X-ray analysis papers
Ed. W. Parrish (1965) Centrex Publ Co

can be followed. The X-ray study of fossils, such as foraminifera and other microspecimens, often reveals details of the internal arrangement that cannot be seen by other methods. The distribution of fibers and filler in papers has been extensively studied by microradiography. (See Plate 3.)

6. Radiography and Fluoroscopy

The use of X-rays to obtain photographs of the interior of objects that are opaque to visible light was applied shortly after Roentgen's discovery of these rays. The method is now widely used in industrial and medical applications. The apparatus is basically simple. The object to be photographed is placed between the X-ray tube (or gamma-ray source) and the film cassette. The image shows the X-ray transparency of the three-dimensional object projected onto the flat film. Regions of high X-ray absorption in the specimen cause less blackening of the film than do regions of low X-ray absorption.

In fluoroscopy the apparatus arrangement is identical to that of radiography, except that the film is replaced by a fluorescent screen to permit direct viewing of the image. The advantages over radiography are that both the film developing time and the cost of the film, which may be as much as one half of the total X-ray inspection cost, are eliminated. The disadvantage is that the image has poorer quality because of the graininess and diffusion in the fluorescent screen. In photofluoroscopy the image on the fluorescent screen is photographed with a small camera; this has the advantage of a permanent record, but the small photograph has poorer quality than the large direct photograph. The film is sometimes placed between a pair of fluorescent screens so that the light from both screens serves to intensify the image on the film, although this causes some loss of definition. Xeroradiography, in which an electrostatically formed image is obtained, has been used in place of film and fluorescent screens in certain applications.

For a given X-ray tube voltage, the product of the tube current expressed in milliamperes (ma) and the exposure time in seconds is referred to as the exposure, which is expressed in milliampere-seconds (ma-sec). In radiography the continuous radiation is used. The X-ray output of the tube may be increased by increasing the voltage or the current, but the penetrating power can be increased only by raising the voltage. Since monochromatic X-rays are not used and since the object may have a nonuniform thickness, the exposure times can be calculated only roughly, and a few trial exposures may be required to obtain the optimum contrast. The elemental composition of the object is most important in determining exposure time and the selection of the X-ray tube voltage. For example, 200-kv X-rays are transmitted with approximately equal intensity through 1.2 in. of steel and 0.1 in. of lead.

The same geometric laws of shadow formation that are used for visible light apply to X-rays. Hence the sharpness of the image on the film is dependent on the size of the X-ray focus, the thickness of the object being X-rayed, the closeness and parallelism of the object, and the film. The smaller the focus and the thinner the object, the sharper the image. The definition becomes distorted when each point of the object casts a shadow that overlaps with the shadows from adjacent points. Increasing the distance between the focus and the film aids in improving the definition, but the intensity at each point in the photograph is reduced by the inverse square of the distance.

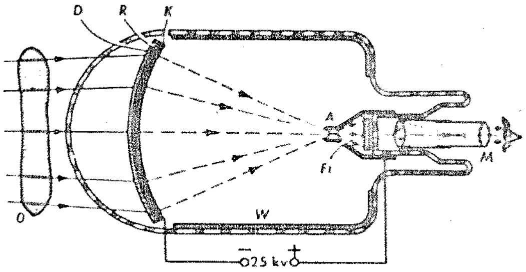
Scattering, diffraction, and fluorescence originating in the object, the film cassette, portions of the apparatus, or floor and walls of the room add to the background on the film, thereby reducing the contrast. Scattering is reduced by means of lead-foil screens surrounding the film to absorb the softer radiations, the use of a thick lead sheet on the back of the film cassette, and the use of various diaphragms to limit the beam.

In order to obtain perspective, it is necessary to make a pair of radiographs by moving the X-ray tube a distance equal to the separation of the eyes and to view the pair with a stereoscope.

