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A HAND METHOD FOR THE COMPUTATION OF FALL-OUT PATTERNS

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LAMS-2019
INSTRUMENTATION

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REPORT WRITTEN: March 1956

REPORT DISTRIBUTED: DEC 1 4 1956

A HAND METHOD FOR THE COMPUTATION OF FALL-OUT PATTERNS

by

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Contract W-7405-ENG. 36 with the U. S. Atomic Energy Commission

ABSTRACT

If suitable wind-weighting factors are used, the displacement of particles which follow the wind during their fall from an initial cloud can be reduced to the problem of the fall of similar particles at a uniform fall rate through these weighted winds. Using a weighted hodograph as a basis, a height-time lattice can be constructed, either upon the assumption of no horizontal wind variability or not. The per cent activity falling into each section of such a lattice is assumed characteristic for all clouds. The contribution to the mean intensity of the resulting fall-out over each lattice section will be the activity expected therein divided by the area of the section augmented by a strip of width equal to the cloud radius at the corresponding height. If the winds are such as to cause lattice sections to overlap, the intensities are additive.

Tables and detailed computational procedures are presented for the preparation of fall-out predictions.

CONTENTS

1. Introduction

This report is a presentation of a hand method for the computation of fall-out patterns with which the Task Force Fall-out Prediction Unit (FOPU) will enter Operation Redwing in the Pacific in the spring of 1956. This method will be but one technique available to that unit; other hand methods and several analogue computers will also be available. It is essentially the method prepared for use during the January phase of Project 56 at the Nevada Test Site, with an informal write-up[1] distributed in December, 1955 to members of the FOPU of Joint Task Force Seven. In its essentials it is similar to the U. S. Weather Bureau hand technique independently developed earlier that year* and reported to Los Alamos at about the same time[2]. This report repeats some elementary facts for workers in the field, so that it may stand by itself as an adequate presentation of the method.

This scheme is primarily applicable to medium and distant fall-out. By medium fall-out is meant fall-out beyond the first 10 miles or so but within the first 40 or 50; by distant fall-out is meant fall-

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*It turned out at Redwing that the Weather Bureau representatives did not use this newer technique, but for their hand method continued to use unaugmented areas.

out in the range of 200 to 250 miles from ground zero. It will not apply to fall-out in the immediate neighborhood of ground zero (within the first 10 miles or so) nor, although in theory it would work, will the weather forecast generally be available for application to very long range fall-out. A separate study[3] has indicated that while single point wind runs are probably an adequate basis for the prediction of medium range fall-out patterns, the space variabilities of the winds almost certainly ought to be taken into account in the forecast of distant fall-out. This requirement was visualized in the conception of this method, and the scheme takes it into account.*

2. The Hodograph and the Height-Time Lattice

In fall-out work, the word hodograph is used to designate that curve which is the projection into the horizontal of the position of a body rising at a uniform rate and simultaneously moving horizontally with the wind. The hodograph is usually approximated by the sum of the mean winds through layers of finite thickness (see Fig. 1). Its significance stems from the fact that the projection of a uniformly falling particle would move under the influence of the same winds (but in reverse order), and so would experience the same net horizontal displacement as would a rising particle of the same vertical speed which is passing through the same slice of the atmosphere.

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*Early field experience at Redwing has shown that adequate time is available for consideration of space-time variability in the fall-out forecasts.

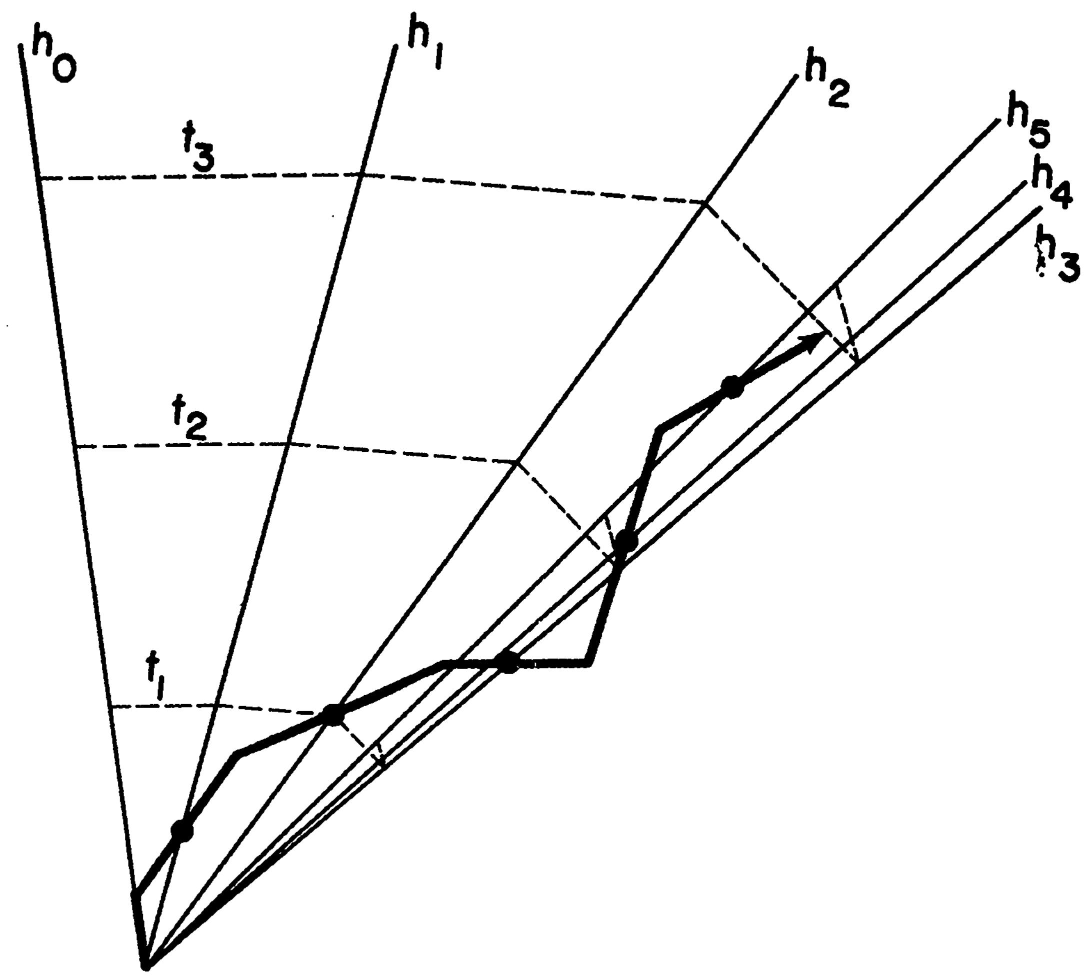

Fig. 1 The hodograph (heavy solid line) and height-time lattice (light solid line and dashed lines, respectively.

