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Qualification of digital mammography imaging systems
Kodak CR 975 – EHR-M2 & EHR-M3

Contents

I. Introduction

The purpose of this work is to study the imaging performance of the new computed radiography mammography cassette Kodak EHR-M3, in comparison with the actual Kodak EHR-M2 cassette. The pre-sampled modulation transfer function (MTF), normalized noise power spectrum (NNPS), noise equivalent quanta (NEQ) and detective quantum efficiency (DQE) of the two systems were determined and compared on a wide range of exposure levels.

II. Material and method

A. Imaging systems and beam quality

The two following digital mammography computed radiography systems were compared : CR 975 with EHR-M2 and EHR-M3 plates (pixel size 49 μm).

Pre-processed digital images in a standard DICOM format were used. The tube current - exposure time product was varied to give different values of air kerma at the cassette entrance surface. All images were obtained at 28 kV (Mo/Mo) with a 2 mm aluminium filter placed at the output of the X-ray tube, i.e. the beam RQA-M2 of the IEC 62220-1-2 standard. No anti-scatter grid was used. Air kerma measurements were made with a Radcal dosemeter and a mammography 6 cm^3 ionization chamber (10x5-6M). The reference exposure level was chosen at 50 µGy at the cassette surface. Two additional exposure levels at 3.2 times under and above the reference exposure level were also studied (range of detector dose levels between 16 μGy and 160 μGy).

B. Systems response

Uniform images were acquired at different exposure levels in order to plot the relationship between the mean pixel value and air kerma at the cassette surface. Regions of interest of 1000 x 1000 pixels were selected at the centre of each image for calculating the mean pixel value. The systems' response curves were fitted using logarithmic equations:

$$PV = a + b \cdot \log\ E \qquad (1)$$

Where PV is the mean pixel value, E is the entrance air kerma at the cassette surface, and *a* and *b* are adjustable coefficients. This curve was used to express the image pixel values into x-ray air kerma levels for the MTF and NPS calculations.

C. Spatial resolution (MTF)

The pre-sampled modulation transfer functions (MTF) of the two systems were assessed using an angled edge method similar to that described by Samei[i]. The impulse response was obtained from the image of a 500 µm thick sharp edged tungsten plate tilted at about 2-3° with respect to the lines or columns of the pixels, and positioned along the central axis of the x-ray beam, close to the surface of the detectors. The line edges were extracted from the linearized image. The exact angle of the edge with respect to the pixel pattern was calculated using a least squares fit to the edge transition position, obtained by calculating the image gradient in the direction perpendicular to the edge transition. The projection of the edge image along the line edge gave the oversampled edge spread function (ESF). An area of interest of 100 mm perpendicular to the edge was used to obtain the ESF. The MTF is the zero-frequency normalized modulus of the fast Fourier transform of the line spread function (LSF), the derivative of the ESF.

D. Normalized noise power spectra (NNPS)

The noise power spectra (NPS) were assessed according to the method described in the international standard IEC 62220-1-2. For each exposure condition, the NPS was obtained from areas of 1024 x 1024 pixels close to the centre of three identical homogeneous images, which

[i] E. Samei, M. Flynn, D. A. Reimann, „A method for measuring the presampled MTF of digital radiographic systems using an edge test device", Med. Phys. **25**, 102-113 (1998)

were converted to exposure levels using the fitted response function. Low-frequency trends of the signal due to the Heel effect and the x-ray beam inhomogeneity were removed by fitting a two-dimensional second-order polynomial to the linearized 1024 x 1024 areas, and then subtracting this function in such a way that the initial average pixel values were not changed. Each 1024 x 1024 area of interest was subdivided into 49 256 x 256 matrices, half overlapping in both directions. Thus, for each exposure condition, the reported NPS was the mean of 147 NPS estimates (9’633’792 pixels). To be representative of the noise characteristics of the whole image, the NPS for both plates were calculated radially. The normalized NPS (NNPS) is the NPS divided by the square of the mean pixel value of the area.

E. NEQ / DQE

The noise equivalent quanta (NEQ) was calculated from the pre-sampled MTF and the normalized NPS according to its usual definition:

$$NEQ(u) = \frac{MTF^2(u)}{NNPS(u)} \qquad (2)$$

The detective quantum efficiency (DQE) was calculated as the ratio of the NEQ to the input photon fluence. The x-ray quantum fluence per unit exposure was taken from the IEC 62220-1-2 standard (5007 photons/(mm^2·µGy)).

