EXPERIENCE WITH A WATER-COOLED X-RAY TUBE
FOR DEEP THERAPY

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Last year W. D. Coolidge and C. N. Moore described a water-cooled high voltage X-ray tube which satisfactorily handles as much as 50 milliamperes at 250,000 volts (1). The best high voltage tube on the market before that time could not be used continuously with more than 8 M.A. at 200,000 volts. Thus an X-ray intensity could be obtained with the new tube many times as great as was possible before. Earlier experience in our Institute made us believe that increased intensity was desirable. Dr. Gaylord, therefore, wished to have a water-cooled tube installed and Dr. Coolidge and the Victor Corporation agreed to furnish the Institute with one of the first tubes of this type, with advice as to where to order necessary equipment for the installation. Even with this information, it was rather difficult to arrive at an arrangement which was suitable for treatment.

1. INSTALLATION, RUNNING CONDITIONS, ARRANGEMENTS FOR TREATMENT

The tube, the cooling-system and those measuring instruments to which high voltage is applied have been enclosed together in a lead room which is well ventilated. The danger connected with high voltage and with X-ray radiation has, therefore, been reduced to a minimum, while ozone and oxides of nitrogen produced around the charged metal parts are eliminated. A sketch of the arrangement is shown in Fig. 1. Fig. 2 is a photograph of the tube, cooling-system, etc. Fig. 3 shows the view of the treatment room from the switchboard.

The tube is stable but the diaphragm can be rotated around it so that the X-ray beam can be directed horizontally, vertically or at any intermediate angle. A table is under construction which can be tilted, raised and lowered and rotated. With this
table the arrangement will be fairly flexible. It would, however, not always permit radiation in the most desirable way, and the 8 M.A. tube in a flexible stand will, therefore, still have a field

![Diagram](image)

**FIG. 1**


of its own. The water-cooled tube has been used for treatments since the first part of January this year under the following conditions: A potential of 200,000 volts, a current of 30 milliamperes and a filter of .48 mm. copper. It is a real surprise to see how easily the tube carries this load, a little over 4 kilowatts, and how steadily it runs. As to the life time of the tube, it can only be stated that so far it has been used with 30 milliamperes for over 150 hours (4,500 milliampere-hours) and that it does not show any signs of old age yet. It has been used as much as 6 hours in one day with full load.

2. MEASUREMENTS

Several groups of measurements have been carried out with the help of a Friedrich iontoquantimeter. The results can be
summarized as follows. The effective wave length determined by Duane's method (2) is .167 Ångstrom units or nearly the same as earlier had been found for the 8 M.A. tube (.161 Å). The X-ray intensity per milliampere when 30 M.A. are used is about 3/4 as great as when 8 M.A. are used for the same filter. The intensity at 30 M.A. thus should be 2.8 times the intensity at 8 M.A. We are, however, using slightly less filtration for the water-cooled tube and the radiation from it is 3.2 times as intense as the radiation from the Universal Type tube under our standard running conditions. The depth dose and the distribution of radiation is practically the same for both tubes when a focus-skin distance of 40 cm. or more is used.

3. Preliminary Results

Many theories have been advanced in explaining the action of radiation upon tissue inside an individual and conclusions
from such theories often have been used as principles for methods of treatment. When it was found that the cells seemed to be more sensitive in the stage of mitoses than during the resting stage, it was argued that a weak radiation for a longer time might prove more effective than an intensive radiation for a short time, as a greater number of cells in that case must be radiated during mitoses. In order to settle such a question, the effect of continuous radiation carried out for a week or more ought to be compared with the effect of intensive radiation given in some few minutes with practically the same dose and with all other conditions comparable. It is evident, however, from what has been published concerning this question, that the difference in results cannot be very great. A very remarkable fact is that the cumulative effect of radiation is so great that similar results are obtained with very different intensities. That must mean that radiation of small intensity produces an irreversible change of organic units (molecules, colloids).
Up to the present, we have not seen at our Institute any indication of better results with long treatments than with short ones. This seems to be in agreement with a recent theory by Pordes (3) which assumes that one part of the cell nucleus regulates the mitosis and that this part is more sensitive to radiation than other parts. Thus the nucleus may live and be active for weeks and months after radiation, but when the time has come for it to divide, it cannot fulfill its function but disintegrates instead.

