Preface

Accelerator beam data commissioning equipment and procedures: Report of the TG-106 of the Therapy Physics Committee of the AAPM

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Med. Phys. 35(9), 4186-4214, 2008

Safety Reports Series No. 17

SAFETY REPORTS SERIES No. 17

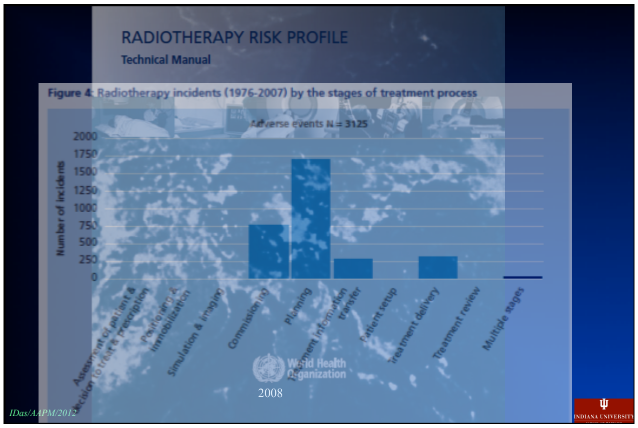
LESSONS LEARNED FROM ACCIDENTAL EXPOSURES IN RADIOTHERAPY

Event No. 25: Incorrect depth dose data

During installation of a linear accelerator, an institution contracted the services of the manufacturer to measure depth dose data. The institution's physicist later checked the data and found an 8% discrepancy between his measurements and those of the manufacturer for some field sizes and depths. He concluded that the manufacturer's data were correct and used them clinically. A review by an outside consultant physicist revealed that the physicist's measurements were correct. During a period of several months, some patients received doses that were 8% lower than prescribed.

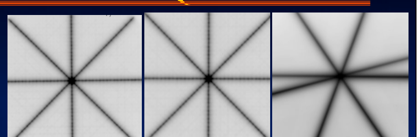
Initiating event

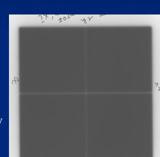
— Incorrect data for patient dose calculations: The manufacturer provided basic data that were incorrect for some field sizes and depths.



Mechanical QA

- Radiation Survey
- Mechanical tests
- Light radiation
- Table, Collimator, Gantry
- Jaws
- MLC
- Imaging parameters
- Other as TG-142





4Qudrant Independent Jaw Test

Planning for Commissioning Data

TABLE I. (a) Typical commissioning measurements for photon beam data for each energy and wedge. (b) Typical commissioning measurements for electron beam data for each energy.

(a)	Description	1	2	3	4	5	6	8	10	12	14	16	20	25	30	40	>40
		Square field size (cm)															
	Application	IMRT data			Traditional radiation oncology fields											Magna field	
Scan data	PDD/TMR	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	Profiles @ 5–7 depths	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	Diagonal or star profiles																
Nonscan data	S_c	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	S_{cp}	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	WF/TF				×	×	×	×	×	×	×	×	×	×	×		
	Surface dose	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×

(b)	Description	5×5	10×10	15×15	20×20	25×25
		Cone size (cm×cm)				
Scan data	PDD	×	×	×	×	×
	Profiles @ 5–7 depths	×	×	×	×	×
Nonscan data	Cone factor	×	×	×	×	×
	Cutout factor	×	×	×	×	×
	Virtual source	×	×	×	×	×
	Surface dose	×	×	×	×	×

Planning for Commissioning Time

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

$\sim 10^5$ s

~ 30 h

Rational For Commissioning Beam Data

First, it is no … near accelerators have produc … l use. For example, va … een beams with the same no…

Second, on- … nce of the user' s accel … s from beam steering will…

Third, the be … y moving jaws that depend … on at site could affect the be…

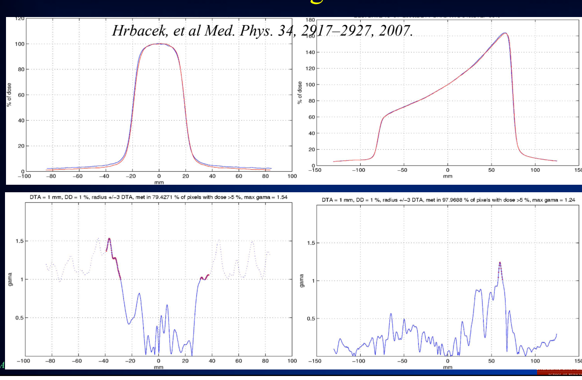
Fourth, alth … et may be found in individua … have multiple errors, which…

The following concerns should be carefully evaluated before the use of any golden beam data within a clinic. First, it is not evident that manufacturing procedures for all linear accelerators have produced a level of reproducibility acceptable for clinical use. For example, variations in beam parameters have been noted between beams with the same nominal energies.[3–5] Second, on-site changes made during installation and acceptance of the user's accelerator (e.g., changes in beam energy and/or profiles from beam steering) will not be modeled in the golden data. Third, the beam characteristics of the soft wedges are made by moving jaws that depend on the speed parameters of the jaws and a deviation at site could affect the beam profile of the soft wedge. Fourth, although acceptable agreement with the golden data set may be found in individual checks, it may be that some clinical setups will have multiple errors, which combine to produce unacceptable results. Finally, the commissioned beam data also provide a thorough check of the accelerator, which may uncover problems that may not otherwise be discovered with a mere spot check.

TG-106

Rational For Not Using Golden Data

Hrbacek, et al Med. Phys. 34, 2917–2927, 2007.



Rational For Not Using Golden Data

$$|x_i - \bar{x}| < \Delta, \ \forall x_i$$

Δ =? (0.5, 1.0 0r 2%)

For all practical purposes, based on the presented results, we suggest 2 mm DTA and 2% DD as a convenient criteria for γ analysis to be met when evaluating the agreement of profiles scanned in common dosimetrical conditions. Better results are attainable by employing different strategies coping with the imperfections of measurements.

It is our opinion that matched beams which do not meet the earlier suggested criteria should not be treated as clinically interchangeable.

Hrbacek, et al "Quantitative evaluation of a beam-matching procedure using one dimensional gamma analysis," Med. Phys. 34, 2917–2927, 2007.

