Data Acquisition for Treatment Planning Systems

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Introduction

What data do we need to acquire for our treatment planning system?

How do we intend to use this data?

- acceptance testing (verify what you specify)
- Commissioning (acquisition of all data necessary to use the system clinically)

Introduction, cont.

- A comprehensive set of beam data must be acquired and entered into the radiotherapy treatment planning (RTP) system.
- “Commissioning” refers to the process whereby the needed machine-specific beam data are acquired and operational procedures are defined.

Outline

- Beam data requirements for treatment planning systems
  - General data requirements for commissioning (Task Group 45) and 3D Planning Systems (Task Group 53)
  - Photon beam data
  - Electron beam data
- Selection of appropriate tools for beam data acquisition
- Basic considerations when collecting TPS data
  - Dosimetric facts
  - Self-consistent dataset
  - Post collection data processing
- Test cases for TPS commissioning
- Future needs
  - MLC characterization (leakage, penumbra)

[redacted]

AAPM Code of Practice for Radiotherapy Accelerators

AAPM code of practice for radiotherapy accelerators: Report of AAPM Radiation Therapy Task Group No. 45

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IV COMMISSIONING. . . . . .
A. Overview of Commissioning a Radiotherapy Accelerator. . . . . .
B. Dosimetry Calibration. . . . . .
C. Commissioning Photon Beams. . . . . .
1. Square and Rectangular Photon Beams. . .
2. Wedged Photon Beams. . . . . .
3. Beam-Shaping Blocks for Photons. . . . . .
D. Commissioning Stationary Electron Beams. . . .
1. Dosimetry Data for Electron Beams. . . . . .
2. Field Shaping for Electrons. . . . . .
3. Corrections for Air Gap or Extended SSD. . . . . .
4. Effects of Oblique Incidence and Tissue Heterogeneities. . . . . .

TG-45 Report

- <u>Commissioning Photon Beams – cax data</u>

  (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.

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- <u>Commissioning Photon Beams – off axis data</u>

  (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,

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<u>Commissioning Electron Beams</u>

- calibration of beam output;
- central-axis depth dose curves in water;
- isodose charts in water;
- cross beam profiles in water;
- output factors;
- corrections for field shaping; and
- corrections for air gap.

TG-45 Report - Electrons

Additional electron beam data often needed for TPS commissioning

- oblique incidence,
- patient contour,
- tissue heterogeneities

Consult AAPM Task Group 25 for recommendations

TG-45 Report – Special Procedures

- Total and Half Body Photon Irradiation
- Total Skin Electron Irradiation
- Electron Arc Therapy
- Intraoperative Radiotherapy
- Stereotactic Radiosurgery

TG-45 Report – Instrumentation Needs

Instrumentation Needed For Acceptance Testing And Commissioning Of A Radiotherapy Accelerator

- Ionization chamber dosimetry system:
  - two ionization chambers, two electrometers, constancy checkers, cables, thermometer, barometer, and phantoms.
- Film dosimetry system:
  - densitometer and phantoms.
- TLD dosimetry system:
  - reader, ovens, jigs, phantoms.
- Dosimetry scanning system:
  - electrometers, scanning devices.
- Personal computer system:
  - computer, software for report generation, data collection and analysis, printer and plotter.

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

(1) sufficient sensitivity;
(2) stability;
(3) negligible leakage;
(4) energy independence;
(5) sufficient spatial resolution, and
(6) linearity.

TG-53 Report

American Association of Physicists in Medicine
Radiation Therapy Committee Task Group 53:
Quality assurance for clinical radiotherapy treatment planning

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Fraas et al, “AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,”Med. Phys. 25,1773-1836 (1998).

TG-53 Report – Basic Dosimetric Facts to Consider When Commissioning a TPS

- Most dose calculation verification tests traditionally involve comparison of calculated doses with measured data for a range of clinical situations. As treatment planning in the institution becomes more sophisticated, the range of dosimetric testing should expand and will eventually become quite extensive. Identifying the various effects or situations to be tested, and defining the limits over which each effect will be tested, will help the physicist organize the testing.

TG-53 Report – Basic Dosimetric Facts to Consider When Commissioning a TPS

- Calculation verification tests generally fall into two categories:1) comparisons involving simple water phantom-type geometries, which are usually easy to interpret; and 2) comparisons involving complex geometries (often with anthropomorphic phantoms) in clinically realistic situations, which are difficult to interpret, since uncertainties in measurements, errors in input data, parameter fitting, algorithm coding and/or design, calculation grid effects, and various other uncertainties are all incorporated into the results. Although these complex tests are critical for evaluating the overall system precision for particular calculations, their usefulness in explaining discrepancies is limited.

