A NOMOGRAM FOR CALCULATING X-RAY DOSAGE

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Dosage charts devised for radiologists are usually arranged to show the length of exposure needed to produce an erythema at different focal distances, when the voltage, milliamperage, and filtration are kept constant. If the dose is determined for one distance it can easily be found for any other distance if the minutes of exposure are plotted against distance on double logarithmic paper. The method of preparing such a chart has been described by Wood (1). In another type of chart, devised by Leddy (2), the length of the erythema dose for different voltages and filtrations at various distances, is shown. Since machines vary greatly in output, even when the operating conditions are the same, such charts are useful only in connection with the machine for which they are prepared.

If one wishes to know the number of Roentgen units delivered during any number of minutes, under constant conditions of voltage, and filtration, another kind of chart must be used for there are now three variables instead of two. In the first type, the number of minutes times the intensity, that is, the distance, equals a constant,—the erythema. In the second, these factors when multiplied together produce a variable, that is, the number of *r* units.

In preparing this second kind of chart one must know the number of *r* units delivered per minute when the machine is operating under standard conditions. This requires a dosimeter which however need be used but once to determine the intensity at some definite distance. If subsequently this distance only is used, a chart is hardly necessary; one need only multiply mentally the number of *r* units per minute by the length of exposure to determine the dose.

But if the focal distance is varied, the calculation of dosage becomes more complicated, for the intensity varies inversely with the square of the distance (3, 4, 5), However, this calculation need be made only once, for the data can be included in a nomogram which will give the needed information regarding the length of exposure at any distance necessary to give a dose of any number of *r* units. Such data of course are valid only when the machine is operated under the same conditions which obtained when the intensity was determined by the dosimeter.

Suppose that under definite conditions of voltage, milliamperage, and filtration, the beam is found to have an intensity of 15.0 *r*/min. without scatter, at a distance of 40 cm. The intensity at any other distance can be calculated by the use of the formula,

$$\text{Int.}_1 : \text{Int.}_2 = /\text{Dist.}_2^2 : \text{Dist.}_1^2$$

Theoretically the law is not strictly applicable for the source of energy is not a point but a fairly broad target, but for practical purposes it holds good, as the following measurements show. With a machine running at 200 KV. and 8 Ma., the filter being 2.0 mm. of copper and 1.0 mm. of aluminum, the intensity at 40 cm. was found to be 4.52 *r*/min, while at 50 cm. it was 2.90 r/min. If we assume that the measurement at the shorter distance is correct, then according to the Inverse Square law, the value at the greater distance should be 2.89 *r*/min. This variation will make a difference of 1 *r* in 100 minutes of exposure. Thus the intensities at different distances calculated by this formula are accurate enough for all practical purposes.

The method of constructing the nomogram can most easily be explained by describing the example shown in Fig. 1. This was made for use with a particular machine, operated at 200 KV. and 8 Ma., the filter being 0.5 mm. of copper and 1.0 mm. of aluminum. The intensity of the beam produced under these conditions was determined by a Victoreen dosimeter and also by the Drosophila egg method. The two results, which were in good accord, showed it to be 16.2 *r*/min. at 40 cm. From this value are calculated the intensities at distances from 36 to 62 cm., these being the extremes which are likely to be used with this machine. At the former distance the intensity is 20 *r*/min., at the latter, 6.75 *r*/min.

In constructing the nomogram I first divided a vertical line (the left one in the figure) into 20 equal parts, labelling them from 0 to 20 r/min. For greater accuracy each is subdivided into 10 parts. On a second scale parallel with the first are now marked the distances in centimeters opposite the appropriate intensities.

