EVALUATION OF
THE KODAK MIN-R EV
MAMMOGRAPHY
FILM-SCREEN SYSTEM

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1. INTRODUCTION

Kodak have developed a new film-screen system for mammography known as Min-R EV. Information on the design and performance features of this system has been described by Kodak.[1] The film has two different emulsion layers to provide ‘higher contrast and wider exposure latitude’. The film is reported to be slower than Min-R 2000 but the screens faster to reduce film noise by reducing granularity. To evaluate the system for the NHS Breast Screening Programme (NHSBSP) it was compared to the existing Min-R 2000 system at one site using the mammography system described in Table 1.

Table 1: Mammography system used for testing screens

Current film	Kodak Min-R 2000
Current screen	Kodak Min-R 2000
New film	Kodak Min-R EV
New screen	Kodak EV
Processor	Kodak Multi-loader 7000
Developer	RP- Xomat EX
Fixer	RP- Xomat LO
Cycle time	120s
Developer temperature	35° C
Screens	Kodak Min-R2000
X-ray set	Siemens Mammomat 3
Target OD	1.80
MGD to standard breast at 28 kV Mo Mo	1.38 mGy

2. LIGHT SENSITOMETRY OF FILMS

The sensitometry of the two films Min-R2000 and Min-R EV was compared using a 21 step light sensitometer, and the results are shown in Figure 1. Maximum and minimum densities and mean film gradients are shown in Table 2. The average film gradients measured for the new film were about 27% higher than those measured for Min-R 2000. It can also be seen from Table 2 that these gradients are much higher than previously reported for other film-screen combinations used in the NHSBSP.[2]

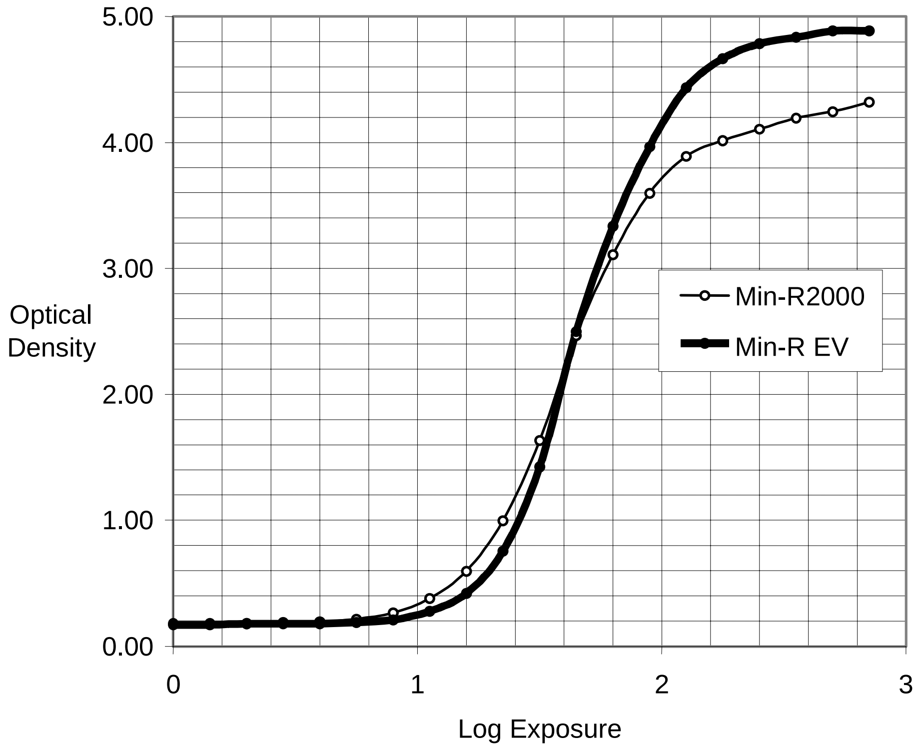

Figure 1: Light sensitometry

Table 2: Sensitometric indices for different types of film

	Gradients measured in the NHSBSP[2]				Measured in this study		
	Agfa HDR	Fuji UMMA	Fuji AD-M	Kodak Min-R2000	Kodak Min-R2000	Kodak Min-R EV	Increase with EV
Average film gradient from densities 0.25 to 2.0 plus base and fog	3.18 ± 0.08	3.05 ± 0.20	3.62 ± 0.21	3.63 ± 0.21	3.41	4.33	+27%
Average film gradient from densities 1.0 to 2.0 plus base and fog	3.72 ± 0.14	3.73 ± 0.31	4.63 ± 0.41	4.97 ± 0.33	4.87	6.21	+28%
Dmin					0.18	0.17	
Dmax					4.32	4.89	

