



## Advanced Techniques for Image Quality Assessment in Digital Radiography

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## Main Course Objectives

- Review definition of the Detective Quantum Efficiency, DQE(f)
- Gain an understanding of the IEC DQE method for general digital radiography and digital mammography
- Learn which commercial and public-domain resources are available for measuring the DQE(f).

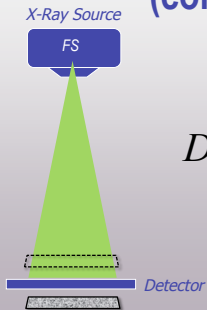
## Overview

- Classes of Digital Radiography Devices
- Review DQE Definition & Formulation
- Motivation for on-site DQE testing
- IEC DQE-related Standards
- DQE Acquisition/Processing Methodology
- Available Resources
- Summary Suggestions

## Digital Radiography Systems

1. Computer Radiography (CR)
2. Flat-panel radiographic systems  
*Direct & Indirect conversion*
3. CCD/CMOS-based radiographic systems  
*Full-field & Scanning-slot detectors*
4. Electrostatic radiographic system  
*Selenium drum detector*

## Detective Quantum Efficiency (conceptually)



$$DQE(f) = \frac{SNR_{out}^2}{SNR_{in}^2}$$

## MTF and NPS (conceptually)

The modulation transfer function (MTF) describes the frequency response of the imaging system or how well it preserves **signal**.

The noise power spectrum (NPS) provides the magnitude and frequency distribution of **noise**.

*Proc. SPIE: Medical Imaging 2000 – handbook of medical imaging Vol 1.*

## Computation of $DQE(f)$

$$DQE(f) = \frac{G^2 \cdot MTF(f)^2}{NPS(f) \cdot X \cdot q}$$

$$= \frac{MTF(f)^2}{NNPS(f) \cdot X \cdot q}$$

- G : gain factor (digital units per mR)
- X : exposure at detector associated with NPS measurement (mR)
- q : ideal  $SNR_{in}^2$  (# incident x-ray quanta per unit area per mR)
- NNPS: normalized noise power spectrum (NPS/G<sup>2</sup>)

## DQE (f) vs “iDQE”

**DQE(f)** is a rigorous, well-established and relatively **precise metric of DR system performance** that must be performed under highly controlled test conditions using specialized test tools and software

**iDQE** (proposed) is a **less precise performance metric or index of DQE** that is measured with a QC test tool typically supplied by the manufacturer to track system performance over time

## DQE(*f*) evaluation: DQE

### REQUIREMENTS

- Good understanding of DQE(*f*) physics
- Specialized (expensive) test equipment and software
- Well-trained, "highly motivated" imaging physicist
- Measurements should be reproducible with low variability (IF PERFORMED CORRECTLY)
- Infrequently - characterize new devices/technology

## CLINICAL PHYSICISTS

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DQE PHYSICISTS  
(aka DQE Gurus)

Should clinical physicists be motivated to learn how to measure the DQE(*f*)?

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Should DQE(*f*) evaluations be performed in the clinical setting?

YES

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YES

## Pros

- **Continuing medical physicist education**
  - Maintaining a competitive skill-set
  - Interest/demand to better understand DQE(f)
- **Increase general body of knowledge**
  - Correlating DQE(f) & spatial domain FOMs
  - Explore relationship between DQE(f) & radiologist perception/performance
  - Evaluating DQE(f) trends over lifetime of equipment
- **Verification of manufacturer's claims**

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## Cons

- **Cost of test equipment**
- **Expertise/training requirements**
- **High degree of precision required**
  - Time-consuming, repetitive measurements & analysis
- **Frequency domain FOMs less intuitive**
  - Interpretation is not always easy
- **Potential to undermine confidence in DQE as a performance metric if done poorly**

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## IEC DQE Standards

### IEC 62220-1:

General Digital Radiography (pub: 10/2003)

### IEC 62220-1-2:

Digital Mammography (pub: 06/2007)

### IEC 62220-1-3:

Digital Fluoroscopy (WIP draft)

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## Other related IEC Standards

### IEC 61267 Ed. 1:

Radiation conditions for use in the determination of characteristics (pub: 09/1994)

### IEC 61267 Ed. 2:

Radiation conditions for use in the determination of characteristics (pub: 11/2005)

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## Where to get IEC standards

International Electrotechnical Commission:

<http://webstore.iec.ch/webstore>

American National Standards Institute:

