TPS COMMISSIONING

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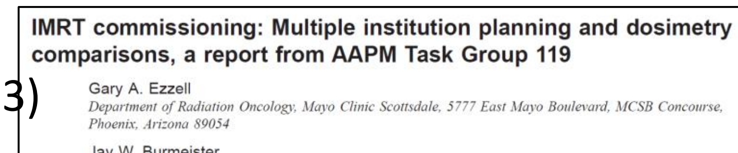
Conflicts of interest

- Court receives funding from NIH, CPIRT, Varian and Elekta

Resources – your first task is to understand the algorithm and commissioning measurements

- Manufacturer manuals (Varian, Elekta,….)
- Khan, Physics of Radiation Therapy and similar
- IAEA reports
- AAPM MPPG5, TG106, TG119 and others (e.g. TG53)



Introduction

Commissioning

- “bring (something newly produced, such as a factory or machine) into working condition”
- Acceptance
- Commissioning
  - Collect data about the treatment device – functionality and beam data – and import into the TPS
  - Create a calculation model
  - Verify that everything works correctly
    - Dose calculations
    - Other functionality

Importance of correct TPS commissioning

- Quality of Plan delivery depends on the accuracy that the RTP system models the linac dosimetric characteristics
- Clinical outcomes depend on dose delivered which in turn depends on how accurately the RTP was benchmarked against the linac commissioning data

An incident from the Lessons learned from Accidental Exposures in radiotherapy, IAEA

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.

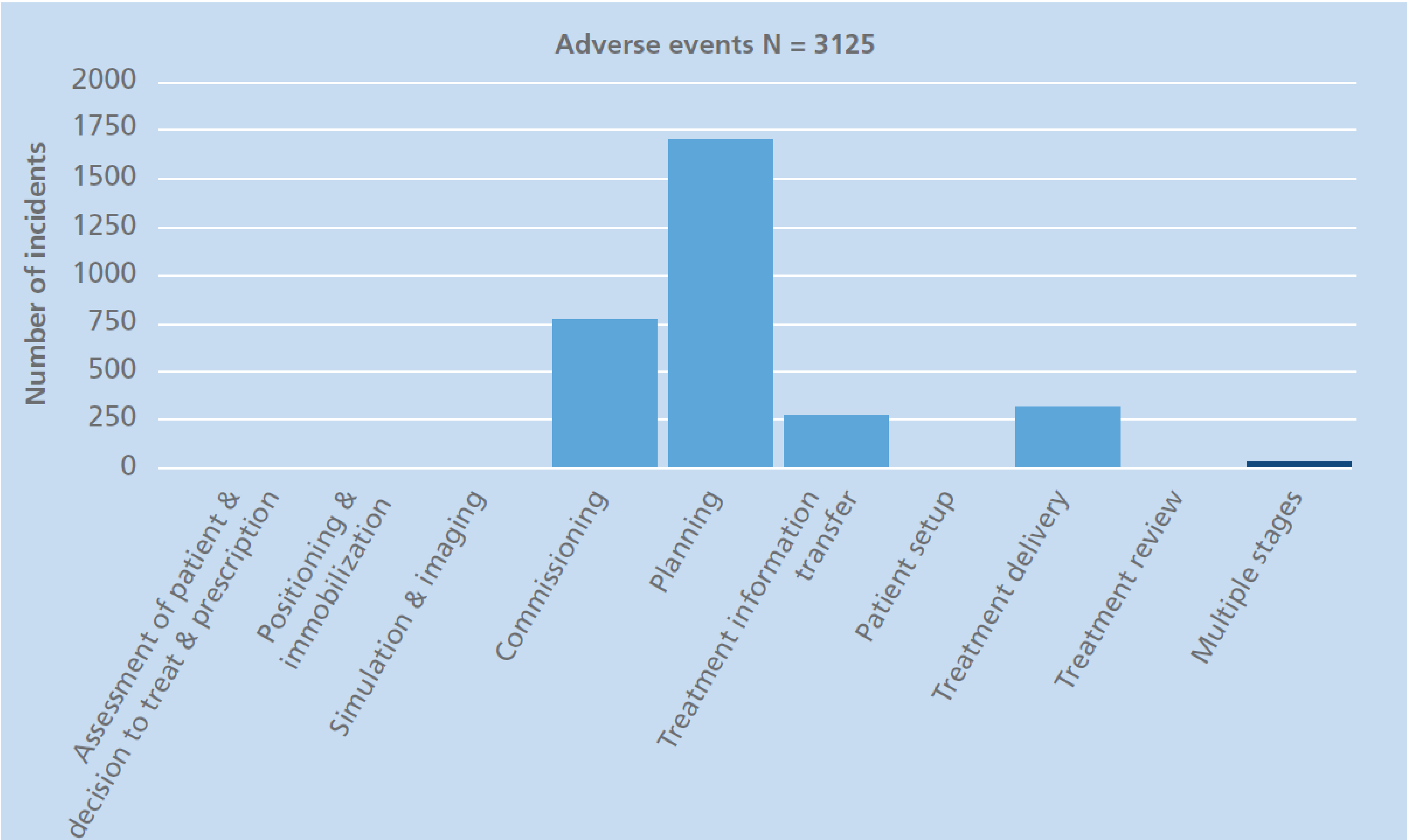
Contributing factors

— Lack of or ineffective procedures, protocols and documentation: Incorrect commissioning (data generated by the manufacturer were accepted for treatments, although the institution's physicist found an 8% discrepancy when he compared these data with his measurements).

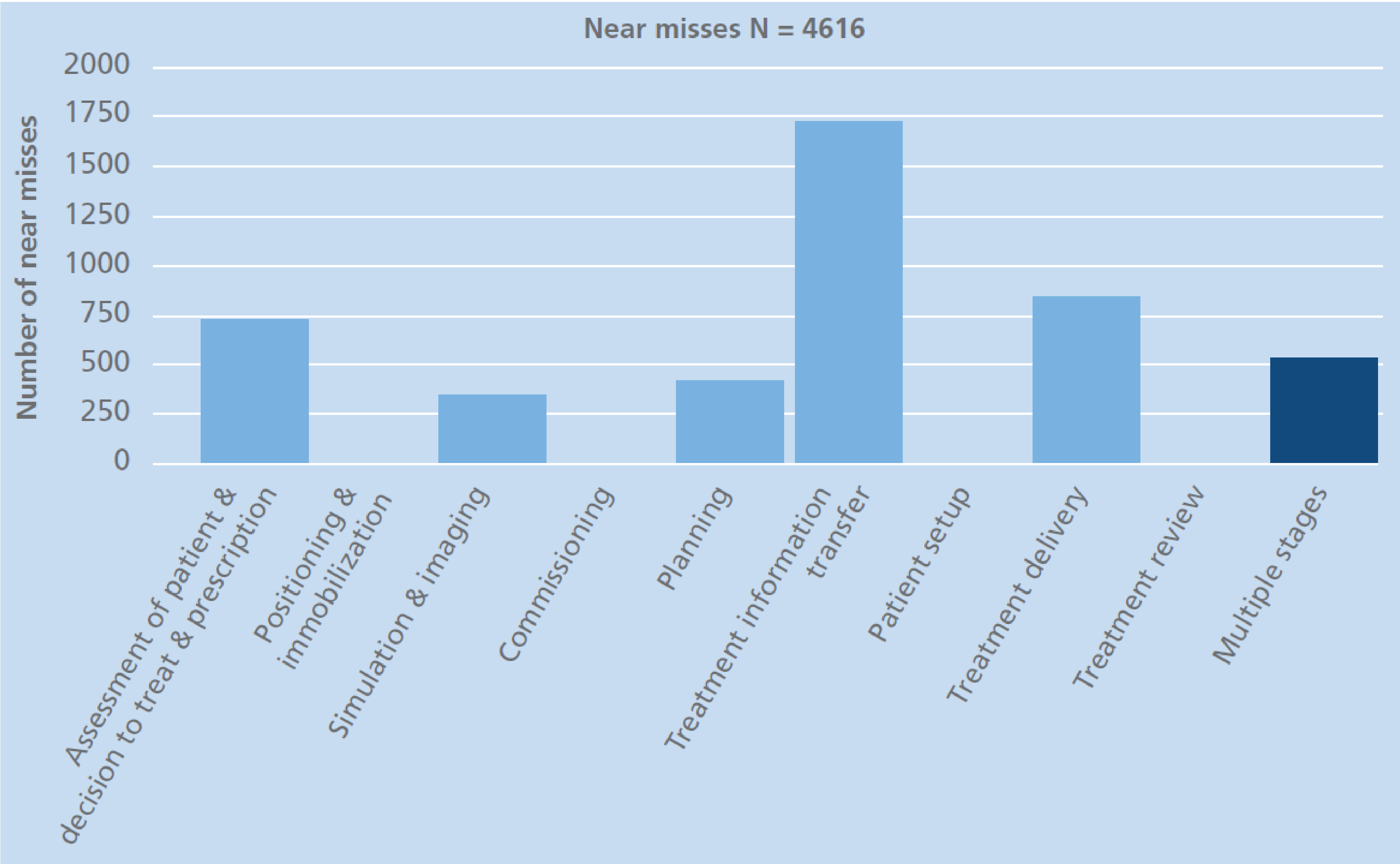
— Insufficient education, training or expertise: A known discrepancy was not resolved.

— Lack of or ineffective assignment of responsibilities: The physicist did not take responsibility for all aspects of dosimetry.

Figure 4: Radiotherapy incidents (1976-2007) by the stages of treatment process



From: World Health Organization, Radiotherapy Risk Profile, 2008



Near misses N = 4616
Number of near misses
2000
1750
1500
1250
1000
750
500
250
0
Assessment of patient & decision to treat & prescription
Positioning & immobilization
Simulation & imaging
Commissioning
Planning
Treatment information transfer
Patient setup
Treatment delivery
Treatment review
Multiple stages

Acceptance Testing

(happens before commissioning)

Acceptance Testing

- Acceptance testing is performed by the physicist to ensure that the machine meets the product specifications and the purchase agreement.
- These tests are conducted according to the acceptance testing procedure agreed on between the manufacturer's representative and the facility physicist.
- They can include a lot of functionality tests (can you calculate dose)
- They do not mean that the system is ready do use, or ready to correctly calculate patient doses
- After Acceptance, detailed beam data is needed to characterize the beam

TABLE 2-2. Acceptance Test Features

Topic	Tests
CT input	Create an anatomical description based on a standard set of CT scans provided by the vendor, in the format which will be employed by the user.
Anatomical description	Create a patient model based on the standard CT data discussed above. Contour the external surface, internal anatomy, etc. Create 3-D objects and display.
Beam description	Verify that all beam technique functions work, using a standard beam description provided by the vendor.
Photon beam dose calculations	Perform dose calculations for a standard photon beam dataset. Tests should include various open fields, different SSDs, blocked fields, MLC-shaped fields, inhomogeneity test cases, multi-beam plans, asymmetric jaw fields, wedged fields, and others.
Electron beam dose calculations	Perform a set of dose calculations for a standard electron beam dataset. Include open fields, different SSDs, shaped fields, inhomogeneity test cases, surface irregularity test cases, and others.
Brachytherapy dose calculations	Perform dose calculations for single sources of each type, as well as several multi-source implant calculations, including standard implant techniques such as a GYN insertion with tandem and ovoids, two-plane breast implant, etc.
Dose display, dose volume histograms	Display dose calculation results. Use a standard dose distribution provided by the vendor to verify that the DVH code works as described. User-created dose distributions may also be used for additional tests.
Hardcopy output	Print out all hardcopy documentation for a given series of plans, and confirm that all textual and graphical information is output correctly.

AAPM TG53

Example acceptance tests (Eclipse)

Specification

The Anisotropic Analytical Algorithm (AAA) Algorithm is properly installed and licensed.

The dose distribution can be calculated and evaluated in 2D and 3D. Treatment time (MU) can be calculated.

Test Method

1. If required, open the Eclipse CAP Phantom (ID: CAP-0001, Series1, CT_PDC)
2. Load RT Plan '**AAA_VARIAN**', '**AAA_VARIANTB**', '**AAA_ELEKTA**', '**AAA_SMNS_PRIM**', '**AAA_SMNS_ART**' or '**AAA_ELEK_AGL**' into the active view.
3. Define prescription and plan parameters per **Table 7**.
4. When defining prescription parameters, acknowledge any information message relating to Reference Point Workspace, no action is required in this particular case.
5. Calculate the 3D dose.
6. From the '**Field Properties**' form in the Focus Window, select the '**Calculation**' tab and review detailed information regarding algorithm and algorithm version used during the test.

Table 7: Section 3.3 - Anisotropic Analytical Algorithm (AAA)

Prescription\Plan Parameter	Value
Primary Reference Point [Volume]:	Ref #1 [Body]
Number of Fractions:	1
Prescribed Dose per Fraction:	1 [Gy] 100[cGy]
Prescribed %	100%
Normalization	100% at Primary Reference Point
Photon Volume Dose Calculation Model	AAA calculation model created during preparations for IPA

Data Table: Section 3.3 - Anisotropic Analytical Algorithm (AAA)		
Calculation Model Configuration	**Specification**	**√ = OK**
Algorithm configured for calculation model	AAA	
Algorithm version configured for calculation model	Verify algorithm is latest version available within DCF [7]	
Varian Clinac	**Specification**	**√ = OK**
Field MU	95 +/- 1	
3D Dose Max	119.8% +/- 1%	
Varian Clinac test not applicable or customer accepts testing against TrueBeam only		
Varian TrueBeam Linac	**Specification**	**√ = OK**
Field MU	101 +/- 1	
3D Dose Max	120.0% +/- 1%	
Varian TrueBeam test not applicable or customer accepts testing against C-Series only		
Elekta Linac	**Specification**	**√ = OK**
Field MU	93 +/- 1	
3D Dose Max	107.7% +/- 1%	
Elekta Linac test not applicable or customer accepts testing against Agility only		
Siemens Primus Linac	**Specification**	**√ = OK**
Field MU	94.5+/- 1	
3D Dose Max	120.1% +/- 1%	
Siemens Primus Linac test not applicable or customer accepts testing against ARTISTE only		
Siemens ARTISTE Linac	**Specification**	**√ = OK**
Field MU	105.4 +/- 1	
3D Dose Max	118.0% +/- 1%	
Siemens ARTISTE test not applicable or customer accepts testing against Primus only		
Elekta Agility Linac	**Specification**	**√ = OK**
Field MU	101+/- 1	
3D Dose Max	118.0% +/- 1%	
Elekta Agility Linac test not applicable or customer accepts testing against SL 20 only		
Eclipse IPA data not used\Add-On Workstation		
Customer Demo Required	☒ New Installation ☒ Add On System ☒ Major Upgrade ☒ MR Client ☒ MR DCF	

Example Eclipse acceptance checklist

Example linac acceptance test

- Photon Energy (100 SSD, 10x10 fs, depth of 10 cm in water)
  - Deviation from stated value ± 3%, ± 3 mm

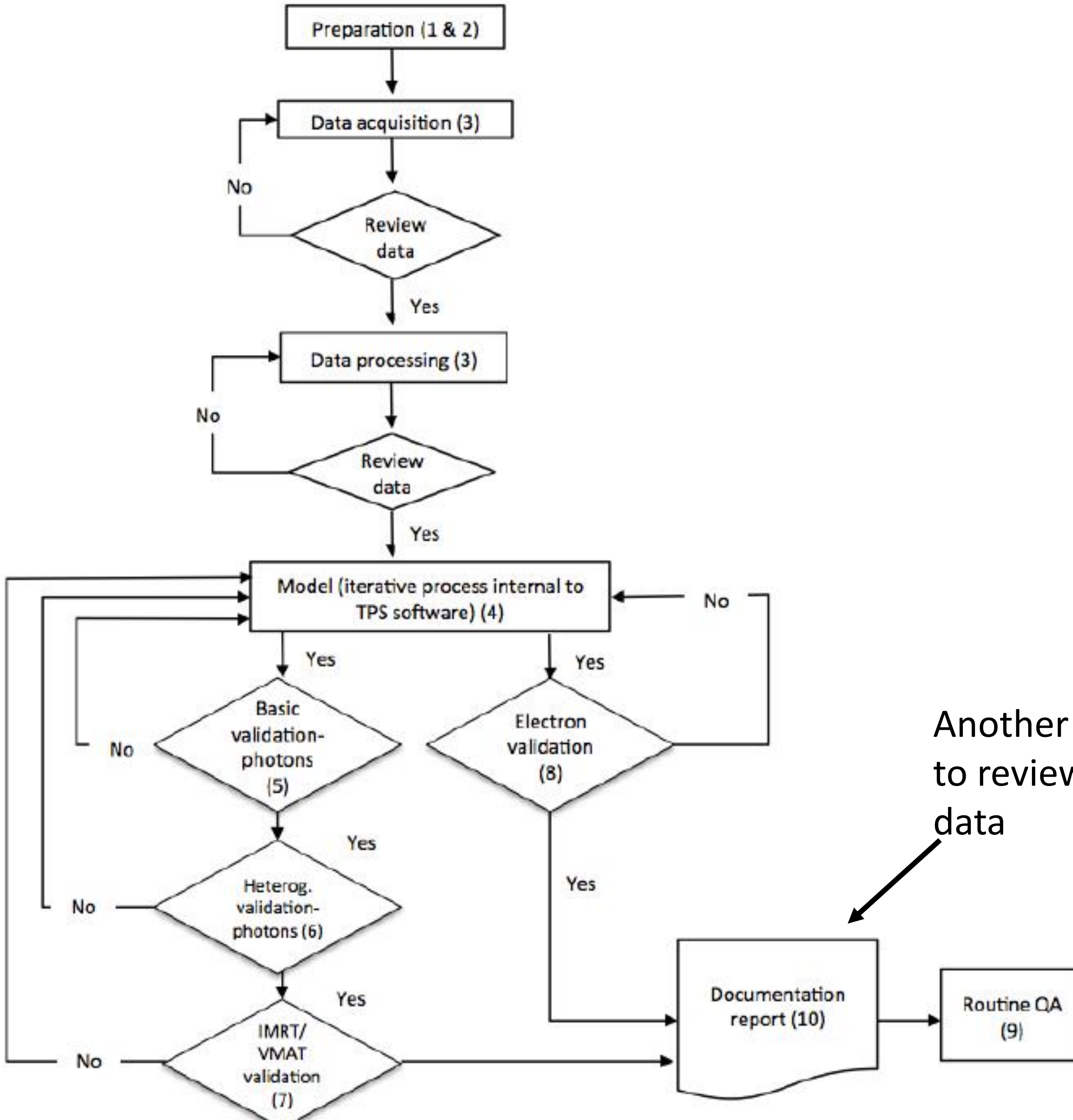
TABLE 5.4.1 PERCENTAGE DEPTH DOSES: 100 cm SSD

Side of square field (cm)	4	5	6	7	8	9	10	12	15	20	25	30	35	40
NPSF	0.979	0.983	0.987	0.990	0.994	0.997	1.000	1.006	1.013	1.023	1.029	1.033	1.037	1.040
Depth (cm)														
1.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2.0	98.5	98.6	98.7	98.7	98.8	98.8	98.8	98.8	98.7	98.6	98.6	98.7	98.7	98.7
3.0	94.3	94.5	94.7	94.9	95.0	95.1	95.1	95.2	95.2	95.3	95.3	95.4	95.4	95.5
4.0	89.6	89.9	90.2	90.5	90.7	90.9	91.0	91.2	91.4	91.5	91.7	91.9	92.0	92.1
5.0	84.6	85.2	85.7	86.1	86.4	86.7	86.9	87.2	87.5	87.9	88.2	88.5	88.7	88.8
6.0	79.9	80.6	81.2	81.7	82.1	82.5	82.8	83.2	83.7	84.2	84.6	85.0	85.3	85.5
7.0	75.4	76.2	76.8	77.5	78.0	78.4	78.8	79.3	79.9	80.7	81.2	81.6	81.9	82.2
8.0	71.0	71.9	72.7	73.4	74.0	74.5	74.9	75.6	76.3	77.1	77.7	78.2	78.6	78.9
9.0	66.9	67.8	68.7	69.4	70.1	70.6	71.1	71.9	72.7	73.7	74.4	75.0	75.4	75.7
10.0	63.0	64.0	64.9	65.7	66.4	67.0	67.5	68.4	69.3	70.4	71.1	71.7	72.2	72.5
11.0	59.3	60.3	61.3	62.1	62.8	63.5	64.0	65.0	66.0	67.2	68.0	68.6	69.1	69.5
12.0	55.8	56.9	57.8	58.7	59.4	60.1	60.7	61.7	62.8	64.1	65.0	65.7	66.2	66.6
13.0	52.6	53.7	54.6	55.5	56.3	57.0	57.6	58.6	59.8	61.2	62.1	62.8	63.4	63.8
14.0	49.5	50.6	51.6	52.4	53.2	53.9	54.5	55.6	56.8	58.2	59.2	59.9	60.5	61.0
15.0	46.7	47.7	48.7	49.5	50.3	51.0	51.7	52.8	54.0	55.5	56.5	57.3	57.9	58.4
16.0	43.9	44.9	45.9	46.7	47.5	48.2	48.9	50.0	51.3	52.8	53.9	54.7	55.3	55.8
17.0	41.3	42.3	43.3	44.2	45.0	45.7	46.3	47.4	48.7	50.3	51.4	52.3	52.9	53.4
18.0	38.9	39.9	40.9	41.7	42.5	43.2	43.8	44.9	46.2	47.9	49.0	49.9	50.5	51.0
19.0	36.7	37.6	38.6	39.4	40.2	40.9	41.5	42.6	43.9	45.6	46.7	47.6	48.2	48.7
20.0	34.6	35.5	36.4	37.2	38.0	38.7	39.3	40.4	41.7	43.4	44.5	45.4	46.0	46.5
21.0	32.6	33.5	34.4	35.2	35.9	36.6	37.2	38.3	39.6	41.3	42.4	43.3	43.9	44.4
22.0	30.7	31.6	32.4	33.2	33.9	34.6	35.2	36.3	37.6	39.3	40.4	41.3	41.9	42.4
23.0	28.9	29.8	30.6	31.4	32.1	32.7	33.3	34.4	35.7	37.3	38.5	39.4	40.0	40.5
24.0	27.3	28.2	29.0	29.7	30.4	31.0	31.6	32.6	33.9	35.5	36.7	37.6	38.2	38.7
25.0	25.7	26.6	27.3	28.1	28.7	29.3	29.9	30.9	32.2	33.8	35.0	35.8	36.5	37.0

Commissioning process

AAPM MEDICAL PHYSICS PRACTICE GUIDELINE # 5: Commissioning and QA of Treatment Planning Dose Calculations: Megavoltage Photon and Electron Beams

- “practice guidelines”
- summary of what the AAPM considers prudent practice for what a clinical medical physics should do with respect to dose algorithm commissioning and validation
- Goals:
  - Summarize the minimum requirements for TPS dose algorithm commissioning (including validation) and QA in a clinical setting
  - Provide guidance on typical achievable tolerances and evaluation criteria for clinical implementation



Another chance to review the data

Figure from MPPG5a

Machine description data

Use forms and guidelines from the TPS manufacturer when available

10 **Physics Data Worksheets**

The worksheets in this section provide checklists for the physics data required by the Pinnacle³ treatment planning system.

The machine description worksheets list the physical description information required for the machines. These worksheets duplicate portions of the physics tool windows into which the data must be entered. Details on the machine physical description information can be found in the **Physical Machine Characteristics** chapter of the *Pinnacle³ Physics Reference Guide*.

The measured data worksheets summarize the measured data required for each treatment modality. These worksheets can be used as checklists when measuring machine data to make sure that you measure all of the data required for each modality. Detailed descriptions of the measured data requirements can be found in the chapters of this manual that cover each modality. The worksheets list the data which must be collected for each measurement geometry for each energy on every machine.

Make as many copies of the worksheets as necessary.

Table 13 Distance Values for Different Treatment Unit Types Defined in the Machine Data Library

	Varian	Elekta	ElektaBM	Elekta Agility MLC 160	Siemens
Distance of second source from target [mm]	125	158	151.5	159	94.6
Distance of Y-jaw top surface from target [mm]	280	431	376	432	197
Distance of Y-jaw bottom surface from target [mm]	358	509	468	509	275
Distance of X-jaw top surface from target [mm]	367	396	479.9	309	283
Distance of X-jaw bottom surface from target [mm]	445	426	522.7	401.8	359
Distance of MLC from target [mm]	509	336	425.3	349.3	283

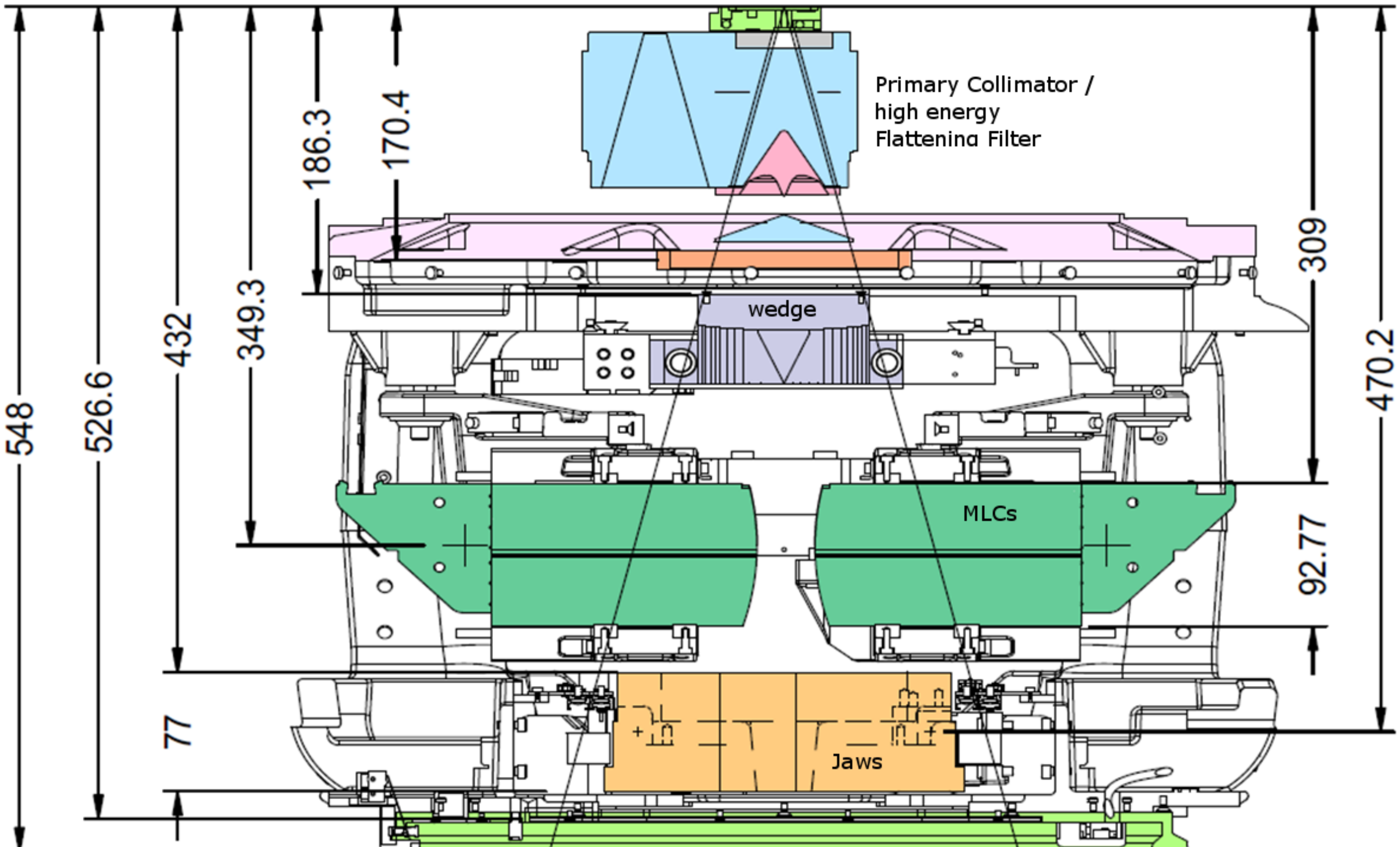
From: Eclipse photon and electron algorithm guide 13.6

Table 66 Treatment Unit Parameters and Limits

General Parameters				
Source axis distance				
Source phantom distance				
Collimator skin distance				
No. of wedges and wedge codes	Code 1	Code 2	Code 3	Code 4
Gantry Parameters				
Angle of minimum rotation				
Direction of the increase	Clockwise/Counterclockwise			
Start angle in CW direction				
Stop angle in CW direction				
Collimator Parameters				
Angle of minimum rotation				
Direction of the increase	Clockwise/Counterclockwise			
Start angle in CW direction				
Stop angle in CW direction				
	FX		FY	
Field edge, X direction				
Field edge, Y direction				
	X1/Y1		X2/Y2	
Jaw labels, X direction				
Jaw labels, Y direction				
	Up	Down	Left	Right
Wedge direction labels				
Allowed wedge directions	Up/down/left/right			

Agility BLD

- Agility is the Head of the linac, that contains all of the BLDs



Elekta Agililty BLD, from Elekta Clinical Mode Instructions for Use

10.2 Machine information - couch & collimator angles

Physicist: ______________________ Date: ______________

Machine name: ______________________________________

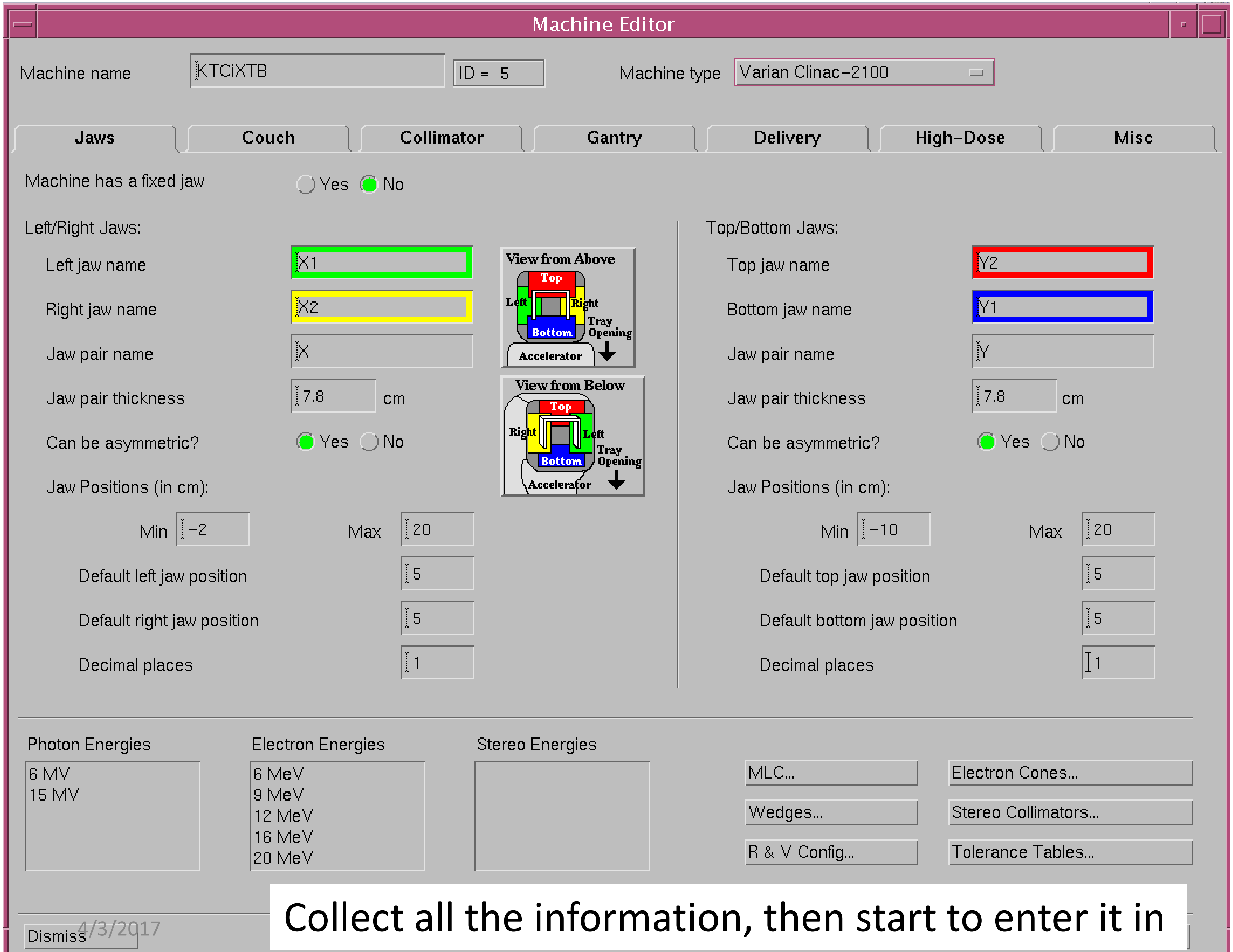
Couch angle information

Setting	Value
Minimum angle	
Maximum angle	
Default angle	
Decimal places	
Couch angle when foot of table points away from gantry	
When viewed from above, is positive rotation clockwise?	

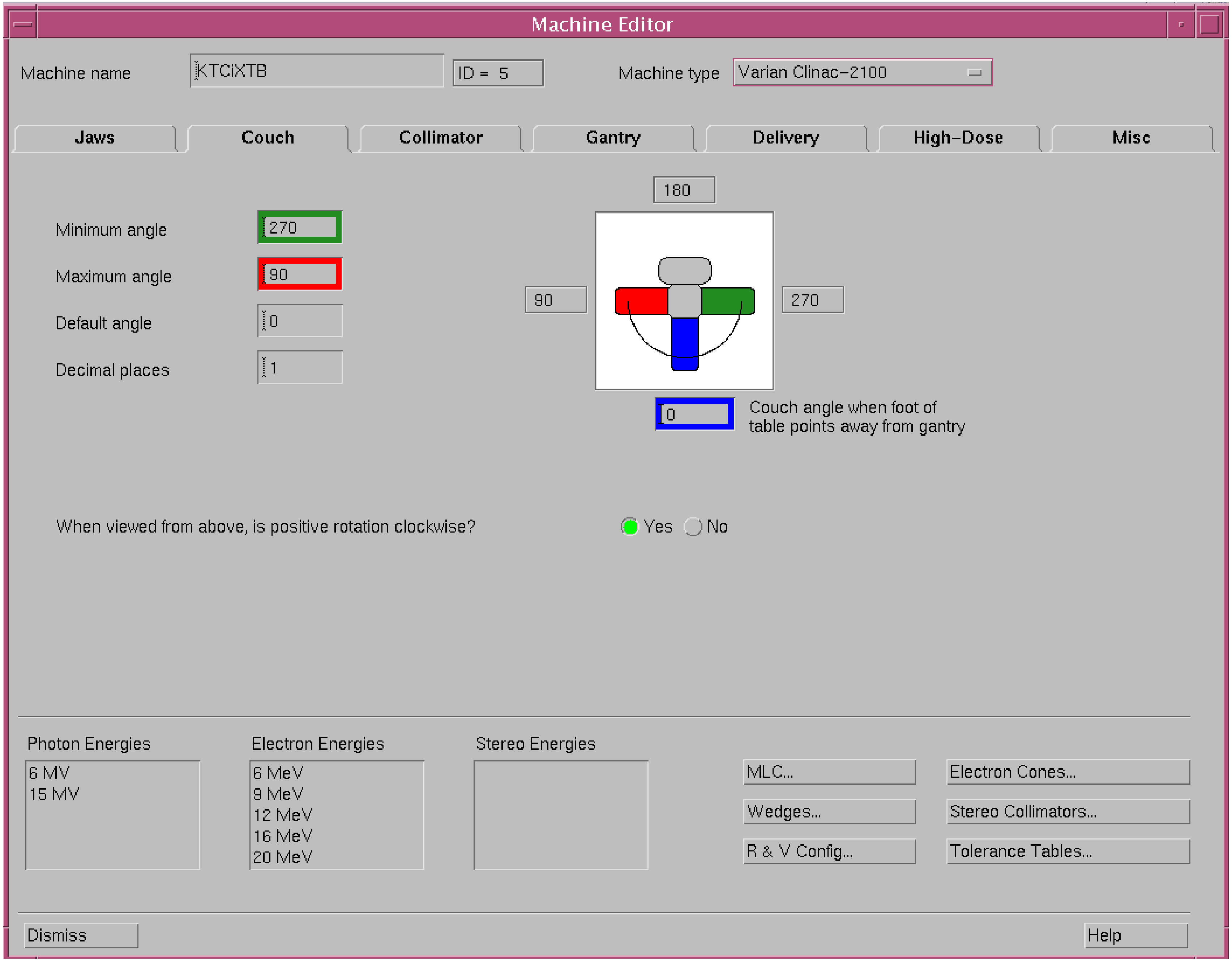
Collimator angle information

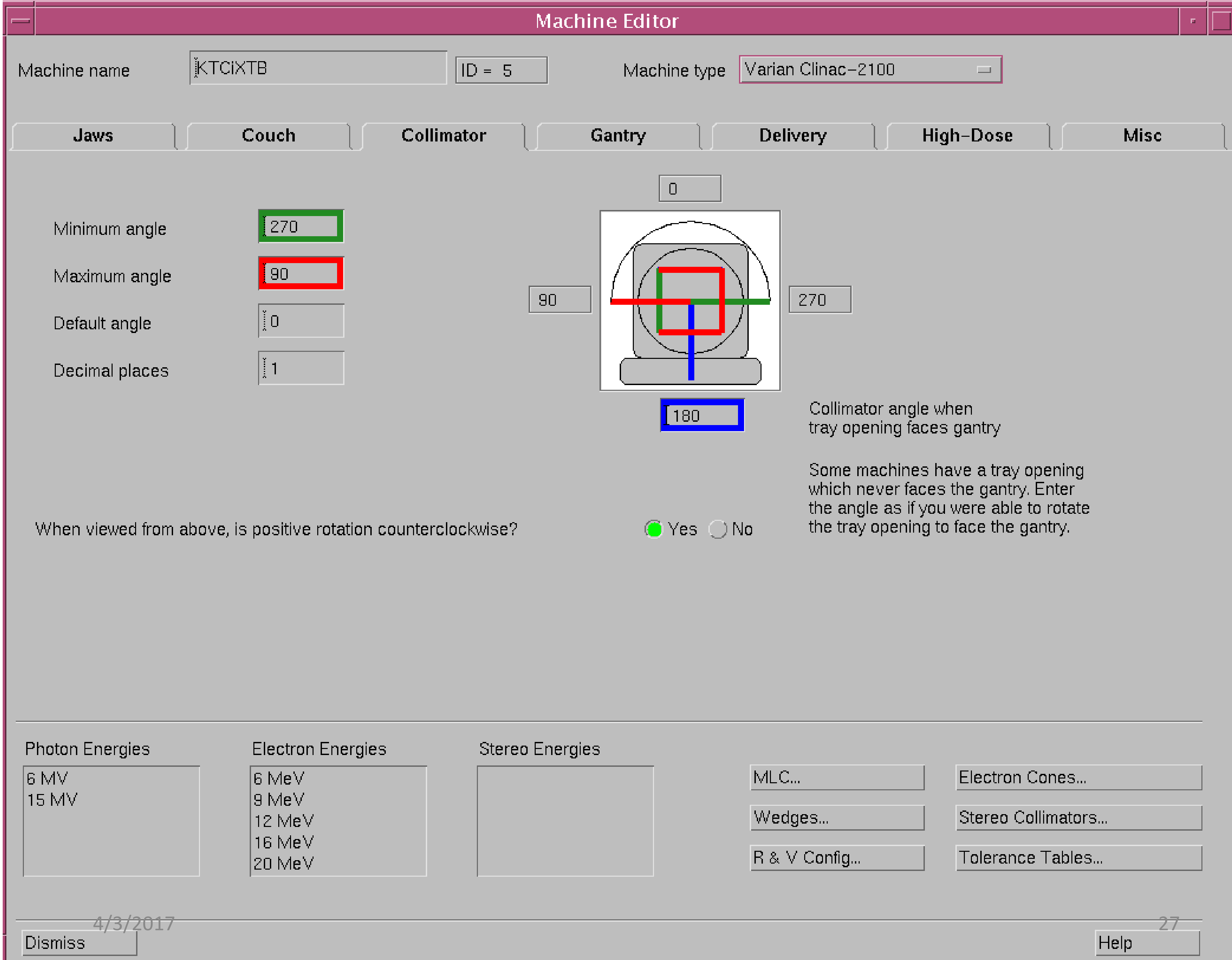
Setting	Value
Minimum angle	
Maximum angle	
Default angle	
Decimal places	
Collimator angle when tray opening faces gantry*	
When viewed from above, is positive rotation counterclockwise?	

