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# (54) Radiographic elements suitable for medical diagnostic imaging employing a symmetrically coated emulsion combination

(57) Radiographic elements for medical diagnostic imaging are disclosed in which silver halide emulsion layer units coated on opposite sides of a transparent support together provide a point $\gamma$ of at least 1.0 at an image density of 1 and a point $\gamma$ of at least 2.0 at an image density of 2.5. The emulsion layer units both contain a combination of tabular grain emulsions including, a polydisperse tabular grain silver halide emulsion portion exhibiting a coefficient of variation of grain diameter of greater than 30 percent and a monodisperse tabular grain silver halide emulsion (a) accounting for from 20 to 50 percent of the combination of tabular grain emulsions, based on total silver, (b) having a mean grain diameter of less than the mean grain diameter of the combination of tabular grain emulsions, and (c) exhibiting a coefficient of variation of grain diameter of less than 10 percent.

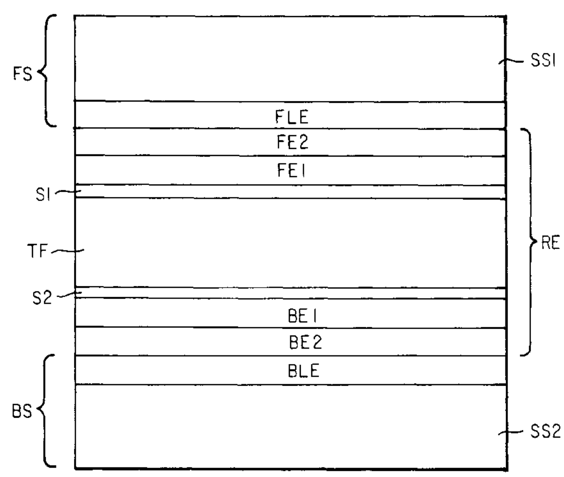


FIG. 1

EP 0 754 973 A1

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## Description

The invention is directed to radiographic elements suitable for medical diagnostic imaging containing silver halide emulsion layer units.

The equivalent circular diameter (**ECD**) of silver halide grain (also referred to as its diameter) is the diameter of a circle having an area equal to the projected area of the grain.

The coefficient of variation (**COV**) of grain diameters is defined as the standard deviation of grain **ECD's** divided by the mean grain **ECD**, with the quotient multiplied by 100.

A tabular grain is one that exhibits a two parallel major faces each clearly larger than any remaining crystal face, with the ratio of grain diameter (**ECD**) to thickness (**t**) being at least 2.

The thickness (**t**) of a tabular grain is measured perpendicular to its major faces.

A tabular grain emulsion is an emulsion in which tabular grains account for greater than 50 percent of total grain projected area.

Tabular grain aspect ratio is the ratio of **ECD** ÷ **t**.

In referring to silver halide grains containing two or more halides, the halides are named in order of ascending concentrations.

A characteristic curve produced by a radiographic element is a plot of density versus log E, where is exposure in lux-seconds.

The term "point $\gamma$" is employed as defined by James, *The Theory of the Photographic Process,* 4th Ed., Macmillan, 1977, at page 502. It is the quotient of the differential density ($\Delta$D) divided by the differential exposure ($\Delta$logE) at a point on the characteristic curve.

The terms "front" and "back" are employed to differentiate otherwise similar features located nearer to and farther from, respectively, the source of X-radiation. Generally, front features intercept X-radiation before it has reached the support forming the radiographic element while back features intercept X-radiation that has passed through the support.

Since the early 1980's the superiority for medical diagnostic imaging of radiographic elements containing tabular grain emulsions coated on the opposite faces of a transparent film support has been generally recognized. Illustrations of this class of radiographic elements and their advantages are provided by Abbott et al U.S. Patents 4,425,425 and 4,425,426 and Dickerson U.S. Patent 4,414,304.

One of the problems that has arisen is that anatomical features differ widely in their X-ray absorption properties. This has resulted in an array of radiographic elements intended to image optimally different anatomical features. The construction of radiographic elements to image optimally anatomical features that exhibit high X-ray absorption, such as bones, or features that exhibit low X-ray absorption, such as lung regions, as well as anatomical features that exhibit intermediate X-ray absorptions, are well within the capability of the art. The burden is that a different diagnostic imaging film must be retained for each imaging application.

When anatomical features differing widely in X-ray absorption properties must be detected employing a single diagnostic imaging radiographic film, no single one of the various diagnostic imaging radiographic films targeted for the detection of a specific anatomical feature may be fully satisfactory. For example, a radiographic diagnostic film constructed for bone or heart examinations, both high X-ray absorption organs, typically lacks the characteristics required for successful lung examination.

One approach that has been taken to permit anatomical features of widely differing absorptions to be imaged within a single radiographic element involves constructing the emulsion layer units with extended exposure latitude. This is achieved by blending polydisperse silver halide emulsions. This results in lower imaging contrast, but an extended useful imaging exposure range. As demonstrated in the Examples below, this approach can be manipulated to allow useful levels of contrast in high density image areas, but it has the disadvantage of requiring higher silver coverages. Higher silver coverages translate into higher element construction costs and, more importantly, larger amounts of silver halide to be removed during fixing, which necessarily increases minimum required processing times.

Dickerson et al U.S. Patent 5,108,881 discloses a medical diagnostic imaging radiographic element construction capable of concurrently successfully imaging both high and low X-ray absorption anatomical features. To accomplish this two separate emulsion layer units are coated on opposite sides of a transparent film support and optically isolated using a processing solution bleachable antihalation dye. One of the emulsion layer units over an exposure range of at least 1.0 log E (where E represents exposure in lux-seconds) exhibits an average contrast of less than 2.0 and point $\gamma$'s that differ by less than ±40%. The remaining emulsion layer unit, coated on the opposite side of the support, requires a mid-scale contrast that is at least 0.5 greater than the average contrast of the first emulsion layer unit. Dickerson et al contemplates that the emulsion layer units will be optically isolated by reducing crossover between the emulsion layer units to less than 10 percent. Thus, this approach is specifically limited to low crossover imaging. A further and more serious limitation is that the radiographic element is asymmetrical, providing quite different images when oppositely oriented during exposure. This complicates handling related to exposure.

The tabular grain emulsions that were applied to photographic and radiographic imaging in the early 1980's were distinctly polydisperse--attributable both to the coprecipitation of nontabular grains with the tabular grains accounting for >50% of total grain projected area and to the size dispersity of the tabular grains themselves. It was not until the early 1990's that Tsaur et al U.S. Patent 5,210,013 produced the first tabular grain emulsion exhibiting a coefficient of variation of less than 10 percent.

The present invention provides a radiographic element intended for medical diagnostic imaging that is suitable for detecting anatomical features of markedly differing X-ray absorption densities in a single exposure. The radiographic elements are symmetrical, thereby simplifying handling related to exposure. Additionally, the radiographic elements achieve required levels of contrast over a broad range of image density levels with lower silver halide coverage levels than can be realized employing conventional blended polydisperse silver halide emulsions to achieve comparable exposure latitude.

In one aspect the invention is directed to a radiographic element for medical diagnostic imaging comprised of a transparent support and first and second silver halide emulsion layer units coated on opposite sides of the film support, wherein the first and second emulsion layer units together provide a point $\gamma$ of at least 1.0 at an image density of 1 and a point $\gamma$ of at least 2.0 at an image density of 2.5, both contain a combination of tabular grain emulsions including, as a first component, a polydisperse tabular grain silver halide emulsion portion exhibiting a coefficient of variation of grain diameter of greater than 30 percent and, as a second component, a monodisperse tabular grain silver halide emulsion (a) accounting for from 20 to 50 percent of the combination of tabular grain emulsions, based on total silver, (b) having a mean grain diameter of less than the mean grain diameter of the combination of tabular grain emulsions, and (c) exhibiting a coefficient of variation of grain diameter of less than 10 percent.

**Brief Description of the Drawings**

Figure 1 is a schematic diagram of an assembly of a radiographic element according to the invention positioned between two intensifying screens.