Applications.—Radiography is used in a large variety of applications, such as to find gas holes in aluminum-alloy castings for aircraft; to inspect welds; to exercise quality control of electronic components such as vacuum tubes, resistors, and printed circuits; to detect porosity and shrinkage cavities in castings; to locate segregations in alloys; and to find cracks, ruptures, inclusions, and other defects in metallic bodies. (See Plate 4.)

Flash-radiographic systems have been developed that can photograph a rapidly moving object in a fraction of a second. A special X-ray tube with a field-emission cathode is used in conjunction with a capacitor charged to the required voltage. The capacitor is discharged by a trigger-ing electrode, causing current to flow to the anode and produce a high-intensity burst of X-rays.

Image Intensifier.—The image intensifier is an evacuated glass tube in which an X-ray fluorescent screen and photocathode are mounted, as shown in Fig. 24. X-rays entering the tube strike the fluorescent screen, and the emitted light causes electrons to be released from the photocathode. The number of electrons released from each point on the cathode is proportional to the luminous intensity of the screen at that point and hence also proportional to the incident X-ray intensity.

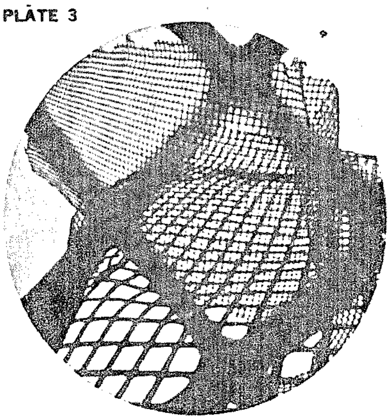


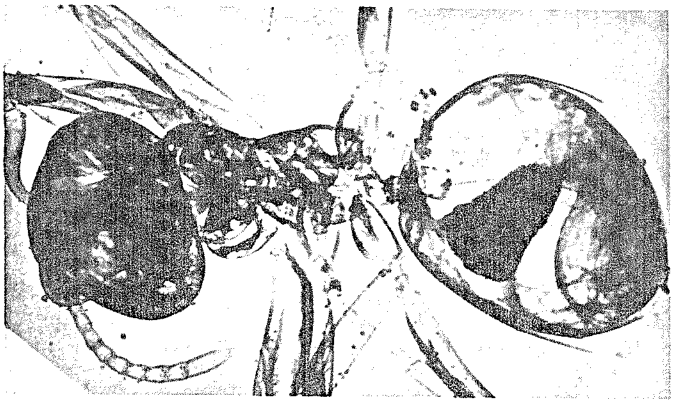
M. C. Teves, "Philips Technical Review," 1955

Fig. 24. Schematic cross section of image-intensifier tube. O, object exposed to X-rays; D, support carrying R, the first fluorescent screen, and K, the photocathode; A, hollow anode surrounding Fl, the viewing fluorescent screen; M, viewing microscope; W, conductive coating on interior of evacuated glass envelope.

An electric field focuses the electrons so that the image is reproduced, reduced by a factor of about 9, on the viewing fluorescent screen. The electrons cause visible fluorescence and the luminous image can then be viewed by a simple microscope or binoculars with about 9× magnification, so that the image is seen in its original size. This

PLATE 3



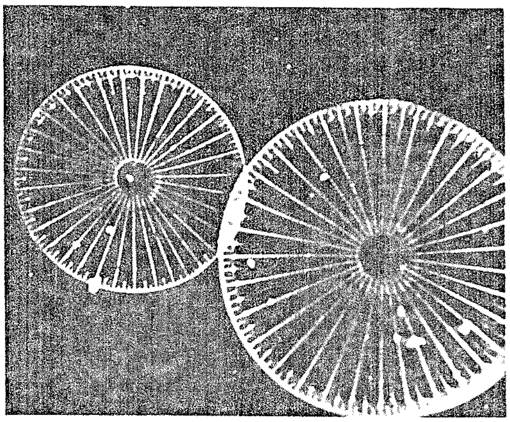


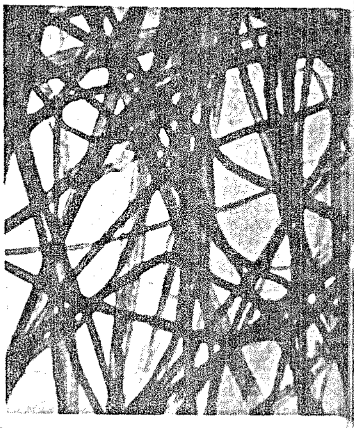
Above: 1,500-mesh-per-inch silver grid wire, showing large depth of focus and exactly correct perspective.