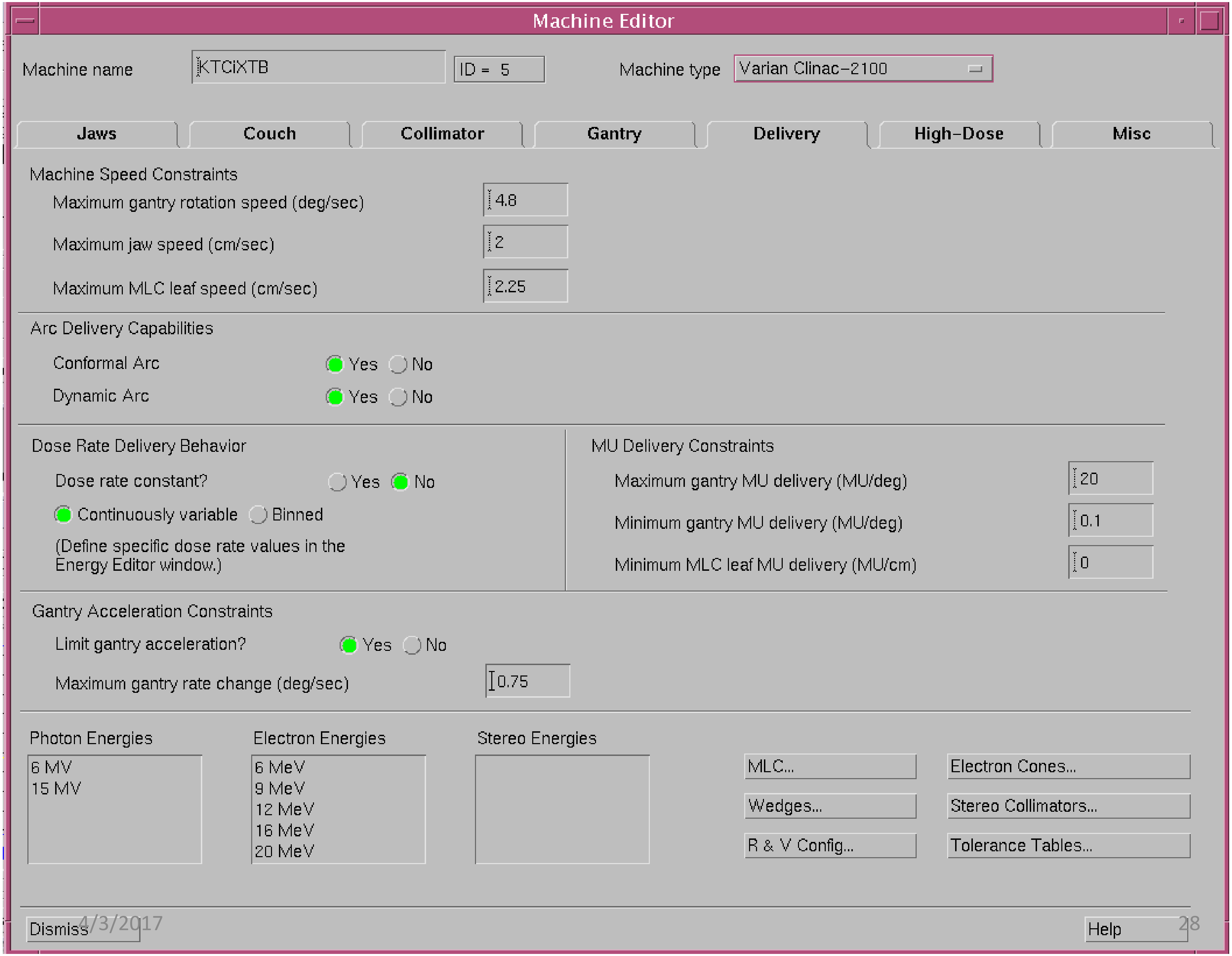
*Some machines have a tray opening that never faces the gantry. Enter the angle as if you were able to rotate the tray opening to face the gantry.

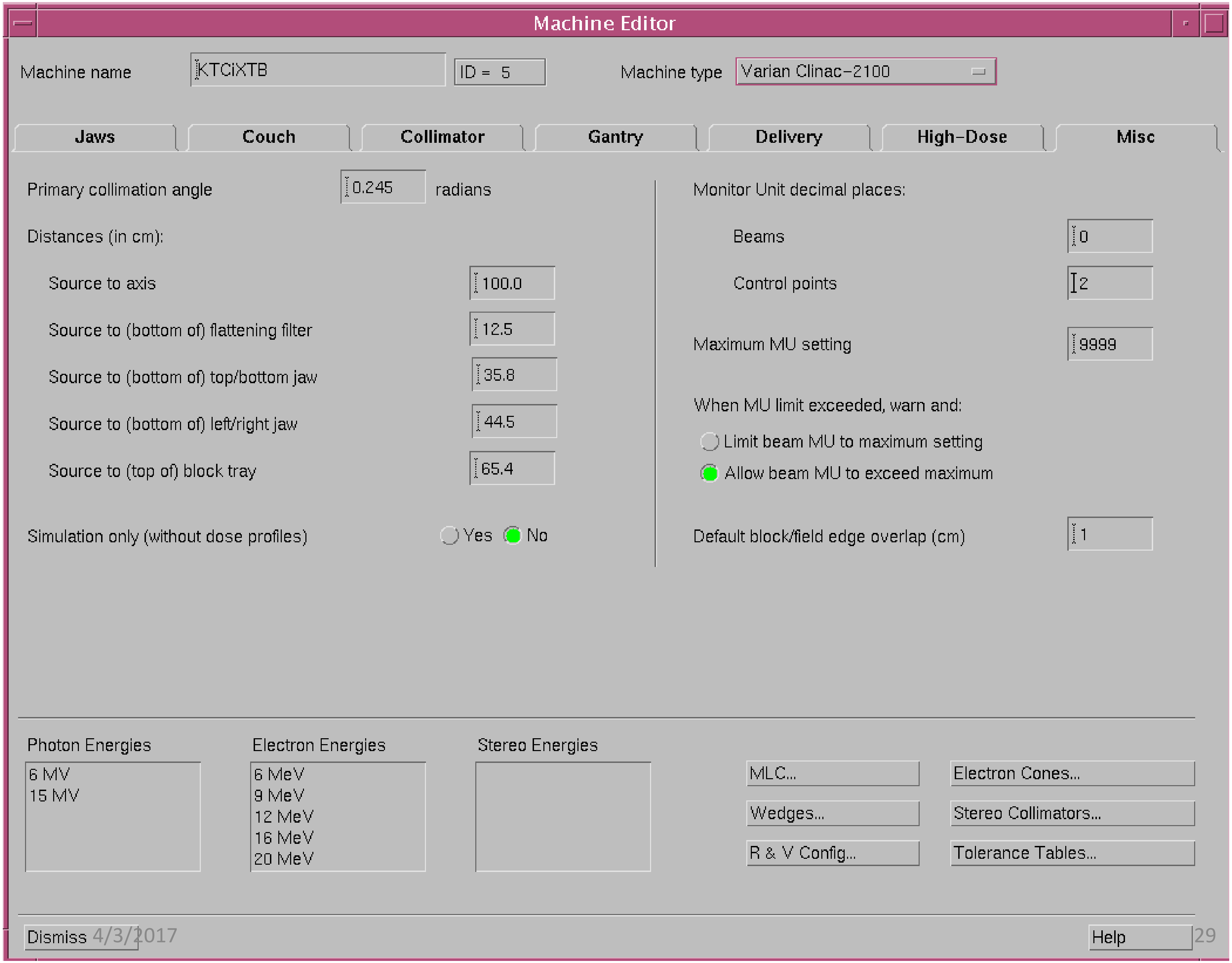


Collect all the information, then start to enter it in


Machine Editor
Machine name
KTCiXTB
ID = 5
Machine type
Varian Clinac-2100
Jaws
Couch
Collimator
Gantry
Delivery
High-Dose
Misc
Minimum angle
270
Maximum angle
90
Default angle
0
Decimal places
1
180
90
270
0
Couch angle when foot of
table points away from gantry
When viewed from above, is positive rotation clockwise?
Yes
No
Photon Energies
6 MV
15 MV
Electron Energies
6 MeV
9 MeV
12 MeV
16 MeV
20 MeV
Stereo Energies
MLC...
Electron Cones...
Wedges...
Stereo Collimators...
R & V Config...
Tolerance Tables...
Dismiss
Help


Machine Editor
Machine name
KTCiXTB
ID = 5
Machine type
Varian Clinac-2100
Jaws
Couch
Collimator
Gantry
Delivery
High-Dose
Misc
Minimum angle
270
Maximum angle
90
Default angle
0
Decimal places
1
0
90
270
180
Collimator angle when tray opening faces gantry
Some machines have a tray opening which never faces the gantry. Enter the angle as if you were able to rotate the tray opening to face the gantry.
When viewed from above, is positive rotation counterclockwise?
Yes
No
Photon Energies
6 MV
15 MV
Electron Energies
6 MeV
9 MeV
12 MeV
16 MeV
20 MeV
Stereo Energies
MLC...
Wedges...
R & V Config...
Electron Cones...
Stereo Collimators...
Tolerance Tables...
Dismiss
Help


Machine Editor
Machine name
KTCIXTB
ID = 5
Machine type
Varian Clinac-2100
Jaws
Couch
Collimator
Gantry
Delivery
High-Dose
Misc
Machine Speed Constraints
Maximum gantry rotation speed (deg/sec)
4.8
Maximum jaw speed (cm/sec)
2
Maximum MLC leaf speed (cm/sec)
2.25
Arc Delivery Capabilities
Conformal Arc
Yes
No
Dynamic Arc
Yes
No
Dose Rate Delivery Behavior
Dose rate constant?
Yes
No
Continuously variable
Binned
(Define specific dose rate values in the
Energy Editor window.)
MU Delivery Constraints
Maximum gantry MU delivery (MU/deg)
20
Minimum gantry MU delivery (MU/deg)
0.1
Minimum MLC leaf MU delivery (MU/cm)
0
Gantry Acceleration Constraints
Limit gantry acceleration?
Yes
No
Maximum gantry rate change (deg/sec)
0.75
Photon Energies
6 MV
15 MV
Electron Energies
6 MeV
9 MeV
12 MeV
16 MeV
20 MeV
Stereo Energies
MLC...
Electron Cones...
Wedges...
Stereo Collimators...
R & V Config...
Tolerance Tables...
Dismiss
Help

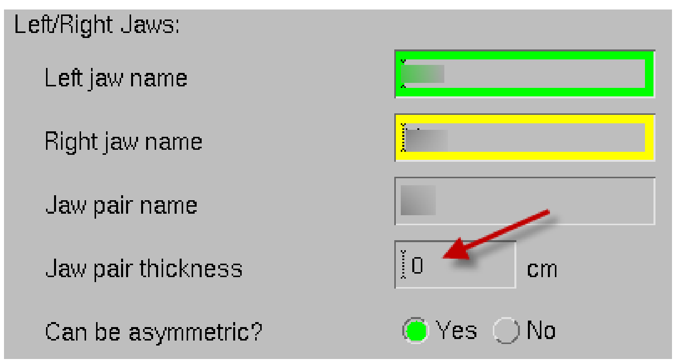

Machine Editor
Machine name
KTCiXTB
ID = 5
Machine type
Varian Clinac-2100
Jaws
Couch
Collimator
Gantry
Delivery
High-Dose
Misc
Primary collimation angle
0.245
radians
Distances (in cm):
Source to axis
100.0
Source to (bottom of) flattening filter
12.5
Source to (bottom of) top/bottom jaw
35.8
Source to (bottom of) left/right jaw
44.5
Source to (top of) block tray
65.4
Simulation only (without dose profiles)
Yes
No
Monitor Unit decimal places:
Beams
0
Control points
2
Maximum MU setting
9999
When MU limit exceeded, warn and:
Limit beam MU to maximum setting
Allow beam MU to exceed maximum
Default block/field edge overlap (cm)
1
Photon Energies
6 MV
15 MV
Electron Energies
6 MeV
9 MeV
12 MeV
16 MeV
20 MeV
Stereo Energies
MLC...
Electron Cones...
Wedges...
Stereo Collimators...
R & V Config...
Tolerance Tables...
Dismiss
Help

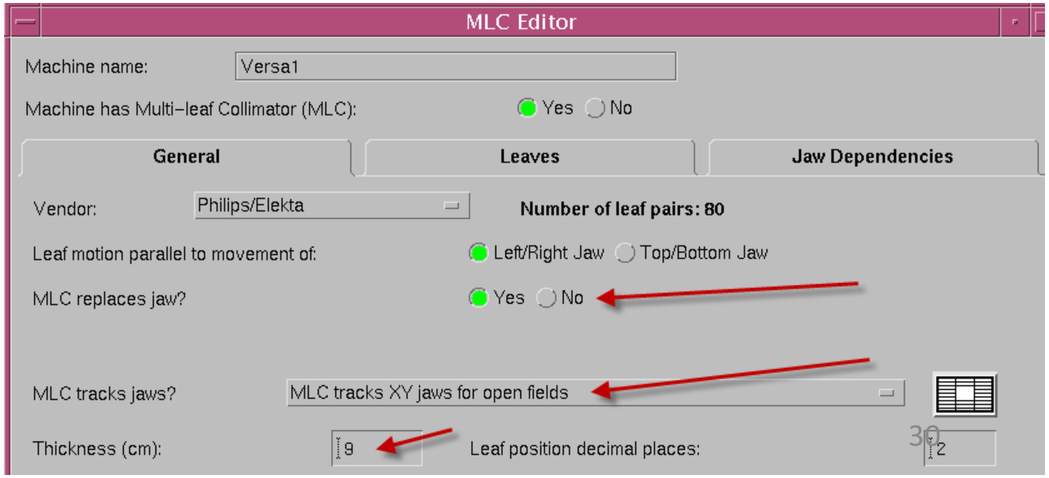
Agility Diaphragms / Jaws

- Elekta calls them Diaphragms
  - Varian and Pinnacle call them Jaws
  - Elekta allows them to move during a dynamic treatment

- Elekta has only one pair of Diaphragms
  - The MLCs replace the other pair of diaphragms
  - MLCs are much thicker than Varian’s (< 0.5% transmission + Leakage)

- Pinnacle handles this by assuming that the MLCs replace the diaphragms
  - The “missing” jaws will still show up in the plan. But won’t be used.





Beam data

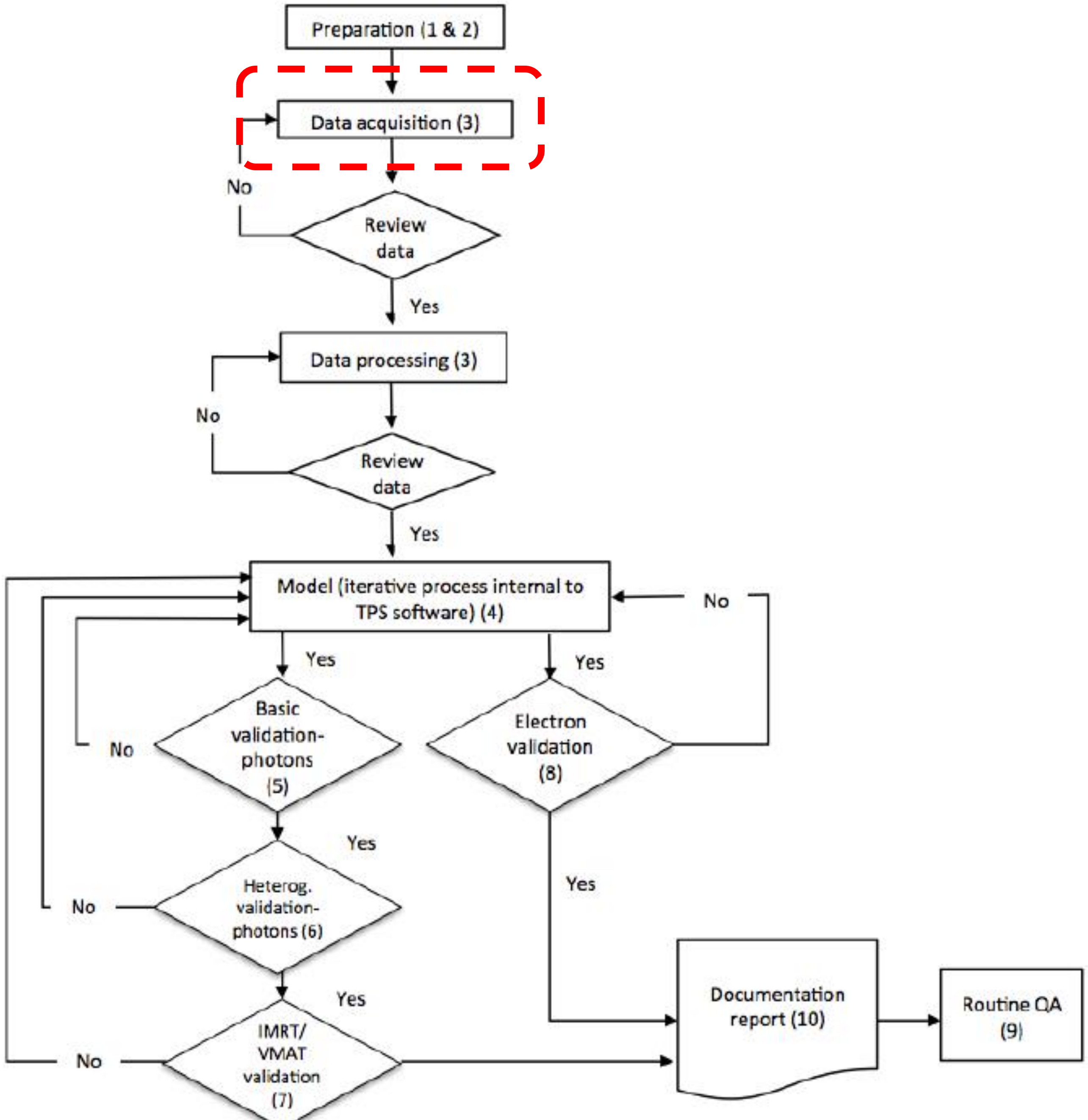


Figure from MPPG5a

Beam data requirements

- TPS data requirements are similar
  - but are vendor specific
  - Also depend on the dose calculation algorithm
- Vendors generally provide good guidelines on what is needed for their TPS – sometimes some interpretation is needed.
- Follow their guidelines for what data is necessary, including measurement conditions
- For IMRT/VMAT, modeling of MLC is crucial

TG106 ‘typical commissioning measurements’

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.

		Square field size (cm)															
(a)	Description	1	2	3	4	5	6	8	10	12	14	16	20	25	30	40	>40
	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	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×

- Have a folder for each beam
- Label each file with the full data: “18MV 15deg in, 10x10 profile” etc.

Pinnacle Minimum Data Requirements

Per Photon Energy:

19 PDDS

117 Profiles

14 Factors

PDD - jaw defined field size

Field Size	Depth
5x5	
10x10	
20x20	
30x30	0-25cm
40x40	
20x5	
5x20	

Profiles - jaw defined field size

Field Size	Depths	Direction
5x5		
10x10	dmax	
20x20	5cm	inplane &
30x30	10cm	crossplane
40x40	20cm	
20x5		
5x20		

PDD - MLC defined field size (jaws at 20x20)

Field Size	Depth
2x2	
3x3	
5x5	0-25cm
10x10	
15x15	

Profiles - MLC defined field size (jaws at 20x20)

Field Size	Depths	Direction
2x2	dmax	
3x3	5cm	inplane &
5x5	10cm	crossplane
10x10	20cm	
15x15		

Wedge PDD - MLC defined field size (jaws at 20x20)

Field Size	Depth
5x5	
10x10	
15x15	0-25cm
20x20	
40x30	

Wedge Profiles - MLC defined field size (jaws at 20x20)

Field Size	Depth	Direction
5x5	dmax	inplane(all)
10x10	5cm	&
15x15	10cm	crossplane
20x20	20cm	(10cm only)
40x30		

Output Factors

Field Size
2x2
5x5
10x10
20x20
30x30
40x40

Wedge Factors

Field Size
2x2
5x5
10x10
20x20
30x30
40x30

Appendix E Beam Data Measurement Forms

Forms for Recording Beam Data Measurements

Table 56 Open Field PDDs[1]

	Field Size											
Field	Smallest	4	6	8	10	12	15	20	25	30	35	Largest
Open												

1. Measured in the surface–30 cm range

Table 57 Wedged Field PDDs[1]

	Field Size									
Field	Smallest	4	6	8	10	12	15	20	Largest square	Largest rectan-gular
Wedge 1										
Wedge 2										
Wedge 3										
Wedge 4										

1. Measured for all hard and motorized wedges in the surface–30 cm range

Table 58 Open Field Profiles at 5 Depths

	Field Size											
Depth	Smallest	4	6	8	10	12	15	20	25	30	35	Largest
1. d_{max_10}												
2.												
3.												
4.												
5.												

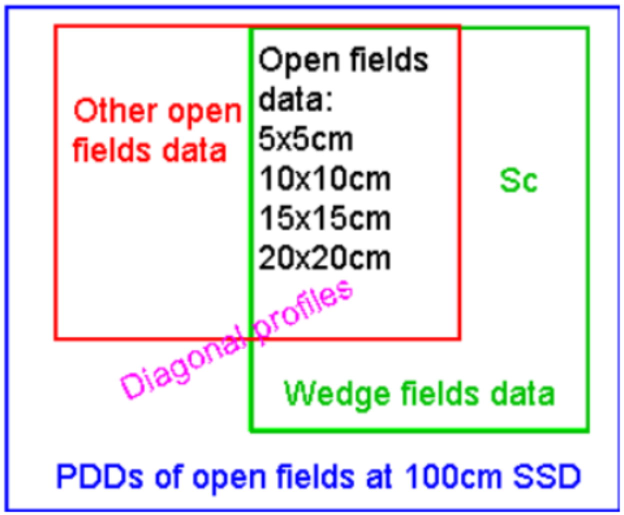
Beam measurement data (Eclipse)

Mandatory vs. optional

Photon energy 1. (__MV)									
	F1 (__cm)	F2 (__cm)	F3 (__cm)	F4 (__cm)	F5 (10cm)	F6 (__cm)	F7 (__cm)	F8 (__cm)	F9 (Larg-est - __cm)
PDD									
Profile at dmax (___cm)									
Profile at d1 (___cm)									
Profile at d2 (___cm)									
Profile at d3 (___cm)									
Profile at d3 (___cm)									
Open diagonal profile at dmax (__cm)									
Open diagonal profile at d1 (___cm)									
Open diagonal profile at d2 (___cm)									
Open diagonal profile at d3 (___cm)									
Open diagonal profile at d4 (___cm)									

Table based on Eclipse (Varian) requirements

Data needed for Elekta TPS (Monaco, XiO)



3. For Monte Carlo model, open fields only, PDDs, Profiles (diagonal profiles at 45 degree), and Scp, SSD 90cm setup.

2. For Collapsed Cone model, open and wedge fields, PDDs, Profiles (true diagonal profiles in positive and negative direction of the largest open field, Star scan profiles of the largest wedge field), Sc measured with brass cap, wedge factors.

1. For XiO Superposition and Convolution mode, add one set of PDDs of open fields that measured with SSD 100cm setup, which is required by XiO to determine electron contamination parameters.

Monaco Data Requirements

IN-WATER MEASUREMENTS

All Scan measurements are to be performed at 90 cm SSD. Point Dose measurements are to be performed at 90 cm SSD and a depth of 10 cm.

OPEN FIELD DATA

1. ***Central Axis Depth Dose Scans and Output Factors.***

Field Sizes (cm)	2x2	3x3	4x4	5x5	7x7	10x10	15x15	20x20	30x30	40x40

NOTE: Output factors must be normalized to 1.0 for the 10x10 cm field.

2. ***Inplane and Crossplane Profile Scans***

Field Sizes (cm)	2 x 2	3 x 3	5 x 5	10 x 10	15 x 15	20 x 20	30 x 30	40 x 40

Profile Depths (cm)	dmax	5	10	20

3. ***Scans of both Diagonals (at 45 and 135 deg) for Maximum open Field Size at two different depths (10 cm and 5 cm depth), extending the geometrical field by at least 2.0 cm. Set scan increment of 3 mm.***

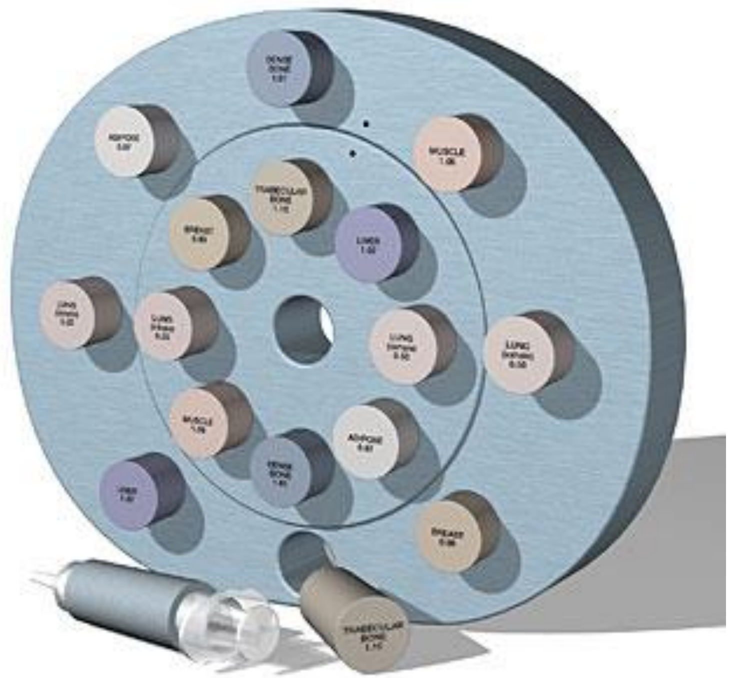
4. ***Absolute Dose for 10 x 10 cm at 100 cm SSD and 10 cm depth.***

5. ***Absolute Dose for 10 x 10 cm at 90 cm SSD and 10 cm depth.***

From: Monaco Photon Beam Data Requirements

etc

Electron density measurements



- MPPG5a recommends CT scanner-specific calibration curves
- If you have more than one CT scanner, at least verify whether a single curve will do

Experimental details

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

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TABLE 1. Detectors suitable for TPS commissioning and validation of photon and electron beams.

Detector	*Use*	*Comments*	*Reference*
Scanning ion chambers	Beam scanning for photons and electrons	Typical scanning chambers have an air cavity of 4–6 mm diameter, (minimum of 2 chambers for measurement and reference)	TG-106 (Das et al.[5])
Electron diodes and film	Beam scanning for electrons, output factors (film)	QMP must confirm the effective point of measurement	TG-25 (Khan et al.[45]), TG-70 (Gerbi et al.[46])
Small field detectors	• Small field scanning & output factors[a], • IMRT/VMAT point measurement • MLC intraleaf measurement & penumbra	Carefully select the detector type and size to fit the application. When scanning for penumbra, diodes are recommended.	TG-106 (Das et al.[5]), TG-120 (Low et al.[18]) Yunice, et al.[16]
Large ion chamber	Aggregate MLC transmission factors	Interleaf transmission	LoSasso et al.[20]
Film and/or array detector	2D dose distributions, including dynamic/virtual wedge and planar fluence maps, intraleaf measurements[b]	• Absolute dosimetry preferred; relative dosimetry adequate. • Desirable if the device can be mounted on the gantry and/or in a phantom at different geometries	TG-106 (Das et al.[5]), TG-120 (Low et al.[18]), IAEA TRS-430[7]

[a] If a diode detector is used for small field measurements, a "daisy chain" approach is recommended to minimize the energy dependence effects; the diode is first cross-compared with an ion chamber for a 4×4cm^2 field and then is used to measure the smaller fields.

[b] Using film for intraleaf transmission is usually less precise than interleaf transmission.

TABLE 2. Equipment required for TPS commissioning of photon and electron beams.

Equipment	*Use*	*Comments*	*Reference*
3D water phantom	Beam scanning	Must have sufficient scanning range and lateral/depth scatter	TG-106 (Das et al.[5]), TG-70 (Gerbi et al.[46])
Electrometers and cables	Beam scanning, output calibration, relative and absolute dosimetry	ADCL calibration, low noise and leakage with wide dynamic range and linear response	TG-106 (Das et al.[5])
Buildup cap or miniphantom	In-air output factor measurement	Measurements required for some planning systems, most second check systems	Yunice, et al.[16]
Water-equivalent phantom material in slab form	Buildup and backscatter for measurements	> 20 cm of total thickness in varying increments, width and length ≥ 30 cm, cavity for detector(s)	TG-106 (Das et al.[5]), TG-120 (Low et al.[18]), IAEA TRS-430[7]
CT density phantom	CT number to electron or mass density calibration	Should include tissue-equivalent materials spanning the clinical range of low-density lung to high-density bone.	TG-66 (Mutic et al.[13])
Heterogeneity phantom with lung-equivalent material	End-to-end testing	Include cavities for detectors, useful for annual QA reference test	TG-65 (Papanikolaou & Stathakis[26]), IAEA TRS-430[7]
Anthropomorphic phantom	Anatomic model testing, end-to-end testing, use testing	Include cavities for detectors	IAEA TRS-430[7]
Software for data processing	Processing, comparing, and analyzing profiles, depth-dose curves, and other beam data	May be included with the 3D water tank scanning software	TG-106 (Das et al.[5])
IMRT/VMAT or arc therapy phantom	VMAT or arc therapy	Options include a solid phantom holding a planar array, 3D detector arrays, film inside a phantom, other	TG-120 (Low et al.[18])

Find center of the chamber

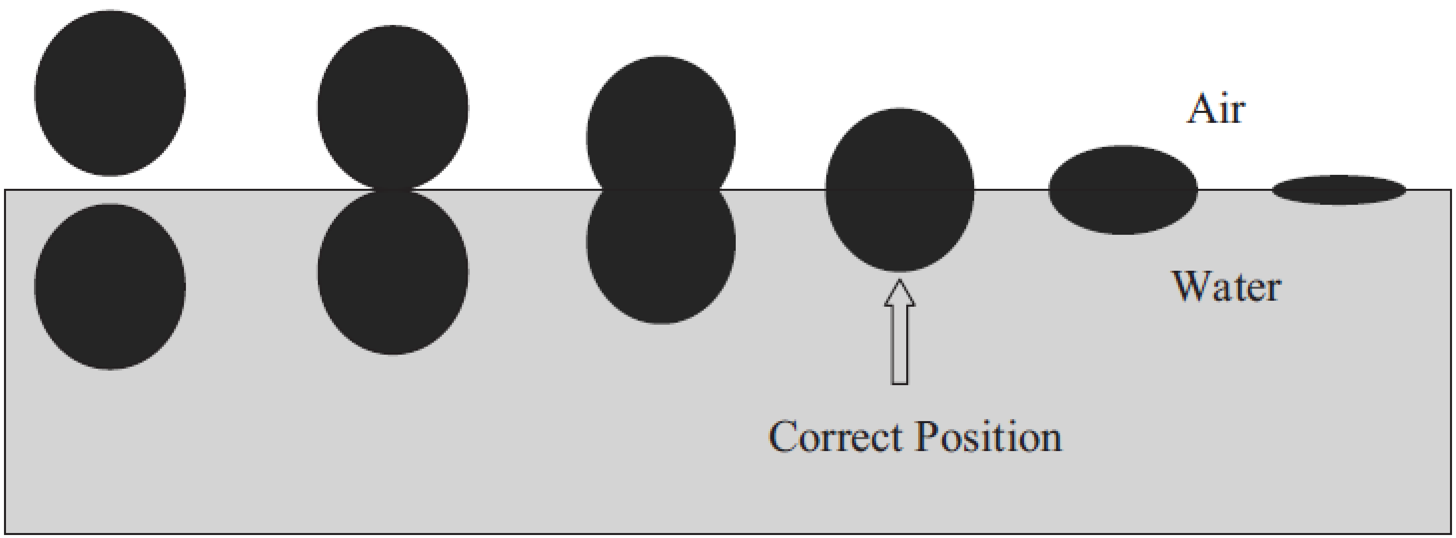
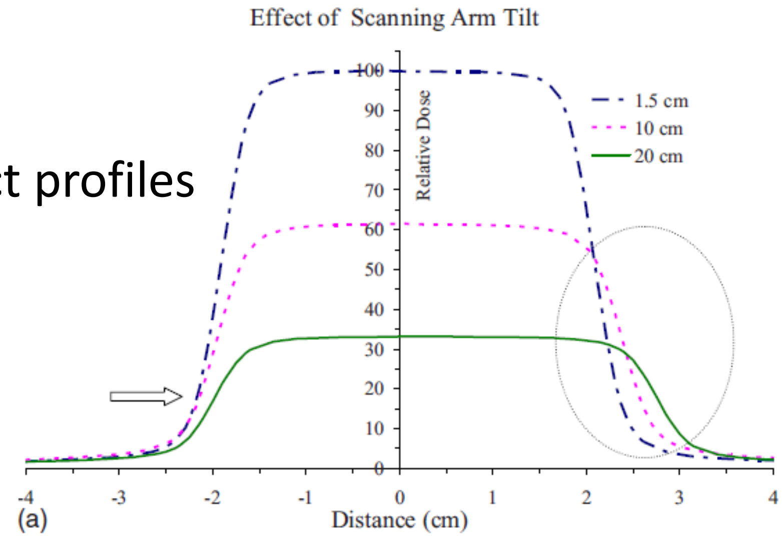


FIG. 6. Sequential appearance of chamber and its reflection in water viewed from tank side. The correct position is when both images form a perfect circle.

Check setup

- Axis alignment (all directions) – can impact profiles
- Tank tilt (figure from TG106)
- Gantry tilt



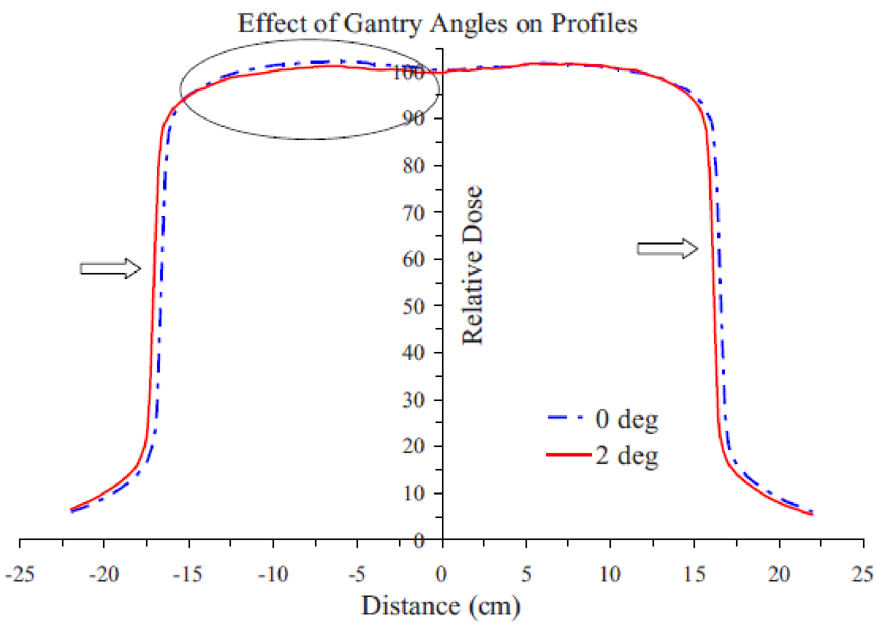


FIG. 8. Effect of gantry angle tilt on the profiles of a 6 MV beam for 30 $\times$ 30 cm^2 field at 10 cm depth.

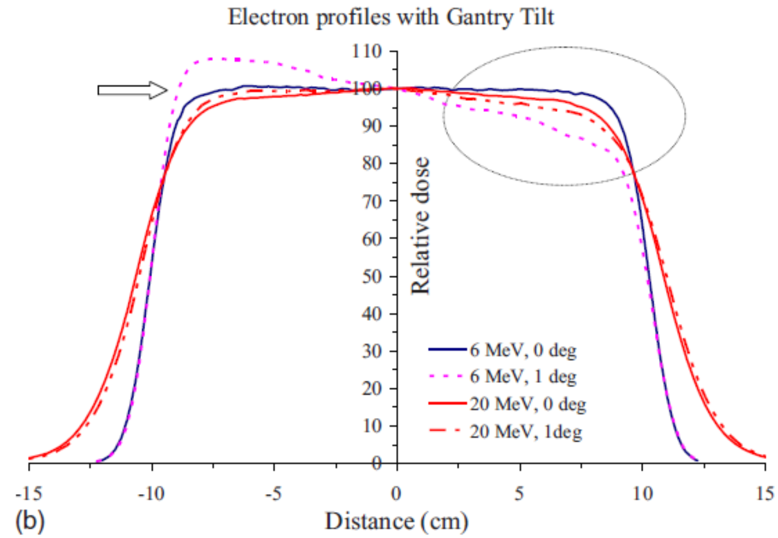


FIG. 7. (a) Beam profiles of a 6 MV beam at different depths with scanning arm tilt for a 4$\times$4 cm^2 field, (b) electron beam profiles at depth of 80% depth dose for 20$\times$20 cm^2 cone with gantry tilt. Arrows and circle are shown to represent the impact of arm and gantry tilt.

Beam Profiles Chamber orientation

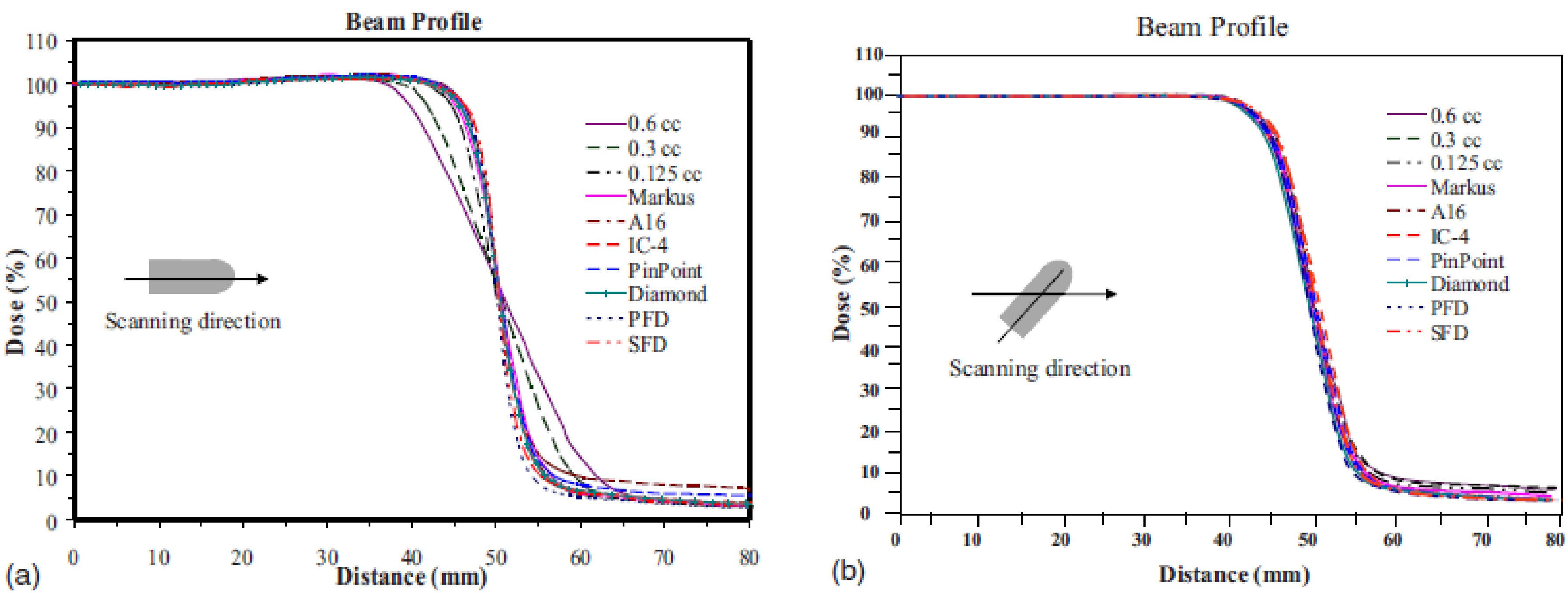
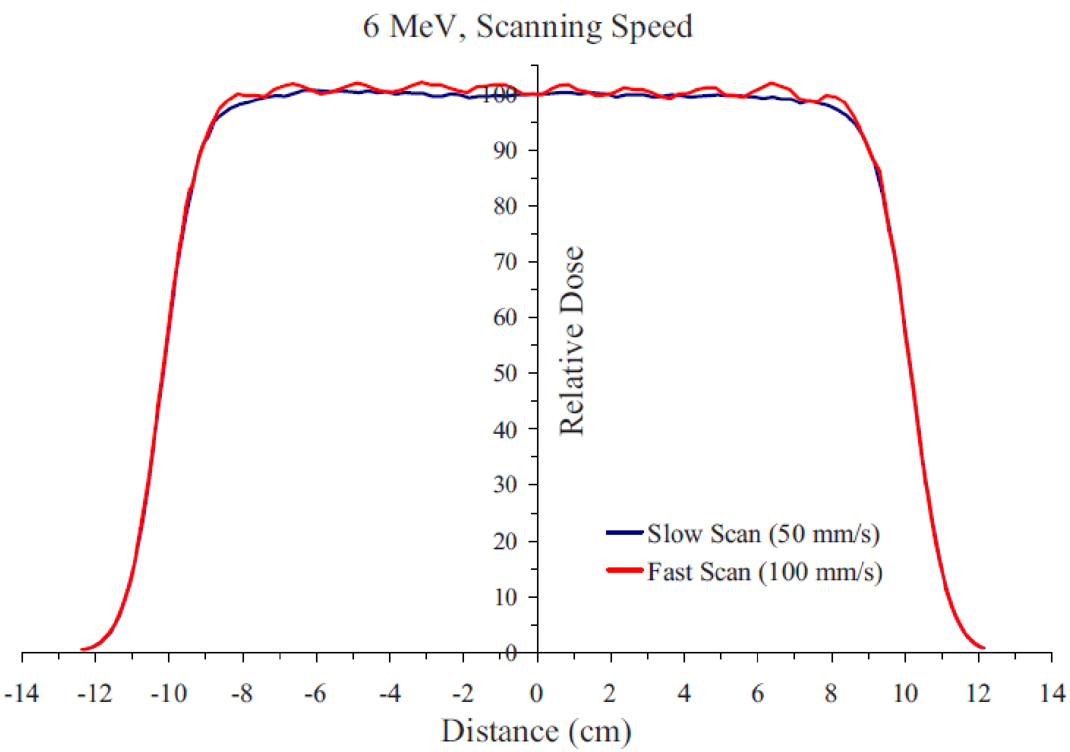


FIG. 11. Effect of chamber orientation on photon beam profiles for a 10 $\times 10$ cm^2 fields: (a) long axis scan, (b) short axis scan with various size detectors. Only half scans are shown.

