Fluoroscopic Examination of Metallic Objects

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ALTHOUGH since their discovery some half century ago, X-rays have been used in a big way for medical applications, their industrial applications to metallic materials has been restricted primarily to the detection of flaws in castings and other metal parts by radiography. In radiography, the image of any defect is recorded on a photographic film. The industrial application of fluoroscopy, that is, the observation of metallic objects by means of fluorescent screens, has been very slow. This condition may be attributed, in part, to insufficient knowledge of the signficance of the observed image on the fluorescent screen. Even in radiography, the absence of a thorough understanding of the significance of certain defects has led to the tendency to play well on the safe side and to reject structural items for any detectable defective condition.

During the war a large tonnage of X-ray film, besides much critical equipment and manpower, was used to inspect radiographically very large quantities of aluminum alloy and magnesium alloy castings used in aircraft. The acceptance standards in many cases were set so high that castings could not have any radiographically detectable defects if they were to pass inspection. This drastic selection procedure may be justified on the basis that if only one bomber could be saved, it would be worth the loss of questionable parts by rejection. However, the real basis for this procedure has been lack of confidence brought about by absence of precise knowledge. The use of the much more rapid and cheaper method of inspection, by fluoroscopy, was not considered to be adequate because the very small defects observed on X-ray film could not be detected with the fluoroscopic equipment then available.

THE PROBLEM

It is recognized that if the limitations of fluoroscopy, as applied to metallic parts, could be established, time and photographic materials could be saved. Several individuals associated with aircraft production problems, sensing the unsatisfactory foundations of X-ray inspection and the benefits to be derived from fluoroscopic inspection, recommended that the Office of Production Research and Development of the War Production Board support an investigation of the possibilities and limitations of fluoroscopic methods of inspecting metallic materials. This investigation was assigned to the California Institute of Technology under a contract with the Office of Production Research and Development of the War Production Board.

The purpose of this investigation was to determine the limitations and the reliability of fluoroscopic methods of examination of metallic materials, in comparison with radiographic methods, as a supplement to, or replacement for, radiography of metallic materials, and to extend the field of usefulness of fluoroscopy by improvement in equipment and technique.

PRELIMINARY SURVEY

As this work was started, commercial fluoroscopic equipment was only beginning to make its appearance for the examination of industrial products. This equipment was largely limited to specially designed industrial units for detecting frozen fruit, or detecting foreign matter in foodstuffs, or for the examination of plastic parts. As one of these industrial units was not immediately available, a somewhat similar unit was constructed at California Institute of Technology. This consisted of an oval, wooden structure on which were mounted sliding trays attached to an endless chain driven by a motor. These trays, traveling within a tunnel structure, were loaded with the object to be examined. The object then passed over an X-ray tube mounted below the trays, suitably protected with lead sheet. Above the trays, on the observer's side of the equipment, were a fluorescent screen and a lead glass protective window. The observer was then able to look through the lead glass screen with safety and observe the image of the object on the fluorescent screen. The X-ray tube, having a focal spot of 2.4 mm., was mounted at a point 20½ inches below the trays carrying the object. The X-ray equipment was operated at a voltage of 140 kvp.

As a preliminary measure, this equipment was taken to several commercial foundries where large numbers of identical castings could be examined. More than 6,000 castings, including sand castings, permanent mold castings, and die castings, of 356T6, 195T6, and 43 aluminum alloy, and sand and permanent mold castings of Dow metal 17 and other magnesium alloys, were examined by members of the project

AT LEFT:
Front view of commercial fluoroscope unit constructed at C.I.T. showing fluoroscent screen and lead glass protective window.