<http://webstore.ansi.org/>

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## Digital Mammography

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## Digital Radiography

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## DQE Acquisition Method

- Device Calibration
- Establish beam quality/technique
- Measure lag time
- Measure the conversion function
- Measure the NPS / Exposure
- Measure the MTF

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## DQE Analysis Method

- Compute the Conversion Function
- Linearize CF, MTF & NPS images
- Compute NPS
- Compute MTF
- Rebin data (if necessary)
- Compute DQE

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## Device Calibration per manufacturer's recommendation

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## Permitted Corrections for "original data"

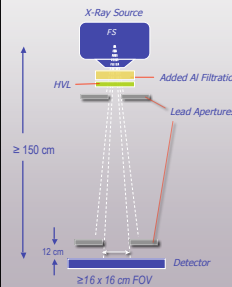
- **Correction for bad detector elements (dels)**
- **Flat-field correction**
  - Correction for radiation field non-uniformity (i.e. Heel Effect)
  - Gain and offset correction for each detector element
  - Correction for velocity variation during scan (CR)
- **Correction for geometric distortion**

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## Establishing Beam Quality per IEC 61267-1

## IEC Radiation Conditions

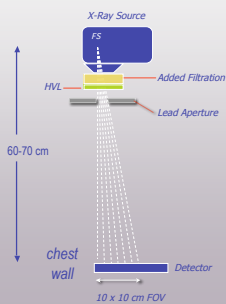
### General Digital Radiography



| Radiation Quality No. | Approx. Tube Voltage (kV) | Additional Filtration (mm Al) | HVL (mm Al) |
|-----------------------|---------------------------|-------------------------------|-------------|
| RQA3                  | 50                        | 10.0                          | 4.0         |
| <b>RQA5</b>           | <b>70</b>                 | <b>21.0</b>                   | <b>7.1</b>  |
| RQA7                  | 90                        | 30.0                          | 9.1         |
| RQA9                  | 120                       | 40.0                          | 11.5        |

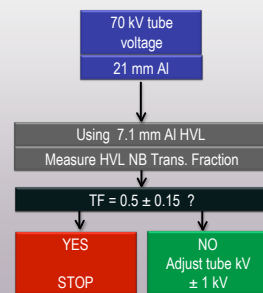
## IEC Radiation Conditions

### Digital Mammography



| Radiation Quality No. | Target & Filter | Approx. Tube Voltage (kV) | Filter Thickness (mm Al) | Additional Filtration (mm Al) | HVL (mm Al) |
|-----------------------|-----------------|---------------------------|--------------------------|-------------------------------|-------------|
| RQA-M-1               | Mo/Mo           | 25                        | 0.032                    | 2.0                           | 0.56        |
| RQA-M-2               | Mo/Mo           | 28                        | 0.032                    | 2.0                           | 0.60        |
| RQA-M-3               | Mo/Mo           | 30                        | 0.032                    | 2.0                           | 0.62        |
| RQA-M-4               | Mo/Mo           | 35                        | 0.032                    | 2.0                           | 0.68        |
|                       | Mo/Rh           | 28                        | 0.025                    | 2.0                           | 0.65        |
|                       | Rh/Rh           | 28                        | 0.025                    | 2.0                           | 0.74        |
|                       | W/Rh            | 28                        | 0.05                     | 2.0                           | 0.75        |
|                       | W/Al            | 28                        | 0.50                     | 2.0                           | 0.83        |

## Flowchart for IEC 61267 Ed 1 RQA5 Beam Quality



| Radiation Quality No. | Approx. Tube Voltage (kV) | Additional Filtration (mm Al) | HVL (mm Al) |
|-----------------------|---------------------------|-------------------------------|-------------|
| RQA3                  | 50                        | 10.0                          | 4.0         |
| <b>RQA5</b>           | <b>70</b>                 | <b>21.0</b>                   | <b>7.1</b>  |
| RQA7                  | 90                        | 30.0                          | 9.1         |
| RQA9                  | 120                       | 40.0                          | 11.5        |

