Mahidol University
Wisdom of the Land

QA in Advanced Medical Imaging

Sawwanee Asavaphatiboon
Medical Physics program, Ramathibodi Hospital

The 15th Annual Scientific Meeting, 1-3 March 2024, Trang, Thailand. "Advanced Medical Physics Improves Patient Outcomes

Quality Assurance (QA) Program

In diagnostic radiology is an organized effort by the staff operating a facility to reach the correct diagnosis by

- performing the most appropriate examination
- producing images of sufficiently high quality and consistency
- using the lowest possible dose

Advanced Medical Imaging in Diagnosis

Computed Tomography

Magnetic Resonance Imaging

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE | Mahidol University

JOURNALS

MEDICAL PHYSICS

The International Journal of Medical Physics Research and Practice

Editor-in-Chief: John M. Boone | University of California at Davis

Significant Advances in CT

Virtual Issues | First published: **20 December 2019** | Last updated: **21 July 2020**

This compilation reflects many important CT developments starting with Hounsfield's Nobel award address on "Computed medical imaging." Some of the topics that are covered include basic image reconstruction technologies, spiral CT, cardiac CT, CBCT, tube current modulation, 4D respiratory CT, dual–source dual-energy CT, and new technologies such as iterative image reconstruction as well as the future technology of photon counting detector CT.

itn imaging technology news

FEATURE | COMPUTED TOMOGRAPHY (CT) | NOVEMBER 01, 2023 | BY MELINDA TASCHETTA-MILLANE

Advancements in Computed Tomography Technology

With advancements in resolution, speed, radiation dose reduction, AI integration and personalized medicine, CT scans will continue to be a cornerstone of modern medical diagnostics

BLOG

What's New in CT Systems and Scanner Technology: 2023 Edition

by Mark Miller on Mar 1, 2023

- Photon-Counting Unleashed

Photon-counting CT was introduced by Siemens Healthineers in the form of the NAEOTOM Alpha, which received 510(K) clearance from the Food and Drug Administration toward the end of 2021. As a result, radiologists are only now beginning to experience the game-changing nature of this dual-source technology.

- Lung Cancer Screenings Grow More Popular Than Ever
- Mobile CT Becomes More Common

https://www.cassling.com/blog/whats-new-in-ct-systems-and-scanner-technology-2023-edition

INDUSTRY NEWS | MARKET ANALYSIS

3 AI-based technology trends on display at the 2023 RSNA conference

Vincent Chan

Nov 22, 2023

- Patient positioning

Radiographers can use to help make patient positioning faster and more precise, and bring consistency to the process, all of which help improve image quality and reduce the need for retakes.

- Image quality

AI and other algorithms also are improving image quality, which, in turn helps enhance diagnosis and improve treatment planning.

Another image processing advancement that is rooted in AI helps balance noise and dose in images.

- Improving the patient experience

The AI advances in patient positioning will have an additional important outcome: improving the patient experience. Patients undergoing a medical imaging exam are often worried, in pain, or both. Radiographers who spend less time on positioning the equipment are free to spend an added moment or two to reassure patients.

Principles and applications of multienergy CT: Report of AAPM Task Group 291

C. H. McCollough, et al.

Med. Phys. 47 (7), July 2020 0094-2405/2020/47(7)/e881/32

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Advanced Medical Imaging in Diagnosis

Computed Tomography

- Wide beam/multi-detector CT &CBCT
- Reconstruction:
  - Iterative reconstruction (IR)
  - Deep learning IR
  - AI deep learning IR
- Automatic tube current modulation
- Dual-energy CT/ Multi-energy CT: quantitative analysis
  - Mono-energetic image
  - Virtual non-contrast image
  - Iodine map
  - Calcium image,...
- etc.

QC Problem

- Image quality QC & CT dosimetry
- image quality QC
- ATCM verification
- CT dosimetry & Quantitative data accuracy and reproducibility

Advanced Medical Imaging in Diagnosis

Computed Tomography

- Wide beam/multi-detector CT &CBCT
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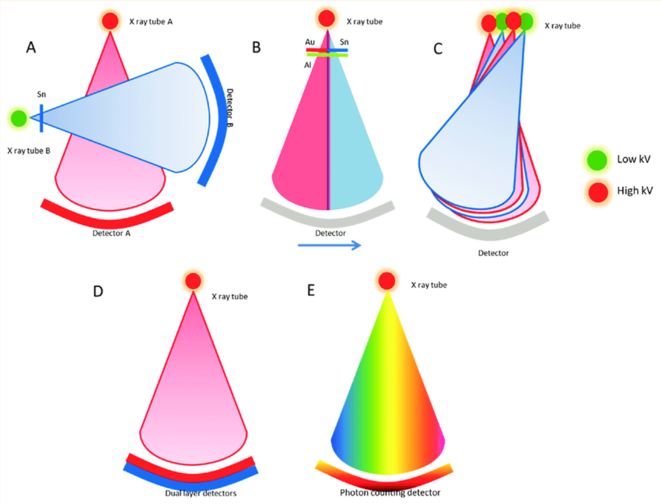
  - Iodine map
  - Calcium image,…
- etc.

QC Problem

- Image quality QC
- image quality QC
-
-

CT QA &QC

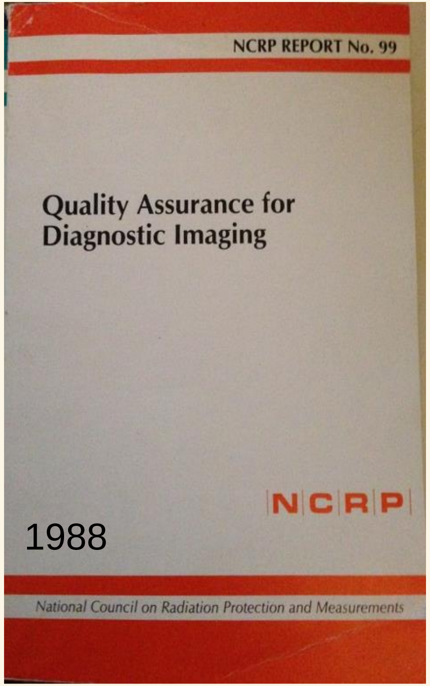


E. Alavandar, et al. Principles and Available Hardware in DECT. Journal of Gastrointestinal and Abdominal Radiology ISGAR © 2022.

CT Quality Control

Purpose

- Technology becoming more complicated, more oversight needed
- Field becoming more quantitative, more focus on numerical values in CT images
- Improved reliability may result in fewer repeat exams
- Overall improvement in quality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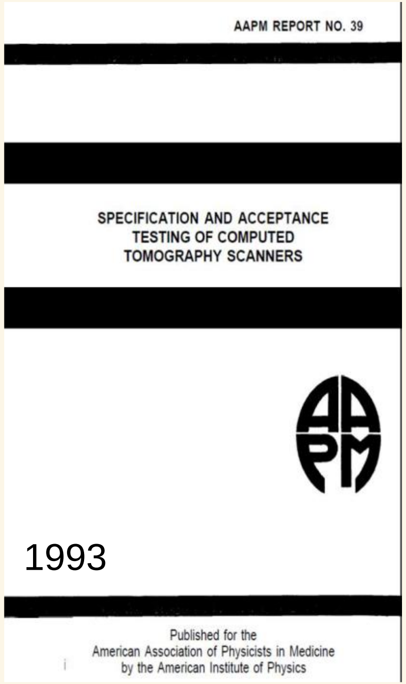
Quality Assurance for Diagnostic Imaging
NCRP
1988
National Council on Radiation Protection and Measurements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SPECIFICATION AND ACCEPTANCE TESTING OF COMPUTED TOMOGRAPHY SCANNERS
AAPM
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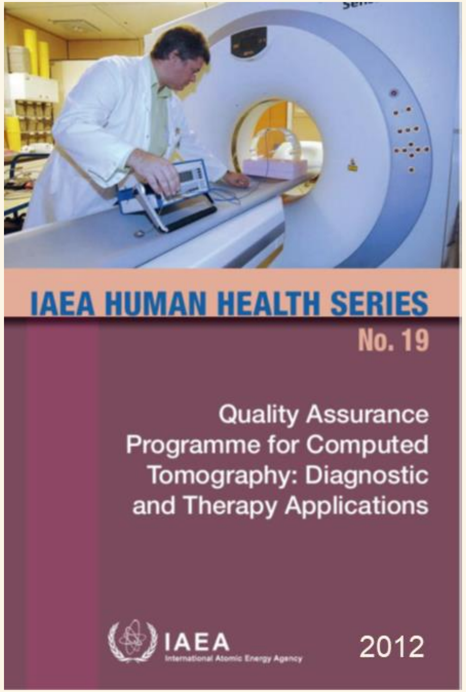
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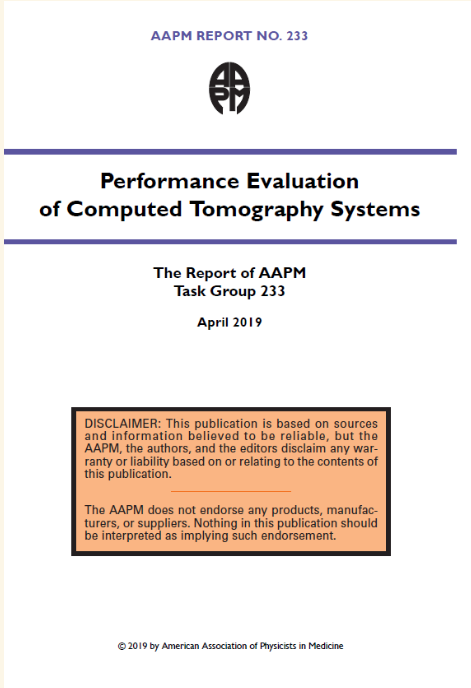
AAPM REPORT NO. 233
Performance Evaluation of Computed Tomography Systems
The Report of AAPM Task Group 233
April 2019
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Performance Evaluation of Computed Tomography Syster

The Report of AAPM
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April 2019

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Table 1. Components of CT performance evaluation as structured in this report

Performance Type	Performance Sub-type (Section Number)	Component
Pre-test inspection	Basic functional and QC (1)	Specific checks prior to basic and operational tests
Basic performance	Geometrical performance (2.1)	Laser alignment accuracy
		Table indexing accuracy
		Image position accuracy
		Image thickness accuracy (axial mode)
		Image thickness accuracy (helical mode)
		Gantry tilt accuracy
	Radiation output performance (2.2)	Half-value layer
		Exposure reproducibility
		Exposure time reproducibility
		Exposure linearity
		Exposure time accuracy
		Tube potential accuracy
		Radiation beam profile
		Displayed $CTDI_{vol}$ accuracy
		CT localizer radiograph dose
	Basic imaging performance (2.3)	CT number accuracy
		CT number uniformity
		Artifact assessment
		Line-pair resolution
		Noise magnitude
		Slice sensitivity profile
Operational performance	Advanced imaging performance (3.1–3.3)	Tube current modulation
		Spatial resolution
		Noise
	Task-based performance (3.4–3.5)	Quasi-linear task-based performance
		Spatial domain task-based performance

QUALITY CONTROL
IN DIAGNOSTIC RADIOLOGY

Report of Task Group #12
Diagnostic X-ray Imaging Committee

Members
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July 2002 AAPM 74

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EUROPEAN COMMISSION

RADIATION PROTECTION N° 162

Criteria for Acceptability of Medical Radiological Equipment used in Diagnostic Radiology, Nuclear Medicine and Radiotherapy

Directorate-General for Energy
Directorate D — Nuclear Safety & Fuel Cycle
Unit D4 — Radiation Protection
2012

IAEA HUMAN HEALTH SERIES
No. 47

Handbook of Basic Quality Control Tests for Diagnostic Radiology

IAEA
International Atomic Energy Agency

2023


มาตรฐานคุณภาพ
เครื่องเอกซเรย์วินิจฉัยทางการแพทย์
Quality Standards of Medical Diagnostic
X-ray Machines

2562


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เครื่องเอกซเรย์วินิจฉัย
Quality Standards of Diagnostic
X-ray Machines

2566

CT QC: IAEA 47

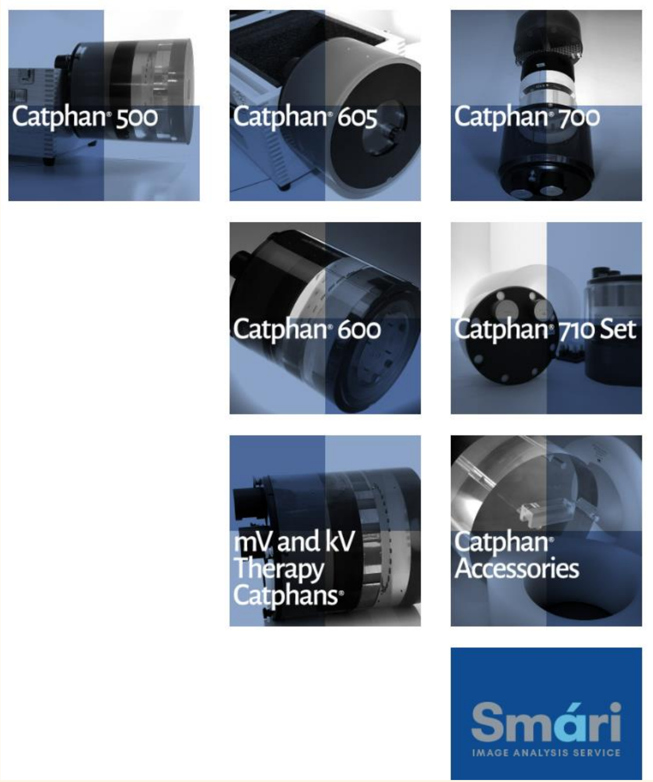
For radiographers

- Daily startup procedure
- Computed tomography laser alignment beams
- Scan projection radiograph accuracy
- Computed tomography number accuracy, image noise, image uniformity and image artefacts
- Accuracy of measured dimensions

For medical physicists

- Computed tomography number accuracy, image noise, image uniformity and image artefacts
- Linearity
- Low contrast detail detectability
- X ray beam width
- Reconstructed image slice width
- Spatial resolution
- Computed tomography dosimetry

Catphan phantoms



The primary Catphan® models are the Catphan® 500, 600, & 700. Each phantom is designed to provide comprehensive evaluation for different CT scanning technologies.

Catphan® 500: The Catphan® 500 provides complete characterization of maximum imaging performance for axial and spiral CT scanners. The Catphan® 500 provides a comprehensive set of measurements to evaluate your CT scanner's sensitometry, uniformity, geometric and low contrast sensitivity performance.

Catphan® 600: The Catphan® 600 builds on the capabilities of the 500 model to enable maximum performance characterization of multi-slice CT's and the enhanced sensitometry measurements required for radiation therapy. The Catphan® 600 has enhanced measurement capabilities for precise measurement of thin slices and higher resolutions found in multi-slice scanners.

