TG142 Quality Assurance of Medical Accelerators

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CHARGE

- Since TG-40 New Technologies Developed and are now Commonly Used in Clinical Practice:
  - Asymmetric jaws
  - Dynamic/Virtual/Universal wedges
  - Multi-leaf collimation (MLC)
  - Electronic portal imaging devices (EPID)
  - Image guidance devices: cone-beam CT (CBCT), static kilovoltage (kV) imaging
  - Respiratory gating
- TG-40 did not Consider the Demands Placed on an Accelerator by Procedures such as Stereotactic Radiosurgery (SRS), Stereotactic Body Radiation Therapy (SBRT), Total-body Photon Irradiation (TBI) And Intensity-modulated Radiotherapy (IMRT) Treatment
- Quality of linear accelerators in terms of accuracy and precision has improved in recent years

CHARGE

- AAPM TG-40 report published in 1994 includes recommendations for general quality assurance tests for medical linear accelerators

  - To update, as needed, recommendations of Table II of the AAPM TG-40 Report on Quality Assurance

  - To add recommendations for Asymmetric Jaws, Multileaf Collimation, and Dynamic/Virtual Wedges

FORMAT OF REPORT

- ABSTRACT
- I. INTRODUCTION
  - A. Purpose
  - B. Background
- II. QUALITY ASSURANCE OF MEDICAL ACCELARATORS
  - A. General
  - B. Test Frequencies
  - C. Guidelines for Tolerance Values
  - D. Ancillary Devices Not in TG-40
    - i. Asymmetric Jaws
    - ii. Dynamic/Virtual/Universal Wedges
    - iii. MLC
    - iv. TBI/TSET
    - v. Radiographic Imaging (EPID, kV imaging, Cone Beam CT)
    - vi. Respiratory Gating
- III. SUMMARY OF RECOMMENDATIONS/IMPLEMENTATION
- IV. REFERENCES

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PURPOSE/DISCLAIMER

- The purpose of this report is 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
- 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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BACKGROUND

- 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 that machine
- Machine parameters can deviate from their baseline values as a result of many reasons
  - 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

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BACKGROUND

- The underlying principle behind TG-40/AAPM Report 13 was the International Commission on Radiation Units and Measurements (ICRU) recommendation 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

QA of MEDICAL ACCELERATORS

- **What This Report Doesn't Do**
  - Describe the experimental 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 in Radiation Oncology – TG-76
  - Kilovoltage localization in therapy – TG-104

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QA of MEDICAL ACCELERATORS

- **What is Noted**
  - **The scope of testing and the number of variables has increased compared to TG-40**
  - **Increased demands on staff - tests should be simple, rapid and reproducible**
  - **Many QA products make execution of these tests more efficient**
  - **Procedures should be able to distinguish parameter changes smaller than tolerance or action levels**
  - **QA program for Linacs is team effort, however *recommendation* that the overall responsibility for a linear accelerators QA program be assigned to one individual: *the qualified medical physicist***
  - ***This task group considers that all of the tests included in the tables are important for ensuring the equipment to be suitable for high quality and safe radiation treatments***

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QA of MEDICAL ACCELERATORS

- Report has 6 Tables of Recommendations
  - Linac Daily (1), Monthly (2), Annual (3)
    - Contain tests for Asymmetric Jaws, Respiratory gating and TBI/TSET
  - Dynamic/Virtual/Universal wedges (4), MLC (5) , Imaging (6)
- Each Table Has Specific Recommendations Based On The Nature Of The Treatments Delivered On Machine
  - Non-IMRT or non-Stereotactic machines
  - IMRT machines
  - IMRT/Stereotactic machines
- Explicit Recommendations Based On Equipment Manufacturer As A Result Of Design Characteristics Of Those Machines
- Recommendations In Each Table Utilize The QA Categories Used In Table II Of TG-40 Plus New Category
  - Dosimetry, Mechanical, Safety *plus* Respiratory gating

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TABLE 1 LINAC DAILY

Procedure	Tolerance (non-IMRT machines)	Tolerance (IMRT machines)	Tolerance (Stereotactic machines)
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		

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TABLE 2 LINAC MONTHLY

Procedure	Tolerance (non-IMRT machines)	Tolerance (IMRT machines)	Tolerance Stereotactic machines
Dosimetry			
X-ray output constancy	2%		
Electron output constancy			
Backup monitor constancy			
Typical dose rate2 output constancy	NA	2% (@ IMRT dose rate)	2% (@ stereo dose rate, MU)
Photon beam profile constancy	1%		
Electron beam profile constancy			
Electron beam energy constancy	2%/2mm		
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)3	2 mm		
Jaw position indicators (Asymmetric)1	1 mm		
Cross-hair centering (walk-out)	1 mm		
Treatment couch position indicators4	2 mm/1 deg	2 mm/ 1 deg	1 mm/ 0.5 deg
Wedge placement accuracy	2mm		
Latching of wedges, blocking tray5	Functional[5]		
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		

