Accelerator Beam Data Commissioning Equipment and Procedures

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Lsiller/followill/accept testing 12 03

Commissioning

- Purposes
  - determine and record beam characteristics
  - acquire data for treatment planning, manual calculations
  - Independent of user and scanning system (< 0.5%)

New Resource

AAPM Task Group 106 Report
Accelerator Beam Data Commissioning
Equipment and Procedures
(early 2007)

RPC

Need for Commissioning

1. Acceptance testing finished ($$$$$).
2. Treat patients?
   Rad. Onc. Administrator – yes
   Radiation Oncologist – yes
   Rad. Onc. Therapist – yes
   Physicist – **NO NO NO NO!!!!!!!!!!**
3. Must have minimum dataset necessary for treatment planning, beam-on time calculations and quality assurance.
4. Dependent on treatment planning system.

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Need for Commissioning

RT outcome ↔ accuracy of patient dose

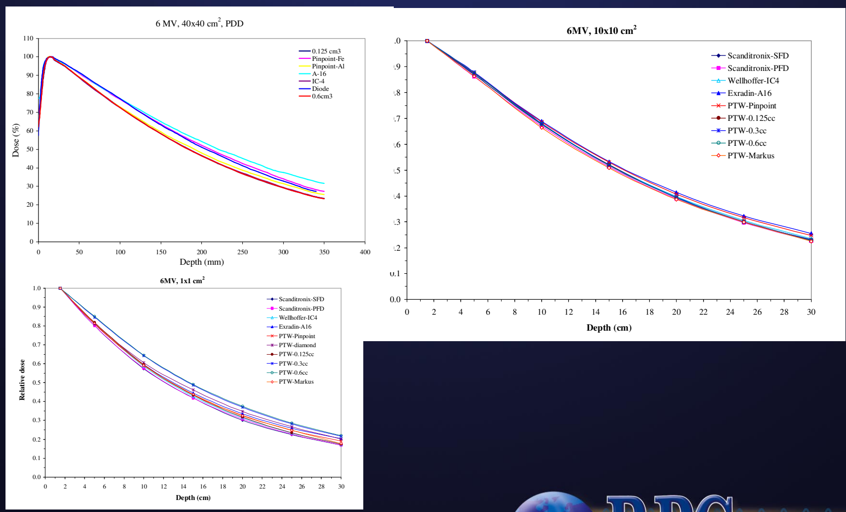
accuracy of patient dose ↔ quality of beam data

Commissioning beam data should be treated as the "Gold Standard"

Need for Commissioning

1. Manufacturers = std. Machine
   - Not yet!!!!
   - Many components depend on moving parts (EDW, MLC, etc)
2. Need to treat each machine individually
3. Compilations of Std. Data from the manufacturer or RPC for QA purposes only

Variations in Data



Commissioning Guidelines and Equipment Recommendations

1. Manufacturers provide guidance for Acceptance testing, but not commissioning
2. Beam data requirements specified by TPS
   - AAPM reports

     - TG 106: Accelerator Beam Data Commissioning
     - TG 45: Code of Practice
     - TG 53: 3D Planning systems
3. Selection of appropriate tools for beam data acquisition

Beam Commissioning

TG-106: Accelerator beam data commissioning equipment and procedures.

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Commissioning Effort

- **Model based vs. correction based algorithms**
  - model based require less data
  - correction based data set similar to what is needed for hand calc's.
- **Planning system should have a "Measured Data Requirements" manual.**
  - Pinnacle – 106 pages
- **Develop a "Commissioning Run Plan"**

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Compilation of the required data for 10 TPS systems

CAX %dd, open fields	Open field profiles, in air	Output factors (Sc,p)
CAX %dd, wedge fields	Open field profiles, 2 SSD's	Output factors measured at 10 cm depth
CAX %dd, 90 cm SSD, open and wedged	Off axis HVL	Collimator factors (Sc)
Diagonal profile for max collimator setting, in phantom	MLC penumbra profiles	Phantom scatter factors (Sp) (either published data or values derived from Sc,p and Sc values)
Diagonal profile for max collimator setting, in air	MLC/Collimator jaw transmission	Collimator transmission
Diagonal profile for max square field	MLC setting and radiation field offset	Wedge transmission factors
Star profiles for max square field	Wedge profiles, nominal SSD	Tray transmission factors
Open field profiles, nominal SSD	Physical wedge dimensions	Absolute dose reference condition and value
Open field profiles, 90 cm SSD	Block edge profiles	Absolute dose for 100cm SSD

Data Type	CMS	NOMOS	Prowess	Nucletron	Multidata	Pinnacle
CAX %dd, open fields	X	X	X	X	X	X
CAX %dd, wedge fields	X	NA		X	X**	X
CAX %dd, 90 cm SSD, open and wedged						
Diagonal profile for max collimator setting, in phant	X	X*	X	X	X	
Diagonal profile for max collimator setting, in air		X*				
Diagonal profile for max square field	X					
Star profiles for max square field						
Open field profiles, nominal SSD	X	X	X	X		X
Open field profiles, 90 cm SSD						
Open field profiles, in air					X	
Open field profiles, 2 SSD's						
Off axis HVL			X**			
MLC penumbra profiles		X				
MLC/Collimator jaw transmission		X				X
MLC setting and radiation field offset		X				
Wedge profiles, nominal SSD	X		X	X	X	X
Physical wedge dimensions						X
Block edge profiles	X		X	X**		X
Output factors (Sc,p)	X	X	X	X	X	X
Output factors measured at 10 cm depth						X
Collimator factors (Sc)	X	X		X	X	
Phantom scatter factors (Sp)	X		X	X	X**	
Collimator transmission						X
Wedge transmission factors	X	NA	X	X	X	X
Tray transmission factors	X	NA	X	X	X	X
Absolute dose reference condition and value	X	X		X	X	X
Absolute dose for 100cm SSD			X			
* = either one						
** = suggested, not required						

