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ARL FALLOUT PREDICTION TECHNIQUE

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TABLE OF CONTENTS

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A manual prediction technique is presented for computing a fallout pattern for a single nuclear surface or air burst. The technique is based on the concept of radioactive particles that fall from a stabilized nuclear cloud, are transported by the winds, and finally deposit over an area on the ground, thus forming a fallout pattern. The computation of a fallout pattern is described in detail.

1. INTRODUCTION

The Air Resources Laboratory (ARL) fallout prediction technique was specifically designed to permit rapid, manual computation of a fallout pattern for a single (actual or simulated) nuclear burst during nuclear test operations and exercises. It is based on the general concept of radioactive particles that fall from a stabilized nuclear cloud*, are transported by the winds (as determined from a single wind sounding), and deposit on the ground. More specifically, ground positions are determined with respect to ground zero (GZ) for a "standard" particle (whose fall rate through the atmosphere is assumed to be known) that falls from various heights within the nuclear cloud. The ground positions of all other particles are then determined on the assumption that their fall times are proportional to those of the standard particle. The particle

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* A nuclear cloud is said to be "stabilized" when it ceases rapid vertical growth, usually within about 6 to 10 min after detonation.

ground positions are used to define a "grid" of fallout areas in which radioactivity is deposited. The activity deposited in each grid area, normalized to deposition in a unit area, has been determined empirically from past nuclear events. Therefore, the activity on the ground can be determined by dividing the normalized activity by associated grid areas. Contours connecting similar ground activity values delineate the fallout pattern.

In the technique originally developed by Nagler et al. (1955), two different procedures were used to compute a fallout pattern; one for the case where the single wind sounding displayed considerable directional wind shear with height, and another for the case of little or no wind shear. This paper presents a revision of the original technique that eliminates the need for separate "wind shear" and "no wind-shear" cases. The revised technique takes into account nuclear cloud diameter effects for any wind shear, whereas the original did so only for the "no wind-shear" case.

The detailed procedure presented in section 3 describes the manual computation of a fallout pattern for a surface burst or an air burst. A condensed operational procedure is presented in section 4, followed by the necessary working charts for the computations and examples of individual steps given in the procedure sections. With practice, a fallout pattern can be completed in about 30 min. (A computerized version of the ARL fallout prediction technique has been developed by Fleshel and Seery, 1968, and is available through ARL.)

2. TECHNIQUE DEVELOPMENT

2.1 Construction of a Fallout Hodograph

A fallout hodograph is defined here as the locus of ground positions for particles of a specific size that have fallen from all heights above the point of detonation (GZ). It is assumed that the particles are transported by the winds in each atmospheric layer through which they fall and, further, that the winds may vary with height but not with horizontal space or time.

The atmosphere is divided into 5000 ft (5 kft) layers, and the average wind direction and speed are estimated or measured in each layer. When the fall time through a layer is known for a given particle, the horizontal particle displacement in the layer can be determined. A fallout hodograph (see fig. 1) is constructed by plotting displacement vectors, with corresponding layer heights, in sequential order head to tail, starting at GZ with the vector representing the lowest(surface to 5 kft) layer. Any point along the the hodograph locates the ground position of the given particle that originated at the indicated (or interpolated) height above GZ.

The standard particle in the technique, designated P_4, is a smooth, spherical particle 100 microns in diameter with a density of 2.5 g/cm^3. For convenience in plotting and subsequent computations, the fallout hodograph is constructed, in practice, for a P_{10} particle whose fall times through atmospheric layers are defined at 10/4 the fall times of P_4. The fall times for P_{10} through 5 kft layers in the U.S. Standard Atmosphere, 1962, are given in table 1. Thus, the hodograph in figure 1 is called a P_{10} hodograph.

2.2 The Nuclear Cloud

The ARL technique is based on the concept of a stabilized nuclear cloud composed of vertically stacked cylinders called wafers. Six wafers are used to represent the typical mushroom-shaped nuclear cloud; three wafers of equal thickness and a given diameter comprise the mushroom cap (upper half of the cloud for a surface burst or upper third of the cloud for an air burst) and three wafers of equal thickness and a smaller diameter comprise the mushroom stem (lower half of the cloud for a surface burst or lower two-thirds for an air burst), as illustrated in figure 2. (The six wafers are numbered consecutively from the top to the bottom of the cloud.) The stem diameter is usually assumed to be 1\3 the cap diameter.

Table 1. Fall Times for Particle P_{10} Through 5 kft Layers in the U.S. Standard Atmosphere, 1962*

Atmospheric Layer (kft, msl)	P_{10} Fall Time (hrs)	P_{10} Time of Arrival at 0 kft From Top of Layer (hrs)
0-5	2.0	2.0
5-10	1.9	3.9
10-15	1.8	5.7
15-20	1.7	7.4
20-25	1.6	9.0
25-30	1.5	10.5
30-35	1.4	11.9
35-40	1.4	13.3
40-45	1.3	14.6
45-50	1.3	15.9
50-55	1.2	17.1
55-60	1.2	18.3
60-65	1.1	19.4
65-70	1.1	20.5
70-75	1.1	21.6
75-80	1.1	22.7
80-85	1.1	23.8
85-90	1.1	24.9
90-95	1.1	26.0
95-100	1.1	27.1

*P_{10} fall times are 10/4 the fall times of the standard particle P_4, a smooth spherical particle 100 microns in diameter with a density of 2.5 g/cm^3.

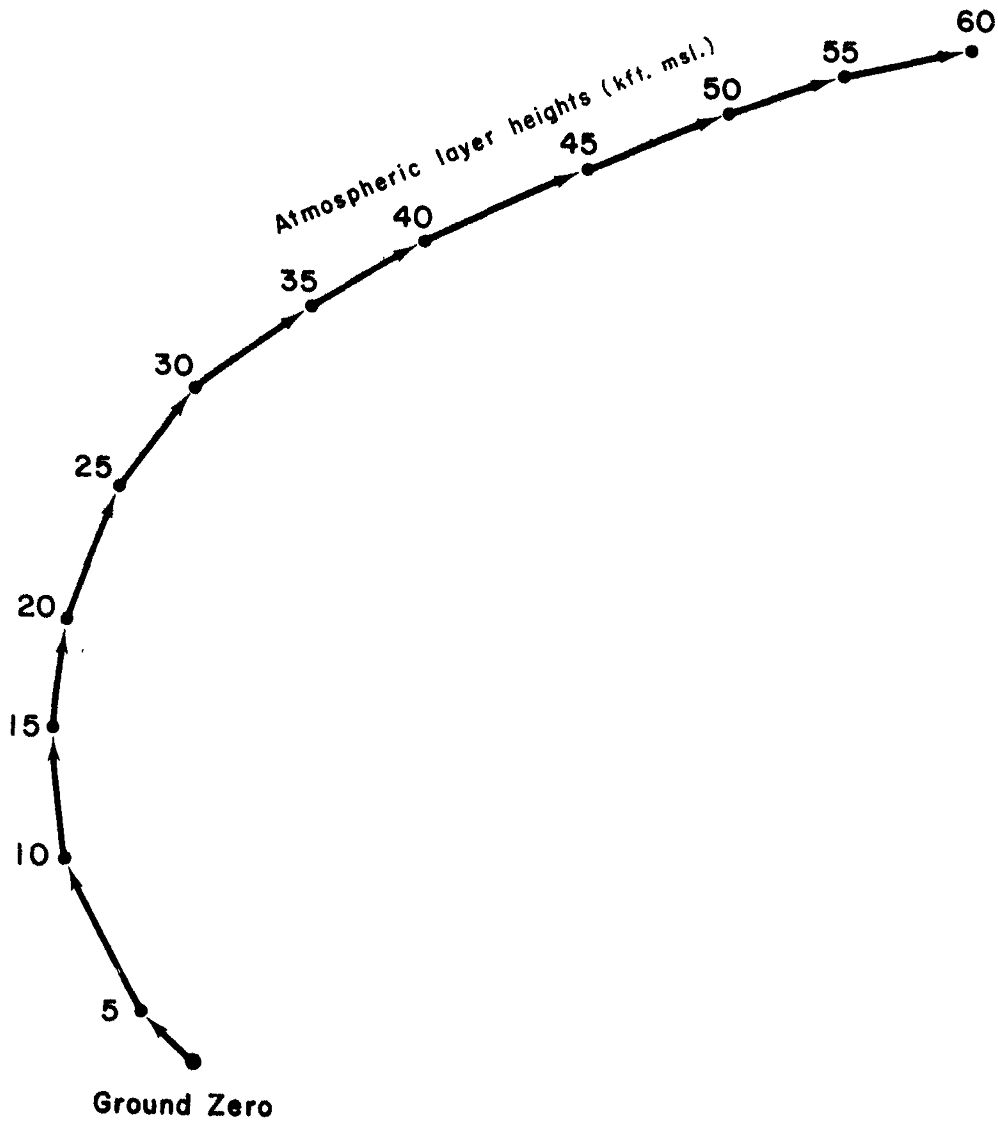


Figure 1. Fallout hodograph (drawn, in practice, for the P_{10} particle).

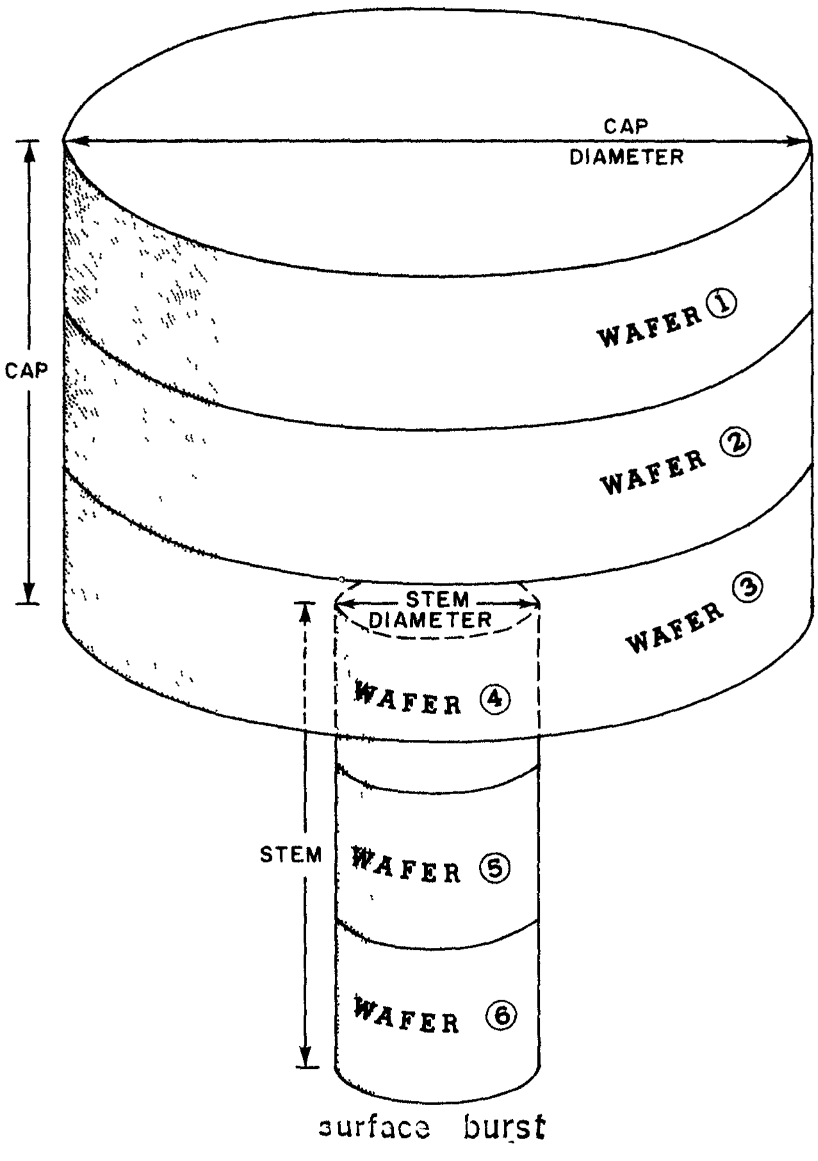


Figure 2. Six wafers of equal thickness comprising a typical mushroom-shaped stabilized nuclear cloud.

2.3 The Fallout Grid

The fallout grid is a diagram that aids in calculating a fallout pattern by locating particle ground positions with respect to the P_{10} particle positions as given by the P_{10} hodograph. It consists of radial lines drawn from GZ through points on the P_{10} hodograph that represent the nuclear cloud wafer heights. Six sectors are thus formed - each sector associated with one of the six cloud wafers. Figure 3 shows an example of a grid where the six sectors are associated with a nuclear cloud 60,000 ft high (surface burst) divided into three cap and three stem wafers, each 10,000 ft thick. Points selected along a sector radial, or any other radial, represent the ground positions of all particles that originated at the indicated or interpolated height. On any radial, the P_{10} particle falls at the intersection with the P_{10} hodograph; particles with shorter fall times than P_{10} fall between GZ and the P_{10} position, while those with longer fall times fall beyond the P_{10} position.

Particle fall times through the atmosphere are assumed to be proportional. That is, a particle designated P_1 has fall-times 1/10 the P_{10} fall times, another designated P_2 has fall-times 2/10 the P_{10} fall times, etc. Therefore, the ground positions of P_1, P_2, P_3, etc., are determined for each sector in relation to the P_{10} particle by 10 equal intervals from GZ to the intersection with the P_{10} hodograph and similar intervals extending beyond the hodograph. The fallout grid in figure 3 shows the ground positions of particles P_1 through P_{15} in sector (2). Figure 3 also includes circles around GZ associated with cap and stem wafer diameters.