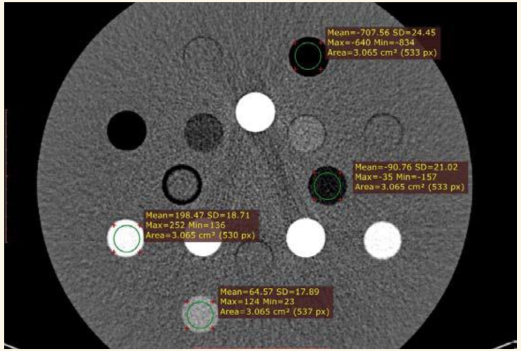
Catphan® 605: The Catphan® 605 provides a compact, inexpensive phantom with a basic suite of tests to measure maximum performance characteristics of multi-slice CT's and other state of the art scanners. The Catphan® 605 has enhanced measurement capabilities for precise measurement of thin slices and higher resolutions found in modern multi-slice scanners.

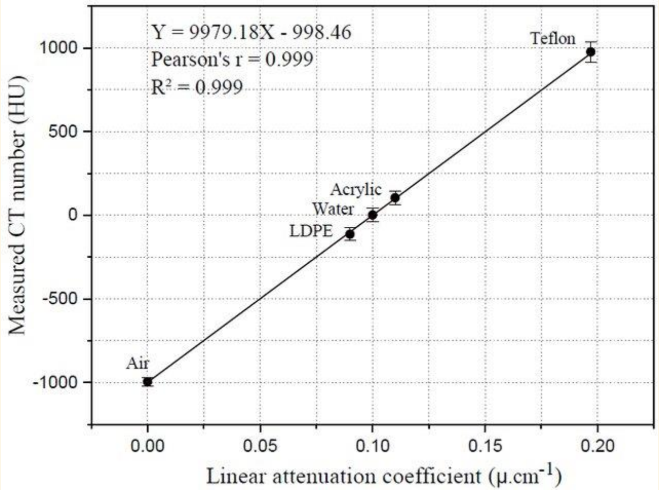
Catphan® 700: The Catphan® 700 is intended for use with state of the art CT scanners and research that require an advanced phantom to measure their full potential. These include resolution patterns up to 30 lp/cm and the CTP 721 wave module for measuring voxel resolution and geometry across the slice area.

Catphan® 710 Set: The Catphan® 710 set combines several tools for advanced CT measurements in one set.

mV and kV Therapy Catphans®: Catphan® models 606, 604, 504, and 503 are used with radiation therapy CBCT systems and designed to evaluate image performance of both mV and kV CT scanners.

Linearity

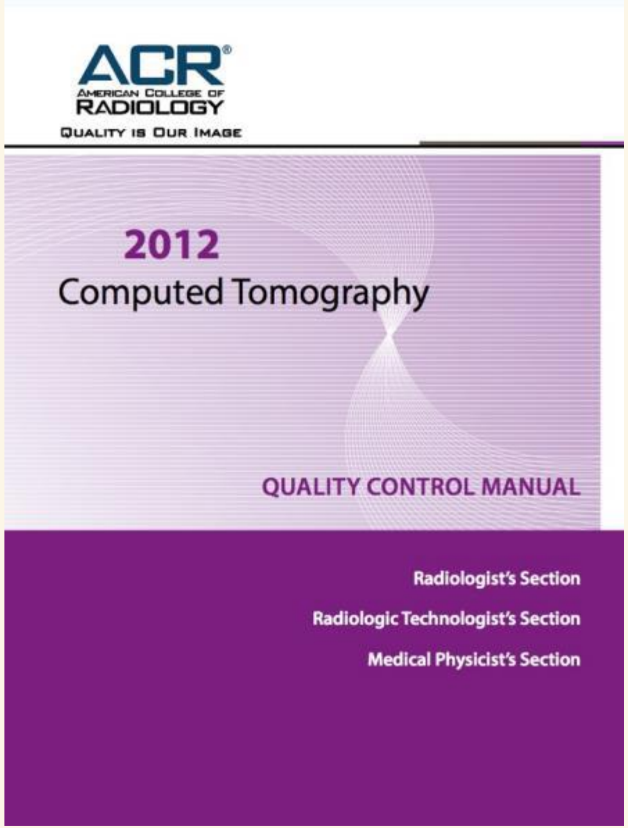




Annually

New Criteria:

- For water, the tolerance is ±4 HU compared to the baseline values; for other materials, it is −10 to 10 HU
- For radiotherapy applications, typical values are usually provided by the manufacturer of the linearity measurement phantom; with reference to these values, the tolerance is −20 to 20 HU.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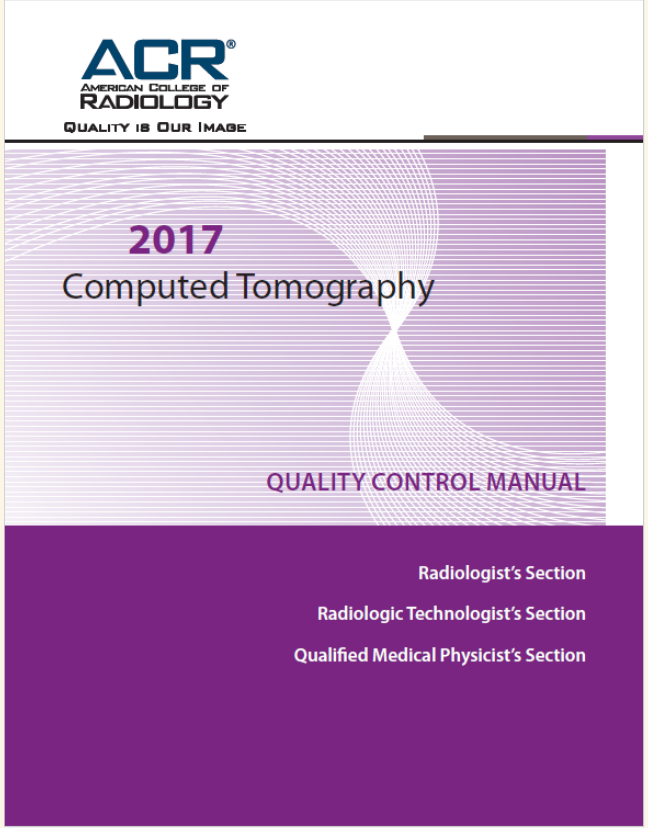
2012
Computed Tomography
QUALITY CONTROL MANUAL
Radiologist's Section
Radiologic Technologist's Section
Medical Physicist's Section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2017
Computed Tomography
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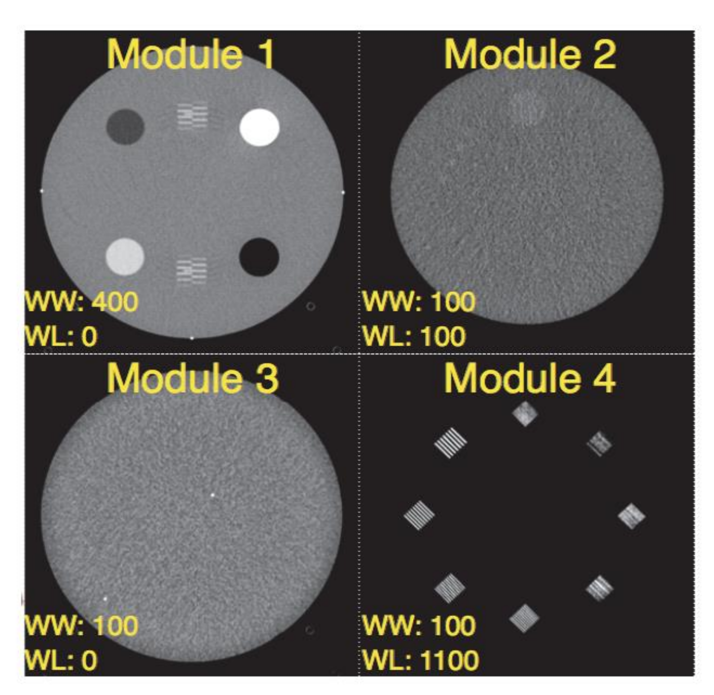
Radiologist's Section
Radiologic Technologist's Section
Qualified Medical Physicist's Section

CT ACR 464 Phantom

Modularity

Four included modules support testing for:

- Positioning and alignment, CT number accuracy and slice thickness
- Low contrast resolution
- CT number uniformity assessment
- High contrast (spatial) resolution



CT Acceptance testing

Basics (ACR QC Man.)

- Protocol review
- Rx & light alignment
- Image thickness
- Table travel accuracy
- Beam width
- Contrast resolution
- Spatial resolution
- CT number accuracy
- Artifact evaluation
- Dosimetry
- CT scanner monitor

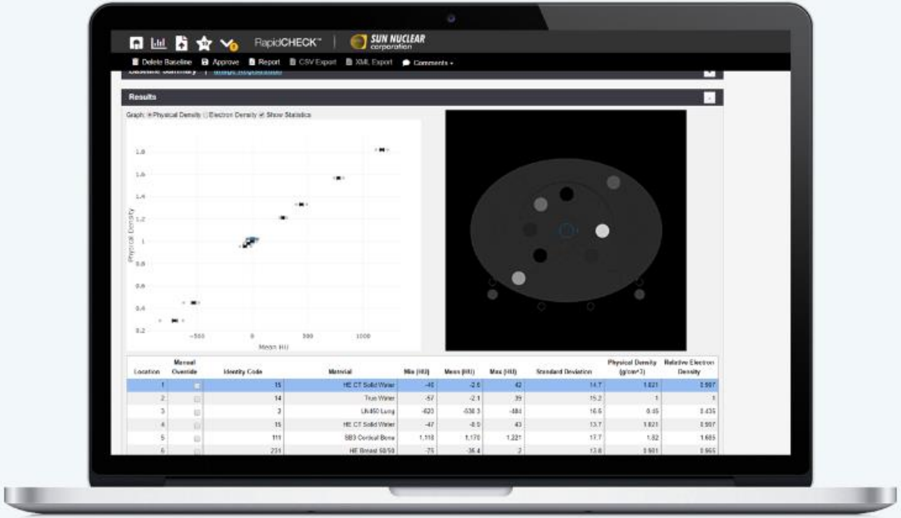
Table 1. QC Test Frequency

TEST	FREQUENCY
Qualified Medical Physicist Survey	
Participation in Review of Clinical Protocols with the CT Protocol and Management Team	Annually
Scout Prescription and Alignment Light Accuracy	Annually
Table Travel Accuracy	Annually
Radiation Beam Width	Annually
Low-Contrast Performance	Annually
Spatial Resolution	Annually
CT Number Accuracy	Annually
Artifact Evaluation	Annually
CT Number Uniformity	Annually
Dosimetry	Annually
CT Scanner Display Calibration	Annually
Radiologic Technologist QC	
Water CT Number and Standard Deviation	Daily
Artifact Evaluation	Daily
Wet Laser Printer Quality Control	Weekly
Visual Checklist	Monthly
Dry Laser Printer Quality Control	Monthly
Gray Level Performance of CT Scanner Acquisition Display Monitors	Monthly

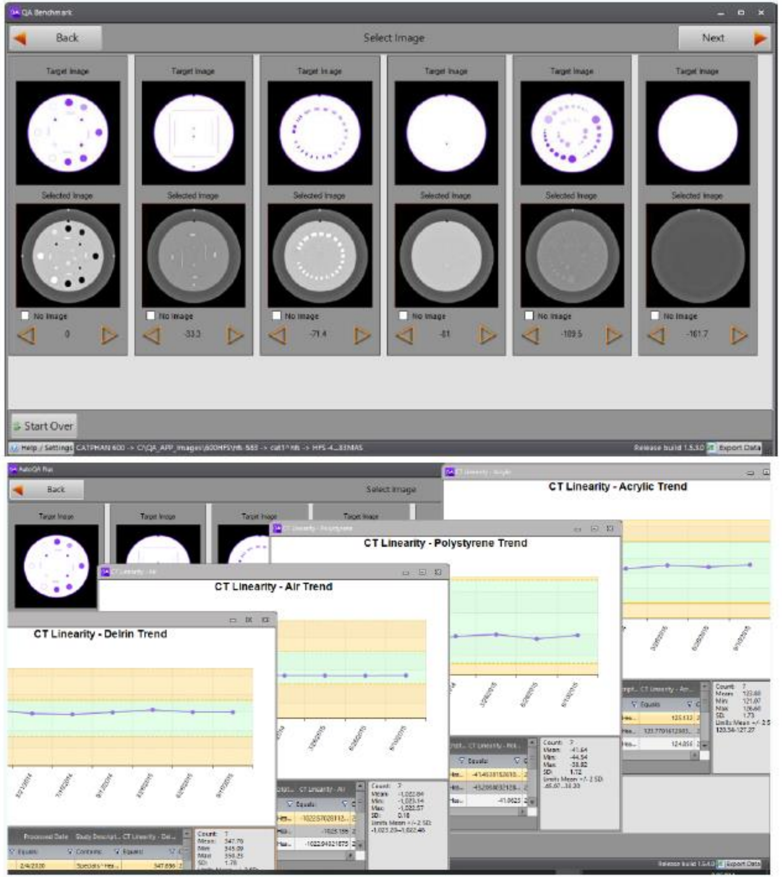
SUN NUCLEAR
A MIRION MEDICAL COMPANY

RapidCHECK™

Automated CT-to-Density Calibration & CT Image Quality Analysis



AUTOMATIC ANALYSIS SOFTWARE



Prapa S. Role of Medical physicist in Diagnostic X-ray:PPT

Quality assurance framework for rapid automatic analysis deployment in medical imaging.

Juha I. Peltonen *, Ari-Pekka Honkanen, Mika Kortesniemi

Physica Medica 116 (2023) 103173

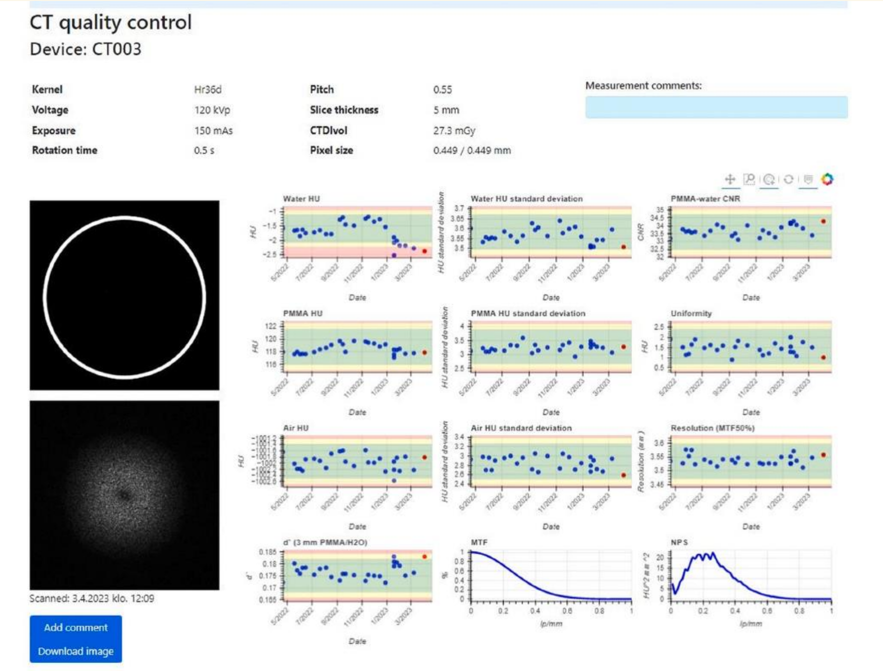


Fig. 2. The user interface used in computed tomography quality assurance. The user can choose a datapoint by clicking on any of the timeseries. The respective source image is presented in a viewport on the upper left along with 2D noise power spectrum (NPS) on the lower left. In our case, the analysed QA parameters included various basic image-quality parameters (CT numbers of basic materials, noise, contrast, uniformity, and resolution values) and expand to task-specific image quality implemented as detectability index (non-prewhitening model observer based on 3-mm round nodule model with PMMA/water contrast corresponding to soft-tissue lesion, applying corresponding radially averaged MTF and NPS curves).

