Implementation of AAPM TG 142: Quality Assurance of Medical Accelerators

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Acknowledgements

- Invitation from organization committee
- QA team physicists in the Department of Radiation Oncology at Duke University

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Objectives

- Understand fundamental principles and the needs of quality assurance for linear accelerator
- Understand principle and contents of TG-142
- Understand strategy and methodology of implementing TG 142
- Understand the limitations of TG 142

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TG-142 Members

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- 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
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- Consultants: Carlos Sandin (Elekta)
  Todd Holmes (Varian Medical Systems)

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Med. Phys. 36:4197-4212 (2009)

Purpose/Disclaimer – TG142

- To build upon the recommendations of TG-40 for QA of medical linear accelerators including the before mentioned technologies and procedures such as SRS, SBRT, TBI and IMRT (exclude VMAT)
- The recommendations of this task group are not intended to be used as regulations
- These recommendations are guidelines for qualified medical physicists (QMP) to use and appropriately interpret for their individual institution and clinical setting
- Each institution may have site-specific or state mandated needs and requirements which may modify their usage of these recommendations

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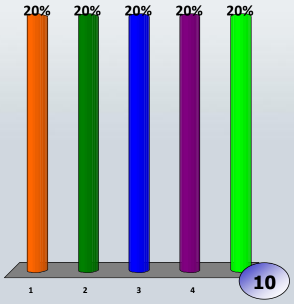
What is the goal of a QA program for medical linear accelerators?

a. To meet the requirement of job description for physicists in an academic university hospital
b. To meet the regulatory requirements from the state government for radiation therapy
c. To meet the requirements and guidelines as described in a number of AAPM task reports
d. To meet the requirements of department chair and/or hospital administrators
e. To assure that the machine characteristics do not deviate significantly from their baseline values acquired at the time of acceptance and commissioning



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Discussion

- Answer: e
- The goal for QA to ensure the quality and safety of the machines meet the criteria and guidelines obtained from ATP and commissioning
- References: TG-40, TG-142

Why QA is Needed?

- The principle of Linac QA: ICRU recommends that the dose delivered to the patient be within ±5% of the prescribed dose
- Many steps involved in delivering dose to a target volume in a patient, each step must be performed with accuracy better than 5% to achieve this recommendation
- The goal of a QA program for linear accelerators is to assure that the machine characteristics do not deviate significantly from their baseline values acquired at the time of acceptance and commissioning

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When QA is Needed?

- Baseline values are entered into treatment planning systems to characterize and/or model the treatment machine, and therefore can directly affect treatment plans calculated for every patient treated on the machine
- Machine parameters can deviate from their baseline values
  - Machine malfunction
  - Mechanical breakdown
  - Physical accidents
  - Component failure
  - Major component replacement
  - Gradual changes as a result of aging
- Theses patterns of failure must be considered when establishing a periodic QA program

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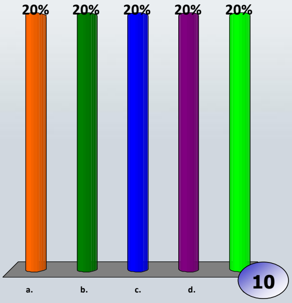
Choose the most appropriate list of components in a QA protocol for medical linear accelerators:

a. Dose output, method, every day, tolerance, MD approval, Radiation Safety Officer, documentation
b. Parameter, electrometer, frequency, tolerance, physicist, performer, daily output
c. Parameter, what tank, frequency, sub-millimeter ruler, action, performer, computer
d. Parameter, method, frequency, tolerance, action, performer, documentation
e. Parameter, method, ion chamber, tolerance, performer, administrator, Therapist



Discussion

- Answer: d
- The process of developing a QA protocol should include several major components: the parameter to be measured, the method and tools used for the measurement, the frequency of measurement, the tolerance can be accepted for the measurement, action levels needed for the data generated, the person to perform measurement, and the method of documentation for audit.
- References: TG-40, TG-142

General QA Considerations

- Measurement parameters
- Measurement methods
  - Phantoms
  - Devices
  - Procedures and policies
- Measurement frequencies
- Measurement tolerances/criteria
- Action levels
- Personnel: training, efforts, finances, ….
- Documentation

Rationale for TG 142

- TG 100 task to develop QA rationales
  - TG 100 – A Method for Evaluating QA Needs in Radiation Therapy -- (based on “Failure Modes and Effects Analysis”)
  - Promotes individual department to be responsible for development of unique QA programs based on procedures and resources performed at individual institutions
- TG-142 fill gap between TG-40 and TG-100
  - Give performance-based recommendation
  - Provide process-oriented concepts and advancements in linacs since 1994

Considerations for QA Frequency

- Are we doing too much for QA?
- The underlying principles for test frequency follow those of TG-40 and attempt to balance cost and effort
- Several authors (Schultheiss, Rozenfeld, Pawlicki) have attempted to develop a systematic approach to developing QA frequencies and action levels
- More recently the work being performed by Task Group 100 of the AAPM – still under evaluation

Considerations for QA Tolerances

The original tolerance values in TG-40 were adapted from AAPM Report 13 which used the method of quadratic summation to set tolerances

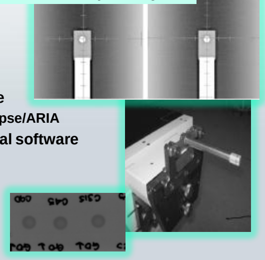
These values were intended to make it possible to achieve an overall dosimetric uncertainty of ±5% and an overall spatial uncertainty of ±5 mm

These tolerances are further refined in this report and those quoted in the tables are specific to the type of treatments delivered with the treatment unit

Considerations for Efficiency

- Challenges:
  - Time
  - Effort
- Potential solutions
  - Combine different tasks
  - Use of integrated software
    - Develop QA plans in Eclipse/ARIA
  - Some available commercial software
    - DoseLab
    - PIPSpro
    - RIT113
  - …

