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

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TG 244

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- Internal review = ✓
- Public review = ✓
- SPG vote = ✓
- CPC vote = ✓
- PC vote = ✓
- JACMP edit = current

Publication expected July 1 2015

"Companion" manuscript for JACMP in the works on initial implementation experience at UW and MUSC.

University of Wisconsin
SCHOOL OF MEDICINE AND PUBLIC HEALTH

NCC AAPM Spring Meeting, 4/17/15

Outline

1. Introduce MPPG's
2. Overview of MPPG #5
3. Introduce MatLab Profile analysis tool written for some of the validation tests
4. Discuss initial implementation experience and some of the lessons learned.

1. What is an MPPG?

- http://www.aapm.org/pubs/MPPG/
- 2011 AAPM BOD approved development of MPPG, under Professional Council
- MPPG will be crucial to ensuring a consistent benchmark for radiation therapy accreditation programs.
- In creating MPPGs, a formal framework for developing Practice Guidelines was defined which can be referenced by clinical physicists, accreditation bodies, regulators, and hospital administrators when determining the **minimum acceptable level of medical physics practice to support a clinical service.**

MPPG Scope and Vision

- Vision: "The AAPM will lead the development of MPPGs in collaboration with other professional societies. The MPPGs will be freely available to the general public. Accrediting organizations, regulatory agencies and legislators will be encouraged to reference these MPPGs when defining their respective requirements."
- Scope: "…provide the medical community with a clear description of the **minimum level of medical physics support that the AAPM would consider to be prudent in all clinical practice settings.**"

Published Guidelines

- AAPM Medical Physics Practice Guideline 1.a.: CT Protocol Management and Review Practice Guideline (JACMP). V 14, No 5 (2013).
- AAPM Medical Physics Practice Guideline 2.a: Commissioning and quality assurance of X-ray–based image-guided radiotherapy systems (JACMP). V15, No 1 (2014).
- Anticipated in May 2015:
  - MPPG 3a: Levels of Supervision for Medical Physicists in Clinical Training
  - MPPG 4a: Safety Checklists (Luis Fong de los Santos)
- In progress:
  - MPPG 6: Dose monitoring software
  - MPPG 7: Medical Physicist Assistants
  - MPPG 8: Linac QA

2. MPPG #5 in a Nutshell

- 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.
- Tolerances & Evaluation criteria (2 tier approach)
  - Wanted minimum acceptable tolerance for TPS “basic” dose calculation.
  - Did **not** want to state or use any minimum tolerance values that are not widely accepted/published.
  - Wanted to push the limit on some evaluation criteria (for IMRT/VMAT) to expose limitations of dose calculations.
- Scope: Limited to the commissioning and QA of the beam modeling and calculation of external beam XRT TPS.

- In the spirit of “practice guidelines”, this MPPG is a summary of what the AAPM considers prudent practice for <u>what a clinical medical physics should do</u> w.r.t. dose algorithm commissioning/validation (e.g: for accreditation)

What to do/check?

The MPPG report only covers dose calculation, the term "commissioning" includes beam data acquisition, modeling, and validation.

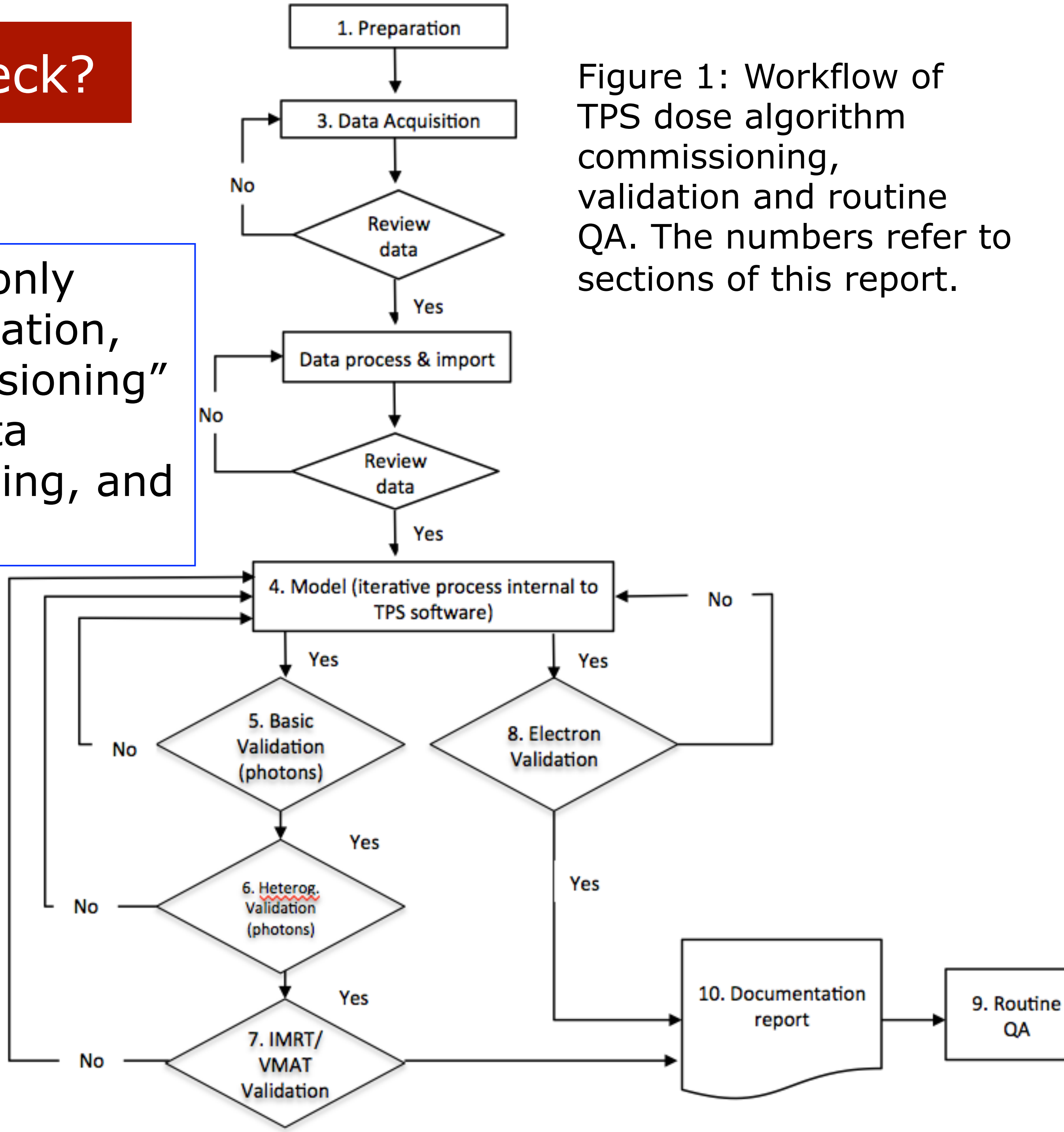


Figure 1: Workflow of TPS dose algorithm commissioning, validation and routine QA. The numbers refer to sections of this report.

MPPG #5: What to do/check?

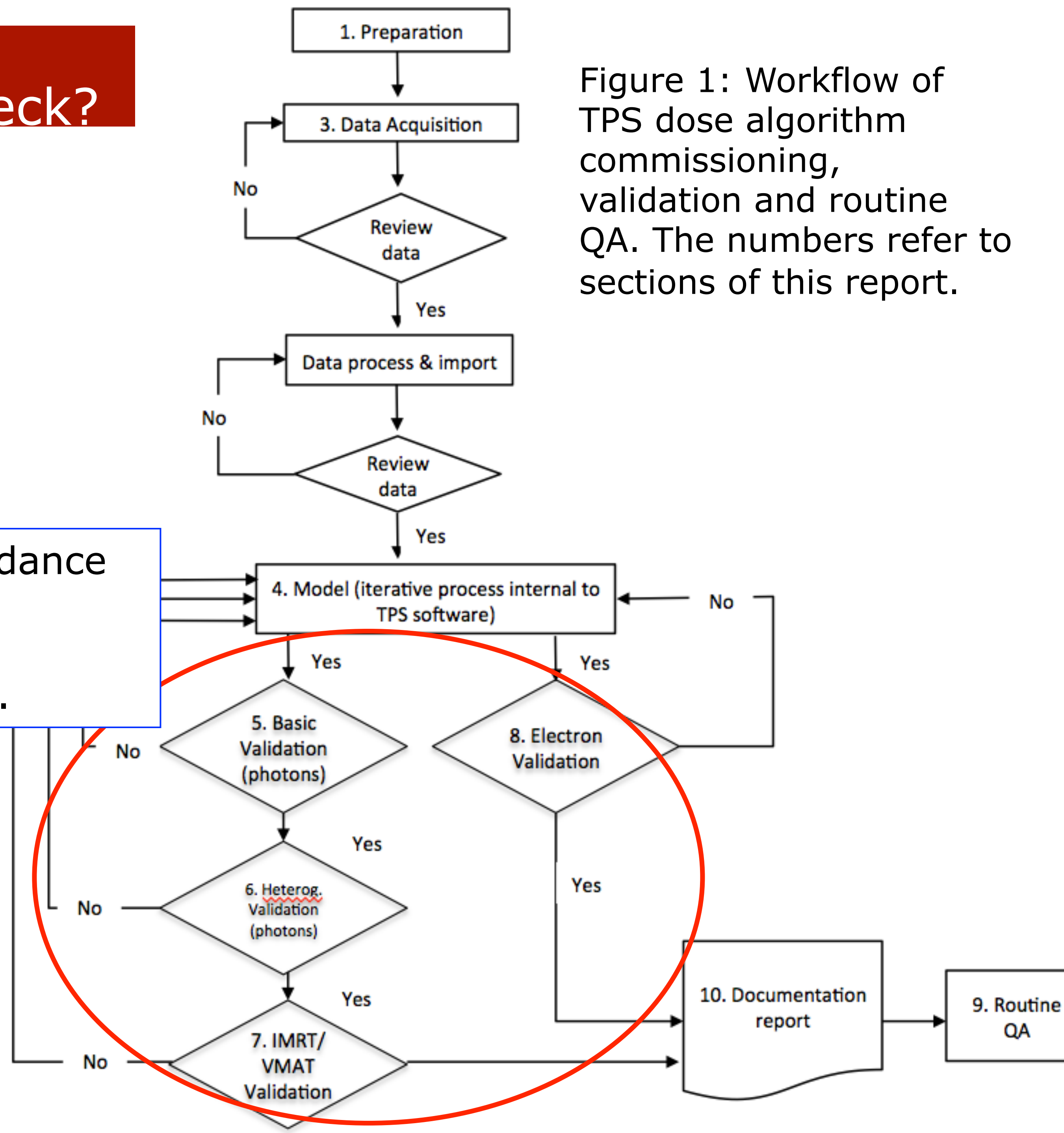


Figure 1: Workflow of TPS dose algorithm commissioning, validation and routine QA. The numbers refer to sections of this report.

