ELECTRICAL DANGERS IN X-RAY LABORATORIES

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THE recent death of Dr. Jaugeas by electrocution in an *x*-ray laboratory in Paris has served to direct attention to the danger in the operation of *x*-ray devices where proper precautions are neglected, or where the idea of safety is based on misconception of the fundamental facts involved. In the July, 1917, number of this Journal the writer described briefly the sources of danger and pointed out some remedies. It is interesting to note the following review of this article in the *Journal de Radiologie et d'Electrologie:*

"The author describes what might happen if the patient were subjected to an accidental spark. Without denying the extreme unpleasantness that would result from a short circuit between the patient and one of the high tension wires we may remind the author that confiding the operations in radiology only to a technician of experience, and continuous oversight of the patient and the apparatus, are, in practice, infinitely more efficacious than the automatic methods he prescribes. *Moreover one has never yet recorded, to our knowledge, a fatality due to contact with a high tension circuit used in radiology.*"

The death of Dr. Jaugeas and of several others less widely known, and the serious injury to patients in numerous instances, is sufficient answer to the ideas advanced in this review, especially as Dr. Jaugeas had had many years' experience. As a matter of fact very few roentgenologists have acquired reliable information on this important subject. On this account, and because of the rapid introduction of low power apparatus, it has seemed advisable to extend the remarks of the previous article even at the risk of some repetition.

While it is true that serious accidents in the operation of modern *x*-ray apparatus have not been numerous, yet the relatively small number of injuries is a matter of good fortune, as opportunities for contact with dangerous conductors have been extremely general.

There is evidently much misunderstanding as to what is or is not dangerous in this connection, resulting in advice often misleading, and, if followed, more likely to increase danger than otherwise. The result of an electric shock will depend in part on the condition of the subject, in part on the current and its duration, and also on the path followed by the current between the areas where current enters and leaves the body. Death is usually regarded as due to action on the heart and respiration, consequently the condition of the heart will be a large factor in the matter. Not only may death be due to an actual lesion, but a fatal result may follow from fright. On this account one is hardly justified in placing a lower limit on the voltage to be regarded as dangerous. Cases are on record where death has been caused by contacts with an alternating power circuit of less than 100 volts. Such cases may be difficult to explain, just as in the case of survival after contact with very high voltages that have not given a fatal result. Yet no one cares to assume that a given individual would not be killed or injured by such shock.

Keeping in mind the possibility of death from comparatively low tension circuits, it is clear that the operation of *any* *x*-ray tube at the voltage and power needed for fluoroscopic, radiographic or therapeutic work requires an outfit *potentially* dangerous. The only exception would be where the *entire* outfit is surrounded by a grounded metal shield or by a complete insulator. For some work such equipment may eventually be realized, but the present appliances must be used for a long time at least.

Leaving out of account the relatively rare cases where ordinary voltages give a fatal shock, it is generally agreed that a current of 100 ma. *maintained* through the vital organs for a few seconds or less is practically sure to be fatal. There have, no doubt, been numerous instances where a current greater than this has not resulted in death, but at any rate one would not care to risk it.

The current through the body will depend on:

1. The resistance of the body, including the contact resistance where current enters and leaves the skin.

2. The voltage at each instant tending to force current from the point of entry to the point or region where it leaves.

The total resistance of the body may be as low as 5,000 ohms depending largely on the area of contact, on the dryness of the skin and on the individual. Thus to originate and maintain a current of 100 ma. we must have 500 or more volts between the points of entry and emergence. Note that any voltage is more dangerous if maintained for more than a brief instant. Although a static machine will give many kilovolts on open circuit it can not maintain voltage when a few milliamperes are drawn and there would be little chance of serious result to a person in good health from contact with its terminals. Most induction coils in the early days were so designed as to give long spark gap on open circuit, but there was very little maintained voltage on an external resistance as low as that of the human body; thus they were not specially dangerous.

A Leyden jar or other condenser charged to several thousand volts may be discharged through the body causing an unpleasant shock but with little danger, as the voltage not being sustained by a generator there is only a brief rush of current rapidly falling to zero.