2.4 Effective Fallout Areas

Particles are grouped into discrete size ranges, r, where r = 0.5 includes particles P_0 to P_1, r = 1.5 includes particles P_1 to P_2, etc., as shown in figure 4. Consider an area on the

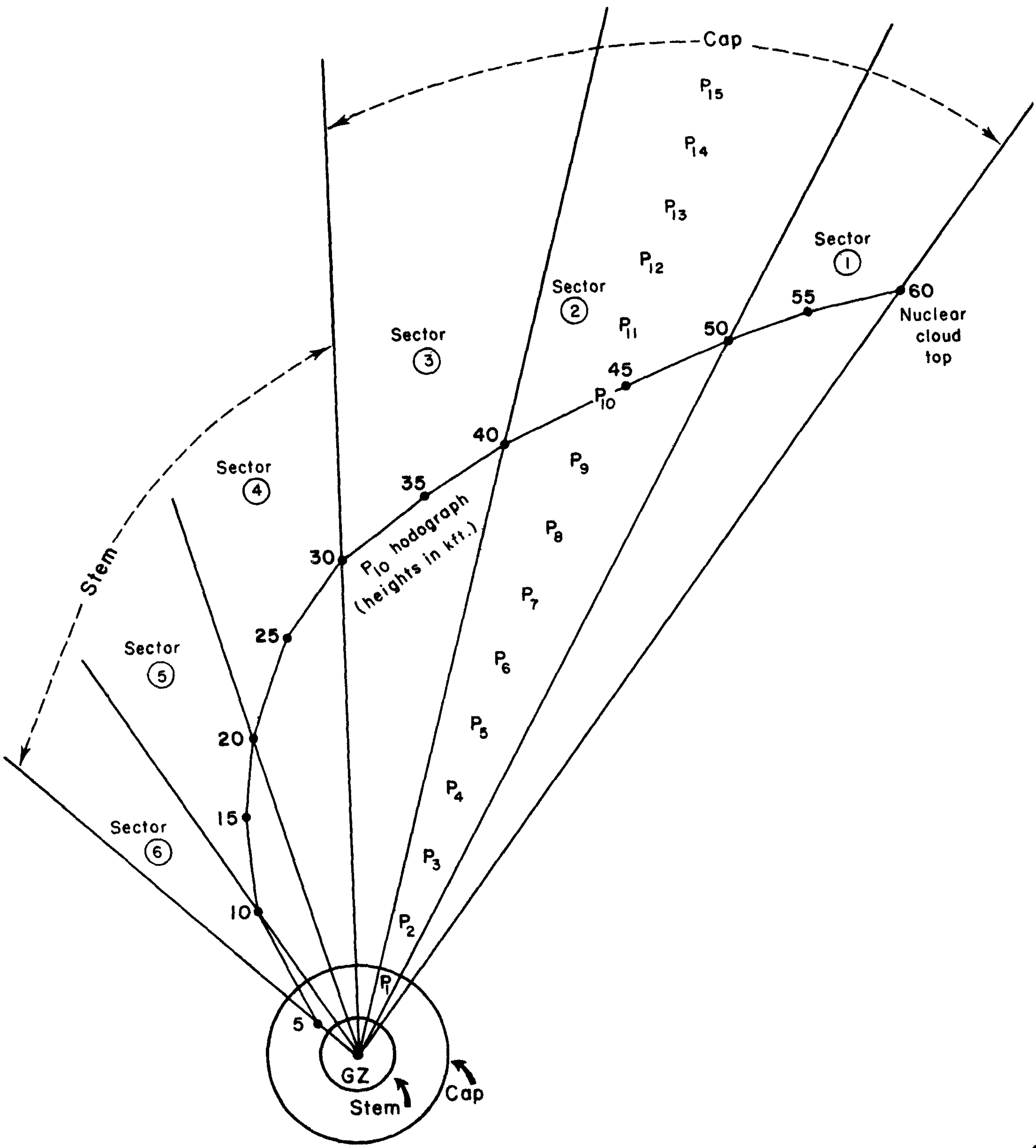


Figure 3. Fallout grid (where the ground positions of particle P_1 through P_{15} are shown in sector ②).

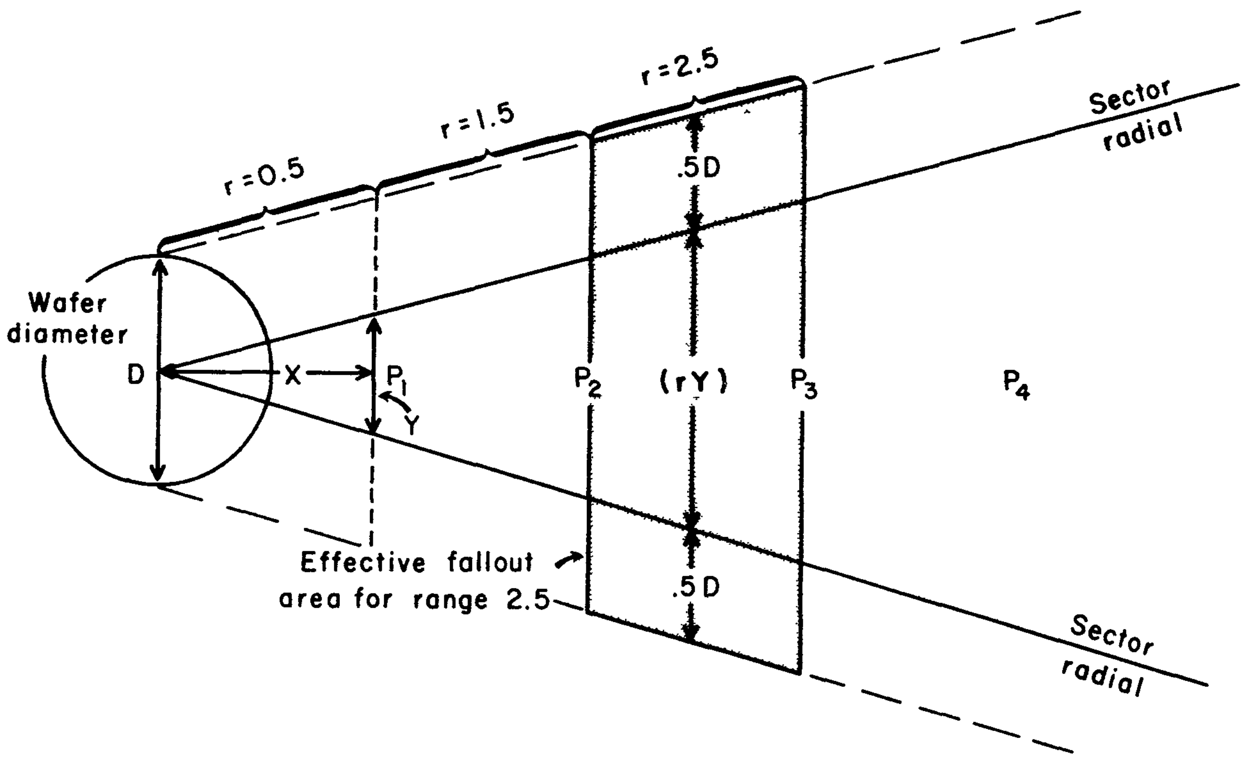


Figure 4. An example of an effective fallout area including a depiction of particle ranges r and the parameters X and Y necessary for calculating the area dimensions.

fallout grid between two consecutive particle positions and between two sector radials plus half a wafer diameter, D, on either side. That area represents the effective ground fallout area for particle range r in a nuclear cloud wafer, with wafer dimensions taken into account. (The area is called "effective" since the true area would include extensions of wafer dimensions between particle ranges. These extensions can be shown to have compensating effects, and thus need not be considered in the area computation.) The shaded area in figure 4 is an example of the effective fallout area for particle range r = 2.5.

Only two parameters from the fallout grid are needed to determine all effective fallout areas in a sector (see fig. 4): X - the radial distance from GZ to P_1 (or the distance between any two consecutive particle positions, since they are equidistant) and Y - the spread between sector radials at P_1.

From the geometry in figure 4, the spread between sector radials at the middle of any range r is equal to rY. The effective fallout area for any range r is, therefore, X(rY+D).

2.5 Determination of Average Exposure

The activity associated with a particle range r in a wafer has been determined from fallout patterns of past nuclear events (based on field exposure-rate readings) and has been normalized to deposition in a unit area. Therefore, activity on the ground can be predicted by dividing the normalized activity by the effective fallout area. Ground activity is calculated in terms of "infinite exposure"* expressed in roentgens (R). The average ground infinite exposure, $\overline{E}_r$ (in roentgens), for range r associated with a cloud wafer, if one assumes that all particles are uniformly distributed throughout the wafer, is given by

$$\overline{E}_r = \frac{M\ W_e\ M_r\ 5t_r^{-0.2}}{X\ (rY + D)} \qquad (1)$$

*The total exposure measured 3 ft above the ground from the onset of fallout to infinite time, on the assumption of no protective shielding.

M = total activity deposited in the fallout pattern per effective yield, measured in units of (R/hr) (n mi^2)/KT 1 hour after detonation (H+1).

W_e = effective yield (KT) - fission yield plus induced activation yield expressed in terms of an equivalent fission yield.

M_r = fraction of M attributed to range r in a wafer. In the ARL technique, M_r is determined from a cloud activity distribution (CAD) that gives activity as a function of particle range and height in the nuclear cloud. (Table 2 gives the air burst CAD and surface burst CAD currently in use.)

$5t_r^{-0.2}$ = conversion factor from exposure rate at H+1 to infinite exposure, where t_r is the particle arrival time (hrs) at the ground for range r. An activity decay of $t_r^{-1.2}$ is assumed. (See corrections for other decays in app. A.)

$X(rY+D)$ = effective fallout area for range r (n mi^2).

The distribution of $\overline{E}_r$ across a sector at the middle of range r is shown by the dashed lines in figure 5 for the conditions $rY/D \leq 1$ (spread between sector radials less than or equal to the wafer diameter) and $rY/D > 1$ (spread greater than the wafer diameter).

2.6 Determination of Peaked Exposure

Because average distributions often appear unrealistic when compared with distributions observed in actual fallout patterns, an attempt is made to predict more realistic peaked distributions. These distributions are shown by the solid lines in figure 5. The areas under the solid and dashed distributions are conserved, giving the following values for the peaked exposure $\hat{E}_r$ at the middle of range r:

Table 2. Cloud Activity Distribution (CAD) for an Air Burst and Surface Burst

M_r values for an air burst (air burst CAD)

	Wafer	P_0–P_1	P_1–P_2	P_2–P_3	P_3–P_4	P_4–P_5	P_5–P_6	P_6–P_7	P_7–P_8	P_8–P_9	P_9–P_{10}
Cap*	①	.0000	.0130	.0260	.0340	.0430	.0430	.0430	.0430	.0430	.0430
	②	.0000	.0130	.0260	.0340	.0430	.0430	.0430	.0430	.0430	.0430
	③	.0000	.0130	.0260	.0340	.0430	.0430	.0430	.0430	.0430	.0430

*Upper third of the stabilized nuclear cloud. $\sum M_r = 1.0$

M_r values for a surface burst (surface burst CAD)

	Wafer	P_0–P_1	P_1–P_2	P_2–P_3	P_3–P_4	P_4–P_5	P_5–P_6	P_6–P_7	P_7–P_8	P_8–P_9	P_9–P_{10}	P_{10}–P_{11}	P_{11}–P_{12}	P_{12}–P_{13}	P_{13}–P_{14}	P_{14}–P_{15}
Cap**	①	.0910	.0460	.0200	.0100	.0063	.0053	.0053	.0052	.0044	.0034	.0027	.0021	.0016	.0013	.0010
	②	.1360	.0680	.0240	.0140	.0066	.0053	.0053	.0052	.0044	.0034	.0027	.0021	.0016	.0013	.0010
	③	.1360	.0680	.0240	.0140	.0066	.0053	.0053	.0052	.0044	.0034	.0027	.0021	.0016	.0013	.0010
Stem	④	.0680	.0280	.0110	.0061	.0037	.0032	.0032	.0031	.0026	.0020	.0016	.0012	.0010	.0008	.0006
	⑤	.0230	.0120	.0058	.0036	.0024	.0023	.0023	.0023	.0020	.0016	.0012	.0010	.0007	.0006	.0005
	⑥	.0110	.0059	.0032	.0023	.0018	.0018	.0018	.0018	.0015	.0012	.0009	.0007	.0006	.0005	.0004

** Upper half of the stabilized nuclear cloud $\sum M_r = 1.0$

The air burst CAD is based primarily on measurements of ground activity vs. time of arrival for Teapot-Wasp (1 KT air burst in Nevada) and Plumbbob-Hood (74 KT balloon burst in Nevada). The total activity in the measured fallout patterns, and hence the individual M_r values, was determined for particles P_0 through P_{10}. It is assumed that no appreciable activity exists in the cloud stem and that all three cap wafers contain identical activities.

The surface burst CAD is based primarily on measurements of ground activity vs. time of arrival as well as measurements of relative particle activity for Sunbeam-Small Boy (1.6 KT near surface burst in Nevada). The total activity in the measured fallout patterns, and hence the individual M_r values, was determined for particles P_0 through P_{15}. It is assumed that the ratio of the total activities in each cloud wafer is about 2/3/3/1.5/.5/.25 from the top to the bottom of the cloud.

