EVOLUTION OF ROENTGEN FILM*

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ROCHESTER, NEW YORK

"Of especial interest in many ways is the fact that photographic dry plates show themselves susceptible to x-rays. We are thus in a position to corroborate many phenomena in which mistakes are easy, and I have, whenever possible, controlled each important ocular observation in fluorescence by means of photography."

THUS, Röntgen's original communication[37] indicated the importance of the photographic plate as a means of *recording* the roentgen ray image and opened the way to a new science—roentgenography. He demonstrated this point by showing the first roentgenogram, one of Mrs. Röntgen's hand, and also the first one taken through metal, which showed a compass card and needle enclosed in a metal case.

Roentgenography is photography.† Like photography, it may use visible light (from the fluorescent screens), or it may use roentgen radiation itself, which differs from visible light only in wave length.

Since roentgenography makes use of photographic emulsions as recording media, the story of roentgen film actually reaches back into the beginning of photography itself when it was observed that certain salts of silver responded to the action of light.

THE BEGINNINGS OF PHOTOGRAPHY

In the 18th century it became known that some silver compounds blackened when exposed to light.[27,30] In 1727, a German chemist, John H. Schultz, discovered that a paste of silver carbonate or chloride mixed with chalk became dark when it was exposed to light in a glass tube. After stencils of letters were placed on the tube and the material exposed to sunlight, black lettered images were seen when the stencils were removed. However, these images were only transient; since he knew of no way to make them permanent, the areas originally protected from light eventually darkened.

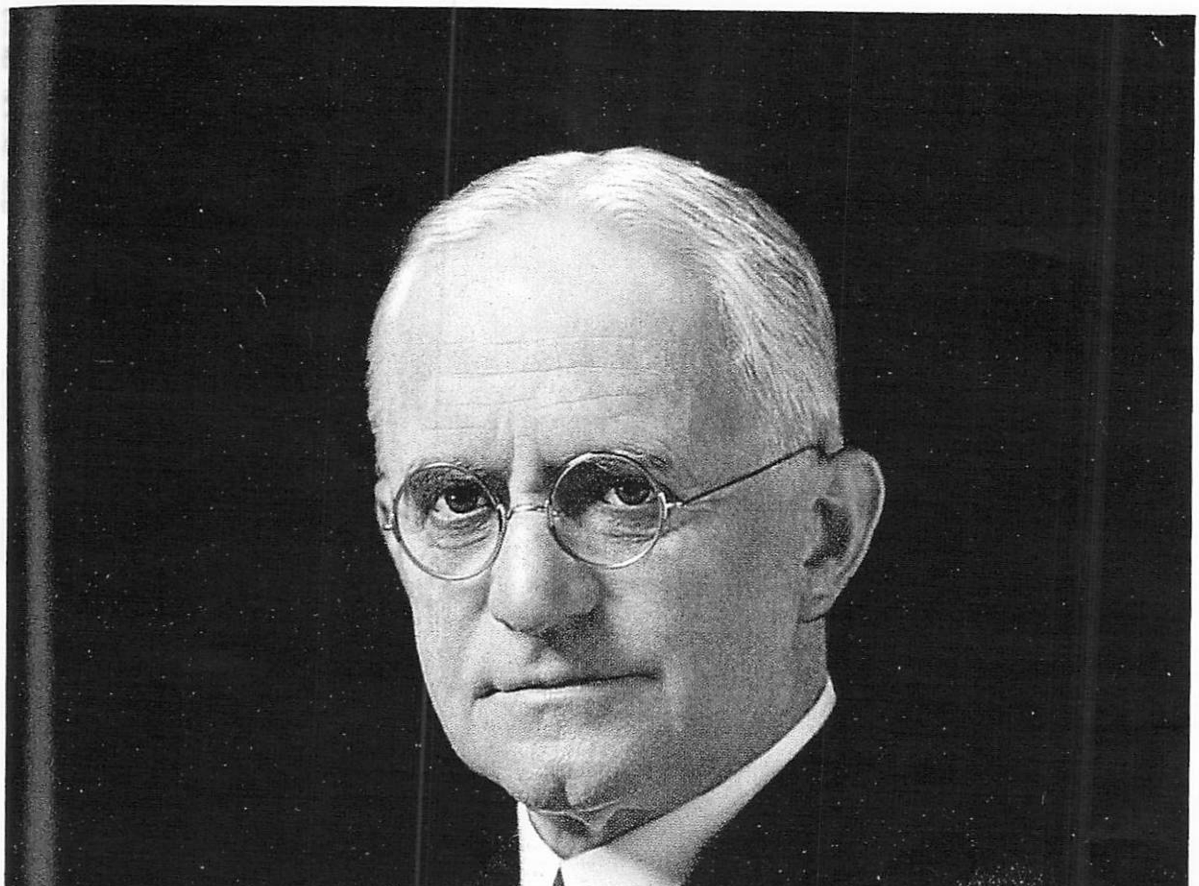
In 1802, Thomas Wedgewood and Sir Humphrey Davy recorded silhouettes on glass by contact printing on paper coated with silver chloride. A crude camera was made in 1816 by Joseph N. Niepce from a jewel box in which a lens from a microscope was inserted. With this device, he secured an image. None of the images obtained could be made permanent.

William Henry Fox Talbot, an Englishman, exposed silver chloride paper in a camera obscura to secure a visible image which was made permanent by treatment with sodium chloride. Talbot made an important discovery in 1840, when he found that he could develop a latent image after exposure of the silver layer. He obtained a negative image and by printing on sensitized paper was able to obtain positive images. Talbot became the inventor of the *negative-positive* method of photography. It is interesting to note that Sir John Herschel, an outstanding scientist of the period, wrote Talbot under the date of February 28, 1839, using the coined world "photography"—drawing with light—in referring to Talbot's work. He also coined the terms *negative* and *positive* in reference to photographic images. The word "photography" then was acquired by the vocabulary of all languages.

In 1819, Herschel discovered the solvent action of hypo (sodium thiosulfate) on silver chloride. However, the Rev. J. B. Reade was the first (1837) to use sodium thiosulfate to dissolve the unexposed silver salts remaining in the photograph. This treatment prevented the possibility of the image darkening upon further exposure to light.

† Photography is the art or process of obtaining images on sensitized surfaces by the action of light or other radiant energy. (*Encyclopedia Americana*, 1955).

* From the Medical Division of the Eastman Kodak Company, Rochester 4, New York.



GEORGE EASTMAN
1854 • 1932

The Frenchman, Louis J. J. Daguerre, recorded images (1839) on plates covered with a silver salt that had been fumed with iodine to form a layer of silver iodide. Long exposures of these plates in a camera produced faint, unsatisfactory visual images. One day he placed one of the exposed plates in his cupboard. Upon removing the plate at a later date, he found that there was a well-defined positive image on the plate. Some mercury had been spilled in the cabinet and its fumes had "developed" the image completely. The unexposed silver iodide was removed by a solution of sodium chloride. Daguerre thereby discovered the phenomenon of *development*.

Paper negatives were used up to this time, but the grainy paper structure was reproduced on the prints. To overcome this condition, C. F. A. Niepce de St. Victor in 1847 coated glass with an albumen emulsion containing silver iodide. Gallic acid was used for developing and resulted in a good quality image of fine grain.

Frederick Scott-Archer, in 1851, published the details of a process wherein wet collodion was used as a binder for the silver salts and coated on glass. The exposure was made before the collodion dried. It soon superseded all other processes. However, the method was laborious and inconvenient. Many variations of the collodion process were tried but none was too satisfactory. Hence, various attempts were made to find a method of coating a plate that could be dried and perhaps stored until used.

Invention of dry plate. The invention of the *dry* plate, using an emulsion of silver bromide in gelatin, by Richard L. Maddox of England in 1871 served as the basis for modern photography. Its speed and stability was improved by J. Burgess, who in 1873 manufactured the first practical dry plate with a washed emulsion. Also, in 1873, H. W. Vogel discovered that such plates, normally sensitive only to blue and violet light, could be made sensitive to all colors by the addition of certain dyes.