It should be noted that a high voltage applied to one point of the body when insulated from all other contacts, thus charging the body to a high potential, is not necessarily dangerous. One can stand on an insulated stool and receive a current charging the body to many thousand volts without danger. But the *maintained* flow of charge through the body is quite a different matter.

In order to understand the reasons for not doing certain things that increase danger, it may be well to consider the fundamental features of an electric circuit.

First, one should note that all electric charge comes from matter being separated from atoms by certain agencies known as generators. The amount thus separated is a very small fraction of the total charge bound up with the atoms of even a limited amount of material. Thus if all existing generators were set to pumping charge of one sign, say from the earth to some other body, the effect on the electrical condition of the earth would be negligible, much as though all the existing pumps were set to pump out the ocean—the resulting change in sea level would not be noticeable even if no water *ran back*. We therefore consider the earth as in a stationary electric condition. This is expressed by saying that earth *potential* is always zero, exactly as we use sea-level as a starting point for measuring levels. When an electric charge tends to move to or from the earth the body on which this charge is located is said to be at a *potential* of a certain number of volts. If a point on any conducting system is joined by a conducting path to the earth that point is said to be brought to *zero potential,* or is grounded.

The function of a generator, battery, dynamo, or transformer is to create differences of potential by the separation and movement of charge, thereby causing and maintaining electric current when conditions permit transfer of charge by any outside conducting path.

To illustrate, consider first the *primary* circuit of the usual *x*-ray transformer. The generator (Fig. 1) causes a voltage or potential difference of 220 volts between its terminals; a portion of this may be used in the control resistance, the rest is consumed in the primary. This *distribution* is quite independent of the potential of any part of this system as referred to the earth. In fact the entire system may be insulated from earth and given a static charge to thousands of volts and operate just as before.

If now we join any single point to earth, as at Q, that *point* acquires earth or zero potential. Assuming a good conductor between Q and A, the latter point will likewise be at zero potential and P will differ from Q by 140 volts, while B will be 220 volts

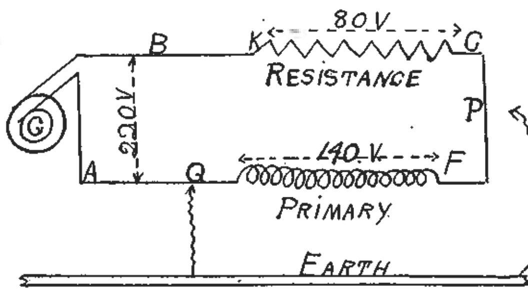

FIG. 1. EFFECT OF "GROUNDING" ONE SIDE OF THE PRIMARY CIRCUIT OPERATING AN *X*-RAY TRANSFORMER THROUGH RESISTANCE.
Potential difference between earth and line G to K, 220 V.
Potential drop in resistance 80 volts.
Potential difference between lines C, F and earth, 140 V.
Fall in potential through primary, 140 volts.
Grounding another point, as P, may seriously disturb electrical conditions, depending on the resistance of path PEQ.

above or below zero. Grounding a second point, say at P between F and C, will tend to divert current from the primary to the earth, thence to Q. The amount of current so diverted will depend on the resistance over the path PEQ as compared to that of the primary. Contact between K and B would cause more current through the body than contact at P.

Now if there is no *ground* on the circuit one would get no shock by contact with either Q or P. But if one point, as Q, is "grounded" and one point of the body is "grounded," contact at P will allow current to flow through the body to earth and thence to Q.

The reader should note that these "grounds" may or may not allow any considerable current to pass depending on the resistance of the path PEQ and on the voltage between these points. In the case shown but little current could pass through a human body, as the resistance would be too great for the potential available. Observe that two contacts are needed; both may be direct to the circuit, or one may be indirectly made through the earth. So that a "ground" may make it easier to get a shock.

When we deal with much higher voltages the principles remain the same, but it becomes possible to force currents over much greater resistances and one does not need so low a resistance between the active line and the earth to have an effectual "ground."