The nature of the active particles in fall-out work is not well known. It is fairly clear, however, that it is quite unlikely that particles fall with uniform vertical speed throughout their descent. Suppose for a moment that we consider some class of particles whose fall times through the various layers are known. Then, for these particles, we could construct a hodograph with the winds for the various layers weighted in proportion to the times spent by the particles under their influence (i.e., to the times spent falling through the various layers). If such a <u>weighted</u> hodograph is used, the problem may be treated as though the particles are falling at a uniform speed but through these fictitious winds. Consider that the hodograph shown in Fig. 1 is such a weighted hodograph.

The particle falling from some level, for example, h_2, will experience such a mean horizontal velocity during its fall as to arrive at the ground at some point along the line h_2. How far from ground zero out along that line the point of arrival of the particle will be depends upon the total fall time. Note, then, that if all the particles initially at the level h_2 have the same <u>relative</u> fall times in the various layers, then the same weighted hodograph will apply to all of them, and they will stretch out upon arrival at the surface along the line h_2. It is then appropriate to call such a line of arrival a height line.

It was noted above that the nature of the active particles in fall-out is not adequately known. At this stage of knowledge, particularly for the case of very high clouds in which the particles fall through layers of the atmosphere of quite varying densities, it has generally been the practice to use aerodynamic fall rates. These are usually computed for spheres of density 2.5 falling in such a way as to have laminar air flow past them. Some investigators[4] have gone beyond this, using Stokesian fall for very small particles, and nonlaminar fall for very large ones.

There is a real question whether these refinements are at present justified. These aerodynamic fall rates themselves should not be taken too seriously. Many of the particles will not be perfect spheres: Some will be agglomerates of spheres of condensed materials which have stuck together; others will be irregular pieces of scavenging material picked up from the surface. The air flow past them will not necessarily be nonturbulent. Presumably they will generally fall more slowly than will spheres of the same mass. In cases in which the particles can most reasonably be regarded as spheres, that is, when they consist either of a solid particle surrounded by a film of water or of a simple water drop, their radius (and so, their mass) will be variable during their fall; in general, it will diminish with time as they evaporate in the relatively dry upper air. This discussion is to emphasize that aerodynamic fall rates for particles of specific radii are not to be taken too literally in fall-out work.

It would be very fine if the same weighting factors would apply for the fall of all particles through the various layers. A look at tables of aerodynamic fall rates for various particle diameters covering the range of interest to us indicates that this is not the case. However, it is not a terribly bad approximation, and in the light of our general uncertainty with respect to the exact nature of the particles and various other uncertainties inherent in present fall-out work, it is an approximation which we feel justified in making here. Accordingly, we assume that we can choose the relative times in the various layers for some selected aerodynamic sphere of density 2.5 and apply these weighting factors to the winds to obtain the hodographs used for all particles. This means, for example, that we assume irregular particles of a given mass ratio have the same relative fall times as spheres of the same mass ratio. With this assumption, the height lines of Fig. 1 will indeed be lines of the assumed loci of deposition of particles from the given initial heights. In the practical application of this scheme, the particular set of wind-weighting factors to be used can be varied by FOPU personnel at their discretion during the course of an operation.

Returning now to the discussion of Fig. 1, we have seen that the radial solid lines marked h_0, h_1, h_2, etc., are height lines. These mark loci of arrival of particles from various heights, with particles initially from intermediate heights arriving at the ground at points intermediate between the corresponding height lines. The dashed lines marked t_1, t_2, etc., together with these height lines, constitute a height-time lattice. These time lines are constructed as follows:

Assume that some standard particle, say one falling at 5,000 feet per hour, will descend from height h_2 to the ground during the time t_1. Remember that by going over to a weighted hodograph we have reduced our problem to that of uniformly falling particles. It is then a simple matter to decide how far out along any other height lines particles starting from the corresponding heights would be at time t_1. The horizontal displacement of a particle as it falls from its initial height to the ground is given by the vector along the height line out to the hodograph. Thus a particle falling from a height h_1, half of h_2, would be two times the distance out to the hodograph along h_1 at at the time t_1. Similarly if h_3 is one and one-half times h_2, then the particle on h_3 will be two-thirds of the distance out from ground zero to the intersection with the hodograph. We thus construct the locus of points at which these standard particles arrive at the time t_1. Points twice as far out would correspond to a time t_2, etc. In this fashion we complete the set of time lines. Note, of course, that these contain some elements of fiction. A standard particle (one falling 5,000 feet per hour) may very well have reached the ground well before t_2, if it falls from certain of the heights. Thus along those height lines, the intersection t_2 would have no meaning for the standard particle; however, it will have meaning as a marker — other particles which take greater time may very well fall to the ground from such heights at these greater distances. The wind weighting factors tabulated in Appendix A have been normalized so that the total fall time through the lowest 5,000 feet for each particle is unity. This corresponds to use of a standard 5,000 feet per hour fall time in construction of the h-t lattice. It clearly fails to give correct times for the various spherical particles; certainly the fall times through upper layers have been overestimated.

It will be seen as our discussion continues that the reality of our standard particle is not vital to us. It is only going to be important that we use the same standard fall rates for a particle which defines the time lines of our hodograph in working up our model as we later use in its application. The concept involved is this: We make the basic assumption necessary if fall-out prediction is to be possible at all, namely, that all clouds are essentially similar. Thus, we assume that a characteristic amount of activity is present between corresponding layers, say between one-half and three-fourths of the height of the cloud, for all clouds. This means that a characteristic amount of activity will fall into each sector defined by two height lines. Similarly, we assume that the particle-size distributions are such that in each of these sectors the relative activities which reach the ground at different times will be the same from cloud to cloud -- that is to say, that in a given sector the same relative fraction of activity will land between corresponding time lines from one cloud to another.

It is not vital to us whether or not we have used the precisely correct fall-time laws. So long as our weighted hodograph is of approximately the right shape, we shall obtain reasonable results. Thus, if our particles fall at rates not at all centered on the 5,000 foot per hour rate used in defining the time lines of our lattice, this will not be of serious consequence to us so long as we are interested in where not when the activity arrives. We empirically determine what fraction of activity falls into a given height-time lattice section from past shots, and then assume that the same fraction will fall into that section on future shots.