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TABLE 2 LINAC MONTHLY

Procedure	Tolerance (non-IMRT machines)	Tolerance (IMRT machines)	Tolerance Stereotactic machines
Dosimetry			
X-ray output constancy	2%		
Electron output constancy			
Backup monitor constancy			
Typical dose rate[2] output constancy	NA	2% (@ IMRT dose rate)	2% (@ stereo dose rate, MU)
Photon beam profile constancy	1%		
Electron beam profile constancy			
Electron beam energy constancy	2%/2mm		

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TEST FREQUENCIES

- Several authors (Schultheiss, Rozenfeld, Pawlicki) have attempted to develop a systematic approach to developing QA frequencies and action levels
- More recently the work of Task Group 100 of the AAPM.
  - TG 100 – A Method for Evaluating QA Needs in Radiation Therapy - based on "Failure Modes and Effects Analysis" FMEA
  - Individual department responsible for development of unique QA programs based on procedures and resources performed at individual institutions
- While the QA program should be flexible the TG recommends using the tests and frequencies outlined in the tables until methods such as TG-100 supersede this report
- Deviations are expected, the clinical significance of these deviations may be mitigated by other control methods that are not anticipated in this document
- In the case of decreasing the frequency of a particular test, the results of the test must be examined and be validated with an appreciable history of that test and a documented analysis of the potential impact of catastrophic results in the event of an occurrence

TEST FREQUENCIES

- Testing is distributed among Daily, Weekly, Monthly, and Annual QA frequencies
  - Daily/Weekly include parameters that can affect dose to the patient by dosimetric (output constancy) or geometric (lasers, Optical Distance Indicator, field size) means
    - Performed by Radiation Therapist - need P&P
  - Monthly tests include those that have lower likelihood of changing over a month
    - Performed by QMP
  - Annual tests are a subset of the tests performed during acceptance testing and commissioning procedures
    - Performed by QMP
- Underlying principles attempt to sensibly balance cost and effort
- Additional factors affecting frequency of the tests
  - type of treatments delivered on the machine
  - manufacturer of the machine

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GUIDELINES FOR 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
- Definitions

1. ***Acceptance Testing Procedure (ATP) Standards***

   Dosimetric and mechanical measurements should satisfy the agreed upon absolute values specified. 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 values.

2. ***Commissioning Baseline Values***

   Treatment beam characteristics needed for clinical use are established by the commissioning process. These baseline values are used to check relative constancy for all future dosimetric validation measurements.

3. ***Tolerances and Action Levels***

   If a parameter exceeds the tabulated value or the change in the parameter exceeds the tabulated value, then an action is required, the equipment should be adjusted to bring the parameters back into compliance: the tolerances are action levels.

   In addition, if certain parameters barely satisfy the tolerance value repeatedly, an appropriate action should be taken to correct the equipment.

GUIDELINES FOR TOLERANCES

- Report Defines 3 Types of Actions:

Level 1 – Inspection Action

  - A sudden and significant deviation from the expected value may not exceed the table tolerance value
  - Normal treatment schedule should continue, but the cause should be investigated

Level 2 – Scheduled Action

  - Consecutive results of a QA procedure that are at or near the threshold value
  - Or a single result that exceeds the threshold value, but not excessively
  - Treatment may continue, mitigation of cause should be scheduled to take place within 1-2 working days

Level 3 – Immediate/Stop Treatment/Corrective Action

  - A result for tests that would require an immediate suspension of the treatment function related to the parameter.
  - Specified treatment functions should not continue until the problem is corrected.

- Institutional need to specify the thresholds associated with Levels 2 and 3
- The Level 1 parameters' thresholds evolve from the QA data

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GUIDELINES FOR TOLERANCES

- Uncertainties, Repeatability, and Precision
- There is an associated measurement uncertainty that depends upon the technique used, the measuring device, and the person using the device and recording the measurement
  - Measurement uncertainty (or accuracy) is in reference to an expected error of the measurement result, with respect to a defined standard.
  - Measurement repeatability is in reference to the device's measurement statistics, i.e., with no change in the quantity being measured and no change in the measurement setup, the recorded values from repeated measurements will have a standard deviation about the mean.
  - Measurement precision is in reference to the measuring device's scale resolution of the display.
- We recommend that the measurement system and procedure repeatability be such that two standard deviations for three or more repeated consecutive measurements is less than the tolerance value.
- However, the monthly schedule expects a higher level of skill and care for those measurements and carries a tolerance value associated with this skill.