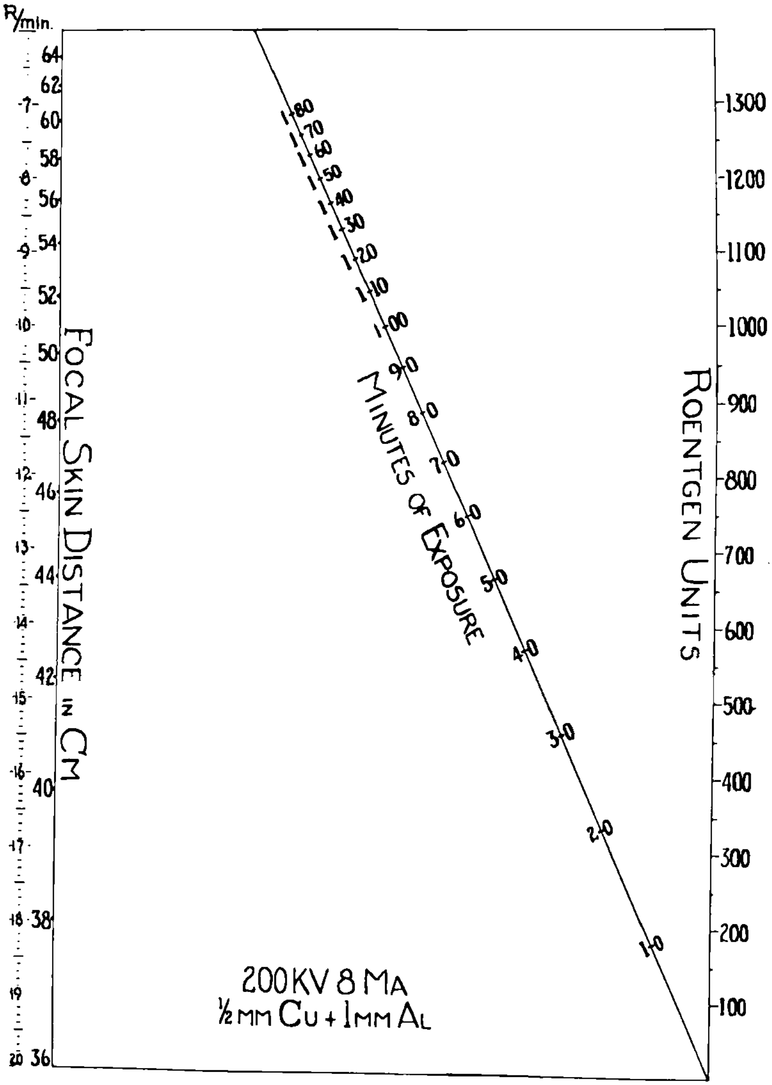

FIG. 1. A DOSAGE NOMOGRAM IN WHICH TWO SCALES ARE LOGARITHMIC AND ONE IS ARITHMETIC.

Thus, opposite 20 r/min. is placed 36 cm.; opposite 6.75 r/min., 62 cm., etc. The vertical line at the right of the figure shows the number of r units to be delivered during the course of the exposure. The scale begins with zero at the bottom and goes up to 1400 r which is above the limit for ordinary doses.

The sloping line labelled "minutes of exposure" is drawn between the zero mark at the top of the intensity scale and the zero mark at the bottom of the r unit scale. In the nomogram shown here the upper part of this construction has been omitted because it is not used. The division of the time scale is easily made. Place a ruler with one end at intensity 10 r/min. and the other at 1000 r on the r unit scale. The point where it intersects the time scale marks 100 minutes. Similarly, when the other end of the ruler is at 500 r, the point of intersection marks 50 minutes. The whole scale can be marked off in this way. The accuracy of the chart is checked by using in addition some other intensity as a starting point.

With this nomogram one can easily find how long an exposure is needed for a chosen number of r units. If, for example, the distance is 46 cm. and the dose is to be 500 r units, you place a card on these two points and read the number of minutes at the point where it intersects the time scale. In this case the length of exposure is found to be a little over 40 minutes. Or, if experience has proved that 60 minutes of irradiation can safely be given at a distance of 50 cm. the nomogram shows that in this time 600 r will be delivered.

The construction shown in Fig. 2 differs from the first in that all three scales are logarithmic. It was designed for use with a machine operated at 200 KV. and 8 Ma. with 2.0 mm. of copper and 1.0 mm. of aluminum as a filter. Dosimeter readings showed that the intensity at 40 cm. is 4.5 r/min. Since the distance is the minimum which can conveniently be used in therapy, the intensity scale starts with 5 r/min. at 38 cm. and goes to 2 r/min. at 60 cm. Opposite the appropriate places are marked the distances at which those intensities are found. The right hand scale is adjusted to fit the needs of this particular machine. With the low intensity employed it is unlikely that less than

250 r or more than 1200 r will be given. The time scale is vertical instead of sloping, but is marked off in the same way as was the other. The only practical difficulty one may meet in laying

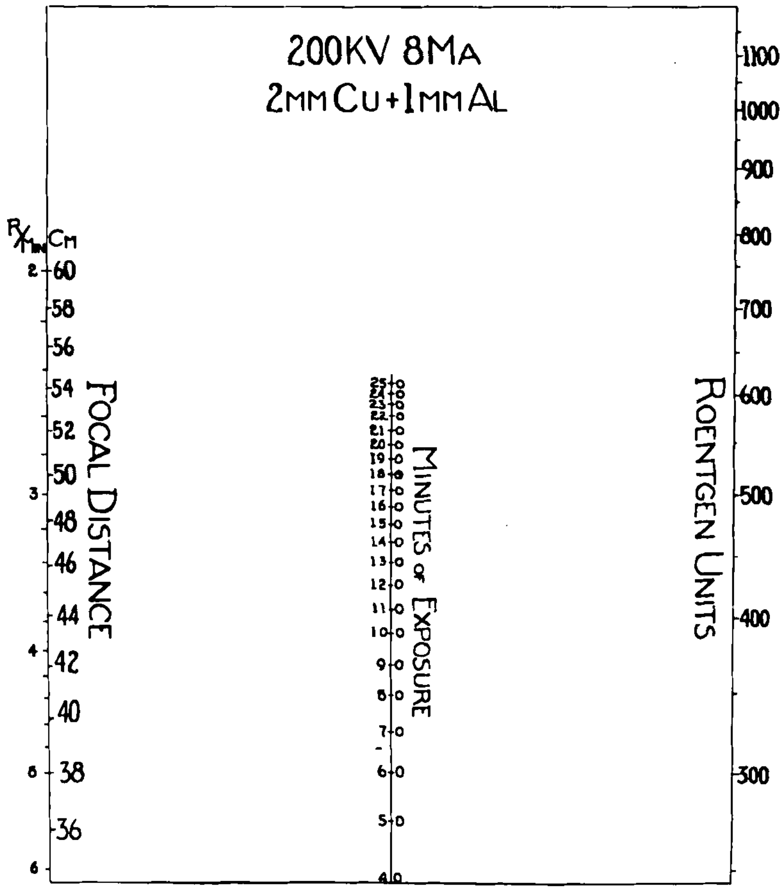

FIG. 2. A NOMOGRAM IN WHICH ALL THREE SCALES ARE LOGARITHMIC.