III. Results

A. Systems response

The response curves of the two mammography CR cassettes measured for the beam quality 28 kV (Mo/Mo) used in the study are presented in the above table and in Figure A1. The data were fitted by linear or logarithmic functions (Eq. 1) with correlation coefficients greater than 0.9999. *a* and *b* are the fitted coefficients calculated for the two systems. These response curves were used to convert the image pixel values into x-ray air kerma units for the resolution and noise measurements.

The comparison between the two response curves shows that the EHR-M3 cassette is about 33% more sensitive than the EHR-M2 cassette. As a consequence, the EHR-M3 cassette needs 20% less dose than the EHR-M2 cassette to give the same signal level.

	curve	coefficient *a*	coefficient *b*
Kodak CR 975 EHR-M2	logarithmic	246.4	1000
Kodak CR 975 EHR-M3	logarithmic	410.3	1000

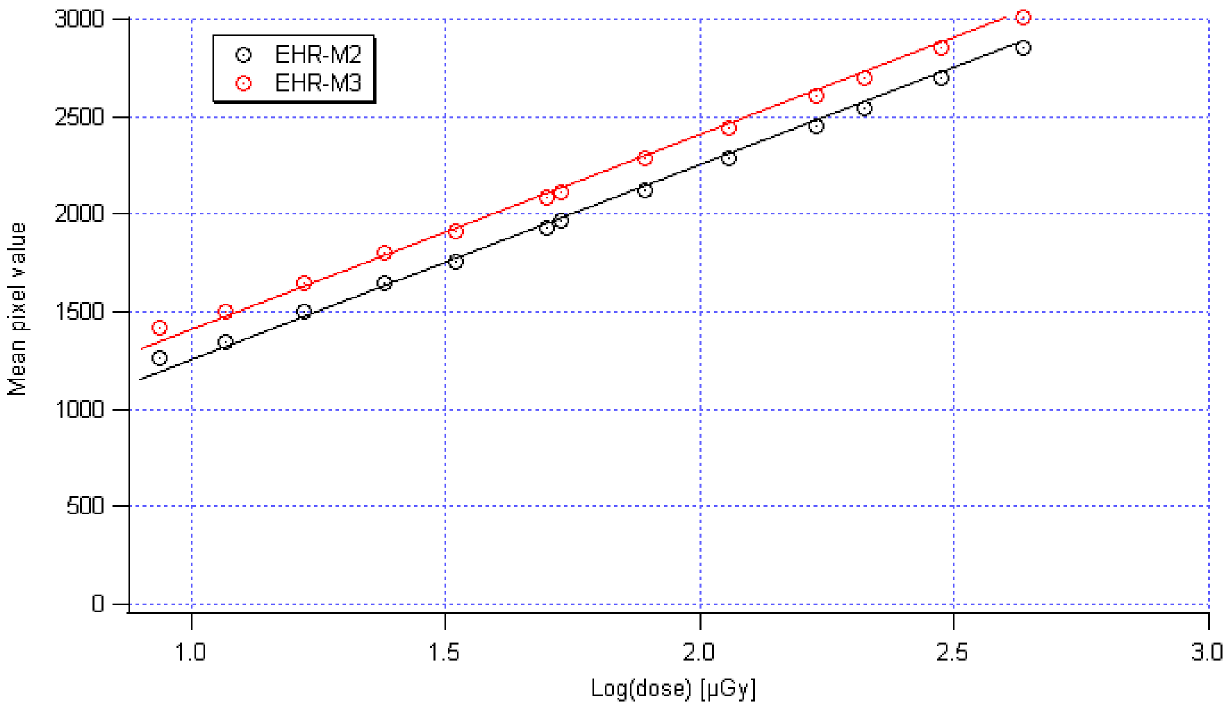

Figure A1: Response curves of the Kodak EHR-M2 and EHR-M3 cassettes

B. Spatial resolution (MTF)

The pre-sampling MTF of the EHR-M2 and EHR-M3 cassettes measured at the RQA-M2 beam are presented in Figure B1. The pixel size of the two cassettes is 49 µm, giving a Nyquist frequency of 10.2 mm^{-1}. The pre-sampled MTF of the new EHR-M3 screen was found to be slightly lower than that of the EHR-M2 screen. For these two systems, the MTF is slightly lower in the laser scan direction than in the subscan direction. It is an effect of the luminance decay time on the readout signal.