Commissioning (Minimum Data)

- Minimum Data Requirements
  - calibration (TRS 398 or TG-51)
  - CAX depth dose (PDD/TPR)
  - dose profiles
  - isodose distributions (open/wedge)
  - output factors (Sc, Sc,p)
  - wedge and tray factors
  - electron applicator/insert factors
  - off-axis ratios (open/wedge)
  - inverse square law (SSD/VSD)
  - entrance dose and buildup region

Typical Commissioning Measurements (photons)

Description		Square field size (cm^2)															
		1	2	3	4	5	6	8	10	12	14	16	20	25	30	40	>40
Application		IMRT Data													Magna field		
				Traditional Radiation Oncology Fields													
Scan data	PDD/TMR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Profiles @ 5-7 depths	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Diagonal or star profiles															x	x
non-scan data	S_c	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	S_{cp}	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	WF/TF				x	x	x	x	x	x	x	x	x	x	x		
	Surface dose	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Typical Commissioning Measurements (electrons)

Description		Cone size (cm x cm)				
		5x5	10x10	15x15	20x20	25x25
Scan data	PDD	x	x	x	x	x
	Profiles @ 5-7 depths	x	x	x	x	x
non-scan data	Cone factor	x	x	x	x	x
	Cutout factor	x	x	x	x	x
	Virtual source	x	x	x	x	x
	Surface dose	x	x	x	x	x

Commissioning Effort

New accelerators

- 1-3 photon energies, 0-8 electron energies
- 4-6 weeks of effort (PRESSURE!!!)

Sample Calculation

Time ≈ (PDD+ 5 profiles)/beam energy * 2 energies* (open+4 wedges) * 60points/scan * [1sec/pts+1 sec (movement and delay)]* 15 fields

= 9×10^5 seconds

= **30 hrs** beam time for each photon beam

Commissioning Effort

- 1.5 weeks per photon beam (allows for problems and setup)
- 1 week for point dose measurements
- 1 week for electrons
- 1 week for verification
- 1-2 weeks for report and data analysis

4-6 weeks total time

(matched machines will be less time)

Commissioning Equipment Requirements

- **Phantom Material**

  - water phantom (scanned data)

    i) scans in three directions (x,y,z)

    ii) min. scan range – 40 cm

    iii) chamber positioning to within 1 mm

    iv) min. setup time

    v) remote control

    vi) data transfer to computer

    vii) lift table

Commissioning Equipment Requirements

- **Phantom Material**
  - water phantom (scanned data)
    - viii) water storage (prevent algae growth)
    - ix) maintain room temperature
    - x) chamber temperature equilibration
    - xi) after scanning, drain and dry
    - xii) oil metal slides

Commissioning Equipment

Commissioning Equipment Requirements

- **Phantom Material**
  - solid phantom (non-scanned data)
    - i) point dose measurements in water or solid phantoms)
    - ii) different stopping powers
    - iii) appropriate cavity for chamber
    - iv) thermal equilibration needed
    - v) phantom integrity verified

Commissioning Equipment Requirements

- **Phantom Material**
  - solid phantoms (point measurements)

Material, manufacturer	Color	Density (kg/m^3)	$(\mu_{en}/\rho)^{water}_{med}$ 6 MV	10 MV	15 MV	18 MV
Polystyrene, NA, RPD	Opaque	1050	1.035	1.037	1.049	1.059
Acrylic/PMMA, RPD	Clear	1185	1.031	1.033	1.040	1.044
Solid water, RMI	Maroon	1030	1.032	1.039	1.049	1.052
Plastic water, CIRS	Lavender	1014	1.032	1.031	1.030	1.030
Blue water, SI (photons only)	Blue	1090	new	new	new	new
White water-RW-3, NA	White	1045	1.035	1.036	1.049	1.056

NA, Nuclear associates, NY; RPD, Radiation product design, Albertsville, MN; RMI, Radiation Measurements Inc, Middleton, WI; CIRS, Computerized Imaging Reference Systems Inc, Norfolk, VA, SI, Standard Imaging, Middleton, WI

Commissioning Equipment

- **Solid Phantom Material**

Commissioning Dosimeters

Dosimetry measurements for acquiring beam data are best performed in water using the appropriate radiation detector. The essential features required of any measuring device are:

1. **sufficient sensitivity;**
2. **stability;**
3. **negligible leakage;**
4. **energy independence;**
5. **sufficient spatial resolution;**
6. **linearity**

Commissioning Dosimeters

Detectors can be categorized in terms of their size:

1. Standard – (~10^{-1} cm^3) typical 0.6 cm^3 farmer chamber
2. Mini – (~10^{-2} cm^3) active volume is on average 0.05 cm^3
3. Micro – (~10^{-3} cm^3) active volume is on average 0.007 cm^3 suited for high gradient dose regions

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Commissioning Dosimeters

Ion chambers:

