TECHNICAL PROBLEMS IN THE STANDARDIZATION
OF THE
INSTALLATION AND OPERATION OF X-RAY EQUIPMENT

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For

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By

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PREFACE

This thesis is not prepared with the idea of listing all the technical problems connected with the installation and operation of X-ray equipment for, obviously, that would be an impossible task. I have collected and compiled here-in data that I have found of real value to me in my work of standardization.

I hope some of this information may be of value to the service engineers who are meeting these problems daily in the X-ray field. If the tests listed do not apply perhaps a study of the method of analysis used may encourage the men to make a more careful study of their problems and therefore be in a better position to arrive at correct solutions. I feel that we need better standardization of our X-ray laboratories everywhere.

My inspiration for attempting such a paper, as well as my inspiration for entering this field of educational work, has come, chiefly, from my personal contact with Mr. Ed. C. Jerman, Technical Director of the Educational Department of the Victor X-Ray Corporation, who has spent the greater part of his life in the endeavor to better standardize X-ray technical work.

Since there is very little written upon this phase of the subject, most of the material for this paper has been gathered from personal contact with men in the field and
from personal experience as a member of the Educational Department of the Victor X-Ray Corporation.

I wish to express my appreciation to Dr. W. E. Chamberlain and Dr. R. R. Newell, of the Stanford University Medical School, for their assistance and ready counsel, and for the use of their department for much of the experimental work. Also, I wish to thank Mr. B. O. Martinsen who assisted me in obtaining much of the experimental data.

E. W. Phillips
1926.
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BRIEF HISTORY OF THE STANDARDIZATION OF EQUIPMENT.

THE BIRTH OF A NEW FIELD OF SCIENCE.

The Discovery of X-Radiation-- In the late summer of 1895 Professor Wilhelm Konrad Roentgen, Professor of Physics at the Royal University of Wurzburg, Germany, discovered almost accidentally, the rays which now bear his name. It was during his search for invisible light rays that he excited a low-pressure discharge tube, which for the purpose was completely inclosed in stout black paper, and noticed, to his surprise, that a fluorescent screen laying on his table some yards distant shone out brightly. Since the tube was inclosed in light-tight paper, he knew that the effect was not due to ordinary light or ultra-violet light but must have been caused by some other radiation of peculiar characteristics. He called this radiation "X" and the rays "X-Rays" since the characteristics of the rays were unknown. He interposed small articles and found that the denser of them cast shadows on his screen. In this way he finally traced the rays to their source which proved to be the region of impact of the cathode rays on
the glass walls of the tube. He later found that X-rays were produced whenever and wherever cathode rays encountered matter.

Roentgen's View of the Possibilities—After a very little experimentation, Roentgen readily saw the significance of his discovery to the Medical Profession. Therefore, in November 1895, he reported his discovery to the Physico-Medical Society of Wurzburg.

Roentgen's Equipment—Roentgen's equipment at that time consisted of an induction coil and a small pear-shaped, low-pressure glass tube similar to the tube shown in Figure 1.

Importance to Science of the Discovery—Out of the discovery with this simple apparatus, has grown in thirty years, a branch of science that has completely revolutionized our theories of atomic structure and of the relation of energy to matter, and that has become an indispensable aid to the medical profession.

STEPS IN THE DEVELOPMENT OF EQUIPMENT.

The advances in all branches of the science have been rapid. For the most part, these advances have been toward standardized equipment, standardized procedure of operation
and standardized technical terms and language.

X-Ray Machines.

The early X-ray machines were of two distinct designs: the common influence or static machine and the induction coil. These had to be built to deliver high voltages since 30,000 volts (peak value) was required to generate X-rays of short enough wave length to be of use in ordinary medical radiography.

_Influence Machines_-- The influence machines generated their own electricity without any external source of supply. These machines were far inferior to the induction coils for they were cumbersome, they were very limited in control and current output, and, worst of all, they were very unreliable since they depended to such a great extent on the atmospheric conditions for satisfactory operation. For these reasons they were used, primarily, only where it was advisable to use a unit generating its own current.

_Induction Coils_-- The induction coils were soon more generally adopted because of their many advantages. They were much easier to control, they were reliable, and they could be designed to give much heavier currents than the influence machines. However, the induction coils had their disadvantages. They were subject to large inverse discharges
and surges that were detrimental to the tube. Also, in order to function, they had to be equipped with some type of interrupter in their primary circuits. These interrupters had to be designed for rapidity of interruption, adjustability of period and had to be mechanically strong and of generous proportions since they were required to break a heavy primary load. Induction coils were built for two kinds of operation: for direct connection of secondary to tube (low frequency) and for discharge through a resonance circuit to build up high frequency excitation for tubes.

**Open-Core Wax Interrupterless Transformers**-- The next step in advance was the designing of the open core, wax insulated interrupterless transformer. This was the first X-ray transformer designed to operate from the ordinary alternating current power supply. These transformers were very inefficient, and, in addition, had to be equipped with a rectifying device to change the high-tension alternating current delivered at the secondary to a uni-directional current for use of the X-ray tube. But, in spite of these disadvantages these transformers were far superior to the old induction coils for they were easily controlled and had much greater capacity.

**Closed-Core Interrupterless Transformers**-- The inefficient open-core transformers soon gave way to the closed-core transformers which were at first insulated by wax or vaseline.
These transformers were much more efficient but they were subject to insulation difficulties. To obviate these difficulties, the transformers were later designed with closed cores and immersed in oil for insulating purposes. This type of high tension-transformer is universally used today.

X-Ray Tubes.

Early Gas Tubes-- The vacuum tube with which Roentgen made his famous discovery in 1895 was pear-shaped, with a flat disc for a cathode mounted in the body of the bulb at its narrow end; the anode was in a small side tube. (Figure 1.) The cathode rays impinged on the large end of the bulb, producing vivid fluorescence. This pattern of tube was widely copied but it was soon found that it did not survive many of the prolonged exposures which were necessary to secure radiographs of any value. Moreover, owing to the large area of emission of the X-rays, the radiographs were always blurred and somewhat indistinct. Experimenters at this time were working along three lines: to prolong the life of the tube, to shorten the exposure needed, and to improve definition in the radiograph.

In 1896 Campbell-Swinton modified Roentgen's original design by adding a sheet of platinum obliquely in the path of the cathode rays. This change was a great improvement
Figure 1.
Roentgen's Early X-Ray Tube.

Figure 2.
Jackson's First Focus Tube.

Figure 3.
The Standard Gas Tube.

Note: These figures taken from "X-Rays" by Kaye.
as far as the life of the tube was concerned. About the same time, Professor H. Jackson of King's College, London, built a tube in which he replaced the flat cathode by a concave one. Sir William Crooks had shown, in 1874, that a concave cathode brought the cathode rays emitted to a focus. Professor Jackson mounted a platinum target at $45^\circ$ to the cathode rays. (Figure 2.) He called this tube a focus tube. The tube was a great improvement, first, because the exposure time was cut to a small fraction of the time required with the older tubes, and second, because the radiographs taken showed wonderful sharpness of detail since the area of emission of X-rays was small.

**Later Standard Gas Tubes**—Although many minor changes have been made since that time, the gas tube of today differs very little in essential design from Professor Jackson's original tube. (Figure 3.) The gas tube at its best is a very unreliable tube since it depends to a great extent on the gas pressure within. A gas tube will operate perfectly satisfactorily one day and refuse to operate the next. Again, two tubes that seem to be identical will show entirely different characteristics.

**Universal or Hot-Cathode Coolidge Tubes**—Because of the unstability of operation and the difficulty of control of these tubes, Dr. W. D. Coolidge of the General Electric Company's research laboratory, designed a new X-ray tube
in 1913 which has proved to be a great advance toward standardized operation. (Figure 4.) In this tube the gas pressure was so low (approximately $1 \times 10^{-9}$ of an atmosphere) that the residual gas had little or no part in the operation of the tube. The source of the electrons was an incandescent cathode which consisted of a small flat spiral of tungsten wire surrounded by a molybdenum tube. The tungsten filament when heated by an auxiliary electric current became a source of electronic emission which, when the tube was energized, was focused to a small area on the anticathode or target. The target was made of solid tungsten. The amount of electronic emission in this tube was proportional to the heat of the tungsten filament and could therefore be controlled easily by regulating the current of the auxiliary circuit.

**Radiator Coolidge Tubes**— In a later Coolidge Tube the target was made by embedding a tungsten button or disc in the surface of a heavy copper anticathode which extended outside of the tube and was fitted with a copper radiator for cooling purposes. Because this tube would dissipate the heat generated at the area of impact of the cathode rays with the target (focal spot) it could be used as its own rectifier and could be connected directly to the high-tension terminals of the X-ray transformer. Also the sizes of the focal spots could be made much smaller in this type of tube. This made the tube very useful where fine detail or definition
Common Universal Coolidge Tube.

200,000 Volt Deep Therapy Coolidge Tube.

Water-Cooled High Voltage Coolidge Tube.

100 Milliampere Radiator Tube.

Common Radiator Coolidge Tube.

Right-Angle Dental Tube.
was desired on the radiograph.