Lecture covers guidance and experience implementing the validation sections.

Overview of MPPG #5 Validation Tests

Verification Section	Test	Measurement tools used in this implementation
5. Basic Photon	5.1 Physics module versus planning module dose	None
	5.2 Clinical calibration dose	Water tank and farmer chamber
	5.3 Planning module dose versus commission data	Water tank and scanning chamber
	5.4-5.9 Basic photon tests *	Water tank and scanning chamber
6. Inhomogeneity	6.1 CT to Density calibration	CT-Density phantom
	6.2 Heterogeneity correction	Custom phantom and ion chamber
7. IMRT/VMAT	7.1 Small field PDD	Water tank and scanning chamber
	7.2 Small MLC defined field output	Diode or micro ion chamber
	7.3 -7.4 TG-119 and clinical tests	IMRT QA devices (Delta4 and MapCheck2)
	7.5 External Review	Diodes and OSLs
8. Electrons	8.1-8.2 Electron basic tests and obliquity tests	Water tank and scanning chamber
	8.3 Electron heterogeneity correction	Custom phantom and ion chamber

Tolerances & Evaluation criteria (2 tier approach)

Test	Comparison	Description	Tolerance
5.1	Dose distributions in planning module vs. modeling (physics) module	Comparison of dose distribution for large (>$30x30cm^2$) field.	Identical *
5.2	Dose in test plan vs. clinical calibration condition**	Reference calibration condition check	0.5%
5.3	Dose distribution calculated in planning system vs. commissioning data	PDD and off axis factors for a large and a small field size	2%

Basic photons

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

Tolerances & Evaluation criteria (2 tier approach)

Test	Objective	Description	Tolerances*	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 (Papanikolaou & Stathakis, 2009); IAEA TRS-430 (International Atomic Energy Agency, 2004)
6.2	Heterogeneity correction distal to lung tissue	5x5 cm^2, measure dose ratio above and below heterogeneity, outside of the buildup region	3%	IAEA TRS-430 (International Atomic Energy Agency, 2004), Carrasco et al. (Carrasco, et al., 2004)

Heterogeneity and IMRT/ VMAT

Table 8: VMAT/IMRT Evaluation Methods and Tolerances

Measurement Method	Region	Tolerance
Ion Chamber	Low gradient target region	2% of prescribed dose
	OAR region	3% of prescribed dose
Planar/Volumetric Array	All regions	2%/2mm*, 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

*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 (Opp, Nelms, Zhang, Stevens, & Feygelman, 2013).

Tolerances & Evaluation criteria (2 tier approach)

Electron beams

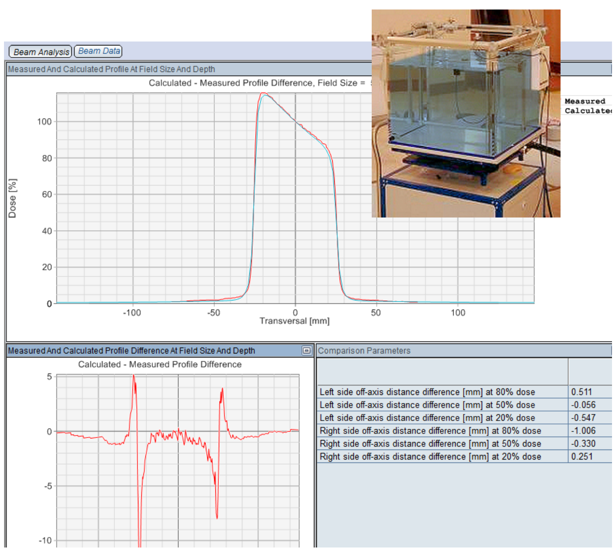
Table 9: Basic TPS validation tests for electron beams and minimum tolerance values

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%
8.3	Inhomogeneity test	Reference cone and nominal clinical SSD	7%

Problem statement:
Validation, what does it mean to you???

Model

- TPS-specific software
- Limited analysis tools (often can't set values) and output reporting
- Standard (not tx) fields
One (or a few) time (s) only

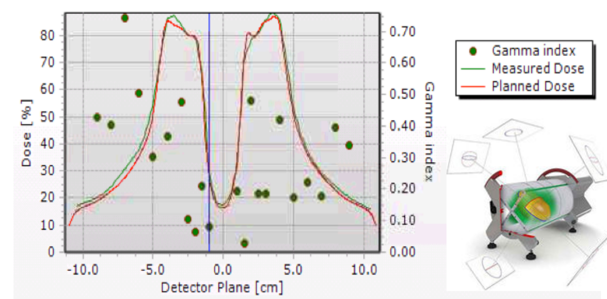


"Validation"

-Realistic Tx fields
-Includes components of both model and DQA
-Water tank scans, IC measurements (we all have different tools and linacs)
-Includes IMRT QA measurements
-Sanity checks
-Software upgrades
-Trouble shooting
-TPS QA
-What criteria to use?

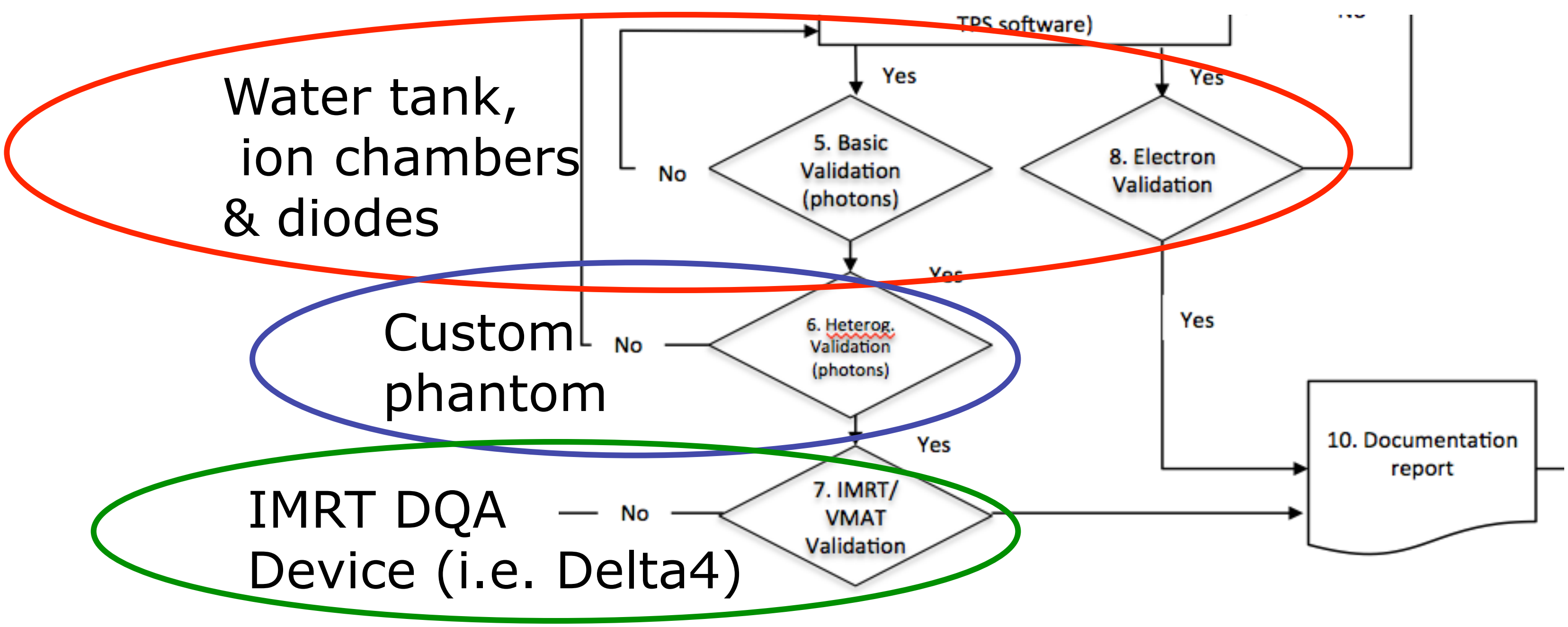
Pt. specific QA (DQA)

- Ubiquitous 3%/3mm tolerance
- Commercial products (Eg: MapCheck, ArcCheck (Sun Nuclear), Delta4 (ScandiDos)
- Not water tank, no always intuititive
- Each IMRT patient



A variety of validation test "types"

1. Non-measurement ("sanity check")
2. Point dose measurement
   - Liquid/solid water
   - Simple heterogeneous phantom
3. IMRT/VMAT dose distribution QA (patient specific QA)
4. Water tank profiles in representative (non-IMRT) treatment fields **DIFFICULT TO ANALYZE



3.The right tools and a bit of forethought makes implementation much easier!

- MPPG #5 Report was written such that user has freedom to use any suitable/available combination of phantoms and detectors. Specific field design is not included in report.
- It is recommended to take data at time of commissioning.
- Create standard test plans for use with upgrades and routine QA.
- The most difficult analysis was:

4. Water tank profiles in representative (non-IMRT) treatment fields
**DIFFICULT TO ANALYZE

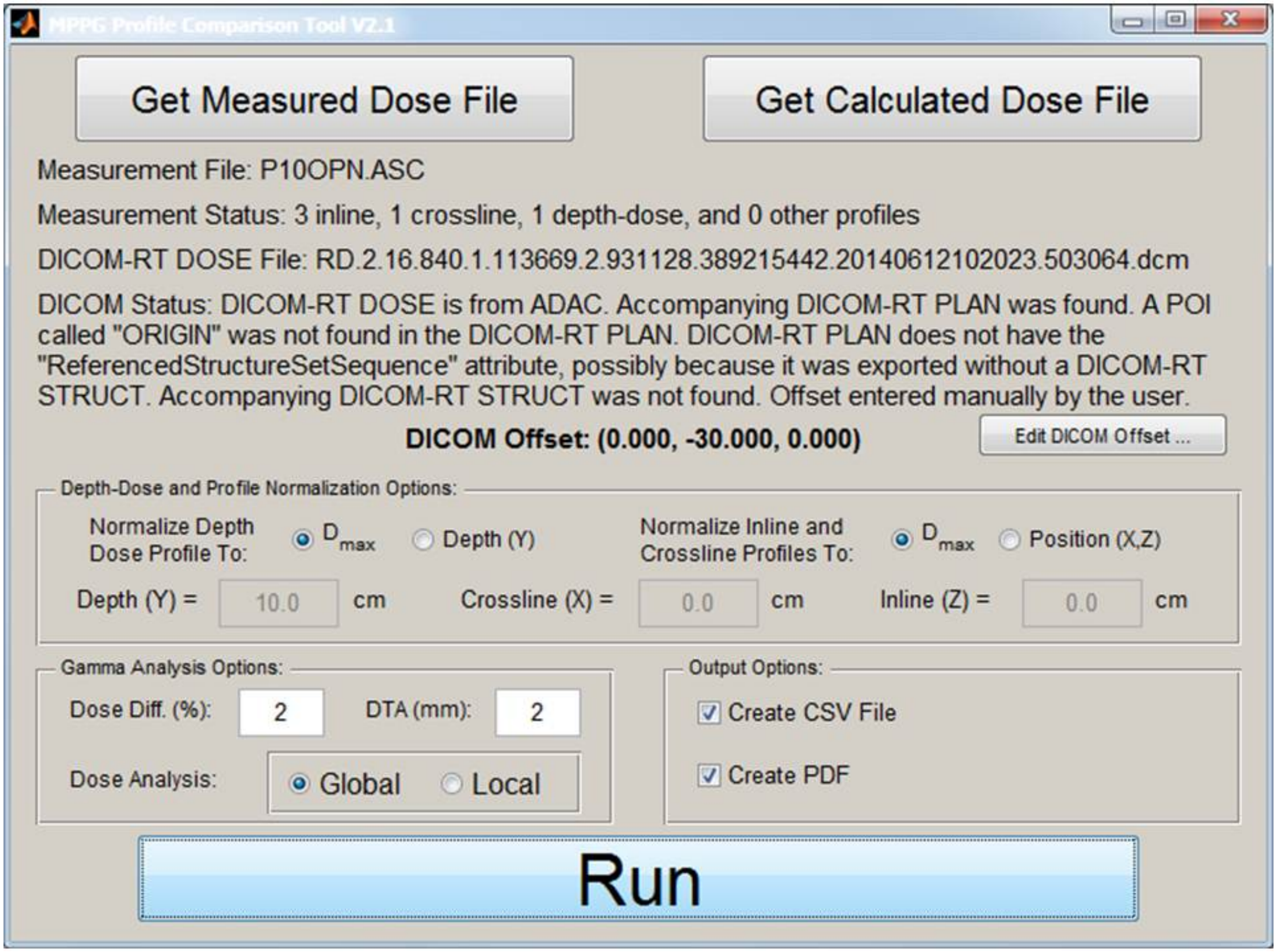
- As part of the implementation at UW and MUSC we created test fields and a robust, open source MatLab code for Profile Analysis and an ‘uber’ spreadsheet.

Uber spreadsheet

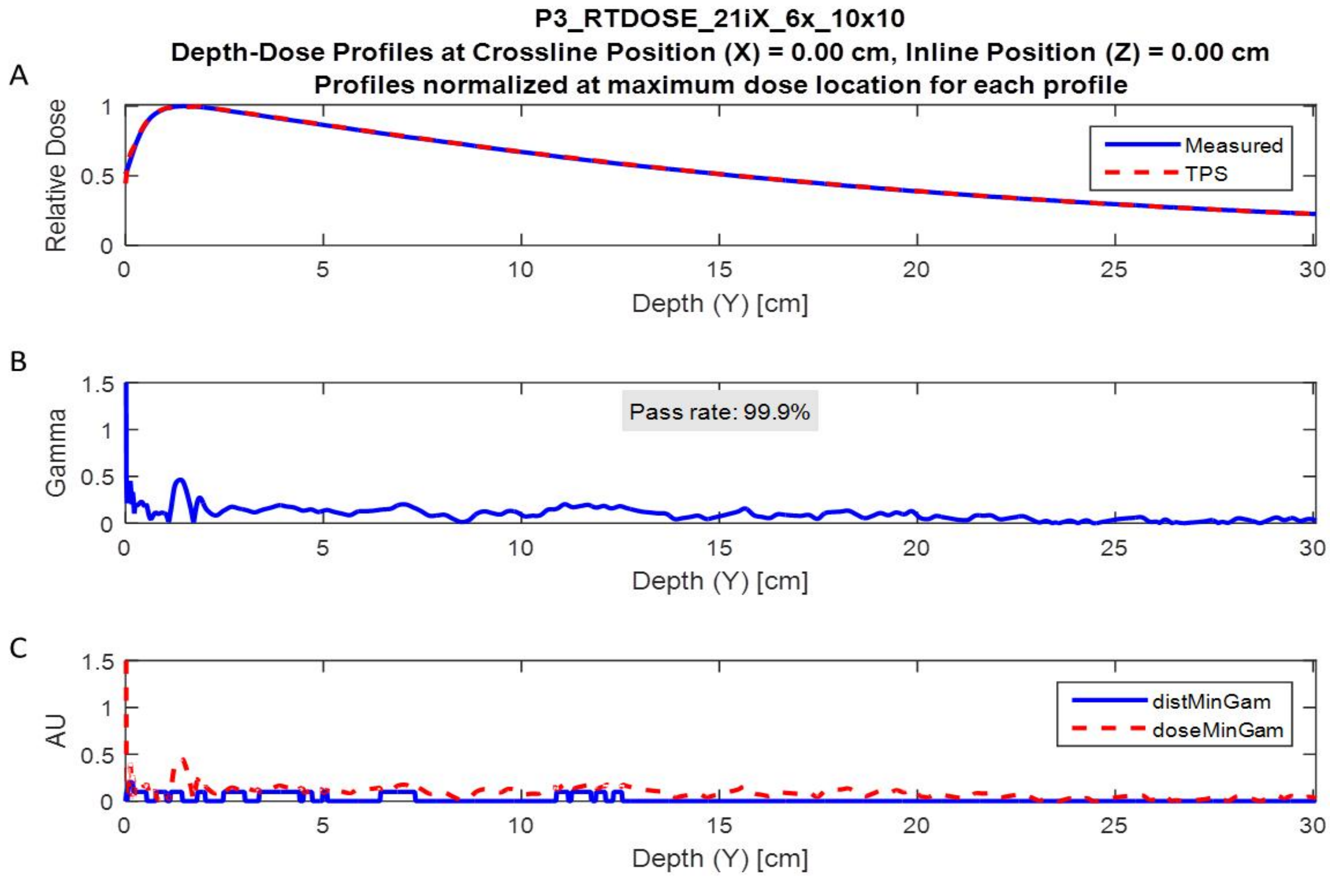
Summary	UW Madison, TrueBeam 1358
Notes:	On PDF printouts the coordinates are that of scanning system (Y is depth and Z is direction parallel to long dir of couch) - clarify this
	Comparisons are: [(measured - calculated)/measured]
	Dicom offset used for the MPPG5 Profile Comparison Tool = (0,-30.25, 0)
5.1 Physics. vs Plan data	Incomplete
5.2 Abs Dose	6 MV and 10 MV Pass, electrons have not been done yet.
5.3 Comm. vs. Plan data	Incomplete
5.4 Small MLC	6 MV and 10 MV Pass at 2%/2mm
5.5 Large MLC	6 MV Pass at 3%/3mm, 10 MV Pass at 2%/2mm
5.6 Off Axis	6 MV and 10 MV Pass at 2%/2mm
5.7 Asym 80 SSD	6 MV and 10 MV Pass at 2%/2mm
5.8 Obliques	6 MV and 10 MV Pass at 2%/2mm
5.9 EDW	Incomplete, EDW not yet commissioned for TB
6.1 CT-Density Cal.	Pass
6.2 Heterogeneity	6 MV and 10 MV Pass at < 0.5%
7.1 Small MLC PDD and OF	6 MV and 10 MV pass at 2%/2mm and OF pass at 2%
7.2 Small MLC shapes OF	6 MV OF pass at 5% and 10 MV pass at 2%
7.3 TG 119	Extensive IMRT DQA run on test suite based on clincal plans run in lieu of the TG-119
7.4 Clincal DQA	All pass (except test 11) at 2%/2mm)
7.5 External	OSLD Check passed photons and electrons
8.1	Incomplete, Jeni will fill in later
8.2	Incomplete, Jeni will fill in later
8.3	Incomplete, Jeni will fill in later

Summary | 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 | 6.1 GE LS | 6.2 | 7.1 | 7.2 | 7.3 | 7.4

MatLab Profile Analysis Code



Sample output



https://morgridge.org/open-source-medical-devices/mppg/

MORGRIDGE INSTITUTE *for* RESEARCH

ABOUT RESEARCH OUTREACH CAREERS NEWS GIVE

MPPG #5 Profile Comparison Tool

Researchers in the Morgridge Institute's Medical Engineering group, in collaboration with physicists at the University of Wisconsin Carbone Cancer Center and Medical University of South Carolina, have developed an open source software tool for aiding in the commissioning and QA of external beam treatment planning systems.

The tool, called the MPPG#5 Profile Comparison Tool (PCT) is being hosted by Open Source Medical Devices in order to help make the source code widely available to the medical physics community.

The MPPG Profile Comparison Tool is a simple but powerful profile comparison tool designed to be used during the commissioning and QA of external beam treatment planning systems.

The program accepts profile data from scanning water tank systems and DICOM-RT DOSE files from commercial treatment planning system, co-registers the data sets, and performs a 1D gamma analysis on the profiles. The user may specify a number of analysis and export settings.

MPPG #5 Profile Comparison Tool Instructions

MPPG #5 Profile Comparison Tool Downloads (UW Box)
MPPG #5 Profile Comparison Tool Downloads (GitHub)

Includes executables, MATLAB files and sample comparison files

OSMD Home
Introduction
bmMLC Design 1
bmMLC Design 2
Small Animal Treatment Planning System
Conference
Video Archive
System Specifications
Collaborate with Us

4. Initial implementation experience

- Now I will step through some of the tests to illustrate the organization, implementation of the validation tests using the various tools.