out such a nomogram as this is in getting the logarithmic scales of convenient size.

These nomograms are adapted for use with particular machines operated under definite and unchanging conditions. The third, shown in Fig. 3, has a more general application for it can be used for calculating doses on any machine within obvious limits provided the intensity at a definite distance is known. It is constructed in this way:—On a large sheet of paper a vertical is drawn at the left side and divided into equal spaces which represent intensities. If the greatest intensity at the shortest useful distance is (as in this case) 24 r/min. the line is divided into 24 parts. If higher intensities are to be used the scale is

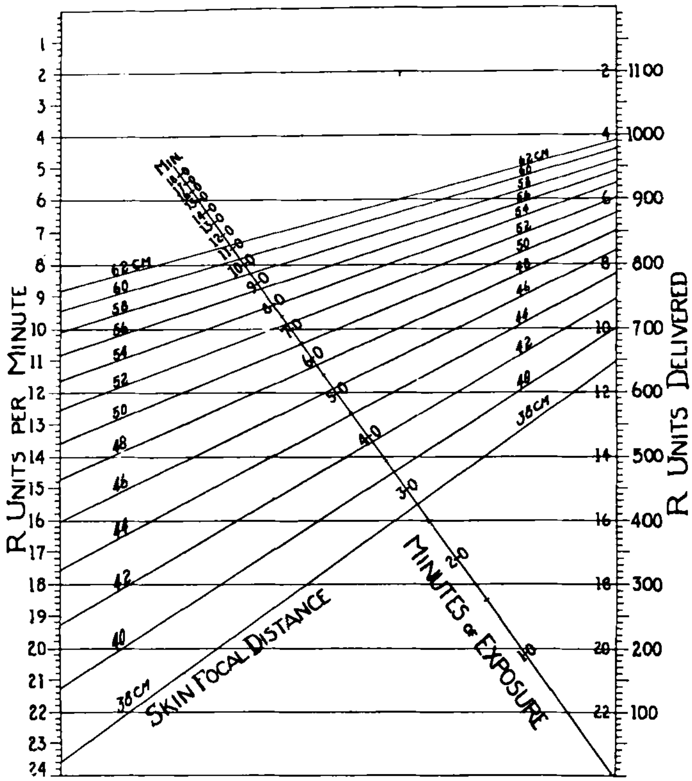

FIG. 3. A GENERAL NOMOGRAM WHICH CAN BE USED IN CONNECTION WITH MACHINES HAVING DIFFERENT INTENSITY OUTPUTS.

laid out accordingly. Next it is necessary to calculate the intensities at distances usually employed in therapy. Naturally one must assume some definite value at some distance in order to secure these data. In preparing this nomogram I used the value of 16.0 r/min. at 46 cm. but other values would have served equally well. The calculations show that at 40 cm. the intensity is 21.2 r/min. and at 50 cm. it is 13.6 r/min. These and the other distances for which calculations are made are marked opposite the proper places on the intensity scale. From each of these, lines are drawn to a fixed point at the upper right hand corner of the paper. The exact position is of no significance. We have now a series of converging lines, each representing a distance. In the figure a part of the construction has been omitted to save space. The Roentgen unit scale and time scale are now drawn, as in the first nomogram.

To use this chart the procedure is as follows:—Suppose that the dosimeter has shown that your machine, when operated under standard conditions, delivers 16.0 *r*/min at 44 cm. A ruler is laid between the points marked 16 on the left hand and right hand intensity scales. Where it crosses the sloping line marked 44 cm. a perpendicular is erected which intersects all the other distance lines. The intensity at each distance can now be read from the scale at the left. Thus, in this example, at 50 cm. it is 12.4 *r*/min. and at 60 cm. it is 8.6 *r*/min. When these have been determined, the distance lines can be ignored; they have served their purpose. The chart can now be used in the same way as the others.

These nomograms are by no means the only ones which might be devised to serve the purpose, but they are easily constructed and easily read, and should prove as useful in determining dosage as they have in radiography and kindred scientific fields.

REFERENCES

1. Wood, F. C.: Am. J. Roentgenol., 1925, xiii, 380.
2. Leddy, E. T.: Am. J. Roentgenol., 1927, xvii, 230.
3. Wood, F. C.: Am. J. Roentgenol., 1925, xiii, 380.
4. Matoni, H. H.: Strahlentherapie, 1924, xviii,375.
5. Packard, C.: J. Cancer Res., 1926, x, 319.