Air Hygiene Foundation of America, Inc.,
4400 Fifth Avenue,
Pittsburgh, Pa.
June 8, 1939.

NOTE TO MEMBERS:

Enclosed is Bulletin No. 2 of the Medical Series issued by Air Hygiene Foundation. This work, under the auspices of the Medical Committee, reports the findings on X-ray research conducted at the University of Pennsylvania under a grant from the Foundation. The results are important both from a medical and an economic standpoint. Extra copies, in addition to the regular membership allotment, are available to members at $1.00.

H. B. Meller
Managing Director

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AIR HYGIENE FOUNDATION OF AMERICA, Inc.

Medical Series, Bulletin No. II

The Comparative Values of Chest Roentgenograms Made on Film and on Paper for Industrial Surveys

PITTSBURGH, PENNSYLVANIA
JUNE, 1939

THE COMPARATIVE VALUES OF CHEST ROENTGENOGRAMS
MADE ON FILM AND ON PAPER
FOR INDUSTRIAL SURVEYS

BY

AIR HYGIENE FOUNDATION OF AMERICA, INC.

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FOREWORD

Increased employer activity in the protection of employee health through elimination or control of occupational disease hazards includes the wider use of the physical examination. not only upon employment but periodically thereafter. An important part of this procedure is the roentgen examination of the chest.

It was deemed desirable to have available x-ray methods compared, the investigators to keep in mind the primary importance of diagnostic accuracy and, as well, the importance of time and cost where large groups of men are involved. Accordingly, in 1938, Air Hygiene Foundation asked the University of Pennsylvania to make such an investigation under a research grant from the Foundation. This bulletin, issued under the auspices of the Medical Committee of the Foundation. is a report on the work accomplished.

The study was directed by Dr. E. P. Pendergrass of the Department of Radiology of the Hospital of the University of Pennsylvania. Technical aspects were developed by the staff of the Moore School X-Ray Laboratory comprising Professor Charles Weyl, Dr. S. Reid Warren, Jr., and Mr. Dallett B. O'Neill. Mr. D. E. Haagensen, M. S. in E. E., conducted many of the tests.

The roentgenographic apparatus was borrowed from the Westinghouse X-Ray Company. The darkroom facilities of the General Electric X-Ray Corporation's Philadelphia office were made available for the processing of all of the test roentgenograms. Powers X-Ray Products, Inc., supplied the roentgenographic paper and the chemicals for processing the paper. Representatives of several x-ray film manufacturers cooperated in the project. In acknowledging the assistance of these companies, it should be stated that the scope of the experimental investigation might have been diminished without their generous cooperation.

Acknowledgment is made also to the 49 roentgenologists listed on page 18, who examined test roentgenograms and recorded their opinions in special questionnaires.

H. B. MELLER,
Managing Director.

4400 Fifth Avenue,
Pittsburgh, Pa.,
June 1, 1939.

THE COMPARATIVE VALUES OF CHEST ROENTGENOGRAMS MADE ON FILM AND ON PAPER FOR INDUSTRIAL SURVEYS*

INTRODUCTION

Throughout industry there has been a trend toward the use of a general physical examination of employees and of applicants for employment. This development has been due in part to increased interest on the part of employers in the health of employees and in part to the development of compensation laws for those employees who are incapacitated due to illness. Since diseases of the chest are thought to be the causes of an appreciable part of such illnesses, increasing importance has been placed upon chest examinations by physicians who are engaged in industrial work. The roentgen examination is an important part of the chest examination, and therefore of the complete physical examination. The question arises, then, as to how the roentgen examination of employees and applicants for employment should be conducted.

Leading roentgenologists agree that stereoscopic x-ray films of the chest made in accordance with the best modern technical methods are the necessary minimum requirement for accurate diagnosis. It is often impracticable for industries to make stereoscopic films of all employees since such a procedure is extremely costly and since the findings would be negative in many cases. It is, therefore, important to consider the use of a survey method which would permit the examining physician to determine which employees had healthy chests, and those in whom the roentgen findings were abnormal. The abnormal group could then be re-examined using stereoscopic x-ray films. The roentgen examination used for survey methods must be of such character that the results may be produced quickly and at low cost; at the same time the diagnostic accuracy of the examination must be such that those men with early lesions in the chest may be referred for further detailed examinations.

Two survey methods are at present available:

(1) Single pieces of 14 inch by 17 inch x-ray film may be used with suitable apparatus to produce single roentgenograms of each employee. The apparatus which is necessary to produce high quality chest roentgenograms is expensive and the personnel required to make the roentgenograms is also costly.

(2) A large number of roentgenograms of employees may be produced on rolls of sensitized paper. This work may be done by an agency which brings the apparatus to the factory, makes the roentgenograms, processes them, and delivers them to the examining roentgenologist. This method is speedy and less expensive than the method described above.

The question immediately arises: "What are the comparative values of single roentgenograms on film and on paper?" It is the purpose of this publication to describe tests which have been conducted during the past

* A preliminary report was presented by Dr. S. Reid Warren, Jr., at the annual meeting of Air Hygiene Foundation, held in Pittsburgh, Pa., November 17, 1938.

eight months for the purpose of answering this question. It is assumed throughout this discussion that, whenever the roentgen examination of a group of employees consists of a single exposure, each employee whose roentgenogram shows definite or suggestive evidence of disease, or some other abnormal findings in the heart or lungs, will be re-examined in order to obtain stereoscopic roentgenograms produced by modern high quality exposure techniques.

In the future there may be developed other survey methods; in fact some such methods are now being studied. In one company employees have been examined by means of the fluoroscope. In several laboratories methods are being studied for photographing the fluorescent image projected on a screen by means of an x-ray apparatus. Since the use of a fluoroscope does not permit the company to keep a permanent record of the results of the examination, this method is not believed to be practicable for industrial surveys. Since the method of photography of the fluorescent image was not developed sufficiently early to permit comparison with the results of these tests, no comments in this report apply to this method. This discussion is confined entirely to a consideration of the relative merits of the single film and paper roentgenograms for surveys. It should not be difficult, however, to use the methods described below to compare any new survey procedure with those procedures herein described.