These tubes with the addition of new heavy duty radiator tubes, are the X-ray tubes commonly used at the present time.

CONTROL DEVICES.

Early Control-- When the influence machine was used as an X-ray generator the voltage was the only factor that could be readily controlled. The voltage was proportional to the speed of the plates. Theoretically there was no limit to the potential obtainable but practically a limit was set by the point of leakage or disruptive discharge and by mechanical limits. In practice the voltage was more commonly regulated by changing the tilt of the rods supporting the brushes. The common, or Wimhurst machine, was peculiar in that the current obtained was almost entirely independent of the voltage. The current output could be raised by increasing the number of plates. However this was not a practical procedure, therefore, the control was limited to changes in voltage.

The Rheostat-- The output of the induction coil as well as of the closed-core transformer was controlled for some time by the introduction of an adjustable rheostat in the primary circuit. This control was used almost universally until the advent of the Coolidge tube and the interrupterless transformer.
The Auto-Transformer-- Since the Coolidge tube current was easily regulated independently of the voltage supply the auto-transformer was brought into use. At the present time this control is used by many although most manufacturers still incorporate a rheostat control along with the auto-transformer.

INSTRUMENTS AND THEIR USE.

Static Machine Period-- The first machines were not equipped with meters for measuring the current flowing through the tube. The operator had to know his equipment well enough to be able to tell by the color of the tube and the characteristic noises of the discharge about what setting to use for his various kinds of radiographic work. He estimated his voltage by measuring the sparking distance between points connected in parallel with his tube. This is still common practice among most operators.

The Standard Gas Tube Period-- With the low-frequency high-tension transformers came the use of a milliampere meter to measure the current flowing through the tube.

The Coolidge Tube Period-- When the Coolidge tube was introduced an ampere meter was placed in the filament circuit to measure filament current so that use might be made of the relation of the heat of the filament to the X-ray tube current.
The improvements in the method of measuring the voltages applied to the tubes have not kept pace with those of measuring the current. Although there are sphere-gaps built for reasonably accurate measurements of the voltage, the operators are very slow to see the advantage of using them. Later we will see more of the need for the use of these instruments.

MODERN X-RAY EQUIPMENT.

The standard X-ray machine of today might best be studied from an electrical standpoint as made up of three distinct electrical circuits: Namely, the Primary, or Voltage Control Circuit, the High-Tension Circuit, and the Filament or Coolidge Circuit. (Figure 5).

THE PRIMARY VOLTAGE CONTROL CIRCUIT.

The voltage delivered to the terminals of the X-ray tube is controlled by regulating the voltage supplied to the primary of the high-tension transformer. The primary voltage is regulated by a rheostat or auto-transformer or more commonly by a combination of the two as shown in the sketch, Figure 5.

The Auto-Transformer-- The auto-transformers are of many sizes and makes but ordinarily they are of the common closed-core type. The number of steps of control varies
To Power Switch

Motor Switch

AUTO-TRANSFORMER

To Power Switch

Coolidge Regulator

Primary

Coolidge Transformer

Secondary

Filament Ammeter

To Rectifier Motor

Resistance

Rheostat

Pre-Reading Voltmeter

X-Ray Switch

High Tension Transformer

Milliammeter

Cathode

Anode

Coolidge Tube

MA

Rectifier

Figure 5.

Schematic Diagram of Common X-Ray Circuit
with the size and make of the machine. One of the common transformers has eleven taps with a switching device that makes possible thirty uniform steps of regulation controlled by one handle. Many machines use two switching levers to obtain the regulation obtained above by one handle. Another machine has fifty-six steps while still others have only ten or twelve. The sketch, Figure 5, shows that the auto-transformer is energized by the closing of the rectifying motor switch. This means that the auto-transformer will not be in circuit unless the motor is in operation. Therefore, the chance of accidentally energizing the high-tension transformer is greatly lessened. Also, the auto-transformer does not have a tendency to heat for it is energized for just the short time that the machine is running. Because of the inherent characteristics of the auto-transformer regulation, it has proved an excellent method of control for the X-ray output.

The Rheostat-- The rheostat is used as a standard control for the primary voltage of the X-ray machine in combination with the auto-transformer or alone. The common standard resistance unit is of the grid type. The spiral resistance coils were discarded because the coils added an inductance effect to the resistance of this type of rheostat.

Resistance control is not nearly as satisfactory as auto-transformer control except where it is desired to
change voltages while the machine is in operation as for therapy or fluoroscopic work. The use of a rheostat to control tube voltage has the disadvantage that slight variation in the tube current results in serious changes in voltage. Also, the characteristics of the rheostat change as the resistance units change temperature.

The X-Ray Switch—The X-ray switch completes the primary circuit of the high-tension transformer. Since this switch is in the primary circuit, it must be built to break loads up to 100 amperes. It is usually a single-pole switch of the quick-acting cut-out type.

The Time-Switch—In addition to the hand-switch a timing device is used for accurate duplication of exposures. This device closes and opens the primary circuit in any desired period of time from 1/20 to 30 seconds. In order that the arcing be a minimum, this breaker is operated in oil. The timing device is an electrically driven mechanism operating electrical contacts which in turn energize a double solenoid to open and close the switch.

The Pre-Reading Voltmeter—The pre-reading voltmeter is an ordinary voltmeter connected in such a way that it will indicate in advance the voltage that will be delivered to the primary of the high-tension transformer when the X-ray switch is closed. (Figure 5.) This reading, when the machine
is properly calibrated, will give an accurate means of pre-determining the amount of voltage that will be impressed upon the X-ray tube. (See calibration, page 78). If part of the rheostat is in circuit, the meter will not indicate the actual voltage delivered to the primary until the X-ray switch is closed and the primary current sent through the resistance. In the class of operation in which the rheostat is useful, the voltage across the tube is built up slowly and a pre-reading is not essential.

THE HIGH-TENSION CIRCUIT.

The High-Tension Transformer--The standard high-tension transformer is a closed-core oil-immersed transformer. The secondary is usually wound in two, three, or four pies which are placed on the same leg of the transformer as the primary. The secondaries of the larger transformers are often grounded from the center to the metal transformer case which in turn is grounded. Since the maximum currents used in X-ray work are small (5 to 100 milliamperes), the secondaries are wound with number 30 to 36 B. and S. guage copper wire. The pies are wound with a paper insulating ribbon between each layer to insure perfect insulation. The general design and specifications of these transformers vary greatly with the make. Some interesting comparisons will be given later.
The Rectifier—There are two general types of mechanical rectifiers commonly used on standard X-ray equipment, the disc and the cross-arm. Both types are driven by synchronized induction motors. These are squirrel-cage motors with enough iron removed from the rotors to make them operate at synchronous speed (1800 R.P.M. on 60 cycle power.).

Figure 6 illustrates the operation of a disc rectifier. The disc is made of some insulating material and the shoes indicated at 5 and 6 are of some metal, usually aluminum because of its weight. In the figure, when the right hand terminal of the transformer is positive (Figure 6 A) the circuit is completed as follows: 4-6-3-tube-1-5-2-negative pole. When the polarity of the transformer reverses, the circuit is as shown in Figure 6 B, namely, 2-5-3-tube-1-6-4.

Figure 7 illustrates the cross-arm rectifier. In this case the current is passed through arms from one collector to another collector half a revolution distant instead of to a collector a quarter of a revolution distant. The circuit can be traced (Figure 7 A) as follows: G-7-3-tube-1-5-F or, when the transformer changes polarity, (Figure 7 B) F-6-2-tube-4-8-G.

The cross-arm type of rectifying switch will handle a much higher voltage for a given size than the disc type. Also because of the better placement of insulation it is more easily designed and manufactured for high-voltage rectification, (Figure 7D).
DISC RECTIFICATION

Correct Polarity

Reversed Polarity

FIGURES 6A, 6B, 6C, 6D
CROSS-ARM RECTIFICATION

Figure 7.

Syn. Motor

Fig. 7A.

Fig. 7B.
Figure 7C.
High-Tension Transformer and Disc Rectifier.

Figure 7D.
High-Tension Transformer and Cross-Arm Rectifier.
It is possible for the motor to fall into step as shown in Figures 6 C and 6 D so that the switch will rectify but will deliver the current to the tube at the reversed polarity as shown. This condition is changed when it occurs, either by using a primary reversing switch or by opening for an instant and again closing the motor switch. This allows the motor to drop back a little with the chance of changing the polarity of the rectifying switch.

The Polarity Indicator-- Most standard apparatus is equipped with a polarity indicator. The polarity indicator consists of a movable coil with a pointer attached which rotates in a permanent magnetic field against a hair spring. It is similar in construction to a direct-current voltmeter. If the current flows in one direction through the coil, the needle will deflect to one side; if the current flows in the reverse direction the needle will deflect to the opposite side. The meter is energized by the current from a small low-tension rectifier placed on the synchronous motor shaft. (Figure 8). When this small rectifier is set properly in relation to the high-tension rectifier, it indicates, as soon as the motor is turned on, the polarity that the rectifier will have when energized.