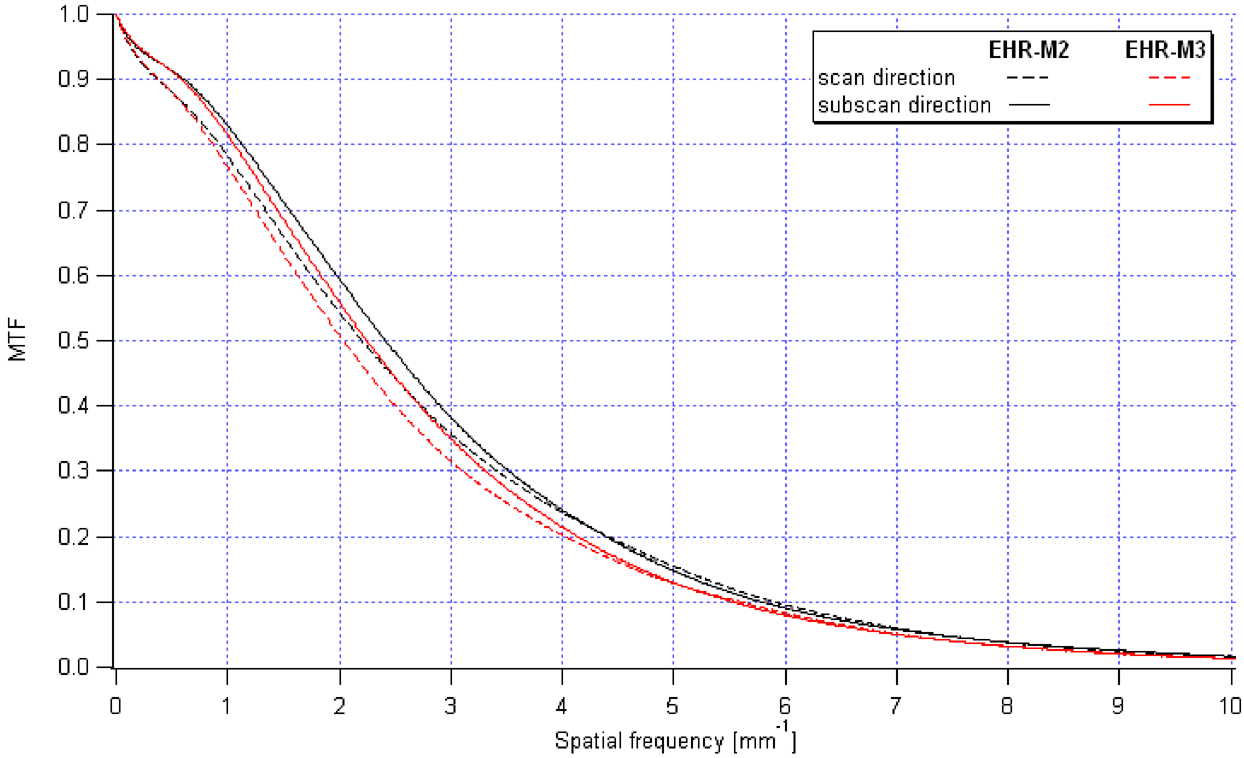

Figure B1: Presampling MTF of the Kodak EHR-M2 and EHR-M3 cassettes

C. Normalized noise power spectra (NNPS)

Figure C1 shows the NNPS of the EHR-M2 and EHR-M3 cassettes for three different air kerma at the cassette level, for the beam quality RQA-M2. The NNPS decreases with an increasing spatial frequency and with dose for the two cassettes. The EHR-M3 cassette has a lower noise of approximately 30% at the same dose compared to the EHR-M2 cassette. The frequency composition of noise is similar for both cassettes.