For the moment it is justification enough of our statement that the labels of our time lines may be quite arbitrary, that the initial empirical computation of the dose would contain in it any error due to erroneous timing (say, from radioactive decay effects), and that a compensating error would reappear in any forecast made. It matters not for our purposes whether a smaller activity lands early, or an erroneously larger one (larger by just the amount required to compensate in the infinite dose) is assumed to land later. This feature is related to both a weakness and a strength of the scheme: A weakness because the scheme cannot be used to compute transient-state maps of activity during the fall-out period (such maps would be both of theoretical interest and of possible practical importance as well since they would provide a "how goes it" check of the forecast against early activity intensity reports coming into the control center); a strength because the scheme is easy to modify in the light of field experience -- its "numbers" being the measurements at the surface themselves, not some stabilization distributions "curve-fitted" to match these surface observations.

In this discussion, and in Fig. 1, we have considered a height-time lattice constructed on the basis of a wind sounding at one point -- that is to say, a height-time lattice constructed on the assumption that there is no horizontal variation in the wind. This is suitable for medium range fall-out situations; however, as we have remarked, it is probably not applicable for long range fall-out -- say the order of the distance between Bikini and Eniwetok, or Bikini and Rongelap. For such long range computations, it is necessary to compute the height and time lines in terms of variable (in the horizontal and, if possible, in time) wind fields. This essentially involves the computation from analyzed and/or forecast wind fields of a series of trajectories of particles falling at the assumed rates. This is a meteorological problem and will not be discussed here. It is perfectly feasible, given a wind forecast, to construct the height-time lattice or, in particular, those distant sections of interest for such space-time variable wind fields. These will differ from the height-time lattices shown in Fig. 1, in that the height lines will no longer be straight lines.

In principle we assume, then, that we have means for the construction of a height-time lattice either based upon one-point winds for medium range work, or based upon space (and perhaps time) variable winds for distant fall-out. How we use the lattice in the actual computation of fall-out pattern is discussed below.

Finally, note that while we have inferred the use of equal time increments for the definition of the time lines, there is no necessity for equal height increments between successive height lines. Indeed, at times it may prove convenient to use varying height increments.

3. The Fall-out Intensity Formula

In the preceding section we have expressed the basic principle involved in our computation: The percent activity of a cloud falling in a particular lattice section is assumed to be the same from cloud to cloud. Accordingly, if we take this percent of the estimated activity going into the primary fall-out from the cloud and divide it by the area of the height-time section, we should arrive at an intensity figure. Our basic formula, then, for the intensity contributed at a particular point characterized by the (h,t)th lattice section will be given by

$$I(h,t) = \frac{KYD\,\alpha(h,t)}{A(h,t)} \qquad (1)$$

In this formula, K is a pure number, the hazard factor. This is the fraction of the total fission yield, Y, which is expected to fall into the primary fall-out (that is to say, that part of the fall-out which we are trying to forecast). The factor D expresses the decay of activity during the period of fall. The quantity $\alpha(h,t)$ is the fraction expected to fall in the (h,t)th lattice section for any cloud. Both h and t are here chosen so as to scale from one cloud height, H, to another: h is in the units H, i.e., h is a fractional cloud height, t is in the units H hours/ H_0, where H and H_0 are cloud height and a reference cloud height. These choices of units in effect define what is meant by "corresponding" lattice sections from one cloud to another. A(h,t) is the augmented area of the (h,t)th lattice section -- augmented because the cloud is not a point source but rather a source of finite area. This will be explained in Sec. 5.

The hazard factor, K, is computed by methods not here discussed, in particular by Shelton's method.[5]

In each instance the fission yield, Y, will be provided from some other source -- say a Los Alamos Scientific Laboratory T-Division estimate. We shall generally wish to map the radiation in terms of roentgens at meter level, "symbolized" R, infinite dose. The yield estimates will ordinarily be given in kilotons of TNT equivalent. We will want our yield converted to R infinite dose times miles squared which we shall later divide by an area in order to get intensity. It is a simple matter to make this conversion. From "Effects of Atomic Weapons," p.251, (LASL, 1950)[6] we find that the gamma radiation at 1 hour from a nominal bomb is 6.0×10^3 megacuries, and from the figure on page 259 of the same publication that 1 megacurie, spread uniformly over a square mile, corresponds for 0.70-Mev particles to about 4.2 RHM at 1 hour, or to about 21.0 R infinite dose. Using these figures, we find that our yield will be 6300 R infinite dose times miles squared for each kiloton of TNT equivalent predicted yield. If wind speeds in knots and distances in nautical miles are used, the factor 6300 is to be replaced by 4751. We discuss the factors D, α, and A of Eq. (1) in more detail in the sections below.

4. The Activity Partition Table, $\alpha(h,t)$, and the Decay Factor, D

Basic to the philosophy of these particular fall-out computations is the assumption that the relative activities to be expected at the ground in each section of the h-t lattice will have been determined empirically from past shots and will be characteristic for other shots. Basic to other fall-out schemes is the assumption that, starting from the same ground-measured data, corresponding partitions of activity and of particle size will have been determined for various parts of a cloud at "stabilization" and will characterize all clouds. We shall see, if we use the simple radioactivity decay law generally assumed, that one such table of relative partitions of activity will suffice for clouds of all sizes -- at least so far as the effects of activity decay during the fall time are concerned. To see this, let us take the attitude adopted in most fall-out schemes, namely, that the invariant from cloud to cloud is the relative activity in the various parts of the cloud at stabilization. For the sake of example, suppose specifically that we choose to divide the cloud into six equal layers (the number is actually irrelevant). Now suppose we treat two clouds of total heights, h and H. Let us compare the activity falling from, say, the fifth and sixth sections of each of these clouds. We seek to ascertain that the ratio of the contributions to the infinite dose at the ground due to the activity of fifth and sixth cloud sections will be the same for each of the two clouds.

