# Part II

# GENERAL CONSIDERATIONS

# Chapter III

## DOSAGE FACTORS (*Continued*)

### Distance and Size of Port

*Technical and Clinical.*—Distance is a term used to designate the proximity of the target of the tube to the nearest surface of the tissue to be treated. Size of the port is used to designate the area on the surface of the skin through which the rays are directed during treatment, usually expressed in centimeters in two dimensions, or, if a circular port is used, its diameter is stated. These two factors are discussed together so that the inverse square law and its effect on *surface energy* and the size of the port and its effect on *volume energy* is thoroughly understood and correctly applied.

In the following pages are many instances in which treatment through a large port, for instance the entire abdomen, is recommended. Consideration of the differences between the calculated effects of radiation for changes in surface energy and those of volume energy is important. In no circumstance may the number of r units which may be given a $2 \times 2$ cm. port in a certain interval of time to produce a definite but safe degree of erythema be given a $20 \times 20$ cm. port in the same interval of time. The greater absorption of radiation in this larger area of tissue causes a greater biologic effect per r unit and would probably produce serious tissue necrosis.

Hence the fact that the rate of absorption of radiation is increased as the size of the port and the mass of tissue radiated are increased must be kept in mind when attempting to transfer a safe, efficient exposure technic from a small area like a furuncle to a larger area like the entire abdomen. The biochemical phenomena and physical laws relative to this fact are discussed briefly.

The *surface energy,* for all practical purposes, might be considered as the energy exerted by a beam of rays as it strikes a flat inanimate surface which has practically no depth, such as an x-ray film. Under such circumstances, these rays become inactive immediately when the x-ray beam is shut off. The same beam, striking an area of tissue which has depth and mass, starts a biologic action which continues after the radiation is shut off. The intensity of this action is dependent upon the amount of radiation absorbed in the exposed tissues. As Hudson stated:

> The effects produced by radiation are dependent upon the amount of radiation absorbed in the material being exposed, that is, on the amount of energy removed from the original beam and transformed into some other form of energy (such as heat, photo-electrons, recoil electrons). Thus, one is interested not so much in the *surface energy* as in the *volume energy,* which may be defined as the energy absorbed per unit volume. The total absorbed energy, of course, produces certain general effects but the local biologic reaction is dependent on the energy absorbed per unit volume and this may be called the "physical dose."
>
> If one wishes to speak of a "biologic dose," the physical dose as just defined must be multiplied by another factor which varies with the type of tissue irradiated and the quality of the radiation. This factor is unknown at present, and so the problem really reduces to a measurement of the energy absorbed per unit volume.[6]

*The inverse square law,* regarding the effect of a change in distance on the amount of radiation striking a given area, applies in therapy as it does in diagnosis: it varies inversely as the square of the distance. For example, owing to the dispersion of the x-ray beam over the enlarged area, doubling the distance reduces to one-fourth the intensity of this beam as it strikes any portion of the enlarged surface at the doubled distance. This is well illustrated in Figure 9; the square nearest the target receives the entire beam of radiation, while at twice the distance of this first square from the target, this beam spreads over an area four times as great. From this fact, it is evident that each single square at the increased (doubled) distance receives only one fourth of the amount of radiation received by the nearest square, since the same beam is divided over four areas each as large as the original square at the lesser distance. Obviously, to deliver radiation to any of the surface at the increased distance equivalent to the 100 per cent dose received by the nearest single square, one must multiply the dose (number of r units as determined at the nearest square) by four. However, if the amount of surface irradiated at the increased distance is greater than the surface at the shorter original distance, owing to the law relative to volume energy effect, the dose must be reduced as the area irradiated at the increased distance becomes larger. This is necessary to compensate for the increased absorption of radiation which takes place in the larger mass of tissue.

Therefore, an increase must be made to meet the requirements of the physical law relative to the distribution of *surface energy* when only flat surfaces as in roentgenography enter into the calculation. In therapy, however, volume energy must be considered.

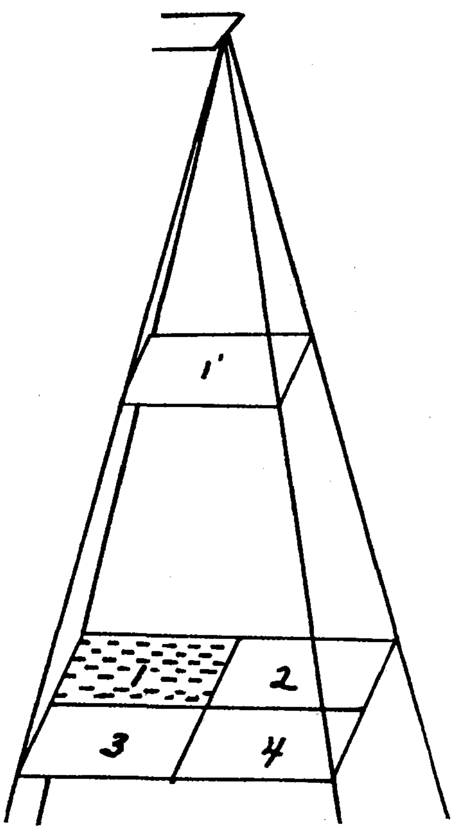


FIG. 9.—Effect of increased distance on dispersion of beam as the distance from the target is increased. This shows that if the distance is doubled, the beam covers four times the original area covered by the beam at *1'*.