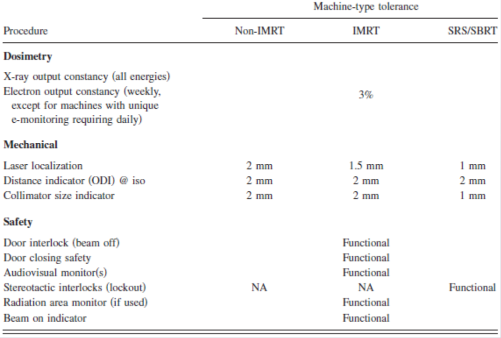
For an SRS system, combine W-L test with daily IGRT QA



QA of Medical Accelerators

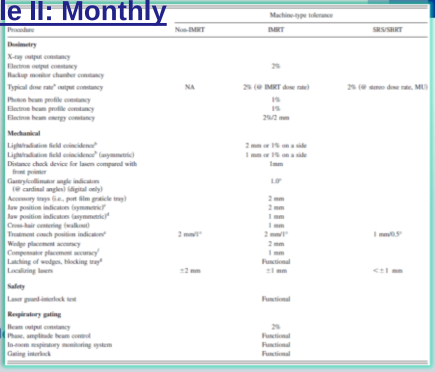
- Report has 6 tables of recommendations
  - Linac daily (T1), Monthly (T2), Annual (T3)
  - Contain tests for asymmetric jaws, respiratory gating, and TBI/TSI
  - Dynamic/virtual/universal wedges (T4), MLC (T5), Imaging (T6)
- Each table has specific recommendations based on the nature of the treatment delivered on machine
  - Non-IMRT, non-SRS
  - IMRT
  - SRS/SBRT
- Explicit recommendations based on equipment manufacturer as a result of design characteristics of these machines

Table I: Daily QA



	Machine-type tolerance		
Procedure	Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray output constancy (all energies)		3%	
Electron output constancy (weekly, except for machines with unique e-monitoring requiring daily)			
Mechanical			
Laser localization	2 mm	1.5 mm	1 mm
Distance indicator (ODI) @ iso	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	

Table II: Monthly



	Machine-type tolerance		
Procedure	Non-IMRT	IMRT	SRS/SBRT
Dosimetry			
X-ray output constancy			
Electron output constancy		2%	
Backup monitor chamber constancy			
Typical dose rate[a] output constancy	NA	2% (@ IMRT dose rate)	2% (@ stereo dose rate, MU)
Photon beam profile constancy		1%	
Electron beam profile constancy		1%	
Electron beam energy constancy		2%/2 mm	
Mechanical			
Light/radiation field coincidence[b]		2 mm or 1% on a side	
Light/radiation field coincidence[b] (asymmetric)		1 mm or 1% on a side	
Distance check device for lasers compared with front pointer		1mm	
Gantry/collimator angle indicators (@ cardinal angles) (digital only)		1.0°	
Accessory trays (i.e., port film graticle tray)		2 mm	
Jaw position indicators (symmetric)[c]		2 mm	
Jaw position indicators (asymmetric)[d]		1 mm	
Cross-hair centering (walkout)		1 mm	
Treatment couch position indicators[e]	2 mm/1°	2 mm/1°	1 mm/0.5°
Wedge placement accuracy		2 mm	
Compensator placement accuracy[f]		1 mm	
Latching of wedges, blocking tray[g]		Functional	
Localizing lasers	±2 mm	±1 mm	<±1 mm
Safety			
Laser guard-interlock test		Functional	
Respiratory gating			
Beam output constancy		2%	
Phase, amplitude beam control		Functional	
In-room respiratory monitoring system		Functional	
Gating interlock		Functional	

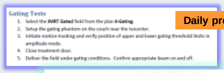
Table II: Monthly – Special Notes

a. Dose monitoring as a function of dose rate
b. Light/radiation field coincidence need only be checked monthly if light field is used for clinical setups
c. Tolerance is summation of total for each width or length
d. Asymmetric jaws should be checked at settings of 0.0 and 10.0.
e. Lateral, longitudinal, and rotational
f. Compensator based IMRT solid compensators require a quantitative value for tray position wedge or blocking tray slot set at a maximum deviation of 1.0mm from the center of the compensator tray mount and the cross hairs
g. Check at collimator/gantry angle combination that places the latch toward the floor

Respiratory Gating

- AAPM report 91 (TG-76, Med Phys 2006) described all aspects of the management of respiratory motion in radiation therapy, including imaging, treatment planning, and delivery
- All respiratory techniques fundamentally require a synchronization of the radiation beam with the patient respiration
- Characterization of the accelerator beam under respiratory gating conditions
- Recommend dynamic phantoms which simulate respiratory organ motion to test target localization and treatment delivery
- Tables II and III include tests for respiratory gated accelerator operation
- Daily tests were added in our institution

Respiratory Gating QA



Gating Tests

1. Select the **IMRT Gated** field from the plan **4-Gating**.
2. Setup the gating phantom on the couch near the isocenter.
3. Initiate motion tracking and verify position of upper and lower gating threshold limits in amplitude mode.
4. Close treatment door.
5. Deliver the field under gating conditions. Confirm appropriate beam on and off.

Daily protocol

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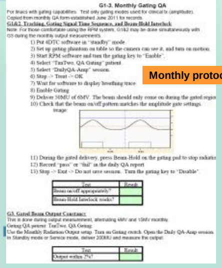


G1-3. Monthly Gating QA

For linacs with gating capabilities. Test only gating modes used for clinical tx (amplitude).
Copied from monthly QA form established June 2011 for records.

G1&2. Tracking, Gating Signal Time Sequence, and Beam-Hold Interlock

Note: For those comfortable using the RPM system, G1&2 may be done simultaneously with G3 during the monthly output measurements.

1) Put 4DTC software in "standby" mode.
2) Set up gating phantom on table so the camera can see it, and turn on motion.
3) Start RPM software and turn the gating key to "Enable".
4) Select "TanTwo, QA Gating" patient.
5) Select "DailyQA-Amp" session.
6) Stop -> Treat -> OK
7) Wait for software to display breathing trace.
8) Enable Gating
9) Deliver 50MU of 6MV. The beam should only come on during the gated regio
10) Check that the beam on/off pattern matches the amplitude gate settings.
image:
11) During the gated delivery, press Beam-Hold on the gating pad to stop radiatio
12) Record "pass" or "fail" in the daily QA report
13) Stop -> Exit -> Do not save session. Turn the gating key to "Disable".