Dry plates were found to be several times faster than the wet plate and were soon manufactured in several countries. At first, dry plates were coated by hand. The first mechanically coated glass plates were made in 1879 by George Eastman who had invented a plate-coating machine. Another product called *American Film* was introduced by Eastman in 1885. This was a stripping film which used paper as a temporary support for the emulsion. After exposure and processing, the paper was stripped away leaving a thin transparent "film" from which prints could be made. At this time also, Eastman began the manufacture of paper sensitized with an emulsion for use in cameras and called Eastman *Negative Paper*. After exposure and development, the paper was made transparent for printing by chemical treatment. In 1889 this firm introduced a flexible transparent base of nitro cellulose coated with a sensitive silver halide emulsion. This product served to advance photography greatly. Thenceforth, photosensitive materials became progressively more efficient as more knowledge concerning the science of photography accrued. Thus, the stage was set for one of man's most important discoveries wherein the photographic emulsion played a dominant role.

BIRTH OF ROENTGENOGRAPHY

In the course of Röntgen's earliest experiments, he found that a photographic "dry plate" was exposed by the "new rays," thus opening to the world a vast field of endeavor—roentgenography.

One of the early problems in the evolution of roentgenographic emulsions had to do with determining just how the roentgen rays produced the image on the photographic plate. Was the effect photoelectric or photochemical, and what was its nature? This subject caused a great deal of speculation and some of the theories advanced are interesting and, in some instances, amusing. In Röntgen's original paper[37], he pointed out that:

"It is still open to question whether the chemical effect on the silver salts of photographic plates is exercised directly by the x-rays.

It is possible that this effect is due to the fluorescent light which . . . may be generated on the glass plate, or perhaps in the layer of gelatin. Films may be used just as well as glass plates."

Röntgen's observations on the roentgen-ray fluorescence of various materials gave rise to many views concerning the effect roentgen rays had on the dry plate. Mr. Chapman-Jones remarked in *Photography*, 1896:

"We may well ask whether the x-rays produce the developable action in gelatino-bromide plates by their direct action or by a secondary action. Is, for example, the plate sufficiently fluorescent to be excited by the x-rays into luminosity, or if not to luminosity, perhaps the excitation results in the production of invisible (say ultraviolet) rays at the surface of the plate, and then these affect it as we know they do. If this kind of secondary action takes place, we may not have here sensitiveness to any new force but merely the production of the new force of radiations which we know are photographically active, and we shall then have no new fundamental principle to add to our knowledge of photography. On the other hand, light is only a form of energy; it is stated that the developable condition can be induced by other forms of energy, such as pressure, contact with certain chemical bodies, heat, etc., and if the x-rays act directly in producing the developable condition, we shall have to add another form of energy to those we know to possess this power. . . Photography is already the recorder of facts; it will, perhaps develop eventually into being the recorder of forces."

Some believed that the effect on the emulsion was produced by "phosphorescence" or action of some unknown kind at the back of the plate. This view was supported by an experiment of Dewar upon ammonium platinocyanide crystals at low temperatures. This salt, ordinarily fluorescent in visible light, lost this property when immersed in liquid air, but when exposed to roentgen rays, fluoresced freely. This condition suggested that whatever the nature of the roentgen rays, they were convertible into visible light; hence, the glass support may have contributed something in producing the image. In 1898 this speculation was disproved by the fact that emulsions supported on nonfluorescent bases, including paper, had been found equally effective.

At first, development of the image was believed to begin at the back of a plate; but this was disproved by workers who exposed an emulsion stripped from the glass. The exposure action was thought to be due almost entirely to fluorescence within the emulsion aided by the fluorescence of the glass support. Some even stated that the roentgen rays exerted no *direct* action upon the sensitive plate!

These controversies have been gradually settled in modern investigations, which have shown that the action of roentgen rays is similar to that of light, in that the radiation is primarily responsible for exposing the silver halide grain. Any fluorescence of the emulsion or support is very slight and does not produce a significant image. These remarks apply, of course, only to direct work with roentgen rays; in screen work it is the light from the screen which produces the exposure.

PIONEER CONDITIONS

The photographic journals were the media for discussion of the roentgen rays following their discovery. In fact, roentgenography was considered as a new specialty in the field of photography. Most of the workers who were actively engaged in making roentgenograms were photographers, or physicians who practiced photography as a hobby. "Roentgen studios" conducted by photographers sprang up in America and Europe, advertising the fact that they were conducting a business in "Roentgen photography" and that appointments could be made for "x-ray sittings." Naturally the medical profession was canvassed, and the majority of the work done by these studios was essentially medical or surgical in character. Occasionally, curious persons requested roentgenograms of various opaque objects such as pieces of sculpture, jewelry, pearls, dia-

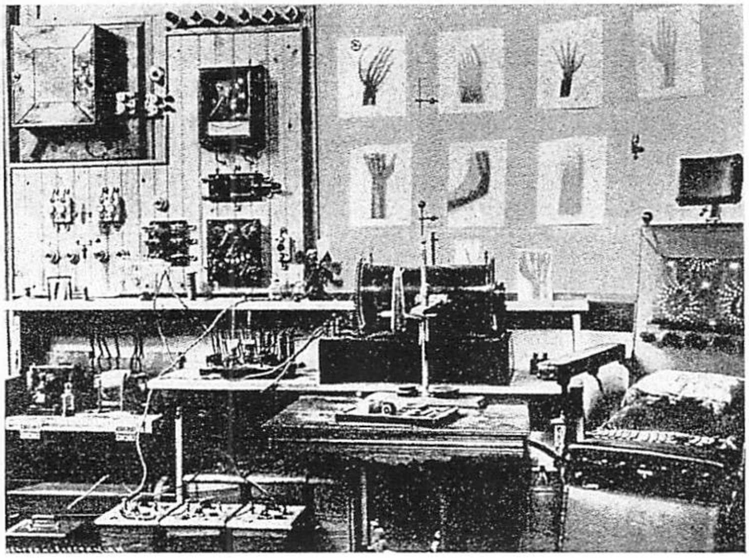


Fig. 1. Reproduction of a photograph appearing in *The Western Electrician* for August, 1896 of the laboratory of Wolfram C. Fuchs of Chicago, Illinois. Note early tubes, coil equipment and examining table used when making roentgenograms.

monds, metal castings, mummies, and other objects of like nature—a prefigure of industrial radiography of modern times.

Some of the pioneer workers achieved impressive results with no more elaborate equipment than an induction coil, a gas tube, and a photographic dry plate—a combination which required exposures of one or more hours to make a roentgenogram of the hand. Obviously, the early roentgenogram lacked density and contrast. As a matter of fact, regardless of the length of the roentgen ray exposure, aftertreatment of the roentgenograms often was necessary in order to make satisfactory prints from them. Since the early roentgen worker followed the procedure practiced by the professional photographer, positive prints of roentgenograms were usually made on a photographic paper which possessed considerable contrast. Moreover, the density and contrast in the print could be increased, thereby enhancing details that were only faintly visible in the plate. The prints were often gold-toned to yield a pleasing sepia positive.

Initial plate problems. Photographic dry plates were slow to roentgen rays in 1896 and 1897, and there was a real need for greater roentgenographic sensitivity. This fact led experimenters to try every conceivable method of increasing the emulsion speeds. Geissler of Bonn, Germany, in April 1896, advocated immersion of the dry plate, before exposure, in solutions of iron chloride, uranium nitrate, or an extract of cuba wood, to obtain a better image. These results were inconclusive. Others soaked the plates in solutions of fluorescent salts, but this method usually resulted in a loss of sensitivity and the production of extreme fog which made the plates worthless. Impregnation of the emulsion with roentgen-ray fluorescent salts was also attempted; in fact, an English plate manufacturer, B. J. Edwards and Company, began to produce plates in May, 1896, the emulsion of which contained a fluorescent salt of this type recommended by Sir Oliver Lodge. This product was called the *Cathodal Plate*.

