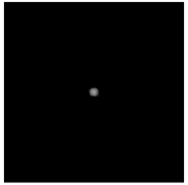

Monthly QA

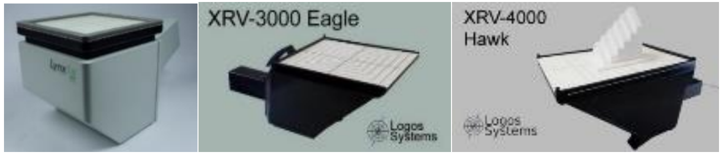
- **Dosimetry**
  - Flatness/Symmetry of broad fields
    - At cardinal gantry angles

[TG-224 Tolerance (Monthly): ±2%]

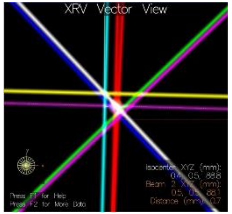
  - Spot profile and position

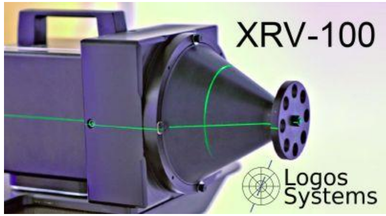




  - Radiation isocenter vs imaging isocenter

[TG-224 Tolerance (Monthly): ±2mm]

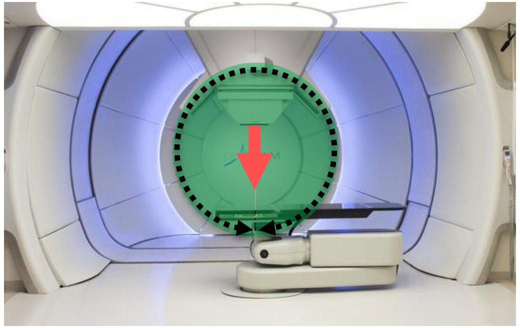




Monthly QA

- **Mechanical**
  - Gantry and couch isocentricity [TG-224 Tolerance (Monthly): ±2mm]
  - Couch rotational accuracy [TG-224 Tolerance (Monthly): ±1°]
  - Couch translational accuracy [TG-224 Tolerance (Monthly): ±1mm]
  - Snout accuracy and trueness [TG-224 Tolerance (Monthly): ±1mm]

  Using digital level, graph paper, ruler, …



- **Safety**
- **Imaging** Refer to TG-142, TG179
- **Respiratory Gating Equipment** Refer to TG-76, TG-142

Outline

Introduction

- AAPM TG-224
- Beam Delivery Technology
  - Pencil Beam Scanning
- Beam Characteristics
  - Bragg Peak parameters
  - Spot Profile

Part 1: Commissioning & Annual QA

- Dosimetry
  - Beam Scanning
  - Output Calibration
  - Spot Profile & Position
  - Other Beam Quality parameters
- Imaging
- Mechanical
- Safety

Part 2: Monthly QA

- Dosimetry
  - Dose per MU
  - Range (Energy)
  - Flatness and Symmetry
  - Spot Profile & Position
  - Radiation Isocenter
- Imaging
- Mechanical
- Safety

Part 3: Weekly QA & Daily QA

- Weekly
  - Gantry angle vs indicators
  - Snout or applicator extensions
  - Imaging Systems
- Daily
  - Dosimetric Parameters
  - Patient Setup Verification
  - Data Communication
  - Safety

Weekly QA

Consider splitting between daily and monthly QA

Gantry angle accuracy [TG-224 Tolerance (Weekly): ±1°]

Couch positional accuracy [TG-224 Tolerance (Weekly): ±1mm/± 1°]

Snout positional accuracy [TG-224 Tolerance (Weekly): ±1cm]

TABLE II. Weekly QA procedures for proton therapy.

Review of daily QA checks	Tolerances	Comments Reviewed for systematic problem
Mechanical (all delivery systems)		
Gantry angle	±1°	
Snout extension	±10 mm	
Optional		
Couch positional accuracy	±1mm/1°	Translational/rotational

Imaging Systems

- Position of out-of-treatment position imaging devices

  (CT on rails, portable CTs, etc.)

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Daily QA

- Daily QA may be performed by RTT or physics assistant
- Results should be reviewed daily by QMP

Compared to monthly QA

- Parameters with higher likelihood of **drifting over short time**

Dosimetric Parameters

Output (Different ranges/energies on different days)
Range (Energy)
Spot delivery constancy (shape and position)

Patient Setup Verification

Data Communication

Safety

Table I. Daily QA procedures for proton therapy.