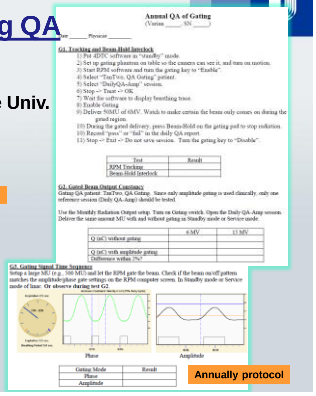
Test	Result
Beam on/off appropriately?	
Beam-Hold Interlock works?	

G3. Gated Beam Output Constancy

This is done during output measurement, alternating 6MV and 15MV monthly.
Gating QA patient: TanTwo, QA Gating.
Use the Monthly Radiation Output setup. Turn on Gating switch. Open the Daily QA-Amp session. In Standby mode or Service mode, deliver 200MU and measure the output.

Test	Result
Output within 2%?	

Monthly protocol



Annual QA of Gating
(Varian ____, SN ____)

Date ______ Physicist ________

G1. Tracking and Beam-Hold Interlock

1) Put 4DTC software in "standby" mode.
2) Set up gating phantom on table so the camera can see it, and turn on motion.
3) Start RPM software and turn the gating key to "Enable".
4) Select "TanTwo, QA Gating" patient.
5) Select "DailyQA-Amp" session.
6) Stop -> Treat -> OK
7) Wait for software to display breathing trace.
8) Enable Gating
9) Deliver 50MU of 6MV. Watch to make certain the beam only comes on during the gated region.
10) During the gated delivery, press Beam-Hold on the gating pad to stop radiation.
10) Record "pass" or "fail" in the daily QA report.
11) Stop -> Exit -> Do not save session. Turn the gating key to "Disable".

Test	Result
RPM Tracking	
Beam-Hold Interlock	

G2. Gated Beam Output Constancy

Gating QA patient: TanTwo, QA Gating. Since only amplitude gating is used clinically, only one reference session (Daily QA-Amp) should be tested.

Use the Monthly Radiation Output setup. Turn on Gating switch. Open the Daily QA-Amp session. Deliver the same amount MU with and without gating in Standby mode or Service mode.

	6 MV	15 MV
Q (nC) without gating		
Q (nC) with amplitude gating		
Difference within 2%?		

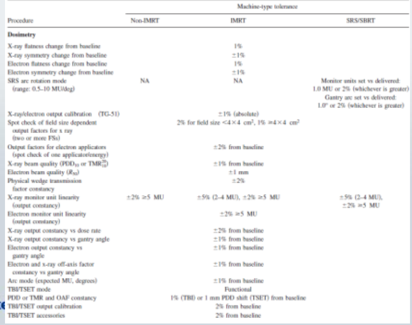
G3. Gating Signal Time Sequence

Setup a large MU (e.g., 500 MU) and let the RPM gate the beam. Check if the beam on/off pattern matches the amplitude/phase gate settings on the RPM computer screen. In Standby mode or Service mode of linac. **Or observe during test G2.**

Gating Mode	Result
Phase	
Amplitude	

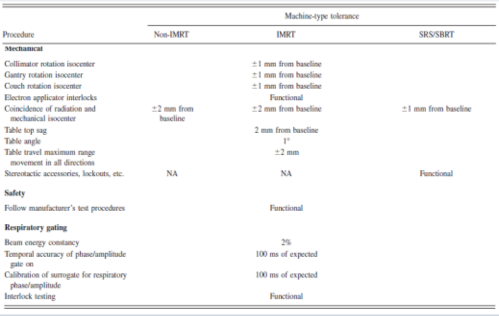
Annually protocol

Table III: Linac Annual QA - 1



	Machine-type tolerance		
Procedure	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: 0.5–10 MU/deg)	NA	NA	Monitor units set vs delivered: 1.0 MU or 2% (whichever is greater) Gantry arc set vs delivered: 1.0° or 2% (whichever is greater)
X-ray/electron output calibration (TG-51)		±1% (absolute)	
Spot check of field size dependent output factors for x ray (two or more FSs)		2% for field size <4×4 cm², 1% ≥4×4 cm²	
Output factors for electron applicators (spot check of one applicator/energy)		±2% from baseline	
X-ray beam quality (PDD_{10} or TMR^{20}_{10})		±1% from baseline	
Electron beam quality (R_{50})		±1 mm	
Physical wedge transmission factor constancy		±2%	
X-ray monitor unit linearity (output constancy)	±2% ≥5 MU	±5% (2–4 MU), ±2% ≥5 MU	±5% (2–4 MU), ±2% ≥5 MU
Electron monitor unit linearity (output constancy)		±2% ≥5 MU	
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 1 mm PDD shift (TSET) from baseline	
TBI/TSET output calibration		2% from baseline	
TBI/TSET accessories		2% from baseline	

Table III: Linac Annual QA - 2



	Machine-type tolerance		
Procedure	Non-IMRT	IMRT	SRS/SBRT
Mechanical			
Collimator rotation isocenter		±1 mm from baseline	
Gantry rotation isocenter		±1 mm from baseline	
Couch rotation isocenter		±1 mm from baseline	
Electron applicator interlocks		Functional	
Coincidence of radiation and mechanical isocenter	±2 mm from baseline	±2 mm from baseline	±1 mm from baseline
Table top sag		2 mm from baseline	
Table angle		1°	
Table travel maximum range movement in all directions		±2 mm	
Stereotactic accessories, lockouts, etc.	NA	NA	Functional
Safety			
Follow manufacturer's test procedures		Functional	
Respiratory gating			
Beam energy constancy		2%	
Temporal accuracy of phase/amplitude gate on		100 ms of expected	
Calibration of surrogate for respiratory phase/amplitude		100 ms of expected	
Interlock testing		Functional	

Table IV: Dynamic/Universal/Virtual Wedges

TABLE IV. Dynamic/universal/virtual wedges.