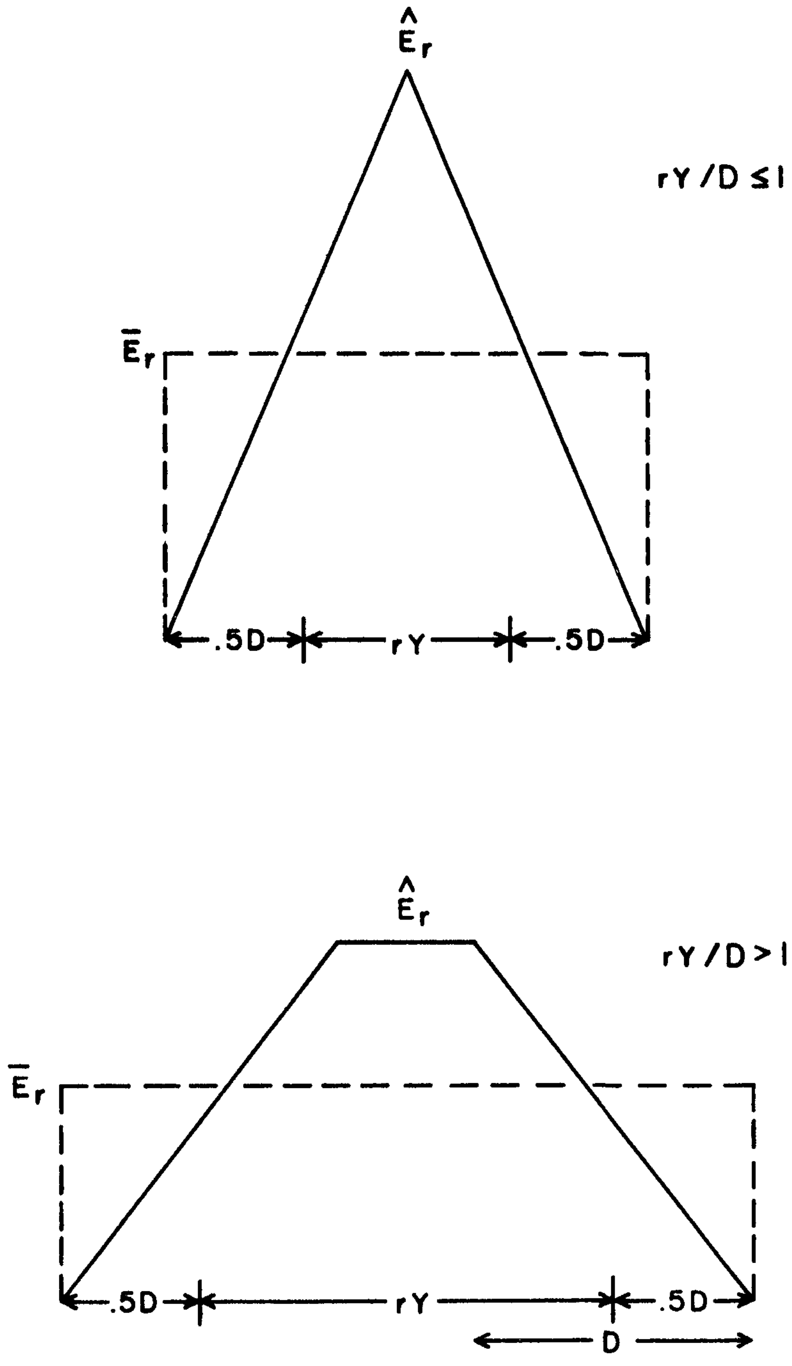


Figure 5. Average ($\bar{E}_r$) and peaked ($\hat{E}_r$) exposure distributions (across a sector).

$$\hat{E}_r = 2\,\bar{E}_r \qquad \text{for } rY/D \leq 1\ , \qquad (2)$$

$$\hat{E}_r = \frac{(rY/D)+1}{rY/D}\,\bar{E}_r \qquad \text{for } rY/D > 1\ .$$

Combining (1) and (2) gives

$$\hat{E}_r = (5t_r^{-0.2}\ M_r\rho_r)\ \ (M\ W_e/DX)\ , \qquad (3)$$

where $$\rho_r = \frac{2}{(rY/D)+1} \qquad \text{for } rY/D \leq 1\ ,$$

$$\rho_r = \frac{1}{rY/D} \qquad \text{for } rY/D > 1\ .$$

The quantity $(5t_r^{-0.2}\ M_r\ \rho_r)$ in (3) can be precalculated (for a given CAD) as a function of range r for discrete values of Y/D. Therefore, multiplication by the constant $(M\ W_e/DX)$ for a sector gives a simple and quick operational method for obtaining all the $\hat{E}_r$ values in that sector.

Some of the $\hat{E}_r$ values, however, must be adjusted because of overlapping ground activity distributions between adjacent sectors, as shown in the fallout pattern cross section in figure 6. (Adjacent sectors are those with consecutive number designators, e.g., sectors ③ and ④.) Adjustments, made by using precalculated adjustment coefficients, are limited to the portion of the fallout grid from GZ to the point where the spread across two adjacent sectors equals 2D (details given in app. B).

The $\hat{E}_r$ values (or adjusted values) are plotted on the grid in each sector. Lines of constant exposure can then be drawn based on a distance of 0.5D from the outer radials as a limiting boundary of the fallout pattern (see fig.7).

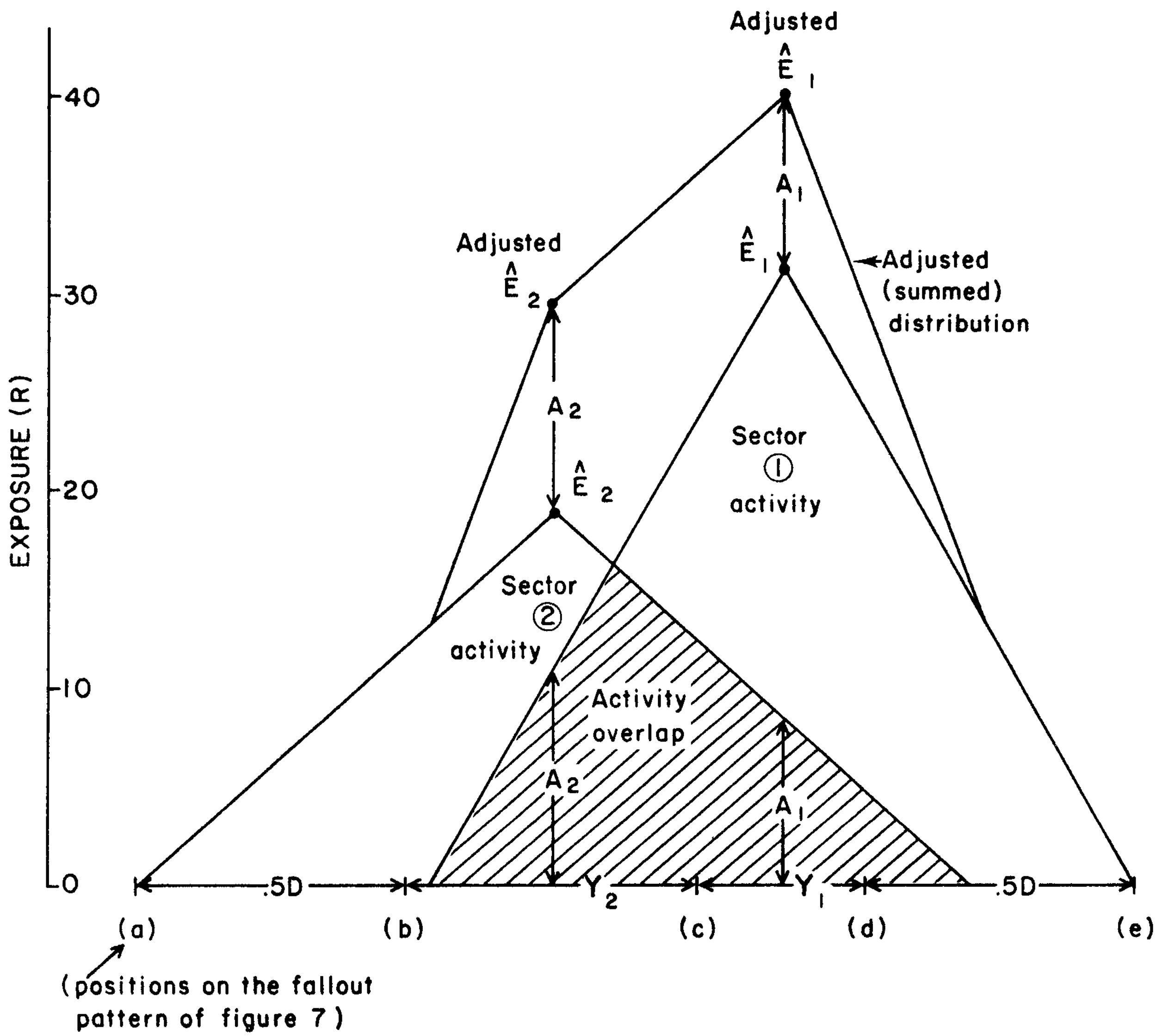


Figure 6. Fallout pattern cross section showing the concept of adjustments to adjacent peaked exposures $\hat{E}_r$ in sector (1) and $\hat{E}_2$ in sector (2) due to overlapping ground activity distributions between adjacent sectors (see app. B for details).

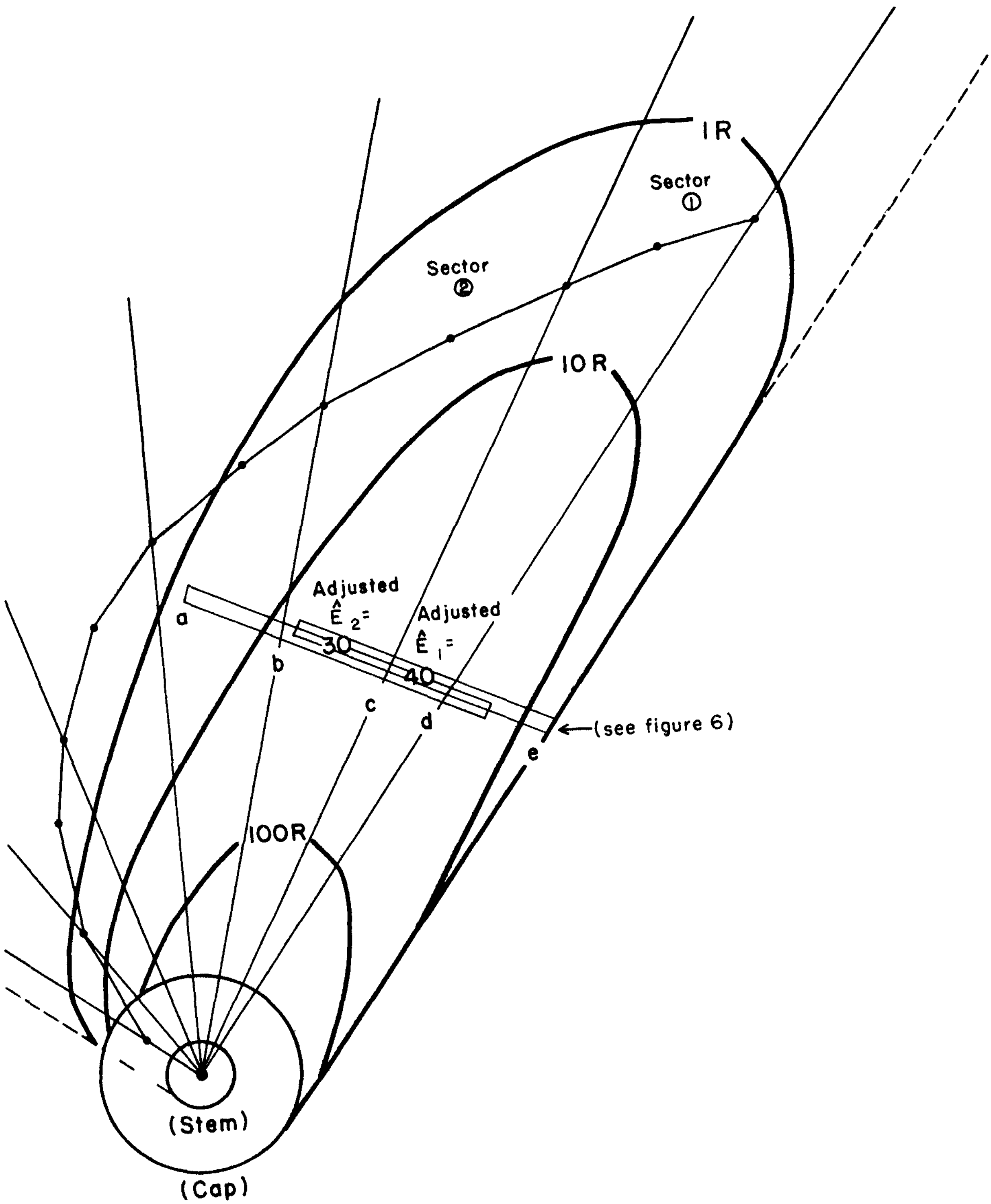


Figure 7. Fallout pattern (including values taken from the cross section of fig. 6).

3. DETAILED PROCEDURE

The following steps outline the procedure for obtaining a predicted fallout pattern. The working charts referred to in these steps and examples of the individual steps are presented after section 4. An accuracy of two significant figures in the computations is generally sufficient.

(1) Complete chart 1 making use of the given burst information and charts 2,3, and 4.

(2) Construct a P_{10} hodograph as follows:

a. Enter the wind direction and speed on chart 5, (using the latest report closest to GZ) ~~and~~ starting at the lowest reporting level and ending at the level immediately above the top of the nuclear cloud (see chart 1).

b. Estimate, by eye, the average wind directions and speeds in the 5 kft layers (10 kft layers above 60 kft) and enter them on the chart. It is preferable to obtain these average winds directly from the wind sounding computations, thereby eliminating step a. and the estimation required in this step.

c. Multiply the average wind speeds by the time-in-layer of the P_{10} particle and enter the results in the displacement column. (For a surface GZ above sea level, the fractional time in the lowest layer should be estimated.)

d. Plot, in sequential order, the displacement vectors, and corresponding atmospheric layer heights, head to tail on a hodograph sheet, starting in the center at GZ with the vector representing the lowest (surface to 5 kft) atmospheric layer.

(3) Construct a fallout grid as follows:

a. Draw radial lines from GZ through heights on the P_{10} hodograph that represent the nuclear cloud wafer heights. The cloud is divided into six wafers with three wafers of equal thickness in the cap (upper half of the cloud for a surface burst or upper third of the cloud for an air burst) and three wafers of equal thickness in the stem (lower half of the cloud for a surface burst or lower two-thirds of the cloud for an air burst). The wafers are numbered consecutively from the top to the bottom of the cloud. Six sectors are thus formed - each associated with one of the six cloud wafers. For a surface or near-surface burst (scaled height burst of burst <250 $ft/KT^{1/3}$ - see chart 1), all six sectors are considered. For an air burst (scaled height of burst ≥ 250 $ft/KT^{1/3}$ - see chart 1) the cap sectors alone are considered, since it is assumed no significant activity exists in the cloud stem.

b. Draw circles of diameter D centered at GZ to represent the nuclear cloud cap and stem horizontal wafer dimensions (see chart 1).

c. Draw a light, dashed line parallel to each of the two outer cap radials and tangent to the cap circle drawn in step (3)b. Do the same using the outer stem radials and the stem circle (four, light, dashed lines are thus drawn). Darken and retain only the outer dashes.