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Medical Physics, 39(2), 569-572, 2012

POINT/COUNTERPOINT

Suggestions for topics suitable for these Point/Counterpoint debates should be addressed to Colin G. Orton, Professor Emeritus, Wayne State University, Detroit: ortonc@comcast.net. Persons participating in Point/Counterpoint discussions are selected for their knowledge and communicative skill. Their positions for or against a proposition may or may not reflect their personal opinions or the positions of their employers.

Vendor provided machine data should never be used as a substitute for fully commissioning a linear accelerator

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Colin G. Orton, Ph.D., Moderator

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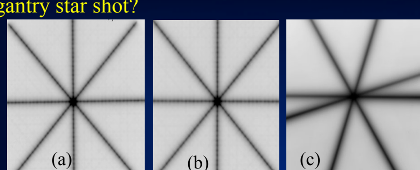
Question

Star shot provides isocentricity of accelerator parameters. Which one is gantry star shot?



2%	A. (a)
2%	B. (b)
79%	C. (c)
14%	D. (a) or (b)
4%	E. None

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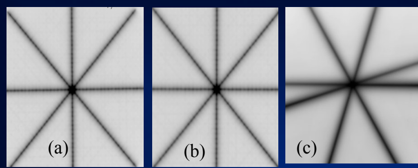
Question

Star shot provides isocentricity of accelerator parameters. Which one is gantry star shot?



A. (a)
B. (b)
C. (c)
D. (a) or (b)
E. None

Answer: C

Reference: Khan, Physics of Radiation Therapy, 2009

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Question

Time required for commissioning a dual energy linear accelerator with photon and electron beam is

0% A. 1 day
5% B. 3 days
42% C. 1 week
44% D. 4-6 weeks
9% E. 2 months

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Question

Time required for commissioning a dual energy linear accelerator with photon and electron beam is

A. 1 day
B. 3 days
C. 1 week
D. 4-6 weeks
E. 2 months

Answer: D

Reference: Das et al, TG-106, Med. Phys. 35(9), 4186-4214, 2008

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Definition of Detectors

- Standard chamber 10^{-1} cm^3—The active volume for a standard Farmer-type ionization chamber is on average 0.6 cm^3.
- Minichamber 10^{-2} cm^3—The active volume for a mini-ionization chamber is on average 0.05 cm^3.
- Microchamber 10^{-3} cm^3—The active volume for a microionization chamber is on average 0.007 cm^3 and ideally suited for small field dosimetry such as radiosurgery,gamma knife, CyberKnife, and IMRT

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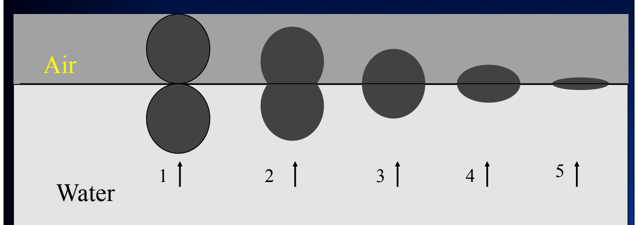
Setting Water Tank & Detector



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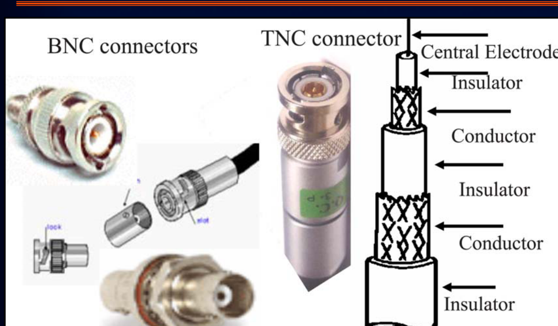
Know Your Connectors



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Understand Detector, Connector & Cable
Srivastava et al, SU-GG-T-270, 2010
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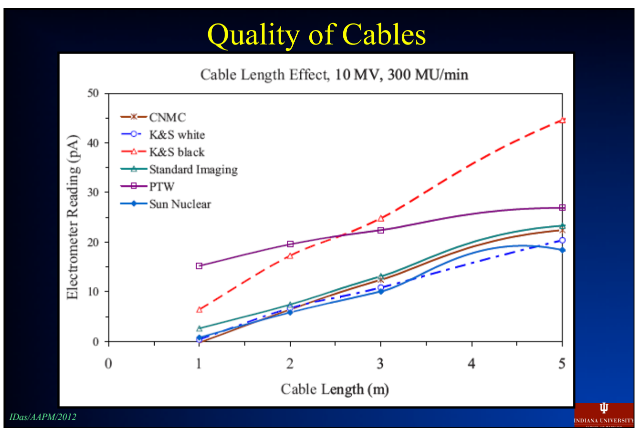
Quality of Cables
Cable Length Effect, 10 MV, 300 MU/min
CNMC
K&S white
K&S black
Standard Imaging
PTW
Sun Nuclear
Electrometer Reading (pA)
Cable Length (m)
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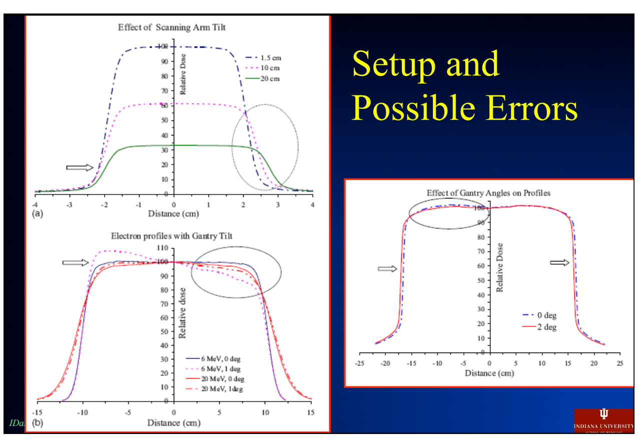
Setup and Possible Errors
Effect of Scanning Arm Tilt
1.5 cm
10 cm
20 cm
Relative Dose
Distance (cm)
(a)
Electron profiles with Gantry Tilt
6 MeV, 0 deg
6 MeV, 1 deg
20 MeV, 0 deg
20 MeV, 1deg
Relative dose
Distance (cm)
(b)
Effect of Gantry Angles on Profiles
0 deg
2 deg
Relative Dose
Distance (cm)
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Electrometer

- Null Setting
- Cable subtraction
- Proper bias
  - >300 V for ion chamber
  - 100 V for diamond
  - 0 v for all diodes
- Proper gain
- Proper mode

Question

High voltage is applied to ion chamber for?