- The QA system was built using freely available open-source software libraries.
- The included features were results database, database interface, interactive user interface, e-mail error dispatcher, data processing backend, and DICOM server.

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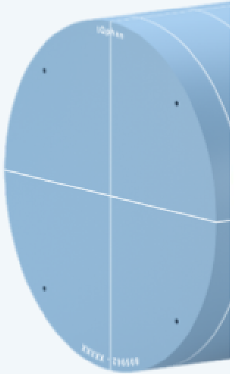
A MIRION MEDICAL



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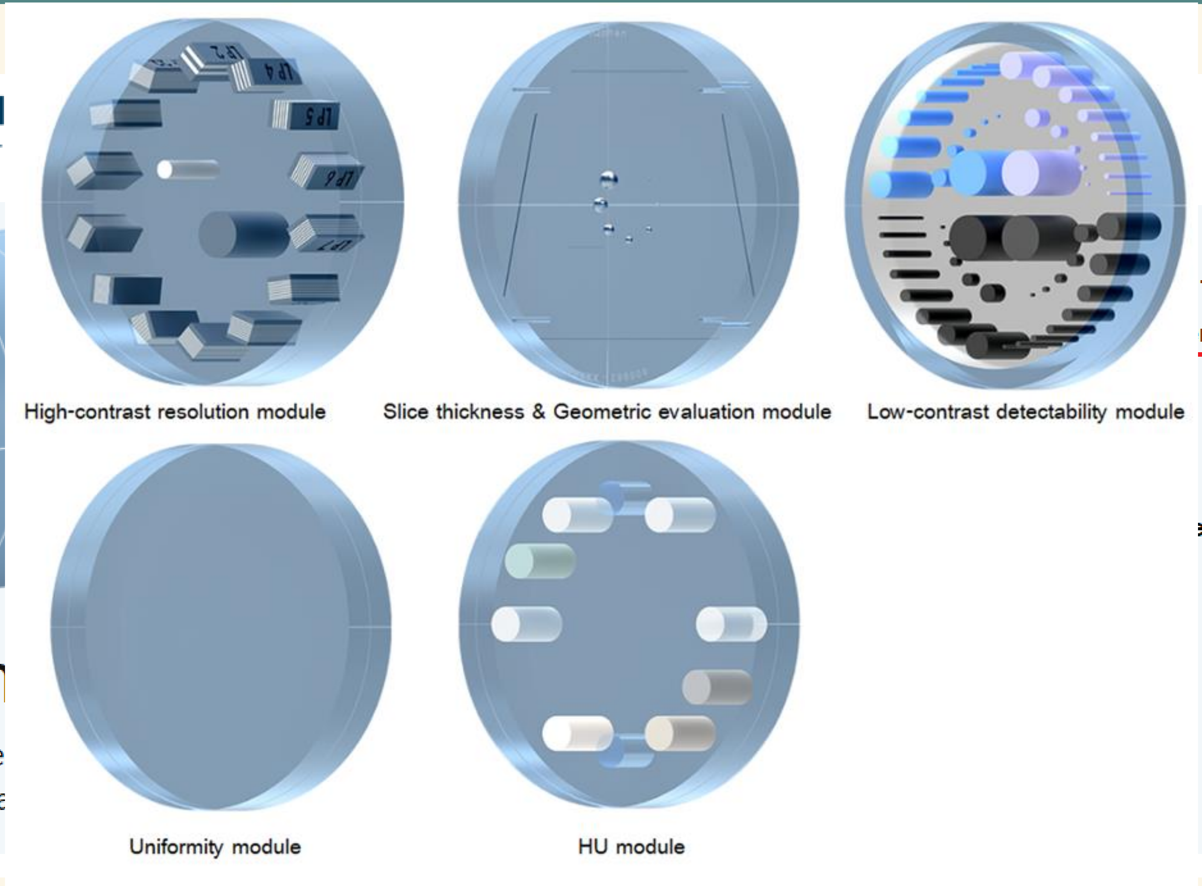

Advanced Medical Imaging in Diagnosis

Computed Tomography	QC Problem
- Wide beam/multi-detector CT &CBCT	-
- Reconstruction:	-
- Iterative reconstruction (IR)	
- Deep learning IR	
- AI deep learning IR	
- Automatic tube current modulation	- ATCM verification
- Dual-energy CT/ Multi-energy CT: quantitative analysis	-
- Mono-energetic image	
- Virtual non-contrast image	
- Iodine map	
- Calcium image,…	
- etc.	

AAPM REPORT NO. 233

Performance Evaluation

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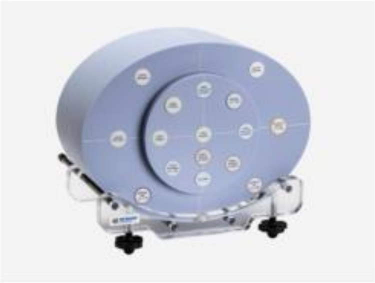
https://www.sunnuclear.com/products/

Mercury 4.0 Phantom

AAPM CT Performance Phantom



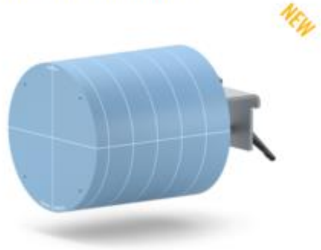
Advanced Electron Density

CT Perfusion Phantom

Advanced iqModules

ATOM Max Dental & Diagnostic Head Phantom

CT ACR 464 Phantom



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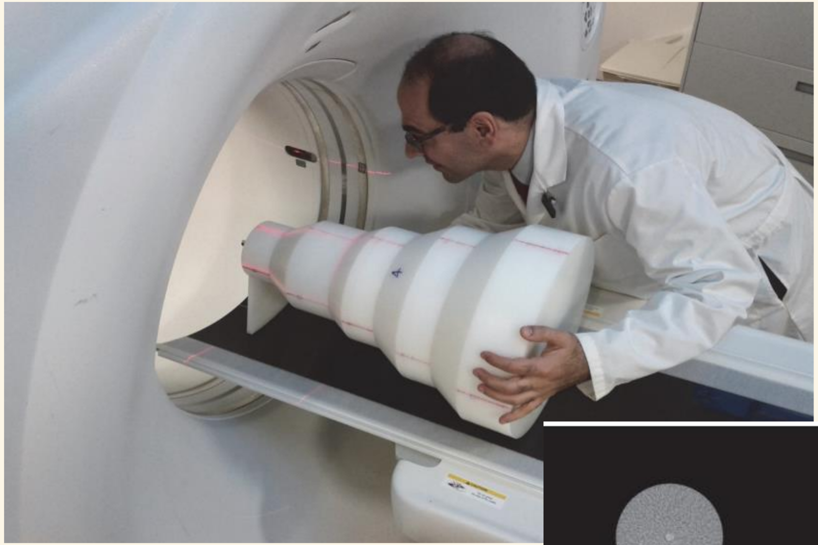
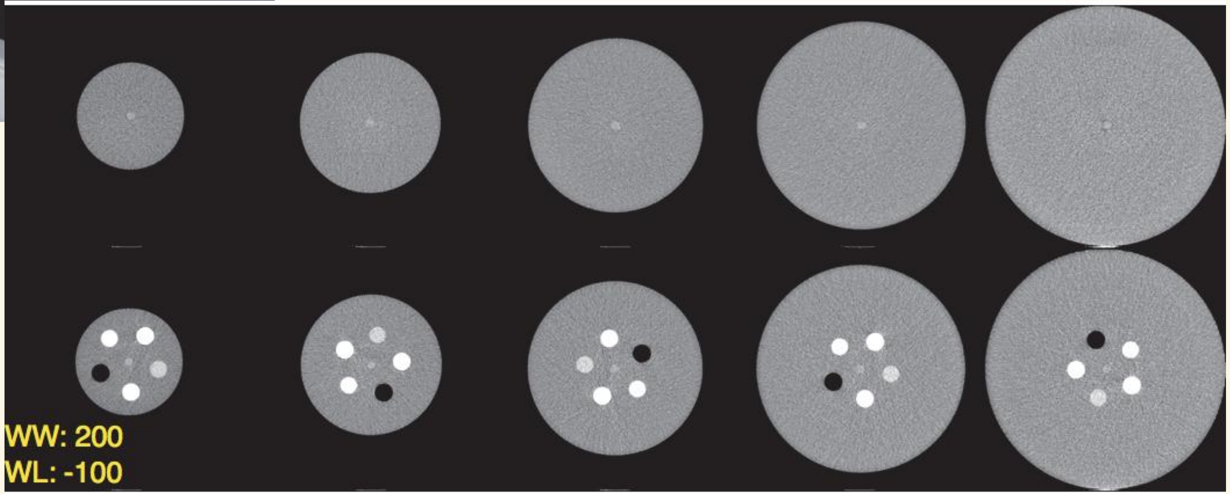


Mercury phantom



Mercury 4.0 Phantom

- This phantom is designed to assess system noise, resolution, and detectability properties of the CT system as a function of patient size and detection task, and can be used for the following characterizations:
    - TCM (both size adaptation and continuous adaptation) using the phantom sections of varying size (section 3.1)
    - In-plane spatial resolution as a function of contrast, patient size, or image noise using the insert rods across variable size phantom sections (section 3.2.5.1)
    - Z-direction spatial resolution using the slanted edge interface (section 3.2.5.2)
    - Noise magnitude and texture as a function of patient size using the uniform phantom sections of varying size (section 3.3)
    - Quasi-linear task-based performance as a function of patient size using the insert rods and the uniform sections of varying size (section 3.4)

Phantoms for TCM tests

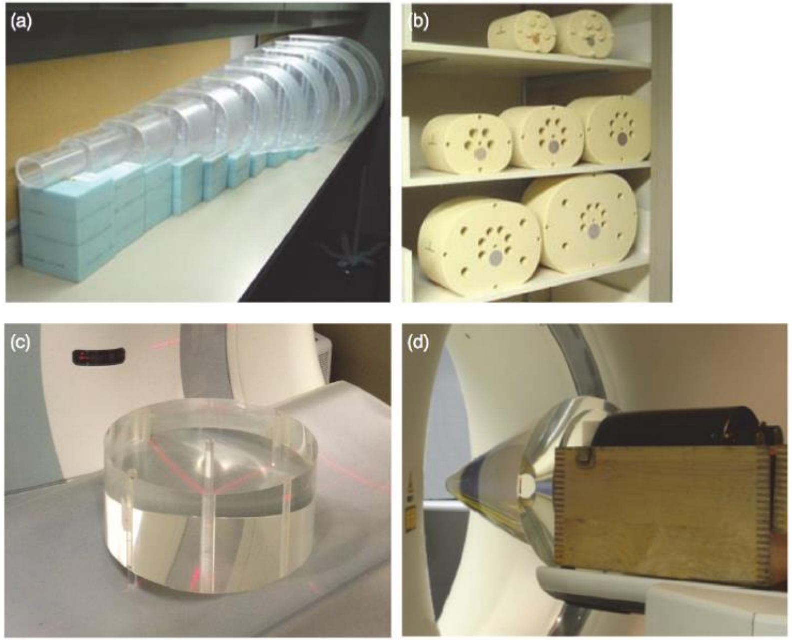


Figure 16. Photographs of various phantoms that can be used for TCM testing. Phantom sets of different sizes such as the collection of water phantoms (a), or CIRS abdominal phantoms (b) can be used for TCM size adaptation tests (see section 3.1.2.1). Phantoms with continuous longitudinal change in size. such as the CTDI phantom turned sideways (c), or the cone-shaped ImpACT phantom (d) can be used for TCM continuous adaptation tests (see section 3.1.2.1).

Advanced Medical Imaging in Diagnosis

Computed Tomography	QC Problem
- Wide beam/multi-detector CT &CBCT	-
- Reconstruction:	-
- Iterative reconstruction (IR)	
- Deep learning IR	
- AI deep learning IR	
- Automatic tube current modulation	-
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- Mono-energetic image	
- Virtual non-contrast image	
- Iodine map	
- Calcium image,…	
- etc.	

Principles and applications of multienergy CT: Report of AAPM Task Group 291

Med. Phys. 47 (7), July 2020 0094-2405/2020/47(7)/e881/32

Cynthia H. McCollough[a)]
Mayo Clinic, 200 First Street SW, Rochester, MN 55905, USA

Kirsten Boedeker
Canon (formerly Toshiba) Medical Systems Corporation, 1440 Warnall Ave, Los Angeles, CA90024, USA

Dianna Cody
University of Texas, M.D. Anderson Cancer Center, 7163 Spanish Grant, Galveston, TX 77554-7756, USA

Xinhui Duan
Southwestern Medical Center, University of Texas, 5323 Harry Hines Blvd, Dallas, TX 75390-9071, USA

Thomas Flohr
Siemens Healthcare GmbH, Siemensstr. 3, Forchheim, BY 91031, Germany

Sandra S. Halliburton
Philips Healthcare, 100 Park Ave, Suite 300, Orange, OH 44122, USA

Jiang Hsieh
GE Healthcare Technologies, 3000 N. Grandview Blvd. W-1190, Waukesha, WI 53188, USA

Rick R. Layman
University of Texas, M.D. Anderson Cancer Center, 7163 Spanish Grant, Galveston, TX 77554-7756, USA

Norbert J. Pelc
Stanford University, 443 Via Ortega, Room 203, Stanford, CA 94305-4125, USA

(Received 12 August 2019; revised 11 February 2020; accepted for publication 10 March 2020; published 28 May 2020)

DECT analyzed data

- Iodine maps
- Virtual non-contrast (VNC) images with iodine subtracted
- Other material decomposition with specific applications
    - Calcium removal
    - Renal stone characterisation
    - Gout characterisation etc.
- CT numbers reconstructed at virtual monoenergetic X-ray energies (monoE+)
    - from 40 to 200 keV (manufacturer-dependent)
    - enhanced contrast at low monoE / improved metal artefacts at high monoE
- Electron density and effective Z maps (rho/Z)
    - Useful for radiotherapy applications

Considerations for accurate quantification

- Multi-energy CT quantification requires the development of a quality control program to ensure accuracy and reproducibility.
- It is the responsibility of the user to ensure quantification accuracy and reproducibility; otherwise, significant caution is warranted regarding clinical conclusions and decisions.
- The development of a quality control program often requires a phantom with known standards.
- Acquisition techniques (tube potential and beam filter combinations), reconstruction, and post-processing can all have dramatic impact on quantitation, as exhibited by Krauss et al.
- Another important consideration with respect to quantitative CT is reproducibility from exam to exam, where variations in exams between different makes and models of scanners, and changes in patient size or table height can lead to erroneous results.

Nute et al. Development of a dual-energy computed tomography quality control program: Characterization of scanner response and definition of relevant parameters for a fast-kVp switching dual-energy computed tomography system. Medical Physics, 45 (4), April 2018

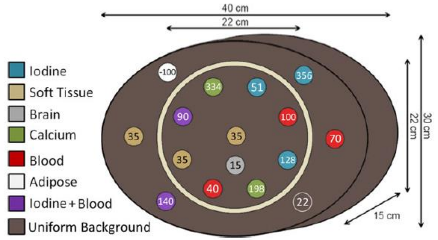


FIG. 1. Basic structure and dimensions of DEQC phantom with DEQC insert layout showing average 120 kVp HU level of inserts.