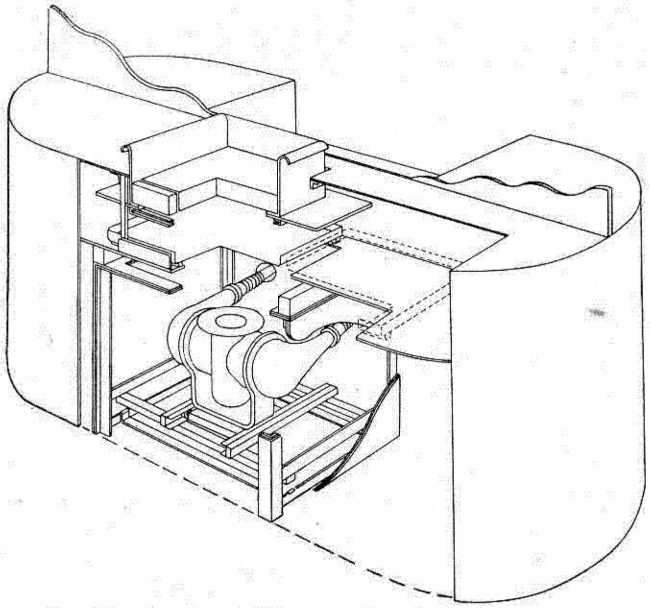
staff. The whole purpose of this program was to become acquainted with the nature of the problem of fluoroscopy.

With fluoroscopic examination it is customary to adapt the observer's eyes to the dark before beginning observation. This is normally done because of the low intensity of brightness on the fluoroscopic screen. Such a procedure was followed in this exploratory study. However, it was found that adaptation to the levels of illumination present on the fluoroscopic screen rather than to the dark was desirable. In general, the results of this preliminary study were enlightening only in the sense that fluoroscopy under the conditions experienced could serve as a screening test prior to radiography for the detection of large defects. Furthermore, conditions were not always reproducible at the places where the investigations were made. It was apparent that certain variables required investigation.

VARIABLES

The fluoroscope was modified so that the effect of some of the variables could be studied. The X-ray tube was mounted so that it could be adjusted to any distance from the object that might be desired. A set of artificial specimens was made. These consisted of sandwiches of two flat blocks of 3SO aluminum alloy, each block being 2½ inches long, 1½ inches wide, and ¼ inch thick, making the total thickness of each specimen ½ inch. The effective thickness of these specimens was increased by adding additional sheets of aluminum. Artificial defects in the forms of spherical cavities, long cylindrical cavities, and flat, washer-shaped cavities were introduced at the surface between the two blocks of each sandwich. These defects were of known dimension. A group of these specimens was then placed in the field of observation together with some specimens which did not have any defects. A large number of observers examined these specimens and reported what they saw. The thickness of the defects varied from 0.005 inch to 0.063 inch. Each of the observers was scored for each observational condition, namely, the position of the tube and the position of the screen with respect to the casting. The first, and probably most significant, result was found when the X-ray tube was only a short distance from the object under examination. This condition had the effect of increasing the intensity on the fluorescent screen by a factor of almost 10. The visual brightness of the screen became sufficiently high to make seeing an easier task and to make dark adaptation of the observer unnecessary. Under this condition it was found that anyone, old or young, having ordinary good vision for reading, made a satisfactory observer, although some persons were more imaginative than others.