Comparisons of paper and film roentgenograms have been conducted several times during the past ten years. Their comparative values have been a controversial question during this period. Many test roentgenograms comparing paper and film have been examined by one or by very few roentgenologists. In order to obtain more decisive results than those which have arisen from this method, the test roentgenograms in this investigation were submitted to 49 roentgenologists in the east and in the middle west. Most of these men are familiar with the problem of chest diagnosis in industry. Some are specialists in tuberculosis; about one-fifth of the total number have had considerable experience in the use of roentgenographic paper. Most of the men, however, have used x-ray film almost exclusively in their work.

The following material comprises a detailed discussion of the experimental procedure which has been used, of all of the experimental data, and of the records of the 49 roentgenologists who examined the test roentgenograms and who commented on their quality from the diagnostic point of view. The material is divided into the following sections:

I. The Physical Characteristics of Roentgenograms on X-ray Film and X-ray Paper.
II. Preliminary Experimental Procedure.
III. Roentgenographic Exposure Techniques.
IV. Test Roentgenograms and Questionnaires.
V. Physical Data of Test Roentgenograms.
VI. Roentgenologists' Comments on Test Roentgenograms.
VII. Conclusions.

A limited number of mimeographed copies of the summary report of these tests presented at the annual meeting of the Air Hygiene Foundation of America, November 17, 1938, are available for those who do not want to study the detailed discussion of the tests recorded in this paper.

I

THE PHYSICAL CHARACTERISTICS OF ROENTGENOGRAMS ON X-RAY FILM AND X-RAY PAPER

X-ray film consists of two layers of sensitized emulsion on the two faces of a sheet of transparent cellulose acetate. X-ray films are exposed by placing them in light-tight cassettes in which two intensifying screens are mounted, one intensifying screen being held in intimate contact with each of the two layers of sensitized emulsion. After exposure and processing, the x-ray film therefore comprises two superposed pictures. X-ray film is examined by means of light transmitted through the film. The characteristics of the finished film may be conveniently described in terms of three measurable quantities: density, contrast, and sharpness. Density is the characteristic of the film which determines how much light is transmitted through it.* It has values from something closely approaching zero for clear film to 2.5 or 3.0 for the extreme blacks. The contrast between two areas of a film is the difference in density between the two areas. The greater the contrast the easier it is for the observer to distinguish between two areas. Sharpness is the characteristic of the film which measures the blurring of shadow borders. Sharpness depends not only upon the roentgenographic apparatus and exposure technique but also upon contrast. In order to use these three descriptive terms during the presentation of the test material the following examples are presented:

Five negative prints of films (Figures 1-5)† are shown. The first, Figure 1, has medium average-density‡ and medium contrast. Note that the density in the shadow of the periphery of the lung does not become too low for adequate representation of the vascular structure of the lung. Note that nowhere within the chest shadow does the density become so high that the eye is unable to see the shadows of the parts within the thorax. The second, Figure 2, has a low average-density. In this illustration the shadows of parts of the lung projected in the areas of the base and of the periphery are not perceptible because the densities in these areas are too low. The converse disadvantage arises if the average-density is too high as in the case of the third illustration, Figure 3. So little light is transmitted through the dark areas that the eye is unable to see small density differences. Finally, in Figure 4 and Figure 5 the average-density has a medium value, but the contrast in Figure 4 is very high and in Figure 5 it is very low. One of the important results of this investigation has been the demonstration that ex-

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* Density D of an area of film which has been exposed and processed is defined by the equation: $D = \log_{10} \frac{I_0}{I}$ where I_0 is the intensity of the light incident upon the film and I is the intensity of the light transmitted through the area of the film.

† These figures, together with the charts mentioned later in the text, will be found in the pocket attached to the back cover of the bulletin.

‡ The average-density refers to half the sum of the maximum density within the diagnostic area of the roentgenogram and the minimum density within the same area. The following relations describe approximately the values of average-density discussed in this bulletin:

$$\text{"Low average-density"} = \frac{0.70 + 0.20}{2} = 0.50$$

$$\text{"Medium average-density"} = \frac{1.60 + 0.40}{2} = 1.00$$

$$\text{"High average-density"} = \frac{1.90 + 1.10}{2} = 1.50$$

perienced roentgenologists prefer a medium average-density and medium contrast film, and further, that it is unnecessary to obtain films having other characteristics for a preliminary diagnostic survey.

Roentgenographic paper is made of a sheet of paper covered with a single thin layer of sensitized emulsion so that only one intensifying screen is required. Since the base is opaque the paper roentgenogram must be examined by means of reflected light. Minimum densities (for paper, density is the characteristic which determines how much of the incident light is reflected by it) in paper roentgenograms are represented by the plain white surface of the processed paper. Maximum densities in the paper do not exceed 1.6. as represented, for example, by the area of a roentgenogram outside of the shadow of the body of the patient.

The two curves of Figure 6 show how the density and contrast characteristics of film differ from those of paper. The ordinates of these curves are densities. The abscissas represent the logarithms of the exposures. Any point on a curve represents therefore the density which is produced by a particular exposure. The following well known conclusions may be derived from these curves:

1. More exposure is required to produce a medium density (for example a density 1.0) on the paper than on the film. In other words film is faster than paper. This result might be expected since the film really comprises two layers of sensitive emulsion on one sheet of material while the paper has only one sensitive layer.
2. The increase in density for a given increase in exposure is greater for film than for paper. In other words the contrast produced on film is greater than that produced on paper for a given exposure of a given subject.
3. A greater density range is available in roentgenograms on film than on paper. This is due to the fact that the surface of the paper reflects a large part of the light even though the exposure of this area has been quite high.

The deficiencies of the paper described above have been generally recognized not only by those who condemn the use of paper for roentgenography but also by those who have supported the use of paper because it is an inexpensive survey medium. The latter have claimed that even though the paper is less effective than film in the reproduction of representative shadows of parts within the chest, these shadows are clear enough for preliminary diagnosis.

It was noted on one occasion during these tests that roentgenographic paper failed in normal use on a day when the temperature was between 90° F. and 95°F. and the relative humidity approximately 95%. The emulsion apparently softened under these conditions with the result that a number of roentgenograms processed under these stringent conditions were sufficiently damaged so that they could not be used. Films developed on the same day were entirely satisfactory.