TABLE I. List of DEQC phantom insert types. **Medical Physics, 45 (4), April 2018**

Insert	Compound	HU at 120 kVp	Electron density	Effective Z[a]	Biology modeled
Blood	Fe_2O_3	40	1.033	6.392	Blood
Blood	Fe_2O_3	70	1.068	6.350	Clot (Normal)
Blood	Fe_2O_3	100	1.102	6.309	Clot (Extreme)
Calcium	$CaCO_3$	198	1.128	6.757	Calcification
Calcium	$CaCO_3$	334	1.191	7.380	Bone
Iodine 2 mg/mL	C_6H_5I	51	1.002	6.306	NA
Iodine 5 mg/mL	C_6H_5I	128	1.003	6.441	NA
Iodine 15 mg/mL	C_6H_5I	356	1.008	6.891	NA
Iodine enhancement	$Fe_2O_3 + C_6H_5I$	40 + 50	1.034	6.478	Typical enhancement threshold for neuro studies
Iodine enhancement	$Fe_2O_3 + C_6H_5I$	40 + 100	1.035	6.568	Typical enhancement threshold for thoracic studies
Soft tissue	NA	35	1.029	6.305	Soft tissue
Adipose	NA	−100	0.944	5.985	Adipose
Brain	NA	15	1.022	6.423	Brain

[a]Effective Z calculation based on elemental composition of each material as provided by Gammex.

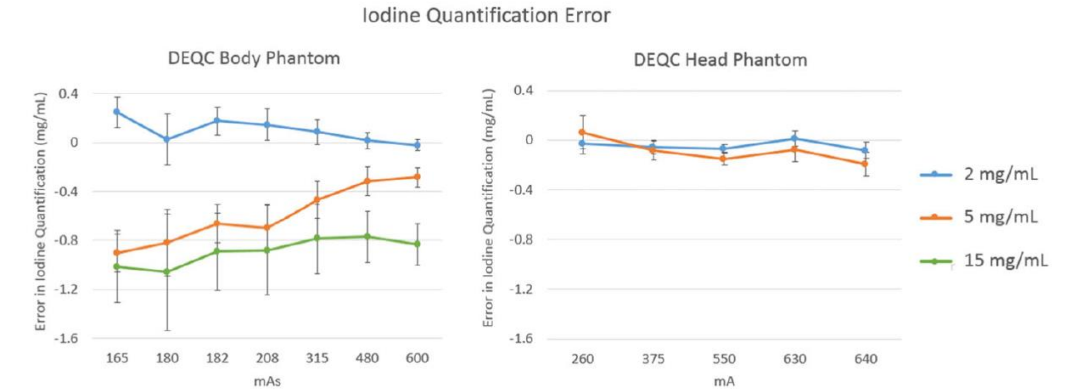


FIG. 3. Iodine quantification error measured on the Iodine (Water) images for the technique parameter isolated as a major variance contributor in Table IX: mAs for the DEQC body phantom (left) and mA for the DEQC head phantom (right). Iodine quantification error was measured as the difference between the nominal and measured iodine concentration for all iodine inserts present (see Fig. 1 for iodine insert positionin
ners and 13 weeks.

-Iodine quantification error was largely unaffected by any of the technique parameters investigated.

-Monoenergetic HU stability was found to be affected by mAs,

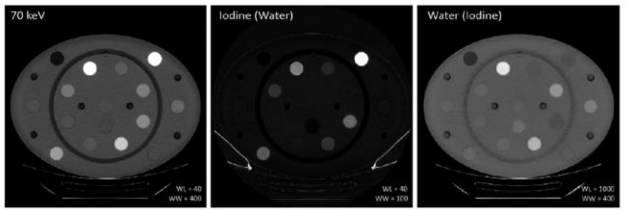


FIG. 2. DECT images of the DEQC body phantom for 70 keV monoenergetic reconstruction and Iodine (Water) and Water (Iodine) material density images. Note the high signal from both the iodine and calcium rods due to the presence of high-Z elements.

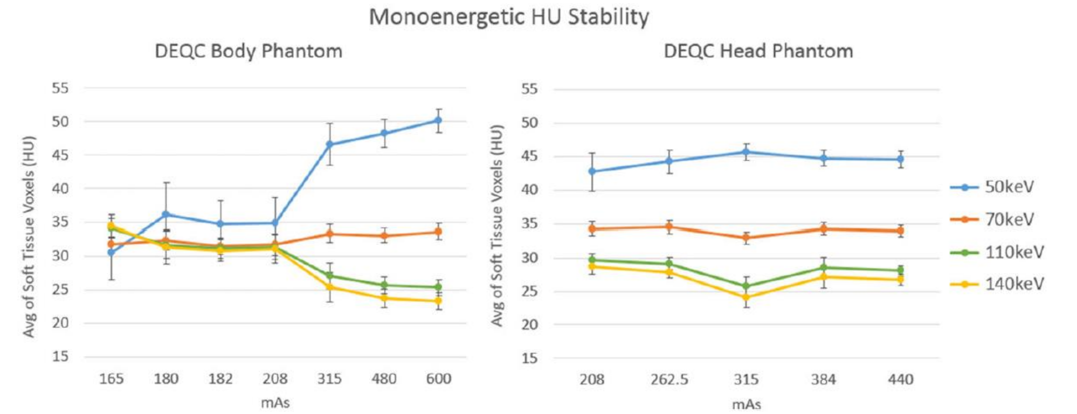


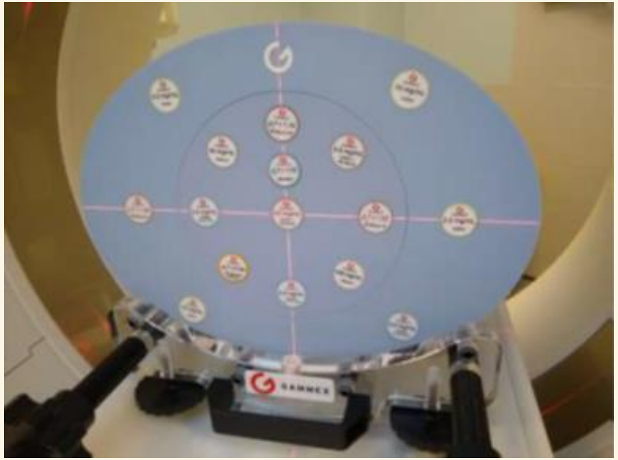
FIG. 4. Monoenergetic HU Stability plotted by the technique parameter isolated as a major variance contributor in Table IX: mAs for both the DEQC body (left) and head phantom (right). Results are shown for all monoenergetic reconstructions investigated (50, 70, 110 and 140 keV). Monoenergetic HU Stability is represented as the average of all voxels across the soft tissue inserts in the phantom (see Fig. 1 for soft tissue insert positioning). Error bars represent standard deviation across 10 scanners and 13 weeks.

Dual energy CT image quality QC

What's that all about then and what should we be doing

Laurence King – Principal Medical Physicist, RUH Bath, 2021

NHS
Royal United Hospitals Bath
NHS Foundation Trust

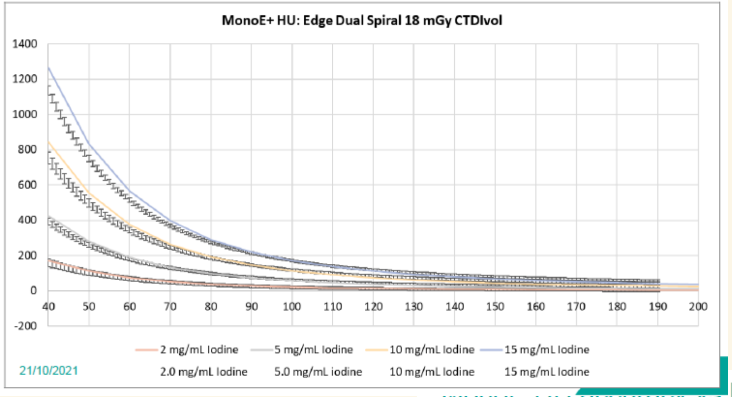


Gammex MECT phantom

-Using three Siemens DECT: Dual Spiral, TwinBeam split filter, Dual Source
-Scanned it based on a default Siemens DE abdomen protocol
- generated MonoE+ images, rho/Z, Iodine maps

MonoE HU accuracy vs NIST-derived HU

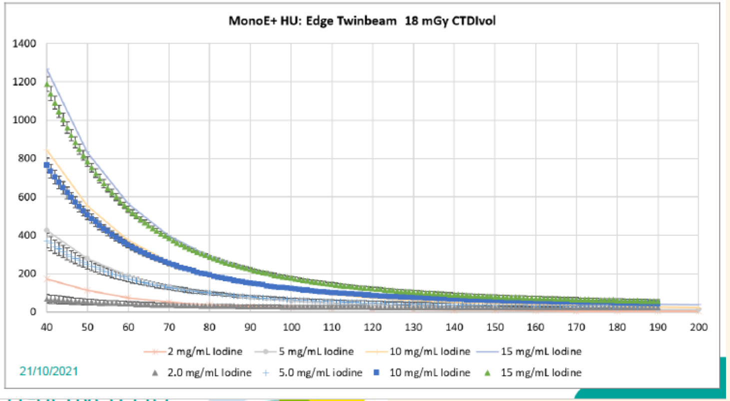
- Nominal MonoE HU values provided in phantom user manual
- EDGE+ DUAL SPIRAL 18 mGy acquisition: IODINE INSERTS



MonoE HU accuracy vs NIST-derived HU

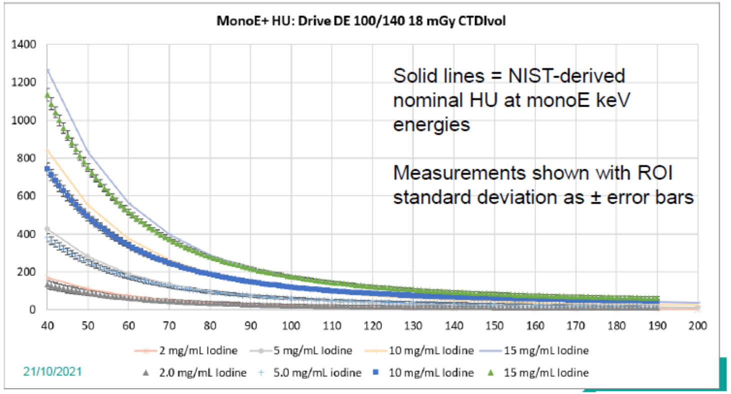
- Nominal MonoE HU values provided in phantom user manual

- EDGE+ TWINBEAM 18 mGy acquisition: IODINE INSERTS



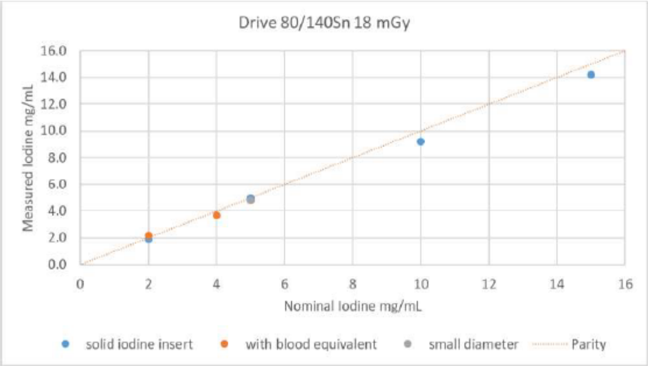
- Nominal MonoE HU values provided in phantom user manual

- DRIVE DUAL SOURCE 100/140Sn 18 mGy acquisition: IODINE INSERTS



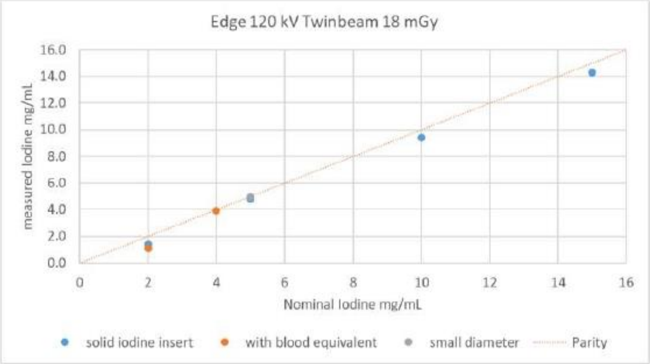
Results – Iodine quantification vs nominal insert values

- DRIVE dual source 80/140Sn at 18 mGy CTDIvol
  - Not significantly different to 100/140Sn data.



Results – Iodine quantification vs nominal insert values

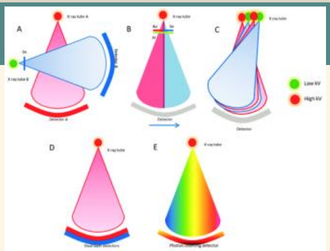
- EDGE TWINBEAM 120 kV 18 mGy CTDIvol
  - Lower iodine quantification accuracy at low concentration? More measurements would be useful.



Advanced Medical Imaging in Diagnosis

Computed Tomography	QC Problem
- Wide beam/multi-detector CT &CBCT	- CT dosimetry
- Reconstruction:	-
- Iterative reconstruction (IR)	
- Deep learning IR	
- AI deep learning IR	
- Automatic tube current modulation	-
- Dual-energy CT/ Multi-energy CT: quantitative analysis	- CT dosimetry
- Mono-energetic image	
- Virtual non-contrast image	
- Iodine map	
- Calcium image,…	
- etc.	