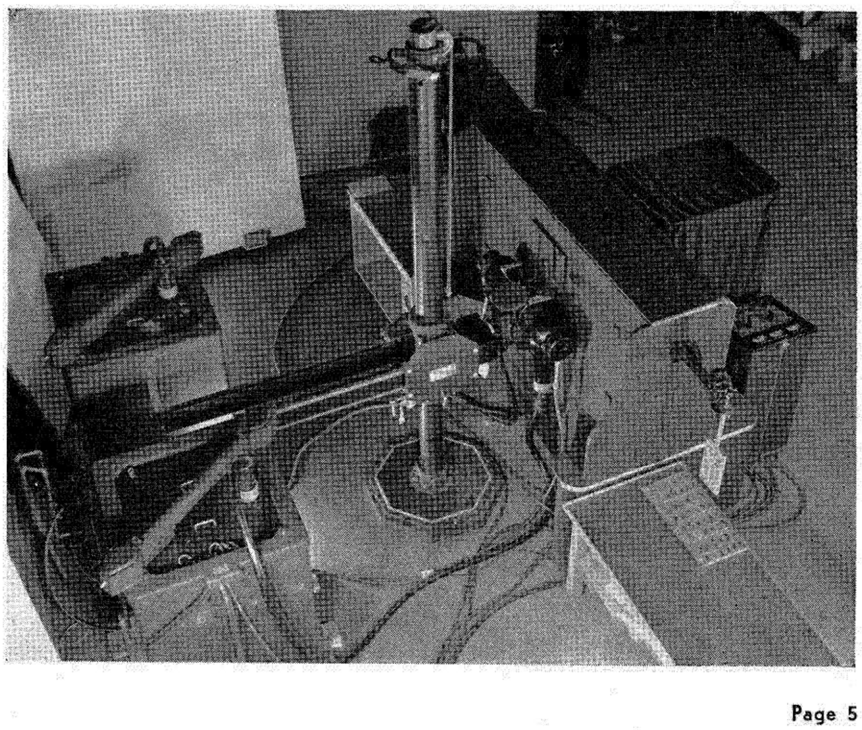
With the higher X-ray intensity obtained with a short tube screen distance, it was found that the lead glass discolored very rapidly, making observation difficult. This difficulty was eliminated by utilizing a new type of protective window. This consisted of a lucite box or cell filled with a saturated acqueous solution of lead perchlorate. Lead perchlorate is sufficiently soluble in water so that the actual lead content of a 3 inch thickness of the saturated solution is equivalent to about ¼ inch of metallic lead. If properly prepared, the solution is as clear as pure water. The refractive index of the solution is about the same as that of lucite, so that no reflections occur at the lucite-solution interface. X-rays appear to have no effect upon this window.



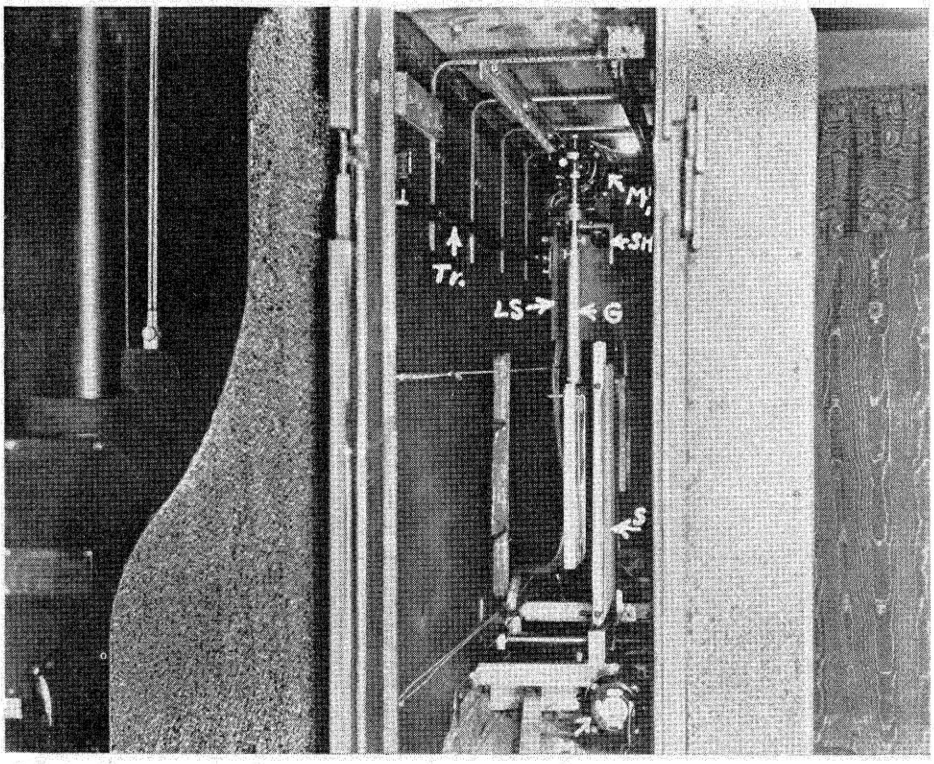
Outline drawing of first model of the fluoroscope

ROTATIONAL EFFECT

When the target of the X-ray tube is not far from the object being examined, a small relative motion of the tube and object produces an appreciable rotational distortion of the X-ray shadow on the fluorescent screen. Advantage was taken of this effect by making the tube movable across the normal field of view. By moving the tube back and forth it was then possible to examine first one side of a rib or lug and then the other. This is an important feature of fluoroscopy, and, coupled with the high X-ray intensity obtainable with short tube object



AT RIGHT:
Rear view of fluoroscope with 220 kv. constant potential X-ray unit (rock of artificial specimens are ready to enter fluoroscope).