1. Response independent of
   - Dose, dose rate, energy
2. Relatively inexpensive
3. Reproducible reading
4. Traceable to National Standard
5. Many sizes

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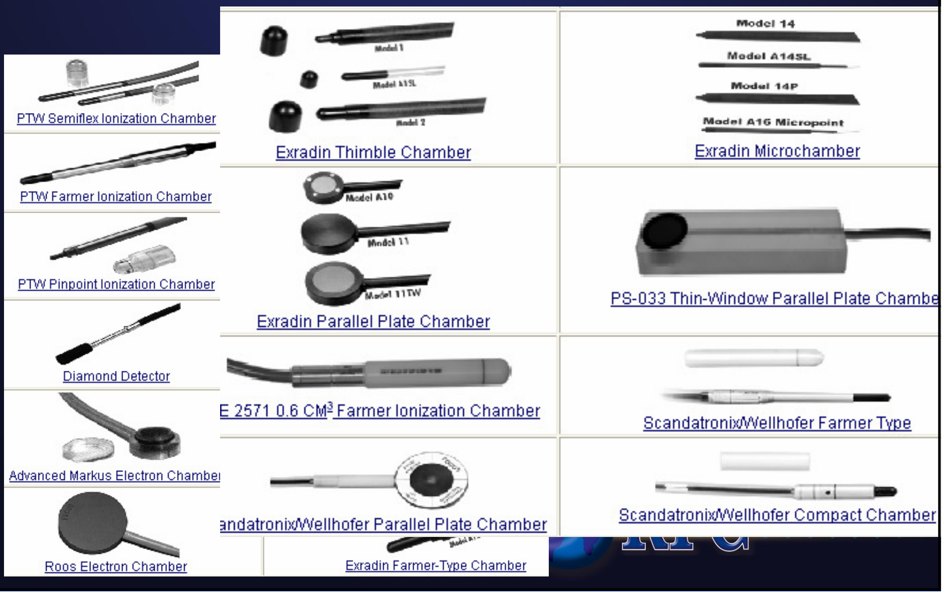
Commissioning Dosimeters

Ion Chambers



Commissioning Dosimeters

Diodes:

1. Quick response time
2. Excellent spatial resolution
3. High sensitivity
4. Absence of external bias
5. Energy independent for electron beams
6. Response can depend on dose rate, energy (photons) , temperature and some have angular dependence

Commissioning Dosimeters

Detector Arrays for simultaneous data acquisition over the entire open beam:

1. Suitable for soft wedge profiles
2. Linear arrays typically
3. Can be diodes or ion chambers
4. Do not store in water

Commissioning Dosimeters

Other detectors:

1. Diamond
   - ideal for small field dosimetry and profiles
   - Tissue equiv./ no directional dependency
   - Some dose rate dependency
2. TLD for point dose and in vivo measurements
   - Energy and dose dependency
3. Film (silver halide or radiochromic) for relative measurements
   - Energy dependence

Selection of Detector

Depends on type of application

1. Field size (volume considerations)
2. Resolution (gradient)
3. Time needed to complete data collection (signal considerations)

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Scanning System Setup

- Check existing cable run (enough room?)
- Do not perform the commissioning measurements with the door open (bad for your health!)
- Set the scanning computer near the accelerator console. (save time!)

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Verification and Validation of Scanner

Scanning systems are extremely accurate and precise, but still need periodic QA

1. Free movement of each arm
2. Accuracy and linearity of movement
3. Physical condition of tank
4. Quality of connecting cables (leakage/reproducibility)
5. Be careful mixing components

Mellenberg et al, Med Phys 17, 311-314, 1990

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Scanning and Reference Detectors

- Scanning chamber moves and acquires the commissioning data
- Reference chamber is stationary and is used to remove fluctuations in the beam output
  - Can be different than scanning chamber
  - No metallic holders to reduce scatter
  - No tape holders
  - Don’t shadow the scanning chamber

