

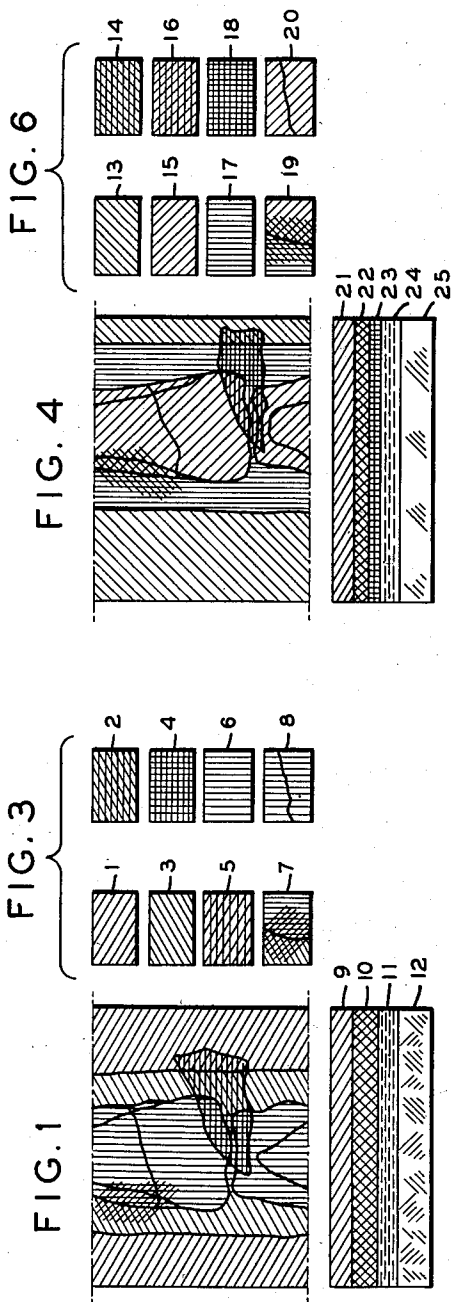
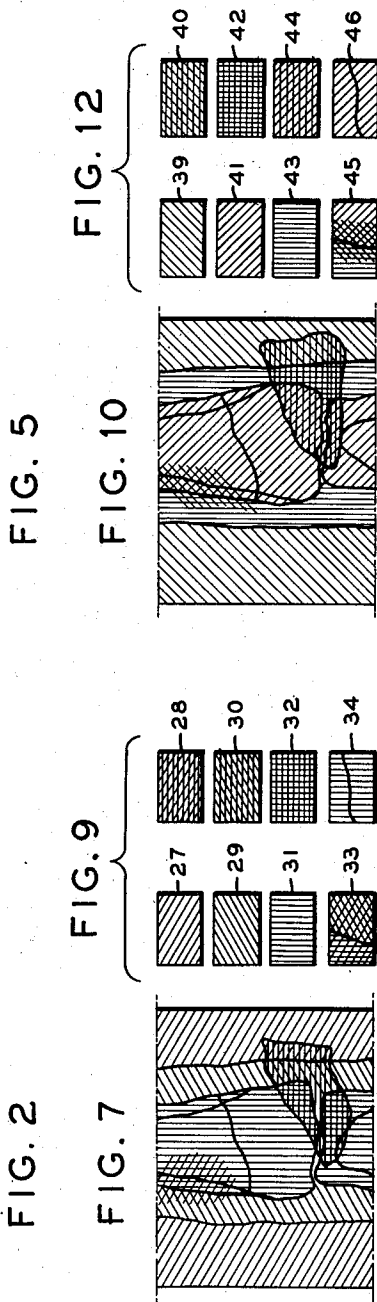
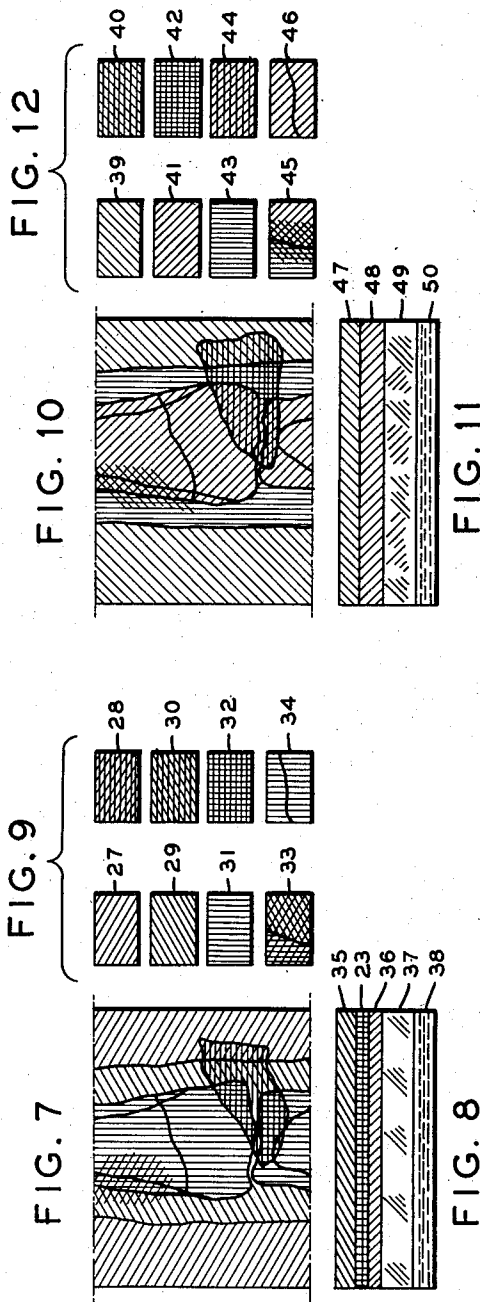
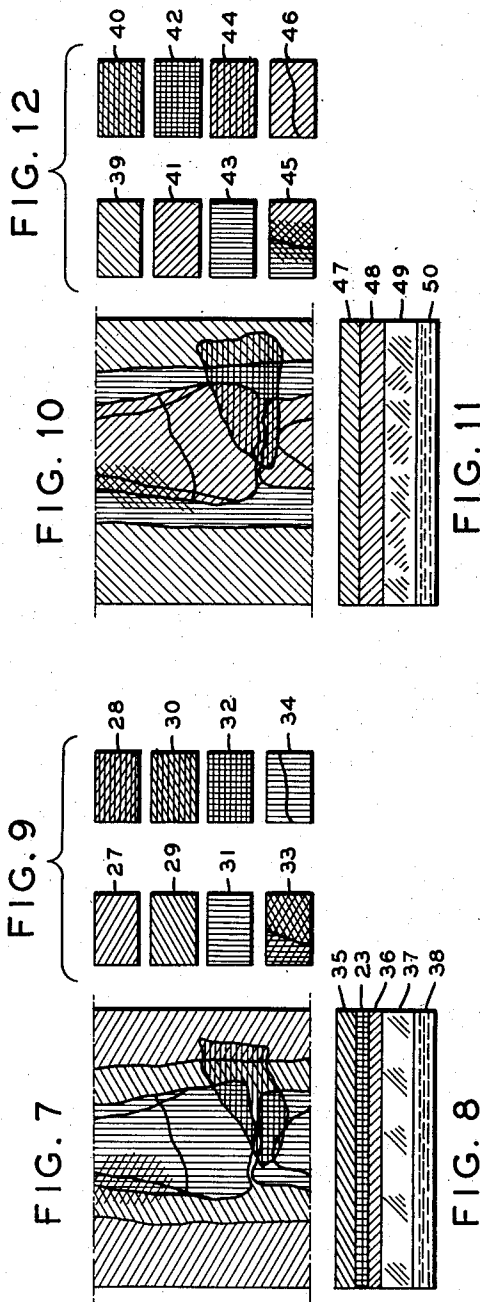
June 30, 1953