AT LEFT:
View of inside of fluoroscope. SH-Shuttle, Tr-Shuttle track, G-Spindle for specimen support, M-Motor to rotate spindle. LS-Lead shield, S-Screen, M_2-Motor to position screen.

distance, brings fluoroscopy into the realm of commercial usefulness.

FIELD TESTS

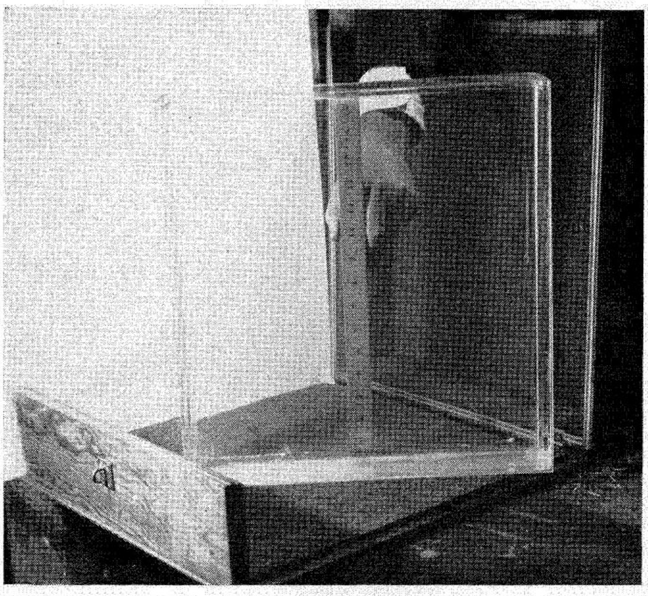
After the most suitable conditions for fluoroscopic observation had been established, the equipment was moved to three commercial X-ray laboratories, where some 10,000 aircraft aluminum alloy castings were examined with the fluoroscope. Installation of the equipment at these places permitted the inspection of large numbers of castings that were being radiographed. The radiographs produced on these particular castings were read by members of the project staff, who then compared the results with those obtained by fluoroscopic inspection. In all of the castings observed there was a total of approximately 14,000 defects. Of this total there were approximately 5,000 very small defects that were detected by radiography, but were not observed fluoroscopically. On the other hand, approximately 1,700 larger defects were observed fluoroscopically, although not detected on the commercial radiographs.

Undoubtedly this latter condition was the result of benefits derived from the rotational scanning effect obtained with the equipment utilized. It is probable that most of these larger defects could have been found radiographically, had more views been taken of the castings.

THE SIGNIFICANCE OF DEFECTS

One of the most important factors in the inspection of castings by radiography or fluoroscopy is a knowledge of the significance of the observed defects in regard to the strength characteristics of the part being examined. The basis for acceptance or rejection must be a rational one. To establish the size and character of a defect that will or will not reduce the strength of a given casting is not simple. The number, distribution, and character of defects are so widely diversified in even one type of casting that the problem becomes very complex.

In most respects the present basis for the rejection of castings by radiography is not strictly rational. It is founded upon the judgment and experience of those concerned with the use of the individual castings and upon the results of a few tests. With the demonstration that the fluoroscopic method of inspection is adaptable to the detection of certain types and sizes of defects within certain limitations of thickness, the question arises: Are the defects which can be seen in the radiograph, but are too small to be seen fluoroscopically, contributory to decreased strength of the casting? It is granted that some attempts have been made to obtain a correlation between the presence or absence of defects, as determined radiographically, and the strength of a given

