Performance-Based QA for Radiotherapy:
In Memoriam of Arnold Feldman

- Performance Based Quality Assurance: TG-142 - Medical Accelerator QA - E. Klein
- Performance-Based QA for Radiotherapy: TG-135 - QA for Robotic Radiosurgery - S. Dieterich
- Performance-Based QA for Radiotherapy: TG-147 – QA for Non-Radiographic Localization Systems - T. Willoughby
- Performance-Based QA for Radiotherapy: TG-148 – Tomotherapy Quality Assurance - K. Langen

Performance Based Quality Assurance:
TG-142 – Medical Accelerators
(TG40 + TG100 ~=TG-142)

Eric E. Klein, Ph.D.
Washington University
St. Louis, MO

TG-40 (1994): Comprehensive QA for Radiation Oncology

Procedure	Tolerance
Dosimetry	
X-ray output constancy	3%
Electron output constancy	3%
Mechanical	
Localizing lasers	2mm
Distance indicator	2mm
Safety	
Door interlock	Functional
Audiovisual monitor	Functional

Daily

Procedure	Tolerance
Dosimetry	
x-ray/electron output calibration constancy	2%
Field size dependence of x-ray output constancy	2%
Output factor constancy for electron applicators	2%
Central axis parameter constancy (PDD, TAR) Off-axis factor constancy	2%
Transmission factor constancy for all treatment accessories	2%
Wedge transmission factor constancy	2%
Monitor chamber linearity	2%
x-ray output constancy vs gantry angle	1%
Electron output constancy vs gantry angle	2%
Off-axis factor constancy vs gantry angle	2%
Arc mode	2%
Safety Interlocks	
Follow manufacturers test procedures	Mfrs. specs.
Mechanical Checks Collimator	
Rotation isocenter Gantry	2 mm diameter
Rotation isocenter Couch	2 mm diameter
Rotation isocenter Collimator	2 mm diameter
Coincidence of collimator, gantry, couch axes with isocenter	2 mm diameter
Coincidence of radiation and mechanical isocenter	2 mm diameter
Table top sag	2mm
Vertical travel of table	2mm

TG-40 Annual

Frequency	Test	Tolerance
Patient Specific	Check of MLC-generated field vs. simulator film (or DRR) before each field is treated	2 mm
	Double check of MLC field by therapists for each fraction	Expected field
	On-line imaging verification for patient on each fraction	Physician discretion
	Port film approval before second fraction	Physician discretion
Quarterly	Setting vs. light field vs. radiation field for two designated patterns	1 mm
	Testing of network system	Expected fields over network
	Check of interlocks	All must be operational
Annually	Setting vs. light vs. radiation field for patterns over range of gantry and collimator angles	1 mm
	Water scan of set patterns	50% radiation edge within 1 mm
	Film scans to evaluate interleaf leakage and abutted leaf transmission	Interleaf leakage <3%, abutted leakage <25%
	Review of procedures and in-service with therapists	All operators must fully understand operation and procedures

[a] This table is reproduced in part from Klein, Low, and Purdy (1996).

MLC QA per TG-50 (2001)

TABLE IV. Frequency of QA tasks.

Interval	Task (P—physicist, M—manufacturer, E—engineer, T—therapist)
Daily	Inspect imager housing (T)
	Test collision interlock (T)
	Acquire day's first image during machine warm-up procedure to verify operation and image quality (T)
	Verify sufficient data capacity for day's images (P or designate)
Monthly	Acquire image and inspect for artifacts (P)
	Perform constancy check of SNR, resolution and localization (P)
	Review image quality
	Perform image and disk maintenance (P)
	Mechanical inspection [latches, collision sensors, optical components (P,E)]
	Electrical connections (P,E)
	Test collision interlock (P)
	Hardcopy output (P)
Annual	Perform full check of geometric localization accuracy (P)

EPID QA per TG-58 (2001)