B. M. FINE
COLOR RADIOGRAPHY

2,644,096

Filed Feb. 25, 1948

2 Sheets-Sheet 1



INVENTOR
BERNARD M. FINE

BY *Sol Shapiro*
ATTORNEY

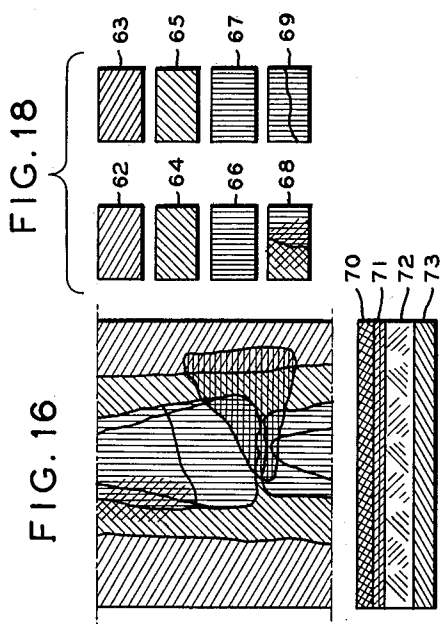
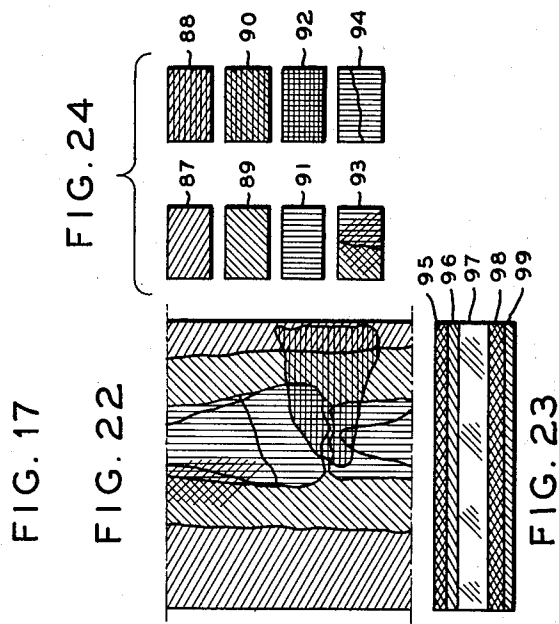
June 30, 1953

B. M. FINE
COLOR RADIOGRAPHY

2,644,096

Filed Feb. 25, 1948

2 Sheets-Sheet 2



INVENTOR
BERNARD M. FINE

BY

Sol Shappirio
ATTORNEY

UNITED STATES PATENT OFFICE

2,644,096

COLOR RADIOGRAPHY

Bernard M. Fine, Lynn, Mass., assignor to Radiograph Development Corporation, Washington, D. C., a corporation of Delaware

Application February 25, 1948, Serial No. 10,655

5 Claims. (Cl. 250—65)

1

This invention relates to multicolor radiography and is particularly concerned with the production of radiographs showing different color values, to instrumentalities enabling such multicolor radiographs to be produced, to the finished multicolor radiographs themselves, and to methods of producing such instrumentalities and their utilization.

Heretofore radiographs have been produced for use in both medicine and also industrially wherein the radiographs are produced in tones of black and white, as for example, by the utilization of films in which the image is the result of development of silver halide containing emulsions. Such radiographs in black and white suffer from a number of disadvantages. Frequently it is found particularly in the study of pathological conditions that there is no substantial registration of differences in structure being investigated in the resulting black and white radiograph which lack of difference may be due to a number of causes. A simple illustration is in the taking of radiographs of the human body in an attempt to locate or differentiate the presence of pieces, particles, or slivers of non-metallic glass. In many cases it is found that the ordinary radiograph produced in black and white shows no differentiation of such glass particles due to the fact that the image registered on the radiograph is of the same intensity or density or both with respect to such glass particles, etc., as portions of the body with which they are in contact. In other instances where such glass particles, etc., are covered or hidden by some body materials such as bone, the glass may be indistinguishable in such radiograph taken by ordinary means. In other cases the differences registered on the film between the glass and the bone for example, are so small as to make the glass indistinguishable. In other cases differences which should show up in such black and white radiographs, for example, in connection with bone pathology are so weak on the usual type of radiograph that they are not readily apparent and are frequently overlooked.

An attempt has been made to overcome some of these difficulties in prior art radiographs by the use of a tinted or colored film support or base as in Patent No. 1,973,886 to Scanlan and Holzwarth. While some improvement is obtained by the utilization of a tinted base in this way with the otherwise produced radiograph in black and white, the improvement is of minor character and does not extend to an elimination of the difficulties and disadvantages frequently experienced in such prior art radiographs, some of which have been referred to above.

Among the objects of the present invention is the production of multicolor radiographs in which the colors are in the range from violet to red of the visible spectrum, whereby due to the multicolor effects obtained, it is possible to differentiate structural differences by such radiographs which is not possible with the prior art types of

2

black and white radiographs with or without tinted bases or films.

Other objects of the invention include the application of the instrumentalities and procedures of color photography in the production of multicolor radiographs.

Still further objects include improved instrumentalities for the production of multicolor radiographs as well as improved modified and entirely new techniques in their production.

Still further objects and advantages of the present invention will appear from the more detailed description set forth below, it being understood, however, that such more detailed description is given by way of illustration and explanation only, and not by way of limitation, since various changes therein may be made by those skilled in the art without departing from the scope and spirit of the present invention.