Finished roentgenograms on film and on paper were placed in a space for which the air temperature was maintained at 100°F. for a period of six weeks. The relative humidity of this test chamber was approximately 50%. It is alleged that a test of this type is a means for finding out how the photographic material will stand up over a long period of time at normal temperatures of the order of 70°F. Both film and paper withstood the six-weeks test satisfactorily.

In the handling of x-ray films care must be taken not to scratch the surfaces of the emulsion. However, films will withstand a great deal of rough treatment in the form of bending with the fingers without being permanently damaged. The paper roentgenograms made in this test must be handled extremely carefully since it is an easy matter to bend the paper sufficiently to cause the emulsion to crack. Since the manufacturer of the paper has produced roentgenograms in large rolls which have been stored for a number of years and which are still in good condition, it seems probable that this cracking of the emulsion with handling is something which may often occur with single sheets of paper but will rarely occur when the roentgenograms are made on rolls of paper which are properly handled.

II

PRELIMINARY EXPERIMENTAL PROCEDURE

In order to conduct tests the purposes of which are described above it is necessary first to determine what roentgenographic apparatus and technique are best adapted to the peculiar conditions of a chest roentgenographic survey in an industrial plant. It is the general consensus of opinion that the best quality chest roentgengrams may be made by using apparatus capable of delivering to the x-ray tube currents of the order of 200 ma to 500 ma at voltages from 45 kvp to 90 kvp; a rotating anode tube should be used in order to produce minimum blurring or unsharpness due to focal spot size; an exposure time of 0.1 second or less should be used in order to minimize the unsharpness or blurring due to the motions of the parts within the chest; the control apparatus must be so designed that the quality of the chest roentgenogram may be reproduced accurately. These conditions can only be met by the purchase and installation of apparatus which is at once expensive and bulky. A company having employees whose chest roentgenograms they want to obtain may install such apparatus and produce roentgenograms of a quality equal to the best which is obtained in any x-ray department. However, this procedure is expensive. On the other hand it is not in general practicable for a company to send its employees to a hospital or to the office of a private roentgenologist where such apparatus is available. Oftentimes such apparatus is not available even in hospitals or private offices. If these two methods are therefore considered to be impracticable it is necessary to find out what apparatus may be obtained which has the following characteristics:

(1) It must be transportable by means of a small truck in order that an agency whose purpose it is to make the survey exposures may bring the equipment to, and set it up within, the industrial plant.

(2) The apparatus must be operable in connection with power supply transformers and lines having different rated voltages, current carrying capacities and voltage variations.

Most roentgenographic equipment requires a supply of alternating voltage which is constant within two percent throughout the times during which roentgenographic exposures are being made. It is often impossible to obtain a supply line having these characteristics in an industrial plant where sudden changes of voltage are produced intermittently by the operation of motors, welding apparatus, electroplating equipment, etc.

The roentgenographic apparatus most generally used for chest work comprises control equipment and a high tension transformer with rectifying valves together with an x-ray tube. It is often necessary to supply to the x-ray tube during the short exposure time energy at the rate of 45 kw. This corresponds to a line current (at 220 volts) of the order of 200 amperes. If the voltage of the supply line varies during the exposure due to the influence of loads other than that of the x-ray equipment, the exposure may vary in such a manner that the roentgenographic results are compromised.

In view of these facts it was decided to test a roentgenographic apparatus in which a condenser is charged to a high potential and subsequently discharged through the x-ray tube at the time of exposure. This type of equipment draws energy from the supply line during a period of 4 to 8 seconds. The peak voltage to which the condenser is charged is a function of the line voltage at the end of this charging period. Variations of line voltage which occur after the condenser is charged have no effect upon the x-ray tube voltage during the roentgenographic exposure. The energy taken from the line to charge the condenser remains in the condenser (which acts as a storage tank) until it is desired to make the roentgenographic exposure.

In general the x-ray tube current at any instant depends upon the x-ray tube voltage and the temperature of the x-ray tube cathode or filament. In this particular apparatus the full condenser voltage is applied to the terminals of the x-ray tube during the charging period. While the condenser is being charged, however, the cathode of the x-ray tube is maintained at such a low temperature that a very small current* flows through the tube.

After the condenser is charged and it is desired to make an exposure, a switch and relay system is used to produce a sudden increase in the cathode current. This causes a sudden increase in the temperature of the cathode. When the temperature of the cathode attains a sufficiently high value the energy stored in the condenser is discharged through the x-ray tube causing a pulse of x-rays to emanate from the tube. The duration of this pulse depends upon the adjustments of the cathode circuit parts. In these tests an exposure time of approximately 1/15 second was used.

The apparatus originally supplied by the manufacturer comprised a condenser having a capacitance of 0.25 microfarad which could be charged to a maximum voltage of 90 kvp. The quantity of electricity stored in this condenser at any peak voltage V kvp is equal to V/4 milliampere-seconds. Thus, if the condenser is charged to a peak voltage of 60 kvp the x-ray exposure will comprise a pulse having a peak voltage of 60 kvp and milliampere-seconds $60/4 = 15$ mas; if the condenser is charged to 80 kvp the exposure is $80/4 = 20$ milliampere-seconds. It was found that this apparatus could be used in conjunction with a line focus roentgenographic tube having an effective focal spot approximately 3 millimeters square at a focal spot-film distance of four feet to produce satisfactory chest roentgenograms of patients having chest diameters up to approximately 26 centimeters. When the chest diameter of the patient was greater than 26 centimeters, it was found that such a high voltage was required that the resultant roentgenogram did not have sufficient contrast within the diagnostic area of the film.

Since the apparatus produced satisfactory films for thin and medium weight patients but did not produce satisfactory films of heavy adults, of

* Even the small current produces x-rays of such intensity that the total "dosage" during the charging period may produce a deflection of two-fifths of full scale deflection of a Victoreen condenser r-meter used with a special bakelite ionization chamber for which the full scale deflection is approximately 0.25 r.

whom many are found in industry, the manufacturer was asked to supply an additional condenser like the one originally installed on the machine to be connected in parallel with it. With this connection the total capacitance was 0.5 microfarad. The milliampere-seconds passing through the x-ray tube when this larger condenser was used was equal to one-half the x-ray tube voltage in kvp. For example, when the condenser was charged to 80 kvp the exposure was 40 mas.