Task Group 100: Method for Evaluating QA Needs in Radiation Therapy

- **Initially "Replacement for TG-40"**
- **Radical departure from previous AAPM recommendations and philosophy**
- **Based on "Failure Modes and Effects Analysis" scoring**
- **Individual departments responsible for development of unique QA programs**
- **Based on procedures performed and resources at individual institutions**

TG-100
Proposed Quality Assurance Process

- **Custom designed QA programs**
- **AAPM Report will provide templates**
- **Scoring by FMEA performed by individual departments**
- **Tolerances set by individual departments**
- **Annual evaluation and modifications based on score changes**

Task Group No. 142: Guidelines for Tolerance Values

- **The recommendations of TG-142 should be considered flexible to take into account quality, costs, equipment condition, available test equipment, and institutional needs.**
- **We recommend using the tests and frequencies outlined in the tables that follow, until methods such as TG-100 augment this report.**

QA of MEDICAL ACCELERATORS

- **What This Report Doesn't Do**
  - Describe the techniques for performing QA tests
  - Accelerator beam data commissioning equipment and procedures – TG-106
  - QA for TomoTherapy –TG-148
  - QA for Robotic Radiosurgery – TG-135
  - QA for Non-Radiographic Radiotherapy Localization & Positioning Systems – TG-147
- **Does add Specific Recommendations / Supplements the Work of**
  - Basic Applications of Multileaf Collimators – TG-50
  - Clinical use of electronic portal imaging - TG-58
  - Management of Respiratory Motion– TG-76
  - Kilovoltage localization in therapy – TG-104

Task Group 142: QA of Medical Accelerators

Members

- Chair: Eric E. Klein, Ph.D., Washington University
- Joseph Hanley, Ph.D., Hackensack Univ Medical Center
- John Bayouth, Ph.D., University of Iowa
- Fang-Fang Yin, Ph.D., Duke University
- William Simon, M.S., Sun Nuclear Corp.
- Sean Dresser, M.S., Northside Hospital
- Christopher Serago, Ph.D., Mayo Clinic, Jacksonville
- Francisco Aguirre, M.S., M.D. Anderson Cancer Center
- Lijun Ma, Ph.D., University of California, San Francisco
- Bijan Arjomandy, Ph.D., M.D. Anderson Cancer Center
- Chihray Liu, Ph.D., University of Florida
- Consultants: Carlos Sandin (Elekta), Todd Holmes (Varian Medical Systems)

Task Group 142: QA of Medical Accelerators

I. INTRODUCTION: Purpose & Background

II. QUALITY ASSURANCE OF MEDICAL ACCELERATORS

A. General

B. Test Frequencies

C. Guidelines for Tolerance Values

D. Ancillary Devices Not in TG-40

- Asymmetric Jaws
- Dynamic/Virtual/Universal Wedges
- MLC
- TBI/TSET
- Radiographic Imaging
  - Planar kV and MV Imaging
  - Serial and Cone-Beam CT
- Respiratory Gating

III. SUMMARY OF RECOMMENDATIONS / IMPLEMENTATION SCHEME

BACKGROUND

- **Baseline dosimetric values entered into TPS to characterize and/or model the treatment machine directly affect calculated plans**
- **Values can deviate from their baseline as a result of;**
  - **Machine malfunction**
  - **Mechanical breakdown**
  - **Physical accidents**
  - **Component failure**
  - **Major component replacement**
  - **Gradual changes as a result of aging**
- **These patterns of failure must be considered when establishing a periodic QA program**

Task Group 142: Guidelines for Tolerance Values

- **Acceptance Testing**
  - *Acceptance testing sets the baseline for future dosimetric measurements for beam performance constancy, verifies that the equipment is mechanically functional and operates within certain tolerances from absolute specified values.*
- **Tolerances and Action Levels**
  - **Level 1 – Inspection Action**
  - **Level 2 – Scheduled Action**
  - **Level 3 – Immediate Action or Stop Treatment Action or Corrective Action**

With these 3 action levels, there is an institutional need to specify the thresholds associated with Levels 2 and 3. Level 1 threshold isn't a critical requirement but can lead to improvements in the QA program.