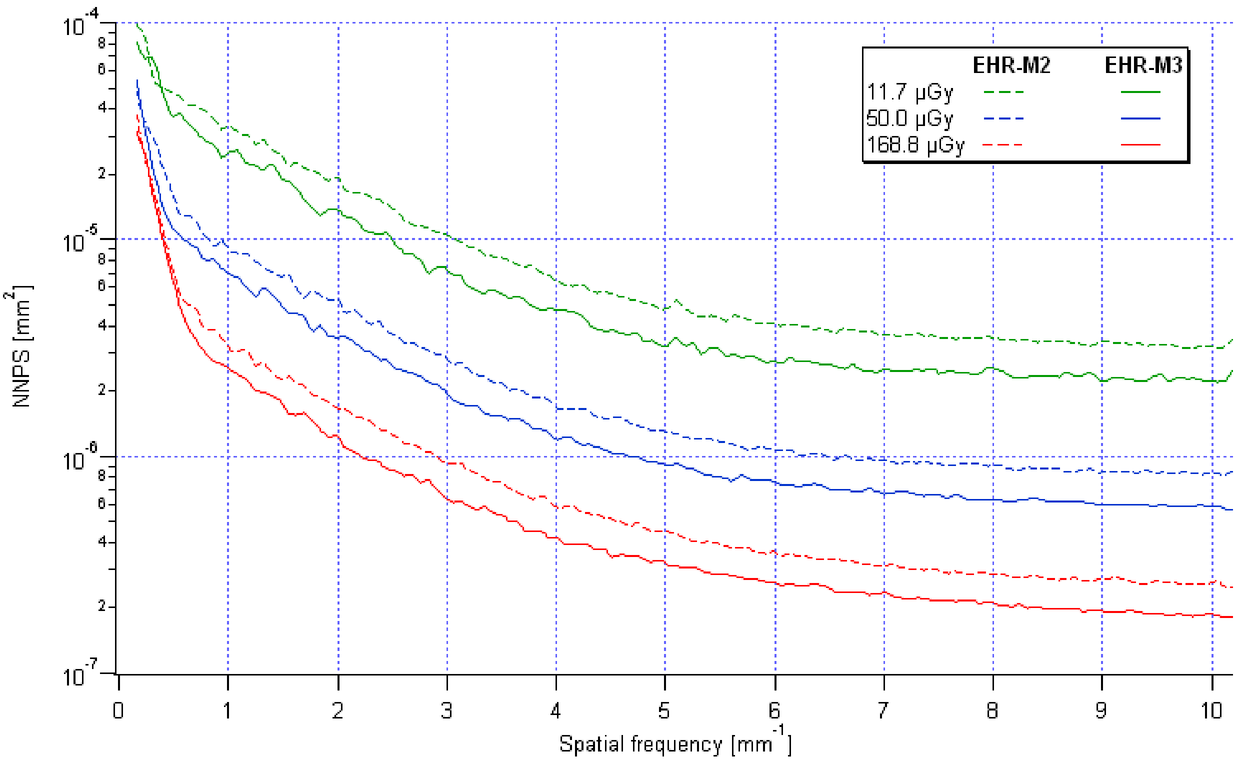

Figure C1: NNPS of the Kodak EHR-M2 and EHR-M3 cassettes at three doses

Figures C2 and C3 are maps representing the two-dimensional iso-frequency and iso-NNPS curves for the EHR-M2 and EHR-M3 cassettes, respectively. They show the directional repartition of the noise amplitude as a function of the spatial frequency over 180°. For both systems, the NNPS shows a radial symmetry in the low and middle frequency range. At higher spatial frequencies, the NNPS of both systems becomes less isotropic.

