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(54) Minimal crossover radiographic elements adapted for flesh and bone imaging.

(57) Radiographic elements are disclosed with dsilver halide emulsion layer units coated on opposite sides of a film support. The radiographic elements are constructed to reduce crossover during exposure by intensifying screens to minimal levels. To permit the minimal crossover radiographic elements to be employed to record both bone and soft tissue structure, a silver halide emulsion layer unit on one side of the support is chosen to exhibit a speed and contrast exceeding that of another silver halide emulsion layer unit on the opposite side of the support.

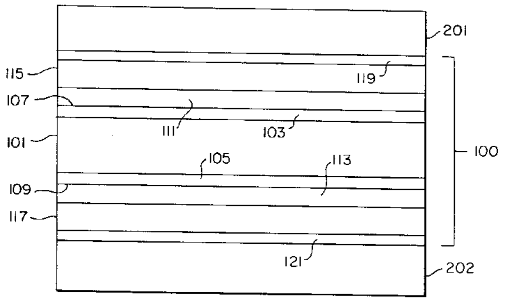

FIG. 1

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The invention relates to radiographic imaging. More specifically, the invention relates to double coated silver halide radiographic elements of the type employed in combination with intensifying screens.

The term "double coated" as applied to a radiographic element means that emulsion layer units are coated on each of the two opposite sides of the support.

The term "low crossover" as applied to double coated radiographic elements indicates a crossover of less than 10% within the wavelength range of imaging and when measured as more fully described below.

The term "sensitometrically symmetric" means that the emulsion layer units on opposite sides of a double coated radiographic element produce identical characteristic curves when identically exposed.

The term "sensitometrically asymmetric" means that the emulsion layer units on opposite sides of a double coated radiographic element produce significantly different characteristic curves when identically exposed.

In medical radiography an image of a patient's tissue and bone structure is produced by exposing the patient to X-radiation and recording the pattern of penetrating X-radiation using a radiographic element containing at least one radiation-sensitive silver halide emulsion layer coated on a transparent (usually blue tinted) film support. The X-radiation can be directly recorded by the emulsion layer where only limited areas of exposure are required, as in dental imaging and the imaging of body extremities. However, a more efficient approach, which greatly reduces X-radiation exposures, is to employ an intensifying screen in combination with the radiographic element. The intensifying screen absorbs X-radiation and emits longer wavelength electromagnetic radiation which silver halide emulsions more readily absorb. Another technique for reducing patient exposure is to coat two silver halide emulsion layers on opposite sides of the film support to form a "double coated" radiographic element.

Diagnostic needs can be satisfied at the lowest patient X-radiation exposure levels by employing a double coated radiographic element in combination with a pair of intensifying screens. The silver halide emulsion layer unit on each side of the support directly absorbs 1 to 2 percent of incident X-radiation. The front screen, the screen nearest the X-radiation source, absorbs a much higher percentage of X-radiation, but still transmits sufficient X-radiation to expose the back screen, the screen farthest from the X-radiation source.

An imagewise exposed double coated radiographic element contains a latent image in each of the two silver halide emulsion units on opposite sides of the film support. Processing converts the latent images to silver images and concurrently fixes out undeveloped silver halide, rendering the film light insensitive. When the film is mounted on a view box, the two superimposed silver images on opposite sides of the support are seen as a single image against a white, illuminated background.

An art recognized difficulty with employing double coated radiographic elements in combination with intensifying screens as described above is that some light emitted by each screen passes through the transparent film support to expose the silver halide emulsion layer unit on the opposite side of the support to light. The light emitted by a screen that exposes the emulsion layer unit on the opposite side of the support reduces image sharpness. The effect is referred to in the art as crossover.

A variety of approaches have been suggested to reduce crossover, as illustrated by Research Disclosure, Vol. 184, August 1979, Item 18431, Section V. Cross-Over Exposure Control. Research Disclosure is published by Kenneth Mason Publications, Ltd., Dudley Annex, 21a North Street, Emsworth, Hampshire P010 7DQ, England. While some of these approaches are capable of entirely eliminating crossover, they either interfere with (typically entirely prevent) concurrent viewing of the superimposed silver images on opposite sides of the support as a single image, require separation and tedious manual reregistration of the silver images in the course of eliminating the crossover reduction medium, or significantly desensitize the silver halide emulsion. As a result, none of these crossover reduction approaches have come into common usage in the radiographic art. An example of a recent crossover cure teaching of this type is Bollen and others European published patent application 276,497, which interposes a reflective support between the emulsion layer units during imaging.

The most successful approach to crossover reduction yet realized by the art consistent with viewing the superimposed silver images through a transparent film support without manual registration of images has been to employ double coated radiographic elements containing spectrally sensitized high aspect ratio tabular grain emulsions or thin intermediate aspect ratio tabular grain emulsions, illustrated by US-A-4,425,425 and US-A-4,425,426, respectively. Whereas radiographic elements typically exhibited crossover levels of at least 25 percent prior to Abbott and others, Abbott and others provide examples of crossover reductions in the 15 to 22 percent range.

Still more recently US-A-Patent 4,803,150, hereinafter referred to as Dickerson and others I, has demonstrated that by combining the teachings of Abbott and others with a processing solution decolorizable microcrystalline dye located between at least one of the emulsion layer units and the transparent film support "zero" crossover levels can be realized. Since the technique used to determine crossover (single screen exposure of a double coated radiographic element) cannot distinguish between exposure of the emulsion layer unit on the side of the support remote from the screen caused by crossover and the exposure caused by direct absorption of X-radiation, "zero" crossover radiographic elements in reality embrace radiographic elements with a measured crossover (including direct X-ray absorption) of less than 5 percent.

US-A-4,900,652, hereinafter referred to as Dickerson and others II, adds to the teachings of Dickerson and others I, cited above, specific selections of hydrophilic colloid coating coverages in the emulsion and dye containing layers to allow the "zero" crossover radiographic elements to emerge dry to the touch from a conventional rapid access processor in less than 90 seconds with the crossover reducing microcrystalline dye decolorized.

US-A-4,997,750 (hereinafter Dickerson and Bunch I) discloses low crossover double coated radiographic elements in which the emulsion layer units on opposite sides of the support differ in speed.

US-A-4,994,355 (hereinafter Dickerson and Bunch II) discloses low crossover double coated radiographic elements in which the emulsion layer units on opposite sides of the support differ in contrast.

US-A-5,021,327 discloses low crossover double coated radiographic elements in combination with a pair of intensifying screens, where the back emulsion layer unit-intensifying screen combination exhibits a photicity twice that of the front emulsion layer unit-intensifying screen combination, where photicity is the product of screen emission and emulsion layer unit sensitivity.