	Tolerances			
	Method of delivery			
	DS/PS	US	PBS	Comments
Dosimetry				
Output constancy	±3%	±3%	±3%	Measured for different ranges on different days with-
Depth verification:				One consistent field
Distal	±2 mm	±1 mm	±1 mm	Difference from baseline at distal 90%[a] depth dose
Proximal	±2 mm	±2 mm	-	Difference from baseline at proximal 90%[a] depth dose
SOBP width	±2%/±2 mm	±2%/±2 mm	-	Width between proximal and distal 90%[a] depth dose
Spot position	-	-	±2/±1 mm	Absolute/relative-If dose pattern is used, the dose uniformity and homogeneity should reflect the same accuracy from baseline.
Mechanical (all delivery systems)				
Couch translation motion		±1 mm		Performed if patient is not reimaged after couch shifts
Lasers position accuracy		±2 mm		At isocenter
Imaging				
X-ray isocenter vs Laser isocenter		±2 mm		
X-ray and proton beam isocenter coincidence		±1 mm		
Image acquisition and communication		Functional		This includes file swap between R&V and delivery system as well as verification of images
CBCT				Daily procedures outlined in TG-179, TG-142, MPPG-2a
Safety				
Door interlock		Functional		
Audio monitor		Functional		
Visual monitor		Functional		
Beam on indicator		Functional		
X-ray on indicator		Functional		
Search/clear button		Functional		
Pause beam button		Functional		
Emergency motion stop button		Functional		
Monitor unit interlocks		Functional		
Collision interlocks		Functional		When applicable
Radiation monitor (Neutron and X-ray)		Functional		
Optional				
Range modulation wheel timing	±2%	–	–	With respect to frequency of rotation
Field light		Functional		
Field width	±2 mm	–	–	
Proximal depth verification	–	–	±2 mm	Difference from baseline at proximal 90%[a] depth dose
SOBP width	–	–	±2%	Width between proximal and distal 90%[a] depth dose
Field symmetry	±1%	–	–	From baseline
Field flatness	±2%	–	–	From baseline
Dose rate	±2%	–	–	
Gantry angle read out accuracy		±1°		
Interlock test therapy delivery system		Functional		
Interlock test therapy verification system		Functional		

DS/PS, Double Scattering/Passive Scattering; US, Uniform Scanning; PBS, Pencil Beam Scanning; TG, Task Group; MPPG, Medical Physics Practice Guidelines.
[a]Some centers may define distal and proximal depth dose at 95% or 98%.

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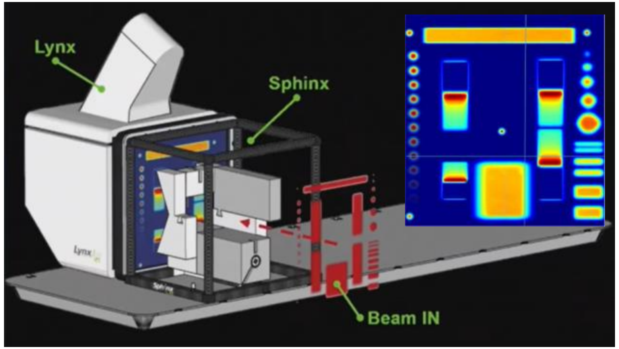
Daily QA

Lynx + Sphinx *(IBA)*

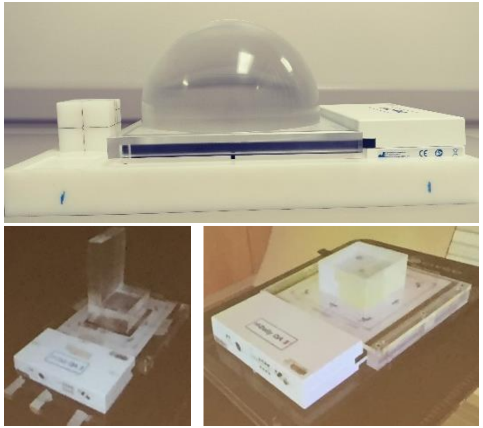
Complete Daily Check

- Energy check (4 energies)
- Spots sigma & position
- Output (using ion chamber)
- Profile & Uniformity
- Isocenter and x-ray to beam coincidence
- Lasers
- Couch translation
- Range Shifter
- Area monitor
- Video/Audio



Custom made Daily QA setup using commercial Daily QA devices *(Sun Nuclear and IBA)*

- Output Check
- Field Size Check
- Flatness/Symmetry Check
- Imaging Registration
- Laser Check
- Couch translation
- 90˚ and 270˚ Couch Rotation
- Range Shifter
- Area Monitor
- Video/Audio

