Features and Weaknesses of Phantoms for CR/DR System Testing

Donald Peck, PhD
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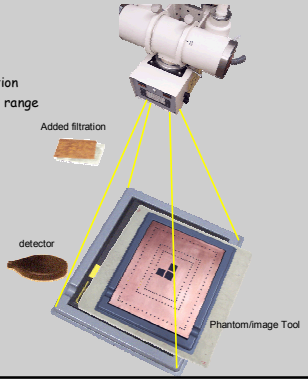
Physics testing of image detectors

- Parameters to test
  - Spatial resolution
  - Contrast resolution
  - Uniformity/geometric distortion
  - Dose response/signal dynamic range
  - Noise
- Experiments/testing methods
  - Direct measurements
  - Phantoms/image tools
    - Qualitative
    - Quantitative



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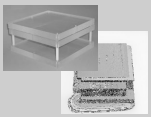
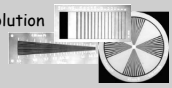
Phantom Types

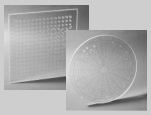
- Attenuation



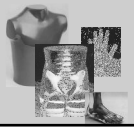
- High Contrast/Spatial Resolution



- Low Contrast/Contrast Sensitivity



- Anthropomorphic



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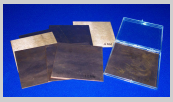
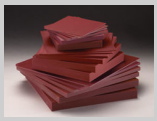
Attenuation test tools

- Metals
  - Aluminum, Copper, etc.



- Plastics/Composite Materials
  - Lucite, Tissue Equivalent, etc.

- Water



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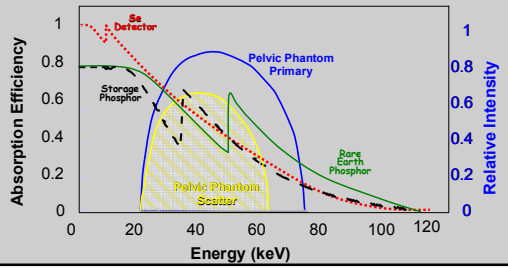
Detectors - CR Scatter Sensitivity

- Digital detectors can be significantly more sensitive to scatter radiation than traditional phosphor screens
  - Scatter needs to considered when testing systems



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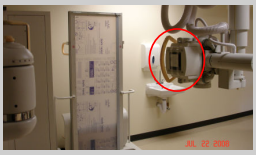
Attenuator positioning

- Modifying beam quality
  - Position attenuators far from detector to minimize scatter contribution in measurement
- Simulating patient attenuation
  - Position close to detector in same location as patient



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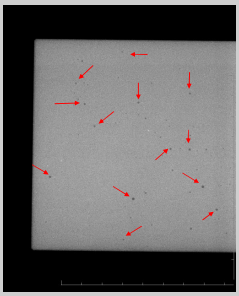
Attenuator Construction

- Attenuator "purity" may not be acceptable for the measurement
  - Measurement of mammography HVL requires attenuators that are at least 99.9% Aluminum
- Tissue equivalent materials may not be uniform



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Attenuation test tools

- Easy to use
- Placement of attenuator needs to be considered based on the test
- Purity or Uniformity of material may not be adequate for some tests

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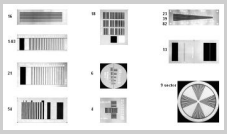
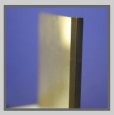
High Contrast/Spatial Resolution Test tools

- Line pair patterns



- Mesh patterns

- Edge phantoms



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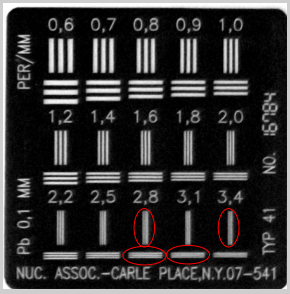
Line pair patterns