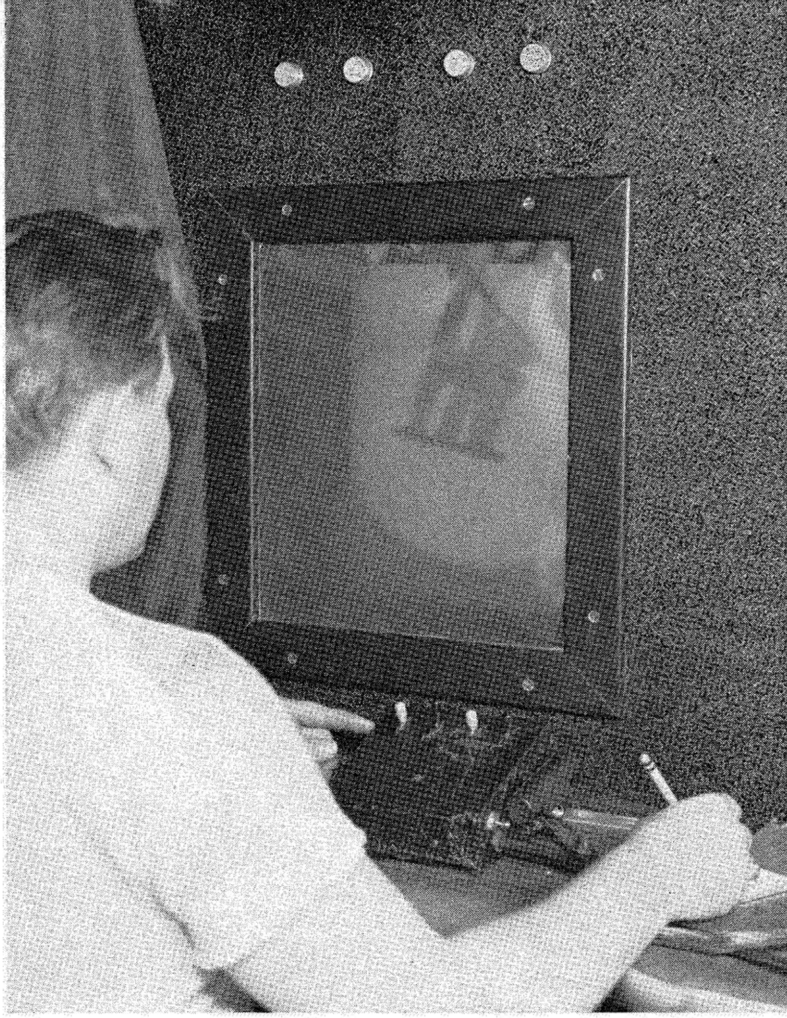


The lucite-lead perchlorate cell for protection of the operator during fluoroscopic observation.

casting. It appears that the study must be carried further on more of a statistical basis.

As an exploratory measure, approximately 500 pieces of a given casting were secured for investigation. Of these 500 castings, approximately 400 had been radiographically rejected by the consumer's inspector. The other 100 castings had been radiographically accepted. These castings were again radiographed by a commercial X-ray laboratory, fluoroscopically examined, and statically tested in a universal testing machine. From these tests it was found that the average strength of the castings which were accepted on the basis of commercial radiography was not greater than the average strength of the rejected castings. It was apparent that very large defects had some effect in reducing the strength of the part. It was particularly noticed that the variation in the strength of the accepted casting was in general as great as that observed in the rejected casting. This variation may well be associated with the variation in the strength of the material itself. It was further observed that defects which communicate with the surface near the region of maximum stress contributed more to failure than any other type of defect.