TG-53 Report – Basic Dosimetric Facts to Consider When Commissioning a TPS

- Often, in an attempt to minimize effort, some of the tests and measured data are used repeatedly to test multiple aspects of the planning system. When this is done, the tests should be designed to be as independent as possible, so that the appropriate analysis and actions are taken when necessary.

TG-53 Report – Basic Dosimetric Facts to Consider When Commissioning a TPS

- The comparison of calculation results and measurements is not a competition. The task of performing the measurements and parameter determination and calculation verification testing should begin by assuming that there are likely to be many errors and inconsistencies uncovered, and that these will have to be resolved by the whole team in an open, cooperative fashion. are difficult or impossible to access, so these systems normally must be maintained on-site at each clinic. A QA program for the test tools must be instituted for the QA tools to be effective.

TG-53 Report – Methods for Obtaining a Self-Consistent Dataset

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

TG-53 Report – Methods for Obtaining a Self-Consistent Dataset

- Make measurements over the shortest time span possible consistent with obtaining representative dose measurements.
- Use the same equipment and procedures for all similar measurements.

TG-53 Report – Methods for Obtaining a Self-Consistent Dataset

- Relate measurements made with different measurement methods to each other. Ideally, some of the measurements should be repeated with an independent, preferably different type, dosimeter.
- Use a reference chamber to account for output fluctuations when making measurements with a scanning ionization chamber.

TG-53 Report – Methods for Obtaining a Self-Consistent Dataset

- Periodically repeat base measurements, such as the dose at 10 cm depth for a 10x10 cm^2 field, to monitor the consistency of the machine output and the measuring system. Note that this may involve use of temperature equilibrated water and/or monitoring the barometric pressure, in certain situations.

[2]R. K. Ten Haken, B. A. Fraass, and K. Lam, "Dosimetry and data acquisition," in *Teletherapy: Present and Future*, edited by J. Palta and T. Mackie (Advanced Medical Publishing, Madison, WI, 1996), pp. 191–219.

TG-53 Report - Post-data collection processing

- Post-processing. All measurements must be converted to dose, either relative or absolute.
- Smoothing. Raw data often should be smoothed to remove artifacts of the measurement technique. Care must be taken to ensure that the smoothing is not done too aggressively, smoothing out real dose variations.

TG-53 Report - Post-data collection processing

- Renormalization. All data (depth doses, profiles, etc) should be renormalized to make the dataset self-consistent.

TG-53 Report

- Tables A3-2 through A3-9 in TG-53 specify the recommended data to be measured for adequate QA of a 3D TPS for photon beams.
- Tables A4-1 through A4-4 cover electron beams.

TG-53 Report

Appendix 3: Photon dose calculation commissioning

- depth dose, output factors, open field data, patient shape effects, wedges, blocks, multileaf collimator, asymmetric fields, density corrections, compensators, anthropomorphic phantoms

TABLE A3-2. Depth Dose Data

FDDs at standard SSD	FDD curves for a number of open field sizes at a standard SSD: • SSD: 90 cm • Norm depth: 10 cm • Field sizes: 3×3, 4×4, 5×5, 6×6, 7×7, 8×8,10×10, 12×12, 14×14, 17×17, 20×20, 25×25, 30×30, 35×35, 40×40 • Rectangular fields for various equivalent squares
FDDs at other SSDs	FDD tables at other SSDs that cover the clinical range used: • SSDs: 80 and 110 cm • Field sizes: 5×5, 10×10, 20×20, 30×30
TPR, TMR	TPR or TMR for a number of field sizes and depths. Since these measurements are quite time intensive, limit to: • Field sizes: 5×5, 10×10, 20×20, 30×30, and 40×40 • Depths: nominal d_{max}, 5, 10, and 20 cm • Norm Point: 10×10, d=10 cm • For all other field sizes, calculate TPR/TMR from FDD and verify calculation

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A3-3. Output Factors

Phantom Scatter Factor (S_p)	These data are typically obtained at the same field sizes used for the standard FDD data: • SSD: isocentric • Norm pt: 10×10, at 10 cm depth
Collimator Scatter Factor (S_c)	These data are typically obtained at the same field sizes used for the standard FDD data: • SSD: isocentric • Norm pt: 10×10, at 10 cm depth
Wedge factors	As required and/or used by the planning system. • SSD: isocentric • Norm pt: 10×10, at 10 cm depth • Wedge factors at various field sizes (5×5, 10×10, 20×20, max)
Tray factors	As required and/or used by the planning system. • SSD: isocentric • Norm pt: 10×10, at 10 cm depth
Other factors	As required and/or used by the planning system. • SSD: isocentric • Norm pt: 10×10, at 10 cm depth

