

Quality Assurance in Radiotherapy: Simulators, Cone Beam CT, EPID and Immobilization Devices

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1 Introduction

1.1 Acceptance

- ❑ Acceptance of equipment is the process in which the supplier demonstrates the baseline performance of the equipment to the satisfaction of the customer.
- ❑ After the new equipment is installed, the equipment must be tested in order to ensure, that it meets the specifications and that the environment is free of radiation and electrical hazards to staff and patients.
- ❑ The essential performance required and expected from the machine should be agreed upon **before** acceptance of the equipment begins.

1 Introduction

1.1 Acceptance (continued)

- ❑ It is a matter of the professional judgement of the responsible medical physicist to decide whether any aspect of the agreed acceptance criteria is to be waived.
- ❑ This waiver should be recorded along with an agreement from the supplier, for example to correct the equipment should performance deteriorate further.
- ❑ The equipment can only be formally accepted to be transferred from the supplier to the customer when the responsible medical physicist either is satisfied that the performance of the machine fulfils all specifications as listed in the contract document or formally accepts any waivers.

1 Introduction

1.2 Commissioning

- ❑ Commissioning is the process of preparing the equipment for clinical service.
- ❑ Expressed in a more quantitative way:
A full **characterization of its performance** over the whole range of possible operation must be undertaken.
- ❑ In this way the **baseline standards of performance** are established to which all future performance and quality control tests will be referred.
- ❑ Commissioning includes the preparation of procedures, protocols, instructions, data, etc., on the clinical use of the equipment.

1 Introduction

1.3 Quality Control

- ❑ It is essential that the performance of treatment equipment remain consistent within accepted tolerances throughout its clinical life
- ❑ An ongoing quality control program of regular performance checks must begin immediately after commissioning to test this.
- ❑ If these quality control measurements identify departures from expected performance, corrective actions are required.

1 Introduction

1.3 Quality Control (continued)

An equipment quality control program should specify the following:

- The **parameters** to be tested and the **tests** to be performed;
- The **specific equipment** to be used for that;
- The **geometry** of the tests;
- The **frequency** of the tests;
- The **staff group** or **individual** performing the tests, as well as the individual supervising and responsible for the standards of the tests and for actions that may be necessary if problems are identified;

1 Introduction

1.3 Quality Control (continued)

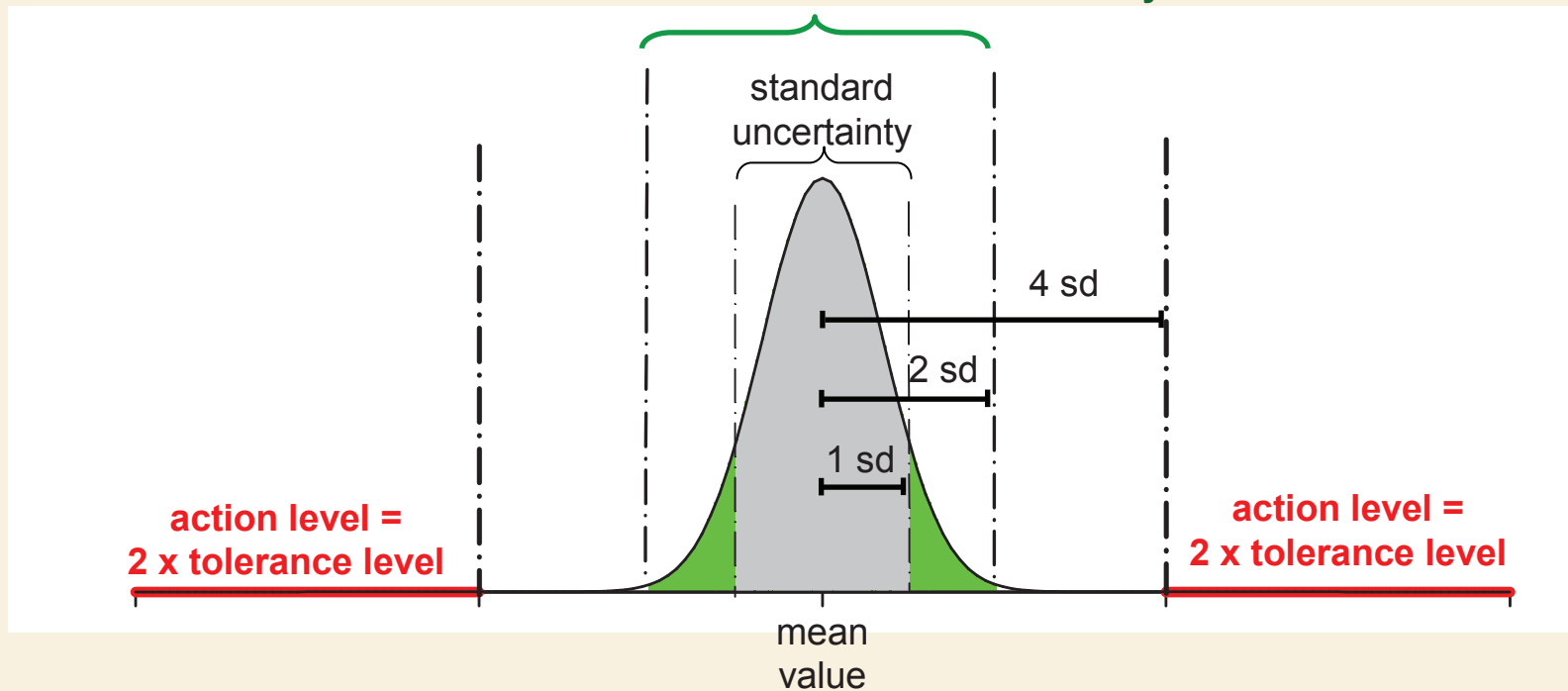
- ❑ An equipment quality control program should specify the following:
 - The expected **results**;
 - The **tolerance and action levels**;
 - The **actions** required when the tolerance levels are exceeded.
- ❑ The actions required must be based on a systematic analysis of the uncertainties involved and on well defined tolerance and action levels.
- ❑ This procedure is explained in more detail in the following slides.