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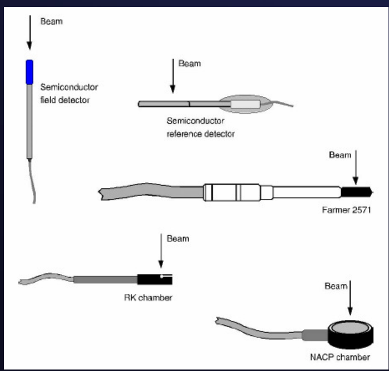
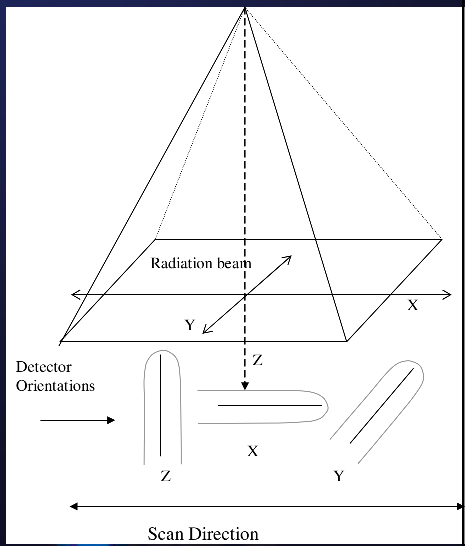
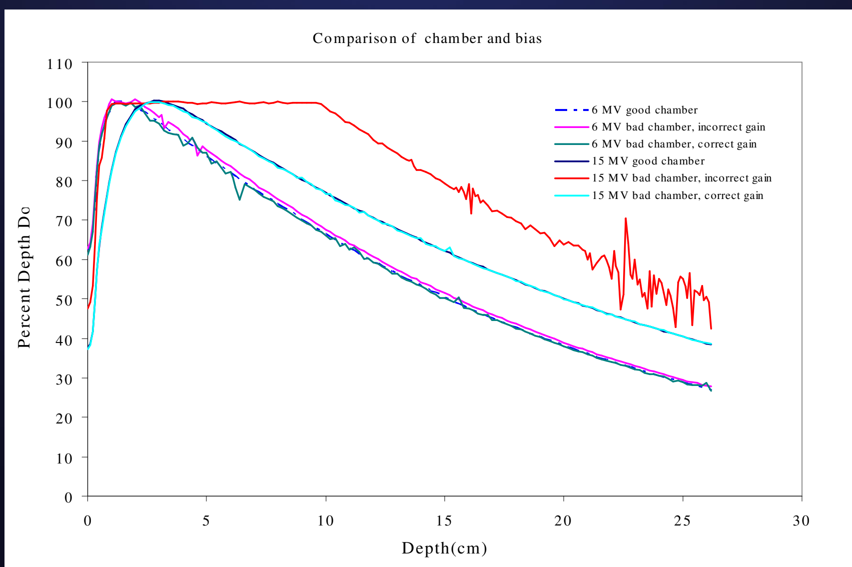
Details about the Detectors

- Detector mounts
  - Orient detector to minimize volume in scan direction





Details about the Detectors



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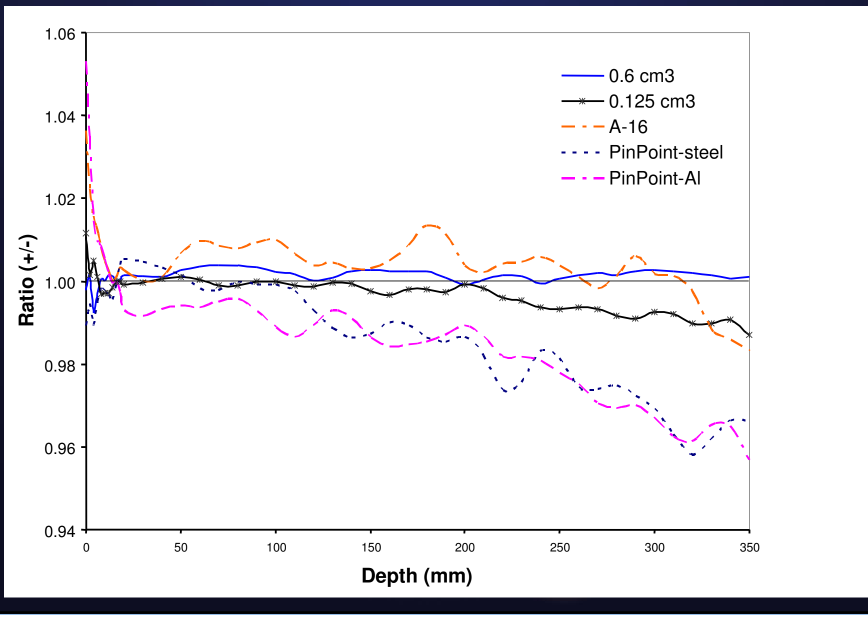
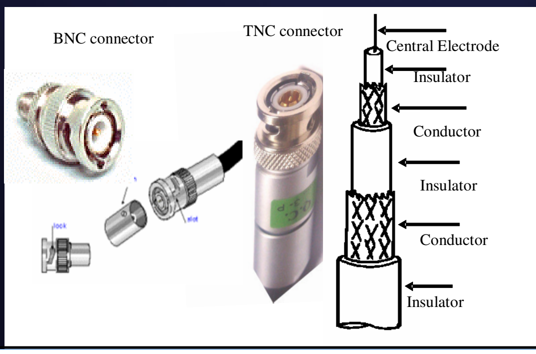


Details about the Detectors

- **Detector re-combination**
  - If possible check re-combination at half voltage. Usually not a problem.
- **Detector sensitivity**
  - Must find a balance between signal-to-noise ratio and saturation.
- **Detector energy response**
  - Flat for most ion chambers
  - Diodes have response in photon beams (do not use). Okay for electron beams.

Cables, Connectors and Adapters

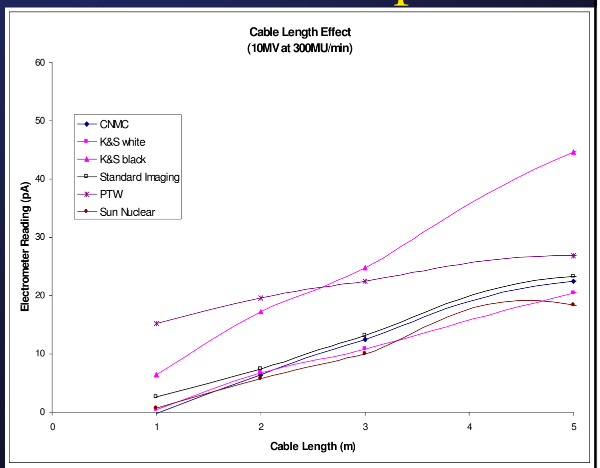
- Accuracy and integrity of the scan data depend on the quality of the cable and connectors
  - Connectors (BNC,TNC – coaxial or triaxial)
  - Adapters are sources of leakage



Do not force a coax BNC into a triax BNC!!