(1) To reduce ion recombination; (2) To reduce polarity effect; (3) 100 volts; (4) 300-400 volts

15%	A.	1 only
15%	B.	1 and 2 only
0%	C.	1, 2 and 3 only
11%	D.	2 and 3 only
59%	E.	1 and 4 only

Question

High voltage is applied to ion chamber for?

(1) To reduce ion recombination; (2) To reduce polarity effect; (3) 100 volts; (4) 300-400 volts

A. 1 only
B. 1 and 2 only
C. 1, 2 and 3 only
D. 2 and 3 only
E. 1 and 4 only

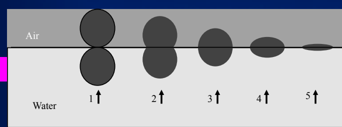
Answer: E

Reference: Das et al, TG-106, Med. Phys. 35(9), 4186-4214, 2008

Question

When setting ion chamber in water tank, the correct position of the chamber as viewed in water tank (as seen in figure) is:

- 2% 1. Position # 1
- 0% 2. Position # 2
- 89% 3. Position # 3
- 5% 4. Position # 4
- 4% 5. Position # 5

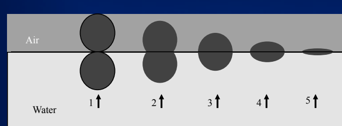


Reference: Das et al, TG-106, Med. Phys. 35(9), 4186-4214, 2008

Question

When setting ion chamber in water tank, the correct position of the chamber as viewed in water tank (as seen in figure) is:

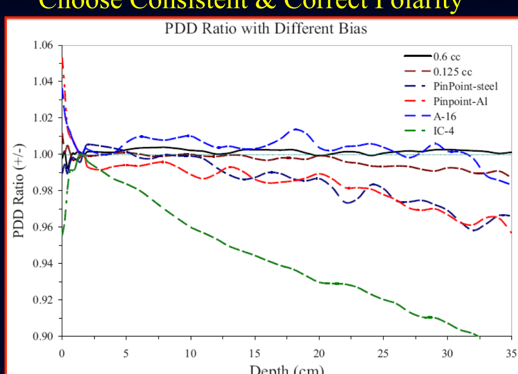
- A. Position # 1
- B. Position # 2
- C. Position # 3
- D. Position # 4
- E. Position # 5