Fig. 2 shows the electrical features of a transformer circuit where the middle of the secondary is connected to the case or is, for high potential purposes, "grounded" even though no conducting wire runs to "earth." Assuming operation at 60 K. V., i.e., at a little more than a 5 inch gap, the center of the

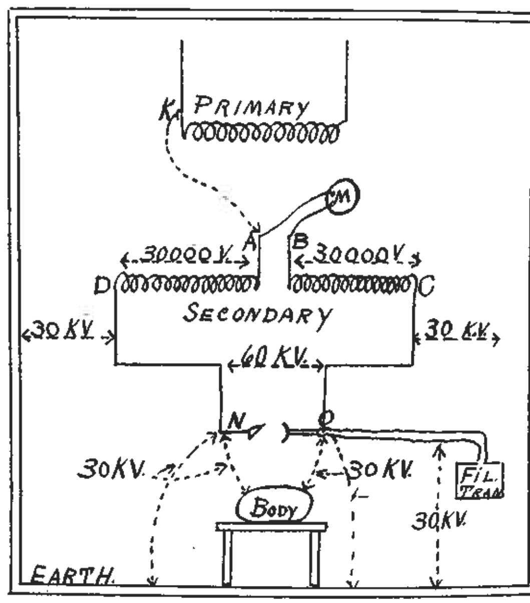

FIG. 2. ELECTRICAL SYSTEM 60 K.V. OPERATION. A AND B MAY BE CONNECTED TO A MILLIAMMETER, OR JUST CONNECTED TOGETHER BY A WIRE. A and B may be regarded for our purpose as having zero or earth potential. If the table is a conductor and is grounded, the patient's body becomes of earth potential. If body is insulated for several thousand volts, the nearest region of earth potential will not be the patient's body. *Note that when the body is between a conductor and the tube or line, danger is increased by grounding either the body or the conductor.*

secondary will be substantially at earth potential, each terminal will differ in potential from earth by 30 K.V. Thus if a pointed conductor connected to earth were brought about 2½ inches from either terminal there would result a discharge to earth. Current passing from C through earth back to B. While one would be quite safe in touching the point B, or a milliammeter connected as shown, there would be grave danger in a simple direct contact with a terminal or even in approaching close enough for a spark from either terminal or the line, although only *half* of the available voltage is involved. The advantage of this construction is that there is never more than *one half* the working tube voltage tending to cause discharge to the earth or anything connected therewith.

Sometimes in outfits designed to operate on *low* gap one terminal or line of the high tension is grounded. This makes contact by operator or patient with that terminal or line entirely safe; but there is twice as great a risk of spark-over from the other terminal as there is in the case of a grounded middle working at the same gap. One may also connect *one* point on the primary circuit to *one* on the secondary without any increase in danger. When this is done no *low resistance ground* is permissible from either primary or secondary. Serious damage to apparatus has resulted when such a second ground has been made; in fact all ground connections for apparatus protection are best made through suitable resistances.

Consider now a human body between two conductors whose potential difference exceeds a safe limit. If there is an adequate additional resistance or insulator between the body and both or one of these conductors there is no danger. Thus in moderately high tension power work, rubber gloves, insulating mats or platforms, oil switches, etc., are utilized to *insulate* the attendants. If both patient and operator were perfectly insulated from earth there would be no danger from contact with *one* side of a high tension circuit, or if sufficient insulating resistance were placed between them and *one* line they could not be injured by contact with the other side or line. Thus complete insulation of patient and operator from all parts of the high tension lines would be ideal if it could be done without interfering with the work. But no possible system that permits contact with or proximity to a high potential can be made entirely safe.

Assume now, as is usually the case, that the operator concerned is grounded. He must then ensure that no part of his body comes within sparking distance of any part of the high tension line.

In fact there should be a considerable factor of safety, so that the insulation between the body of operator or patient and any point on the high tension circuit ought not to be less than that of an air gap of twice the spark length of a discharge from the high tension line to a pointed conductor connected to the earth.

Thus when using a 9 inch gap on a transformer with a secondary grounded at the middle the shortest distance from the body to the nearest point of the circuit should not be *less* than nine inches. A much greater distance is desirable and except in deep therapy there is no reason why it should not always exceed double the sparking distance to earth.