Variable fall rates, remember, have been eliminated from our problem by the use of weighted winds. Hence, if we call t_5 and t_6 the mean times of fall of particles from the fifth and sixth sections of the small cloud, and T_5 and T_6 the corresponding mean times for the fall from the corresponding parts of the large cloud, we have

$$\frac{t_5}{T_5} = \frac{t_6}{T_6} = \frac{h}{H} \qquad (2)$$

Let s_5 and s_6 be the percent activities in the fifth and sixth layers of the small cloud at stabilization, and let S_5 and S_6 be the corresponding quantities for the large cloud. Also let d_5 and d_6 be the infinite dose at the appropriate lattice point due to activity arriving at the ground from these layers for the case of the small cloud, and let D_5 and D_6 be the corresponding quantities for the large cloud. We assume the usual 1.2 decay law. Accordingly, the intensity of the radiation arriving at the ground from the fifth layer of the small cloud will be $s_5(t_5/t_s)^{-1.2}$, where t_s is the time of stabilization. The infinite dose, then, will be given by $d_5 = 5t_5$ x this intensity, that is by

$$d_5 = 5t_s^{1.2}s_5t_5^{-0.2} \qquad (3)$$

Similarly,

$$d_6 = 5t_s^{1.2}s_6t_6^{-0.2}; \; D_5 = 5t_s^{1.2}S_5T_5^{-0.2}; \; D_6 = 5t_s^{1.2}S_6T_6^{-0.2} \qquad (4)$$

Using these results we can compare the ratios of the infinite doses originating from the fifth and sixth layers from one cloud to the other:

$$\frac{d_5/d_6}{D_5/D_6} = \frac{s_5/s_6}{S_5/S_6}\left(\frac{t_5}{T_5}\right)^{0.2}\left(\frac{T_6}{t_6}\right)^{0.2} \tag{5}$$

We have assumed at the outset equality of the ratios s_5/s_6 and S_5/S_6. Also, from Eq. (2) we see that the last two factors of the right member of Eq. (5) are reciprocal. Hence, we see that the ratios of the infinite doses resulting at the ground from the fifth and sixth layers are indeed the same from one cloud to another. This means that we can use a universal set of percent activities going into each lattice section, that is to say, one universal set of $\alpha(h,t)$'s in the notation of Eq. (1). However, it is certainly not the case that, in the notation we are here using, $d_5/s_5 = D_5/S_5$. In fact, it is clear that for the larger cloud the infinite doses will be smaller, assuming that the same initial activity is spread over the two clouds. This is because more is lost to decay during the longer fall times from the higher cloud; or, put another way, the infinite dose deposition at the ground begins at a later date for the larger cloud. Thus, although we can use one universal set of α's, we must accompany this by a table of decay factors, D, each dependent upon the total height H of the cloud.

Since the variable fall rates have been eliminated by the transition to the weighted winds, so that we have a uniform fall problem, it is clear that the fall times from corresponding parts of the cloud will be in proportion to the total heights of the clouds. The infinite dose at the ground arising from each part of the cloud is proportional to the mean time of fall to the minus 0.2 power; this gives us a ready means of computing the decay factors. Suppose, for example, that we have computed the infinite dose resulting at the ground from an initial distribution of activity of unit amount in a 12,000-foot cloud, using a 12-layer model. Fig. 2 is a display of such a model and the results of such a computation. The top number in each box is the percent activity at 1-hour assigned to that lattice section under the currently accepted FOPU cloud model; the middle number in the box is the resulting infinite dose at the ground (for the 12,000-foot case chosen), and the lowest figure in each box is the percent infinite dose. The sum of the computed infinite doses turns out to be 1.0329. This means that for a cloud of height H, the decay factor is

$$D(H) = 1.033(12{,}000/H)^{0.2} \qquad (6)$$

Eq. (6) is tabulated in Table B-I of Appendix B.

Table B-II is a repetition of the normalized contributions to the infinite dose (the lowest figures in each box of Fig. 2). Table B-III is the corresponding one for a 6-layer cloud model, derived by adding up appropriate entries from Table B-II. If, for example, the wind is turning rapidly in the lowest layers, so that the lowest lattice sections are badly fitted by representation as triangles,* smaller increments of height, corresponding to the 12-layer model, could be taken at first; then increments corresponding to the 6-layer model

*We shall find it convenient to use such representations; see Sec. 5.

Height												
H	0.7 0.92 0.9	1.3 1.38 1.3	0.9 0.86 0.8	0.9 0.80 0.8	0.7 0.60 0.6	0.4 0.33 0.3	0.3 0.24 0.2	0.3 0.23 0.2	0.3 0.22 0.2	0.2 0.15 0.1	0.2 0.14 0.1	0.2 0.14 0.1
	2.0 2.64 2.6	3.0 3.17 3.1	2.6 2.48 2.4	1.6 1.43 1.4	0.9 0.77 0.7	0.8 0.65 0.6	0.7 0.55 0.5	0.7 0.54 0.5	0.6 0.45 0.4	0.3 0.22 0.2	0.2 0.14 0.1	0.1 0.07 0.1
	4.2 5.54 5.4	4.5 4.76 4.6	3.6 3.44 3.3	3.6 3.22 3.1	2.2 1.87 1.8	1.2 0.98 0.9	1.1 0.87 0.8	0.9 0.69 0.7	0.6 0.45 0.4	0.3 0.22 0.2	0.1 0.07 0.1	
$\frac{9}{12}H$	5.9 7.79 7.5	6.7 7.09 6.9	3.8 3.63 3.5	2.3 2.06 2.0	1.8 1.53 1.5	1.3 1.06 1.0	1.1 0.87 0.8	0.7 0.54 0.5	0.4 0.30 0.3	0.1 0.07 0.1		
	5.6 7.39 7.2	6.0 6.36 6.2	2.7 2.58 2.5	1.7 1.52 1.5	1.1 0.94 0.9	0.8 0.65 0.6	0.4 0.32 0.3	0.2 0.15 0.1				
	3.9 5.15 5.0	2.4 2.54 2.5	1.2 1.15 1.1	0.8 0.72 0.7	0.3 0.26 0.2	0.2 0.16 0.2	0.2 0.16 0.2	0.1 0.08 0.1				
$\frac{6}{12}H$	0.6 0.79 0.8	0.4 0.42 0.4	0.1 0.10 0.1									
	0.8 1.06 1.0	0.3 0.32 0.3	0.1 0.10 0.1									
	0.9 1.18 1.1	0.2 0.21 0.2										
$\frac{3}{12}H$	1.1 1.45 1.4	0.1 0.11 0.1										
	1.2 1.58 1.5											
0	1.2 1.58 1.5											

Horizontal axis: 0, 1, 2, 3 — $t\left(\frac{H \text{ hours}}{6000}\right) \longrightarrow$

Fig. 2 Activity partition in a 12,000-foot cloud, 12-layer model. In each box, the top entry is percent activity at 1 hour; the middle entry is the resulting infinite dose at the ground; the last entry is percent infinite dose.

used thereafter. This has been suggested by the small entries in the upper corners of the top-left lattice section entry of Table B-III. If 6 layers are to be used, but with the smaller time intervals corresponding to the 12-layer model, the required table is readily prepared from the 12-layer one. The required tabular entries are exemplified by the small entries in the right hand corners of the top-second-from-the-left lattice section entry in Table B-III. Obviously, yet other combinations are derivable from Table B-II.

