MASTER

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WORKBOOK IN ATMOSPHERIC
DIFFUSION CALCULATIONS

G. A. De Marrais

United States Weather Bureau
February 1959
Idaho Operations Office
Idaho Falls, Idaho

NATIONAL REACTOR TESTING STATION

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ABSTRACT

This workbook was prepared in response to numerous inquiries about the practical applications of the material in Meteorology and Atomic Energy. Although designed primarily for use at the National Reactor Testing Station, the application of the material is not restricted to that location. The most frequently used equations and nomograms are demonstrated.

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UNITED STATES DEPARTMENT OF COMMERCE
Weather Bureau Office
Idaho Falls, Idaho

ERRATA - WORKBOOK IN ATMOSPHERIC DIFFUSION CALCULATIONS

<u>Page</u>	<u>Line</u>	<u>Should Read:</u>
1	23	"TID = total integrated dosage (instantaneous only: grams-seconds per cubic meter, curies-seconds per cubic meter, etc.)"
2	5	"TID(max) = total integrated dosage at d(max dosage) (grams-seconds per cubic meter, curies-seconds per cubic meter, etc.)"
3	16	". . . is a certain percentage of the concentration in the plume center (meters)."
7	5	". . . fair approximation in the plume.*" Footnote at bottom of page. "* It should be pointed out that due to reduced diffusion in the vertical great distances can be travelled before the plume touches the ground under fanning conditions."
8	12	". . . for this case.*" Footnote at bottom of page. "*Modifications of Sutton's basic formulae for fumigating conditions have been made, but little quantitative information is available."
8	19	". . . Table II and Figure 2 . . ."
25	2	". . . continuous point source equation in form (equation #1) . . ."
25	13	". . . 4.07×10^{-2} gm-sec/m ³ ."
26	4	". . . 2.80×10^{-1} gm-sec/m ³ ."
26	13	". . . 8.16×10^{-1} gm-sec/m ³ ."
27	4	". . . 62.9 gm-sec/m ³ ."
27	11	Replace the words "Since most reactors at NRTS are not operated when precipitation is falling," by the words "Since the normal annual precipitation at the NRTS is only 7.5 inches, . . ."
58	8	". . . 11 a) TID = 3.939×10^{-1} gm-sec/m ³ ."
58	9	". . . b) TID(max) = 6.506×10^{-1} gm-sec/m ³ ."
58	11	". . . 12 a) TID = 10.09 gm-sec/m ³ ."
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WORKBOOK IN ATMOSPHERIC
DIFFUSION CALCULATIONS

I. INTRODUCTION

Numerous inquiries about the practical application of the material in Meteorology And Atomic Energy indicated that there was a need for a workbook based on the pertinent information in the text. With this in mind, the U. S. Weather Bureau Office at Idaho Falls, under the auspices of the Atomic Energy Commission, has prepared this manual. The most frequently used equations are worked out in detail and the uses of the most applicable nomograms are demonstrated.

II. NOMENCLATURE

One of the most important requirements for a person computing diffusion is that he understand the nomenclature and know the units in which quantities should be stated. In all the following equations and on the nomograms, except for the Bryant-Davidson equation, the metric system is used. The nomenclature and units employed are as follows:

χ = (pronounced kye) concentration (grams per cubic meter, curies per cubic meter, etc.)

Q = source strength (instantaneous: grams, curies, etc.)

Q $\dot{Q}$ emission rate (continuous point source: grams per second, curies per second, etc.)

Q = emission rate (continuous line source: grams per second, per meter, etc.)

TID = total integrated dosage (instantaneous only: grams per cubic meter, curies per cubic meter, etc.)

$\chi_{(\max)}$ = concentration at $d_{(\max)}$ (grams per cubic meter, curies per cubic meter, etc.)

$d_{(\max)}$ = distance, downwind from the source, of the maximum concentration (meters).

$TID_{(\max)}$ = total integrated dosage at $d_{(\max \text{ dosage})}$ (grams per cubic meter, curies per cubic meter, etc.)

$d_{(\max \text{ dosage})}$ = (same as $d_{(\max)}$) distance, downwind from the source, of the maximum total integrated dosage (meters).