During these tests the apparatus was supplied by means of a 110 volt, 60 cycle alternating current line. It is a relatively simple matter to provide a transformer which will permit the use of alternating currents of this frequency at voltages other than 110 volts. Thus the equipment may be operated using power supply transformers and lines having various rated voltages, limited current carrying capacity, and relatively high variations of voltage without compromising the quality of roentgenographic results. It is this feature of the condenser discharge type of equipment which is advantageous in industrial survey work.

It was concluded therefore that the condenser discharge apparatus is satisfactory for chest roentgenographic surveys if both capacitances (0.25 mfd and 0.50 mfd) are available.

For all exposures with x-ray film, a bakelite front cassette was used with two Patterson Par-Speed intensifying screens. For all exposures using roentgenographic paper a similar bakelite front cassette was used with a single Patterson Par-Speed screen mounted on the back of the cassette. Thus in the case of film the x-ray beam passed through the patient, the front of the cassette, the front intensifying screen, the front emulsion of the film, the film base, the back emulsion layer, and the back intensifying screen in the order named. In the case of roentgenograms using paper the x-ray beam passed through the patients, the front of the cassette, the paper base of the sensitized material, the single emulsion layer, and finally the intensifying screen. The x-ray film is therefore a superposed double exposure produced by two intensifying screens and two layers of sensitive emulsion while the roentgenographic paper has only one intensifying screen and one layer of emulsion.

All of the x-ray film was developed in fresh developer for six minutes at 65°F. It should be noted that deviations from these values are permissible with x-ray film so long as one of the deviations is compensated by the other. For example, it is permissible to develop the film for five minutes at 68°F., or 4 minutes at 70°F., without compromising appreciably the appearance of the finished roentgenogram.

Roentgenographic paper was processed in the manner recommended by the manufacturer. The chemicals for making developer were supplied by the manufacturer of the paper. In this solution the paper roentgenograms were developed for 3 minutes at 68°F. Longer development sometimes produced brown stains on the finished roentgenogram, although no such stains were obtained when the paper and the solutions were used in accordance with the manufacturer's recommendations.

A viewing box was obtained for the examination of the x-ray films comprising a 250 watt frosted blue glass lamp mounted in a commonly used 14 inch by 17 inch film illuminator on the front of which there is a sheet of blue flashed opal glass. The light intensity of the surface of this viewing box under normal conditions is 250 foot candles with a maximum deviation over the surface of ±100 foot candles.

For viewing the paper roentgenograms the manufacturer of paper supplied a device comprising a flat metal surface on which the paper could be mounted, together with a light similar to a desk lamp which was held by means of brackets near the top of the paper holder. Two 60 watt lamps are used in this light and the light is projected through a piece of flashed blue opal glass to the surface of the paper. This light is reflected by the paper to the eyes of the observer. The light intensity at the surface of the paper holder has a maximum value of 100 foot candles and varies greatly over the surface, having a minimum value of 88 foot candles. Experiments indicate that it would be advantageous to increase the intensity of the light incident upon the roentgenographic paper. It is a relatively simple matter to take care of this defect in the paper illuminating device by increasing the lamp wattage, or by modifying the lamp mounting, or both.

An aluminum ladder having three steps of thicknesses 3/8 inch, 1/2 inch, and 5/8 inch was mounted on the cassette holder over the upper right hand corner of the cassette. For each exposure therefore x-rays passed through this ladder and produced an image of the ladder on the film. By this means a record of the overall roentgenographic effect of each exposure was obtained. Measurements of the densities of the steps of the ladder and of the densities within the shadows of the lung fields were made by means of two densitometers, a photoelectric densitometer being used for the film and a reflection densitometer being used for the paper. The densitometer used for the paper was of a type which may be used for the measurement of transmission densities as well as reflection densities. A few films were measured on both densitometers in order to be sure of the comparability of the final results.

III

ROENTGENOGRAPHIC EXPOSURE TECHNIQUES

The roentgenographic apparatus was adjusted to produce exposures of approximately 1/15 second. This adjustment was left unchanged throughout the tests. A focal spot-film distance of four feet was chosen since the average-density and the contrast of roentgenograms obtained with this machine were judged to be satisfactory at this distance. The use of a greater focal spot-film distance makes necessary an increase in the x-ray tube voltage and therefore a decrease in contrast. The use of a shorter focal spot-film distance produces excessive enlargement of the shadows of the parts within the lungs. This factor also remained constant throughout the tests. Records were kept of the weight of the patient and of the chest diameter measured by means of a rule after the patient had been placed in position in front of the cassette holder. The tube was always placed at the level of the second interspace below the prominent cervical vertebra.

In order to avoid differences in the appearances of films which were to be compared due to exposures in different phases of the cardiac cycle a device was installed to produce exposures always in the late diastolic phase of the cardiac cycle when the heart and vessel motions are thought to be minimum. By the use of this device direct comparison may be made of the roentgenograms made on paper and on film for a given patient without being confused by differences in sharpness which would have been produced if the exposures had been made in different phases of the cardiac cycle.

To summarize: The developing procedures, the focal spot size, the focal spot-film distance, the intensifying screens, the exposure time, and the cardiac phase during exposure were maintained constant throughout the tests.

X-ray tube voltage is therefore the only variable factor. It is necessary to measure and to judge the structure of the chest and then to specify what x-ray tube voltage will produce a roentgenogram having the desired characteristics. It is well known that, if the chest diameter alone is measured, the average-density of roentgenograms may vary considerably. There will be some films with low average-density because some patients have chest walls which are extremely fat or muscular or both. There may also be some patients' films for which the average-density is quite high because the chest walls are very thin. In order to produce uniform roentgenograms, therefore, it is necessary at least to measure the chest diameters and to estimate the type of chest wall.

In the preparation of the test material for this investigation roentgenograms were made both on paper and on film with low average-densities, medium average-densities, and high average-densities. Although it was believed that the medium-density films were most acceptable from the diagnostic point of view, it was also recognized that many roentgenologists have formed the habit of using light or dark films. Some films of this type were therefore included in order to find out how many roentgenologists liked medium-density films and how many liked high or low average-density films. For the medium-density films of patients with average chest walls the technique was as given in Table 1. Note that the x-ray tube voltage was approximately 6 kilovolts higher for the paper than for the film.