The Spark-Gap-- An adjustable spark-gap is usually a part of the high-tension circuit. This gap is used as a rough check of the voltage of the high-tension circuit or
Figure 8.
Schematic Diagram of Common Polarity Indicator

Figure 10.
Schematic Diagram of Nearsley Milliamperage Stabilizer
merely as a spark-over protection for the rest of the circuit. In the latter case the gap is set to break over at the voltage rating of the apparatus. In case of a surge or any form of voltage over-load, the gap will break down before any damage can be done to the insulation of the transformer or to the X-ray tube. The use of the gap as a means of measuring the voltage delivered to the tube is not a satisfactory procedure as will be shown later.

The Milliampere-Meter-- A double scale 9 inch milliampere-meter (0-20, 0-200) is placed in the high-tension circuit to indicate the current in milliamperes that is flowing through the tube. These meters are commonly placed on a wall bracket of some type high enough above the floor so that the operator will not be in danger of receiving a high-tension shock.

The Overhead-- The overhead, or high-tension distribution system, is usually made of 3/8 inch or 3/4 inch brass tubing supported by insulated brackets. The energy for the tube is taken from this system by flexible cords attached to spring cord reels.

Figure 9 shows a typical overhead installation of 3/4 inch tubing. These overheads are made as nearly corona-proof as possible by using long bends, terminal balls at the ends and by leaving no sharp projection at meter connections or elsewhere.
Figure 9.

The X-Ray Installation at the San Francisco Office of

The Victor X-Ray Corporation.

Note:— This installation was used for much of the experimental work for the preparation of this thesis.
THE FILAMENT OR COOLIDGE CIRCUIT.

The filament circuit, as shown in the sketch, Figure 5, is an auxiliary circuit used to energize and control the heat of the filament of the tube.

The Coolidge Regulator-- The power for the Coolidge circuit is taken from a 110 volt line. An inductance regulator gives the control in the primary circuit of the filament step-down transformer.

The Coolidge Transformer-- The transformer has its primary and secondary well insulated from each other by oil since the secondary is always at the potential of the X-ray tube. The transformer steps the voltage down from 110 to about 12 volts.

The Filament Ammeter-- A 9 inch filament ammeter with a scale calibrated from 3 to 5 amperes is used in the filament circuit to indicate the amperage supplied to the filament. There is a direct relation between this amperage and the milliamperage of the tube circuit.

The Overhead Connections-- The filament current is carried to the filament by one side of the brass tubing of the overhead and returned by an insulated wire running through the tubing. This makes a neat installation since the two parallel brass tubes carry the two circuits.
The Stabilizer-- An accessory device that is often installed as a part of the overhead system is the Kearsley Stabilizer. This device operates on the principle of a Tirrill Regulator. It keeps the filament current, and therefore the milliamperage of the tube, constant in spite of fluctuations in the power supply. Schematically the device might be represented as shown in Figure 10. The armature actuated by the variation of the electro-magnetic field of the coils at A in the high-tension circuit cuts in and out the resistance, $R$, which is a part of the filament circuit. Thus an increase in milliamperage causes an increase in the field at $A$ and the resistance $R$, is cut in to lower the filament current which in turn lowers the tube current. When the tube current is normal or tends to be low the spring of the armature closes the contact and shorts out the resistance $R$. By raising or lowering the two coils at $A$ this device will stabilize at any desired current. An insulated rod attached to a screw device for raising or lowering these coils and a scale calibrated in milliamperes makes this adjustment an easy matter. The stabilizer will take care of the tube current if the fluctuation of the line is not more than ten per cent.

The Tube-- The Coolidge tube that completes the high-tension circuit of the X-ray machine has already been considered. These tubes are held in place by insulated supports.
at each end. They are partially or completely surrounded by a lead-glass bowl for the protection of the operator and the patient. The tube-stands that support the tubes and bowls are designed so that the tube may be raised, lowered, or tilted at the various angles necessary in radiographic work.

PROBLEMS IN THE STANDARDIZED INSTALLATION OF NEW EQUIPMENT.

PLANS FOR DEPARTMENTS.

One does not have to look far in almost any city in the United States to find a hospital that offers an excellent example of the great need for more carefully planned and better standardized X-ray departments. Too often the X-ray department is crowded into quarters in no way suitable. The architect who drew up the plans knew nothing of the problems connected with this department or perhaps he was forced to make use of the space left after all other departments were planned. Until recently the medical men or those interested in planning a hospital, paid little attention to the placing of, or the plans for, the X-ray department. And yet this department needs almost as much careful planning as the operating rooms if it is to function efficiently.
The Space Needed-- The first consideration should be
the size of the department desired. This will depend to
a large extent on the size of the hospital and the class
of work expected. Certainly a hospital located near a
large industrial center would need a different department
than a tubercular sanitarium of the same size located in
the mountains. When these questions are settled the space
that will be needed can be determined.

The Location-- The next problem is that of the location
of the department. The X-ray department should be located
so that it will be convenient to the Surgery and yet
convenient for patients from the outside and emergency cases.

Many hospitals have chosen to place the department in
the basement because of the latter considerations. The
difficulty with this location is that high-tension equip-
ment of this kind requires very dry atmospheric conditions.

The writer has in mind a carefully planned department
with an installation costing approximately $15,000. The
high-tension transformers and rectifying units were installed
in the basement. The building contractor guaranteed the
basement to be dry but in less than a month enough moisture
collected on the insulating members of the rectifiers to
cause one of them to break down completely and to set fire
to the equipment.

The Arrangement-- Besides the general location of the
department, care is needed in the arrangement of the various parts of the department itself. It will be impossible to consider more than a very few parts of the problem in this paper.

The X-ray exposure rooms should be easily accessible from the halls so that a patient can be carried in conveniently on a stretcher or gurney and easily placed in position for the exposure.

The dark-room should be conveniently located in respect to the radiographic rooms.

Wherever possible the high-tension transformers and rectifiers should be built into separate rooms and equipped with remote control. These transformer rooms should be deadened so that the noise of the motor-driven rectifying switches will not be annoying. These rooms should be well ventilated to carry off the gases that are liberated as the air is ionized by the continual arcing in the rectifier.

Care should be taken in the planning of a control booth for the protection of the operator. The booth should be located as near the equipment of the exposure room as possible. It should be well ventilated. The booth should be equipped with lead glass windows so placed that the maximum view of the room will be obtained at all times.

The rooms of the department should be planned to accommodate standard X-ray equipment and standard installations. Many times it is advisable to arrange the rooms so
that one transformer and control unit may be used to operate two separate radiographic rooms, a radiographic and a fluoroscopic room, or a radiographic and a therapy room.

Another important consideration in the designing of a department should be that of growth and future requirements. This point is too often overlooked.

All these problems and many more should be considered in connection with plans for departments. Figures 11, 12 and 13 show the floor plans of several departments designed by the writer.

POWER PROBLEMS.

Many problems are connected with the power supply for modern X-ray departments. The power requirements are unusual, for although the maximum loads are used only for fractions of a second (1/10 to 1/30), this power must be available at all times and must be delivered without much line drop.

Power Available--The type and voltage of the power used is often predetermined by the power available. The X-ray machines are designed to operate on alternating-current power at any of the common frequencies. If direct-current power is all that is available, rotary converters are used as part of the installation. However, the direct-current installations are always more complicated; they are limited
SAN JOAQUIN TUBERCULAR SANATORIUM
Plan of X-RAY DEPARTMENT

THE VICTOR X-RAY CORP.
239 Sutter St., San Francisco,
California

Figure 12.
Proposed Plan of Deep Therapy Department
Letterman General Hospital
San Francisco, Cal.

Plan by the Plan Department of the Victor X-Ray Corporation
270 Market St., San Francisco, California

Figure 13.

Therapy Core Roll
Treatment Table
Remote Control
Control Stand
Floor Insulators

Scale 1:1

Singe Special Transformer Installed on Lower Floor of Building.
in output and far less efficient than alternating-current installations of the same size. For these reasons alternating-current power is used wherever possible.

The ordinary radiographic machine requires, for maximum efficiency, a power supply of 25 kilo-watts. This is usually supplied at 220 volts. By changing the input taps of the auto-transformer used as a part of the control device, the same equipment can utilize power at 110 volts.

**Power Stability**-- The X-ray equipment requires unusual stability of the power supply for satisfactory operation. Sudden changes in voltage are apt to set up surges in the high-tension circuit. Voltage fluctuation makes it impossible to do consistent work since the X-ray energy delivered from the tube is directly proportional to the square of the high-tension voltage. This makes any small changes on the line very noticeable on the end result or film.

It is very important, unless a stabilizer is used, to have the voltage as near constant as possible for filament supply. A voltage change of 10% on the filament circuit of the tube will cause a milliamperage variation of approximately 300%. Therefore, the power should be taken from a separate transformer wherever possible, or at least, from separate busses on the main distribution system. In no case should this power be taken from lines carrying very irregular loads, such as lines supplying current for elevators or heating or cooking units.
The power supply should also be at a constant frequency. The motors are designed for a certain frequency and will tend to hunt if that frequency is not held constant.

The power lines to the equipment should be of copper heavy enough to carry the maximum load with not more than a 1% drop. One of the problems of the designing department is to persuade the electrical contractor that such lines are needed. It is hard for the engineer to realize that the loads used are for fractions of a second only and that everything must favor the delivery of a full load instantly.