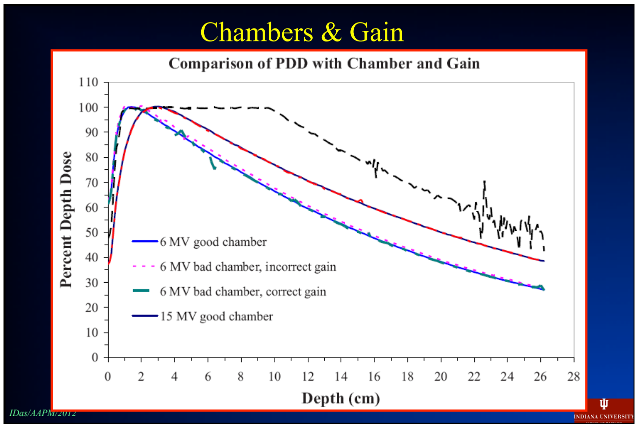


Answer: C

Reference: Das et al, TG-106, Med. Phys. 35(9), 4186-4214, 2008

Choose Consistent & Correct Polarity




Chambers & Gain
Comparison of PDD with Chamber and Gain
Percent Depth Dose
Depth (cm)
6 MV good chamber
6 MV bad chamber, incorrect gain
6 MV bad chamber, correct gain
15 MV good chamber
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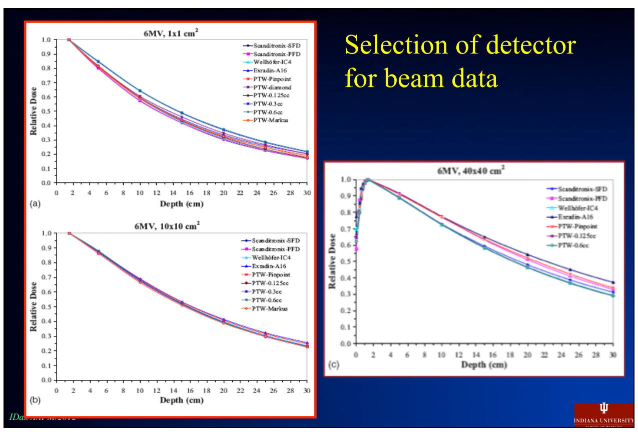
Selection of detector
for beam data
6MV, 1x1 cm²
6MV, 10x10 cm²
6MV, 40x40 cm²
Relative Dose
Depth (cm)
(a)
(b)
(c)
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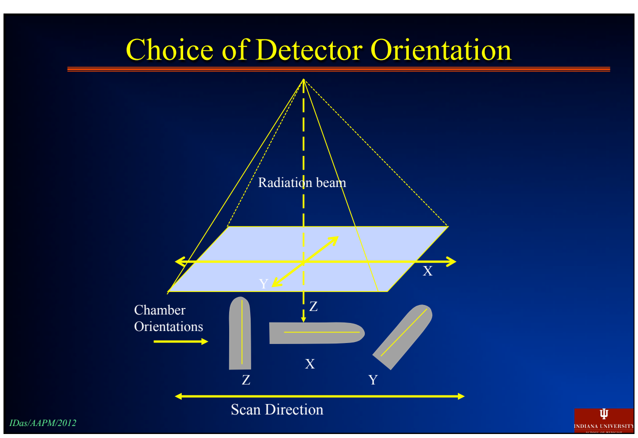
Choice of Detector Orientation
Radiation beam
X
Y
Z
Chamber
Orientations
Z
X
Y
Scan Direction
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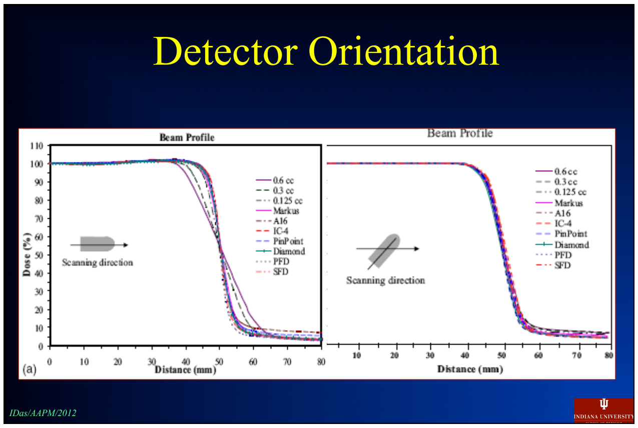
Detector Orientation
Beam Profile
Beam Profile
Dose (%)
Scanning direction
Scanning direction
Distance (mm)
Distance (mm)
0.6 cc
0.3 cc
0.125 cc
Markus
A16
IC-4
PinPoint
Diamond
PFD
SFD
(a)
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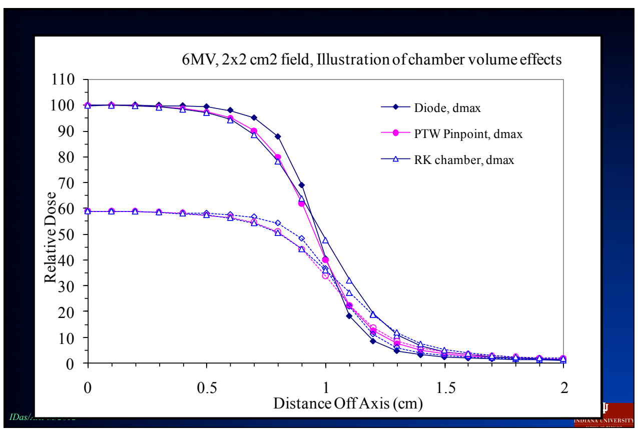
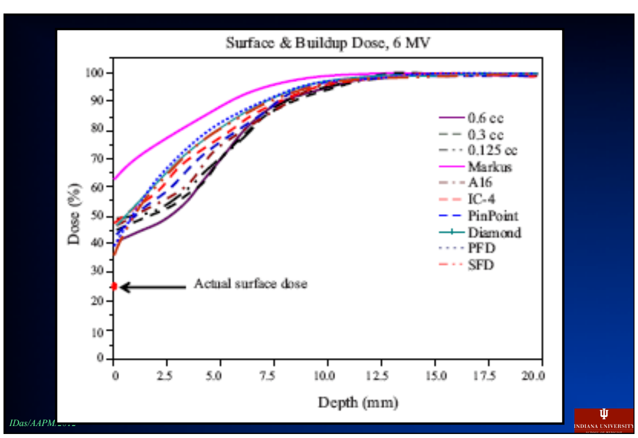
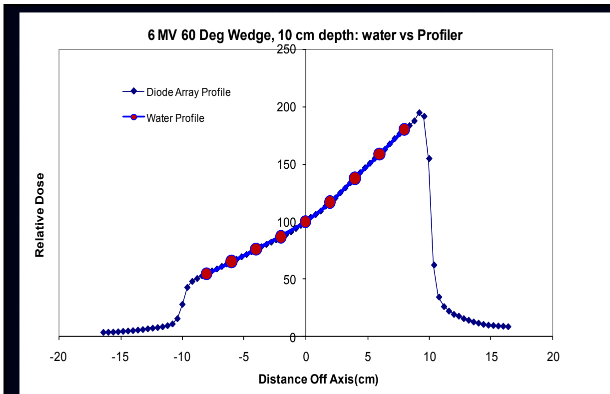
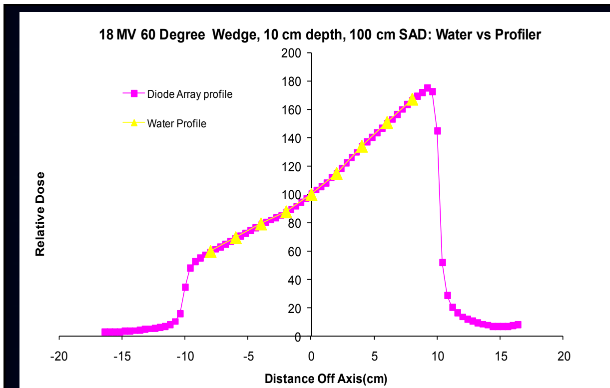

6MV, 2x2 cm2 field, Illustration of chamber volume effects
Relative Dose
Distance Off Axis (cm)
Diode, dmax
PTW Pinpoint, dmax
RK chamber, dmax


Surface & Buildup Dose, 6 MV
Dose (%)
Depth (mm)
Actual surface dose
0.6 cc
0.3 cc
0.125 cc
Markus
A16
IC-4
PinPoint
Diamond
PFD
SFD





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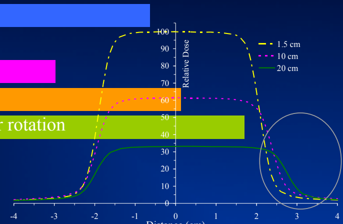
Question

The possible setup error that causes the photon beam dose profile in figure is due to:

- 25% A. Gantry tilt
- 0% B. Collimator rotation
- 19% C. Tank arm tilt
- 26% D. Gantry and arm tilt
- 30% E. Gantry tilt, collimator rotation and tank arm tilt



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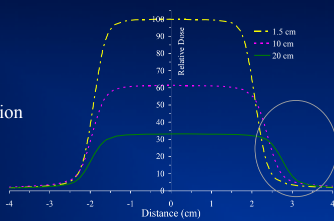
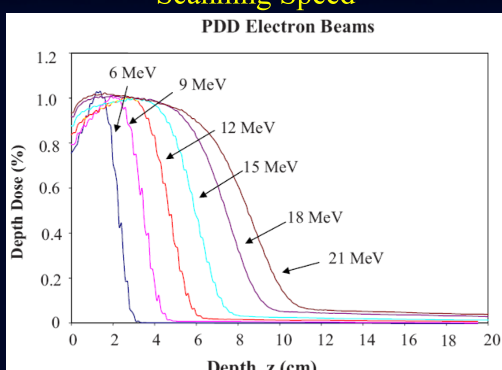
C. Tank arm tilt
D. Gantry and arm tilt
E. Gantry tilt, collimator rotation and tank arm tilt