TABLE 1
Chest Roentgenographic Exposure Technique for Condenser Discharge Apparatus Used in These Tests

Chest Diameter (Average Chest Walls) cm	Condenser Capacitance — microfarad	Charged Condenser Voltage—kilovolts	
		For Film	For Paper
15	0.25	52.2	58.3
16	0.25	55.7	61.6
17	0.25	58.2	64.1
18	0.25	60.2	66.2
19	0.25	62.2	68.2
20	0.25	64.2	70.2
21	0.25	66.2	72.2
22	0.25	68.2	74.2
23	0.25	70.2	76.2
24	0.25	72.2	78.3
25	0.25	74.2	80.3
26	0.50	68.0	74.0
27	0.50	71.2	76.5
28	0.50	73.6	78.6
29	0.50	76.0	80.6
30	0.50	78.7	83.0
31	0.50	82.2	86.2
32	0.50	87.0	90.1

The data in Table 1 have been read from curves showing averages of experimental data. With the apparatus used for these tests the peak charging voltage could be changed in steps of 2 kv. These tests lead to the conclusion that the voltage control should permit the choice of voltage in steps not exceeding 1 kv.

IV
TEST ROENTGENOGRAMS AND QUESTIONNAIRES

From all of the roentgenograms made during these tests, two groups were chosen as being representative of the most important problems. These two groups of roentgenograms were taken to the laboratories of 19 roentgenologists in the east and in the middle west. Each roentgenologist examined the roentgenograms and recorded his opinion in a special questionnaire. Brief description of the character of these test roentgenograms, and of the mimeographed questionnaire is given below.

A single roentgenogram on film and a single roentgenogram on paper of each of 27 individual patients were selected from the test roentgenograms. These patients had chest diameters from 20 cm to 29 cm. Their weights varied from 104 lbs. to 210 lbs. Most of these roentgenograms were films of medium average-density. A few of the films were of low average-density and a few were of high average-density. The low and high density films were included in order to find out whether roentgenologists recognize a difference in the diagnostic values of films of various average-densities.

The second series of film and paper roentgenograms was made of 12 patients whose weights and chest diameters lie within approximately the same range as those included in the series described above. Six roentgenograms of each of the 12 patients were made on film and six on paper. The first exposure either on film or paper was purposely chosen to produce a roentgenogram of low average-density. The exposure was increased in five equal steps so that the sixth film and the sixth paper roentgenograms were of quite high average-density.

The names of the patients and the code numbers of their roentgenograms were listed on the first three pages of the mimeographed form. The x-ray film and the paper roentgenogram of the first patient were placed in their respective viewing devices. The roentgenologist was asked to examine the two roentgenograms and then to record on the mimeographed form the following data:

1. His opinion concerning the acceptability, from the interpretative point of view, of each roentgenogram, using the symbols D for "Diagnostic" and ND for "Not Diagnostic."
2. His opinion concerning the relative merit of each roentgenogram for preliminary diagnosis, using 4 for excellent; 3 for good; 2 for fair; 1 for poor.
3. A check mark in either the film or paper column to show which he preferred.

This procedure was followed for each of the 27 patients having single film and paper roentgenograms.

The roentgenologist then examined the series of 6 films of one of the 12 patients of whom 12 exposures had been made. He was asked to choose the particular film of the 6 which he thought to be of the best diagnostic quality. He was then given the series of 6 paper roentgenograms of the same patient and asked to choose the one of the best diagnostic quality. Finally he was asked to compare the film and the paper which he liked best for this patient and to record his opinion as described above for the individual film-paper comparisons. A minimum number of 4 patients was examined in this manner by each roentgenologist.

On the fourth page of the mimeographed form the following question was presented: "From the given examples of film and paper roentgenograms presented, do you believe that paper roentgenograms are satisfactory for industrial survey work? Yes.............. No................" Space was available below this question for each roentgenologist to write qualifying comments on the question and on his answer.

On Page 5 of the mimeographed form each roentgenologist was asked to state whether he thought that films or paper roentgenograms were easier to read and to describe in detail the reasons for his answer.

The roentgenograms were shown in this manner to 49 roentgenologists. The answers of these roentgenologists form the results of this investigation.

It should be emphasized that relatively few of the roentgenologists on this list have had wide experience in the use of, or the interpretation of, paper roentgenograms. It has been almost universally accepted, and nothing in this test procedure appears to contradict, that roentgenograms on x-ray film provide more accurate diagnostic data than roentgenograms on paper. This is due to the facts mentioned previously that the density range and the contrast on paper are less than those obtained on film. In view of these facts many roentgenologists in large hospitals and in private practice have used only x-ray film. Some roentgenologists who are interested in public health problems, and therefore in mass roentgenographic surveys, have made use of paper roentgenograms; a few of these men have examined the test results of this investigation and have commented upon them.

V

PHYSICAL DATA OF TEST ROENTGENOGRAMS

Since there are so many physical data of the test roentgenograms they are presented in the form of a series of charts. These charts have been prepared in such a manner that they may be examined individually or they may be placed on a table or desk to form one large chart comprising all of the experimental data. It is important to note certain correlations between the physical data and the data taken from the answers of the roentgenologists who examined the test roentgenograms. Thus, for example, in Chart B it may be noted that the roentgenogram on film of patient WB has received 9 votes "not diagnostic." Reference to the physical data of Chart A shows that this roentgenogram had a maximum density of 0.89 and a minimum density of 0.21. According to the discussion presented in Section I above this roentgenogram has a low average-density. Therefore, these "not diagnostic" comments indicate that more than one-fifth of all of the roentgenologists who examined the test roentgenograms cannot accept this film which has a low average-density. Interpretations of this general nature are presented in some detail in the following sections.

VI

ROENTGENOLOGISTS' COMMENTS ON TEST ROENTGENOGRAMS

The data recorded in the questionnaires by the 49 examining roentgenologists are presented in the form of charts (A, B, C, D, E, F), which are enclosed in an envelope fastened to the back cover of this bulletin. The following general notes concerning these comments have been abstracted from these data:

As stated in the introduction, roentgenologists in general agree that a single roentgenographic exposure, whether it be on paper or on film, does not constitute a sufficient basis for accurate diagnosis. If a single exposure

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method is used it must be recognized that all roentgenograms which show definite signs of pathology, or even shadows which lead the roentgenologist to suspect the presence of an abnormal condition, are indications for further detailed roentgen examination on film of the patients which they represent.