Cables, Connectors and Adapters

- Quality of cables
  - Leakage from badly twisted or bent cables
  - Leakage is important for measurements in small fields where signal is low
  - Length of cable in field may lead to noisy data



Scanning Water Tank

- Positioning and Labeling
  - Never place tank on treatment couch
  - ~280 kgs (too much for couch)
  - Use platform provided by manufacturer

- Set tank up for desired x- and y- convention as to minimize material moving through water

- Make sure tank labeling agrees with what is expected by TPS

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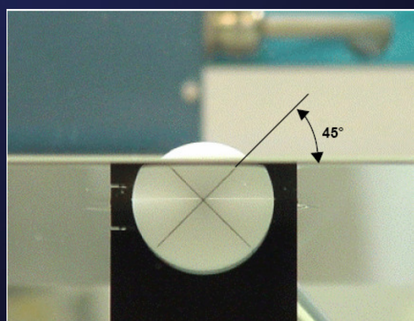
Scanner Movement

- Make sure chamber is level at all 4 corners
- CAX vertical movement

  1.Use string plumb-bob

  2.Use light field with 1mm flash on each side of chamber

  Above test should be done for acceptance testing of scanner



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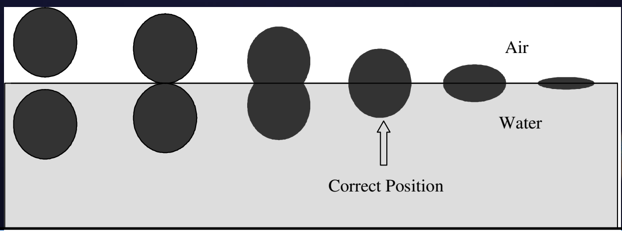
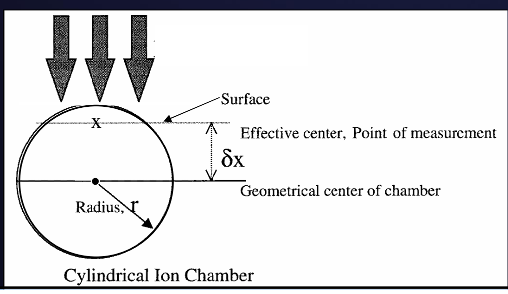
Setting zero depth

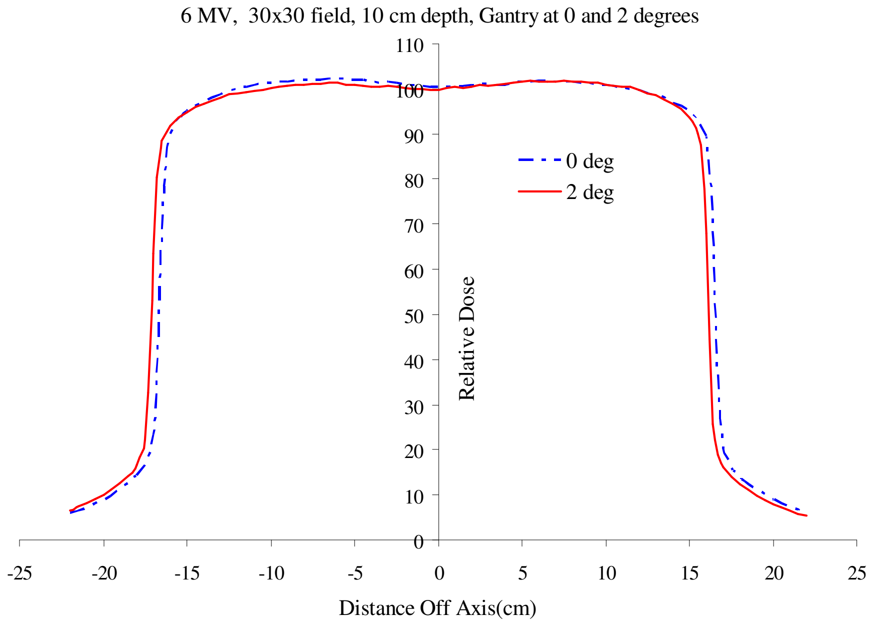
- Set SSD and verify by two means (laser, ODI, distance stick, etc.)
- Precisely set the tank coordinate (0,0,0) to coincide with the machine isocenter and it should be near the center of the tank
- Position the detector so that the detector splits the water surface.



Chamber Shift

- Once the detector has been positioned, a shift to the effective point of measurement is needed
  - Different for photons and electrons
  - Depends on chamber shape
- Scanner software or manual adjustment





Scan Mechanism and Movement

1. Array detector weight too much for scan mechanism??? (read manual)
2. Speed and position accuracy – scan across 40 cm with a 20 cm field at highest and lowest speed. (compare profiles)
3. Hysteresis – scan a field in one direction and then again in the opposite direction. (compare profiles)
4. Corrosion!!!