Dosimetric considerations

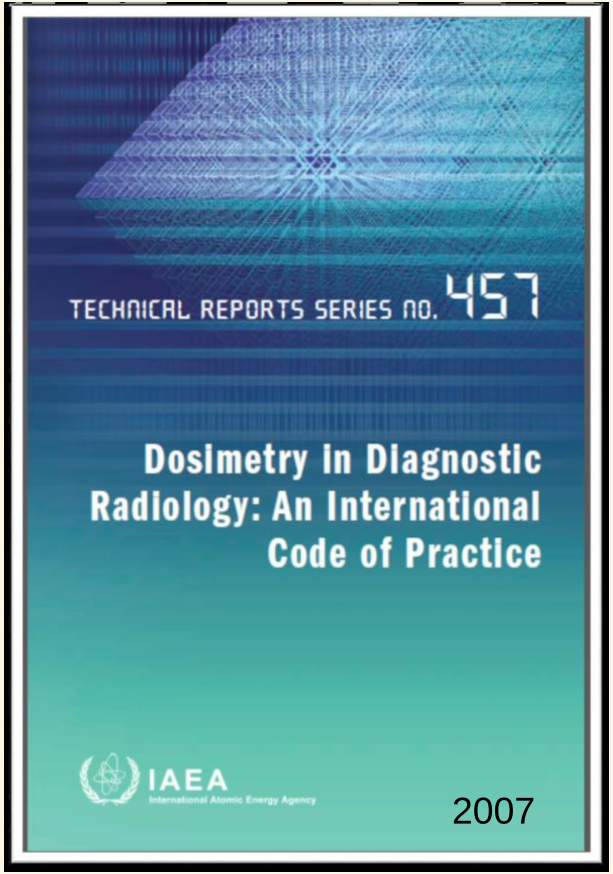


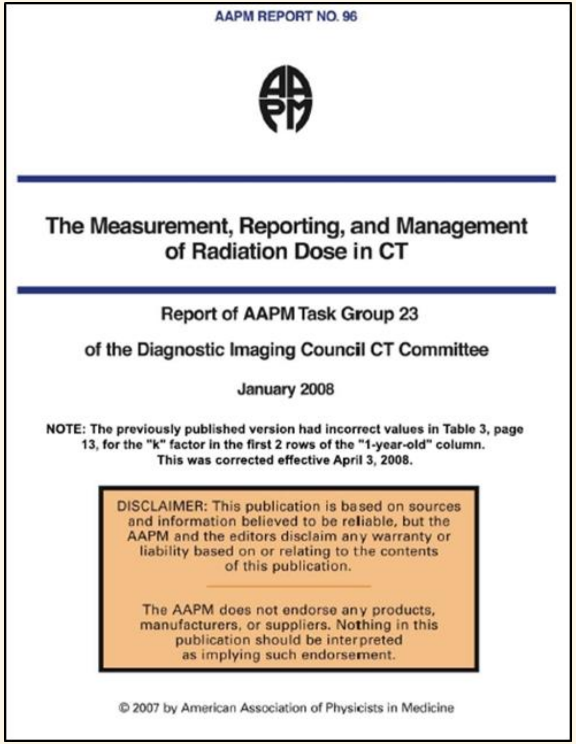
- CTDI-based dosimetry metrics quantify the radiation output of the CT scanner, which is important for standardization and performance assessment.

- Provided that there is increased value in the material-specific information or increased iodine contrast-to-noise ratio, an increase in dose for multi-energy CT with respect to single-energy CT is justified.

- Development of multi-energy protocols therefore requires attention to the quality of the low-energy acquisitions, in addition to dosimetric considerations.

Mccollough et al.: Principles and applications of MECT. Medical Physics, 47 (7), July 2020




AAPM REPORT NO. 96

The Measurement, Reporting, and Management of Radiation Dose in CT

Report of AAPM Task Group 23

of the Diagnostic Imaging Council CT Committee

January 2008

NOTE: The previously published version had incorrect values in Table 3, page 13, for the "k" factor in the first 2 rows of the "1-year-old" column. This was corrected effective April 3, 2008.

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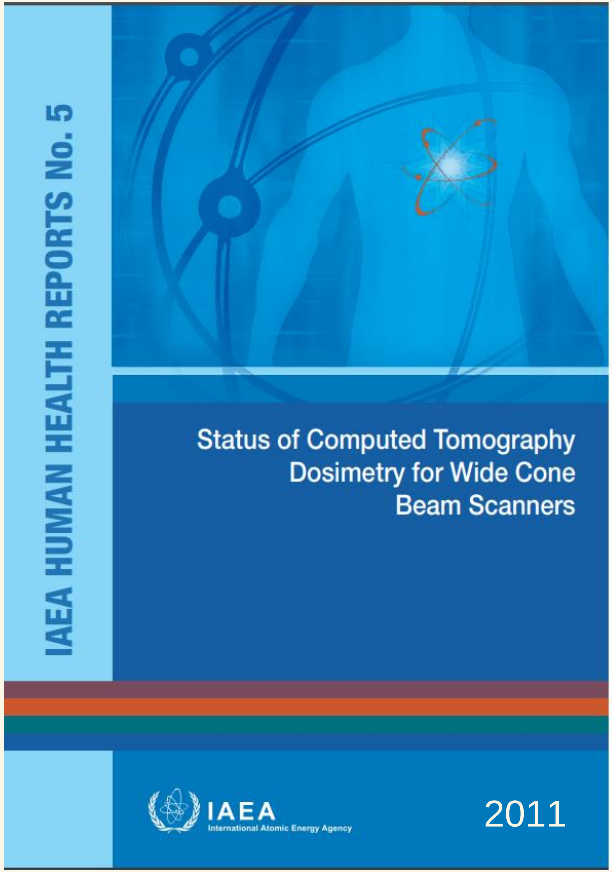
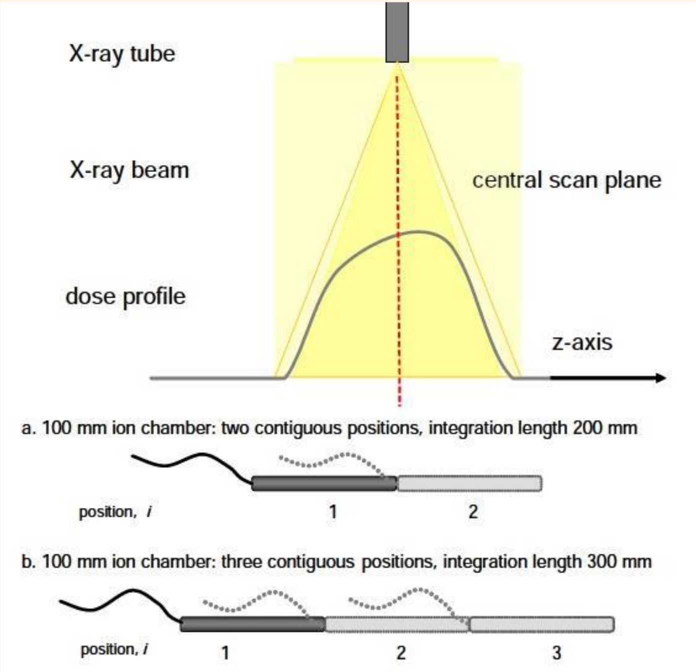




Status of computed tomography dosimetry for wide cone beam scanners' (IAEA human health reports No.5)

TABLE 1. EXAMPLES OF INTEGRATION LENGTHS AND NUMBER OF MEASUREMENTS REQUIRED FOR CTDI$_{FREE\text{-}IN\text{-}AIR}$, ACCORDING TO THE PROPOSED IEC DEFINITION [15] WITH A 100 MM CHAMBER

Nominal beam width (mm)	Minimum integration length (mm)^	Number of incremented measurements of 100 mm ion chamber	Associated Integration length (mm)
20	100	1	100
40	100	1	100
60	100	1	100
80	120	2	200
160	200	2*	200
160	200	3*	300

^ At least, 100 mm or (*N x T*) +40 mm, whichever is the greater

* The 200 mm integration length is sufficient according to the requirement of IEC, however the 300 mm integration length can also be used since the length is a minimum requirement stated.

$$CTDI_{100,(NxT)>40} = CTDI_{100,ref} \times \left(\frac{CTDI_{free\ in\ air,(NxT)}}{CTDI_{free\ in\ air,ref}}\right)$$

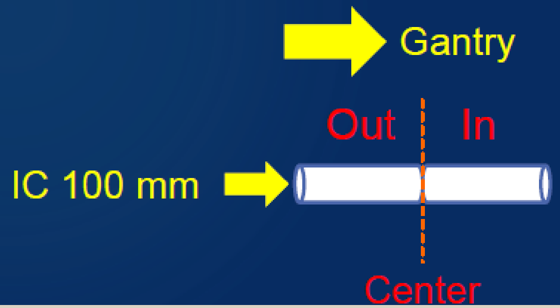
CTDI wide beam: Reference collimation

In Air

No.	$Collimation_{ref}$ (40 mm) [mGy]	$Collimation_{NT}$ (160 mm) [mGy]	
		In	Out
1	9.735	19.62	15.54
2	9.731	19.66	15.38
Ave	9.733	19.64	15.46
Total	9.733	35.1	
$CTDI_{in\ air}$	24.33	21.94	

In Phantom

Position	Reading (mGy)			$CTDI_{100}$ (mGy)	$CTDI_w$ (mGy)
	1	2	Ave		
Center	5.898	5.897	5.90	14.74	15.70
0°	6.889	6.898	6.47	16.18	
3°	6.479	6.481			
6°	5.958	5.942			
9°	6.562	6.565			



$CTDI_{w,160}$ = 15.7 x (21.94/24.33) = 14.16 mGy

Displayed CTDI at 160 mm : 14.12 mGy

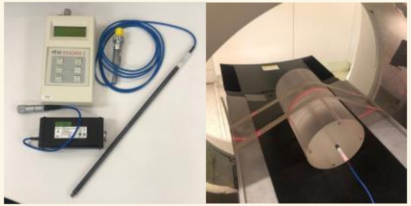
$CTDI_W$: Comparing techniques

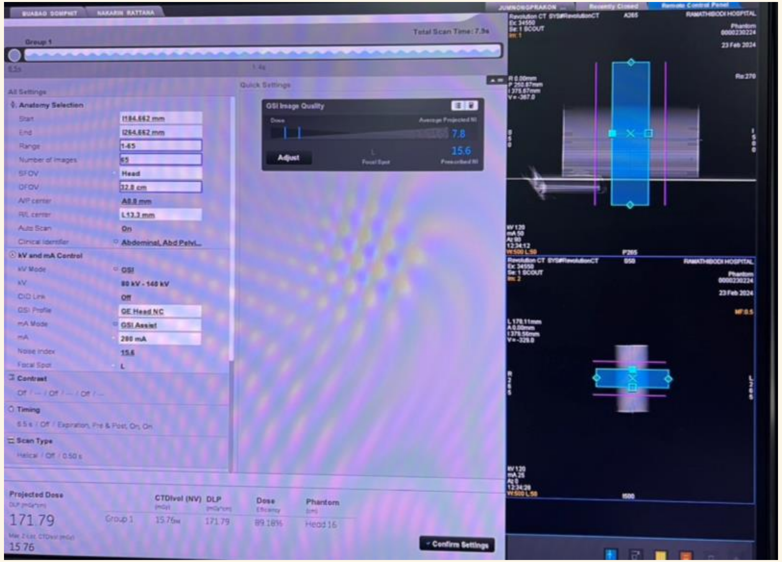
Beam Width	IC, step	$CTDI_w$ (mGy)		Percentage Difference (%)	
		Brain	Abdomen	Brain	Abdomen
80 mm	100 mm, no-step	27.34	8.68	-17.06	-15.05
	100 mm, 2-step	31.88	10.40	-3.29	1.88
	calculated of 100 mm, 2-step	30.02	9.86	-8.94	-3.45
	300 mm, no-step	32.97	10.21	-	-

Beam Width	IC, step	$CTDI_w$ (mGy)		Percentage Difference (%)	
		Brain	Abdomen	Brain	Abdomen
160 mm	100 mm, no-step	19.07	6.46	-41.27	-36.38
	100 mm, 2-step	31.13	10.09	-4.15	-0.58
	100 mm, 3-step	32.99	10.36	1.58	2.05
	calculated of 100 mm, 2-step	27.31	8.92	-15.90	-12.12
	calculated of 100 mm, 3-step	27.35	8.94	-15.79	-11.93
	300 mm, no-step	32.48	10.15	-	-

S. Payothip. CTDI measurements in wide beam CT scanner: Thesis Medical physics program, Ramathibodi Hospital

kV switching DECT





300 mm ionization chamber

GSI Techniques:

- 280 mA, 0.5 sec, pitch 0.984
- collimation 0.625*40 = 25 mm, scan range 80 mm
- Displayed $CTDI_{vol}$ 15.76 mGy, DLP 173.09 mGy.cm

Position	Avg. reading (mGy)	$CTDI_{100}$ (mGy)	$CTDI_{vol}$ (mGy)
Center	158.75	19.84	18.95
Peripheral	148.11	18.51	

% error = -14.8%

Principles and applications of multienergy CT: Report of AAPM Task Group 291

C. H. McCollough, et al.

Med. Phys. 47 (7), July 2020 0094-2405/2020/47(7)/e881/32

- CTDI-based dosimetry metrics quantify the radiation out-put of the CT scanner, which is important for standardization and performance assessment.
- The effective dose is often desirable used to estimate the relative risk from a specific CT exam in comparison to other sources of ionizing radiation.
- Two common methods used to determine effective dose from CT examinations are

(a) Monte Carlo simulations that calculate organ-dose estimates and use tissue-weighting coefficients from the International Commission on Radiological Protection (ICRP),

(b) a method that converts the dose-length product (DLP) to effective dose using published conversion coefficients

AAPM REPORT NO. 111

Comprehensive Methodology for the Evaluation of Radiation Dose in X-Ray Computed Tomography

A New Measurement Paradigm Based on a Unified Theory for Axial, Helical, Fan-Beam, and Cone-Beam Scanning With or Without Longitudinal Translation of the Patient Table

Report of AAPM Task Group 111:
The Future of CT Dosimetry

February 2010

AAPM REPORT NO. 200

The Design and Use of the ICRU/AAPM CT Radiation Dosimetry Phantom: An Implementation of AAPM Report 111

The Report of AAPM Task Group 200

January 2020

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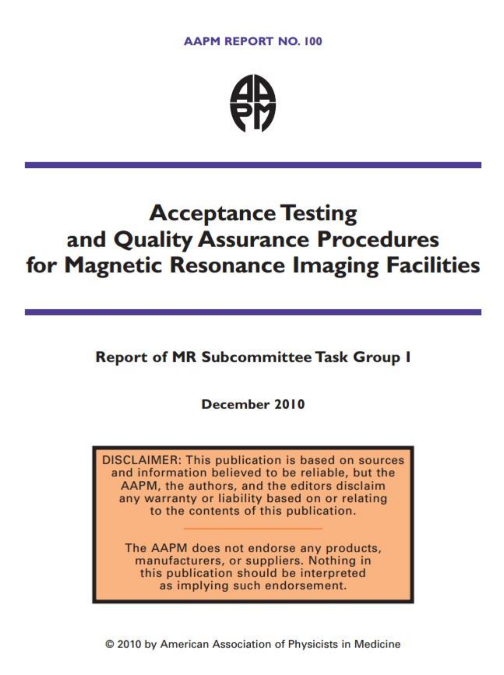
- L. King. Dual energy CT image quality QC- What’s that all about then and what should we be doing: PPT.. CTUG MEETING 2021 • DEVELOPING A DUAL ENERGY CT QA PROGRAM.
- C. H.McCollough, et al. Principles and applications of multienergy CT: Report of AAPM Task Group 291. Med. Phys. 47 (7), July 2020.
- J.L.Nute, et al. Development of a dual-energy computed tomography quality control program: Characterization of scanner response and definition of relevant parameters for a fast-kVp switching dual-energy computed tomography system. Med. Phys. 45 (4), April 2018.
- C.A.Green, et al. Design and implementation of a practical quality control program for dual-energy CT. . J Appl Clin Med Phys. 2021;22(10):249–260.