The radiographic elements of the invention are suitable for medical diagnostic imaging. To minimize patient exposure to X-radiation the elements are dual-coated (that is, constructed with emulsion layer units on the front and back side of the support) and are intended to be used with front and back intensifying screens, which absorb X-radiation and emit longer wavelength, non-ionizing electromagnetic radiation, which the radiographic elements can more efficiently capture. Dual-coating and intensifying screens together reduce patient exposures to X-radiation to less than 5 percent of the levels that would otherwise be required for imaging.

In the simplest form contemplated the radiographic elements of the invention exhibit the following structure:

(I)

Emulsion Layer Unit (**ELU**)
Transparent Support (**TS**)
Emulsion Layer Unit (**ELU**)

The transparent support **TS** can take the form of any conventional transparent radiographic element support. Transparent film supports, such as any of those disclosed in *Research Disclosure,* Vol. 365, Sept. 1994, Item 36544, Section XV, are contemplated. *Research Disclosure* is published by Kenneth Mason Publications, Ltd., Dudley House, 12 North St., Emsworth, Hampshire P010 7DQ, England. The transparent film support typically includes subbing layers to facilitate adhesion of hydrophilic colloids, as illustrated by Section XV, paragraph (2). Although the types of transparent film supports set out in Section XV, paragraphs (4), (7) and (9) are contemplated, due to their superior dimensional stability, the transparent film supports preferred are polyester film supports, as illustrated by Section XV, paragraph (8). Poly(ethylene terephthalate) and poly(ethylene naphthenate) are specifically preferred polyester film supports. The support is typically blue tinted to aid in the examination of image patterns. Blue anthracene dyes are typically employed for this purpose. For further details of support construction, including exemplary incorporated anthracene dyes and subbing layers, attention is directed to *Research Disclosure,* Vol. 184, Aug. 1979, Item 18431, Section XII. Film Supports.

The emulsion layer units (**ELU**) are in their simplest and preferred form identical. Variance between the emulsion layer units merely complicates fabrication, but can be tolerated to the extent that essentially similar images are obtained, regardless of which **ELU** is located nearer the source of exposing radiation in use. That is, the radiographic elements are at least sensitometrically symmetrical and preferably structurally symmetrical as well.

Since the radiographic elements are sensitometrically symmetrical, it is not necessary to isolate optically one emulsion layer unit from the other during exposure. Thus, there is no requirement to reduce crossover less than 10 percent of the type imposed on asymmetrical radiographic elements having two emulsion layer units coated on opposite sides of the support, each intended to image a different anatomical feature. It is, of course, recognized that to the extent crossover occurs it will reduce image sharpness. However, the tabular grain emulsions themselves possess the capability of reducing crossover to acceptable levels for at least some medical diagnostic imaging applications.

The emulsion layer units of the radiographic element are chosen to provide a point $\gamma$ of at least 1.0 at an image density of 1.0 and a point $\gamma$ of at least 2.0 at an image density of 2.5. The lungs are typically cited as an example of an anatomical feature exhibiting low X-ray absorption. Thus, a radiographic image of the lungs exhibits a higher density than a comparably acquired image of other features of the anatomy, such as the heart or mediastinum. The image density of radiographic elements to be used only for lung examinations can be readily adjusted to optimum diagnostic levels. However, when a radiographic element must simultaneously provide diagnostic information for anatomical features spanning a broad range of X-ray absorptions, optimization of imaging properties for lung examination is not feasible.

In the radiographic elements of the invention lung features are recorded in a higher density range than in a radiographic element dedicated to lung examinations only. It has been observed that this can be reliably and usefully undertaken, provided a sufficiently high contrast exists at the higher imaging densities recording lung features. Thus, the emulsion layer units of the radiographic elements of the invention are constructed to provide a point $\gamma$ of at least 2.0 at an image density of 2.5. By maintaining a point $\gamma$ of at least 2.0, the eye is able to pick out lung features recorded in the optical density range in the vicinity of 2.5 (i.e., relatively light areas range below 2.5 while relatively dark areas range above 2.5). The relatively high point $\gamma$'s of the radiographic elements of the invention at higher density levels distinguish them from typical medical diagnostic radiographic elements.

In addition to exhibiting high point $\gamma$'s at an image density of 2.5, the radiographic elements exhibit relatively high point $\gamma$'s over an extended image density range. At an image density of 1.0 the point $\gamma$ remains at least 1.0. Between the image densities of 1.0 and 2.5 point $\gamma$'s remain at or above the values predicted by linear interpolation. In fact, when the point $\gamma$ requirements at densities of 1.0 and 2.5 are both satisfied, still higher point $\gamma$'s are readily realized at all intermediate image densities. It is preferred that at an image density of 1.5 the radiographic elements exhibit a point $\gamma$ of at least 2.0.

With a broad image density range of relatively high point $\gamma$'s it is possible to make diagnostic observations for a number of different anatomical features from a single exposed and processed radiographic element. This reduces or eliminates the need for maintaining an inventory of radiographic elements each having a specialized anatomical diagnostic utility. It also offers the advantage of allowing anamolous anatomical features to be observed which might have otherwise gone unseen, simply because they were not within the X-ray absorption range of the anatomical feature of interest prompting X-ray examination.

To realize the broad useful imaging ranges contemplated the emulsion layer units each contain a combination of tabular grain emulsions. As a first component each emulsion layer unit contains a polydisperse tabular grain silver halide emulsion portion exhibiting a **COV** of greater than 30 percent. This emulsion portion can be a single emulsion or a blend of separately precipitated emulsions. When emulsions of significantly differing **ECD**'s are blended to form the polydisperse tabular grain emulsion portion, any or all of the individual emulsions can exhibit a **COV** of less than 30 percent. However, no single emulsion blended to form the polydisperse tabular grain emulsion portion exhibits a **COV** as low as 10 percent and, more typically, the **COV** of each of these emulsions is at least 20 percent.

As demonstrated in the Examples below, if the polydisperse tabular grain emulsion portion is coated alone to form the emulsion layer units, it will either fail to satisfy the referenced contrast requirements or will require increased levels of silver to reach referenced contrast requirements. Thus, the resulting radiographic element will either (a) exhibit inferior diagnostic capabilities or (b) require elevated levels of silver, resulting in inefficient use of silver, higher unwanted pressure sensitivity, and slower processing, attributable to the larger amounts of residual silver required to be removed by fixing. If vehicle coverages are increased along with silver to avoid higher pressure sensitivity, this increases drying time and further slows processing.

It has been observed that all of the above disadvantages can be avoided and converted to imaging and processing advantages by employing in combination with the polydisperse tabular grain emulsion portion a monodisperse tabular grain emulsion accounting for from 20 to 50 (preferably 25 to 40) percent of the emulsion blend, based on total silver.

The monodisperse emulsion is chosen to exhibit a mean ECD that is less than the overall mean **ECD** of the combination of tabular grain emulsions. Additionally the monodisperse emulsion exhibits a **COV** of less than 10 percent. Specific examples of tabular grain emulsions exhibiting a **COV** of less than 10 percent are provided by Tsaur et al U. S. Patents 5,147,771, 5,147,772, 5,147,773, 5,171,659 and 5,210,013 and Sutton et al U.S. Patent 5,300,413.

The monodisperse and polydisperse emulsions can be coated in separate layers in any order or blended. If the monodisperse tabular grain emulsion is coated above (nearer the source of exposing radiation) or blended with the polydisperse tabular grain emulsion, it is contemplated that to employ a monodisperse tabular grain emulsion that exhibits a mean **ECD** less than 75 (preferably <60) percent the overall mean **ECD** of the combination of tabular grain emulsions. Blending has the advantage that only a single layer need be coated to form each emulsion layer unit. When the monodisperse emulsion is blended with the polydisperse tabular grain emulsion portion, the resulting emulsion blend exhibits an unusual bimodal grain size-frequency profile. A sharp grain frequency maximum, hereinafter referred to as a first maximum, is observed in a substantially smaller grain size range region than a second grain frequency maximum (i.e., second maximum) provided by the polydisperse tabular grain emulsion portion. The polydisperse tabular grain emulsion portion contributes to image densities over a broad range of exposure levels. The grains forming the first maximum, exhibiting a smaller grain diameter than the grains forming the second maximum, require higher levels of imaging exposure before contributing to image densities. Hence, the monodisperse tabular grains "kick in" (contribute to image density) only above a relatively high threshold exposure level. By requiring that the monodisperse emulsion exhibit an unusually low **COV**, less than 10%, the monodisperse emulsion raises the overall point $\gamma$ of the blended emulsion to the required reference point $\gamma$ level of 2.0 at a density of 2.5. If a significantly higher **COV** emulsion is employed to provide the first maximum, the enhancement in contrast is largely dissipated and the radiographic elements revert to or approach the performance characteristics of inferior comparative radiographic elements reported in the Examples.