C_x, C_y, C_z = diffusion coefficients in the x, y and z directions respectively $\text{[(meters)}^{n/2}\text{]}$

C = generalized diffusion coefficient for isotropic turbulence, i.e., $C = C_x = C_y = C_z$ $\text{[(meters)}^{n/2}\text{]}$

n = parameter associated with stability (nondimensional)

x, y, z = downwind, crosswind and vertical coordinates measured from a ground point beneath a continuous source and from the center of the moving cloud in the instantaneous source (meters).

t = time (seconds)

$\bar{u}$ = mean wind speed (meters per second)

h = effective height of source or, alternatively, height of plume (meters)

$(\bar{u}t)_0$ = distance upwind from a real source required to produce the required volume at the point (0, 0, 0) and $t = 0$ (meters)

$\chi(0)$ = central concentration (grams per cubic meter, etc.)

ω (dry-max) = (pronounced omega) maximum fallout deposition rate (grams per square meter per second) for a steady source (Q in grams per second) or maximum fallout deposition (grams per square meter) for an instantaneous source (Q in grams).

ω (rain-max) = maximum wash-out deposition rate (grams per square meter per second) for a steady source (Q in grams per second) or maximum wash-out deposition (grams per square meter) for an instantaneous source (Q in grams).

$a_m = C_z/C_y$ (nondimensional).

y_0 = crosswind distance from the center of the plume to where the concentration is a certain specific percentage (p) of the concentration in the plume center (meters).

z_0 = height to where concentration is a certain percentage of peak (meters).

p = percentage (nondimensional)

m = meter

mps = meters per second

mph = miles per hour

fps = feet per second

Δh = the rise of the effluent plume above the stack (feet)

d = stack diameter (feet)

v_s = stack draft velocity (feet per second)

ΔT = excess temperature of stack gas over ambient air temperature ($^{\circ}\text{C}$)

T_s = absolute temperature of the stack gas ($^{\circ}\text{A}$)

(t) = find a tangent to

f = reference number (nondimensional)

R = reference (nondimensional)

r^2 = radial distance squared (meters squared). This quantity is used on nomograms and is sometimes two-dimensional (equal to $x^2 \neq y^2$ or $y^2 \neq h^2$) and other times three-dimensional (equal to $x^2 \neq y^2 \neq h^2$); Table IV indicates the manner in which this quantity is to be used.

III. BEHAVIOR OF STACK EFFLUENTS

Since the meteorological fundamentals for air pollution studies are not pertinent to the data in this workbook and are adequately described in Meteorology And Atomic Energy, they will not be considered. However a review of the behavior of stack effluents is appropriate. The five principal types of behavior are shown in Figure 1.

Looping generally occurs with superadiabatic temperature lapse rates. The stack effluent, when visible, appears to loop because of thermal eddies in the wind flow. Gases diffuse rapidly, but sporadic puffs having strong concentrations are sometimes brought to the ground near the base of the stack for a few seconds during light winds. This is primarily a fair weather daytime condition since strong solar heating of the ground is required. Looping conditions are not favored by cloudiness, snow cover or strong winds. Long period

Fig.1 SCHEMATIC REPRESENTATION OF STACK GAS BEHAVIOR UNDER VARIOUS CONDITIONS OF VERTICAL STABILITY

(10 minutes or greater) concentrations would be obtained from the continuous point source formulae with the parameters chosen to fit existing stability conditions.

Coning occurs when the temperature gradient is between dry adiabatic and isothermal and may occur periodically (between thermals) with a superadiabatic lapse rate. The effluent forms a cone with the axis horizontal. The distance from the stack at which the effluent first comes to the ground is greater than with looping conditions because the thermal turbulence, and hence vertical motion, is less. It generally is favored by cloudy and windy conditions and may occur day or night. In dry climates, like at the National Reactor Testing Station (NRTS), it may occur infrequently, and in cloudy climates it may be the most frequent type observed. Much of the development of diffusion formulae has been for stability conditions similar to this type of lapse rate; hence the continuous point source formulae should be expected to give good results with effluent behavior of this type.

Fanning usually occurs with temperature inversions or near-isothermal lapse rates. The plume with its very smooth, almost laminar, flow is somewhat dependent on the wind speed and the roughness of the terrain. The effluent diffuses very little in the vertical and its trail may frequently resemble a meandering river, widening gradually in the horizontal with the distance from the stack. The concentration within the stream varies inversely as the wind speed, but the distance that it travels is directly proportional to wind speed, the variation in wind direction and the duration of this flow pattern. Fanning is

mostly a nighttime condition and is favored by light winds, clear skies and snow cover. The conditions can persist for several consecutive days in winter in some climates, particularly at high latitudes. Formulae applied to this type condition are considered fair approximations.