**Power Rates**—Considering these requirements, it is little wonder that the power companies have difficulty in fixing the rates for the power supplied. These rates are usually set on the flat-rate basis as a compromise between the power available and the actual power used.

**INSTALLATION PROBLEMS.**

**Arrangement of Equipment**—Although the arrangement of the equipment of an X-ray installation is more or less determined by the size and position of the rooms, it should be arranged to the best possible advantage in the space available.

The control should be located in a booth as far as possible from the X-ray tube because distance is one of the
best protections from X-radiation. It should be located so that the operator may see the patient and the X-ray tube while making adjustments or taking exposures.

The high-tension transformer and rectifier should be placed so that they are out of the way but easily accessible for cleaning, oiling and repair, and so that the overhead connections from the transformer to the tube are as short as possible.

The meters and stabilizer should be placed where they may be easily seen from the control stand and where all adjustments and changes of scales may be made easily.

**Insulation Problems**--One of the greatest problems connected with the installation of X-ray equipment is the insulation of the high-tension parts of the equipment. The high-tension transformer and rectifier must be placed at a safe distance from the walls. The distance from any terminal to ground should be at least twice the maximum spark-over distance of the transformer.

The Coolidge transformer is in the high-tension line and must be placed on an insulated shelf.

The overhead must be supported by heavy insulated posts at a safe distance from the ceiling. Wherever it is necessary to run the overhead through walls a heavy insulating tube must be used. This tube should extend out ten or twelve inches on each side of the wall surface to insure against leakage to the wall. Similar insulation must be used wherever
the overhead crosses steam or other iron pipes or girders in the room. All insulation between the overhead and grounded objects should be sufficient to withstand half of the total potential of the high-tension transformer, plus an allowance for a factor of safety. This means for a radiographic installation, insulation sufficient to withstand 100 kilovolts, for a therapy installation, insulation sufficient to withstand 200 kilovolts (peak).

All metal equipment in the vicinity of the high-tension circuit or the tube act as static condensers and collect, by induction, charges that at times become troublesome. If a patient is placed on a metal table or chair he will complain of a stinging sensation as the current is turned on. This is due to a static discharge from the table or chair to the body of the patient. To prevent this discharge all metal chairs, tables and other objects used as part of the installation should be grounded. Also metal parts of the control stand that might become charged with high-or-low-tension should be grounded for the protection of the operator. Many institutions insist that the floor be covered with a heavy insulating material if it is of concrete or tile, thus lessening the danger of high-tension shock in the department.
TESTS FOR THE STANDARDIZATION OF EXISTING INSTALLATIONS.

No set of routine tests can be used for the work of standardizing an X-ray installation because each installation is different and has its own peculiar problems. It will be impossible to record here all of the tests that might be applied to solve all the problems that might arise. Many problems are common to various installations, however, and it is the writer's purpose to consider some of the more interesting ones.

POWER TESTS.

Power difficulties are great sources of trouble to X-ray installations. Consequently the testing of the power conditions is one of the first problems.

Line Conditions-- It is often found that difficulty can be attributed to voltage drop. The following is a list of places at which the voltage drop should be tested, given in the order in which the tests should be made:

I. Drop across primary terminals of the high-tension transformer.--This drop is the total drop that is effecting the energy output of the transformer. The readings can be taken by removing one of the primary terminal leads of the high-tension transformer and reading the no-load voltage across the input terminals, then replacing the lead and reading the drop under a heavy load.

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II. Drop across auto-transformer out-put.-- The difference between this drop and the drop of I indicates the drop in the leads from the control stand to the high-tension transformer.

III. Drop across line terminals (L I and L 2) of the control stand.-- The difference between this drop and the drop at II indicates the drop in the auto-transformer itself.

IV. Drop at cut-out box in the X-ray room.-- The difference in drop between this and III indicates the drop in the lines from the box to the control stand.

V. Drop across the power busses on the distribution board.-- If the drop at this point is still above 2% the trouble is due to the power supply.

When such a system is followed and complete data obtained the service man has adequate information to start his work. Often he may find short-cuts can be taken but unless he has followed some such method of analysis he will have difficulty in locating the trouble.

The following is an example of the above tests applied to a practical problem by the writer, and the final solution:
<table>
<thead>
<tr>
<th>Milli-</th>
<th>Kilo-</th>
<th>No</th>
<th>Drop</th>
<th>% Drop</th>
<th>Place of test.</th>
</tr>
</thead>
<tbody>
<tr>
<td>amperes.</td>
<td>Voltage</td>
<td>Load</td>
<td>Drop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I.</td>
<td>250</td>
<td>70</td>
<td>160</td>
<td>18</td>
<td>11.3</td>
</tr>
<tr>
<td>II.</td>
<td>250</td>
<td>70</td>
<td>160</td>
<td>18</td>
<td>11.3</td>
</tr>
<tr>
<td>III.</td>
<td>250</td>
<td>70</td>
<td>220</td>
<td>23</td>
<td>10.9</td>
</tr>
<tr>
<td>IV.</td>
<td>250</td>
<td>70</td>
<td>220</td>
<td>20</td>
<td>9.10</td>
</tr>
<tr>
<td>V.</td>
<td>250</td>
<td>70</td>
<td>220</td>
<td>19</td>
<td>8.64</td>
</tr>
</tbody>
</table>

An analysis showed that of a total of 11.3% drop, 76.5% could be traced directly to the power in-put, 4.07% to the drop in the lines from the busses to the cut-out box, 15.9% to the line from the box to the control stand, and 3.53% to the auto-transformer.

As soon as the tests were completed the engineer from the power company was called. A quick survey showed that the entire block was fed from two 25 Kw. transformers connected in parallel. Upon close examination, one of the transformers was found to have a burned out primary fuse. From all indications it had been out, and one transformer had been carrying the load, for six or seven months. Replacing this fuse rectified most of the trouble.

Many other illustrations might be cited that would show the valuable use that has been made of this standard.
method of testing voltage drop.

Another type of power difficulty can be classed as line surge. These are often very troublesome in X-ray work. To test for line surges, the high-tension transformer should have its secondaries disconnected from the rectifier and connected to the terminals of the standard sphere-gap. A voltmeter should be connected across the primary terminals. At a medium input the kilo-voltage (peak) should be measured with the sphere-gap several times and the average taken. Then the sphere-gap should be set for a kilo-voltage from 10% to 15% in excess of the kilo-voltage measured and the transformer energized. If the line is subject to line surges, the current will break down this gap consistently several times a minute. All X-ray transformers should be protected against line surges by a high resistance shunt across the primary terminals. The protective resistance may be in the form of a carbon rod, an open winding of fine resistance wire, a resistance wire baked into an enameled porcelain shell, or an ordinary incandescent carbon lamp.

Stability—Often the power supply is very unstable. Many times this condition cannot be rectified. Here again a complete analysis of the power condition may be of great assistance both to the engineer and to the roentgenologist. The following is a practical example of the tests made at a hospital.
The power for the hospital, as that for the entire city is supplied by a two-phase, four-wire distribution system. This system also supplies power for heating as well as for several large manufacturing plants. In order to discover just what the voltage characteristic was, a recording voltmeter was placed across the busses supplying the X-ray department. Voltage variations were recorded for a week. In this particular case, a 220 volt meter could not be obtained so a 120-volt meter was connected from one side of the 220 volt line to the neutral. Figure 14 shows an average of the curves for the week. An analysis of this curve shows that the voltage starts to drop at 6 A.M. when the hospital cooking and heating load, and the city's morning load begins to come on. At 9 A.M. the voltage has become fairly constant. At 11:45 A.M., when most of the industrial load begins to be cut off for the noon hour, the voltage raises 6 volts and stays at that peak until 1 P.M. when it suddenly drops back to the lower level again. It is fairly constant until 5:30 P.M. when the hospital cooking load and the lighting load of the city is cut in again.

From this analysis it was possible to recommend that the roentgenologist plan his high-voltage X-ray treatment work for the hours from 9 to 11 A.M. and from 2 to 5 P.M. As soon as he carried out this plan he had little difficulty from line fluctuation. Formerly he had been trying to operate
Figure 14.
his equipment from 11 A.M. to 1 P.M. and in some cases after 5 P.M. The complete study of the voltage characteristics made it possible for him to get perfect satisfaction out of his equipment in spite of the poor power characteristic.

Stability of frequency is essential for satisfactory operation of X-ray equipment. Tests for stability of frequency are usually made with a vibrating-reed frequency meter. The meter should be connected and readings taken at regular periods for a day or more. If the frequency is variable the problem should be taken to the power company. Fortunately, the cases of variable frequency are few.

CONTROL TESTS.

Control tests might be arranged under three heads as follows:— 1. Steps of main voltage control— 2. Filament regulation tests — 3. Timer tests.

Steps of Main Voltage Control— The great variety of X-ray machines offers a wide variation of primary voltage control, ranging from the units with no voltage control to those with 700 steps. It is not enough for the operator of an X-ray machine to know the number of steps obtainable. He should know the exact change of voltage for each change in control setting. Unfortunately, these steps are often very uneven. As stated before the control device is an auto-transformer or a rheostat or a combination of the two.
The Standard Victor Sphere Cap.

