DQE Methodology—Step by Step

Paul R. Granfors
G.E. Medical Systems

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I. Background

DQE measures transfer of signal to noise ratio from the input to the output of a detector.

The methodology for measuring DQE in a digital detector has been standardized in **IEC 62220-1**. This standard applies to 2-D detectors used for general radiography.

- Includes any area detector used for general radiography, examples:
  - Storage phosphor systems
  - Image intensifiers used in radiographic mode
  - Flat panel detectors, either scintillator-based or direct-conversion
  - Systems with a full 2-D input projected onto one or more CCDs
- Excludes, for example,
  - Scanning systems with detector input smaller than full size of image
  - Dental imaging systems
  - Mammography systems
  - CT systems

DQE is often defined as

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

where G is the detector gain, Φ is the x-ray quanta per area at the detector input, MTF is modulation transfer function, NPS is noise power spectrum. The second expression (where S is the detector signal) applies only if the response of the detector is linear and has zero intercept.

In the IEC standard the expression used is:

$$DQE(f) = \frac{MTF^2(f) \cdot \Phi}{NPS(f)}$$

The MTF and NPS are obtained from images that have been **linearized** to quanta per unit area at detector input

DQE measurement requires:

- Standard spectrum
- Standard geometry
- Measurement of air kerma at detector surface
- Determination of quanta per area from air kerma
- Measurement of characteristic function of detector
- Measurement of MTF
- Measurement of NPS

II. Establishment of a Standard X-ray Spectrum

Spectra are defined according to:

IEC 61267: 1994, *Medical diagnostic X-ray equipment—Radiation conditions for use in the determination of characteristics*

Spectra are achieved with

- specified thickness of added Al filter (>99.9% purity)
- specified HVL of Al
- kVp of generator adjusted to achieve specified HVL with specified filter

IEC 62220-1 specifies 4 spectra

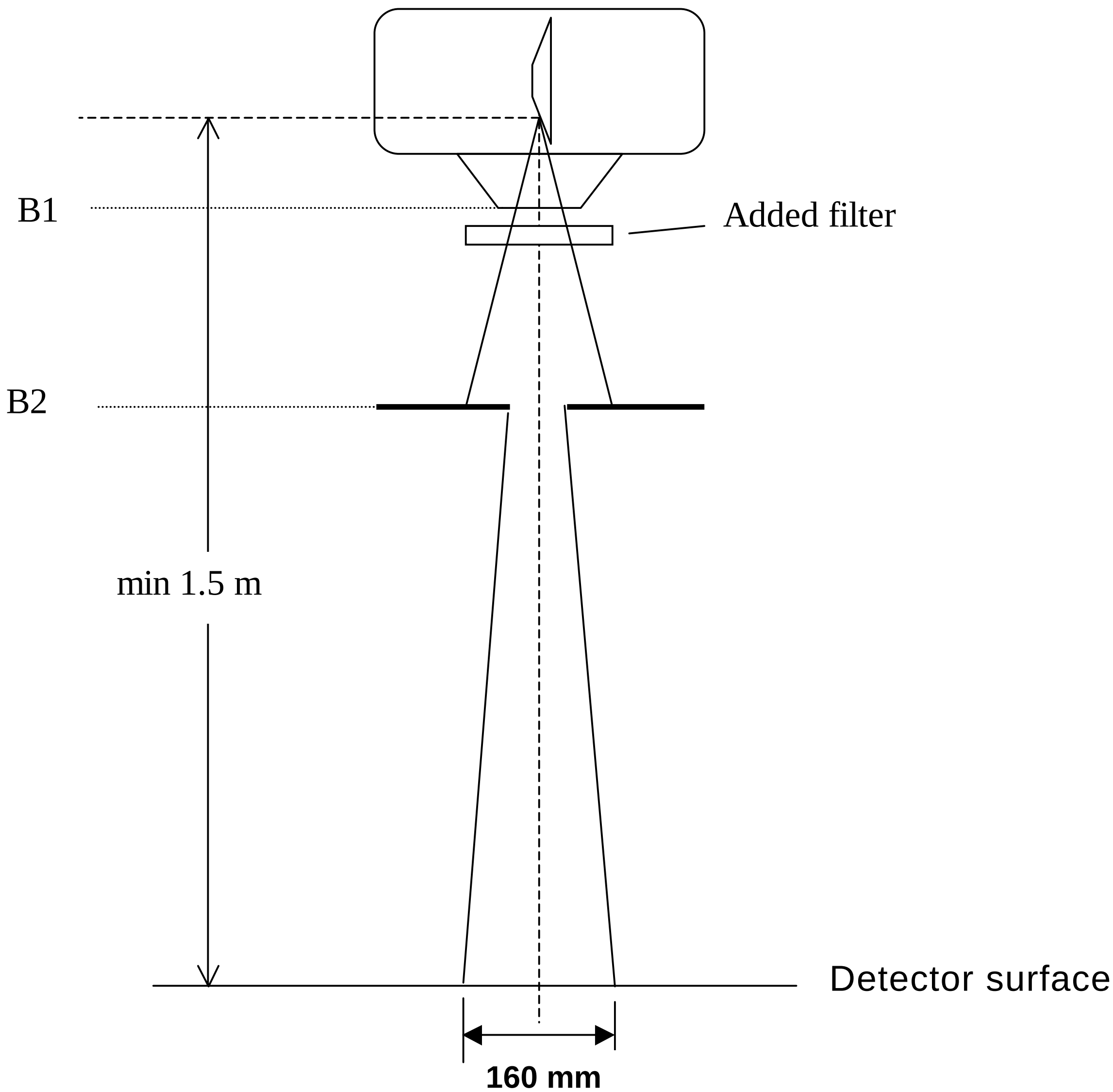
Spectrum	Added filtration (mm Al)	HVL (mm Al)
RQA 3	10	4.0
RQA 5	21	7.1
RQA 7	30	9.1
RQA 9	40	11.5