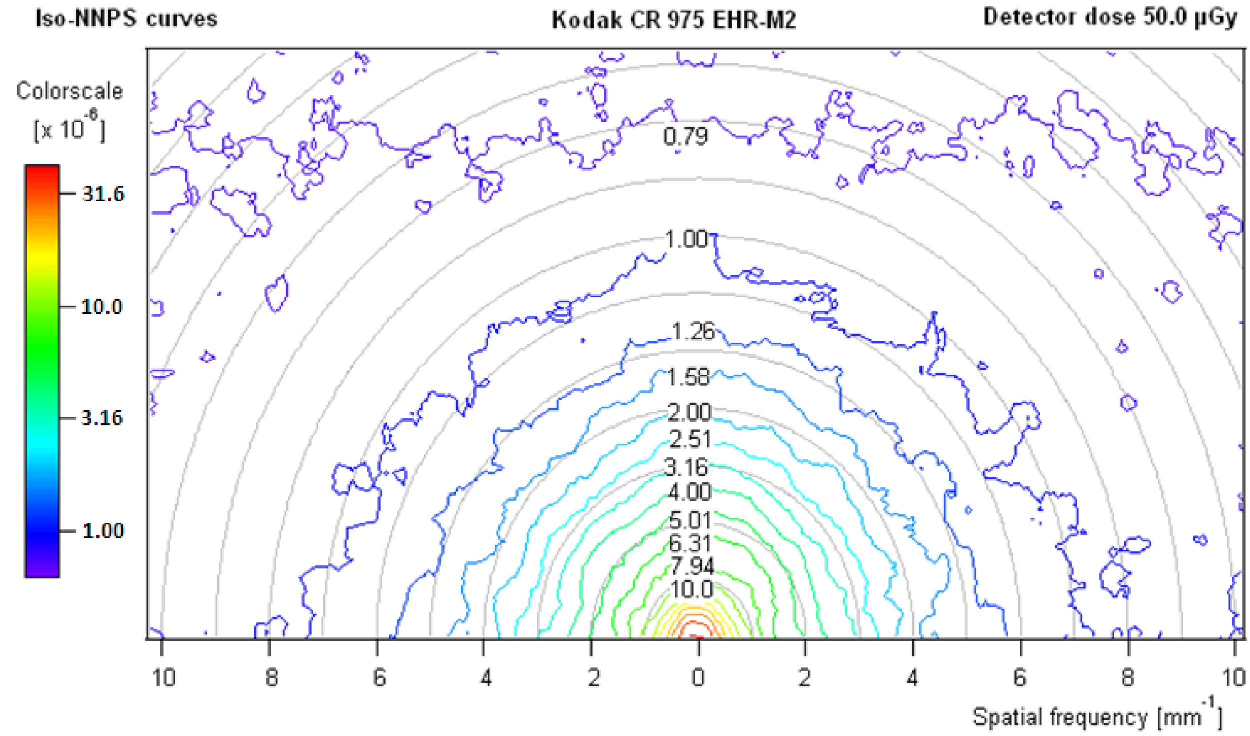

Figure C2: Iso-frequency and iso-NNPS curves of the Kodak CR 975 EHR-M2 system at 50 μGy (RQA-M2)

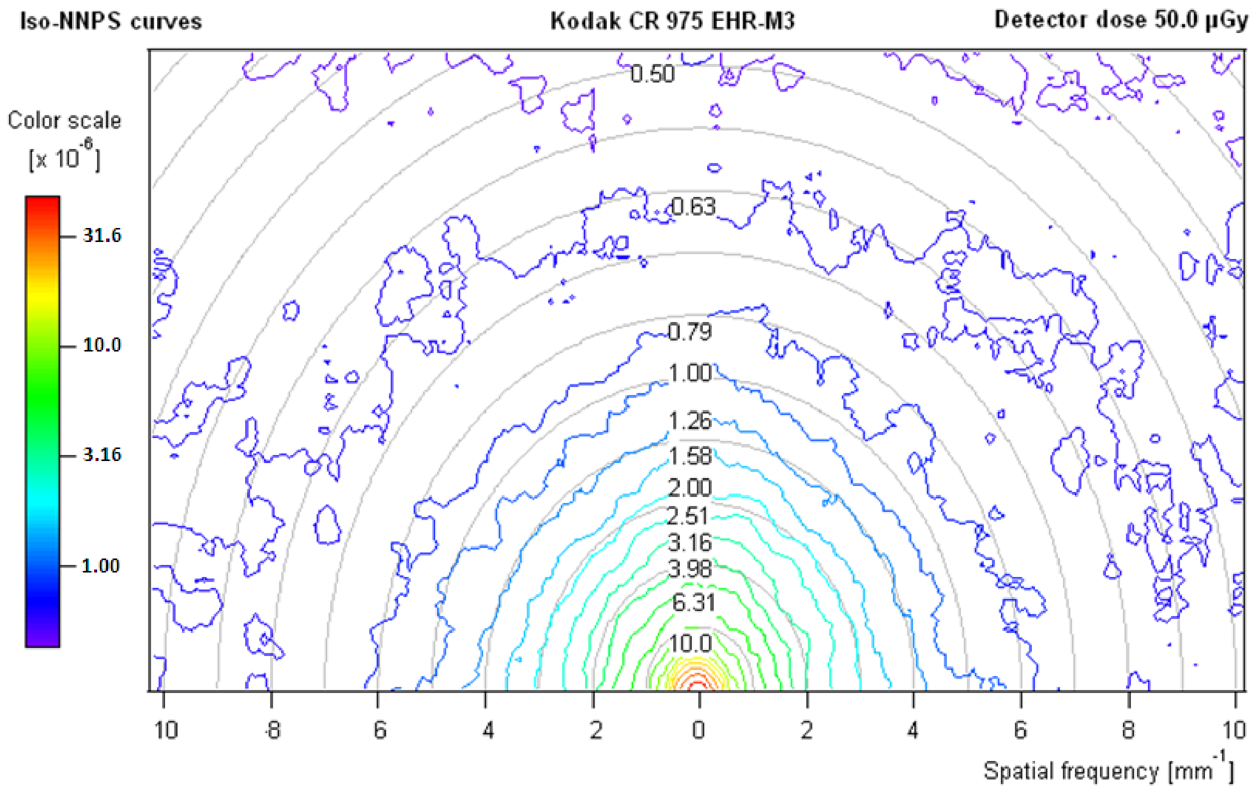

Figure C3: Iso-frequency and iso-NNPS curves of the Kodak CR 975 EHR-M3 system at 50 μGy (RQA-M2)

Figure C4 shows the relative noise at different cassette doses, with the estimated relative contributions of electronic, structural and quantum noise for the EHR-M2 and EHR-M3 cassettes. The quadratic sum of these contributions were fitted to the measured noise.