Dickerson and Bunch I and II as well as Bunch and Dickerson disclose a low crossover double coated radiographic element having a fast low contrast emulsion layer unit on one side of the support and a slow high contrast emulsion layer unit on the opposite side of the support.

Jebo and others Statutory Invention Registration H1105 discloses low crossover double coated radiographic elements with emulsion layer units on opposite sides of the support that differ in sensitometric properties. A feature is included for ascertaining which of the emulsion layer units is positioned nearest a source of X-radiation during exposure.

US-A-5,108,881 discloses a low crossover radiographic element in which a faster silver halide emulsion layer unit coated on one side of the support exhibits a lower contrast that an slower silver halide emulsion layer unit coated on the opposite side of the support.

Radiographic elements that produce higher contrast images at lower densities and lower contrast images at higher densities are disclosed by Suzuki and others published European Patent Application 0 126 644 and Belgian Patent 530,129. Suzuki and others blended emulsions to achieve this result while the Belgian Patent suggests coating higher and lower contrast emulsions on the opposite sides of a support.

Figure 1 is a schematic diagram of an assembly consisting of a low crossover radiographic element sandwiched between two intensifying screens.

Figure 2 illustrates the overall sensitometric characteristic curve of a conventional sensitometrically symmetric double coated radiographic element and the characteristic curve of each of two identical individual emulsion layer units forming the radiographic element.

Figure 3 illustrates the overall sensitometric characteristic curve of a sensitometrically asymmetric low crossover double coated radiographic element according to the invention and the characteristic curves of the individual emulsion layer units as positioned by their screen exposures.

Figure 4 illustrates the overall and individual emulsion layer unit characteristic curves of an example radiographic element according to the invention.

In the characteristic curves of Figures 2 and 3, presented as aids to visualization of significant features of the prior art and the invention rather than as characteristic curves produced by measurement of actual emulsions, the density of the support, being irrelevant, has been assigned a value of zero and the minimum density of each emulsion layer unit has been exaggerated for ease of visualization. In the example characteristic curve of Figure 4, based on actual measurements, the minimum density shown is principally attributable to the density of the conventional blue tinted transparent film support while the minimum density of the individual emulsion layer units in each instance fell below the limits of plotting accuracy.

For ease of visualization the characteristic curves of Figures 2 and 3 have been drawn to conform to an ideal configuration. Ignoring superscripts, which are employed to distinguish one curve from another, the points A, B, C and D indicate corresponding reference points in the curves. A is the point beyond which additional exposure results in an increase in density--that is, A is the highest exposure level consistent with obtaining minimum density (Dmin). The curve segment A-B is in each instance the toe of the characteristic curve. In the toe of a characteristic curve incremental increases in density become larger with each incremental increase in the logarithm of exposure. The curve segments B-C are shown as linear--that is, as regions in which each incremental increase in the logarithm of exposure produces a corresponding incremental increase in density. In this region contrast or γ, the ratio of $\Delta D/\Delta \log E$, remains constant. In practice the mid-scale portion of a characteristic curve is rarely truly linear, and the $\Delta D/\Delta \log E$ interval used to calculate average contrast is usually based on characteristic curve points at arbitrarily selected low and high density values. The curve segment C-D is the shoulder of the characteristic curve. In this region each incremental increase in the logarithm of exposure produces a smaller increase in density than that which preceded. Exposure beyond point D produces no further increase in density. Therefore point D lies at maximum density (Dmax). BONE and FLESH indicate the general locations that exposures penetrating these tissue would be located, based on exposure assumptions described in detail below.

In radiographic imaging sharp images of bone tissue are required to pick up hairline fractures and trabecular detail. Obtaining sharp bone images requires relatively high contrasts.

It is in many instances highly desirable to be able to see the soft tissue (hereinafter referred to as flesh) surrounding the bones in a radiographic image. Achieving both bone and flesh imaging in a single radiograph is difficult if not impossible using conventional radiographic elements. The reason is that when film exposure has been optimized for bone imaging the film is receiving 0.6 log E (subject to some patient to patient variation) more exposure in areas in which the exposing X-radiation has penetrated only flesh. Given the requirement of relatively sharp images for bone feature definition, contrast levels are too high to provide film exposure latitude sufficient to capture both bone and flesh features in a single image. In other words, in a conventional radiographic image once a properly exposed image of bone has been obtained, the surrounding areas, whether flesh is present or absent, are all at or approaching maximum density and are accordingly recorded with very low contrast. Surrounding flesh is either invisible or barely perceptible under standard light box illumination.

The present invention has as its purpose to provide radiographic elements that exhibit the sharp imaging advantages of low crossover radiographic elements, allowing optimum sharp imaging of bone tissue while at the same time obtaining functionally serviceable images of surrounding flesh.

In one aspect, this invention is directed to a radiographic element comprised of a transparent film support, first and second silver halide emulsion layer units coated on opposite sides of the film support, and means for reducing to less than 10 percent crossover of electromagnetic radiation of wavelengths longer than 300 nm capable of forming a latent image in the silver halide emulsion layer units, the crossover reducing means being decolorized in less than 30 seconds during processing of the emulsion layer units.

The radiographic element is characterized in that, at a density of 1.0, the first silver halide emulsion layer unit exhibits a speed exceeding by from 0.3 to 1.0 log E that of the second silver halide emulsion layer unit, the first silver halide emulsion layer unit exhibiting a contrast in the range of from 2.0 to 4.0, and the second silver halide emulsion layer unit exhibiting a contrast in the range of from 0.5 to 1.7.

The present invention constitutes an improvement over low crossover double coated radiographic elements, such as, for example, those disclosed by Dickerson and others I and II, the disclosures of which are here incorporated by reference. The advantages of the present invention are that in addition to improved image sharpness attributable to low crossover the radiographic elements are also capable of producing both sharp images of bone and useful images of surrounding soft tissue (that is, flesh) exhibiting a much lower capability of attenuating X-radiation.

In another aspect, the invention is directed to an imaging assembly as claimed in Claim 7.

The imaging characteristics of low crossover double coated radiographic elements can be appreciated by referring to Figure 1. In the assembly shown a low crossover double coated radiographic element 100 is positioned between a pair of light emitting intensifying screens 201 and 202. The radiographic element support is comprised of a transparent radiographic support element 101, typically blue tinted, capable of transmitting light to which it is exposed and, optionally, similarly transmissive subbing units 103 and 105. On the first and second opposed major faces 107 and 109 of the support formed by the subbing units are crossover reducing hydrophilic colloid layers 111 and 113, respectively. Overlying the crossover reducing layers 111 and 113 are light recording latent image forming silver halide emulsion layer units 115 and 117, respectively. Each of the emulsion layer units is formed of one or more hydrophilic colloid layers including at least one silver halide emulsion layer. Overlying the emulsion layer units 115 and 117 are optional hydrophilic colloid protective overcoat layers 119 and 121, respectively. All of the hydrophilic colloid layers are permeable to processing solutions.