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A3-4. Open Field Data

Square fields, standard SSD	2-D dose distributions at standard SSD: • Field sizes for axial planes: 3×3, 5×5, 10×10, 20×20, 30×30, 40×40 • Field sizes for sagittal planes: 5×5, 20×20, 40×40
Square fields, extended SSD	2-D dose distributions: • SSDs: 90 and 110 cm • Field sizes: 5×5, 10×10, 20×20, 30×30
Rectangular fields	The behavior of the depth dose for rectangular fields should be tested. Check at least that the equivalent square is reproduced. For example, use a series of rectangular fields with equivalent square equal to 6 and 12 cm^2.

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A3-5. Patient Shape Effects

Oblique incidence	The oblique incidence data should be obtained at the largest angle possible. A 30×30 field at 30 degree oblique incidence may be barely possible in some water tanks, and a 10×10 field at a 40 degree oblique angle may also work.
Surface irregularity	Use a step phantom to look at the effects of non-flat surface contours using a 30×30 field incident on a large (5 cm) step in the surface of the phantom. Repeat the calculation with the beam displaced laterally by half of the dose grid spacing to assess effect of dose grid size.
Tangential geometry	Measure dose delivered to axial plane for square phantom by 10×20 tangential fields. Normalize the MU so absolute dose at isocenter is known. Compare isodose lines.
Square phantom	20×20 or 25×25 beam normal to a large square phantom. Compare measurements with beam centered on phantom and with beam off-center and flashing off one edge.

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A3-6. Wedges

Input data	The minimum set of input data must include 2-D isodose distributions in the axial and sagittal planes for the largest wedged field size.
Depth dose	Wedged field depth dose curves must be verified as a function of field size, SSD, etc., for each wedge. • 5×5, 10×10, 20×20, max field size, at least.
Field size checks	2-D isodose distributions: • Axial plane: 5×5, 10×10, 20×20, max field size • Sagittal plane: 10×10, max field size • Coronal planes at $d=d_{max}$, $d=10$, $d=20$ cm (or full 3-D distribution): 10×10, max field size
Extended SSDs	Axial 2-D isodose distributions: • SSDs: 80 and 110 cm • Field sizes: 10×10, 20×20
Asymmetric and shaped fields	Wedged asymmetric and/or shaped fields also should be verified, at least at a standard SSD.

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A3-7. Blocks

Input data	• 15×15 blocked to 4×15 • 30×30 blocked to 20×20, 10×10, 5×5 • 30×30 with island blocks of size 20×20, 10×10, 5×5
SSD checks	30×30 blocked to 10×10 at SSD of 80 and 110 cm
Conformal blocks	Oval, C and squiggle shapes (shown in Fig. A3-1).
Transmission blocks	10×10 island block in 30×30 field, but with calc'd primary transmission through island block of 10%, 25%, 50%. Also do 100% transmission calculation.
Clinical checks	• Mantle field blocks • Spinal cord block

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A3-8. MLC

Input data	Same as that for conventional blocks.
Standard shapes	• Circular field ($r = 3$ cm). • Diagonal Edge test: 15, 30, 45, and 60 degrees to MLC edges
SSD checks	Circle shape at SSD 80 cm and 110 cm.
Conformal shapes	Oval, C and squiggle shapes (shown in Fig. A3-1).
Leaf transmission	Jaws open, leaves closed to small field (5×5). Deliver>1000 cGy or so, so leaf transmission can be measured.
Clinical checks	• Mantle field block or other large commonly-treated MLC shape • Spinal cord block • Others

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A3-9. Asymmetric Field Tests

Jaw X1	Jaw X2	Jaw Y1	Jaw Y2	Other
5	5	5	5	-
0	10	5	5	-
−5	15	5	5	-
−10	20	5	5	-
5	5	0	10	-
5	5	−5	15	-
5	5	−10	20	-
0	10	−10	20	-
−5	15	−10	20	-
−10	20	−10	20	-
−10	20	−10	20	W45
−10	20	−10	20	Block
−10	20	−10	20	MLC shape

Fraas et al, “AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,”Med. Phys. 25,1773-1836 (1998).