1 Introduction

1.3 Quality Control (continued)

Illustration of a possible relation between uncertainty, tolerance level and action level

tolerance level
equivalent to
95% confidence interval of uncertainty

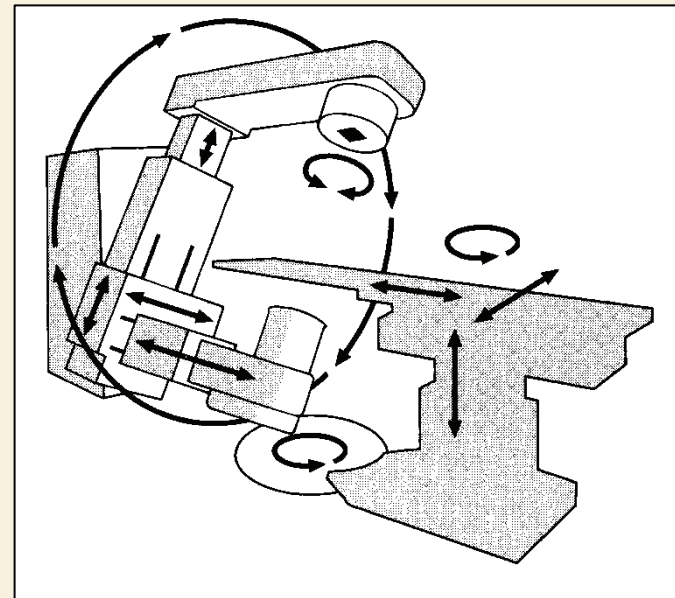


2 Quality Control of a Simulator

2.1 Radiotherapy Simulator

- ❑ Treatment simulators replicate the movements of isocentric ^{60}Co and linac treatment machines and are fitted with identical beam and distance indicators. Hence all measurements that concern these aspects also apply to the simulator.

- During 'verification session' the treatment is set-up on the simulator exactly like it would be on the treatment unit.
- A verification film is taken in 'treatment' geometry



2 Quality Control of a Simulator

2.1 Radiotherapy Simulator (continued)

- ❑ Radiotherapy simulator consists of a **diagnostic x-ray tube** mounted on a **rotating gantry** to simulate geometries of isocentric teletherapy machines and isocentric linacs.



2 Quality Control of a Simulator

2.1 Radiotherapy Simulator (continued)

- ❑ If mechanical / geometric parameters are out of tolerance on the simulator, **this will affect treatments of all patients.**
- ❑ The performance of the **imaging components** on the simulator is of equal importance to its satisfactory operation.
- ❑ **Therefore critical measurements of the imaging system are also required.**

2 Quality Control of a Simulator

2.2 QC for Radiotherapy Simulators

- ❑ A sample quality assurance program (quality control tests) for treatment simulators with recommended test procedures, test frequencies and action levels is given in the following tables.
- ❑ They are again structured according daily, monthly, and annually tests.

2 Quality Control of a Simulator

2.2 QC for Radiotherapy Simulators (continued)

Daily Tests

Procedure or item to be tested	Action level
Safety switches	functional
Door interlock	functional
Lasers	2 mm
Distance indicator	2 mm

2 Quality Control of a Simulator

2.2 QC for Radiotherapy Simulators (continued)

Monthly Tests

Procedure or item to be tested	Action level
Field size indicator	2 mm
Gantry / collimator angle indicators	1°
Cross-hair centering	2 mm diameter
Focal spot-axis indicator	2 mm
Fluoroscopic image quality	baseline
Emergency/collision avoidance	functional
Light / radiation field coincidence	2 mm or 1%
Film processor sensitometry	baseline

2 Quality Control of a Simulator

2.2 QC for Radiotherapy Simulators (continued)

Annually Tests

Procedure or item to be tested	Action level
Collimator rotation isocenter	2 mm diameter
Gantry rotation isocenter	2 mm diameter
Couch rotation isocenter	2 mm diameter
Coincidence of collimator, gantry, couch axes with isocenter	2 mm diameter
Table top sag	2 mm
Vertical travel of couch	2 mm

2 Quality Control of a Simulator

2.2 QC for Radiotherapy Simulators (continued)

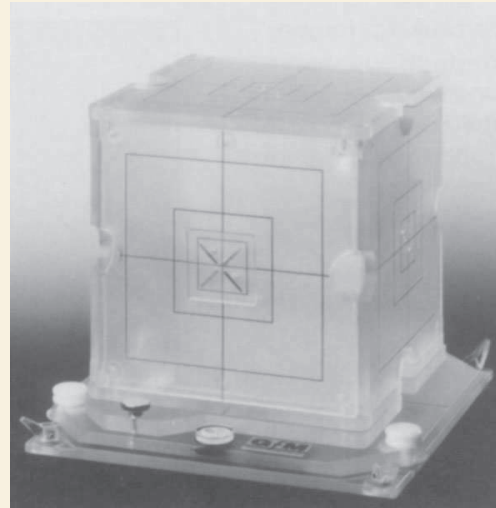
Annually Tests (continued)

Procedure or item to be tested	Action level
Exposure rate	baseline
Table top exposure with fluoroscopy	baseline
kVp and mAs calibration	baseline
High and low contrast resolution	baseline

2 Quality Control of a Simulator

2.2 QC for Radiotherapy Simulators (continued)

- ❑ Cube phantom for verification of the following features:
 - Indicator of radiation fields (light and radiation field)
 - Display of the central ray
 - Congruence of opposing fields
 - field compensation
 - distance display
 - Isocentre indicator
 - Height adjustment of the table top
- ❑ Disc attachment:
 - Attachment for checking the Isocenter sphere (Star irradiation)
- ❑ Boom cylinder:
 - Essay to check the isocentre under fluoroscopy to therapy simulators over the entire 360 ° angle of gantry rotation



3 Quality Control of a CT Simulator

3.1 CT Simulator

- ❑ The Lightspeed RT16 CT simulator is a “modified” third-generation scanner (16- slice scanner with 888 detector elements per row and 24 detector elements along the z-axis; 0.5 s per rotation)