The Victor-Kearsley Stabilizer.

The Victor X-Ray Timer.

Figure 15.
The steps of voltage possible from the auto-transformer control may be found by taking the voltage readings across the output of the transformer for every setting of the control. In Figure 26 in the column headed auto-transformer volts are the voltage readings for various steps of regulation on one of the larger auto-transformers.

If a rheostat is used for the control, the readings may also be made across the output circuit. In this case, however, only the voltages under load are of any value since the voltage depends upon the current used.

**Filament Regulation Tests**—Careful tests should be made of the possible regulation of the filament current and the corresponding milliamperage change. These tests are usually made by varying the hand inductance regulator and taking the readings of the filament current and the milliamperes of tube current for each change. The curve in Figure 16 shows the importance of having a fine control of this filament voltage. The curve also shows the need of a stable voltage supply for this circuit. If possible it should be taken from a separate 110 volt line although it may be taken from taps on the auto-transformer.

**Timer Tests**—Usually the X-ray timer is tested for its accuracy of time interval and its duplication of this interval. For medium or long exposures, a stop-watch may be used in making the tests. But for short exposures
Relation of Tube Current to Primary Voltage of Filament Transformer.

**Figure 16.**

Tube Current in Milliamperes

Line Voltage
(fractions of a second) some other method must be used. One of the simplest methods of checking these time intervals is the top method.

The energy delivered to the X-ray tube is not an ordinary direct current but a pulsating direct current. This can be best understood by referring to Figure 17. Here, curve A shows the wave delivered to the rectifier. The rectifier reverses the circuit so that the current delivered to the tube during the time, M to N, is in the same direction as that delivered from O to M. The best mechanical rectifiers are not designed to use more than 85% of the voltage wave delivered. Some are designed to take as little as 10 to 15%. The result is that the current is delivered to the tube as shown by curve B. The time interval, T₂ to T₃, varies with the make and type of the rectifier. If the frequency of the alternating current line is known, the time of exposure may be accurately checked to within 1/120 of a second.

A metal top about 3 or 4 inches in diameter, with a small hole cut near the periphery, is used. The timer is set on the lowest setting and everything arranged for an exposure. Then the top is spun and the test exposure made. Usually several of these exposures are made on the same film so that a check may be made on the accuracy of the duplication. When the film is developed a small black spot indicates each exposure due to each energy wave.
**Sine Wave of Transformer Current.**

**Waveform of Current Delivered to Tube**

**Figure 17.**

**Relation of Secondary Current to Voltage**

**Figure 18.**
These spots will be separated by an unexposed part of the film proportional in length to the time that elapsed between the waves. (Figure 19). Changes in the speed of rotation of the top will change only the relative lengths of the parts of the film exposed, not the number of exposures in a given time. The number of these small exposures divided by twice the frequency of the power supply gives the actual time of exposure for a rectified machine. The number of exposures divided by the frequency gives the time for non-rectified units. Thus for a 60 cycle power supply 1/10 of a second exposure should show 12 dots on the test film. A little care must be used in counting the small exposures because sometimes the timer will cut in in the center of one wave and out in the center of another. This might be taken as two small exposures when actually the two small exposures on each end added together make one full pulse. This can be seen by comparing the length of these exposures with the length of the others.

It is interesting to know that some timers on the market graduated to 1/60 of a second can not be made to give an exposure less than 1/5 of a second. There is no change in the time interval at any setting below 1/5 of a second.
Top for Timer Tests.

Note:— Film of top is here photographically reversed.

Figure 19.

Timer Tests.

Showing the film result of a test for $1/10$ of a second on a sixty-cycle current.
HIGH-TENSION PROBLEMS AND TESTS.

Most of the high-tension problems that the field men have to solve can be classified under one of the following heads:-- high-tension transformer problems, rectification problems, and high-tension overhead problems.

High-Tension Transformer Tests-- The high-tension X-ray transformer is not designed for electrical efficiency but rather for a high voltage output at a very low secondary current and for a minimum size.

In order to determine the main characteristics of some of the common transformers on the market, the writer made tests of the transformer constants. The constants of most interest were: 1. the ratio of turns, \( \frac{n_1}{n_2} \), 2. the primary impedance, \( Z_i = \sqrt{r_i^2 + x_i^2} \), and 3. the secondary impedance, \( Z_s = \sqrt{r_s^2 + x_s^2} \). The primary exciting admittance, \( Y_e = \sqrt{g_e^2 + b_e^2} \), was not calculated. The first was obtained from an open-circuit test and the last two from a short-circuit test. For the open circuit test full voltage, \( E_1 \), at rated frequency, was impressed on the primary, and the primary, and the secondary terminal voltage, \( E = E_2 \), was read on a sphere-gap. The average of six readings at different primary voltages was taken since the transformer operates with varying primary input voltages.

In the short-circuit test, the secondary was short-circuited and a voltage, \( E_{sc} \), was impressed on the primary.
of such a value that approximately a full-load current, \( I_1 \), flowed in the primary; the secondary was then carrying the full load current, \( I_2 \). Readings were taken of \( E_{sc} \), \( I_1 \), and the power input \( W_{sc} \).

The power factor was then \( \cos \theta = \frac{W_{sc}}{E_{sc} I_1} \). The exciting current was so small it was neglected.

Since the terminal voltage of the secondary was zero, the impressed voltage, \( E_{sc} \), was consumed by the impedance of the transformer and was the full load impedance drop.

\[
E_{sc} = I_1 \left( Z_1 + \frac{n_1}{n_2} \right) I_2 Z_2
\]

\[
= I_1 \left\{ Z_1 + \left( \frac{n_1}{n_2} \right)^2 Z_2 \right\}
\]

\[
= I_1 \sqrt{r_1^2 + \left( \frac{n_1}{n_2} \right)^2 r_2^2} + \left( x_1 + \left( \frac{n_1}{n_2} \right)^2 x_2 \right)
\]

\[
= I_1 \sqrt{r^2 + x^2} = I_1 z.
\]

Where \( r, x, \) and \( z \) are the equivalent resistance, reactance and impedance of the transformer as primary quantities.

The power input, \( W_{sc} \), was primary and secondary copper losses plus a very small core loss and was neglected.

\[
W_{sc} = I_1^2 r_1 + I_2^2 r_2 = I_1^2 \left\{ r_1 + \left( \frac{n_1}{n_2} \right)^2 r_2 \right\} = I_1^2 r
\]

\[
r = r_1 + \left( \frac{n_1}{n_2} \right)^2 r_2 = \frac{W_{sc}}{I_1^2}
\]

\( r_1 \) and \( r_2 \) were determined by assuming that the two windings were designed for the same current density and, therefore, that the two copper losses were approximately the same.
In a similar way \( x = x_i + \left( \frac{n_i}{n_z} \right)^2 x_z \) was separated into its two components

\[
x_i = \left( \frac{n_i}{n_z} \right)^2 \quad \text{and} \quad x_z = \frac{x}{2}
\]

This would be correct of the leakage fluxes about the two windings were equal, which was assumed to be the case, since the magnetomotive forces were equal and the leakage paths very similar.

The following is a comparison of two transformers of the same rated capacity tested at the same place:

<table>
<thead>
<tr>
<th>Transformer #1</th>
<th>Transformer #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding ratio, ( \frac{n_i}{n_z} )</td>
<td>508 to 1</td>
</tr>
<tr>
<td>Power factor, ( \cos \theta )</td>
<td>.713</td>
</tr>
<tr>
<td>Angle of lag, ( \theta )</td>
<td>( 44^\circ 30' )</td>
</tr>
<tr>
<td>Primary resistance, ( r_i )</td>
<td>.2575 Ohms</td>
</tr>
<tr>
<td>Primary reactance, ( x_i )</td>
<td>.2425 Ohms</td>
</tr>
<tr>
<td>Secondary resistance, ( r_z )</td>
<td>66,200 Ohms</td>
</tr>
<tr>
<td>Secondary reactance, ( x_z )</td>
<td>63,100 Ohms</td>
</tr>
</tbody>
</table>

-54-
A careful study of these transformer constants made it possible to predict certain characteristics that each type of transformer would show.

The curves of Figure 20 give the ratio of lead impedance drop to secondary current output, and primary load current to secondary current.

Figures 21 and 22 show the equipment used for these tests.

**Rectifier Tests**—The majority of the mechanical rectifiers used as part of the X-ray machines complete a
Figure 20.
Curves Showing the Relation of the Secondary Current of Two Transformers to the Impedance Drop in Primary Load Current.
Figure 21.

Equipment as Arranged for the Open-Circuit Test of the High-Tension Transformer.

Figure 22.

Equipment as Arranged for the Closed-Circuit Test of the High-Tension Transformer.
rectification cycle every 180 degrees of rotation. In other words, a complete rotation of the rectifying switch (360 mechanical degrees) means a change of 720 electrical degrees. For this reason, a slight error in setting the rectifier may result in a much greater error in actual electrical rectification.