Dynamic-including EDW (Varian), virtual (Siemens), universal (Elekta) wedge quality assurance				
		Tolerance		
Frequency	Procedure	Dynamic	Universal	Virtual
Daily	Morning check-out run for one angle	Functional		
Monthly	Wedge factor for all energies	C.A. axis 45° or 60° WF (within 2%)[a]	C.A. axis 45° or 60° WF (within 2%)[a]	5% from unity, otherwise 2%
Annual	Check of wedge angle for 60°, full field and spot check for intermediate angle, field size	Check of off-center ratios @ 80% field width @ 10 cm to be within 2%		

[a] Recommendation to check 45° if angles other than 60° are used.

Table V: Multileaf Collimation (MLC)

TABLE V. Multileaf collimation (with differentiation of IMRT vs non-IMRT machines).

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)	2 mm
Backup diaphragm settings (Elekta only)	2 mm
Travel speed (IMRT)	Loss of leaf speed >0.5 cm/s
Leaf position accuracy (IMRT)	1 mm for leaf positions of an IMRT field for four 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 (four cardinal gantry angles)	<0.35 cm max. error RMS, 95% of error counts <0.35 cm

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Multi-leaf Collimator (MLC)

Early recommendations Varian (Klein, Galvin, Losasso) Elekta (Jordan) Das (Siemens)

1998 AAPM TG-50 to address multi-leaf collimation, including extensive sections on multi-leaf collimator QA not specific for MLCs as used for IMRT

TG-142 recommend testing (Table V) that depends on whether or not the MLC system is used for IMRT

Geometry accuracy:

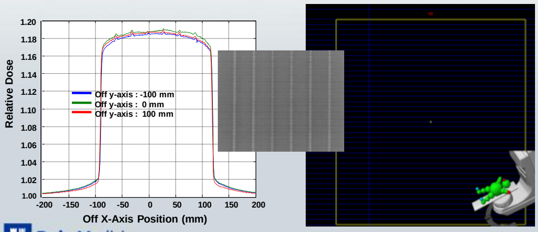
Leaf position, speed, gantry angles, etc.

Dosimetry accuracy:

Abutting field, travel speed, gantry angles, dose rate,

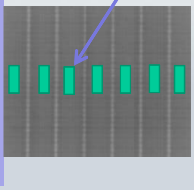
Sample MLC QA Test

Combined to VMAT QA - to test the accuracy of dose rate and gantry speed control with P-F method



Sample MLC QA Test

ΔMU/Δt (MU/min)	Δθ (degree)	Δθ/Δt (degree/s)	Ave Δ (%)
111	90	5.54	1.1
222	45	5.54	0.5
333	30	5.54	0.0
443	22.5	5.54	0.1
554	18	5.54	-0.2
600	15	5.00	-0.5
600	12.9	4.30	-1.1



Measurement ROIs (same MUs)

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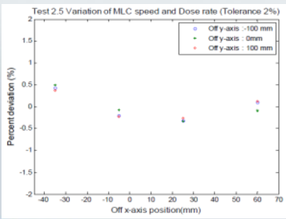
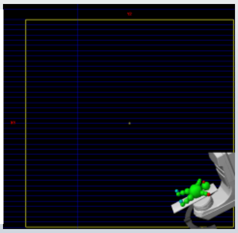
Sample MLC QA Test

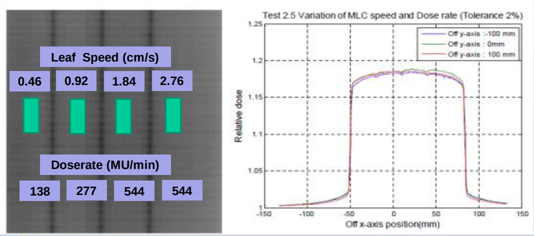
Combinations of leaf speed/dose-rate to give equal dose to four strips in a RapidArc





Sample MLC QA Test

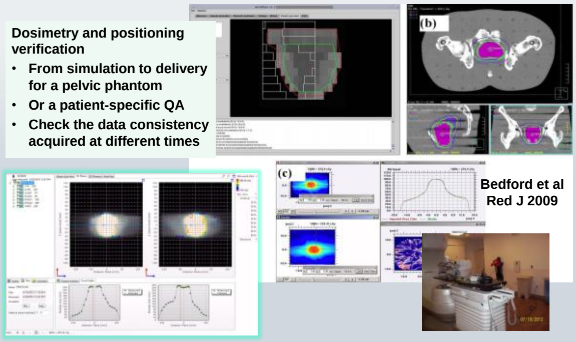
Combinations of leaf speed/dose-rate to give equal dose to four strips in a VMAT



Sample MLC QA: End-to-End Tests

Dosimetry and positioning verification

- **From simulation to delivery for a pelvic phantom**
- **Or a patient-specific QA**
- **Check the data consistency acquired at different times**



Bedford et al Red J 2009

TBI/TSI

- **Total Body Photon irradiation (TBI) is described in detail in AAPM Report 17 (TG-29) and Total Skin Electron Therapy (TSET) in AAPM Report 23 (TG-30)**
- **This report recommends repeating a subset of the commissioning data for TBI or TSET on an annual basis to ensure the continued proper operation of the accelerator**
  - Should replicate commissioning test conditions i.e. Special dose rate mode for TBI/TSET treatment, Extended distance, TBI/TSET modifiers
- **Annual TBI/TSET (Table 3) performed in the TBI/TSET mode for the clinical MU range at clinical dose rates**
  - Functionality
  - Modifiers' transmission constancy
  - TPR or PDD constancy
  - Off-axis factor (OAF) constancy
  - Output constancy

Table VI: Imaging

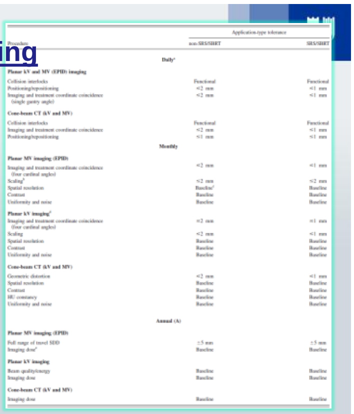
a. **Or at a minimum when devices are to be used during treatment day.**

b. **Scaling measured at SSD typically used for imaging.**

c. **Baseline means that the measured data are consistent with or better than ATP data.**

d. **kV imaging refers to both 2D fluoroscopic and radiographic imaging.**

e. **Imaging dose to be reported as effective dose for measured doses per TG 75.**