A simple calculation shows that the great majority of the nuclei (of about 3 μ diameter) are hit many times by electrons if exposed to an erythema dose of X-rays. If the generative part of the nucleus occupies one tenth of the volume, it should be hit at least once in most nuclei exposed to an erythema dose.

Such a short time has elapsed since we started treatments with the water-cooled tube that nothing can be said yet about the curative effects. However, the improvements which usually follow one to two months after the treatments seem to be about the same for 30 M.A. as for 8 M.A.

It is a well-known fact that the patients become nauseated and show other symptoms of what has been called X-ray sickness immediately after heavy irradiation. B. Schreiner and the author have discussed the assumed causes of this illness in a recent publication (4). We concluded that the total body dose is the most important factor, and that the nervous strain upon the patient during a long treatment seemed to increase the sickness. The last statement was based upon our experience that the X-ray sickness decreased as the current through the tube was increased. When the time was shortened further by radiation of one patient with two or three tubes simultaneously, the X-ray sickness was observed only during the last minutes of the treatment, and often not until the patient had left the X-ray room. Still better results have been obtained with the water-cooled tube. Out of about 150 patients treated with this tube, none have been sick during the treatment (5). Some of those who received a heavy dose later reported that they felt weak for some time after the treatment and a few had vomited.
It has already been mentioned that the X-ray intensity was increased 3.2 times when the current was increased from 8 to 30 M.A. In order to give the same dose as before, the radiation time therefore ought to have been reduced in this proportion. The time for an erythema skin dose with 80 cm. target skin distance and a 20 x 20 cm. field thus figured out to be 33 minutes. This would be correct if the biological reaction was independent of the time in which the dose is given. It is a well-known fact that if two adjacent skin areas receive the same dose and ten times as great X-ray intensity is used for one as for the other, the reaction will be noticeably more marked on the area treated with the greater intensity. When the intensity is increased about three times it can be expected therefore that the reaction is slightly increased or practically unchanged. For the sake of safety, we decided to start with a dose about 10 per cent smaller than the calculated one. We believe that we can judge the average skin reaction for a number of patients with an error of less than 10 per cent. The erythema produced by the 90 per cent dose seems to be just as strong as the one we previously used as our standard, and consequently 30 minutes is the time for our erythema dose for a target skin distance of 80 cm., a field of 20 x 20 cm., a filter of 0.48 mm. copper, a voltage of 200 K.V. and a current of 30 M.A.

SUMMARY

(1) A water-cooled high-voltage X-ray tube has been used for deep therapy work in our Institute since the beginning of this year under the following running conditions: 200 K.V. peak, 30 M.A. 0.48 mm. copper filter. A 280 K.V. Victor machine with four-arm rectification delivered the current.

(2) The arrangements for treatments have been briefly described.

(3) The tube has been running as much as 6 hours in one day and for over 150 hours altogether without any change. It has never given any trouble, is easy to handle and runs with less relative fluctuation of voltage and current than the 8 milliampere high-voltage Universal Type tube.
Measurements with ionization chamber showed that nearly the same effective wave length and the same depth dose is obtained with 30 as with 8 M.A., that the distribution of the radiation at a focus-skin distance of 40 cm. or more is practically the same for the water-cooled tube as for the Universal tube and that 100 milliampere-minutes obtained with 30 M.A. produces approximately the same X-ray radiation as 75 M.A. minutes obtained with 8 M.A.

It cannot yet be settled whether the clinical results will be better or worse after the short intense treatments given with this tube than after those requiring longer time. The X-ray sickness immediately after the treatment is, however, reduced. The erythema of the skin is produced by a slightly smaller dose as measured by ionization chamber when 30 M.A. are used than when 8 M.A. are used.

REFERENCES
(1) Coolidge and Moore: Am. J. Roentgenol., 1923, x, 884.
(2) Duane: Am. J. Roentgenol., 1922, ix, 788.