In connection with that more detailed description, there is shown in the accompanying drawings, a series of illustrations of radiographs having multicolor values produced in accordance with the present invention, each illustration including a series of figures illustrating differences in effects obtained by differences in instrumentalities and techniques.

Figure 1 is a plan view of a developed color film after X-ray exposure;

Figure 2 is a section of the film of the preceding film, prior to exposure;

Figure 3 is a group of legends explanatory of the two immediately preceding figures;

Figure 4 is a plan view of a modified color film after X-ray exposure and development;

Figure 5 is a section of the film of the preceding figure, prior to exposure;

Figure 6 is a group of legends explanatory of the two immediately preceding figures;

Figure 7 is a plan view of a further modified color film after X-ray exposure and development;

Figure 8 is a section of the film of the preceding film prior to exposure;

Figure 9 is a group of legends explanatory of the two immediately preceding figures;

Figure 10 is a plan view of a further modified color film after X-ray exposure and development;

Figure 11 is a section of the film of the preceding film, prior to exposure;

Figure 12 is a group of legends explanatory of the two immediately preceding figures;

Figure 13 is a plan view of a further modified color film after X-ray exposure and development;

Figure 14 is a section of the film of the preceding film, prior to exposure;

Figure 15 is a group of legends explanatory of the two immediately preceding figures;

Figure 16 is a plan view of a further modified color film after X-ray exposure and development;

Figure 17 is a section of the film of the preceding film, prior to exposure;

Figure 18 is a group of legends explanatory of the two immediately preceding figures;

3

Figure 19 is a plan view of a further modified color film after X-ray exposure and development;

Figure 20 is a section of the film of the preceding film prior to exposure;

Figure 21 is a group of legends explanatory of the two immediately preceding figures;

Figure 22 is a plan view of a further modified color film after X-ray exposure and development;

Figure 23 is a section of the film of the preceding film, prior to exposure; and in

Figure 24 is a group of legends explanatory of the two immediately preceding figures.

In accordance with the present invention radiographs are obtained having a developed-color image, particularly multi-color radiographs are produced in which the colors fall in the range from violet to red of the visible spectrum. Thus the term color as used here is employed in its true sense differentiating from black, white and gray. The term color is, however, employed to include any variation in color value. Thus two or more colors may be present in the finished multi-color radiograph, which colors are either entirely different in character, that is fundamentally different colors which contrast with one another, or are variations in color values of the same or different colors, or are complementary colors or variations in complementary color values, or any combinations of such effects. The term color value will, therefore, be used herein to cover multicolor effects whether the colors are contrasting, complementary, or mere variations in shade or tone of the same color but sufficient to show the differentiation desired in the radiograph.

The radiant energy employed in producing radiographs in accordance with the present invention may be X-rays, gamma rays, or other portions or combinations of the electro-magnetic spectrum that are not visible to the human eye. The invention will be particularly illustrated by the use of X-rays and radiographs produced by X-rays are hereinafter denominated exographs while those produced by utilization of gamma rays will be referred to specifically as gammagraphs. As stated above, the invention will be particularly explained and illustrated below by the use of X-rays since the technique of making exographs is very well developed and any of the techniques and procedures employed in the prior art production of X-ray films of the black and white or black and gray type may be utilized in the present invention in the production of radiographs of multicolor character.

However, in accordance with the present invention, instead of using prior art types of X-ray films in the production of radiographs, the present invention utilizes plates, films, etc., in which a multicolor effect is obtained in the finished radiograph. Accordingly utilization may be made in the present invention of the instrumentalities, techniques and procedures of color photography applied, however, to the production of multicolor radiographs. In this connection it should be pointed out that in the present invention there is no attempt made to reproduce in color corresponding with the natural color of the object or material of which the radiograph is taken. What is sought is a radiograph showing structural differentiation of the article or material by means of color values which need have no relation whatsoever to the true or natural color of the object or material being "X-rayed," the color differentiation being employed entirely for the purpose of differentiating structural fea-

4

tures of the object or material of which the radiograph is taken. Consequently the present invention is not concerned with the techniques of color photography from the standpoint of reproducing in color the object or material of which the radiograph is taken, but employs the instrumentalities, techniques and procedures of color photography in the production of radiographs in multicolor effects. While, therefore, the techniques and procedures and instrumentalities of color photography may be readily employed in carrying out the present invention for the purposes in hand, it becomes possible because of the differentiation pointed out above, that is, because no attempt is made to reproduce in color the object or material of which the radiograph is taken, (although in some cases this may be done), to employ instrumentalities, techniques and procedures which result in a multicolor radiograph by simplification of such instrumentalities, techniques and procedures of normal color photography. This will be further explained and illustrated below.

Thus the method of the present invention includes exposure of a ray sensitive photographic film to non-visible radiant energy such as X-rays, gamma rays, etc., and the production from such ray exposed film of a multicolor radiograph, the colors being those in the range from violet to red of the visible spectrum. In utilizing the present invention, one of the simplest procedures at present available with materials and instrumentalities that may be immediately purchased on the market, is the utilization of any of the so-called color films now available as commercial products including for example, "Kodachrome," "Kodacolor," "Ektachrome," "Ansco Color," "Agfacolor," "Agfa Printon," "Dufay," "Gaspar," color films, etc., as well as the utilization of silver-dye-bleach processes, etc. Any of these commercial color films available on the market may be utilized in accordance with the present invention, a portion of such color film being cut to the size desired and placed in a cassette or other protective casing which casing is impervious to visible radiant energy but permits X-rays, gamma rays, or other portions of the non-visible electro-magnetic spectrum to penetrate and affect the emulsion. The film may thus be put up in the same form as present X-ray films are available employing for example, a cardboard or Bakelite and metal, or plastic cassette or casing but in which the film includes color producing elements in the emulsion or is available for development of multicolor effects in the emulsion by color photographic methods. Such cassettes in which commercial color film now available on the market can be placed, may then be utilized in lieu of the black and white type films employed for the production of radiographs but employing the techniques and procedures of making such radiographs as are heretofore employed in the prior art. After exposure for example, to X-rays by such usual radiograph technique, the exposed films may then be subjected to color development.