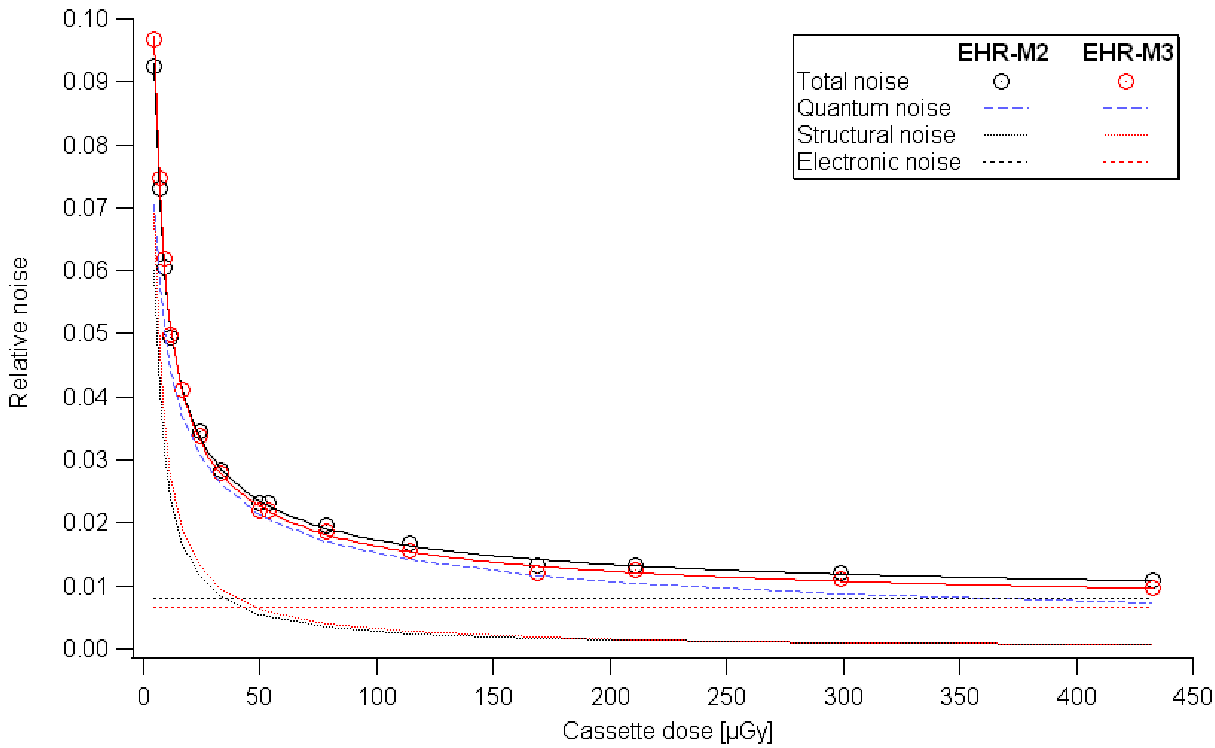

Figure C4: Relative noise of the Kodak CR 975 EHR-M2 and EHR-M3 cassettes (RQA-M2)

D. NEQ

Figure D1 shows the NEQ of the EHR-M2 and EHR-M3 cassettes for three different air kerma at the cassette level, for the beam quality RQA-M2. The NEQ decreases with an increasing spatial frequency and increases with dose for the two cassettes. The EHR-M3 cassette has a higher NEQ of approximately 20% at the same dose compared to the EHR-M2 cassette.