5. The Area Computation

The reasoning above in the discussion of the construction of the height-time lattice refers to a cloud treated as though it were a filament, that is to say, a point source at each level. In actual fact, at any given height the cloud will have some finite area. In the first approximation, we treat this as a circle of radius r, assumed known at least in terms of some cloud model, for each elevation. Referring to Fig. 3, where such a circle has been placed at the vertex of two height lines, it is fairly clear that the fall-out will not be into an h-t lattice section but actually into an augmented h-t lattice section -- that is to say, a lattice section augmented by a strip of width equal to the cloud radius, r.

It turns out that in the particular case of medium range fall-out, where space variation of the wind is ignored, the computation of these augmented lattice section areas is particularly quick and easy. Measurements need be made only on the innermost lattice sections, that

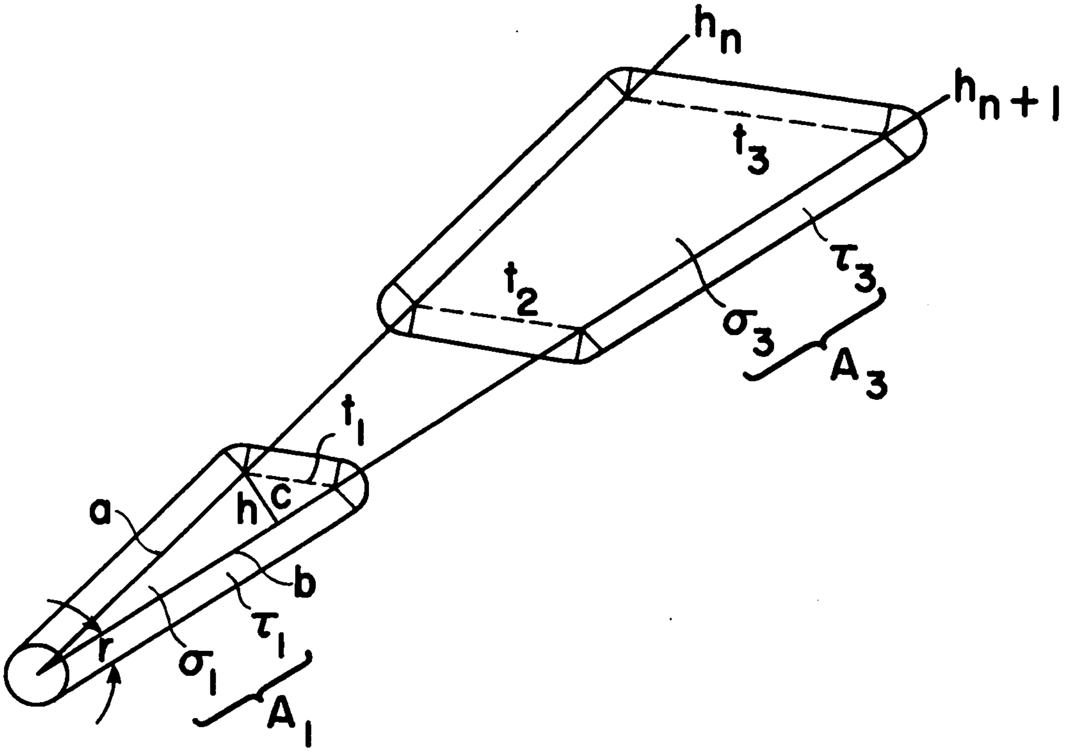

Fig. 3 Notations used in the computation of the augmented lattice section areas (see Sec. 5).

is to say, the ones between ground zero and the first time line. This is a consequence of the fact that each lattice area is the difference between the areas of two similar triangles (extending from ground zero to successive time lines). Suppose we call the sides of the innermost of one such triangle a, b, and c, and the altitude of that triangle, h; see Fig. 3. Further, let us call the area of the innermost triangle σ_1, that of the augmenting strip τ_1, and the total augmented lattice section area A_1; call the corresponding areas of the other sections, their augmentations, and the augmented areas σ_2, τ_2, A_2; σ_3, τ_3, A_3; etc., numbering them successively from ground zero outwards.

Evidently $A_1 = \sigma_1 + \tau_1$ is given by:

$$A_1 = 1/2bh + \pi r^2 + r(a + b + c) \qquad (7)$$

From considerations of the similarity of the triangles involved and the equal spacing of the time lines,

$$\sigma_2 = 1/2(2b)(2h) - 1/2bh = (2^2 - 1)\sigma_1$$

and, in fact, in general

$$\sigma_n = \left[n^2 - (n - 1)^2\right] \sigma_1 = (2n - 1)\sigma_1$$

so that

$$\sigma_{n+1} = \sigma_n + 2\sigma_1 \qquad (8)$$

Also,

$$\tau_2 = \pi r^2 + r(a + c + b + 2c) = \tau_1 + 2rc$$

In general,

$$\tau_{n+1} = \tau_n + 2rc \qquad (9)$$

Combining (8) and (9), we get

$$A_{n+1} = A_n + (bh + 2rc) \quad (10)$$

Thus, if we but compute A_1, from Eq. (7), and the increment in the A's, the quantity in parentheses in the right member of Eq. (10), and enter them into the register and keyboard of a desk computer, we can get all the A's for those lattice sections between the two chosen height lines simply by repeatedly pressing the "add" key.

For the case of distant fall-out, where this nice similarity of triangles fails (we no longer even have triangles), it will be necessary to use a planimeter or similar device for the determination of the requisite augmented areas. However, since these computations will probably be for a relatively few, distant, lattice sections, the work ought not to be too time consuming.

The factor $A^{-1}(h,t)$ whose computation has here been discussed was called the "wind factor" in the description of the method[1] prepared prior to Project 56 in Nevada. This is a resonable name, perhaps more descriptive of its physical meaning than "area factor," since evidently the variation of the wind conditions from shot to shot -- the only meteorological variable in the computation -- enters only through this factor.

6. Preparation of the Isodose Contours

Intensities computed from Eq. (1) for each lattice section are entered at the center of each on a map of the lattice. Depending upon the wind structure, some such lattice sections may overlap. For example, in Fig. 1 it is quite evident that the activity falling between the height lines h_4 and h_5 will be completely superimposed upon that falling between h_2 and h_3. Thus, at the centers of those lattice sections between the h_4 and h_5 lines, the (h_2, h_3) contributions must be added. In other cases, the overlapping will be only because of the augmentation of the areas. In practice, it will probably be good enough to test each central point of a lattice section with a pair of dividers to see if it is within one radial distance of other lattice sections. If so, the intensities of the sections involved should be added to obtain the contribution to the intensity at that point. More than two sections may contribute to the intensity at one spot, of course. Once the summed intensity contributions have been determined and entered at each point, it is a relatively simple matter to analyze the resulting data in order to get the contour presentation.