In use, the assembly is imagewise exposed to X-radiation. The X radiation is principally absorbed by the intensifying screens 201 and 202, which promptly emit light as a direct function of X-ray exposure. Considering first the light emitted by screen 201, the light recording latent image forming emulsion layer unit 115 is positioned adjacent this screen to receive the light which it emits. Because of the proximity of the screen 201 to the emulsion layer unit 115 only minimal light scattering occurs before latent image forming absorption occurs in this layer unit. Hence light emission from screen 201 forms a sharp image in emulsion layer unit 115.

However, not all of the light emitted by screen 201 is absorbed within emulsion layer unit 115. This remaining light, unless otherwise absorbed, will reach the remote emulsion layer unit 117, resulting in a highly unsharp image being formed in this remote emulsion layer unit. Both crossover reducing layers 111 and 113 are interposed between the screen 201 and the remote emulsion layer unit and are capable of intercepting and attenuating this remaining light. Both of these layers thereby contribute to reducing crossover exposure of emulsion layer unit 117 by the screen 201. In an exactly analogous manner the screen 202 produces a sharp image in emulsion layer unit 117, and the light absorbing layers 111 and 113 similarly reduce crossover exposure of the emulsion layer unit 115 by the screen 202.

Following exposure to produce a stored latent image, the radiographic element 100 is removed from association with the intensifying screens 210 and 202 and processed in a rapid access processor--that is, a processor, such as an RP-X-Omat^{TM} processor, which is capable of producing a image bearing radiographic element dry to the touch in less than 90 seconds. Rapid access processors are illustrated by US-A-3,545,971 and European published patent application 248,390.

As employed herein the term "low crossover" means reducing to less than 10 percent crossover of electromagnetic radiation of wavelengths longer than 300 nm capable of forming a latent image in the silver halide emulsion layer units. As indicated above, low crossover is achieved in part by absorption of light within the emulsion layer units and in part by the layers 111 and 113, which serve as crossover reducing means. In addition to having the capability of absorbing longer wavelength radiation during imagewise exposure of the emulsion layer units the crossover reducing means must also have the capability of being decolorized in less than 90 seconds during processing, so that no visual hindrance is presented to viewing the superimposed silver images.

The crossover reducing means decreases crossover to less than 10 percent, preferably reduces crossover to less than 5 percent, and optimally less than 3 percent. However, it must be kept in mind that for crossover measurement convenience the crossover percent being referred to also includes "false crossover", apparent crossover that is actually the product of direct X-radiation absorption. That is, even when crossover of longer wavelength radiation is entirely eliminated, measured crossover will still be in the range of 1 to 2 percent, attributable to the X-radiation that is directly absorbed by the emulsion farthest from the intensifying screen. Taking false crossover into account, it is apparent that any radiographic element that exhibits a measured crossover of less than 5 percent is in fact a "zero crossover" radiographic element. Crossover percentages are determined by the procedures set forth in US-A-4,425,425 and US-A-4,425,426.

Once the exposure crossover between the emulsion layer units has been reduced to less than 10 percent (that is, low crossover) the exposure response of an emulsion layer unit on one side of the support is influenced to only a slight extent by (that is, essentially independent of) the level of exposure of the emulsion layer on the opposite side of the support. It is therefore possible to form two independent imaging records, one emulsion layer unit recording only the emission of the front intensifying screen and the remaining emulsion layer unit recording only the emission of the back intensifying screen during imagewise exposure to X radiation.

Historically radiographic elements have been constructed to produce identical sensitometric records in the two emulsion layer units on the opposite sides of the support. The reason for this is that until practical low crossover radiographic elements were made available by Dickerson and others I and II, cited above, both emulsion layer units of a double coated radiographic element received essentially similar exposures, since both emulsion layer units were simultaneously exposed by both the front and back intensifying screens.

To provide a specific illustration, consider the performance of the radiographic element 100 converted to a high crossover radiographic element by eliminating the crossover reducing layers 111 and 113. In this instance the emulsion layer units 115 and 117 are each exposed by both the intensifying screens 201 and 202. Referring to Figure 2, a typical overall characteristic curve A-B-C-D is produced by exposing a high crossover double coated radiographic element. The overall characteristic curve is the sum of two identical characteristic curves A'-B'-C'-D' produced by the individual emulsion layer units. The same individual characteristic curves are produced even when the front and back intensifying screens are varied in their emission intensities, since each emulsion layer unit is exposed by both intensifying screens and therefore receives essentially the same exposure.

Since image sharpness is not a feature that shows up in a characteristic curve, the same overall and individual emulsion layer unit characteristic curves can be produced by substituting a low crossover sensitometrically symmetric radiographic element, such as radiographic element 100 with identical emulsion layer units 115 and 117 and with the crossover reducing layers 111 and 113 present, provided front and back intensifying screens 201 and 202 having similar light emission properties are employed.

In Figure 2 a point at mid-scale between points A and C is labelled BONE and a point at mid-scale between points A' and C' is labelled BONE', indicating the optimum film exposure for bone imaging. BONE represents the composite bone image produced the emulsion layer units on both sides of the support while BONE' represents the bone image produced by only one of two identical emulsion layer units on opposite sides of the support. While the same characteristic curve can be obtained using either a dual coated radiographic of either high or low crossover, the low crossover radiographic element produces a sharper BONE image, since unsharpness due to crossover has been minimized, if not eliminated.

However, neither of the characteristic curves shown in Figure 2 produce a useful image of flesh, regardless of the crossover characteristics of the radiographic element. The reason is that the portion of the film exposed through flesh, indicated by the FLESH and FLESH' on the overall and individual characteristic curves, respectively, has in each instance received an exposure in excess of that required to produce a maximum density, indicated by points D and D'. In other words, reducing the exposure of the film by some increment reflecting flesh attenuation is insufficient to reduce exposure of the film to a level less than that indicated by points D and D', and, as a result, no reduction in film density is produced by the this increment of exposure reduction.

In Dickerson and Bunch I and II as well as Bunch and Dickerson, each cited above, it is taught to employ a fast low contrast emulsion layer unit in combination with a slow high contrast emulsion layer unit in a low crossover double coated radiographic element to obtain a heart image while at the same time obtaining a sharp lung image. This combination is not useful for producing a sharp bone image, alone or in combination with a flesh image.