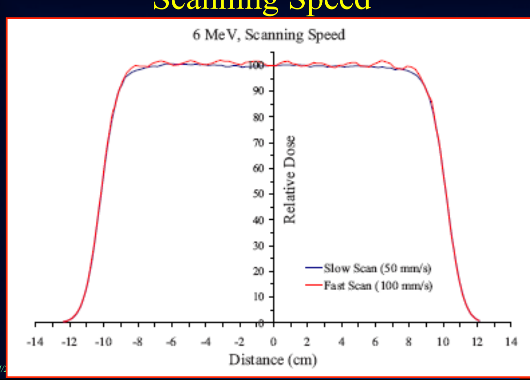
Answer: D

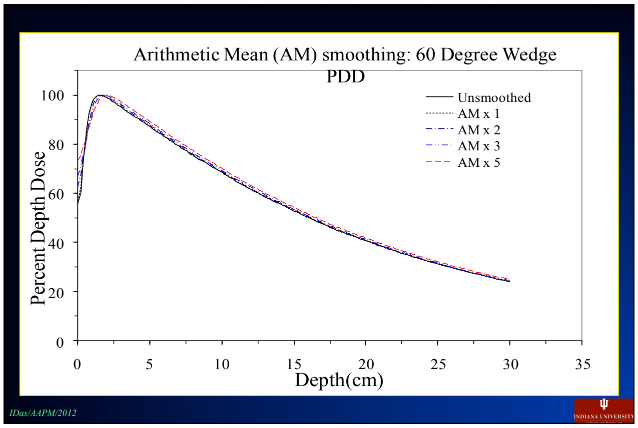
Reference: Das et al, TG-106, Med. Phys. 35(9), 4186-4214, 2008

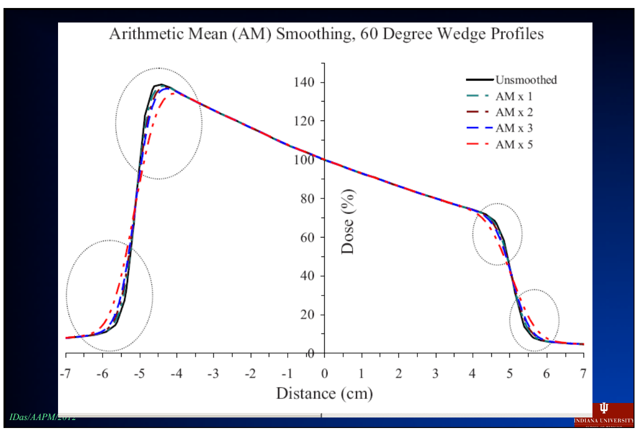
Scanning Speed



Scanning Speed

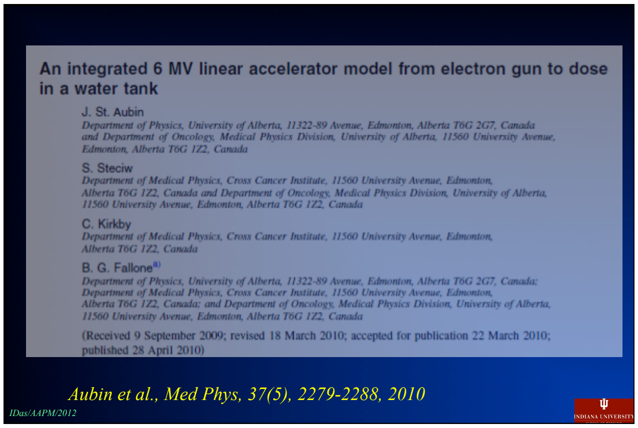






Future of Beam Data Commissioning

- ❖ Standardization of linear accelerators
- ❖ Monte Carlo based commissioning
- ❖ Newer Radiation Detectors & Cables
- ❖ Newer Scanning Systems
- ❖ Smart algorithms



An integrated 6 MV linear accelerator model from electron gun to dose in a water tank

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(Received 9 September 2009; revised 18 March 2010; accepted for publication 22 March 2010; published 28 April 2010)

Aubin et al., Med Phys, 37(5), 2279-2288, 2010

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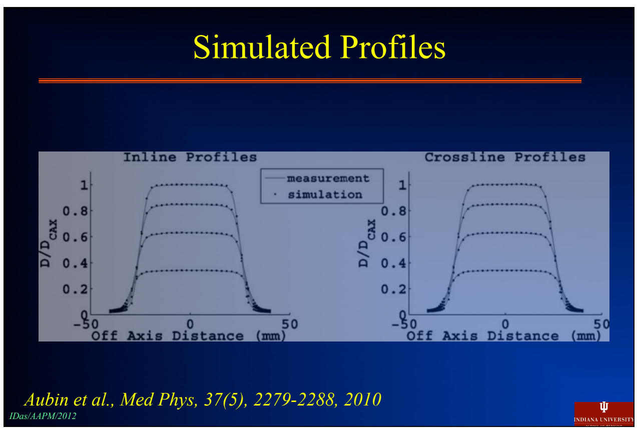
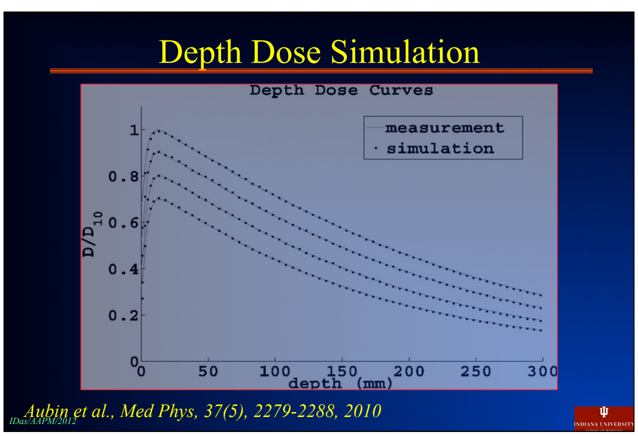
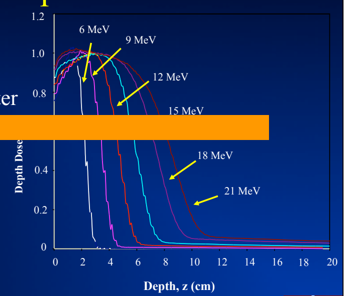