Lofting occurs with the transition from lapse to inversion and is thus observed most often near sunset. Depending on the height of the stack and the rate of deepening of the inversion layer, the lofting condition may be very transitory or may persist for several hours. At NRTS it has sometimes been found to persist through the night, although its usual duration is one to three hours. The zone of strong effluent concentration, shown by shading in Figure 1, is caused by trapping by the inversion of effluent carried into the stable layer by turbulent eddies that penetrate the layer for short distances. Except when the inversion is very shallow, the lofting condition may be considered as the most favorable diffusion situation. The inversion prevents the effluent from reaching the ground, and simultaneously the effluent may be rapidly diluted in the lapse layer above the inversion. Since the lapse rate associated with lofting will prevent the effluent (except gamma radiation which could reach the ground from a cloud several hundred feet above the surface) from reaching the ground, diffusion computations would be meaningless.

Fumigation takes place at the time when the nocturnal inversion is being dissipated by heat from the morning sun. The lapse layer generally begins at the ground and works its way upward, less rapidly in winter than in summer. At some time the inversion is still present

just above the top of the stack and it acts as a lid, while convective eddies mix the effluent plume within the shallow lapse layer near the ground. This condition may also develop in sea breeze circulations. Large concentrations are brought to the ground along the entire effluent stream (which may be long due to the previous presence of fanning conditions) by thermal eddies in the lapse layer. The zone of high concentration shown by shading in Figure 1 is that portion of the plume that has not yet been mixed downward. Sutton's basic formulae are not suitable for diffusion computations during fumigation periods and since reactors are seldom operated at such times no attempt will be made to determine downwind concentrations for this case.

A tabulated summary of the pertinent variables connected with each plume is shown in Table I.

Another frequently used classification system for diffusion conditions is the wind direction trace type classification of Brookhaven National Laboratory. Since numerous inquiries are made concerning the features of this system and how it compares with the plume shape classification, Table II and Figure 3 are included. It should be noted that these classifications were determined with a vane exposed at a height of 355 feet (108 meters) over a terrain which is relatively rough.

IV. DETERMINING n AND THE COEFFICIENTS OF DIFFUSION

Exact determination of a number of the quantities employed in diffusion equations would require a rather extensive meteorological network. However, inasmuch as the equations give solutions which are

TABLE I

VARIABLES ASSOCIATED WITH PLUME TYPES

TYPE	PREVALENT LAPSE RATE	LARGE DOWNWIND GROUND CONCENTRATION	FAVORABLE WEATHER CONDITIONS	UNFAVORABLE WEATHER CONDITIONS	MOST FREQUENT OCCURENCE
Looping	superadiabatic	close to release point	clear skies and light winds	cloudy, windy snow cover	daylight hours
Coning	between dry adiabatic and isothermal	short distance from release point	cloudy, windy	dry climate, light winds	night and day
Fanning	inversion or near isothermal	long distance from release point	light winds, clear skies snow cover	strong winds with cloud cover	nighttime
Lofting	transition from lapse to inver- sion	long distance from release point	light winds, clear skies, snow cover	strong winds with cloud cover	near time of sunset
Fumigation	breaking-up of inversion	along the entire effluent stream	clear skies, deep layers of radiation fog	cloudy weather	generally an hour or two after sunrise

TABLE II

WIND DIRECTION TRACE CLASSIFICATIONS AND RELATED CONDITIONS (SMITH)

10

TYPE	ANGULAR WIDTH OF TRACE	TYPE OF TURBULENCE	STABILITY CONDITION	TIME OF DAY	SEASON	REMARKS
A	$> 90^\circ$	Largely thermal (convective)	Great instability	0900-1500 only	Uncommon in winter	The stronger the lapse the greater the wind speed possible before trace be- comes type B
B ₂	$45^\circ - 90^\circ$	Largely thermal	Great instability	0900-1500 only	Mostly summer	Same as above
B ₁	$15^\circ - 45^\circ$	Thermal and mechanical	Moderate instability	0600-1800 (occasional- ly night with steep lapse)	Any	Generally associated with brisk winds and moderate lapse
C	$> 15^\circ$	Mechanical	Moderate stability	Night (or day with heavy cloud cover)	Any	Typical trace under over- cast skies and neutral lapse rate
D	$0^\circ - 15^\circ$	None	Great stability	Mostly night	Any	Typical inversion trace