Task Group 142: General

- **A *Consistent beam profile* is an important quantity for accurate and reproducible dose delivery in radiotherapy.**
- **In our tables, monthly tolerance values are specific to a consistent beam shape, whereby baseline off axis factors are measured with a QA device immediately following commissioning or annual data.**
- **Ongoing QA measurements are compared to the baseline off axis factors.**

Task Group 142: General

Chosen O.A. points that fall within core of the field

$$\frac{1}{N}\cdot\sum_{L=1}^{N}\left|\frac{TP_L - BP_L}{BP_L}\right|\cdot 100\% \le Tolerance\ \%$$

- **where: TP_L and BP_L are off-axis ratios at Test and Baseline Points, respectively, at off axis Point L**
- **N is the number of off-axis points**
- **$TP_L = (MP_L/MP_C)$ where M represents the measured value, and C is the central axis measurement.**
- **Similarly, the baseline points are represented by $BP_L = (MBP_L/MBP_C)$**

Task Group 142: Philosophy

- **The types of treatments delivered with the machine should also have a role in determining the QA program that is appropriate for that treatment machine.**
- **For example, machines that are used for SRS/SBRT treatments, TBI or IMRT require different tests and/or tolerances.**

TG-142: Daily

Procedure	Machine Type Tolerance		
	non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray output constancy (all energies)	3%		
Electron output constancy (Weekly, except for machines with unique electron beam monitoring systems requiring daily review)			
Mechanical			
Laser localization	2 mm	1.5 mm	1 mm
Optical Distance Indicator (ODI) at isocenter	2 mm	2 mm	2 mm
Collimator size indicator	2 mm	2 mm	1 mm
Safety			
Door interlock (beam off)	Functional		
Door closing safety	Functional		
Audiovisual monitor(s)	Functional		
Stereotactic interlocks (lockout)	NA	NA	Functional
Radiation area monitor (if used)	Functional		
Beam-on indicator	Functional		

TG-142: Monthly

Procedure	Machine Type Tolerance		
	non-IMRT	IMRT	SRS/SBRT
Mechanical			
Light/radiation field coincidence	2 mm or 1% on a side		
Light/radiation field coincidence (Asymmetric)	1 mm or 1% on a side		
Distance check device used for lasers/ODI (vs. front pointer)	1mm		
Gantry/collimator angle indicators (@ cardinal angles) (Digital only)	1.0 deg		
Accessory trays (i.e. Port film graticle tray)	2 mm		
Jaw position indicators (Symmetric)	2 mm		
Jaw position indicators (Asymmetric)	1 mm		
Cross-hair centering (walk-out)	1 mm		
Treatment couch position indicators	**2 mm/1 deg**	**2 mm/ 1 deg**	**1 mm/ 0.5 deg**
Wedge placement accuracy	2mm		
Latching of wedges, blocking tray	Functional[5]		
Localizing lasers	±2 mm	±1 mm	<±1 mm

TG-142: Annual

*If PDD_{10}, measured during TG51 calibration deviates >1%, discretion to measure more PDD points

Procedure	Machine Type Tolerance		
	non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray flatness change from baseline	1%		
X-ray symmetry change from baseline	±1%		
Electron flatness change from baseline	1%		
Electron symmetry change from baseline	±1%		
SRS arc rotation mode (range: 0.5 to 10 MU/deg)	NA	NA	Monitor units set vs. delivered:1.0 MU or 2%
			Gantry arc set vs. delivered: 1.0 deg or 2%
X-ray/electron output calibration (TG-51)	±1%(absolute)		
Spot check of field size dependent output factors for X-ray (2 or more FS)	2% for field size < 4x4 cm^2, 1% ≥4x4 cm^2		
Output factors for electron applicators (spot check of 1 applicator/energy)	±2% from baseline		
X-ray beam quality (PDD_{10} or TMR_{10}^{20}) *	**±1% from baseline**		
Electron beam quality (R_{50})	±1mm		
Physical wedge transmission factor constancy	±2%		