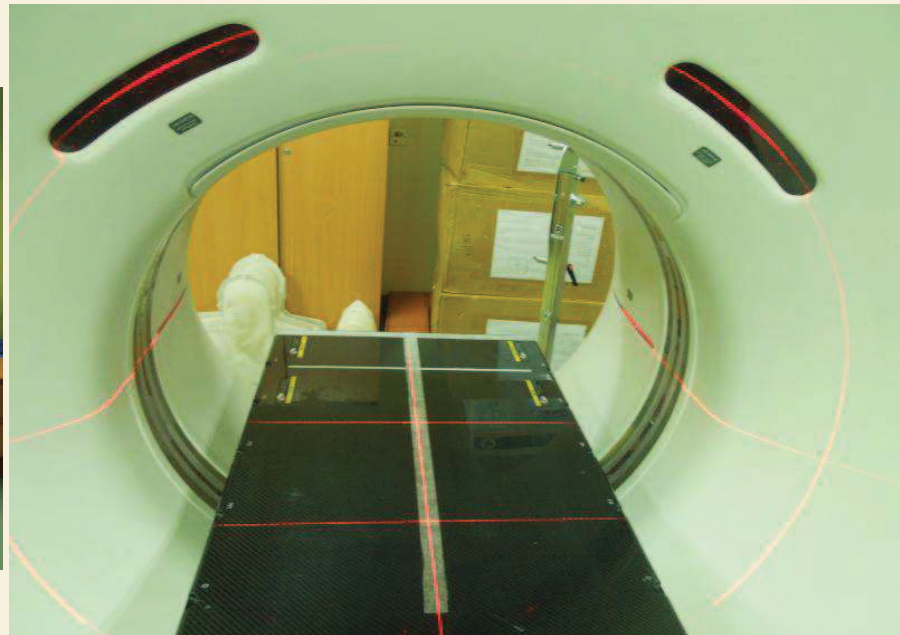


CT simulator courtesy by SQUARE Hospitals Ltd, Bangladesh

3 Quality Control of a CT Simulator

3.1 CT Simulator (continued)

- ☐ External laser
- ☐ Internal laser



3 Quality Control of a CT Simulator

3.2 QC Program for CT Scanners and CT-Simulation (continued)

- ❑ A sample quality assurance program (quality control tests) for CT scanners and CT-simulation with recommended test procedures, test frequencies and action levels is given in the following tables (AAPM TG-66 Protocol and Light speed RT-16 Book).
- ❑ They are again structured according daily, monthly, and annually tests.

3 Quality Control of a CT Simulator

3.2 QC Program for CT Scanners and CT-Simulation (continued)

Daily Tests

Performance parameters	Purpose	Action level
1. Alignment of the gantry laser	1. To verify proper identification of scan plane with gantry lasers	± 2 mm
2. Image noise and uniformity	2. To verify the mean of center ROI for standard algorithm and small SFOV, standard deviation of the center ROI and the uniformity difference between the center ROI and the average ROI	1. If the image is reconstructed with standard algorithm and small SFOV, the mean of center ROI should equal 0 ± 3 2. Standard deviation of the center ROI should equal 3.2 ± 0.3 3. The uniformity difference between the center ROI and the average of the edge ROIs should be 0 ± 3 .
3. CT number of water	To verify the average CT number of water	For water, 0 ± 5 HU

3 Quality Control of a CT Simulator

3.2 QC Program for CT Scanners and CT-Simulation (continued)

Monthly Tests

Performance parameters	Purpose	Action level
1. Alignment of the moving laser	To verify that the wall lasers are parallel and orthogonal with the imaging plane over the full length of laser projection	± 2 mm over the length of laser projection
2. Tabletop position	To verify that the CT-scanner tabletop is level and orthogonal with the imaging plane	± 2 mm over the length and width of the tabletop
3. Motion	To verify that the table longitudinal motion according to digital indicators is accurate and reproducible	± 1 mm over the range of table motion
4. Contrast scale	To verify the CT number of water and Plexiglas in the phantom	The difference should equal 120 ± 12
5. High contrast spatial resolution	To verify the standard deviation for an ROI in the 1.6mm bar pattern	Standard deviation should equal 37 ± 4 , if I used standard algorithm
6. Low contrast detectability	To verify the number of visible holes	
7. Slice thickness	To determine the slice thickness, display the image at the recommended window level and width, and count the visible holes.	Black lines in the image represent a 1mm of slice thickness Gray lines count as fractions of a mm, two equal gray holes count as a single 1mm slice thickness

3 Quality Control of a CT Simulator

3.2 QC Program for CT Scanners and CT-Simulation (continued)

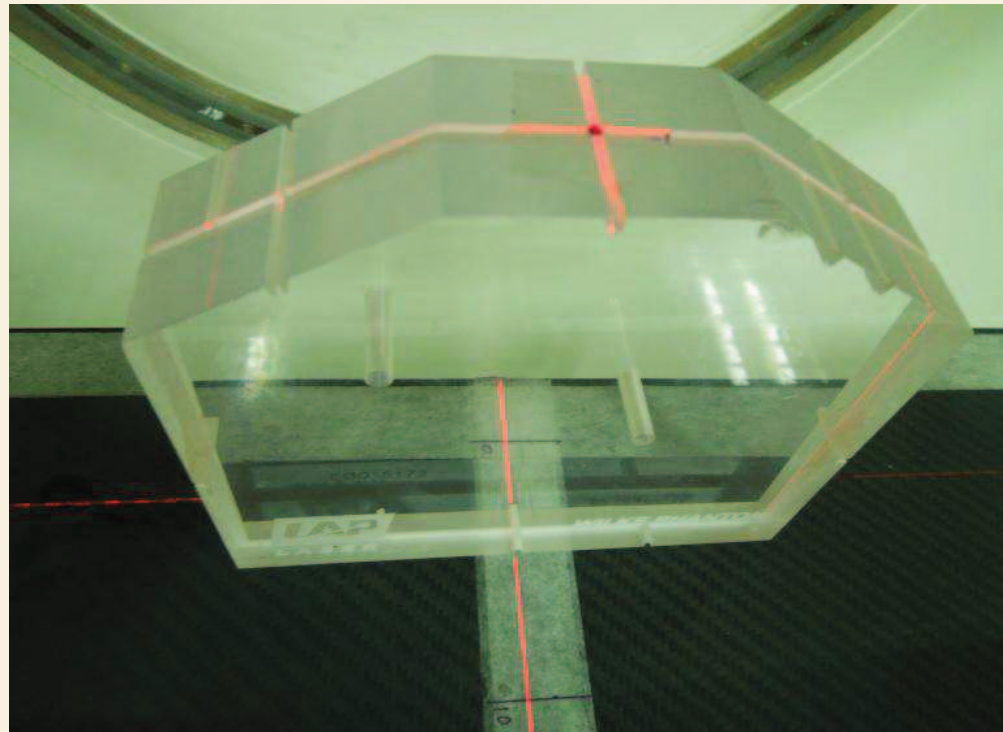
Annually Tests

Performance parameters	Purpose	Action level
1. Table indexing and positioning	To verify table indexing and position accuracy under scanner control	± 1 mm over the scan range
2. Gantry tilt accuracy	To verify accuracy of gantry tilt indicators	$\pm 1^\circ$ over the gantry tilt range