FIG.2 WIND DIRECTION TRACE TYPES

only approximations, it has been found satisfactory to accept certain experimentally determined values as representative of typical meteorological conditions at NRTS. During the day when a superadiabatic lapse rate prevails an n value of 0.20 is used. When the lapse rate is between dry adiabatic and isothermal, which can occur anytime in the day, an n of 0.25 is satisfactory. Isothermal or inversion conditions normally occur at night and when the inversion is greater than 2.5°F per 100 feet an n equal to 0.50 is used, otherwise an n equal to 0.33 is employed.

The C -values depend on wind speed as well as n . Computed C -values for the typical n -values, various wind speeds and the two stack heights employed at NRTS are shown in Table III (Table VII in the appendix lists the C -values for 25m and 100m stacks). At sites other than NRTS where stack or source heights are different than those employed here (or listed in the appendix), a consultant meteorological service could supply a similar tabulation of average C -values.

V. APPLICATION OF BASIC EQUATIONS

Although the following equations are carried out to many places for the purpose of demonstration, it should be remembered that the solutions are approximations and slide rule accuracy would be sufficient. As previously indicated all quantities in the equations, except for those of Bryant-Davidson, are in the metric system. In all but the application of the Bryant-Davidson equations it is assumed that the physical and effective stack heights are the same. Conversion

TABLE III

COMPUTED COEFFICIENTS $C(h, n, u)$ FOR
50m AND 75m STACK HEIGHTS
(Based on method suggested by Barad and Hilst)

WIND SPEED (mph)	SUPERADIABATIC $n = 0.2$		ADIABATIC TO ISOTHERMAL $n = 0.25$		ISOTHERMAL AND SLIGHT INVERSION* $n = 0.33$		STRONG INVERSION** $n = 0.50$	
	STACK HEIGHT		STACK HEIGHT		STACK HEIGHT		STACK HEIGHT	
	$h = 50m$	$h = 75m$	$h = 50m$	$h = 75m$	$h = 50m$	$h = 75m$	$h = 50m$	$h = 75m$
1	.358	.329	.176	.163	.089	.083	.044	.042
2	.336	.308	.163	.149	.079	.075	.038	.037
3	.321	.297	.155	.143	.075	.071	.034	.033
4	.316	.288	.150	.137	.072	.068	.031	.031
5	.306	.283	.145	.133	.069	.065	.029	.029
6	.300	.276	.142	.130	.067	.063	.027	.027
7	.295	.271	.138	.127	.065	.061	.025	.025
8	.291	.267	.135	.125	.063	.059	.024	.024
9	.288	.263	.133	.123	.062	.058	.024	.024
10	.285	.260	.131	.121	.060	.057	.023	.023
11	.282	.258	.129	.119	.059	.056	.023	.023
12	.279	.256	.128	.118	.058	.055	.023	.023
13	.277	.254	.127	.117	.058	.055	.022	.022
14	.275	.252	.126	.116	.057	.054	.022	.022
15	.273	.251	.125	.115	.057	.053	.022	.022
16	.271	.249	.125	.115	.056	.053	.022	.022
17	.269	.248	.124	.114	.055	.052	.021	.021
18	.267	.246	.123	.113	.055	.052	.021	.021
19	.266	.245	.122	.112	.055	.052	.021	.021
20	.265	.244	.121	.112	.054	.051	.020	.020
25	.259	.239	.118	.109	.053	.050	.019	.019
30	.255	.233	.115	.106	.051	.048	.018	.018
35	.250	.229	.113	.104	.050	.047	.017	.017
40	.246	.226	.111	.102	.049	.045	.017	.017
45	.244	.224	.110	.100	.048	.044	.017	.017
50	.242	.222	.109	.100	.047	.043	.017	.017

* $\leq 2.5^\circ\text{F}/100 \text{ feet}$

** $> 2.5^\circ\text{F}/100 \text{ feet}$

tables for the British-metric systems are in the appendix.