Practically all of the roentgenologists who examined the test material remarked that the quality of the paper roentgenograms in this test far excels the quality of paper roentgenograms which they had previously examined. They also stated that the films were of excellent quality.

Many of the roentgenologists (including ten men who favor the use of paper for chest survey work) stated that film has a greater density range than paper, that the contrast on film is greater than that obtained on paper and that in general roentgenograms on film appear to have greater sharpness than those which are made on paper.

There are tabulated below a few of the data recorded by the examining roentgenologists concerning the preference of film over paper or vice versa, and the relative diagnostic values of film and paper.

Of a total of 1,323 comments on the films of patients of whom single films and single paper roentgenograms were made, there were 39 "not diagnostic" comments concerning film and 117 "not diagnostic" comments for paper. If these data are correlated with the measured densities in the chest shadows it is found that no film having medium contrast and medium density has received a "not diagnostic" vote. In a similar manner the very light paper roentgenograms and the very dark paper roentgenograms received many more votes "not diagnostic" than those in the middle range. There were, however, some men who thought that a few of the best paper roentgenograms were not diagnostic. In the case of an industrial survey such patients would have to be called for special examination along with those in whose roentgenograms shadows indicating the presence of disease were found. For the same group of roentgenograms 912 comments indicated a preference for film over paper; 267 thought that the film and paper were equal from the diagnostic point of view; 116 preferred paper roentgenograms.

Although the number of those who prefer film is high, it is the opinion of those who have conducted this investigation that these facts are to be interpreted as an expression of the definite possibility of the use of paper in industrial surveys. In the first place approximately one-fifth of the 49 roentgenologists have had a large experience in the use of paper. In spite of this fact more than one-fourth of the votes on the series of individual films show either a preference for paper or no preference. This is a particularly important fact when it is also recognized that all of the roentgenologists believe film to be superior to paper from the physical point of view.

In the case of the patients for whom a series of roentgenograms was made on paper and on film the number of votes "not diagnostic" was naturally lower. No films were marked "not diagnostic" and only three of 169 notes on paper roentgenograms were "not diagnostic."

Several roentgenologists recorded their emphatic opinion that both paper and film would have the value shown in their respective reports only if the technique used in these tests were accurately reproduced. It is extremely important, therefore, to set up definite standards of quality and to maintain these standards in any industrial survey. It is a relatively easy matter to produce poor roentgenograms either on paper or on film and so to compromise the diagnostic results and to confuse the controversial question concerning the use of these two photographic media for survey work.

In answer to question 1 as to whether paper would be satisfactory for industrial surveys, 31 roentgenologists answered "yes" while 18 roentgenologists answered "no." In answer to question 2 as to whether film or paper is easier to read, 36 thought that film was easier to read, 3 thought that paper was easier to read, while 9 thought that there was no choice in the matter. The answer to question 2 again reflects the lack of experience of many men in the use of high quality paper roentgenograms. Although this is an important fact tending now to discourage the use of paper roentgenograms, it is quite likely that roentgenologists may learn quickly to use them.

The following statements are taken from the comments given by the roentgenologists to the questions 1 and 2 in the mimeographed form. Interpretative comments are added to each statement.

The following comments are from the questionnaires of those roentgenologists who believe that paper is unsatisfactory for industrial surveys:

"Range of density with paper is quite narrow so that part of the diagnostic area may have suitable density while another part is too light or too dark." Another roentgenologist makes the following statement: "These paper roentgenograms are superior to any we have seen but they still lack contrast and detail such as are seen in good films." These roentgenologists have clearly recognized the physical characteristics of paper and film roentgenograms which are discussed in detail in the first section (I) of this report.

"The sharpness on paper appears to be poorer than that which is obtained with film." This criticism probably arises from the fact that the contrast of paper is less than that of film and therefore the apparent sharpness in the case of paper is inferior to the apparent sharpness in the case of film.

"Roentgenograms of heavy patients are poorer than roentgenograms of patients with thin chests." It is not at present possible to produce equal contrast for all chest thicknesses using either paper or film. Since the density limits of paper are less wide than those of film and since the contrast of paper is less than that of film, paper roentgenograms of very heavy patients occasionally may not be satisfactory. On the other hand, the apparatus and technique used in these tests are peculiarly adapted to the production of high contrast roentgenograms of heavy patients. Several roentgenologists who examined the results of these tests stated that the contrast of these roentgenograms (on both paper and film) of heavy patients was superior to those usually produced.

"More paper roentgenograms are found to be 'not diagnostic.'" This comment is in part based upon the lack of experience in the use of paper. However, even roentgenologists who are experienced in the use of paper are likely to find fewer "not diagnostic" films than they find in a series of paper roentgenograms.

"Gross pathology easily seen in paper; early lesions may be missed." Some of the roentgenologists believe that this is particularly true of early lesions of silicosis. There can be no doubt that roentgenograms on film will show early changes in the structure of the lungs due to either tuberculosis or silicosis more accurately. It seems to have been the opinion of many roentgenologists that in cases such as these the paper would have shown suspicious shadows and the patient would therefore have been asked to have a re-examination using stereoscopic films.

"Some changes in the lung structure are reproduced in roentgenograms on film which cannot be seen on paper roentgenograms of the same patient." This comment was made by three roentgenologists, none of whom has had great experience in the use of paper.

"One case of tuberculosis missed in a survey may prove to be extremely

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costly in the long run." This is an argument which has long been used to support the contention that a complete x-ray examination including stereoscopic films of high quality is the only means by which early lesions may be detected with certainty. While there can be little doubt that this statement is true, the practical exigencies of the industrial survey problem require a means for quick, inexpensive x-ray survey. Every one should recognize, nevertheless, that the use of single roentgenograms on film or paper may lead to occasional errors.

The following comments are made by those men who believe that paper is satisfactory for roentgenographic surveys in industry:

"The paper radiographs shown in this demonstration are technically far superior to any I have seen to date." "I was impressed by the good quality of radiograph that the paper produced as they were much superior to the films that we went over in an industrial survey here in———————last year." "Paper is satisfactory if the technical procedure can be maintained at the level represented by the test films." "From previous experience I am convinced that it is very doubtful that so uniformly good a series of paper radiographs could be obtained under ordinary working conditions." The practical aspects of this problem are extremely important. It will be difficult but not impossible to arrange in the future by collaboration between the agencies who make roentgenograms, the roentgenologists, and those who have specified the technique used in these tests to arrive at the specification of a procedure such that most of the roentgenograms produced in an industrial survey will have average-density, contrast, and sharpness equivalent to those roentgenograms produced in these tests.