3. X-RAY SENSITOMETRY OF FILM-SCREEN COMBINATIONS

To assess the characteristic curves using X-rays rather than light, an aluminium step-wedge was imaged at 28 kV Mo Mo with the two film-screen combinations. The step-wedge had been previously calibrated for this spectrum. The characteristic curves for the two film-screen combinations are shown in Figure 2 and the gradients calculated from these curves shown in Table 3.

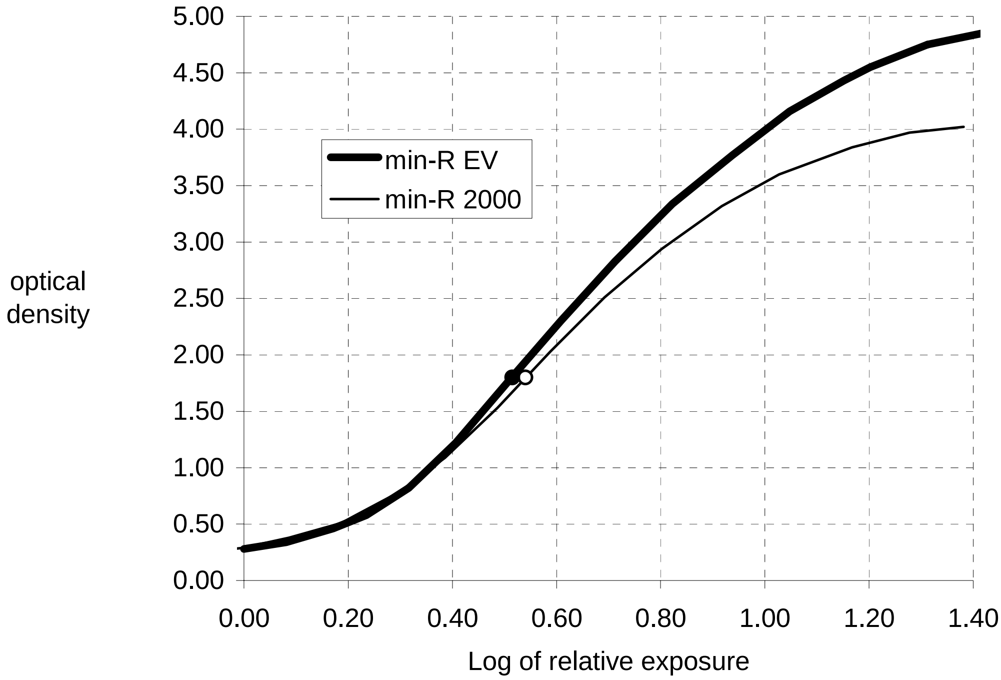

Figure 2: X-ray sensitometry. Operating points selected by the AEC at a density of 1.80 are shown as circles.

Table 3: Average film gradients measured using a calibrated aluminium step-wedge

	Kodak Min-R2000	Kodak Min-R EV	Increase with EV combination
Average film gradient from densities 0.25 to 2.0 plus base and fog	3.53	4.01	+14%
Average film gradient from densities 1.0 to 2.0 plus base and fog	4.67	5.31	+14%

4. SPEED MEASUREMENTS

The relative speeds of the two film-screen combinations were tested at 28kV MoMo with a 4cm thickness of PMMA and a target density of 1.80. The results are shown in Table 3. The mAs selected for the cassette with the new Min-R EV film-screen combination was 8% higher than for the cassette with the existing Kodak Min-R2000 film-screen combination. This means that the new cassette and film-screen combination has higher attenuation so that the AEC would need to be readjusted for routine use. The new film-screen combination was about 6% faster than the existing system leading to a corresponding reduction in dose. In fact Kodak claim the speed of the new combination is unchanged from the Min-R2000. However the assessment of speed depends on the density selected for comparison. If a lower density of say 1.2 had been used instead of 1.8 there would have been no significant difference between the two systems as seen in Figure 2.