It is the discovery of this invention that a low crossover double coated radiographic element can be constructed to produce sharp bone images and useful flesh images by employing the combination of a relatively high contrast emulsion layer unit and a relatively low contrast emulsion layer unit. This requires that the relatively high contrast emulsion layer unit exhibit a higher photographic speed than the relatively low contrast emulsion layer unit and that the contrast of each emulsion layer unit and the difference in speed between the emulsion layer units be maintained within workable limits discussed in detail below.

The BONE and FLESH imaging capability of the low crossover double coated radiographic elements of this invention can be appreciated by reference to Figure 3. In Figure 3 the overall characteristic curve A^T-B^T-C^T-D^T of the radiographic element of the invention is similar to the overall characteristic curve A-B-C-D, except that point D^T is not the maximum density point of the characteristic curve. As in curve A-B-C-D optimum BONE exposure remains at mid-scale between points B^T-C^T, allowing the same sharp BONE images to be obtained as in the Figure 2 low crossover radiographic element. However, the FLESH exposure point is now located in a portion of the characteristic curve that shows a significant contrast (that is, $\Delta D/\Delta E$). Because the FLESH image is in a lower contrast portion of the characteristic curve than the BONE image, the FLESH image is less sharp. From the radiologist's viewpoint this is an advantage, since sharp images also contain a large high frequency noise content that would be distracting in attempting an accurate BONE diagnosis from the image. The radiologist is provided with exactly the information sought in the overwhelming majority of BONE diagnoses, a sharp BONE image and a view of surrounding FLESH that shows its general location and density, but not all of its fine detail.

The characteristic curve A^T-B^T-C^T-D^T is the composite of the individual characteristic curves A^H-B^H-C^H-D^H and A^L-B^L produced by a relatively higher contrast emulsion layer unit on one side of the support and a relatively lower contrast emulsion layer unit on the opposite side of the support of the low crossover radiographic element of the invention. The characteristic curve A^H-B^H-C^H-D^H is qualitatively similar to curves A-B-C-D and A'-B'-C'-D' described above. Note that the ideal $BONE^H$ exposure level remains at mid-scale between points B^H-C^H, resulting in the $FLESH^H$ exposure level occurring beyond the maximum density exposure level D^H.

The characteristic curve A^L-B^L is strikingly different than individual emulsion layer unit characteristic curves A'-B'-C'-D' and A^H-B^H-C^H-D^H. The location of $BONE^L$ on the A^L-B^L characteristic curve is at a lower exposure level than point A^L, indicating that insufficient exposure has been received to produce a useful $BONE^L$ image. On the other hand, the $FLESH^L$ image lies to the right of point B^L on a portion of the characteristic curve that exhibits sufficient contrast for useful imaging. In Figure 3 the A^L-B^L curve has not been extended to show a shoulder portion of the curve, since extended patient exposure to reach the shoulder portion of the A^L-B^L curve will seldom, if ever, occur.

As shown in Figure 3 the lower contrast curve makes no contribution to $BONE^T$ imaging while the higher contrast curve makes no contribution to $FLESH^T$ imaging. In practice it is recognized that the lower contrast curve may make some contribution to $BONE^T$ imaging, although this is not its primary imaging role, while the higher contrast curve can make some contribution to $FLESH^T$ imaging, although again this is not its primary imaging role and its contribution to $FLESH^T$ imaging will be too small to be serviceable in and of itself.

To realize the desired shape of characteristic curve A^T-B^T-C^T-D^T capable of satisfying practical imaging requirements for most human imaging subjects it is important that certain relationships of speed and contrast be incorporated in the individual emulsion layer units of the low crossover double coated radiographic elements of the invention.

Conventional double coated radiographic elements are sensitometrically symmetric. It is therefore customary to perform sensitometric measurements on the double coated element rather than on a single emulsion layer unit. To keep the sensitometric parameters of this invention comparable to customary measurements individual emulsion layer unit speeds and contrasts are determined by coating the emulsion layer unit to be measured on both sides of a conventional transparent (usually blue tinted) film support and measuring speed and contrast at a reference overall density of 1.0, which includes any increment of density (typically less than

0.24) contributed by the film support. This is done to allow those skilled in the art to compare readily the numerical parameters recited to those they customarily employ in characterizing double coated radiographic elements. In the various plots of density versus log E for a particular example emulsion layer unit each curve represents a single emulsion layer unit rather than a pair of identical emulsion layer units, since this permits the contribution of each emulsion layer unit to the overall characteristic curve to be more readily visually appreciated.

On average there is a 0.6 log E exposure differential in the exposure of a radiographic element in areas receiving X-radiation penetrating bone and that penetrating flesh alone. Allowing for patient to patient variances as well as anatomical variances, it is generally contemplated that the difference in speed of the faster and slower emulsion layer units will be in the range of from 0.3 to 1.0 log E, preferably 0.4 to 0.8 log E.

The faster, higher contrast emulsion layer unit is contemplated to have a contrast in the range of from 2.0 to 4.0, preferably 2.5 to 3.5 while the slower, lower contrast emulsion layer unit is contemplated to have a contrast in the range of from 0.5 to 1.7, preferably 0.7 to 1.5. As herein employed the term "contrast" is the slope of the characteristic curve at a reference density of 1.0 and is not an average of contrasts over a range of densities.

Apart from the features noted above the radiographic elements of this invention can take any convenient conventional form. Features and details of features not specifically discussed preferably correspond to those disclosed by Dickerson and others I and II, Dickerson and Bunch I and II and Bunch and Dickerson, cited above and here incorporated by reference above.

Examples

The invention can be better appreciated by reference to the following specific examples:

Screens

The following intensifying screens were employed:

Screen Y

This screen has a composition and structure corresponding to that of a commercial, general purpose screen. It consists of a terbium activated gadolinium oxysulfide phosphor having a median particle size of 5.9 µm coated on a white pigmented polyester support in a Permuthane™ polyurethane binder at a total phosphor coverage of 7.0 g/dm^2 at a phosphor to binder ratio of 15:1.

Screen Z

This screen has a composition and structure corresponding to that of a commercial, high resolution screen. It consists of a terbium activated gadolinium oxysulfide phosphor having a median particle size of 5 µm coated on a blue tinted clear polyester support in a Permuthane™ polyurethane binder at a total phosphor coverage of 3.4 g/dm^2 at a phosphor to binder ratio of 21:1 and containing 0.0015% carbon.

Screen Emissions

The relative emissions of electromagnetic radiation longer than 370 nm in wavelength of the intensifying screens were determined as follows:

Screen Y = 230
Screen Z = 100

The screens exhibited no significant emissions at wavelengths between 300 and 370 nm.