Surface Energy—Volume Energy

In roentgenography, the effect of the increased distance on the distribution of the energy in the x-ray beam over the area on the flat surface of the film is all that is observed, and no biologic problem is involved. In therapy, however, Grotthus' law states: "Radiant energy must be absorbed in order to produce an effect."[9] It is evident, therefore, that with other factors remaining constant, the more tissue irradiated, the greater the absorption per unit volume.

These facts simply mean that the size of the port and the thickness of the part have a distinct bearing on the biologic response obtained from the radiation. When irradiating tissues for therapeutic purposes, therefore, the depth and the total bulk as well as the surface area must be considered, and the factor, volume energy, must enter into the calculations of the dosage.

If the distance is doubled but the area to be treated remains the same size, four times the number of r units given at the original distance may be given to the increased distance and the dose as well as the biologic effect would be the same. Thus, in Figure 9, if area *1'* received 500 r as the original dose, area *1*, which is twice the distance (but the same size) would receive 500 r if radiation measured at the same distance as *1'* were 2,000 r, since only 500 r of the 2,000 r would hit the dotted area, *1*. The other 1,500 r would be delivered to the other three areas, *2*, *3* and *4*.

If, however, the ionizing chamber were placed at the distance shown as area *1*, 500 r as indicated by the ionizing chamber would be all that was necessary to equal the same dose of 500 r at area *1'*. In other words, one must state at what distance the ionizing chamber was placed to measure the dose. And 500 r in the same area of tissue at the two distances gives the same biologic effect; but, and this is extremely important, 500 r into the area of tissue represented by areas *1*, *2*, *3* and *4* (four times the size of *1* or *1'*) would have a much greater biologic effect than 500 r in areas *1* or *1'*. The mass of tissue radiated in areas *1*, *2*, *3* and *4* would be greater; therefore the amount absorbed (per unit volume) in the larger mass of tissue would be greater and an increased reaction would result.

This clears up the matter of increased distance as far as the expression of the dose is concerned. It must be stated where the dosage is measured, at the original or at the increased distance, and whether the size of the port is the same at the two distances. If, however, the size of the port is automatically allowed to become larger with the increased distance, the increased biologic effect in the larger port, since it involves more tissue, must be given consideration as a factor in increasing the effect of the 500 r dose. The point is as stated before: the larger port cannot safely receive the same number of r units as a smaller port if the danger of tissue damage is to be considered. Thus, the changes in distance and the changes in the size of the port call for special consideration in dosage calculation.

The safe procedure is to know the r units given at the surface treated, including the back-scatter for the kilovoltage and filter used and for the size of the port to be employed. This procedure eliminates the possibility of error in making changes by calculating or estimating what should take place when one factor is omitted and some other factor substituted. This means that one should use measured dosage at the surface of the port through which it is delivered and not a calculated or figured the skin surface to measure the radiation effect. Since this in-dosage. The ionizing chamber is safer than the pen or pencil.

By *back-scatter* is meant the secondary radiation created in the tissues which is scattered back and shows an increased ionization effect in the ionizing chamber when this chamber is used at creased effect is due to the secondary radiation originating in the tissues, its effect is not present when measurements of radiation are made with the ionizing chamber suspended in the air. The secondary radiation which produced the back-scatter in the measurements at the skin surface is effective in the biologic action of the rays, and it must enter into all dosage calculations. Also, secondary radiation or back-scatter varies with the kilovoltage, with the filter and with the size of the port. (For more complete data on back-scatter, see Quimby.[13])

Any statement of the number of r units delivered in a given case must always indicate whether or not back-scatter is included. The administration of a full dose of "measured in air" r units to the skin of a patient without proper allowance for increased effect from back-scatter would lead to overdosage, the seriousness of which would depend on the quality of the radiation, the size of the port, the total amount given and the rate of administration.

*Size of the Port—Technical and Clinical.*—The port or ports used must include all involved tissues and adjacent suspected areas. The size of the port may therefore vary. A small port 4 to 5 cm. in diameter is used to treat a single furuncle; several ports may be necessary to treat a large area of trunk.

When more than one port is used, the exact area of the port must be defined by the use of a cone, leaded diaphragm, leaded rubber or other opaque material placed along all borders of the port to protect adjacent tissues from excessive irradiation due to overlapping if the adjacent tissue is also to receive a dose.

No treatment should be confined strictly to the known border of the infected areas; one should always go some distance beyond and include adjacent normal tissue. The one thing always to be remembered is: the larger the port, the greater the biologic effect from the same number of r units, other factors being equal.