Electron measurements can be particularly sensitive to scanning parameters

- Tank scanning parameters – speed and undersampling can give suboptimal data, especially for low energy electron beams (TG106)
- High scanning speed can cause ripples so scanning probe sees varying depths
- If small volume ion chamber is used, then slower speeds can help smooth out statistical variations in signal
- Delay time: can be useful to delay time between subsequent points to avoid ripple effects



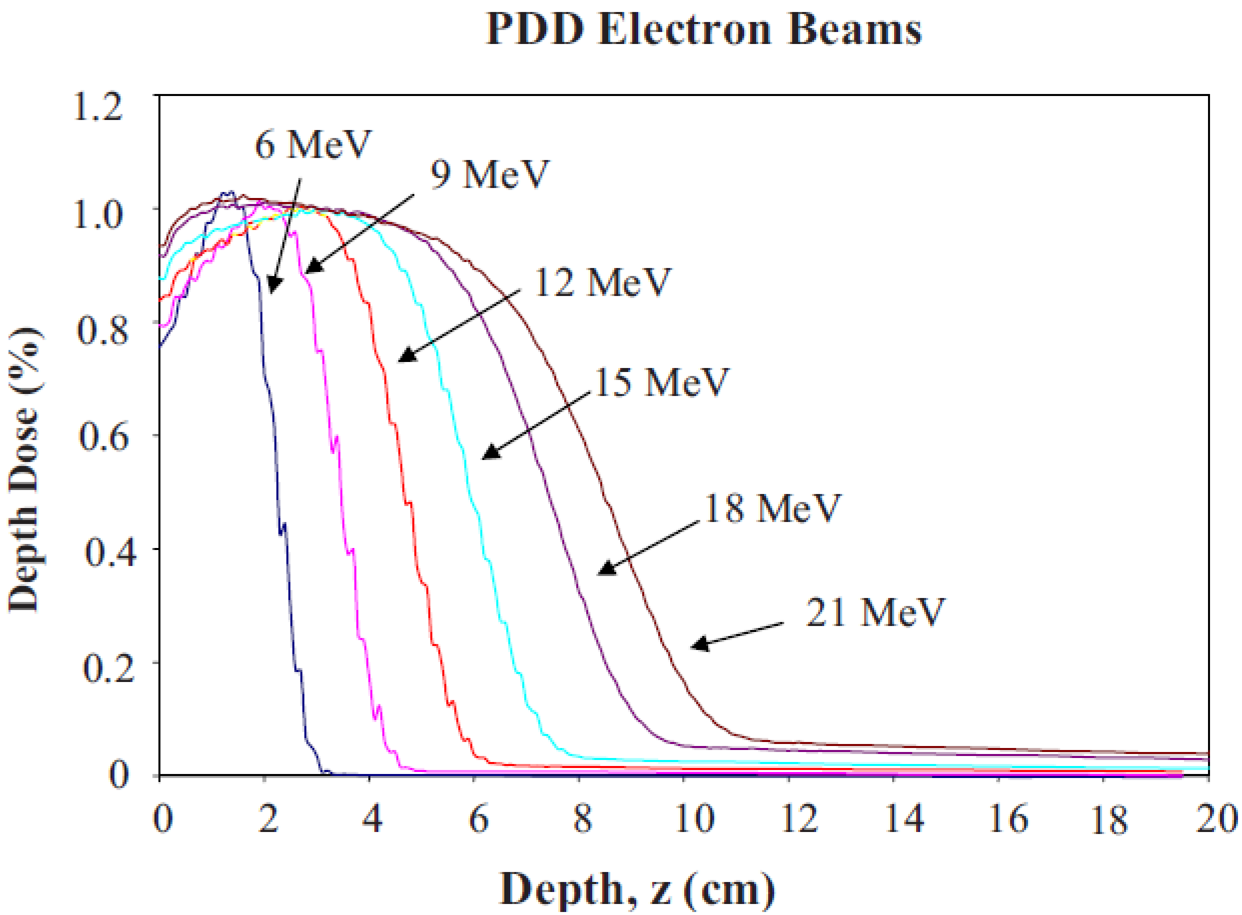


FIG. 12. Effect of water ripple on low energy electron beam depth dose.

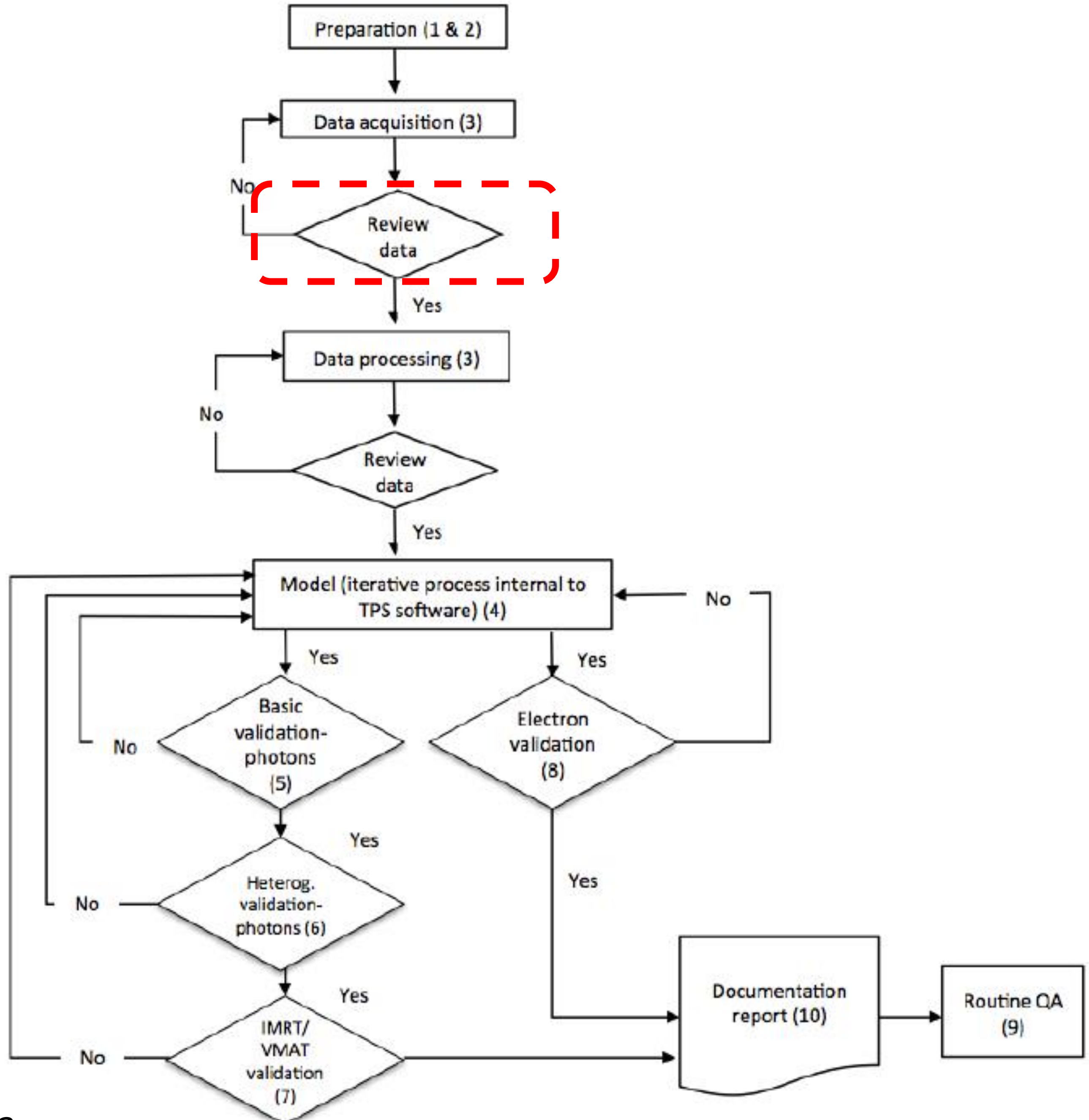


Figure from MPPG5a

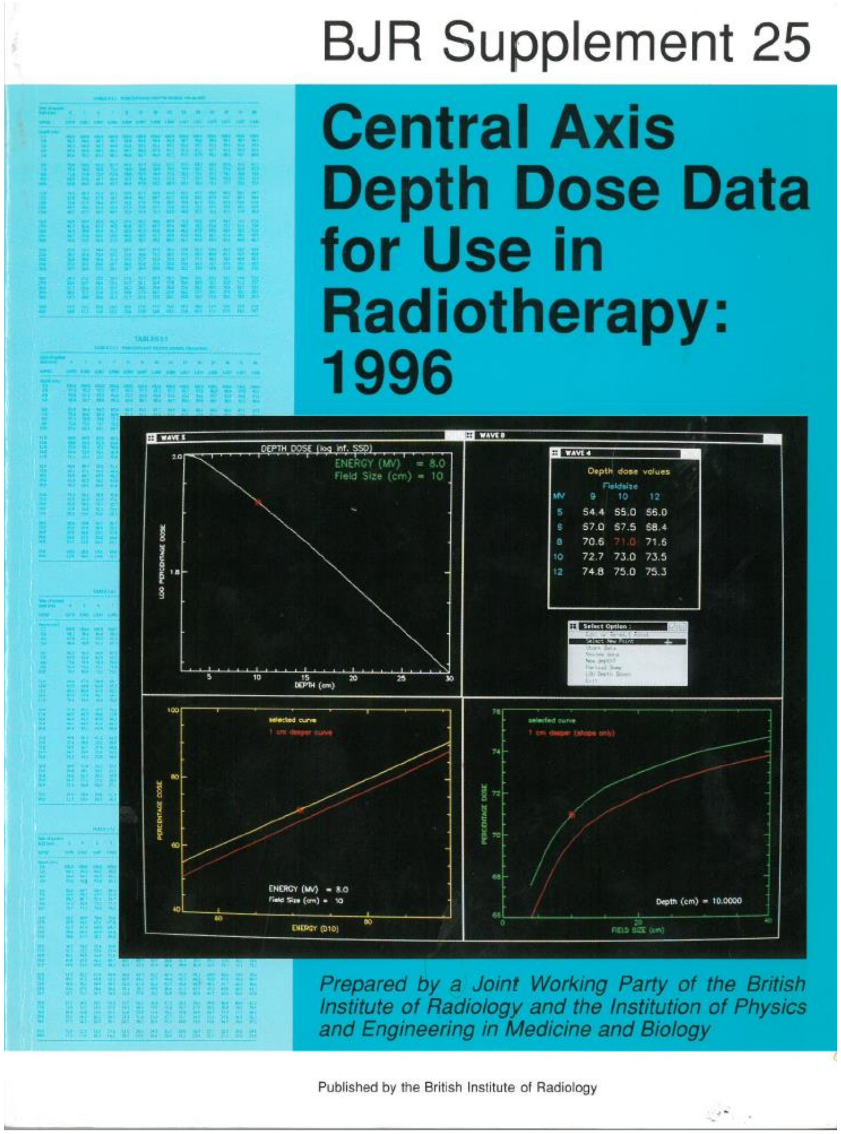
Data Review

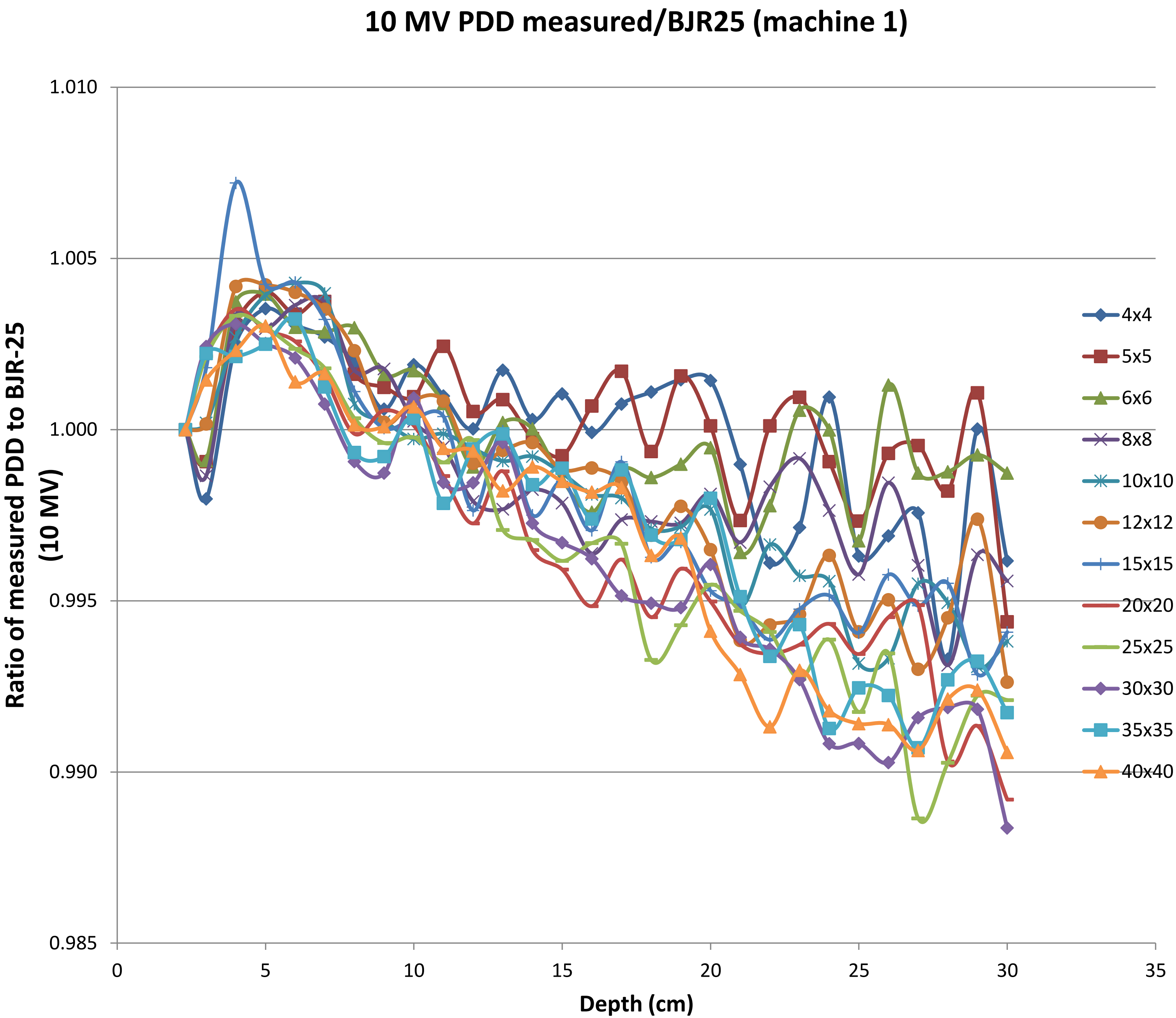
Data Review

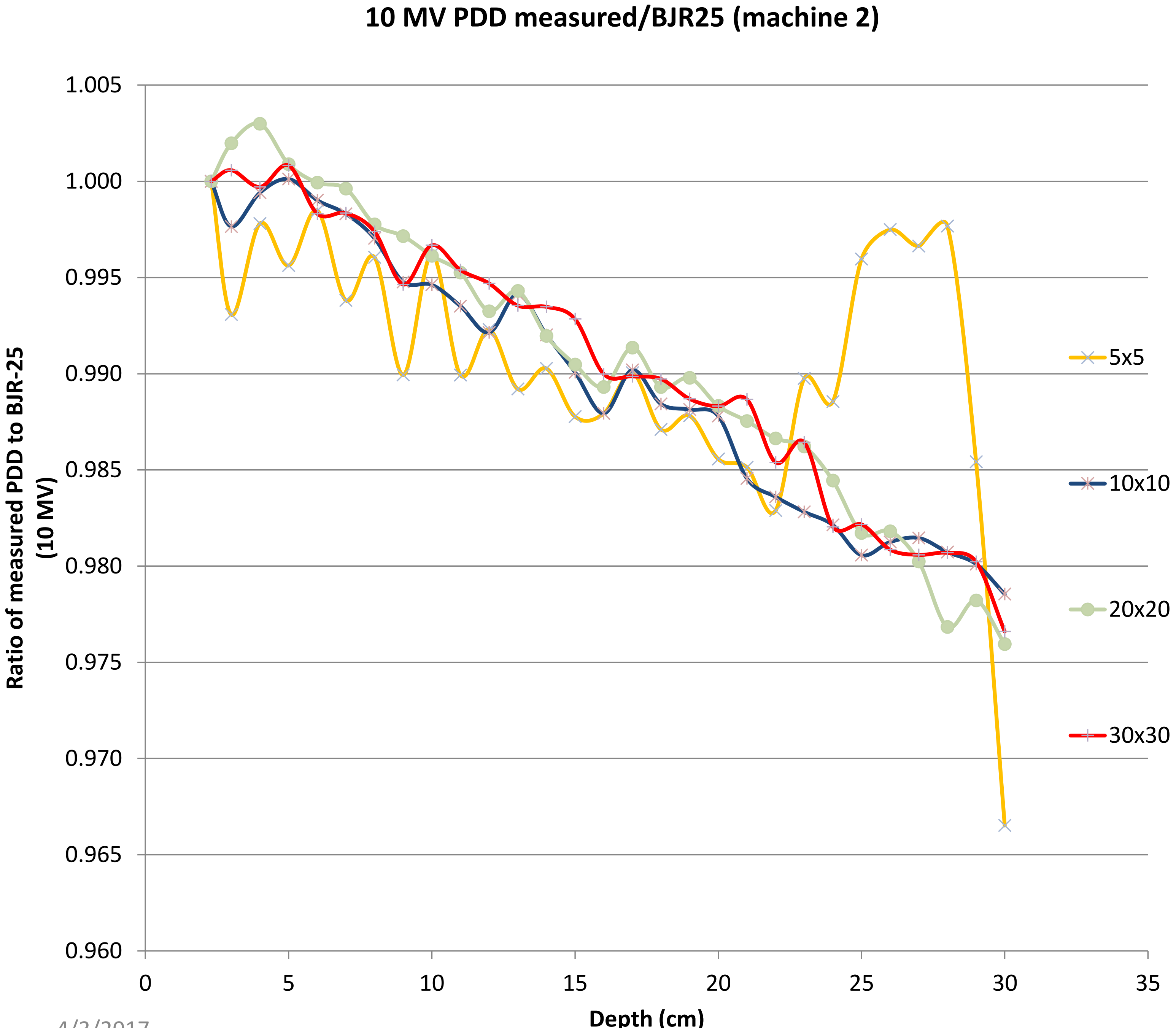
- Review data before and after entry into the planning system
    1. Check for potential setup and measurement errors prior to importing data to TPS
        - Inverse square
        - Beam divergence
        - Expected changes with field size
        - PDDs
    2. Compare data to reference dataset
        - Do for as much of the data as possible – not just PDDs
    3. Re-evaluate data after entering into TPS
        - Check for import problems, mirroring of data, smoothing

Use a second datasource

- Data should be checked against an independent source whenever possible
  - BJR-25
  - Machine standard data
  - Spot checks by an independent physicist (with independent equipment)




10 MV PDD measured/BJR25 (machine 1)
Ratio of measured PDD to BJR-25 (10 MV)
1.010
1.005
1.000
0.995
0.990
0.985
0
5
10
15
20
25
30
35
Depth (cm)
4x4
5x5
6x6
8x8
10x10
12x12
15x15
20x20
25x25
30x30
35x35
40x40


10 MV PDD measured/BJR25 (machine 2)
1.005
1.000
0.995
0.990
0.985
0.980
0.975
0.970
0.965
0.960
Ratio of measured PDD to BJR-25 (10 MV)
0
5
10
15
20
25
30
35
Depth (cm)
5x5
10x10
20x20
30x30

Data processing

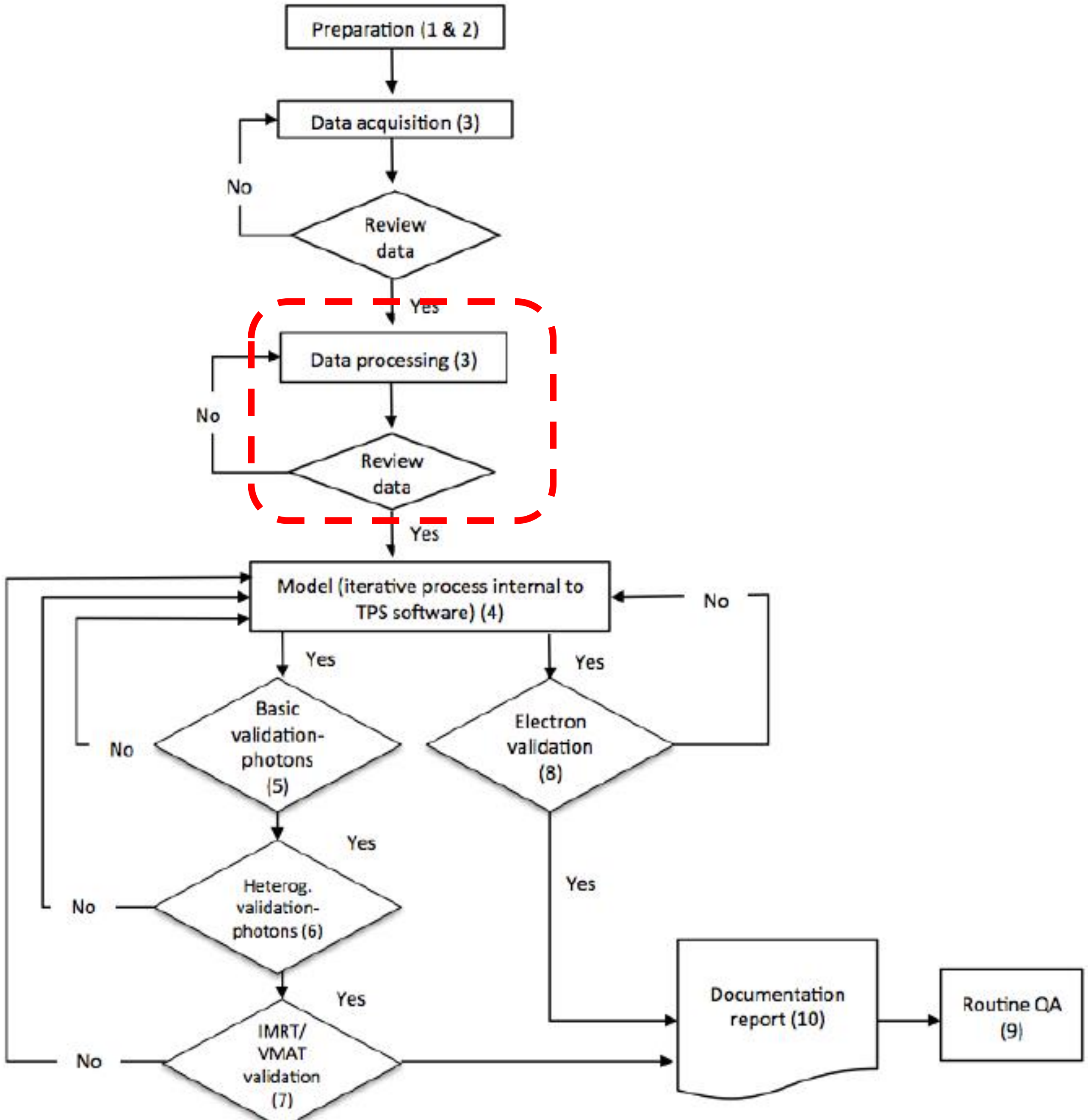
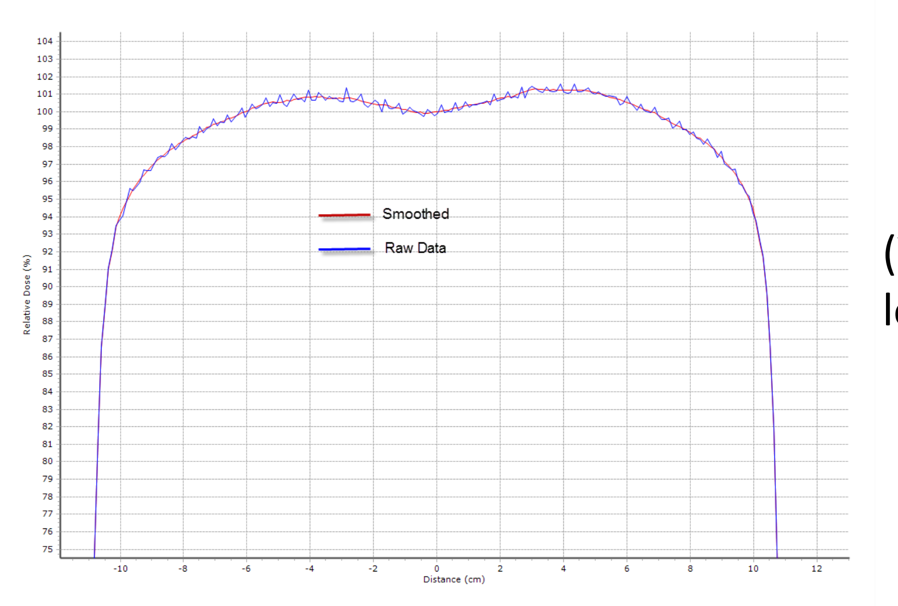


Figure from MPPG5a

Preparing Data for Modeling

- Want our model to be based on good data.
- Measured Data has a certain amount of "noise".
- Smoothing the data can remove noise
  - Care must be taken not to over-smooth the data
  - This can alter how the data represents the beam



(Your data should not look as noisy as this!)

Data processing for wedges data (TG106)

- Orientations – can compromise data entry (TG106)
- Signal saturation – signal varies significantly from toe to heel of the wedges, so examine profiles for evidence of this.
- Over smoothing data can degrade the data – review the data and use common sense.

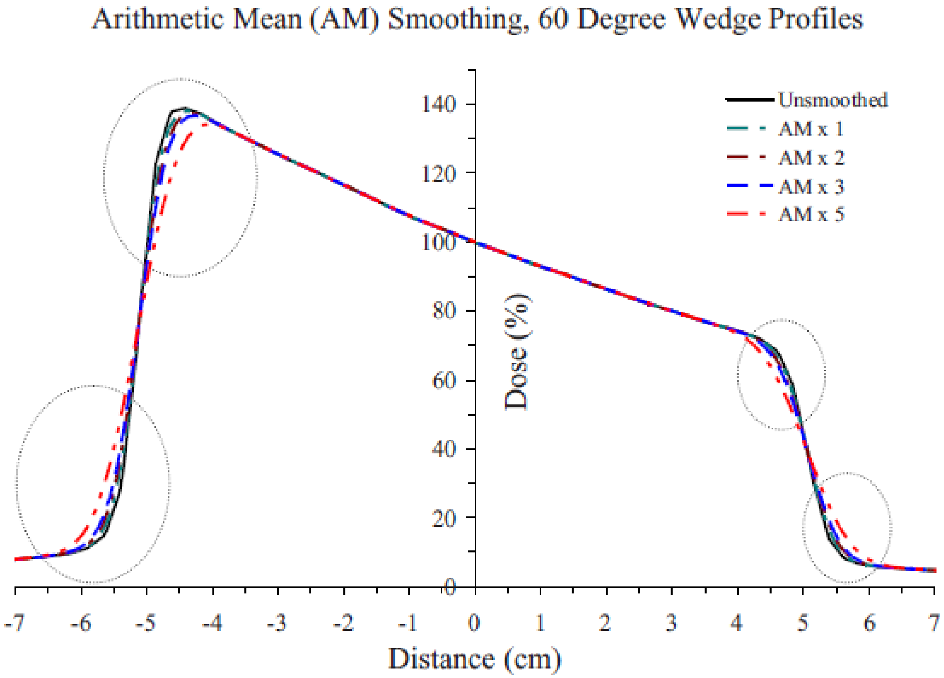


FIG. 13. Effect of data smoothing on the 6 MV 60° wedge profiles. Circles are drawn to show the effect of smoothing.

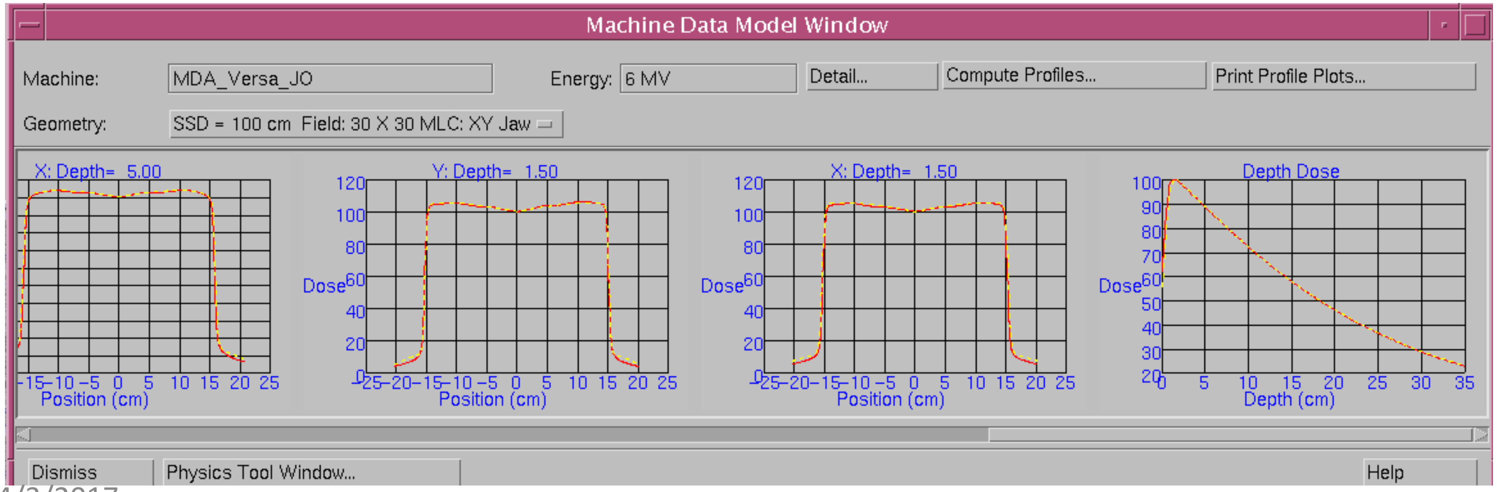
Beam modeling

Approaches:

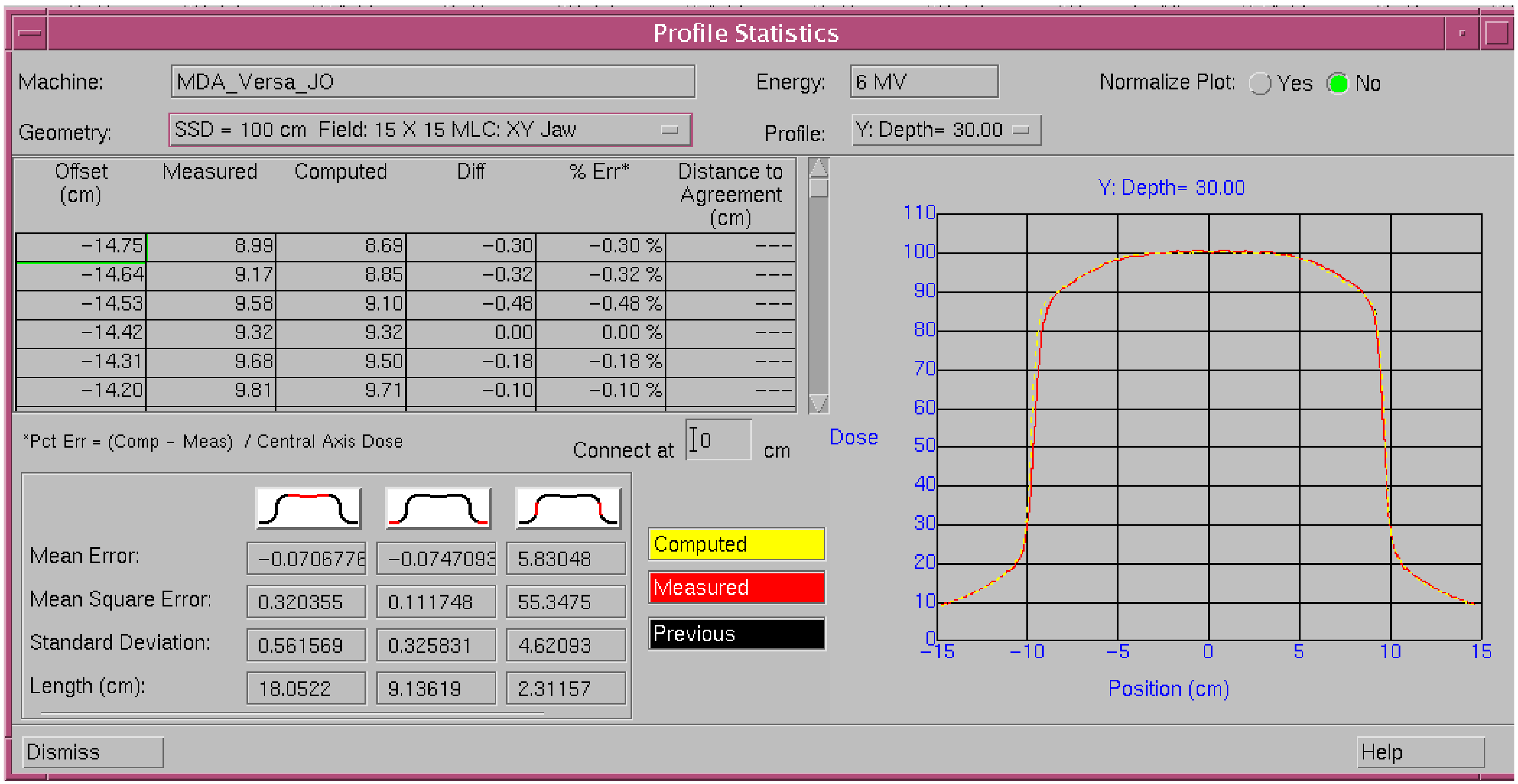
- Do-it-yourself
- Vendor creates the models based on customer data
- Vendor provides pre-configured model

Pinnacle Modeling Process

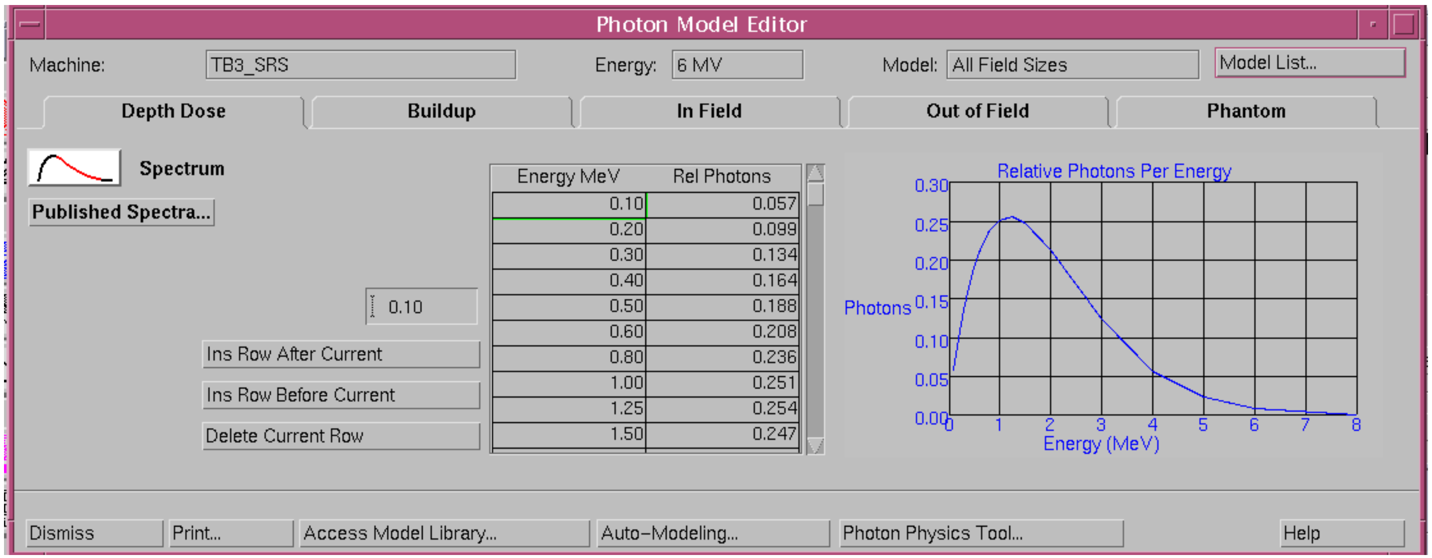
- Measured Data is imported into the Pinnacle Physics Tool
- Pinnacle AutoModeling Scripts guide you through Modeling.
  - The AutoModeling is run
  - The resulting Model is analyzed visually and quantitatively
  - Adjustments are made and the automodeling may be repeated
  - Similar to optimizing an IMRT Plan

