Implementation of Medical Physics Practice Guideline #5: TPS Verification Tests

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

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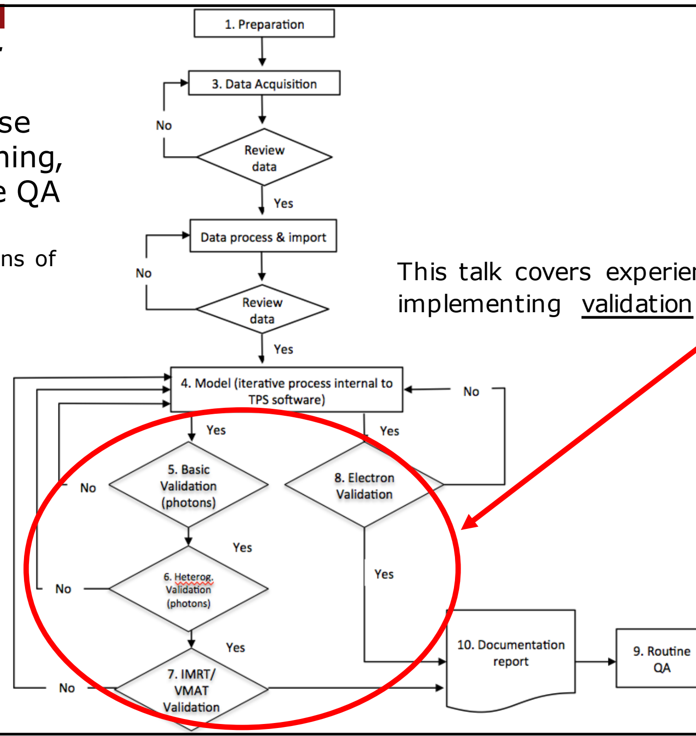
MPPG #5 in a Nutshell

- In the spirit of "practice guidelines", this document is a summary of what the AAPM considers prudent practice for what a clinical medical physics should do with respect to dose algorithm commissioning/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.
- Scope: Limited to the commissioning and QA of the beam modeling and dose calculation for external beam (photon and electron) treatment modalities.
- 2 tier approach to tolerances & evaluation criteria
  - Minimum acceptable tolerance for TPS "basic" dose calculations.
  - Did **not** want to state or use any minimum tolerance values that are not widely accepted/published.
  - Wanted to push the limit on evaluation criteria for IMRT/VMAT to expose limitations of dose calculations.

MPPG#5 Figure 1:

Workflow of TPS dose algorithm commissioning, validation and routine QA

(The numbers refer to sections of report.)



This talk covers experience implementing validation sections.

A variety of test types in each section

- Non-measurement "sanity checks" (e.g.: confirming calibration setup dose with test calculation fields in the TPS)
- Point dose measurement
- Water tank profiles in representative (non-IMRT) treatment fields
- IMRT/VMAT dose distribution QA

To validate our dose algorithms, we wanted:

- A set of standard plans (loosely comparable from one treatment system to another)
- An "easy" way to assess the water tank profiles – we generated an open source MatLab code to analyze scan data (from any scanning system) and DICOM data (from any planning system)
- A spreadsheet to track all the tests and results.

30K ft. view of validation process illustrated with this fancy color-coded spreadsheet

Test	Status
5.1 Physics. vs Plan data	pending
5.2 Abs Dose	PASS
5.3 Comm. vs. Plan data	pending
5.4 Small MLC	PASS
5.5 Large MLC	PASS
5.6 Off Axis	PASS
5.7 Asym 80 SSD	PASS
5.8 Obliques	PASS
5.9 EDW	awaiting IC profiler data
6.1 CT-Density Cal.	pending measurement on East CT
6.2 Heterogeneity	PASS
7.1 Small MLC PDD and OF	OF PASS, processed with 2016-06-25 model, PDD matlab analysis pending.
7.2 Small MLC shapes OF	PASS, processed with 2016-06-25 model
7.3 TG 119	7.4 will replace this.
7.4 Clincal DQA	Pending recomputed dose with new model when its ready
7.5 External	OSL delivered, awaiting results
8.1	All PASS, except: large profile, crossline depth 2 all energies and inline 6 MeV depth 2
8.2	PASS, at 80% threshold
8.3	PASS

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

Spreadsheet is available, along with the Matlab PCT code on github.

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

Examples of tolerances/evaluation criteria for two sections: Basic photon and IMRT/VMAT

Table 5. Basic TPS photon beam evaluation methods and tolerances

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 are relative to local dose unless otherwise noted.
**e.g.: off axis with physical wedge.