When two ports are so placed that their beams of radiation may overlap or meet in the tissues, as would be the case in treating a thin portion of the body from two sides, the depth effect from the two beams must be considered and care taken not to deliver an overdose to the deeper structures. This is not likely to occur if the small doses advocated for acute infection are used, but the warning will do no harm.

*Distance—Technical and Clinical.*—Treatments are usually given at 40 cm. but may be given at any reasonable distance. The distance should always be sufficient to permit the beam of rays to cover the entire port; but if proper allowance is made for the increased biologic effect due to shortening the distance or loss of radiation from dispersion at an increased distance, there is no difference when one uses the 50 cm. distance in preference to the 40 cm. distance or vice versa.

Sufficient distance must be allowed to cover the entire port, or two smaller ports with no overlapping must be selected and a full dose given through each port. We make a practice of using 40 cm. distance and any number of ports necessary to cover all the tissue to be treated.

## Milliamperage and Time

*Technical and Clinical.*—Milliamperage designates the magnitude of the electrical current expressed in thousandths of an ampere. The milliamperage and the time are factors which vary directly and have to do with the quantity of radiation produced by the tube in a given period. Before introduction of the r unit, the quantity of x-rays in the dose was designated not in r units but in milliampere-minutes; for instance, 20 milliampere-minutes might have meant 10 ma. for two minutes or 5 ma. for four minutes. In present terminology, time and milliamperes may be stated as a matter of courtesy, but the number of r units which the apparatus produces with that time and milliamperage or is delivered in a treatment must be stated for accuracy.

It is well known that the same number of milliampere-minutes, even with all factors identical, does not necessarily produce the same number of r units in different installations of apparatus. But the number of r units per dose with all the factors the same would have the same biologic effect in two different installations. To know the r units given per treatment with stated operative conditions is more scientific, more accurate and more desirable from a clinical point of view than the old, uncertain milliampere-minute designation.

## The r Unit

*History and Definition.*—At the second International Congress of Radiology at Stockholm in 1928, the r unit became established as the international unit of roentgen ray dosage. It is determined on the basis of the ionizing effect of the rays on air in a properly constructed ionization chamber.

The unit of dose is that quantity of roentgen radiation which, when the secondary electrons are fully utilized and the wall effect of the chamber is avoided, produces in 1 cc. of atmospheric air at 0 C. and 760 mm. mercury pressure such a degree of conductivity that 1 electrostatic unit of charge is measured at saturation current. This unit shall be called the roentgen and designated by r.

Anyone who desires more details on the r unit is advised to study the literature from the early work of Holmes[14] and Duane[15] to the present time.

*The r Units per Dose—Technical and Clinical.*—For practical purposes, the dose consists of the quantity of radiation designated in multiples of the standardized r unit as measured on the surface of the treated area with or without back-scatter as stated. When back-scatter is included, the ionizing chamber is affected by the x-ray beam proper and also registers the effect of the secondary radiation created in the tissues and scattered back through the skin, varying with the quality of the beam and the size of the port.

For clinical work, the r unit output for each installation may be recorded on charts after the apparatus has been carefully calibrated by one trained in this work. The calibrations must include all the probable settings of the apparatus to be used in treatment. It is also possible to use a portable ionizing chamber every time a treatment is given, or one may have some form of ionizing chamber built in the equipment to operate at all times when treatments are being given.

Before any x-ray apparatus may be used for therapeutic purposes, its r unit output, usually with back-scatter, must be determined and charted by one competent for the task, using various kilovoltages, filters and different sizes of ports which are to be employed in the future. No physician should be allowed to give a treatment, and certainly no patient should receive a treatment, from uncalibrated apparatus.

By the designation "r units per dose" is meant the amount of x-rays or the number of r units given at the particular treatment. In addition to stating the number of r given, it should include the amount in percentage, i. e., the percentage of the total number of r units which are considered to be a 100 per cent dose if the entire dose were to be given in a single treatment and a mild but visible skin reaction would result. For example, if 500 r units is considered the maximum safe number of r for a particular case in a given port with a given set of technical factors and 100 r given in the first dose, the record would show 100 r and 20 per cent on the saturation graph. (See Figure 65.)

In treatment of the acute infections, it is necessary to stipulate before the first treatment is given what the 100 per cent dose for each port is to be in r units with back-scatter. Owing to the uncertainty of the duration of these acute infections, the estimation of the total dose (1 erythema) must be considered as the guide for safe treatment; but, after a few days have elapsed and there is still need for more treatment, the calculated loss of radiation from the tissue will make it obvious that the original number of r units stipulated as 100 per cent dose may be exceeded before treatment is discontinued. As one gains experience in the work, one will find the margin of safety of the radiated tissues surprisingly large. Many r units above the original total estimated at 100 per cent may eventually be given without harm, *but there is always a safe limit beyond which damage to the tissues will result.*

## Rate of Administration

Obviously, the rate of administration, which is extremely important in any radiation therapy, depends on the size of the dose given with each treatment and the length of time between each two treatments.