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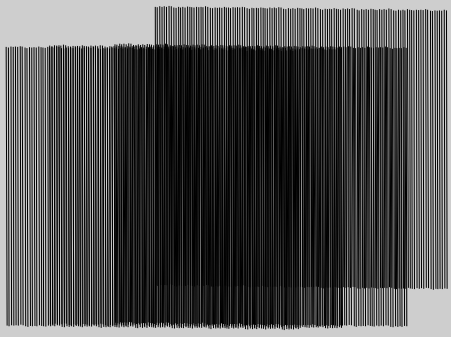
Aliasing and Moiré Effect



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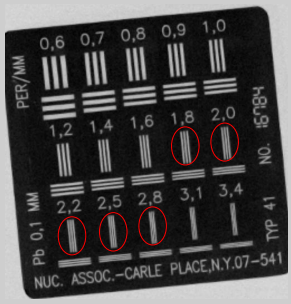
Line pair patterns



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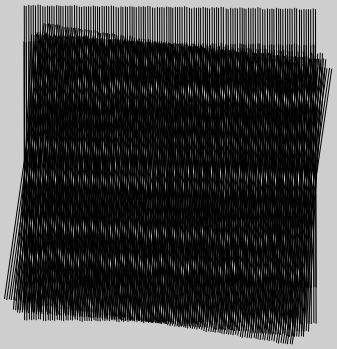
Moiré Effect



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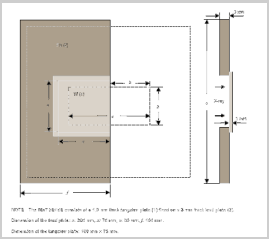
MTF/DQE Measurement

- IEC 62220-01 (2003)
  - Method for determining Detective Quantum Efficiency (DQE) of digital imaging systems
  - Defines specifications for a test device required to make these measurements



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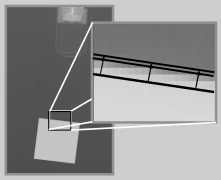
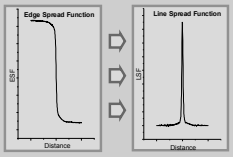
MTF/DQE Measurement Issues

- Requires Pre-processed image values that are "linear" with exposure
- Determination of edge response
  - Need to bin pixel data along edge
  - Phantom positioning critical for consistent results



- Smoothing/fitting of edge response curves to allow utilization of Fourier Analysis
  - Variations in method used may produce different results
  - Important to standardize if comparing to other MTF/DQE measurements



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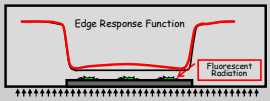
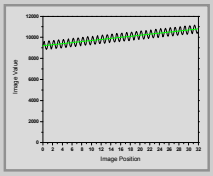
MTF/DQE Measurement Issues

- Fluorescent radiation
  - Only issue at high kVp
  - Important if comparing to other MTF/DQE measurements



- Noise Power Spectrum (NPS) determination
  - Need to remove effects of trends associate with heel effect, etc.
  - Variations in method used may produce different results
  - Important to standardize if comparing to other MTF/DQE measurements



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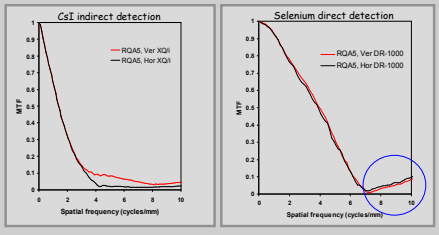
MTF Measurements

- Quantitative results
- Good indication of changes
- Subtleties in the measurement can make comparisons between measurements by different tests inaccurate



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High Contrast/Spatial Resolution Test tools

- Line pair patterns
  - Subjective
- Edge Phantoms
  - Objective
    - MTF Determination
  - Requires development of software to do the calculations
    - Task Group No. 162 "Research Software for 2D Image"
  - Valid for determining if changes have occurred over time if performed "consistently"
  - Requires standardization of methods used if comparisons between systems or results from different physicists are compared