From the transformer tests above, it will be seen that the best power factor is about .713. This means that the current wave lags almost 45° behind the voltage wave. Therefore, if the rectifier is set to rectify at the maximum voltage, the current delivered will be only a fraction of maximum. Again, if it is set to rectify at the maximum current value of the wave, the voltage characteristic will be poor. The setting must vary a little for the particular machine and the use to which it is put. For instance, a therapy machine that is to be used at high voltages with currents never more than 10 to 15 milliamperes can use a setting nearer the peak of the voltage wave than a machine that is to use therapy settings one time and 100 milliamper radiographic setting the next. These settings must be made with a full knowledge of the field of service required. The radiographic rectifier should be set near the point shown by the intersection of the two waves in Figure 18.

Improper setting usually shows up in tests for ratings of a machine. A rectifier set too near the voltage peak will not deliver the rated maximum current, while the voltage
would be above the rated-voltage. The opposite would be true for error in the direction of the current peak.

The rectifier is a good place to look for losses in energy of the equipment. The common test is to take voltage between the high-tension transformer and the rectifier and compare this with the voltage of the tube circuit. Here again, the loss will vary widely with the type of rectifier. Often the losses can be lessened by adjusting all the shoes to a small sparking distance at all points.

The kilo-volt limits of all rectifiers vary with the type. The limits of the disc type are much less than the limits of the cross-arm type. These limits will also vary with the current used. If at any given current the voltage is raised slowly until the energy jumps the air gaps and flows completely around the disc from shoe to shoe the limits for that current is reached.

**Overhead Tests**—Tests for standardizing the overhead of an installation might be classified as follows:
1. insulation tests, 2. corona loss tests, and 3. capacity tests.

1. Fortunately insulation leakages usually make themselves known by noise, smoke or fire, or by visible sparking. One excellent way of looking for insulation leakage in the overhead is to darken the room and operate the equipment at as near maximum voltage as possible. In many cases the leakage will be seen as a luminous spray or a sparking.
Another test is to use a milliamperemeter in the circuit to read the leakage current.

2. Corona losses, like insulation losses, can readily be seen in a darkened room. A method of measuring the amount of this loss is to take voltage and current readings at various parts of the overhead installation and compare the readings. The corona loss on a well-designed overhead of brass tubing is very little but the loss on the wire overhead sometimes used often becomes a problem. This loss varies with the size and length of the overhead, the number of sharp points left by the installation man and so forth.

3. It is often necessary to run two pieces of overhead tubing, one near the other, to carry energy to a switch and back to a table connection. Whenever these tubes run parallel, even though they are each on the same side of the line, the capacity of the two is apt to cause trouble. Many times this is the source of the surge that periodically breaks across the sphere-gap 10% above the kilo-voltage peak being used. A good test for this capacity is to connect the two tubes with a small point gap separated about 1/4 inch. If there is a continual discharge between the two a high resistance should be placed between them to drain off this capacity charge.

TUBE TESTS.

Tube tests are usually performed on tubes for the
information of the operator. They are namely, tests for gas or increase of pressure in the tube, tests to determine the size of the focal spot and tests of electronic emission of the tube (ratio of filament current to tube current).

Tests for Gas-- Tests for gas, or an increase of pressure within the tube, should be made at a low voltage setting. If possible a resistance control should be used to limit the current that might follow through the tube if the tube vacuum were low. If there is an increase of pressure it will be detected by a brilliant green or blue color in the tube when the high-tension voltage is applied. Such a tube may be reduced again by long exposures at low current, 2 to 4 milliamperes, at a voltage of about 50 to 60 kilo-volts peak, providing the increased pressure is not due to a leak.

Tests for Electronic Emission-- Tubes should also be checked to see that the filaments emit enough electrons at low enough temperatures to be practical in the X-ray laboratory. This is usually done by checking the milliamperage current the tube will allow to pass at various readings of the filament ammeter.

Tests for Focal Spot-- The size of the focal spot, that is the area of the target on which the cathode stream is focussed, plays an important part in the detail or definition of the radiograph. Therefore, it is important
that the actual size of the focal spots of all tubes be tested. A common method is to make use of the pin-hole camera principle. A lead diaphragm with a hole from .005 to .01 of an inch in diameter is interposed half way between the tube target and an unexposed film. Then a heavy exposure is made. When the film is developed, an image of the target will be shown with a heavy spot showing the size of the focal spot. (Figure 23). It is interesting to note that the whole target gives off X-rays as indicated by the image of the whole target on the film. It can be proved that much of the lack of detail in a film is caused by this characteristic radiation. This effect can be shown by making an exposure with the tube target and focal spot turned toward the ceiling. Here the whole shadow will be due to characteristic radiation from other parts of the tube than the focal spot, the radiograph will lack definition of course.

PROTECTION TESTS.

Protection and the methods of testing for protection are important parts in the standardization work. Protection for the operator and other workers in the department should be considered and, also, protection for unexposed films.

Operator's Safety-- The danger of continued exposure of the body to X-radiation, although this radiation may be
FOCAL SPOTS OF X-RAY TUBES

Focal Spot $d_1$: $d_2$

Lead Diaphragm
Pin-hole $-$

FILM

Shadow of Focal Spot $d_1 = d_2$

Figure 23A.
Pin-hole Camera Method of Determining the Size of the Focal Spot of an X-ray Tube.

Note: - Focal Spots are here Photographically Reversed.

Fine-focus Universal

Medium-focus Universal

Broad-focus Universal

5-10 Radiator

5-30 Radiator

Figure 23.
Pin-hole Camera Records of the Focal Spots of the Common Tubes
very small, cannot be over-emphasized. Many of the tragedies among the pioneers of the X-ray science came from continued exposures at very low energy, 1/4 to 1/2 a milliampere of tube current. Of course, the danger is greater when the machine is used for treatment work at heavy voltages (110 – 120 kilo-voltage peak) and for long exposures. The effect on the body is accumulative. For this reason careful tests should be made of the protection offered the operator and other workers in close proximity to the X-ray room.

The presence of X-radiation is commonly determined by its effect on the emulsion of a film. The film is either worn by the operator or placed on the wall near the control stand for a day or longer and later developed. The amount of fog, blackening of the film, is then a check of the amount of radiation being received at that point. Special tests can be made by focusing the tube directly toward the walls to be tested and checking the radiation on the other side with a film.

Lead is a common protection used. Another method of giving protection is to make the walls of a special plaster made of barium sulphate.

A very common error is to suppose that no protection is necessary if the tube is surrounded by lead except for the treatment port. Tests show that a treatment room is filled with secondary radiation from the patient and the table although the tube is thus surrounded by lead.
Lead-glass, a trade name for glass containing enough lead salts to make it a good protective medium, is used for windows and wherever unobstructed vision is desired along with protection. Lead-glass has approximately the protective value of 1/4 the thickness of sheet lead. Figure 24 shows one of the experimental rooms at the Stanford University Hospital used by the writer in obtaining data for this paper.

Film Chests for the Protection of Loaded Cassettes--X-ray films are very sensitive to X-radiation and must be stored in boxes or rooms free from such radiation. When these films are loaded in a cassette between intensifying screens they are five or six times as sensitive as when stored in their ordinary containers. For this reason, special protection should be designed for films loaded and ready for exposure. A lead-lined box or chest is often placed in the X-ray room where the loaded films can be placed and be safe and convenient for use. These boxes should be checked to make sure they are safe. These tests can be made as described above.

General Film Storage Protection--Vaults should be built for the storage of both exposed and unexposed films. These vaults should be designed so as to be safe from X-radiation. Tests should be made in the usual way.

In addition to this, however, the vaults should be
Figure 24.

One of the Radiographic Rooms at the Stanford University Hospital.

Note:— Much of the experimental work for this thesis was carried on in this room. The picture shows the lead-booth for the protection of the operator and the lead-glass window to give a view of the room to the operator at all times.
designed for fire protection. Films are made of celluloid, a compound of camphor and gun-cotton, and are very inflammable. The vaults should be equipped with adequate automatic sprinkler attachments, automatic fire doors, and special flues for ventilation.

DARK-ROOM TESTS.

The dark-room is an important part of the X-ray laboratory. The following are some of the common sources of difficulties in the dark-room for which tests must be made: light, radiation, solutions, films and intensifying screens.

Light Tests— The dark-room should be tested to make sure it is a safe place to handle films. Tests should be made for light leakage and for defects in the ruby lamps. A strip of a film should be exposed in the dark-room for a minute while the remainder of the film is covered with a piece of paper. Then the paper should be moved on to a second strip and this and the first strip exposed for a minute (the first strip will then have had two minutes of exposure). This should be continued until four or five exposures have been made. The first strip will have received four minutes, the second three, the third two and so forth. If the room is light safe, this film when developed will show
no blackening. If, however, the room is not light safe the film will show the amount of fogging for each minute of time that the film is handled in the room.

Radiation Tests-- Since the films are loaded in the dark-room, tests should be made to be sure the loading shelves are free from radiation from the X-ray room. The loading shelves should be leaded or the walls leaded if the X-ray room is near.

