RADIOLOGY RESEARCH

Calibration of the Exposure Index

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Annual Meeting

Acknowledgements:
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David Leong

Exposure Indicators

CR and DR systems assess the recorded signal to indicate whether the radiographic technique used is appropriate.

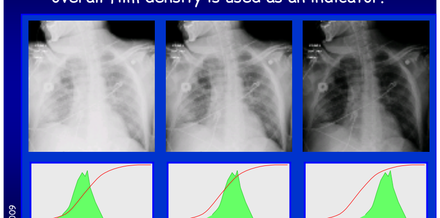
- Tests using defined beam conditions are used to verify that correct indicators are being reported.
- Recommended indicator ranges are used by technologists to check each radiographic exposure.

Topics

A. Exposure Indicators
B. Manufacturer Indices
C. IEC – AAPM Standardization
   i. Beam Spectrum (kVp & filtration)
   ii. Measurement of entrance exposure
   iii. Exposure Index & Deviation Index

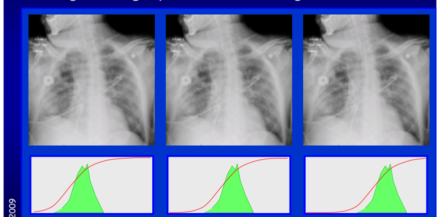
Screen-Film system indicators

For traditional screen-film systems, overall film density is used as an indicator.



CR & DR system indicators

For CR & DR systems, image processing aligns the grayscale with the signals.

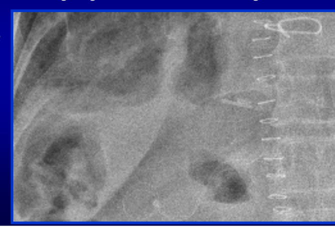


Noise

The image processing adjusts the grayscale, however;

- Images with low signals are noisy and
- Images with high signal are associated with high dose..

Exposure Indicators describe image quality in terms of the signal to noise ratio.



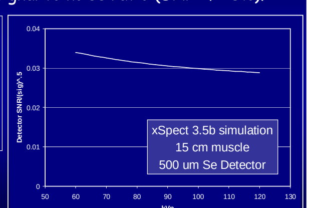
Signal to Noise ratio

The signal recorded by the detector is indicative of the image signal to noise ratio (SNR +/- 8%).

SNR α $(mAS)^{1/2}$

SIG α mAS

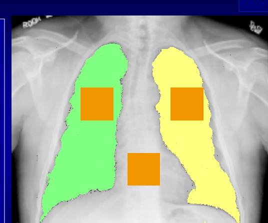
$SNR/(SIG)^{1/2}$ is therefore independent of mAS

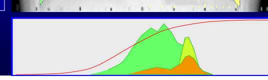


Region to assess signal indicator

Systems vary in the region used to assess the signal for an image.

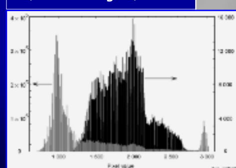
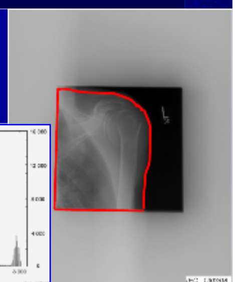
- Full Image
- Regular regions
- Anatomic regions





Region to assess signal indicator

IEC 62494-1
- Gray histogram for the entire image.
- Black histogram for the anatomic region (relevant region)

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Computation of an indicator

Exposure indicators are typically computed from the probability distribution of signal values.

- IEC 62494-1: "The [indicator] shall be calculated using the mean, median, mode, trimmed mean, trimean, or other recognized statistical method for the description of central tendency of the [values] in the relevant image region."
- AAPM TG 116: "The median is recommended rather than the mean or mode because it is less affected by data extremes and outliers."