The X-radiation response of each screen was obtained using a tungsten target X-ray source in an XRD 6™ generator. The X-ray tube was operated at 70 kVp and 30 mA, and the X-radiation from the tube was filtered through 0.5 mm Cu and 1 mm Al filters before reaching the screen.

The emitted light was detected by a Princeton Applied Research model 1422/01™ intensified diode array detector coupled to an Instruments SA model HR-320™ grating spectrograph. This instrument was calibrated to within % 0.5 nm with a resolution of better than 2 nm (full width at half maximum). The intensity calibration was performed using two traceable National Bureau of Standards sources, which yielded an arbitrary intensity scale proportional to Watts/nm/cm^2. The total integrated emission intensity from 250 to 700 nm was calculated on a Princeton Applied Research model 1460 OMA III™ optical multichannel analyzer by adding all data points within this region and multiplying by the bandwidth of the region.

Actual emission levels were converted to relative emission levels by dividing the emission of each screen by the emission of Screen Z and multiplying by 100.

Radiografhic Exposures

Assemblies consisting of a double coated radiographic element sandwiched between a pair of intensifying screens were in each instance exposed as follows:

The assemblies were exposed using an intensity scale X-ray sensitometer of the type described by A.G. Haus, K. Rossman, C.Vyborny, P.B. Hoffer and K. Doi, "Sensitometery in Diagnostic Radiology, Radiation Therapy, and Nuclear Medicine", *J. Appl. Photog. Eng.,* vol. 3, pp. 114-124 (1977). Exposure conditions were as follows: 80 KVp X-radiation (constant potential), total filtration consisting of 3 mm berylium + 0.5 mm copper + 2.2 mm aluminum; 7.5 mm aluminum half-value layer; 1.5 mA, 0.11 sec exposure.

Processing

The films were processed in 90 seconds in a commercially available Kodak RP X-Omat (Model 6AW)™ rapid access processor as follows:

development	20 seconds at 35°C,
fixing	12 seconds at 35°C,
washing	8 seconds at 35°C, and
drying	20 seconds at 65°C,

where the remaining time is taken up in transport between processing steps. The development step employs the following developer:

Hydroquinone	30 g
1-Phenyl-3-pyrazolidone	1.5 g
KOH	21 g
$NaHCO_3$	7.5 g
K_2SO_3	44.2 g
$Na_2S_2O_5$	12.6 g
NaBr	35 g
5-Methylbenzotriazole	0.06g
Glutaraldehyde	4.9 g

Water to 1 liter at pH 10.0, and

the fixing step employs the following fixing composition:

Ammonium thiosulfate, 60%	260.0 g
Sodium bisulfite	180.0 g
Boric acid	25.0 g
Acetic acid	10.0 g
Aluminum sulfate	8.0 g
Water to 1 liter at pH 3.9 to	4.5.

Sensitometry

Optical densities are expressed in terms of diffuse density as measured by an X-rite Model 310™ densitometer, which was calibrated to ANSI standard PH 2.19 and was traceable to a National Bureau of Standards calibration step tablet. The character-istic curve (density vs. log E) was plotted for each radiographic element processed. Average contrast in each instance was determined from the characteristic curve at densities of 0.25 and 2.0 above minimum density.

Element EX (example) (Em.FHC) LXOA (Em.SLC)

Radiographic element EX was a double coated radiographic element exhibiting near zero crossover.

Radiographic element EX was constructed of a low crossover support composite (LXO) consisting of a blue-tinted transparent polyester film support coated on each side with a crossover reducing layer consisting of gelatin (1.6g/m^2) containing 220 mg/m^2 of a crossover control dye.

Slow low contrast (SLC) and fast high contrast (FHC) emulsion layers were coated on opposite sides of the support over the crossover reducing layers. Both emulsions were green-sensitized high aspect ratio tabular grain silver bromide emulsions, where the term "high aspect ratio" is employed as defined by US-A-4,425,425 to require that at least 50 percent of the total grain projected area be accounted for by tabular grains having a thickness of less than 0.3 μm and having an average aspect ratio of greater than 8:1. The slow low contrast emulsion was a 1:1 (silver ratio) blend of a first emulsion which exhibited an average grain diameter of 2.0 μm and an average grain thickness of 0.13 μm and a second emulsion which exhibited an average grain diameter of 1.2 μm and an average grain thickness of 0.13 μm. The fast high contrast emulsion exhibited an average grain diameter of 2.4 μm and an average grain thickness of 0.12 μm. The fast high contrast emulsion was monodispersed, exhibiting both thickness and diameter coefficients of variation of less than 10%. Both the fast high contrast and slow low contrast emulsions were spectrally sensitized with 400 mg/Ag mol of anhydro-5,5-dichloro-9-ethyl-3,3'-bis(3-sulfopropyl)oxacarbocyanine hydroxide, followed by 300 mg/Ag mol of potassium iodide. The slow low contrast emulsion was coated at a silver coverage of 1.6 g/m^2 and a gelatin coverage of 3.3 g/m^2. The fast high contrast emulsion was coated at a silver coverage of 2.2 g/m^2 and a gelatin coverage of 3.3 g/m^2. Protective gelatin layers (0.7 g/m^2) were coated over the emulsion layers. A red absorbing dye (44 mg/m^2) was added to the protective overcoat of the high contrast side to provide visual identification of the respective sides under safelight conditions. Each of the gelatin containing layers were hardened with bis(vinylsulfonylmethyl) ether at 1% of the total gelatin.

When Element EX was tested for crossover as described by US-A-4,425,425, it exhibited a crossover of 2%.

When Emulsion FHC of Element EX was exposed by Screen Z employed as a front screen and Emulsion SLC was exposed by Screen Y employed as a back screen, the individual and combined characteristic curves shown in Figure 4 were obtained, where FHC designates the front screen-emulsion layer unit combination, SLC designates the back screen-emulsion layer unit combination, and EX designates the overall characteristic curve. Notice that if BONE exposure were occurring anywhere in the 1.0 to 1.4 relative log exposure range useful FLESH exposure ranges extend to 2.4 relative log exposures and beyond. Thus Element EX has the capability of obtaining sharp images of bone tissue and useful images of surrounding soft tissue. The purpose of choosing the fine screen for exposure of the FHC emulsion layer unit was to obtain the highest practical image detail and sharpness in areas intended to record bone tissue while a medium screen was chosen for use with the SLC emulsion layer unit, since fine image detail of surrounding soft tissue is not sought or desired by radiologists.

When coated as described above, but symmetrically, with Emulsion SLC coated on both sides of the support and Emulsion FHC omitted, using a Screen Y pair, Emulsion SLC exhibits a contrast of 1.7 at an overall density of 1.0. Similarly, when Emulsion FHC is coated symmetrically with Emulsion SLC omitted, Emulsion FHC exhibits a contrast of 2.9 at an overall density of 1.0. The speed difference in the two coatings at an overall density of 1.0 is 0.7 log E.