A safe practice to follow after a few days of treatment is to calculate the daily loss from the total number of r units which has been delivered during the previous treatments and give that number of r units each day for three or four days if continued treatment is necessary, provided the amount previously given is not more than 100 per cent. For example, if 400 r units was the total given in the previous three days and 40 r units was the estimated daily loss, one might replace this daily loss in a single dose of 40 r or in two doses of 20 r each day for a few days and still be quite safe. At all times, be alert for evidence of skin reaction, and cease treatment at its earliest appearance. Or, in other words, the maximum intensity of tissue saturation at which any part is to be carried should be decided on after a few days' treatment. Then the daily loss from the total given as estimated in r units should be replaced each day. By such a procedure, one may hold the degree of radiation activity (maximum intensity) at a uniform level for a few days without danger to the patient.

## Variations in Dose

The number of r units per dose varies from 25 to 100, usually 50 or 60. The larger doses are given at the beginning of the series of treatments, to smaller ports or for lesions at greater depth, to patients with severe toxemia and to those in whom the disease is seen late after the infection has made considerable progress. If, for some reason, frequent treatments cannot be given, larger doses are advisable. As a rule, some special reason must warrant doses above 75 r. A moribund patient may be given half the total dose on the first day in three treatments and a correspondingly large dose on the second day, again divided into two or three treatments, less on the third day, and after that the number of r per day which is calculated to maintain the tissue saturation at an effective level.

Small doses are usually given: toward the end of the series of treatments after the infection is under control; to larger ports; to more superficial lesions; and to children over areas which may contain sensitive structures, particularly the sex glands. Acute fulminating infections are best treated twice each day, receiving 40 to 60 r, reaching 70 to 80 per cent intensity in the tissues on the fourth or fifth day.

## Space Factor

*Technical and Clinical.*—Space factor is the term used to designate the length of time elapsing between individual treatments, regardless of how much is given or how short the time. It may be only a few hours or as much as several days, but it must be recorded, and the loss of radiation effect from the tissues estimated accordingly.

Our insistence on two treatments each day for many of the fulminating infections is based on the observation that the results are better when the space factor approximately coincides with the rate of growth (on culture mediums or by clinical estimation) of the etiologic organism. For example, blastomycosis, glandular tuberculosis, etc., are treated with a relatively long space factor, i. e., four or five days between treatments. Infections with more rapidly growing organisms, such as staphylococcus, found in the ordinary boil or carbuncle, are treated with a shorter space factor, once each day. Erysipelas, which is even more fulminating, requires a still shorter space factor and is treated twice each day. Since gas gangrene is undoubtedly as fulminating as erysipelas, a short space factor has been used in its treatment from the beginning. Clinically, in gas gangrene the x-ray has a prompt and thoroughly detoxifying effect.

In certain of the more slowly developing infections, a large dose of radiation has seemed to be followed by suppuration more often than a smaller dose with a short space factor, but this has not been verified.

Another factor which may have some bearing on the termination of localized infections by suppuration seems to be the stage of the infection in which the x-ray treatment is started. A late start is often followed by suppuration, and an early start is seldom followed by pus formation. Too large a dose at the beginning of treatment may also be a factor in suppuration.

It is recommended, therefore, that treatment be started early and that smaller doses be used. This necessarily requires that the dose be given more frequently, as the radiation effect cannot be maintained with small doses at long intervals.

We have not yet observed a sufficient number of cases to draw any final conclusions regarding suppuration, but our tendency is to give the smallest dose possible which is judged to be effective; the space factor is then determined; that is, in the granulomatous cases, the size of the initial x-ray dose determines the space factor. In other words, if the initial dose is 35 per cent, the next treatment may be deferred to the third or fourth day, but the amount of local activity, size of area treated and other clinical factors must be given consideration.

In some other conditions, for example, the more acute infections, the rapid invasion of the disease is given first consideration in the selection of the space factor, and the size of the dose is varied to suit the number of treatments to be given in a day. For example, if 120 r units is to be given during the day and three treatments are necessary because of the character of the infection, 40 r will be given every eight hours.

A short space factor, i. e., two or three treatments each day, is especially indicated in any invasive, rapidly developing infection, in acute infections which are in a well developed or late stage before x-ray treatment is started and in any infection in which toxemia is severe.

The effectiveness of x-rays in reducing the patient's toxemia seems to make frequent treatments imperative, and in this class of infections the x-rays do their greatest good. There are still many points to be determined in connection with the use of x-rays in infections, but the use of a short space factor in the toxic patient with a localized infection is definitely established.

Infections which have passed through their invasive and toxic phases, are more or less stationary, probably suppurating and tending to become subacute do just as well with a longer space factor. A prompt response cannot be anticipated.

### The Loss Factor

*Technical and Clinical.*—One cannot lose something one does not have, but one may lose something one does have; if one has much one can lose much, and if time is a factor, the longer the time the greater the loss.