Question

Electron beam depth doses shown in figure represents the problem of

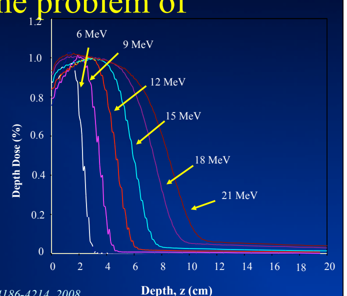
- 4% 1. Noise in the cable
- 2% 2. Electrometer gain
- 4% 3. Bias on the electrometer
- 91% 4. Speed of scanning
- 0% 5. Tuning of accelerator



Question

Electron beam depth doses shown in figure represents the problem of

A. Noise in the cable
B. Electrometer gain
C. Bias on the electrometer
D. Speed of scanning
E. Tuning of accelerator



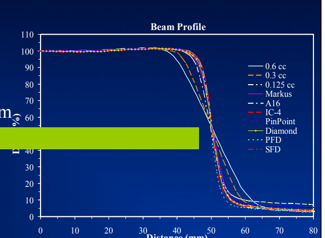
Answer: D

Reference: Das et al, TG-106, Med. Phys. 35(9), 4186-4214, 2008

Question

Photon beam dose profiles taken with various detectors as shown in figure is possibly due to:

- 2% A. Speed of scanning
- 0% B. Beam asymmetry
- 0% C. Pb piece in the beam
- 2% D. Hysteresis of scanning system
- 97% E. Orientation of scanning detector



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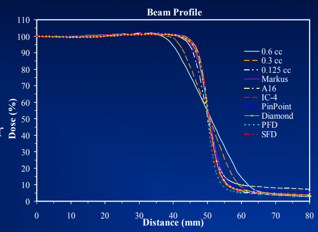
D. Hysteresis of scanning system
E. Orientation of scanning detector



Answer: E

Reference: Das et al, TG-106, Med. Phys. 35(9), 4186-4214, 2008

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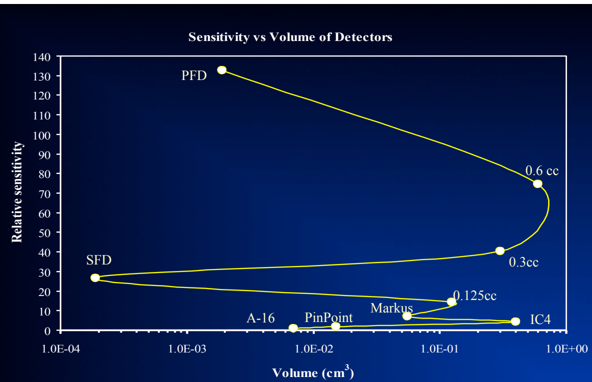

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Treatment Fields

Magna-Fields

200x200 cm²

Traditional Fields

40x40 cm² ⟷ 4x4 cm²

Advance Therapy Fields
- SRS/SRT
- Gamma Knife
- Cyber-Knife
- Tomotherapy
- IMRT

Small Field

4x4 cm² ⟷ 0.3x0.3 cm²

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What is a Small Field?

- Lack of charged particle
  - Dependent on the range of secondary electrons
  - Photon energy
- Collimator setting that obstructs the source size
- Detector is comparable to the field size

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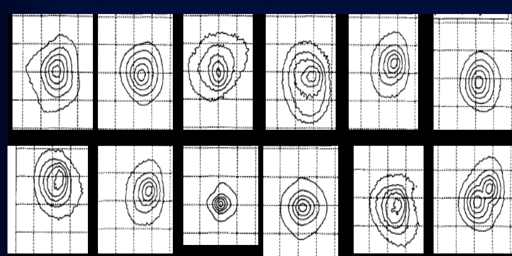
Views of Source Sizes



*Jaffray et al, Med Phys **20**, 1417-1427 (1993).*

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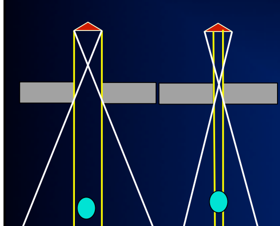
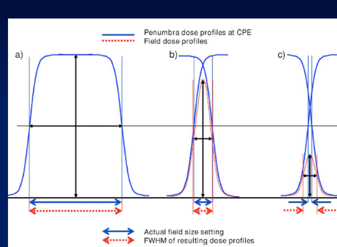
Definition of Small Fields





Das et al, Med. Phys. 35, 206-215, 2008

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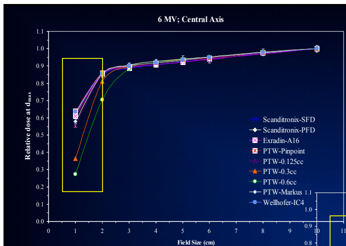
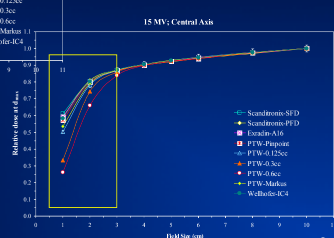
Dosimetry

- Absolute
  - Dose
- Relative
  - Depth Dose [D(r,d)/D(r,dm)]
  - TMR
  - Profiles
  - Output, S_{cp} (total scatter factor), [D(r)/D(ref)]



Field Size Limit for Accurate Dose Measurements with Available Detectors



Das et al, TG-106, Med Phys, 35, 4186, 2008

Relative Dosimetry

$$D^{f_{msr}}_{w,Q_{msr}} = M^{f_{msr}}_{Q_{msr}} N_{DW,Q_o} k_{Q,Q_o} k^{f_{msr},f_{ref}}_{Q_{msr},Q}$$

$$\Omega^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}} = \frac{M^{f_{clin}}_{Q_{clin}}}{M^{f_{msr}}_{Q_{msr}}}\left[\frac{\left(D^{f_{clin}}_{w,Q_{clin}}\right)/\left(M^{f_{clin}}_{Q_{clin}}\right)}{\left(D^{f_{msr}}_{w,Q_{msr}}\right)/\left(M^{f_{msr}}_{Q_{msr}}\right)}\right] = \frac{M^{f_{clin}}_{Q_{clin}}}{M^{f_{msr}}_{Q_{msr}}} k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$$

$$k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}} = \frac{\left(D^{f_{msr}}_{w,Q_{clin}}\right)/\left(M^{f_{clin}}_{w,Q_{clin}}\right)}{\left(D^{f_{clin}}_{w,Q_{msr}}\right)/\left(M^{f_{clin}}_{w,Q_{msr}}\right)} = \frac{(Output)_{rel}}{(\mathrm{Re}\,ading)_{rel}}$$

$$k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}} = \frac{\left(S_{w,air}\right)_{fclin}\cdot P_{fclin}}{\left(S_{w,air}\right)_{fmsr}\cdot P_{msr}}$$

New Data on Correction Factor

TABLE III. Ratio of detector readings $M^{f_{clin}}_{Q_{clin}} / M^{f_{msr}}_{Q_{msr}}$ and correction factors $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$ for the 5, 7.5, and 10 mm fields. Corresponding uncertainties at 68% level are shown in parentheses, indicating the uncertainty in the final one or two digits.