Photon beams: TPS model comparison (5.1-5.3)

Table 3: TPS model comparison tests and minimum tolerances*

Test	Comparison	Description	Tolerance
5.1	Dose distributions in planning module vs. modeling (physics) module	Comparison of dose distribution for large (>30x30) field.	Identical
5.2	Dose in test plan vs. clinical calibration condition*	Reference calibration condition check	0.5%
5.3	Dose distribution calculated in planning system vs. commissioning data	PDD and off axis factors for a large and a small field size	2%

* No additional measurements required for these tests

** Calibration condition of TPS, not the necessarily of linac per TG 51

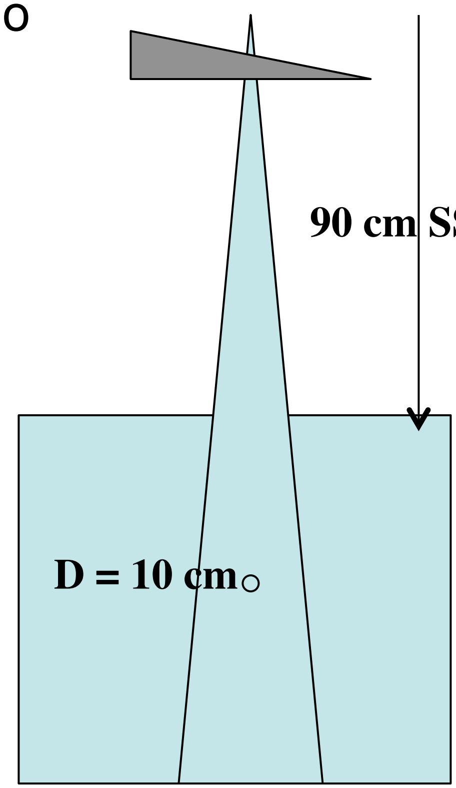
No additional measurements beyond commissioning data needed for these tests.

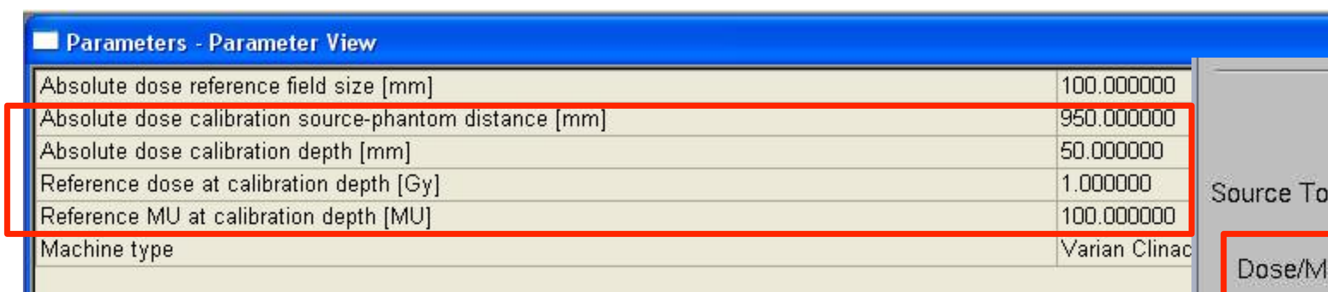
Implementation: Dose in test plan vs. TPS calibration (0.5% tolerance)

- Part of an exercise to confirm "match" between two Varian 2100s

10 MV beams	Meas.(Gy)	TPS calc (Gy)	% diff
Open, 90 cm SSD	0.893	0.891	-0.18
15° W, 90 cm SSD	0.669	0.669	-0.01
30° W, 90 cm SSD	0.543	0.544	0.21
45° W, 90 cm SSD	0.470	0.473	0.71
60° W, 90 cm SSD	0.392	0.394	0.42
Open 100 cm SSD	0.744	0.741	-0.34

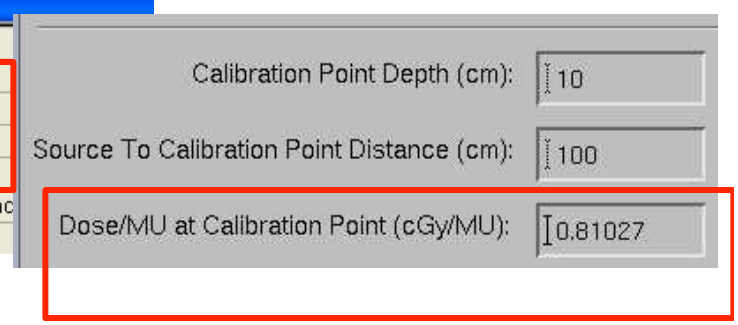
10 MV open and wedge absolute dose comparison, 10x10 cm^2 and d=10 cm. The 10 MV 45° wedge exceeded the 0.5% tolerance suggested in the MPPG and is being investigated





Parameters - Parameter View

Absolute dose reference field size [mm]	100.000000
Absolute dose calibration source-phantom distance [mm]	950.000000
Absolute dose calibration depth [mm]	50.000000
Reference dose at calibration depth [Gy]	1.000000
Reference MU at calibration depth [MU]	100.000000
Machine type	Varian Clinac



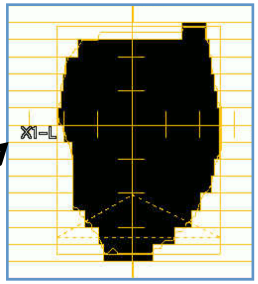
Calibration Point Depth (cm): 10

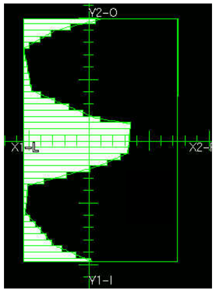
Source To Calibration Point Distance (cm): 100

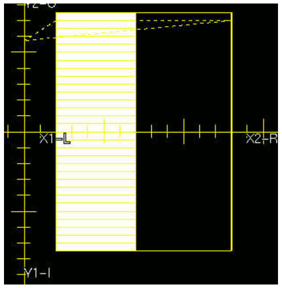
Dose/MU at Calibration Point (cGy/MU): 0.81027

Basic photon tests

Test	Description
5.4	Small MLC shaped field (non SRS)
5.5	Large MLC shaped field with extensive blocking (e.g.: mantle)
5.6	Off-axis MLC shaped field, with maximum allowed leaf over travel.
5.7	Asymmetric MLC shaped field at minimal anticipated SSD
5.8	MLC shaped field at oblique incidence (30°)
5.9	Large (>15cm) MLC field for each a non-physical wedge angle**

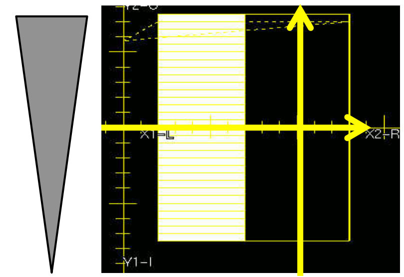






Show the workflow for 5.6 , and results for 5.5 &5.6

Sample workflow for 1 basic photon test: 5.6 off axis MLC/jaw field for 6 MV 15° wedge

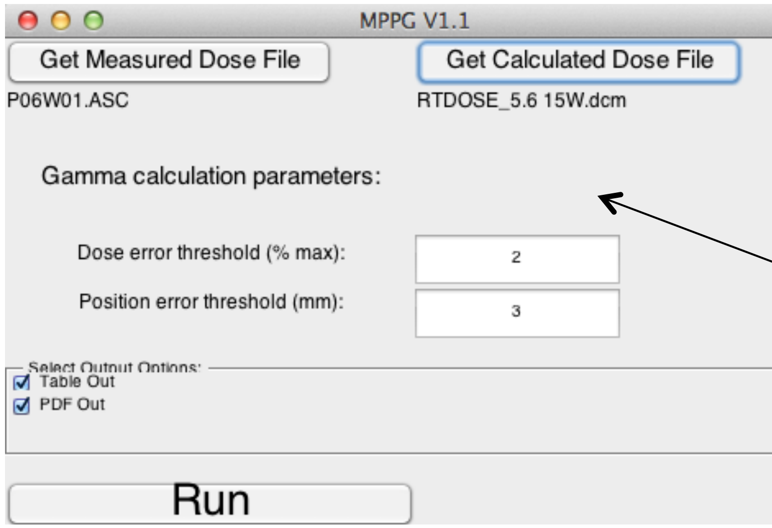


(~30 min, excluding tank setup)

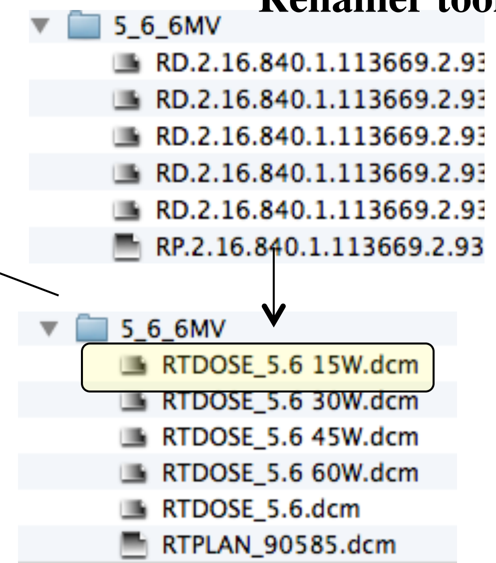
1. In TPS
   - Adjust field for model (e.g.: energy, wedge)
   - Calculate dose on virtual phantom (ρ=1 g/cc)
   - Export DICOM files: dose per beam (RD files) & plan file (RP)
2. Scanning system (Exradin cc13, 0.053 cc)
   - 3 profiles in wdg dir (Y), 1 in X and an off axis PDD (10,0)
   - Export W2CAD (.asc) file
3. MatLab “MPPG_GUI” (also use “Renamer” code- renames RD files according to information in RP file)
   - Run Input: scan file, dose file and gamma criteria (%/mm)
   - Output: profiles and csv file

MPP_GUI

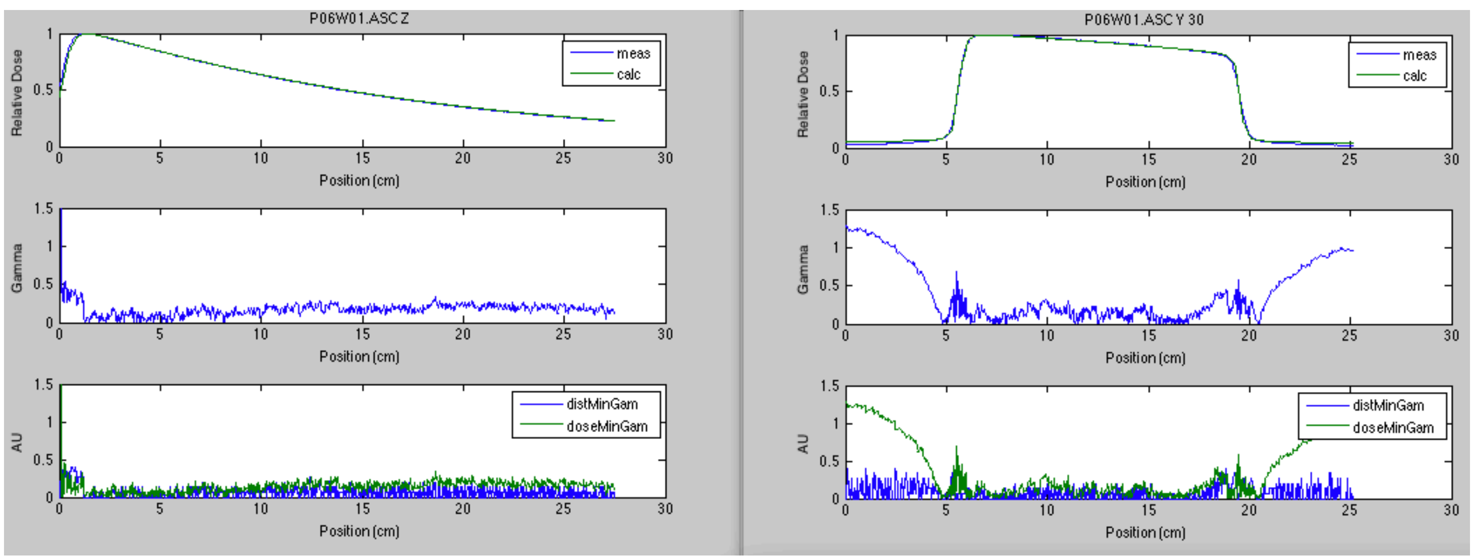
Input:



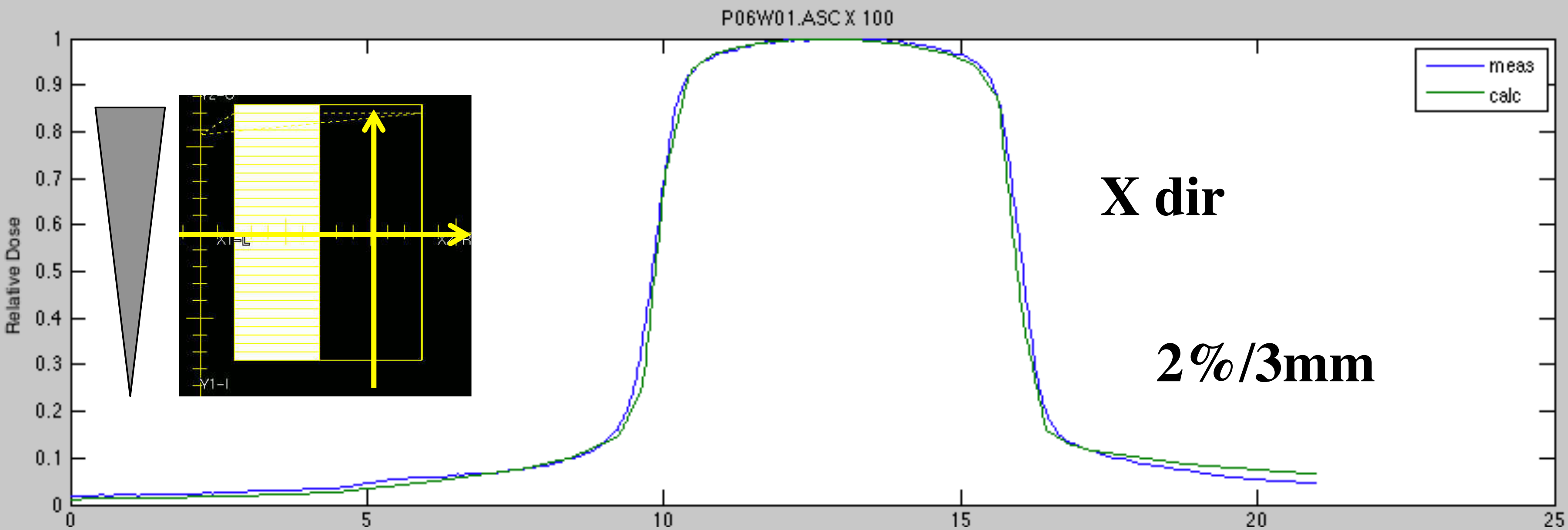
Renamer tool:

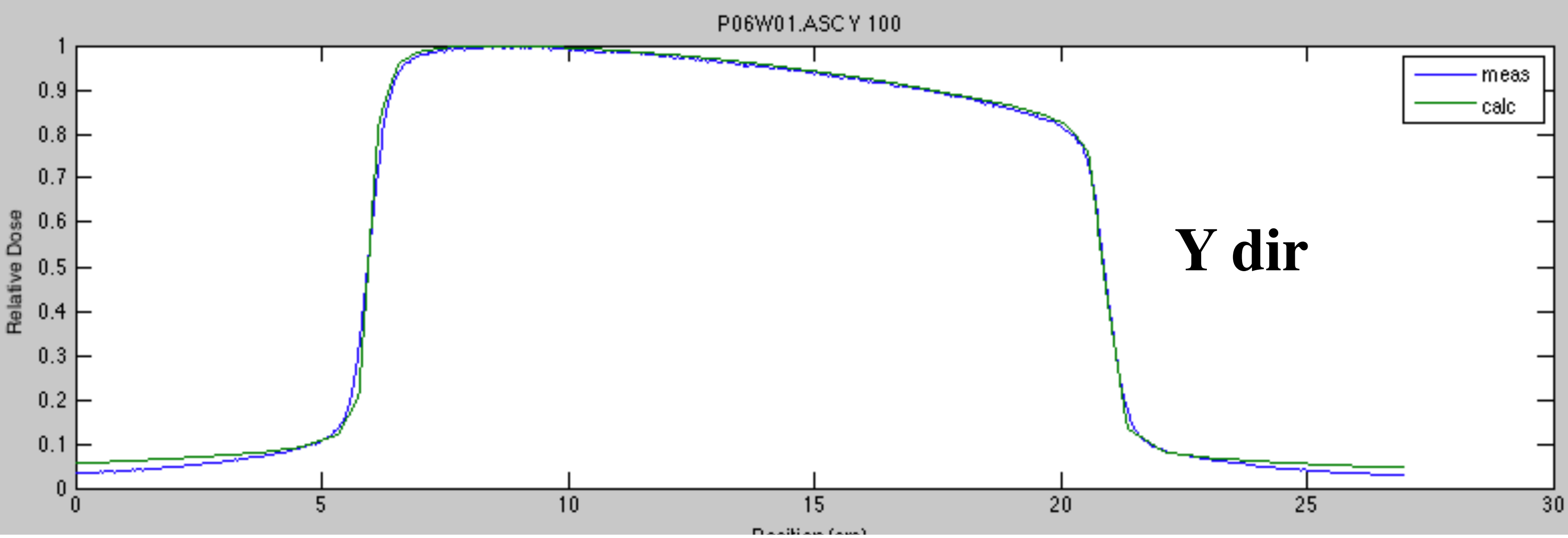


Output:

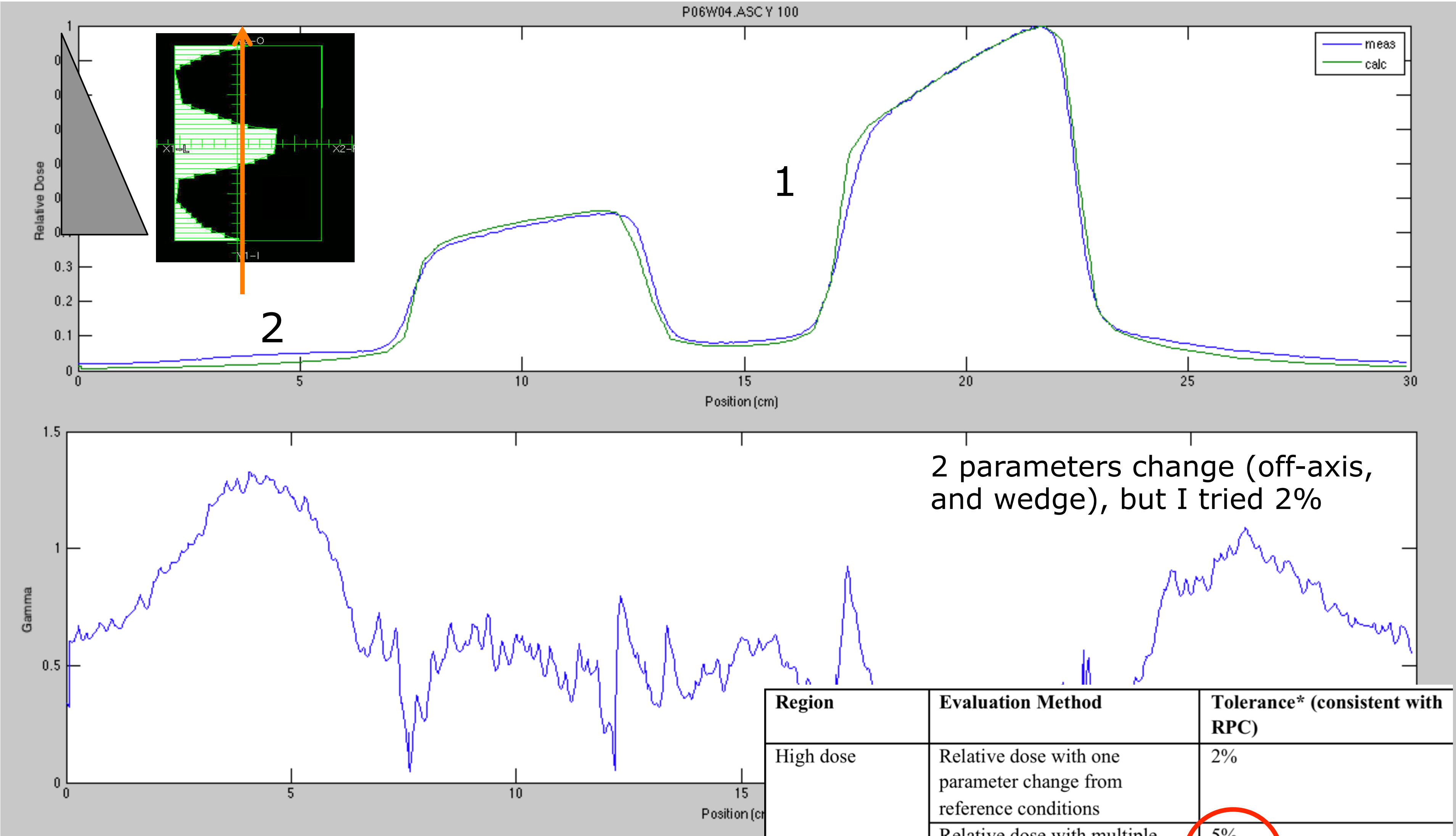


Detail for 2 plots, both at d=10 cm





Results from Test 5.5 Large MLC: d=10 cm inline profile for 60° wedged 6MV field, γ = 2%/3mm