Element C (control) (Em.FHC) HXOA (Em.SLC)

To further demonstrate the advantages of the invention a control radiographic element was constructed similarly as Element EX, described above, except that the crossover control dye was omitted.

When the Elements C and EX were identically exposed and processed as described above, it was observed that Element EX exhibited a larger useful dynamic range of exposure and exhibited higher contrast in the density regions 1.0 to 1.4 in which bone images are viewed. When the dynamic range is taken as the difference in exposure levels between the limit of minimum bone densities (1.0) and the limit of maximum flesh densities (3.0), Element EX exhibits a 0.36 log E larger exposure range than Element C. Stated another way, with bone density exposures optimized for a particular subject it is much less likely with Element EX that flesh image features would be recorded at such high densities as to be difficult to distinguish. If instead of working at the limits it is assumed that an ideal bone image density is at least 1.2 and that ideally flesh image features should exhibit a density of 2.4 or less, Element C offers a restricted exposure latitude of only 0.58 log E between these limits whereas Element EX offers a much larger dynamic latitude of 0.86 log E. This means that a radiologist is much more likely to obtain both bone and flesh images at near ideal density levels using Element EX than when using Element C. Further, higher contrast bone images are obtained with Element EX.

Claims

1. A radiographic element intended to produce relatively sharp images of bone and useful images of surrounding tissue when exposed to X-radiation between a back intensifying screen and a relatively higher resolution front intensifying screen, comprised of

   a transparent film support,

   front and back silver halide emulsion layer units coated on opposite sides of the film support, and

   means for reducing to less than 10 percent crossover of electromagnetic radiation of wavelengths longer than 300 nm capable of forming a latent image in the silver halide emulsion layer units, said crossover reducing means being decolorized in less than 30 seconds during processing of said emulsion layer units,

   wherein, at a density of 1.0,

   said front silver halide emulsion layer unit exhibits a speed exceeding by from 0.3 to 1.0 log E that of said second silver halide emulsion layer unit,

   said front silver halide emulsion layer unit exhibits a contrast in the range of from 2.0 to 4.0, and

   said back silver halide emulsion layer unit exhibits a contrast in the range of from 0.5 to 1.7.

   the speed and contrast of the front silver halide emulsion layer unit being determined with the front silver halide emulsion unit replacing the back silver halide emulsion unit to provide an arrangement with silver halide emulsion units corresponding to the front silver halide emulsion unit present on both sides of the transparent support and

   the speed and contrast of the back silver halide emulsion layer unit being determined with the back silver halide emulsion unit replacing the first silver halide emulsion unit to provide an arrangement with silver halide emulsion units corresponding to the back silver halide emulsion unit present on both sides of the transparent support.

2. A radiographic element as claimed in claim 1 wherein said crossover reducing means decreases crossover to less than 5 percent.

3. A radiographic element as claimed in claim 2 wherein said crossover reducing means decreases crossover to less than 3 percent.

4. A radiographic element as claimed in claim 1 wherein the speed difference between the front and back silver halide emulsion layer units is in the range of from 0.4 to 0.8 log E.

5. A radiographic element as claimed in claim 1 wherein the front silver halide emulsion layer unit exhibits a contrast in the range of from 2.5 to 3.5.

6. A radiographic element as claimed in claim 1 wherein the back silver halide emulsion layer unit exhibits a contrast in the range of from 0.7 to 1.5.

7. An imaging assembly intended to produce relatively sharp images of bone and useful images of surrounding tissue when exposed to X-radiation consisting of

   a front and back pair of intensifying screens, wherein the front intensifying screen exhibits a relatively higher resolution than the back intensifying screen, and

   a element comprised of

   a transparent film support,

   front and back silver halide emulsion layer units coated on opposite sides of the film support with the front and back emulsion layer units located adjacent the front and back intensifying screens, respectively, means for reducing to less than 10 percent crossover of electromagnetic radiation of wavelengths longer than 300 nm capable of forming a latent image in the silver halide emulsion layer units, said crossover reducing means being decolorized in less than 30 seconds during processing of said emulsion layer units, wherein, at a density of 1.0,

said front silver halide emulsion layer unit exhibits a speed exceeding by from 0.3 to 1.0 log E that of said back silver halide emulsion layer unit,

said front silver halide emulsion layer unit exhibits a contrast in the range of from 2.0 to 4.0, and

said back silver halide emulsion layer unit exhibits a contrast in the range of from 0.5 to 1.7.

the speed and contrast of the front silver halide emulsion layer unit being determined with the front silver halide emulsion unit replacing the back silver halide emulsion unit to provide an arrangement with identical silver halide emulsion units present on both sides of the transparent support and

the speed and contrast of the back silver halide emulsion layer unit being determined with the back silver halide emulsion unit replacing the front silver halide emulsion unit to provide an arrangement with identical silver halide emulsion units present on both sides of the transparent support.

8. An assembly as claimed in claim 7 wherein said crossover reducing means decreases crossover to less than 5 percent.

9. An assembly as claimed in claim 8 wherein said crossover reducing means decreases crossover to less than 3 percent.

10. An assembly as claimed in claim 7 wherein the speed difference between the front and back silver halide emulsion layer units is in the range of from 0.4 to 0.8 log E.

11. An assembly as claimed in claim 7 wherein the front silver halide emulsion layer unit exhibits a contrast in the range of from 2.5 to 3.5.

12. An assembly as claimed in claim 7 wherein the back silver halide emulsion layer unit exhibits a contrast in the range of from 0.7 to 1.5.

13. An assembly as claimed in claim 7 wherein the photicity of the front intensifying screen and the front emulsion layer unit in combination exceeds the photicity of the back intensifying screen and the back emulsion layer unit in combination.