The radiographic elements can take any convenient conventional form compatible with providing the identified high point $\gamma$ profile over the referenced image density range of from 1.0 to 2.5, hereinafter referred to as characteristic (1). However, in their preferred form the radiographic elements combine characteristic (1), with other important characteristics to offer a combination of advantageous characteristics never previously realized in a single radiographic element.

Such a preferred embodiment of the invention is illustrated by reference to Figure 1, wherein an assembly is shown comprised of a preferred radiographic element **RE** positioned between front and back intensifying screens **FS** and **BS** comprised of supports **SS1** and **SS2** and layers **FLE** and **BLE** that absorb X-radiation and emit light.

Located between the screens when intended to be imagewise exposed is preferred radiographic element **RE** satisfying the requirements of the invention. The radiographic element is comprised of a transparent support **TF**, which is usually a transparent film support and is frequently blue tinted. To facilitate coating onto the support, subbing layers **S1** and **S2** are shown. Subbing layers are formed as an integral part of transparent film supports, but are not essential for all types of transparent supports. The transparent support and the subbing layers are all transparent to light emitted by the intensifying screens and are also processing solution impermeable. That is, they do not ingest water during processing and hence do not contribute to the "drying load"--the water that must be removed to obtain a dry imaged element.

A front emulsion layer unit satisfying the requirements of the invention as described above, formed by first and second hydrophilic colloid layers **FE1** and **FE2**, respectively, is coated on the major surface of the support positioned adjacent the front intensifying screen. Similarly, a back emulsion layer unit, similar to the front emulsion layer unit and formed by first and second hydrophilic colloid layers **BE1** and **BE2**, is coated on the major surface of the support positioned adjacent the back intensifying screen. Also usually present, but not shown, are hydrophilic colloid layers, referred to as a surface overcoats, that overlie **FE2** and **BE2** and perform the function of physically protecting the underlying hydrophilic colloid layers during handling and processing. In addition to hydrophilic colloid the overcoats can contain matting agents, antistatic agents, lubricants and other non-imaging addenda.

The preferred radiographic elements **RE** of the invention differ from those previously available in the art by offering a combination of advantageous characteristics never previously realized in a single radiographic element:

(1) A high point $\gamma$ profile over the referenced image density range of from 1.0 to 2.5, described above.

(2) Full forehardening.

(3) Crossover of less than 15 percent.

(4) Processing in less than 45 seconds.

(5) Low wet pressure sensitivity.

(6) Relatively high levels of sensitivity. While prior to the present invention the combination of characteristics (1)-(6), had it been contemplated, would have been thought to impose incompatible construction requirements, by careful selection of components it is possible to combine all of these characteristics in a single preferred radiographic element satisfying the requirements of the invention.

The preferred radiographic element **RE** is fully forehardened. This better protects the radiographic element from damage in handling and processing and simplifies processing by eliminating any necessity of completing hardening during processing.

As employed herein, the term "fully forehardened" means that the hydrophilic colloid layers are forehardened in an amount sufficient to reduce swelling of these layers to less than 300 percent, percent swelling being determined by (a) incubating the radiographic element at 38°C for 3 days at 50 percent relative humidity, (b) measuring layer thickness, (c) immersing the radiographic element in distilled water at 21°C for 3 minutes, and (d) determining the percent change in layer thickness as compared to the layer thickness measured in step (b).

Full forehardening is achieved by hardening the hydrophilic colloid layers. The levels of forehardening of a fully forehardened radiographic element are similar to those employed in forehardening photographic elements. A summary of vehicles for photographic elements, including hydrophilic colloids employed as peptizers and binders, and useful hardeners is contained in *Research Disclosure,* Vol. 365, September 1994, Item 36544, Section II. Vehicles, vehicle extenders, vehicle-like addenda and vehicle related addenda. Preferred vehicles for the hydrophilic colloid layers **FE1**, **FE2**, **BE1** and **BE2** as well as protective overcoats, if included, are gelatin (e.g., alkali-treated gelatin or acid-treated gelatin) and gelatin derivatives (e.g., acetylated gelatin or phthalated gelatin). Although conventional hardeners can be used more or less interchangeably with little or no impact on performance, particularly preferred are the bis(vinylsulfonyl) class of hardeners, such as bis(vinylsulfonyl)alkylether or bis(vinylsulfonyl)-alkane hardeners, where the alkyl moiety contains from 1 to 4 carbon atoms.

The fully forehardened characteristic (2) restricts the choices of the silver halide emulsions in the following manner: It is well recognized in the art that silver image covering power can decline as a function of increased levels of forehardening. Covering power is expressed as image density divided by silver coating coverage. For example, Dickerson U.S. Patent 4,414,304 defines covering power as 100 times the ratio of maximum density to developed silver, expressed in $mg/dm^2$. Dickerson recognized that tabular grain emulsions are less susceptible to covering power reduction with increasing levels of forehardening.

If the hydrophilic colloid layers are not fully forehardened, excessive water pick up during processing prevents processing in less than 45 seconds, characteristic (4). If tabular grain emulsions are not employed, excessive amounts of silver must be coated to realize characteristic (1), and characteristics (4) and (5) cannot be both realized. If the hydrophilic colloid is increased in proportion to the increase in silver, processing cannot be completed in less than 45 seconds. If silver is increased without increasing the hydrophilic colloid, the processed radiographic element will show localized density marks indicative of roller pressure applied in passing the exposed element through the processor, generally referred to as wet pressure sensitivity. Tabular grain emulsions frequently display higher levels of wet pressure sensitivity than nontabular grain emulsions.

With various other selections discussed below, all of characteristics (1)-(6) listed above can be realized by the incorporation of tabular grain emulsions in the radiographic element **RE**. To be compatible with characteristics (1)-(6), the tabular grains of the emulsion having a thickness of less than 0.3 µm (preferably less than 0.2 µm) must have an average aspect ratio of greater than 5 (preferably greater than 8) and account for at least 50 percent (preferably at least 70 percent and, most preferably, at least 90 percent) of total grain projected area.

Although the thinnest obtainable tabular grains should be most effective, it is generally preferred that the tabular grains noted above have a thickness of at least 0.1 µm. Otherwise, the tabular grain emulsion will impart a undesirably warm image tone. Thus, for preferred radiographic element constructions there is a seventh characteristic to be taken into account:

(7) Relatively cold image tone.

Tabular grain silver halide emulsions contemplated for use in the preferred radiographic elements of the invention can be of any of the following silver halide compositions: silver chloride, silver bromide, silver iodobromide, silver chlorobromide, silver bromochloride, silver iodochloride, silver iodochlorobromide and silver iodobromochloride, where the mixed halides are named in order of ascending concentrations. Since it is recognized that the presence of iodide slows grain development, it is advantageous to choose emulsions that contain no iodide or only limited levels of iodide. Iodide concentrations of less than 4 mole percent, based on silver, are specifically preferred. Of the three photographic halides (chloride, bromide and iodide), silver chloride has the highest solubility and hence lends itself to achieving the highest rates of development. It is therefore preferred in terms of achieving characteristic (4). When characteristics (4) and (6) are considered together, silver chlorobromide and silver bromide compositions are preferred.