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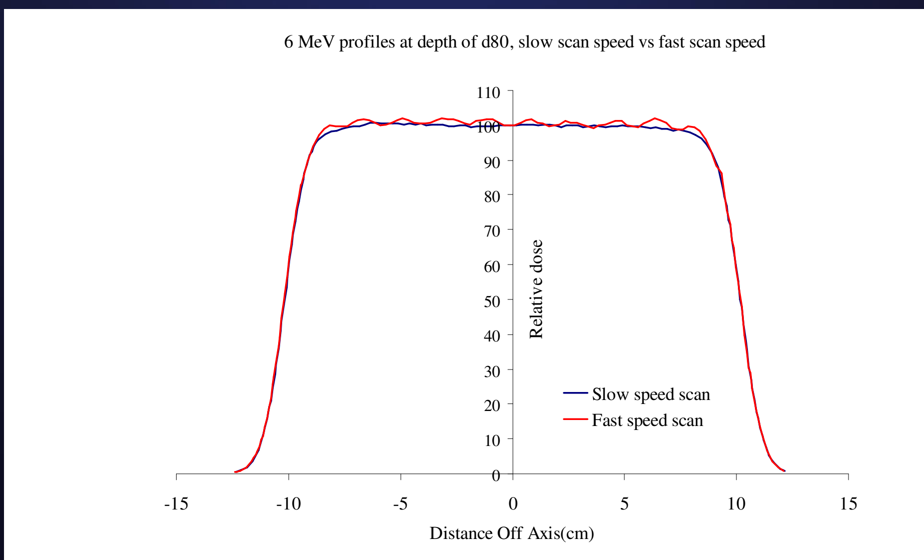
Pre-Measurement Tests

- Dry run
  - air scan of a 20x20 field going from -20 cm to +20 cm (buildup cap)
  - Repeat with turning beam off when detector at CAX
    - Flat region std dev – noise of beam
    - Flat region – COV give signal to noise ratio
- Water run (make sure devices are waterproof)
  - Repeat above scans (shallow and deep) and calculations

Results should be the same for water and air scans

Data Acquisition

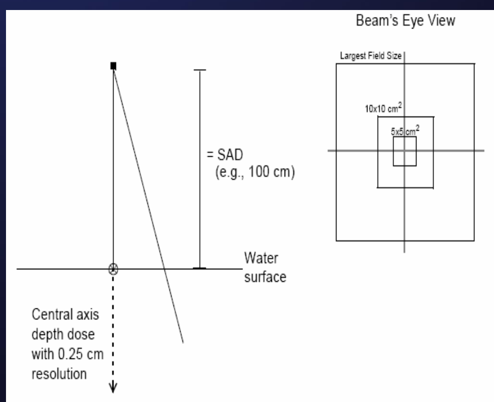


Photon Beam data

- Scope of the measurements depend on the requirements of the dose calculation system (TPS, mu calc. , etc.)
  - Depth dose and profile scans
- Additional data may be needed to verify the TPS calculations
  - May be acquired with the scanning system or by point dose measurements

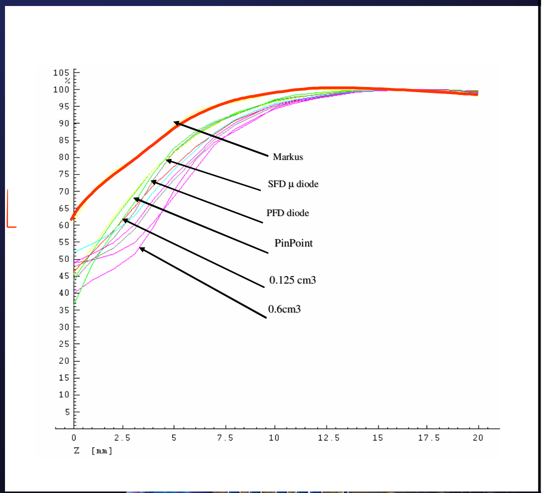
Photon Depth Dose data

- Do not use the acceptance testing data
- Typically 100 cm SSD
- Start from the bottom
- Clinical conditions
- Measurements
  - Open field CAX depth dose (min.)
    - i) 100 SSD
    - ii) FS 5, 10, 20, 40 cm^2
    - iii) depth 25 cm (0.25 cm increments)



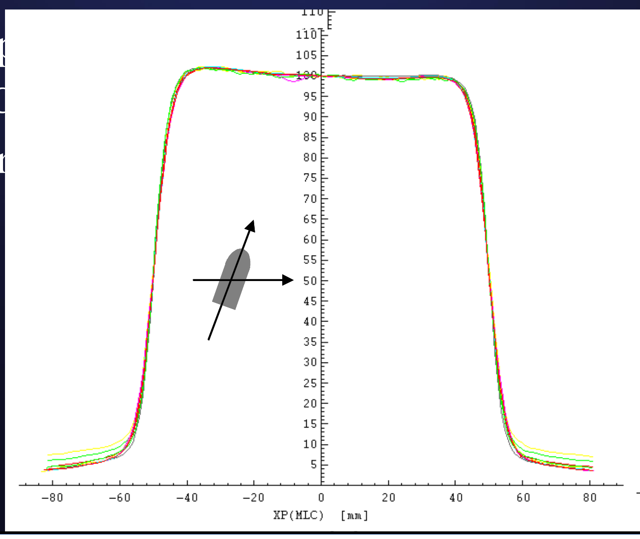
Photon Surface Dose and Buildup Region

- Surface dose is machine dependent and depends on:
  - Field size, SSD, angle of beam incidence, beam modifiers
  - Careful selection of detectors