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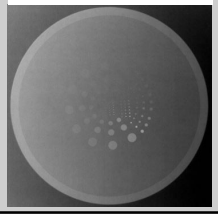
Low Contrast/Contrast Sensitivity test tools

- Contains objects of varying size and attenuation
- Requires observers to determine which objects are visible
  - Subjective



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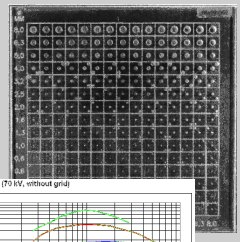
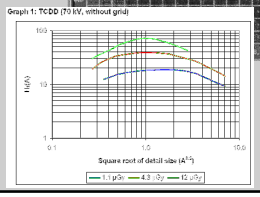
Contrast threshold detection index (TCDD)

- TCDD gives an indication of the lowest contrast detectable (C_T) as a function of the detail size (the square root of the detail Area, A) and can be quoted in terms of the threshold detection index (H_T)

$$H_T(A) = 1/[C_T * A^{\frac{1}{2}}]$$

- High value for $H_T(A)$ indicates good visibility





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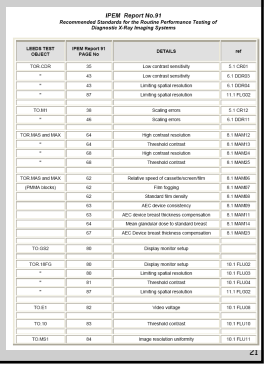
Institute of Physics and Engineering in Medicine (IPEM)

- Goals:
  - Improving standards in clinical practice
  - Providing advice on scientific and engineering issues in healthcare to other healthcare professionals, *government* and the public.
- Develops Reports and other publications to achieve these goals
  - Owns several journals:
    - Physics in Medicine and Biology
    - Physiological Measurement
    - Medical Engineering and Physics
  - Report 91 Recommended Standards for the Routine Performance Testing of Diagnostic X-Ray Imaging Systems
    - Specifies the use of phantoms throughout the testing procedures



IPEM Report No.91
Recommended Standards for the Routine Performance Testing of Diagnostic X-Ray Imaging Systems

IEC61674 TEST OBJECT	IPEM Report 91 PAGE No	DETAILS	HF
TOR CDR	35	Low contrast sensitivity	5.1 CR01
"	43	Low contrast sensitivity	6.1 DDR03
"	43	Limiting spatial resolution	6.1 DDR04
"	67	Limiting spatial resolution	11.1 PL002
TO.9H	38	Scaling errors	5.1 CR12
"	46	Scaling errors	6.1 DDR11
TOR MAS and MAX	64	High contrast resolution	8.1 MAM12
"	64	Threshold contrast	8.1 MAM13
"	68	High contrast resolution	8.1 MAM24
"	68	Threshold contrast	8.1 MAM25
TOR MAS and MAX (PMMA blocks)	62	Relative speed of cassette/screen/film	8.1 MAM86
	62	Film fogging	8.1 MAM87
	62	Standard film density	8.1 MAM88
	63	AEC device consistency	8.1 MAM89
	63	AEC device breast thickness compensation	8.1 MAM11
	64	Mean glandular dose to standard breast	8.1 MAM14
	67	AEC Device breast thickness compensation	8.1 MAM23
TO.SW2	66	Display monitor setup	
TOR 18FQ	66	Display monitor setup	10.1 FLU02
"	66	Limiting spatial resolution	10.1 FLU03
"	91	Threshold contrast	10.1 FLU04
"	67	Limiting spatial resolution	11.1 PL002
TO.9.1	62	Video voltage	10.1 FLU08
TO.10	63	Threshold contrast	10.1 PLU16
TO.MS1	64	Image resolution uniformity	10.1 FLU11

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IPEM Criteria (example)

- Most results are subjective !