Conventional high (greater than 50 mole percent) chloride tabular grain emulsions compatible with requirements of the radiographic elements of this invention are illustrated by the following citations:

Wey et al U.S. Patent 4,414,306;
Maskasky U.S. Patent 4,400,463;
Maskasky U.S. Patent 4,713,323;
Takada et al U.S. Patent 4,783,398;
Nishikawa et al U.S. Patent 4,952,491;
Ishiguro et al U.S. Patent 4,983,508;
Tufano et al U.S. Patent 4,804,621;
Maskasky U.S. Patent 5,061,617;
Maskasky U.S. Patent 5,178,997;
Maskasky and Chang U.S. Patent 5,178,998;
Maskasky U.S. Patent 5,183,732;
Maskasky U.S. Patent 5,185,239;
Maskasky U.S. Patent 5,217,858;
Chang et al U.S. Patent 5,252,452;
Maskasky U.S. Patent 5,264,337;
Maskasky U.S. Patent 5,272,052;

Maskasky U.S. Patent 5,275,930;
Maskasky U.S. Patent 5,292,632;
Maskasky U.S. Patent 5,298,387;
Maskasky U.S. Patent 5,298,388; and
House et al U.S. Patent 5,320,938.

Conventional high (greater than 50 mole percent) bromide tabular grain emulsions compatible with requirements of the radiographic elements of this invention are illustrated by the following citations:

Abbott et al U.S. Patent 4,425,425;
Abbott et al U.S. Patent 4,425,426;
Kofron et al U.S. Patent 4,439,520;
Maskasky U.S. Patent 4,713,320;
Nottorf U.S. Patent 4,722,886;
Saito et al U.S. Patent 4,797,354;
Ellis U.S. Patent 4,801,522;
Ikeda et al U.S. Patent 4,806,461;
Ohashi et al U.S. Patent 4,835,095;
Makino et al U.S. Patent 4,835,322;
Daubendiek et al U.S. Patent 4,914,014;
Aida et al U.S. Patent 4,962,015;
Black et al U.S. Patent 5,219,720;
Dickerson et al U.S. Patent 5,252,443;
Tsaur et al U.S. Patent 5,272,048;
Delton U.S. Patent 5,310,644;
Chaffee et al U.S. Patent 5,358,840; and
Delton U.S. Patent 5,372,927.

The tabular grain emulsions contemplated for use have a mean **ECD** of less than 10 μm. Typically the average **ECD** of the grains is less than 5 μm. As indicated above, the monodispersed emulsion has a maximum mean **ECD** less than 75 (preferably less than 60) percent of the mean **ECD** of the combination of tabular grain emulsions.

When tabular grain emulsions satisfying the requirements set forth above are employed, total silver coating coverages in the range of from 15 to 60 mg/dm$^2$ are capable upon processing of producing a silver image having a maximum density of at least 2.5. Increasing total silver coating coverages to at least 20 mg/dm$^2$ or 25 mg/dm$^2$ increases the maximum density levels that can be realized; however, it is in general preferred to employ the lowest silver coating coverages compatible with achieving a workable maximum density level. Radiographic elements are typically constructed to provide a maximum density in the range of from 3.0 to 4.0.

It is contemplated to incorporate a blend of tabular grain emulsions satisfying characteristic (1) described above in each of hydrophilic colloid layers **FE2** and **BE2**.

If all of the radiation silver halide grains contained in the radiographic element were restricted to just layers **FE2** and **BE2**, spectrally sensitizing tabular grain emulsions to be incorporated in these layers is capable of itself reducing crossover to just less than 20 percent, as illustrated by Abbott et al U.S. Patents 4,425,425 and 4,425,426 (hereinafter referred to collectively as Abbott et al).

All references to crossover percentages are based on the crossover measurement technique described in Abbott et al. The crossover of a radiographic element according to the invention under the contemplated conditions of exposure and processing can be determined by substituting a black object (e.g., kraft paper) for one of the two intensifying screens. To provide a verifiable standard for measuring percent crossover, the exposure and processing described in the Examples, below, should be employed. Exposure through a stepped density test object exposes primarily the emulsion on the side of the radiographic element nearest the intensifying screen, but the emulsion on the side of the radiographic element farthest from the intensifying screen is also exposed, but to a more limited extent by unabsorbed light passing through the support. By removing emulsion from the side of the support nearest the intensifying screen in one sample and the side of the support farther from the intensifying screen in another sample, a characteristic curve (density vs. log E, where E is the light passing through the stepped test object, measured in lux-seconds) can be plotted for each emulsion remaining. The characteristic curve of the emulsion on the side farthest from the substituted light source is laterally displaced as compared to the characteristic curve of the emulsion on the side nearest the substituted light source. An average displacement ($\Delta$log E, where E is exposure in lux-seconds) is determined and used to calculate percent crossover as follows:
(II)

$$\text{Percent Crossover} = \frac{1}{\text{antilog}(\Delta\log E)} \times 100$$

If screen emission is in the spectral region to which silver halide possesses native sensitivity, then the silver halide grains themselves contribute to light absorption and therefore crossover reduction. This occurs to a significant extent only at exposure wavelengths of less than 425 nm. Spectral sensitizing dye adsorbed to the grain surfaces is primarily relied upon for absorption of light emitted by the screens. The silver halide emulsions can contain any conventional spectral sensitizing dye or dye combination adsorbed to the grain surfaces. Typically dye absorption maxima are closely matched to the emission maxima of the screens so that maximum light capture efficiency is realized. To maximize speed (6) and minimize crossover (3), it is preferred to adsorb dye to the grain surfaces in a substantially optimum amount--that is, in an amount sufficient to realize at least 60 percent of maximum speed under the contemplated conditions of exposure and processing. To provide an objective standard for reference-the conditions of exposure and processing set out in the Examples below can be employed. Illustrations of spectral sensitizing dyes useful with the radiographic elements of the invention are provided by Kofron et al U.S. Patent 4,439,520 particularly cited for its listing of blue spectral sensitizing dyes. Abbott et al U.S. Patents 4,425,425 and 4,425,426 also illustrate the use of spectral sensitizing dyes to reduce crossover. A more general summary of spectral sensitizing dyes is provided by *Research Disclosure,* Item 36544, cited above, Section V. Spectral sensitization and desensitization, A. Sensitizing dyes.

To reduce crossover to less than 15 percent and, preferably, to less than 10 percent it is contemplated to introduce additional dye capable of absorbing within the wavelength region of exposure into the hydrophilic colloid layers **FE1** and **BE1**. The additional dye is chosen to absorb exposing light that is not absorbed by the silver halide grains and spectral sensitizing dye contained in hydrophilic colloid layers **FE2** and **BE2**. If the additional dye is incorporated into the hydrophilic colloid layers **FE2** and **BE2** as well, the result is a marked reduction in photographic speed.

In addition to its absorption properties the additional dye is chosen to impart still another characteristic to the radiographic element:

(8) Decolorization during processing.

Dickerson et al U.S. Patents 4,803,150 and 4,900,652, disclose particulate dyes capable of (a) absorbing radiation to which the silver halide grains are responsive to reduce crossover to less than 15 percent and (b) being substantially decolorized during processing. The particulate dyes can, in fact, substantially eliminate crossover. The mean **ECD** of the dye particles can range up to 10 μm, but is preferably less than 1 μm. Dye particle sizes down to about 0.01 μm can be conveniently formed. Where the dyes are initially crystallized in larger than desired particle sizes, conventional techniques for achieving smaller particle sizes can be employed, such as ball milling, roller milling, sand milling, and the like.

Since the hydrophilic colloid layers are typically coated as aqueous solutions in the pH range of from 5 to 6, most typically from 5.5 to 6.0, the dyes are selected to remain in particulate form at those pH levels in aqueous solutions. The dyes must, however, be readily soluble at the alkaline pH levels employed in photographic development. Dyes satisfying these requirements are nonionic in the pH range of coating, but ionic under the alkaline pH levels of processing. Preferred dyes are nonionic polymethine dyes, which include the merocyanine, oxonol, hemioxonol, styryl and arylidene dyes. In preferred forms the dyes contain carboxylic acid substituents, since these substituents are nonionic in the pH ranges of coating, but are ionic under alkaline processing conditions.