Photon Profiles

- Detector size and orientation are crucial
- In-
  - C ... dir.
- Ver



Photon Profiles

- Required by TPS and hand calc's
- Small to large Field Sizes (depend on TPS)
  - To model the penumbra
  - Open and wedged fields
  - 1mm spacing in penumbra and 2mm elsewhere
- Number of scans depend on TPS
  - 5-7 depth profiles per FS
  - 1cm spacing up to 6x6 and then 5cm for ≥ 10x10

Wedged fields

- Physical wedges
  - same requirements as open fields
- Soft wedges (moving jaw)
  - Requires different dosimeter
    - Film, diode arrays, ion chamber arrays
    - Arrays may attach to scanning system
    - Arrays are the preferred method (in-water)

Photon Point Dose Data

- Total Scatter factor (S_{cp})

$$S_{cp}(s) \equiv \frac{D(s, d_{ref})/M}{D(s_{ref}, d_{ref})/M}$$

- Depth = d_{max} or 10 cm
- SSD or SAD
- IMRT (1,2,3,4,5,6,8,10 cm^2)

Photon Point Dose Data

- In-air Output ratio (S_c)

$$S_c \equiv \frac{K_p(c; z_{ref})/M}{K_p(c_{ref}; z_{ref})/M}$$

- 100 cm SCD = z_{ref}
- Miniphantom in air
- Small fields – extended distances may be needed

Photon Point Dose Data

- Phantom Scatter factor (S_p)

$$S_p(s) \equiv \frac{SF(s, d_{ref})}{SF(s_{ref}, d_{ref})}$$

or

$$S_p(s) \approx \frac{S_{cp}}{S_c}$$

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Wedge Factors

- Depend on:
  - wedge angle
  - Field size
  - Depth
  - Wedge type (physical, EDW, internal, virtual)
- Measure at reference depth for many FS
- Care in placing ion chamber
- For depth dependence use wedged depth dose data

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Tray factors

- Measured at reference depth (10 cm or d_{max})
- Trays, jaws, MLC
- Large monitor unit setting may be needed

$$TF = \frac{Rdg_{tray}}{Rdg_{open}}$$

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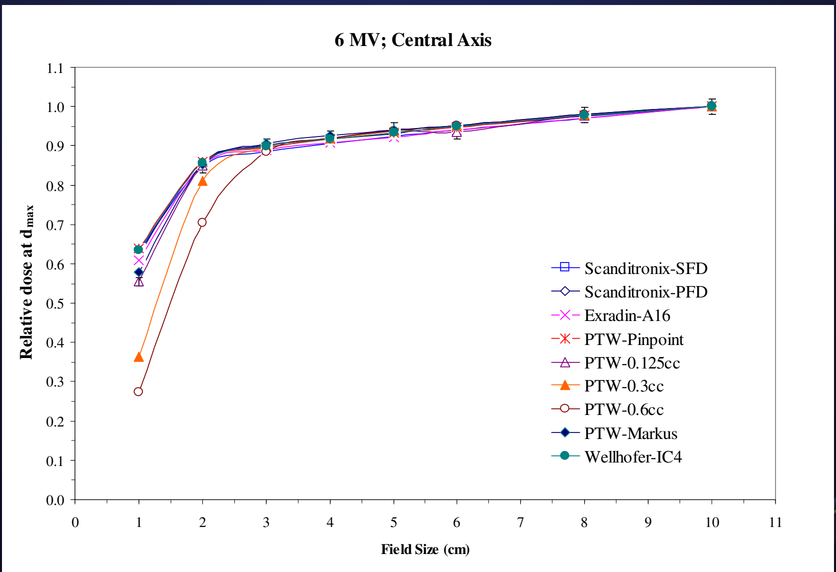
Photon Small Field Dosimetry



Electron Beam Measurements

- Scanning
  1. Depth dose
  2. Profiles
- Point dose
  1. Cone factors
  2. Cut-out factors
  3. Virtual source position

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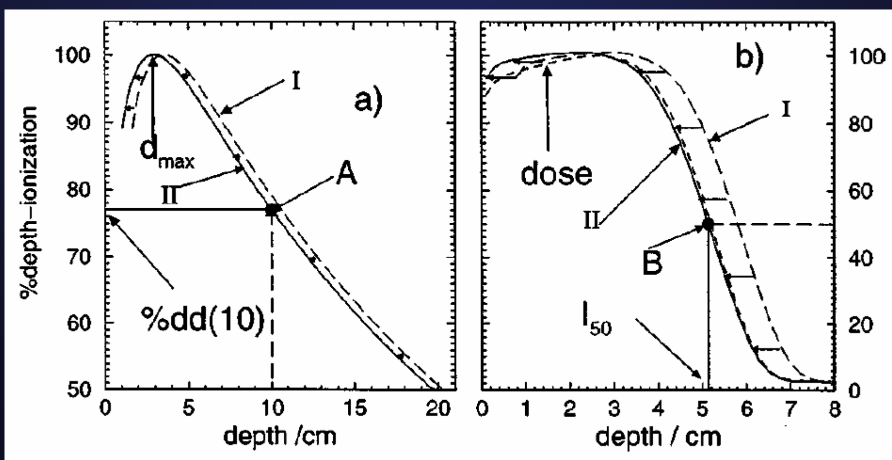
Electron Depth Dose