**IEC AI filtration purity  
specification  
per 61267 Ed. 1 (and 2)**

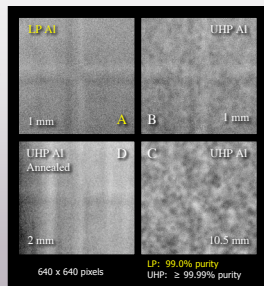
**$\geq 99.9\%$  purity Al**

**Problems with  $\geq 99.9\%$  purity Al filtration**

1. Availability
2. Cost
3. Larger grain size contributes to radiographic non-uniformities

**Problems with  $\geq 99.9\%$  purity Al filtration**

*Lower purity  
Al alloy  
"gold standard"*



A & D: Alfa Aesar  
B & C: Goodfellow Corp

**Lag Time**

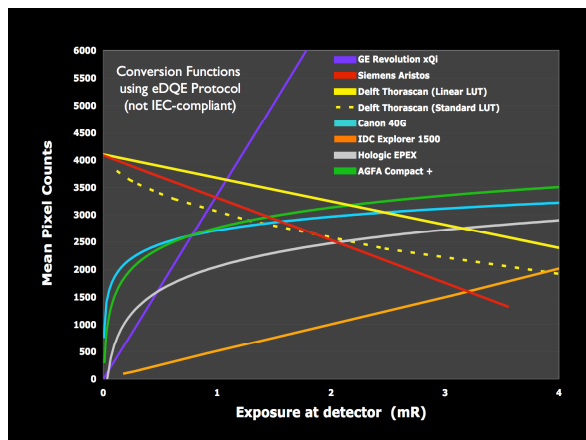
## Practical Advice

- Follow the manufacturer's recommendations
- Wait the minimum specified interval of time between image acquisitions – longer when imaging high contrast objects. (Better to be conservative than sorry.)
- Acquire images in a progression from:
  1. low to high exposures
  2. low to high contrast
- Protect the detector when taking high exposure measurements by draping it with Pb apron(s)

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## Determining the conversion function

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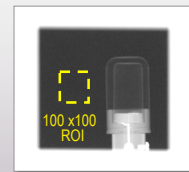


## Conversion Function

Exp. Range:  $0 - 4E_{nl}$

IEC Standard  
beam geometry/quality

RQA/RQM



LINEAR systems

Use 5 mAs stops  
spanning full range

All other systems

Use "N" mAs stops  
such that  $\log E_i - \log E_{i+1} \leq 0.1$   
for  $i = 1, N-1$

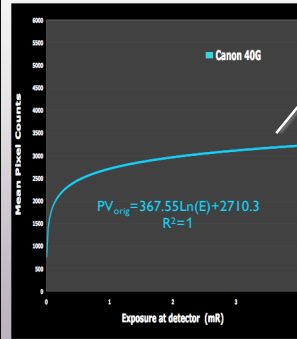
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$$PV_{lin} = \mathcal{F}^{-1}(PV_{orig})$$

where

$$PV_{lin} = C \cdot E$$

### Determining the inverse CF:



$$E = e^{\frac{(PV_{orig} - 2710.3)}{367.55}}$$

$$= k \cdot e^{\frac{(PV_{orig})}{367.49}}$$

$$PV_{lin} = C \cdot E$$

$$PV_{lin} = C'' \cdot e^{\frac{(PV_{orig})}{367.49}}$$

### Linearize images

Example using  
Matlab v7.4  
for Mac OS X 10

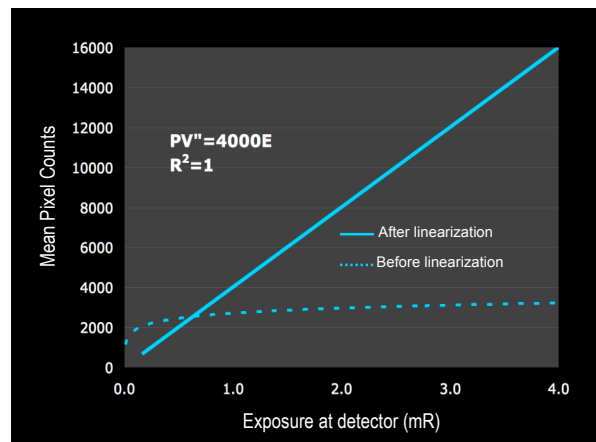
```

for i = 1:30;
info=dicominfo(['im_num2str(i)_'_NNPS.dcm']); % read DICOM Meta Data
filename=info.FileName
sdim=info.Columns
ydim=info.Rows
DIM=dicomread(['im_num2str(i)_'_NNPS.dcm']); % Read DICOM Image
% dcomread(filename.dcm)

fmaxval_1=max(max(DIM))
slope=367.55; % slope of PV vs lnE
alpha=double(1.0/slope);
sF=2.521273243 % sf of which yields final slope of 4000;
% so that PV_lin=4000E

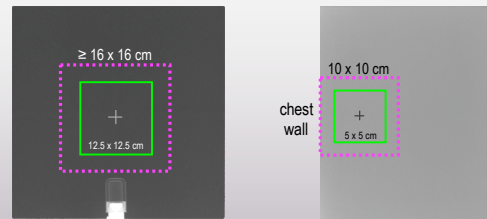
LPV=exp(alpha*double(DIM));
sDIM=(sf * LPV);
fmaxval_2=max(max(sDIM))
% write linearized raw file
rDIM=roi(sD,sDIM);
fDIM=flipdim(DIM,1);
fid=fopen(['im_num2str(i)_'_NNPS_linearized.raw'],'w');
fwrite(fid,DIM,'uint16','ieee-be');
fclose(fid);
end