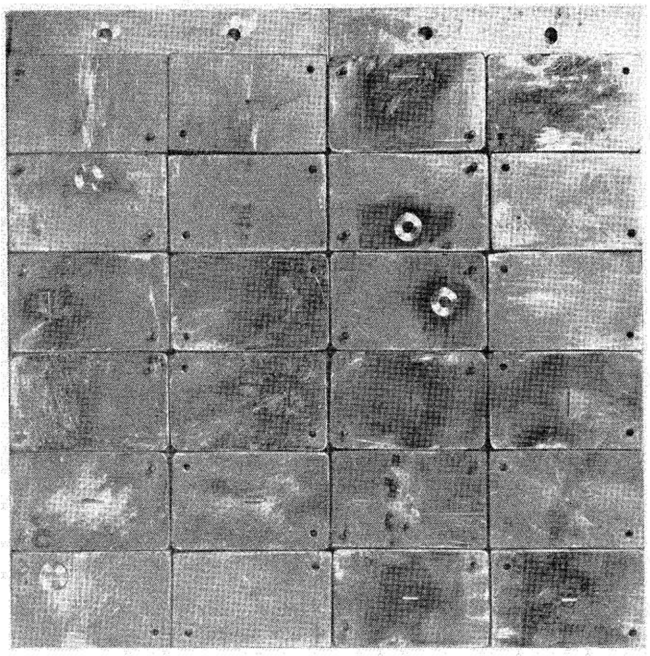
This preliminary work was carried out on some additional castings, although in not quite such large numbers. In general the results were about the same, and in general it was concluded, as a first approximation, that defects which could not be detected fluoroscopically had a negligible effect upon the strength of the casting. While these results do not give any quantitative evaluation of the significance of various types of defects, they have definitely pointed to a problem which should be investigated further.



A casting being viewed in the fluroscope.

RADIOGRAPHIC CONSISTENCY

One may pose the question: If a particular casting is radiographed independently by three different X-ray laboratories, all of which are well qualified to conduct such work, will the three radiographs all reveal the same defects? To assist in securing an answer to this question, approximately 2,000 castings were submitted in turn to three different commercial X-ray laboratories. Each laboratory used its own technique in making the radiographs. All of the radiographic films produced by all of the laboratories were then read by a member of the project staff. These same castings were then inspected fluoroscopically and a record made of the examination of each casting. These results were then analyzed, defect for defect. This analysis showed that less than half of the defects detectable on the films of one of the three laboratories were detectable on the films of the other two laboratories. In other words, approximately 5,000 of the total of 10,000 defects were detectable on the films of all three laboratories. Approximately this same number of defects was observed fluoroscopically.



Showing artificial defect specimen—inner surface. The number, distribution and character of defects are widely diversified.

It appears from this study that the number of defects that can be detected in an aluminum alloy with a fair degree of certainty by commercial radiography is comparable with the number that can be detected with high brightness rotational fluoroscopy.

HIGH VOLTAGE FLUOROSCOPY

With the experiences cited so far, in which equipment operating at a voltage of approximately 150 kvp was employed, one may ask: "If higher brightness of the screen resulted in considerable improvement in the results, why would not higher X-ray voltage give considerable improvement?" Certainly with thicker castings higher brightness can only be secured by using higher voltages, thus securing greater penetration of X-rays. However, it is known that at higher voltages the X-ray contrast is decreased. In spite of this decrease in contrast, the increase in brightness of the screen may have a compensating effect.

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The data which are presented on the atmospheric chart represent the best information available at the present time and have been gathered from many authorities on the subject. As more and more information is obtained these data may have to be modified and extended.

One potential source of direct measurement of atmospheric characteristics at extremely high altitudes is the sounding rocket. Notice that the German V-2 rocket is reported to have achieved altitudes of more than six times as high as any other man-made device yet flown. Balloons are definitely restricted as to their maximum altitude. since they rely on the weight of the surrounding air to support them.

NEW RESEARCH FIELDS

For our present knowledge of the air we fly in. we are greatly indebted to the painstaking and sometimes unrecognized research of many scientific institutions. As man's inquisitive nature forces him to venture outside of the air realm in which we fly at present, he must rely entirely on the knowledge of these scientists if he hopes to return to the earth in safety. It is clearly seen, therefore, that air transportation's desire to learn more about the composition and characteristics of the earth's upper atmosphere opens a vast new field of scientific research. The development of the rocket has supplied the scientist with a new tool with which he can investigate the upper atmosphere. It is hoped that now the scientist will be able to supply the aeronautical engineers with a reliable and complete knowledge of the atmosphere beyond which man-carrying vehicles have flown so that he, in turn. may design aircraft to extend the realm of "The Air We Fly In" to "The Atmosphere We Fly In" and. one day. "The Universe We Fly In."