Advanced Medical Imaging in Diagnosis

Magnetic Resonance Imaging	QC problem
- High Magnetic Field strength - Quantitative data - AI analysis report	- MRI QC: Phantom - Update: ACR MR safety 2023

MRI QC


AAPM REPORT NO. 100

Acceptance Testing
and Quality Assurance Procedures
for Magnetic Resonance Imaging Facilities

Report of MR Subcommittee Task Group I

December 2010

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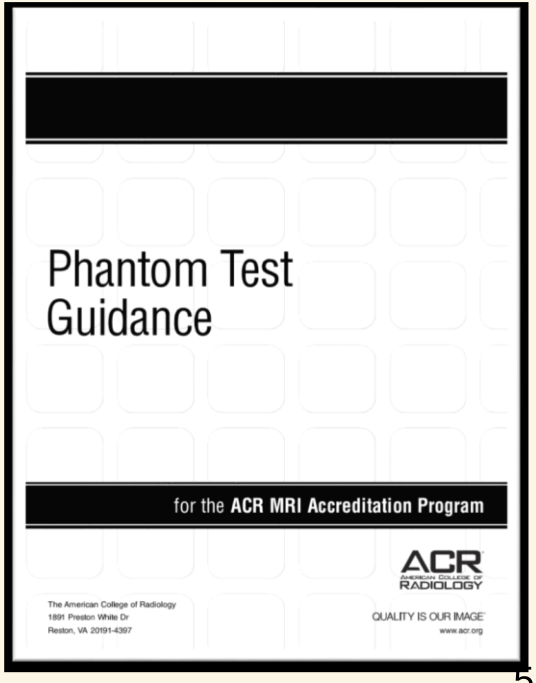
2015
Magnetic Resonance Imaging

QUALITY CONTROL MANUAL

Radiologist's Section
MRI Technologist's Section
Medical Physicist/MRI Scientist's Section


Phantom Test
Guidance

for the ACR MRI Accreditation Program

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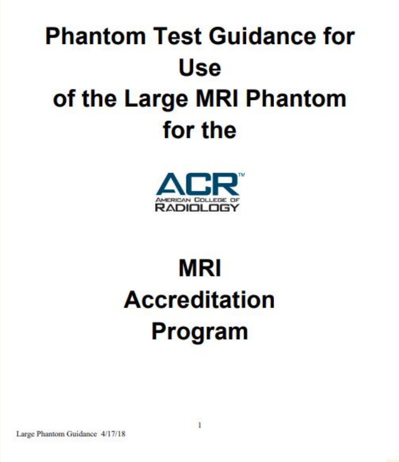
Phantom Test Guidance for Use
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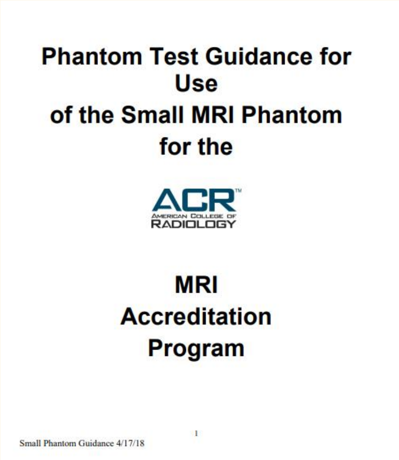
1

Large Phantom Guidance 4/17/18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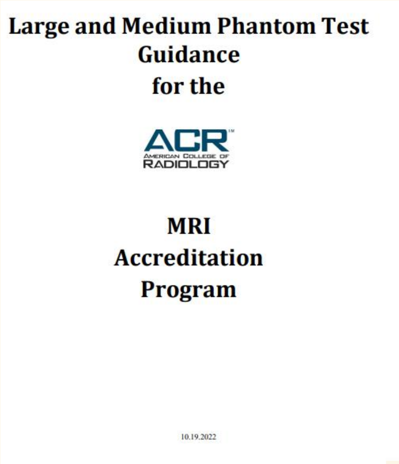
Small Phantom Guidance 4/17/18


Large and Medium Phantom Test Guidance
for the

ACR AMERICAN COLLEGE OF RADIOLOGY

MRI
Accreditation
Program

10.19.2022

Task group 284 report: magnetic resonance imaging simulation in radiotherapy: considerations for clinical implementation, optimization, and quality assurance

Carri K. Glide-Hurst[a)]
Department of Human Oncology, University of Wisconsin—Madison, Madison, WI 53792, USA

Eric S. Paulson
Department of Radiation Oncology, Medical College of Wisconsin, Milwaukee, WI 53226, USA

Kiaran McGee
Department of Diagnostic Radiology, Mayo Clinic, Rochester, MN 55905, USA

Neelam Tyagi
Medical Physics Department, Memorial Sloan-Kettering Cancer Center, New York, NY 10065, USA

Yanle Hu
Department of Radiation Oncology, Mayo Clinic, Phoenix, Arizona 85054, USA

James Balter
Department of Radiation Oncology, University of Michigan, Ann Arbor, MI 48109, USA

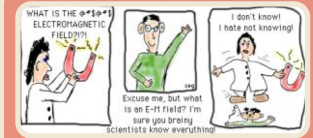
John Bayouth
Department of Human Oncology, University of Wisconsin—Madison, Madison, WI 53792, USA

(Received 30 June 2020; revised 12 December 2020; accepted for publication 16 December 2020; published 27 July 2021)

Committee on ACR MRI QC program

Radiologist

Technologist



Physicist /Scientist

Nurses/ other physicians

	Performance Tests (Those in italics indicate tests that can be performed by scanning the ACR MRI Phantom)	Technologist QC (Weekly)	Medical Physicist/ MR Scientist (Annually)
1	Setup and Table Position Accuracy	X	X
2	Center Frequency	X	X
3	Transmitter Gain or Attenuation	X	X
4	*Geometric Accuracy Measurements*	X	X
5	*High-Contrast Spatial Resolution*	X	X
6	*Low-Contrast Detectability*	X	X
7	Artifact Evaluation	X	X
8	Film Printer Quality Control (if applicable)	X	X
9	Visual Checklist	X	X
10	Magnetic Field Homogeneity		X
11	*Slice-Position Accuracy*		X
12	*Slice-Thickness Accuracy*		X
13	Radiofrequency Coil Checks		X
	a. SNR		X
	b. Percent Image Uniformity (PIU)		X
	c. Percent Signal Ghosting (PSG)		X
14	Soft-Copy (Monitor) Quality Control		X
15	MR Safety Program Assessment		X

ACR MRI QC program

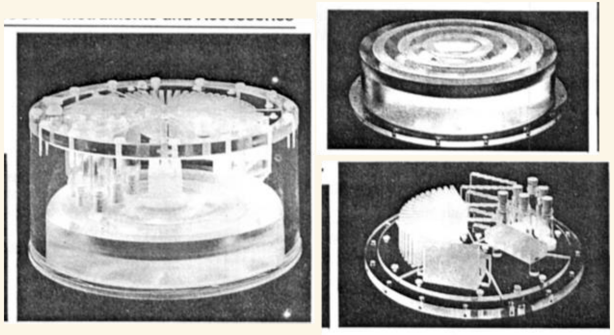
Technologist's role

- weekly QC Test

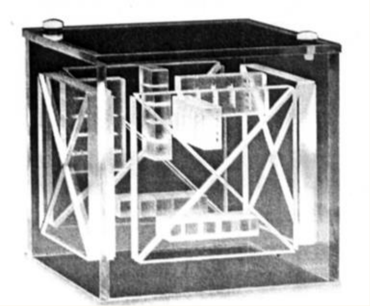
Physicist's role

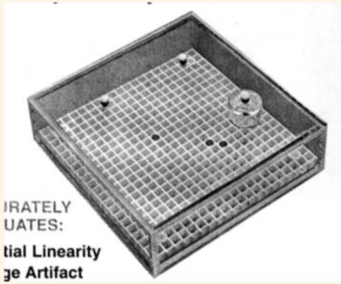
- Acceptance test
- Setting up QC program
- Annual QC

Quality Control: Phantom



AAPM phantom





Old

New

Large ACR MRI phantom

mid-2021

Small

Medium ACR MRI phantom

Table 1: Large and Medium Phantom resolution patterns and internal (signal producing) dimensions.

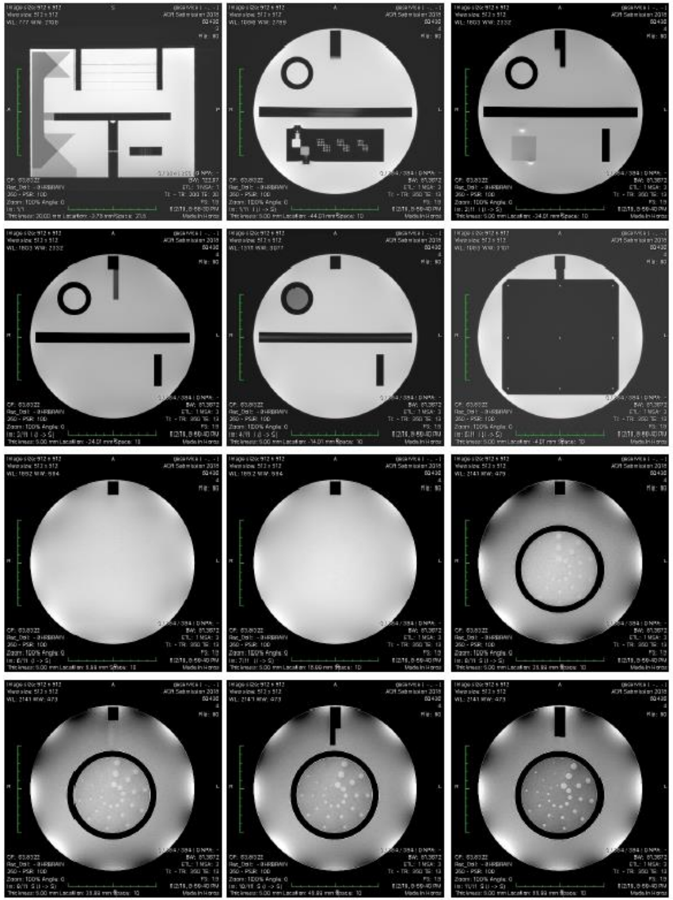
Phantom	Head Coil	Resolution Pattern (mm)	Internal Length (mm)
Large	Head coils large enough to fit the large phantom	1.1, 1.0, 0.9	148
Medium	Smaller phased-array head coils	1.1, 1.0, 0.9, 0.8	134

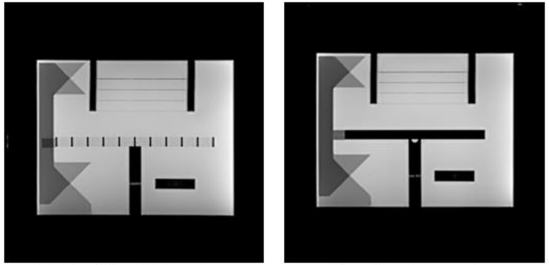
Note: - Now that both medium and large phantoms are approved for accreditation of MR scanners in the modular Magnetic Resonance Accreditation Program (MRAP), sites must submit phantom images acquired using a head coil that is routinely used for clinical brain imaging on the scanner and must use the largest phantom that fits inside that head coil.

- Facilities with scanners that do not have a head coil and/or do not routinely perform brain imaging should use the small phantom in the knee coil to obtain phantom images for accreditation review.

Additional recommendation

- It is not acceptable to cool the phantom before scanning, to improve SNR.
- Phased array head coils naturally produce images that are less uniform due to the smaller coil elements, as compared to quadrature coils. Be sure to apply the vendor’s intensity correction to the ACR T1 and T2 series if they were acquired using a multi-channel phased array coil. The correction goes by different names depending on vendor (SCIC, PURE, CLEAR, Normalize, Pre-scan normalize, and B1 Filter are some examples).
- It is not acceptable to use deep learning or artificial intelligence (DL or AI) reconstruction options for phantom submissions.

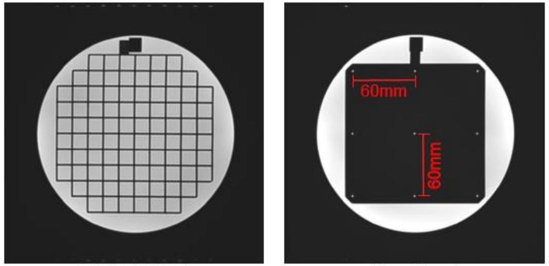




Original Sagittal Localizer

New Sagittal Localizer

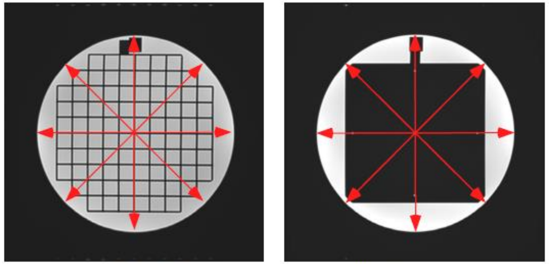
Solid bar instead of grid structure.



Original Slice 5

New Slice 5

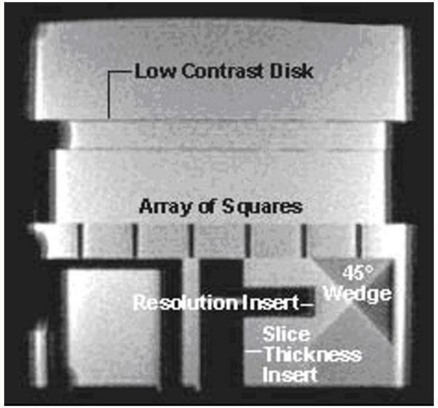
3 x 3 grid of holes

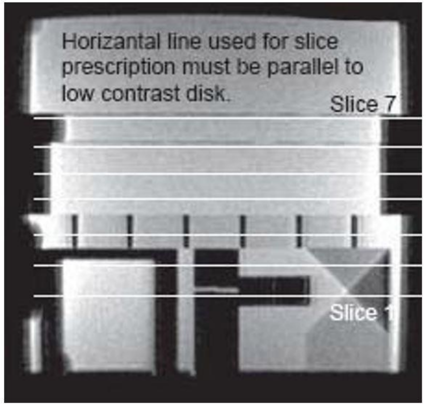


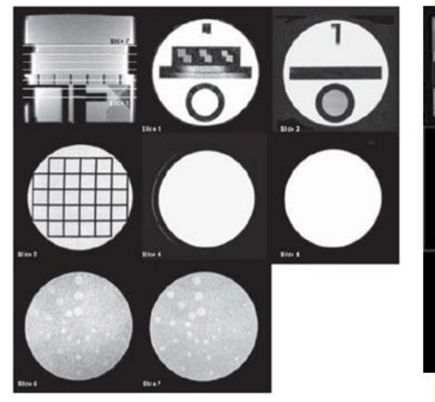
Diameter measurements are still 190mm

June of 2019

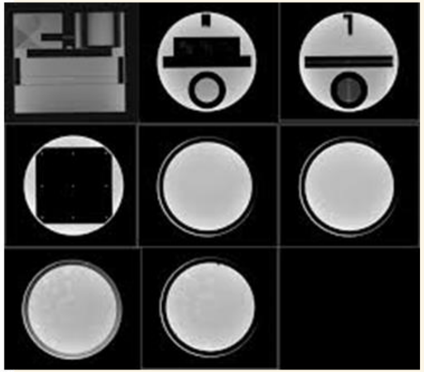
Small phantom for knee coil







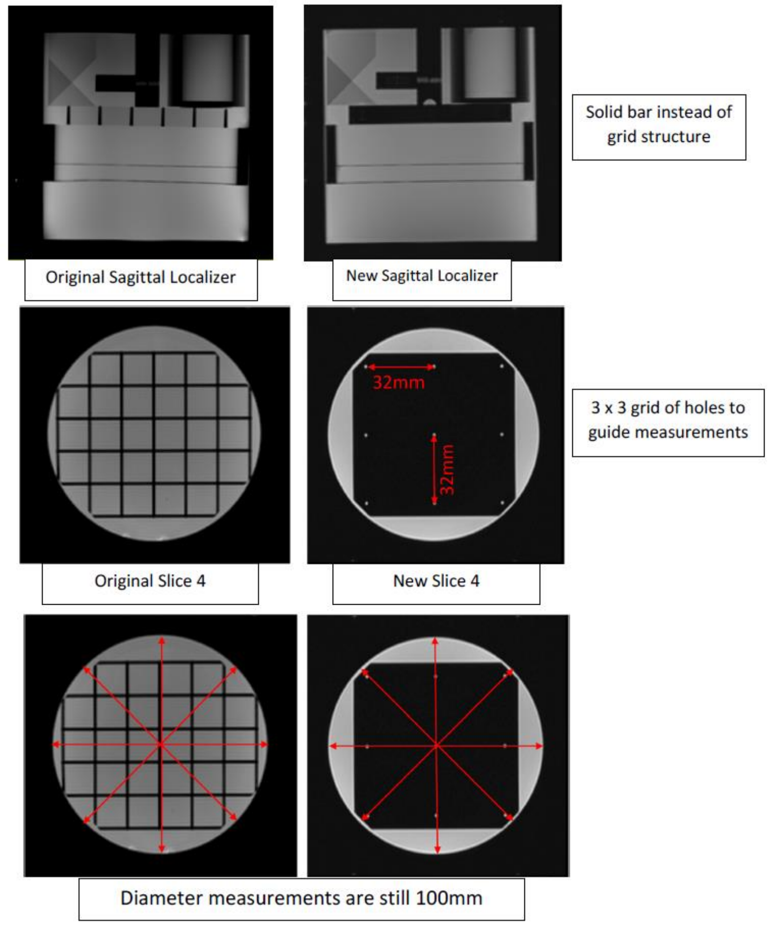
April of 2018



New-January of 2021

- A horizontal line used for slice prescription should be parallel to the low contrast disks located at the top of phantom.
- 5 mm slice thickness, 3 mm gap, 12 cm FOV, 192 × 152 matrix.