The most successful method, however, was the employment of the fluorescent screen which will be discussed later. Mention should be made of the early observation that the sensitivity of an emulsion when subjected to the fluorescence from

Fig. 2. A Schleussner advertisement (1899) listing roentgen plates and celluloid films.

screens is dependent largely upon the *color* of the fluorescent light emitted by the screen. Sensitization of the plates before exposure with a four-minute immersion in a bath of silver erythrosine was advised. Such sensitized plates, it was said, required only one-ninth the exposure of ordinary, directly exposed plates. The most suitable plates for roentgenography seemed to be the English brands, *Cadett Lightning*, *Paget xxxxx*, Imperial (May, 1896), and *S. W. Roentgen Plates*, Sandell Works Co.; the French, *Lumière* (1896), and the American, *Cramer C Plate* and the *Carbutt X-ray Plate* (1896).

A constant query in 1896 was, "What sensitive emulsion is best for roentgen-ray work?" The answers in most cases were quite contradictory, as every plate on the market was claimed to be the most sensitive.

The prevailing types of emulsions recommended or used in early roentgenographic work were: the orthochromatic, for it was sensitive to the yellow-green fluorescence of the barium platinocyanide screen; the collodion, or wet emulsion, which was but slightly affected by roentgen rays; mixtures of silver bromide gelatin emulsions, with silver iodide or chloride, which were fairly satisfactory; and the pure silver bromide gelatin emulsion. The common agreement was reached that the emulsions, irrespective of their color sensitivity, should be very much thicker than those employed for pictorial photography.

The reduction in the time of exposure was one of the early problems to be met, for it was realized that if this "new photography" was to be of any value, prolonged exposure was entirely out of the question. Prior to May 1901, no very startling improvement was made in the manufacture of plates, and the consensus was that any good brand of very fast photographic plate gave results in keeping with the best efforts of the roentgen-ray workers.

The recommendation usually advanced by many of the best workers was to use a plate with which the roentgenographer was familiar. This recommendation was so widely accepted that it tended to delay whatever efforts manufacturers were willing to make in producing a special roentgen-ray emulsion. As long as the consumer

Fig. 3. Early Cramer advertisement (1903) of a very popular roentgen plate of the time.

was content with the photographic plate, it was apparently thought advisable to let well enough alone.

One of the problems in development was to obtain adequate density. The roentgenograms were apt to be thin and lacking in contrast. To overcome this difficulty and at the same time to decrease the time of exposure, multi-emulsion coated plates, and gelatin or celluloid films were made, for it was claimed that greater detail and contrast was obtained as compared to a single-coated plate or film. Special plates and films also were coated on both sides of the support. The rays passed through the support and, in the case of film, affected the emulsion on both sides to the same degree so that the image on one side reinforced that of the other. This method in use today, doubled the density of the image and greatly improved the roentgenogram's diagnostic value.

EARLY PROCESSING METHODS

In the early days the roentgenographer developed roentgenograms and prints by means of the old "four bottle" photographic method, covering his sensitive material first with a solution containing the developing agent, preservative, accelerator, and then the bromide. As development proceeded he added a little of the solution from one or another of the bottles containing the essential components as his judgment dictated, until development was completed. He thought that by doing so he was thus able to bring out the anatomical detail desired. The most prevalent method of increasing the density of the image was through after-treatment (intensification)

ILFORD
X-RAY PLATES
SPECIALLY PREPARED FOR RADIOGRAPHIC WORK
Supplied in ORDINARY packing, DOUBLE ENVELOPES, or in DOUBLE WRAPPERS.
X-RAY FILMS specially wrapped for Dental work.
ILFORD, Limited, ILFORD, LONDON, E.

Fig. 4. Advertisement (May, 1912) featuring the Ilford roentgen plate; also mentioned are specially wrapped dental films.

Wratten
X-Ray Plates

A Wratten X-Ray Plate requires less exposure for a given subject than any other X-Ray Plate.

This is because the emulsion of the Wratten X-Ray plate contains a salt of a very heavy metal.

This salt prevents the powerful X-Rays from passing through the emulsion without serving any useful purpose.

Wratten X-Ray Plates have not been increased in price. Their use means a gain in quality and a saving in cost.

Use Wratten Plates for all your X-Ray Exposures.

Kodak Limited (Wratten Division),
Kingsway, London, W.C

Fig. 5. Advertisement (1914) of a unique type of roentgen plate called the Wratten X-ray Plate which contained a heavy metal salt in the emulsion.

of the negatives, and many of the leading roentgen workers of that time resorted to that practice.

The roentgenographers were used to the complicated and nonstandardized photographic methods of those days, and accepted the attendant inconveniences with little thought of possible simplification. Typical of the ingenuity and intelligence brought to bear on these problems is the experience of Dr. E. R. Corson of Savannah, Georgia, described in one of his early papers:

"In my earlier x-ray work I intrusted the developing and printing of plates to a professional photographer; but I soon found that, unless I had him entirely at my beck and call it was impossible to do any systematic work. There were certain differences in photographic technique to produce prints from negatives, such, at any rate, as I conceived they should be, that he had much to learn, just as I had to learn the entire process, having had no previous knowledge or experience in photographic work. I found that what the professional would regard as a fine negative did not always give a satisfactory print, one that gave the deep and essential details without the superficial ones and the flesh. Thus I found that every negative had to be intensified just as regularly as the plate was developed and fixed. There were further difficulties to be overcome in printing which did not exist in ordinary photographic work. . . I have used the Carbutt x-ray plates as well as the Seed's extra-rapid plate, No. 27. This latter plate is cheaper and just as good as the Carbutt, and I use it now entirely. I have found that the Eastman hydrochinon developing powders are as good as, perhaps better than, any other developer, and very handy. I use a chrome-alum fixing bath as given by Carbutt and Carbutt's formula for the intensifier. . . . For a printing paper I use solely the "Carbon matt Velox," which has many advantages over all other printing papers, at least to produce prints as I conceive they should be."

All types of developers were employed in the days of the glass plate—no two were alike. The quantities of chemicals employed in the various formulas were not standard, and development was entirely empirical with each roentgen worker. The lack of precision was nicely summed up by Dr. Preston Hickey who said (1907) that any developer when handled properly would develop a plate!

THE QUEST FOR SHORT EXPOSURES

Fluorescent screens. While improvements in tubes and apparatus were being rapidly made, the photographic emulsion had not kept pace. It remained for Thomas Alva Edison to again call attention to the problem by his work with fluorescent screens.[11,15]

Edison's intense interest in scientific advances compelled him to plunge into the new field of roentgenology with tremendous energy and enthusiasm. He developed and improved tubes, apparatus, and fluorescent screens.

The fluoroscopic screen of 1896 was a crude affair—flimsy, unstable, and expensive. Consequently, there were many who were advised to make their own fluoroscopic screens in order to improve fluoroscopic detail. The screen images revealed only a suggestion of detail in the body structures; they were in effect crude silhouettes. These diffuse images usually were obtained when using non-focus tubes; but, with the advent of focus tubes, the use of the fluorescent screen gained greater impetus because sharper images were possible, although they were far from ideal.

From January to March, 1896, Edison tested some 8,500 different materials in his effort to build a new incandescent lamp. In the course of this work, 1,800 substances were found to be fluorescent. Of these, calcium tungstate had approximately 6 times more intensity than barium platinocyanide. He recommended the use of calcium tungstate for roentgen fluoroscopic screens in March, 1896.

Professor Michael Pupin of Columbia University had been keenly interested in the work conducted by Goldstein of Germany on discharge-tube phenomena; consequently, he was about the only person in the New York area who had equipment adequate to produce roentgen rays early in 1896. Pupin immediately began to study this new radiation and did a tremendous amount of experimental work. In examining the large numbers of patients that physicians sent to him, he made every effort to increase the efficiency of his apparatus so that he could shorten the exposure.

In his autobiography,[35] Pupin wrote:

"My good friend, Thomas Edison, had sent me several fluorescent screens, . . . I decided to try a combination of Edison's fluorescent screen and the photographic plate. The fluorescent screen was placed on the photographic plate and the patient's hand placed on the screen. . . The combination succeeded even better than I had expected. A beautiful photograph was obtained with an exposure of a few seconds. . . . That was the first x-ray picture obtained by that process during the first part of February, 1896. . . "

Further work on the fluorescent screen tended to overemphasize the idea that all roentgen-ray work could be satisfactorily performed by means of the fluoroscope. This trend was influenced in some degree by a telegram given wide publicity, which Edison sent to Lord Kelvin in March, 1896:[15]

"Just found calcium tungstate properly crystallized gives splendid fluorescence with Roentgen rays, far exceeding platinocyanide, rendering photographs unnecessary."