ANCILLARY DEVICES NOT IN TG40

- The AAPM TG-40 report made it clear that new devices coming on-line during this time period (1994) would be beyond the scope of the report
- The TG-40 report did not address asymmetric jaws, multi-leaf collimation, or dynamic/virtual wedging
- This section addresses these ancillary devices/options in terms of QA checks
  - We have incorporated asymmetric jaws, Respiratory gating and TBI/TSET within the Table 1-3 recommendations
  - Separate tables have been created for Dynamic/Virtual Wedges, MLC & Imaging
- Hence, it is the goal of this task group to make specific recommendations for asymmetric jaws, jaw based wedge delivery systems, and multi-leaf collimation that are both vendor specific and operation specific

ASYMMETRIC JAWS

- For asymmetric jaws, there should be additional scrutiny due to beam matching provided, and the accuracy of dynamic/virtual wedge delivery depends on jaw positioning accuracy.
  - For example, Klein et al published a paper using a single isocentric technique relying on asymmetric jaws with beam matching at the isocentric plane for breast irradiation
- Monthly
  - Light-radiation coincidence and asymmetric jaw positional accuracy for each jaw used clinically at 0.0 cm (for beam matching) and also at 10.0 cm

DYNAMIC/VIRTUAL/ UNIVERSAL WEDGES

- Include 3 Technologies
  - Varian: Dynamic & Enhanced Dynamic Wedge (Jaw)
  - Siemens: Virtual wedge (Jaw)
  - Elekta: Universal Wedge (Fixed internal 60º wedge)
- Reliance on jaw accuracy for the dynamic wedge type delivery published by Klein et al. showed very small changes in jaw position could affect wedge factor
- We recommend that tests be performed for a 45º for systems that deliver an 'effective' wedge angle by using a combination of 60º and open beam.
  - If, however, a facility opts to deliver a 60º wedge as a unique field, then the 60º wedge angle should be checked

DYNAMIC/VIRTUAL/ UNIVERSAL WEDGES

- ***Daily***
  - **Morning Check 1 angle**
- ***Monthly***
  - **1 Wedge factor for all energies**
- ***Annual***
  - **Full Check of 60 degree wedge including OAFs**

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TABLE 4
Dynamic/Universal/Virtual Wedges

Dynamic-incl. EDW (Varian), Virtual (Siemens), Universal (Elekta) Wedge quality assurance				
Frequency	**Procedure**	**Tolerance**		
		Dynamic	**Universal**	**Virtual**
Daily	Morning Check-out run for 1 angle	Functional		
Monthly	Wedge factor for all energies	C.A. Axis 45º or 60° WF (within 2%)*	C.A. Axis 45º or 60° WF (within 2%)*	5% from unity, otherwise 2%
Annual	Check of wedge angle for 60°, full field & spot check for intermediate angle, field size	Check of Off-center ratios @ 80% field width @ 10cm		

* Recommendation to check 45º if angles other than 60º are used.

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
- Publications have documented the impact of leaf positioning accuracy and interleaf or abutted leaf transmission on the accuracy of delivered IMRT fields
- We therefore recommend testing (Table 5) that depends on whether or not the MLC system is used for IMRT

MLC

- *Weekly*
  - picket fence test with careful examination of image acquired by static film or on-line portal image
- *Monthly*
  - Setting vs. Radiation field (Non-IMRT)
  - Backup diaphragm (Elekta)
  - Travel Speed (IMRT)
  - Expansion of the leaf position accuracy test to account for gantry rotation (IMRT)
- *Annual*
  - Quantitative analysis of the leaf transmission
  - Leaf position repeatability
  - MLC spoke shot
  - Coincidence of light field and x-ray field
  - Vendor specific tests
    - Dynalog Analysis for Varian

TABLE 5 MLC

Multi-leaf collimation quality assurance (with differentiation of IMRT vs. non-IMRT machines)		
Frequency	**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 trransmission
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
	Arc dynamic leaf-speed test	<0.35 cm Max Error RMS, 95% of error counts <0.35 cm (Varian)
	Arc dynamic interlock trip test	Leaf position interlock occurs (Varian)
	Arc dynamic typical plan test	<0.35 cm Max Error RMS, 95% of error counts <0.35 cm (Varian)
	Segmental IMRT (Step and Shoot) Test	<0.35 cm Max Error RMS, 95% of error counts <0.35 cm (Varian)
	Moving window imrt (4 cardinal gantry angles)	<0.35 cm Max Error RMS, 95% of error counts <0.35 cm (Varian)