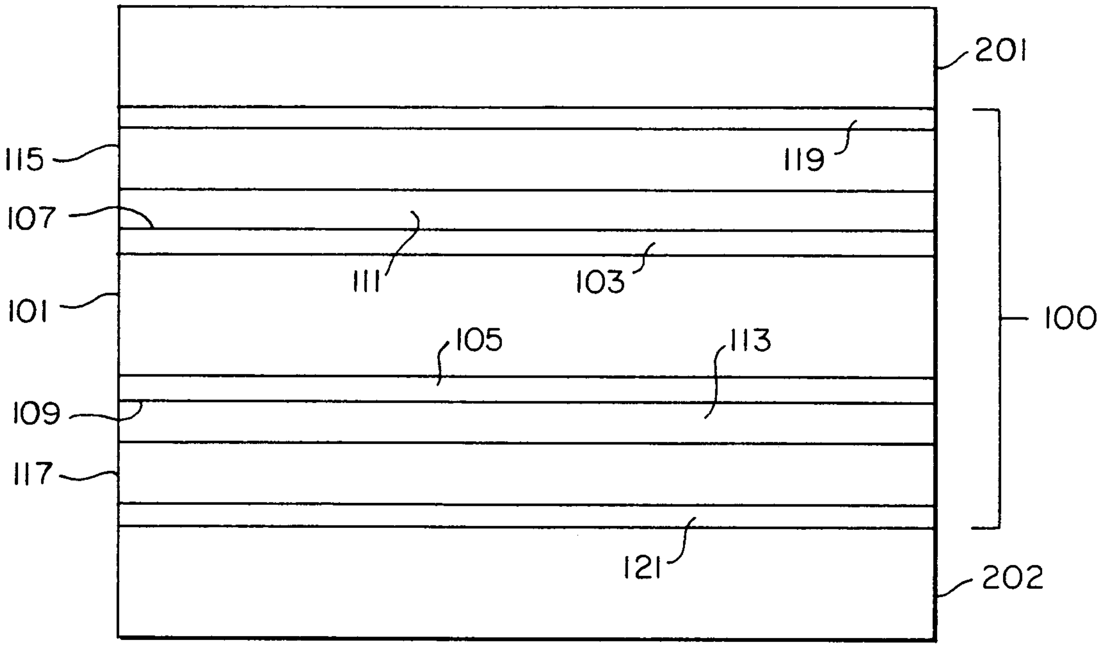
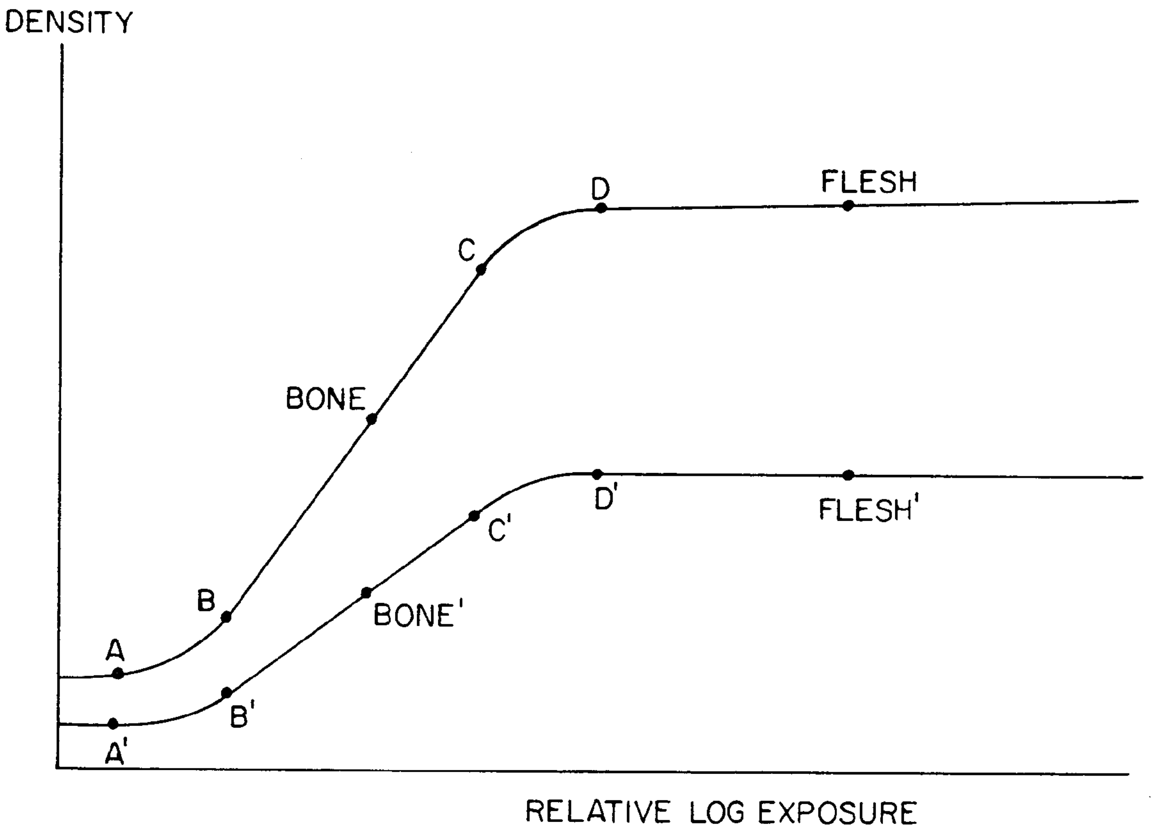