(4) Complete the computations section of chart 6:

a. Enter M and W_e (see chart 1) on the top of the computations section and compute their product. (A decay correction factor from app. A can be applied here for decays other than $t_r^{-1.2}$.)

b. Enter D for each sector (see chart 1).

c. Determine (from the fallout grid) the radial distance at which the spread across two adjacent sectors equals 2D and enter that distance for successive adjacent sectors. The 2D spread across sectors ③ and ④ is equal to $D_{cap} + D_{stem}$. If the radial distance to the 2D spread extends beyond the hodograph sheet, determine the radial distance to the 1D spread and enter it with the notation 1D. If the radial distance to the 1D spread extends beyond the hodograph sheet, enter the infinity symbol, ∞ .

d. Determine (from the fallout grid) and enter the IOX and 10Y values for each sector where:

10X = radial distance to the P_{10} hodograph (measured along the bisector of a sector angle).

10Y = spread across the sector at radial distance 10X.

e. Make the remaining computations to determine values of M W_e/DX and Y/D for each sector. (For an explanation of the multiplication factors appearing in the stem section of chart 6, see footnote on the following page).

(5) Plot the following on the working grid of chart 6 using the same scale as the fallout grid:

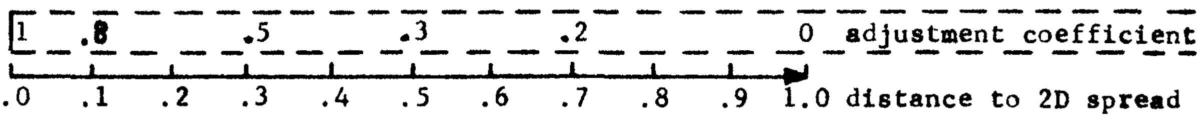
a. An asterisk (*) for each sector at the indicated 10X distance.

b. An adjustment coefficient zero (0) between sectors at the indicated distance to the 2D spread. When the 1D notation has been indicated in step (4)c., plot adjustment coefficient .3 at that distance; for an infinite distance plot adjustment coefficient one (1) at intervals along the entire scale.

c. **Small pluses** (+) representing particles P_1, P_2, P_3, etc., at 10 equal intervals from GZ to each 10X asterisk **(step a.) for an air burst, and 5** similar intervals beyond each 10X asterisk for a surface burst.

d. The adjustment coefficients 1, .8, .5, .3, and .2 at, respectively, the fractions 0, .1, .3, .5, and .7 the distance to each 2D spread (the zeros from step b.).

The following diagram can be used as a guide:



(An instrument that will divide a distance into equal intervals, such as a Gerber Variable Scale, is most helpful for steps c. and d.)

(6) a. Obtain infinite exposures in roentgens (R) for each sector. The following graphical multiplication procedure uses chart 7a for an air burst or chart 7b for a surface burst* ($5t_r^{-0.2}$ M_r ρ_r vs. particle P, for discrete values of Y/D) as an overlay to chart 8 (working base with a dual-purpose ordinate axis representing values of $M\ W_e/DX$ or infinite exposure vs. particle P):

*Chart 7b is based on a modified version of the surface burst CAD presented in table 2. An average M_r in each of the first five particle ranges in the cap giving approximate ratios of .60/.45/.35 between cap and upper to lower stem wafers, respectively, has been assumed for operational expediency.

Superimpose the ordinate value, 1, of chart 7 over the ordinate value of chart 8 corresponding to M W_e/DX (computed in chart 6) for the sector being considered. Read infinite exposures from the ordinate of chart 8 as a function of particle P using the Y/D curve or interpolated curve (computed in chart 6) for the sector being considered. It is suggested that, for speed and simplicity, only the indicated infinite exposure values on the ordinate of chart 8 be considered as a function of particle P. The darkened horizontal lines corresponding to each indicated value can be used as a guide.

b. Plot the infinite exposures at each P position, (or interpolated position if necessary) on the working grid of chart 6 for the sector being considered.

(7) Calculate adjustments (when adjustment coefficients are greater than zero) for plotted exposures in a given sector on the working grid of chart 6 as follows:

a. Adjustment from an adjacent sector.

1. Determine the exposure (an inter olated value if necessary) in an adjacent sec or at the same distance from GZ as the exposure being considered for adjustment.
2. Determine the adjustment coefficient (an interpolated value if necessary) between the sectors and at the same distance from GZ as the exposure being considered for adjustment.
3. Multiply the values determined in the two steps above and plot the product (adjustment) between sectors near the exposure being considered.

b. Adjustment from a next-to-adjacent sector if, and only if, the adjustment coefficient as determined in step a.2. is greater than .5.

1. Determine the exposure (an interpolated value if necessary) in a next-to-adjacent sector at the same distance from GZ as the exposure being considered for adjustment.
2. Determine the adjustment coefficient (an interpolated value if necessary) between the adjacent and next-to-adjacent sector and at the same distance from GZ as the exposure being considered for adjustment.
3. Multiply the values determined in the two steps above and plot the product (adjustment) near the exposure being considered.

Note: Exposures in a given sector may require adjustment from an adjacent or next-to-adjacent sector on both sides.

(8) Transfer each exposure or adjusted exposure (sum of the exposure and all adjustments) from the working grid to the bisector of each appropriate sector on the fallout grid. (The use of a light-table simplifies this step.) Draw isoexposure contours using the dashed lines parallel to the outer radials (step (3)c.) as the limiting boundary of the fallout pattern.

Note: Since the technique was not designed for predictions in the immediate vicinity of GZ, exposures calculated and drawn within about two wafer radii of GZ may be in error.

(9) As an optional step, particle time of arrival at the ground can be superimposed on the fallout pattern as follows:

a. Plot the P_{10} time of arrival (last column of table 1) on the P_{10} hodograph at the radial intersections using the indicated, or interpolated, heights.

b. Draw time-of-arrival isolines assuming linear proportionality along each radial from GZ to the plotted value and beyond.

4. CONDENSED OPERATIONAL PROCEDURE

For someone familiar with the detailed procedure in the preceding section, the following condensed operational procedure should be helpful as a guide for quick computation:

(1) Complete chart 1.

(2) P_{10} hodograph (chart 5).

- a. Enter reported winds at levels. } Enter reported average winds.
- b. Estimate average winds. }
- c. Compute displacements.
- d. Plot displacement vectors and heights on hodograph sheet.

(3) Fallout grid (hodograph sheet).

- a. Draw sector radials using chart 1 - cloud height.
- b. Draw wafer circles over GZ, using chart 1.
- c. Draw dashed parallels tangent to wafer circles.

(4) Computations (chart 6).

- a. Compute (M) (W_e) using chart 1.
- b. Enter D using chart 1.
- c. Determine distance to 2D spread using fallout grid.
- d. Determine 10X and 10Y using fallout grid.
- e. Make remaining computations.

(5) Working grid (chart 6).

- a. Plot 10X asterisk (*).
- b. Plot adjustment coefficient zero (0) at 2D distance.
- c. Plot particle position pluses (+).

d. Plot all adjustment coefficients.

(6) *a*. Obtain infinite exposures using charts 7 and 8.

b. Plot infinite exposures on working grid.

(7) Calculate and plot adjustments on working grid from

a. Adjacent sectors.

b. Next-to-adjacent sectors.

(8) Transfer values to fallout grid and draw isolines.

Name of event ______________________

Item	Value	Source
Total yield	________ KT	given
W_e (effective yield = fission plus induced)	________ KT	given
Height of burst	________ ft	given
Scaled height of burst = $\frac{\text{Height of burst}}{(\text{Total yield})^{1/3}} = \frac{(\quad)}{(\quad)}$	________ $\frac{ft}{KT^{1/3}}$	
Cloud top height	________ kft	chart 2
Cloud cap diameter	________ n. mi	chart 3
Cloud stem diameter (1/3 cap diameter)	________ n. mi	
M (total activity deposited per effective yield)	________ $\frac{(R/hr)(n.\ mi)^2}{KT}$ at H+1	chart 4

Chart 1

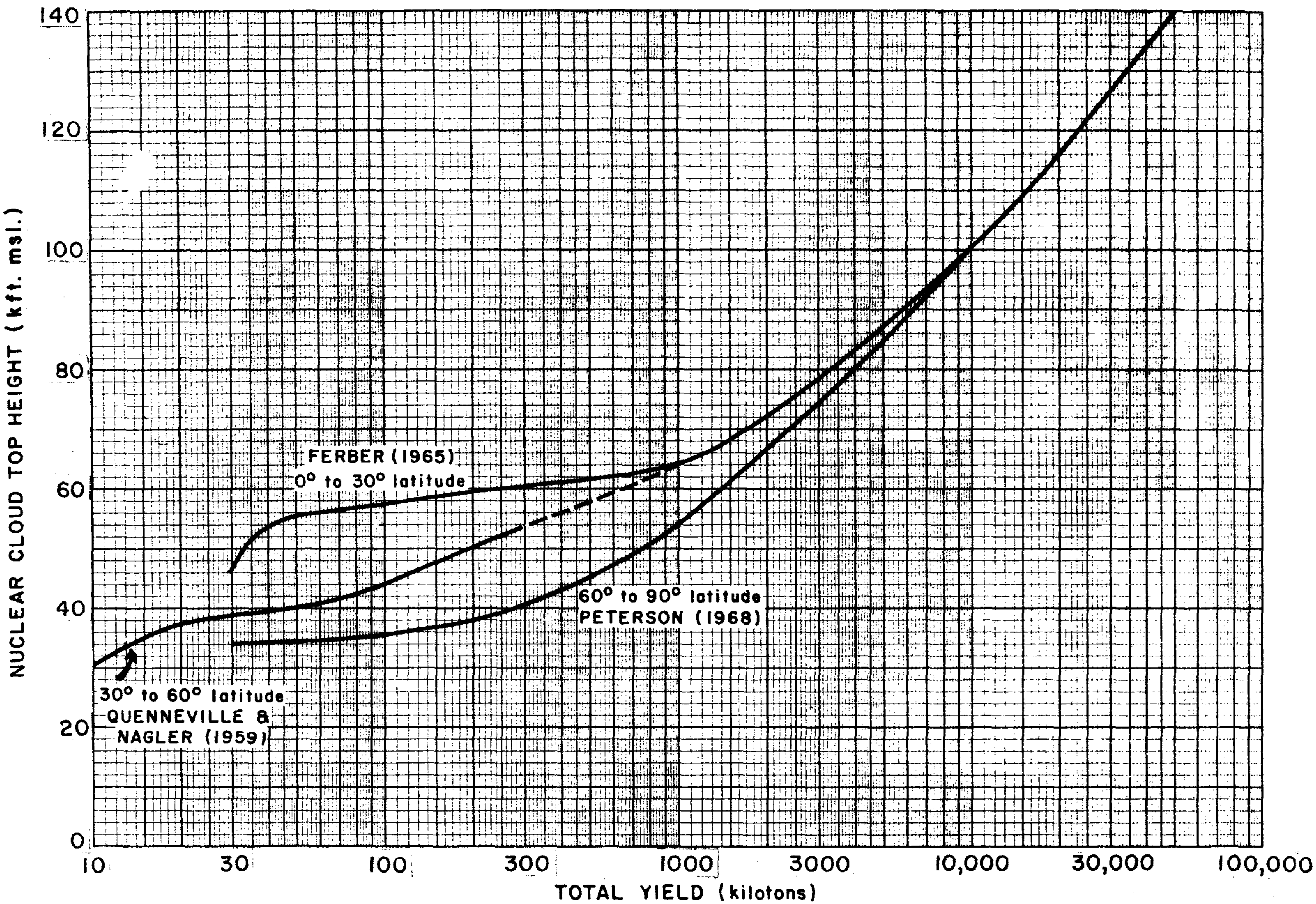


Chart 2. Nuclear cloud top height vs. total yield (for a height of burst less than 20% of the computed cloud top height).

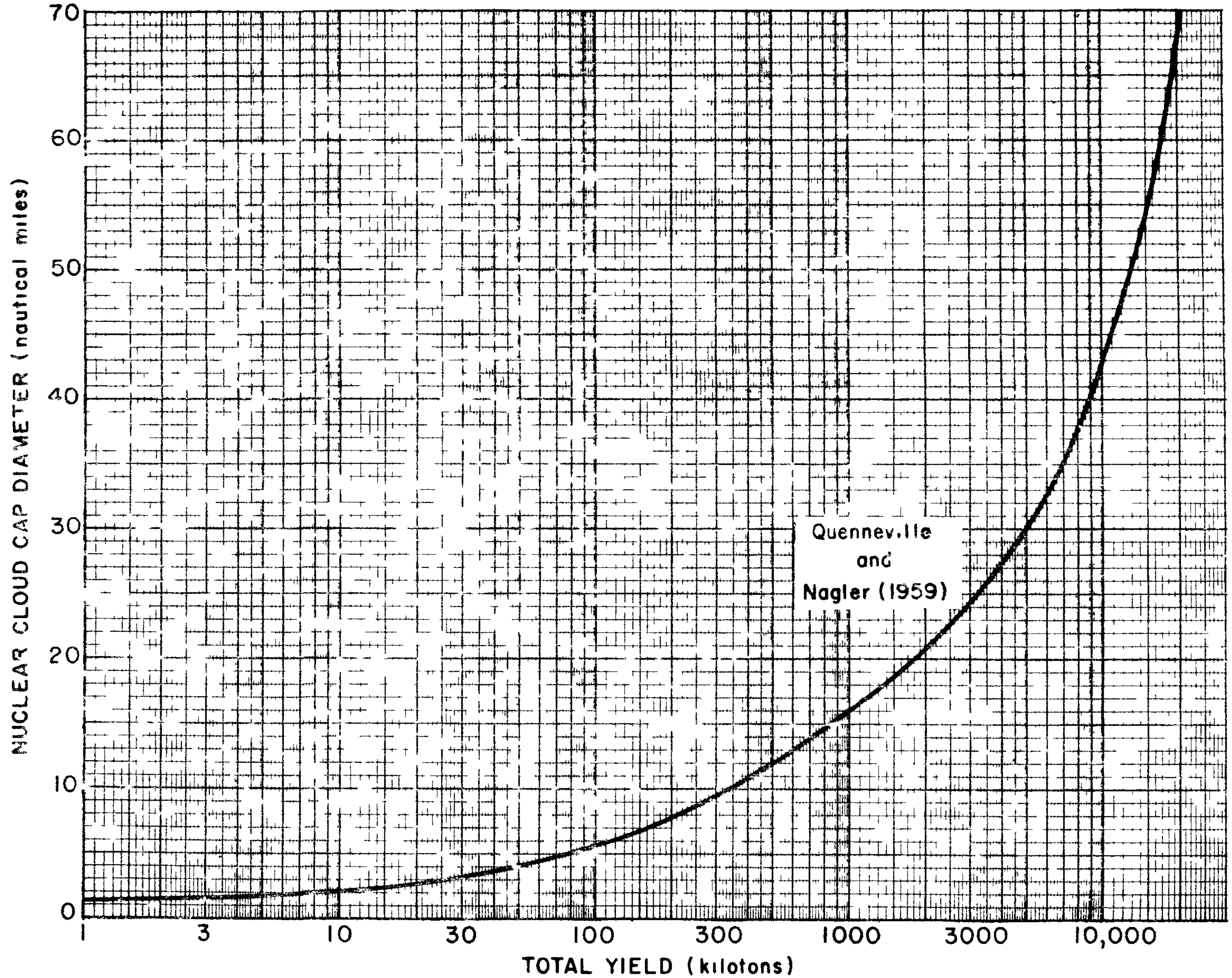


Chart 3. Nuclear cloud cap diameter vs. total yield.