Table 3: Results of speed tests using 4cm PMMA at 28 kV MoMo

Film	Screen	mAs selected in AEC mode	OD of film	mAs for OD of 1.8	Relative speed (%)	Relative mAs selected (%)
Min-R2000	2000	39.9	1.80	39.9	100	100
Min-R EV	EV 150	43.2	2.23	37.6	106	108

5. HIGH CONTRAST LIMITING RESOLUTION

The high contrast limiting resolution of the two film-screen combinations was measured using a CIRS gold resolution test pattern on top of 4cm of PMMA, both parallel and perpendicular to the tube axis. The test object has gratings every 1 line pair per mm. The results shown in Table 4 are the average of three observers. No difference was detected between the film-screen combinations.

Table 4: High contrast limiting resolution

		HC Resolution (lp/mm)	
Screen	Film	Parallel	Perpendicular
Min-R2000	2000	16.0 ± 0.5	19.0 ± 0.5
Min-R EV	EV 150	16.0 ± 0.5	19.0 ± 0.5

6. IMAGE QUALITY (USING TOR-MAX AND TOR-MAM)

Image quality was assessed using a TOR-MAM test object on top of 3cm of PMMA, and a TOR-MAX test object on top of 4cm of PMMA. All exposures were made with 28kV Mo/Mo and a target density of 1.8. The results are shown in Table 5. There was no significant difference between the two films, considering the errors in the method of visual inspection. Both film-screen combinations easily meet the NHSBSP minimum image quality requirements.

Table 5: Image quality test results with TOR-MAM and TOR-MAX test objects

	Criteria	Min-R2000	Min-R EV
TOR-MAM score	≥ 70	93 ± 5	91 ± 5
Number of 6mm details in TOR-MAX	≥ 7	9 ± 0.5	9 ± 0.5
Number of 0.5mm details in TOR-MAX	≥ 8	9 ± 0.5	9 ± 0.5
Number of 0.25mm details in TOR-MAX	≥ 7	8 ± 0.5	8 ± 0.5

7. IMAGE QUALITY (USING CD-MAM)

Threshold contrast was measured using the CDMAM (version 3.4) contrast detail test object, imaged at 28kV Mo Mo. The test object was sandwiched in the middle of a 4cm thick stack of PMMA plates. The results are shown in Figure 3 and appear to indicate slightly better results with the new film-screen combination.

