X-RAY PROTECTION.

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The increasing value and consequent more general use of X-rays for diagnostic purposes, and also as a therapeutic agent, render it very necessary that the fundamental physical principles involved should be more generally understood. The reason for this is mainly that protective measures may always be intelligently employed when X-rays are being used. In medical X-ray practice, X-ray dangers may be regarded as threefold:

1. Danger from the actual beam of X-rays.
2. Danger from the high tension electricity.
3. Danger owing to inadequate ventilation.

Each of these sources of danger threatens the patient, and all who happen to be present in the X-ray room during exposures; especially those who are constantly employed in X-ray work. Further, the result of improper or careless use of the rays and neglect of due precautions may not, by any means, be immediately apparent. The effect may be cumulative and symptoms only appear when the trouble is very far advanced. On the other hand all these dangers may be considerably modified if not entirely eliminated, by carefully designed protective measures.

It is proposed to consider the question of X-ray protection under each of the foregoing headings separately and to explain in very general terms the source of the trouble and show how due precautions may be observed.

In the first place it is pointed out that all exposures in radiography should be reduced to a minimum consistent with the production of good radiographs. Long exposures mean that the patient is having a large dose of radiation, for the same reason careful attention should be paid to the diaphragm, the opening of which should be as small as possible. Screen work, i.e., visual X-ray examination, should be reduced as much as possible; and all work as far as requirements allow, should be done by means of radiographs.

DANGERS FROM X-RAYS.

X-radiation is known to be a form of radiant energy exactly the same as light and radiant heat, the only difference being one of frequency, i.e., the wave lengths in the case of X-rays are very much shorter than those of heat and visible light. X-rays are produced when the speed of an electron is altered, and this is achieved in all X-ray tubes by stopping an electron stream (cathode rays) by means of a block of metal (target or anti-cathode); the method of producing this cathode stream being different.
in the case of a "gas" or "ion" tube, and a "hot cathode" tube of which type the Coolidge is a familiar example.

When the cathode particles strike the target, electro-magnetic disturbances are set up which result in the short wave vibrations known as X-rays.

It is pointed out that not all the cathode particles will be stopped at the same rate and consequently the resulting waves will not all have the same length, hence it follows that the X-ray beam produced in any X-ray tube is made up of different wave lengths and is mixed or "heterogeneous."

The X-ray wave length is determined by the change of speed of the electron, the greater the change of speed the shorter the resulting wave length and the more penetrating the beam of X-rays.

The speed of the cathode beam when striking the target is determined by the strength of the electric field between the electrodes; therefore penetrating or hard X-rays are generated when the electrical pressure across the terminals of the tube is high; but as stated above, soft or long wave length X-rays are also produced at the same time.

The property of the rays which is chiefly utilized in medicine is their ability to penetrate different substances, and as I have said, this ability to penetrate increases with the shortness of the wave length. The penetrability of any substance by X-rays depends upon its atomic weight. The greater the atomic weight of a body the greater its capacity as an absorber of X-rays and the greater the difficulty of penetration. Similarly to light, X-rays travel in straight lines, and so when passing through a substance and encountering another substance of higher atomic weight increased absorption takes place, resulting in the usual shadowgraph.

Whenever X-rays are impinged upon a body, a certain proportion of the radiation is scattered both at the surfaces of that body and also internally. In medical practice it should be remembered that this scattered radiation tends to have a fogging effect on the plate. The effect of this phenomenon, in this respect, may be lessened to a certain extent by a careful technique and proper adjustment of the "hardness" of the rays (i.e., the voltage) to the particular radiograph required.

The question of secondary radiation does not come within the scope of this article as in general Army medical practice, the question of protection is not concerned with it.

It will be seen from the foregoing remarks that the danger from X-rays is entirely bound up in the X-ray tube itself as the source of the radiation and therefore it is the tube that must be "protected" in the first place and not the operator. If it were possible adequately to protect the tube in such a way that no radiation should escape, then obviously lead aprons, gloves, etc., would be entirely unnecessary—this, however, for many reasons is not possible but at the same time the principle to be kept in mind is that the tube, as the very fount of the trouble, must be carefully protected as far as possible.
It has been said that the absorbing capacity of a substance with regard to X-radiation depends upon its atomic weight, therefore, it is clear that for a protective material this is the one desirable quality and for this reason metallic lead is usually chosen: other materials which are commonly used for the purpose, invariably contain lead in more or less quantity.

It may be noticed here that generally speaking, about 3 millimetres of commercial "lead rubber" is equivalent in absorbing power to 1 millimetre of metallic lead, and similarly about 7 or 8 millimetres of "lead glass" is also equivalent to 1 millimetre of metallic lead.