Detector	5 mm $M^{f_{clin}}_{Q_{clin}} / M^{f_{msr}}_{Q_{msr}}$	5 mm $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$	7.5 mm $M^{f_{clin}}_{Q_{clin}} / M^{f_{msr}}_{Q_{msr}}$	7.5 mm $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$	10 mm $M^{f_{clin}}_{Q_{clin}} / M^{f_{msr}}_{Q_{msr}}$	10 mm $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$
A16	0.626 (15)	1.089 (3)	0.811 (10)	1.018 (3)	0.866 (6)	1.010 (3)
PinPoint	0.620 (17)	1.101 (3)	0.801 (7)	1.024 (3)	0.862 (5)	1.015 (3)
Diode 60008	0.726 (1)	0.943 (3)	0.873 (1)	0.949 (3)	0.912 (1)	0.964 (3)
Diode 60012	0.705 (1)	0.956 (3)	0.847 (2)	0.966 (3)	0.891 (1)	0.978 (3)
EDGE	0.726 (1)	0.948 (3)	0.864 (1)	0.955 (3)	0.906 (1)	0.966 (3)
Alanine	0.544 (8)	1.249 (8)	0.785 (12)	1.059 (4)	0.855 (13)	1.019 (3)
TLD	0.668 (4)	⋯	0.809 (6)	⋯	0.880 (8)	⋯
EBT films	0.659 (17)	⋯	0.811 (16)	⋯	0.853 (18)	⋯
Polymer gels[a]	0.702 (21)	⋯	0.872 (27)	⋯	0.929 (29)	⋯

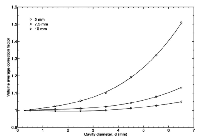


FIG. 5. Volume averaging correction factors, calculated using 3D polymer gel dosimetry results (Ref. 6) and assuming cylindrical detectors of 2.5 mm height and varying cavity diameter for the 5, 7.5, and 10 mm fixed collimator beams at 800 mm SDD. The uncertainty of the presented results is of the order of 4% and the solid lines correspond to weighted least square regression fit results. In the absence of all other measurement perturbations, these data correspond to $k^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$ values.

TABLE IV. Output factors $\Omega^{f_{clin},f_{msr}}_{Q_{clin},Q_{msr}}$ for the 5, 7.5, 10, and 15 mm fields, after correction factors are applied at all field sizes except 15 mm, as shown in Table III. Corresponding uncertainties at 68% level are shown in parentheses indicating the uncertainty in the final one or two digits.

Detector	5 mm	7.5 mm	10 mm	15 mm
A16	0.682 (17)	0.825 (10)	0.874 (7)	0.939 (3)
PinPoint	0.683 (18)	0.820 (8)	0.875 (5)	0.939 (2)
Diode 60008	0.684 (2)	0.829 (3)	0.879 (3)	0.960 (1)
Diode 60012	0.674 (2)	0.818 (3)	0.872 (3)	0.949 (1)
EDGE	0.689 (2)	0.825 (3)	0.875 (3)	0.956 (1)
Alanine	0.679 (11)	0.831 (13)	0.872 (13)	0.945 (14)
TLD	0.668 (4)	0.809 (6)	0.880 (8)	0.941 (7)
EBT films	0.659 (17)	0.811 (16)	0.853 (18)	0.935 (20)
Polymer gels[a]	0.702 (21)	0.872 (27)	0.929 (29)	⋯
Weighted mean	0.681 (1)	0.824 (1)	0.875 (1)	0.954 (1)

Pantelis et al, Med Phys, 37(6), 2369-2378, 2010

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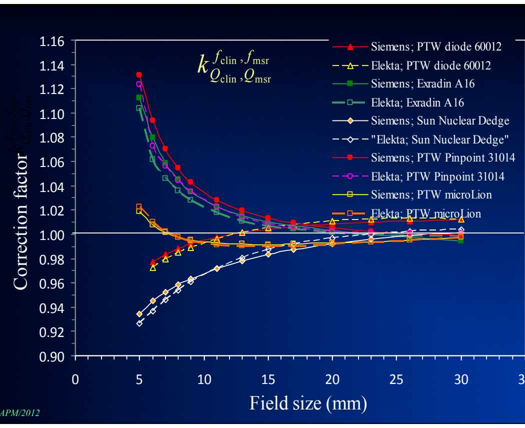

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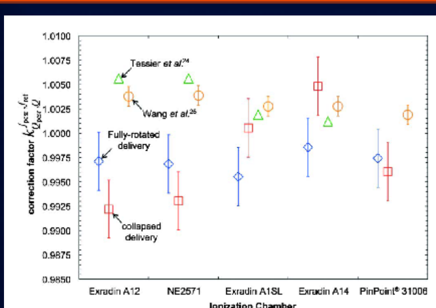
New Data on Correction Factor