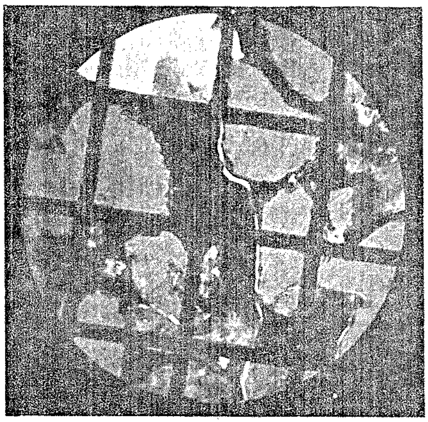
Upper right: Ant, showing internal structure. Gold target, 10 kv.

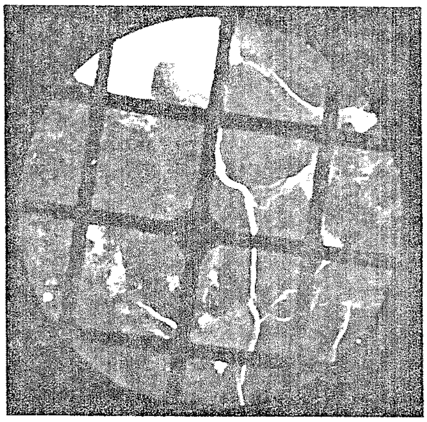
Right: Diatoms (*Arachnoidiscus*), gold-shadowed.

Far right: Tissue paper, treated with alcohol-iodine solution to enhance fiber contrast.









Far left: Sandstone, mounted on 75-mesh-per-inch copper grid. Cu target.

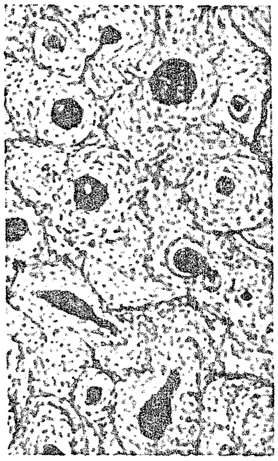
Left: Same field and specimen as for (far left), but Fe target. Specimen contains an iron-bearing mineral that strongly absorbs the Cu radiation and transmits the Fe radiation. By comparing the two photographs the exact distribution of iron can be seen.

X-RAY MICRORADIOGRAPHY

Left: Thin section of bone. White areas have greater X-ray absorption than black areas. Osteocytes and differences in density of mineralization are clearly visible.