Fluoroscope Examination

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To investigate the possibilities of higher voltage fluoroscopy, a fluroscope was constructed incorporating features which were found to be desirable in the use of the earlier model. The fluoroscopic viewing unit consists of a wooden frame structure mounted on heavy rubber-tired casters. The viewing window, a lucite cell filled with lead perchlorate solution, is 4½ inches thick and gives a viewing area of 16 inches by 14 inches. The fluorescent screen is mounted in an aluminum frame which can be moved toward or away from the viewing window by means of a motor. The object under examination is hung from a support mounted on a shuttle. This shuttle, mounted on small ball-bearing wheels, runs on tracks within the cabinet. The shuttle can then be driven into or out of the cabinet. bringing the object to be examined in front of the viewing window. When one end of the shuttle is outside the cabinet the other end is in the viewing position. The cabinet is lined with lead sheet ¼ inch thick. providing ample protection for personnel. During observation the operator may move the part being examined back and forth across the field of view. Provision is also made so that the casting can be rotated as it hangs in front of the viewing window.

The X-ray tube is mounted on its tube stand and is provided with a counter-balance so that it can be moved up or down with ease. The tube port extends through a hole in the cabinet. and protection is provided by means of suitable lead flanges. The tube can be moved up or down a distance of 4 inches from the center position by means of a motor mounted on the cabinet itself.

For the higher voltage work a 220 kv constant potential unit was secured as a loan through the courtesy of the Westinghouse Electric Corporation. This tube had a focal spot of approximately 5 mm. It is common practice to employ X-ray equipment producing half-wave rectified voltage. However. one might expect for fluoroscopic examination that the higher output of constant potential type equipment would prove to be superior. in view of the higher screen brightness attainable. The aluminum artificial specimens referred to before were again utilized in the evaluation of this equipment. Complete tests were made with aluminum varying in thickness from ½ inch to 2½ inches. at voltages varying from 140 to 220 kv. In all of these tests the tube current was maintained at approximately 15 ma.

The results of these tests indicated that no particular advantage was to be gained in the detection of defects 0.050 inch or less in maximum dimension in aluminum in the range of thickness from ½ inch to 2½ inches by using X-ray tube voltages greater than approximately 150 kv. Furthermore. it was evident that there is no particular advantage in constant potential X-ray equipment over the commonly used half-wave rectified type.

In view of the greater X-ray density of steel, it was believed desirable to study the performance of this equipment with samples of steel containing artificial defects. A series of samples was made in the same manner as described for aluminum; thicknesses of from ¼ inch to ½ inch. and voltages of from 140 to 200 kv were employed. The results of these tests indicated definitely that the results secured by operating at a voltage of 200 kv were better than those obtained at 140 kv. It is therefore apparent that with higher voltages fluoroscopy of steel is possible within a certain range of thickness.

FURTHER STUDY REQUIRED

While these studies have been exploratory. they have shown that fluoroscopy can be employed for the detection of certain classes of defects which may appear to be structurally significant. There is no reason why fluoroscopy should not be used as an inspection tool. provided its limitations are recognized. The influence of defects which either can or cannot be observed fluoroscopically, or for that matter radiographically, must be determined in any event, and this leads to a very fundamental research program which it is hoped may be considered sometime in the future.

RED CROSS FUND

THE American Red Cross enters its 1946 campaign for funds in February. The generous contributions made during the war must continue even though the budget has been reduced 45 per cent. More than any other agency. the Red Cross administers to the comfort and welfare of:

a) Our occupational forces. which still number 1,500,000.
b) The 170,000 servicemen still in the hospitals.
c) The several hundred thousand disaster victims (floods. tornadoes, etc.) in our own country each year.
d) Those unfortunates in the war-devastated areas overseas.

While this is but a partial list of major Red Cross activities. everyone should be able to pick out a particular reason for the urgency of his gift.

At C.I.T.. the campaign is being started February 25 by Bob Lehman '31. The support of your local solicitation is strongly encouraged.

R. A. Millikan.