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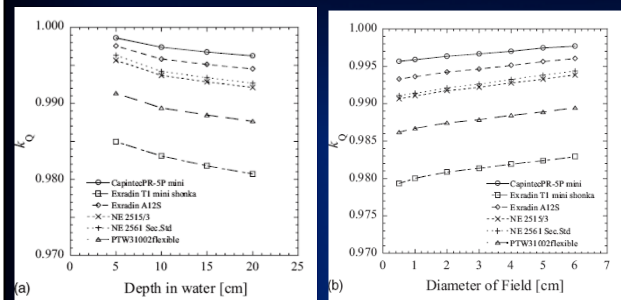
Chung et al, Med Phys, 37(6), 2404-2413, 2010

k_Q is not Constant in Small Field



Kawachi et al, Med Phys, 35, 4591-4598, 2008

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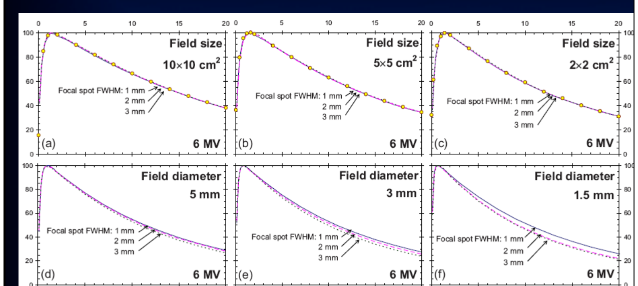
Depth Dose & Source Size



Sham et al, Med Phys, 35, 3317-3330, 2008

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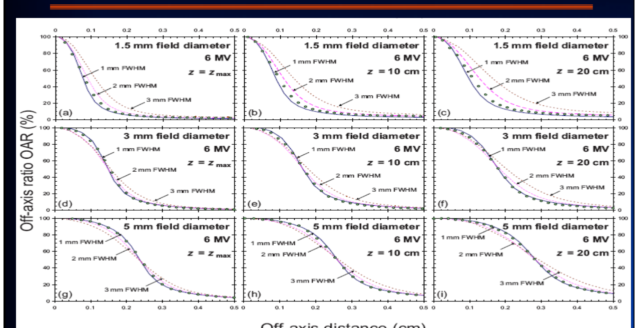
Profile & Source Size



Sham et al, Med Phys, 35, 3317-3330, 2008

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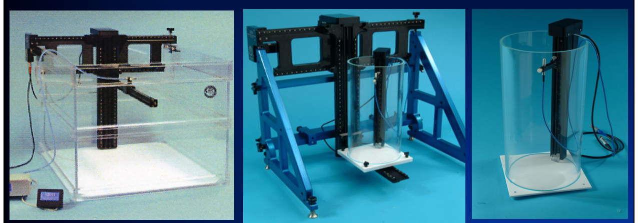
Comparison of Large Tank and Small SRS Cylinder Tank for SRS, TMR & Profiles

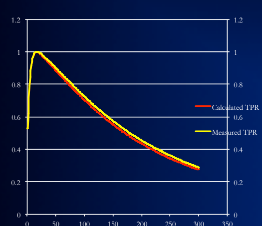


Moving Tank System for TMR

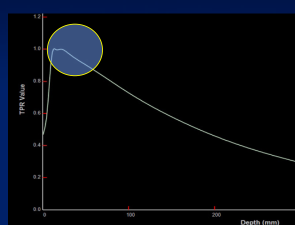
ARM Inc., Port Saint Lucie, FL 34983

Direct TMR Data Acquisition

No SSD to SAD calculations required, No cubic spline fit of a limited number of fixed data points needed



Calculated TPR ˜2% less at depth



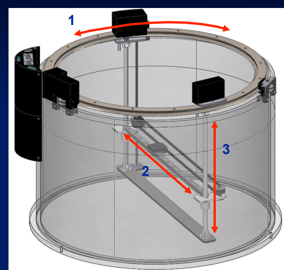
Cubic spline fit of 12 data points

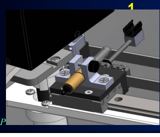
Nikesch et al, CyberKnife Center , Palm Beach, FL

3D Scanner (Sun Nuclear)

- Setup Subjectivity
  - Automatic leveling, water surface detection and beam center detection
  - No tank shifts
- Detector orientation/resolution
  - 3D Scanner design always using the short dimension of chamber to scan
- Time
  - Setup is faster and more accurate
  - No tank shifts
  - Smaller tank fills and drains faster

Sun Nuclear 3D Scanner





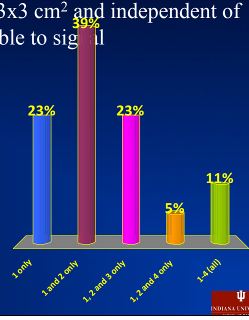
1. Ring drive maintains consistent scanning direction
2. Diameter drive has maximum scanning range of 640mm
3. Vertical drive has maximum travel of 400mm

Question

What is a Small Field?

(1) Lack of charged particle equilibrium; (2)Collimator setting that obstructs the source size; (3) Fields <3x3 cm^2 and independent of beam energy; (4) Leakage is comparable to signal

A. 1 only
B. 1 and 2 only
C. 1, 2 and 3 only
D. 1, 2 and 4 only
E. 1-4 (all)



Question

What is a Small Field?

(1) Lack of charged particle equilibrium; (2)Collimator setting that obstructs the source size; (3) Fields <3x3 cm^2 and independent of beam energy; (4) Leakage is comparable to signal

A. 1 only
B. 1 and 2 only
C. 1, 2 and 3 only
D. 1, 2 and 4 only
E. 1-4 (all)

Answer: B

Reference: Das et al, Med. Phys. 35, 206-215, 2008

Question

What is $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$?

- 17% A. Defined in TG-51 for chamber correction factor
- 46% B. Defined in noncompliant TG-51 dosimetry for correcting reading to actual dose
- 33% C. Conversion factor from K_Q to Dose
- 0% D. Used in dynamic and Arc therapy dose calculation
- 4% E. Used primarily in Tomotherapy dosimetry

Question

What is $k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$?

A. Defined in TG-51 for chamber correction factor

B. Defined in noncompliant TG-51 dosimetry for correcting reading to actual dose

C. Conversion factor from K_Q to Dose

D. Used in dynamic and Arc therapy dose calculation

E. Used primarily in Tomotherapy dosimetry

Answer: B

Reference: Alfonso, et al. Med Phys ***35****, 5179-5186 (2008)*

Conclusions

- Golden Data should be taken as a reference only
- Understand time and amount of data to be taken
- View each parameters properly, double check by another individual
- Use proper detector for each type of data collection
- Set optimum speed for scanning, do not rush

-Conclusions

- Understand the limits and measuring condition
- Question every unusual data set
- Do not smooth data too much
- Write report for future reference
- Future technology & resources could help commissioning simpler