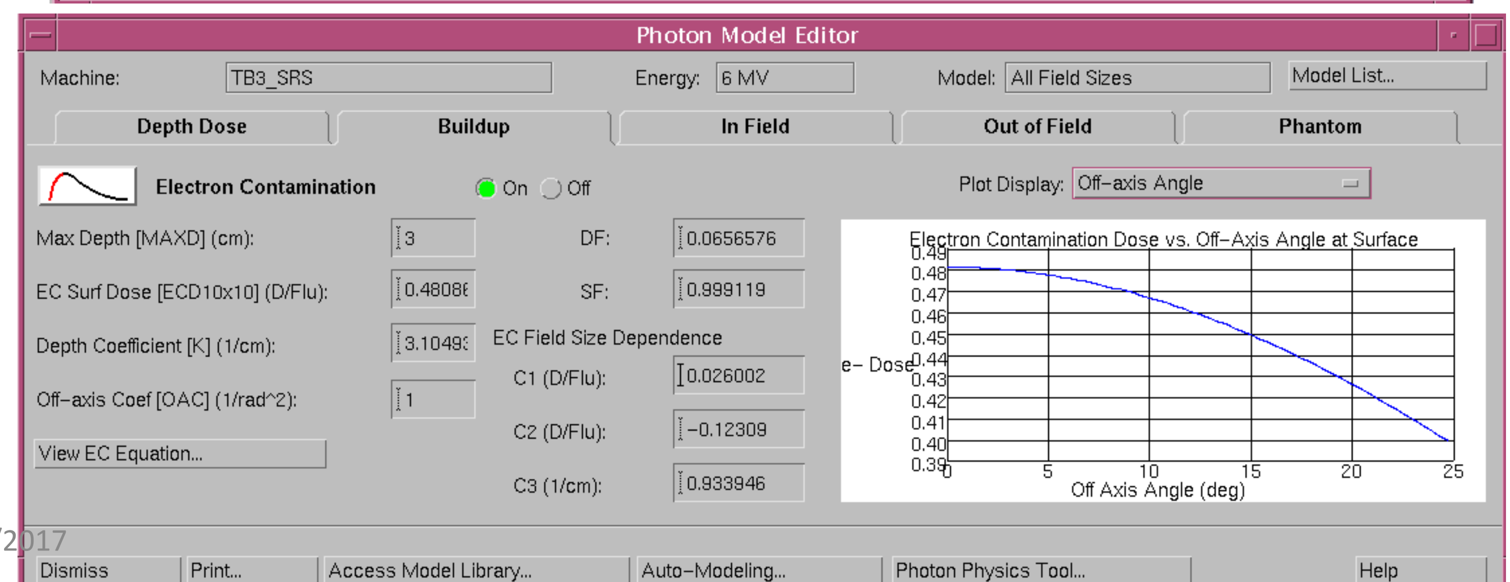


Pinnacle Modeling Process

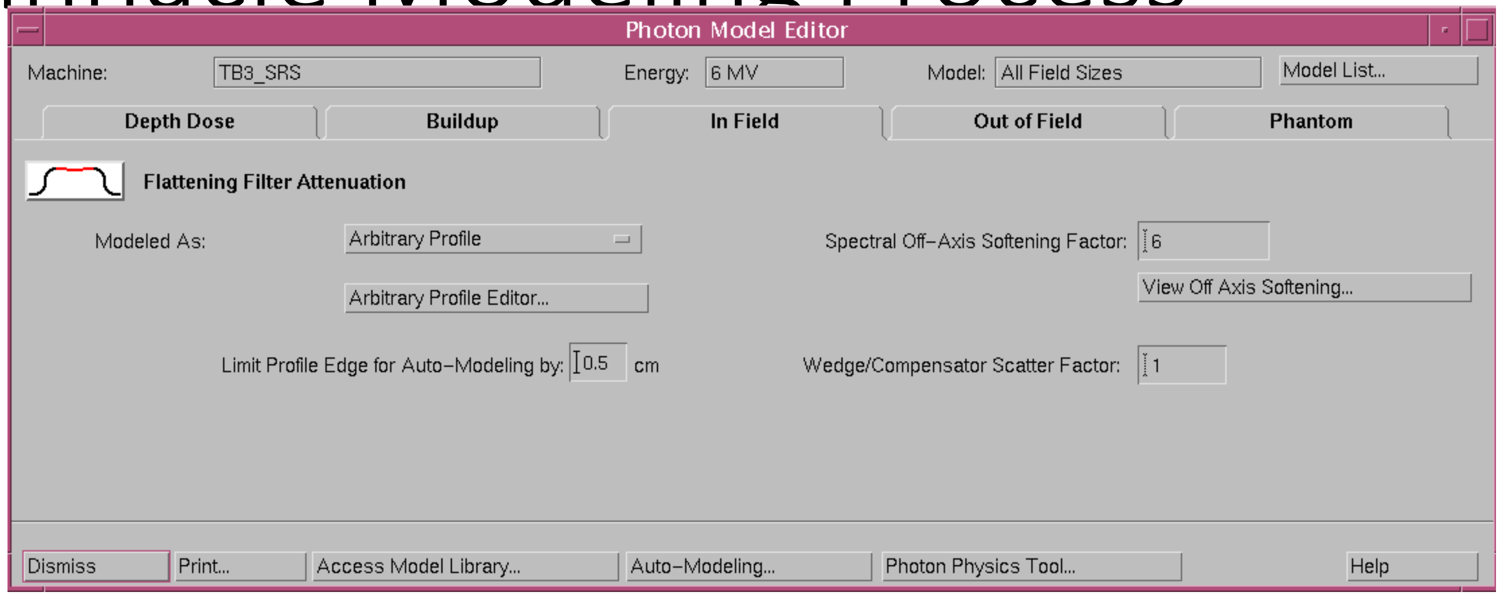


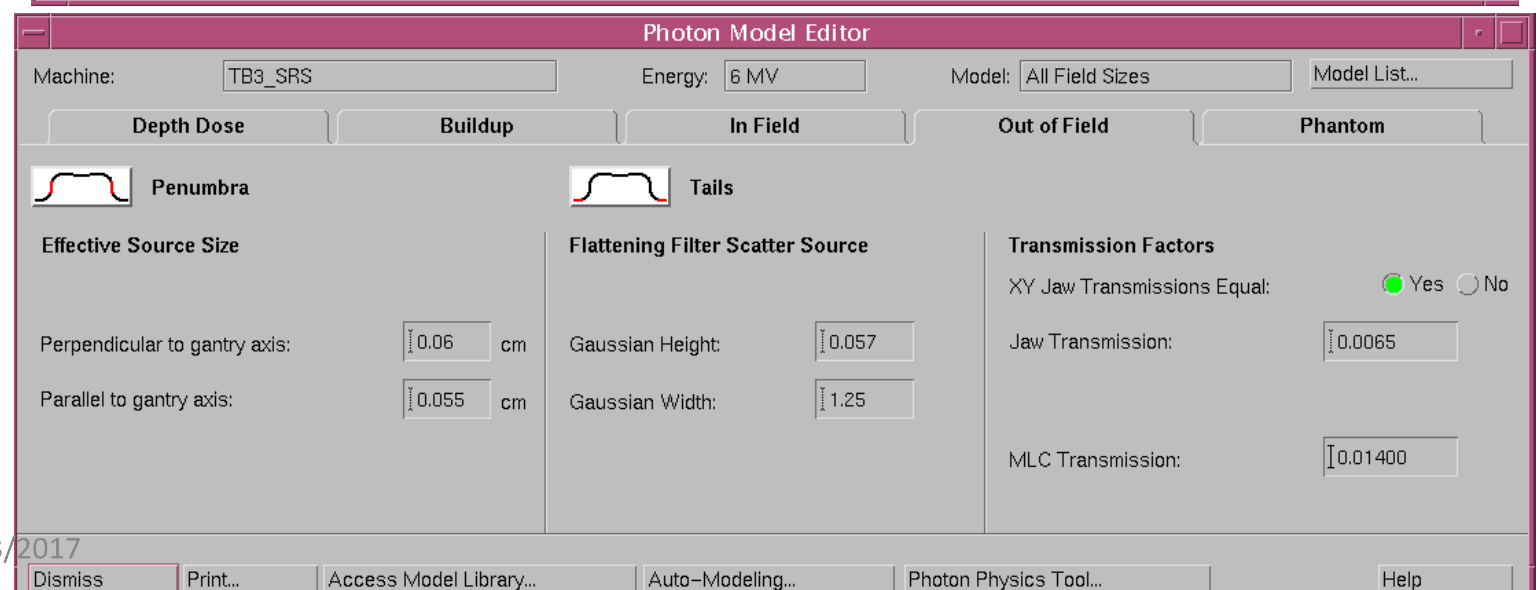
Pinnacle Modeling Process



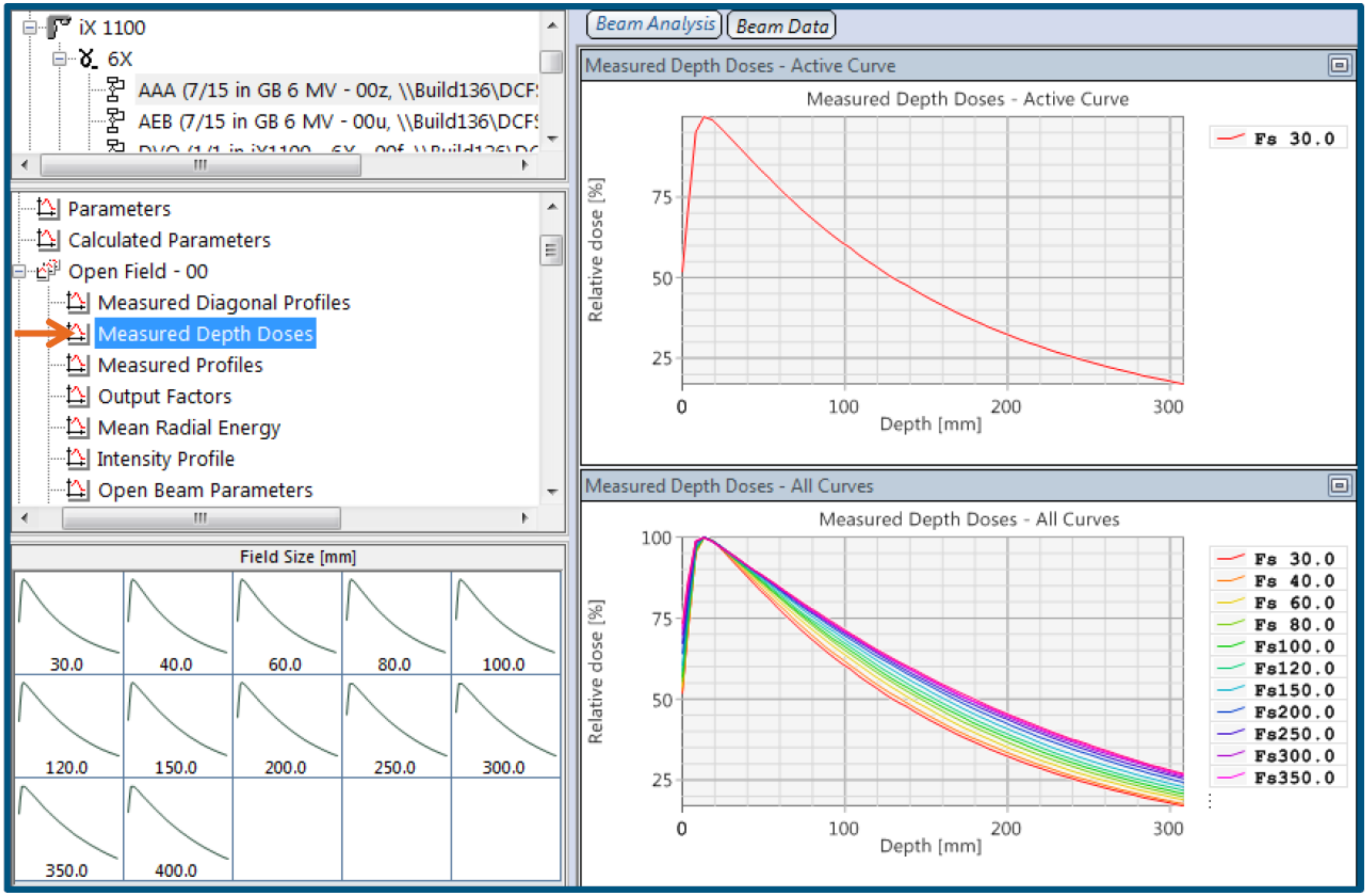


Pinnacle Modeling Process



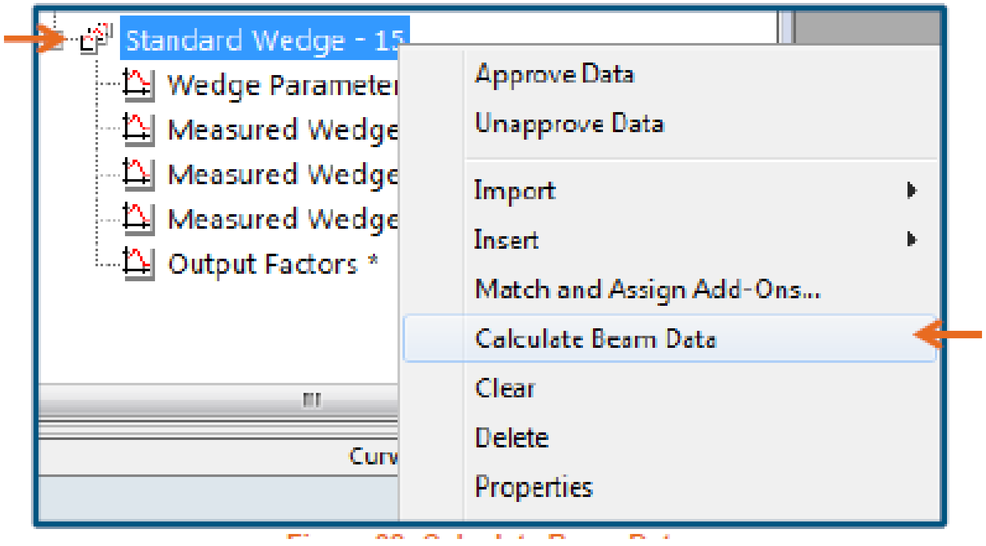


Eclipse

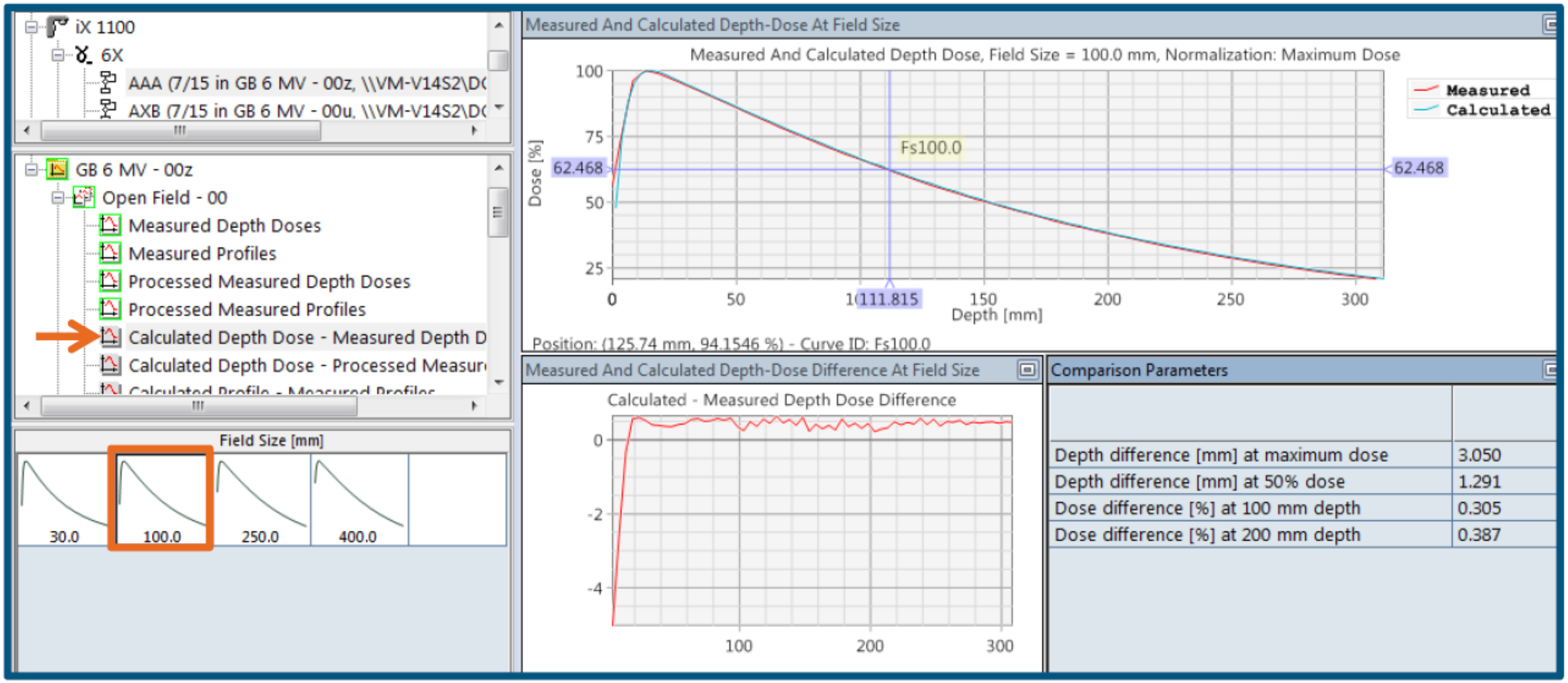


First review the data to ensure it was properly imported

Calculate beam data in Eclipse



Analysis in Eclipse



Depth difference [mm] at maximum dose	3.050
Depth difference [mm] at 50% dose	1.291
Dose difference [%] at 100 mm depth	0.305
Dose difference [%] at 200 mm depth	0.387

Figure 8: Example - PDD Comparison: Calculated vs Measured

Use pre-configured data?

Varian can provide golden beam dta, but with caveats:

Note: *Eclipse Beam Data are valid for Varian Clinac 21/23EX Series medical linear accelerators and other Clinacs conforming to the beam specifications detailed in Sections 1.0 and 2.0 of Clinac 21/23EX Equipment Specification (Document RAD 4205) the clinic iX Accelerator Specifications (Document RAD 9510), the Trilogy Accelerator Specifications (Document RAD 9515), and Clinac Beam Matching (Document RAD 2055). These include all Clinac iX accelerators, all Trilogy accelerators, Clinac 2100C/CD/EX accelerators with Serial Number 865 or later and Clinac 2300CD/EX accelerators with Serial Number 146 or later. For older machines that have been upgraded to EX specifications, it is necessary to confirm that the part number of the 6-MV photon-field-flattening filter is P/N 1103282.*

Caution: *The validation of Preconfigured Eclipse Beam Data imported for use in Eclipse treatment planning and dose calculation is the sole responsibility of the customer.*

Warning from Eclipse manual

- I am a big fan of pre-configured data, if available
- You do still need to verify the TPS calculations
- At a minimum, standard beam data is great for sanity checks
- You also have to decide this yourselves ☺

MLC measurements

Good starting point for understanding different MLCs

AAPM REPORT NO. 72

BASIC APPLICATIONS OF MULTILEAF COLLIMATORS

**Report of Task Group No. 50
Radiation Therapy Committee**

Guidance document on delivery, treatment planning, and clinical implementation of IMRT: Report of the IMRT subcommittee of the AAPM radiation therapy committee

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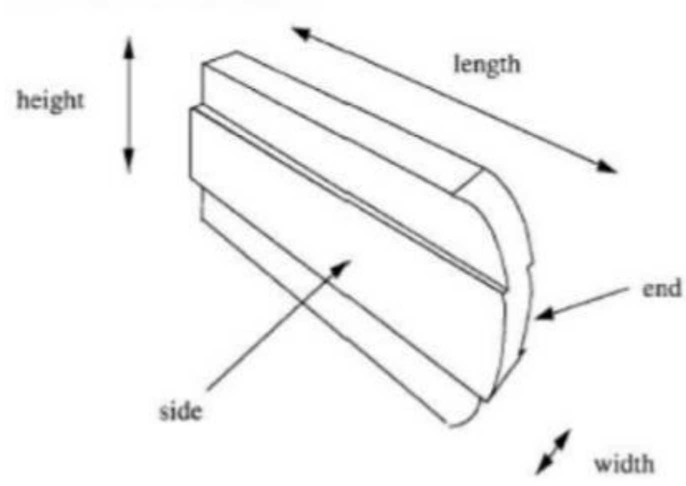
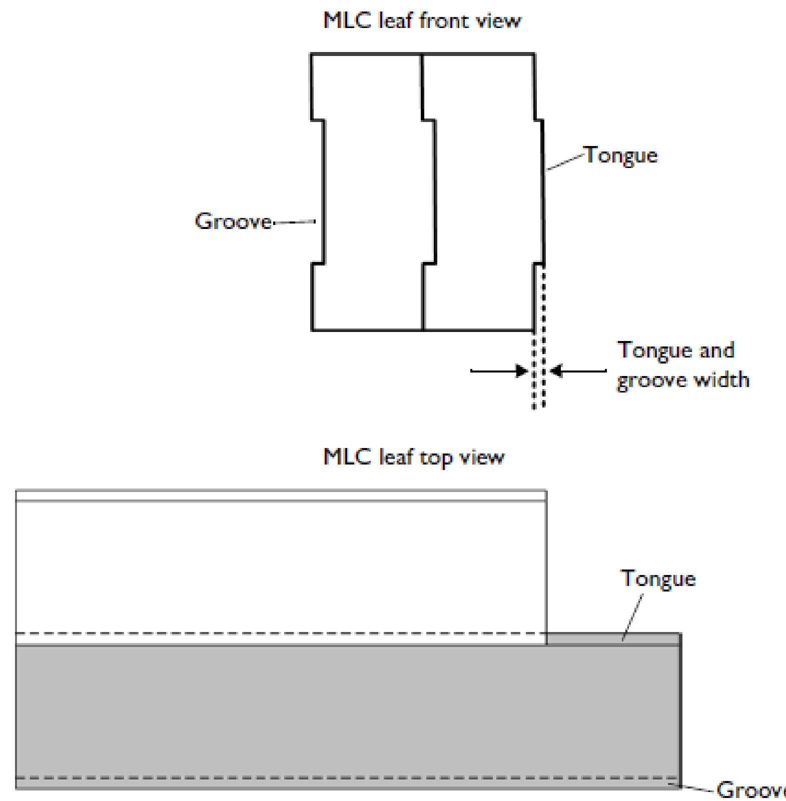
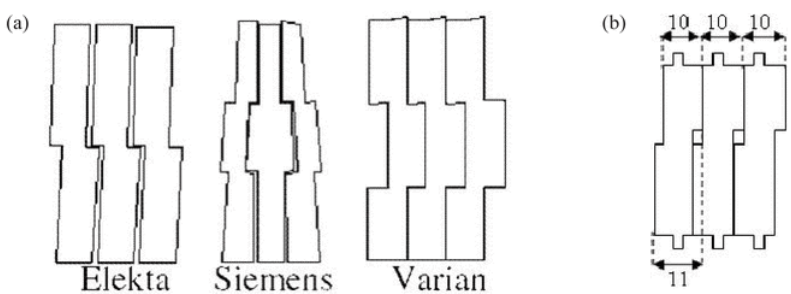
- Leaf transmission (inter-leaf and intra-leaf)
- Dynamic Leaf Gap (leaf edges)
- Tongue and Grove effect







- First measure leaf transmission following vendor recommendations

Rounded leaf ends

- For single focus MLCs a rounded leaf end is used to maintain approximately the same penumbra size as the leaf moves off axis
- This causes the light field to be offset with respect the projected leaf motion

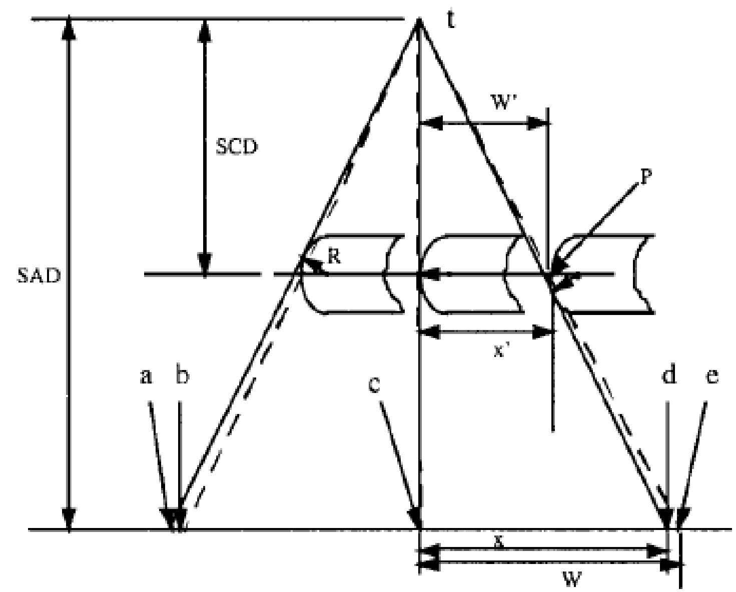


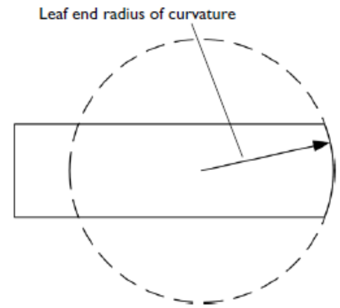
Figure 8. Schematic of ray lines that determine the form of the edge of the radiation field and light field at the curved end of an MLC leaf. SAD is the distance from the source to isocenter and SCD is the distance from the source to the center of the leaf. R is the radius of curvature of the leaf end.

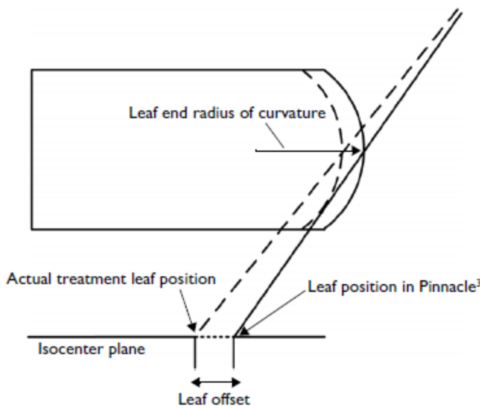
MLC offset table

- The MLC motions on single focused MLCs are not constant as a function of off-axis distance
- On Varian machines the offset is calculated to make the light field always agree with the position programed in the MLC controller
- On the Elekta machine the offset is calculated to make the 50% radiation line match the position programed in the MLC controller
- Some TPS require that these offset tables are entered into the TPS for proper calculation of dose (e.g. Pinnacle)
- Be careful that you understand and follow the vendor's specifications
- Some TPS (e.g. Eclipse) have already included these offsets – and they are not editable by the user.

2.2 Rounded leaf ends

The rounded leaf end is modeled as a circle segment that extends between the top and bottom of the MLC leaf (defined by MLC leaf thickness). The rounded leaf end model approximates the actual shape for the leaves that do not have a perfectly circular profile. The radiation through the leaf tip is attenuated by the thickness of the leaf traversed by the beam at each point in the tip.





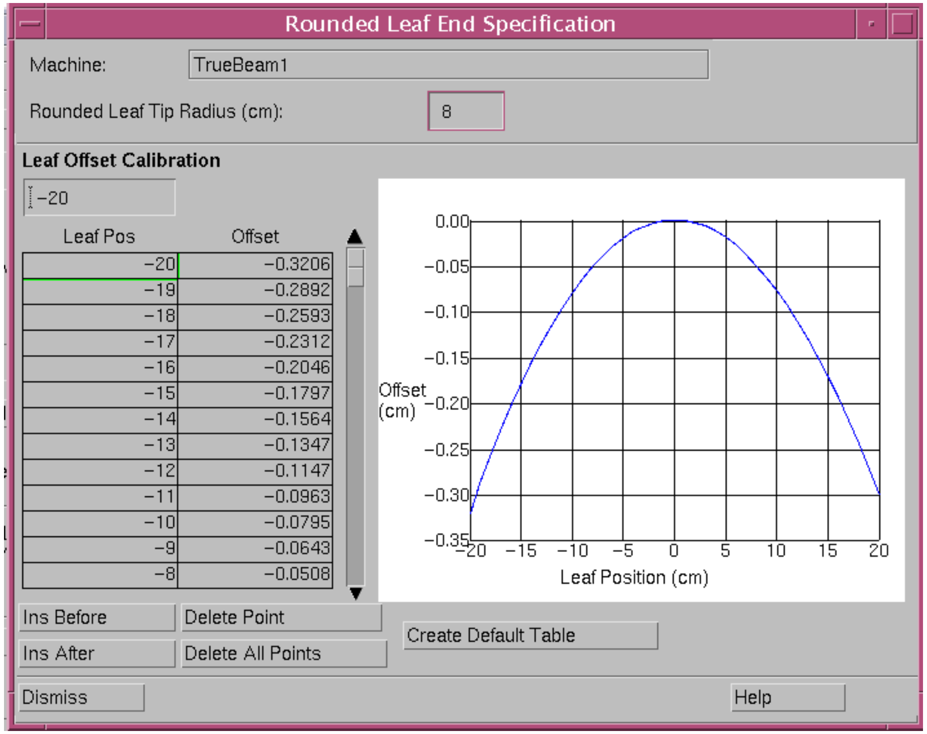
The radius of curvature for the MLC leaves in published literature is about 8 cm for a Varian MLC[1], and this is the default in Pinnacle[3]. The radius of curvature for Elekta MLC leaves should be approximately 12.2 cm for

4/3/2017

Interpretation of the MLC position in Pinnacle

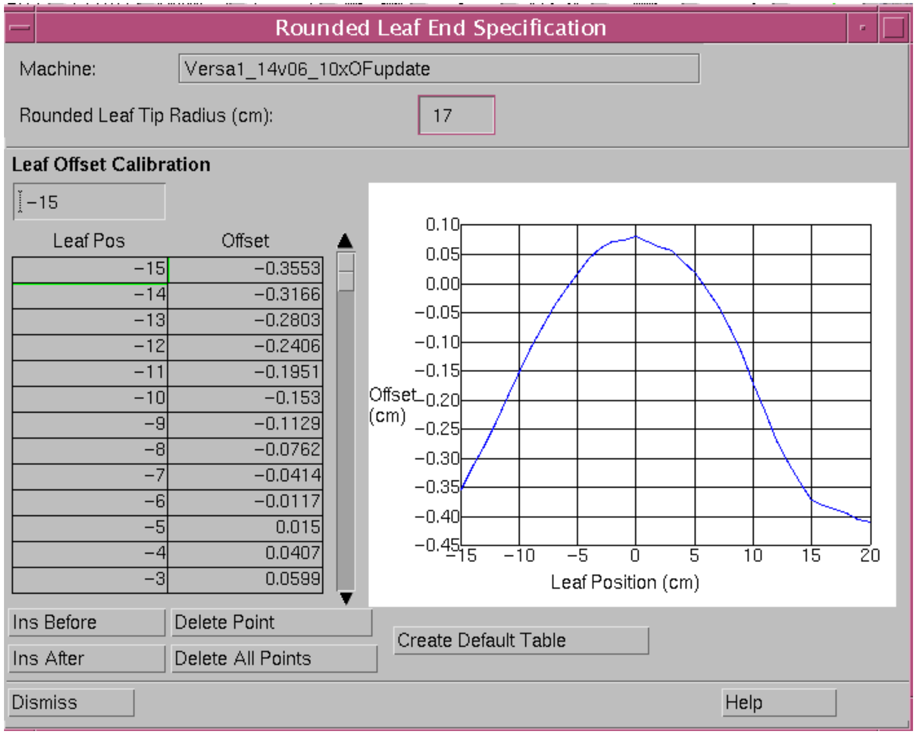
MLC offset table

Should be a physical set of parameters stored in the MLC controller
Needs to be verified against measurements
Can be used as a “tuning parameter” in beam modeling



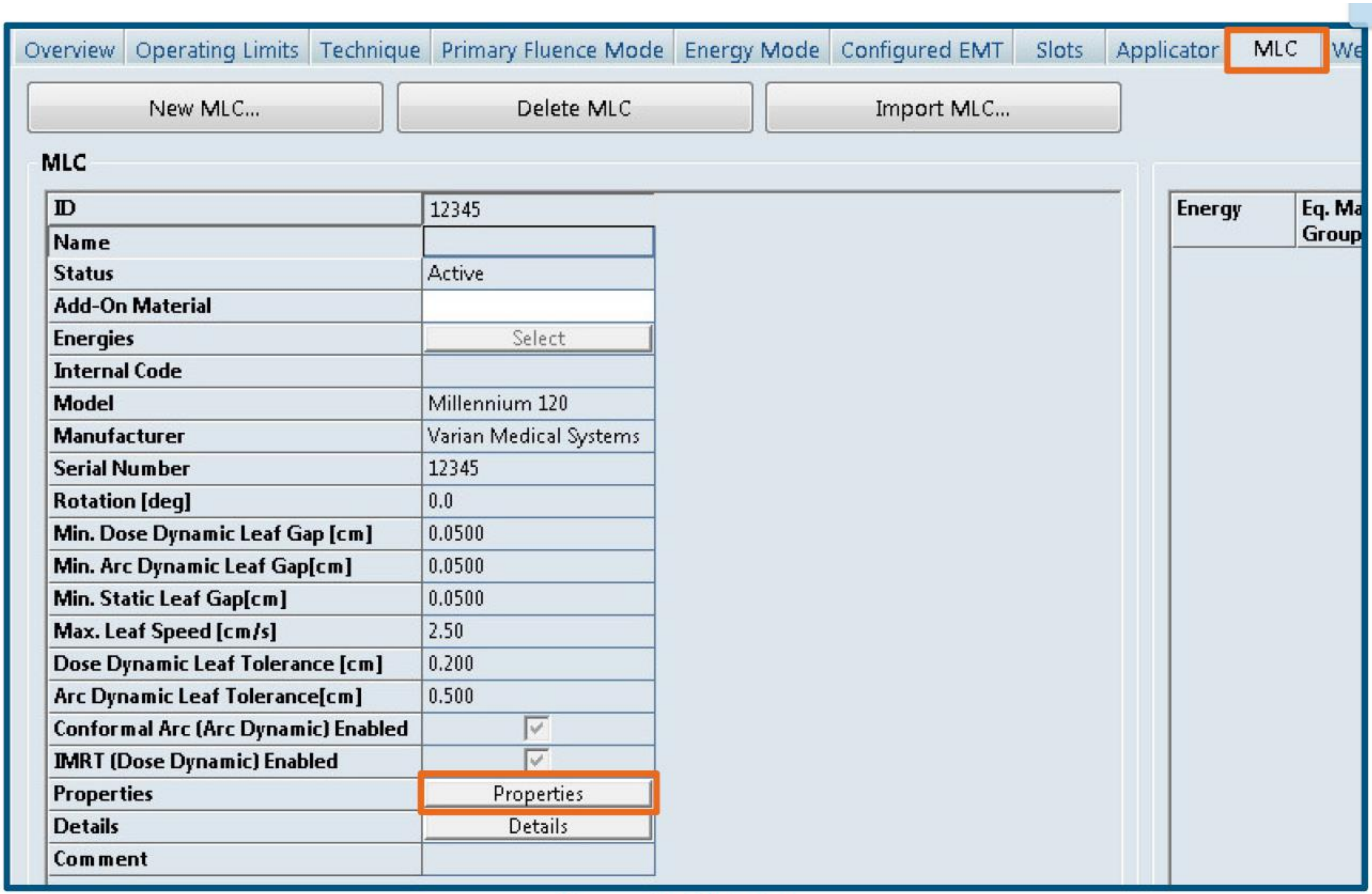
Leaf Pos	Offset
−20	−0.3206
−19	−0.2892
−18	−0.2593
−17	−0.2312
−16	−0.2046
−15	−0.1797
−14	−0.1564
−13	−0.1347
−12	−0.1147
−11	−0.0963
−10	−0.0795
−9	−0.0643
−8	−0.0508

Varian (from manufacturer)

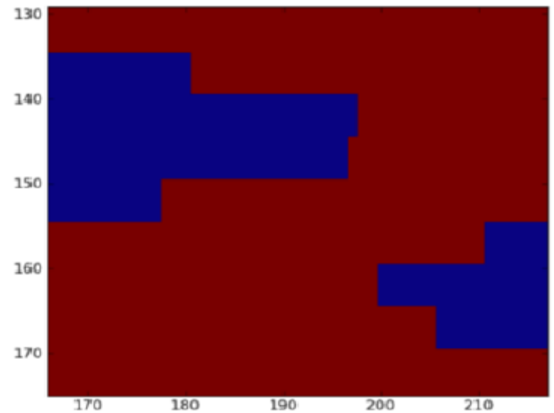


Leaf Pos	Offset
−15	−0.3553
−14	−0.3166
−13	−0.2803
−12	−0.2406
−11	−0.1951
−10	−0.153
−9	−0.1129
−8	−0.0762
−7	−0.0414
−6	−0.0117
−5	0.015
−4	0.0407
−3	0.0599

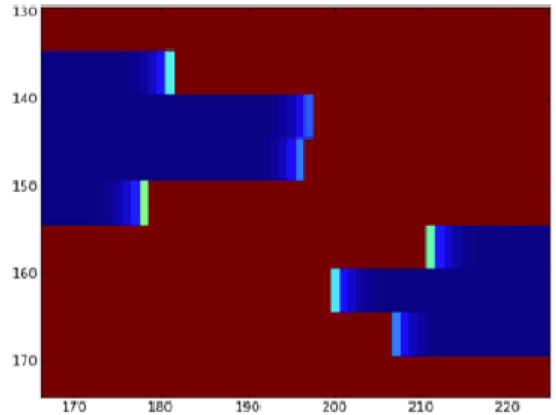
Elekta(empirically determined)


Overview
Operating Limits
Technique
Primary Fluence Mode
Energy Mode
Configured EMT
Slots
Applicator
MLC
New MLC...
Delete MLC
Import MLC...
MLC
ID
12345
Name
Status
Active
Add-On Material
Energies
Select
Internal Code
Model
Millennium 120
Manufacturer
Varian Medical Systems
Serial Number
12345
Rotation [deg]
0.0
Min. Dose Dynamic Leaf Gap [cm]
0.0500
Min. Arc Dynamic Leaf Gap[cm]
0.0500
Min. Static Leaf Gap[cm]
0.0500
Max. Leaf Speed [cm/s]
2.50
Dose Dynamic Leaf Tolerance [cm]
0.200
Arc Dynamic Leaf Tolerance[cm]
0.500
Conformal Arc (Arc Dynamic) Enabled
IMRT (Dose Dynamic) Enabled
Properties
Properties
Details
Details
Comment
Energy

Dynamic leaf gap (Eclipse)



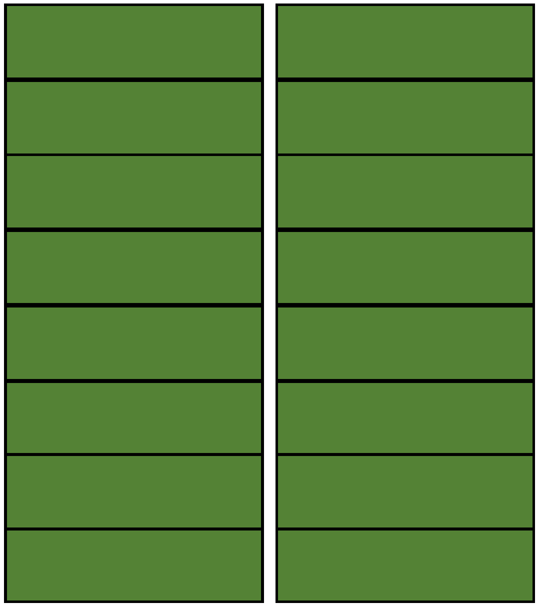
Ideal fluence map

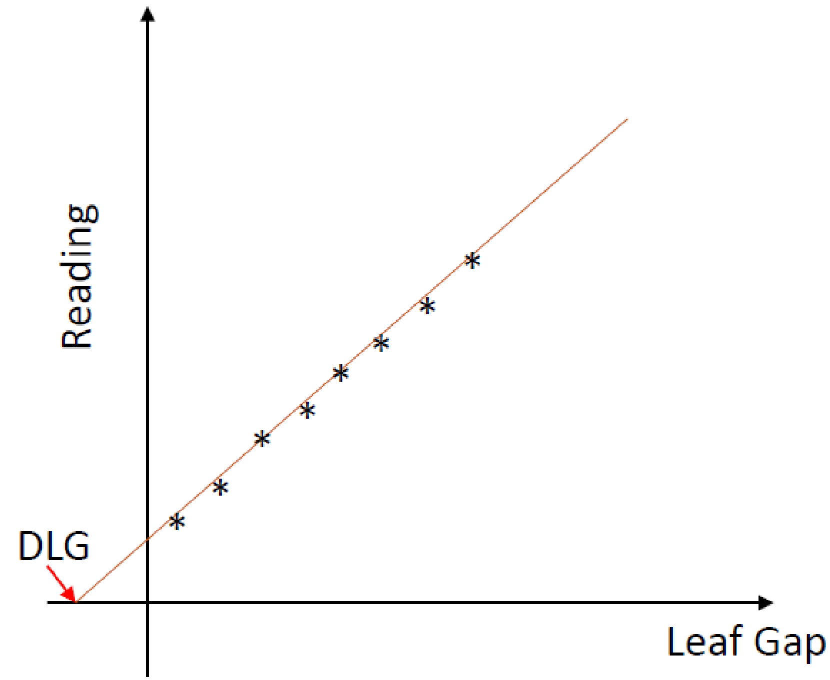


Actual fluence map

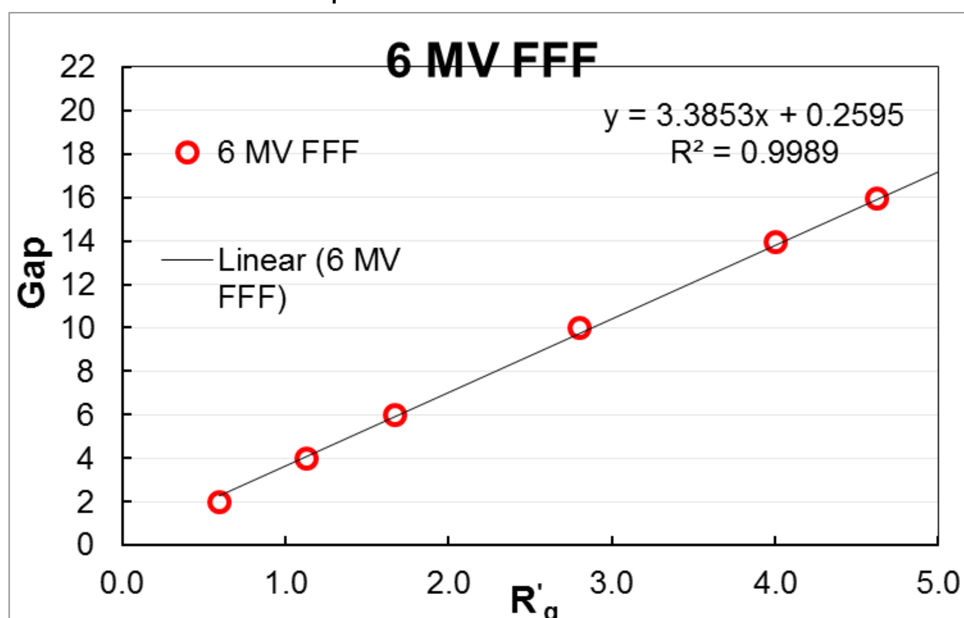
Based on a slide by Ke Sheng

Measure output for MLC leaf gaps varying from 1 to 20 mm.





DLG is typically around 1-2 mm



Based on a slide by Ke Sheng

Dose calculations are sensitive to DLG setting

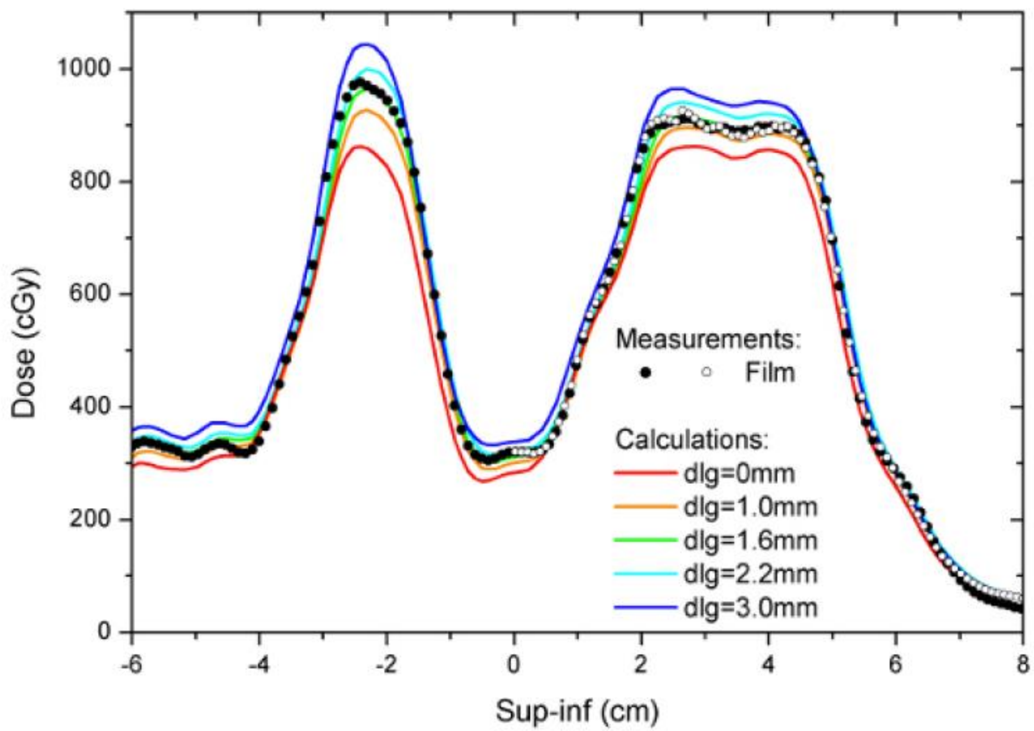


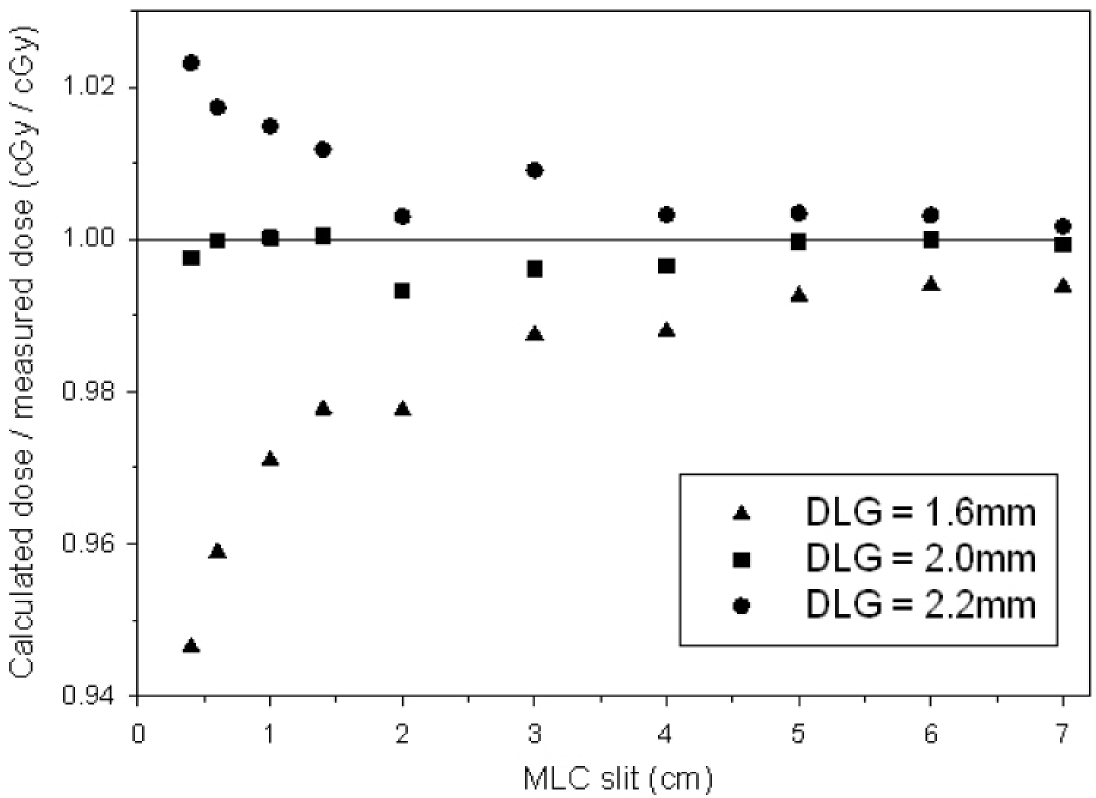
FIG. 4. The calculated and measured with film superior–inferior profiles across two PTVs in the VMAT plan analyzed in the Results section A.1. The calculated dose (color lines) in the center of each PTV increases with an increase of the DLG and matches the measured profile (black circles) for the DLG of about 1.6 mm (green line). Repeated film measurements are plotted as open circles.