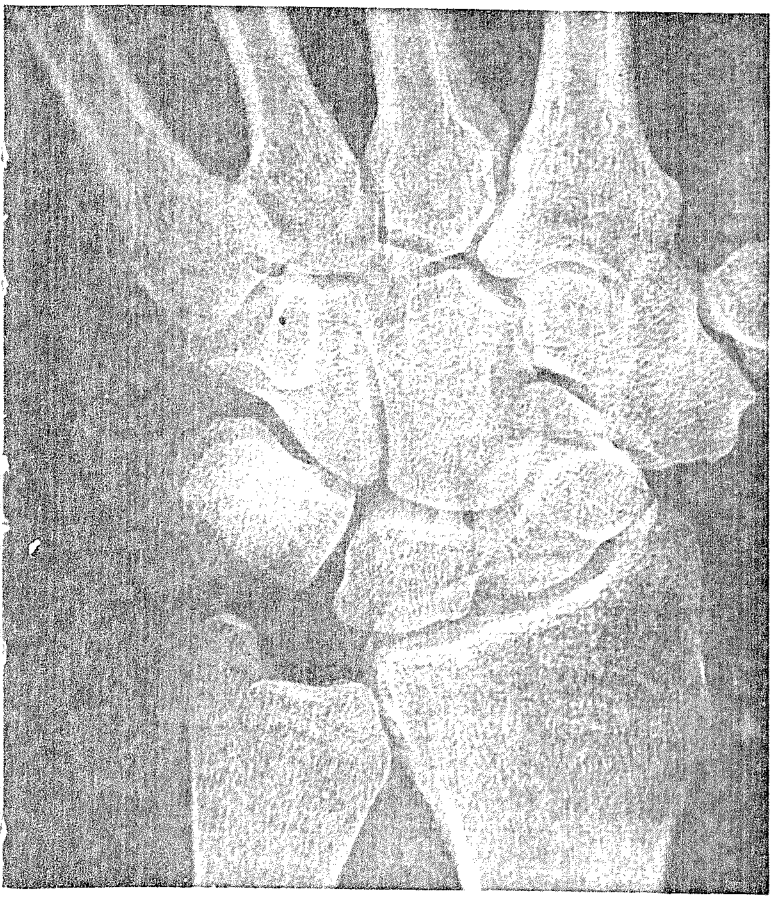
Center: Microscope view of same section as for (left) in ordinary light. Note that mineralization does not show.

Right: Microscope view of same section in polarized light.



The three bottom right panels are contact microradiographs. All others are projection microradiographs. (Top row) Ong Sing Poen, "Microprojection with X-Rays," Martinus Nijhoff, The Hague, 1959; Ong Sing Poen. (Second row) Ong Sing Poen, "Microprojection with X-Rays"; Ong Sing Poen. (Third row) Ong Sing Poen. (Bottom row) R. Amprino and A. Engström, "Studies on X-Ray Absorption and Diffraction of Bone Tissue," Acta Atomica, S. Karger, Basel/New York, 1952

PLATE 4

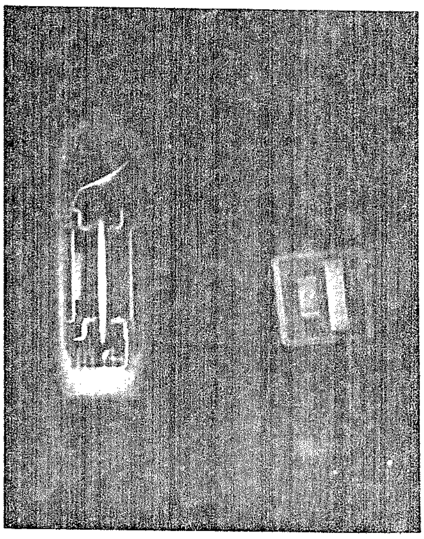


Left: Human wrist. X-ray absorption in bone is much stronger than in surrounding flesh, and bones appear as light areas. Where bones are superimposed, additional absorption outlines the details of overlapping bone structure.