https://accreditationsupport.acr.org/support/solutions/articles/11000061036-small-phantom-testing-mri-revised-3-6-23-



1. Geometric accuracy
2. High contrast spatial resolution
3. Slice thickness accuracy
4. Slice position accuracy
5. Image intensity uniformity
6. Percent signal ghosting
7. Low contrast object detectability

Series	Pulse Sequence	TR/TE (ms)	FOV (mm) (frequency)	FOV (mm) (phase)	# Slices	Slice thickness (mm)	Slice gap (mm)	#Avgs	Matrix (frequency)	Matrix (phase)	Scan Time (min:sec)
*ACR Sag localizer	Spin echo	200/20	250	250	1	10*	N/A	1	256	256	0:56
ACR Axial T1	Spin echo	500/20	250	250	11	5	5	1	256	256	2:16
ACR Axial T2	**Spin echo	2000/80	250	250	11	5	5	1	256	256	8:56
***Site Axial T1 Brain					11 22†	5 5†	5 0†				
***Site Axial T2 Brain					11 22†	5 5†	5 0†				

*For the ACR Sag localizer 10mm slice thickness is preferred, but 20 mm is acceptable.

**For the ACR T2 series single echo spin echo is preferred, but double echo spin echo (TR 2000, TE 20/80) is acceptable. Fast/Turbo spin echo must not be used.

***Blank fields indicate where to use the site's clinical parameters from routine brain protocols.

†For 3DFT clinical sequences only

Slice locations in Large and medium phantom

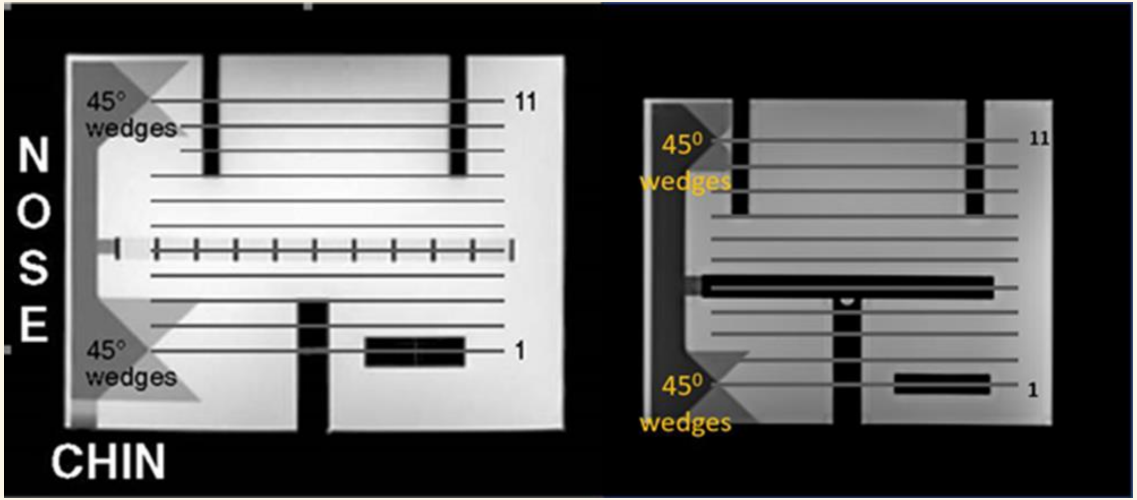
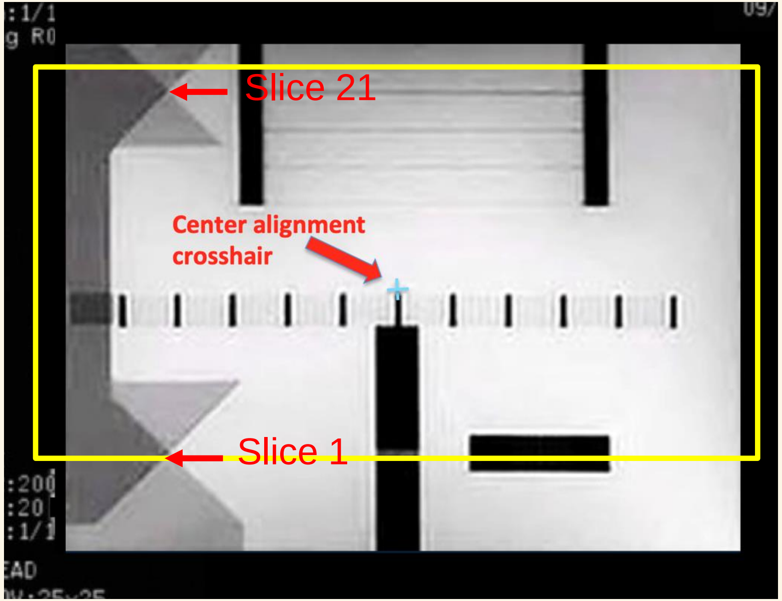


Figure 2: Sagittal localizers of the Large (left) and Medium (right) phantoms showing the 11 required axial slice locations and the paired 450 wedges. The words “CHIN” and “NOSE” indicate where those words are etched into the phantoms as an aid to orienting them for scanning as if they were a head.

3DFT site protocols



https://mriquestions.com/slice-parameters.html

- When replicating 3DFT site protocols in the phantom, the operator should prescribe 21 slices of 5mm thickness to ensure that Slice 1 is centered on the vertex of the angle formed by the crossed wedges at the inferior end of the phantom and slice 21 falls on the vertex at the superior end of the phantom.
- In this case the images to be analyzed will be images 1, 3, 5, 7, 9, 11,13, 15, 17, 19, and 21. The others are just “gap” slices.

Low-contrast object detectability: Update criteria

ACR 2004

Criteria : ≥ 9 spokes (for <3T)

≥ 37 spokes (for 3T)

ACR 2015

Table 1. Recommended slice of the ACR large MRI phantom to use for weekly low-contrast detection QC and typical number of spokes visible in the recommended slice and on all slices as a function of magnetic field strength.

Low-Contrast Detectability Recommendations by Field Strength for Large ACR Phantom for the ACR T1 Series

Field Strength	Recommended weekly QC slice #	Typical number of spokes visible in recommended QC slice	Total number of spokes on all slices
0.2	11	4	12
0.3	11	5–7	21
0.5	10	6–9	27
0.7	10	6–8	31
1.0	9	7–8	34
1.5	8	6–9	36
2.0	8	9–10	38
3.0	8	10	40

Nominal Field Strength	ACR T1 LCD Limit (total spokes)	ACR T2 LCD Limit (total spokes)
<1.5T	≥7	≥7
1.5T - <3T	≥30	≥25
3T	≥37	≥37

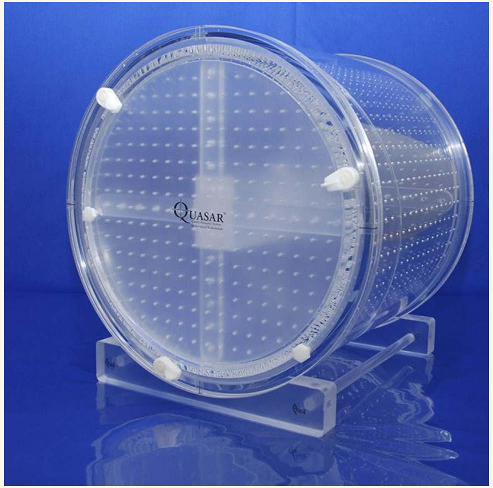
Limits apply to both the Large and Medium phantoms.

Beginning mid-2021 the LCD limits for 1.5T - <3T scanners were raised.

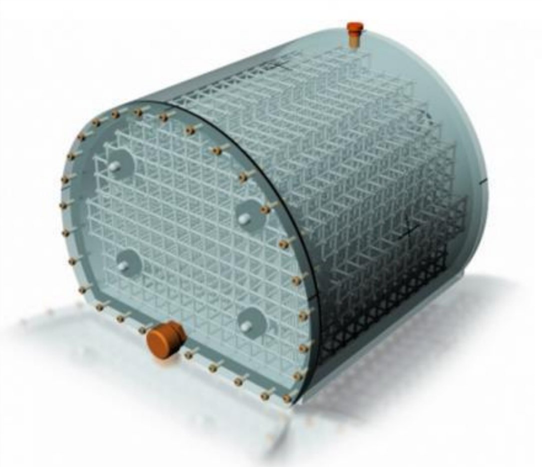
-The ACR T1 axial series must have a total LCD score of at least 30 to pass and the ACR T2 series must score at least 25 to pass If either ACR series fails, the site can pass if the site T1 series total LCD score is at least 30 and the site T2 score is at least 25.

- For 3T scanners, both ACR axial series must have a total score of 37 spokes to pass. If the score for either ACR series fails, then evaluate the site series. If the score for both site series is at least 37, then the scanner passes this test.

Large field distortion phantom of MRI



MR Guided Radiation Therapy, Geometric Distortion
- Software features include the ability to separate distortions caused by main magnetic field inhomogeneities from those caused by gradient non-linearities.

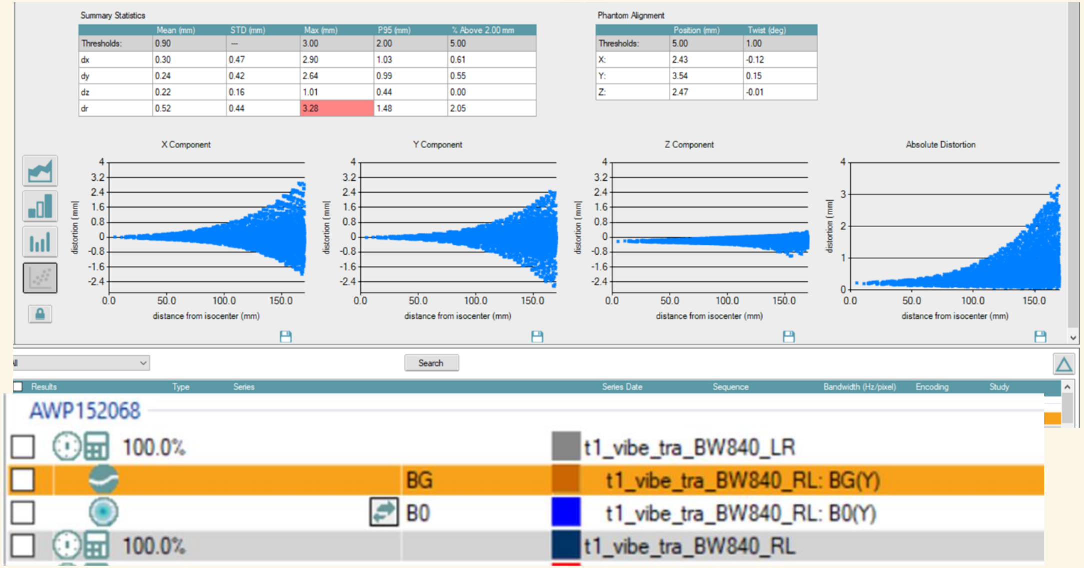


Large Field MRI Distortion Phantom, Model 604-GS
- used to assess magnetic resonance imaging distortion caused mainly by the nonlinearity of the magnetic gradients.

Figure 1. The commercially available phantom from Spectronic Medical AB is designed to assess geometric accuracy. It was placed on the MRI table without table top. Lines on the phantom surface were used to align the phantom using the built in laser positioning system on the MRI.

Limitation: cannot separate the object induces distortion of phantom even though the small magnitude and considered negligible

QUASAR MRID^{3D} Geometric distortion phantom and software analysis

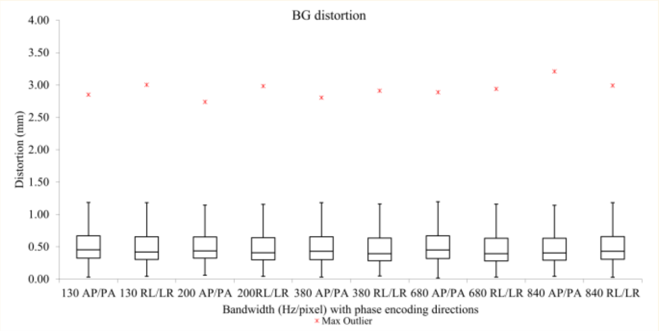


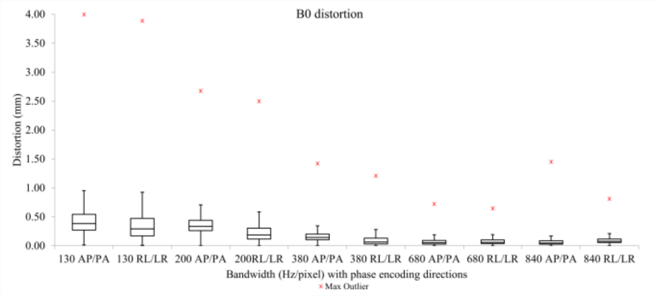
Calculate geometric distortion by software analysis (**Inverse gradient method**) separated:

- B_G distortion
- B_0 distortion

Effects of systemic geometric distortion of MRI simulation on dosimetry accuracy.
K. Chaknam's Thesis, 2023

To quantify the residual systemic geometric distortion of 1.5T MRI simulation and evaluate the effect on dosimetric accuracy of prostate cancer radiotherapy.