While the above materials and procedures make it possible to utilize the present invention effectively in the production of multicolor radiographs by the employment of instrumentalities, techniques and procedures readily available in the art, it should again be noted that because the present invention is not concerned with the reproduction of the colors of the object or ma-

terial of which the radiograph is taken, but is concerned with the production of multicolor values in radiographs to illustrate and differentiate structural features of the object or material, there is no limitation on either the materials, instrumentalities, techniques or procedures employed in the present invention which are restrictions on the reproduction of natural color photographs. As a result it becomes possible to simplify the instrumentalities, the techniques and the procedures, enormously, since all that is necessary is to produce a radiograph in which there are differentiation in color values resultant from differences in structure in the object or material of which the radiograph is taken. Thus instead of employing a film which utilizes three color layers or three layers each of which develops its particular color effect so that by either addition or subtraction, natural color effect is produced, it becomes possible in accordance with the present invention to use two layers which produce a differentiated color value in the ultimate radiograph without concern as to reproduction of the color of any portion of the object or material of which the radiograph is taken. It is only necessary that it be possible in the radiograph to produce a multicolor effect in which there is color value differentiation in accordance with structural differences in the article or material "X-rayed." In the same way the techniques and procedures for the development of the color in the radiograph may be enormously simplified from those required in the production of natural color photographs. Even in connection with the commercially available color films that may be employed as explained above, the development procedures utilized in the production of multi-color radiographs from the exposed film, need not be the complex development procedures required in natural color photography, but the development procedures may be reduced materially both with respect to the solution treatments involved as well as the time element and steps employed since again it is only necessary to point out that the radiograph produced in accordance with the present invention requires merely that there be color value differentiation in such radiograph in accordance with structural detail of the object or objects or material or materials being viewed.

To illustrate various features of the invention, the examples given below will first refer to the utilization of commercially available color films and the results obtained with them. Radiographs produced from such commercially available color films in accordance with the present invention have demonstrated beyond any question that such films may be used for making X-ray photographs, radiographs, etc., in which two or more color values are present to differentiate structural features. The results so obtained are far superior to those obtained with prior art types of X-ray black and white films now on the market and in use for radiographic purposes including such films which carry a tinted base. The differentiation is so marked that in some cases at least diagnosis may be made with the multicolor radiograph which is not possible with the prior art X-ray black and white radiographs. In all of these following examples, the commercially available color film was utilized by being cut to the required size and enclosed in a cardboard cassette to protect it from visible light but in which cassette the film was available for radiographic purposes.

A. Ansco color film (daylight type) was exposed in a cardboard cassette using a human hand as the object. Exposures were made at varying time intervals of from one second to 12 seconds using 65 kilovolts and 10 milliamperes. The resulting radiograph appeared in browns and yellows of such sharp contrast and such clear detail that the resultant radiograph was far superior to any of the black and white films now on the market. Exposure at one second was not considered satisfactory because it was not sufficiently clear and was rather weak in detail. Exposure at 12 seconds gave a slightly fogged effect due to over-exposure. The intermediate exposures from 2 to 11 seconds were well balanced in various intensities and gave easily readable radiographs. It may be noted that the longer exposure showed greater detail in the bone while the shorter exposures showed better detail in flesh. The results set forth above were obtained without the use of any fluorescent screen during exposure to the X-rays. (Ansco color film, tungsten type, produces slightly different color values but with favorable results.)

Utilizing a fluorescent screen commonly employed in making X-ray radiographs it was found that the color values in the film changed radically. Thus using the standard X-ray fluorescent screen with an exposure of 3 seconds under the conditions otherwise set forth above, it was found that the color results obtained on the film were in blue and red and magenta. The results showed even more striking contrast to that obtained without the use of the fluorescent screen.

With respect to the use of "Printon" it should be noted that this product uses a semi-opaque base. For some purposes this does not give the best radiographic results while in other instances in certain types of radiology, it will give superior results. For example, in X-ray radiographs of the full body where certain pathological conditions are being considered, "Printon" will be considered superior by the physician for some purposes.

In this example as in the following examples, the conditions of exposure involved the use of 65 kilovolts and 10 milliamperes for the time specified. However, both the kilovoltage and milliamperage may be varied. It was found that change in the kilovoltage alone maintaining the constant of 10 milliamperes varied the colors slightly, while a variance in both kilovoltage and milliamperage gave marked changes in color values. Voltage as high as 100 kilovolts and amperage of 30 milliamperes may be used and even higher values, but it is unlikely that body radiology will require such high effect. In some cases in commercial and industrial work such higher ranges may be desirable. Variation in kilovoltage and milliamperage may also be employed in connection with material reduction in exposure time, and for example, using 75 kilovolts and 15 milliamperes it was found that the exposure time could be cut in half as compared with exposures employed under the conditions set forth in the examples. This is important where it may be necessary to maintain a minimum of exposure with certain patients. Variations in these factors including variation in kilovoltage, milliamperage, and exposure time will frequently result in substantial variation in the color values which result.

B. In this case "Kodak Ektachrome" film was employed in a cardboard cassette and results substantially the same as those obtained with Ansco color film set forth above were obtained. The Ektachrome film was exposed to X-ray without the use of a fluorescent screen and at 3 seconds for example, gave excellent results. At 2 seconds with the use of a fluorescent screen, it also gave excellent results comparable to those described above for "Ansco Color" film, (day-light type), in Example A. The Ektachrome film was developed by using a standard Ektachrome kit available on the market and is quite similar to the Ansco development technique.

To exemplify the differentiation of the present invention from attempts to reproduce color films or photographs of the usual type, it may be noted that it was found that the time in the development baths could be shortened to about one-half of the maximum that is recommended in the procedures utilizing the Ektachrome development outfit, however, it should be noted that changes in developing time will also vary the colors and color values and contrast.

Other commercially available color films such as "Kodachrome," "Kodacolor," "Gaspar" color, "Dufay" color, may also be used in accordance with the present invention in the production of color radiographs.

The drawing illustrates results obtained in color radiography producing exographs in multicolor effects. Each figure in each illustration represents a radiograph of a finger showing a glass intrusion and an infection. Each figure represents the final result in the developed and finished color radiograph while below each figure is given a cross-section through the film illustrating the film before exposure. Also accompanying each figure is a series of legends identifying particular layers, images and color values in the respective figures.

Referring to Figures 1-3 of the drawing, this group of figures shows the utilization of three color emulsions in the film. Referring particularly to Figure 2, the film before exposure is shown in cross-section illustrating an upper emulsion 9 which will develop to a blue-green or cyan. The intermediate emulsion 10 will develop to a magenta while the innermost emulsion 11 will be one that develops to a yellow.

The film base 12 is clear and colorless in this particular instance.