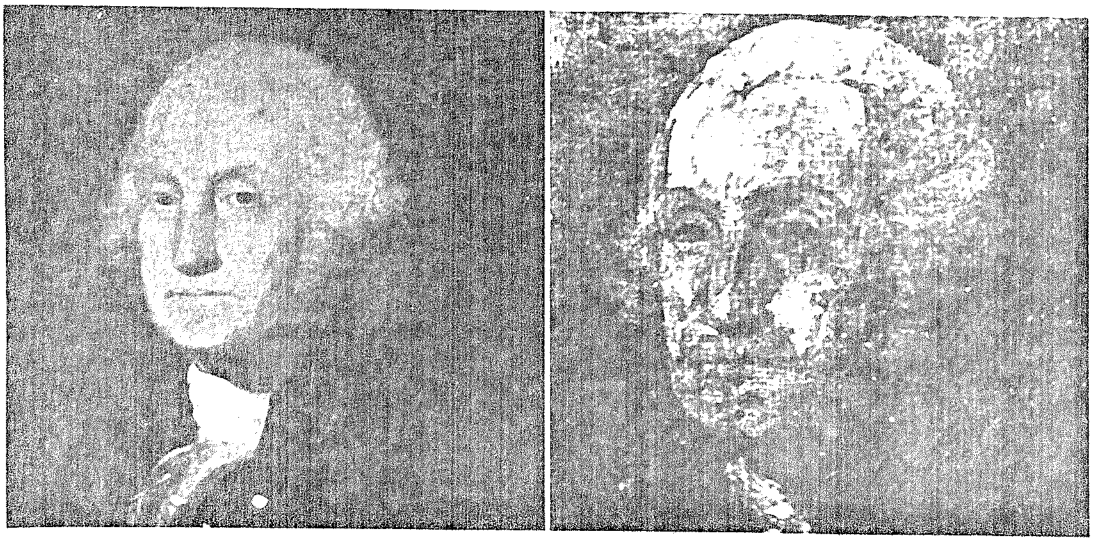
RADIOGRAPHY

(Left) St. Francis Hospital, Evanston, Ill.; (below) Philips Electronic Instruments; (bottom, left and right) from "Roentgen Examination of Paintings" by Stanley H. Macht, M.D., and Bruce Etchison, The American Journal of Roentgenology, Radium Therapy and Nuclear Medicine, Detroit, Mich., November 1960

Right: Electron tube and microphone. X-rays used for checking internal structure not visible to eye for quality control. Both pictures are two-minute exposures on single-emulsion film obtained with a fine focus (0.4 mm) X-ray tube operated at 120 kv, 5 ma.



Below: This portrait of George Washington was examined to determine whether it was one of many painted by Gilbert Stuart. By comparing the roentgenographic study (below right) with one of an authenticated Stuart work, similarities and differences were noted, and it was established that this was not the work of Stuart.



image, however, is much brighter than the original image on the first fluorescent screen. This intensification results from two factors. First, the high voltage applied between the photocathode and viewing screen imparts high energy to the electrons, thereby increasing the fluorescence intensity on the viewing screen to 10 to 15 times that on the first fluorescent screen. Second, the size of the image on the viewing screen is reduced by 9^2, so that the light is emitted from an area 81 times smaller than the first screen. The product of these two factors gives a gain in intensity of from 800 to 1,200, and the image resolution is as good as that of the fluorescent screen normally used in fluoroscopy. Hence it is possible to decrease greatly the normal X-ray dose received by a patient in, say, chest fluoroscopy and also enable the patient to be examined in a room with moderate lighting without the physician requiring eye adaptation. The increased intensity also makes possible X-ray motion pictures without excessive radiation dose to the patient. The image intensifier has also been used in many types of industrial radiographic examinations.

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7. Medical Uses of X-Rays

With the advent of X-rays mankind gained one of the most powerful tools in the long history of medicine. For the first time it became possible to peer into the innermost recesses of the body without the aid of the surgeon's scalpel. It also became possible to apply medical diagnostic methods to hitherto completely inaccessible areas of the human body by painless, efficient techniques. Few discoveries have had such far-reaching effects and universal application as that of Roentgen. His X-rays are employed all over the world and have made an immeasurable contribution to the early diagnosis, control, and treatment of disease. It is equally true that the full possibilities of X-rays are not yet understood and that increasing uses of them may be achieved in the future.

The term "radiology" is used to designate those branches of medicine concerned with X-rays, other ionizing radiations, and radioactive substances. From the beginning the diagnostic uses of X-rays have been chiefly divided into fluoroscopic and radiographic techniques. X-rays are also employed as a method of treatment and have a wide application ranging from the acne or pimples of the adolescent to the widely prevalent bursitis or shoulder pain and deep-seated cancers in remote areas of the body. See RADIOTHERAPY.