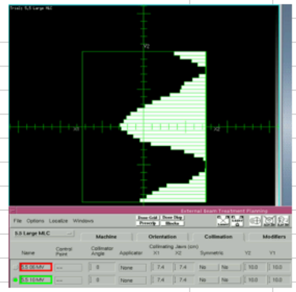
Table 8: VMAT/IMRT Evaluation Methods and Tolerances

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, et al. 2013).

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

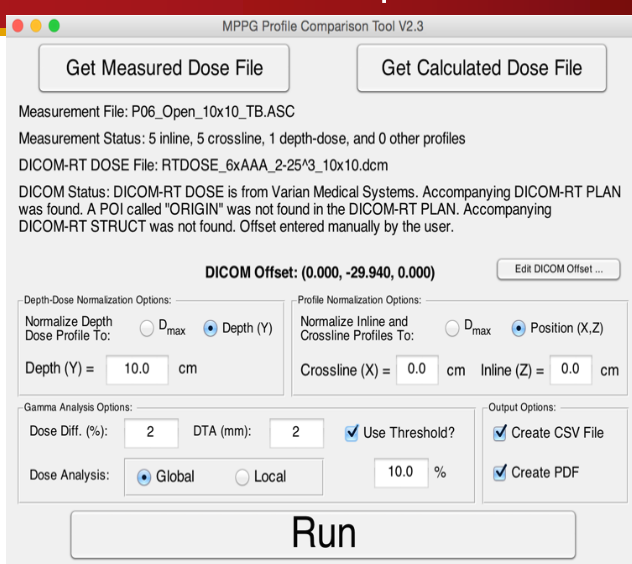


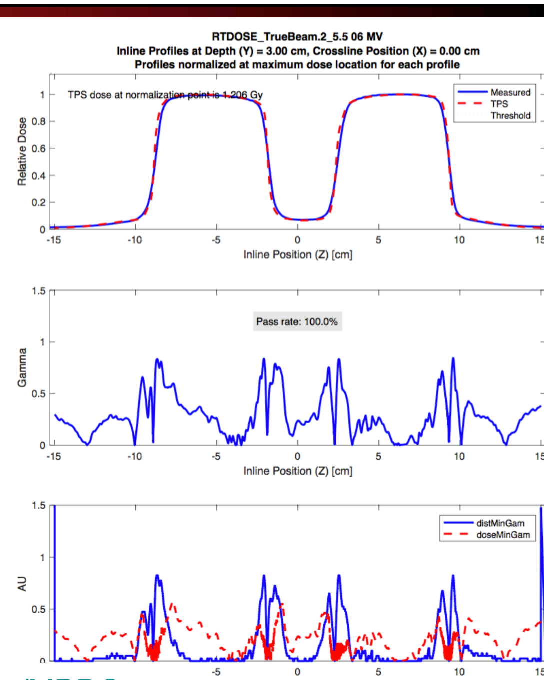
all scans were extended 4 cm beyond defined field dimension

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

MPPG 5 Profile Comparison Tool

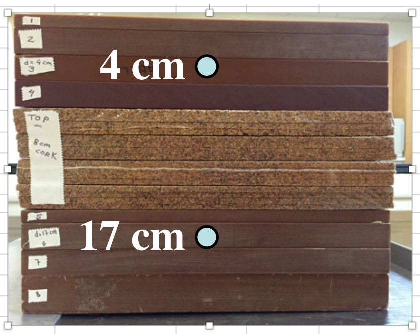




https://github.com/Open-Source-Medical-Devices/MPPG

Example 2: 6.2 Heterogeneity Correction (C/S. MC, GBBS, no PB)

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

What does MPPG#5 recommend for small field validation (Section 7)?

Summary	UW Madison, TrueBeam 1358
Test	**Status**
5.1 Physics. vs Plan data	pending
5.2 Abs Dose	PASS
5.3 Comm. vs. Plan data	pending
5.4 Small MLC	PASS
5.5 Large MLC	PASS
5.6 Off Axis	PASS
5.7 Asym 80 SSD	PASS
5.8 Obliques	PASS
5.9 EDW	awaiting IC profiler data
6.1 CT-Density Cal.	pending measurement on East CT
6.2 Heterogeneity	PASS
7.1 Small MLC PDD and OF	OF PASS, processed with 2016-06-25 model, P
7.2 Small MLC shapes OF	PASS, processed with 2016-06-25 model
7.3 TG 119	7.4 will replace this.
7.4 Clincal DQA	Pending recomputed dose with new model wi
7.5 External	OSL delivered, awaiting results
8.1	Pt dose PASS, 100 SSD, < 4%, 105 cm SSD. PDD
8.2	PASS, at 80% threshold
8.3	PASS

- Dosimetry for small fields is often extrapolated by TPS. Verification measurements for small fields and MLC characteristic are recommended.
- Even if not specified by the TPS vendor, the QMP should measure PDD with a small volume detector down to at least 2x2 cm^2 field size for comparison with dose calculation.
- Leaf-end penumbra should be obtained with a small detector (such as a diode or micro-chamber) to avoid volume-averaging effects.
- Small field output factors (down to 2x2 cm^2 or smaller) should be measured for beam modeling and/or verification.