TBI/TSET

- 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

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RADIOGRAPHIC IMAGING

- Radiographic imaging systems commonly integrated with accelerators
  - Megavoltage (MV) planar imaging
  - Kilovoltage (kV) planar imaging
  - MV or kV computed tomographic imaging (serial and cone beam)
- Table 6 contains QA recommendations for the imaging systems
  - Different recommendations for SRS/SBRT machines
- Each radiographic imaging device has its own geometric coordinate system that is correlated to delivery coordinate system through a calibration process
  - Critical to ensure coincidence of these two coordinate systems and is verified in "Imaging & treatment coordinate coincidence" test
- Each system performing patient positioning and/or repositioning relies upon vendor software to compare & register on-board and reference images.
  - QA of this process done by a phantom study with known shifts, and is recommended for each system used clinically
  - The accuracy of this process should be tested on the daily basis, especially for SRS/SBRT

TABLE 6 IMAGING

Procedure	Non-SRS/SBRT Applications Tolerances	SRS/SBRT Applications Tolerances
Daily		
MV imaging (EPID)		
Collision interlocks	Functional	Functional
Spatial linearity1 (x and y) (single gantry angle)	< 2 mm	≤ 1 mm
Imaging & Treatment coordinate coincidence (single gantry angle)	< 2 mm	≤ 1 mm
Positioning/repositioning	< 2 mm	≤ 1 mm
KV imaging[2]		
Collision interlocks	Functional	Functional
Imaging & treatment coordinate coincidence	< 2 mm	≤ 1 mm
Positioning/repositioning	< 2 mm	≤ 1 mm
Cone-beam CT (kV & MV)		
Collision interlocks	Functional	Functional
Positioning/repositioning	< 2 mm	≤ 1 mm
Monthly		
MV imaging (EPID)		
Imaging & treatment coordinate coincidence (4 Cardinal angles)	< 2 mm	≤ 1 mm
Scaling3	< 2 mm	< 2 mm
Spatial resolution	Baseline[4]	Baseline
Contrast	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
kV imaging		
Imaging & treatment coordinate coincidence (4 Cardinal angles)	< 2 mm	≤ 1 mm
Scaling	< 2 mm	≤ 1 mm
Spatial linearity (x and y) (single gantry angle)	< 2 mm	≤ 1 mm
Spatial resolution	Baseline	Baseline
Contrast	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Cone-beam CT (kV & MV)		
Imaging & treatment coordinate coincidence	< 1.5 mm	≤ 1 mm
Geometric distortion	< 2 mm	≤ 1 mm
Spatial resolution	Baseline	Baseline
Contrast	Baseline	Baseline
HU constancy	Baseline	Baseline
Uniformity and noise	Baseline	Baseline
Spatial linearity (x and y) (single gantry angle)	< 1 mm	≤ 1 mm
Annual (A)		
MV imaging (EPID)		
Full range of travel SDD	±5 mm	±5 mm
Imaging dose5	Baseline	Baseline
Beam quality / energy	Baseline	Baseline
kV imaging		
Beam quality / energy	Baseline	Baseline
Imaging dose	Baseline	Baseline
Cone-beam CT (kV & MV)		
Imaging dose	Baseline	Baseline

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RADIOGRAPHIC IMAGING: Megavoltage Portal Imaging

- Clinical use of electronic portal imaging devices has been addressed by TG-58 Table IV describes frequency of tests but provides no tolerances

- Some of the recommended QA tests presented here (Table 6) are directly from the TG-58 report, though updated to account for on-board-imaging tests

RADIOGRAPHIC IMAGING: Megavoltage Portal Imaging

- *Daily*
  - Collision interlocks
  - Spatial linearity (1 gantry angle)
  - Imaging & treatment coordinate coincidence (1 gantry angle)
  - Positioning/Repositioning
- *Monthly*
  - Imaging & treatment coordinate coincidence (4 Cardinal angles)
  - Scaling
  - Spatial resolution
  - Contrast
  - Uniformity and noise
- *Annual*
  - Full range of travel SDD
  - Imaging dose
  - Beam quality / energy

RADIOGRAPHIC IMAGING: Planar kV Imaging

- Clinical use of kV imaging devices is being systematically summarized in TG104 although there are no specific recommendations for the QA tolerances in that report
- In this report, we set basic recommendations for the use of in-room kV imaging systems
- A variety of kV imaging systems was recently introduced
  - 2-D radiographic imaging
  - 2-D fluoroscopic imaging
  - 3-D as well as 4-D tomographic imaging
- Acceptance testing criteria should include parameters related to safety, image quality and dose, and localization accuracy
- The baseline data established during the acceptance testing are used for the QA criteria