```



# Measuring the NPS

## NPS Irradiated/Analysis Area:



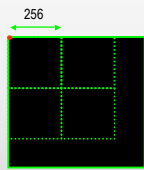
Digital Radiography

Digital Mammography

$$\frac{E_{nl}}{3.2}, E_{nl}, 3.2E_{nl}$$

$$\frac{E_{nl}}{2}, E_{nl}, 2E_{nl}$$

Where  $E_{nl}$  is normal exposure level specified by the manufacturer



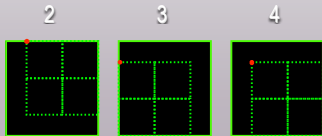
For each of  $N$  images, the NPS analysis area is divided into 256 pixels x 256 pixels ROIs

$N = \#$  of images to achieve "4 million independent pixels"

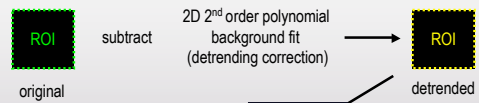
ROI "ensembles" are replicated and overlapped by shifting their reference coordinates by 128 pixels

ROI ensemble reference point (•) for each pass

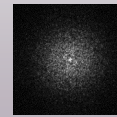
- 1: (x,y)
- 2: (x+128, y)
- 3: (x, y+128)
- 4: (x+128, y+128)



## Spatial Domain



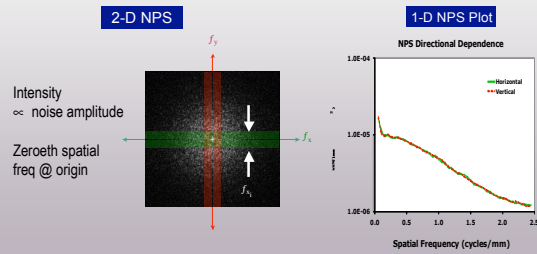
## Frequency Domain



average all 2D NPS images for the ROI ensemble/group

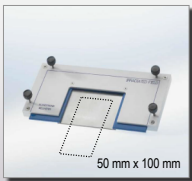
2D NPS image

The x- and y- NPS results are obtained by band-averaging each freq. bin  $\pm 7$  pixels on either side of the x- and y-axes (axes excluded)



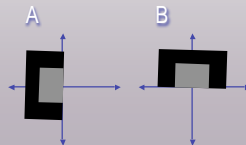
## Measuring the MTF

### MTF Test Device: IEC 62220-1 (General)



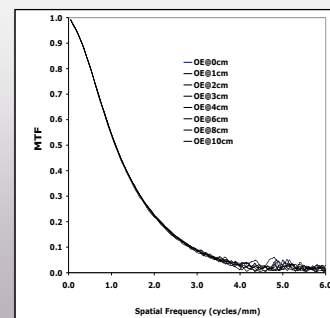
- 90% Tungsten, 1.0 mm thick, 100 x 75 (min) mm area
- highly polished 90° edge
- 3 mm thick Pb plate surround
- Angular offset 1-3° from axis.
- Measure at detector surface in X(A) and Y(B) directions using FS < 1.0 mm

Co-ordinate system @ beam/det. center



### MTF On-Axis Alignment Dependence

IEC 62220-1 Compliant radio-opaque edge device

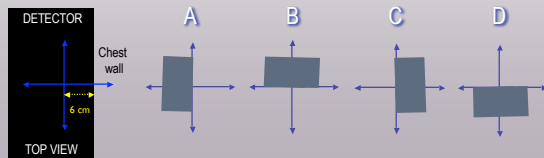
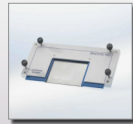


Med Phys 33: 1454-1465 (2006)