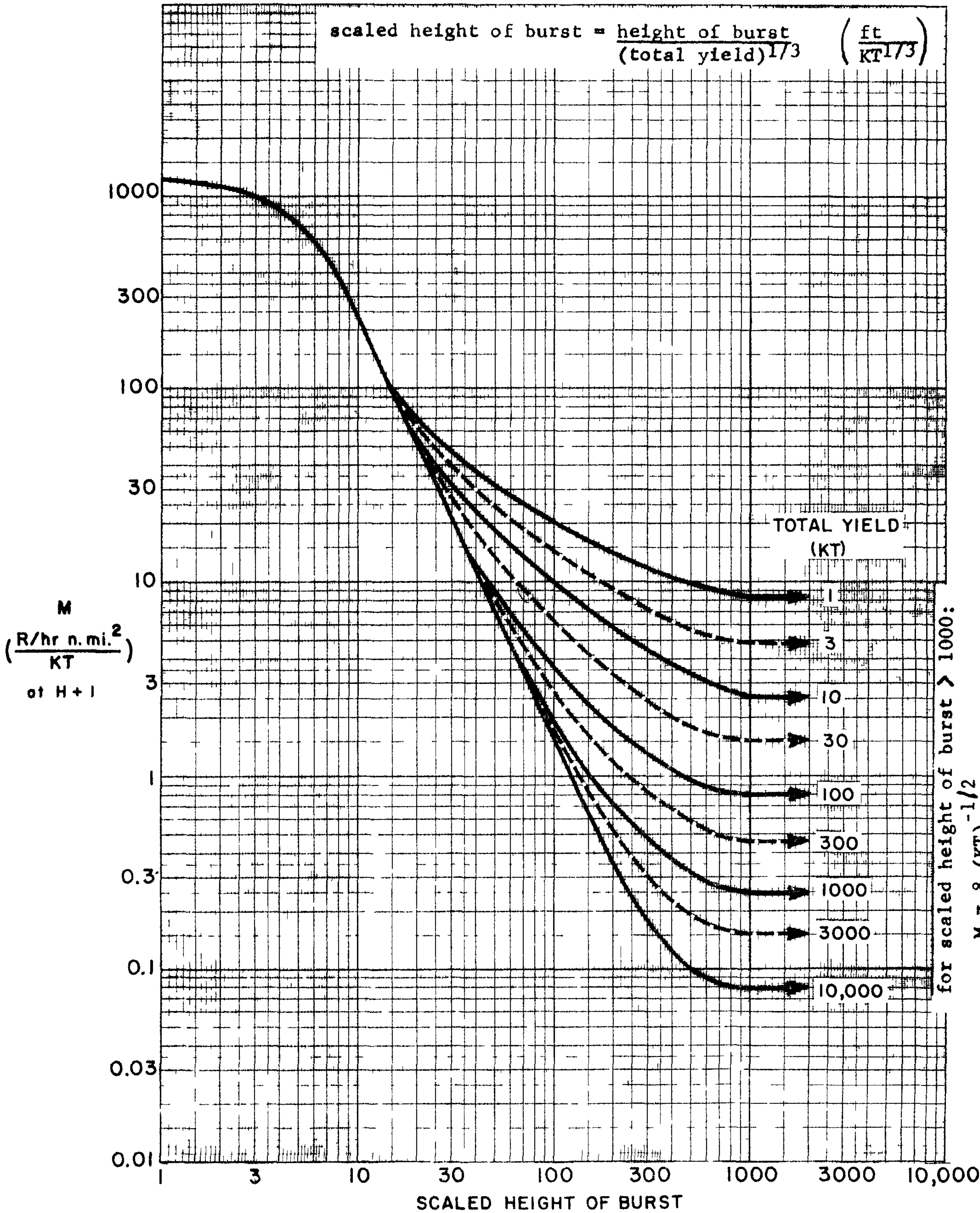


Chart 4. M (total activity deposited per effective yield) vs. scaled height of burst.

STATION ______________

DATE-TIME ______________

Reporting level (kft)	(mb)	WIND Direction (degs)	Speed (kts)
0	1000		
1			
2			
3			
4			
5	850		
6			
7			
8			
9	700		
10			
12			
14			
16			
18	500		
20			
23	400		
25			
30	300		
35	250		
40	200		
45	150		
50			
53	100		
60	70		
70	50		
80	30		
90	20		
100	10		

Height (kft)	AVERAGE WIND Direction (degs)	Speed (kts)	Time-in-layer (P_{10}) (hrs)	Displacement (nautical miles)	(kft)
0					0
			2.0		
5					5
			1.9		
10					10
			1.8		
15					15
			1.7		
20					20
			1.6		
25					25
			1.5		
30					30
			1.4		
35					35
			1.4		
40					40
			1.3		
45					45
			1.3		
50					50
			1.2		
55					55
			1.2		
60					60
			2.2		
70					70
			2.2		
80					80
			2.2		
90					90
			2.2		
100					100

Chart 5.

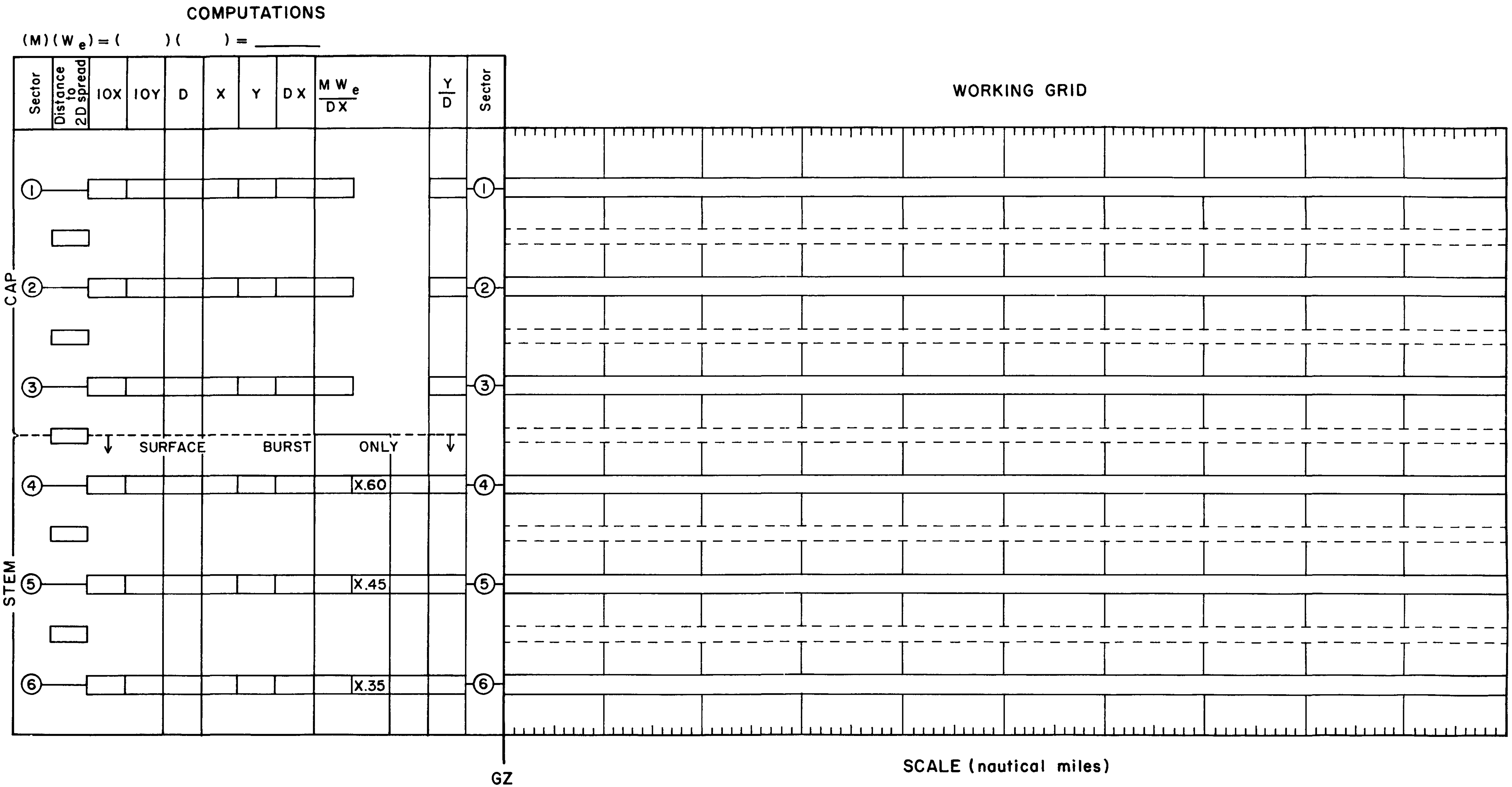

COMPUTATIONS
(M)(W e)=(   )(   ) = ______
Sector
Distance to 2D spread
10X
10Y
D
X
Y
DX
M We / DX
Y / D
Sector
WORKING GRID
CAP
STEM
SURFACE BURST ONLY
X.60
X.45
X.35
GZ
SCALE (nautical miles)

Chart 6.

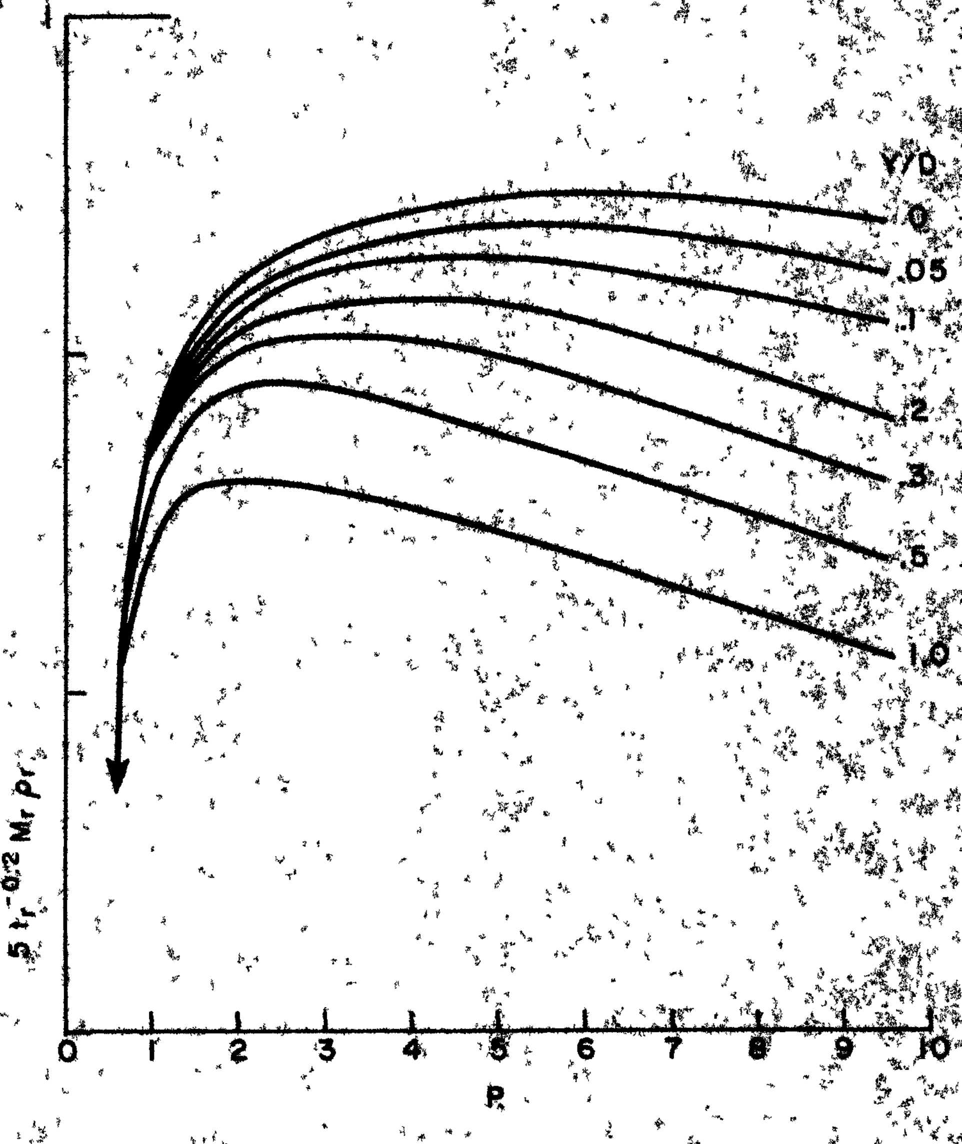


Chart 7a. $5t_r^{-0.2} M_r \rho_r$ vs. particle P for an air burst (based on the air burst CAD of table 2).