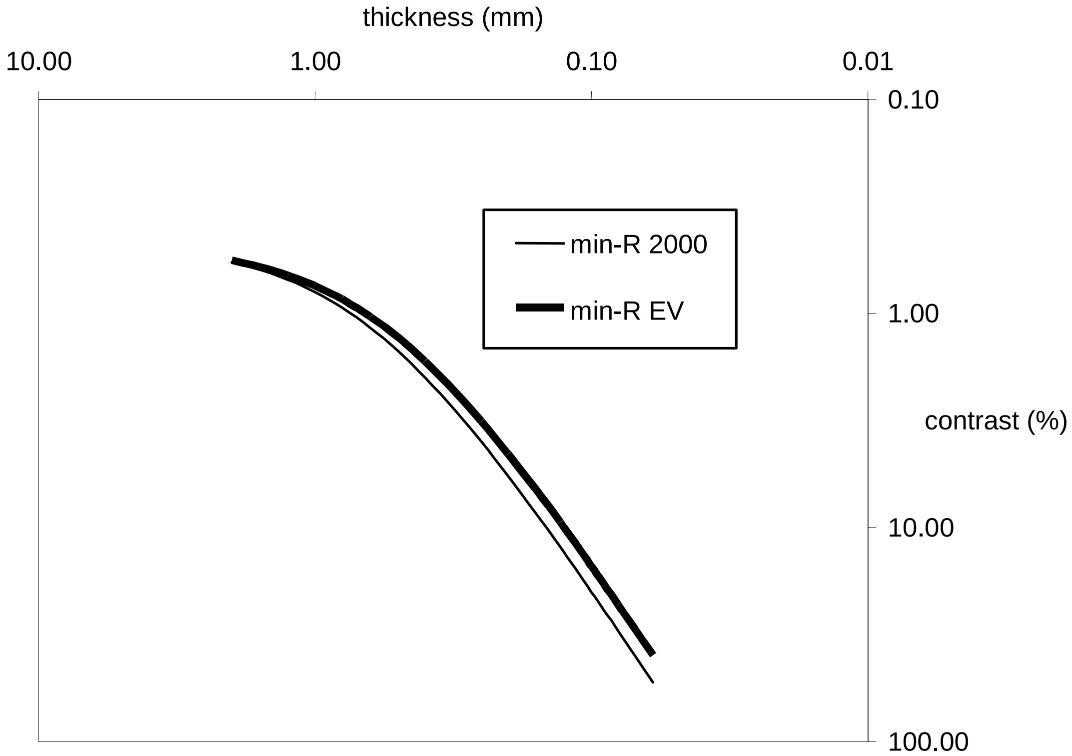

Figure 3: Contrast detail curves

8. LATITUDE

The Kodak literature provided with the new film claims both higher contrast and improved latitude. This is a surprising claim to make given that a high contrast is generally associated with lower latitude. In order to understand how this new film may affect latitude the characteristic curve has been analysed as shown in Figure 4. This analysis is derived from the light sensitometry curves for the two films. (It therefore makes the assumption that the characteristic curve has the same shape when light from the screens are used.) Latitude is not generally well defined. However we have previously published an approach similar to the one adopted here.[3] Latitude can be defined as the range of exposures over which differences in film density can be seen by the observer and defined here as in equations 1 to 3.

$L_{lower} = \log_{10} E_{mid} - \log_{10} E_{min}$ ……………………. (1)

$L_{upper} = \log_{10} E_{max} - \log_{10} E_{mid}$ ……………………. (2)

$L_{total} = L_{upper} + L_{lower}$ ……………………. (3)

where, E_{mid} is the relative exposure corresponding to a density of 1.8, E_{min} is the relative exposure corresponding to the minimum density at which density differences can be detected and E_{max} is the relative exposure corresponding to the maximum density at which density differences can be detected.

An upper and lower latitude is defined because the reasons why one may cease to visualise density differences are different at high and low densities. At low densities the limit is likely to be determined mainly by the film gamma. (There may be other factors such as image noise, but these are assumed to be secondary.) For film densities of 0.65 to greater than 4.0 the Min-R EV film has greater film gamma than that on Min-R 2000 for the same exposure range. Thus if film gamma is the main determinant then Min-R EV film will show density differences as well or better than Min-R 2000 down to a density of about 0.65. Little contrast information will be present at densities below this. It is therefore important not to underexpose dense tissues with this film. Hence the need to set relatively high average film densities of about 1.8 using the X-ray set's AEC control.