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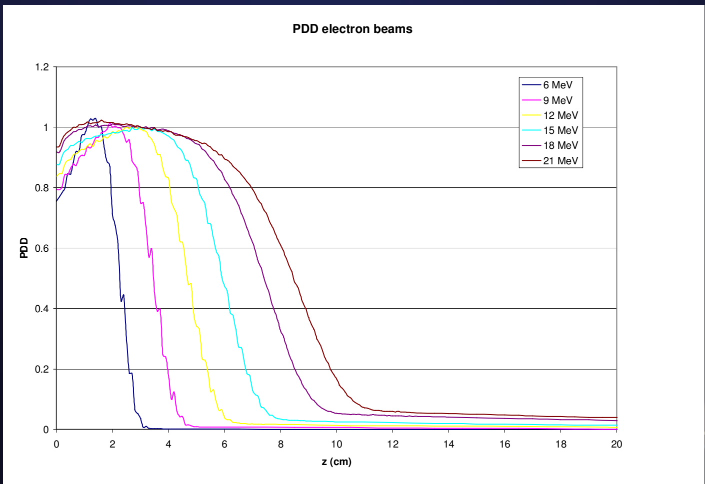
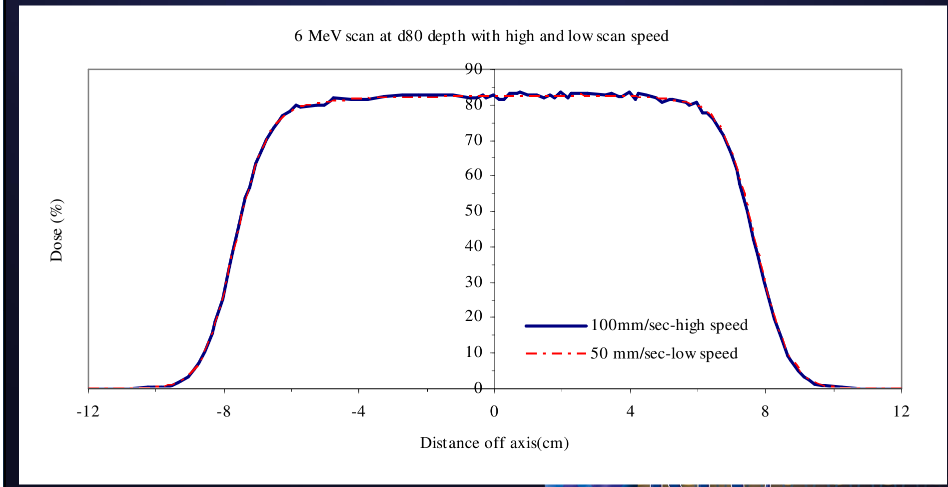
Electron Depth Dose

- Diodes are ideal due to small size
  - No ripples or wakes



Electron Profile Measurements



Cone and Cut-out Factors

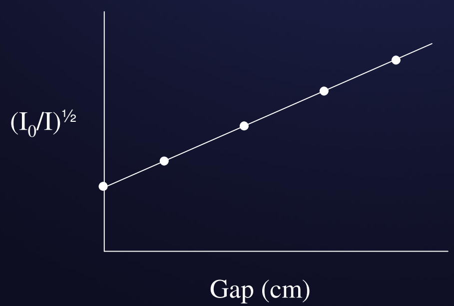
- Measured in water or solid phantom

$$CF = \frac{Rdg_{cone}(P_{repl})(L/p)}{Rdg_{refcone}(P_{repl})(L/p)}$$

- Prepare a table of cut-out factors

Virtual Source Position

- Gap method
  - Measurements at d_{max} for various air gaps



$$f = \frac{1}{slope} - dmax$$

Kahn technique

Commissioning Data Accuracy

Methods for Obtaining a Self-Consistent Dataset

• Design the measurements so that the data required to tie all the various separate measurements together are obtained during the same measurement session.

• Make measurements over the shortest time span possible consistent with obtaining representative dose measurements.

• Use the same equipment and procedures for all similar measurements.

• Use a reference chamber to account for output fluctuations when making measurements with a scanning ionization chamber.

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Commissioning

Methods for Obtaining a Self-Consistent Dataset

• Periodically repeat base measurements, such as the dose at 10 cm depth for a 10x10 cm2 field, to monitor the consistency of the machine output and the measuring system. Note that this may involve use of temperature equilibrated water and/or monitoring the barometric pressure, in certain situations.

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Recommendations

1. Define the scope of the data collection
2. Roughly calculate the time needed
3. Use proper detector
   - High sensitivity
   - Small dimensions
   - Low noise
   - No dose rate or energy dependence

Recommendations

4. Ion chambers with small volumes are preferred for relative dosimetry
5. Diodes are preferred for electron beam relative dosimetry
6. Verify labeling and positioning accuracy before measurements
7. Set optimal speed, time delay and acquisition time on scanner

Recommendations

8. Scan from deeper depth to surface for PDD
9. Adjust step size for optimum data collection
10. Maintain proper bias and polarity
11. Minimize amount of cable in beam
12. Orient detector to provide best resolution
13. Scrutinize data carefully
14. Write final report

Precautions

1. Do not rely on Manufacturers beam data
2. Do not rely on acceptance testing data
3. Do not scan in the axial direction of the detector
4. Do not over process (smooth) the data
5. Pay attention to the data collected
6. Check water level daily

Through data acquisition and TPS commissioning is laborious and necessary work. In the end, we don’t want any surprises …