Annual

Procedure	Machine Type Tolerance		
	non-IMRT	IMRT	SRS/SBRT
X-ray monitor unit linearity [output . constancy]	±2% ≥5MU	±5% (2-4 MU), ±2% ≥5MU	±5% (2-4), ±2% ≥5MU
Electron monitor unit linearity [output . constancy]	±2% ≥5MU		
X-ray output constancy vs dose rate	±2% from baseline		
X-ray output constancy vs gantry angle	±1% from baseline		
Electron output constancy vs gantry angle	±1% from baseline		
Electron and X-ray Off-axis factor constancy vs gantry angle	±1% from baseline		
Arc mode (expected MU, degrees)	±1% from baseline		
TBI/TSET Mode	Functional		
PDD or TMR and OAF constancy	1% (TBI) or 1mm PDD shift (TSET) from baseline		
TBI/TSET Output calibration	2% from baseline		
TBI/TSET accessories	2% from baseline		

Multileaf Collimation

Procedure	Tolerance
Weekly (IMRT machines)	
Qualitative test (i.e. matched segments, aka, "picket fence")	Visual inspection for discernable deviations such as an increase in interleaf transmission
Monthly	
Setting vs. radiation field for two patterns (non-IMRT)	2mm
Backup diaphragm settings (Elekta only)	2mm
Travel speed (IMRT)	Loss of leaf speed > 0.5 cm/sec
Leaf position accuracy (IMRT)	1mm for leaf positions of an IMRT field for 4 cardinal gantry angles. (*Picket fence* test may be used, test depends on clinical planning – segment size)
Annually	
MLC Transmission (Average of leaf and interleaf transmission), All Energies	±0.5% from baseline
Leaf position repeatability	±1.0 mm
MLC spoke shot	≤1.0 mm radius
Coincidence of Light Field and X-ray Field (All energies)	±2.0 mm
Segmental IMRT (Step and Shoot) Test	<0.35 cm Max Error RMS, 95% of error counts <0.35 cm
Moving window IMRT (4 cardinal gantry angles)	<0.35 cm Max Error RMS, 95% of error counts <0.35 cm

Imaging Tests: Daily

[1] Or at a minimum when devices are to be used during treatment day

Procedure	Application Type Tolerance	
	non-SRS/SBRT	SRS/SBRT
Daily[1]		
kV and MV (EPID) imaging		
Collision interlocks	Functional	Functional
Positioning/repositioning	≤ 2 mm	≤ 1 mm
Imaging & Treatment coordinate coincidence (single gantry angle)	≤ 2 mm	≤ 1 mm
Cone-beam CT (kV & MV)		
Collision interlocks	Functional	Functional
Imaging & treatment coordinate coincidence	≤ 2 mm	≤ 1 mm
Positioning/repositioning	≤ 1 mm	≤ 1 mm

SUMMARY OF RECOMMENDATIONS/ IMPLEMENTATION SCHEME

The tabulated items have been considerably expanded compared with the original TG 40 report, and the recommended tolerances accommodate differences in the intended use of the machine functionality (non-IMRT, IMRT, and Stereotactic Delivery).

SUMMARY OF RECOMMENDATIONS/ IMPLEMENTATION SCHEME

- **QA team <u>led by the QMP</u> supports all QA activities & policies and procedures.**
- **The 1st step is to establish institution-specific baseline and absolute reference values.**
- **Daily QA tasks may be carried out by a RTT using a cross-calibrated dosimetry system that is robust and easy-to-setup.**
- **There is overlap of tests for daily, monthly, and annual that can achieve independence with independent measurement devices.**

SUMMARY OF RECOMMENDATIONS/ IMPLEMENTATION SCHEME

- **End-to-end system checks ensure fidelity of overall system.**
- **During the annual QA, absolute outputs should be calibrated as per TG51 and all secondary QA dosimeters cross-checked.**
- **Upon completion of an annual QA report be generated, signed and reviewed by the QMP and filed for future machine maintenance and inspection needs.**