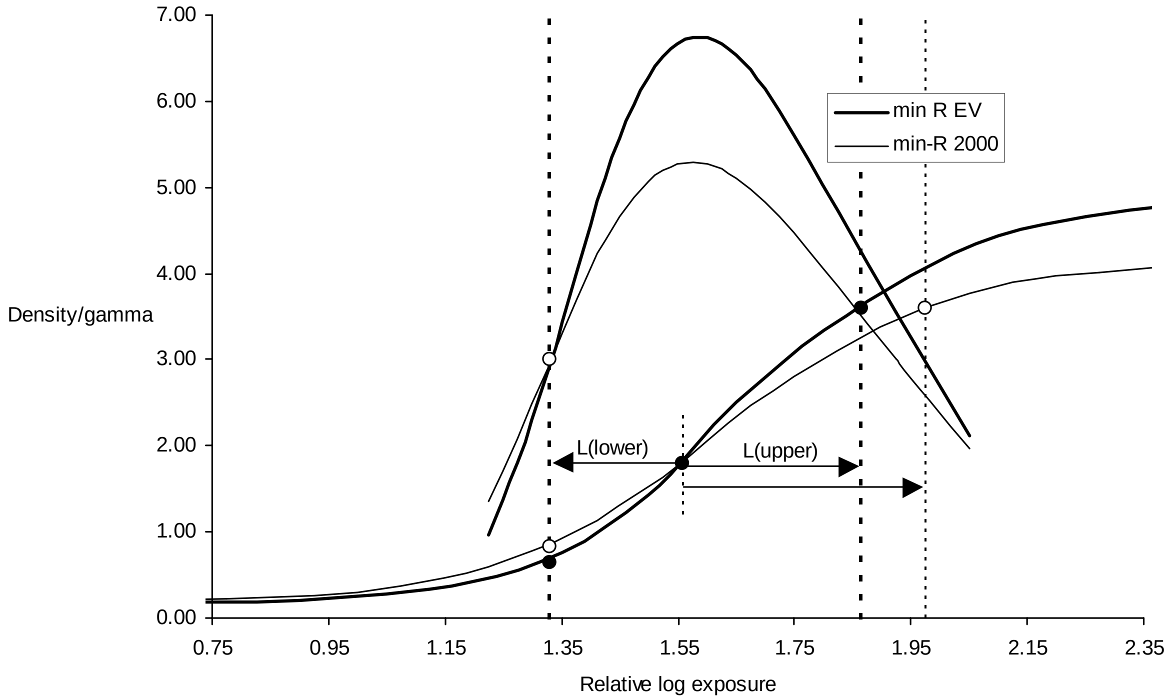

Figure 4: Analysis of characteristic curves to compare latitude. The curves have been derived from light sensitometry and shifted to have the same relative exposure at a gross film density of 1.80.

At high densities the visibility of density differences on film is mainly limited by the dynamic range of the human visual system. (This is why bright lighting can reveal structure not seen with normal viewing conditions.) In this case it is the actual optical density rather than the film gamma that mainly limits visibility. (Film gamma also may have an effect and Kodak is assuming that this is the dominant factor in their latitude claims.) In a previous publication it was found that a density of approximately 3.6 corresponded to the upper limit of visibility in the skin edge of mammograms using Fuji UMMA and Agfa HDR films.[4] Figure 4 shows that the new film reaches a density of 3.6 over a narrower range of exposures than Min-R 2000. Using this definition of latitude at higher densities L_{upper} was calculated in Table 6 to be 27% less using Min-R EV than Min-R 2000. The effect of this will be to show the tissues in the main breast at higher contrast, but make it very difficult to see the tissues close to the skin edge unless bright lighting is used.

Table 6: Data used to calculate latitude from characteristic curves

	Min-R2000		Min-R EV	
	log exposure	density	log exposure	density
Exposure for equal gamma	1.330	0.83	1.330	0.65
Exposure for OD = 1.80	1.555	1.80	1.555	1.80
Exposure for OD = 3.60	1.974	3.60	1.863	3.60
L_{lower}	0.225		0.225	
L_{upper}	0.419		0.308	

9. CLINICAL EVALUATION

The new film-screen combination was used for screening at the Butterfly Walk static screening site of the Kings College Hospital Breast Screening Programme in London. The purpose of this evaluation was to review image appearance from a radiologist's perspective and to determine whether Kodak's claim that the system gives higher contrast and greater latitude had been achieved. The appearance of new screening mammograms was compared to the screening mammograms on the same women taken three years previously. Both sets of films were mounted on a roller viewer routinely used for assessing screening mammograms using a method described previously.[3] For each film the radiologist classified the visibility of the skin edge for both medio-lateral oblique films into the three categories; visible, just barely visible and too dark. The radiologist also compared the overall image quality of the new mammograms compared to the previous films taken with the old film. The optical density of tissues close to the skin line and of the adjacent fully exposed film were measured for each film using an X-rite 301 densitometer with a 2mm aperture.

The results of the analysis of skin edge visibility are shown in Figure 5. In only 18% of cases was the skin edge *visible* or *just visible* using the Min-R EV film. In 62% of cases the skin edge was *visible* or *just visible* using the Min-R2000 film.

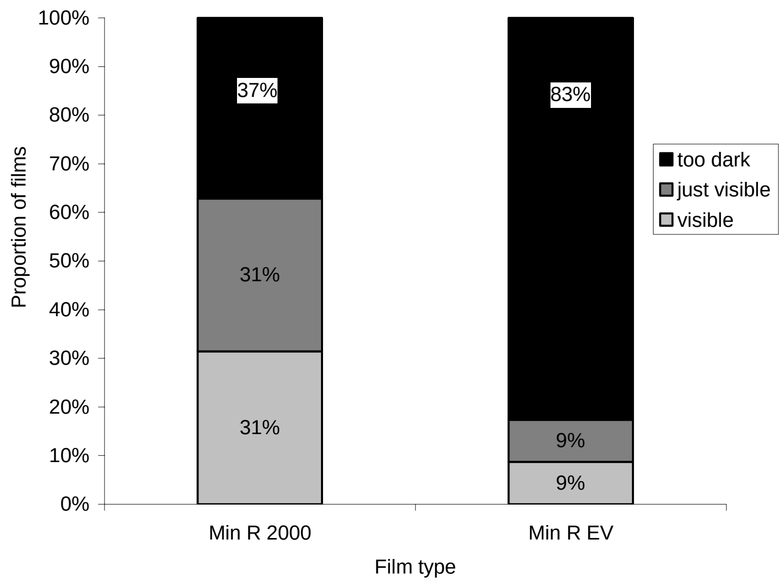

Figure 5: Skin edge visibility for the two film types.