TABLE A3-10. Density Corrections

Algorithm verification tests	Square phantoms with various inhomogeneities are used. These tests are verifications that the algorithm is working correctly and have nothing to do with analysis of clinical results.
Benchmark data	To document the accuracy of the correction method in a number of basic but clinically relevant geometries, the dataset measured and reported by Rice[61] is used. Check results with all 4 geometries included in the Rice dataset, with both 4 and 15 MV. Further benchmark data, especially 2-D and 3-D data for various geometries, are needed.
2-D and 3-D inhomogeneity checks	Measure depth dose and profiles for layer, partial layer, complex 2-D and 3-D inhomogeneity geometries. These tests can be performed on benchmark data, if available, but the beam definition/ parameterization for the beam used must be carefully completed in the same fashion that the user's clinical beams are fit.

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A3-12. Anthropomorphic Phantom

Mantle field	Verify dose in coronal midline plane of phantom using TLD or film.
Tangential breast fields	Include lung. Verify dose in axial plane.
3-field non-coplanar plan	Verify dose in axial, sagittal, and/or coronal planes.

Fraas et al, “AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,”Med. Phys. 25,1773-1836 (1998).

TABLE A3-11. Compensators

Missing tissue compensation	Only a few simple phantom tests are needed: • Lateral Head/Neck field • Anterior Mantle field with lung blocks
Dose compensation	Many different geometries of patient and compensator need to be checked, particularly if density corrections are used. The complexity of the algorithm should be the main guide in designing the tests. Typical geometries include: • Lateral Head/Neck field • Anterior Mantle field with lung blocks • Non-coplanar brain plan, 3 fields • Non-axial abdomen plan, 3 fields

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TG-53 Report

Appendix 4: Electron dose calculation commissioning

- depth dose and open fields, output factors, extended distance, shaped fields, ECWG test cases

TG-53 - Electrons

TABLE A4-1. Open Fields

FDD on Cx	FDD curves for each energy for a number of field sizes at a standard SSD. • SSD: 100 cm • Norm depth: d_{max} • Field sizes: 4×4, 6×6, 10×10, 15×15, 20×20, 25×25
Profiles/2-D dose distribution	2-D isodose distributions in the axial plane for each energy. • SSD: 100 cm • Field sizes: 4×4, 6×6, 10×10, 15×15, 20×20, 25×25
Coronal or 3-D data	For 3-D algorithms, 3-D verification checks should be performed. Measure multiple coronal plane dose distributions or generate 3-D distributions.

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A4-2. Output Factors

Output factor	Typically obtained at same field sizes used for standard FDD data: • SSD: 100 cm • Norm pt: 15×15, at d_{max}.
Effective source distance (ESD)	Measure output as a function of distance to determine effective source distance to use for inverse square law corrections.
Output for shaped fields	Many clinics determine output factors for a set of standard shaped fields.

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A4-3. Extended Distance

FDD on Cx	FDD curves are measured for each energy for a subset of field sizes at various SSDs. • SSD: 110 cm, others used clinically • Norm depth: d_{max} • Field sizes: 6×6, 15×15, 25×25
Profiles/2-D dose distribution	2-D isodose distributions in axial plane for each energy. • SSDs: 110 and others used clinically • Field sizes: 6×6, 15×15, 25×25.
Coronal or 3-D data	For 3-D algorithms, 3-D verification checks should be performed. Measure multiple coronal plane dose distributions or generate 3-D distributions.

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

TABLE A4-4. Shaped Fields

Expt #	Shape	Applicator	SSD
1	max circle, $r = 12$ cm	25×25	stnd
2	circle, $r = 2$ cm	6×6	stnd
2_S110	circle, $r = 2$ cm	6×6	stnd + 10
3	Oval 8×20	20×20	stnd
4	"C" shape	25×25	stnd
5	Squiggle shape	25×25	stnd
6	ECWG House Block	15×15	stnd

Fraas et al, "AAPM Radiation Therapy Committee TG53: Quality assurance program for radiotherapy treatment planning,"Med. Phys. 25,1773-1836 (1998).

AAPM Radiation Therapy Committee Task Group 67 Benchmark Datasets for Photon Beams

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Charge of TG-67

- Define a benchmark dataset and a set of test cases that could be used as a tool to perform algorithm verification for any TPS. Further, the accelerators and test conditions specified will cover an extensive list of clinical situations.
- The finished project will define a global dataset that could be used to complete the dose calculation checks outlined in TG-53.