5.1 Continuous point source

The most commonly encountered diffusion problem is that dealing with a stack which is continuously emitting an effluent. In this type problem it is assumed that the output or rate of emission is constant. The equations for 1) the concentration at position downwind, 2) the distance to the place of maximum ground concentration ($d_{\max}$) and 3) the concentration at $d_{\max}$ ($\chi_{\max}$) are as follows:

Concentration downwind (anisotropic case)

$$\chi_{(x,y,z=0)} = \frac{2Q}{\pi C_y C_z \bar{u} x^{(2-n)}} \exp \left[-\frac{1}{x^{(2-n)}} \left(\frac{y^2}{C_y^2} + \frac{h^2}{C_z^2} \right) \right] \quad (1)$$

$$d_{\max} = \left(\frac{h^2}{C^2} \right)^{\frac{1}{2-n}} \quad (2)$$

$$\chi_{\max} = \left(\frac{2Q}{e\pi \bar{u} h^2} \right) \quad (3)$$

Hypothetical Problem #1 During the afternoon when there is a strong lapse rate ($n = .20$), the average wind speed is 15 mph (6.7 mps) and the rate of emission is 20 grams each second from a 164-foot (50 meter) stack. This stack height

is great enough to assume that diffusion in the y- and z- directions is the same. Using the above n-value (.20), the wind speed (15 mph) and the stack height (50 m) with Table III, we see that C_y and C_z each equal .273.

Part 1 - What is the concentration one mile (1609 meters) downwind and 20 feet (6.1 m) to the right (or left) of the plume axis?

$$\chi = \frac{2(20)}{\pi(.273)(.273)6.7(1609)} \exp \left[- \frac{1}{(2.0-0.2)} \left(\frac{(6.1)^2}{(.273)^2} + \frac{(50)^2}{(.273)^2} \right) \right]$$

$$\chi = \frac{40}{927235} e^{-.0576} = .0000407 \text{ or } 4.07 \times 10^{-5} \text{ gm/m}^3$$

Part 2 - What is the distance to the place of maximum ground concentration? (Note: C^2 equals $C_y \times C_z$)

$$d_{(max)} = \left[\frac{(50)^2}{(.273)^2} \right]^{\frac{1}{2.0-0.2}}$$

$$d_{(max)} = (33557)^{.5556} = 327 \text{ m}$$

Part 3 - What is the concentration at $d_{(max)}$?

$$\chi_{(max)} = \frac{2(20)}{2.718 (3.1416) 6.7 (50)^2}$$

$$\chi_{(max)} = \frac{40}{143027} = .000280 \text{ or } 2.80 \times 10^{-4} \text{ gm/m}^3$$

Hypothetical Problem #2 About an hour before sunset when a slightly lapse condition exists ($n = .25$), the average wind speed is 9 mph (4 mps) and the rate of emission is 100 grams each second from a 246-foot (75 m) stack. Assume that the diffusion in the y- and z- directions is the same. Using the above n-value ($n = .25$), the wind speed (9 mph) and the tower height (75 m) with Table III, we see that C_y and C_z each equal .123.

Part 1 - What is the concentration one-half mile (805 m) downwind and in the center of the plume? (Note: There is no y- component.)

$$\chi = \frac{2(100)}{\pi(.123)(.123)4(805)^{(2.00-0.25)}} \exp \left[-\frac{1}{805^{(2.00-0.25)}} \frac{(75)^2}{(.123)^2} \right]$$

$$\chi = \frac{200}{23086} e^{-3.06195} = .00866 (.0468) = .000406 \text{ or } 4.06 \times 10^{-4} \text{ gm/m}^3$$

Part 2 - What is the distance to the place of maximum ground concentration?

$$d_{(max)} = \left[\frac{(75)^2}{(.123)^2} \right] \frac{1}{2.00 - 0.25}$$

$$d_{(max)} = (372517)^{.5714} = 1525 \text{ m}$$

Part 3 - What is the concentration at $d_{(max)}$?

$$\chi_{(max)} = \frac{2(100)}{2.718(3.1416)4(75)^2}$$

$$\chi_{(max)} = \frac{200}{192125} = .001041 \text{ or } 1.041 \times 10^{-3} \text{ gm/m}^3$$

5.2 Instantaneous point source

The instantaneous point source equation has two applications at reactor sites. Quite frequently an effluent is released as a puff or single cloud. In such a case the instantaneous point source formula is used without any correction. Probably the more important application is in making evaluations of the possible hazards with a runaway reactor. This would call for a large volume source of the dimensions of a reactor or reactor building.