	Application-type tolerance	
Procedure	non-SRS/SBRT	SRS/SBRT
Daily[a]		
Planar kV and MV (EPID) imaging		
Collision interlocks	Functional	Functional
Positioning/repositioning	≤2 mm	≤1 mm
Imaging and treatment coordinate coincidence (single gantry angle)	≤2 mm	≤1 mm
Cone-beam CT (kV and MV)		
Collision interlocks	Functional	Functional
Imaging and treatment coordinate coincidence	≤2 mm	≤1 mm
Positioning/repositioning	≤1 mm	≤1 mm
Monthly		
Planar MV imaging (EPID)		
Imaging and treatment coordinate coincidence (four cardinal angles)	≤2 mm	≤1 mm
Scaling[b]	≤2 mm	≤2 mm
Spatial resolution	Baseline[c]	Baseline
Contrast	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Planar kV imaging[d]		
Imaging and treatment coordinate coincidence (four cardinal angles)	≤2 mm	≤1 mm
Scaling	≤2 mm	≤1 mm
Spatial resolution	Baseline	Baseline
Contrast	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Cone-beam CT (kV and MV)		
Geometric distortion	≤2 mm	≤1 mm
Spatial resolution	Baseline	Baseline
Contrast	Baseline	Baseline
HU constancy	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Annual (A)		
Planar MV imaging (EPID)		
Full range of travel SDD	±5 mm	±5 mm
Imaging dose[e]	Baseline	Baseline
Planar kV imaging		
Beam quality/energy	Baseline	Baseline
Imaging dose	Baseline	Baseline
Cone-beam CT (kV and MV)		
Imaging dose	Baseline	Baseline

The IGRT QA program for an imaging system attached to a linear accelerator is primarily designed to check

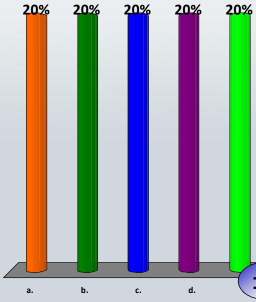
a. **Geometric accuracy, imaging quality, safety, and imaging dose**

b. **Positioning and repositioning, noise, and CTDI, software accuracy**

c. **Geometric accuracy, pixel number consistency, contrast, imaging dose**

d. **Isocenter accuracy, Cone-beam CT dose, safety, imaging dose**

e. **Detector sag, reconstruction algorithm, resolution, and CT/CBCT dose**



10

Discussion

- **Answer: a**
- **IGRT QA is aimed to check the geometric accuracy-the coincidence between imaging isocenter and delivery system isocenter; the proper imaging dose, the proper image quality is maintained compared to accepted system, and operational safety such as collision detection etc.**
- **References: TG-142, TG-104**

Components for IGRT QA

- The goal for imaging is to improve accuracy and precision
- Geometric accuracy
  - Geometric center coincidence
  - Positioning and repositioning
- Image quality
  - Resolution, noise, contrast, artifacts, image fusion, etc.
- Safety
  - Collision interlocks, warning indications, etc.
- Imaging dose
  - 2D, 3D, 4D, fluoroscopy, etc.

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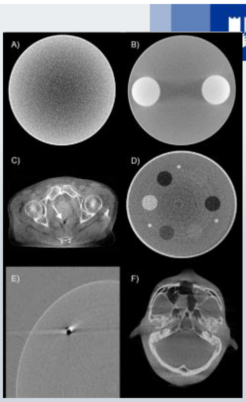
Artifacts in kV CBCT

- Cupping and streaks due to hardening and scatter (A&B)
- Gas motion streak (C)
- Rings in reconstructed images due to dead or intermittent pixels (D)
- Streak and comets due to lag in the flat panel detector (E)
- Distortions (clip external contours and streaks) due to fewer than 180 degrees + fan angle projection angles (F)



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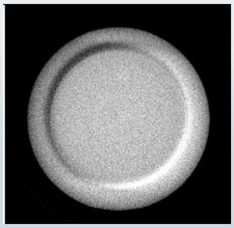
Crescent Artifact in CBCT Scans

An apparent shift of the bow tie profile from projection to projection deriving most likely from minor mechanical instabilities, such as a tilt of the source or a shift of the focal spot



W Giles et al: Crescent artifacts in cone-beam CT Med Phys 2011 Apr;38(4):2116-21.

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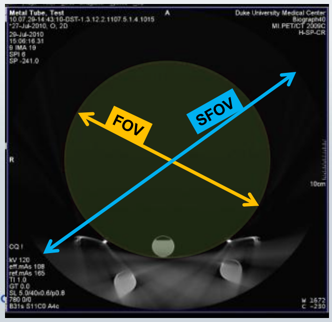
Artifacts in CT Imaging



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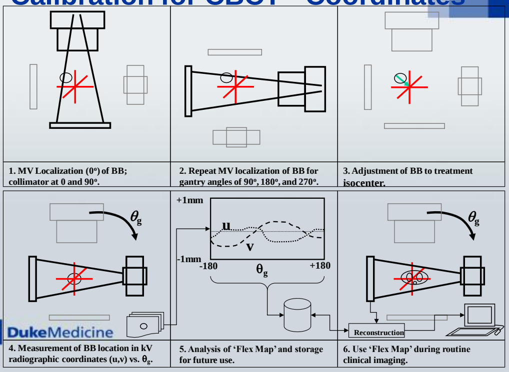
Calibration for CBCT - Coordinates



1. MV Localization (0°) of BB; collimator at 0 and 90°.

2. Repeat MV localization of BB for gantry angles of 90°, 180°, and 270°.

3. Adjustment of BB to treatment isocenter.

4. Measurement of BB location in kV radiographic coordinates (u,v) vs. θ_g.

5. Analysis of 'Flex Map' and storage for future use.

6. Use 'Flex Map' during routine clinical imaging.

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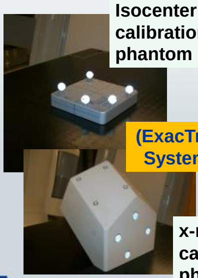
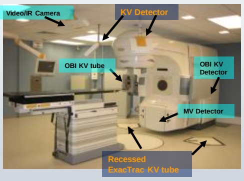
Calibration of 2D System - Coordinates