Clearly, one loses the effect of radiation from the tissues according to the amount introduced into the tissues, according to Grotthus' law of tissue absorption and according to clinical estimations of the loss of x-ray effect from the tissues, as first suggested by Kingery.[16]

On the work of Kingery in superficial lesions and of Pfahler[17] in deep-seated lesions is based the present-day method of administering certain amounts of radiation to a given area of tissue and of estimating from past experiences the amount of radiation effect lost from the tissues for any given period of time. This loss is variable and depends on the factors used in administration. One should never forget that the figures in various tables showing radiation loss are based on clinical estimation and therefore should be used with clinical judgment. The calculation may be on the basis of loss of radiation effect from the tissue, as expressed by Weatherwax,[18] or in equivalent terminology, the rate of the tissue recovery from the radiation administered, as expressed by Quimby.[13]

Kingery was the first to use repeated small doses for skin diseases and to suggest that there is a constant rate of *loss of radiation effect* from the tissues which starts immediately after the tissues are irradiated. This rate of loss of radiation effect is dependent on the amount of radiation effect which is present in the tissues. The total amount lost depends on the amount present and the duration of time.

The maintenance of the optimum tissue effect must necessarily depend on the rate at which the effects of the roentgen rays are lost. Depending on this time rate, is the frequency with which exposures may be repeated and the quantity that may be administered at each exposure. It seems but logical to assume that tissues exposed to roentgen rays lose that effect in a constant manner. That the greater the concentration of the biochemical products of irradiation the higher the velocity of loss, would not only seem to follow naturally, but also apparently is borne out by the observations cited below. If this be true, and if we may assume that the rate of loss varies directly as the concentration of some hypothetical decomposition product, then as this concentration decreases, the velocity of loss will become less in direct ratio. Thus, at such a time as this concentration has decreased by one-half, the velocity of loss will have become less by a similar amount, and so on until the residual effect has become negligible. This rate of loss, theoretically, would represent a logarithmic curve and may be so calculated. Such a curve has been established for many chemical and biologic reactions, which we know as mass reaction, and if we may be permitted to draw an analogy, the biochemical change resulting from the absorption of roentgen rays by tissue elements may follow a similar law.[17]

The loss factor is therefore the estimated amount of radiation effect lost from the tissues in a given time and calculated between each two treatments. It is calculated to protect the patient who has had one or more doses of x-ray from receiving a higher degree of saturation than the tissues will tolerate. It indicates how many additional r units may be given by estimating the margin of safety remaining in the tissues.

The percentage saturation of radiation effect in the tissues is estimated at the termination of the first treatment. At each treatment thereafter, the loss (according to the amount contained in the tissues and the time elapsed) is subtracted from the last previous estimate of radiation activity present in the tissues at the time of the last treatment. To this remaining percentage of saturation (after the loss is deducted) is added the percentage given in the present treatment. This latter total percentage then constitutes the amount from which the daily loss is subtracted before the next treatment is given.

The percentage calculated as lost each day is an amount arbitrarily set by pioneers in this work who, by years of experience, have found that with a given set of factors so much can be given at one time with definite but safe reaction. Thus, the general trend of dosage is dependent on the kilovoltage, the filter, the size of the port and the character of the tissue being irradiated. For instance, 500 r may be 100 per cent in one set of circumstances, whereas 700 r may be 100 per cent with other factors.

The experimental work of Quimby[13] in New York City and of Reisner in Germany has shown the loss of radiation effect from the tissues or the recuperation from irradiation by the tissues to be greater in the time immediately after irradiation than was indicated in Kingery's hypothesis. We have designated Kingery's hypothesis as a satisfactory method to estimate the amount of dosage delivered and lost in the few days required to treat the conditions discussed in this book. The principle of tissue absorption of radiation and its constant loss is maintained in either case, and since the dosage we recommend for the treatment of the conditions discussed in this book has such a wide margin of safety, the discrepancy between the two sets of figures may be disregarded as of no clinical consequence. This is especially true since the loss actually taking place is greater than we have stated. It is highly important, however, if one were to engage in treating lesions requiring a number of erythema doses in a short space of time, such as skin cancer, that the more exact loss be calculated with each treatment.

If any fraction of the dose is given, it is designated in percentage of the known safe amount, and a 100 per cent graph is started on which a daily or twice daily record of the number of r given and the loss the tissues sustained are recorded.

The losses, as a matter of convenience, are figured on a 24 hour or longer basis. There has never been any necessity for an hourly calculation of loss.

## The Total Dose Factor

*Technical and Clinical.*—The amount of radiation or the number of r units to be given for any infection to a given mass of tissue in a specified time is the total dose factor. As a rule, it means the total amount to be given through each port in a period of three to six days, as specified in the order given at the beginning of treatment. It may mean six treatments of 50 r or eight treatments of 60 r or any other combination of dosage. Rarely, in acute diseases, does it include any allowance for accumulation of radiation effects in the deeper tissues as a result of cross-firing.*

The danger of an accumulation due to cross-firing must be appreciated if any portion of the body is treated from two sides or through two ports at such an angle that the beams of rays converge or overlap to strike the same tissues with more than a single treatment. In such cases, allowance for the effect of multiple beams must be calculated.