Beam Data Requirements for the Planning Systems Listed Below

- ADAC Pinnacle
- CMS Focus
- Helax
- Isis
- Medicalibration
- Multidata
- DSS
- NOMOS Corvus
- Nucletron Plato
- Prowess
- Theratronics
- Theraplan

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Verification of the accuracy of a photon dose-calculation algorithm

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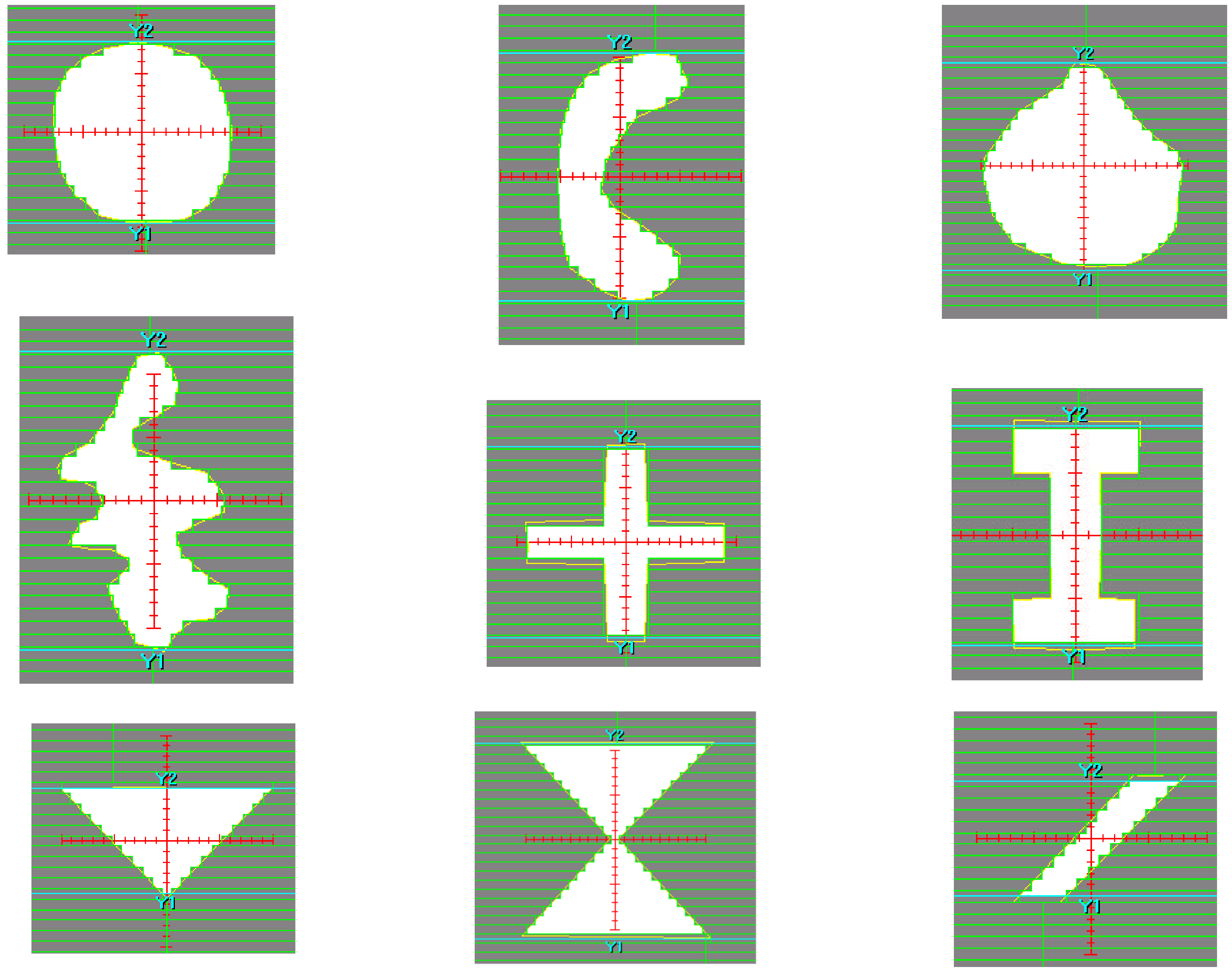
Compilation of the required data for 10 TPS systems