2 parameters change (off-axis, and wedge), but I tried 2%

1. Problem in leaf penumbra (T&G) region
2. Problem with jaw/MLC leakage?

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

1D Gamma analysis– open source MatLab code

- Save scan data in Excel and output dicom dose files from TPS (note dose grid origin and resolution).
- Script/detailed users manual will be available on the UW Open Source Medical Devices website and code revision history at github
- Code interpolates data, shifts for best agreement and does gamma analysis according to Low et al, Med. Phys 25(5), 1988

$$\gamma(\mathbf{r}_m) = \min\{\Gamma(\mathbf{r}_m, \mathbf{r}_c)\} \forall \{\mathbf{r}_c\},$$

where

$$\Gamma(\mathbf{r}_m, \mathbf{r}_c) = \sqrt{\frac{r^2(\mathbf{r}_m, \mathbf{r}_c)}{\Delta d_M^2} + \frac{\delta^2(\mathbf{r}_m, \mathbf{r}_c)}{\Delta D_M^2}},$$

$$r(\mathbf{r}_m, \mathbf{r}_c) = |\mathbf{r}_c - \mathbf{r}_m|,$$

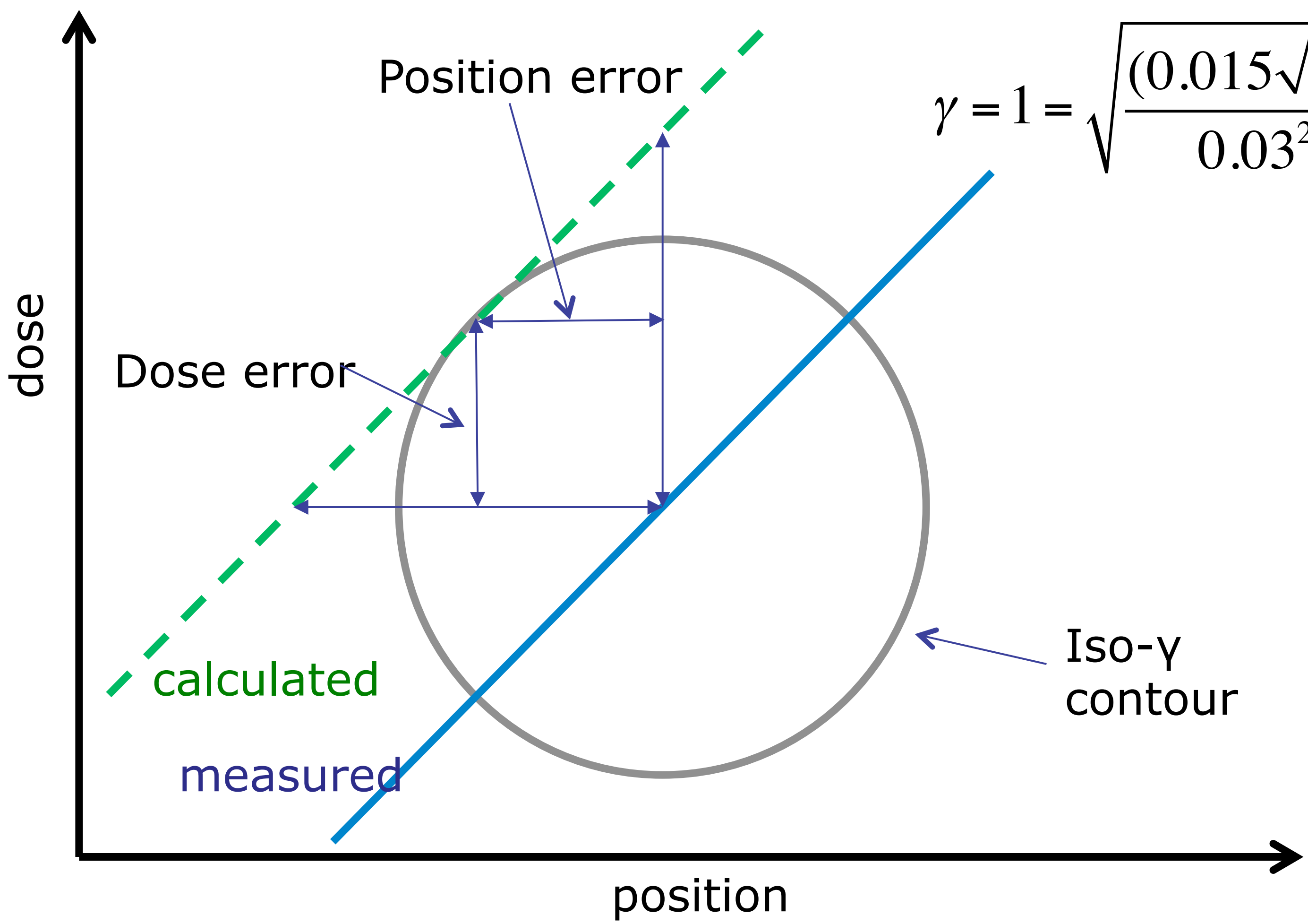
Validate gamma calculation with 3%/3mm threshold

- Create simulated dose profiles A and B
  - A = dose ramp with slope = 0.03 Gy/3mm
  - B = A + 0.03*sqrt(2)
- Input A and B into gamma calculation
- Verify that gamma = 1 at all positions

Thanks to MatLab Master Jeremy Bredtfeldt!

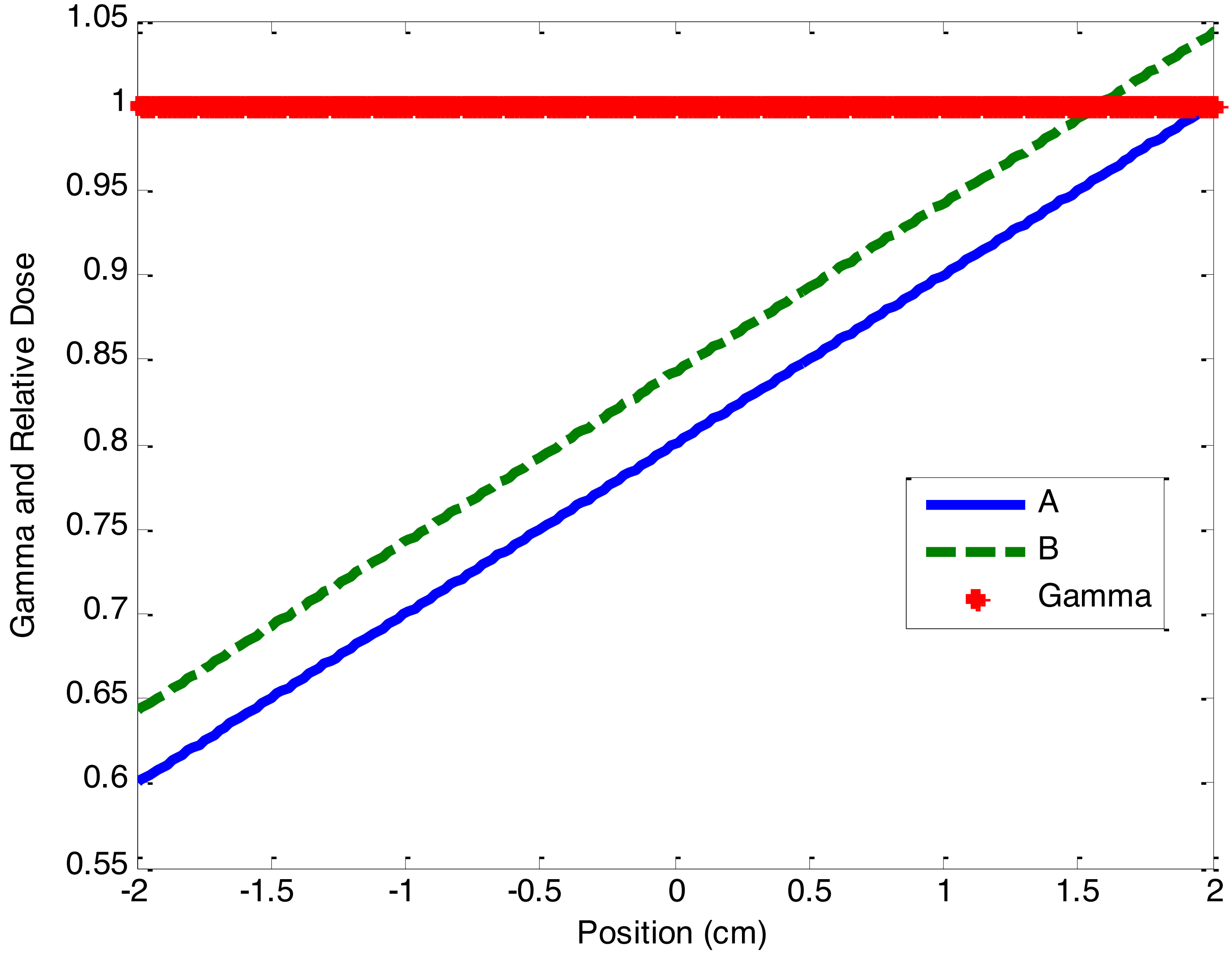
Gamma Calculation Test Case

Min. γ will occur with a dose error is 0.015 √(2) and position error is 1.5 √(2



$$\gamma = 1 = \sqrt{\frac{(0.015\sqrt{2})^2}{0.03^2} + \frac{(1.5\sqrt{2})^2}{3^2}}$$

Gamma Calculation Test Results



Section 6: Heterogeneity

Table 6: Heterogeneous TPS photon beam validation tests.