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]

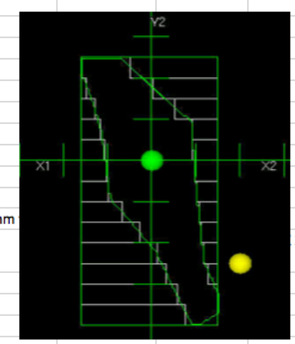
Use any combination of:
- Clinical cases
- Downloadable plans
- TG119 cases

Example 3: 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
Bias:	0	
Rep. rate:	400 MU/min	
MU:	100	
Data aquired:	2016-06-24	
By:	JS and KS	



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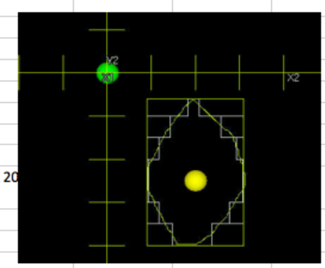


dose:	Pinnacle 9.8									
ance - 2% for one neter change		measurement (nC)					Calculated (Gy)			
Field Name	Description	rdg 1	rdg 2	rdg 3	average	OF	Dose	OF	% diff	Within 2 %?
7.2_0 06MV	open	2.90	2.90		2.90		0.716			
7.2_1 06MV	bolt	2.71	2.71		2.71	0.934	0.675	0.943	-0.88	Yes
7.2_2 06MV	diamond	2.64	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

Example 4: 7.4 Clinical Tests – Delta4 Diode Phantom

ose Measurement

Patient	Level	Pinnacle 9.8											
		Percent Passing										Number Failing	Comment
		Beam											
		01	02	03	04	05	06	07	08	09	Composite		
Test11	3%/3mm	100.0	99.4	99.0	100.0	100.0					100.0	0	Single fraction brain SRS
	2%/2mm	99.3	93.6	94.9	100.0	100.0					99.4	2	
Test12	3%/3mm	96.9	95.0	96.6	98.3	92.9	99.3	99.1		*	88.7	1	Brain, 7 field, large PTV, GBM?
	2%/2mm	87.1	84.2	85.0	95.6	80.0	97.7	91.8			71.7	5	
Test13	3%/3mm	100.0	100.0	99.4	99.5						99.5	0	4 field lung SBRT
	2%/2mm	98.1	97.8	98.9	96.8						98.5	0	
Test14	3%/3mm	99.8									99.8	0	single arc, abdomen
	2%/2mm	98.9									98.9	0	
Test15	3%/3mm	100.0	100.0								100.0	0	2 arc abdomen
	2%/2mm	99.6	99.6								99.4	0	
Test16	3%/3mm	99.7	99.6								99.5	0	Prone prostate
	2%/2mm	97.2	92.6								95.3	1	
Test17	3%/3mm	100.0	99.7								99.5	0	HN, 4 PTVs
	2%/2mm	98.8	97.4								96.2	0	
Test18	3%/3mm	100.0	100.0	100.0	100.0	100.0	100.0				100.0	0	6 beam, large lung PTV
	2%/2mm	100.0	100.0	99.7	100.0	100.0	100.0				99.4	0	
Test19	3%/3mm	99.4	99.9								99.3	0	Prostate with nodes
	2%/2mm	95.9	97.0								95.2	0	
Test20	3%/3mm	100.0	100.0	99.9	99.8						99.5	0	Brain with hippocampal sparing
	2%/2mm	99.1	99.4	98.6	98.1						97.4	0	

*Further investigation revealed that this plan pushed the limits of deliverability in terms of small segment size and large beam quantity (MU) combinations

Section 8: Electron Beam Verification

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

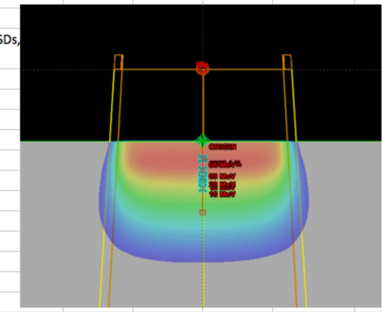
Test	Objective	Description	Tolerance
8.1	Basic model verification with shaped fields	Custom cutouts at standard and extended SSDs	3%/3 mm
8.2	Surface irregularities-obliquity	Oblique incidence using reference cone and nominal clinical SSD	5% [50]
8.3	Inhomogeneity test	Reference cone and nominal clinical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