Specific examples of particulate dyes are described by Lemahieu et al U.S. Patent 4,092,168, Diehl et al WO 88/04795 and EPO 0 274 723, and Factor et al EPO 0 299 435, Factor et al U.S. Patent 4,900,653, Diehl et al U.S. Patent 4,940,654 (dyes with groups having ionizable protons other than carboxy), Factor et al U.S. Patent 4,948,718 (with arylpyrazolone nucleus), Diehl et al U.S. Patent 4,950,586, Anderson et al U.S. Patent 4,988,611 (particles of particular size ranges and substituent pKa values), Diehl et al U.S. Patent 4,994,356, Usagawa et al U.S. Patent 5,208,137, Adachi U.S. Patent 5,213,957 (merocyanines), Usami U.S. Patent 5,238,798 (pyrazolone oxonols), Usami et al U.S. Patent 5,238,799 (pyrazolone oxonols), Diehl et al U.S. Patent 5,213,956 (tricyanopropenes and others), Inagaki et al U.S. Patent 5,075,205, Otp et al U.S. Patent 5,098,818, Texter U.S. Patent 5,274,109, McManus et al U. S. Patent 5,098,820, Inagaki et al EPO 0 385 461, Fujita et al EPO 0 423 693, Usui EPO 0 423 742 (containing groups with specific pKa values), Usagawa et al EPO 0 434 413 (pyrazolones with particular sulfamoyl, carboxyl and similar substituents), Jimbo et al EPO 0 460 550, Diehl et al EPO 0 524 593 (having alkoxy or cyclic ether substituted phenyl substituents), Diehl et al EPO 0 524 594 (furan substituents) and Ohno EPO 0 552 646 (oxonols).

If all of the silver halide required for imaging is located in the hydrophilic colloid layers **FE2** and **BE2**, it is impossible to satisfy characteristics (4) and (5). If hydrophilic colloid is reduced to less than 35 mg/dm$^2$ per side, processing in less than 45 seconds (4) can be realized, but high levels of wet pressure sensitivity are observed. Wet pressure sensitivity is observed as uneven optical densities in the fully processed image, attributable to differences in guide roller pressures applied in rapid processing. If the amount of hydrophilic colloid in the layers **FE2** and **BE2** is increased to an extent necessary to eliminate visible wet pressure sensitivity, the radiographic element cannot be processed in less than 45 seconds.

Successful rapid processing and low levels of wet pressure sensitivity can be both realized if at least a portion of the spectrally sensitized radiation-sensitive tabular grain emulsion combination used to satisfy characteristic (1) is incorporated in the hydrophilic colloid layers **FE1** and **BE1**. When a portion of the spectrally sensitized tabular grain emulsion combination is coated in the hydrophilic colloid layers containing the particulate dye used for crossover reduction, fully acceptable photographic speeds can still be maintained. This is in direct contradiction to observations that particulate dye and silver halide emulsion blending in a single hydrophilic colloid result in unacceptably low levels of photographic speed. By incorporating both a portion of the combination of tabular grain emulsions and the particulate dye in hydrophilic colloid layers **FE1** and **BE1**, it is possible to reduce the total coverage of hydrophilic colloid per side of the radiographic elements of the invention to less than 35 mg/dm$^2$, preferably less than 33 mg/dm$^2$ while satisfying characteristics (1)-(6). In preferred forms of the invention, the low levels of hydrophilic colloid per side allow processing characteristic (4) to be reduced to less than 35 seconds.

The silver halide emulsion incorporated in the hydrophilic colloid layers **FE1** and **BE1** is a portion of the same blended tabular grain emulsion incorporated in hydrophilic colloid layers **FE2** and **BE2**. Alternatively, it is possible to locate the polydisperse tabular.grain emulsion portion entirely in layers **FE1** and **BE1** and to coat the monodisperse tabular grain portion of the combination of tabular grain emulsions entirely in the layers **FE2** and **BE2**. However, the opposite arrangement is preferred. That is, preferably the monodisperse tabular grain emulsion is located entirely in layers **FE1** and **BE1**, and the polydisperse tabular grain portion of the combination of tabular grain emulsions is located entirely in the layers **FE2** and **BE2**. This arrangement has the advantage of allowing relatively higher levels of contrast to be realized over the entire image density range--i.e., up to and beyond a maximum density of 2.5. The monodisperse emulsion in the layers **FE1** and **BE1** offsets the tendency of the dye particles to reduce contrast. When the monodisperse emulsion is located entirely in the layers **FE1** and **BE1**, the effective imaging speed of the monodisperse tabular grains is reduced, since more light is absorbed before reaching these grains. It is therefore contemplated that the monodisperse tabular grains will still have a mean **ECD** less than, but in most instances at 60 percent of, the mean **ECD** of the combination of tabular grain emulsions.

To satisfy characteristics (1)-(6), from 20 to 80 (preferably 30 to 70) percent of the total silver forming the radiographic element must be contained in the hydrophilic colloid layers **FE2** and **BE2**. Similarly, from 20 to 80 (preferably 30 to 70) percent of the total silver forming the radiographic element must be contained in the hydrophilic colloid layers **FE1** and **BE1**. It is generally preferred that at least 50 percent of the total silver forming the radiographic element be contained in the hydrophilic colloid layers **FE2** and **BE2**.

In addition, to satisfy characteristics (1)-(6), the silver halide grains in hydrophilic colloid layers **FE2** and **BE2** account for from 30 to 70 (preferably 40 to 60) percent of the total weight of these layers. Similarly, in hydrophilic colloid layers **FE1** and **BE1** the silver halide grains and dye particles together account for from 30 to 70 (preferably 40 to 60) percent of the total weight of these layers.

While the invention has been described in terms of the simplest possible structure, illustrated by (I) above, and a specifically preferred embodiment of Figure 1 satisfying at least performance characteristics (1)-(6) and preferably performance characteristics (7) and (8) as well, it can be readily appreciated that intermediate radiographic element constructions between these extremes are possible realizing advantageous characteristic (1) and one or more of characteristics (2)-(9).

Selections of features of the radiographic elements of the invention compatible with the required and preferred selections described can take any convenient conventional form. For example, chemical sensitization of the emulsions is disclosed in *Research Disclosure* Item 36544, Section IV. Chemical sensitization and *Research Disclosure* Item 18431, Section I.C. Chemical Sensitization/Doped Crystals. The chemical sensitization of tabular grain emulsions is more particularly taught in Kofron et al U.S. Patent 4,429,520.

The following sections of *Research Disclosure* Item 18431 summarize additional features that are applicable to the radiographic elements of the invention:

II. Emulsion Stabilizers, Antifoggants and Antikinking Agents
III. Antistatic Agents/Layers
IV. Overcoat Layers

The following sections of *Research Disclosure* Item 36544 summarize additional features that are applicable to the radiographic elements of the invention:

VII. Antifoggants and stabilizers
IX. Coating physical property modifying addenda

**Examples**

The invention can be better appreciated by consideration in connection with the following specific embodiments. The letters C and E are appended to radiographic element numbers to differentiate control and example radiographic elements. All coating coverages are in mg/dm$^2$, except as otherwise indicated.

Emulsions

Four conventional tabular grain silver bromide emulsions were selected and individually evaluated. Each emulsion was sulfur and gold sensitized and spectrally sensitized with 400 mg/Ag mole of anhydro-5,5'-dichloro-9-ethyl-3,3'-bis (3-sulfopropyl)oxacarbocyanine hydroxide, followed by 300 mg/Ag mole of potassium iodide.

The speed and contrast of the emulsions were evaluated by separately coating each emulsion on both major faces of a blue tinted poly(ethylene terephthalate) radiographic film support at a per side coating coverage of 17.44 mg/dm$^2$ silver and 32.2 mg/dm$^2$ gelatin. Protective gelatin layers (3.5 mg/dm$^2$ per side) were coated over the emulsion layers. Each of the gelatin containing layers were hardened with bis(vinylsulfonylmethyl)ether at 2.35% by weight, based on total gelatin.

Exposures

Samples of the coated emulsions were exposed through a graduated density step tablet to a MacBeth sensitometer for 1/50th second to a 500 watt General Electric DMX projector lamp calibrated to 2650°K filtered with a Corning C4010 filter to simulate a green emitting X-ray screen exposure.