In considering the question of overlap above, we have tacitly assumed that an intensity distribution for the activity across the cloud at any given level, which is zero outside the cloud, jumps to a constant value within the cloud, and then is zero again at the other edge of the cloud. Various workers have assumed different sorts of distributions of activity across the cloud. White (see Reed[7]), for example, assumed a drop-off of activity toward the edges (a bell-shaped distribution); Nagler et al.[2] and Felt[8] assumed our flat distribution. Others might reasonably wish to choose a "toroidal" distribution -- one with a relative minimum of activity at the cloud center. It might also be reasonable to choose a step function; for example, one with the level of activity rising to a constant, remaining that for part of the way into the cloud, rising to yet another constant, remaining that for a distance, descending then again to the first constant value, and then again to zero; this would be an approximation of the bell-shaped distribution.

We actually do not have adequate experimental evidence upon which to make a choice between the various distributions. Part of the differences between the various choices is compensated for by the "curve fittings" involved in getting the relative activity distributions. The differences can also be partly compensated for by different choices of radiological cloud diameter -- a factor determined empirically after the general choice of cloud model has been made and, in fact, part of the "curve fitting" involved in getting the "numbers" for that model. Since the choice is to some extent an arbitrary one, it was made here in terms of computational convenience. The essential point to remember is that the question of overlap of extended lattice sections does not deserve more than a rough treatment -- there is no use kidding ourselves about our present accuracies. Hence the simple attack here proposed, to be combined with judicious smoothing of the pattern when the forecaster draws his final isodose contours. The final result is, of course, to be taken with the usual king-size grain of salt. For an estimate of the size of this grain, see reference 3.

7. Discussion

Several comments are appropriate. In the first place, it will be remembered that in Sec. 4 we qualified our statement that a single set of α's would suffice with the clause, "at least so far as effects of activity decay during the fall time are concerned." What we had in mind there was the fairly obvious conclusion that the activity distributions in a cloud may very well be, in the first place, a function of the sort of sub-surface over which the bomb bursts. The nature of the scavenging particles clearly may depend upon whether the surface is coral or clay in the case of a dry surface, and, perhaps more important, whether the surface is water or land. In the course of the discussion, we have mentioned the possibility that water droplets or particles covered with a film of water may be important in certain fall-out situations, and that these particles may change their mass as they fall. Should they change their mass in a characteristic way from one cloud to another (that is to say, should the evaporation into the upper atmosphere be more or less the same from one case to another -- as it may very well be, given the relative constancy of atmospheric conditions on "shot days"), then it should be possible to compute a table of α's for such shots. Remember that we do not care what the exact fall laws are so long as they are reproducible. If part of the variability of the fall time is due to a variable mass of the particles, that is perfectly all right as far as we are here concerned. We are no worse off in not knowing the exact fall laws for this reason than we are in not knowing them for other reasons.

In the second place, it may also very well be that the characteristic distributions (that is, the α table) depend in a qualitative way upon the magnitude of the shot. That is to say, there may be a qualitative difference between kiloton shots on the one hand and megaton shots on the other. Obviously, of course, there is in fact a gradual transition; the whole range is continuous. However, if we break it into two classes, it may be desirable to use different tables of α for each class. We enter the forthcoming operation with but one set of α's, for lack of knowledge of how to vary them for the various cases. This may be changed in the field as experience dictates; here the simplicity of this scheme will be an advantage.

Perhaps the single greatest change from previous fall-out forecasting practice visualized in this present scheme is the use of space (and perhaps time) variable winds for the computation of distant fall-out patterns. Reference to a previous report[3] will show the high desirability of at least experimenting with this. This advance has long been visualized as being a desirable and perhaps necessary one by many workers in the field.

It is obvious that we do not yet have the last word in fall-out cloud models. During the forthcoming operation, we shall be interested in trying to get as good data as possible with respect to the deposition both in terms of the space and time distribution and of the particle sizes. We shall also want to collect cloud geometry data. Given such information, we can afterwards take another look at the model and perhaps improve it.

In the preliminary presentation of this scheme[1], one of the final conclusions was that it might be important to take into account the divergence of the wind field (or, what is linked to the divergence, the vertical velocity). Since large scale synoptic vertical velocities ranging in extreme cases to 25-50 cm/sec are measured in the Marshall Islands area[9], and since the 5,000 foot/hour fall rate of our "standard" particles corresponds to about 42 cm/sec, it is clear that if these vertical velocities can be at all reliably forecast, they should be taken into account, at least experimentally. This is contemplated for the forthcoming operation.

Three effects upon the intensity of the resulting fall-out pattern can be anticipated. Upward vertical velocities would increase the fall times. This would result in greater loss of activity to decay during the fall, contributing to a decrease of intensity of the deposition; this would be a very small effect. The greater fall times would mean an increase in the area of the lattice sections; this also would tend to decrease the intensity of the fall-out (for upward motions) and would be a much larger effect. From considerations of continuity, upward vertical motions are accompanied by low-level convergence and high-level divergence of the horizontal winds. Assuming that the time-weighted mean effect on the falling particles for the case being considered will be a net convergence, as is likely, this will result in a diminution of the area of each cloud slice as it falls; that is to say, a diminution of the augmenting strip, in the terminology of this paper.

For post operational analyses to re-check our cloud models the course is clear, but just which of several possible rough and dirty approaches to the problem of taking the atmospheric vertical motions into account in operational forecasts will prove to be the best, considering both computational ease (and so, time) and the accuracies of the vertical velocity estimates, is not yet clear.

8. A "Cook Book" Procedural Outline

In this section we list serially the steps involved in making a fall-out prediction using the procedure of this report. Some of this work will be done well in advance of the actual forecast, that is to say, well before the final wind-run to be used is available; other steps are dependent upon that wind-run and must be done at the last moment. In order, the steps are as follows.

In advance of knowledge of the actual wind-run to be used:

(1) Determine the anticipated cloud dimensions from the yield estimate, if the computation is a pre-shot one; from observation, if the computation is a post-shot one.

(2) Given these dimensions, determine the number of layers to be used in the cloud model for the computation, and compute the quantity πr^2 for each of the elevations. In general, r will be a function of height.