Fluoroscopic Techniques.—Frequently, fluoroscopic examination of portions of the human body precedes other X-ray methods and constitutes a way of examining the body in motion. It is accomplished by placing the patient between the X-ray tube and a special fluorescent screen. When the rays strike the screen they cause the particles in the screen to glow strongly enough to be easily seen in a completely darkened room. When the patient is placed between the X-ray tube and the screen, the difference in density of various parts of the body causes a varying shadow to be cast on the screen, enabling the observer to distinguish between different parts of the body. This effect is further enhanced if the observer has accommodated the pupils of his eyes by wearing special goggles before going into the darkroom. In addition, various techniques are adopted to accentuate contrast in this method, such as the use of radio-opaque solutions that cause a dense shadow to be cast on the screen.

One of the most frequent uses of fluoroscopy is in the investigation of the alimentary canal or digestive system. This method was pioneered by Dr. Walter Bradford Cannon (1871–1945). In order, for example, to diagnose disease of the esophagus or swallowing tube, the patient is given a solution to drink that is sufficiently dense to cast a clear-cut shadow on the fluorescent screen. The opaque medium usually employed here and for other parts of the digestive system is barium sulphate. The patient stands behind the screen in the darkroom holding a glass of barium sulphate, and the observer takes a position in front of the screen with the controls of the X-ray unit at hand. The patient is then told to drink from the glass, and on the screen the observer is able to see the entire swallowing process and follow the barium into the stomach. If there is any adverse condition affecting the esophagus, such as inflammation, a swallowed bone, or a tumor, the drink of barium sulphate will outline the effect of the condition on the structure of the esophagus. For example, if the patient had swallowed, whole, a chunk of meat that had lodged midway down the esophagus, the barium sulphate would stop at that point and indicate just where the meat was located. If it became necessary to operate, knowledge of the exact location of the obstruction would be of extreme value to the surgeon.

A similar technique is employed for investigation of the stomach. The stomach is filled with barium sulphate and outlined on the fluorescent screen. The motion and action of the stomach are clearly seen, and abnormalities of function as well as structure may be identified. Examination of the large colon or intestine is also carried out by this method. In this case the barium sulphate is administered as an enema from the rectum and the observer is able to visualize the rectum and the colon. Many persons have been saved from cancer by having the curable conditions that precede cancer in the colon discovered and corrected in time.

Examination of the heart as a moving organ is best done with the fluoroscopic screen. Where previously doctors labored with listening and tapping aids to draw a mental picture of their patients' hearts, it now is possible to see the heart in its functioning state and to watch it expand and contract. At the present time this method has become so well accepted that it is a rare heart specialist who does not have a fluoroscopic device in his office for this purpose. At the same time that the heart is examined the lungs are inspected and the movement of the diaphragm is observed.

The fluoroscopic screen has different uses for the various specialties in medicine. The orthopedic or bone surgeon checks fractures with it. The industrial or military surgeon uses it to locate metallic fragments resulting from industrial accident or military gunshot. The pediatrician or baby doctor looks for an inhaled candy ball or toy. The chest physician searches for early evidence of lung tumor. This partial list of present uses of fluoroscopy is continually being expanded.

Radiographic Techniques.—Techniques to obtain a picture of some part of the interior of the body are now standard medical practice all over the world. These methods differ from fluoroscopy in that a still picture is obtained, with no indication of the motion of the part X-rayed except when enough separate films are taken to simulate a cycle of motion. These stills, however, play a most important role in medical diagnosis and generally show a finer detail throughout than it is possible to obtain on the fluoroscopic screen.

An enumeration of all the uses of X-ray films would be extremely lengthy. Suffice it to say that there is no part of the body that is exempt from the probing of the X-ray eye and that medical diagnosis has become markedly dependent upon X-ray findings, so much so that a complete medical specialty has grown up around Roentgen's discovery and doctors devote years to training in the various aspects of X-ray technology.