Note: reduction in DLG has a similar effect to reduction in leaf transmission

Figure from Szpala et al, JACMP 15(2), 67-84, 2014

Also see Keilar et al, Med Phys 39(10), 6360-6371, 2012 for similar results

Impact of DLG error reduced for larger MLC slits

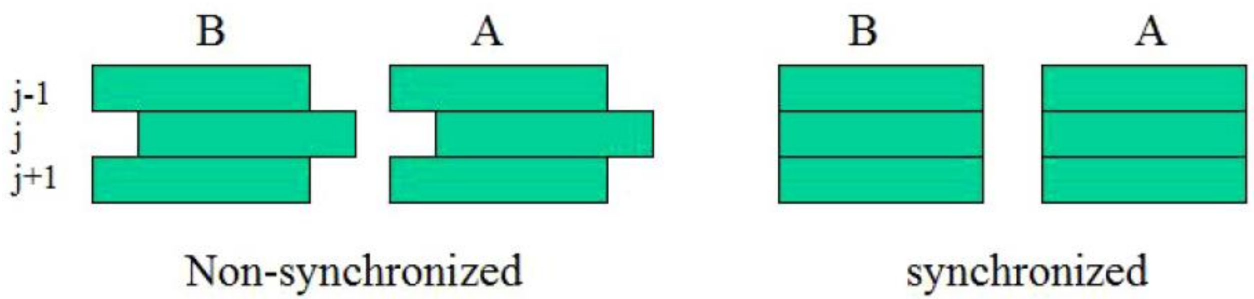


Szpala et al, JACMP 15(2), 67-84, 2014

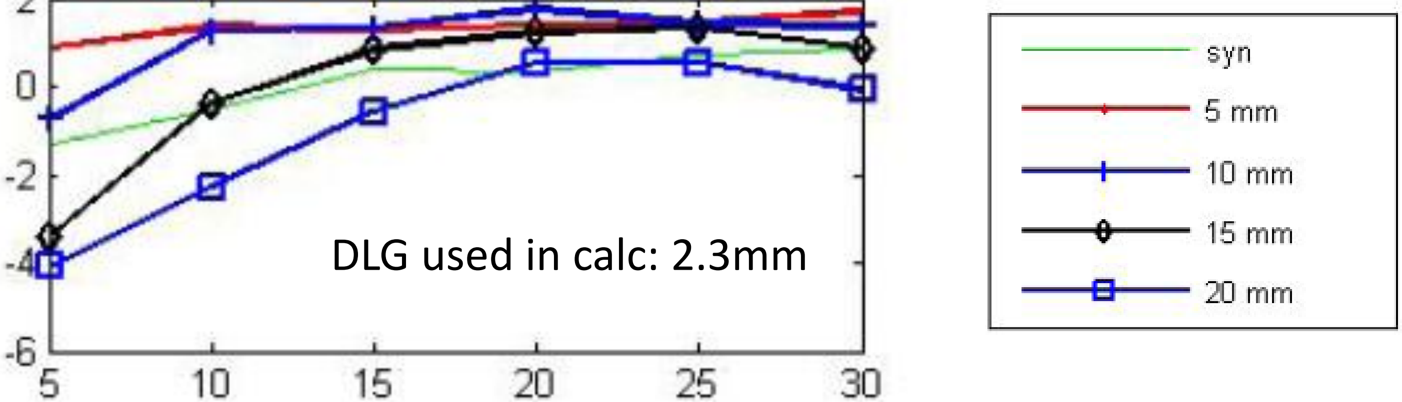
JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 16, NUMBER 4, 2015

Determining the optimal dosimetric leaf gap setting for rounded leaf-end multileaf collimator systems by simple test fields

Weiguang Yao[a] and Jonathan B. Farr
Department of Radiation Oncology, St. Jude Children's Research Hospital, Memphis, TN, USA



T&G extensions



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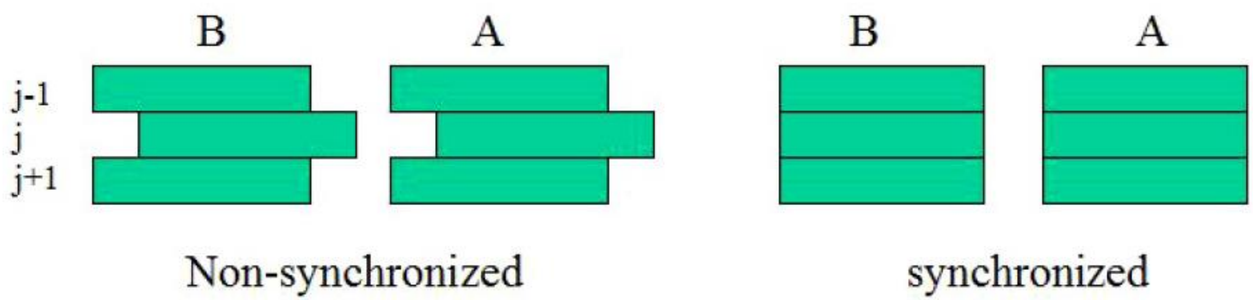


MLC System	*Linac*	*MLC TR (%)*	*Optimal DLG From Test Fields (mm)*	*DLG From Extrapolation (mm)*
Millennium 120	Trilogy	1.4	2.3	1.6
Millennium 120	Clinac 2300 iX	1.4	2.3	1.6
Millennium 120	Clinac 21 EX	1.4	2.5	1.8
High definition 120	TrueBEAM STx	1.3	0.6	0.3
Siemens 160	Artiste 1	0.26	0.3	0.2

DLG summary

- More segments with large gaps and small T&G extensions (i.e. large fields) increases the dose agreement
- Measuring DLG is a good starting point, but need additional IMRT or VMAT data to finetune
- Should review data after initial experience to see if additional fine tuning is needed.

Calculation Validation

Repeat for each individual beam

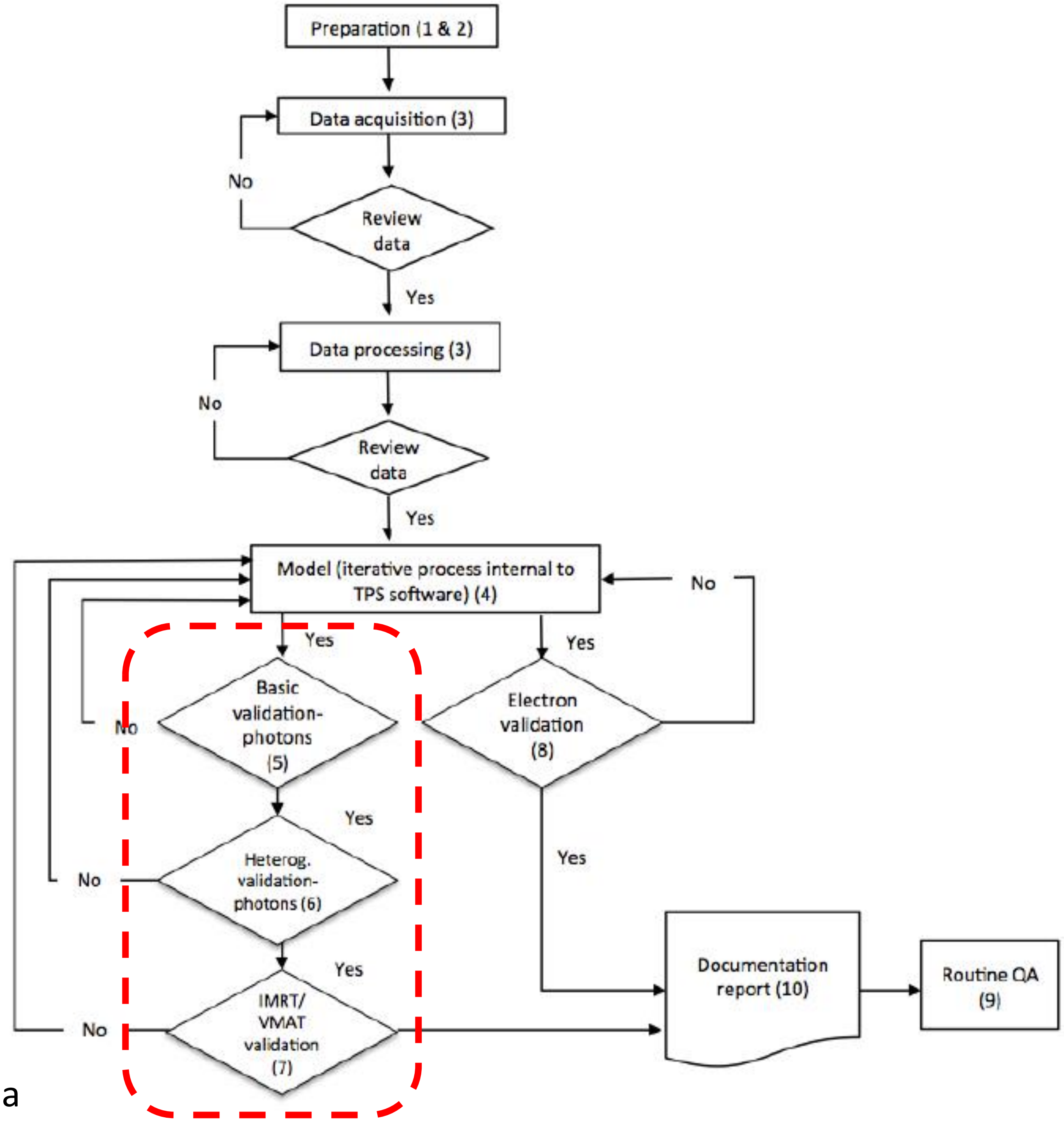


Figure from MPPG5a

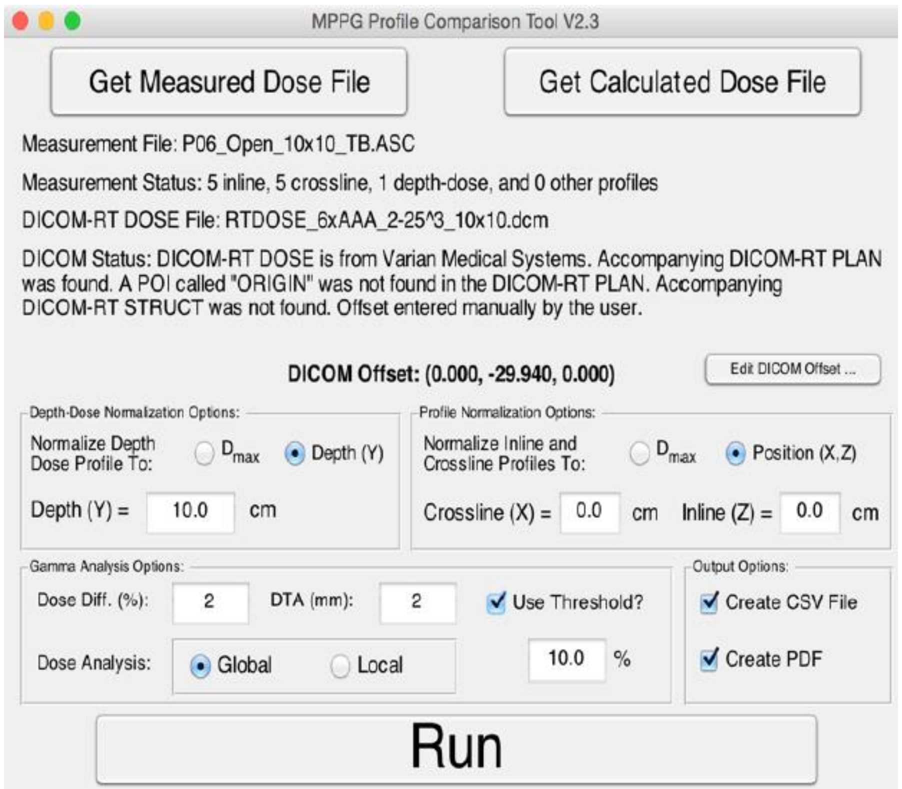
MPPG5a spreadsheet available on github

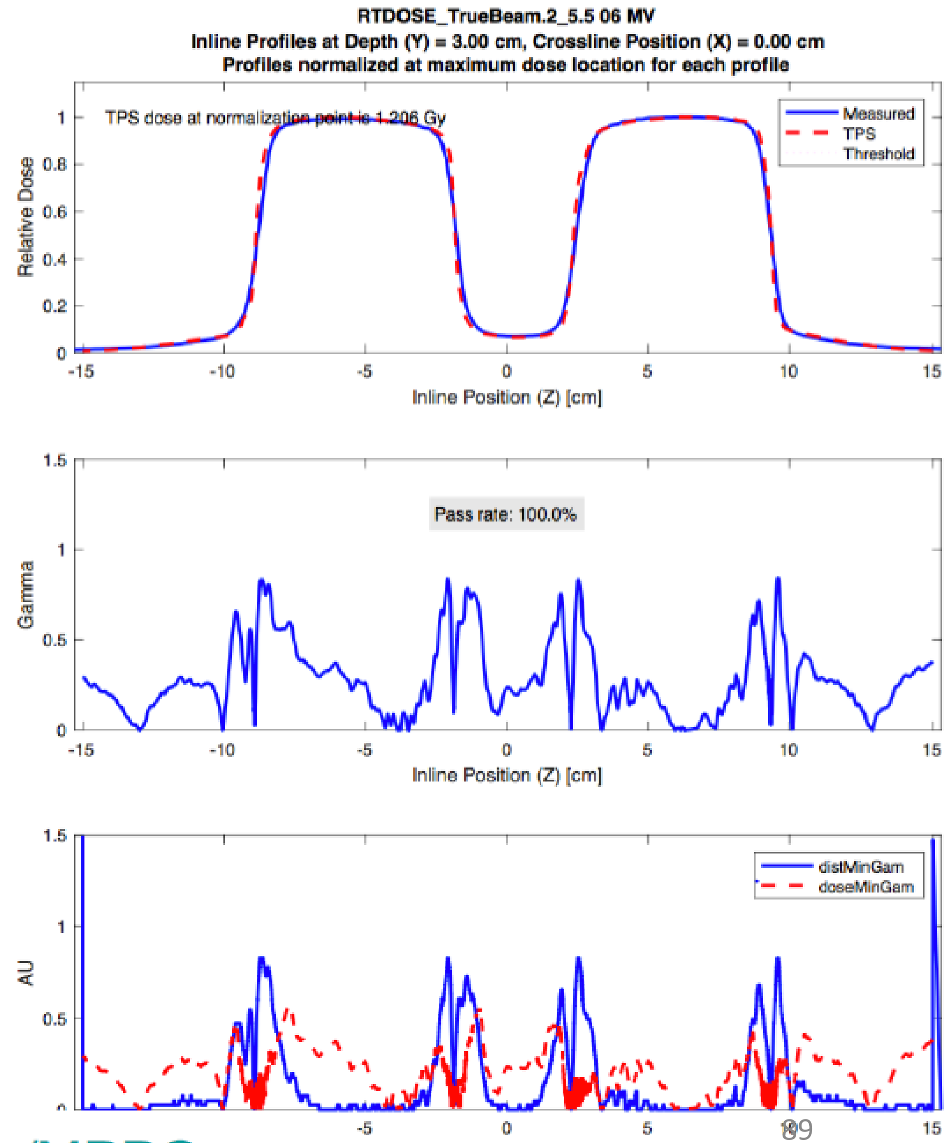
	A	B
1	**MPPG Validation Summary**	
2		
3	Institution	
4	Treatment Delivery System	
5	Treatment Planning System	
6	Version	
7	Machine	
8	Photon Model	
9	Electron Model	
10	oriented paralled to couch.	
11		
12	**Test**	**Status**
13	5.1 Physics. vs Plan data	
14	5.2 Abs Dose	
15	5.3 Comm. vs. Plan data	
16	5.4 Small MLC	
17	5.5 Large MLC	
18	5.6 Off Axis	
19	5.7 Asym 80 SSD	
20	5.8 Obliques	
21	5.9 EDW	
22	6.1 CT-Density Cal.	
23	6.2 Heterogeneity	
24	7.1 Small MLC PDD and OF	
25	7.2 Small MLC shapes OF	
26	7.3 TG 119	
27	7.4 Clincal DQA	
28	7.5 External	
29	8.1	
30	8.2	
31	8.3	
32		

Summary | 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 | 6.1 | 6.2 | 7.1 & 7.2 | 7.3 | 7.4 | 8.0 | 8.1 | 8.2 | 8.3

- https://github.com/Open-Source-Medical-Devices/MPPG

MPPG5a profile comparison tool
https://github.com/Open-Source-Medical-Devices/MPPG





MPPG5: Basic condition tolerances

TABLE 5. Basic TPS photon beam evaluation methods and tolerances.

Region	*Evaluation Method*	*Tolerance*[a] *(consistent with IROC Houston)*
High dose	Relative dose with one parameter change from reference conditions	2%
	Relative dose with multiple parameter changes[b]	5%
Penumbra	Distance to agreement	3 mm
Low-dose tail	Up to 5 cm from field edge	3% of maximum field dose

[a] Tolerances are relative to local dose unless otherwise noted.
[b] For example, off-axis with physical wedge.

TABLE 6. Heterogeneous TPS photon beam validation tests.

Test	*Objective*	*Description*	*Tolerances*[a]	*Reference*
6.1	Validate planning system reported electron (or mass) densities against known values	CT-density calibration for air, lung, water, dense bone, and possibly additional tissue types	–	TG 65,[26] IAEA TRS-430[7]
6.2	Heterogeneity correction distal to lung tissue	5×5 cm^2, measure and calculate dose ratio above and below heterogeneity, outside of the buildup region	3%	IAEA TRS-430,[7] Carrasco et al.[28]

[a] Tolerances are relative to local dose unless otherwise noted.

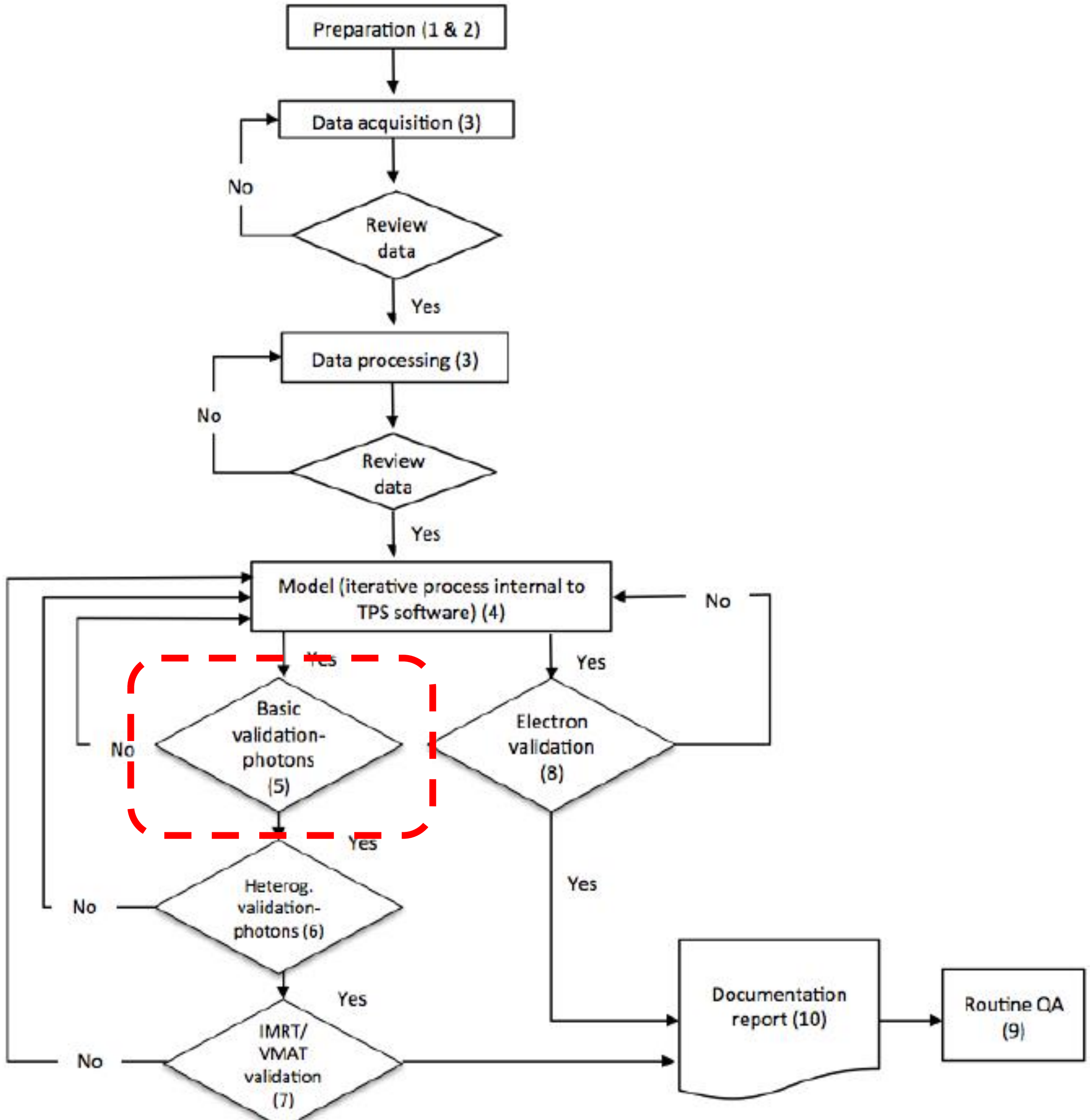


Figure from MPPG5a

TABLE 3. TPS model comparison tests and tolerances.

Test	*Comparison*	*Description*	*Tolerance*
5.1	Dose distributions in planning module vs. modeling (physics) module	Comparison of dose distribution for large (> 30×30cm^2) field.	Identical[a]
5.2	Dose in test plan vs. clinical calibration condition[b]	Reference calibration condition check	0.5%
5.3	Dose distribution calculated in planning system vs. commissioning data	PDD and off axis output factors for a large and a small field size	2%

[a] Identical to within the expected statistical uncertainty (considering noise and calculation grid size).
[b] TPS absolute dose at reference point.

TABLE 4. Basic photon beam validation tests summary[a].

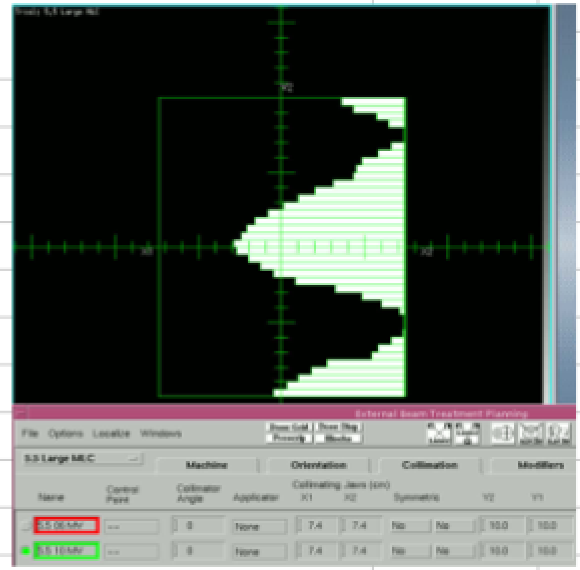
Test	*Description*	*Sample tests from literature*[7]
5.4	Small MLC-shaped field (non SRS)	Photon Test 1
5.5	Large MLC-shaped field with extensive blocking (e.g., mantle)	Photon Test 3
5.6	Off-axis MLC shaped field, with maximum allowed leaf over travel	Photon Test 2
5.7	Asymmetric field at minimal anticipated SSD	Photon Test 6
5.8	10×10 cm^2 field at oblique incidence (at least 20°)	Photon Test 10
5.9	Large (> 15 cm) field for each nonphysical wedge angle[b]	–

[a] For all tests, measurements in the high-dose region, penumbra, and low-dose tail regions should be compared to calculated values at various depths (including slightly beyond dmax, midrange/10–15 cm, and deep/25–30 cm). SSDs, other than those used at commissioning and that reflect the clinically expected range, should be used. The MLC should be used for tests 5.4–5.6. The MLC or jaws may be used for tests 5.7–5.9.

[b] Tests 5.4–5.8 are intended for each open and (hard) wedged field. Nonphysical wedges are considered an extension of the corresponding open field in terms of spectra and only require the addition of Test 5.9.

Example 1: Basic Photon Test: 5.5 Large MLC

Test: 5.5 Large MLC
Description: Profiles of large MLC shaped field with extensive blocking (e.g.: mantle)
Comments: The field shape for this test is shown to the right.



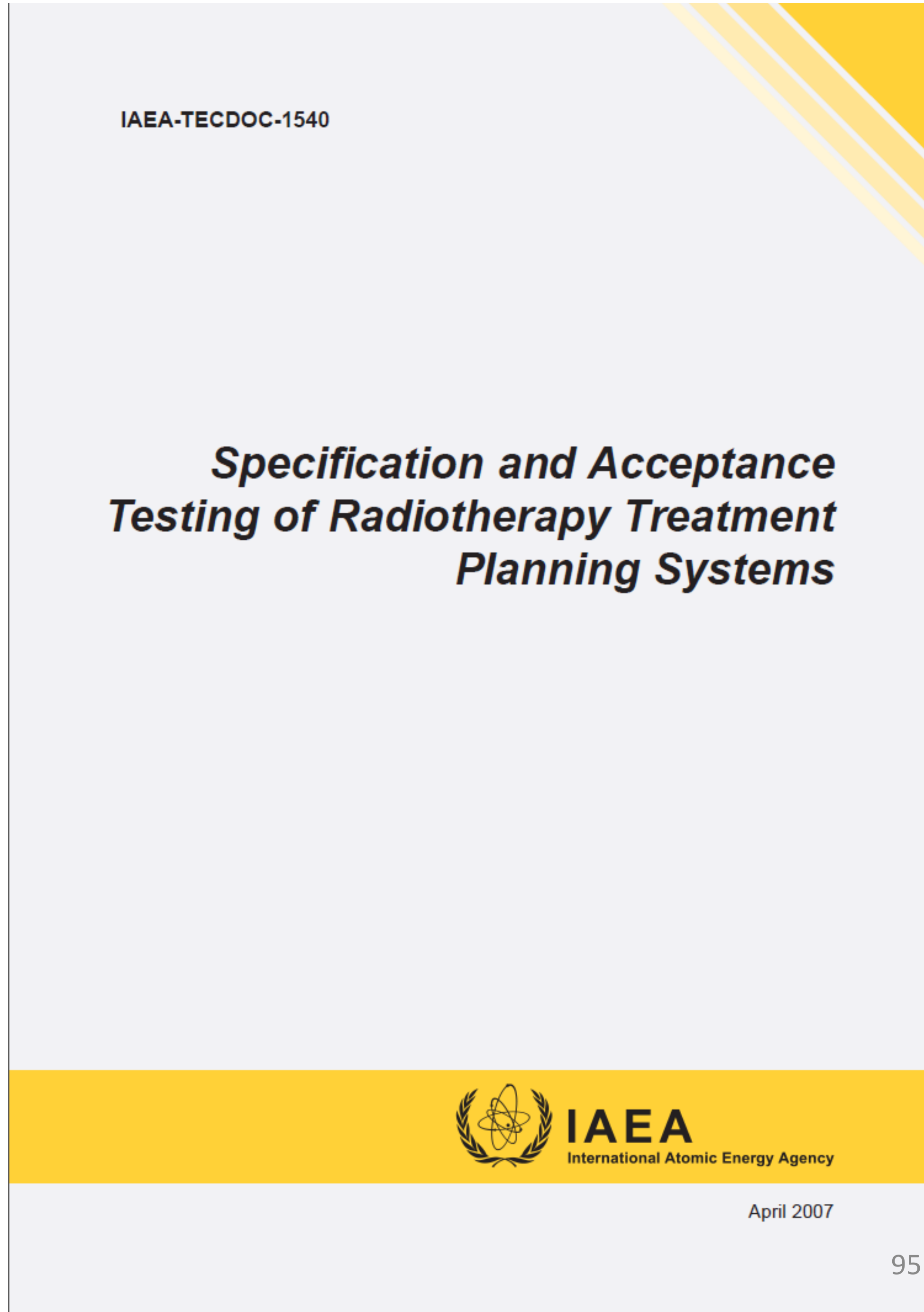
Test Patient: ZZUWQA_Pinnacle, Validation MPPG_Hom
Test Plan: TrueBeam
Trial Name: 5.5 Large MLC
Plan Settings: 2 mm dose grid
Model Version:
Ion chamber (SN): CC13 7307
Ref chamber (SN) CC13 4340
Scan SSD: 90 cm
Inline Profile Depths: 3 cm, 10 cm, 20 cm
Crossline Profile Depths: 10 cm
Data aquired:
By: JS, PY, KS

all scans were extended 4 cm beyond defined field dimension

Profile Passing Rates:

	Pinnacle 9.8				
Criteria: 2%/2mm Global	Inline			Crossline	PDD
Field Name	3 cm	10 cm	20 cm	10 cm	
5.5 06MV	100.0	97.9	92.3	97.7	99.9
5.5 10MV	98.8	99.2	94.8	100.0	99.8

- This report contains a very extensive set of tests



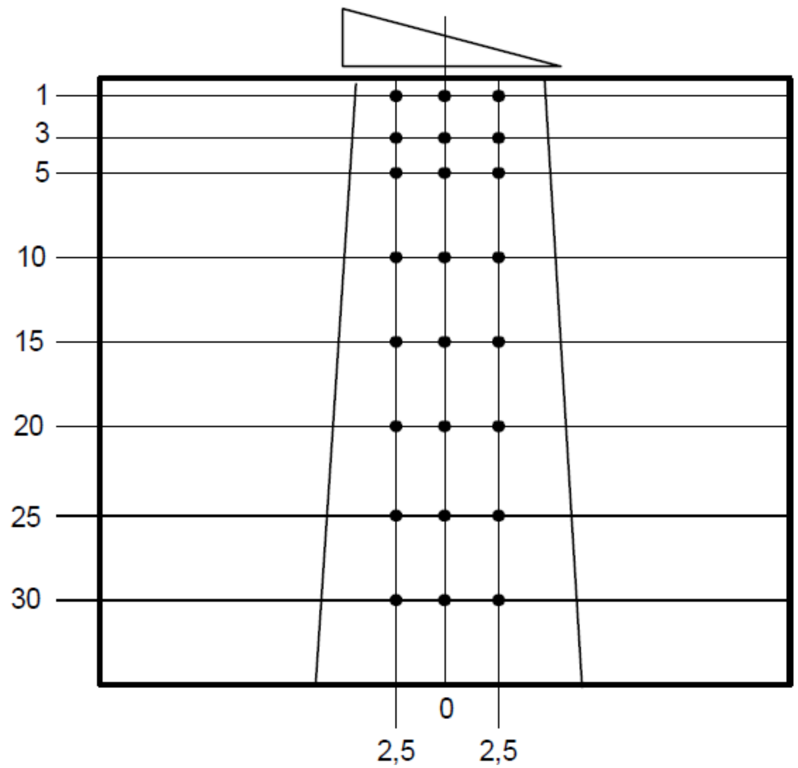
IAEA-TECDOC-1540

Specification and Acceptance Testing of Radiotherapy Treatment Planning Systems

IAEA
International Atomic Energy Agency

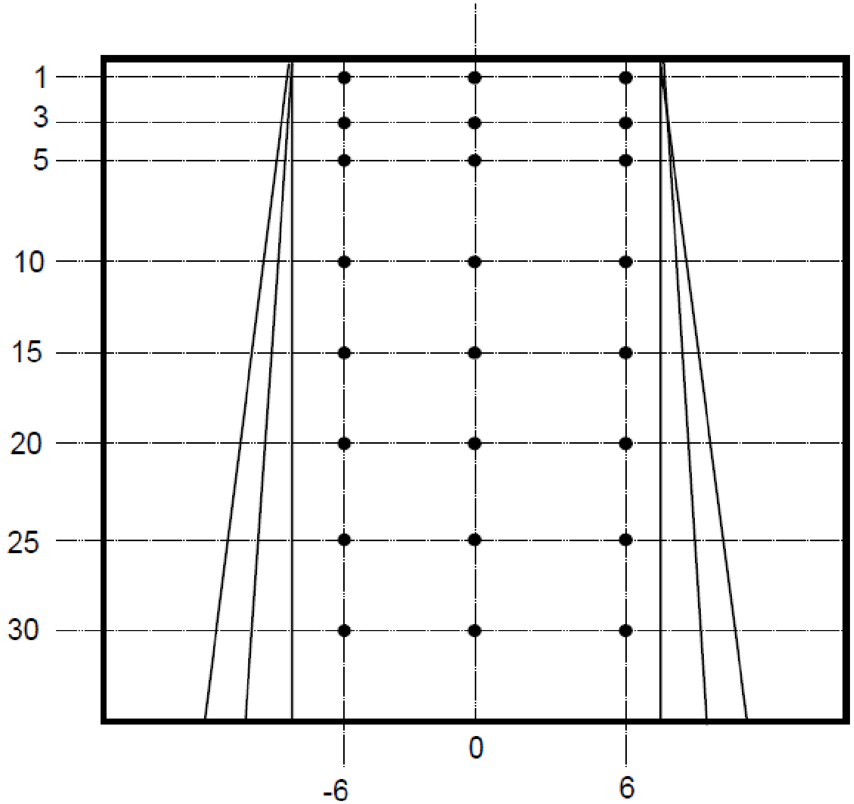
April 2007

- **9cm x 9cm 45deg (Co) or 60deg (LINAC) wedge**. Dose calc ... :m. Depths: 1,3,5,10,1 ...



Type and optional tests include more complicated geometries:

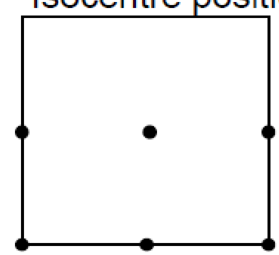
- **Asymmetric open half and quarter wedged fields (LINACs only).**



TEST 11
Asymmetrical open field
TEST 12
Asymmetrical wedged field

Field size 15 cm x 15 cm
SSD = 100 cm

Isocentre positions:



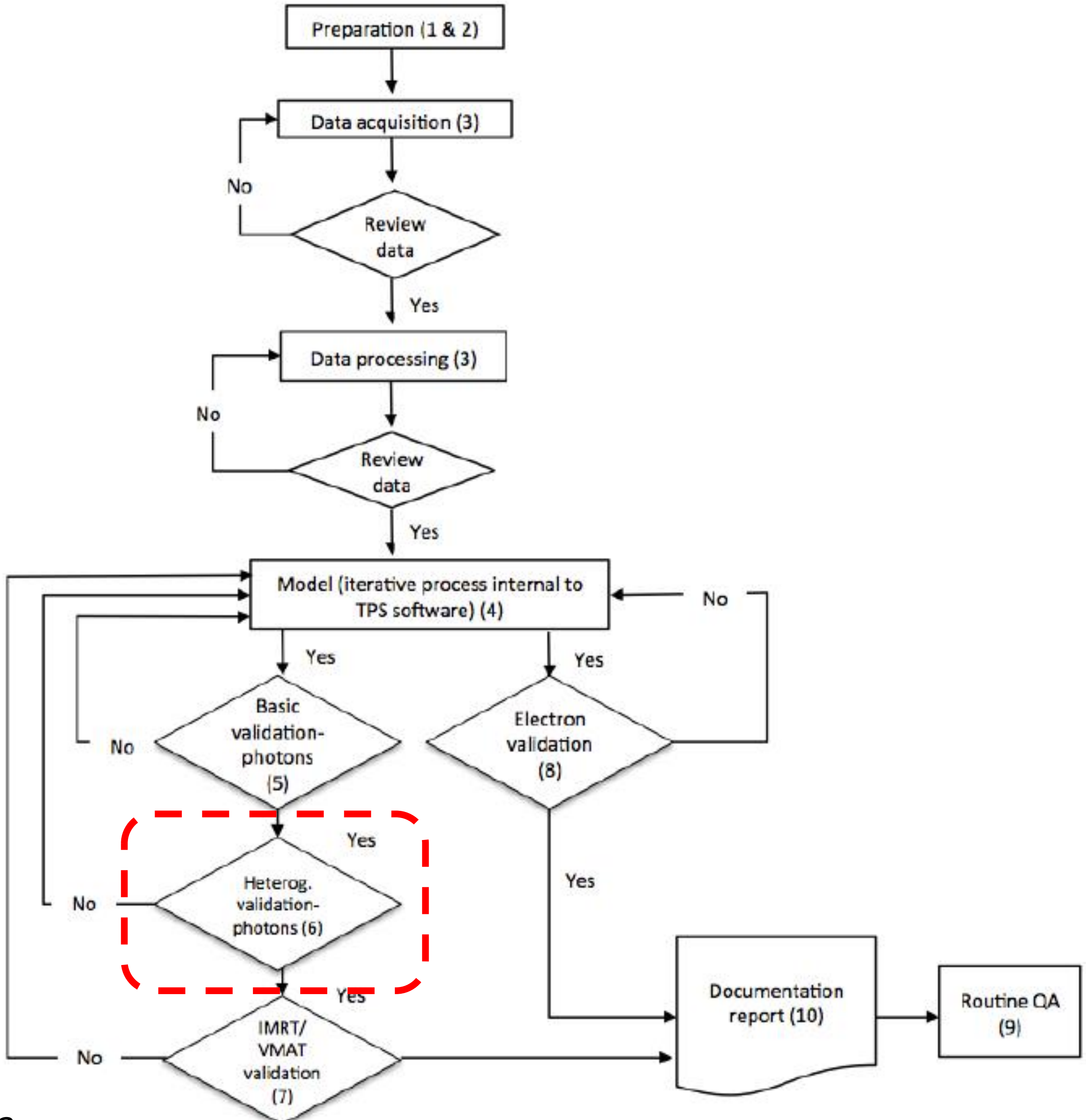
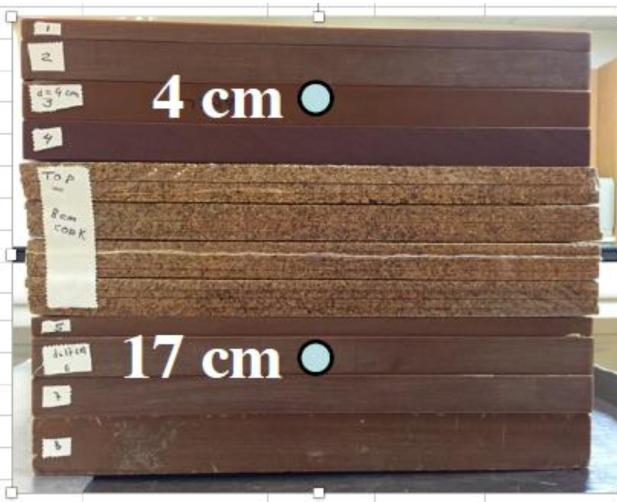


Figure from MPPG5a

Test 6.2. Heterogeneity correction

Test Patient:	ZZUWQA_Pinnacle, Validation MPPG_Het		
Test Plan:	All machines		
Trial Name:	TrueBeam		
Plan Settings:	2.5 mm dose grid		
Model Version:	6/25/16 8:16		
Measurement SSD:	100		
Field size:	5x5		
Ion chamber:	572	IBA FC65-P	
Electrometer:	NONE (XXXX)	SI CDX 2000B East Electrometer	
Bias:	300	V	
Rep. rate(s):	600/1200	MU/min	FFF both at 1200
MU:	100		
Data aquired:	2016-05-27		
By:	PY, JS		



Point Dose Results:									
3% tolerance		**Measurement**				**Pinnacle V 9.8**			
Beam	**Depth**	**M1**	**M2**	**Mave**	**ratio**	**Calc Dose. (cGy)**	**ratio**	**% Diff**	**Within 3%?**
6 MV	4	15.98	15.98	15.98		0.839			
	17	9.03	9.00	9.02	0.564	0.474	0.565	-0.14%	Yes
10 MV	4	17.38	17.38	17.38		0.895			
	17	10.70	10.69	10.70	0.615	0.548	0.612	0.50%	Yes
6 MV FFF	4	15.96	15.94	15.95		0.84			
	17	8.59	8.58	8.59	0.538	0.45	0.536	0.47%	Yes
10 MV FFF	4	17.63	17.65	17.64		0.91			
	17	10.50	10.49	10.50	0.595	0.531	0.584	1.96%	Yes

IAEA-TECDOC-1583

Commissioning of Radiotherapy Treatment Planning Systems: Testing for Typical External Beam Treatment Techniques

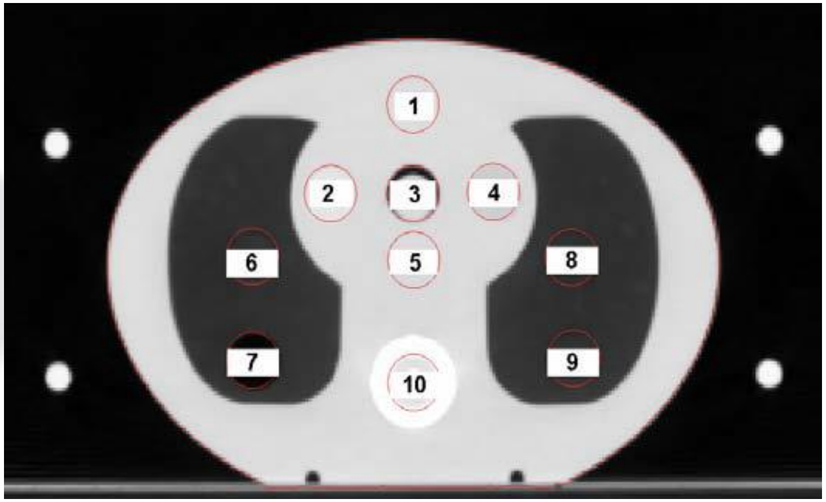
Report of the Coordinated Research Project (CRP) on Development of Procedures for Quality Assurance of Dosimetry Calculations in Radiotherapy

(end-to-end treatment planning tests)

IAEA
International Atomic Energy Agency

January 2008

- IAEA examples are with this CIRS phantom
- Any appropriate phantom can be used (IAEA Technical Report Series No. 430)



http://www.cirsinc.com/products/all/12/imrt-thorax-phantom/

Case 2: Oblique incidence, lack of scattering and tangential fields

The purpose of this test is to verify calculations in case of lack of scattering for the tangential field. A 15 cm x 10 cm field with a wedge and a gantry angle of 90° and collimator angle depending on the wedge orientation is used. This test corresponds to photon tests 7, 10 and MU test 2 in TRS 430.