Isocenter calibration phantom

(ExacTrac System)

x-ray calibration phantom



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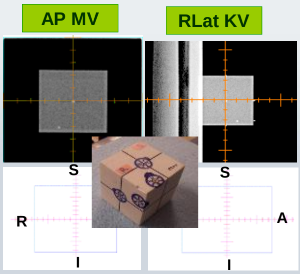
Geometry – kV/MV 2D Imaging Test

- Touch a pedal to get beep
- Put a cube phantom @iso
- Set OBI/PV at 50, 0, 0
- Take AP MV/RLat KV
- Measure the distance between BB and graticle



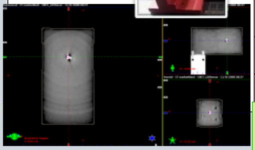
MV PD imaging isocenter	AP L/R: ; S/I:
KV OBI imaging isocenter	RLAT A/P: ; S/I:

Geometry – kV/MV & CBCT Combined Testing (for Iso & Positioning)

- Touch a pedal to get beep
- Put a cube phantom @iso
- Set OBI/PV at 50, 0, 0
- Take AP MV/RLat kV
- Measure the distance between BB and graticle
- Shift couch: Vert +0.5cm; Lat +1.0cm; Lng +2.0cm;
- Take CBCT
- Perform matching
- Apply shift

Geometry – kV/MV & CBCT Combined Testing (For Iso & Positioning)

MV PD imaging isocenter	AP L/R: ; S/I:
KV OBI imaging isocenter	RLAT A/P: ; S/I:
CBCT Isocenter and Couch Movement QA	Initial couch position: vert = ; long = ; lat = Planned shift: vert = 0.5cm; long = 2.0cm; lat = 1.0cm Couch position after planned shift: vert = ; long = ; lat = Matched shift: vert = ; long = ; lat = Discrepancies: vert = ; long = ; lat = Couch position after matched shift: vert = ; long = ; lat =

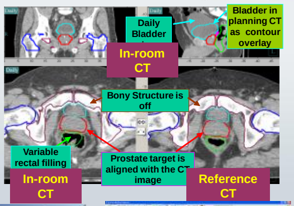


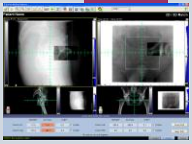
Match BBs – Contour from CT vs CBCT

Geometry - Imaging Fusion Software Test

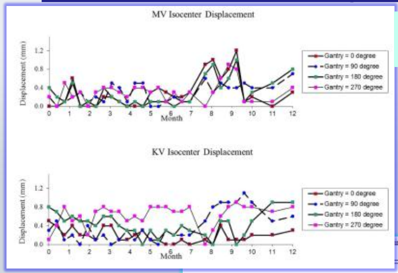
Correcting actions:

Image alignment
Image fusion
Couch shift
6-D rotations
…..





IGRT QA Outcome Analysis



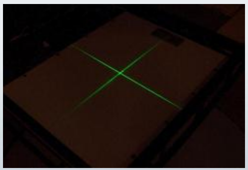
Imaging system QA of a medical accelerator NovalisTx for IGRT per TG 142: our 1 year experience Chang et al JACMP 13 (2012)

The measured discrepancies of the coincidence of CBCT imaging and treatment isocenters: 1.0 mm over 12 months

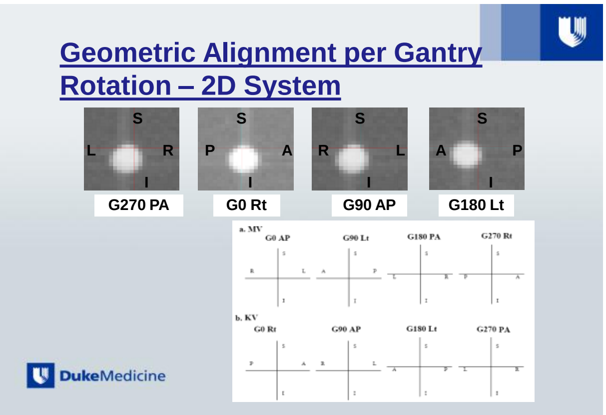
ng the Unfors Xi system with a cylindrical phantom

CBCT Protocols	Phantom	Integrated Dose-length Value Baseline (mGy.cm)
Standard-dose Head	Small	50.9
Low-dose Head	Small	26.3
High-quality Head	Small	250.5
Pelvis	Large	139.4
Pelvis Spot Light	Large	158.1
Low-dose Thorax	Large	37.1

Mechanical Accuracy Test

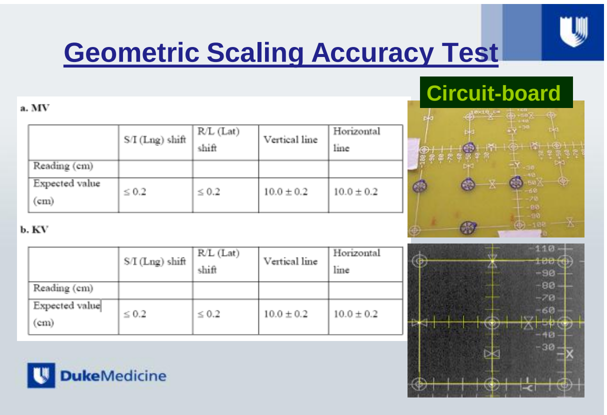


Align the center of the detector – traveling distance test



Geometric Alignment per Gantry Rotation – 2D System

G270 PA | G0 Rt | G90 AP | G180 Lt



Geometric Scaling Accuracy Test

a. MV

	S/I (Lng) shift	R/L (Lat) shift	Vertical line	Horizontal line
Reading (cm)				
Expected value (cm)	≤ 0.2	≤ 0.2	10.0 ± 0.2	10.0 ± 0.2

b. KV

	S/I (Lng) shift	R/L (Lat) shift	Vertical line	Horizontal line
Reading (cm)				
Expected value (cm)	≤ 0.2	≤ 0.2	10.0 ± 0.2	10.0 ± 0.2