The total dose or the number of r units to be given as a rule for the infections varies from 300 to 900 r units through any given port. A smaller dose, as low as 250 or 200 r, is occasionally given to children or to processes which are seen early and apparently are aborted after two or three small doses.

The larger dose, 900 r, which is twice as large as the usual dose given in acute infections which run a full course of treatment, would only be given occasionally to the more stubborn processes. Furthermore, administration of this number of r

* For data relative to cross-firing in depth dosage, the reader is referred to the work of Glasser[6] and of Weatherwax.[18]

units is extended over a longer period of time, permitting considerable loss to occur during their administration. The last treatments are generally given through heavier filtration than that used at the beginning of the series. In this high r unit group fall the more stubborn glandular infections of the subacute, nonspecific variety. They require the use of relatively small ports.

For glandular tuberculosis, blastomycosis and like conditions, no limit to the number of r units to be given should be estimated. A maximum intensity factor should be set, and a minimum intensity factor should also be designated. The dose should be delivered with such a space factor and in such quantities that the radiation effect is maintained between the minimum and the maximum degree of saturation, and for such a total length of time as one believes the area of tissue being treated will tolerate without serious harm.

One must remember that the larger areas of tissue do not tolerate the high percentage of saturation over a long period that a smaller area will tolerate. Areas of tissue lying over superficially placed bones such as the flat posterior aspect of the sacrum, areas previously irradiated, scar tissue and other tissues having some degree of fibrosis should also be treated carefully at all times. Those diseases which require more experienced management should not be treated by anyone except a trained radiologist. When radiation effect must be continued for a period of time and for the most part according to clinical judgment, training and experience are both requisites of the operator. Such procedures are not emergency treatments, and there is no necessity for one who is not properly trained to give such treatments.

## The Maximum and Minimum Intensity Factors

*Technical and Clinical.*—The maximum intensity factor means the greatest amount of radiation effect (tissue saturation) to be accumulated in a given mass of tissue at any time during the period of treatment. This is usually expressed in terms of percentage saturation based on estimates from previous experience. The length of time this saturation is to be maintained should also be specified or estimated at the beginning of the series. It is finally decided as the case progresses. If the condition responds promptly, the degree of saturation and the duration of its maintenance are lessened; but if improvement is slow, a certain degree of saturation is maintained according to clinical requirements of the case.

In none of the aforementioned calculations or estimations is it ever necessary to exceed the higher level of what is commonly considered safe dosage. Only rarely does one approach an erythema dose. Visible reactions occur in less than 1 per cent of the cases.

The minimum intensity factor means the minimum degree of saturation to be allowed until such time as the infection is definitely under control or administration of x-rays is no longer indicated. Maximum and minimum intensity factors simply designate the range of tissue saturation to be maintained until the outcome is certain. This means that x-rays are administered in such quantities from time to time as will maintain the radiation effect above the minimum saturation point and not exceeding the maximum designated saturation. This calculation may require the administration of a given number of r every day, every third day or every fifth day, as the case may be, depending on the rate of loss from the tissues.

One is usually able to designate 80 per cent of the skin erythema dose as the upper limit of tissue saturation.* Often, the disease has subsided as this point of saturation is reached for the first time, and generally by the second time, after a small loss has been permitted. Occasionally, it is necessary to calculate the loss beyond the usual replacement, which is generally on a daily basis for a few days. To treat beyond this period is the exception and not the rule. It is well to designate a degree of saturation below which the radiation effect is not allowed to fall during the onset or the toxic stages of the disease or while its outcome is still in doubt. It is also well to hold the degree of saturation up until the possibility of relapse or complications has passed. (Screen off unnecessary areas.)

## General Comments on Dosage Factors

The biologist and the physicist, like the pharmacist, can only prepare the remedy; the physician must administer it. It must

* It is understood that this discussion concerns the treatment of acute infections and does not apply to neoplasms.

be kept in mind that one can produce as many combinations of radiation therapy with a modern roentgen ray apparatus as the pharmacist can make with a mixture of various strengths of the ordinarily used drugs. The strength of the drug may be considered comparable with the type of irradiation. The amount given, the frequency with which it is given, the termination and resumption of treatment and other such details are all matters of clinical judgment, whether one is giving morphine, digitalis or r units. As in other branches of medicine and surgery, so in radiology, one gains confidence and judgment from experience in the work. The particular field of roentgen therapy under discussion is the simplest and safest and the only type of roentgen therapy one is justified in attempting without special training in radiology. *All other types of roentgen therapy are much more complicated and are to be avoided unless one has special training in therapeutic radiology.*

Success in treating acute infections can be attained with such small doses and so little reaction that no training or experience whatever is gained for use in that type of roentgen therapy in which success depends on repeated large doses and sustained radiation effects over a long period. In all diseases except the acute infections, the necessary radiation effect is little short of permanent damage to the tissues. One who has successfully treated a few infections should not be misled to believe that even superficial malignancies will yield to such dosage as are here discussed. Only harm will come to the patient with cancer if he is treated like one with an infection, because the malignant lesions will develop radioresistant characteristics and will then not yield to any radiation dosage.