Case	Number of beams	Set-up	Reference point	Measurement point	Field Size [cm] L x W	Gantry angle	Collimator angle	Beam modifiers
2	1	SAD	1	1	15x10 RL	90	0 or based on wedge orientation	45 degree wedge or the largest wedge angle available

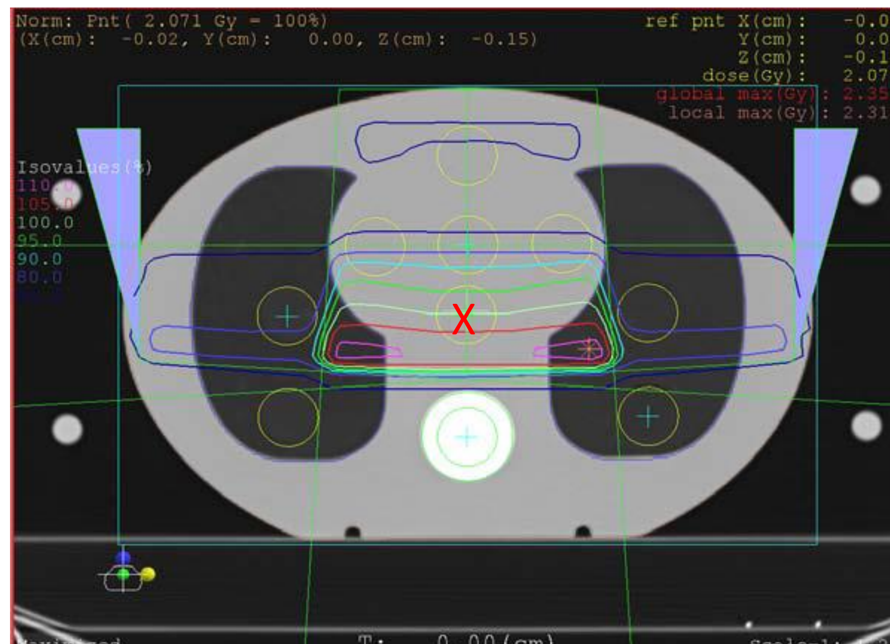
- Create plan (2Gy to reference point)
- Check with manual MU/time calculation
- Position phantom
- Treat (with ionization chamber at reference point)
- Repeat 3+ times
- Compare measured and calculated values (3% criterea)
- Repeat for each dose calculation algorithm

Case 7: Three fields, two wedge-paired, asymmetric collimation

The purpose of this test is to verify the calculations with wedge-paired fields and asymmetric collimation (if asymmetric collimators are not available, half-beam block may be used). This test corresponds to MU test 3 and overall clinical test 3 a described in TRS-430.

Case	Number of beams	Set up	Reference point	Measurement point	Field Size [cm] L x W	Gantry angle	Collimator angle	Beam modifiers
7	3	SAD	5	5	10x12	0	0	None
					10x6 assym	90	According to wedge orientation	Physical wedge 30° Soft wedge 30°
					10x6 assym	270		

Location of measuring point		Agreement criterion [%]
5	F1: 0°	2
	F1: 90°	4
	F1: 270°	4
	Σ	



VMAT/IMRT

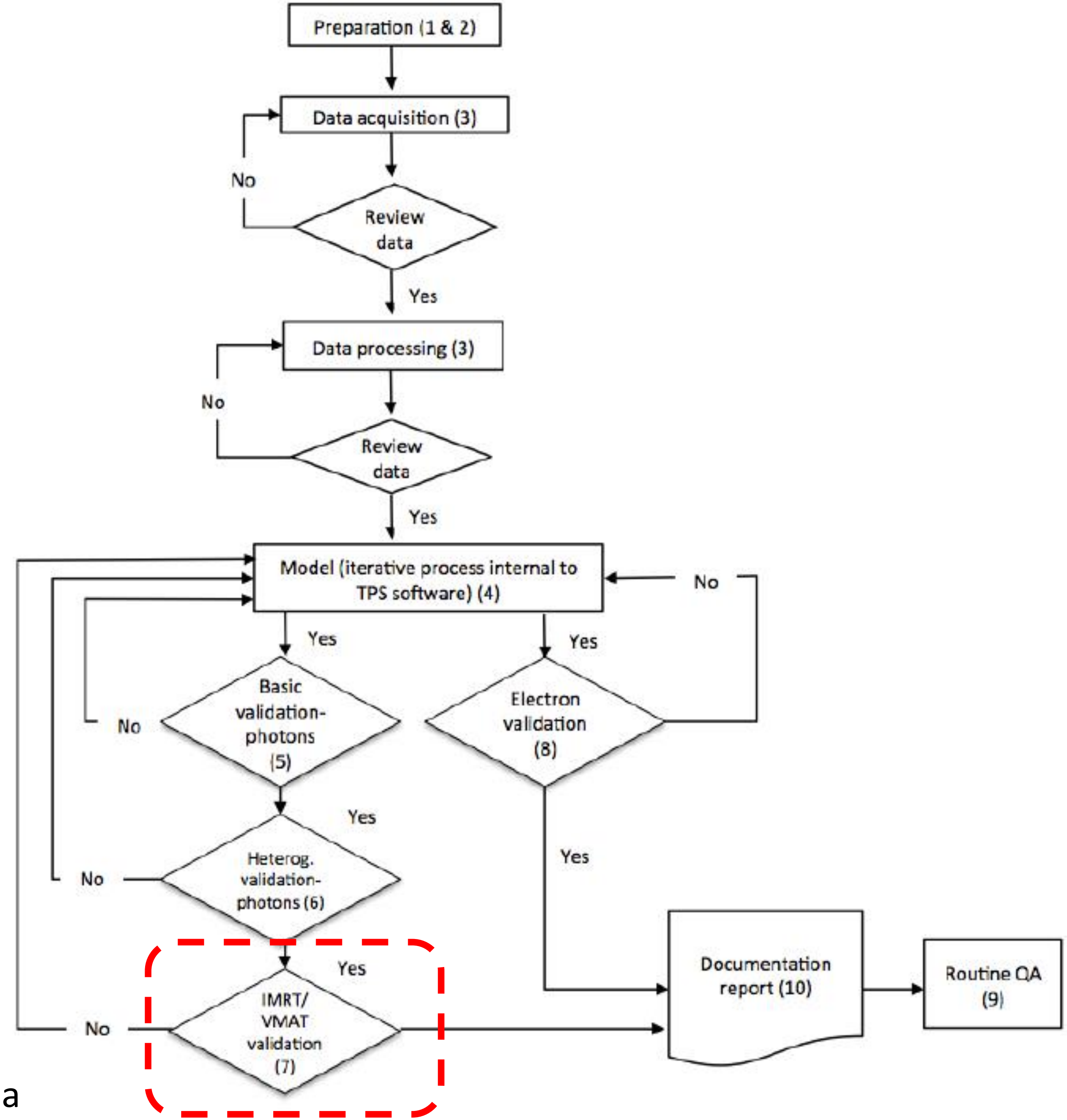


Figure from MPPG5a

Some additional settings in the TPS. E.g. Dose Rate in Pinnacle

- In the Pinnacle beam Model
  - We will underestimate the maximum dose rate:
    - Ensures the Pinnacle VMAT plans will not violate machine capabilities
- Because we want to use one Pinnacle model for both of our Versa's
  - We will use the lesser of the two maximum dose rates

- VMAT delivery
  - Elekta will take the Pinnacle generated plan from Mosaiq, and calculate a way to deliver it as fast as it can.
  - Because machines will have different dose rates, the VMAT plan delivered will be slightly different for each.
  - Uses continuously variable dose rate
    - 256 bins between max dose rate and about 37 MU/min

MPPG5 VMAT.IMRT test summary

Table 7. VMAT/IMRT test summary.

Test	*Objective*	*Description (example)*	*Detector*	*Ref*
7.1	Verify small field PDD	≤ 2×2 cm^2 MLC shaped field, with PDD acquired at a clinically relevant SSD	Diode or plastic scintillator	Yunice et al.[16]
7.2	Verify output for small MLC-defined fields	Use small square and rectangular MLC-defined segments, measuring output at a clinically relevant depth for each[a]	Diode, plastic scintillator, minichamber or microion chamber	Cadman et al.[58]
7.3	TG-119 tests	Plan, measure, and compare planning and QA results to the TG119 report for both the Head and Neck and C-shape cases	Ion chamber, film and/or array	TG-119 (Ezzell et al.[37])
7.4	Clinical tests	Choose at least 2 relevant clinical cases; plan, measure, and perform an in-depth analysis of the results	Ion chamber, film and/or array	Nelms et al.[42]
7.5	External review	Simulate, plan, and treat an anthropomorphic phantom with embedded dosimeters.	Various options exist[b]	Kry et al.[39]

[a] A bar pattern scanned with a diode can be used to obtain additional absolute dose profile comparison in the direction perpendicular to MLC movement

[b] If IROC Houston service is used, they typically employ TLDs and radiochromic film. Certain commercial phantoms can accommodate ion chambers for point dose measurements

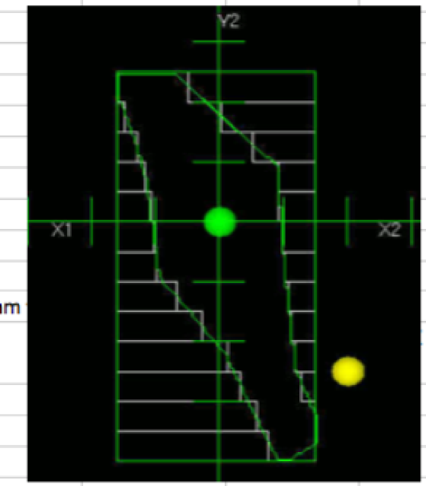
Table 8. VMAT/IMRT evaluation methods and tolerances.

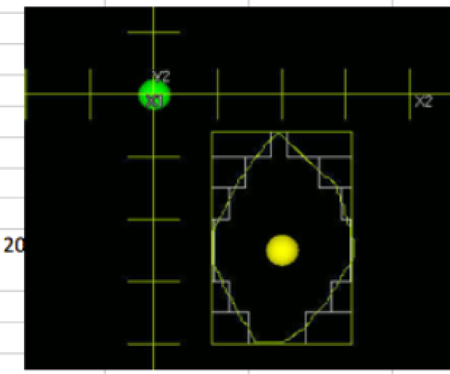
Measurement Method	*Region*	*Tolerance*
Ion Chamber	Low-gradient target region OAR region	2% of prescribed dose 3% of prescribed dose
Planar/Volumetric Array	All regions	2%/2 mm[a], no pass rate tolerance, but areas that do not pass need to be investigated
End-to-End	Low-gradient target region	5% of prescribed dose

[a] Application of a 2%/2 mm gamma criterion can result in the discovery of easily correctable problems with IMRT commissioning that may be hidden in the higher (and ubiquitous) 3%/3 mm passing rates.[(39)]

MPPG5: Test 7.2. Small MLC-defined field

Test Patient: ZZUWQA_Pinnacle, Validation MPPG_Hom
Test Plan: TrueBeam
Trial Name: 7.2 Sm Fld OF
Plan Settings: 2 mm dose grid
Model Version:
Scan SSD: 90 cm
Measurement depth: 10 cm
offset for bolt point: 2.0 X1, -2.5 Y2





urement parameters/tools
Razor field diode/SN: IBA RAZOR (SN 0055) effective pt of msmt 0.8 mm +/- 0.2 mm
Electrometer/SN: NONE (XXXX) SI CDX 2000B East Electrometer 20

Bias: 0
Rep. rate: 400 MU/min
MU: 100
Data aquired: 2016-06-24
By: JS and KS

dose:	Pinnacle 9.8									
ance - 2% for one neter change		measurement (nC)					Calculated (Gy)			
Field Name	**Description**	rdg 1	rdg 2	rdg 3	average	**OF**	Dose	OF	% diff	**Within 2 %?**
7.2_0 06MV	open	2.90	2.90		2.90		0.716			
7.2_1 06MV	bolt	2.71	2.71		2.71	0.934	0.675	0.943	-0.88	Yes
7.2_2 06MV	diamond	2.64	2.63		2.64	0.909	0.649	0.906	0.24	Yes
7.2_0 10MV	open	3.25	3.24		3.25		0.811			
7.2_1 10MV	bolt	3.04	3.03		3.04	0.935	0.760	0.937	-0.20	Yes
7.2_2 10MV	diamond	2.96	2.96		2.96	0.912	0.737	0.909	0.37	Yes

MLC examples downloadable from GITHUB

IMRT commissioning: Multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119

- Test suite, instructions and spreadsheets: http://www.aapm.org/pubs/tg119/default.asp

Series of downloadable tests:

Test P1: AP:PA. . . . .
Test P2: Bands. . . . .
Test I1: Multitarget. . . . .
Test I2: Mock prostate. .
Test I3: Mock head/neck.
Tests I4 and I5: Cshape. .

MPPG5 recommends these

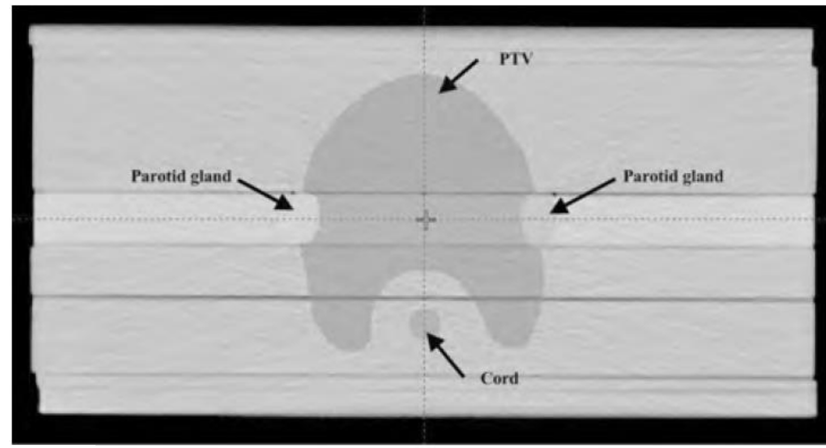
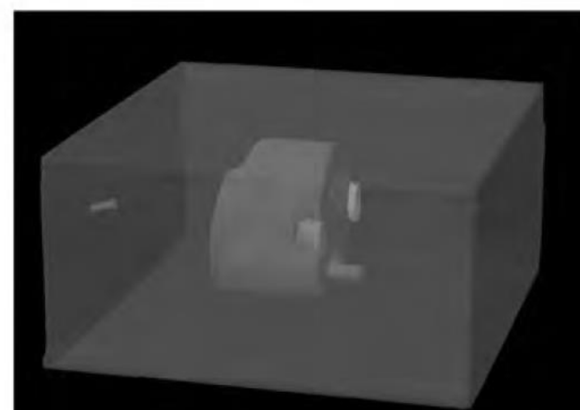
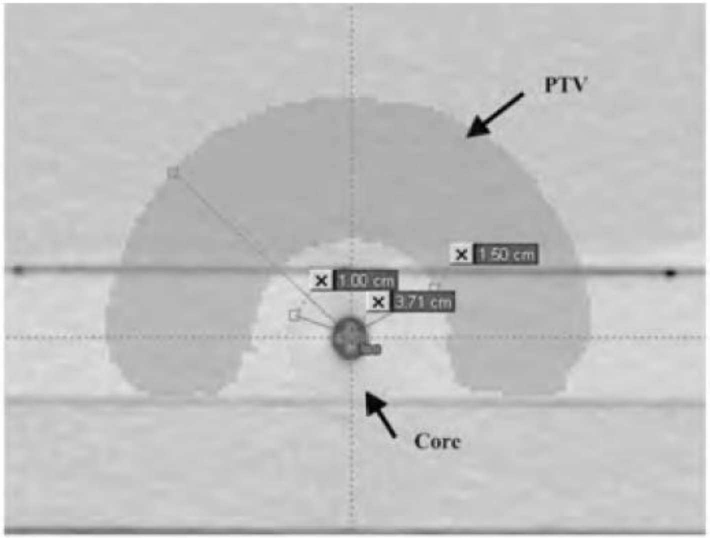


TABLE IV. Treatment plan statistics for mock head and neck.

Planning parameter	Plan goal (cGy)	Mean (cGy)	Standard deviation (cGy)	Coefficient of variation
PTV D90	5000	5028	58	0.013
PTV D99	>4650	4704	52	0.011
PTV D20	<5500	5299	93	0.018
Cord maximum	<4000	3741	250	0.067
Parotid D50	<2000	1798	184	0.102



Ezzell et al, Med Phys 36(11), 5359-5373, 2009 (also downloadable from the above link)



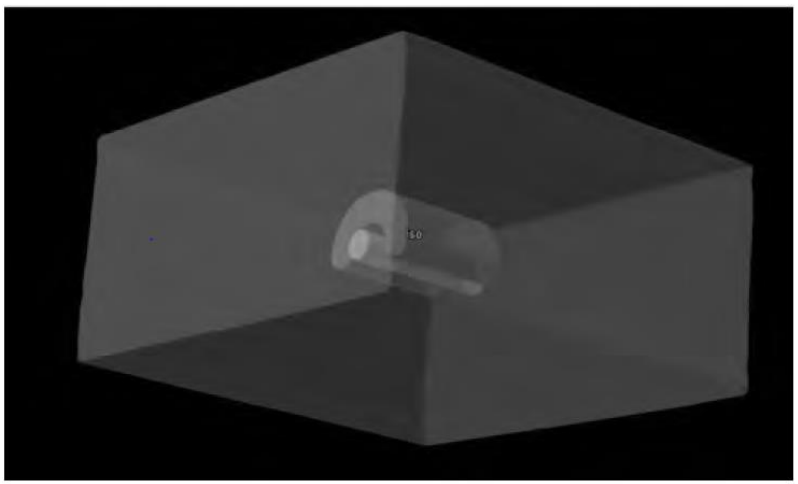


FIG. 5. CShape structures: CShape PTV and core. The center core is a cylinder 1 cm in radius. The gap between the core and the PTV is 0.5 cm, so the inner arc of the PTV is 1.5 cm in radius. The outer arc of the PTV is 3.7 cm in radius. The PTV is 8 cm long and the core is 10 cm long. Transverse and 3D views are shown.

TABLE V. Treatment plan statistics for CShape (easier).

Planning parameter	Plan goal (cGy)	Mean (cGy)	Standard deviation (cGy)	Coefficient of variation
PTV D95	5000	5010	17	0.003
PTV D10	<5500	5440	52	0.010
Core D10	<2500	2200	314	0.141

TABLE VI. Treatment plan statistics for CShape (harder).

Planning Parameter	Plan goal (cGy)	Mean (cGy)	Standard deviation (cGy)	Coefficient of variation
PTV D95	5000	5011	16.5	0.003
PTV D10	<5500	5702	220	0.039
Core D10	<1000	1630	307	0.188

Ezzell et al, Med Phys 36(11), 5359-5373, 2009

TABLE VII. High dose point in the PTV measured with ion chamber: [(measured dose) −(plan dose)]/prescription dose, averaged over the institutions, with associated confidence limits.

Test	Location	Mean	Standard deviation (σ)	Maximum	Minimum
Multitarget	Isocenter	0.001	0.017	0.030	−0.020
Prostate	Isocenter	−0.001	0.016	0.022	−0.026
Head and neck	Isocenter	−0.010	0.013	0.011	−0.036
CShape (easier)	2.5 cm anterior to isocenter	−0.001	0.028	0.038	−0.059
CShape (harder)	2.5 cm anterior to isocenter	−0.001	0.036	0.054	−0.061
Overall combined		−0.002	0.022		
Confidence limit=($\|mean\|+1.96\sigma$)			0.045		

TABLE IX. Low dose point in the avoidance structure measured with ion chamber: [(measured dose) −(plan dose)]/prescription dose, averaged over the institutions, with associated confidence limits.

Test	Location	Mean	Standard deviation (σ)	Maximum	Minimum
Multitarget	4 cm inferior to isocenter	−0.008	0.019	0.014	−0.050
Prostate	2.5 cm posterior to isocenter	0.000	0.018	0.030	−0.025
Head and neck	4 cm posterior to isocenter	0.004	0.024	0.061	−0.017
CShape (easier)	Isocenter	0.010	0.024	0.050	−0.037
CShape (harder)	Isocenter	0.009	0.025	0.055	−0.021
Overall combined		0.003	0.022		
Confidence limit ($\|mean\|+1.96\sigma$)			0.047		

Ezzell et al, Med Phys 36(11), 5359-5373, 2009

Functionality review

Functionality checks

- The TPS performs many non-dosimetric functions – need to verify
  - (includes “is the license turned on?”)
  - Import (images etc)
  - Export (to R&V – Mosaiq etc)
  - Dataset management + presentation
  - Coordinate systems
  - Image generation (DRRs)
  - DVH calculation……..
- Much of this may be in the acceptance document
- Good information source: IAEA documents and TG53

Checking display and other software functionality

9.4.2.13. Beam test 13: Wedges (hard, motorized and dynamic)

Purpose: To check that wedges are applied and displayed correctly.
Procedure:

(a) Select each wedge, and each wedge direction, and perform a simple dose calculation to confirm that the wedge has been selected and that both the graphics describing the wedge and the wedge shaped dose distribution are correctly orientated.
(b) Check that the wedge rotates correctly when the collimator is rotated. These are not calculation checks, just functional checks to demonstrate that the wedge dose distribution appears to be correct.
(c) For each wedge, enter field sizes that are too large for that wedge and check that the wedge cannot be selected. Similarly, change the field size to too large after selecting the wedge.
(d) Repeat for small fields if a lower field size limit can be set.
(e) Repeat for asymmetric jaws, to ensure that invalid jaw–wedge combinations are disallowed.

IAEA TRS 430

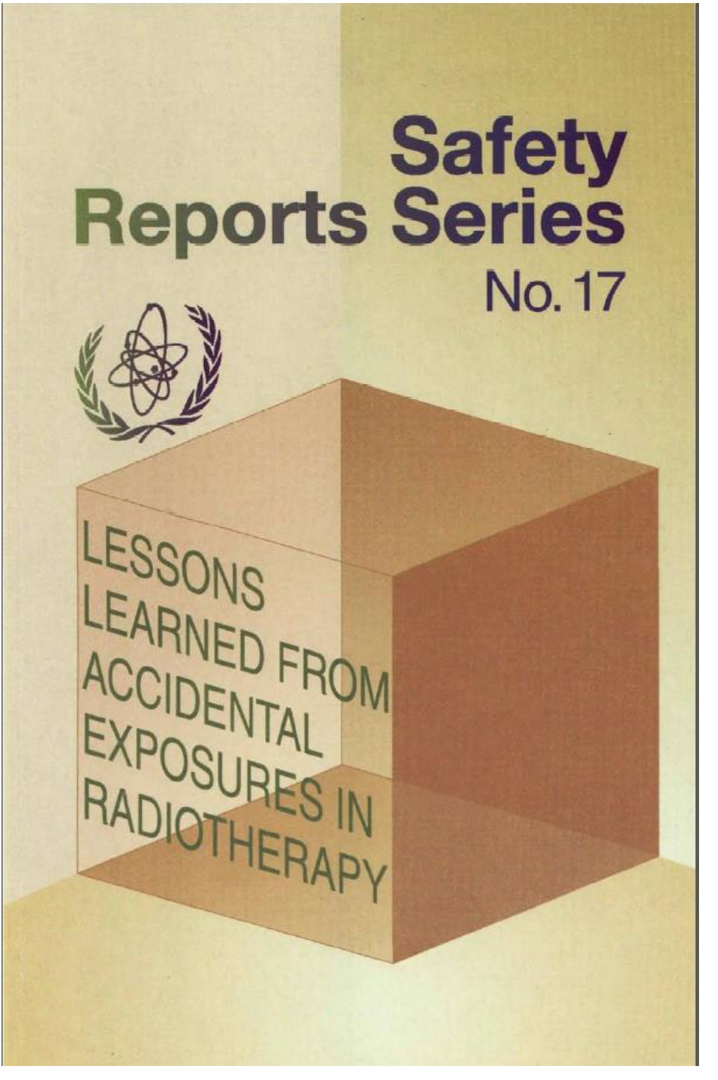
Independent verification

The Role of Independent Dosimetry Audits in Patient Safety

What sort of events can happen?

One way to categorize event:

- Events that involve individual patients
- Events that are related to equipment, and affect many patients
  - Commissioning
  - Change in machine function



An Example:

Event No. 10: Calibration error after changing a ^{60}Co teletherapy source

Physics staff calibrated the output of a new source installed in a ^{60}Co unit. About three and a half months later, nursing staff began to notice that the skin reactions of some of the patients treated on the machine were not healing as rapidly as would be expected. These concerns were communicated to the physics staff, who reviewed the output tables in clinical use as well as the original calibration; they reported that the data were correct. There was no explanation for the slow healing of the patients, which continued to be observed.

An intercomparison exercise, organized by a national association of medical physics, led to the discovery of a miscalculation in the original calibration. Over the five month period, the 207 patients treated on the ^{60}Co machine had received a dose that was 25% higher than prescribed.

- The IAEA report has many more examples of these types of events that affect many patients

Event No. 9: Incorrect calibration of machine output

electron

Electron beams of 7 and 11 MeV were calibrated incorrectly, resulting in underdosage of 17–18%. On the same machine, a photon beam was calibrated incorrectly, resulting in overdosage of 5%. In addition, there was a drift in the beam output over time, up to 7%. Mailed TLDs indicated a potential problem, and a review by an independent, outside physicist revealed that the calibrations were incorrect. Apparently, the incorrect calibrations had been used clinically for at least 11 months. During that time, there was no record of quality control performed by the institution's physicist. The cause of the incorrect calibrations was unknown.

Initiating event

— Incorrect calibration of the beam: The cause was unknown.

Contributing factors

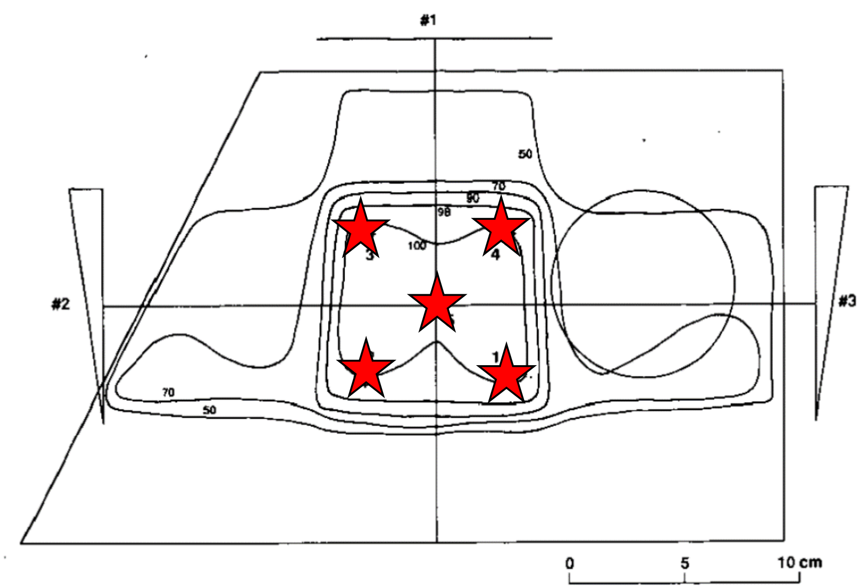
— Insufficient safety provisions (defence in depth): There was no independent beam calibration by another physicist.

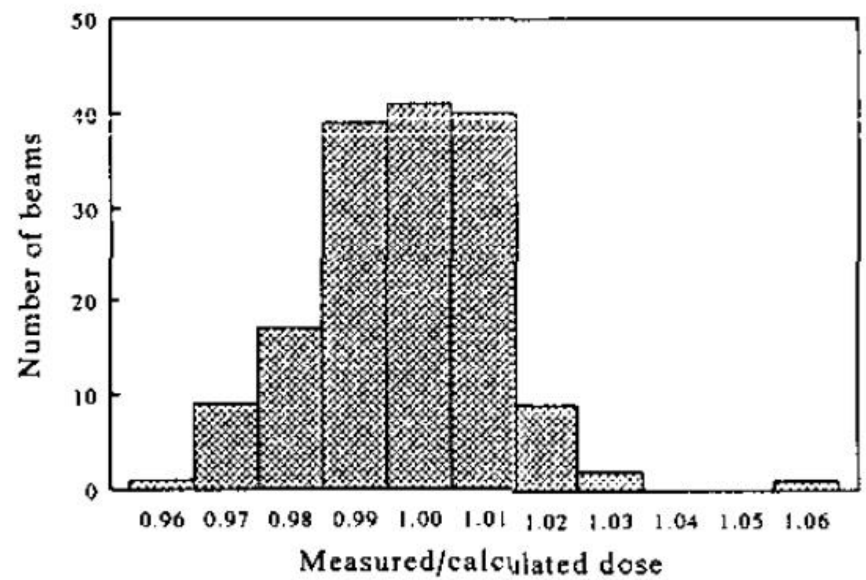
— Lack of or insufficient quality control: Over an 11 month period no checks were carried out on the beams.

IAEA Safety Reports Series No.17. Lessons learned from accidental exposures in radiotherapy

First Comprehensive UK Audit (1987-91):

- Inter-comparison of all 64 UK centers
- Organized by 15 regional coordinators who took equipment and made measurements with a local physicist
- Central axis measurements (5cm depth, 5, 10, 15cm fields)
- Dose at 5 points in a phantom
- 5% difference seen for 9 centers
- 25% difference seen for 1 center





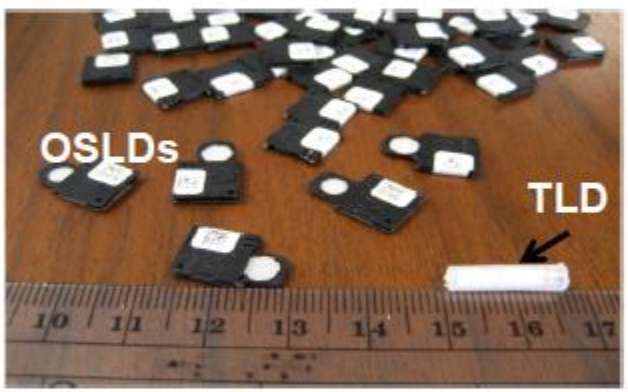
Thwaites et al, PMB 1992: 37;445-61.

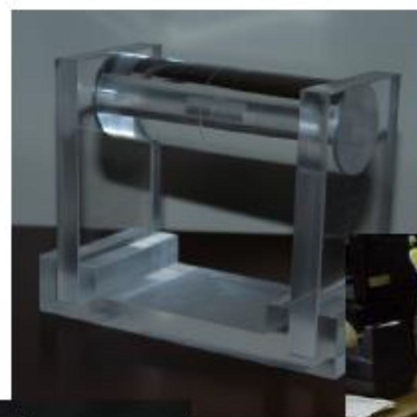
Independent Dosimetry Audits:

- The purpose of independent audits is to aim for consistent treatments (between centers)
- Many different approaches:
  - On-site visits by an auditing body (e.g. IAEA, IROC, other national institutions)
  - Remote audits – dosimeters sent by post
  - Virtual audits – remote evaluation of dosimetry, planning data
  - Voluntary "buddy visit" audits (especially when introducing new treatment techniques)

Remote Audits of Machine Output

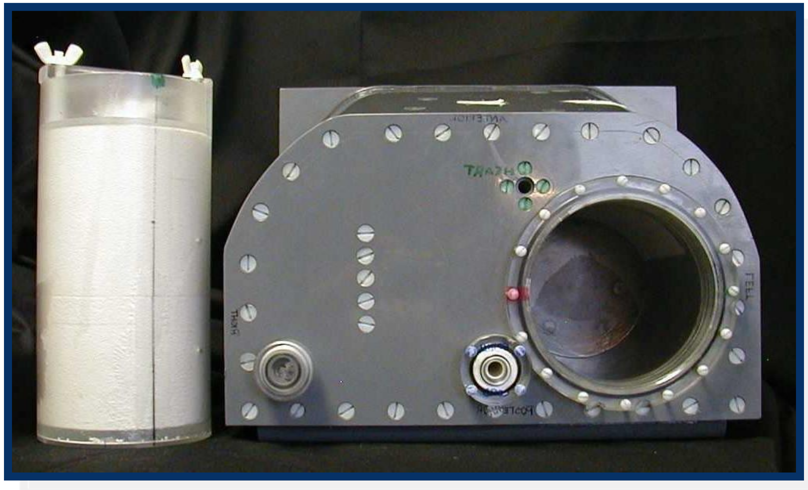
- Verification of Reference Calibration for photon, proton and electron beams
- Units of special design
  (Gamma Knife, CyberKnife, Tomotherapy)

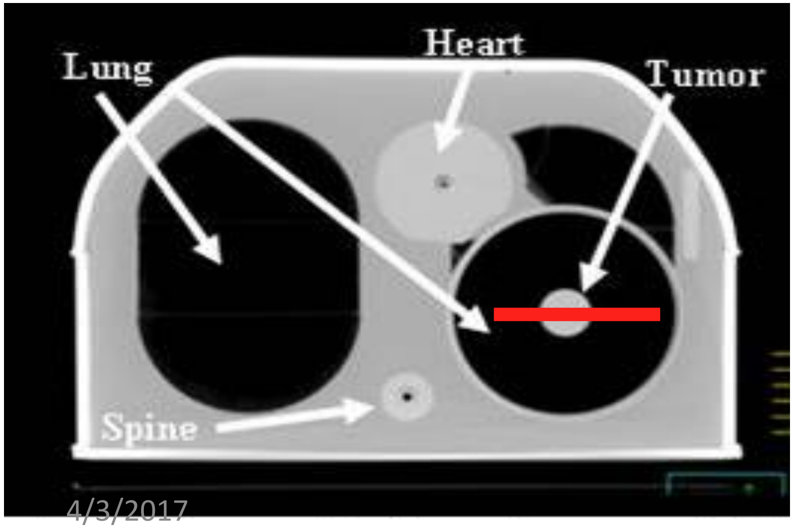


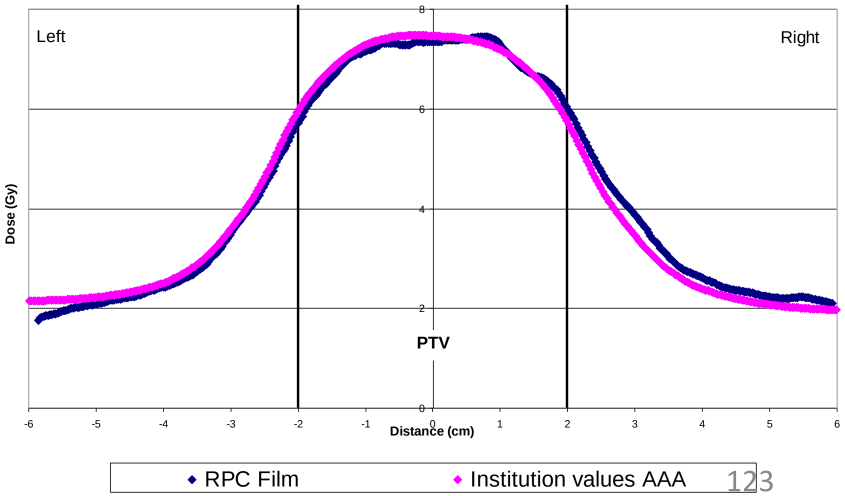


IROC-Houston Lung Phantom

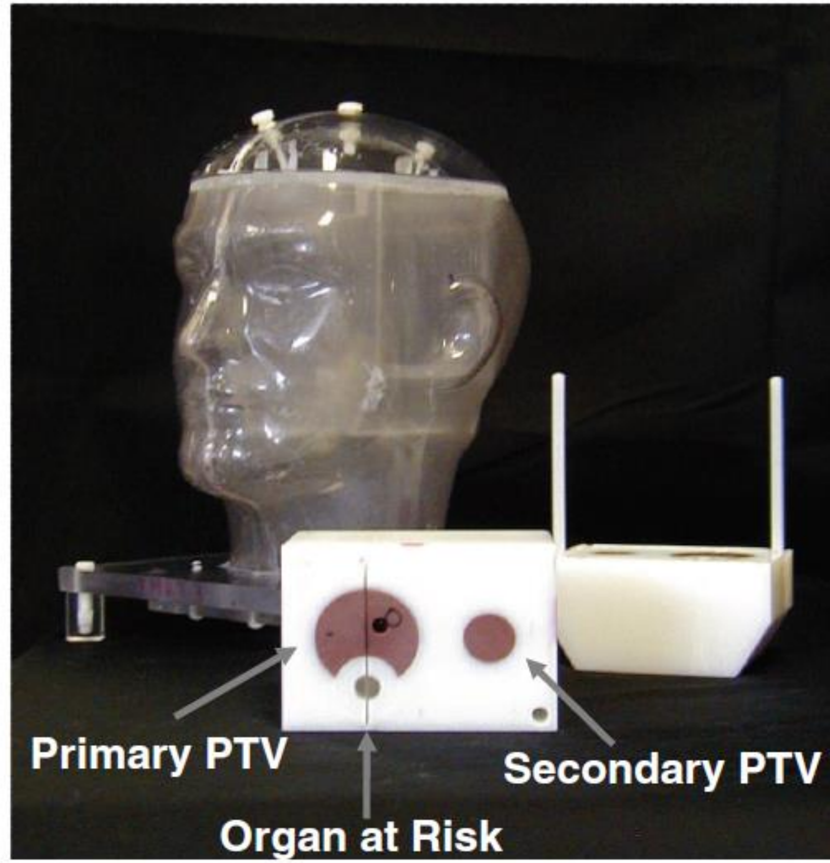
- Anthropomorphic shape
- Water filled
- Plastic inserts containing targets and organs at risk (heterogeneity)
- Point dose (TLD) and planar (radiochromic film) dosimeters
- Purpose is to evaluate the complete treatment process: (imaging to planning to delivery)







IROC-Houston Phantom – example results for the H/N phantom



The dosimetric precision of the TLD is 3%, and the spatial precision of the film and densitometer system is 1 mm.

Summary of TLD and film results:

Location	IROC-H vs. Inst.	Criteria	Acceptable
Primary PTV sup. ant.	0.99	0.93 – 1.07	Yes
Primary PTV inf. ant.	0.98	0.93 – 1.07	Yes
Primary PTV sup. post.	0.98	0.93 – 1.07	Yes
Primary PTV inf. post.	1.00	0.93 – 1.07	Yes
Secondary PTV sup.	0.99	0.93 – 1.07	Yes
Secondary PTV inf.	0.98	0.93 – 1.07	Yes

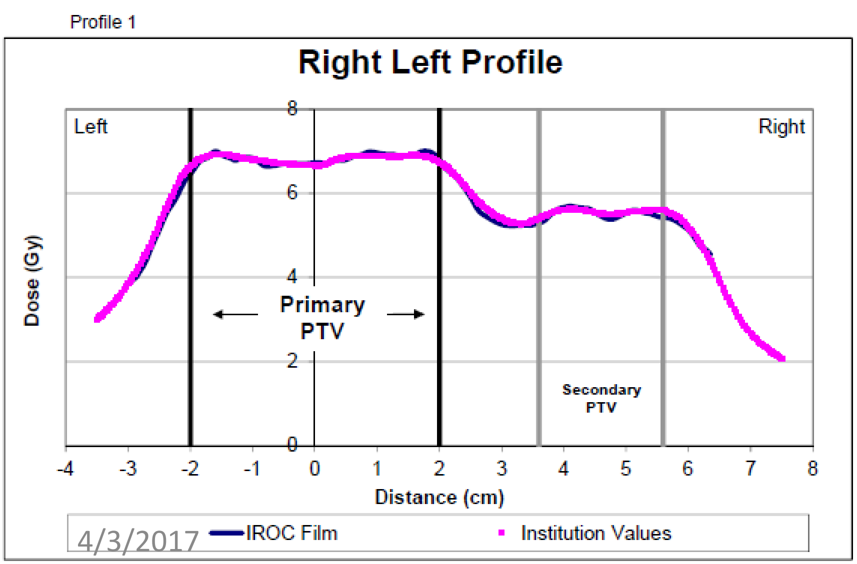
Film Plane	Gamma Index*	Criteria	Acceptable
Axial	99%	≥85%	Yes
Sagittal	99%	≥85%	Yes

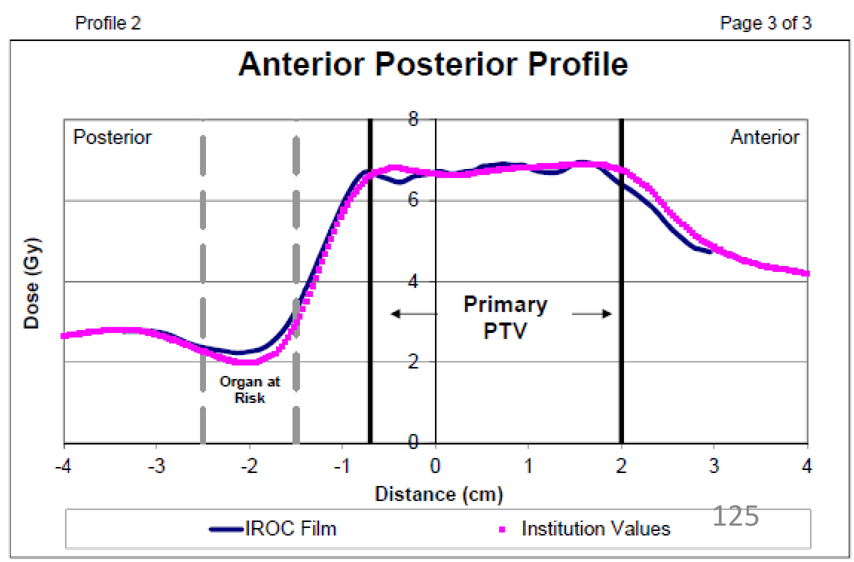
*Percentage of points meeting gamma-index criteria of 7% and 4 mm.