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

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

Use the appropriate dosimeter…

Type of Measurement	Recommended Dosimeter
Profile	Small Volume Ion Chamber(<0.1cc), Diode, or Diamond
Depth Dose	Small Volume Ion Chamber (0.125cc)
Soft Wedge Profile	Ion Chamber Array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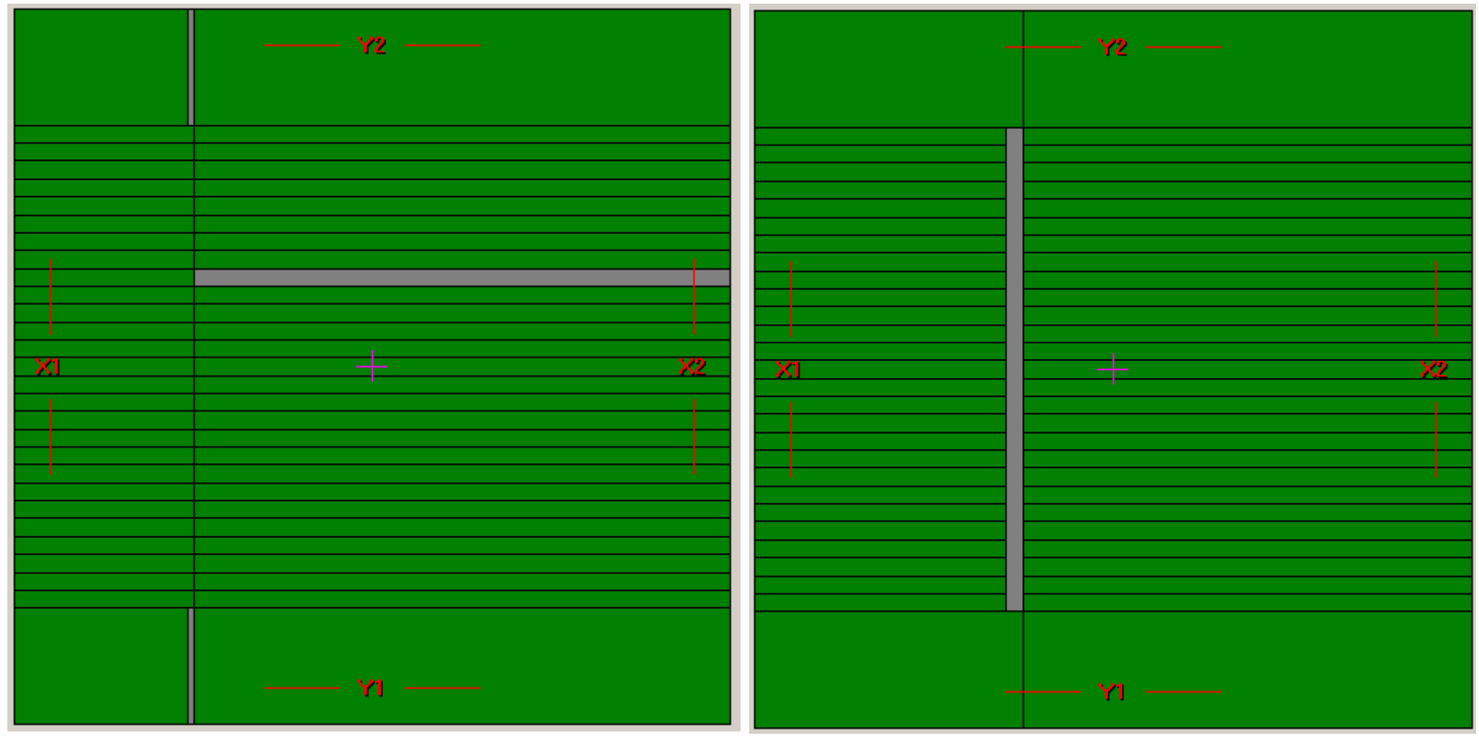
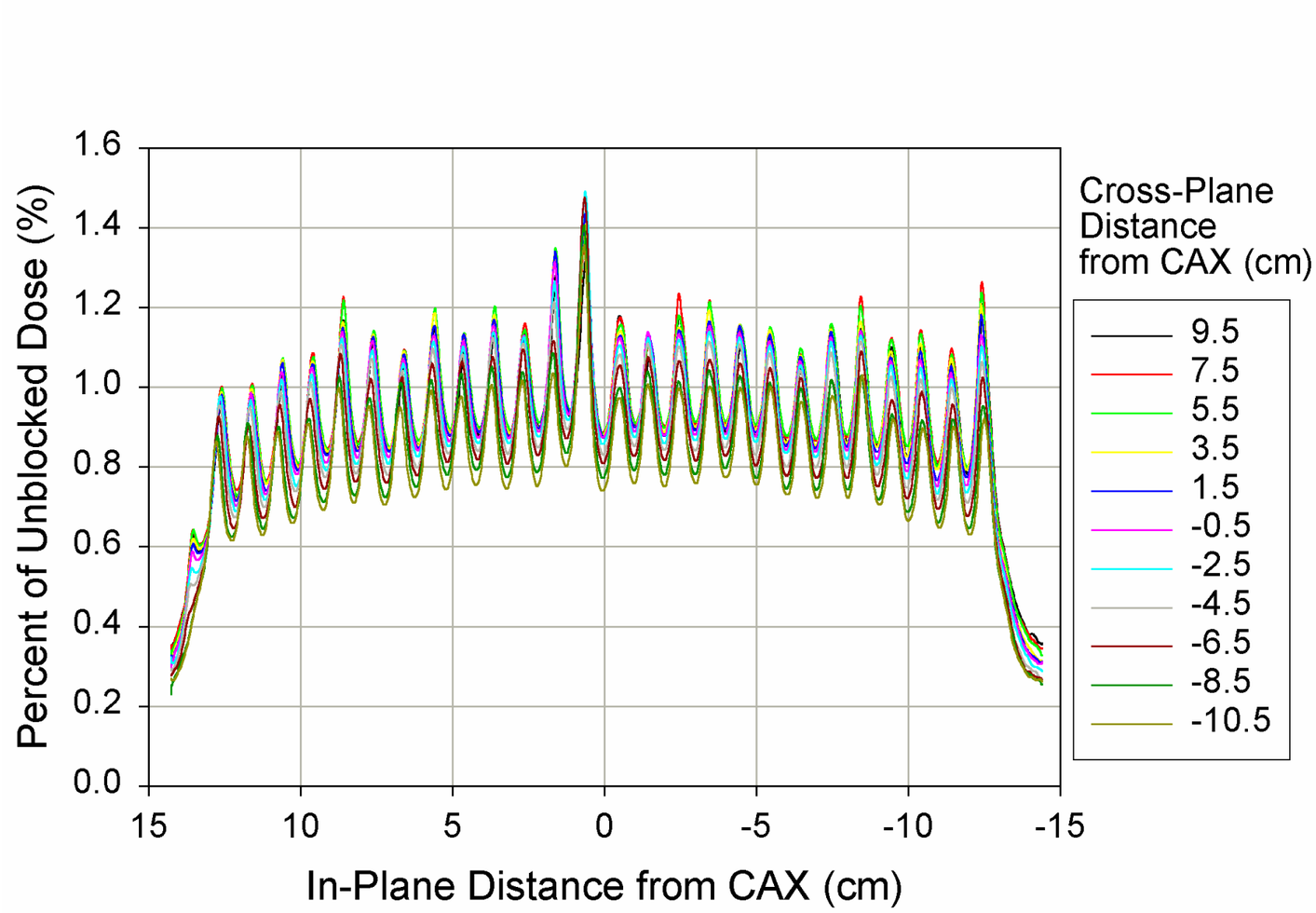
MLC penumbra