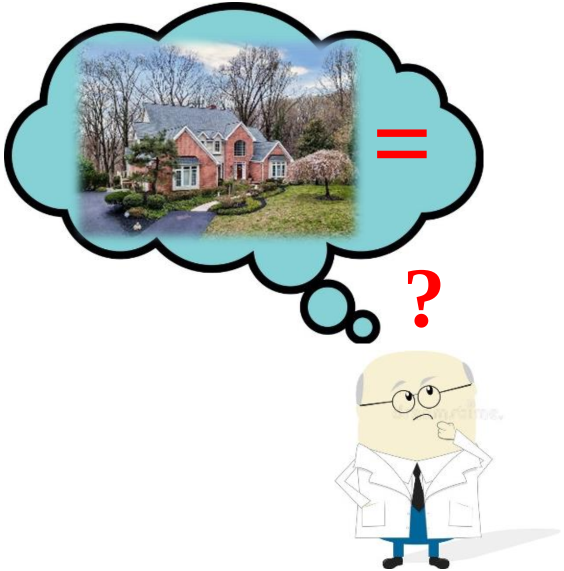


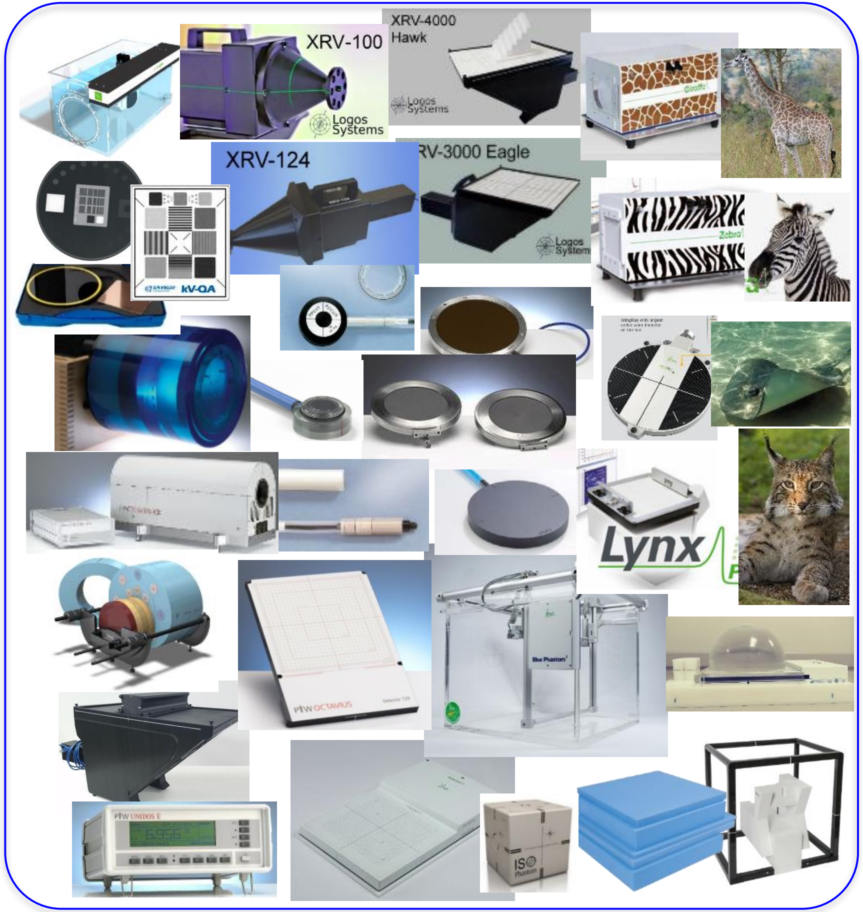
Summary

- You need lots of toys to perform machine & patient QA for proton therapy

- And they are really expensive

- For multi-room proton center the QA tools can be **+$800,000**





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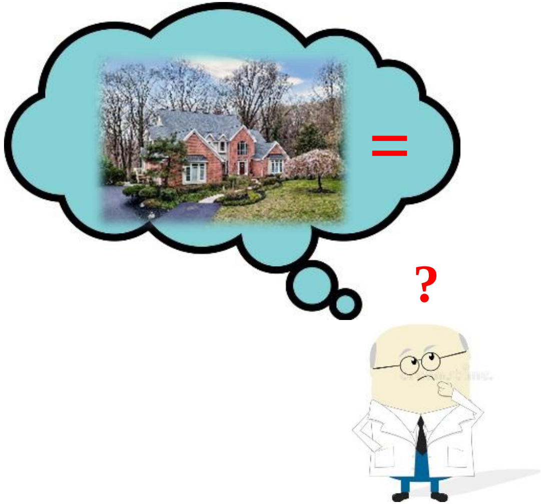

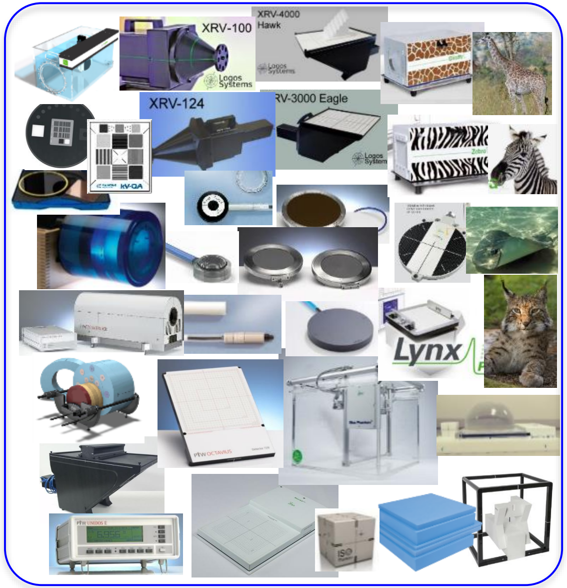

Thank you!