3 Quality Control of a CT Simulator

3.2 QC Program for CT Scanners and CT-Simulation (continued)

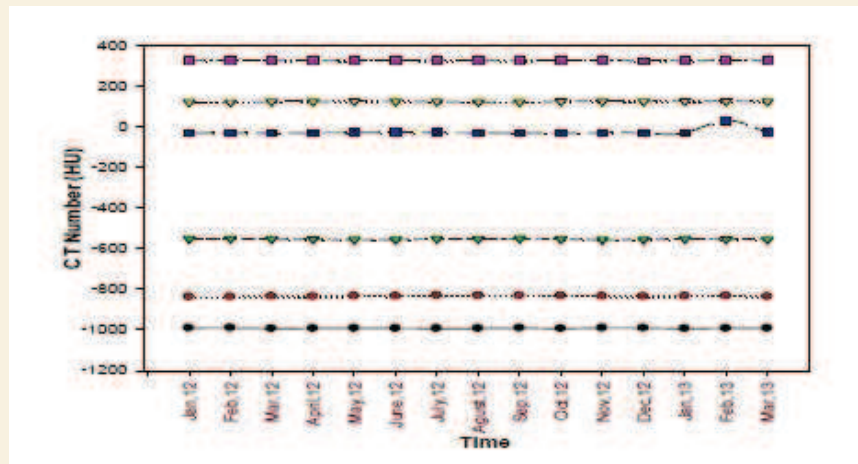
- ❑ CT scan techniques in LASER check WILKE Phantom



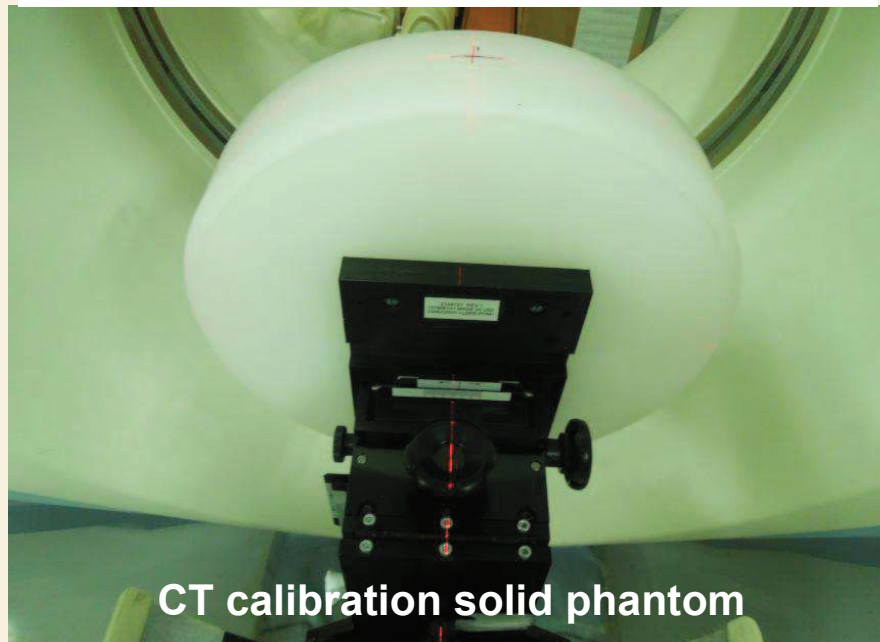
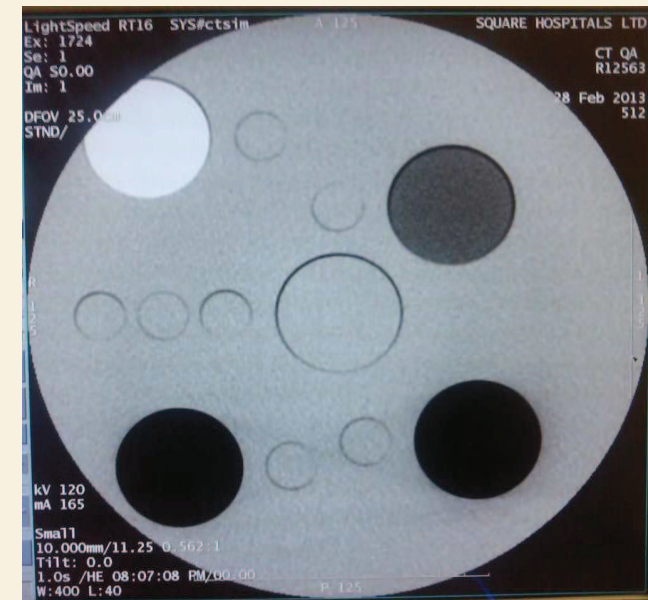
3 Quality Control of a CT Simulator

3.2 QC Program for CT Scanners and CT-Simulation (continued)

CT number constancy respectively Air, Balsa-Holz, Cork, Polystyrol, PMMA, Delrin.