FIG. 1


DENSITY
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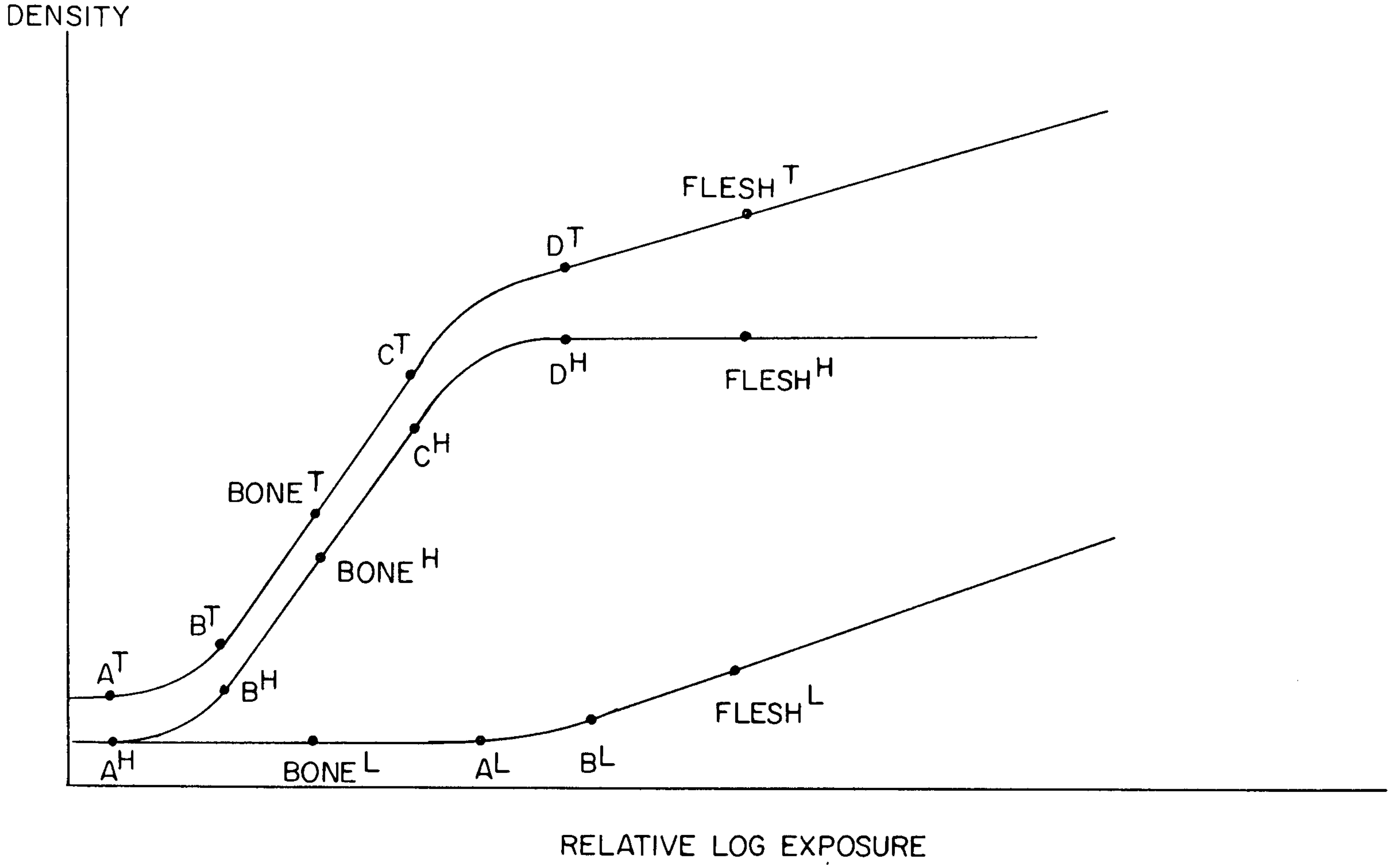
C
BONE
D'
FLESH'
C'
B
BONE'
A
B'
A'
RELATIVE LOG EXPOSURE

FIG. 2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C^H
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BONE ^{H}
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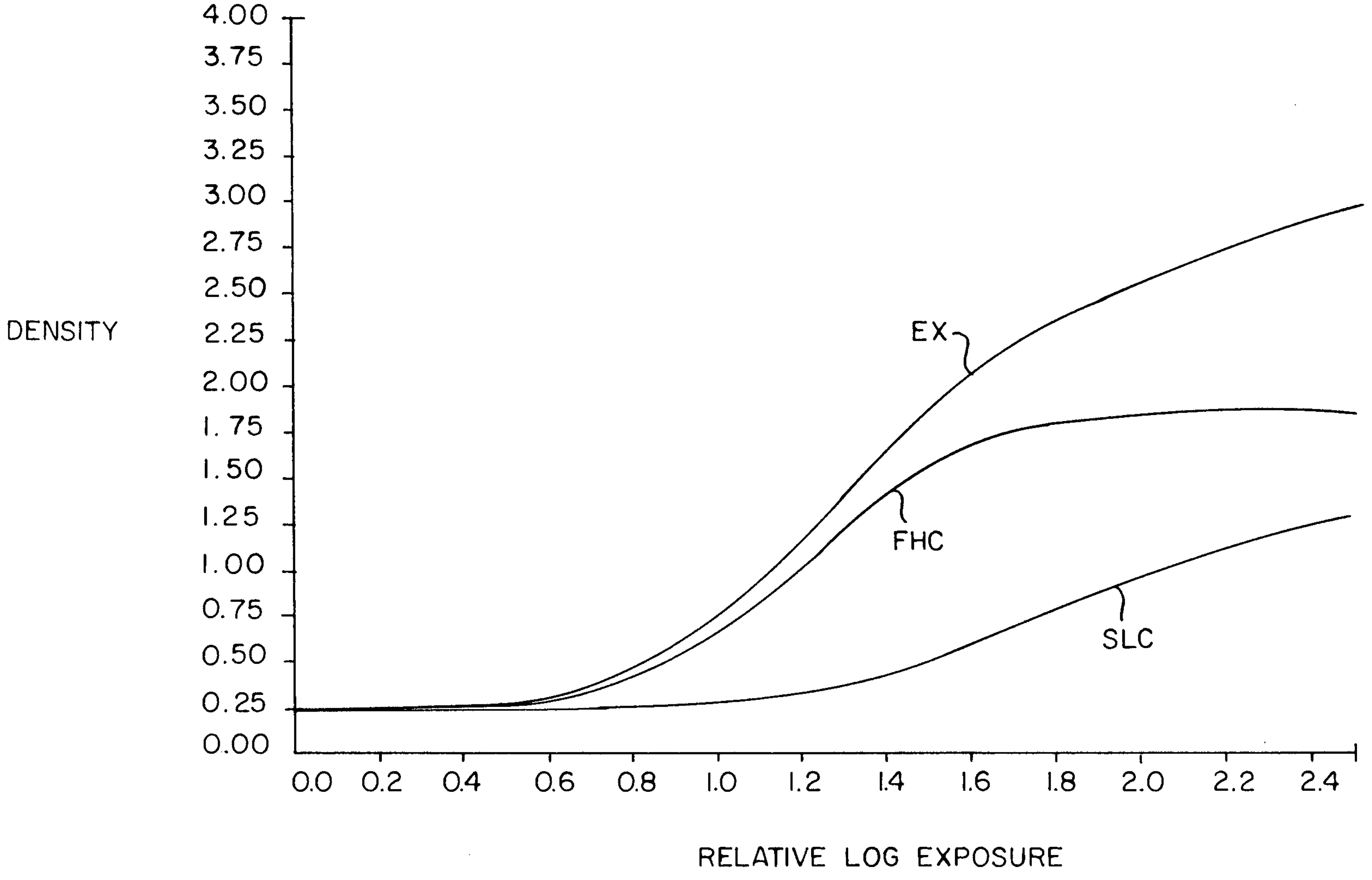
B^L
RELATIVE LOG EXPOSURE

FIG. 3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0.75
0.50
0.25
0.00
EX
FHC
SLC
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
RELATIVE LOG EXPOSURE

FIG. 4

European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 42 0028

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
P,X	EP-A-0 530 117 (KODAK) * the whole document * ---	1-12	G03C5/17
D,A	US-A-5 108 881 (DICKERSON ET AL.) * column 7, line 61 - column 8, line 30; claims 1-9 * -----	1-13	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
			G03C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	21 March 1994	Magrizos, S

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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L : document cited for other reasons

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