Processing

Processing of the exposed coatings was in each instance undertaken using a processor commercially available under the Kodak RP X-Omat™ film processor M6A-N. The processor employed the following processing cycle:

| | |
|---|---|
| Development | 24 seconds at 35°C |
| Fixing | 20 seconds at 35°C |
| Washing | 10 seconds at 35°C |
| Drying | 20 seconds at 65°C |

The developer employed exhibited the following formula, where all ingredient concentrations, except that of water, are reported in grams per liter:

| | |
|---|---|
| Hydroquinone | 30 |
| 4-Hydroxymethyl-4-methyl-1-phenyl-3-pyrazolidinone | 1.5 |
| Potassium hydroxide | 21 |
| Sodium bicarbonate | 7.5 |
| Potassium sulfite | 44.2 |
| Sodium sulfite | 12.6 |
| Sodium bromide | 35 |
| 5-Methylbenzotriazole | 0.06 |
| Glutaraldehyde | 4.9 |
| Water to 1 liter @ pH10 | |

The properties of the individual emulsions are summarized in Table I. Speed is reported in relative log units--that is, 100 units = 1.0 log E, where E is exposure in lux-seconds. Contrast was measured as the slope of a line drawn on the characteristic curve from a density of Dmin + 0.25 to a density of Dmin + 2.0.

Table I

| Emulsion | ECD (μm) | t (μm) | COV | Speed | Contrast |
|---|---|---|---|---|---|
| PDE-1 | 4.0 | 0.13 | 31 | 481 | 2.54 |
| PDE-2 | 2.0 | 0.13 | 31 | 442 | 2.54 |

Table I (continued)

| Emulsion | ECD (μm) | t (μm) | COV | Speed | Contrast |
|---|---|---|---|---|---|
| PDE-3 | 1.3 | 0.13 | 36 | 395 | 2.34 |
| MDE-1 | 1.1 | 0.13 | 7 | 395 | 3.16 |
| MDE-2 | 2.0 | 0.13 | 8 | 440 | 3.20 |

**Example 1**

This example demonstrates the application of the invention to a simple dual coated radiographic element construction in which spectrally sensitized tabular grain emulsions are primarily relied upon to recontrol crossover.

Radiographic Elements

Using portions of the emulsions above three blended emulsions were prepared for radiographic element evaluation. The emulsion blends and the radiographic elements in which they were incorporated are listed in Table II. The amount of each emulsion shown in Table II is the total coating coverage (mg/dm$^2$, both sides).

Table II

| Element | Total Coverage | PDE-1 | PDE-2 | PDE-3 | MDE-1 |
|---|---|---|---|---|---|
| RE-1C | 34.66 | 4.36 | 18.09 | 12.21 | |
| RE-2C | 41.63 | 4.36 | 18.09 | 19.18 | |
| RE-3E | 34.66 | 4.36 | 18.09 | | 12.21 |

The radiographic elements were constructed as follows:

Surface Overcoat (**SOC**)
Interlayer (**IL**)
Blended Emulsion layer (**ELU**)
Transparent Film Support (**TFS**)
Blended Emulsion layer (**ELU**)
Interlayer (**IL**)
Surface Overcoat (**SOC**)

| Blended Emulsion Layer (**ELU**) | |
|---|---|
| Contents | Coverage |
| Ag | see Table II |
| Gelatin | 31.6 |
| 4-Hydroxy-6-methyl-1,3,3a,7-tetraazaindene | 2.1 mg/Ag mole |
| Potassium nitrate | 1.8 |
| Ammonium hexachloropalladate | 0.0022 |
| Maleic acid hydrazide | 0.0087 |
| Sorbitol | 0.53 |
| Glycerin | 0.57 |
| Potassium bromide | 0.14 |
| Resorcinol | 0.44 |
| Bis(vinylsulfonyl)ether | 2.4% |
| (based on wt. of gelatin in all layers) | |

Interlayer (**IL**)

| Contents | Coverage |
|---|---|
| Gelatin | 3.4 |
| AgI Lippmann | 0.11 |
| Carboxymethyl casein | 0.57 |
| Colloidal silica | 0.57 |
| Polyacrylamide | 0.57 |
| Chrome alum | 0.025 |
| Resorcinol | 0.058 |
| Nitron | 0.044 |

| Surface Overcoat (**SOC**) | |
|---|---|
| Contents | Coverage |
| Gelatin | 3.4 |
| Poly(methyl methacrylate) matte beads | 0.14 |
| Carboxymethyl casein | 0.57 |
| Colloidal silica | 0.57 |
| Polyacrylamide | 0.57 |
| Chrome alum | 0.025 |
| Resorcinol | 0.058 |
| Whale oil lubricant | 0.15 |

The radiographic elements were exposed and processed as described above in connection with the emulsion sample coatings. Optical densities are expressed in terms of diffuse densities 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. Point $\gamma$'s were calculated from the characteristic curves.

Performance of the radiographic elements is summarized in Table III.

Table III

| **Element** | **Dmin** | **Dmax** | **Speed** | **Point $\gamma$ @ Density of** | | |
|---|---|---|---|---|---|---|
| | | | | **1.0** | **1.5** | **2.5** |
| RE-1C | 0.20 | 2.9 | 435 | 1.9 | 2.3 | 0.9 |
| RE-2C | 0.20 | 3.4 | 435 | 2.0 | 2.6 | 2.3 |
| RE-3E | 0.20 | 3.0 | 433 | 1.8 | 2.3 | 2.0 |

RE-1C, which contained a blend of polydisperse emulsions, failed to provide a point $\gamma$ of at least 2.0 at a density of 2.5. In medical diagnostic terms, this means that it would have been difficult to pick out anatomical features in high density image areas, since the local image contrast was too low to allow ready visual detection of features in a region exhibiting densities at or near 2.5. RE-3E, which contained the same silver coating coverage as RE-1C, but substituted a monodisperse emulsion for a portion of the polydispersed emulsions, exhibited a point $\gamma$ of 2.0 at a density of 2.5. Thus, RE-3E was clearly superior to RE-1C for medical diagnostics in high density image regions. By increasing the coating coverages of polydisperse emulsion it was possible to raise the performance of RE-1C, as illustrated by RE-2C. However, increasing silver coating coverages is a disadvantage, both in element construction and processing. Radiographic element RE-3E contains less silver than RE-2C and can therefore be processed more rapidly. This, together with the silver saving, provides a distinct advantage for radiographic element RE-3E satisfying the requirements of the invention.

**Example 2**

This example demonstrates the application of the invention to dual coated radiographic elements that employ processing solution decolorizable dye particles to achieve very low crossover levels.

Radiographic Element 4C

A conventional dual coated asymmetrical radiographic element was constructed having a single emulsion layer coated on each side of the support and a dye containing crossover over control layer interposed between the emulsion layer and the support.

The radiographic element was constructed as follows:

Surface Overcoat (**SOC**)
Interlayer (**IL**)
Low Contrast Emulsion layer (**LCELU**)
Crossover Reduction Layer (**CXRL**)
Transparent Film Support (**TFS**)
Crossover Reduction Layer (**CXRL**)
High Contrast Emulsion layer (**HCELU**)
Interlayer (**IL**)
Surface Overcoat (**SOC**)

**SOC** and **IL** were in each occurrence identical to the description above in Example 1.

| Low Contrast Emulsion Layer (**LCELU**) | |
|---|---|
| Contents | Coverage |
| PDE-1 | 7.8 |
| PDE-2 | 3.9 |
| PDE-3 | 7.8 |
| Gelatin | 31.6 |
| 4-Hydroxy-6-methyl-1,3,3a,7-tetraazaindene | 2.1 mg/Ag mole |
| Potassium nitrate | 0.83 |
| Ammonium hexachloropalladate | 0.0022 |
| Maleic acid hydrazide | 0.0087 |
| Sorbitol | 0.53 |
| Glycerin | 0.57 |
| Potassium bromide | 0.14 |
| Resorcinol | 0.44 |
| Bis(vinylsulfonyl)ether | 2.5% |
| (based on wt. of gelatin in all layers) | |

High Contrast Emulsion Layer (**HCELU**)

The high contrast emulsion layer was identical the low contrast emulsion layer **LCELU**, except that MDE-2 at a coverage of 24 was substituted for the PDE-1, PDE-2 and PDE-3.

| Crossover Reduction Layer (**CXRL**) | |
|---|---|
| Contents | Coverage |
| 1-(4'-Carboxyphenyl)-4-(4'-di-methylaminobenzylidene)-3-ethoxycarbonyl-2-pyrazolin-5-one (Dye XOC-1) | 2.2 |

(continued)

| Crossover Reduction Layer (**CXRL**) | |
|---|---|
| Contents | Coverage |
| Gelatin | 6.8 |

The crossover control dye was coated in the form of particles have a mean diameter of less than 1 μm.