Before using the infinite point source formula, a finite volume correction would have to be made. This correction gives the distance upwind from a real or actual source necessary to produce the required concentration at the point (0,0,0) and $t = 0$ (i.e. the assumed geometric center of the puff at the instant of the explosion.)

a) The case of the puff

The equation for 1) the concentration at position downwind,
2) the distance to the place of maximum ground concentration
($d_{\max}$) and 3) the concentration at $d_{\max}$ ($\chi_{\max}$) are as follows:

Concentration downwind

$$\chi_{(x,y,z,t)} = \frac{Q}{\pi^{3/2} C^3 (\bar{u}t)^{3(2-n)/2}} \exp \left[-\frac{r^2}{C^2 (\bar{u}t)^{2-n}} \right] \quad (4)$$

$$d_{(\max)} = \left(\frac{2h^2}{3C^2} \right)^{1/(2-n)} \quad (5)$$

$$\chi_{(\max)} = \frac{2Q}{\left(\frac{2}{3} e \pi \right)^{3/2} h^3} \quad (6)$$

Hypothetical Problem #3 During the afternoon when there is a strong lapse rate ($n = .20$), the average wind speed is 15 mph (6.7 mps) and 20,000 grams are emitted from a 164-foot (50 m) stack in a single puff. Assume that $C_x = C_y = C_z$. Using the above n -value (.20), the wind speed (15 mph) and the stack height (50 m) with Table III, we see that C_x , C_y and C_z each equal .273. (Note: x is measured from the center of the moving cloud, $\bar{u}t = \text{wind speed} \times \text{time}$ or the distance downwind and $C^3 = C_x \times C_y \times C_z$.)

Part 1 - What is the ground concentration one mile (1609 m) downwind and 20 feet (6.1 m) to the right (or left) of the center of the puff? $[r^2 = x^2 + y^2 + h^2 = 0 + (6.1)^2 + (50)^2]$

$$\chi = \frac{20,000}{(3.1416)^{3/2} (.273)^3 (1609)^{3(2.0-0.2)/2}} \exp \left[-\frac{(6.1)^2 + (50)^2}{(.273)^2 (1609)^{(2.0-0.2)}} \right]$$

$$\chi = \frac{20,000}{51,411,798} e^{-.057596} = .000367 \text{ or } 3.67^{-4} \text{ gm/cm}^3$$

Part 2 - What is the distance to the place of maximum ground concentration?

$$d_{(\max)} = \left[\frac{2(50)^2}{3(.273)^2} \right]^{\frac{1}{2.0-0.2}}$$

$$d_{(max)} = \left(\frac{5000}{.2235} \right)^{.5556} = (22371)^{.5556} = 261 \text{ m}$$

Part 3 - What is the concentration at $d_{(max)}$?

$$\chi_{(max)} = \frac{2(20000)}{\left[\frac{2}{3}(2.718)(3.1416) \right]^{3/2} (50)^3}$$

$$\chi_{(max)} = \frac{40,000}{13.582(125,000)} = .0236 \text{ or } 2.36 \times 10^{-2} \text{ gm/cm}^3$$

Hypothetical Problem #4 About an hour before sunset when a slightly lapse condition exists ($n = .25$), the average wind speed is 9 mph (4 mps) and 100,000 grams are emitted from a 246-foot (75 m) stack in a single puff. Assume $C_x = C_y = C_z$. Using the above n -value (.25), the wind speed (9 mph) and the stack height (50 m) with Table III, we see that C_x , C_y and C_z each equal .123. (Note: x is measured from the center of the moving cloud, $\bar{u}t$ = wind speed $\times$ time or the distance downwind and $C^3 = C_x \times C_y \times C_z$.)