Circuit-board

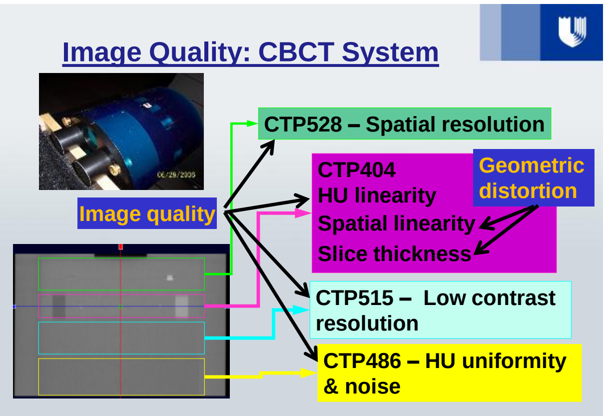


Image Quality: CBCT System

Image quality

CTP528 – Spatial resolution

CTP404
HU linearity
Spatial linearity
Slice thickness

Geometric distortion

CTP515 – Low contrast resolution

CTP486 – HU uniformity & noise

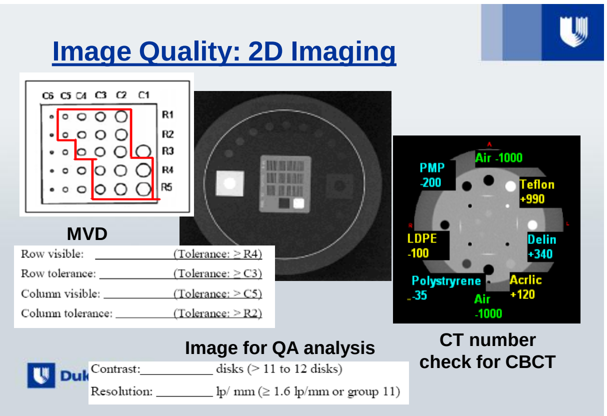


Image Quality: 2D Imaging

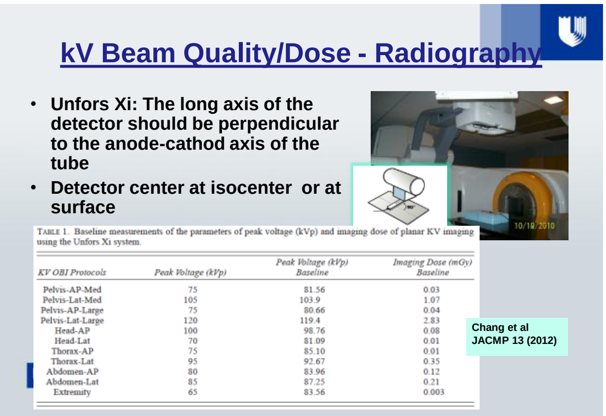
MVD

Row visible: ____________ (Tolerance: ≥ R4)
Row tolerance: ____________ (Tolerance: ≥ C3)
Column visible: ____________ (Tolerance: > C5)
Column tolerance: ____________ (Tolerance: > R2)

Image for QA analysis

Contrast:____________ disks (> 11 to 12 disks)
Resolution: ____________ lp/ mm (≥ 1.6 lp/mm or group 11)

CT number check for CBCT



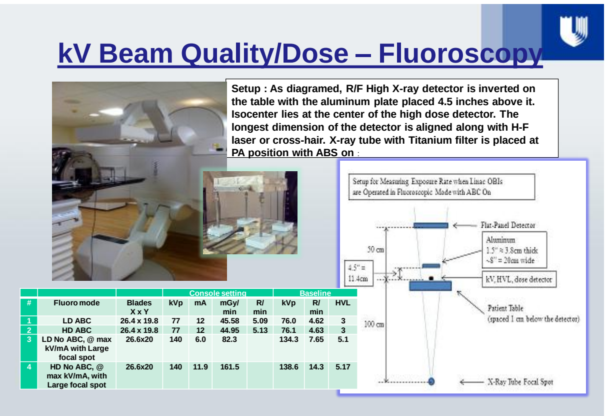
kV Beam Quality/Dose - Radiography

- Unfors Xi: The long axis of the detector should be perpendicular to the anode-cathod axis of the tube
- Detector center at isocenter or at surface

Table 1. Baseline measurements of the parameters of peak voltage (kVp) and imaging dose of planar KV imaging using the Unfors Xi system.

KV OBI Protocols	*Peak Voltage (kVp)*	*Peak Voltage (kVp) Baseline*	*Imaging Dose (mGy) Baseline*
Pelvis-AP-Med	75	81.56	0.03
Pelvis-Lat-Med	105	103.9	1.07
Pelvis-AP-Large	75	80.66	0.04
Pelvis-Lat-Large	120	119.4	2.83
Head-AP	100	98.76	0.08
Head-Lat	70	81.09	0.01
Thorax-AP	75	85.10	0.01
Thorax-Lat	95	92.67	0.35
Abdomen-AP	80	83.96	0.12
Abdomen-Lat	85	87.25	0.21
Extremity	65	83.56	0.003

Chang et al
JACMP 13 (2012)



kV Beam Quality/Dose – Fluoroscopy

Setup : As diagramed, R/F High X-ray detector is inverted on the table with the aluminum plate placed 4.5 inches above it. Isocenter lies at the center of the high dose detector. The longest dimension of the detector is aligned along with H-F laser or cross-hair. X-ray tube with Titanium filter is placed at PA position with ABS on :

			Console setting				Baseline		
#	Fluoro mode	Blades X x Y	kVp	mA	mGy/ min	R/ min	kVp	R/ min	HVL
1	LD ABC	26.4 x 19.8	77	12	45.58	5.09	76.0	4.62	3
2	HD ABC	26.4 x 19.8	77	12	44.95	5.13	76.1	4.63	3
3	LD No ABC, @ max kV/mA with Large focal spot	26.6x20	140	6.0	82.3		134.3	7.65	5.1
4	HD No ABC, @ max kV/mA, with Large focal spot	26.6x20	140	11.9	161.5		138.6	14.3	5.17

Setup for Measuring Exposure Rate when Linac OBIs are Operated in Fluoroscopic Mode with ABC On

Imaging Dose: CBCT

TABLE 4. Baseline measurements of the imaging dose of CBCT using the Unfors Xi system with a cylindrical phantom mimicking a human body.