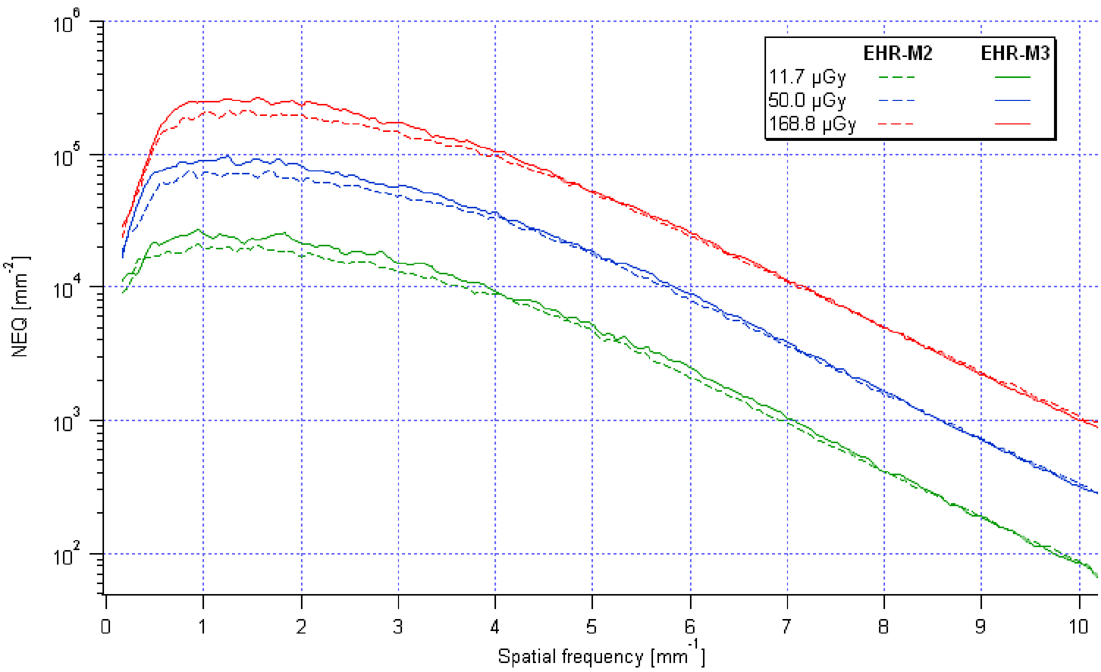

Figure D1: NEQ of the Kodak EHR-M2 and EHR-M3 cassettes at three doses

E. DQE

The DQE curves of the EHR-M2 and EHR-M3 cassettes are presented in Figure E1 for three different air kerma at the cassette level, for the beam quality RQA-M2. For all the doses, the EHR-M3 screen has a higher DQE of approximately 20%. The maximal (low-frequency) DQE reaches 35% for the new EHR-M3 screen at the reference dose of 50 µGy. The maximal DQE of the EHR-M2 screen is lower, at 28%.

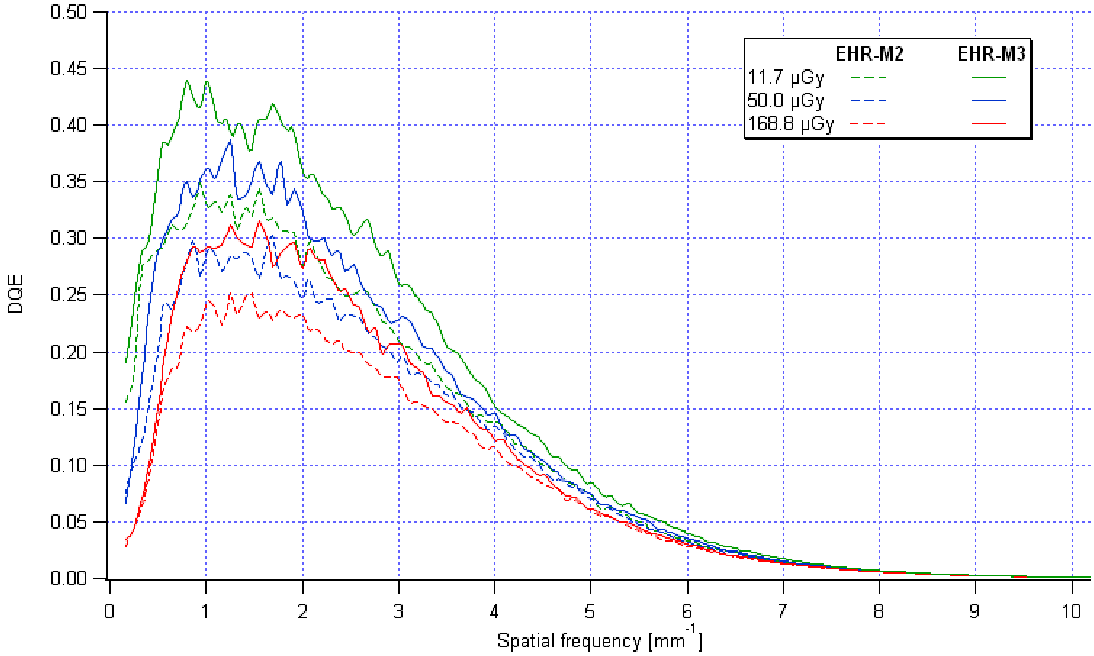

Figure E1: Iso-frequency and iso-NNPS curves of the Kodak CR 975 EHR-M3 system at 50 µGy (RQA-M2)