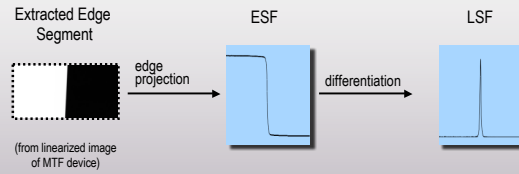
## MTF Test Device: IEC 62220-1-2 (Mammo)

- Type 304 stainless steel
- 0.8 mm thick, 120 mm x 60 mm
- highly polished 90° edge
- Angular offset 1-3° wrt axis.
- Measure at detector surface:  
A,B for DR  
A,B,C,D for CR

OR

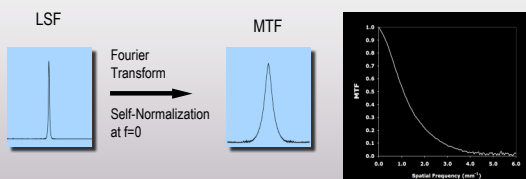


## MTF Analysis



Example shows 100 mm x 50 mm edge image per IEC 62220-1 (General DR)

## MTF Analysis



## Spatial Frequency Sampling for DQE Computation

### IEC REQUIREMENT

Spatial Frequency Interval,  $f_{int}$

$$\text{where } f_{int} = \frac{0.01}{\text{pixel pitch (mm)}}$$

Average data in freq. interval:  $f - f_{int} \longrightarrow f + f_{int}$

## Spatial Frequency Rebinning

### WHY ?

- To comply with standard requirements
- To match frequency sampling of NPS & MTF for computation of the DQE
- Reduces variance per frequency bin

## Computing DQE(*f*)

## Computation of DQE(*f*)

$$DQE(f) = \frac{G^2 \cdot MTF(f)^2}{NPS(f) \cdot X \cdot q}$$
$$= \frac{MTF(f)^2}{NNPS(f) \cdot X \cdot q}$$

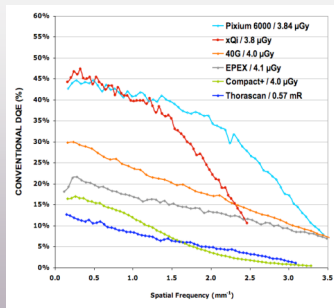
- G : gain factor (digital units per mR)  
X : exposure at detector associated with NPS measurement (mR)  
q : ideal  $SNR_m^2$  (# incident x-ray quanta per unit area per mR)  
NNPS: normalized noise power spectrum (NPS/G<sup>2</sup>)

## q-values per IEC 62220-1

|      |       |                          |    |         |                         |
|------|-------|--------------------------|----|---------|-------------------------|
| RQA3 | 21759 | 1/(mm <sup>2</sup> -μGy) | or | 190,826 | 1/(mm <sup>2</sup> -mR) |
| RQA5 | 30174 |                          |    | 264,626 | "                       |
| RQA7 | 32362 |                          |    | 283,815 | "                       |
| RQA9 | 31077 |                          |    | 272,545 | "                       |

μGy: micro-Gray (SI unit)  
mR: milli-Roentgens

## DQE of a Range of DR Systems



Data provided compliments of Alistair MacKenzie of K-CARE (UK)

## Reporting DQE

### IEC REQUIREMENT

DQE is reported at spatial frequencies intervals of 0.5, 1.0, 1.5 mm<sup>-1</sup> .... from 0.5 mm<sup>-1</sup> up to the Nyquist Frequency.


$$\text{Nyquist Frequency (mm}^{-1}\text{)} = \frac{1}{2 \cdot \text{pixel pitch (mm)}}$$

## RESOURCES

## EQUIPMENT


- Well-calibrated ionization chamber with an uncertainty of ≤ 5.0 %
- Precision-machined MTF edge device
- Lead apertures (optional)
- Radiographic quality Al filtration

# DQE EVALUATION SOFTWARE



**Contributors:**

- Ehsan Samei
- Robert Saunders
- Andrew Maidment
- Jeff Siewerdsen



## Recommendations

- Take advantage of the free resources available
- Invest in a high quality edge device
- Use lower purity (99.0%) Al, i.e. Type 1100 not the  $\geq 99.9\%$  purity Al specified by the standard

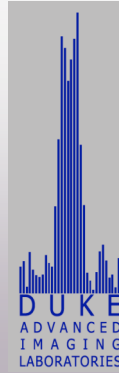
Test Al before use!

## Recommendations

- Review the fundamentals of DQE physics
- Study the literature on DQE testing
- Obtain the IEC standards for reference
- Recruit a “DQE Mentor”

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Thank you for your attention.



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Thank You  
for  
Your Attention

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