As illustrated in Figure 1, after exposure and development with reversal in development, exposure being of the character set forth above in the examples describing the use of color film in the production of color radiographs and as identified in Figure 3, the background 1 where no finger bone is shown, is a yellow. The glass 2 in the flesh portion, due to the resultant emulsion referred to above, shows a color tan. The flesh 3 appears also as a tan color but different

in value, being lighter, from that of the tan color showing the glass, the latter being much more emphasized. In this particular instance the flesh appears as a substantially lighter tan at 3 than that of the glass in the flesh at 2. The glass appearing through the bone is shown at 4 and may be described as a half-tone or full tone of brown, darker or slightly darker than the bone itself at 6. The glass by itself in the background is shown at 5 and will appear as a tan color value against the yellow. That is, it is separated from the background yellow by a slight tint of brown making it a tan. At 6 the outline of the bone will appear brown. An infection 7 between the flesh and the bone which appears as a lighter brown area showing a slightly different color in the bone due to the fact that the film used in this instance is a reversible film and the area at this point has been reversed, 7 showing also a slightly different color value in the flesh where the flesh is tan. A break 8 in the bone appears against the brown of the bone in a light tan color value making a clear definition of the break with the contrast of the almost yellow light tan to a dark brown.

Referring to Figures 4 to 6 of the drawing, this represents the standard color films now on the market having multi-emulsion layers for each color. The film as shown in cross-section in Figure 5 before exposure illustrates emulsions 21, 22 and 24 as now used on any standard color film, for example "Ansco" or "Kodak," while 23 is a masking layer to add density to the film. The film base 25 in this instance is clear and colorless. The resultant radiograph after exposure to X-rays and development is as follows. As shown in Figure 4 with accompanying legend in Figure 6, the background 13 appears bright yellow, the bone 15 as dark brown, the flesh at 17 as tan, and the area of infection 19 appears in the bone as a lighter brown and in the flesh as a lighter tan. This is due to the fact that the infection has broken down the structure of the cells and permits greater passage of the rays. Reversing the film would result in this area appearing lighter. The glass is shown at 14 and appears as a tan color value against the background of yellow. At 16 the glass appears against the bone as a darker brown than the brown of the bone shown at 15. At 18 the glass within the flesh is shown as a darker tan almost brown than the color of the flesh at 17. The break 20 in the bone appears as a tan line defining the break very clearly against the brown of the bone. The masking layer 23 adds density to the color values, permitting even greater contrast in light transmission by some added limitation of the light used for viewing the film.

The use of certain types of fluorescent intensifying screens for the exposures and emulsions shown in Figures 1 and 4 would change the resultant color values to those listed below.

Description	Figure 1	Figure 4	Color Value
background.....	(section) 1....	(section) 13....	blue.
flesh.....	(section) 3....	(section) 17....	(against background) light magenta.
glass against background.....	(section) 5....	(section) 14....	Do.
glass against flesh.....	(section) 2....	(section) 18....	magenta.
bone.....	(section) 6....	(section) 15....	dark red with slight tinge of magenta.
glass against bone.....	(section) 4....	(section) 16....	darker red.
break against bone.....	(section) 8....	(section) 20....	(bone is red) light magenta.
infection against bone.....	(section) 7....	(section) 19....	Do.
infection against flesh.....	do.....	do.....	(flesh is light magenta) lighter magenta with tinge of blue or violet.

Variation of the fluorescent elements in the screen may vary the resultant colors produced with the use of the fluorescent intensifying screen in dependence upon the fluorescent color values when excited by non-visible radiant energy such as X-rays or gamma rays. The image may be formed merely by the fluorescence of such screens or by the combination of fluorescence and the X-rays or gamma rays, or both, for example. The relative density of the different colors and color values is the same as set forth for Figures 1 and 2, preceding.

Referring to Figures 7 to 9, these are similar to Figures 4-6 except that one of the emulsions has been placed on the back of the film to speed up development. Thus the emulsion layers in Figure 8, 35, 36 and 38 correspond respectively with layers 21, 22 and 24 in Figure 5, the base is shown at 37 as a clear colorless base and a masking layer 23 is shown between emulsion layers 35 and 36. In this case exposure to X-rays was carried out using a fluorescent intensifying screen and somewhat similar results obtained as those set forth above in Figure 4. The background 27 in this instance appears as a dark blue, the flesh 29 as magenta, the bone 31 as dark red with a very slight tint of magenta. The glass 28 against the background of plain blue is slightly magenta. The glass 30 against the background of the flesh is a magenta. The glass 32 in the bone area appears almost an actual darker red against the magentish-red of the bone 31. The differentiation is in tones of color. The break at 34 appears as a light magenta against the dark red of the bone. The area of infection 33 in the flesh and the bone appears in the flesh as a somewhat lighter magenta with a tinge of blue than the light magenta of the flesh while in the bone it appears as a brighter or darker red than that of the bone per se.

In Figures 10-12 a film is used which omits the masking layer and has been exposed to X-rays without the use of a fluorescent screen. Here as shown in Figure 11, the emulsion layers 47, 48 and 50 correspond respectively with layers 9, 10, and 11 of the film used in Figure 1, the base 49 corresponding with base 12 in Figure 1. The results obtained on exposure without a fluorescent screen illustrated in Figure 10 and the legends of Figure 12 are comparable with those obtained using the film of Figure 1 as explained above except that since the masking layer has been omitted, the density of color is not as great, but the color values obtained and indicated by the legends 39 to 46 inclusive are the same color values as obtained at comparable points or areas in Figure 1 shown there in Figure 3 by the legends 1 to 8 inclusive and explained above.

It has been pointed out above that the present invention is not concerned with the reproduction of the true colors of the object or material being viewed but instead is concerned with the use of color to accentuate structural differentiation in the article or material being X-rayed. Consequently in carrying out the present invention it is not necessary to use composite emulsions which will result in natural color effects. And accordingly it becomes possible in the present invention to use very much more simplified films in the production of color radiographs. This is illustrated in Figures 13 to 24. As shown in Figure 14, a two emulsion film is used with a colorless base. The base 60 carries emulsions 59 and 61 which develop to yellow and blue respectively. On exposure and development, there

is obtained the radiograph illustrated in Figure 13 and corresponding legends of Figure 15 where the background 51 is bright green. For preferred purposes, one of the colors 59 or 61 should be stronger than the other. Thus if the yellow is the brighter, the background 51 will be bluish-green or greenish-blue. The flesh at 53 appears as a yellowish-green, the bone at 55 appears rather yellowish with a slight tint of green. The glass at 52 against the green background 51 appears as a brighter green; the glass 54 in the flesh portion appears as approximately the same shade as the bone against the flesh; while the glass in the bone at 56 appears as a yellow with a slight tinge of green. The break at 58 appears as a yellowish-green against the yellow of the bone 55. The infection area 57 appears as a brighter yellowish-green in the bone area and as a brighter green color value against the yellowish-green of the flesh in the flesh area.