One roentgenologist called attention to a group of problems which are important though not primarily technical. "Every effort must be made to prevent the use of paper radiographs from having a deleterious effect upon the development of the science and practice of radiology; that it has sometimes produced such deleterious effects is due to the aims and practices of individuals, not to any of the technical factors involved."

"Paper is cheaper and in the form of rolls may be used as the basis of a very fast exposure procedure. In addition there is greater ease in handling the finished roentgenograms in rolls." This point is of extreme importance. If it were possible to make single 14 inch by 17 inch roentgenograms on film, to process them and to view them as easily, as quickly and as inexpensively as to make serial roentgenograms on roll paper, there would be no question that the film would be used. At the present time, however, the roll paper is the only medium which permits quick exposures using semi-portable apparatus, continuous processing and the use of a simple, convenient method of viewing the finished roentgenograms.

One radiologist who offered opinions on this test, in a conversation with one of the authors of this report stated that he felt that the charges for paper roentgenographic surveys were too high, when considered in the light of actual costs. He felt that if paper surveys were to be used, technical charges should be materially reduced. It was the opinion of this radiologist that a definite effort should be made to develop the survey method on roll film using an exposure size of 13 x 14 inches. It is possible that the size of the exposure area could be reduced to 12 x 14 or 10 x 12 inches. Films of such sizes as mentioned above could cover most of the lung field except the diaphragmatic region. Since the charge for film is based on the number of square inches, a considerable saving may be effected by reduction in the size of the film.

"Even if paper is used for industrial survey work to cover those employees now working in industry it is considered important that all applicants for positions be examined using x-ray film." The men who made this comment recognize the importance of the fast survey method using roll paper but also recognize that the paper is deficient when compared to film. Applicants for new positions come usually in small numbers and may be handled without too great expense without recourse to mass survey methods. In these cases, therefore, they insist upon having high quality roentgenograms on film.

Finally, several of the men mentioned that other methods may be available for industrial survey work. Although this is certainly true and such other methods should in the future be carefully considered, it was the purpose of this investigation to test the methods now available.

VII
CONCLUSIONS

In this section certain conclusions based upon the experimental data and the opinions of the roentgenologists who examined the film are briefly presented.

It has been shown clearly that experienced roentgenologists require chest roentgenograms having densities within the diagnostic area in the range 0.35 to 1.65. If the minimum density is below 0.35 or the maximum density greater than 1.65 roentgenologists in general react unfavorably to the film. This fact, which may be clearly derived from the experimental data of this investigation, was predicted upon the basis of an analysis of the physical and physiological phenomena which has been published.* It was also demonstrated by means of a series of test roentgenograms exhibited at the annual meeting of the National Tuberculosis Association in Los Angeles in June, 1938. There are very few roentgenologists who insist upon using films whose maximum and minimum densities lie outside of the range 0.35 to 1.65. This was certainly not true as recently as five years ago. It is a particularly encouraging fact to note that progress has been made toward the achievement of an accurate specification of an optimum roentgenogram.

It is concluded from these tests, just as it has been concluded from former tests by other workers, that the average-density and contrast of roentgenograms made on paper are inferior to those which may be produced on film using simple practical apparatus and technique. In view of this fact it is believed that roentgenographic paper should never be used unless important practical reasons prevent the use of film.

If a large group of employees is to be examined and a part of this examination is a single roentgenogram of each employee, then it is less expensive and quicker to use paper in rolls than to use single pieces of x-ray film. Such a survey may be made with paper if the technical methods outlined in this report are used or if other methods are used which produce equal or better results. Paper roentgenograms obtained by means of pulsating apparatus of rating less than 200 ma are not likely to be satisfactory, particularly for heavy individuals. If paper is used for survey work in conjunction with apparatus and technique at least equal to those described above, the best interests of all parties concerned will be served if pathological and doubtful cases are referred for a more thorough radiologic examination.

* Apparatus and Technique for Roentgenography of the Chest: Weyl, Charles; and Warren, S. Reid, Jr.; published by C. C. Thomas, 1935.

Doubtful cases from the use of the paper roentgenograms fall in either one of two classes: (1) roentgenograms showing definite evidence of disease of the chest; (2) roentgenograms showing shadows which make the roentgenologist doubtful as to whether or not there may be lesions within the chest. In some instances even a careful fluoroscopic and stereoscopic examination of the chest may not be sufficient.

Although only ten of the 40 roentgenologists who examined the test roentgenograms have had great experience in the use of paper roentgenograms, 31 were of the opinion that paper roentgenograms like those produced in these tests would be satisfactory for a preliminary survey. It is concluded that these results demonstrate two points:

(1) The paper roentgenograms produced in these tests are of better quality than those produced by other methods heretofore used in survey work.

(2) Many roentgenologists learn easily and quickly the technique of viewing paper roentgenograms even though they formerly may have been unfamiliar with the use of this roentgenographic medium.

Some time will be rquired to set up methods whereby paper roentgenograms may be routinely made in accordance with the technical procedures described in this paper. However, it is possible to set up such methods, and an effort will be made to devise them and to put them into use as soon as possible.

The authors believe that in view of the fact that no evidence has been produced to show that paper roentgenograms are in any way superior to those on film from the diagnostic point of view, it would be best in the long run to attempt to work out a scheme for making roentgenograms on film quickly and at low cost. There appear to be no insurmountable difficulties in the processes of devising methods for using x-ray film in rolls. It is quite likely also that the cost of survey roentgenograms might be reduced when using either paper or film by decreasing the size of the roentgenogram from 14 inches by 17 inches to 13 inches by 14 inches or whatever size might be found to be adequate.

It is apparent that it would be extremely useful to devise a detailed specification of all of the technical factors involved in the chest roentgenographic procedure in such a manner that these specifications might be accurately followed in any laboratory: Work along these lines has been begun, and it will be the purpose of this work to submit to Air Hygiene Foundation of America a report describing precisely what methods should be used for making chest roentgenograms under any of the circumstances which arise in industry.