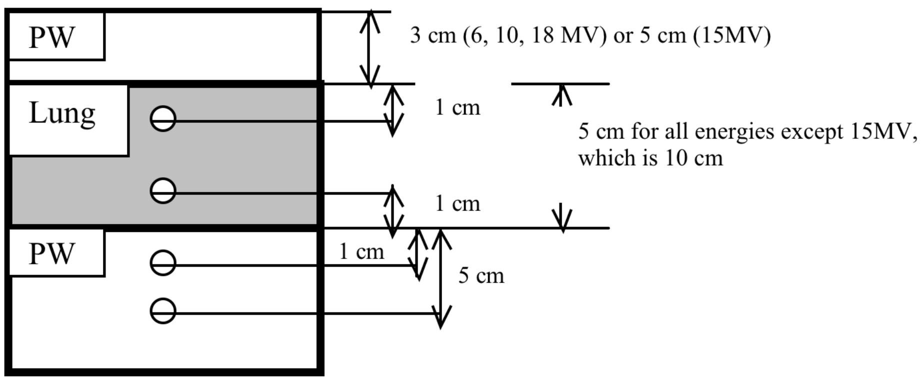
Test	Objective	Description	Tolerances*	Reference
6.1	Validate planning system reported electron (or mass) densities against known values.	CT-density calibration for air, lung, water, dense bone, and possibly additional tissue types.	--	TG 65 [23]; IAEA TRS-430 [7]
6.2	Heterogeneity correction distal ~~and proximal~~ to lung tissue	5x5 cm2, measure dose ratio above and below heterogeneity outside of the buildup region	3%	Carrasco et al. [52]

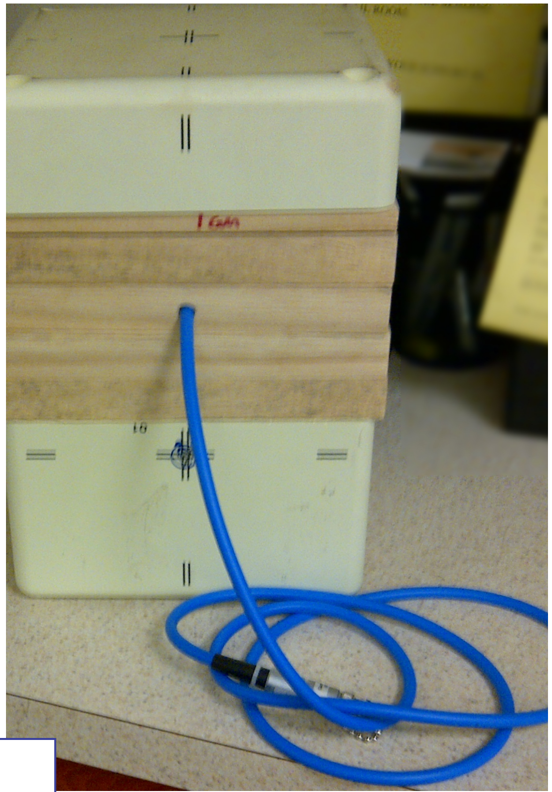
* Tolerances are relative to local dose unless otherwise noted.

- Modern algorithms (C/S. MC, GBBS, no PB)
- Test 6.2 only tests beyond heterogeneity (not in or at boundaries, areas at which it is difficult to measure)
- Only low density tissue

Implementation : Heterogeneity tests (3% tolerance)

- Follow the methodology of the AAPM TG65[4].
- A CIRS 20x20x20 cm^3 Cube Plastic Water phantom ("Cube Phantom") with low density wood (0.27 g/cm^3) inserts.



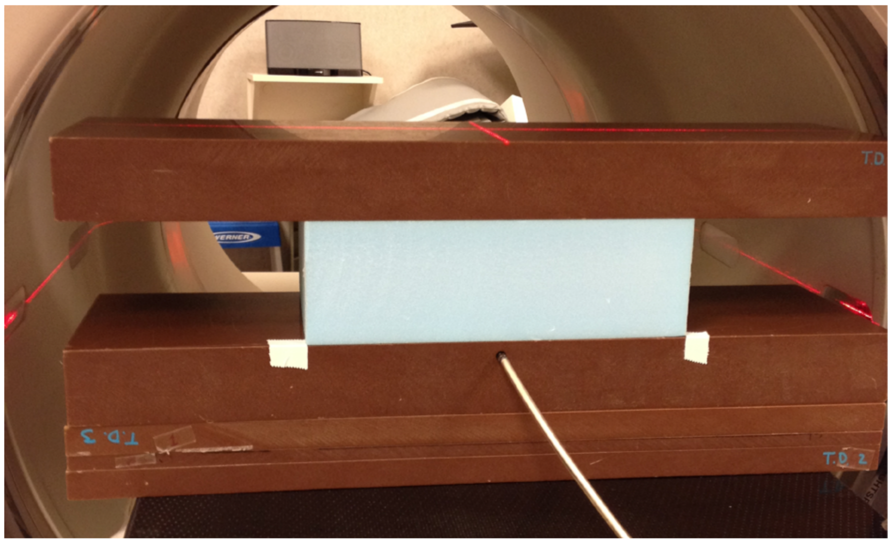


Phys. Depth (cm)	FS, cm	Pinnacle vs. Measured Dose No Lung	W/Lung	CF(Meas.)	CF (Pin.)	CF P-M
4	10x10	-1.9%	-0.8%	0.993	1.003	**1.1%**
7.3		-2.3%	-2.1%	1.067	1.069	**0.2%**
9.3		-2.1%	-2.2%	1.112	1.111	**-0.1%**
13.3		-2.3%	-1.9%	1.140	1.144	**0.4%**
4	5x5	-1.3%	0.3%	0.987	1.004	**1.6%**
7.3		-1.7%	-1.3%	1.055	1.058	**0.3%**
9.3		-1.6%	-1.7%	1.138	1.136	**-0.2%**
13.3		-2.0%	-1.8%	1.172	1.174	**0.2%**

Images from Vladimir Feygelman

Homemade Heterogeneity Phantoms

Figure 2: Examples of homemade heterogeneity phantoms



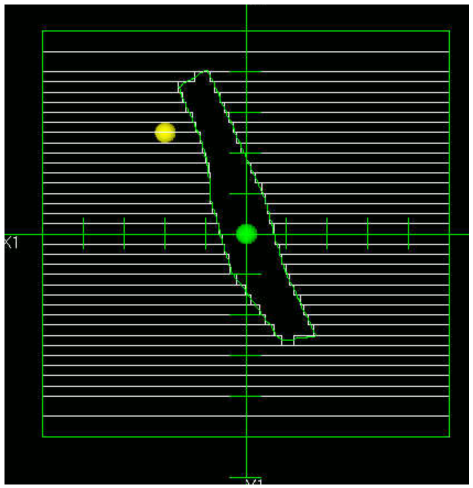
a) UW (Solid water and Styrofoam)

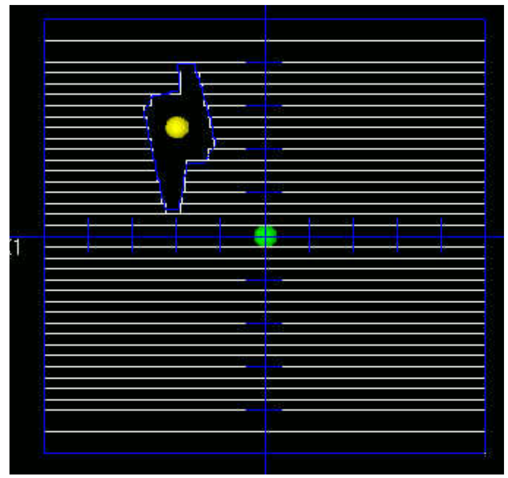
b) UMSC (solid water and cork)

Section 7: IMRT/VMAT Verification

Test	Objective	Description (example)	Detector
7.1	Verify small field PDD	$\geq$ 2x2 cm^2 MLC shaped field, with PDD acquired at a clinically relevant SSD.	Diode or plastic scintillator
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*	Diode, plastic scintillator, mini-chamber or micro-ion chamber
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.	--
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
7.5	External review	Simulate, plan, and treat an anthropomorphic phantom with embedded dosimeters.	Various options exist.**

7.2 Small MLC Defined Field





IBA EF Diode, 10 cm depth

Point dose:	Pinnacle 9.8									
Tolerance - 2% for one parameter change		measurement (nC)					Calculated (Gy)			
Field Name	**Description**	rdg 1	rdg 2	rdg 3	average	**OF**	Dose	OF	% diff	**Within 2 %?**
7.2_0 10MV	open	197.1	197.1	197.1	197.1		1.8			
7.2_1 10MV	banana	154.4	154.4	154.3	154.4	0.7832	1.4	0.7955	-1.57	Yes
7.2_2 10MV	bolt	154.4	154.4	154.4	154.4	0.7834	1.4	0.7784	0.63	Yes

IMRT/VMAT Validation Tests (section 7)

Table 7: VMAT/IMRT Test Summary.

Test	Objective	Description (example)	Detector	Ref
7.1	Verify small field PDD	$\geq$ 2x2 cm^2 MLC shaped field, with PDD acquired at a clinically relevant SSD.	Diode or plastic scintillator	TG-155 (to be published in MP)
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*	Diode, plastic scintillator, mini-chamber or micro-ion chamber	Cadman et al. [53]
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.	--	TG-119 [31]
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. [54]
7.5	External review	Simulate, plan, and treat an anthropomorphic phantom with em	Various options exist.**	Kry et al. [32]

C-shape plan, on tomo

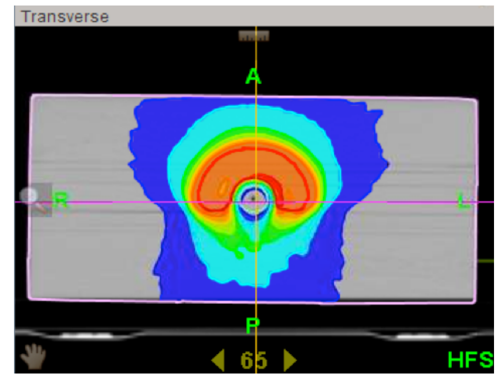
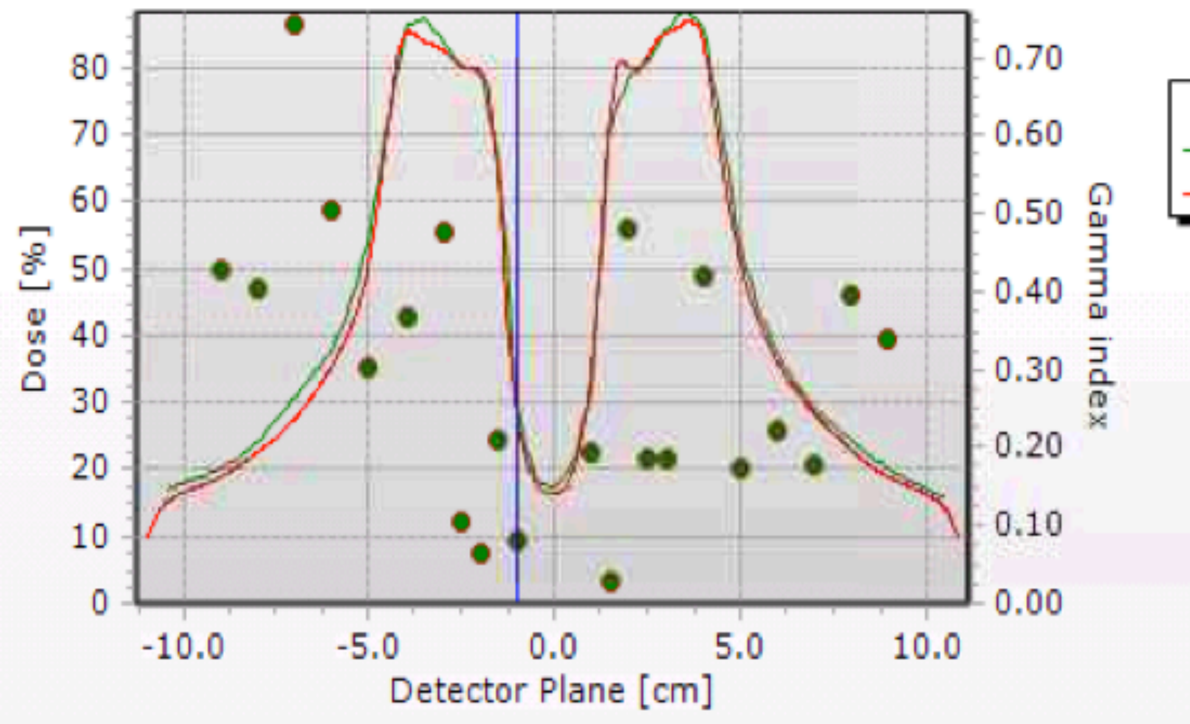