Table 6.1 DDR system

Reference paragraph	Physical parameter	Level of expertise	Frequency	Priority	Remedial level	Suspension level
DDR01	Detector dose indicator monitoring	A	1–3 monthly	1	Baseline ±20%[a]	Baseline ±50% (a)
DDR02	Image uniformity	A	1–3 monthly	1	Lines or rectangles apparent	Gross non-uniformity
DDR03	Low contrast sensitivity	A	4–6 monthly	2	Baseline ±2 groups	
DDR04	Limiting spatial resolution	A	4–6 monthly	2	Baseline minus 25%	
DDR05	Detector dose indicator repeatability	B	12 monthly	1	Baseline ±10%[a]	Baseline ±20% (a)
DDR06	Detector dose indicator reproducibility	B	12 monthly	1	Baseline ±20%[a]	Baseline ±50% (a)
DDR07	Measured uniformity	B	12 monthly	1	Mean ±5%	
DDR08	Threshold contrast detail detectability	B	12 monthly	1	See Comments	
DDR09	Limiting spatial resolution	B	12 monthly	2	Baseline minus 25%	
DDR10	Uniformity of resolution	B	12 monthly	2	Increase in blurring from baseline	
DDR11	Scaling errors	B	12 monthly	2	>2%	
DDR12	Dark noise	B	12 monthly	2	Baseline +50%	

[a] These remedial and suspension levels are based on dosimetry, since the DDI is not linear with exposure.

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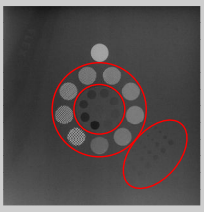
ACR Radiography/Fluoroscopy Accreditation Phantom

- Modules included
  - Chest
  - General
  - Fluoroscopy
- Phantom image
  - Radiography Chest/Abdomen
- ACR Discontinued Radiography/Fluoroscopy Accreditation Program in 2005



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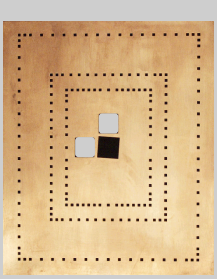
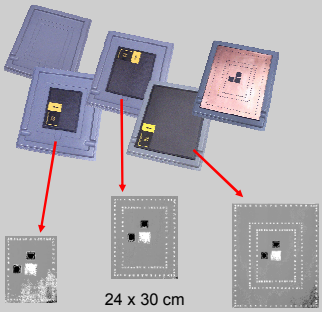
Original Equipment Manufacturer (OEM) Products

- Automated Image Quality Control Tool
  - Reproducible quantitative results
  - May detect sub-visible changes in image quality performance to initiate timely preventive maintenance
  - Highly automated procedure
  - Most provide data reporting in spreadsheet format

Test Phantom for Kodak (i.e. CareStream) DIRECTVIEW Total Quality Tool





18 x 24 cm

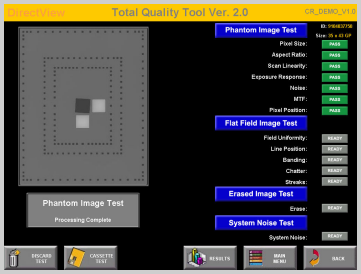
24 x 30 cm

35 x 43 cm

*Images provided by Eastman Kodak Company

KODAK User Interface

- Uniformity
- Noise
- Spatial frequency response (MTF)
- Exposure linearity
- Pixel size accuracy and aspect ratio
- Phantom image artifacts
- Laser Beam Function
- Residual signal erase



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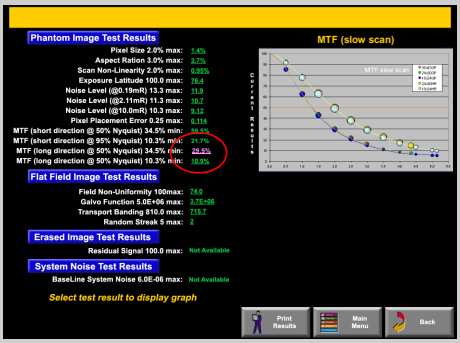
Kodak Test Result Details