CBCT Protocols	*Phantom*	*Integrated Dose-length Value Baseline (mGy.cm)*
Standard-dose Head	Small	50.9
Low-dose Head	Small	26.3
High-quality Head	Small	250.5
Pelvis	Large	139.4
Pelvis Spot Light	Large	158.1
Low-dose Thorax	Large	37.1

- Detector at the center of CT dose phantom
- The center of phantom at the isocenter


Detectors

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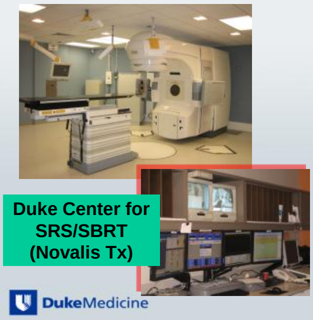
Sample QA for an Integrated System


Duke Center for SRS/SBRT (Novalis Tx)

- QA for delivery system
- QA for imaging system
- QA for planning system
- QA for immobilization system
- QA for patient specific plan (IMRT/RapidArc)
- QA for record & verifying system
- QA for match software
- QA for gating system
- QA for 6D couch movement
- ……

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QA Consideration for QA Phantoms


Daily QA phantom

Block Tray

How to select:

- Purpose
- Multiple purposes
- Accuracy
- Ease of use
- Simplicity
- Size and weight
- Quality
- Cost
- …..

- **Maintenance**

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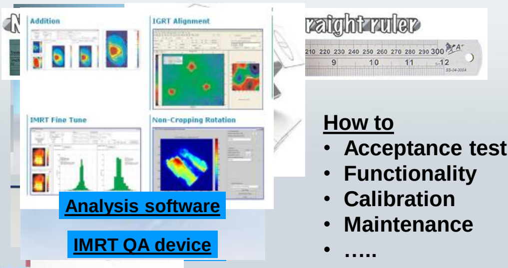
QA Considerations for QA Devices



Analysis software

IMRT QA device

How to

- Acceptance testing
- Functionality
- Calibration
- Maintenance
- …..

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Sample QA Protocols and Documents at Duke University Hospital

- Daily QA
- Monthly QA
- Annually QA
- Gating QA - monthly
- Gating QA – annually
- Imaging QA - annually

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QA Considerations for the Process

- QA will not be done automatically
- QA will not automatically and correctly done
- We know human makes mistakes, even you have policies and procedures in place
- QA policies and procedures should be in place before machine use and be updated periodically
- Policy for monitoring QA program
- Mechanism for auditing QA documents
- Education/training and re-education/re-training

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Sample of QA Process Error

- *2 physicists/2 linacs, each for one linac and backup for the other linac. This primary/backup arrangement was switched once a year.*
- *Each physicist independently designed his own monthly output check, one using an SSD setup and the other an SAD setup.*
- *One day when Physicist A was on-site alone, the therapists reported >3% daily output based on diode measurements on his backup linac.*

Sample of QA Process Error

- *Physicist A decided to perform a monthly output check after patient treatments for the day were complete (follow the guideline).*
- *In the evening, Physicist A assembled the monthly output check in SSD setup rather than the designed SAD setup.*
- *The measurements showed that the photon beam outputs were 8% low, and the electron beam outputs were 2%–4% low.*
- *After attempting to contact Physicist B without success, Physicist A decided to increase the machine outputs based on his measurements.*
- *The next morning, the two physicists discussed this issue. On hearing of such a large adjustment of all energies and modalities, Physicist B investigated further, and discovered the setup discrepancy.*
- *The outputs were immediately corrected, but unfortunately six patients had already received 8% higher doses that day.*

Sample of QA Process Error

- So what can we learn from this description?
  - Education: two different QA procedures for the two linacs (importance of standardized procedures)
  - Communication: not clearly understood setups by both physicists
  - Results of lack of education for Physicist A:
    - the linac worked (outputs for each modality/energy are controlled by separate boards, making it highly unlikely for all of them to suddenly be 2%–8% low)
    - the daily QA measurement worked (knowing that the diode response changes over time due to radiation damage, probably causing the observed underdose).

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Sample of QA Process Error

- Results of lack of training for Physicist A
  - in output adjustment (not performing an independent check of output after adjustment with the daily QA device
  - not minimizing the risk of such a large change by adjusting by 50% of the measured difference pending further investigation)
- Results of lack of communication by Physicist A
  - failing to contact other physicists at nearby affiliated facilities for advice when Physicist B was reached.
- Corrective actions: unify the calibration protocol; set guideline for output adjustment; …

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Summary

TG 142 provides an effective guidelines for quality assurance of medical linear accelerators.

Implementation of TG 142 requires a team efforts from different expertise to support all QA activities and develop necessary policies and procedures. Institution-specific baseline and absolute reference values for all QA measurements should be established and also be evaluated for proper use and appropriateness of the particular QA test

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Summary

- The introduction of new technologies provides new opportunities to further improve treatment accuracy and precision. At the same time, it presents new challenges for its efficient and effective implementation.
- Quality assurance measures with phantoms are requisite. Expertise must be developed and must be re-established from time to time. One must also be cognizant that in actual clinical practice, inherent uncertainties of the guidance solution exist, as each technique has its own range of uncertainties.

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Summary

- A QMP should lead the QA team
  - Daily QA tasks may be carried out by a radiation therapist and checked by a QMP
  - Monthly QA tasks should be performed by (or directly supervised by) a QMP
  - Annual measurements be performed by a QMP with proper involvement of the entire QA team
  - QA per service and upgrade
- An end-to-end system check is recommended to ensure the fidelity of overall system delivery whenever a new or revised procedure is introduced. An annual QA report be generated

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Thank you for your attention