Subsequent events, however, have proved the fallacy of this hasty assumption.

While the more brilliant visual image of Edison's new fluorescent screen of calcium tungstate was some improvement over the earlier type of screen, it still had many disadvantages. In the examination of the thicker parts of the body, the image was difficult to decipher because of its grain; detail, even in the thinner parts, was almost impossible to discern. On the other hand, the photographic plate offered not only a permanent record, but a clearer one with greater definition and more minute detail than the image seen on the fluoroscopic screen. Further, the effect of the roentgen rays on the sensitive plate was cumulative so that an image only faintly perceptible on the fluoroscopic screen could be more satisfactorily registered on a plate by merely prolonging the exposure. In this way roentgenograms of an adult pelvis could be made, whereas a detailed image could not be observed directly on the fluoroscopic screen.

Max Levy, a German, was apparently the first to recommend and use, in 1897, a *double-coated* film sandwiched between two fluorescent screens.

It is strange that although screens for intensification purposes were introduced very early in the history of roentgen rays, yet they seem to have been dropped out of use for many years. The reason perhaps was that those old screens possessed an extreme amount of afterglow and excessive grain due to the use of very large-sized

Fig. 6. The first roentgenogram for which a fluorescent screen was employed for intensifying purposes was made by Professor Pupin in February, 1896.

fluorescent crystals. Such crystals always gave the brightest fluorescence but caused a granular appearance both in the fluoroscopic image and roentgenogram, obscuring detail. About the only examinations in which they were extensively employed were those of the gastrointestinal tract, spine, hip, and skull, where the increased density and possibility of movement necessitated a short exposure. At that time some workers found that roentgenograms made of the kidneys without a screen gave a negative diagnosis but those made with screens rendered calculi visible. Others obtained splendid roentgenograms of calculi without the aid of screens. The failure to obtain better results in some instances was no doubt due to the extreme exposure and great penetration which was then being advocated.

Progress in emulsion making. All through this early period, American researchers experimented extensively with emulsions. The first plate strictly for roentgen-ray purposes was made by John Carbutt co-opera-

FIG. 7. An early Carbutt advertisement (1896) for the first specially prepared American roentgen plate.

ting with Professor Goodspeed of the Physical Laboratories of the University of Pennsylvania. This product, called the *Roentgen X-ray Plate*, possessed a thicker and heavier silver emulsion than the usual photographic plate and permitted a radical reduction in the time of exposure. It was tried out on February 11, 1896, at the Maternity Hospital, Philadelphia, Pennsylvania by Professor W. W. Magie of Princeton University. The first exposure was made for Dr. W. W. Keen whose patient had an ankylosis of the finger joints caused by a burn. The exposure was twenty minutes; previously, such projections required exposures of one hour or more.[16,22]

With further improvement in apparatus and roentgen plates, the exposure ranged (April, 1896) from a few seconds for a hand to thirty to sixty seconds for heavier parts. Projections of the trunk, however, were still a problem because exposures were of the order of minutes rather than seconds.

What was then thought to be the proper characteristics of a roentgen-ray emulsion may be summed up in John Carbutt's words (June, 1897):

"It should be of medium sensitiveness, have a good body of emulsion, be capable of absorbing the x-rays, thereby giving more detail and perspective to the bones."

A decade later, Dr. Eugene W. Caldwell seemed to obtain best results on plates of medium or fast photographic speed such as the Hammer *Extra Fast*, the Cramer *Banner*, Seed's *26X or 27*. Plates coated on one side with a double emulsion which were obtainable as non-halation plates offered some advantage. The Hammer *Aurora* was found to give excellent results where it was desirable to use a double-emulsion coated plate to lessen exposure.

Manufacturing defects in plates were beginning to be a critical problem among roentgenologists because the artefacts interfered with diagnosis. During the Meeting of the American Roentgen Ray Society in 1902,* a discussion occurred on this subject with particular reference to diagnoses in cases of calculi. The comments of Wolfram C. Fuchs of Chicago are of interest because they describe emulsion problems that no longer plague the profession:

"I have not found a platemaker yet whose product does not have some defect. After the negative has been developed we find spots all over it. The hardest stones to locate are the small stones. The large ones you can see at a distance. Take a very small stone, as, for instance, in this radiograph (indicating). You can distinctly see the outline of the kidney and the darker shadow in the center, with many darker spots all over. These are even visible to the patient and that is not good. I usually take two plates, one on top of the other, and expose them at the same time with the envelope around them. In this way, while the spots will still show on a plate, yet the spots are not in

* Transactions of American Roentgen Ray Society, 1902, pp. 172–175.

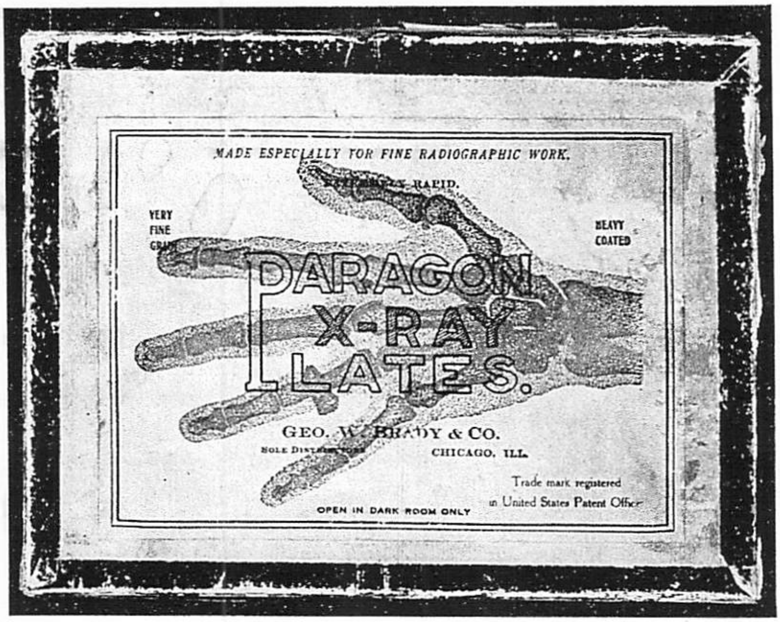


Fig. 8. Label on a box of Paragon X-ray Plates (circa 1914). This was a very popular American brand of roentgen plate used prior to the advent of roentgen film.

the same place on both plates. In that way you can overcome the difficulty of the plate defects. I have spoken to the expert platemakers about this and they recognize it; they try to remedy it, but have not, as yet, succeeded in doing so. I have spoken to them about if for the last three years, but they do not seem to be able to overcome the trouble. I thought at first that it was all my fault, that, perhaps, my developer was bad. I took special pains in the mixing of the different ingredients of the developer, made a perfect solution, and still I found spots and streaks all over the plate. . . . I use a French plate, because I think they are much more sensitive than the American plates. I also take another film with an emulsion on it and put that right next to the plate. This seems to add to the sensitiveness of the plate."

When first supplied (1896), roentgen plates were inserted in lightproof wrappers and sealed, but it was found that the plates deteriorated through interaction between the chemically unpurified paper and the emulsion. The envelopes were later furnished separately and the operator "loaded" his own plates as needed.

It is interesting to note that as late as 1918, a calcium tungstate plate was suggested by Dr. Max Levy and manufactured by the Imperial Dry Plate Company in England. This plate consisted of a glass support coated with emulsion on one side, over which was placed a coat of calcium tungstate crystals. After exposure and before development the plate was held under the water tap to wash off the screen coating. The plate was then developed in the ordinary manner. These plates were expensive to manufacture, showed considerable grain, and were somewhat impractical.

The great demand for roentgen plates led to the manufacture of many American brands such as the *Paragon X-ray Plate*, *Forbes X-ray Plate*, *Cramer X-ray Plate*, *Central X-ray Plate*, *Universal X-ray Plate*, *Diagnostic X-ray Plate*, and many others in England, France, and Germany. In 1912 Eastman introduced the *Wratten X-ray Plate*, which was coated with a heavy silver halide emulsion impregnated with a bismuth salt, the purpose of which was to

EASTMAN

X-Ray Films

EASTMAN X-Ray Films mean—convenience in *handling, developing, mailing* and *filing.* They are flexible, light and unbreakable and in quality are *at least* the equal of the best X-Ray plates make.