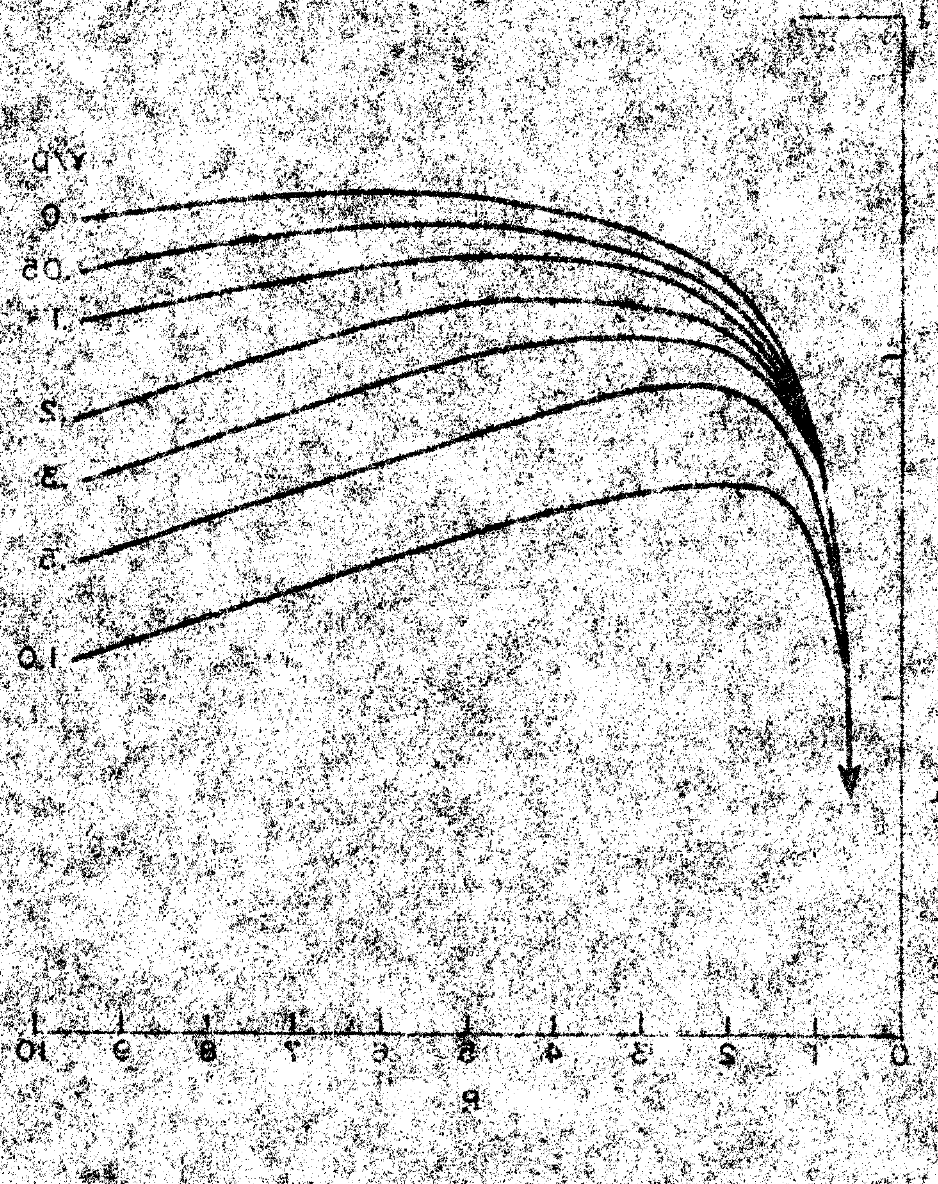


Chart 7a. $St^{-0.2}$ M d vs. particle P for an air burst (based on the air burst CAD of table 2).

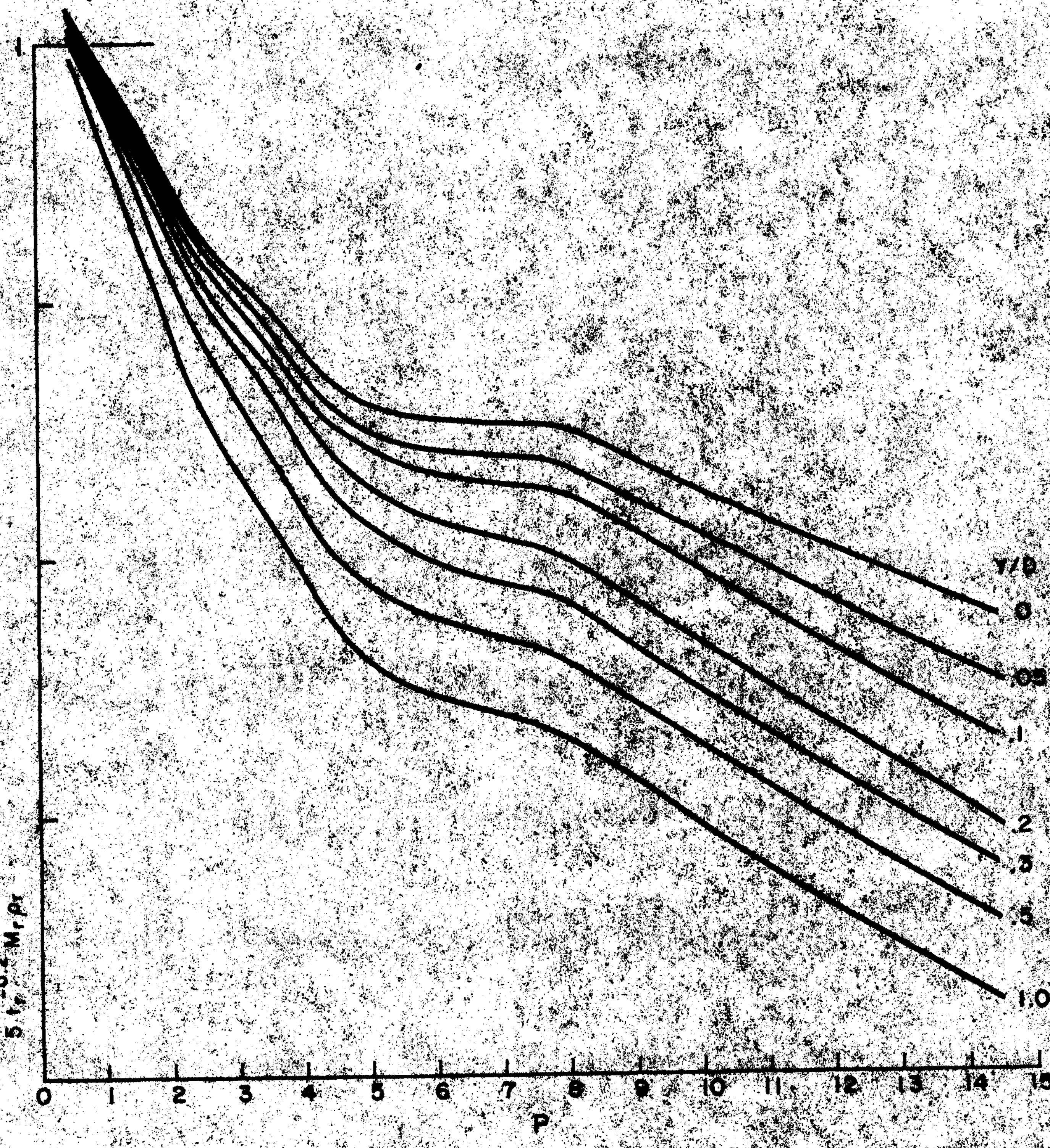


Chart 7b. $5t_r^{-0.2} M_r \rho_r$ vs. particle P for surface burst (based on a slightly modified version of the surface burst CAD of table 2).

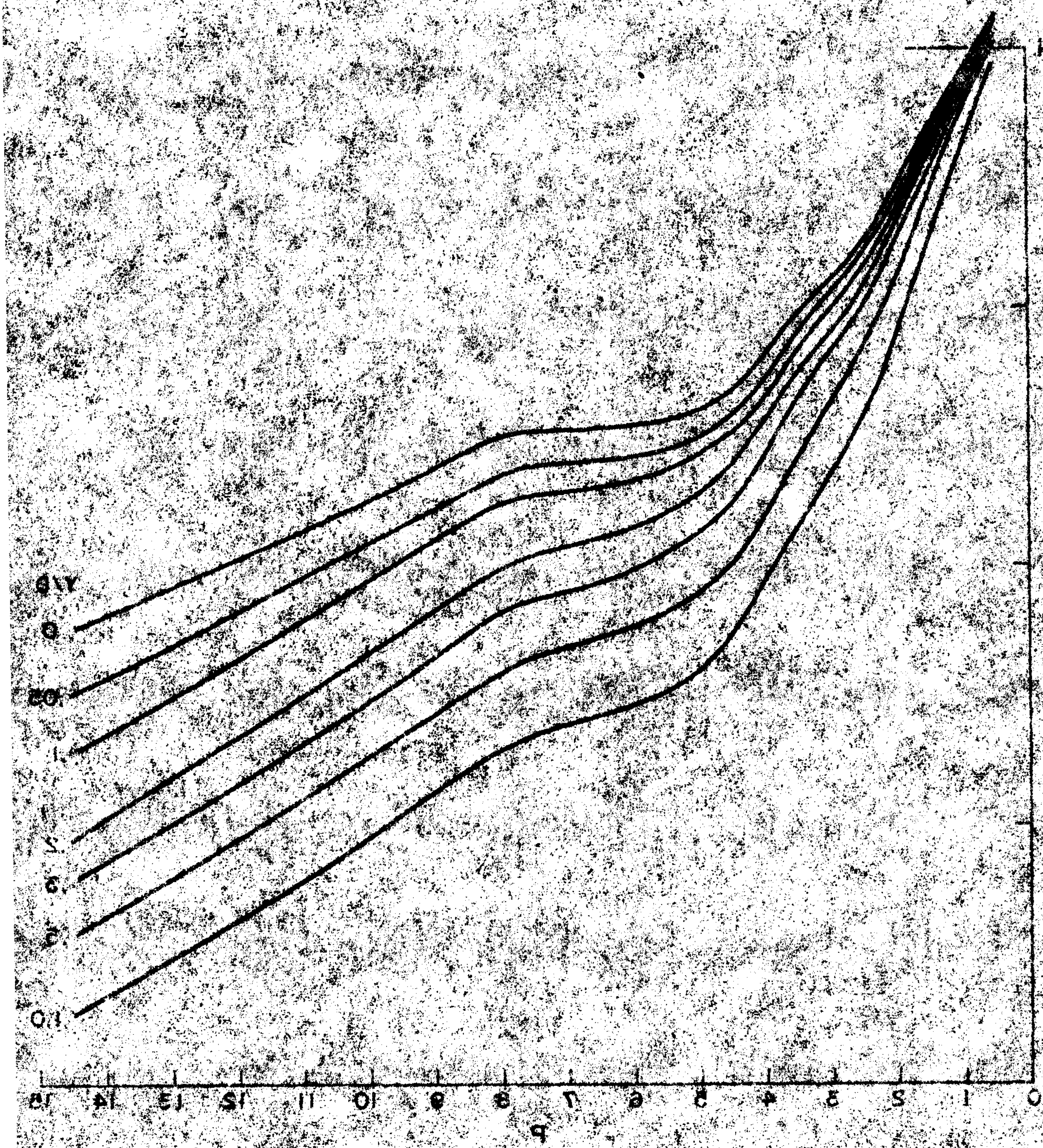


Chart 7b. Sr $t^{-0.2}$ K_f Q vs. particle p for surface burst (based on a slightly modified version of the surface burst CAD of table 2).

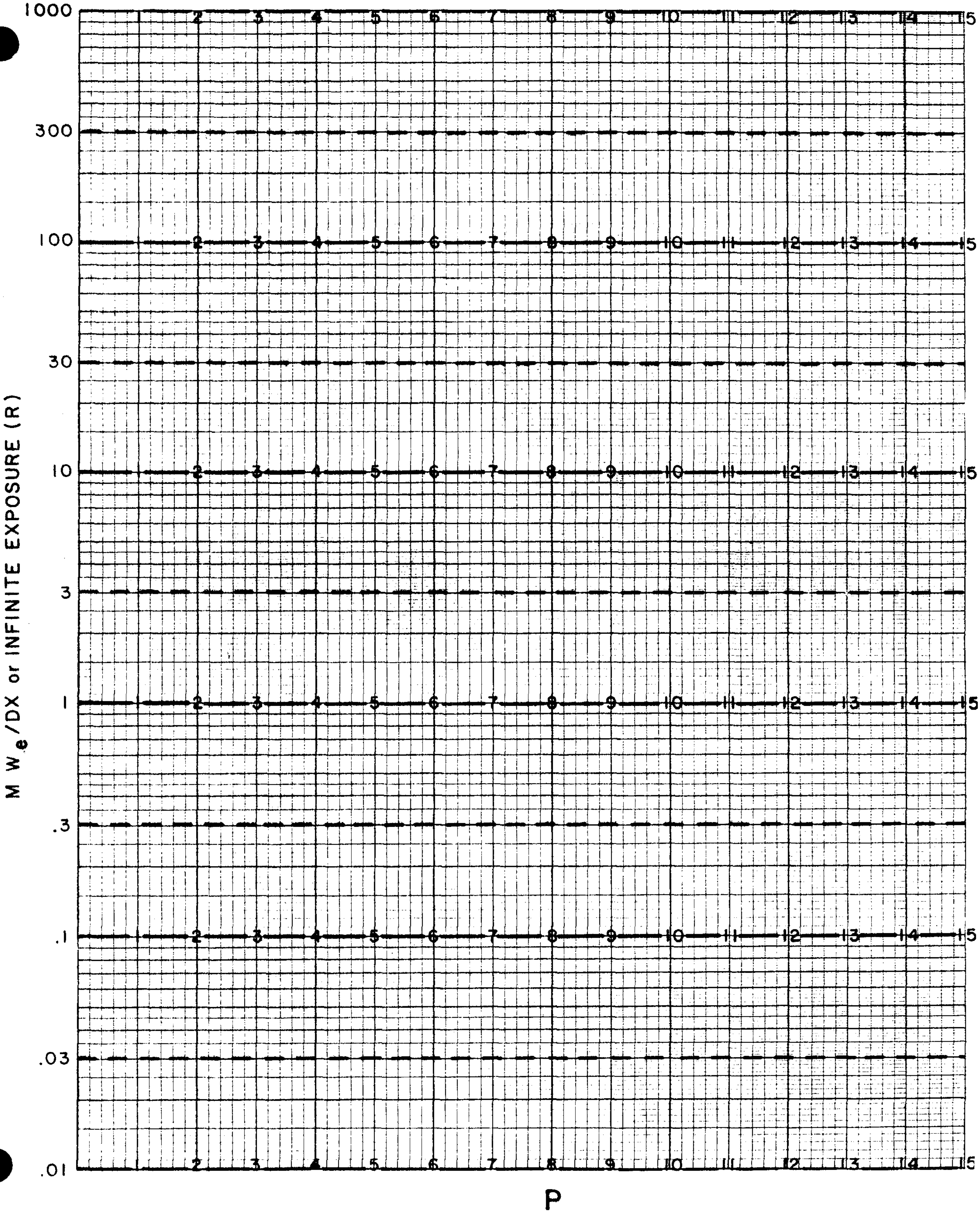


Chart 8. Working base (M W_e/DX or infinite exposure vs. particle P).