In Figures 16 to 18, a film similar to that of Figure 14 was employed in that in Figure 17 the emulsion layers 70 and 73 correspond with emulsion layers 59 and 61 of Figure 14 and the base 72 of Figure 17 corresponds with the base 60 of Figure 14 but in Figure 17 a masking layer 71 has been included with the result that the additional silver gives added depth and density to the colors. The legends 62 to 69 inclusive of Figure 18 correspond respectively with legends 51 to 58 of Figure 15.

In Figures 19 to 21, a film is used which contains intermingled in its color layers elements of any of the numerous standard X-ray films now available thus as shown in Figure 20, 82 and 83, being identical with 86 are multiple layers of any standard X-ray emulsion containing also elements to form the color values of yellow, 85 is a masking layer that would be retained after the film is reversed. The base 84 is blue-green or cyan that is not too dense or dark, and in proper depth to emphasize the yellow. Thus the finished film as shown in Figure 19 with the legends of Figure 21, would show values of blue-green or cyan for the background 74, 75, the glass against the background would be green, and the flesh 76 against the background would also be green, while the glass against the flesh 77 would have a color value of light green; the bone 78 would be a pale green almost yellow, while the glass against the bone 79 would be yellow with a very slight touch of green; the break 81 would appear as green against the yellowish-pale green of the bone. The infection in the bone 80 would show as light green against the yellowish-pale green of the bone, while the infection in the flesh 80 would show as a green against light green of the flesh.

Figure 22 is a cross-section through film that has color value elements intermingled in the layers of any standard X-ray film or emulsion now available. 95 and 98 are identical, having incorporated in them the elements to form the color medium dark magenta, 96 and 99 are identical having incorporated in smaller quantity in them the elements to form the color yellow. The base of this film 97 is also yellow in color. This film is not reversible. Thus as shown in Figure 22 with legends of Figure 24, the bone 91 would appear as yellow with a very slight tint of red. The infection in the bone 93 would appear as a red color value against the yellow of the bone, while the glass against the bone 92 would appear as a brighter yellow with almost no red in it.

The flesh 89 would appear as a red with a slight tint of yellow, while the background 87 would appear as bright red. The glass against the background would appear as a lighter red with a slight tint of yellow against the background of red. The infection against the flesh would appear as red against the lighter red with a slight tint of yellow. The break in the bone 94 would appear as red with a little yellow against the yellow with a slight tint of red. Thus the contrasting color values ranging from yellow to red would appear.

In connection with any of the illustrated films shown above it should be pointed out that the emulsions employed can be of any type utilized in color photography including dye coupling, developer, diazo, etc., or they may have incorporated therein an inherent dye which appear upon development, or in conjunction with any X-ray film or X-ray film emulsion elements. Since no actual filtration of visible color is necessary, and therefore, no color filter layers of the type used with light are necessary, the order in which the emulsions are placed upon the base need be considered only in the light of the type of developer to be used. Thus the type of developer may be that which will attack the first emulsion first, and the succeeding emulsions may be developed in order.

The above examples and illustrations are intended to exemplify the instrumentalities, techniques, and methods that may be utilized in carrying out the present invention but illustrate but a few of the various ways in which the results of the present invention may be accomplished. Thus the colors and color combinations in the examples and illustrations given above may be varied in any desired way and any combination of color values employed. If desired the radiographs containing color developed images may also be subjected to further toning operations but this is not necessary and would not be carried out unless special effects are sought.

The results obtained in accordance with the present invention by the utilization of X-rays, gamma rays, or other non-visible rays of the electro-magnetic spectrum, are markedly different from those obtained by the use of visible rays in photography. The X-rays, etc., have an effect which is quite different from that of visible light. The results obtained by exposure to X-rays or similar form of radiant energy differentiate themselves from the effects of visible light in that X-rays and related rays produce effects which vary dependent on such factors as differences in atomic weights, differences in molecular structure, and differences in thickness of layers, as well as other phenomena associated with the use of radiant energy such as X-rays, etc. The energy transmitted by two different substances of different atomic weights, or of different molecular structure, or of different thicknesses, will vary and produce differences in effect, therefore, in radiographs produced in accordance with the present invention. Thus given two substances of different atomic weights or molecular structures but each having the same absorptive qualities of a given source of radiant energy such as X-rays, so that the transmitted energy will have the same intensity after passing through each substance or after being transmitted by said substance, the resultant energy after being so transmitted by each substance of different atomic weight or molecular structure while having the same intensity will

show differences in wave length or in the quanta of which the particular energy consists which cause differentiation in the color values obtained in accordance with the present invention. Thus a change in wave length of the energy or a filtration of wave length by substances of different molecular structure or atomic weight is detectable with the use of color values; and even where such different substances transmit wave lengths of energy that are difficult to separate, changes in the quanta of the energy will take place that permit the differentiation by or with the use of color. In the event that a change in both wave length and quanta takes place, the results will also be separable by or with the use of color. So that even where the transmitted energy has the same intensity, a differentiation is obtainable; however, where the intensity of the transmitted energy varies also the contrast will be even greater. In instances where substances cannot be distinguished on prior art types of radiographic films, they can be distinguished on radiographs produced in accordance with the present invention. Thus where radiographs were taken to differentiate pieces, particles and slivers of non-metallic glass, by the use of differences in color values developed in accordance with the present invention, where the glass was indistinguishable or hardly detectable in prior art types of radiographs, the color values brought out and differentiated the glass, as for example, from the bone. Thus the differences in wave lengths, or quanta, or intensity can be differentiated in various manners, the type of differentiation desired or required being dependent upon the molecular or atomic structure of the films and emulsions or the solutions and baths being used to bring out the differentiation, all of which result in variance or change in the energy which is detectable on the color radiographs.

Striking results are obtained in cases where there is little differentiation in prior art radiographs. In for example, bone pathology that is weak on ordinary or tinted films of the prior art, a very clear differentiation is obtained on the radiographs produced in accordance with the present invention since the differences become clearly defined in color values or differences in color. In accordance with the present invention, therefore, it is preferred to use at least two colors in the emulsions as illustrated in Figure 14 above but various combinations may be employed, as for example, where a tinted base is employed together with a single emulsion producing a developed color or where two sensitive emulsions are employed, one of which produces the black and whites or grays of the silver developed type whereas the other produces a color developed image.