The dosage and method of administration of x-ray discussed in these pages apply only to the diseases discussed and to other infections having a similar clinical behavior or the same general etiologic classification.

The dosage and the space factors are important in x-ray treatment of infections and are discussed more fully in later pages.

The loss factor is less important in infections than in other diseases because the upper limits of tissue toleration are seldom reached; therefore the calculation of the loss of radiation effect is seldom necessary in the treatment of acute inflammatory processes. Nevertheless every treatment must be carefully recorded. If it is necessary to approach an erythema total before treatments are to be discontinued, one can calculate how to proceed with the last few treatments and still be certain that no harm comes to the patient. It is well to have the exact figures in case of a reinfection or the necessity for renewal of radiation therapy arises later.

The number of r given at each treatment (the dose factor), the length of time between treatments (the space factor) and the amount of radiation effect lost from the tissues (the loss factor), when taken together, determine the *maximum and minimum intensity factors.* With a working knowledge of the dosage factors one can easily avoid, if one is careful, all serious radiation accidents and at the same time do a great amount of good in treating certain acute conditions. But some knowledge of the dosage factors is necessary before undertaking even the simplest form of radiation therapy, which is, in the writers' opinion, the treatment of acute infections.

The foregoing data relative to the dosage factors are the generally accepted fundamentals, whereas the clinical comment which follows is personal opinion based on clinical experience and, accordingly, should be considered as subject to change from time to time.

The combinations of factors, shown in Table 2 are suggested as a general guide and *are based on our clinical experiences in this work.* Smaller areas receive larger doses (r units), and vice versa. The dosage is indicated on the basis that the full number of r units is to be given at one time, but as a matter of practice, not over one sixth or one eighth of the total number of r units is given at one time; in other words, the number of r indicated in the table is usually divided into six or more doses over a period of three or more days. Then, if more is required, the loss of radiation activity is calculated and the subsequent doses are given according to the requirements of the case and the margin of dosage safety.

The loss of radiation activity from the tissues amounts to 10 to 15 per cent per day *of the total radiation activity present* at the time the calculation is made. This percentage varies slightly according to the filter, kilovoltage and size of port. For more complete data on the loss factor, one should consult the writings of Weatherwax and Quimby.

TABLE 2

X-Ray Dosage Table (with Back-Scatter)*

| Kilovoltage (Peak) | Filter | Size of Port | Total Dose† |
|---|---|---|---|
| 90 | 1 mm. Al | 5 × 5 cm. | 475 r units |
| 90 | 2 mm. Al | 5 × 5 cm. | 500 r units |
| 90 | 3 mm. Al | 5 × 5 cm. | 525 r units |
| 90 | 1 mm. Al | 10 × 15 cm. | 425 r units |
| 90 | 2 mm. Al | 10 × 15 cm. | 450 r units |
| 90 | 1 mm. Al | 20 × 30 cm. | 400 r units |
| 90 | 2 mm. Al | 20 × 30 cm. | 425 r units |
| 100 | 1 mm. Al | 5 × 5 cm. | 500 r units |
| 100 | 2 mm. Al | 5 × 5 cm. | 525 r units |
| 100 | 3 mm. Al | 5 × 5 cm. | 550 r units |
| 100 | 1 mm. Al | 10 × 15 cm. | 475 r units |
| 100 | 2 mm. Al | 10 × 15 cm. | 500 r units |
| 100 | 3 mm. Al | 10 × 15 cm. | 525 r units |
| 100 | 1 mm. Al | 20 × 30 cm. | 450 r units |
| 100 | 2 mm. Al | 20 × 30 cm. | 475 r units |
| 100 | 3 mm. Al | 20 × 30 cm. | 500 r units |
| 110 | 1 mm. Al | 5 × 5 cm. | 525 r units |
| 110 | 2 mm. Al | 5 × 5 cm. | 550 r units |
| 110 | 3 mm. Al | 5 × 5 cm. | 575 r units |
| 110 | 4 mm. Al | 5 × 5 cm. | 600 r units |
| 110 | 1 mm. Al | 10 × 15 cm. | 475 r units |
| 110 | 2 mm. Al | 10 × 15 cm. | 500 r units |
| 110 | 3 mm. Al | 10 × 15 cm. | 525 r units |
| 110 | 4 mm. Al | 10 × 15 cm. | 550 r units |
| 110 | 1 mm. Al | 20 × 30 cm. | 450 r units |
| 110 | 2 mm. Al | 20 × 30 cm. | 475 r units |
| 110 | 3 mm. Al | 20 × 30 cm. | 500 r units |
| 110 | 4 mm. Al | 20 × 30 cm. | 525 r units |
| 120 | 2 mm. Al | 5 × 5 cm. | 550 r units |
| 120 | 3 mm. Al | 5 × 5 cm. | 600 r units |
| 120 | 4 mm. Al | 5 × 5 cm. | 650 r units |
| 120 | 2 mm. Al | 10 × 15 cm. | 500 r units |
| 120 | 3 mm. Al | 10 × 15 cm. | 550 r units |
| 120 | 4 mm. Al | 10 × 15 cm. | 600 r units |
| 120 | 2 mm. Al | 20 × 30 cm. | 450 r units |
| 120 | 3 mm. Al | 20 × 30 cm. | 500 r units |
| 120 | 4 mm. Al | 20 × 30 cm. | 550 r units |

* This dosage table, with its variation of factors stated in round figures which are within safe margins, is to be used only as a general guide. It is seldom necessary to exceed the number of r units designated in four or five days.