The screening mammograms using the new film-screen combination were assessed for 47 women. Screening mammograms were available from the previous screening round using the old film system for 36 of these women. The proportions of the women with mammograms in which the skin edge had the three visibility classifications are shown in Figure 2. The skin edge could not be seen under normal viewing conditions in mammograms of 83% of the women using the new film, and for 37% of the women where the old film was used. In comparing the overall image quality, the films were thought to be of similar quality in 56% (20) of cases and the new film was thought to have slightly better image quality in the remaining 44% (16) of cases.

The mean background density for the new film was 4.55 ± 0.05 (SD). The mean background density for the old film was 4.11 ± 0.15 (SD). The mean skin edge density for the new film was 4.23 ± 0.25 (SD). The mean skin edge density for the old film was 3.83 ± 0.18 (SD). The link between the density of the skin edge and the visibility of the skin line was investigated. The density at which the skin edge ceased to be visible was determined to be 3.8 for Min-R2000 and 3.9 for Min-R EV. No difference in latitude was observed between the films at low densities.

10. DISCUSSION

The new film screen combination is substantially different from the Kodak Min-R2000 film-screen systems in widespread use in the NHSBSP. Kodak claim many technical improvements and clinical advantages for this new system. The Kodak literature supplied with the film indicates that the new film has a contrast that is about 25% higher than Min-R2000. This is achieved by using two emulsion layers. The light sensitometry results reported here indicate about a 27% increase in film gradient, which is very similar to the 25% claimed in the Kodak literature. The characteristic curve of the new film also has a high Dmax and high film contrast maintained down to quite low densities (of about 0.65).

The results of X-ray sensitometry suggest that the increase in film gradient with the new film is about 14%. The absolute values of the film gradients measured with the aluminium step-wedge are dependent on a previous calibration (at 28 kV Mo/Mo) and are subject to some calibration error (eg the spectra used in these tests may be slightly different from that used for the calibration). However any calibration error is likely to have the same effect on both film types.

Although it would be interesting to know the reason for the difference in film gradients between light and X-ray sensitometry, the important point to note is that this is a very high contrast film-screen combination.

Kodak claims that this film has both ‘greater overall contrast, yet wider exposure latitude’. This is a claim that depends on one’s definition of exposure latitude. Kodak are implicitly assuming that film gamma is the main determinant of latitude at both high and low densities. It is the authors’ view that this claim may be justified at low densities, ie in dense glandular tissues and pectoral muscle down to a density of 0.65. However, we would expect that the shape of the new film’s characteristic curve will make it more difficult to see tissues at high densities, ie tissues close to the skin edge, unless a bright light is used. The results of the clinical evaluation bore out both these findings. Some of the issues involved in using high contrast mammography film have been discussed previously and also apply here.[2] It will be particularly important to achieve the correct exposure with this new film. For most types of breast the images will appear better, but for a few the contrast may be excessive and this will be mainly observed as a difficulty in visualising the skin edge.

The new combination was found to be about 6% faster than Min-R2000. This is probably a useful outcome given the gradual rise in doses in the NHSBSP in recent years. The fact that Kodak indicate the speed is unchanged may relate to a different method of measuring speed (i.e. at a lower density than in this study). In any case such a small difference is probably close to manufacturing tolerances and may depend on the chemistry used when conducting the speed tests.

It should be noted that the results reported here were for specific processing conditions, and slightly different results may be found when using different conditions eg another type of developer.

Most of the image quality tests indicate little difference between the two film-screen combinations and both were well within the requirement of the NHSBSP. The contrast detail tests with the CDMAM test object suggest that the new film screen combination is better. This is something that merits further investigation but is beyond the scope of this short report.

11. CONCLUSION

This new film-screen combination performs largely as described by Kodak. It has substantially greater contrast than the Min-R2000 system and image quality is at least up to the standard of Min-R2000. Kodak’s claim that there is also greater latitude does not seem to be justified, particularly at high film densities.

12. REFERENCES

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13. ACKNOWLEDGEMENTS

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