CT slice of multi material phantom



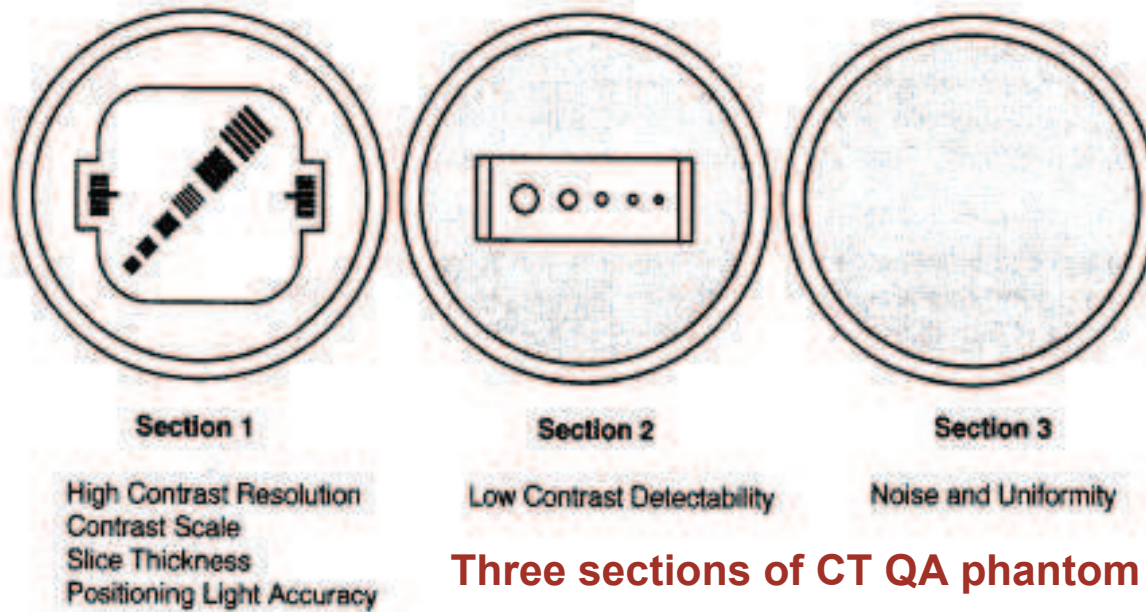
CT calibration solid phantom



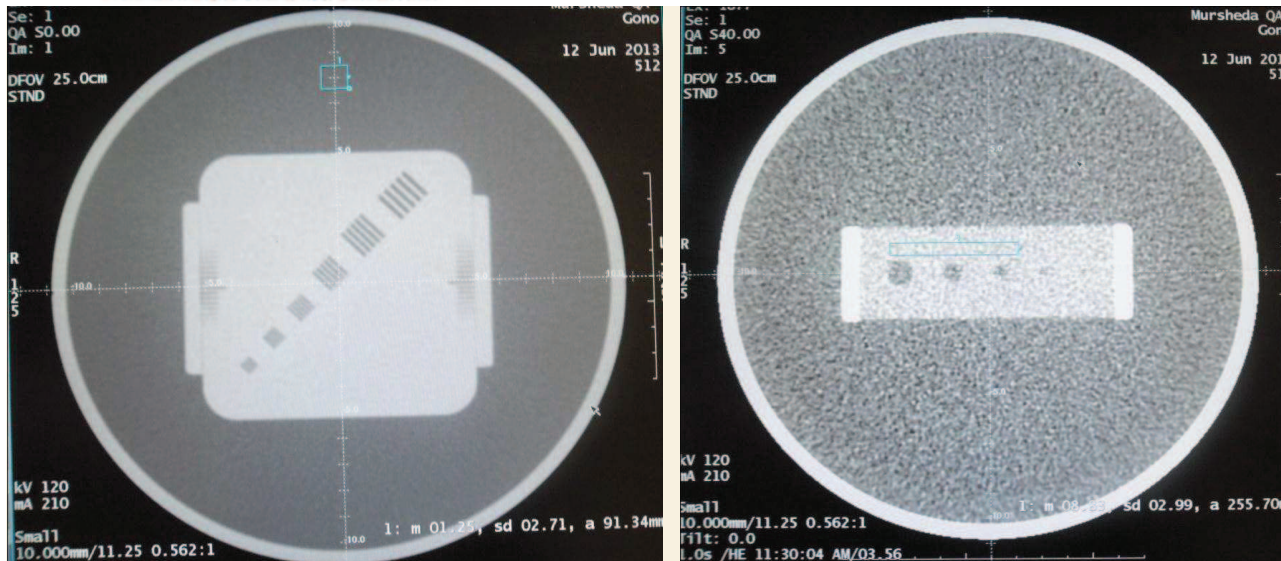
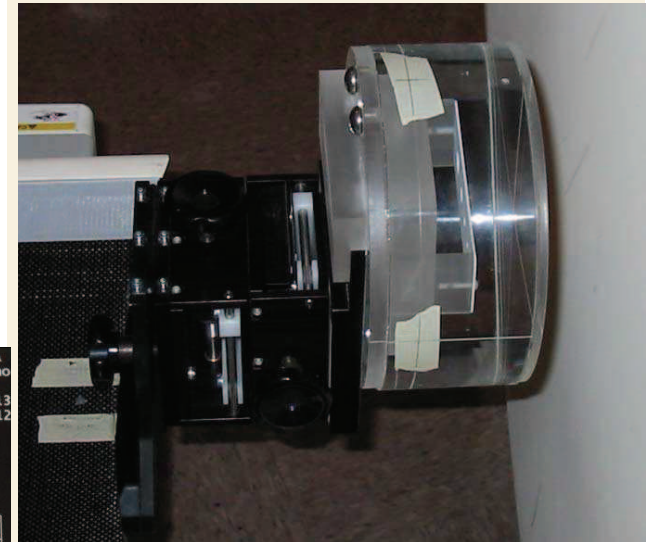
Inhomogeneous solid phantom

3 Quality Control of a CT Simulator

3.2 QC Program for CT Scanners and CT-Simulation (continued)



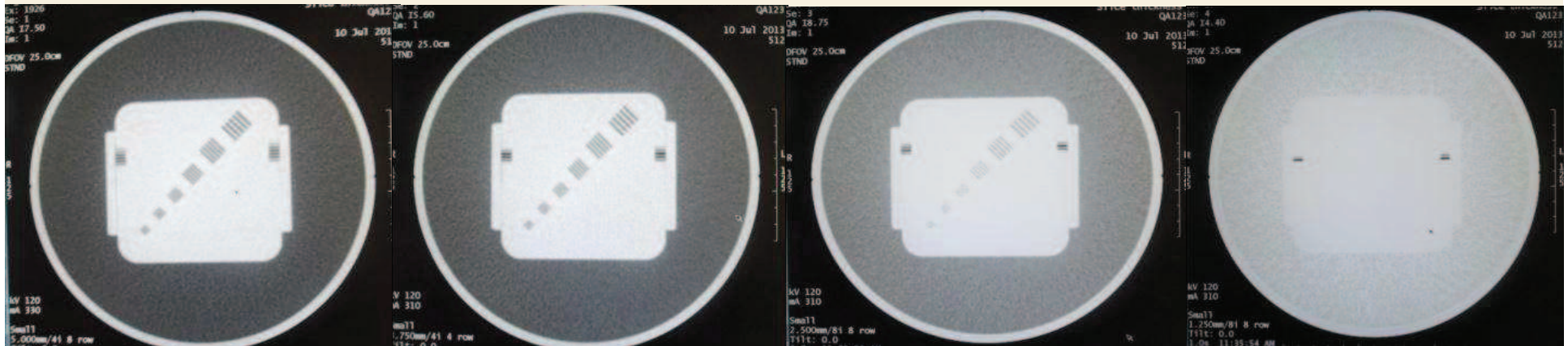
CT QA Water-PMMA phantom connecting to CT couch



3 Quality Control of a CT Simulator

3.2 QC Program for CT Scanners and CT-Simulation (continued)

❑ Slice thickness



❑ Test of Slice thickness for (5mm, 3.75mm, 2.5mm, 1.25mm)

3 Quality Control of a CT Simulator

3.2 QC Program for CT Scanners and CT-Simulation (continued)

❑ CTDI100 measurement setup



❑ Head Phantom for CTDI100 measurement



4 Quality Control of In-Room KV x-ray Imaging

4.1 Cone Beam CT

Type of MV / KV imaging

- ❑ There are quite a variety of commercially available system for IGRT which are used to assure correct geometric targeting.
 - Cone beam CT (CBCT): X-ray tube and flat-panel detector attached to linac. The axis of the x-ray beam is perpendicular to the MV beam axis
 - MV CT: Use megavoltage beam to produce CT image. It is used in tomotherapy unit
 - Linac/CT: A linac and a CT scanner that share a common couch
 - Ultrasound image registration for prostate treatment