† The total dose is to be delivered in three days; if any longer time is required, calculation of tissue loss of radiation should permit at least a 25 to 30 per cent addition to these doses. The dose after the third day may be relatively small and quite effective as it serves only to maintain the radiation effect. (See Tables 20 and 23.)

## Emergency Dose

For one not accustomed to giving x-ray therapy (p. 79), we recommend the following procedure. Virtually all practitioners who have x-ray equipment do some fluoroscopy, and if the factors necessary to make a fluoroscopic examination of the stomach were used for a three to five minute exposure, sufficient x-rays would be delivered to the infected tissues to protect an extremity for six to eight hours. The factors indicated would be about as follows: (1) 80 kv.; (2) 1 mm. Al filter (the filter is important); (3) 5 ma. (be certain about the milliamperage); (4) 15 in. distance; (5) three to five minutes.

The r unit output from this group of technical factors will vary from 25 to 50 r for the three to five minute dose (8 to 10 r units per minute), depending on the type of equipment and other variations affecting the quantity of radiation which it is not possible to estimate for all installations. Apparatus used regularly for therapy must be calibrated. Subsequent treatments should be delivered with calibrated apparatus. One millimeter of aluminum or its equivalent is essential for filter.*

## Protection for the Patient

*Routine Essential Preliminaries.*—Before x-ray therapy is given to anyone, the reason for giving it should be determined as accurately as possible. In other words, the final diagnosis should be made, and if this is not possible a tentative diagnosis should be arrived at. Then, the previous x-ray history relative to diagnosis and therapy must be recorded on the chart. The condition of the skin through which treatments are given should also be recorded.

As stated many times in these pages, the doses suggested should cause no visible evidence of radiation reaction in the patient's skin. If the skin shows any unusual redness, treatments should be discontinued until the reason for the erythema is determined.

Radiation necrosis of any serious degree is not discussed in this text because it should not occur. However, one must not get the impression that if mistakes are made a dangerous reaction might not result. A serious, destructive reaction may occur after a three or four minute exposure if the wrong factors are used, as, for instance, a high r output, very short distance and

* This consideration of an emergency dose was the suggestion of Dr. Howard B. Hunt, Professor of Radiology, University of Nebraska Medical School.

the omission of filter. This combination is not likely to occur but is not impossible. Therefore, although no skin reaction should be evident, if it does appear the treatments must be discontinued.

The administration of x-rays for therapeutic purposes always has an element of danger, and although the dosage recommended for the acute infections is the safest of any type of x-ray therapy, it is still not wholly without danger and requires care in all details of its administration.

## X-ray Reactions

*Measures Which Intensify X-ray Reaction.*—Care should be taken not to use external applications which, when added to the x-ray effects, might give rise to superficial destruction of tissues. Concentrated tincture of iodine and other chemical irritants and prolonged applications of extreme heat or cold may have undesirable effects.

*Measures Which Minimize X-ray Reaction.*—Opaque ointments such as the metallic ointments, mercury, zinc or lead wash, or other opaque solutions should not be applied because of their tendency to lessen the effect of the x-rays and lead to inadequate dosage. Our experiences have shown that sulfanilamide and its first derivatives prevent beneficial results from x-rays when both agents are used at the same time.

*Measures Safe in Combination with X-rays.*—A moist pack of saturated solution of magnesium sulfate or boric acid may be bandaged over the infected area and is commonly used without harm in many localized suppurative infections.

*Skin Reaction Due to X-rays.*—One should always keep in mind that the reaction to small doses of x-rays used in treating acute infections is internal. It is remarkable how infrequently any visible skin reaction occurs in the treatment of these conditions. If a skin reaction should be visible, discontinue treatment.

## When to Stop X-ray Treatments in Acute Infections

X-ray treatments should be discontinued under the following conditions:

1. As soon as the temperature recedes to normal and the infection appears to be under control, irradiation should be stopped. Occasionally, in a severe infection, a daily dose for a few days after the temperature has reached normal may be indicated, as, for instance, in severe mastoiditis or peritonitis.
2. If sulfanilamide or any of its early derivatives are to be used, x-ray therapy should be stopped.
3. If the tissue tolerance has been approached or exceeded or if, for any reason, a reaction becomes apparent, it is usually necessary to discontinue treatment temporarily.
4. If there has been any possibility of error in any of the treatment given, it might be well to stop x-ray therapy or to proceed cautiously.
5. In general, irradiation should be stopped for any special reason which, in the opinion of the clinician, seems to indicate its discontinuation.

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