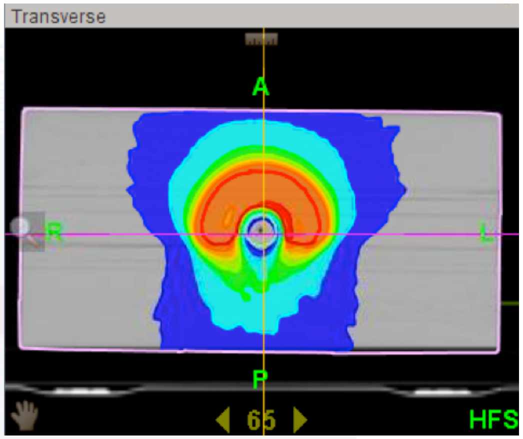
Table 8: VMAT/IMRT Evaluation Methods and Tolerances

Measurement Method	Region	Tolerance
Ion Chamber	Low gradient target region	2% of prescribed dose
	OAR region	3% of prescribed dose
Planar/Volumetric Array	All regions	2%/2mm*, 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

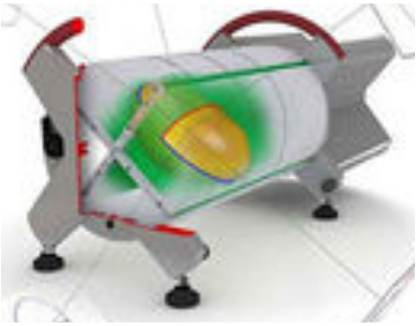
*Application of a 2%/2 mm gamma criterion can result in the discovery of easily correctable problems with IMRT commissioning that may be hidden in the higher (and ubiquitous) 3%/3 mm passing rates [33].

Implemention:
TG 119 C-shaped plan on tomo with Delta4





- Delta4 2%2mm (global) gamma analysis
- Use only detectors with >20% signal
- Excellent results, 100% pass



Downloadable data sets with plan instruction

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NOTE: Do not share this website link at this time. The page has been activated only for those individuals invited to review the draft MPPG at this time.

MPPG-TPS

The *Medical Physics Practice Guideline (MPPG) for Commissioning and QA of External Beam Treatment Planning System (TPS) Dose Calculations* includes recommendations to validate the dose for IMRT/VMAT/helical delivery plans through comparison of the individual beams and/or composite measurements with TPS calculations. In addition, the MPPG recommends the establishment of a routine QA program that validates dose calculation consistency through recalculation of reference plans for photon and electron beams. The MPPG has provided six sample datasets (DICOM CT and RT Structure Sets) that are available for users to download.

IMRT/VMAT Validation Datasets

Plans should be developed using a dose calculation method that accounts for tissue heterogeneities in primary and scatter interactions (e.g., Convolution/Superposition, Monte Carlo, or grid-based Boltzmann transport equation solvers). The following datasets are available and include a PDF of sample objectives that can be used for optimization and prescription.

- **Case 1: Prostate fossa and nodal region (Simultaneous Integrated Boost)** [21MB]
- **Case 2: Abdomen (Simultaneous Integrated Boost)** [33MB]
- **Case 3: Lung, Right upper lobe (single PTV)** [47MB]
- **Case 4: Anal (Simultaneous Integrated Boost)** [22MB]
- **Case 5: Head & Neck (Simultaneous Integrated Boost)** [27MB]

Additional Routine QA Dataset

Dose calculation consistency can be performed by re-calculating a subset of the IMRT/VMAT datasets provided above and by using the following dataset for simple photon and electron fields.

- **Case 6: Thorax for electron and/or photon beams (Chest Wall)** [32MB]

Section 8: Electron Beam Verification

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.

MUSC Electron Results

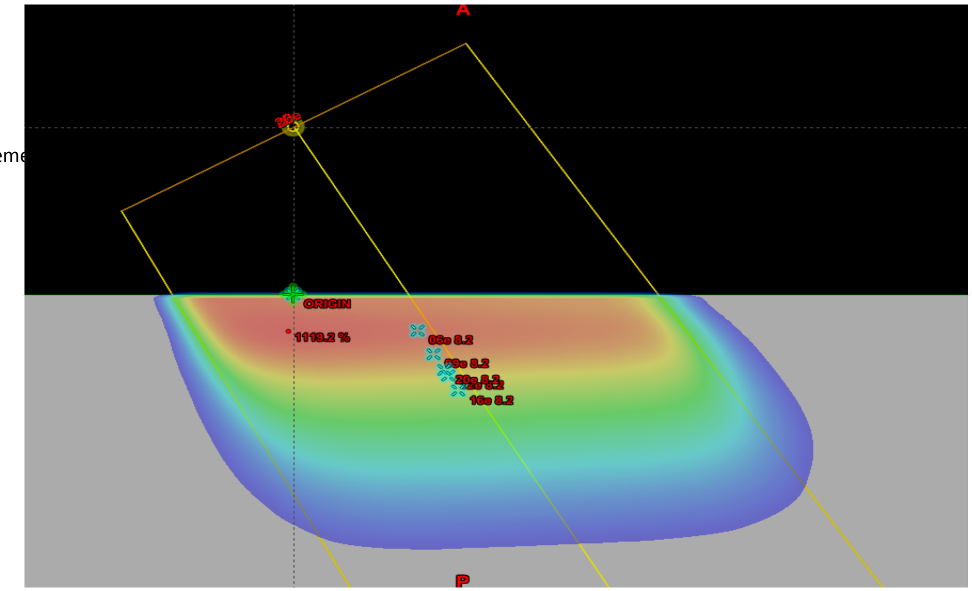
Test: 8.2
Objective: Surface irregularities - obliquity

Description: Oblique incidence using reference cone and nominal clinical SSD. Measureme
10x10 applicator, 105 SSD and 30 degree gantry rotation.

Tolerance: 5%

Test Patient:
Test Course: MPPG
Test Plan: 8.2 105 SSD
Plan Settings: 2 mm dose grid, all beams have 500 MU

Scan SSD: 105 SSD
Crossline Profile Depths: Energy Dependant
Inline Profile Depths: Energy Dependant



Point Dose Results:

							Measurement					EMC		
Plan Name	Field Name	Dose Rate	Description	X	Y	Z	T	P	M	M_{corr}	Rel. Dose	Calc Dose.	Rel. Dose	% Diff
Standards	06e	600 Servo On	6e 10x10 Standard	0	0	1.25	20.9	767	1.594	1.574	1.000	494	1.000	0.00%
Standards	09e	600 Servo On	9e 10x10 Standard	0	0	2.05	20.9	767	1.6103	1.590	1.000	501	1.000	0.00%
Standards	12e	600 Servo On	12e 10x10 Standard	0	0	2.8	20.9	767	1.6062	1.586	1.000	497.8	1.000	0.00%
Standards	16e	600 Servo On	16e 10x10 Standard	0	0	3.3	20.9	767	1.6463	1.625	1.000	508.4	1.000	0.00%
Standards	20e	600 Servo On	20e 10x10 Standard	0	0	2.6	20.9	767	1.7032	1.681	1.000	507.8	1.000	0.00%
8.2 105 SSD	06e	600 Servo On	MPPG 8.1	3.13	0	1.08	21	767	1.3206	1.304	0.829	408.7	0.827	-0.17%
8.2 105 SSD	09e	600 Servo On	MPPG 8.1	3.53	0	1.78	21	767	1.3601	1.343	0.845	418.1	0.835	-1.23%
8.2 105 SSD	12e	600 Servo On	MPPG 8.1	3.9	0	2.42	21	767	1.4069	1.389	0.876	432.8	0.869	-0.77%
8.2 105 SSD	16e	600 Servo On	MPPG 8.1	4.15	0	2.86	21	767	1.4928	1.474	0.907	457.2	0.899	-0.86%
8.2 105 SSD	20e	600 Servo On	MPPG 8.1	3.8	0	2.25	21	767	1.5343	1.515	0.901	459	0.904	0.31%

Section 9 QA

- Annually or after major TPS upgrades
- Reference plans should be selected at the time of commissioning and then re-calculated 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.

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**

Time Estimates Per Test

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**

Checklist to guide commissioning report

TG244 Section	TG244 Item	Commissioni Report Page
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 vendor's instructions.	
4	Beam models evaluated qualitatively and quantitatively using metrics within the modeling software.	
5	For each beam model perform validation tests 5.1-5.8 (5.9 for non-physical wedge) according to methods and tolerances in Tables 3 and 4.	
6	Heterogeneity corrections validated for photon beams according to Table 6.	
7	IMRT and VMAT validations accomplished for each configured beam according to tests 7.1-7.4 in Table 7.	
7	End-to-End test with external review accomplished for IMRT and VMAT (test 7.5 in Table 7).	
7	Understand and document limitations of IMRT/VMAT modeling and dose algorithms.	
8	Electron validations performed according to tests 8.1-8.3 in Table 9.	
9	Baseline QA plan(s) (for model constancy) identified for each configured beam and routine QA established.	
10	Peer review obtained and any recommendations addressed.	

Conclusion

- Do-able, well organized approach to dose calculation validation
- Creation of robust infastructure so you can re-use tests, measurements and analysis tools for routine QA and/or upgrade validation.
- Fills the space between commissioning and patient DQA and routine machine QA
- Thanks to Jeremy Bredfelt, Sean Frigo and Dustin Jacqmin (co-authors of implementation manuscript)
- Many thanks to UW and MUSC clinical physics groups for help on validation tests!