4 Quality Control of In-Room KV x-ray Imaging

4.1 Cone Beam CT (continued)

- ❑ There are quite a variety of commercially available system for IGRT which are used to assure correct geometric targeting.
 - Implanted markers: These markers can be observed in MV images provided that there are a sufficient number of these, the location and orientation of the organ in which they are embedded can be determined. Markers have been used widely for prostate treatments.
 - A more exotic illustration of IGRT is provided by the imaging capabilities of a robotic linac

4 Quality Control of In-Room KV x-ray Imaging

4.1 Cone Beam CT (continued)

- ❑ The shape of the KV x-ray beam is a cone and thus this modality is referred to as cone beam CT
 - For CBCT, the gantry rotates around the patient while the KV x-ray tube is on and the MV beam is off.
 - During gantry rotation the KV imaging panel is acquiring numerous projections. The projection data can be reconstructed to provide a set of CT axial images.
 - For IGRT, it is crucial that the MV beam and the KV beam share the same isocenter. During gantry rotation the x-ray tube and imager may sag or flex. It is necessary to correct for this by use of a “flexmap” which characterizes the flex with gantry angle.
 - CBCT images can be compared to the treatment planning CT. The CBCT software on the linac allows the operator to determine the shift in patient position that will best bring the two sets of images into alignment. If the movements are small, the table can be moved automatically from the control console without having to enter the treatment room

4 Quality Control of In-Room KV x-ray Imaging

4.1 Cone Beam CT (continued)



Illustration of Synergy image-guidance system. (Courtesy of Jean-Pierre Bissonnette, Ph.D., Princess Margaret Hospital, Toronto, ON, Canada)

4 Quality Control of In-Room KV x-ray Imaging

4.1 QC Program of a Cone Beam CT (continued)

TABLE VI. Imaging.

Procedure	Application-type tolerance	
	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

4 Quality Control of In-Room KV x-ray Imaging

4.1 QC Program of a Cone Beam CT (continued)

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 SSD	± 5 mm	± 5 mm
Imaging dose ^b	Baseline	Baseline
Planar kV imaging		
Beam quality/energy	Baseline	Baseline
Imaging dose	Baseline	Baseline
Cone-beam CT (kV and MV)		
Imaging dose	Baseline	Baseline

^aOr at a minimum when devices are to be used during treatment day.

^bScaling measured at SSD typically used for imaging.

^cBaseline means that the measured data are consistent with or better than ATP data.

^dkV imaging refers to both 2D fluoroscopic and radiographic imaging.

^eImaging dose to be reported as effective dose for measured doses per TG 75³⁶.

4 Quality Control of In-Room KV x-ray Imaging

4.1 QC Program of a Cone Beam CT (TG- 104)

THE ROLE OF IN-ROOM KV X-RAY IMAGING FOR PATIENT SETUP AND TARGET LOCALIZATION

Table 2. Summary of QA Recommendations for CBCT on a Linac from Princess Margaret Hospital. Tolerances may change according to expectations, experience and performance.

Frequency	Procedure	Tolerance
Daily or each use	Detector stability and system performance	
	Dark image calibration acquisition before each scan	
	Geometry	
	Localizing lasers	<1 mm
	MV/kV/laser alignment	
	Accuracy of shift	±2 mm
	Safety	
	Collision detectors: interrupts or prevents irradiation	Functional
	Warning lights	Functional
	Warm-up	
	Generator operation	Functional
	Detector operation	Functional
	Detector signal	Within expected range
	Collimator operational	Functional
	Clinical process issues	
	Database integrity	
	Storage space availability	
Weekly	Safety	
	X-ray arm and door interlocks: interrupts or prevents irradiation	Functional
Monthly or after service	Imaging system performance	
	Gain stability	Replace/refresh
	Defect maps	Replace/refresh

4 Quality Control of In-Room KV x-ray Imaging

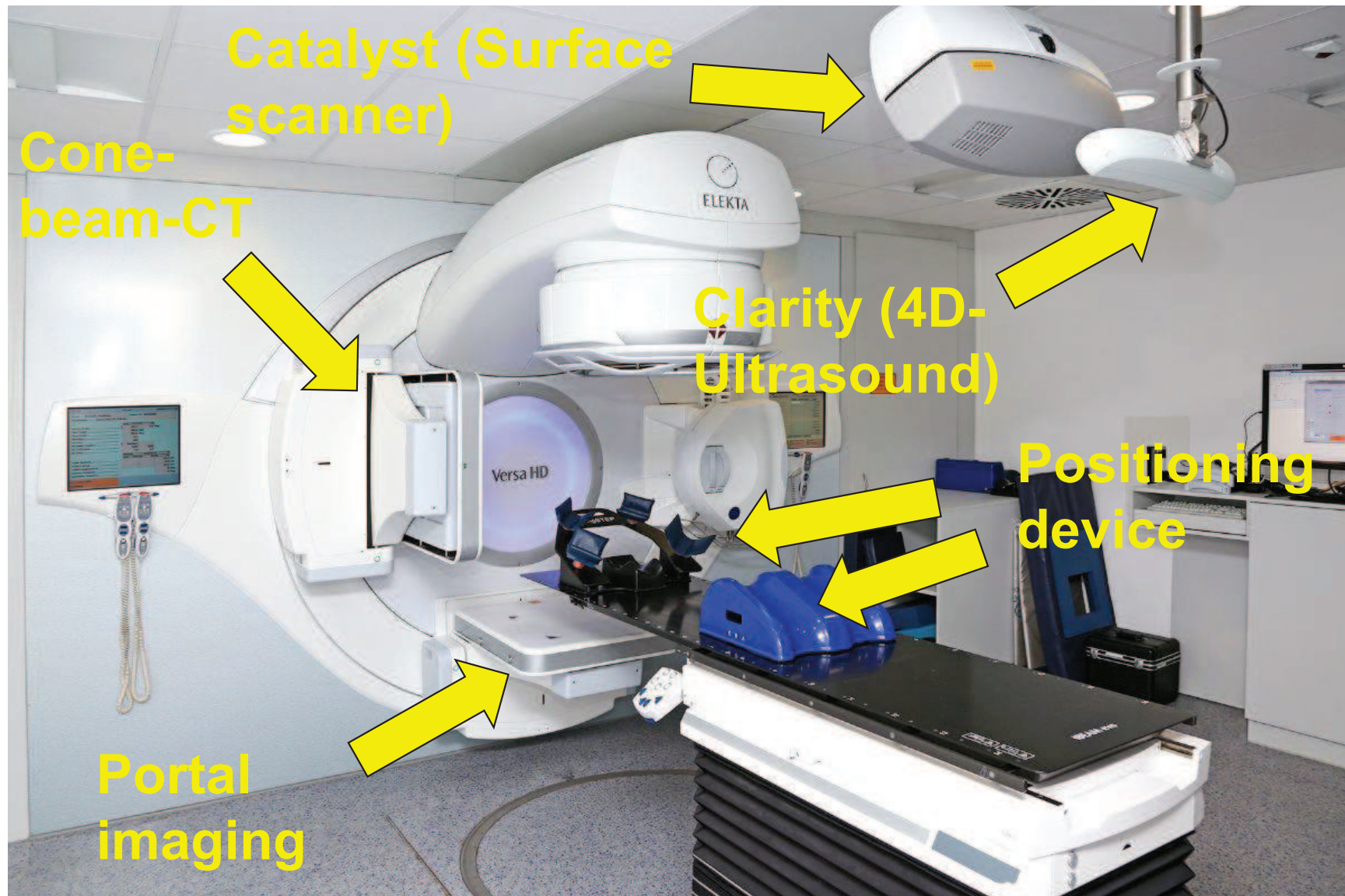
4.1 QC Program of a Cone Beam CT (continued)