(3) Given an estimate of the fission yield, probably in kilotons of TNT equivalent, convert it to roentgens infinite dose times miles squared, determine the hazard factor, K, and the decay factor, D, from the estimated height of the cloud. Form the product KYD and then multiply each of the α's by it, thereby preparing a working table of quantities which need only to be divided by the areas determined for the various lattice sections at the last moment in order to get intensity contributions. Note that since, for convenience of tabulation, percents, not fractional doses, appear in the $\alpha(h,t)$ tables, an added factor of 0.01 must be entered. In effect this means using 63 R miles squared for each kiloton TNT equivalent for Y, and the $\alpha(h,t)$'s as tabulated. A suggested working form is one like Table B-II less the α's. In place of the $\alpha(h,t)$ entries there shown, the quantities $KYD\alpha$, computed in this step, would be entered. Note that the boxes are large enough for the subsequent entry of the areas and the quotients (i.e., the intensities).

After the wind run comes in:

(4) Given the wind run, construct the weighted hodograph, using a table such as one of those in Appendix A.

(5) From the weighted hodograph, construct the height-time lattice, using the procedures of Sec. 2 for the medium range, and using selected meteorologically determined fall trajectories for the determination of the distant parts of the lattice.

(6) For the medium range, prepare to determine the various augmented areas by measuring the lengths of the sides and the altitudes of the innermost lattice sections. A suggested form for recording these is indicated on Table B-II. Here, if it seems desirable in order to better fit these innermost lattice sections by triangles, the procedure of using a closer height interval for certain selected layers, mentioned in Sec. 5 above, may be used. For each layer, then determine the augmented areas of the innermost lattice sections and the increments, using Eqs. (7) and (10). Enter these on the work sheet as indicated in the left margin of Table B-II, and into a desk computer and determine the corresponding quantities for the other lattice sections, entering them under the previously determined quantities of the working table.

(7) Divide the quantities KYDα, previously determined by the areas for each lattice section, and enter the results in the working table and on the map of the lattice sections.

(8) For the distant lattice sections, determine the augmented areas by means of a planimeter and make the corresponding entries in the computational table. Again divide the quantities KYDα by the augmented area for each such distant lattice section of interest, and enter the result in the map of the lattice.

(9) Using the radius appropriate to the mean height of each lattice section, test for overlap, adding mean lattice section

intensity contributions where overlap exists. Enter this result on a lattice section map.

(10) Analyze the resulting intensity figures. The resulting contours will be the required fall-out map. At this stage, if necessary, change scale from the working map scale to the scale of some reference geographic map in order to link fall-out with significant geography.

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APPENDIX A

Sample Wind-Weighting Tables

The tables are identified by a reference particle diameter in microns. The entries are, at the left, the standard levels at which winds will be reported and, across the top, wind speeds. The tabulated quantities are the weighted wind speeds.

The tables are based upon aerodynamic fall times for various particles as computed by Rand Corporation. The weightings are in proportion to the time spent by the aerodynamically falling reference particle in each layer whose mean wind will be represented by the reported wind for the indicated level. The weighting factors were normalized so as to make the total fall time through the lowest 5,000 feet correspond to unity.

Table A-1

WEIGHTED WIND SPEEDS,
100-μ particle diameter

Standard wind levels, H(10^3 ft)	Reported Wind Speeds																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0	0	0	1	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	4	4	4	5	5	5	5	5	6	6	6
2	0	1	1	2	2	2	3	3	4	4	4	5	5	6	6	6	7	7	8	9	9	9	9	10	10	10	11	11	12	12
4	0	1	1	2	2	2	3	3	4	4	4	5	5	6	6	6	7	7	8	8	8	9	9	9	10	10	11	11	11	12
6	0	1	1	2	2	2	3	3	4	4	4	5	5	5	6	6	7	7	7	8	8	9	9	9	10	10	11	11	11	12
8	0	1	1	2	2	2	3	3	3	4	4	5	5	5	6	6	7	7	7	8	8	8	9	9	10	10	10	11	11	12
10	0	1	1	2	2	2	3	3	3	4	4	5	5	5	6	6	6	7	7	8	8	8	9	9	9	10	10	11	11	11
12	0	1	1	1	2	2	3	3	3	4	4	4	5	5	6	6	6	7	7	7	8	8	8	9	9	10	10	10	11	11
14	0	1	1	1	2	2	3	3	3	4	4	4	5	5	5	6	6	7	7	7	8	8	8	9	9	9	10	10	11	11
16	0	1	1	1	2	2	2	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	9	9	9	10	10	10	11
18	0	1	1	1	2	2	2	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	11
20	1	1	2	2	3	4	4	5	5	6	6	7	8	8	9	9	10	11	11	12	12	13	14	14	15	15	16	17	17	18
25	1	2	2	3	4	5	6	6	7	8	9	10	11	11	12	13	14	15	15	16	17	18	19	19	20	21	22	23	23	24
30	1	2	2	3	4	5	5	6	7	8	8	9	10	11	12	12	13	14	15	15	16	17	18	18	19	20	21	21	22	23
35	1	1	2	3	4	4	5	6	7	7	8	9	9	10	11	12	12	13	14	15	15	16	17	17	18	19	20	20	21	22
40	1	1	2	3	3	4	5	6	6	7	8	8	9	10	10	11	12	13	13	14	15	15	16	17	17	18	19	20	20	21
45	1	1	2	3	3	4	5	5	6	7	7	8	8	9	10	10	11	12	12	13	14	14	15	16	16	17	18	18	19	20
50	1	1	2	2	3	4	4	5	6	6	7	7	8	9	9	10	10	11	12	12	13	14	14	15	15	16	17	17	18	19
55	1	1	2	2	3	4	4	5	5	6	7	7	8	8	9	9	10	11	11	12	12	13	14	14	15	15	16	17	17	18
60	1	1	2	2	3	4	4	5	5	6	6	7	8	8	9	9	10	11	11	12	12	13	14	14	15	15	16	16	17	18
65	1	1	2	2	3	4	4	5	5	6	7	7	8	8	9	10	10	11	11	12	12	13	14	14	15	15	16	17	17	18
70	1	1	2	2	3	4	4	5	5	6	7	7	8	8	9	9	10	11	11	12	12	13	14	14	15	15	16	17	17	18
75	1	1	2	2	3	4	4	5	5	6	7	7	8	8	9	9	10	11	11	12	12	13	14	14	15	15	16	17	17	18
80	1	1	2	2	3	4	4	5	5	6	6	7	8	8	9	9	10	11	11	12	12	13	14	14	15	15	16	16	17	18
85	1	1	2	2	3	4	4	5	5	6	6	7	8	8	9	9	10	11	11	12	12	13	13	14	15	15	16	16	17	18
90	1	1	2	2	3	3	4	5	5	6	6	7	8	8	9	9	10	10	11	12	12	13	13	14	15	15	16	16	17	17
95	1	1	2	2	3	3	4	5	5	6	6	7	8	8	9	9	10	10	11	12	12	13	13	14	14	15	16	16	17	17
100	1	1	2	2	3	3	4	5	5	6	6	7	7	8	9	9	10	10	11	12	12	13	13	14	14	15	16	16	17	17