If only one spectrum is used, it should be RQA 5

III. Measurement Geometry

- Same geometry used for measurements of
  - Air kerma at detector surface
  - Conversion function
  - MTF
  - NPS

- Defined to minimize effects of scatter
  - SID at least 1.5 meters
  - X-ray field size at detector ~16 cm x 16 cm
  - Added filtration as close as possible to source



IV. Measurement of Air Kerma at Detector Surface

Air kerma is measured at the detector surface (closest position to image receptor plane with all covers, grids, ion chambers, etc. removed)

Measurement of air kerma is made with a radiation meter containing a radiation detector (air ionization chamber)

Measurement is made

- Preferably with imaging detector removed
    - Ion chamber at position of imaging detector surface
    - Nothing behind chamber to cause scatter into chamber
- Alternatively, imaging detector not removed
    - Ion chamber positioned between source and imaging detector
    - Position chamber to avoid scatter from source filtration and detector
    - Exposure at detector surface determined with inverse square law

V. Conversion of Air Kerma to Quanta per Unit Area

The IEC standard uses the definition that the square of input signal to noise ratio is the quanta per unit area. (The ideal detector is photon counting.)

Need a conversion from air kerma to quanta per area, Φ

Conversion obtained from X-ray spectral modeling:

$$\Phi = \frac{\int n(E)\cdot f(E)\,dE}{\int n(E)\,dE}$$

n(E) = relative number of photons in x-ray spectrum at energy E
f(E) = quanta per area per air kerma at energy E

Different models can give different results. In the IEC standard, the conversion is defined and these factors must be used

Spectrum	added filtration (mm Al)	HVL (mm Al)	Quanta per area per air kerma (photons/(mm$^2\cdot$nGy))
RQA 3	10	4.0	21.76
RQA 5	21	7.1	30.17
RQA 7	30	9.1	32.36
RQA 9	40	11.5	31.08

VI. Measurement of Conversion Function

Conversion function is detector output level as a function of number of exposure quanta per unit area

Used to linearize the detector response to input quanta

Steps:

1. Irradiate the detector using the standard spectrum and geometry
2. Measure the air kerma at the detector surface for each exposure
3. Convert air kerma to quanta per area using the specified factor
4. Plot average detector output level of 100 x 100 pixel region of interest vs. quanta per area
5. Fit a curve to the data:

Conversion function = Output level (quanta per area)

The inverse of the conversion function is used to transform the images used for MTF and NPS to units that are linear with respect to the exposure quanta