The uses of special substances to show organs in the body reach into many branches of medicine. The kidney specialist may wish to determine the location and effect of a kidney stone. There are available to him several medications that, when injected intravenously, will render opaque the internal kidney structures as well as the tubes leading to the urinary bladder and the bladder itself. In some cases he will inject the contrast medium through an instrument inserted from below into the bladder. X-rays taken at this time show the structures in considerable detail and enable the physician to locate the site of disease.

The gallbladder is a relatively frequent offender. A contrast medium has been perfected that, when taken by mouth, will render the gallbladder dense enough to be seen on an X-ray film. In this way gallbladder function and the possibility of stones are determined. Even after the gallbladder is removed there are ways of studying the remaining bile passages with contrast media and X-ray films.

The problem of sterility, or inability to bear children, has come under X-ray observation. The specialist may inject material that will render the female reproductive tract opaque and show the structures on X-ray film. In this way the exact cause of sterility may be found and its correction attempted. Following conception, X-rays are used to measure the female pelvis in order to determine whether the unborn infant can pass safely down the birth canal. By means of this technique, many children are now delivered safely, whereas formerly they might have hemorrhaged intracranially and as a result been born with brain damage and paralysis because of small maternal passages.

X-ray studies have been of great assistance to the neurologist and neurosurgeon. X-ray photographs of the skull and spine may point the way to the diagnosis. Specialized techniques are also available. For example, in the diagnosis of spinal-column disease the specialist may inject an opaque solution and watch its passage up and down the spinal canal with the fluoroscope. He may also inject air for special brain studies, especially to diagnose and locate brain tumors.

Preventive medicine has benefited vastly by the employment of X-ray techniques. Chest surveys for the early diagnosis of tuberculosis, with resultant decreased time of treatment and diminished risk to contacts, are a commonplace. This screening technique has been applied in government, industry, the armed services, and community life.

Many advances have been made in refining techniques for the purpose of early diagnosis, especially in the heart and cancer fields. Methods of showing the inner structures of the heart are of particular importance to children born with defective hearts who had previously been condemned to ever-constricting activity and ultimate death. These cases include the so-called blue babies, babies with a faulty circulation of the blood that causes them to have a bluish cast. Diagnostic methods now make possible an early determination of just where the heart defect may be and enable the surgeon to utilize appropriate surgical techniques.

Another development of note enables the radiologist to take films at designated levels in the body in an attempt to determine more precisely the site of disease. This technique is known as laminography and is particularly important in the chest, where tuberculous cavities must be located precisely for the chest surgeon. For the further determination of depth and for the localization of objects within the body, a stereo technique called stereoroentgenology is employed. In this method, two films are exposed following a small shift in position of the X-ray tube corresponding to the distance between the radiologist's eyes. The object being X-rayed remains stationary. The two films are then viewed in a stereoscope so that the illusion of depth is achieved. This method is used, for example, to localize a foreign body in the skull preparatory to surgical removal.

The X-ray apparatus used for radiography and fluoroscopy is undergoing constant change and there is a steady flow of specialized accessories designed to facilitate more modern procedures. One of the most notable of these is an electronic device that increases the brightness of the fluoroscopic image. See also VETERINARY MEDICINE—*Practice* (Specialization): Radiology.

Radiation Hazards.—The hazards of X-rays are being reemphasized in this age of atomic radiations. Improper use may result in damage being done to all personnel concerned, and the history of radiology is replete with its martyrs. This means, in effect, restricting X-ray procedures to those types of disease in which the expectation of useful and pertinent information is a reasonable one. In addition, there should be full employment of protective devices and techniques directed principally toward reducing the amount of radiation received by the patient, the physician, and the technical staff. These include the proper use of leaded shields, modern equipment, and skilled technicians.

The government has begun to exert its influence on safety requirements, and inspection for compliance with existing regulations may become a routine occurrence. At the same time it must be stated that the preeminent position of the X-ray method in the diagnosis of disease should not be downgraded because of radiation hazards. In the hands of skilled technicians and well-trained radiologists, the risks can be reduced to a minimum and the great benefits retained.

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