IROC-Houston Phantom – example results for the H/N phantom

TLD Results:

Location	Institution Reported Mean Dose	TLD Dose (cGy)	Measured/Institution
Primary PTV sup. ant.	684	676	0.99
Primary PTV inf. ant.	674	659	0.98
Primary PTV sup. post.	687	675	0.98
Primary PTV inf. post.	688	686	1.00
Secondary PTV sup.	550	542	0.99
Secondary PTV inf.	551	540	0.98
Organ at risk sup.	203	186	0.92
Organ at risk inf.	196	185	0.94



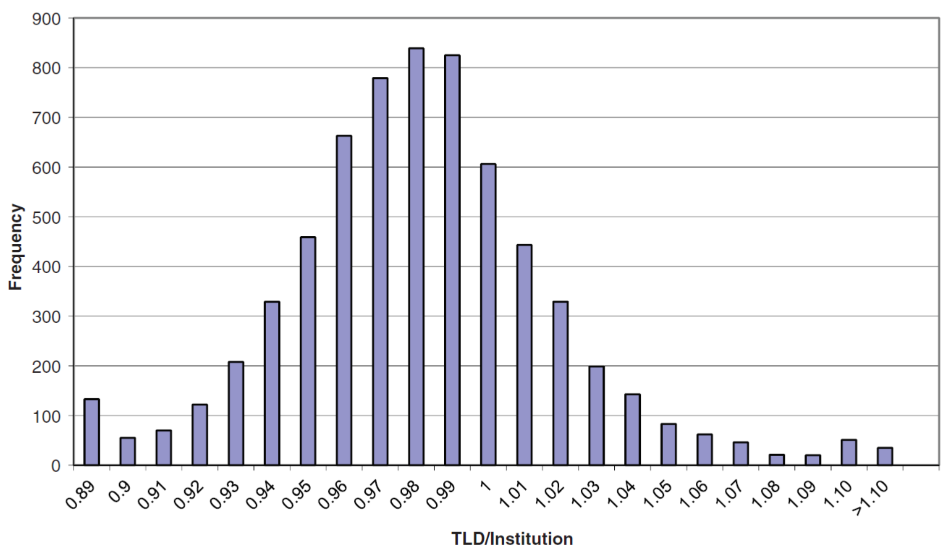


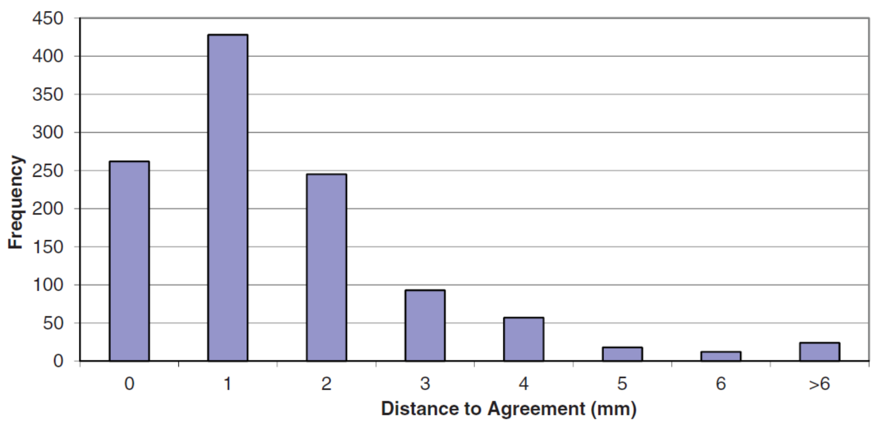
Credentialing results from IMRT irradiations of an anthropomorphic head and neck phantom

Andrea Molineu,[a] Nadia Hernandez, Trang Nguyen, Geoffrey Ibbott, and David Followill
Department of Radiation Physics, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030

- 1139 irradiations, 763 institutions

	Ratio		
	1PTV	2PTV	DTA (mm)
Mean	0.98	0.98	1.6
SD	0.047	0.041	1.9
Range	0.44–1.26	0.40–1.23	0–17



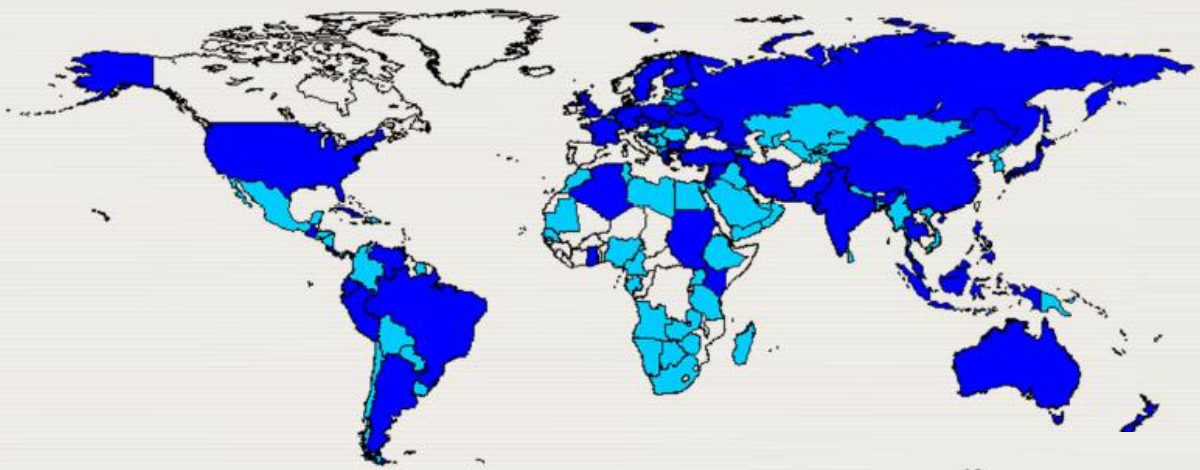


Molineu et al, Med Phys 40(2) 022101-1, 2013

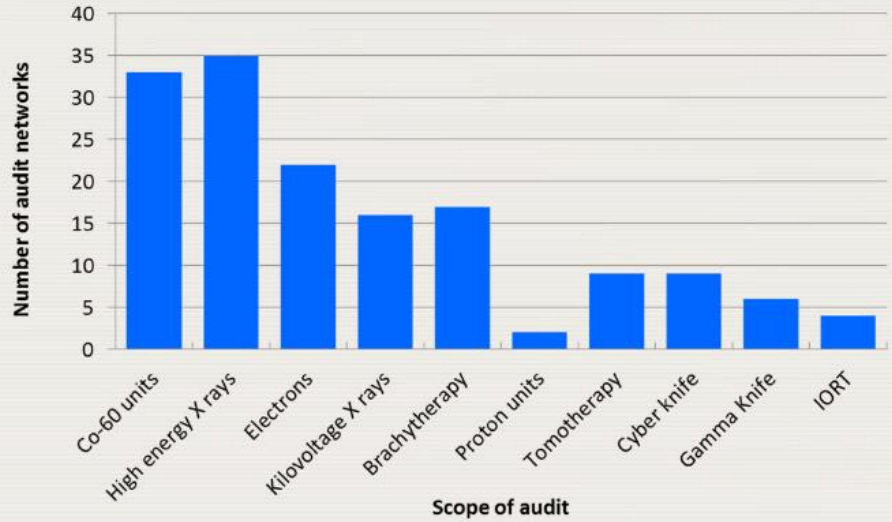
	Pass rate (%)	Attempts	Criterion failed		
			Dose	DTA	Dose and DTA
IMRT technique					
Dynamic MLC	88	296	26	5	5
IMAT	86	103	11	0	3
Segmental	76	634	109	15	25
Solid attenuator	43	7	4	0	0
TomoTherapy	93	99	6	1	0
Treatment planning system					
Eclipse	88	387	30	8	7
Pinnacle^3	75	425	84	8	13
TomoTherapy	93	99	6	1	0
XiO	76	137	19	4	10
Other	78	91	17	0	3
Linear accelerator manufacturer					
Elekta	67	130	37	4	2
Siemens	70	135	32	3	6
TomoTherapy	93	99	6	1	0
Varian	85	775	81	13	25
Linac-TPS combination					
Elekta-Pinnacle^3	66	90	28	3	0
Siemens-Pinnacle^3	67	76	21	0	4
TomoTherapy-HiArt	93	99	6	1	0
Varian-Eclipse	90	372	22	7	7
Varian-Pinnacle^3	81	267	38	5	9
Varian-XiO	77	74	10	1	6

Molineu et al, Med Phys 40(2) 022101-1, 2013

Response to survey: national audit activities



Country operating national audit
Country participating in IAEA/WHO a



Audit Summary:

- The purpose of independent audits is to aim for consistent treatments (between centers)
- Much (published) evidence independent audits can prevent mistreatment of many patients
- Many different ways to achieve independent audits

So where are we?

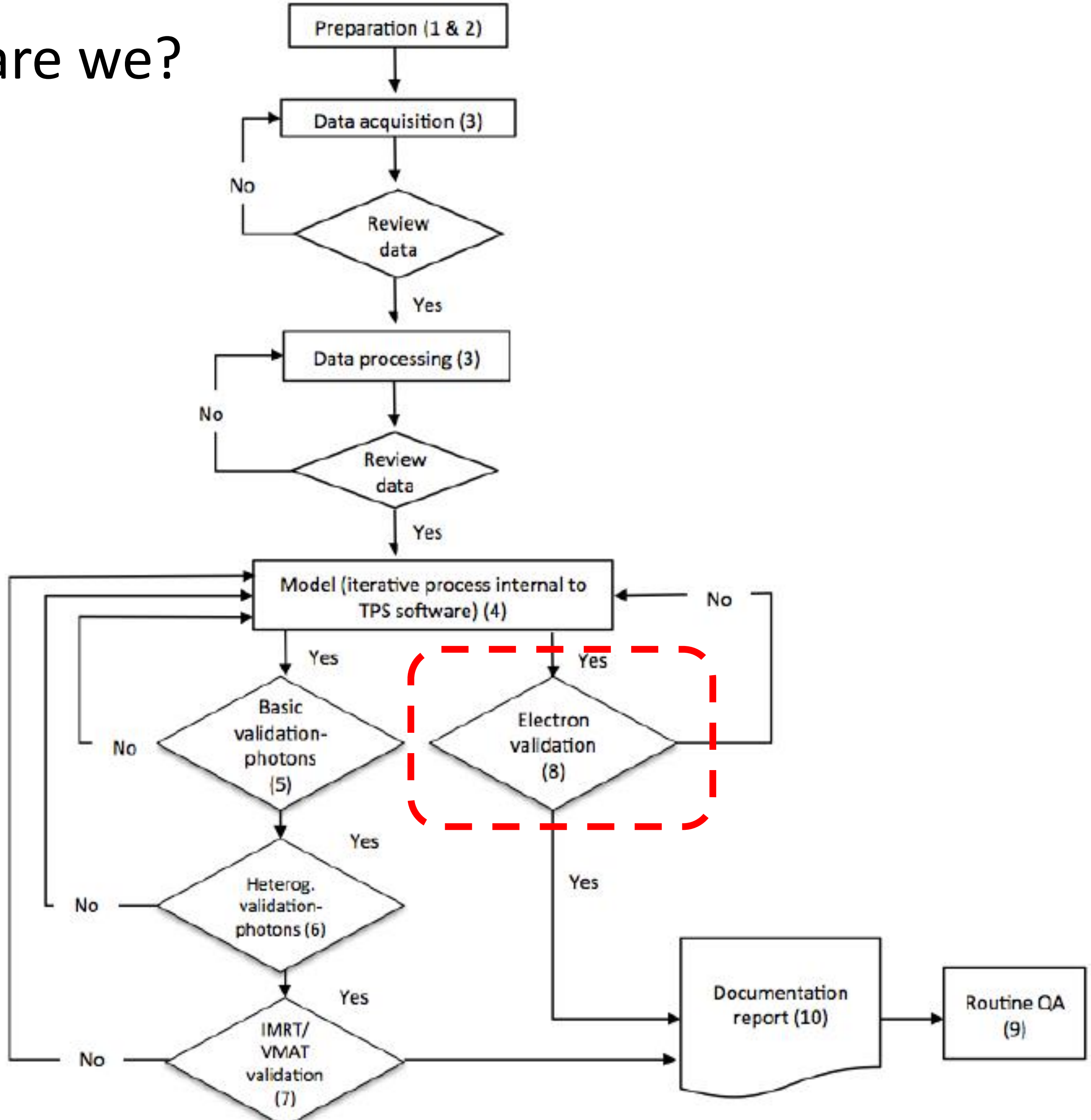


Figure from MPPG5a

Electrons

MPPG5

TG25

TG70

Commissioning data examples

eMC in Eclipse

For each electron energy:

- Profile in air for NO CONE
- PDD in water for NO CONE
- Absolute dose in water for NO CONE
- PDD in water for each cone
- Absolute dose in water for each cone

Diamond:

Output factors:
100cm SSD, all field sizes for all cones and all energies….

PDDs:
All energies, field sizes 2cm to 25cm (e.g. 2,3,4,5,6,8,10,15,20,25). 100cm SSD.

Airgap factors
Output factor relative to 100cm SSD for field sizes 2cm to 25cm (e.g. 2,3,4,5,6,8,10,15,20,25) for SSD=105,110,115,120cm

Decide on calculation parameters (Eclipse)

Parameter	Values	Description
Calculation grid size	1 mm, 1.5 mm, 2 mm, 2.5 mm, 5 mm	Spacing of calculation points in the CT image plane. Calculation spacing in the longitudinal direction is the CT slice spacing.
Accuracy	1%, 2%, 3%, 5%, 8%	Mean statistical error in dose within the high dose volume.
Accuracy limit	1%, 2%, 3%, 5%, 8%	Monitor units are calculated only if the achieved accuracy is ≤ Accuracy Limit. Can only be set in calculation defaults.
Maximum number of particle histories	≥ 0	Specifies the maximum number of particles to be transported in a calculation. Calculation stops once set number of particles have been transported even if desired Accuracy is not reached. Option off if set to 0.
Random generator seed number	1 to 2100000000	Sets start point of the random number generator.
Smoothing method	No smoothing	Dose distribution is not smoothed.

seed number		generator.
Smoothing method	No smoothing	Dose distribution is not smoothed.
	2-D Median	Applies a median filter to the dose distribution on each CT slice. The dose at each calculation point is replaced by the median dose in a neighborhood defined by the Smoothing Level.
	3-D Gaussian	Convolves the dose distribution with a 3 dimensional gaussian, the standard deviation of which is defined by the Smoothing Level.
Smoothing level	1-Low	2-D Median: neighborhood = 5mm x 5mm.
		3-D Gaussian: standard deviation = 0.5 x Calculation Grid Size.
	2-Medium	2-D Median: neighborhood = 10mm x 10mm.
		3-D Gaussian: standard deviation = Calculation Grid Size.
	3-Strong	2-D Median: neighborhood = 15mm x 15mm.
		3-D Gaussian: standard deviation = 1.5 x Calculation Grid Size.

Example data table for Diamond

6MeV									
cone:		6	6	6	6	10	15	20	25
SSD/FS		2	3	4	6	10	15	20	25
100	100	1	1	1	1	1	1	1	1
105	105	0.779769	0.898332	0.945715	0.961729	0.986681	0.990248	0.992925	0.993341
110	110	0.581114	0.775123	0.88404	0.919613	0.965417	0.976786	0.986224	0.987967
115	115	0.440675	0.656516	0.812396	0.878801	0.952642	0.966392	0.979013	0.983869
120	120	0.341656	0.549858	0.73287	0.831277	0.932387	0.954826	0.969782	0.976696

Evaluation of eMC (and datasheets)

- 25 cutouts + 5 open cones
- 5 electron energies
- 100 and 110cm SSD (to check calculations)
- Absolute dose (water phantom, solid water)
- Relative dose distributions (water phantom)

- 30 x 5 x 2 = 300 output measurements
- Same number (or subset) of relative dose distributions (2D)

Table 9: Basic TPS validation tests for electron beams and minimum tolerance values

Test	Objective	Description	Tolerance
8.1	Basic model verification with shaped fields	Custom cutouts at standard and extended SSDs	3%/3 mm
8.2	Surface irregularities-obliquity	Oblique incidence using reference cone and nominal clinical SSD	5% [50]
8.3	Inhomogeneity test	Reference cone and nominal clinical SSD	7% [7]

[50] J Van Dyk, R B Barnett, J E Cygler, and P C Shragge, "Commissioning and quality assurance of treatment planning computers," *Int. J. Rad. Onc. Biol. Phys.*, vol. 26, pp. 261-273, 1993.

[7] International Atomic Energy Agency, "Commissioning and quality assurance of computerized planning systems for radiation treatment of cancer," Vienna, 2004.

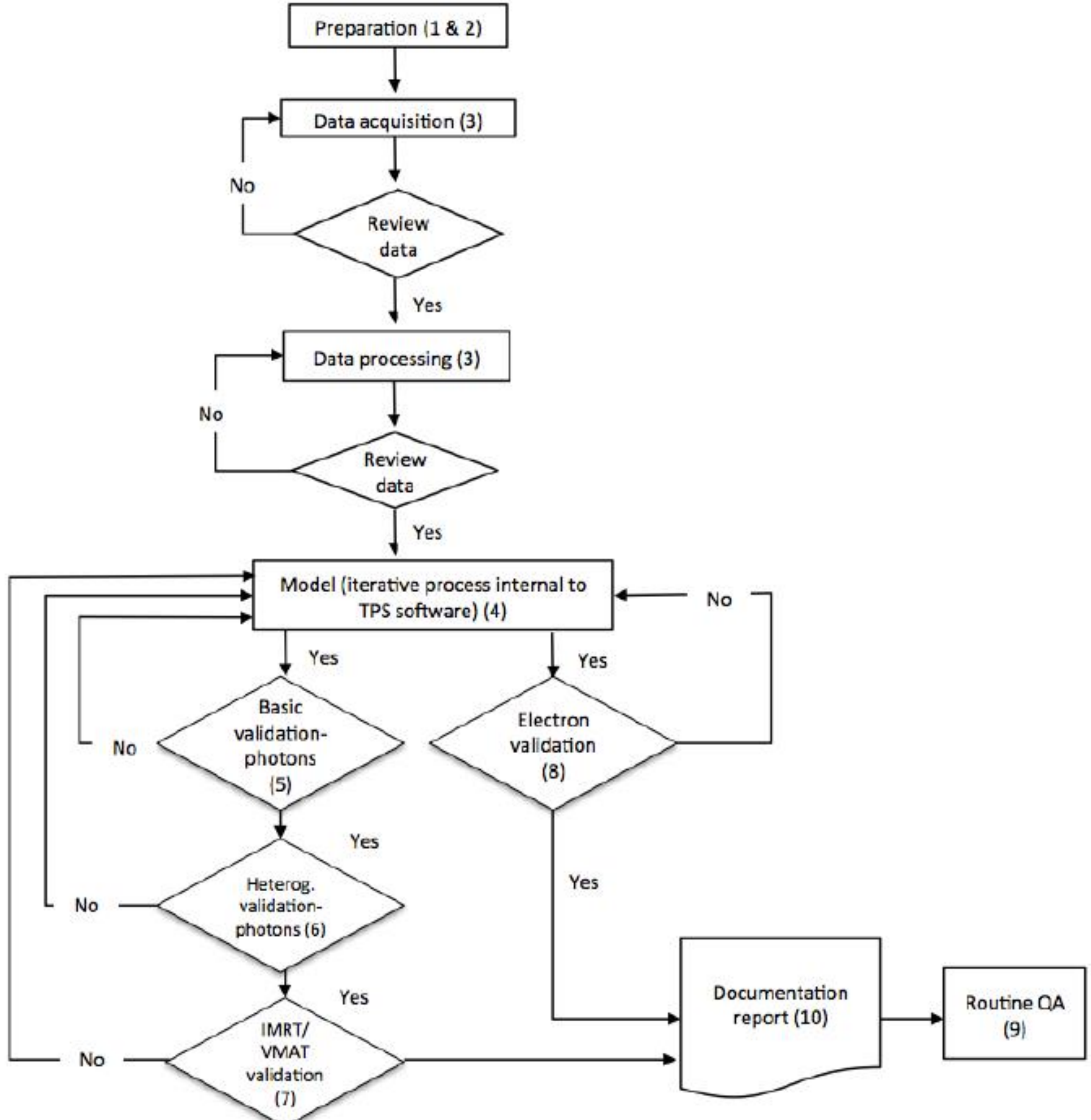


Figure from MPPG5a

More data review

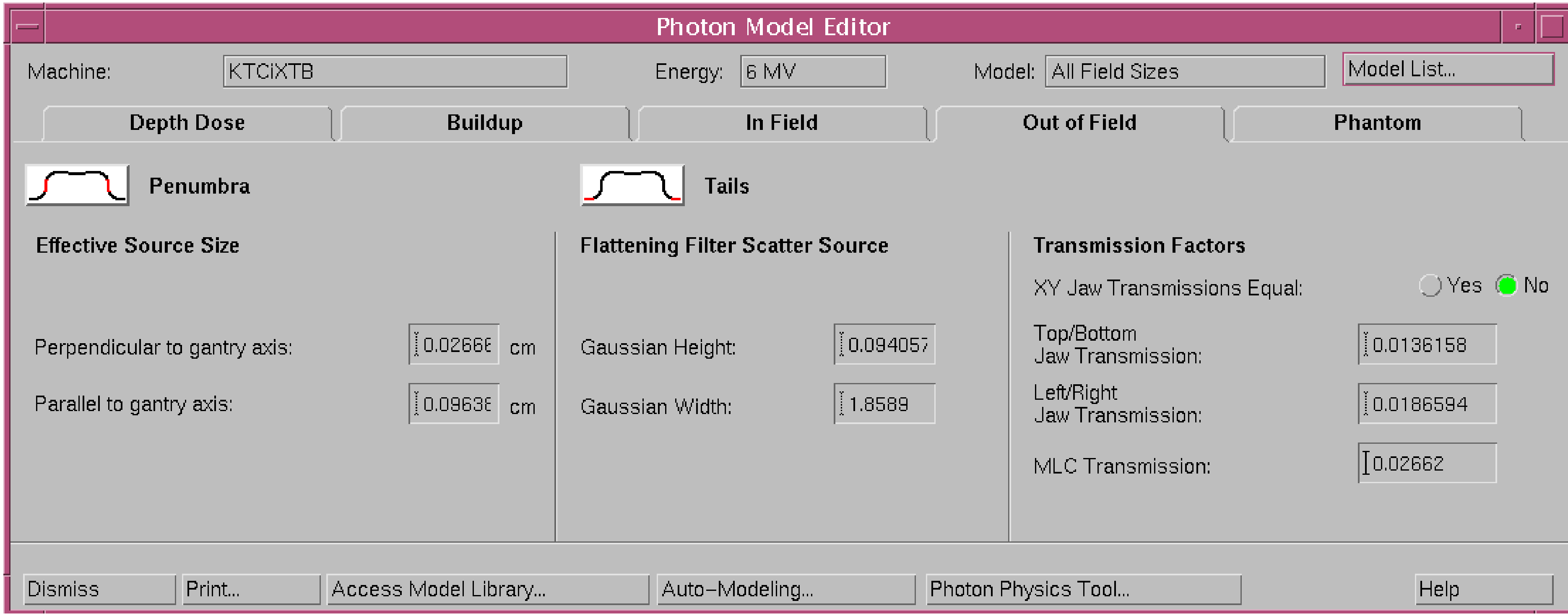
A good idea

We’ve done a lot of measurements and comparisons – how do they look? Why not have another review…..

It’s another chance to catch any issues….

Data Quality

- What is wrong with this 6X model (Varian truebeam)



Profile Statistics

Machine: KTCiXTB Energy: 6 MV Normalize Plot: ○ Yes ● No

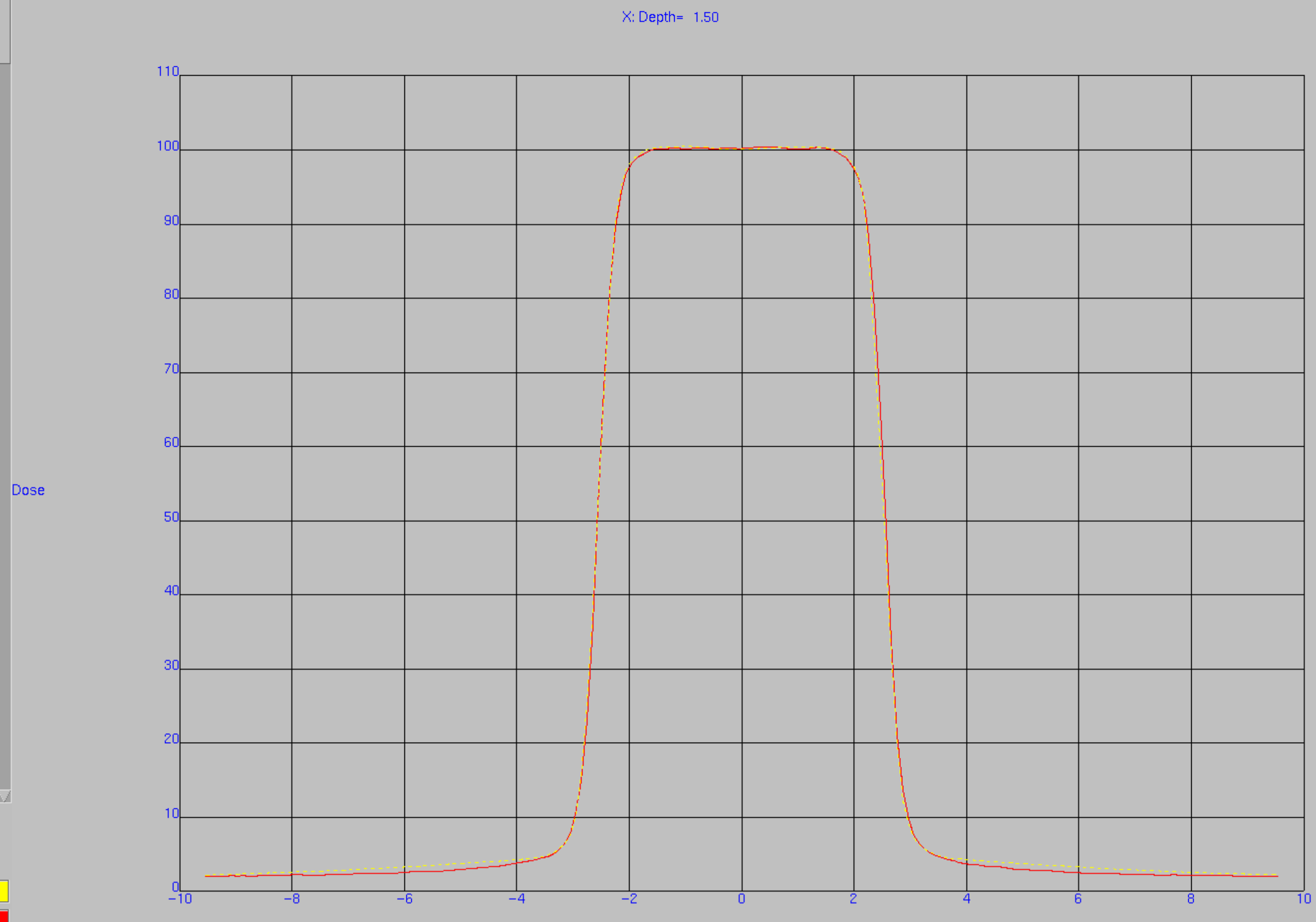
Geometry: SSD = 100 cm Field: 5 X 5 Profile: X: Depth= 1.50

Offset (cm)	Measured	Computed	Diff	% Err*	Distance to Agreement (cm)
−9.53	1.92	2.06	0.14	0.14 %	---
−9.48	1.90	2.09	0.19	0.19 %	---
−9.36	1.89	2.13	0.24	0.24 %	---
−9.27	1.90	2.17	0.27	0.27 %	---
−9.17	1.92	2.20	0.27	0.27 %	---
−9.07	1.99	2.22	0.23	0.23 %	---
−8.97	1.97	2.25	0.28	0.28 %	---
−8.87	1.99	2.27	0.27	0.27 %	---
−8.77	1.98	2.29	0.31	0.31 %	---
−8.66	1.98	2.31	0.33	0.33 %	---
−8.56	2.04	2.33	0.30	0.30 %	---
−8.47	2.03	2.36	0.33	0.33 %	---
−8.37	2.05	2.38	0.33	0.33 %	---
−8.27	2.08	2.41	0.33	0.33 %	---
−8.16	2.09	2.43	0.34	0.34 %	---
−8.07	2.07	2.47	0.40	0.40 %	---
−7.97	2.13	2.49	0.36	0.36 %	---
−7.86	2.15	2.52	0.37	0.37 %	---
−7.76	2.10	2.55	0.45	0.45 %	---
−7.66	2.08	2.58	0.50	0.50 %	---
−7.56	2.11	2.61	0.50	0.50 %	---
−7.46	2.12	2.64	0.53	0.52 %	---
−7.36	2.14	2.68	0.53	0.53 %	---
−7.26	2.17	2.71	0.54	0.54 %	---
−7.16	2.20	2.74	0.54	0.54 %	---
−7.06	2.20	2.77	0.57	0.57 %	---
−6.96	2.25	2.81	0.56	0.56 %	---
−6.86	2.29	2.85	0.55	0.55 %	---
−6.76	2.29	2.88	0.59	0.59 %	---
−6.66	2.34	2.92	0.58	0.58 %	---
−6.56	2.32	2.96	0.63	0.63 %	---
−6.46	2.34	2.99	0.65	0.65 %	---
−6.36	2.36	3.03	0.67	0.67 %	---
−6.26	2.36	3.07	0.71	0.71 %	---
−6.16	2.38	3.11	0.74	0.74 %	---
−6.06	2.41	3.16	0.75	0.75 %	---
−5.96	2.44	3.20	0.76	0.76 %	---
−5.86	2.54	3.25	0.71	0.71 %	---
−5.76	2.56	3.29	0.73	0.73 %	---

*Pct Err = (Comp − Meas) / Central Axis Dose Connect at 0 cm

Mean Error:	0.137527	0.496162	−0.891375
Mean Square Error:	0.0517576	0.307952	6.01346

Computed
Measured



Profile Statistics

Machine: KTCiXTB
Energy: 6 MV
Normalize Plot: Yes / No
Geometry: SSD = 100 cm Field: 5 X 5
Profile: X: Depth= 20.00

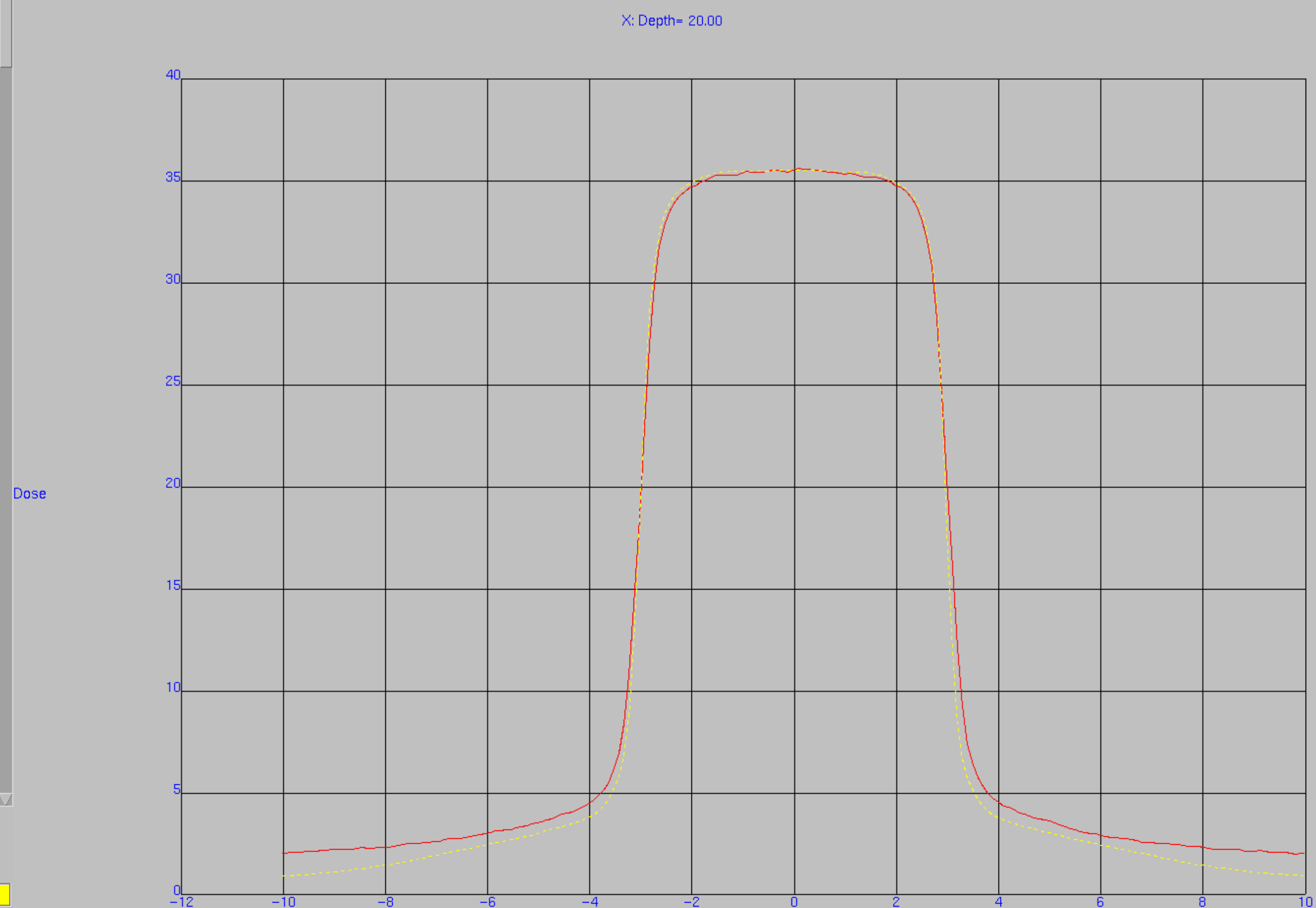
Offset (cm)	Measured	Computed	Diff	% Err*	Distance to Agreement (cm)
−10.02	2.01	0.89	−1.12	−3.15 %	---
−9.95	2.01	0.90	−1.11	−3.12 %	---
−9.85	2.04	0.91	−1.12	−3.17 %	---
−9.75	2.05	0.93	−1.13	−3.17 %	---
−9.65	2.04	0.94	−1.10	−3.10 %	---
−9.56	2.08	0.96	−1.12	−3.15 %	---
−9.45	2.12	0.98	−1.14	−3.20 %	---
−9.35	2.11	0.99	−1.12	−3.14 %	---
−9.25	2.12	1.02	−1.11	−3.12 %	---
−9.15	2.15	1.04	−1.11	−3.12 %	---
−9.05	2.19	1.07	−1.12	−3.15 %	---
−8.95	2.20	1.09	−1.11	−3.13 %	---
−8.85	2.20	1.12	−1.08	−3.03 %	---
−8.75	2.19	1.15	−1.04	−2.94 %	---
−8.65	2.21	1.19	−1.02	−2.88 %	---
−8.55	2.23	1.22	−1.01	−2.84 %	---
−8.45	2.28	1.25	−1.04	−2.92 %	---
−8.35	2.25	1.29	−0.96	−2.70 %	---
−8.25	2.24	1.32	−0.92	−2.59 %	---
−8.15	2.30	1.35	−0.95	−2.67 %	---
−8.05	2.30	1.40	−0.90	−2.53 %	---
−7.95	2.30	1.43	−0.87	−2.45 %	---
−7.85	2.36	1.46	−0.90	−2.53 %	---
−7.75	2.39	1.52	−0.87	−2.46 %	---
−7.65	2.45	1.56	−0.90	−2.52 %	---
−7.55	2.48	1.59	−0.89	−2.50 %	---
−7.45	2.48	1.68	−0.80	−2.25 %	---
−7.35	2.48	1.72	−0.76	−2.15 %	---
−7.25	2.55	1.77	−0.78	−2.20 %	---
−7.15	2.54	1.84	−0.71	−1.99 %	---
−7.05	2.55	1.87	−0.68	−1.92 %	---
−6.95	2.60	1.92	−0.68	−1.91 %	---
−6.85	2.67	2.00	−0.68	−1.91 %	---
−6.75	2.72	2.03	−0.69	−1.94 %	---
−6.65	2.72	2.07	−0.65	−1.82 %	---
−6.55	2.73	2.16	−0.58	−1.62 %	---
−6.45	2.77	2.19	−0.59	−1.66 %	---
−6.34	2.80	2.23	−0.57	−1.60 %	---
−6.25	2.86	2.30	−0.55	−1.56 %	---

*Pct Err = (Comp − Meas) / Central Axis Dose

Connect at 0 cm

Mean Error:	0.309291	−2.17298	−2.15385
Mean Square Error:	0.178973	5.10785	23.9708

Computed
Measured



Profile Statistics

lachine: Varian 2109

Energy: 6 MV

Normalize Plot: Yes No

eometry: SSD = 100 cm Field: 5 X 5

Profile: X: Depth= 1.50

Offset (cm)	Measured	Computed	Diff	% Err*	Distance to Agreement (cm)
−5.12	0.01	0.01	0.00	0.12 %	---
−4.92	0.01	0.02	0.00	0.19 %	---
−4.72	0.02	0.02	0.00	0.26 %	---
−4.53	0.02	0.02	0.00	0.33 %	---
−4.34	0.02	0.02	0.00	0.36 %	---
−4.13	0.02	0.03	0.00	0.40 %	---
−3.94	0.02	0.03	0.00	0.47 %	---
−3.74	0.03	0.03	0.00	0.41 %	---
−3.54	0.03	0.04	0.00	0.46 %	---
−3.35	0.04	0.04	0.01	0.50 %	---
−3.15	0.05	0.06	0.01	0.97 %	0.05
−2.96	0.09	0.13	0.03	3.31 %	0.06
−2.75	0.21	0.25	0.04	3.81 %	0.03
−2.56	0.45	0.46	0.01	1.39 %	0.01
−2.37	0.71	0.74	0.03	3.32 %	0.04
−2.16	0.89	0.91	0.03	2.90 %	0.08
−1.97	0.96	0.96	0.00	0.47 %	---
−1.78	0.98	0.99	0.00	0.17 %	---
−1.57	0.99	0.99	0.00	0.09 %	---
−1.38	1.00	1.00	−0.00	−0.04 %	---
−1.18	1.00	1.00	−0.00	−0.08 %	---
−0.98	1.00	1.00	−0.00	−0.03 %	---
−0.79	1.00	1.00	−0.00	−0.03 %	---
−0.59	1.00	1.00	−0.00	−0.01 %	---
−0.40	1.00	1.00	−0.00	−0.01 %	---
−0.19	1.00	1.00	0.00	0.01 %	---
0.00	1.00	1.00	0.00	0.00 %	---
0.19	1.00	1.00	−0.00	−0.01 %	---
0.40	1.00	1.00	−0.00	−0.03 %	---
0.59	1.00	1.00	−0.00	−0.01 %	---
0.79	1.00	1.00	−0.00	−0.02 %	---
0.98	1.00	1.00	−0.00	−0.04 %	---
1.18	1.00	1.00	−0.00	−0.10 %	---
1.38	1.00	1.00	−0.00	−0.10 %	---
1.57	0.99	0.99	−0.00	−0.07 %	---
1.78	0.98	0.98	0.00	0.01 %	---
1.97	0.96	0.96	0.00	0.47 %	---
2.16	0.89	0.89	0.00	0.39 %	−0.01
2.37	0.71	0.69	−0.03	−2.53 %	0.02