Figure E2 shows that the DQE of the two systems decreases strongly with dose, especially at low dose. An important decrease of the DQE level from 40% to 25% was found between 20 and 200 µGy for the EHR-M3 cassette, and from 33% to 20% for the EHR-M2 cassette. The falloff of the DQE level with dose is caused by the noise components added by the detectors that increase as the exposure level increases.

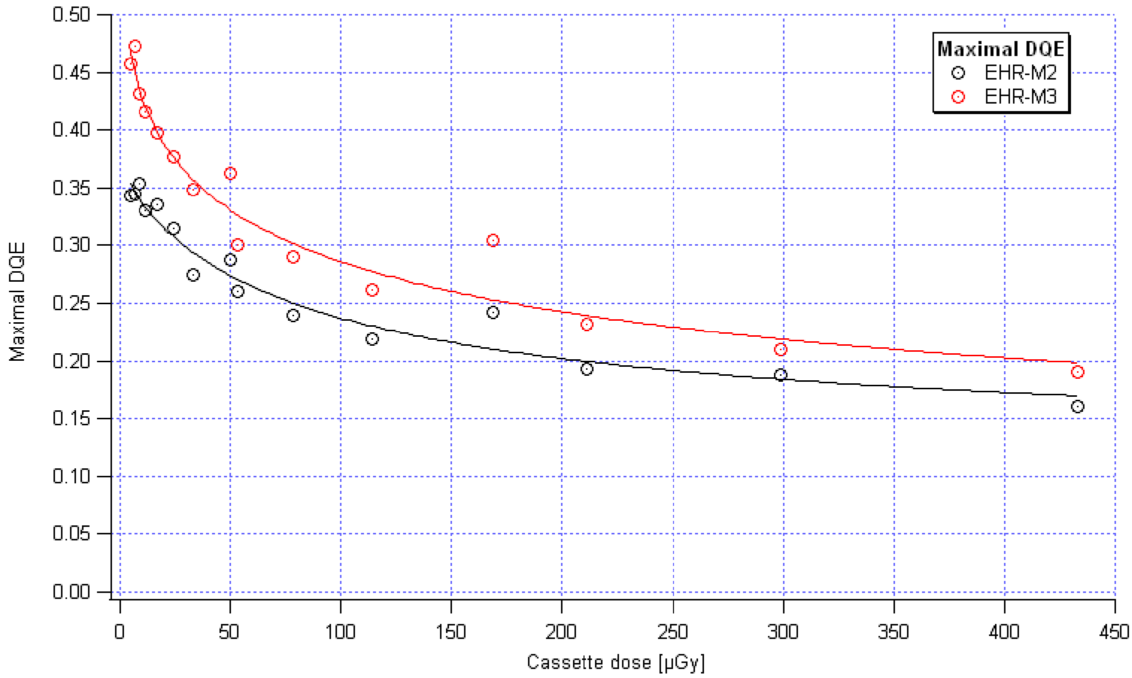

Figure E2: Maximal (low-frequency) DQE of the Kodak CR 975 EHR-M2 and EHR-M3 cassettes (RQA-M2)

IV. Conclusion

The study of the two Kodak EHR-M2 and EHR-M3 CR cassettes leads to draw the following main conclusions

1. The EHR-M3 screen is 33% more sensitive than the EHR-M2 screen, i.e. the mean signal level is increased of 33% for the same dose level.

2. The new EHR-M3 screen has a slightly lower pre-sampled MTF than the EHR-M2 screen. The difference can reach a maximal value of 0.04. No part of signal of frequency above the Nyquist frequency can be aliased.

3. For a comparable dose of 50 μGy, the new EHR-M3 screen has a significantly lower noise level of approximately 25% than the EHR-M2 screen whichever the dose, for the whole frequency bandwidth of the signal.

4. The DQE of the new EHR-M3 cassette is approximately 20% higher than the EHR-M2 cassette. The DQE of the two systems decreases as the dose increases, especially at low dose.