The present extensive use of cut films for professional portraiture is proof that the film's advantage over glass plates is appreciated by the photographer—the advantages to the Roentgenologist are even more marked.

For sale by all Supply Houses. Illustrated booklet, "X-Ray Efficiency" by mail on request.

EASTMAN KODAK CO.,
ROCHESTER, N. Y.

Fig. 9. Early Kodak advertisement (April, 1914) of the first single-coated roentgen film.

absorb the roentgen rays and increase the effect on the silver halide crystals in the emulsion. The Seed Dry Plate Company of St. Louis soon offered the *Seed X-ray Plate* to the profession. These plates were well received and were in popular favor for many years until the advent of roentgen film.

ROENTGEN FILMS

In Röntgen's original communication, it was indicated that either plates or films might be used to record the roentgen image. As a consequence, many workers employed whatever photographic material was available for roentgenography. *Eastman Transparent Film—New Formula,* was still being manufactured in 1896 and used for roentgenography in a limited way, just as were other photographic films and plates.

Films used for roentgen-ray purposes in England prior to 1901 were the *Austin-Edwards'* snapshot film and the *Cristoid* made by the Sandell Plate Company. The latter films were essentially gelatin rather than cellulose, and were made of two emulsions—one very rapid and one of regular speed—coated on glass and then stripped off. The films were supplied packed in dark envelopes, were difficult to develop, and much slower than fast *plates.*

Gelatin and celluloid films were not so desirable because of their tendency to curl or crack, but they had this advantage—they were thin and could be used with one or two intensifying screens with a consequent reduction in exposure. Also, they were not subject to breakage as were the glass plates. In Germany this type of film was made for roentgen-ray work about 1896 by the Schleussner Company, such film having a double emulsion on *each* side, making four coats in all. This company also made roentgen plates and was probably the only firm in those days making an emulsion which approached the density, contrast, and speed suitable for roentgen work. The finest roentgenograms seemed to be made on their films but due to their high cost they were not very popular. Production of double-coated films soon declined, perhaps because of manufacturing difficulties.

Prior to World War I, the glass used for photographic plates was secured from Belgium. The war soon curtailed this source and procuring the glass became a very serious problem. The demand for roentgen plates in Army hospitals became almost impossible to satisfy. Even when glass plates were available in large quantities, their bulk and fragility made them exceedingly difficult to transport without breakage. The problem finally made it imperative to provide some other support than glass for the emulsion.

Roentgenography made special demands upon a film support. It required sensitive surfaces of large area. The base upon which the emulsion was to be coated had to support the roentgen-ray emulsion without buckling to any great extent. It also had to be glass-clear. The only thing to be done was to adopt the cellulose nitrate base used in the manufacture of photographic film. In 1914, a single-coated roentgen film was manufactured with an emulsion of greater sensitivity than that on any roentgen plate made. However, even this film was not ideal; it curled excessively and was therefore very difficult to develop in trays.

The urgency of World War I demanded greater efficiency and speed in roentgen film because of its use with portable roentgen-ray apparatus in the field. This need accelerated the extensive research work then being conducted on a film coated on both sides which made possible the double-screen technic.

Intensifying screens appropriate for the double-coated films were introduced by Carl V. S. Patterson of the Patterson Screen Company[13] in 1916, and much of the credit for continued improvement in screen manufacture must be given to him. It was his work in particular which determined the characteristics of a satisfactory screen: a pure, fine grain, fluorescent chemical; brilliant and uniform fluorescence; and minimal afterglow.

The then current practice of tray development was a deterrent to rapid adoption of these double-coated or "dupli-tized" films. A few laboratories employed deep tanks for processing plates vertically and were able to change over readily when a suitable film hanger became available about 1920. Also, cassettes and other types of film holders to accommodate the new film were placed on the market.

The introduction of film was no easy task. Roentgen workers had so accustomed themselves to glass plates that it took time to convince them that film held forth any advantages over the plates. In 1923, a still faster roentgen film became available. It allowed a radical shortening of exposure time or a lowering of the kilovoltage. The base of this film, like that of its predecessors, consisted of cellulose nitrate.

Cellulose nitrate as a film base had always presented a fire hazard which manufacturers and users recognized. Consequently, other materials of less flammability were sought. By 1906 it appeared that cellulose acetate might provide a practical answer. The actual production of a useful cellulose acetate base, however, required many years of research and development. The contributions of George Eastman and his company to this program are outstanding, although basic inventions and technological improvements were also contributed by other workers and concerns. The program included reduction in brittleness, improved clarity, and greater strength.

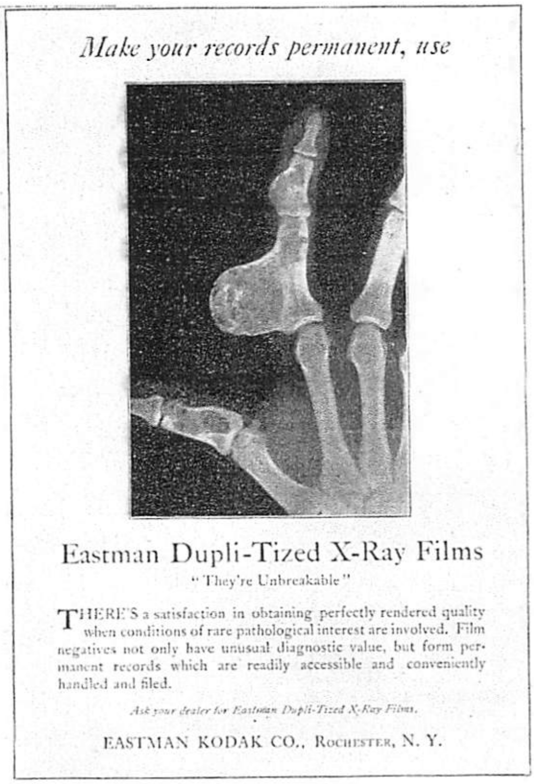


Fig. 10. An early Kodak advertisement (November, 1918) describing "Dupli-Tized X-ray Film"

Great strides were also made in the recovery processes of by-products of the chemical reactions in cellulose acetate manufacture, which permitted the price to be kept down. World War I gave great impetus to the production of cellulose acetate for other than photographic purposes. This huge consumption made it possible to

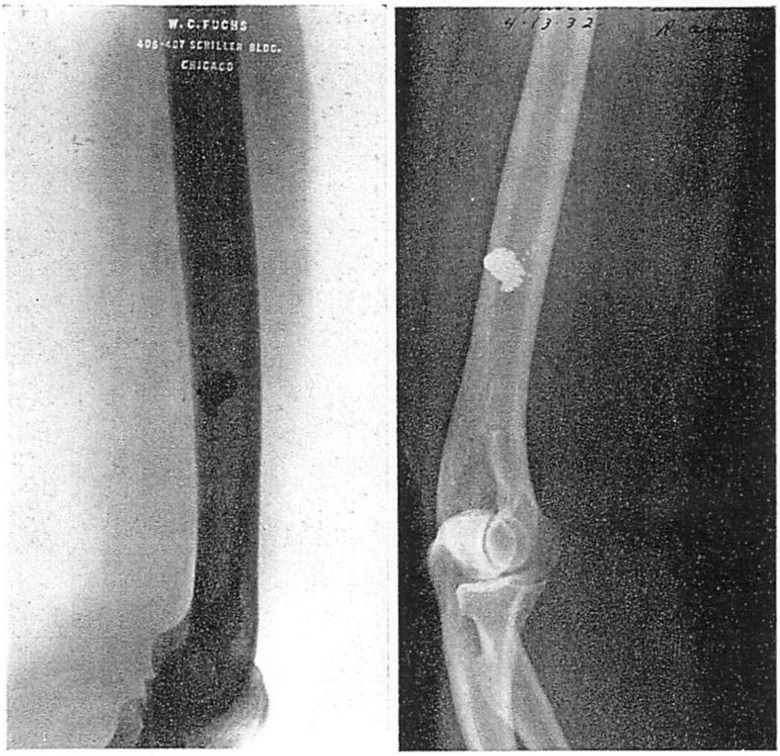


FIG. 11. Courtesy—Miss Margaret Hoing, Chicago. An unusual historical item showing an early roentgenogram and a "follow-up" made thirty-five years later. The patient was a girl who had been shot by a rifle bullet in 1897. The roentgen examination was made in the laboratory of Wolfram C. Fuchs, Chicago, Illinois. After the examination gold-toned contact prints were made from the *original glass plate*. One was sent to her physician; another was given to the patient and reproduced herewith (left). The original print is in a remarkable state of preservation today. The patient was reexamined in 1932 with modern roentgen film (right) and the bullet may still be seen in its original position.

increase greatly the knowledge regarding the efficient manufacture of cellulose acetate. The results of research finally reached a point where a roentgen film on a safety base of cellulose acetate was produced and placed on the market in 1924.