We now need to consider the danger to the patient more in detail. Were the patient placed on a perfect insulator and *also* prevented from getting dangerously near both lines on opposite sides of the tube at the same time, he would be electrically safe. But when placed on a *grounded conducting table danger is greatly increased,* quite contrary to traditional belief. This may be seen from Fig. 2. The path of least resistance from either terminal to earth is from the terminal to the body, thence to the metal table. It makes no difference whether the tube stand is grounded as well as the table or not in so far as danger of electrocution is concerned, since the tube terminals are insulated from the stand in all cases. Also we may call attention to the fact that for high tension work the resistance of the body may be regarded as negligible in comparison with that of a small air gap.

Hence safety of the patient when in contact with any conducting body and between this conductor and any portion of the high tension line is only insured by suitable insulation *between* the line and the patient. Grounding such a conductor, so that discharge from the line to earth would have *least resistance by passing through* the body, increases danger. The use of any metallic table for radiography or treatment where the patient is between the tube and the table should be prohibited. It should, however, be observed that when a horizontal or vertical fluoroscope is used the patient is *not between* the *high tension* and the metal and no danger to the patient arises from grounding.

Keeping in mind the above principles, one may ask: How are they to be applied, or in what particulars are present installations dangerous? One way to answer these questions would be to point out how a laboratory might be arranged so as to reduce the possibilities of danger.

First one must condemn the relegation of *x*-ray work to cellars, closets or dark and damp quarters where no one has a right to ask operators or patients to risk their lives in operating high tension apparatus. A considerable number of hospitals are open to just criticism in this respect. Also one must unqualifiedly condemn the crowding of apparatus into inadequate space. The room in which Dr. Jaugeas met his death was reported some months earlier as containing so many odds and ends of apparatus as to make it hardly possible to move about. Rooms to be used for radiography or therapy should be well lighted, dry, well ventilated and not overcrowded.

The present custom in American laboratories of using a large transformer for all work and running high tension lines from one room into another is a continuous menace, as it is always possible for one to attempt to make connections when the line is alive. The practice of having the operating switch board in a separate room at some distance from the tube stand and often having only a small window for observation is a great risk. There have been several cases of severe shock to roentgenologists or assistants when someone entered the booth or separate room and closed the switch without observing that the other party was adjusting the tube or that the patient had moved to a point of danger. There should be no possibility of closing the switch without standing facing the tube and with a clear, unobstructed view of the entire high tension system. The writer would advise a spring floor switch in series with the timer or operating switch, so that the operator must stand in one position in order to close the circuit, and in case of accident removing the foot would open the circuit irrespective of the timer. This would correspond to the "dead man's" button on electric cars.

Fluoroscopy can now be done with self-rectifying tubes and small transformers, avoiding all risk of having several connections to the same machine, as well as all expensive and complicated over-head systems. In a fluoroscopic room, since operation in darkness is essential, all high tension lines should be so protected as to preclude the possibility of any person, whether familiar with the apparatus or not, coming within ten inches of any part of the high tension circuit. The handles controlling the diaphragm should be of good insulating material and mounted so as to avoid proximity to the high tension line. A red light in shunt with the foot switch and in series with a line switch may serve two purposes: it indicates danger by showing that the main switch is closed, and also serves for weak room illumination when the foot switch is open. If both a horizontal and a vertical fluoroscope are to be operated by a single transformer, changes in connection from one to the other should be made by an oil-immersed switch of proper design. This will eliminate corona and needless exposure of the high tension circuit.

There should be no radiography or therapy using a metal table with the tube above the table, quite irrespective of whether the stand is attached to the table or not. This means the use of a table top of insulating material with ample insulating supports between it and the metal frame or support.

The overhead high tension system should be of tubing (this may be brass instead of copper) firmly mounted in insulating supports. These tubes should extend to the transformer terminals. No part of the overhead should be less than seven feet from the floor and *only one set of reels should be attached.* No wires or other conductors should be suspended above or below the overhead system, or so that they may swing near to it. *Coolidge filament* wires are part of the high tension circuit and must be treated as such. Reels should be of substantial construction and mounted so as to preclude any possibility of their falling. Any reel permitting a sagging wire should be discarded or repaired at once. The wire on reels is often unsatisfactory, it should be stronger and ought to be inspected frequently.