The tube should be, as far as possible, surrounded by three millimetres of metallic lead or its equivalent; and this should afford very generous protection and should allow of any type of X-ray work being safely carried out. It is pointed out that care must be exercised in fixing the protective material and ample space must be allowed round the tube, otherwise sparking may occur from the material used to the wall of the tube, resulting in its puncture. X-ray tube boxes and holders are invariably fitted with an adjustable diaphragm and it is again emphasized that this opening should always be as small as possible.

Fluorescent screens are usually covered with a layer of lead glass, but from the figures quoted above it will be seen that this is not to be regarded as adequate protection. Radiation passes through the screen and by the very nature of its employment constitutes a real danger to the operator. Its use, therefore, as already stated, should be severely restricted. It is obvious also that palpation under X-rays is dangerous; especially as efficient palpation inhibits the use of protective gloves, here again this work should be restricted to the greatest possible extent.

There is one aspect of X-ray danger which is very often overlooked, namely the different physiological effects of a beam of X-rays. It has been said that every beam of X-rays is "heterogeneous." It is comparatively easy to absorb efficiently the soft or long wave component of the beam, but it is not easy, in fact it is impossible in any practical manner to absorb completely the hard, or short wave component. The physiological effect of X-rays entirely depends upon the absorption of the rays by the tissues; and from what has been said it will be understood that the soft radiation will be absorbed in the skin and superficial tissues, consequently any effect will be apparent there and in a comparatively short time. This, however, is not the case with regard to the hard radiation which, being more penetrating, is absorbed by the deeper tissues and the results are infinitely more obscure. X-rays have been shown to have a serious effect on the blood and glands. These effects are certainly cumulative and being unaccompanied at the outset by obvious symptoms are much the most dangerous. The protection recommended above will certainly absorb a very large proportion of the total radiation, but at the same time, some will escape and that which does so is potentially a danger. These remarks
apply of course to tubes operated at high voltage. Where the voltage is low there will be no radiation of high penetration produced. In addition to the lead protection recommended, the operator should remain several feet from the tube during exposures in heavy radiography.

It is to be noticed that when radiographing a thick subject with a low spark gap, i.e., low voltage and even when employing a heavy current through the tube, the exposure will be long and thus the risk to the patient of skin trouble is very much increased. Hence the need for adequate training and careful technique on the part of the operator.

X-rays as a therapeutic agent are becoming more widely recognized. The attendant risks in this work are considerable both for the patient and the operator.

Apropos of ringworm treatment, it must be remembered that X-rays have a deleterious effect upon hair follicles and unsuitable treatment may result in complete loss of hair. X-ray treatment should never be undertaken except by a trained and experienced radiologist and then only with extreme precaution, and the dosage should be carefully measured. It should never be undertaken unless suitable apparatus is available, i.e., filters and devices for measuring intensity.

DANGERS FROM HIGH TENSION ELECTRICITY.

High tension is necessarily always employed in an X-ray installation. The high voltage necessary to give acceleration to the cathode stream is usually provided by means of either an induction coil (Ruhmkorff coil) in which the primary current is made and broken mechanically, or by a closed core static transformer.

To consider in the first place the induction coil. This consists of an open core static transformer and used with it is a device for interrupting the primary current. This is the most general type of installation found in military hospitals and is admirably suited to the work that is usually required. In addition to outlining the precautions which must be adopted in the use of all very high voltages, it would be as well perhaps to say a word or two here about the general care and operation of an induction coil. The proper performance of a coil depends very largely on the type and efficiency of the "interrupter" which is used to make and break the current. The modern type of interrupter in common use consists essentially of a jet of mercury rapidly rotated in a dielectric of coal gas by means of an electric motor and so making a series of intermittent electrical contacts. Perhaps the most common cause of failure of coil outfits is traceable to the indifferent performance of the interrupter. This instrument should be periodically taken to pieces and cleaned and the mercury channels kept free; the mercury should frequently be taken out and filtered before replacing. A condenser is also supplied with every coil equipment, and connected across the terminals of the interrupter in the
primary circuit. The condenser should prevent any arcing in the interrupter. Induction coils produce inverse current, i.e., current which endeavours to pass in the wrong direction through the X-ray tube, and in order to "cut out" this current it is necessary to employ a special device. This usually takes the form of a commutating vane mounted on the top of the interrupter and rotated by the motor—the device works well as a general rule, its chief disadvantage from our point of view being that it occasions sparking at each contact. This sparking is a thing which it is desired to eliminate for reasons that will be given later; if, therefore, a rectifier of this type is used, it is desirable that it shall be enclosed in a cupboard.