Table A-2

WEIGHTED WIND SPEEDS,

160-μ particle diameter

Standard wind levels, H(10^3 ft)	Reported Wind Speeds																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0	0	0	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6
2	0	1	1	2	2	2	3	3	4	4	4	5	5	6	6	6	7	7	8	8	8	9	9	10	10	10	11	11	12	12
4	0	1	1	2	2	2	3	3	4	4	4	5	5	6	6	6	7	7	7	8	8	9	9	9	10	10	11	11	11	12
6	0	1	1	2	2	2	3	3	3	4	4	5	5	5	6	6	7	7	7	8	8	9	9	9	10	10	10	11	11	12
8	0	1	1	2	2	2	3	3	3	4	4	5	5	5	6	6	6	7	7	8	8	8	9	9	10	10	10	11	11	11
10	0	1	1	1	2	2	3	3	3	4	4	4	5	5	6	6	6	7	7	7	8	8	9	9	9	10	10	10	11	11
12	0	1	1	1	2	2	3	3	3	4	4	4	5	5	5	6	6	7	7	7	8	8	8	9	9	9	10	10	11	11
14	0	1	1	1	2	2	3	3	3	4	4	4	5	5	5	6	6	6	7	7	8	8	8	9	9	9	10	10	10	11
16	0	1	1	1	2	2	2	3	3	4	4	4	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	11
18	0	1	1	1	2	2	2	3	3	3	4	4	4	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10	10
20	1	1	2	2	3	3	4	5	5	6	6	7	7	8	9	9	10	10	11	12	12	13	13	14	14	15	15	16	17	17
25	1	2	2	3	4	5	6	6	7	8	9	9	10	11	12	13	13	14	15	16	17	17	18	19	20	21	21	22	23	24
30	1	1	2	3	4	4	5	6	7	7	8	9	10	10	11	12	13	13	14	15	16	16	17	18	19	19	20	21	22	22
35	1	1	2	3	3	4	5	6	6	7	8	8	9	10	10	11	12	13	13	14	15	15	16	17	17	18	19	19	20	21
40	1	1	2	3	3	4	5	5	6	7	7	8	8	9	10	10	11	12	12	13	14	14	15	16	16	17	18	18	19	20
45	1	1	2	2	3	4	4	5	6	6	7	7	8	9	9	10	10	11	12	12	13	14	14	15	15	16	17	17	18	18
50	1	1	2	2	3	3	4	5	5	6	6	7	8	8	9	9	10	10	11	12	12	13	13	14	14	15	16	16	17	17
55	1	1	2	2	3	3	4	4	5	6	6	7	7	8	8	9	9	10	10	11	12	12	13	13	14	14	15	15	16	17
60	1	1	2	2	3	3	4	4	5	5	6	6	7	8	8	9	9	10	10	11	11	12	12	13	13	14	15	15	16	16
65	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15	16
70	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	11	11	12	12	13	13	14	14	15	15	16
75	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	15	15	16
80	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15
85	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15
90	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15
95	0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15
100	0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15

APPENDIX B

Computational Tables

B-I. The Decay Factor

B-II. Infinite Dose Partition in Per Cent, Twelve-layer Model

B-III. Infinite Dose Partition in Per Cent, Six-layer Model

Table B-1

THE DECAY FACTOR

$D(H) = 1.033(12,000/H)^{0.2}$; H = cloud height in feet.

H (10^3 ft)						6	7	8	9	10
D						1.19	1.15	1.12	1.10	1.07
H	11	12	13	14	15	16	17	18	19	20
D	1.05	1.03	1.02	1.01	0.99	0.99	0.97	0.96	0.95	0.94
H	21	22	23	24	25	26	27	28	29	30
D	0.93	0.92	0.91	0.91	0.90	0.89	0.88	0.88	0.87	0.87
H	31	32	33	34	35	36	37	38	39	40
D	0.86	0.86	0.85	0.84	0.84	0.83	0.83	0.83	0.82	0.82
H	41	42	43	44	45	46	47	48	49	50
D	0.81	0.81	0.81	0.80	0.80	0.80	0.79	0.79	0.79	0.78
H	51	52	53	54	55	56	57	58	59	60
D	0.78	0.78	0.77	0.77	0.77	0.77	0.76	0.76	0.76	0.75
H	61	62	63	64	65					70
D	0.75	0.75	0.74	0.74	0.74					0.73
H	75	80	85	90	95	100	105	110	115	120
D	0.72	0.71	0.70	0.69	0.69	0.68	0.67	0.67	0.66	0.66

Table B-II

INFINITE DOSE PARTITION IN PER CENT, TWELVE-LAYER MODEL

h (a, b, c) — A_1, ΔA

h/H												
1	0.9	1.3	0.8	0.8	0.6	0.3	0.2	0.2	0.2	0.1	0.1	0.1
	2.6	3.1	2.4	1.4	0.7	0.6	0.5	0.5	0.4	0.2	0.1	0.1
	5.4	4.6	3.3	3.1	1.8	0.9	0.8	0.7	0.4	0.2	0.1	
$\frac{9}{12}H$	7.5	6.9	3.5	2.0	1.5	1.0	0.8	0.5	0.3	0.1		
	7.2	6.2	2.5	1.5	0.9	0.6	0.3	0.1				
	5.0	2.5	1.1	0.7	0.2	0.2	0.2	0.1				
$\frac{6}{12}H$	0.8	0.4	0.1									
	1.0	0.3	0.1									
	1.1	0.2										
$\frac{3}{12}H$	1.4	0.1										
	1.5											
0	1.5											
$t\left(\frac{H \text{ hours}}{6000}\right) \rightarrow$				1				2				3

Table B-III

INFINITE DOSE PARTITION IN PER CENT, SIX-LAYER MODEL

h/H ↑ \ $t\left(\frac{H\ hours}{6000}\right)$ →	0		1		2		3
$\frac{5}{6}H$ – H	3.5 : 4.4 ; 7.9	1.6 ; 5.4 .... ; 3.8	2.2	1.4	0.9	0.4	
$\frac{4}{6}H$ – $\frac{5}{6}H$	24.4	11.9	5.2	2.8	1.0	0.1	
$\frac{3}{6}H$ – $\frac{4}{6}H$	20.9	5.8	1.9	0.7			
$\frac{2}{6}H$ – $\frac{3}{6}H$	2.5	0.2					
$\frac{1}{6}H$ – $\frac{2}{6}H$	2.8						
0 – $\frac{1}{6}H$	3.0						