INFORMATION CONCERNING THE CHARTS WHICH FOLLOW

CHART A — TECHNICAL DATA
CHART B — SURVEY DATA
CHART C — SURVEY DATA
CHART D — SURVEY DATA
CHART E — SURVEY DATA
CHART F — SURVEY DATA

LIST OF ROENTGENOLOGISTS WHOSE COMMENTS ARE SUMMARIZED ON CHARTS B, C, D, E, F, ARRANGED ALPHABETICALLY*

Dr. K. D. A. Allen, Denver, Colorado
Dr. J. B. Amberson, New York, New York
Dr. Chesley Bush, Livermore, California
Dr. W. E. Chamberlain, Philadelphia, Pa.
Dr. G. W. Chamberlin, Philadelphia, Pa.
Dr. A. C. Christie, Washington, D. C.
Dr. H. P. Doub, Detroit, Michigan
Dr. H. K. Dunham, Cincinnati, Ohio
Dr. H. R. Edwards, New York, New York
Dr. D. E. Ehrlich, New York, New York
Dr. H. H. Fellowes, New York, New York
Dr. G. W. Grier, Pittsburgh, Pa.
Dr. E. W. Hall, Detroit, Michigan
Dr. W. C. Hall, Philadelphia, Pa.
Dr. P. J. Hodes, Philadelphia, Pa.
Dr. F. J. Hodges, Ann Arbor, Michigan
Dr. P. C. Hodges, Chicago, Illinois
Dr. B. R. Kirklin, Rochester, Minnesota
Dr. A. J. Lanza, New York, New York
Dr. D. Lasbor, Boston, Massachusetts
Dr. D. O. N. Lindberg, Decatur, Illinois
Dr. R. P. Meader, Philadelphia, Pa.
Dr. W. J. McConnell, New York, New York
Dr. J. T. McGreer, Ann Arbor, Michigan
Dr. E. M. McPeak, Washington, D. C.
Dr. Maurice McPhedran, Philadelphia, Pa.
Dr. Sherwood Moore, St. Louis, Missouri
Dr. J. T. Murphy, Toledo, Ohio
Dr. J. A. Myers, Minneapolis, Minnesota
Dr. V. V. Norton, Cincinnati, Ohio
Dr. F. W. O'Brien, Boston, Massachusetts
Dr. L. H. Osmund, Pittsburgh, Pa.
Dr. E. P. Pendergrass, Philadelphia, Pa.
Dr. G. S. Pesquera, Mt. McGregor, New York
Dr. A. S. Pope, Boston, Massachusetts
Dr. H. E. Potter, Chicago, Illinois
Dr. R. R. Rathbone, Washington, D. C.
Dr. Ada C. Reid, New York, New York
Dr. D. Reisner, New York, New York
Dr. Lawrence Reynolds, Detroit, Michigan
Dr. Leo G. Rigler, Minneapolis, Minnesota
Dr. A. B. Robins, New York, New York
Dr. A. E. Russell, Chicago, Illinois
Dr. H. S. Sampson, Saranac Lake, New York
Dr. L. R. Sante, St. Louis, Missouri
Dr. W. G. Scott, St. Louis, Missouri
Dr. Merrill C. Sosman, Boston, Massachusetts
Dr. J. E. Wissler, Washington, D. C.
Dr. H. H. Wright, Ann Arbor, Michigan

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* The roentgenologists' code numbers used in Charts B, C, D, E, F, are not arranged alphabetically.

GENERAL COMMENT

1. CAPACITANCE OF CONDENSER USED FOR ROENTGENOGRAPHIC EXPOSURES

¼ mfd Capacitance		½ mfd Capacitance	
Individual-Patient	— R. R.	Individual-Patient	— B. W.
" "	— E. T.	" "	— J. Z.
" "	— W. B.	" "	— F. M.
" "	— E. C.	" "	— J. A.
" "	— C. B.	" "	— L. M.
" "	— R. M. B.	" "	— J. R.
" "	— E. R.	" "	— A. P.
" "	— E. K.	" "	— M. S.
" "	— M. M.	" "	— M. C.
" "	— A. A.	Serial-Patient	— T. P.
" "	— H. M.	" "	— O. H.
" "	— M. B.	" "	— N. I.
" "	— J. S.	" "	— J. K.
" "	— W. M.	" "	— W. N.
" "	— L. C.	" "	— S. H.
" "	— L. K.	" "	— E. W.
" "	— S. B.		
" "	— D. L.		
Serial-Patient	— A. H.		
" "	— E. A. K.		
" "	— E. S. K.		
" "	— C. E.		
" "	— J. O. B.		

(Individual-Patient: Patient for whom one roentgenogram on film and one roentgenogram on paper were made.

Serial-Patient: Patient for whom a series of roentgenograms of different average-densities was made on film, and a similar series of roentgenograms was made on paper.)

2. CHART A

The "minimum densities" for all film and paper roentgenograms were measured under the intersection of two ribs just inside the periphery of the chest.

The "maximum densities" for both film and paper roentgenograms were measured in the lung field.

The average-density refers to half the sum of the maximum density within the diagnostic area of the roentgenogram and the minimum density within the same area. The following relations describe approximately the values of average-density discussed in these charts:

$$\text{"Low average-density"} = \frac{0.70 + 0.30}{2} = 0.50$$

$$\text{"Medium average-density"} = \frac{1.60 + 0.40}{2} = 1.00$$

$$\text{"High average-density"} = \frac{1.90 + 1.10}{2} = 1.50$$

The optimum values in the serial-patient roentgenograms data are taken from the net findings of the 49 roentgenologists' data. See Charts E and F.

3. CHART B

Question 1 — From the given examples of film and paper roentgenograms presented would you state that paper roentgenograms are satisfactory for industrial survey work? Yes.................. No.................. Comments:

Question 2 — It is desired to obtain the answer to the question of the relative ease of diagnosis of the paper roentgenograms versus the film roentgenograms. Which of the two would you state is easier to diagnose and why?

4. CHARTS B, C, D, E, F — INDEX OF SYMBOLS USED

D. — Diagnostic
N. D. — Not Diagnostic
Pref — Preference
F. — Preferred roentgenogram on Film
P. — Preferred roentgenogram on Paper
N. P. — No Preference
4 — Excellent roentgenogram
3 — Good roentgenogram
2 — Fair roentgenogram
1 — Poor roentgenogram