In 1925 a film was introduced possessing a high degree of contrast and combining a high sensitivity to roentgen rays and to the light from intensifying screens. Further improvements in sensitivity and other characteristics were made in the early 1930's. During this period also a film having a blue-tinted base was introduced by the Du Pont Film Manufacturing Company (1933), and a film for direct roentgen exposure (Non-Screen) was placed on the market by Ansco (1936). Similar products were soon made available by other American and European film manufacturers.

To meet the demand for less and less roentgen exposure to patients, increases in sensitivity have continued to be made, together with improvements in contrast and keeping qualities, and reduction in the inherent fog level.

DENTAL ROENTGEN PLATES AND FILM

The story of dental roentgen plates and film closely parallels the progress of medical plates and film from the earliest days of roentgenography. Special emulsions and film sizes and a practical packet were problems that had to be met in order to satisfy the needs of the dental profession.

Perhaps the first dental roentgenogram on record was made by Dr. Otto Walkhoff of Braunschweig, Germany, two weeks after the announcement of the discovery of the roentgen rays. This roentgenogram was made of Dr. Walkhoff's own teeth with an exposure of twenty-five minutes. He used an ordinary photographic plate cut to a small size, wrapped in black paper, and covered with rubber-dam.

An Englishman, Frank Harrison, first published an article describing the method of making dental roentgenograms on film in the *Journal of the British Dental Association*, September, 1896. Dr. W. J. Morton of New York was the first in America to make a dental roentgenogram on film prior to April, 1896, using Eastman NC roll film.

The results of these early roentgenograms were rather crude and of little diagnostic value, but they brought to the attention of the dental profession the fact that here was the basis for an invaluable diagnostic adjunct.

The small difference between the density of bone and tooth required that the roentgenogram be of good contrast. Early dental roentgenography was done on photographic plates, films, and bromide papers. However, following the lead of Dr. C. Edmund Kells, Jr., of New Orleans, Louisiana, many preferred to use films.

About 1900, Dr. Weston Price of Cleveland, Ohio, designed a celluloid-base dental film. The celluloid was said to be thick enough to prevent curling but flexible enough to be introduced into the mouth. In an effort to obtain a greater degree of contrast between the tooth structures and the surrounding alveolar process, three emulsion layers were coated on the base instead of one. This product was made and marketed by the Seed Dry Plate Company. The films were cut to size from large sheets and wrapped in black unvulcanized dental rubber.

While glass plates proved satisfactory for the anterior region of the mouth where the curved surfaces did not cause undue distortion, in the posterior region distortion was a problem. Film presented many advantages, particularly its thinness and flexibility which made it easy to place in the mouth. Soon film was used extensively, and Kodak roll film and Seed's double- and triple-emulsion films became favorites.

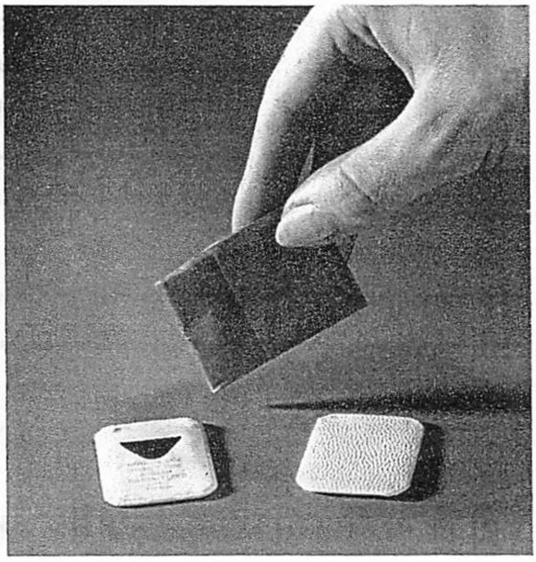


Fig. 12. The old style hand-wrapped dental film packet above presents quite a contrast to the modern dental film packet appearing below.

The need for a specially wrapped packet containing dental films was an important one. Various wrappers were used, the most successful being black and orange or ruby paper, and black dental sheet rubber then employed as dams. Dr. Kells was probably the first to suggest and use two dental films in a packet so as to have duplicate roentgenograms in case one was lost or sent to a referring physician. Each exposure in those early days required from twenty to ninety seconds.

In 1913, a red, waxed, moistureproof, hand-wrapped paper packet was introduced; in it were two single-coated dental films enclosed in a black wrapper. Various emulsion speeds were employed. These packets were superseded in 1921 by machine-made packets containing single-coated film. They facilitated placement, were more sanitary, and more comfortable in the patient's mouth.

In 1925, the introduction of dental films coated on both sides with a fine-grain, high-contrast emulsion ("radia-tized"), greatly aided visualization of detail. The first "bite-wing" film packet, designed by Howard R. Raper, D.D.S., to detect interproximal caries, was introduced in 1926.

Like all medical films of that period the early dental films were coated on a base of cellulose nitrate. In 1929, however, the use of cellulose acetate (safety) base was begun. At about this time, the packet was also changed from black to white.

In 1938, a "rapid processing" dental film was announced. An extremely fast film was introduced in 1941, and further improved in speed in 1955. This fast film permits a reduction in the roentgen dose to the patient, particularly desirable in a complete dental examination. The speed of other dental emulsions has been materially increased also for this reason. Over the years, many styles of packets have been employed but the most efficient seems to be a machine-made packet of moistureproof paper with easy opening features. It is a far cry from the first crudely wrapped photographic plates to the neat, sanitary, comfortable dental packet of today.

ROENTGEN PAPER

The first use of sensitized paper dates back to the days of Röntgen's experimental work, for he mentions it in his early publications. In America, the first roentgenogram on paper was made by Professor A. W. Wright, Sloane Physical Laboratory, Yale University, on January 27, 1896.

The quest for more satisfactory sensitive material than glass plate led many workers to experiment with bromide papers. The first sensitized paper, prepared especially for roentgenographic purposes, was announced in the *Kodak News*, a photographic trade magazine, in December, 1896. The title of the announcement, "*Eastman's X-ray Bromide Paper Takes the Place of Plates in Radiographic Work,*" is evidence of the high hopes that periodically were felt for such a recording medium. The *stated* advantages of this paper over the use of plates were as follows: It was non-breakable. It could be bent to conform to the shape of the body and thereby secure better contact. It needed less exposure than plates. Its latitude was greater. It was cheaper and simpler to handle. There was no need of making a negative—then a print. Unlike glass plates, there was no useful limit to their size. The time required to produce a finished roentgenogram consumed not more than five minutes. As each sheet of paper was packed by the company in special envelopes, the trouble of "loading" them was eliminated. In addition, any number of "prints" could be made with one exposure, as it was very "transparent" to roentgen rays.

Unquestionably the fundamental reason for the failure of roentgen paper to find general favor has always been its inability to show detail and contrast as clearly as the glass plate or transparent film.

With the average intensity of illumination used in viewing roentgenograms, the range of brightness which can be rendered by the roentgen *film* is approximately in the ratio 1 to 200 (from lowest to highest). This range can be extended by increasing the illumination; in fact, a small illuminator of high intensity is often used to view unusually dense areas in a roentgenogram, inasmuch as the detail is there and only requires more intense illumination to show it. In this way, it is entirely feasible to increase the range of brightness visible in the roentgenograms to the ratio 1 to 1,000. In the case of *paper*, the maximum range of brightness available is about 1 to 30 regardless of the illumination. In practice this means that the range of densities which can be rendered on paper is much less than that which can be rendered on film.