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Tg116 v10b : Appendix D

Agfa CR
- 75 kVP
- 1.5 mm Cu
- 400 Speed Class
- lgM = 1.96 @ Kcal = 2.5 μG

lgM = 1.9607 + log(μG/2.5) + log(Speed/400)

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Tg116 v10b : Appendix E & G

Fuji & Konica CR

- 80 kVP
- No added filtration - "3 mm Total Filtration"
- "Semi" EDR mode (Fuji
- "Sensitivity" processing
- S = 200 @ Kcal = 1 mR

S = 200/mR

Recommend using 0.5 mm Cu + 1 mm Al
FSE will argue - be prepared to call corporate HQ

Tg116 v10b : Appendix F

Kodak CR & DR

- 80 kVP
- 0.5 mm Cu + 1 mm Al
- EI = 2000 @ Kcal = 1 mR
- May have an offset at low exposure

EI = 1000*log10(mR) + 2000

Tg116 v10b : Appendix H

Imaging Dynamics

- 80 kVP
- 1 mm Cu
- S_E = 200 @ Kcal = 1 mR
- Defined target speeds, S_T

S_E = 200/mR

f# = $\log_2(S_T/S_E)$

Tg116 v10b : Appendix I

Philips DR

- 70 kVp (RQA5)
- 21 mm Aluminum
- HVL = 7.1 mm Al
- EI = 400 @ Kcal = 0.26 - 0.32 mR
- EI coarsely rounded, kV correction applied

EI = 1000/μG

Tg116 v10b : Appendix J

GE DR (Definium)

- 80 kV_p
- 1 mm Al in collimator filter slot/wheel
- 20 mm AL (with system) at collimator face
- Uncompensated detector µG (standard beam)
- Compensated detector µG (kVp, grid, filter)
- DEI – ratio of PV to target PV.

Tg116 v10b : Appendix J

Additional Systems

- Appendix K: Alara CR
- Appendix L: Siemens Medical Systems
- Appendix M: iCRco
- Appendix N: Canon Medical Systems
- Appendix O: Swiss Vision

Summary of manf. EIs

Manu-facturer	Indicator Name	Symbol	Units	Exposure Dependence	Calibration Conditions
Fujifilm	S Value	S	Unitless	200/S α X (mR)	80 kV_p, 3 mm Al "total filtration" S=200 @ 1 mR
Kodak	Exposure Index	EI	mbels	EI + 300 = 2X	80 kVP + 1.0 mm Al + 0.5 mm Cu EI = 2000 @ 1 mR
Agfa	Log of Median of histogram	lgM	bels	lgM + 0.3 = 2X	for 400 Speed Class, 75 kVP + 1.5 mm Cu lgM=1.96 at 2.5 µGy
Konica	Sensitivity Number	S	Unitless	for QR = k, 200/S α X (mR)	for QR=200, 80 kVP S=200 @ 1 mR
Canon	Reached Exposure Value	REX	Unitless	Brightness = c_1, Contrast = c_2, REX α X [1]	for Brightness = 16, Contrast = 10, REX ≈ 106 @ 1 mR[1]
Canon	EXP	EXP	Unitless	EXP α X	80 kVp, 26 mm Al HVL = 8.2 mm Al DFEI = 1.5 EXP = 2000 @ 1 mR

[1] From empirical data

Summary of manf. EIs

Manu-facturer	Indicator Name	Symbol	Units	Exposure Dependence	Calibration Conditions
GE	Uncompensated Detector Exposure	UDExp	µ Gy Air KERMA	UDExp α X (µ Gy)	80 kVp, standard filtration, no grid
GE	Compensated Detector Exposure	CDExp	µ Gy Air KERMA	CDExp α X (µ Gy)	
GE	Detector Exposure Index	DEI	Unitless	DEI ≈ 2.4X (mR) [1]	Not available
Swissray	Dose Indicator	DI	Unitless	Not available	Not available
Imaging Dynamics Company	Accutech	f#	Unitless	$2^{f\#}=X(mR)/X_{tgt}(mR)$	80 kVp + 1 mm Cu
Philips	Exposure Index	EI	Unitless	100/S α X (mR)	RQA5, 70 kV, +21 mm Al, HVL=7.1 mm Al
Siemens Medical Systems	Exposure Index	EXI	µ Gy Air KERMA	X(µ Gy)=EI/100	RQA5, 70 kV +0.6 mm Cu, HVL=6.8 mm Al
Alara CR	Exposure Indicator Value	EIV	mbels	EIV + 300 = 2X	1 mR at RQA5, 70 kV, +21 mm Al, HVL=7.1 mm Al => EIV=2000
iCRco	Exposure Index	none	Unitless	Exposure Index α log [X (mR)]	1 mR at 80 kVp + 1.5 mm Cu => =0

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The AAPM TG 116 report on exposure indicators was published in July of 2009

An exposure indicator for digital radiography: AAPM Task Group 116 (Executive Summary)

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Medical Physics, Vol. 36, No. 7, July 2009

IEC published a standard for Exposure Index definitions in August of 2008

IEC 62494-1

Edition 1.0 2008-08

INTERNATIONAL STANDARD

Medical electrical equipment – Exposure index of digital X-ray imaging systems –
Part 1: Definitions and requirements for general radiography

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Beam Quality

TG116 & IEC used RQA5 as a reference for the beam quality

- 70 kVp
- RQR5 pre-filtered beam
- 21 mm added pure Al filtration
- 6.8 mm Al HVL

Both groups recognized that RQA5 is impractical for field measurements and sought an alternative.