Use of the conversion function

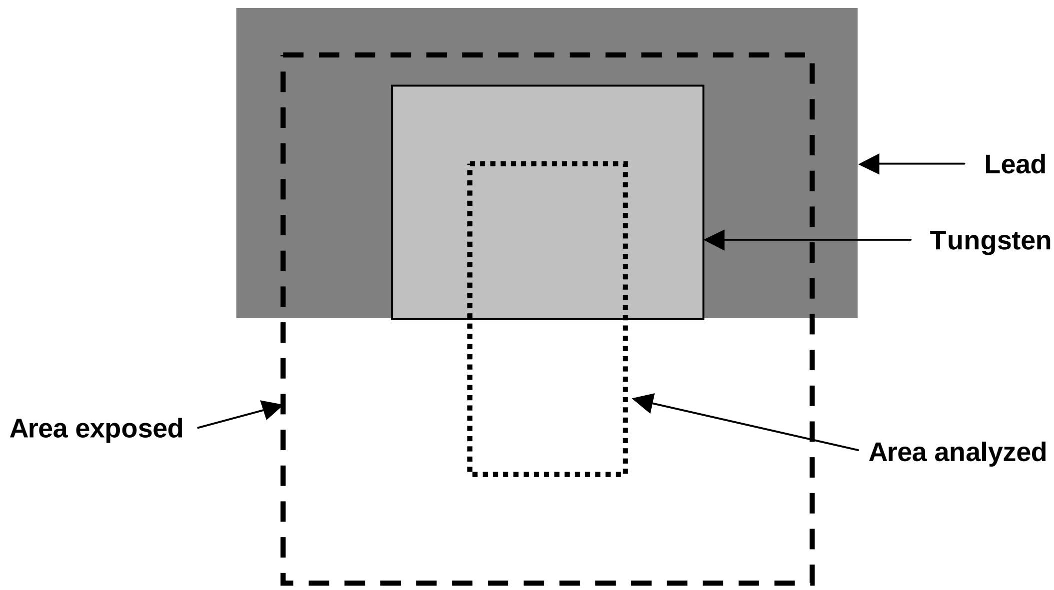
- Linearizes the detector response
- Converts the detector response to units of exposure quanta per area (this absorbs the gain factor that is often seen in the DQE equation)

VII. Measurement of MTF

Edge response method

Test object

- Consists of a tungsten plate with a precision edge surrounded by lead



- Lead surround improves approximation of “infinitely long” edge
- Object is “opaque to x-rays” (1 mm thick tungsten, 3 mm thick lead) to minimize effect of secondary radiation from the test object
- Area analyzed is +/-50 mm from edge transition to include tails of line spread function—low frequency drop in MTF

Measurement method

- Test object placed on detector surface (tilted 1.5-3 degrees to detector axis to measure MTF perpendicular to that axis)
- Image of object made with standard spectrum and imaging geometry
- Image linearized using inverse of characteristic function
- Edge spread function determined from data within analysis ROI
- Edge spread function numerically differentiated to obtain LSF
- MTF is calculated as modulus of Fourier transform of LSF
- MTF at frequency, f, obtained by averaging over f +/- 0.01/pitch

VIII. Measurement of NPS

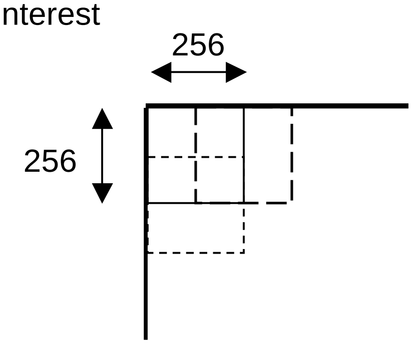
Images are acquired with standard spectrum, standard geometry, no test object in beam; the number of images is such that at least 4 million independent image pixels are used in the analysis

Images are converted to units of quanta per area by application of the inverse of the conversion function

A region of interest ~ 125 x 125 mm is used for analysis

Trend removal may be performed by subtracting a 2-dimensional second order polynomial from the region of each image used for analysis

The analysis region is broken up into half-overlapping 256 x 256 regions of interest



Calculate modulus-squared of 2-D Fourier transform of each region

Average all 2-D transforms—this gives the 2-D NPS

$$NPS(u_n, v_k) = \frac{\Delta x \Delta y}{M \cdot 256 \cdot 256} \sum_{m=1}^{M} \left| \sum_{i=1}^{256} \sum_{j=1}^{256} \big(I(x_i, y_j) - S(x_i, y_j) \big) \exp(-2\pi\, i(u_n x_i + v_k y_j)) \right|^2$$

where

$\Delta x \Delta y$	is the pixel spacing in respectively the horizontal and vertical direction
M	is the number of ROI's;
$I(x_i, y_j)$	is the LINEARIZED DATA
$S(x_i, y_j)$	is the optionally fitted two-dimensional polynomial

NPS at frequency, f, in direction of axis is obtained by averaging over the 2-D NPS

+/- 7 points on either side of axis, excluding axis
f +/- 0.01/pitch along the axis