OTHER APPLICATIONS

Polaroid-Land process. The newest addition[25,36] to the list of commercially available roentgenographic recording media is an adaptation of the Polaroid-Land proc-

AN IMPORTANT RADIOGRAPHIC DISCOVERY.

EASTMAN'S

...X-RAY PAPER

ENTIRELY SUPERSEDES DRY PLATES WITH THEIR ATTENDANT DRAWBACKS.

Of Unparalleled Advantage in Surgical Diagnosis by means of the Röntgen Rays.

Being Non-Breakable, the patient can lie down upon it without injury to himself or the paper.

When Distorted Limbs or Curved Parts of the Body are to be radiographed, the X-Ray Paper can be bent to form the perfect contact necessary to a sharp picture.

Positives are made direct on the paper; no after-printing necessary.

Unlike Glass Plates, there is no limit as to size.

No Reversal is needed to obtain a correct print. The first results are accurate, both as to right and left, and as to the lights and shadows of the picture.

Bones appear White, Muscles and Flesh form the Half-tones, and the Background is Black.

Eastman's X-Ray Paper is as rapid as the most rapid X-Ray plate on he market, while the latitude of exposure is greater.

One dozen or more prints can be made and finished at one exposure.

The whole process from the commencement of exposure to the attainment of perfect prints need not occupy more than five minutes.

A Dark Room is not essential prior to development, each sheet of Eastman's X-Ray Paper being packed in a special envelope.

Size.	*Price.*
8½ × 6½	4/3 per Packet of 1 doz. sheets.
10 × 8	7/3 .. .. ..
12 × 10	10/6 .. .. ..
15 × 12	18/- .. .. ..

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Rochester, N.Y., U.S.A.
Eastman Kodak Co.

Fig. 13. The first Kodak advertisement claiming special roentgen ray qualities of an emulsion coated on paper. Published in *Kodak News*, February, 1897.

ess. In the roentgenographic modification, a dry positive roentgenogram on paper is available within about one minute after exposure is complete. This process has found some application where portability or high processing speed is important, e.g., in military roentgenography in the field or in operating-room roentgenography.

Photoroentgenography. Photography of the fluoroscopic screen was first attempted in 1897 by J. M. Bleyer[4] in his investigation of thoracic disease. Many workers since that time have developed apparatus and cameras to make photoroentgenography a success. Large scale use of this technique for chest surveys employing 35 mm. photographic film was made in 1938-1939 by M. de Abreu and A. de Paula in Brazil.[9]

About 1938 a photoroentgen unit was developed by Dr. Hollis E. Potter,[32] in which 4×5-inch dupli-tized roentgen film was used. In 1940, this unit was adopted by the U. S. Army for examining the chest of all personnel. A stereoscopic device was soon added and stereophotoroentgenograms were made on 4×10-inch film. Image definition—especially of the margins of many lesions—was not entirely satisfactory when double-coated film was employed. To overcome this problem, 4×5 and 4×10-inch *single-coated*, blue-sensitive film was produced in 1941. When a stationary grid and standardized exposure factors were used,

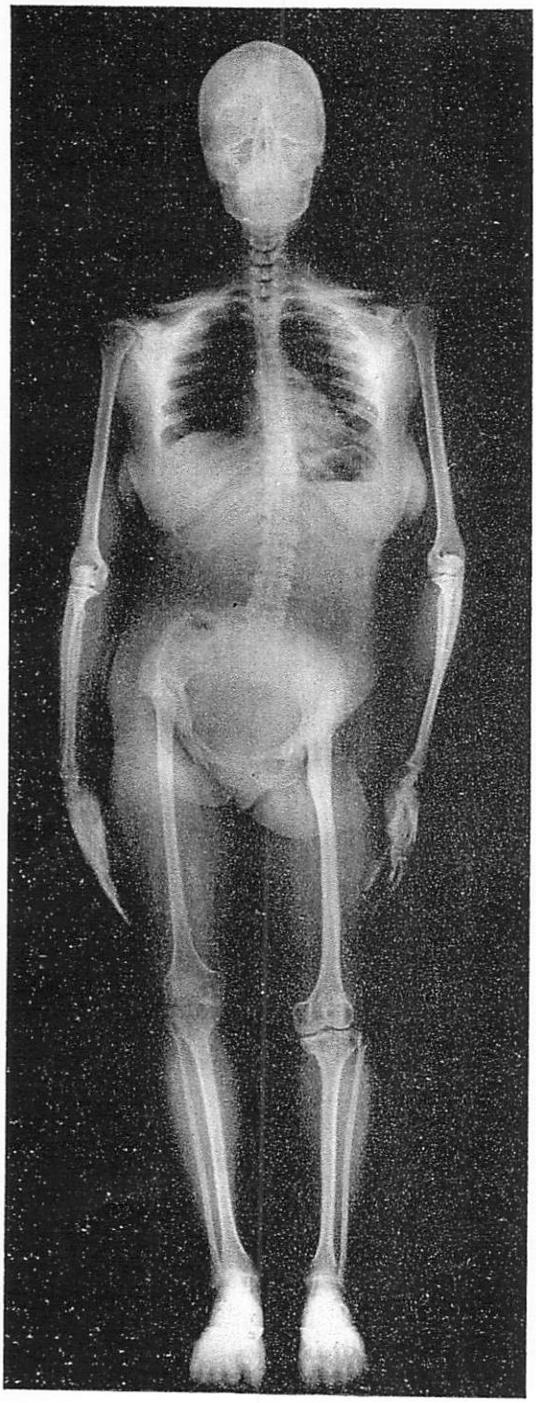

FIG. 14. Roentgen film has been prepared in many sizes for medical work. The largest film (32 by 72 inches) used was for entire body roentgenography of a woman, aged thirty-three, exhibiting hip pathology. The roentgenogram was made with a one-second exposure, 75 kvp., 150 ma. 12 feet focus-film distance, fast screens, and tissue compensating filtration.

this new film was quite successful.[10,14] Since then, emulsions have steadily been improved to satisfy various photoroentgenographic systems employing 35 or 70 mm. green- and blue-sensitive roll films.

Autoradiography. Autoradiography is the technic of locating and measuring the distribution of radioactive elements by means of photographic registration of these elements. This technique has been used for years in the study of naturally radioactive constituents of minerals such as radium, actinium, and thorium.

Discovery of the phenomenon soon followed that of the roentgen rays. Because of the apparent influence of roentgen rays on fluorescence, Henri Becquerel in 1896 investigated a number of fluorescent substances to determine their action upon a photographic plate protected from visible light.[5] He discovered that uranium ores gave off rays which resulted in the exposure of the photographic plate, even when fluorescence was not apparent. Although he did not recognize them as such, these were autoradiographs, since the images were produced by the self-contained radioactivity of the uranium salts. It was Marie Curie's work that proved the phenomenon to be due to radioactivity.

The first published biological use of autoradiography appeared in 1904, as described by E. S. London.[5] In his experiment, he subjected a frog to radium emanation; when the frog was placed on a photographic plate, an image of it was obtained. Others did experimental work along similar lines:[5] Kotzareff obtained autoradiographs of whole organs of animals injected with radium; Lacassagne experimented with polonium; Lomholt, with radiolead.

As long as the radioactive elements were limited to the few naturally occurring ones, the field of autoradiography was correspondingly restricted and the need for special films had not arisen. However, with the advent of the cyclotron and the development of the atomic pile, it became possible to produce radioactive isotopes of practically all the elements in considerable abundance. The use of such isotopes in conjunction with the photographic plate has placed an extremely valuable tool in the hands of the medical researcher, chemist, metallurgist, and biologist, whereby chemical elements can be traced in various substances, reactions, and processes peculiar to each of these fields of work. A great variety of special films are being used, including fast roentgen-ray films, nuclear track plates, stripping films, and liquid nuclear track emulsions which are applied to mounted sections.