Beam Quality – IEC vs TG116

AAPM TG116 beam conditions

- 70 ± 4 kV_p
- 0.5 mm Cu + (0 – 4) mm Al (type 1100)
  - Brass acceptable as a Cu substitute
  - 21 mm pure Al acceptable.
- HVL = 6.8 mm Al (type 1100)
- Adjust Al and (if necessary) kV_p to get HVL

IEC Beam condition differences

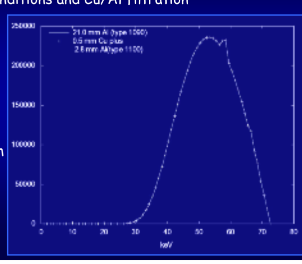
- 0.5 mm Cu + 2 mm Al
- No added Al filter adjustment
- HVL = 6.8 +/- 0.3 mm Al

Beam Quality – spectral shape

TG 116 showed reported equivalent spectral shape with RQA5 conditions and Cu/Al filtration

HVL
6.8 mm Al

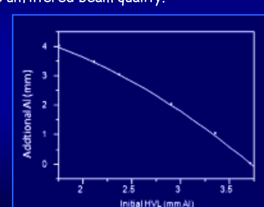
Normalized Spectra,
Cu/Al spectrum is about 2X that of RQA5



Beam Quality – Al trim filters

TG 116 illustrated how the addition of different Al filters to a Cu filter could compensate for differences in the unfiltered beam quality.

Approximate Al to add to 0.5 Cu to achieve 6.8 mm HVL at 70 kVp. Averaged from about 25 systems tested.



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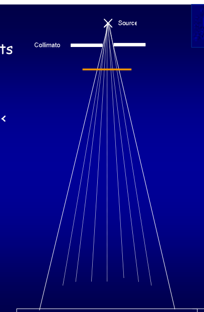
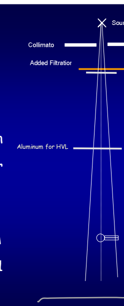
Beam setup – step 1

- Prior to any measurements verify that the x-ray source has acceptable exposure reproducibility (coefficient of variation < 0.03) and kV accuracy (within ± 3%) at the standardized condition.
- Add 0.5 mm copper filtration at the face of the collimator.



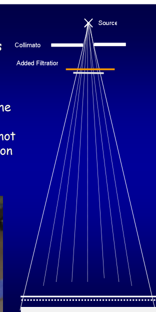
Beam setup – step 2

- Collimate the x-ray beam to only cover the ion chamber with no more than 1 inch margins.
- For DR systems, the detector should be covered with a lead apron or similar barrier when making the exposures for HVL determination and adjustment.
- Measure the HVL of the filtered beam and adjust the kVP and/or aluminium filtration within the limits specified in Table 1 to obtain a HVL as close as possible to 6.8 mm Al.



Beam setup – step 3 (DR)

- The detector should be placed as far from the x-ray source as is practical, at least 100 cm.
- If present, remove the grid and any other components between the ion chamber and the image detector. If any components cannot be removed, obtain the attenuation factors from the DR system or component vendor.

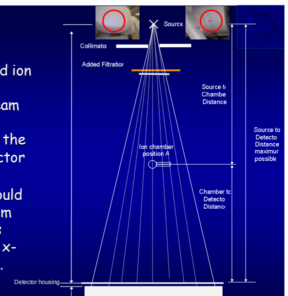


Beam setup – step 3 (CR)

- If the detector is a CR plate the cassette should be separated from any surface that may increase backscatter from that surface entering the cassette, as recommended in AAPM Report 93 (TG10). Use lead behind the plate to further reduce backscatter.
- If the detector is not square, the long axis of the detector should be perpendicular to the x-ray tube A-C axis.

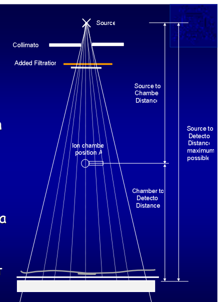
Beam setup – step 5

- Place a calibrated ion chamber at the center of the beam approximately midway between the source and detector (Position A).
- All distances should be measured from the focal spot as indicated on the x-ray tube housing.