Annual or after service	Image quality	
	Scale and distances	± 0.5 mm
	Uniformity	Baseline
	High contrast spatial resolution	> 7 lp/mm
	CT Number Accuracy	Baseline
	Artifacts	Absence
	Geometry	
	Geometric calibration (flexmap)	Replace/refresh
	Couch shifts: accuracy of detection and correction motions	± 1 mm
	Review of daily test results	Complete
	X-ray generator system performance	
	kVp accuracy and waveform	Baseline
	mAs linearity	Baseline
	Radiation quality (HVL)	Baseline
	Accuracy of mA and mAs	Baseline
	Geometry	
	Detector tilt	Baseline
	Detector skew	Baseline
	Couch scale and motion accuracy	± 1 mm
	Data transfer	
	Link to treatment planning	Functional and accurate
	Long term and short term storage	Functional
	Dosimetry	
	Axial and skin dose	Baseline
	Clinical process issues	
	Database integrity and maintenance	Baseline
	Documentation of imaging parameters	Up-to-date
	Review of daily and monthly test results	Complete

(Modified and reprinted from Table 7.3, p. 278, *The Modern Technology of Radiation Oncology*, Volume 2, J. Van Dyk (Ed.), with permission from Medical Physics Publishing.)

The frequency of the tests have been set from device elements and TG-142

Reproducible and exact patient positioning

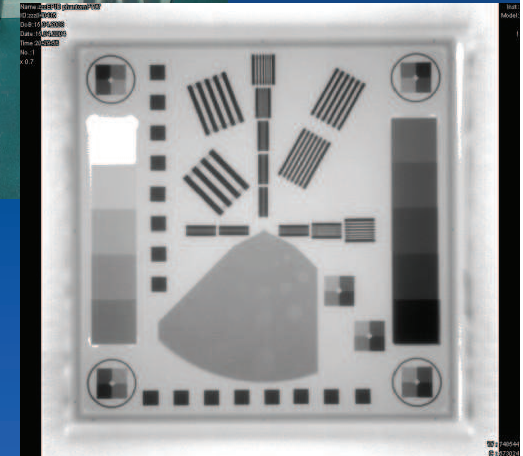
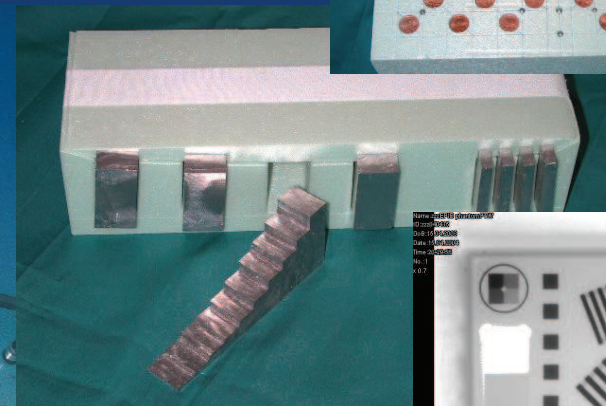
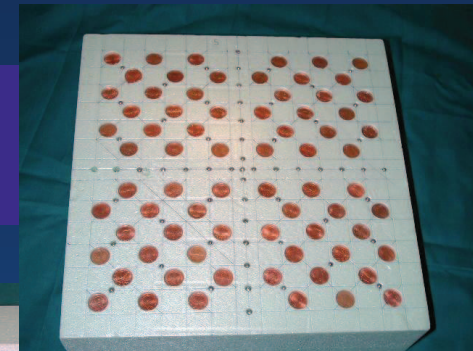
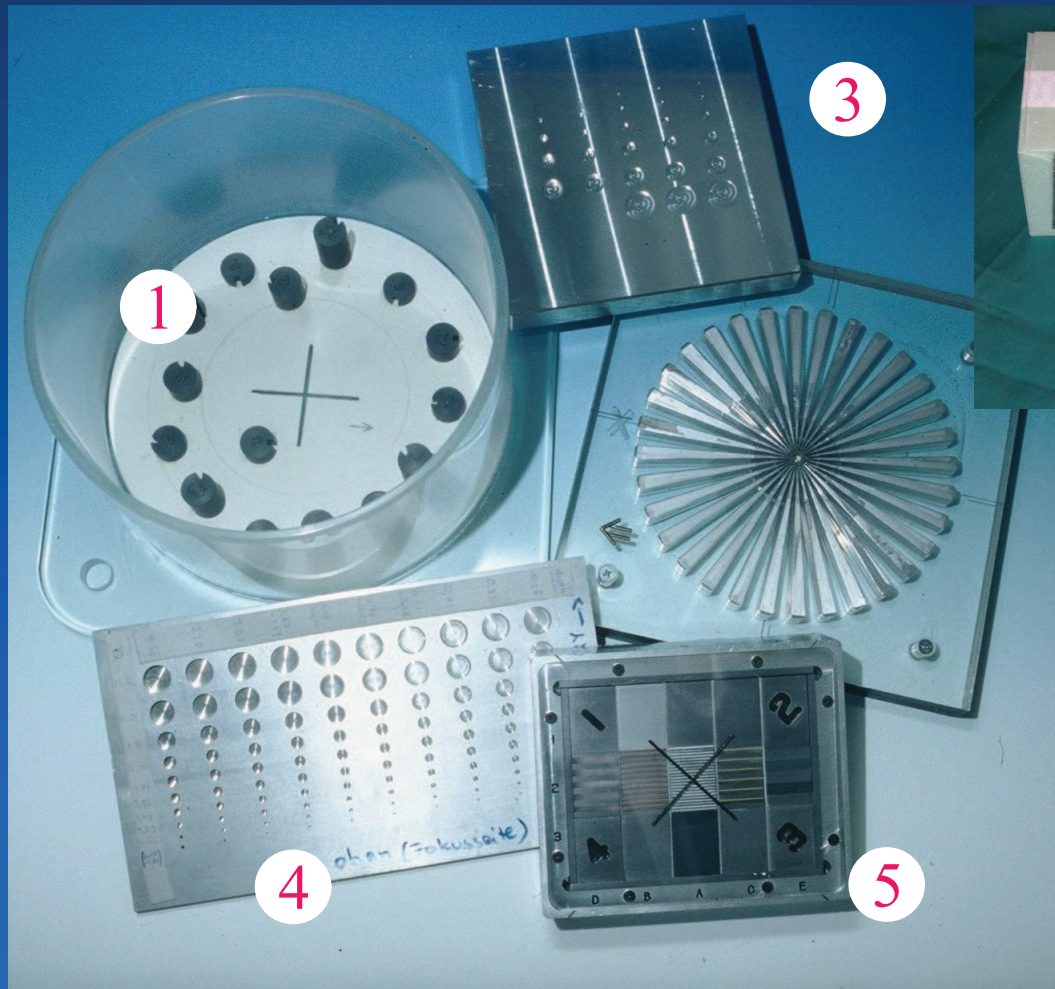