Variations in the results obtained result from modifications of the instrumentalities, techniques, and procedures employed in carrying out the present invention. Since we are dealing here with the effects produced by X-rays or similar radiant energy, it is possible to vary the effect obtained not alone by variation in the emulsion or development procedure, but also by modification of the energy which is transmitted to the film depending for example, on fluorescent screens, filters, etc., and the nature of such screens and filters. As has been indicated above, fluorescent intensifying screens may produce a marked difference in the color values obtained. Further, the films, film emulsions, and film supports may have added to them individual-

ly or in any combination, fluorescent substances or radio-active substances that produce a modification of the color effect obtained. Or a radiolucent substance or paste containing a percentage as desired of radio-opaque or radiolucent substance or substances may be employed to modify the results obtained. Variation in the color values may also be secured by varying the atomic weights of the substances used in preparing or manufacturing the film supports, film emulsions, or adhesives, or coatings employed in preparing such films; or such substances of variable atomic weights may be used to vary the intensity of the radiant energy to obtain a variable in the color values. Substances of different atomic weights may be placed between the film emulsions, or the emulsion and the supports, or on the surfaces of the completed film, or be used as a separate filter element in conjunction with any of the other variations set forth above.

While multicolor radiographs have been particularly emphasized above, the present invention may be employed in combination with the usual gray type or normal silver type emulsions. Further, such gray type, black type, silver type, or silver halide type emulsions may be colorless or may have added or inherent in it a color, colorer, or a coloring agent, or a chemical agent to form color by immersion in solution or by chemical coupling or by the absorption of dyes. Such gray type, black type, or silver type, or silver halide emulsions may be used in combination with color elements or color layers.

The type of cassette or film holder employed has an effect on the transmission values of the energy and variation in the results obtained may be effected by variation in the nature and character of the cassette or film holder applying the principles referred to above.

The instrumentalities themselves including the cassettes, color films, plates, etc., may be those which are available in the art or they may be materially modified from prior art practices. Thus the type of supports employed may be glass or plastic and any type of plastic ordinarily employed as the base support for films or emulsions or coatings may be utilized in this connection, particularly the cellulose esters and cellulose ethers including for example, cellulose acetate, cellulose nitrate, combinations thereof, etc., or the plastic may be of the type known as "Dyrite," or "Vinylite" or other vinyl plastics, polyethylene, etc. Single or laminated sheets of the support whether glass or plastic may be employed and the techniques in laminating the plastic sheets such as cellulose acetate or cellulose nitrate either in combination with each other or with other plastics such as "Dyrite" or "Vinylite" may be employed.

While in the past it has been the objective of film manufacturers to eliminate any foginess effect which gives a veiled appearance in the finished negative, under some circumstances at least the effect of foginess or of a veil has some advantages in connection with radiography so that this effect may actually be sought by specially treating the surfaces of the base to be coated or in any other way. Such special treatment may consist of for example, graining the surfaces, etching the surfaces, or creating a simulated etched or grained effect on the surface of the material to be used or within the material or substance used as by employing chemical compounds or substances, or materials or substances may be applied to the surface of the sheets of

materials. The support may have its surface finely grooved either with parallel lines or lines which are at angles to each other or combinations of lines and angles as desired or the support surfaces may be lenticulated. To the extent that such surfaces are modified in this way, they may serve to secure better adhesion of coatings or emulsions applied thereto in addition to creating the foginess or screened or veiled effect.

The color values produced in the radiograph in accordance with the present invention have an objective to supply additional detail and contrast. The color may, therefore, be of such type that it will not materially decrease the transmission of light in the process of viewing the finished product or it may be of the type that will be translucent and provide a definite limitation in the light transmission which is effected or it may provide the effect of subdued contrast so that faint tones and colorations will be visible. Or an impression of glowing or fluorescence may be produced. The dyes or coloring matter may be added directly to or included within the base material itself or may be included with the cement or substance used in the production of laminated supports or a sheet of colored or coated substances may be inserted between the materials when laminated, or the materials used as film supports or film bases can be treated or coated with a dye or coloring or colored colloidal substance. For example, the support may be tinted by application of a dye in solution thereto. For example, a dye solution consisting of approximately 8 to 9 grams of basic pure blue E and approximately 9 to 10 grams of fuchsine dissolved in approximately 90 to 110 pounds of a solvent such as acetone, Cellosolve, and ethyl alcohol, or any mixture thereof, and which may be evenly applied to the film as by immersion. The quantity of dye supplied to the film or film base or support or lamination may range from approximately 2 to 5 grams of basic pure blue E and approximately $\frac{1}{10}$ to $\frac{1}{5}$ gram of fuchsine per one thousand square feet of film or supporting surface or lamination surface. The solution or solutions may be varied with the intensity desired to set up the light limitation or color contrast for the type of emulsion being used.

While basic pure blue E and fuchsine have been specifically referred to above, to illustrate the invention, various other dyes may be used including for example, Congo red, alizarin, eosin, basic pure blue E, methyl violet, butter yellow, indigo, acid violet, acrinol blue, Victoria blue, rose bengal, amido naphthol red, alizarine red, tartrazine, fluorescein, cobalt chromate, naphthol green, filter blue green, aniline green naphthol B, cupric chloride, resorcin blue, ethyl violet, gentian violet, iodine, xylene red, fuchsine, Victoria blue BX, acid fast violet, hematoxyline, acid rosolic (pure), aniline yellow phosphene, orange B naphthol, martius gelp, brilliant green, malachite green, neptune green, aniline blue methyl, dianil blue, magenta, rasazeine, rhodamine, and uranine.

These dyes may be used in any combination to produce any colored effect desired in order to obtain contrast with the color in the emulsion of the film. It may be pointed out that the base or support may be left clear or without any added dye or tint and coated instead with a photosensitive dye or emulsion that will produce the color contrast by reaction from exposure or development. Another means for producing col-

ored base for additional contrast is to use a base or film support that has a permanent tint or color added to or in it and then using a similar photo-sensitive coloring or tint in the emulsion or emulsions to produce the effect of increased color density or tint density, but it is noted that this is a permanent tinting effect and is to be distinguished from the development of a color image in an emulsion.

A laminated film base or laminated film support may desirably be produced to provide greater strength, absence of curling, less shrinkage or expansion during processing, and less temperature coefficient of change than is experienced with prior art types of films and supports, making such laminated bases or supports particularly valuable in the production of films for scientific and engineering studies such as in radiology, areophotography, photomicroscopy, and other photogrammetric work, etc.