Name of event *Example*

Item	Value	Source
Total yield	100 KT	given
W_e (effective yield = fission plus induced)	50 KT	given
Height of burst	41 ft	given
Scaled height of burst = $\frac{\text{Height of burst}}{(\text{Total yield})^{1/3}} = \frac{(41)}{(4.6)}$	9 $\frac{\text{ft}}{\text{KT}^{1/3}}$	
Cloud top height	55* kft.	Chart 2
Cloud cap diameter	6 n. mi	Chart 3
Cloud stem diameter (1/3 cap diameter)	2 n. mi	
M (total activity deposited per effective yield)	300 $\frac{(\text{R/hr})(\text{n. mi})^2}{\text{KT}}$ at H+1	Chart 4

* 0° to 30° latitude, taken to the nearest 5 k ft in this example.

Step (1)

STATION *Example*

DATE-TIME ________

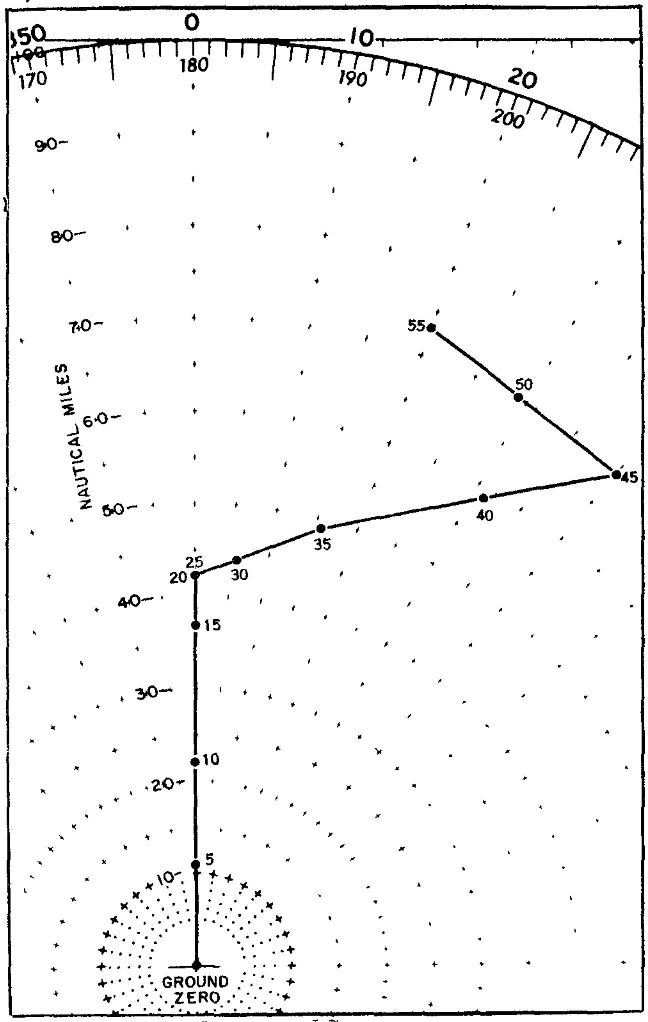
WIND

Reporting level (kft)	(mb)	Direction (degs)	Speed (kts)
0	1000	180	5
1		180	5
2		180	5
3		180	6
4		180	6
5	850	180	6
6		180	6
7		180	6
8		180	6
9	700	180	6
10		180	7
12		180	8
14		180	9
16		180	5
18	500	180	3
20		180	1
23	400	00	00
25		250	1
30	300	250	4
35	250	250	10
40	200	270	14
45	150	250	8
44		130	10
50		130	10
53	100	130	10
60	70	130	10
70	50		
80	30		
90	20		
100	10		

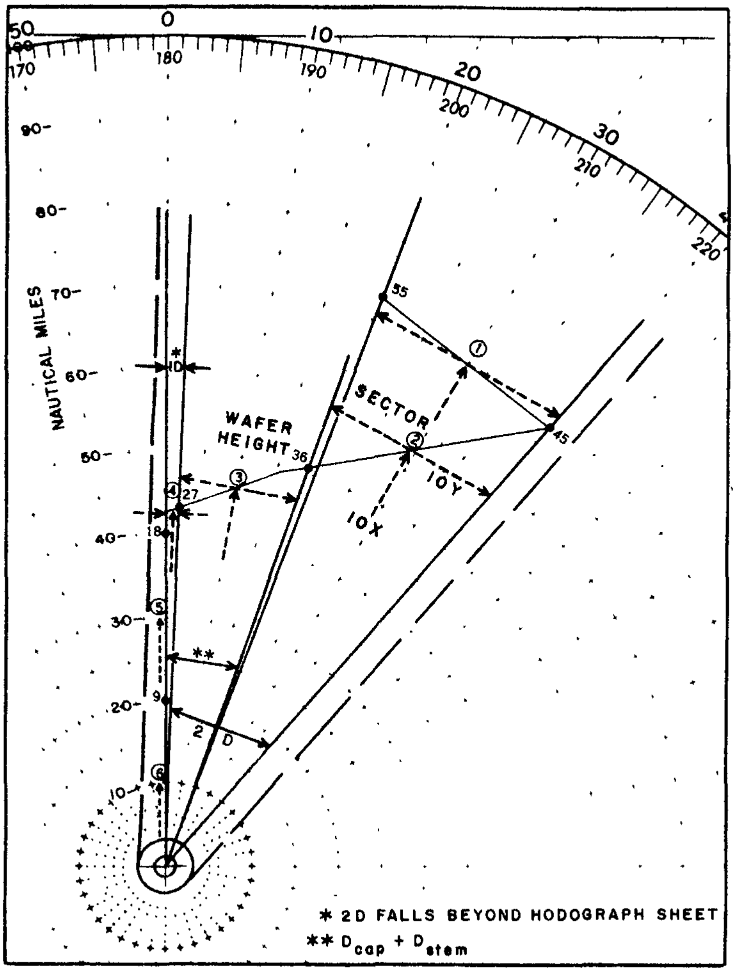
AVERAGE WIND

Height (kft)	Direction (degs)	Speed (kts)	Time-in-layer (P_{10}) (hrs)	Displacement (nautical miles)
0–5	180	5.5	20	11
5–10	180	6	1.9	11
10–15	180	8	18	14
15–20	180	3	1.7	5
20–25	00	00	16	0
25–30	250	25	15	4
30–35	250	7	14	10
35–40	260	12	14	17
40–45	260	11	13	14
45–50	130	10	13	13
50–55	130	10	12	12
55–60			12	
60–70			22	
70–80			22	
80–90			22	
90–100			22	

Step (2) a, b, c.



Step (2) d.



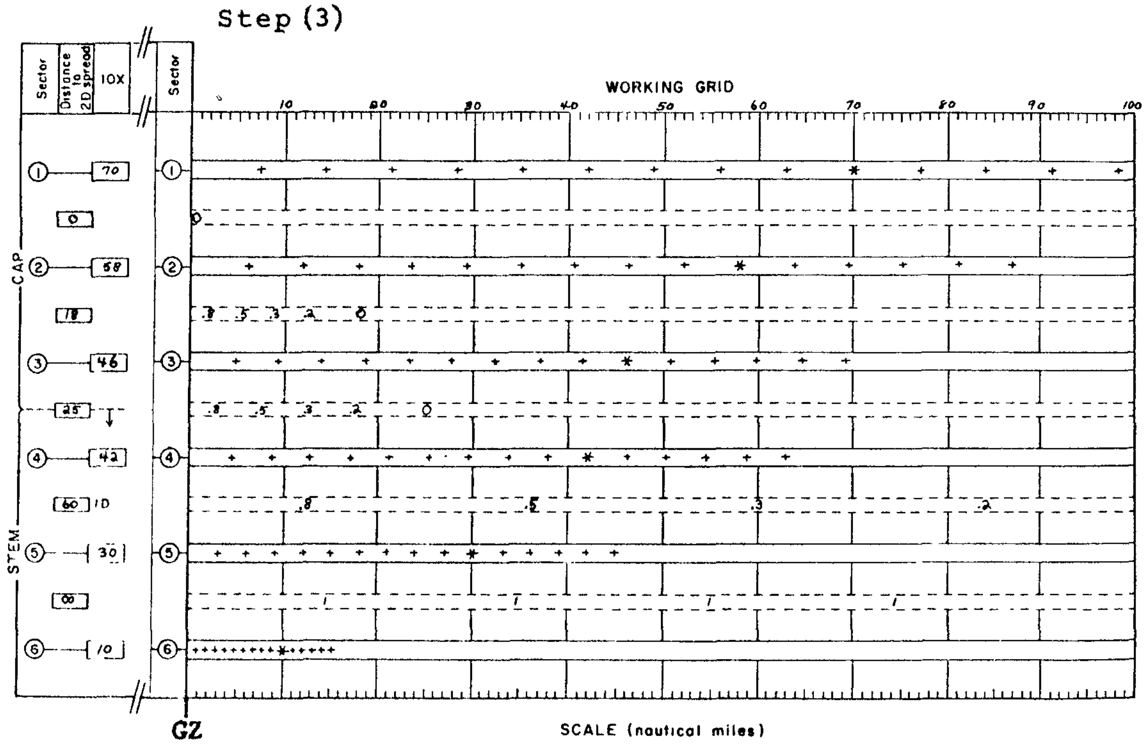
Step (3)

COMPUTATIONS

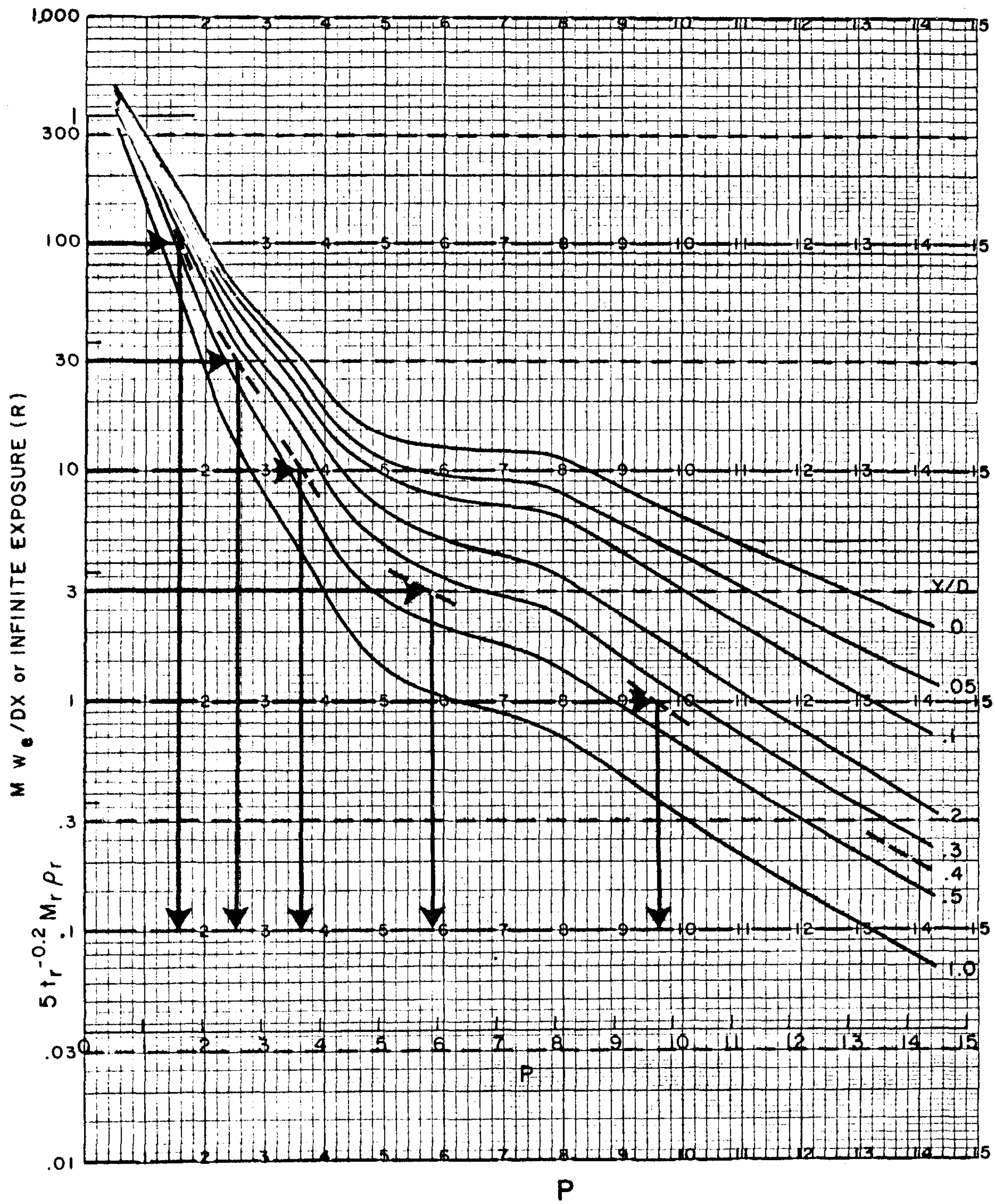
(M)(W_e) = (300)(50) = 15000

	Sector	Distance to 2D spread	10X	10Y	D	X	Y	DX	$\frac{M W_e}{DX}$			$\frac{Y}{D}$	Sector
CAP	1		70	25	6	7.0	2.5	42	360			.42	1
		0											
	2		58	22	6	5.8	2.2	35	430			.37	2
		18											
	3		46	14	6	4.6	1.4	28	540			.23	3
		25	SURFACE BURST ONLY										
STEM	4		42	1.5	2	4.2	.15	8.4	1800	X 60	1100	.075	4
		60 1D											
	5		30	0	2	3.0	0	6.0	2500	X 45	1100	0	5
		∞											
	6		10	0	2	1.0	0	2.0	1500	X 35	2600	0	6