Roentgen cinematography. Within months after Röntgen's discovery, attention was being given to the study of motion by means of roentgenography. John Macintyre, a Glasgow physician, succeeded in demonstrating the flexion of a frog's leg. He tried both the direct method—exposure of a film, and the indirect method—photography of the fluorescent screen. The latter, however, was unsatisfactory because of the dimness of the screen image. While his results were serial roentgenograms rather than true motion pictures, from that time on the idea of recording movement engaged the attention of experimenters.

In subsequent years[18] the work of Köhler (1907), Eykman (1909), Cole (1910), Levy-Dorn (1912), and Groedel (1913) gave emphasis toward improving the direct method, but the mechanical problems of that day made progress very difficult and slow. At first glass plates were used, until Cole and Groedel, working independently, designed special apparatus in which a wide strip of photographic film was used.

The pressure of World War I put an end to the work for several years, but it was resumed in the 1920's. During the past three decades interest has centered on the indirect method, generally called cinefluorography. Continued improvements in apparatus, screens, lenses, and films have spurred activity by workers throughout the world.

In the earlier attempts at cinefluorography, the faster motion picture films were used. Later on, the development of a special fluoroscopic screen permitted the use of highly orthochromatic films the sensitivity of which responded best to the color of the screen light, and with satisfactory contrast and grain.

With the introduction of fluoroscopic image amplification systems, experimentation with various cine films was begun to determine which were best. This work is still continuing. In the meantime, films primarily designed for other purposes are being successfully used.

CONCLUSION

This narrative of the evolution of roentgen plates and film in medical roentgenography is but a small part of the complete story. The associated development of apparatus, tubes, and screens, the research in the chemistry of processing—all contributed a great deal in shaping the character of the recording medium. All this progress has been possible only through the cumulative efforts of many minds—projects in industrial research the constant aim of which is to advance still more the marvelous growth of roentgenology.

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REFERENCES

1. Ackerman, C. W. George Eastman. Houghton, Mifflin Company, Boston, 1930.
2. Barnard, M. W. The adaptability of paper roll film in roentgenography. *Quart. Bull. Millbank Mem. Fund.*, 1932, *10*, No. 3.
3. Barnard, M. W., Amberson, J. B., Jr., and Loew, M. F. Technique of using paper films for roentgenograms of chest. *Am. Rev. Tuberc.*, 1932, *25*, 752–766.
4. Bleyer, J. M. An original research on the fluoroscopic diagnosis of certain forms of lung, throat, and heart disease. *Med. J. N. C.*, 1897.
5. Boyd, G. A. Autoradiography. Academic Press, Inc., New York, 1955.
6. Bryan, G. S. Edison—The Man and His Work. A. A. Knopf, New York, 1926.
7. Christie, A. C. Evaluation of methods for mass survey of chest. Am. J. Roentgenol. & Rad. Therapy, 1942, *47*, 76–82.

8. Cole, L. G. The bromide paper screen technique. Am. Quart. Roentgenol., 1911, *3*, 200.
9. de Abreu, M. Collective fluorography. *Radiology*, 1939, *33*, 363–371.
10. de Lorimier, A. A. Mass roentgenography of chest for United States Army. *Radiology*, 1942, *38*, 462–472.
11. Dyer, F. L., and Martin, T. C. Edison—His Life and Inventions. Harper & Brothers, New York, 1929.
12. Fitzgerald, P. J. Simmel, E., Weinstein, J. and Martin, C. Radioautography: theory, technic, and applications. *Lab. Invest.*, 1953, *2*, 181–222.
13. Fuchs, A. W. Radiographic Recording Media and Screens. In: The Science of Radiology, Otto Glasser, Editor. Charles C Thomas, Publisher, Springfield, Ill., 1933.
14. Fuchs, A. W. Military photoroentgen technique employing optimum kilovolt (peak) principles. Am. J. Roentgenol. & Rad. Therapy, 1945, *53*, 587–596.
15. Fuchs, A. W. Edison and roentgenology. Am. J. Roentgenol. & Rad. Therapy, 1947, *57*, 145–156.
16. Goodspeed, A. W. Radiography and its application. *Photographic Times*, 1896, *28*, 305–316.
17. Houston, E. J., and Kennelly, A. E. The röntgen rays. *J. Franklin Inst.*, 1896, *141*, 241–278.
18. Jarre, H. A. Roentgen Cinematography. In: The Science of Radiology, Otto Glasser, Editor. Charles C Thomas, Publisher, Springfield, Ill., 1933.
19. Jones, F. A. The Life Story of Thomas Alva Edison. Thomas Y. Crowell Company, New York, 1907–1908.
20. Kassabian, M. K. Röntgen Rays and Electrotherapeutics. J. B. Lippincott Company, Philadelphia, 1907.
21. Kaye, G. W. C. X-rays. Longmans, Green & Company, London, 1918.
22. Keen, W. W. The use of the röntgen x-rays in surgery. *McClure's Mag.*, 1896.
23. Kirkpatrick, S. D. Building an integrated industry in times of depression. *Chem. and Metal Eng.*, 1933, *40*, 236.
24. Köhler, A. Ärztlicher Röntgenbetrieb um die Jahrhundertwende. *Strahlentherapie*, 1937, *60*, 283–289.
25. Land, E. H., New one-step photographic process. *J. Opt. Soc. Amer.*, 1947, *37*, 61–77.
26. Martin, F. C., and Fuchs, A. W. Historical evolution of roentgen-ray plates and films. Am. J. Roentgenol. & Rad. Therapy, 1931, *26*, 540–548.
27. Matthews, G. E. Technical highlights of the past fifty years. *Amer. Photo.*, 1951, *45*, 93–100.
28. Meadowcroft, W. H. The ABC of the X-Rays. American Technical Book Company, New York, 1896.
29. Myers, J. A. Progress in diagnosis of tuberculosis, with special reference to x-rays. *J.A.M.A.*, 1933, *100*, 2004–2006.
30. Newhall, B. History of Photography. Simon and Schuster, New York, 1949.
31. Photographing the unseen—A symposium on the roentgen rays. *Century Mag.*, 1896, *52*, 120.
32. Potter, H. E., Douglas, B. H., and Birkelo, C. C. Miniature x-ray chest film. *Radiology*, 1940, *34*, 283–291.
33. Potts, C. S. Electricity. Lea & Febiger, Philadelphia, 1911.
34. Pullin, V. E. and Wiltshire, W. J. X-Rays Past and Present. Ernest Benn, Ltd., London, 1927.
35. Pupin, M. From Immigrant to Inventor. Charles Scribner's Sons, New York, 1930.
36. Robbins, L. L. and Land, E. H. Application of the Land method of film processing in roentgenology. *J.A.M.A.*, 1951, *147*, 1217–1219.
37. Röntgen, W. C. Eine neue Art von Strahlen. Sitzungsberichte der Würzburger Phys.-Med. Ges., 1895 and 1896.
38. Rowland, S. Report on the application of the new photography to medicine and surgery. *Brit. M. J.*, Feb. 8, 1896, p. 361.
39. Tousey, S. Medical Electricity and Röntgen Rays. W. B. Saunders Company, Philadelphia, 1910.
40. Tr. Am. Roentgen Ray Society, 1902, 1903, 1907.
41. Walsh, D. The Röntgen Rays in Medical Work. William Wood & Company, New York, 1898.
42. Webb, J. H. The latent image. *Physics Today*, 1950, *3*, 8–15.
43. Webb, J. H. Theory of the photographic latent image formation. *J. Appl. Physics*, 1940, *11*, 18–34.
44. Weigel, L. A. Practical points in use of x-ray. *Philadelphia M. J.*, 1900.
45. Williams, F. H. The Roentgen Rays in Medicine and Surgery. Second edition. The Macmillan Company, New York, 1903.

The majority of facts relating to the roentgen rays in the early years following their discovery was contained in news items that appeared in the following publications:

American Journal of Photography
Anthony's Photographic Bulletin
British Journal of Photography
British Medical Journal
Chicago Medical Record
Electrical Engineer
Journal of the American Medical Association
Journal of the Franklin Institute
Kodak News, The
McClure's Magazine
Photogram, The
Photographic Journal, The
Photographic Times