When treating or radiographing nervous patients, children or those not likely to understand instructions, a sheet of strong canvas should be passed over the patient and fastened to the table so limiting movement as to prevent the patient from contact with line or tube by raising his arms or legs or by suddenly rising from the table. There is room for improvement in tube holders and terminal connections to assist in this matter. But even if this is done care must still be exercised, especially in deep therapy. The writer questions the advisability of deep therapy at as close a range as 8 inches. The terminals are as close as the target or may even be closer to the body. Further the ratio of deep dose-to-skin dose is much improved by working at greater target skin distance. Special terminals, such as described by Johnson, would help if not too cumbersome. A special screen might be developed if desired.

A quick acting circuit breaker should be inserted in the primary of *every x*-ray transformer. This should be set to act on not more than a 20 per cent overload. Thus if normal operation uses 35 amperes, then 42 amperes should open the breaker. Since on normal operation with a properly designed transformer nearly one milliampere tube current is secured for one ampere of primary current, it is not difficult to set a breaker for the largest current permitted. A short circuit through the body or otherwise would cause a primary current much above normal, thus opening the breaker.

Do not depend on line fuses. It takes time to raise a fuse to the melting point and delay is dangerous. They often stand a high overload for a long period without rupture.

If a double scale milliammeter is used it should be provided with an insulating device for changing the scale.

No complicated apparatus that will allow the terminals of the tube or the lines leading thereto to come near the patient or near to anything in contact with the patient should be permitted.

All switches should be self opening, requiring the operator to *hold them closed throughout an exposure, or treatment.* This should be done even though a time switch is used. Foot switches should not be constructed so as to lock or stick, but should open quickly and positively on release of pressure. Power switches should open down so that it would not be possible for them to fall shut.

Do not assume that a small outfit is essentially safe. One may be electrocuted by a small transformer if conditions are favorable, and he surely could be no more than killed on a large machine.

The rapidly increasing use of small transformer outfits with self-rectifying tubes for dental and bedside work demands special attention. There is danger from too close proximity to the lead wires, especially where both wires come near the patient or where one is near the patient and the other near metal, as in a metallic chair or metal bed. Also such outfits should never be operated by means of a foot switch. In two instances already reported to the writer an operator has been seriously shocked by some one accidentally stepping on such a switch. Connections of the high tension wires to the tube should be substantial and certain. If one should become detached, unhooked or broken, it may put the patient in series with the tube, causing an unfortunate shock if nothing worse.

It must not be assumed that safety is *insured* by any *system of grounds* or special make of apparatus. In this connection the writer may call attention to the implication in the editorial section of the March issue of this JOURNAL that the American type of transformer is more dangerous because the "secondary high tension wires are in direct connection with the primary current through the transformer." As stated above there is *not* usually a direct or metallic connection between primary and secondary, and in any case the construction serves to avoid a potential to ground of more than one half of that operating the tube—a matter of considerable importance when operating at high gap as in deep therapy.

Ill advised grounding of electric power circuits may also cause a great deal of trouble and damage. The grounding of ordinary electric appliances such as transformer cases, conduits, panel board boxes, etc., has been worked out on the basis of long experience and is used to reduce risk in case of breakdown of insulation, accidental crossing of high and low tension wires, etc. Also where dampness or unusual conducting conditions are encountered lamp sockets and fixtures of special design are used further to protect the user and reduce fire risk. It is not permitted to ground a point on the active circuit except under very explicit conditions, since a second ground may be very dangerous. It follows that it is not wise to ground in the usual sense the case of an *x*-ray transformer. When it is done it should be through a suitable non-inductive resistance which will carry off surge or "static" without endangering the installation.

Aside from grounding for the real or supposed protection of the patient from discharge likely to endanger life, we have to consider the so-called static that often scares patients and troubles operators although not essentially dangerous. Whenever a high tension line is operated near insulated conducting bodies, such as metal plates, wires or the human body when on an insulating support, there will develop electric charges on these surfaces. The amount will depend on the area and proximity of the conductor, on the voltage of the line and somewhat on atmospheric conditions and the dryness of the walls and surfaces. When a person joined through more or less resistance to the earth, as the operator always is, approaches such a conductor, as for example the body of the patient, a brief spark discharge occurs. This is not painful or dangerous but tends to scare the patient and to suggest electrocution, *x*-ray burn, etc. It rarely occurs in radiography, but may be troublesome in treatment and fluoroscopy. In the latter it may be avoided by grounding the table if conducting, since the body is not between the tube and a grounded support. If trouble of this kind occurs in treatment it may be overcome by discharging the body through a pointed conductor connected to earth and brought near the body *after the operating switch has been opened.* There is rarely any difficulty of this kind in treatment, however, except where sheets of metal are used for protection and are so placed as to discharge to the skin, and this may be avoided by using felt or rubber between metal and skin.