DIN 6847-6 Zusammenfassung

Abschnitt	DIN 6847-6	f	Phantom
4.3.3	ARTEFAKTE	d	Offenes Feld
4.3.1	Anzeige des ZENTRALSTRAHLS	w	Aquilab
4.3.5	Genauigkeit der Längenanzeige	m	Aquilab
4.3.6	NIEDRIGKONTRASTAUFLÖSUNG	m	LAS Vegas/ PTW
4.3.2	Detektorposition relativ zum ISOZENTRUM (z-Richtung)	q	Manuell
4.3.4	Bildverzeichnung	q	Aquilab
4.3.7	HOCHKONTRASTAUFLÖSUNG	q	3 mal PTW / („LAS Vegas“)
4.3.8	Querverteilung (Bildhomogenität)	q	Offenes Feld
4.3.2	Detektorposition relativ zum ISOZENTRUM (x- und y-Richtung)	y	Manuell

Phantome, Phantome:



- 1) Struktur-Phantom
- 2) Radial-Phantom
- 3) "Las Vegas"
- 4) "Las Vegas" - Typ
- 5) QC-3

5 Immobilizing Devices for Patient-Positioning

5.1 Immobilizing Devices

- ❑ The best collimation does not help if the patient is not stable
 - need good immobilization devices
 - need to put patient in a reasonably comfortable position (this is often difficult with very sick patients)
 - need to make them feel comfortable

Inter-/intrafractional: Maximal Immobilisation reproducibility of the patient



6 Quality audit

6.1 Definition

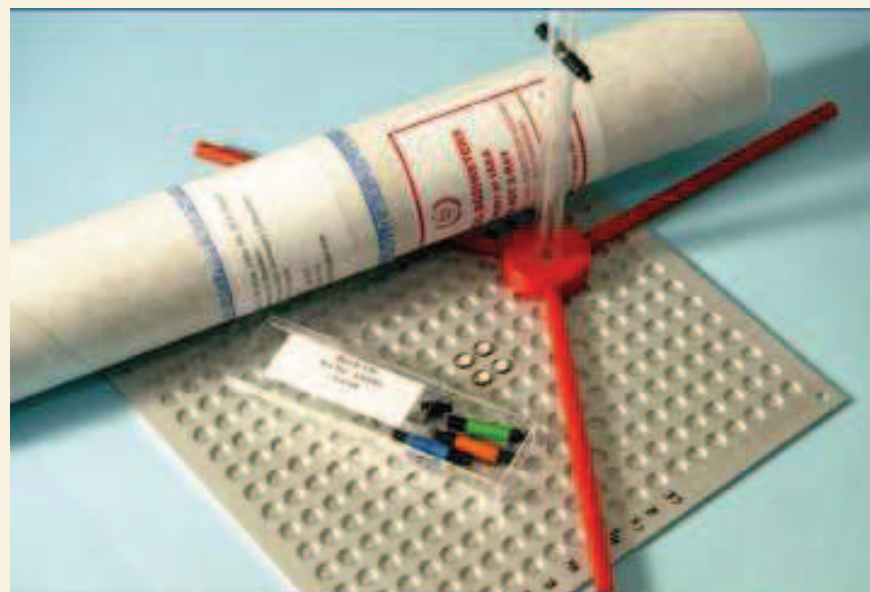
Definition

- ❑ Quality audit is a systematic and independent examination to determine whether or not quality activities and results comply with planned arrangements and whether or not the arrangements are implemented effectively and are suitable to achieve the stated objectives

6 Quality audit

6.2 Practical Quality Audit Modalities

- ❑ A good example for an external audit is the simple but very effective dosimetry audit organized as postal audit with mailed dosimeters (usually TLD).
- ❑ These are generally organized by SSDL or agencies, such as the IAEA, Radiological Physics Center (RPC) in the U.S., ESTRO (EQUAL), national societies, national quality networks, etc.



Material used in IAEA/WHO TLD audits

6 Quality audit

6.3 What should be reviewed in a Quality Audit Visit?

Example for a comprehensive international external audit:
The QATRO project by the IAEA

- ❑ Based on:
 - a long history of providing assistance for dosimetry audits in radiotherapy to its Member States,
 - the development of a set of procedures for experts undertaking missions to radiotherapy hospitals in Member States for the on-site review of the dosimetry equipment, data and techniques, and measurements, and training of local staff,
 - numerous requests from developing countries to perform also comprehensive audits of radiotherapy programs
- ❑ IAEA has developed the "Quality Assurance Team for Radiation Oncology" (QUATRO) project.

6 Quality audit

6.3 What should be reviewed in a Quality Audit Visit? (continued)

- ❑ In response to the requests, the IAEA convened an expert group, comprising of radiation oncologists and medical radiation physicists, which have developed guidelines for IAEA audit teams to initiate, perform and report on such audits.
- ❑ **The guidelines have been field-tested by IAEA teams performing audits in radiotherapy programs in hospitals in Africa, Asia, Latin America and Europe.**
- ❑ QUATRO procedures are endorsed by European Society for Therapeutic Radiology and Oncology, The European Federation of Organizations for Medical Physics and the International Organization for Medical Physics.

References

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