Radiographic Element 5C

A conventional dual coated symmetrical radiographic element was constructed having upper and lower emulsion layers coated on each side of the support with the crossover controlling dye located in each lower emulsion layer. Each emulsion layer contained polydispersed emulsions.

The radiographic element was constructed as follows:

Surface Overcoat (**SOC**)
Interlayer (**IL**)
Upper Emulsion layer (**UELU**)
Lower Emulsion Layer (**LELU**)
Transparent Film Support (**TFS**)
Lower Emulsion Layer (**LELU**)
Upper Emulsion layer (**UELU**)
Interlayer (**IL**)
Surface Overcoat (**SOC**)

**SOC** and **IL** were in each occurrence identical to the description above in Example 1.

| Upper Emulsion Layer (**UELU**) | |
|---|---|
| Contents | Coverage |
| PDE-1 | 3.3 |
| PDE-2 | 6.5 |
| Gelatin | 12.0 |
| 4-Hydroxy-6-methyl-1,3,3a,7-tetraazaindene | 2.1 mg/Ag mole |
| Potassium nitrate | 0.83 |
| Ammonium hexachloropalladate | 0.001 |
| Maleic acid hydrazide | 0.0044 |
| Sorbitol | 0.24 |
| Glycerin | 0.26 |
| Potassium bromide | 0.06 |
| Resorcinol | 0.2 |

| Lower Emulsion Layer (**LELU**) | |
|---|---|
| Contents | Coverage |
| PDE-2 | 13.1 |
| Gelatin | 13.1 |
| Dye XOC-1 | 2.2 |
| 4-Hydroxy-6-methyl-1,3,3a,7-tetraazaindene | 2.1 mg/Ag mole |
| Potassium nitrate | 1.1 |
| Ammonium hexachloropalladate | 0.0013 |
| Maleic acid hydrazide | 0.0053 |
| Sorbitol | 0.32 |

(continued)

| Lower Emulsion Layer (**LELU**) | |
|---|---|
| Contents | Coverage |
| Glycerin | 0.35 |
| Potassium bromide | 0.083 |
| Resorcinol | 0.26 |
| Bis(vinylsulfonyl)ether | 2.5% |
| (based on wt. of gelatin in all layers) | |

Radiographic Element 6E

A dual coated symmetrical radiographic element satisfying the requirements of the invention exhibiting low levels of crossover attributable to the incorporation of the processing solution decolorizable dye particles was constructed identically as Radiographic Element 5C above, except that MDE-2 was substituted for PDE-2 in the lower emulsion layers **LELU**.

Exposure

The radiographic elements were identically exposed when mounted between a symmetrical pair of Lanex ™ Regular general purpose screens. These screens incorporated a green emitting terbium activated gadolinium oxysulfide phosphor. The screen-film assemblies were exposed to 70 KVp X-radiation, varying either current (mA) or time, using a 3-phase Picker Medical (Model VTX-650 ™) X-ray exposure unit containing filtration of up to 3 mm or aluminum. Sensitometeric gradations in exposure were achieved by using a 21 step (0.1 log E, where E is exposure in lux-seconds) aluminum step wedge of varied thickness. Radiographic element 4C was oriented with the high contrast emulsion layer nearest the source of exposing X-radiation.

Processing

The exposed elements were processed using a Kodak X-Omat RA 480 processor set for the following processing cycle:

| | |
|---|---|
| Development | 11.1 seconds at 40°C |
| Fixing | 9.4 seconds at 30°C |
| Washing | 7.6 seconds at room temperature |
| Drying | 12.2 seconds at 67.5°C |

The following developer was employed. Components are expressed in g/L, except as indicated:

| | |
|---|---|
| Hydroquinone | 32 |
| 4-Hydroxymethyl-4-methyl-1-phenyl-3-pyrazolidinone | 6 |
| Potassium bromide | 2.25 |
| 5-Methylbenzotriazole | 0.125 |
| Sodium sulfite | 160 |
| Water to 1 liter @ pH 10 | |

From processed samples of the radiographic elements characteristic curves were constructed using optical densities 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 traceable to a National Bureau of Standards calibration step tablet.

The speed, contrast, maximum density, and minimum density (Dmin) obtained by these measurements are summarized in Table IV. Speed and contrast were measured as described in Example 1.

Dye stain was measured as the difference between density at 505 nm, the peak absorption wavelength of Dye XOC-1, and 440 nm. Since silver exhibits essentially the same density at both of these wavelengths, subtraction of the 440 nm density from the 505 nm density provides a measure of dye stain. Densities were measured in samples that were processed as described above, but were not exposed. Hence, the only silver present was that corresponding to Dmin.

To compare the ability of the processor to dry the film samples, samples of the radiographic elements were flash exposed to provide a density of 1.0 when processed. As each film sample started to exit the processor, the processor was stopped, and the sample was removed from the processor. Roller marks were visible on the film in areas that had not dried. A film that was not dry as it left the processor was assigned a % dryer value of 100+. A film that exhibited roller marks from first encountered guide rollers, but not the later encountered guide rollers, indicating that the film had already dried when passing over the latter rollers, was assigned a % dryer value indicative of percentage of the rollers that were guiding undried portions of the film. Hence lower % dryer values indicate quicker drying film samples.

To permit crossover determinations samples of the Elements were exposed with a Lanex Regular ™ green emitting intensifying screen in contact with one side of the sample and black kraft paper in contact with the other side of the sample. The X-radiation source was a Picker VGX653 3-phase X-ray machine, with a Dunlee High-Speed PX1431-CQ-150 kVp 0.7/1.4 focus tube. Exposure was made at 70 kVp, 32 mAs, at a distance of 1.40 m. Filtration was with 3 mm Al equivalent (1.25 inherent + 1.75 Al); Half Value Layer (HVL)-2.6 mm Al. A 26 step Al step wedge was used, differing in thickness by 2 mm per step.

Processing of these samples was undertaken as described above. By removing emulsion from the side of the support nearest the screen at some sample locations and from the side of the support opposite the screen at other sample locations the density produced on each side of the support at each step was determined. From this separate characteristic (density vs. log E) curves were plotted for each emulsion layer. The exposure offset between the curves was measured at three locations between the toe and shoulder portions of the curves and averaged to obtain $\Delta$log E for use in equation (I), above.

The results summarized in Table IV demonstrate the advantages of the radiographic elements of the invention.

TABLE IV

| Element | Gelatin per side | XOC Coverage | Dye Location | % Crossover | Speed | Pt. g D =1.0/2.5 | Dmax | Dmin | Dye Stain | % Dryer |
|---|---|---|---|---|---|---|---|---|---|---|
| 4C | 45.2 | 2.2 | CXRL | 3 | 100 | 1.2/2.5 | 3.7 | 0.22 | 0.04 | 100+ |
| 5C | 31.9 | 2.2 | LELU | 3 | 92 | 1.4/1.8 | 3.6 | 0.28 | 0.06 | 70 |
| 6E | 31.9 | 2.2 | LELU | 3 | 92 | 1.4/2.3 | 3.6 | 0.26 | 0.06 | 70 |

Element 4C could not be used in the processing cycle employed, which is typical of recently introduced shorter duration processing cycles. The added gelatin required to provide an additional layer in the radiographic element to the extent that the element was still wet when in emerged from the processor, indicated in Table IV as requiring 100+ percent of the processor for drying.

On the other hand, both Elements 5C and 6E, which incorporated the crossover reducing dye in the lower emulsion layers, required only 70 percent of the processor drying cycle to be fully dried. Both were satisfactory for more rapid processing.

However, only Element 6E exhibited a point $\gamma$ of $\geq$1.0 at a density of 1.0 and $\geq$2.0 at a density of 2.5. The sole difference between Elements 5C and 6E was the incorporation of a monodisperse tabular grain emulsion in the lower emulsion layers of Element 6E as compared to an otherwise comparable polydisperse tabular grain emulsion in the lower emulsion layers of Element 5C.