There is an impression current among many that auto-transformer operation is essentially more dangerous than with resistance control. As is often true in other cases, a categorical statement of this kind cannot cover the facts. Keeping in mind that electrocution or serious injury may result from improper use with either control, there are two essential points to consider. When a tube is in operation at a given voltage the danger of spark-over to the patient is the same for both types of control, all conditions being alike. If an actual discharge to the body occurs the auto-transformer will maintain a larger current, and in that respect be more dangerous; but the smaller current with the rheostat control may cause death or serious injury. Also when a circuit breaker is used it is likely to open much quicker with auto-transformer control than with rheostat, in part, at least, offsetting increased current by decreased duration. Even a moderate series resistance will delay the opening of a breaker somewhat.

In one important particular the rheostat control is much more dangerous than the autotransformer. Suppose a tube taking say 40 ma. at a 5 inch gap suddenly ceases to take current (a cranky gas tube, or a failure in the filament circuit on a Coolidge tube), with a rheostat control *the open circuit* or no current gap on this setting may be 10 or 12 inches, while with the autotransformer the difference between the 40 ma. and the no-current voltage may not exceed an inch. So that the danger of *starting* an arc by tube failure is much greater with the rheostat than with the other control, even though when once started the rheostat may be somewhat less dangerous because of lower current. This is of special importance when using a self-rectifying tube. The voltage of the suppressed wave will be very high on resistance control; hence an auto-transformer with a good circuit breaker is much safer with these tubes than is a rheostat.

Neither the precautions here mentioned nor indeed any formulation of rules or regulations can ensure safety to those concerned. But if they are followed they may help to avoid risk especially to those not familiar with the outfit who may be either patients or assistants. Nothing can relieve the roentgenologist in charge from the duty of knowing that reasonable precautions are taken and that every effort is exerted to secure protection. Neither are hospital authorities free from responsibility. They should not turn over equipment with such possibilities of danger to untrained people or accept advice only from those whose interest is exclusively in sales of apparatus.

Finally, medical colleges may some day come to realize that special training is needed for those who are to utilize such powerful agencies in their profession. It is quite true that there is not time to train all medical practitioners in all topics, but there should be provided opportunity for those who do specialize in radiology to secure adequate training. When this is accomplished this practice should be restricted to medical graduates who have, in *addition* to the regular medical course, such special training as is needed to increase both the usefulness of this agent and the safety of all concerned.

Note: The leaflet quoted in the March Journal issued by Messrs. Watson & Sons may be questioned in some important particulars at least as applied to American laboratories. The matter of grounding has been discussed above, so that paragraph 1 may be passed. All will agree with 2, 4, 10, 11, 13 and 14. The advice given in 3 is dangerous, as the rate of insulation deterioration leading to breakdown is often high and a feeling of false security is encouraged by *assuming* that such insulation protects.

As regards 5 there should never be any *high tension overhead wires*. The writer pointed out some years ago the great advantage of metal tubes. These should be mounted with care and well braced and should extend clear to the transformer terminals. The idea of stretched grounded wires below the overhead would not only be cumbersome but would fail by breaking when an arc results from contact, and would short-circuit the transformer—a very dangerous procedure.

Paragraph 7 is surely bad advice. The writer had occasion a few years ago to test hundreds of fuses. They will often carry an overload of 100 or 200 per cent for some time before blowing and sometimes not blow at all. A quick acting circuit breaker is infinitely better.

In reference to paragraph 8, why are the metal terminals of the *Coolidge* tube assumed to be any closer to the patient or more dangerous than those of any other tube when operated at the same control setting? As regards metallic gauze one may cite an instance in France where one of our grounding enthusiasts used a wet sheet over a patient with quite unexpected results.