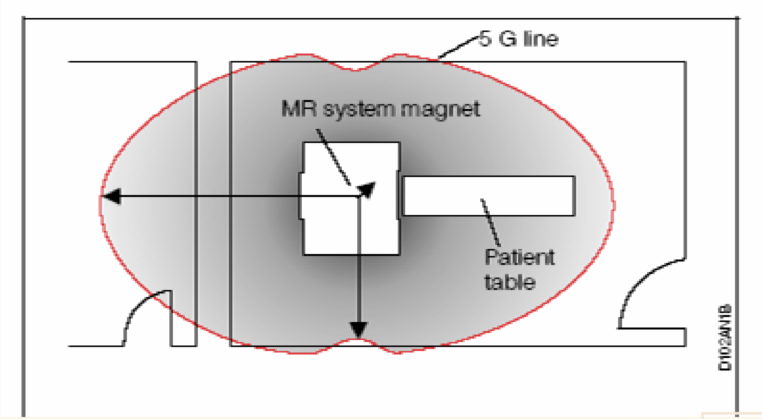
-The results demonstrated that mean residual magnitudes of the systemic geometric distortion for all bandwidth and phase encoding directions agree with the criteria of ACR recommendation and AAPM TG-284.

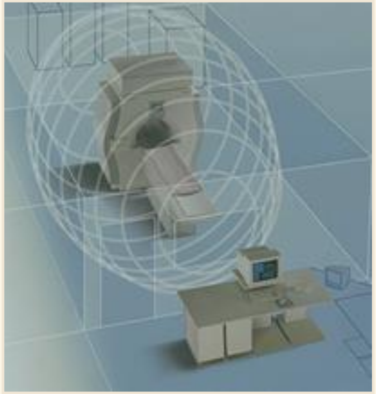
- The effect of varying bandwidth showed that impact on the inhomogeneity of main magnetic field or B0 distortion more than the GNL distortion.

-The percentage dose error of all structures at all bandwidths and phase encoding directions were within 2% except rectum and bladder in some cases, but slightly.

Date	Section	Change
2/1/2023 *	All	Reformat of the manual into chapters
	Introduction	Includes basic introduction of MR risks and safety concerns related to the MR fields.
	Management of MR Safety and Polies and Standard Operating Procedures	Formerly, establishing, implementing and maintaining MR safety policies and procedures. Provides new points to consider when developing MR policies and procedures.
***	MR Environment	IEC update of fringe field to 9 gauss.
	MR Personnel	Includes updated language for MR Safety Training levels and responsibilities.
		Includes training checklist.
		Includes updated staffing guidance.
		Includes remote scanning guidance.
	MR Screening	Includes reorganization of information involving staff/personnel screening, patient screening, screening for ferromagnetic material, risk identification, MR Safe attire and ferromagnetic detection
	Final Stop/Final Check	Includes routine and augmented guidance and new language about removal of hearing aids before Zone IV entry.
***	Zone IV Exam Preparation and Completion	New section
	MRI Fields and Safety Concerns	Includes reorganization of Time-Varying Radiofrequency (RF) Magnetic Field to include whole body heating, focal heating and resonant heating.
		Includes reorganization of Time-Varying Magnetic Field Gradient (dB/dt) to include auditory considerations, induced voltages and peripheral nerve stimulation.

Date	Section	Change
	Classification of Objects and Medical Devices in the MR Environment	Formerly implants, devices and objects section. Includes MR safety labeling classifications.
	Introducing Portable Metallic Objects and Equipment in the MR Environment	New section (formerly included in implants, devices and objects) contains labeling and testing, MR Unsafe transport equipment temporary provisions and portable objects in Zone IV
	Managing Patients/Subjects with Medical Devices in the MR Environment	New section (formerly included in implants, devices and objects) containing active implanted/on-planted devices, passive implanted devices, and implants, devices, or objects discovered during MR examination.
***	Emergency Situations	New Section (formerly included in MR Environment) includes emergency stop and emergency power off, quench, fire, code, and entrapment.
	Special Patient and Personnel Considerations	Formerly, special patient population considerations. Includes reorganization of information including pregnancy, pediatric MR safety concerns, claustrophobia, anxiety, and sedation, high BMI/large body habitus (new), prisoners/detainees and parolees.
*	Alternative MR Environments	New Section (formerly found in MR environment) includes PET/MR, intraoperative/interventional MR, MR Simulator & MR-LINAC (new), point of care MR system (new) and mobile MR scanner (new) information.
	Appendix 1	New appendix containing MR Safety Policies and Standard Operating Procedures guidance.
	Appendix 5	New appendix containing implanted device MR risk/safety assessment.





	0.5 T	1.0 T	1.5 T
Radial (x and y)	2.1 m	2.3 m	2.4 m
Axial (z)	2.8 m	3.3 m	3.8 m

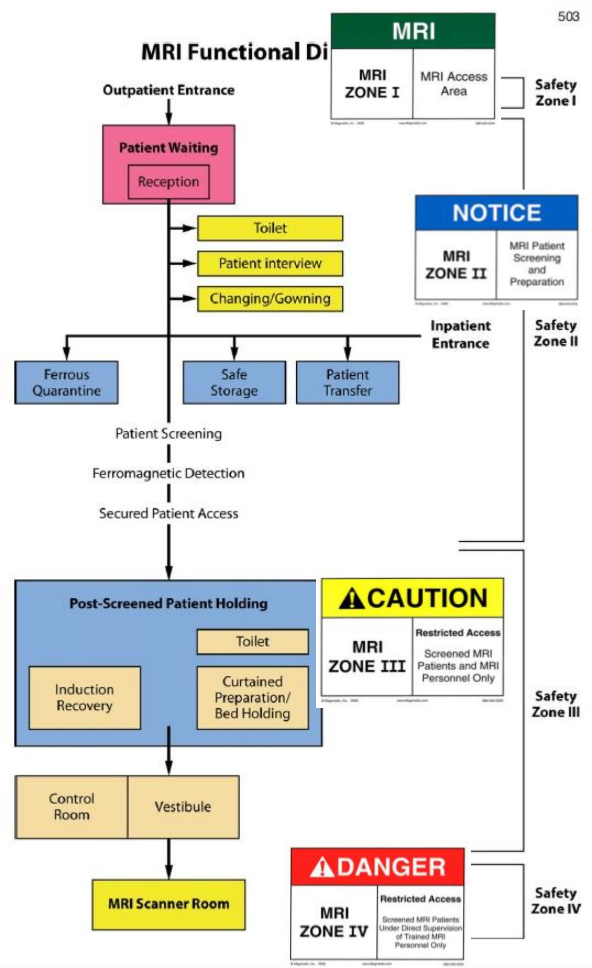
Location of 5 G or 0.5 mT line for MR system – Identify it clearly

Update!!!

Prior IEC standard: The 5 gauss (G) line (0.50 mT field contour) has been the standard threshold for risk.

Recent update!!!

A recent update to the IEC standard has revised the fringe field limit to 9 gauss (0.9 mT) (IEC 60601-2-33:2022)



- MRI site divided in 4 zones:
  - Zone I: This is a public access area with no restrictions.
    - safe, freely accessible
  - Zone II: This is a semi restricted area where patients and hospital staff can interact.
    - zone where patients are screened
  - Zone III: This area is completely physically restricted from non MR personnel especially the general public.
    - access strictly restricted, directly connected to zone IV, screening before entering
  - Zone IV: Magnet room and associated projectile zone:
    - Access restricted, free access might result in serious injury

JOURNAL OF MAGNETIC RESONANCE IMAGING 37:501–530 (2013)

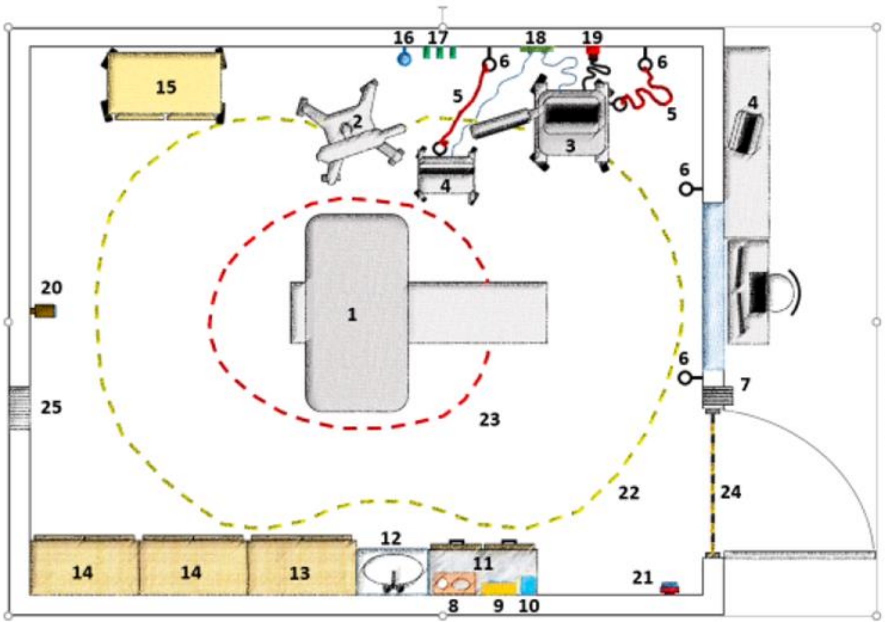


Figure 21. Typical configuration of an inpatient MR scanner. The design of Zone IV should consider the optimal workflow during more complex MR examinations, such as those requiring anesthesia. It is recommended that dedicated space is devoted to the anesthesia ventilator and physiologic patient monitoring equipment, typically away from the door. Similarly, anesthesiologists, respiratory technicians and other personnel supporting the patient must have dedicated space to perform their functions. A clear path between the scanner door and the patient ensures easy access to the patient by the MR Technologist and nursing, and a route for fast transportation of the patient out of Zone IV in the event of a medical emergency. In addition to the standard 5 gauss line marking on the floor, a 200-gauss line is recommended since this limit is often stipulated in labeling for MR Conditional equipment frequently used in Zone IV. Reliable tethering prevents this equipment from crossing the 200-gauss line.

Specific Absorption rate (SAR)

is the mass normalized ***rate*** of energy absorption. measured in watts/kg of tissue.
SAR is of the type:

$$SAR \propto \frac{B_0^2 \cdot \alpha^2 \cdot B_1^2 \cdot D}{\rho}$$

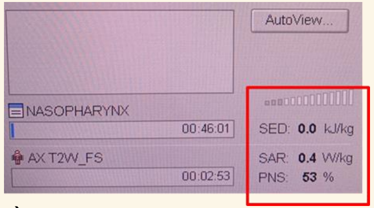
with:

B_0 = static magnetic field amplitude
B_1 = RF pulse amplitude
α = flip angle
D = cyclic ratio (fraction of the duration of the sequence during which the RF waves are transmitted)
ρ = density

Time-Varying Radiofrequency (RF) Magnetic Field(B1): SAR limits

IEC 60601-2-33:2010: medical electric equipment

	Whole-body SAR	Partial-body SAR	Head SAR	Local SAR (a)		
Body region →	whole body	exposed body part	head	head	trunk	extremities
Operating mode ↓	(W/kg)	(W/kg)	(W/kg)	(W/kg)	(W/kg)	(W/kg)
Normal	2	2–10 (b)	3.2	10 (c)	10	20
1st level controlled	4	4–10 (b)	3.2	20 (c)	20	40
2nd level controlled	>4	>(4–10) (b)	>3.2	>20 (c)	>20	>40
Short-duration SAR	The SAR limit over any 10 s period shall not exceed two times the stated values					



Note: Averaging time of 6 minutes.
(a) Local SAR is determined over the mass of 10 g.
(b) The limit scales dynamically with the ratio "exposed patient mass / patient mass":
Normal operating mode: Partial body SAR = 10 W/kg − (8 W/kg × exposed patient mass / patient mass).
1st level controlled: Partial body SAR = 10 W/kg − (6 W/kg × exposed patient mass / patient mass).
(c) In cases where the orbit is in the field of a small local RF transmit coil, care should be taken to ensure that the temperature rise is limited to 1 °C.

https://en.wikipedia.org/wiki/Specific_absorption_rate

Specific Energy Dose (SED)

- SED is not a rate, but rather the ***total* energy absorbed** by a patient during an MRI scan.
- It is usually measured in Joules/kg body weight. The two measures are related by the equation:

SED = SAR x total sequence acquisition time

- Unit is Joule/kg, (SAR –W/kg, W=Joule/sec)
- The SED can be more meaningful than SAR because it reflects the total energy deposited during the entire scanning period.

https://mriquestions.com/sed-vs-sar.html

SED & SAR

IEC 60601-2-33	SED Kj/Kg	SAR Whole-Body W/Kg	SAR Head W/Kg	SAR local head/torso W/Kg	SAR local extremities W/Kg	dB/dt (PNS %)
LOW SAR		IEC 60601-2-33:2010+AMD1:2013+AMD2:2015 CSV Consolidated version				
NORMAL LEVEL	14,4	< 2	< 3,2	< 10	< 20	PNS 80%
FIRST LEVEL	14,4	≥2 < 4	< 3,2	< 20	< 40	PNS 100%
SECOND LEVEL	14,4	≥ 4	> 3,2	IRB Limit	IRB Limit	IRB Limit

-The SED limit for the Siemens scanner is 14,400 J/Kg.
-This is equivalent to scanning in normal operating mode (2W/kg) for 2 hours.
-Siemens will display a warning threshold at 6,000 J/Kg. This will occur if scanning in normal mode (2W/Kg, continously for 50 mins).

MRI for Pregnant Patient

Patient pregnancies: The vast majority of data today has failed to show that exposure to MR has deleterious effects on the developing fetus. Nevertheless, if pregnancy is established, the decision to proceed with a noncontrast MR study at 1.5 T should be based on the medical benefits weighed against unknown potential risk.

The safety of MRI at field strengths higher than 1.5 T (ie, 3 T, 7 T) during pregnancy has not been thoroughly assessed. However, the preponderance of research studies has failed to discover any reproducible harmful effects of exposure of the mother or developing fetus to the 3 T or weaker magnetic fields used in the routine clinical MRI process.[25] Theoretical concerns include time-varying gradient and RF magnetic fields, potential acoustically related safety issues, and heat deposition in tissue, respectively. There is not much peer-reviewed literature regarding the acoustic safety of fetal scanning, but the majority of published material on this topic has failed to find deleterious effects on newborn hearing if exposed to MRI in utero.[26–30] The thermally related theoretical concerns are mitigated by results from experiments in pregnant pigs exposed to standard MR sequences commonly used in clinical practice that are associated with relatively high specific absorption rate (SAR) levels (ie, half-Fourier single-shot spin echo). Such studies failed to demonstrate substantial heating in fetal tissues or amniotic fluid when imaging at 3 T with normal-operating-mode SAR levels and a maximum scan time of 30 minutes.[31,32] Therefore, 3 T MR examinations performed within normal operating mode for durations less than 30 minutes should be considered safe in pregnant patients. Ultimately, the decision to image a pregnant patient at 3 T should be based on local institutional policies, medical needs, and accessibility to 1.5 T versus 3 T MR scanners. At this point, the safety of imaging pregnant patients at field strengths greater than 3 T (ie, 7 T) is unclear.

MR safety_ACR_p 15

Thanks to

- TMPS
- Medical Physicists and Technologist teams at Ramathibodi Hospital
- Medical Physics Program, Faculty of Medicine Ramathibodi Hospital

Thank you for your attention ☺☺☺