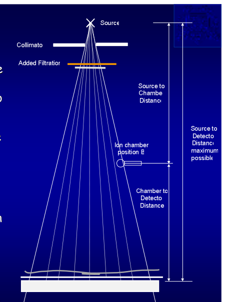
Beam setup – step 6

- Use lead to protect a DR detector.
- Make an exposure to determine the air kerma at the detector (K_{STD}) using an inverse square correction
- Apply the grid attenuation factor, if necessary.
- Change the mAs setting to obtain the desired air kerma at the detector. In general, the desired air kerma will produce a value of K_{STD} that is in the middle of the detector response range.



Beam setup – step 6

- Move the ion chamber perpendicular to the tube axis such that it is at the edge of the field of view (Position B).
- Place the ion chamber as close to the edge of the x-ray beam as possible within the field of view of the detector. Ensure that the entire ion chamber is the radiation beam and is not shadowed by a collimator blade.
- Make an exposure using the mAs found earlier and determine the ratio of the air kerma at Position A to that at Position B.
- Remove the protective lead and expose the receptor.
- Correct the recorded exposure for position and distance to determin the detector air kerma.



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Exposure Index – TG116

AAPM TG116

- Indicated equivalent air kerma (K_{IND}):
  An indicator of the quantity of radiation that was incident on regions of the detector for each exposure made.
- The value reported may be computed from the median for-processing pixel values in defined regions of an image that correlate with an exposure to the detector.
- The median value is then converted to the air kerma K_{STD} from a standardized radiation exposure that would produce the same detector response, i.e., result in the same median for processing signal value Q in a predefined ROI.
- The value should be reported in µG units with three significant figures of precision.

Exposure Index – TG116

AAPM TG116

- Normalized for-processing pixel values Q_K are for-processing pixel values Q which have been converted to have a specific relation to a standardized radiation exposure (K_{STD}).
- Q values are converted to Q_K using the DR system's relationship between Q and K_{STD}.
- After conversion of Q to Q_K, the relationship between air kerma at the input surface of the detector and the Q_K value is.

$$Q_K = 1000 \log_{10} [K_{STD} / K_O]$$

where K_{STD} is in microgray units, K_0=0.001 µGy, and $K_{STD} > K_0$.

Exposure Index – TG116

IEC

- Exposure Index (EI):
  measure of the detector response to radiation in the relevant image region of an image acquired with a digital x-ray imaging system.
- Note: For a fixed radiation quality, the signal generated in the detector is proportional to the image receptor air kerma.
- The exposure index EI shall be calibrated for the digital x-ray imaging system over the specified operating range of image receptor air kerma such that

$$EI = 100\ K_{CAL}$$

where K_{CAL} is the image receptor air kerma in µGy under the calibration conditions.

Deviation Index (DI)

AAPM TG116 & IEC

$$DI = 10 \times Log_{10}\left\{\frac{K_{IND}}{K_{TAR}(b.v)}\right\}$$

- K_{TAR} is a target index value that is to be determined for each body part, view, procedure type, and clinical site.
- When K_{IND} equals K_{TAR}, $DI = 0$
  - $DI = +3.0$ for 2x target exposures
  - $DI = -3.0$ for ½ target exposure
  - ± 1 is one step on a standard generator mAs control or AEC compensation (ISO R5 scale)

	AAPM TG116 Med Physics 2009	IEC 62494-1 © IEC:2008
Exposure Index	Air-kerma at the receptor $K_{IND} = K_{rec}$ (uGy)	$EI = K_{cal} \times 100\ \mu Gy^{-1}$ (unitless)
Calibration Energy	RQA-5 66 - 74 kVp	RQA-5 66 - 74 kV_p
Calibration Filtration	RQA-5 Equivalent 0.5 mm Cu (+ 0-3 mm Al) or 21 mm Al 6.8 ± 0.2 mm Al HVL	RQA-5 Equivalent 0.5 mm Cu + 2 mm Al or 21 mm Al 6.8 ± 0.3 mm Al HVL
Deviation Index	Deviation Index $DI = 10 * \log_{10}(K_{IND}/K_{TGT})$	Deviation Index $DI = 10 * \log_{10}(EI/E_{TGT})$
DI format	Signed decimal string with 1 decimal point	Unspecified

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