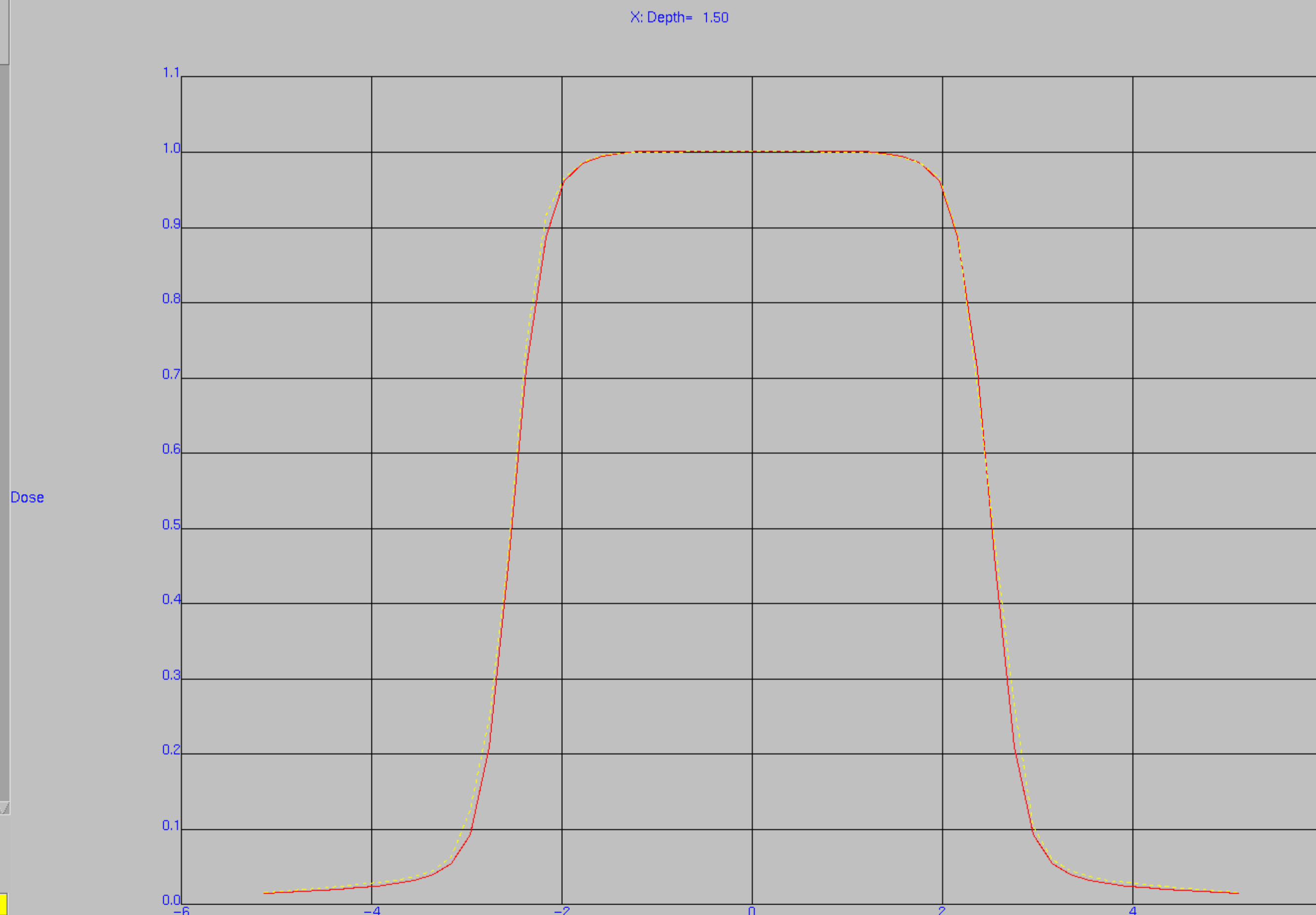
Pct Err = (Comp − Meas) / Central Axis Dose

Connect at 0 cm

Mean Error:	−0.0161692	0.382724	1.89017
Mean Square Error:	0.00403063	0.175202	7.69548

Computed

Measured



Profile Statistics

Machine: Varian 2109 | Energy: 6 MV | Normalize Plot: Yes / No (No selected)

Geometry: SSD = 100 cm Field: 5 X 5 | Profile: X: Depth= 22.00

Offset (cm)	Measured	Computed	Diff	% Err*	Distance to Agreement (cm)
−6.21	0.04	0.05	0.00	0.17 %	---
−5.98	0.05	0.05	0.00	0.43 %	---
−5.74	0.05	0.05	0.01	0.52 %	---
−5.50	0.05	0.06	0.01	0.56 %	---
−5.26	0.06	0.07	0.01	0.70 %	---
−5.02	0.06	0.07	0.01	0.79 %	---
−4.78	0.07	0.08	0.01	0.83 %	---
−4.55	0.08	0.08	0.01	0.68 %	---
−4.30	0.08	0.09	0.01	0.60 %	---
−4.07	0.09	0.10	0.00	0.45 %	---
−3.82	0.11	0.11	−0.00	−0.07 %	---
−3.59	0.16	0.14	−0.01	−1.38 %	−0.07
−3.35	0.26	0.25	−0.02	−1.66 %	−0.04
−3.11	0.46	0.44	−0.02	−1.99 %	−0.02
−2.87	0.70	0.69	−0.01	−0.99 %	−0.01
−2.63	0.86	0.89	0.03	2.85 %	0.09
−2.39	0.94	0.95	0.01	1.09 %	---
−2.16	0.97	0.97	0.00	0.32 %	---
−1.91	0.98	0.98	0.00	0.30 %	---
−1.68	0.99	0.99	0.00	0.29 %	---
−1.43	0.99	0.99	0.00	0.29 %	---
−1.20	0.99	1.00	0.00	0.15 %	---
−0.96	1.00	1.00	−0.00	−0.04 %	---
−0.72	1.00	1.00	−0.00	−0.09 %	---
−0.48	1.00	1.00	−0.00	−0.07 %	---
−0.24	1.00	1.00	0.00	0.06 %	---
0.00	1.00	1.00	0.00	0.00 %	---
0.24	1.00	1.00	−0.00	−0.07 %	---
0.48	1.00	1.00	−0.00	−0.06 %	---
0.72	1.00	1.00	−0.00	−0.09 %	---
0.96	1.00	1.00	−0.00	−0.06 %	---
1.20	0.99	1.00	0.00	0.06 %	---
1.43	0.99	0.99	0.00	0.22 %	---
1.68	0.99	0.99	0.00	0.31 %	---
1.91	0.98	0.98	0.00	0.33 %	---
2.16	0.97	0.97	0.00	0.35 %	---
2.39	0.94	0.94	0.01	0.74 %	---
2.63	0.86	0.86	0.00	0.07 %	−0.00
2.87	0.70	0.69	−0.01	−1.17 %	0.01

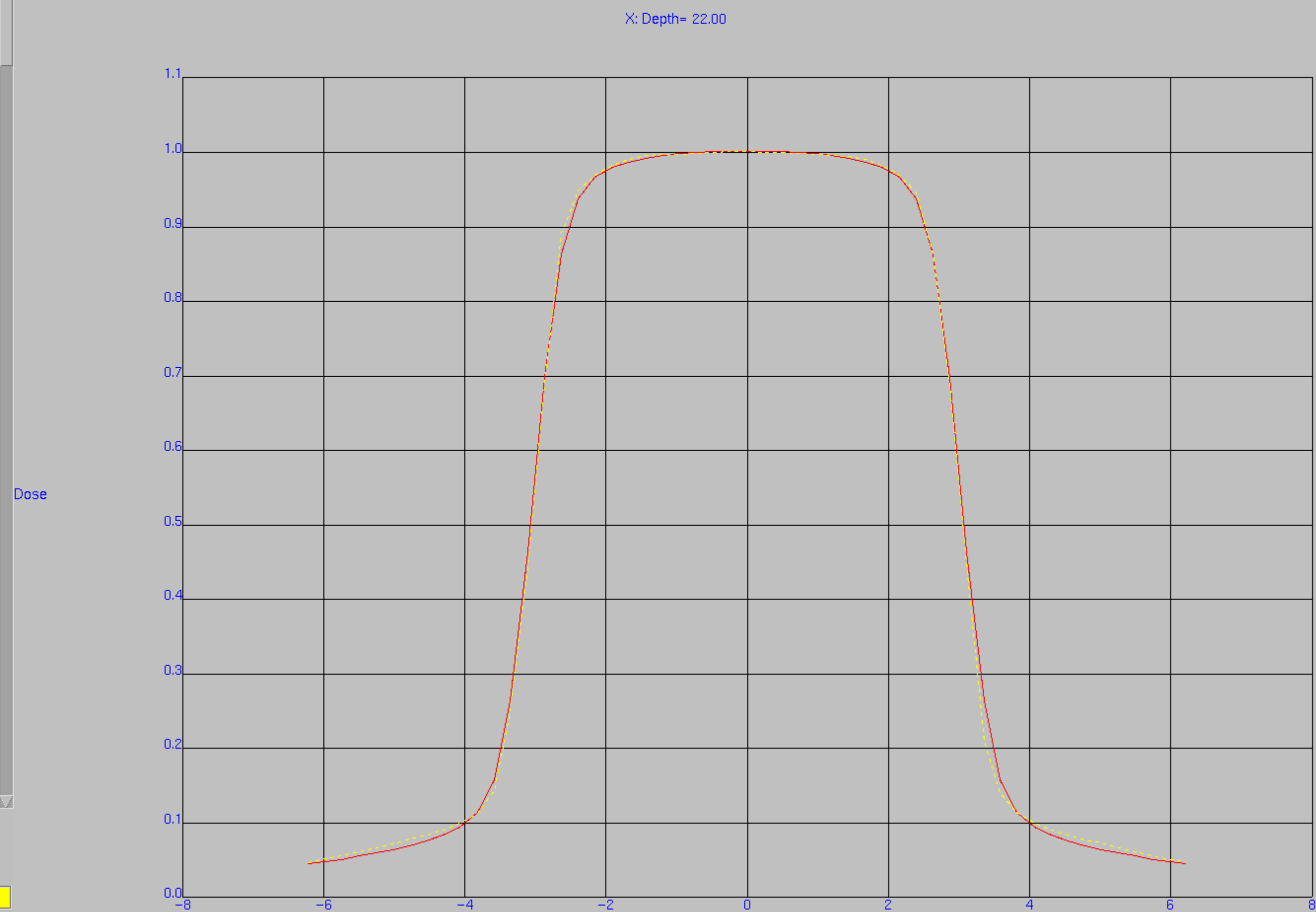
*Pct Err = (Comp − Meas) / Central Axis Dose

Connect at 0 cm

Mean Error:	0.116745	0.527896	−0.923254
Mean Square Error:	0.0421828	0.341621	4.60655

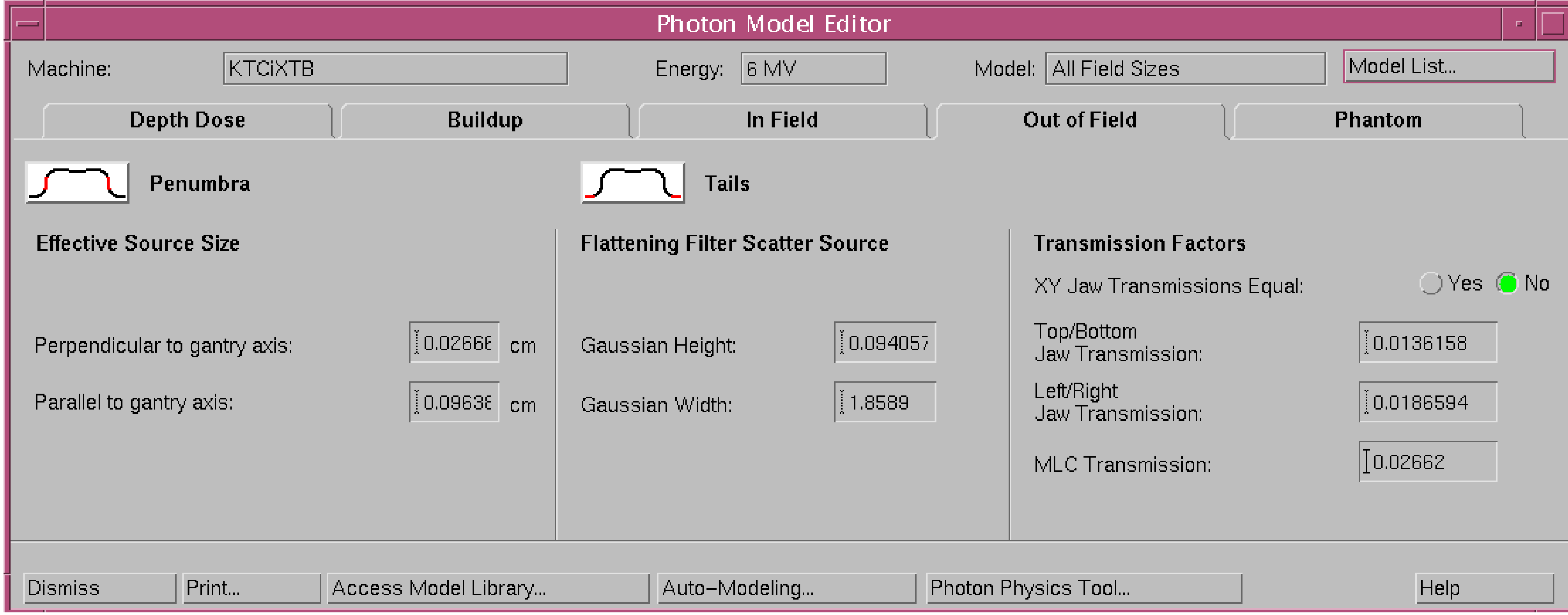
Computed

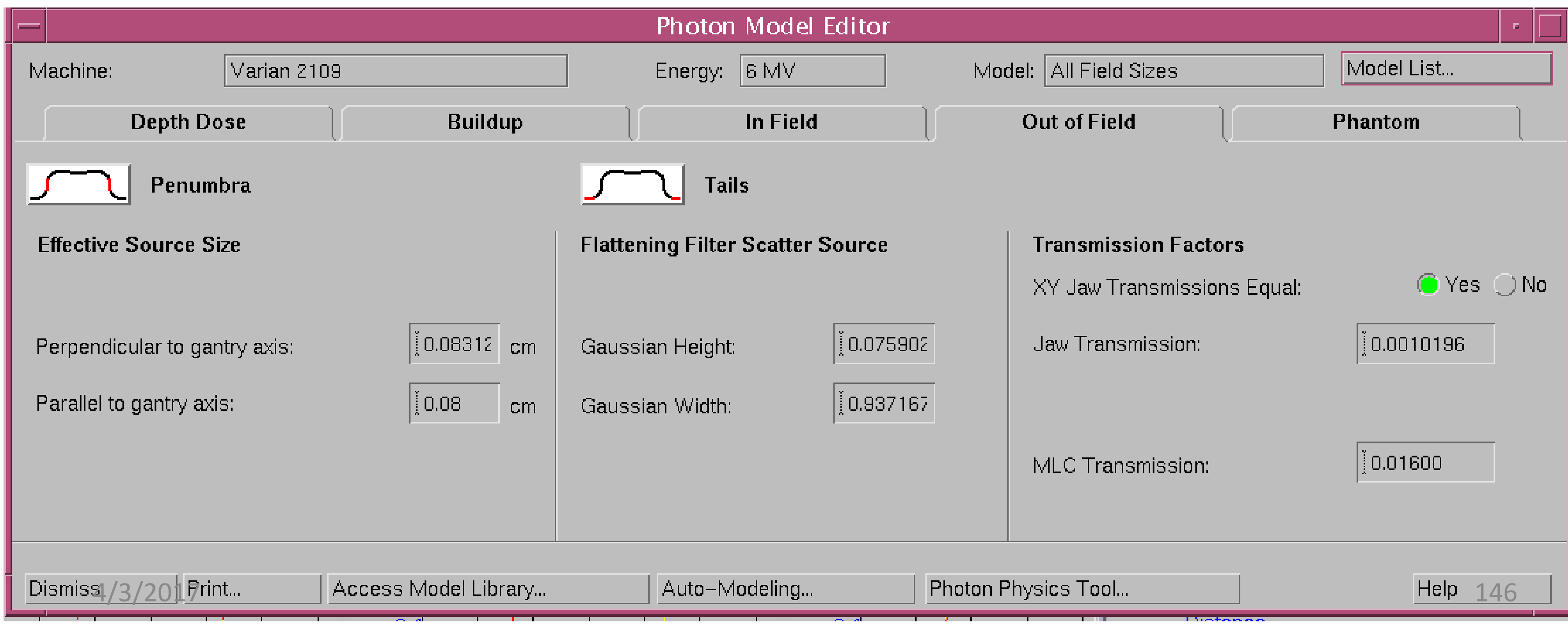
Measured



How was the problem detected

- IMRT QA had poor results for highly modulated fields
- A bad electrometer was found being used for the IMRT QA
  - Caused random spurious IMRT results that made it had to detect the trend with modulation
- IMRT QA was compared running the same plans on the new truebeam and our existing 2100 machines
  - It was noted that the measurements matched but the calculations did not
  - We did a parameter by parameter check between the two models


Photon Model Editor
Machine: KTCiXTB
Energy: 6 MV
Model: All Field Sizes
Model List...
Depth Dose
Buildup
In Field
Out of Field
Phantom
Penumbra
Tails
Effective Source Size
Perpendicular to gantry axis: 0.02666 cm
Parallel to gantry axis: 0.09638 cm
Flattening Filter Scatter Source
Gaussian Height: 0.094057
Gaussian Width: 1.8589
Transmission Factors
XY Jaw Transmissions Equal: Yes No
Top/Bottom Jaw Transmission: 0.0136158
Left/Right Jaw Transmission: 0.0186594
MLC Transmission: 0.02662
Dismiss
Print...
Access Model Library...
Auto-Modeling...
Photon Physics Tool...
Help


Photon Model Editor
Machine: Varian 2109
Energy: 6 MV
Model: All Field Sizes
Model List...
Depth Dose
Buildup
In Field
Out of Field
Phantom
Penumbra
Tails
Effective Source Size
Perpendicular to gantry axis: 0.08312 cm
Parallel to gantry axis: 0.08 cm
Flattening Filter Scatter Source
Gaussian Height: 0.075902
Gaussian Width: 0.937167
Transmission Factors
XY Jaw Transmissions Equal: Yes No
Jaw Transmission: 0.0010196
MLC Transmission: 0.01600
Dismiss
Print...
Access Model Library...
Auto-Modeling...
Photon Physics Tool...
Help

What happened

- New Linac – no previous history on this type of machine
- New model water scanner
    - Had history with the manufacture/software
    - No history with the new electrometer
- New physicist
    - Physics group that had previously managed TPS system left over the course of a few years
    - Physicist who took was very prominent and experienced but not with TPS modeling
    - Another new physicist then took over during the acceptance testing of our 2nd truebeam.

What happened technically

- New electrometer on the scanning system was an in-room design which had a relatively high background signal
- Chamber used for all scanning was a 0.04 cc chamber that has been used in the past as a universal scanning chamber
- Inside the field the noise was trivial and not easily detected
- Outside the field the noise was misinterpreted as a higher jaw/MLC transmission

Commissioning Report

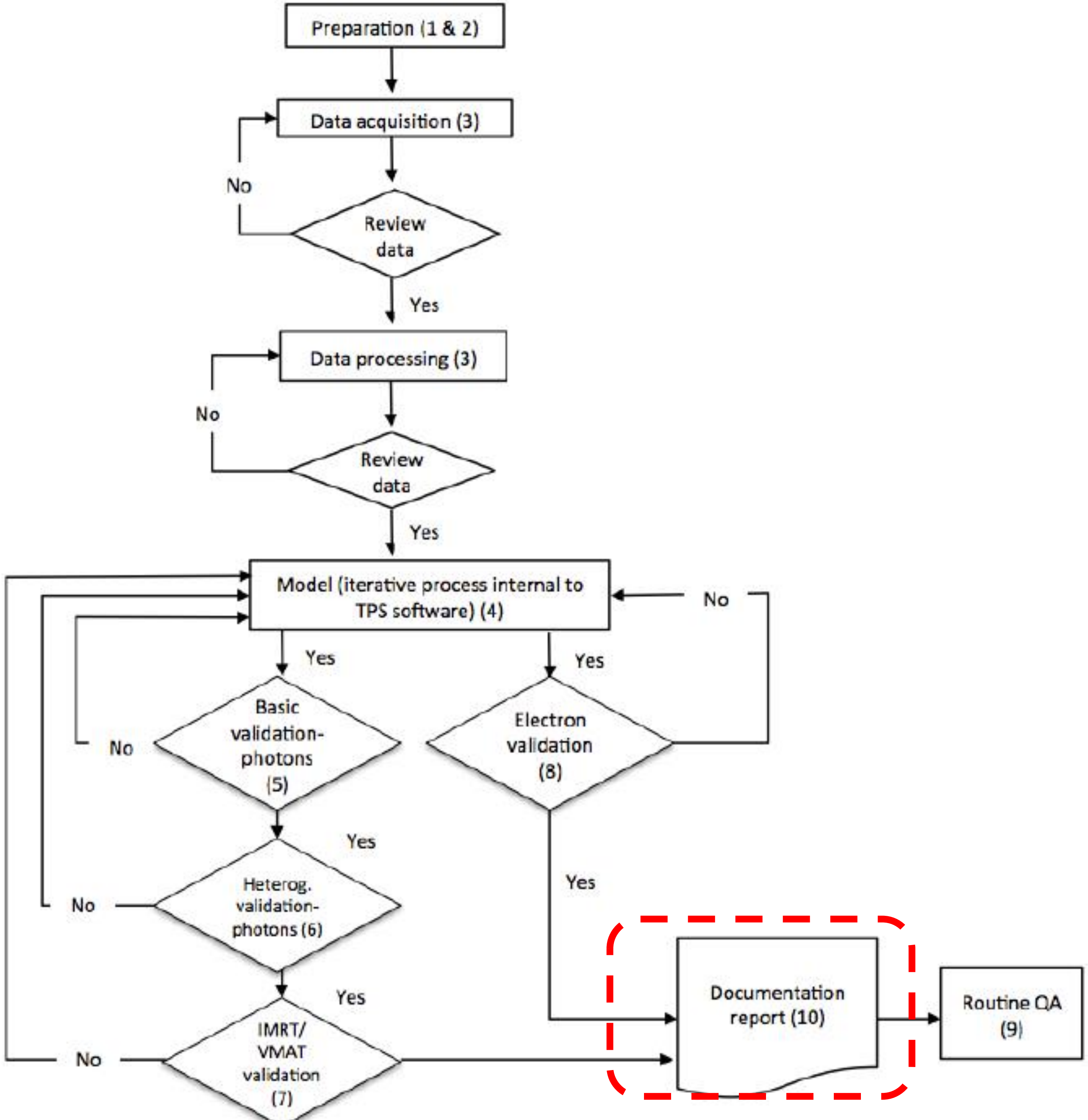


Figure from MPPG5a

Commissioning report

- TG-106 recommendations

VII.C. Commissioning report

It is recommended that a clear and descriptive report of the commissioning data with proper signature and date be written so that this data can be verified in the future and in case of litigation, some degree of accountability can be maintained. The following is a sample of what should be included in the report.

(1) Formal commissioning report, which clearly outlines the scope of the project, what was measured, how, what equipment was used, and the results, with appropriate attention to describing normalization procedures
(2) Open field x-ray PDD and TMR tables
(3) Wedged field x-ray PDD and TMR tables
(4) X-ray output factor tables (S_{cp}, S_c, S_p)
(5) Field size and depth dependent wedge factor tables
(6) Soft wedge (electronic wedge) factor tables
(7) Transmission factor tables
(8) Open field off axis tables at selected depths, large field sizes
(9) Wedge field off axis tables at selected depths, largest field size for wedge
(10) Soft wedge off axis tables at selected depths, largest field size for wedge
(11) Electron cone ratios and effective source distances
(12) Electron PDD tables
(13) Provide at least selected isodose curves for reference fields both for electron and photon beams from PDD and profiles.
(14) Printout of all scan data
(15) Compare data from similar machines within your own department or from different institutions. Comparison to vendor supplied golden data is also acceptable but do not blindly use this data.
(16) Vendor provided data could be used as a reference but it should never be used as a substitute for the commissioned data.
(17) Backup entire electronic data, analyzed data and spread sheets.
(18) Write the report with detailed description of how the beam data were collected and conditions of the beam data collection.

Dose Algorithm Commissioning Inventory (MPPG5)

MPPG Section	*MPPG Item for Each Beam Model*	*Commissioning Report Pages*
1	QMP understands algorithms and has received proper training.	
3	Manufacturer's guidance for data acquisition was consulted and followed.	
3.B	Appropriate CT calibration data acquired.	
3.D	Review of raw data (compare with published data, check for error, confirm import into TPS).	
4	Beam modeling process completed according to manufacturer's instructions.	
4	Beam models evaluated qualitatively and quantitatively using metrics within the modeling software.	
5	Basic photon beam validation: Tests 5.1–5.8 (5.9 for nonphysical wedge).	
6	Heterogeneity correction validation for photon beams: Tests 6.1–6.2	
7	IMRT/VMAT validation: Tests 7.1–7.4	
7	IMRT/VMAT End-to-End test with external review: Test 7.5	
7	Understand and document limitations of IMRT/VMAT modeling and dose algorithms.	
8	Electron validation: Tests 8.1–8.3	
9	Baseline QA plan(s) (for model constancy) identified for each configured beam and routine QA established.	

An example

TPS QA

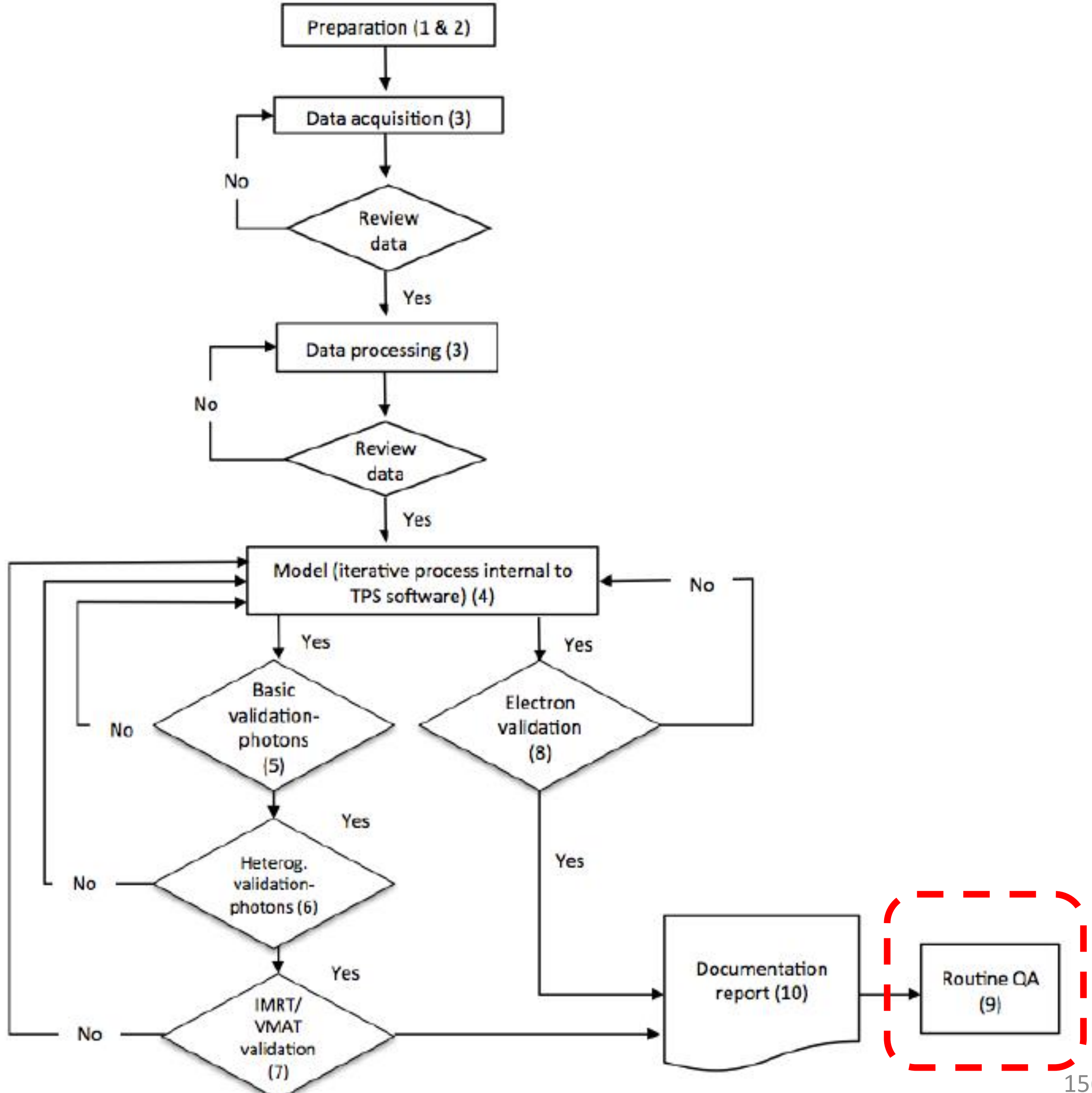


Figure from MPPG5a

MPPG5: QA recommendations

- Annually or after major TPS upgrades
- Reference plans should be selected at the time of commissioning and then recalculated for routine QA comparison.
- Photons: representative plans for 3D and IMRT/VMAT, from validation tests
- Electrons: for each energy use a heterogeneous dataset with reasonable surface curvature.
- No new measurements required!
- The routine QA re-calculation should agree with the reference dose calculation to within 1%/1mm. A complete re-commissioning (including validation) may be required if more significant deviations are observed

(AAPM TG53 can also be a useful resource)

Hand calculation data

Hand Calc vs TPS data

- The machine databook may require different data than the TPS
  - Example Output factors for Pinnacle are at 10 cm depth vs at D_{max}(or $D_{reference}$) for most hand calculation systems
  - Wedge factors for hand calc need to be a function of FS and depth (Dr. Court will discuss)
- Hand calc data should not be derived from the TPS
  - Loss of independence
  - This includes data for secondary software calculation systems (ie RadCalc)

Hand Calc Data (TG-45)

The following are needed for the calculation of the number of monitor units required to deliver a prescribed absorbed dose at a point at a given depth along the central ray of a square or rectangular beam in a unit density medium

1. Square and rectangular photon beams

The following are needed for the calculation of the number of monitor units required to deliver a prescribed absorbed dose at a point at a given depth along the central ray of a square or rectangular beam in a unit density medium:

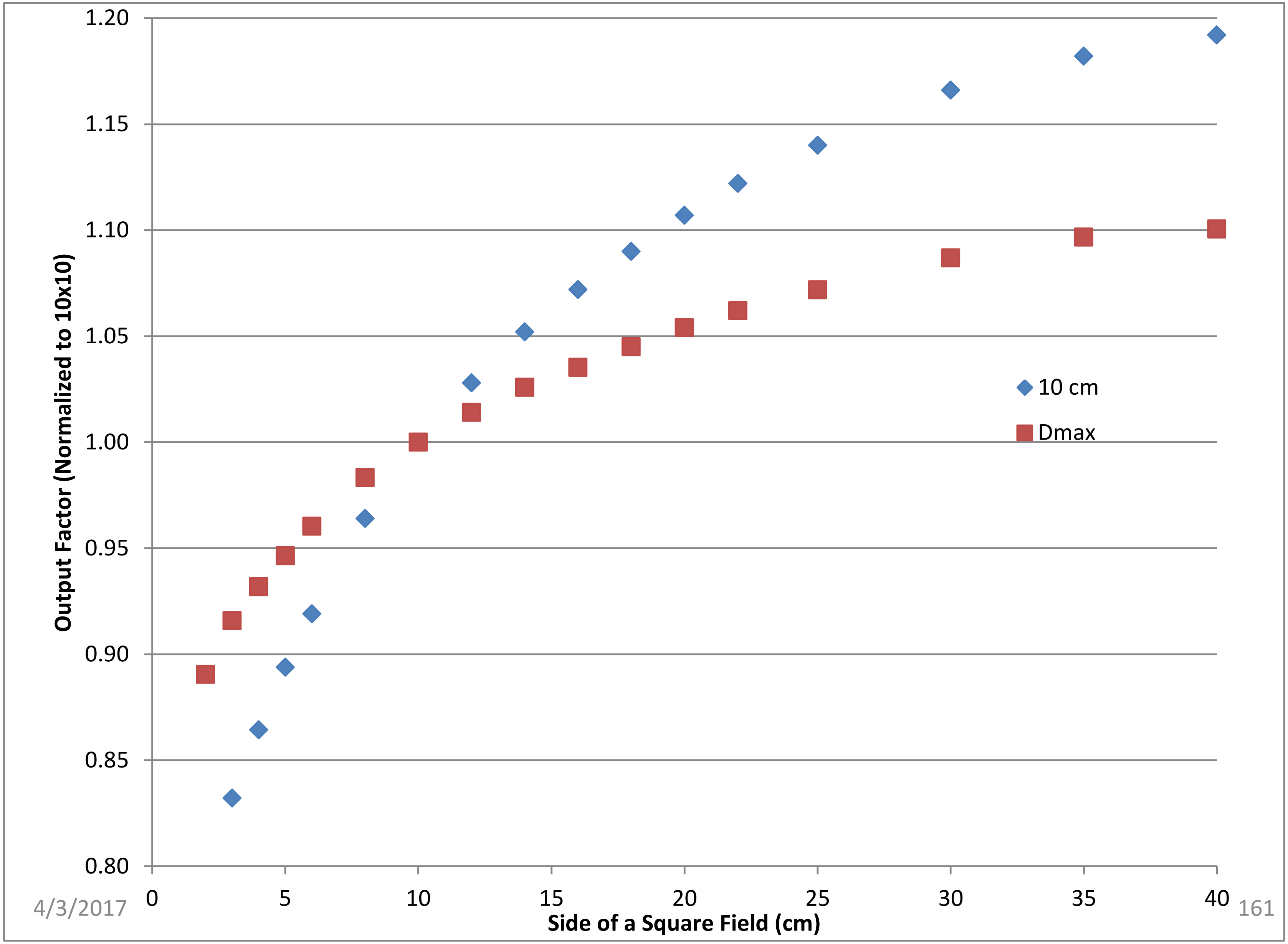
(1) tables and/or graphs of percentage depth dose and/or tissue air ratios and/or tissue phantom ratios, for all square fields with suitable increments in dimensions;
(2) a table of "equivalent square fields;"
(3) a table of output factors in air and in phantom;
(4) correction factors for changes in PDD for nonstandard SSDs;
(5) peak scatter factors;
(6) tray and wedge correction factors.

For the manual calculation of absorbed dose at an off-axis point, the following additional data are necessary:

(1) isodose charts (for constant SSD) for square fields, with suitable increments in field size;
(2) isodose charts (for constant SSD) for a selection of elongated fields, and/or suitable rules to convert charts for square fields to the desired rectangular field:
(3) a method to correct for oblique incidence,

Measurements of PDD are usually taken for square fields of sides 4,5,6,8,10,12,15,20 and at further increments of 5 cm up to the largest setting. Field sizes are generally expressed in cm at the isocentric distance. Isodose charts are usually taken for the same square fields, and normalized at the d_{max} on the central ray. These measurements are best taken in water using a scanning dosimetry system.

Output (Scp) vs FS at Dmax and 10 cm



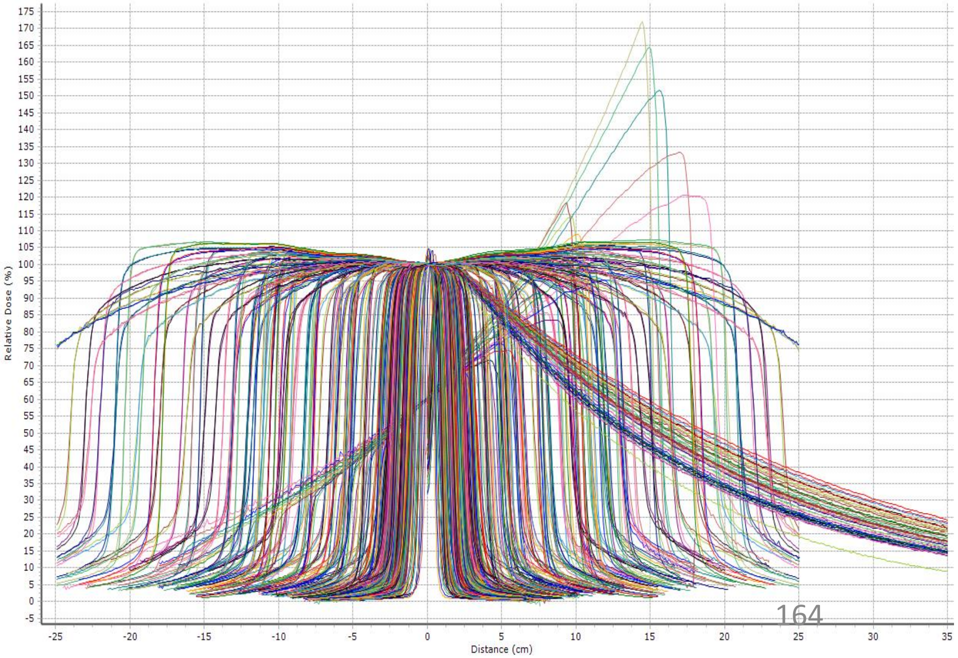
Planning the commissioning process

Plan your measurements

- Create a list for Hand calc
- Create a list for TPS
- Include time for auditing
- If possible work in teams
  - One person taking data
  - One person auditing and processing the data
- Have a spare day every few days of data taking for problem solving/investigation
- Use caution with trainees
  - Ensure you know the equipment before letting them "help"
  - Spot check any data generated without direct supervision

Time Required

- Beam Scanning
  - A day per photon energy
  - Extra scanning can take additional time
    - Not used for modeling, but useful data
- Relative Output Factors
  - Half a day per photon energy
- Data Smoothing
  - About a day or more per energy
- Pinnacle Modeling
  - A week per photon energy



Verification

- The Model is used Compute dose distributions that are compared to measurement
  - TLDs: In-house and/or RPC
    - Must read TLDs
    - 24 hours for in-house TLDs, Weeks for RPC TLDs
  - IMRT / VMAT QA Measurements - Days
    - Must generate a plan for several CTs / phantoms
    - And take measurements
  - RPC Phantoms – Days to Weeks
    - Simulate phantom
    - Generate a plan
    - Setup Phantom and Deliver plan
    - Send to RPC for analysis
  - Direct comparison with data - Days
    - Must generate and export data from Pinnacle
    - Comparison in a manual process

MPPG5 time estimates (4 photon energies, 5 electron energies)

Activity	Description	Time (person-hr)
Preparation	Create Plan in TPS	18.7
Preparation	Create Scan Queues	1.2
Preparation	Create Spreadsheet	4.3
Preparation	CT Scan Phantom	2.3
Preparation	Scan Background Films	0.5
Measurement	Ion Chamber Measurements in Phantom	9.0
Measurement	DQA Measurements (Delta4, MapCheck)	8.5
Measurement	Scanning Measurements	8.5
Measurement	Measurements (Misc.)	1.0
Analysis	Analysis with MPPG Program	3.6
Analysis	Analysis with SNC Patient	4.5
Analysis	Data Processing in OmniPro	4.5
Analysis	Film Analysis	2.5
Analysis	Data Analysis (Misc.)	14.5
Total	**Total**	**83.6**

It is recommended to take data at time of commissioning.

Test	Time (person-hr)
5.1	0.0
5.2	0.3
5.3	8.5
5.4	2.7
5.5	2.4
5.6	2.4
5.7	2.4
5.8	2.4
5.9	1.6
6.1	1.0
6.2	3.7
7.1	2.4
7.2	0.0
7.3	16.0
7.4	11.8
7.5	15.0
8	0.3
8.1	3.9
8.2	2.5
8.3	4.4
Total	**83.6**

Final slide ☺

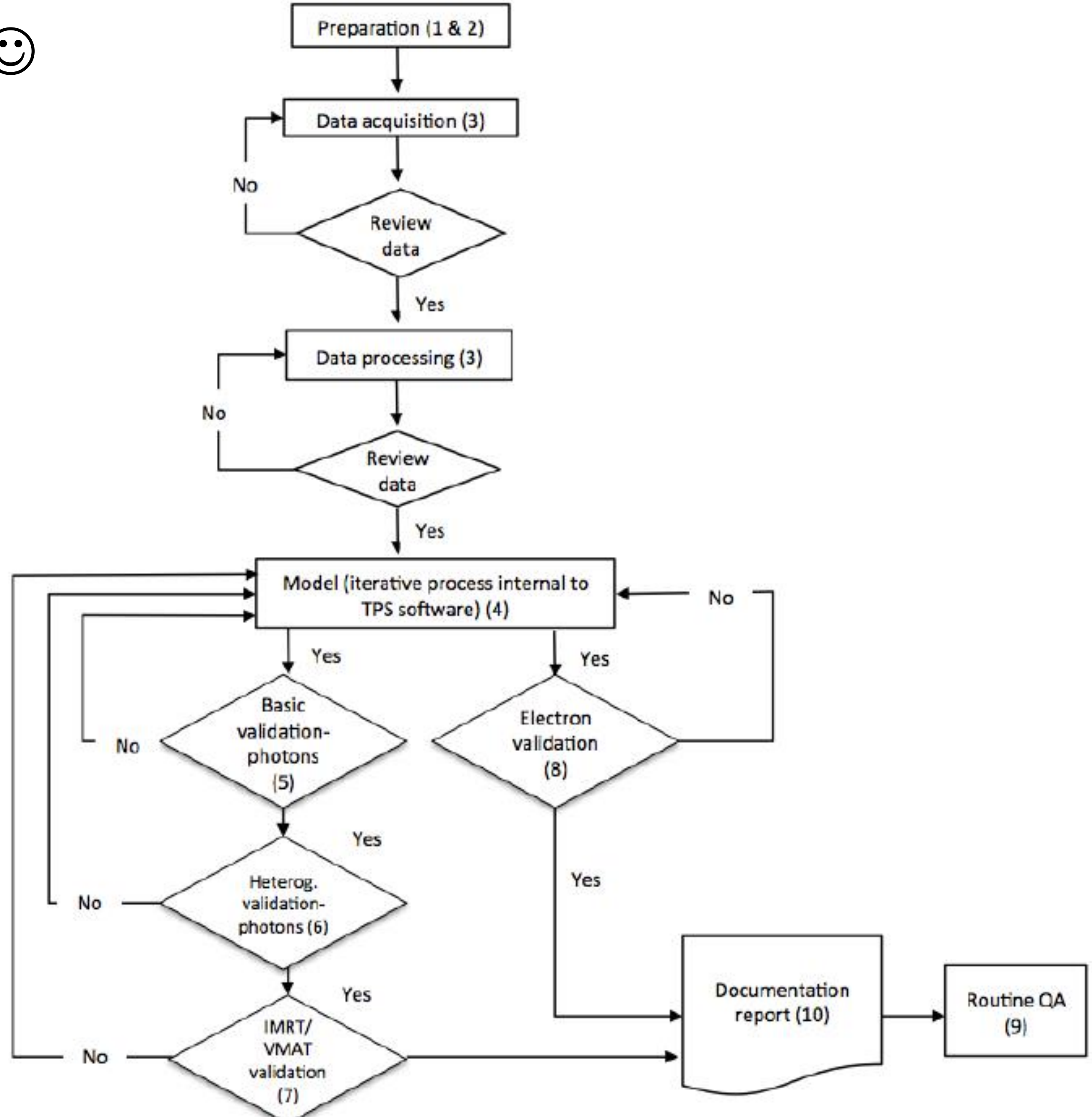


Figure from MPPG5a