Example 5: Test 8.1 Electron

Test:	8.1
Objective:	Basic model verification with shaped fields
Description:	Two custom cutouts at standard and extended SSDs, cutout small, the other large.
Tolerance:	3%/3mm
Detector:	IBA EFD (100103)
Test Patient:	ZZUWQA_Pinnacle, Validation MPPG_Hom
Test Course:	MPPG
Test Plan:	8.1 100 SSD, 8.1 105 SSD
Plan Settings:	2 mm dose grid, all beams have 200 MU
Scan SSD:	100 cm, 105 cm
Crossline Profile Depths:	Energy Dependant
Inline Profile Depths:	Energy Dependant
Performed by:	JS, PY, KS
Date:	5/27/16

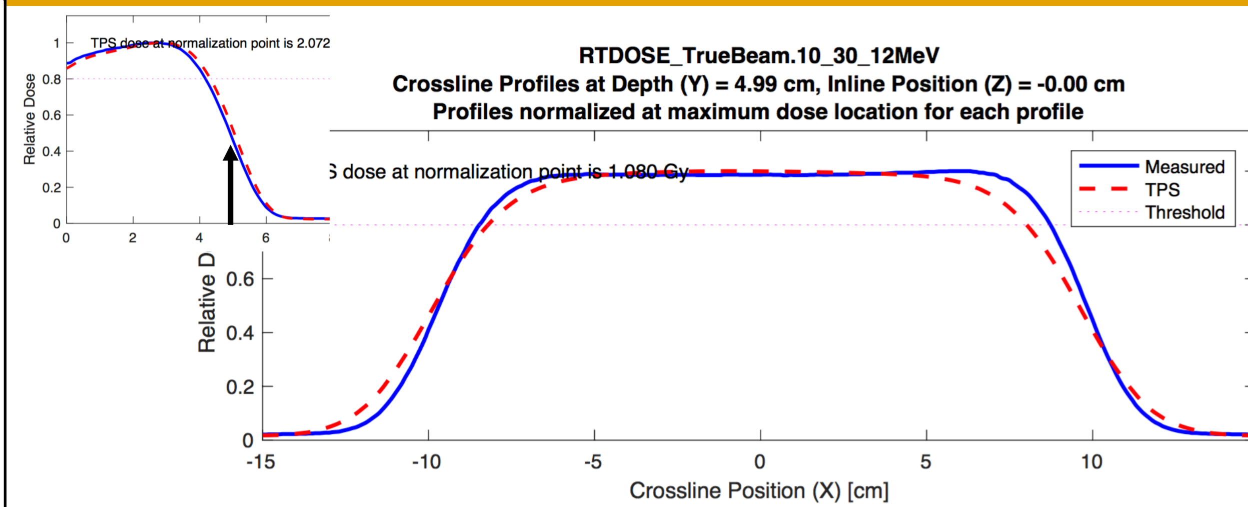


80% threshold used for profiles because profile tolerace is for high dose region only

Cutout 1 Small, 6x6 applicator

100 CM SSD, SMALL		Pinnacle				
Profile Passing Rates:	Threshold:	PDD	Depth 1		Depth 2	
Criteria: 3%/3mm Global	80%		Crossline (y)	Inline (x)	Crossline (y)	Inline (x)
8.1 105 SSD	06e	96.7	100.0	100.0	100.0	100.0
8.1 105 SSD	09e	100.0	100.0	100.0	100.0	100.0
8.1 105 SSD	12e	98.2	100.0	100.0	100.0	100.0
8.1 105 SSD	15e	100.0	100.0	100.0	100.0	100.0
8.1 105 SSD	18e	18 MeV collected, but not analyzed because it has not been modeled				

Not everything passes with flying colors: "failures" reveals limitations of electron PB model



Profiles at deeper depth (D50) match OK in field center and at 50%, but shoulders and tails do not. Note: there are limited parameters to tweak in a PB electron model to fix this, and we are aware of this in our clinical practice.(profiles at Dref passed very well)

Section 9: QA recommended by MPPG#5

- 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.

MPPG #5 even includes a Checklist to guide commissioning report

Validation sections:

TG244 Section	TG244 Item	Commissioni Report Pag
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.	

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**

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**

It is recommended to take data at time of commissioning.

Conclusion

- MPPG#5 is a do-able, well organized approach to dose calculation validation
- Creation of robust infrastructure takes time, but you can re-use tests, measurements and analysis tools for routine QA and/or upgrade validation.
- The right tools and a bit of forethought makes implementation much easier! Water tank profiles in representative (non-IMRT) treatment fields were the most difficult to analyze. As part of the implementation here at UW (and with collaborators in NC) we created test fields and a robust, open source MatLab code (and spreadsheet):

  https://github.com/Open-Source-Medical-Devices/MPPG
- Validation fills the space between commissioning and patient DQA and routine machine QA.
- Validation can reveal limitations of beam models, especially for small fields and electrons.

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