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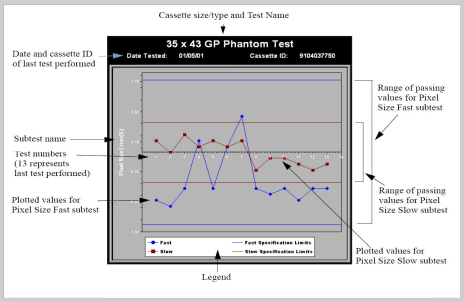
Kodak Temporal Test Results



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Test Limits

- Pre-set by OEM
- Basis for limit may not be justified in OEM literature
- If system fails a test, Service Engineer may not be educated how to correct problem

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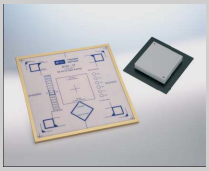
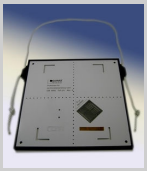
DIN 6868-58 (2001) and 6868-13 (2002)

- Acceptance testing and constancy checks of projection radiography systems with digital image receptors
  - German standard for testing of Storage Phosphor systems using a specially designed phantom to measure image quality parameters
  - Can purchase a phantom that will meet the requirements of this standard from several vendors





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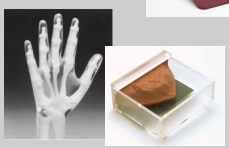
Anthropomorphic phantoms

- Shape "mimicking"

- Anatomically Accurate



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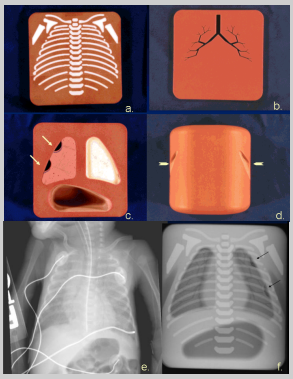
Shape "mimicking"



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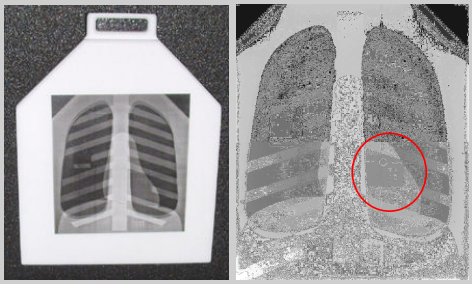
Shape "mimicking"



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Anatomically Accurate

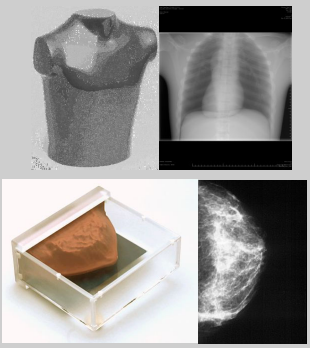

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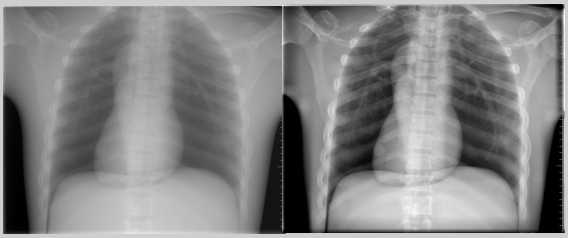
Image Processing



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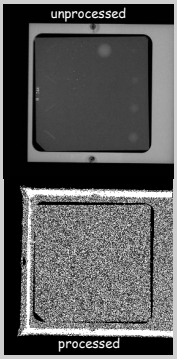
European Protocol for QC of … mammography Addendum on Digital Mammography

- It is acknowledged that at present it is not possible to get unprocessed images from some systems.
- The image processing may introduce artifacts on phantom images and may be different from image processing for mammograms due to histogram or local texture based processing techniques.
- Therefore care needs to be taken in interpretation of these processed images.



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