Solution Tests-- The dark-room solutions, the developer and the fixing bath, must be checked from time to time to make sure that they are in good condition. There is no absolute rule as to the length of time these solutions will keep. Their life depends on the temperatures at which they are kept, the surface exposed to the air, the number of square inches of film run through, the cleanliness of the tank when the solution is made and several other factors.

The developing solution is a strong oxidizing agent. As it ages it gradually becomes oxidized and consequently looses its value as an oxidizing agent. An oxidized developer slows up the development process, has a tendency to produce stain and lessens the density and contrast of the film. The solutions are tested by checking the time required for proper development and the amount of stain on the film. The curve in Figure 25 is plotted from data given by the Eastman Film Company for the proper development.
The Variation of Development Time with Temperature of the Developer

Temperature in Degrees Fahrenheit

Time of Development in Minutes
of their films.

The safest procedure to follow in the making of solutions is to use one of the standard packages put up by a reliable company. In these packages the formula is in powder form and needs only to be mixed with water. The chemicals are pure and the formula is standard.

The action of the developing solution changes with the temperature. The solution should be kept between 65 and 70 degrees Fahrenheit. Figure 25 gives the time of development needed for complete development of films at various temperatures.

Film Tests-- Often difficulties in the X-ray results can be traced to the films themselves. The films should be tested for the following conditions: 1. light fog or radiation fog, 2. speed of emulsion and 3. clarity of base.

1. The best test for light or radiation fog is to develop and fix in the regular way a film taken from the film box to be tested. It is impossible to differentiate between light fog and fog from stray radiation unless the light fog happens to effect part of the film. This condition will be seen if a film box is opened in a lighted room. The light will fog only a portion of the film. But, aside from this particular case, the result of the test will be the same for light and radiation fog.

If the film is not fogged, the fixed film will be perfectly
clear. If the emulsion has been affected by light or radiation the finished film will be gray, the amount of coloring depending on the amount of light or radiation.

2. Tests for the speed of an emulsion, or the amount of blackening caused by a given amount of X-ray exposure, are usually comparative tests. Strips of a test film are exposed at given settings of the machine for various periods of time. The best method is to cover all of the film except a small strip with a piece of sheet lead. This strip is exposed about 1/4 second. Then the lead is moved, uncovering another strip of film. Again the film is exposed for 1/4 second. This means that the first strip has received 1/2 second and the second 1/4 second. This procedure should be repeated until the final film has strips of film exposed from 1/4 second to 2 or 3 seconds. When these films are developed and fixed they can be compared with standard films and the speed determined in relation to the standard film.

3. To test for clarity of the base of a film, the film should be taken from the box, and without developing, placed in the fixing bath. The result should be a clear film, providing the film base is clear. Sometimes the result will show a yellowish or grayish tinge in the film base.

**Intensifying Screen Tests**-- The films in most exposure
work are placed between two intensifying screens. These screens are made of calcium tungstate crystals which have the property of fluorescing when exposed to X-radiation. Their effect on the film is to intensify the shadows cast on them by the X-rays. These screens should be tested for: 1. contact, 2. speed, 3. lag, and 4. grain.

1. The screens must be in close contact with the film or the resulting image will not be sharp in outline or definition. The common test is to radiograph a section of iron screening. Wherever the screen is not in contact with the film the shadow of the screening will not be clear cut. This gives a quick method of checking the contact at all parts of the film holder, or cassette.

2. The speed of the screens can be tested by making comparisons of exposures made at given settings with and without the screens. If the film made at 5 seconds without screens has the same apparent density as that made at 1 second with the screens, the screens have a speed factor of 5 to 1. Actually, for most screens, this factor is between 5 and 6 to 1.

3. Some poorer grades of screens have the property of retaining the fluorescent effect for some time after the exposure is terminated. This property is called "lag". Lag is very noticeable when two films are taken in the same holder in succession, for the shadow of the first
object will be faintly seen on the second film. It is possible with some screens on the market to take an exposure of an object on the empty screens, then to place a film between the screens and after 15 minutes develop the film and find a clear image of the shadow cast on the empty screens.

An easy test for lag is to expose the screens in a darkened room to the X-ray for a time and watch the length of time it takes for the fluorescence to disappear. The fluorescence should disappear almost immediately. If it lasts from 5 to 15 minutes the screens are very poor.

4. The grain of an intensifying screen is due to the size and the distance between the crystals of the fluorescent salt. Grain shows up on a test film as a motteling of light and dark spots. Good screens should not show grain on the film.

PROBLEMS IN THE STANDARDIZATION OF OPERATION.

The last pages above have been devoted to a discussion of some of the tests that may be used to standardize the equipment of an X-ray laboratory. It may be interesting to follow with a discussion of some of the problems in the standardization of the operation of such a laboratory.
USE OF STANDARD TERMS.

The Need of Standard Nomenclature-- A study of this field of science quickly reveals the need for general acceptance of a standard nomenclature. Until just the last few years there has been no accepted nomenclature. Many of our roentgenologists are talking about a 5 or a 9 inch "spark gap" or "back-up gap" and in many cases are even trying to give treatments with such a voltage measurement. Nothing is said as to the sharpness or bluntness of the points of the gap. No consideration is given to the difference in this gap as read by two different individuals.

The writer has found as high as 30,000 volts maximum variation in the voltage measured by two individuals as a 6-inch gap. The energy delivered to the patient or the film varies as the square of the voltage, therefore, such variation may be disastrous.

The following factors influence the measurement of voltage by the gap method: altitude, humidity, wave shape, uniformity of waves, temperature, corona frequency, oscillations, shape of points, method of mounting points, the way the points are brought together, the way the current is turned on and the objects close to the gap.

The factors of time and distance are easy to measure and therefore they are well standardized.

The factor of tube current, especially in therapy work, is troublesome. Often treatment settings are measured in
milliampere-minutes at given peak and distance. Careful tests have proved that the actual dosage varies with the type of machine, the type of rectification and even with various tubes.

Standardization Committee-- At the mid-annual meeting of the Radiological Society of North America in 1925, a resolution was adopted for the appointment of a committee for Standardization. The personnel was to include no less than three physicists and three radiologists. They were to study the problems in relation to the adoption of a standard X-ray unit. The following committee was chosen:

Edwin C. Earnst, M. D., Chairman

Wilhelm Stentarom, Ph. D.

Otto Glasser, Ph. D.

N. E. Dorsey, Ph. D.

F. L. Hunt, Ph. D.

W. E. Chamberlain, M. D.

Arthur W. Erskine, M. D.

The problems of the committee were stated as follows:
1. To study and establish a standard X-ray unit, physically defined.
2. To determine the comparative variation of the X-ray dose measured in the unit for different qualities of radiation energy.
3. To devise ways and means of transferring such a
unit of measurement from a standardization center or centers (preferably the United States Bureau of Standards) to different roentgen institutions and private laboratories.

4. To further study the proposed physical X-ray unit in relation to its equivalent biological effect or value.

The following is a portion of the preliminary report of the committee at the last meeting (1926).

"Dr. Behnken of the Physikalisch-technische Reichsanstalt, Berlin, has perhaps given us the most accurate and theoretical definition of the "e" unit, as described by him at the recent International Congress of Radiology. He changed the name of this "e" unit to the "Roentgen" unit (1 R).

The definition of this unit is as follows:

* The absolute unit of the roentgen-ray dose is obtained from that roentgen-ray energy, which, by fully utilizing the secondary electrons produced, and by avoiding secondary radiations from the wall of the ionization chamber, produces in one c.c. of atmospheric air of 18° C. (64.4 F.) and 760 mm. atmospheric pressure, such a degree of conductivity that the quantity of electricity measured by saturation current equals one electrostatic unit."

The German Bureau of Standards has taken further steps to bring into practical use the unit "R", on the basis of the definition given above.

Without going into detail as to the relative merits of
the various methods of measurement, the Committee feels at this time that in all probability there are fundamental advantages in adopting the ionometric unit of X-ray measurement. The weak point of this method, as emphasized by Beclere, is that the present type of measuring apparatus will necessarily require further standardization.

In order to overcome some of these difficulties, Dr. Solomon in 1920 described an ionization unit which he called a "Roentgen" unit, and designated it by the letter "R", defining it as "that amount of roentgen rays producing the same ionization as one gram of radium element at a distance of two centimeters from the graphite ionization chamber, in the same axis after filtration through 0.5 millimeter of platinum."

Fricke and Glasser, in 1924, defined the "R" unit as described by Szilard, Friedrich, Dusne, and Behnken, by constructing a small ionization chamber made of materials having the same effective atomic number as atmospheric air.

It is important to remember that commercial substances such as aluminum, horn, ivory, graphite, paper, etc., are some of the materials employed in the manufacture of the various measuring apparatuses. The individual values of these materials largely depend upon their purity and the differences of their effective atomic number from that of atmospheric air.

In 1923 Beets and Arens described an ionization chamber
and an electroscope consisting of two circular parallel conducting plates. The filtered X-ray beam, in passing between these plates, traverses no substance other than air.

The comparison of the French with the German unit is as 2.25 is to 1. The (German) Behrken "R", therefore, is equal to 2.25 (French) Solomon "R" units, but this ratio changes with different wave lengths. All of the other present measurement units might be so converted, but unless an international unification is finally adopted, confusion will always be paramount to the simplification of our dosage problems."