J.E. Bayouth and S. Morrill “MLC Dosimetric Characteristics for Small Field and IMRT Applications”, Med Phys (in press).



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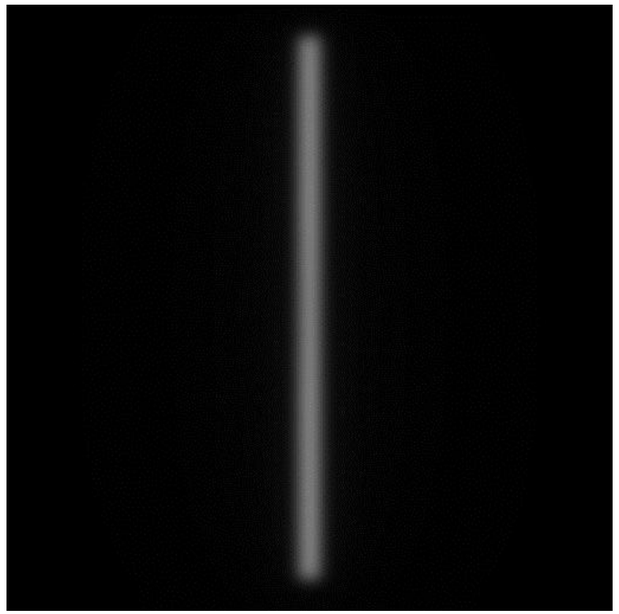
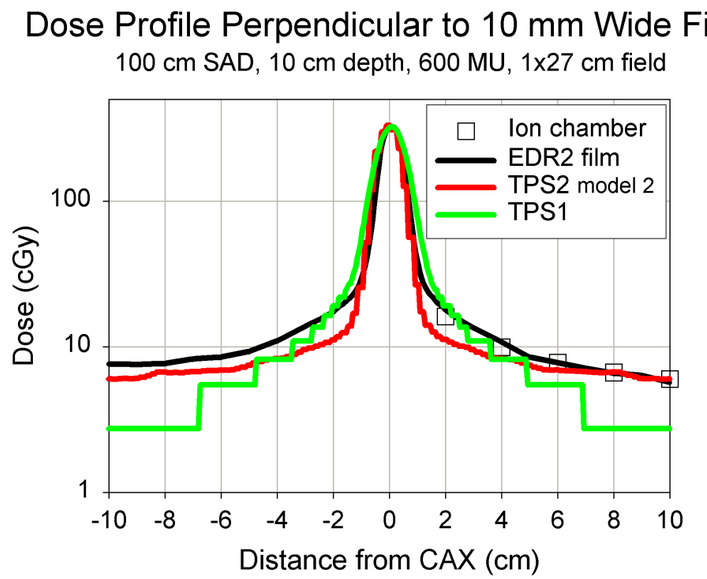
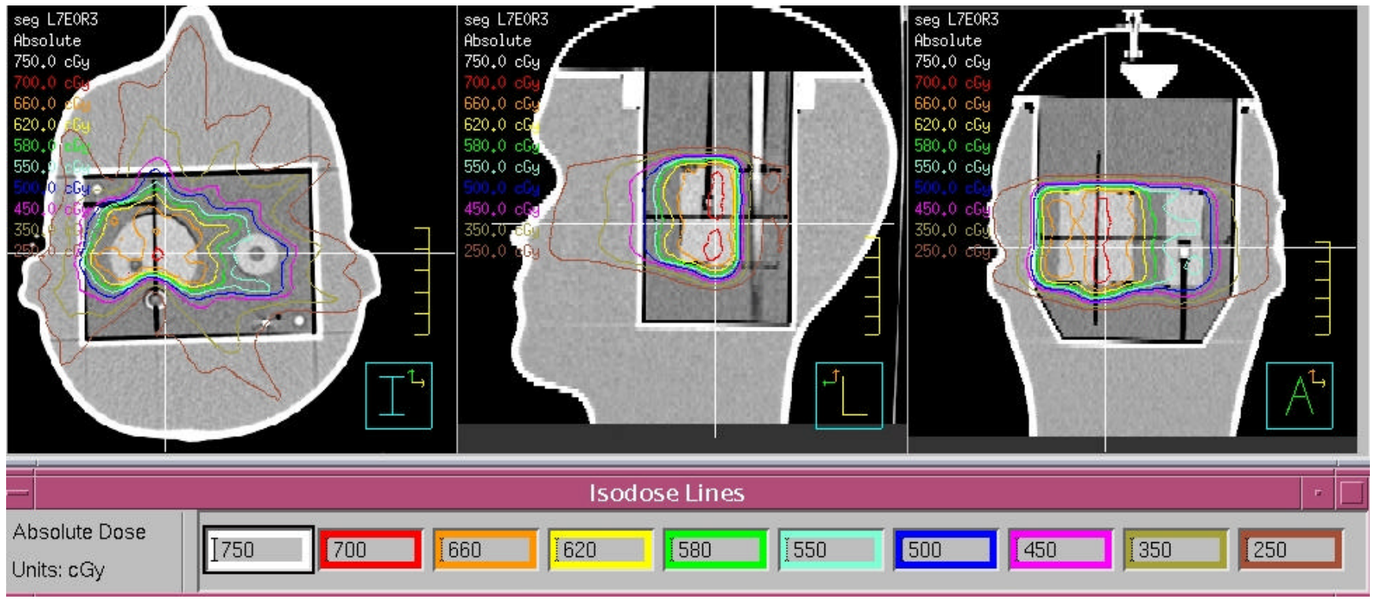




JE Bayouth and SM Morrill, “Study Of IMRT Dose Model Inadequacies”, ESTRO 2002



Comparison of TLD Measurements with TPS Results

(model 1 – conventional, model 2 – adjusted for IMRT)

	Measured	TPS 2	TPS 2		TPS 2	TPS 2
TLD	TLD	model 1	model 2		model 1	model 2
Location	Dose (Gy)	Dose (Gy)	Dose (Gy)		% diff	% diff
Primary PTV Superior	6.84	7.00	6.98		**2.3**	**2.0**
Primary PTV Inferior	6.90	7.05	6.70		**2.2**	**-2.9**
Secondary PTV	5.51	5.69	5.42		**3.3**	**-1.6**
Critical Structure	2.07	2.35	2.13		**13.5**	**2.9**

JE Bayouth and SM Morrill, “Study Of IMRT Dose Model Inadequacies”, ESTRO 2002

Finally, How long with this process take?

An appropriate time must be scheduled for the proper commissioning

The length of time needed depends on many factors, such as availability and experience of personnel and proper instrumentation and type of accelerator.

- a single energy photon machine can be commissioned in about 2-4 weeks
- a multimodality accelerator with two photon energies and several electron energies can take about 6-8 weeks of intensive effort (requiring 16-h shifts)

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