As an example of the production of a laminated film, the following is given. A sheet of cellulose acetate-butyrate about $\frac{1}{16}$ to $\frac{1}{8}$ of a millimeter thick, and 2 sheets of polymerized vinyl chloride-acetate approximately $\frac{1}{16}$ to $\frac{1}{8}$ of a millimeter thick are taken and the cellulose ester sheet cemented between the vinyl polymer sheets, the latter being either plasticized or unplasticized as desired. The cementing of the layers together may be carried out by heat and pressure or by pressure alone or by the use of an ester or ketone solvent including for example, methyl acetate, ethyl acetate, ethyl lactate, acetone, methyl ethyl ketone, etc. The stated solvents may be used by themselves to cement the plastic sheets together or such solvents may carry from 2 to 10% of the polymer of the stated plastics to form a solution containing 4 to 20% by volume of the plastic solids in solution in the stated solvents and used as a solvent cement, the amount of solids in such cement being variable depending on the consistency desired. If a permanently colored base is to be produced, any of the dyes or coloring matters referred to above may be utilized to color one or more of the laminated layers or a fluorescent material may be incorporated within such layers including for example, such fluorescent materials as uranine (fluorescein), yangonin, etc.

While cellulose acetate, butyrate, and the vinyl chloride acetate polymer has been mentioned specifically, other plastics may be employed as indicated including the methacrylates such as methyl methacrylate, etc.

The surfaces of the laminations may be grained or lenticulated or treated as set forth above to produce greater adhesion between the layers, or an effect on the diffusion or diffraction of the light, or both.

It should be pointed out that when the action in the film is caused directly by the radiant energy such as X-rays, it is due to the action of the radiant energy on the emulsion or emulsions that contain in or that can have added to them a dye or dye coupler or other material that will supply the color desired in the finished or developed unit. While visible light may be used during the process of development or finishing of the radiographs produced in accordance with the present invention, such use of visible light subsequent to the exposure which in accordance with the present invention is made by X-rays or other non-visible portions of the electro-magnetic spectrum, is not to be treated as forming a part of the exposure operation. The use

of visible light in this way during the process of development or finishing the radiograph, as for example, in connection with reversal or partial reversal of the image is quite distinct from the production of the image by the use of visible light. In the present invention the visible light is used not to create the initial or original image and is used only for chemical or secondary effect only nor is such use of visible light necessary in any of the developing processes unless special effects are sought.

Any of the X-ray films now available may have incorporated in them color elements to form images of more than one color value or tone, or any of the color films or film containing color elements can have added to them elements of any X-ray emulsion to make them more suitable for radiography producing radiographs containing more than one color value or tone.

As indicated above, any radiographic film or plate can be used modified as set forth above in accordance with the present invention. The usual type of radiographic film consists of a radio-sensitive emulsion produced from a colloidal suspension of one of the silver halides such as silver chloride, silver bromide or silver iodide. For example, such emulsions may be obtained by mixing a gelatinous solution of silver nitrate with potassium bromide (in the absence of light), silver bromide being produced by interreaction. The resulting milky emulsion is cooled to gel and the latter washed with water to remove soluble salts. It is then melted at a gentle heat and applied uniformly on both sides of the base material such as a sheet of cellulose acetate. When dry each layer of the emulsion should measure preferably about 25 microns in thickness but this is variable. Sensitivity of X-ray films may be increased by a small quantity of a sensitizer such as uranine, eosin, erythrosin, quinoline red, rhodamine, etc., incorporated into the soluble bromide emulsion. Other types of sensitizers that may be incorporated include cyanine, methyl violet, nigrosine, di-cyanin, neocyanine, etc. The latter influences speed of blackening which is obtained.

It may be stated that X-rays of different frequencies and this is true of other portions of the non-visible electro-magnetic spectrum do not have an equal quantitative effect and while shorter wave lengths are desirably used for penetration of deep or thick parts of the body or for metallographic work, the shorter or soft rays produce the greatest blackening. Greater density can be obtained by increasing the thickness of the layer of sensitive silver salts or alternatively, the silver halide content of the emulsion. Or a multiplicity of layers of the silver salt containing sensitive emulsion may be applied on one or both sides of the base. The silver halides like silver bromide are the preferred sensitive salt commonly used but other heavy metal salts such as silver tungstate or salts of heavy metals themselves having a high molecular weight may be used in the sensitive layers for absorption of a greater amount of the radiation.

Introduction of intensifying screens is desirably employed such as a piece of cardboard or Celluloid coated with a layer of artificial scheelite (calcium tungstate) which grows a brilliant blue to bluish-white under the influence of X-rays and materially intensifies the effect obtained. Other types of screens may similarly be employed in accordance with the usual X-ray technique. And intensifying screens may be used on both sides

where the emulsion is placed on both sides. But as noted above, intensifying screens do not have to be employed. Where screens are employed, X-ray film may be used inside the sandwich of intensifying screens where the film carries a double coating.

Any of the X-ray films as set forth above may be employed for the purposes of the present invention by incorporating the materials which will develop color either into any of the sensitive layers containing the silver halide salts, or by supplying separate layers which will develop color in addition to the silver salt layers. The technique of natural color photography may be used in modifying the X-ray films for this purpose for use in accordance with the present invention.

The grain size in the X-ray film materially affects the characteristics of the final radiograph. While variations in grain size may be used, a grain size of from 2 to 4 microns is most desirably used. Such film of that grain size may then be modified as set forth above by the incorporation of materials or layers which develop color or color images in one or more colors or color values by incorporation of such materials into the silver halide emulsions employed for such films or by the addition of separate sensitive layers containing such materials which develop color, as added layers on the normal or standard type X-ray film.

Having thus set forth my invention, I claim:

1. The method which comprises exposing an undeveloped ray sensitive photographic film having color producing elements from which a color image may be produced upon exposure and development to non-visible radiant energy selected from the group of alpha, beta, gamma, and X-rays and developing said exposed film to produce therefrom a radiograph having a developed ray-modified color image, the color being in the range from violet to red of the visible spectrum to

produce color differentiation of structural features delineated by the aforementioned non-visible radiant energy.

2. The method which comprises exposing an undeveloped ray sensitive photographic film having color producing elements from which a color image may be produced upon exposure and development to non-visible radiant energy selected from the group of alpha, beta, gamma, and X-rays and developing said exposed film to produce therefrom a multicolor radiograph carrying a ray-modified color image, the colors being in the range from violet to red of the visible spectrum to produce color differentiation of structural features delineated by the aforementioned non-visible radiant energy.

3. The method as set forth in claim 2, in which the film contains color producing elements in an emulsion thereof and the color values are produced by color processing.

4. The method as set forth in claim 1, in which the multicolor radiograph includes a base of one color value and an image of at least one other color value.

5. The method as set forth in claim 1, in which the radiograph includes an image in at least two different color values.

BERNARD M. FINE.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,973,886	Scanlan et al.	Sept. 18, 1934
2,172,262	Schinzel	Sept. 5, 1939
2,251,965	Verkinderen	Aug. 12, 1941
2,509,766	Gross	May 30, 1950

FOREIGN PATENTS

Number	Country	Date
276,678	Great Britain	Nov. 3, 1927