From this report it will be seen that the task set is no easy one. But it represents a step in the direction toward standardization.

CALIBRATION OF EQUIPMENT.

To facilitate the handling of the equipment and to remove the necessity of making laboratory measurements every time the unit is used, the equipment should be calibrated.

Therapy-- The therapy machine should be calibrated for kilo-voltage peak and for dosage at the different tube currents to be used with each tube.

The machine should be equipped with a primary voltmeter. This meter, reading the primary, or input, voltage, should
be calibrated against the kilo-voltage peak at the various milliamperages used. A sphere-gap with 125 millimeter spheres is used for this calibration. Once this calibration is made, the operator should be able to duplicate accurately the kilo-voltage peak by reference to the primary voltmeter.

Radiographic—The problem in radiographic work is not so difficult for an error only means the loss of a film. It is not a case of danger to a human body.

The problem is a little different for the operator must know before the exposure is made just what kilo-voltage will be delivered to the tube. In this case, as in the case of therapeutic work, a primary voltmeter is calibrated against the sphere-gap readings for each current load used. Figure 26 shows a radiographic calibration chart filled out. Figures 27 and 28 are curves plotted from calibration charts. Figure 29 shows a case designed by the writer to carry complete equipment for the calibration of radiographic installations. Figure 30 shows the same equipment assembled. The equipment consists of a double scale voltmeter (0-150 and 0-300 volts) and a quick-adjusting sphere-gap with high resistors for protection against pitting of the spheres. The sphere-gap is equipped with a sea-level scale. The curves of Figures 31 and 32 were plotted by the writer to be used for finding the correction factor for this scale at
## Calibration Chart

**Prepared by Educational Dept.**

**VICTOR X-RAY CORPORATION**

**Chicago**

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**NOTEs:**
- This data is plotted in the figure.
- These values are average values.

**Voltage Fluctuation:** None

**Maximum Line Drop:** 6 Volts

**Charted by:** E. W. Phillips
LOAD CURVES. X-RAY TRANSFORMER
SNOOK MODEL

Plotted from average values.

Showing the relation between the pre-reading voltage and the kilo-voltage delivered to the x-ray tube, for various tube currents.

Figure 27.
LOAD CURVES X-RAY TRANSFORMER
WANTZ JR MODEL

Showing the relation between the pre-reading voltage and this kilo-voltage delivered to the x-ray tube for various tube currents.

Figure 28.
Figure 29.
Case for Calibration Equipment.

Figure 30.
Calibration Equipment Assembled.
Curves Showing the Relation Between Elevation and Pressure, A
Elevation and Relative Air Density, B

Relative Air Density = \( \frac{0.392 b}{273 + t} \)
where:
- \( b \) = barometric pressure in mm Hg
- \( t \) = temperature in deg C

Fig. 91 A

Elevation Above Sea Level in Feet

Fig. 91.
Relative Air Density

\[ \text{Relative Air Density} = \frac{0.03364}{T + 1} \]

Where:
- \( b \) = Barometric Press in min. of Hg
- \( t \) = Temperature in Degrees C

Graph A

- Spheres 62.5 cm D
- Spheres 125 cm D

Graph B

- Spheres 62.5 cm D
- Spheres 125 cm D

Note: Graph B to be used when relative humidity is approximately 35% or less. Results will be approximately correct for temperatures of approximately 35°C or less.

Elevation Above Sea Level in Feet

Fig 32 A

Fig 32
the various altitudes. The data for these curves was computed at a temperature of 25° Centigrade and at standard barometer pressure from the following formula:

\[
\frac{b_1 - b_2}{b_1 + b_2} = \frac{H \times 30.48}{1,600,000 \left(1 + 0.004 \cdot t\right)}
\]

where \( b_1 \) = barometer at sea level
\( b_2 \) = barometer at various levels
\( H \) = elevation above sea level in feet
\( t \) = mean temperature.

Since the sphere gap used for calibration is not accurate to more than 2%, the curves of 31 A and 31 B were computed at 25°, assuming \( b_1 = 76 \). From Curve A and the formula the relative air density = 

\[
\frac{0.392 \cdot b}{273 + t}
\]

where \( b \) = barometer in millimeters and \( t \) = temperature in degrees C., curve B was drawn.

From data given in the Standard Handbook the curves in Figure 32 A were plotted. Then from curves 32 A and 31 B the curves of 30 B were plotted. If a barometer is accessible the relative air density may be computed and the correction factor taken from the curves of Figure 32 A. But, unfortunately at most of our sanatoriums in the mountains, no barometer is to be had. In this case, for all practical purposes the curves of Figure 32 B are sufficiently accurate. However, for deep therapy treatment work a barometer should be used.
The time scale of the X-ray timer should be calibrated to make sure it is accurate.
Also the scale or scales to record the height of the focal spot from the film should be carefully calibrated.

USE OF STANDARD TECHNIQUE.

Results more uniform and far better are obtained when the laboratory adopts as far as possible a standard technique, or method of procedure. Often several operators are called upon to operate a machine or various machines. When the laboratory has a standard technical procedure the results will be less affected by the personality of the operator. There are two places for the adoption of a standard procedure: the operating room and the dark room.

Standard Technique in the Operating Room-- The four prime factors that are controlled in the radiographic room are: the milliamperage, the time, the distance and the kilo-voltage peak. The ratio between the effect of these factors on the film is best shown by the equation

\[ E_x = \frac{I \times T \times V^2}{D^2} \]

where \( E_x \) = the X-ray energy delivered
\( I \) = the milliamperage
\( T \) = the time of exposure
\( D \) = the focal film distance
\( V \) = the voltage across the tube
The tube circuit is measured by the milliamperemeter and easily controlled by controlling the heat of the filament.

The time of exposure is easily measured and controlled for ordinary exposure work. The product of these two factors or the milliamperes-seconds, control the radiographic density of the film. Twice the milliamperes-seconds should give twice the amount of blackening of the film emulsion if the other factors are kept constant.

The distance of the focal spot from the film is also easy to measure and control. From the above equation it will be noticed that the energy varies inversely as the square of this distance. The distance factor also controls the detail or definition of the shadows on the film. It must be remembered that the X-rays emanate from a focal spot of definite size on the target face, this size varying with the type of tube. Figure 33 shows the relation of the distance to the sharpness of shadow outline. It will be noted that two distances should be considered, the distance of the object from the film and the distance of the focal spot to the object. The object should be placed as near the film as possible. But this distance cannot always be controlled. The object may have to be radiographed through a splint or a cast. Here the distance becomes important. With a given size of focal spot, the greater the distance of the tube from the object, the sharper will be the shadows. Of course it is necessary to limit this distance.
Figure 33.
Showing the effect of distance, $D$, and $d$, on the radiograph and the effect of the size of focal-spot.
A practical limit should be used for the size of the focal spot.

The X-ray energy varies directly as the square of the impressed voltage. This factor controls the frequency of the radiation, or the wave length. The higher the voltage, the shorter the wave length. The wave length in turn controls the distance the rays will travel in the medium of the body without meeting interference and being absorbed. Or, in other words, the voltage actually controls the penetrating power of the beam of the ray. Since this is true why should we not set the other three factors for our ordinary work and control everything as far as our exposure is concerned by controlling the penetrating power of the rays. Then any failure to get the desired result may be attributed directly to this factor. If the film is over-exposed, the wave length was too short and the voltage should be lowered. If the film is under-exposed, the wave length was too long and the voltage should be raised. It is possible for the operator to manipulate the voltage to get the desired result.

Such a standardized method of procedure is far more simple than a method of varying two or more factors for various results as is commonly done.

Standardized Technique in the Dark Room-- The standardization of the dark room procedure should include the use of standard films and standard solutions. No one
should be in a better position to know just the proper proportions of the chemicals of the developing and fixing solutions than the chemical engineers who make the films. Chemicals purchased at the drug stores are often not satisfactory for photographic or radiographic work. Wherever possible a standard package developer should be used.

Films should be put through a standard development. An over-exposed film may be removed from the developer before it has been completely developed and thus be kept light. But such a film will not have the density and contrast of a film taken at the proper exposure and developed full time. The curve in Figure 25 gives the time a film should be developed for a given temperature. The best results will be obtained where this developing procedure is followed.

USE OF SPECIAL TECHNIQUE TO MEET AN EMERGENCY.

The problem of completely standardizing the technique of the radiographic room will never be completely solved for there are too many special cases. That is why the experienced operator is always in demand.

A beautiful exposure of a head is made at a 10 second exposure. But, alas, the patient may have a bad fracture of the head and along with it a nervous shock that makes it impossible to hold the head still for a tenth of that
time. This case must be taken at $1/10$ of a second to get an exposure without movement. Thus the problems come, each one peculiar to itself. However, the nearer the operator can work to a standard procedure the better will be his chances of getting the desired result.

With the equipment of a laboratory standardized as far as possible, and with a standardized technique of handling the equipment, the laboratory should be able to render high grade service to the public. Certainly nothing that can be done to raise the standard of service rendered to humanity for the alleviation of suffering, should be overlooked.
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