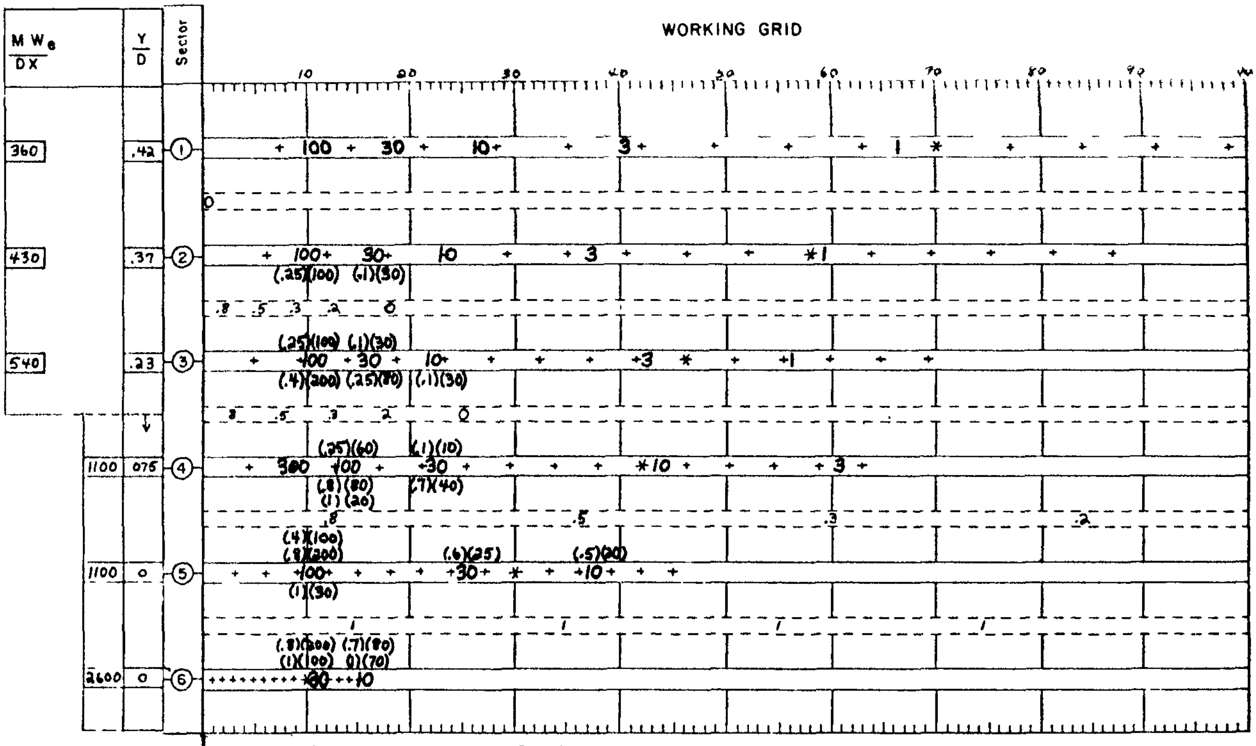
Step (4)



Step (5)

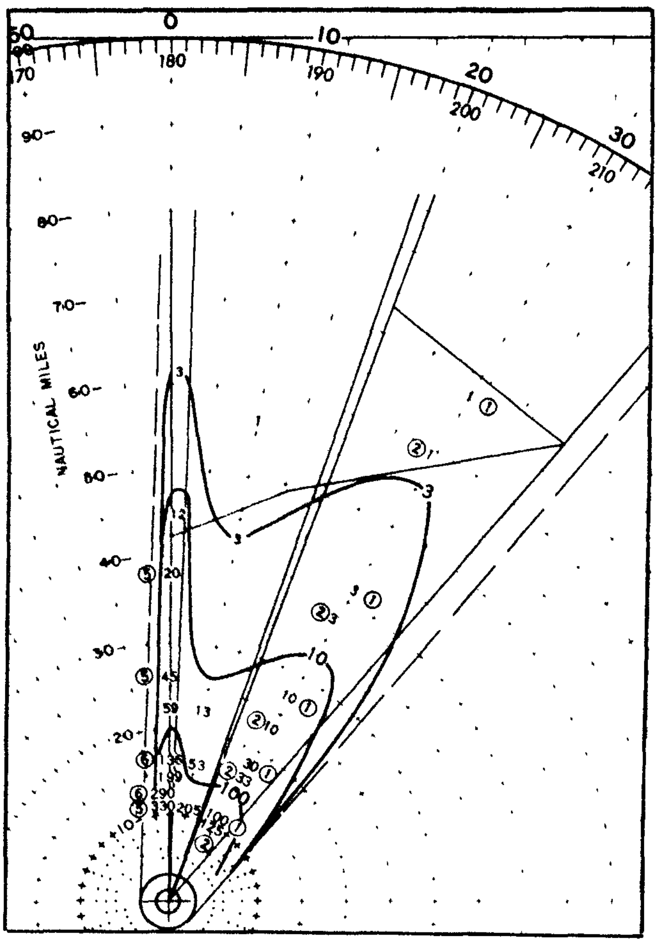


Step (6)a. For sector ①.



Step (6)b and (7).

For illustrative purposes only, both terms of each adjustment have been plotted.



Step(8)

Values in adjacent sectors ① and ② are added when drawing isoexposure contours since the sectors overlap because of the hodograph reversal in direction.

5. SIGNIFICANT LIMITATIONS

To view the significant limitations in the proper perspective, the following discussion is in terms of (1) limitations in the ARL technique that are common to most fallout prediction schemes and (2) those associated with the ARL technique in particular.

The ARL fallout prediction technique can be applied to most nuclear weapon yields in any wind situation. However, the specific CAD's presented in table 2 are based on relatively low yield weapons (less than 75 KT) detonated in Nevada and must be used with caution for higher yields or in other environments. Very little information exists on particle size activity distributions in nuclear clouds from large yield weapons.

The nuclear cloud top height (chart 2) and cap diameter (chart 3) curves are based on data with considerably variability. Values predicted from these curves may be in error by as much as ±25 percent. This, together with an uncertainty in estimating the mushroom cap thickness could lead to significant errors in the orientation of the cap and stem ground sectors. Therefore, caution should always be used when interpreting fallout pattern boundaries.

Caution should also be used in applying chart 4, M (total activity deposited per effective yield) vs. scaled height of burst. The curves on this chart were based on values computed from the best documented fallout patterns. The patterns were associated with eight near-surface, nine tethered balloons, and two air bursts in Nevada. The scatter of values was, however, quite large, especially for the two latter burst categories, which were predominantly in the scaled height of burst range from 100 to 1000. These categories were therefore grouped by total yield in order to reduce the data scatter. The remainder of the diagram (KT greater than 100 and scaled height of burst greater than 1000) is largely conjecture!

Clearly, additional data are needed to better predict this very critical parameter, M. Chart 4 should not be used for bursts that have appreciable additions of material near the nuclear device, such as tower material in the case of a tower burst.

Several limitations in the technique itself must also be borne in mind. To simplify the computations, the factor $5t_r^{-0.2}$ in determining chart 7 has been normalized to particle arrival times from 40 kft. This simplification introduces an error of less than 15 percent in exposures associated with particles falling from as low as 20 kft or as high as 100 kft. For surface and air bursts with total yields greater than 30 KT (nuclear cloud top heights greater than about 40 kft and, therefore, the greatest percentage of radioactivity in the cloud cap about 20 kft), the simplfication would have little effect on the predicted fallout pattern. However, for bursts with total yields less than 30 KT, where a great percentage of radioactivity in the nuclear cloud could be below 20 kft, the simplification could introduce a significant fallout pattern error. Therefore, it is recommended that the technique be used only for total yields greater than 30 KT, unless chart 7 is revised with the factor $5t_r^{-0.2}$ normalized to arrival times from a more appropriate lower level than 40 kft. If decays other than $t_r^{-1.2}$ are assumed in the calculations (the use of a decay correction factor given in app. A), the particle arrival time error in chart 7, for all particles falling from other than 40 kft, would be increased for decay exponents larger than 1.2.

The peaked distribution chosen, the operational modification of the surface burst CAD, and the overlapping between sectors may all combine to give erroneous results within about two cloud radii of GZ. Other methods should be used if predictions in the vicinity of GZ are required.

Finally, the use of a single wind sounding eliminates any wind variation in space and time. In practice, however, forecast winds can be used to curve computed patterns along the predicted wind flow.

6. REFERENCES

Ferber, G.J. (1965), "Distribution of radioactivity with height in nuclear clouds", Radioactive Fallout from Nuclear Weapons Tests, Alfred W. Klement, Jr., ed., 629 (Fallout Studies Branch, Division of Biology and Medicine, U.S. Atomic Energy Commission).

Fleshel, B., and C.J. Seery (1968), Computer programs for evaluating fallout associated with nuclear excavation, Final Rept. Contract E22-78-68(N) for ESSA, Ford Instrument, Long Island City, N.Y.

Nagler, K.M., L. Machta, and F. Pooler, Jr. (1955), A method of fallout prediction for tower bursts at the Nevada test site, U.S. Weather Bureau, Washington,D.C. (out of print), 23 pp.

Peterson, K. R. (1968), An empirical model for estimating world-wide deposition from atmospheric nuclear detonations, Air Resources Laboratory, ESSA, Silver Spring, Md. (unpublished).

Quenneville, L.R., and K.M. Nagler (1959), A note on nuclear cloud dimensions, U.S. Weather Bureau, Washington, D.C., 1 p. (Air Resources Laboratory, ESSA, R321, Silver Spring, Md. 20910).

APPENDIX A

If the induced activation yield contributes significantly to the effective yield, decays may differ from $t_r^{-1.2}$. (t_r is the particle arrival time at the ground for range r.) A decay correction factor for decays other than $t_r^{-1.2}$ may be applied to the exposure predictions (E_r) as follows:

$$E_r \propto \int_{t_r}^{\infty} t^{-n}\, dt$$

$$\propto t_r^{-n+1.0}/(n-1.0) \quad , \qquad (A-1)$$

[From (A-1) with N=1.2, $E_r \propto 5t_r^{-0.2}$ as given in (1).]

The ratio of an exposure with decay t_r^{-n} to that with the assumed decay $t_r^{-1.2}$ is given by

$$\frac{t_r^{-n+1.0}/(n-1.0)}{t_r^{-1.2+1.0}/(1.2-1.0)} = 0.2\ t_r^{1.2-n}/(n-1.0) \quad ,$$

from which the following table can be constructed:

n	Decay Correction Factor
1.1	2.6
(1.2)	(1.0)
1.3	0.5
1.4	0.3
1.5	0.2

A decay correction factor from the above table can thus be applied to the computations (see step (4)a. in sec. 3).

APPENDIX B

A method of obtaining approximate adjustment coefficients for peaked exposures due to overlapping activity distributions between sectors (see fig. 6) is as follows:

Given adjacent peaked exposures

$\hat{E}_1$ in sector ①

$\hat{E}_2$ in sector ②,

find

A_1 = Adjustment to $\hat{E}_1$ due to activity overlap from adjacent sector ②,

A_2 = Adjustment to $\hat{E}_2$ due to activity overlap from adjacent sector ①,

so that

$$\text{adjusted } \hat{E}_1 = \hat{E}_1 + A_1 = \hat{E}_1 + K_1 \hat{E}_2 ,$$

$$\text{adjusted } \hat{E}_2 = \hat{E}_2 + A_2 = \hat{E}_2 + K_2 \hat{E}_1 ,$$

where K_1 and K_2 are defined as adjustment coefficients.

From the geometry in figure 6 it can be shown that

$$K_1 = \frac{D - Y_2}{D + Y_1} \text{ and } K_2 = \frac{D - Y_1}{D + Y_2} . \qquad \text{(B-1)}$$

For operational simplicity, the following assumption is made only in calculating the activity overlap:

$$Y_1 = Y_2 = \frac{Y_1 + Y_2}{2} ,$$

which implies, from (B-1), that the adjustment coefficient

$$K_1 = K_2 = \frac{2D - (Y_1 + Y_2)}{2D + (Y_1 + Y_2)} . \qquad \text{(B-2)}$$

Therefore,

$Y_1 + Y_2$, (Spread Across Two Adjacent Sectors)	Fraction of the Radial Distance From GZ to 2D Spread	Adjustment Coefficient K_1 and K_2 From ~~(2D)~~ $(\beta-\alpha)$
2.0D	1.0	.0
1.4D	0.7	.2
1.0D	0.5	.3
0.6D	0.3	.5
0.2D	0.1	.8
0.0D	0.0	1.0