Another method which is often adopted in order to "cut out" the inverse current is the use of "valve" tubes.

The valve tube is essentially a vacuum tube which is designed to have a low electrical resistance in one direction and a high resistance in the other. The use of suitable "valve" tubes is a highly efficient method of suppressing "inverse," but it requires constant care, and a certain amount of technical skill is necessary to operate the valves to the best advantage.

To consider now the question of the high tension closed core transformer. Insulation in this instrument may be effected either by air (dry) or the coils may be immersed in oil. It is worked directly by alternating current (usually single phase). There is considerable difference between these two forms of high potential generator, the chief being in the resulting voltage wave form, which has a very important bearing, not only on the resulting X-rays, but also on the life of the X-ray tube. The chief point of difference from our present point of view is one of power. It must be very thoroughly understood that the power of a closed core transformer is infinitely greater than that of an induction coil and the danger, therefore, is very much enhanced.

Both types of generator give "inverse" current and similar methods are employed in each case for its suppression. The method usually adopted in the case of the closed core transformer is to employ a synchronously rotating commutator—here again the resultant sparking is a drawback and the rectification is therefore usually done in a closed cupboard.

The most generally understood electrical danger is shock; although in the case of an induction coil shock is not likely to have fatal effect, it may cause serious discomfort, and it is often a cause of fear in uneducated persons, who inevitably associate the idea of X-rays with a very unpleasant electric shock and there is constant expectation during exposure of worse to come. It is in order to eliminate all risk of shock that a general earthing of all metal parts of an X-ray installation is recommended. This applies to all the metal work of the couch, diascop, and in fact all metal fittings. The earth connexion should be robust and well marked, and should be securely connected to a "good earth," e.g., a water main.

This general recommendation is not altogether an unmixed blessing, for example, a person touching an earthed part of the apparatus and at the
same time a high tension live wire will get the whole discharge through his body to earth with the best, serious results; but if instead of an induction coil we have for the source of the current a high tension closed core transformer the greater power of the latter, under these circumstances, may result in death. Such circumstances should be impossible of realization in any well-designed installation, but at the same time, their possibility must not be overlooked. The obvious precaution is to always have the high tension leads as remote as possible. As an additional precaution against shocks to the operator it is recommended that rubber matting should be provided around all X-ray couches and screening stands.

The second danger to be apprehended from the electrical part of the installation is that of sparking, which will be dealt with under the next heading but it should be noted here that sparking should always be reduced to a minimum. This may be done by arranging all high tension leads and terminals in such a way that there are no sharp angles or loose ends which encourage corona. In addition all high tension leads should be round in section and as big as possible in diameter. All loose or even slack wires must be avoided. The main overhead leads should be metallic tubes of half or three-quarter inch diameter and spring leads also round in section should be used for other connexions. Apparatus should be arranged in such a way that all high tension leads may be as short as possible.

**Ventilation.**

Artificial ventilation of X-ray rooms is recommended. The air should if possible be changed at least once every three minutes during screening and in fact whenever the X-ray installation is operated. The number of persons present in the X-ray room during operation should in all cases be reduced to a minimum.

It has been stated that corona discharge (sparking) should be reduced as much as possible by adopting certain general precautions, but with modern high power sets it is impossible entirely to suppress it. The result of corona discharge in the atmosphere is the production of ozone and nitrous fumes which have probably a deleterious effect on the occupants of the room especially if they are there for long periods of time. There is yet another possibility of danger, the effects of which may be much more obscure and may cause some physiological action due to ionization. It will be remembered that the whole of the atmosphere of an X-ray room becomes ionized during the operation of the installation and many of the headaches and other symptoms so frequently complained of by workers may be due to this phenomenon. These symptoms may be associated with the inhalation of the ionized air, or on the other hand may be due to a more direct electrical effect, but certain it is that complaints of this nature are very much reduced when ventilation is forced and efficient.
Enough has been said to indicate the general safety precautions to be observed in ordinary hospital radiography and also, while not attempting to treat at all seriously of the physics of X-rays, at the same time to show very roughly the reasons underlying the safety measures recommended. The writer had the privilege recently of inspecting the X-ray installations in the Military Hospitals and the foregoing remarks are based very largely on his experience of the points likely to prove of more general interest to the ordinary medical officer, who though not trained as a radiologist, is very often called upon to undertake some radiological work and who may wish to understand a little more concerning the physical aspect of his apparatus.