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RADIOGRAPHIC IMAGING: Planar kV Imaging

- *Daily*
  - Collision interlocks
  - Imaging & treatment coordinate coincidence
  - Positioning/repositioning
- *Monthly*
  - Imaging & treatment coordinate coincidence (4 Cardinal angles)
  - Scaling
  - Spatial linearity (x and y) (single gantry angle)
  - Spatial resolution
  - Contrast
  - Uniformity and noise
- *Annual*
  - Beam quality / energy
  - Imaging dose

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RADIOGRAPHIC IMAGING: Serial & Cone-Beam CT

- Recommendations for the use of serial and cone-beam CT (CBCT) systems, including both kV and MV are found in Table 6
- Although spatial accuracy of image reconstruction is paramount, image quality parameters (e.g., contrast, noise, uniformity, spatial resolution) are also considered
- Since this imaging system is often used daily and is capable of delivering significant radiation doses, direct measure of imaging dose and beam quality/energy is recommended at least annually
  - sufficient due to minimal impact on overall dose and by virtue of existing daily/monthly reviews of many parameters would detect changes that could potentially affect dose
- As with the recommendations for kV imaging, the baseline data established during the acceptance testing are used for QA criteria

RADIOGRAPHIC IMAGING: Serial & Cone-Beam CT

- ***Daily***
  - Collision interlocks
  - Positioning/repositioning
- ***Monthly***
  - Imaging & treatment coordinate coincidence
  - Geometric distortion
  - Spatial resolution
  - Contrast
  - HU constancy
  - Uniformity and noise
  - Spatial linearity (x & y - single gantry angle)
- ***Annual***
  - Imaging dose

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RESPIRATORY GATING

- AAPM Report 91 (TG-76), published in 2006, described all aspects of the management of respiratory motion in Radiation Oncology, including imaging, treatment planning, and radiation delivery
- All respiratory techniques fundamentally require a synchronization of the radiation beam with the patient's respiration
- Characterization of the accelerator beam under respiratory gating conditions
- Dynamic phantoms which simulate human organ motions associated with respiration are recommended to test target localization and treatment delivery
- Tables 2 and 3 include tests for respiratory gated accelerator operation

RESPIRATORY GATING

- ***Monthly***
  - **Beam output constancy**
  - **Phase, Amplitude beam control**
  - **In room respiratory monitoring system**
  - **Gating interlock**
- ***Annual***
  - **Beam energy constancy**
  - **Beam output constancy**
  - **Temporal accuracy of Phase/Amplitude Gate-on**
  - **Calibration of surrogate for respiratory phase/amplitude**
  - **Interlock testing**

SUMMARY OF RECOMMENDATIONS

1. Departmental QA team be formed to support all QA activities and draft necessary P&P
2. Establish institution-specific baseline and absolute reference values for all QA measurements
3. A QMP should lead the QA team
4. Daily QA tasks may be carried out by a radiation therapist
5. Monthly QA tasks should be performed/directly supervised by a QMP
6. Annual measurements performed by a QMP with proper involvement of the entire QA team
7. An end-to-end system check is recommended to ensure the fidelity of overall system delivery
8. During annual QA absolute machine output should be calibrated as per the TG-51 calibration protocol
9. Annual QA report should be generated

TABLE 3 LINAC ANNUAL

Procedure	Tolerance (non-IMRT machines)	Tolerance (IMRT machines)	Tolerance Stereotactic machines
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% (whichever is greater) Gantry arc set vs. delivered: 1.0 deg 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 (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}, TMR_{10}^{20})	±1% from baseline		
Electron beam quality (R_{50})	±1mm		
Transmission factor constancy for all treatment accessories	±1% from baseline		
Physical wedge transmission factor constancy	±2%		
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		

Safety interlocks			
Follow manufacturers test procedures	Functional		
Mechanical checks			
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	±2mm from baseline	±2mm from baseline	±1mm from baseline
Table top sag	2mm from baseline		
Table Angle	1 degree		
Table travel maximum range movement in all directions	±2mm		
Stereotactic accessories, lockouts, etc	NA		Functional
TBI/TSET Mode	Functional		
TBI/TSET accessories	Functional		
PDD or TMR and OAF constancy	1% (TBI) or 1mm PDD shift (TSET) from baseline		
Output calibration	2% from baseline		
Dose Rate Dependence	2% from baseline		
Respiratory gating			
Beam energy constancy	2%		
Beam output 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		

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