Thus, it has been demonstrated that combinations of monodisperse and polydisperse emulsions provide the desired point $\gamma$'s. By splitting the emulsions, so that they in part occupy a separate layer containing a crossover reducing dye, it is possible to combine very low crossover characteristics while retaining the desired point $\gamma$'s. This represents an impressive improvement over state-of-the-art radiographic elements.

## Claims

**1.** A radiographic element for medical diagnostic imaging comprised of

a transparent support and
first and second silver halide emulsion layer units coated on opposite sides of the film support,

CHARACTERIZED IN THAT the first and second emulsion layer units

together provide a point $\gamma$ of at least 1.0 at an image density of 1 and a point $\gamma$ of at least 2.0 at an image density of 2.5,
both contain a combination of tabular grain emulsions including,
as a first component, a polydisperse tabular grain silver halide emulsion portion exhibiting a coefficient of variation of grain diameter of greater than 30 percent and,
as a second component, a monodisperse tabular grain silver halide emulsion
accounting for from 20 to 50 percent of the combination of tabular grain emulsions, based on total silver,
having a mean grain diameter less than the mean grain diameter of the combination of tabular grain emulsions, and
exhibiting a coefficient of variation of grain diameter of less than 10 percent.

**2.** A radiographic element for medical diagnostic imaging according to claim 1 further characterized in that the tabular grains contain at least 50 mole percent bromide and from 0 to 4 mole percent iodide.

**3.** A radiographic element for medical diagnostic imaging according to claim 2 further characterized in that the tabular grains are chosen from among silver bromide and silver iodobromide tabular grains.

**4.** A radiographic element for medical diagnostic imaging according to any one of claims 1 to 3 further characterized in that the emulsions are spectrally sensitized.

**5.** A radiographic element for medical diagnostic imaging according to any one of claims 1 to 4 further characterized in that the monodisperse tabular grain emulsion accounts for from 25 to 40 percent of the combination of tabular grain emulsions, based on total silver.

**6.** A radiographic element for medical diagnostic imaging according to any one of claims 1 to 5 inclusive further characterized in that the first and second components are blended and the monodisperse tabular grain emulsion exhibits a mean grain diameter that is less than 75 percent the combined mean grain diameter of the emulsions blended.

**7.** A radiographic element for medical diagnostic imaging according to claim 6 further characterized in that the monodisperse tabular grain emulsion exhibits a mean diameter that is less than 60 percent the combined mean grain diameter of the emulsions blended.

**8.** A radiographic element for medical diagnostic imaging according to any one of claims 1 to 7 inclusive further characterized in that the emulsion layer units provide a point $\gamma$ of at least 2.0 at a image density of 1.5.

**9.** A radiographic element for medical diagnostic imaging according to any one of claims 1 to 8 inclusive further characterized in that the emulsion layer units together contain at least 15 mg/dm$^2$ total silver.

**10.** A radiographic element for medical diagnostic imaging according to any one of claims 1 to 9 further characterized in that the radiographic element contains less than 35 mg/dm$^2$ of total hydrophilic colloid on each side of the support and the hydrophilic colloid is fully forehardened.

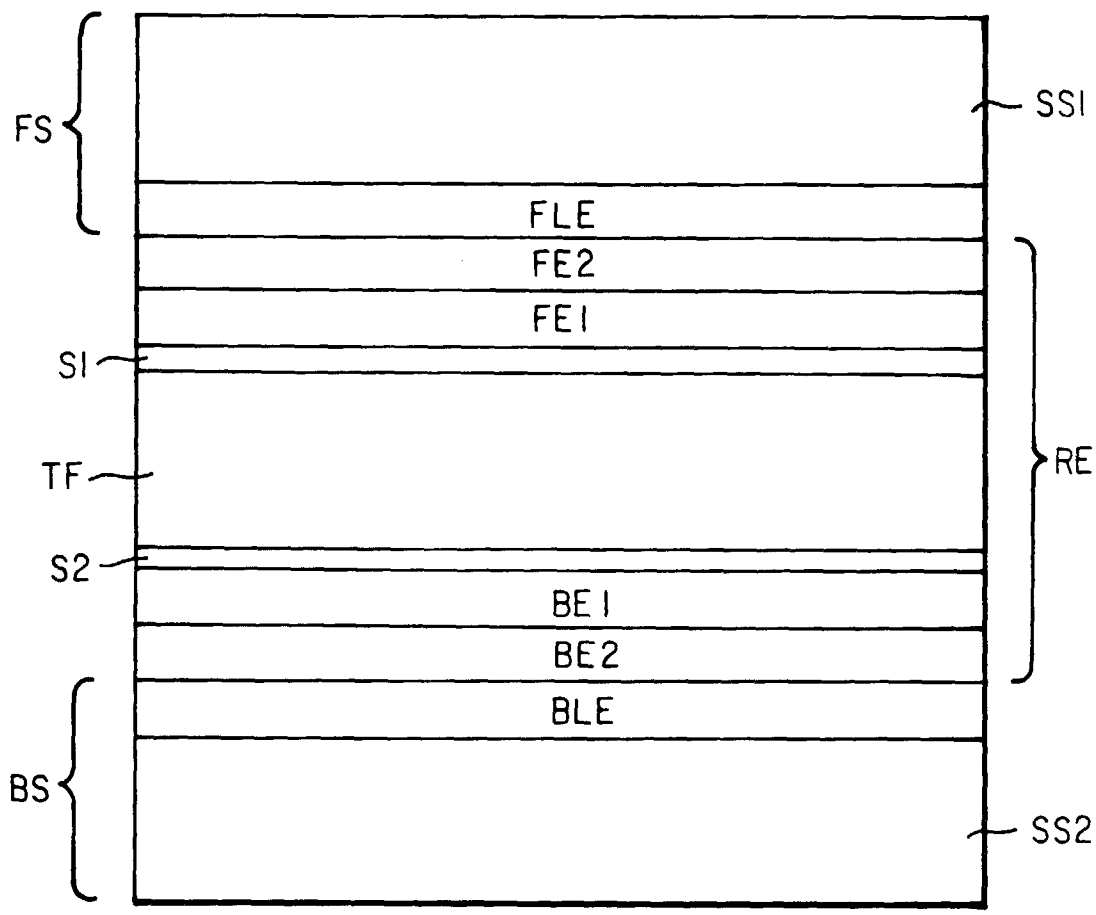


FIG. I

European Patent Office

# EUROPEAN SEARCH REPORT

Application Number
EP 96 42 0219

## 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.6) |
|---|---|---|---|
| Y | EP-A-0 661 592 (MINNESOTA MINING & MFG) 5 July 1995<br>* page 2, line 17 - line 25 *<br>* page 2, line 41 - line 44 *<br>* page 3, line 23 - line 39; figure 1 *<br>* page 4, line 20 - line 45 *<br>* page 5, line 5 - line 53; claims 1-18 *<br>--- | 1-10 | G03C5/16<br>G03C1/46 |
| P,Y | US-A-5 462 832 (IWASAKI NOBUYUKI) 31 October 1995<br>* column 7, line 15 - line 28; claim 1 *<br>* column 8, line 10 - line 40 * | 1-10 | |
| Y | & JP-A-07 028 203<br>--- | 1-10 | |
| Y | US-A-5 290 655 (IWASAKI NOBUYUKI) 1 March 1994<br>* Example 1, emulsions 1-5 *<br>** Table 2, samples 7,8,10 *<br>* column 1, line 55 - column 2, line 12 *<br>--- | 1-10 | |
| A | EP-A-0 518 066 (EASTMAN KODAK CO) 16 December 1992<br>* page 3, line 11 - line 34 *<br>--- | 1-10 | TECHNICAL FIELDS SEARCHED (Int.Cl.6)<br>G03C |
| A | EP-A-0 126 644 (KONISHIROKU PHOTO IND) 28 November 1984<br>* page 2, line 3 - page 3, line 28 *<br>* page 7, line 20 - page 8, line 13 *<br>* page 11, line 27 - page 12, line 1 *<br>--- | 1-10 | |
| A | DE-B-10 17 464 (DR. C. SCHLEUSSNER FOTOWERKE GMBH) 10 October 1957<br>* column 1, paragraph 3 - paragraph 4; figure 1 *<br>----- | 1-10 | |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| THE HAGUE | 29 October 1996 | Bolger, W |

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