Part 1 - What is the ground concentration one-half mile (805 m) downwind and in the center of the puff? (Note: There is no y - component. Therefore $r^2 = 0 + 0 + (75)^2$.)

$$\chi = \frac{100,000}{(3.1416)^{3/2} (.123)^3 (805)^{\frac{3(2.00-0.25)}{2}}} \exp \left[- \frac{0 + (75)^2}{(.123)^2 (805)^{(2.00-0.25)}} \right]$$

$$\chi = \frac{100,000}{5.57(.00186)(805)^{2.625}} e^{-\left[\frac{5625}{.0151(121660)}\right]}$$

$$\chi = \frac{100,000}{439627} e^{-3.06195} = .01065 \text{ or } 1.065 \times 10^{-2} \text{ gm/m}^3$$

Part 2 - What is the distance to the place of maximum ground concentration?

$$d_{(\max)} = \left[\frac{2(75)^2}{3(.123)^2} \right]^{\frac{1}{2.00-0.25}}$$

$$d_{(\max)} = \left(\frac{11250}{.0453} \right)^{.5714} = 1210 \text{ m}$$

Part 3 - What is the concentration at $d_{(\max)}$?

$$\chi_{(\max)} = \frac{2(100,000)}{\left[\frac{2}{3}(2.718)(3.1416) \right]^{3/2} (75)^3}$$

$$\chi_{(\max)} = \frac{200,000}{13.582(421875)} = .0349 \text{ or } 3.49 \times 10^{-2} \text{ gm/m}^3$$

b) The case of the large volume source

The equation for the finite volume correction for instantaneous large volume sources is as follows:

$$(\bar{u}t)_0 = \left(\frac{2Q/\chi(0)}{\pi^{3/2} C^3} \right)^{\frac{2}{3(2-n)}} \quad (7)$$

Although this equation was developed primarily for a ground level source it can be used for low-level sources. This correction is added to the $(\bar{u}t)$ in equation (4) above and then one proceeds as he did in the ordinary puff problem. With this type problem it would be unrealistic to compute $\chi_{(max)}$ or $d_{(max)}$ because the maximum concentration would ordinarily be at or near the explosion.

Hypothetical Problem #5 A reactor in a building 30 meters by 30 meters and 10 meters high explodes and knocks out all the walls of the building. The prevailing relevant meteorological conditions are 1) an afternoon with a strong lapse rate ($n = .20$) and 2) a wind speed of 15 mph (6.7 mps). There is a release of 180,000 grams. Assume that diffusion is equal in all directions ($C_x = C_y = C_z$) and that the release point is the top of the building. Since the elevation is only 10 m we will assume a C-value higher than that indicated in Table III for an n of .20, $h = 50$ m and a wind speed of 15 mph; we will use $C = .325$.

Part 1 - What is the finite volume correction?

$$(\bar{u}t)_0 = \left(\frac{2(180,000)/\frac{180,000}{9000}}{\pi^{3/2} (.325)^3} \right)^{\frac{2}{3(2.0-0.2)}}$$

$$(\bar{u}t)_0 = \left(\frac{18,000}{.191} \right)^{-.37037} = 70 \text{ m}$$

Part 2 - What is the concentration at a point one-half mile (805m) downwind and in the center of the puff? (Use equation 4 with the correction determined above, i.e., $\bar{u}t = 805 / 70 = 875\text{m}$).

$$\chi = \frac{180,000}{(\pi^{3/2} (.325)^3 (875)^{3(2.0-0.2)/2})} \exp \left[- \frac{10^2}{(.325)^2 (875)^{(2.0-0.2)}} \right]$$

$$\chi = \frac{180,000}{16,771,515} e^{-.00479} = .01068 \text{ or } 1.068 \times 10^{-2} \text{ gm/m}^3$$

Hypothetical Problem #6 A reactor in a building 20 meters by 20 meters and 25 meters high explodes and knocks out all the walls of the building. The prevailing relevant meteorological conditions are 1) a weak lapse condition exists ($n = .25$) and 2) the average wind speed is 9 mph (4mps). The release contains 200,000 grams. Assume that diffusion is equal in all directions ($C_x = C_y = C_z$) and that the release point is the top of the building. The C-value for an n of .25 with a wind speed of 9 mph and a tower height of 25 m is .143, according to Table VII in the appendix.

Part 1 - What is the finite volume correction?

$$(\bar{u}t)_0 = \left(\frac{2(200,000) / \frac{200,000}{10,000}}{\pi^{3/2} (.143)^3} \right)^{\frac{2}{3(2.00-0.25)}}$$

$$(\bar{u}t)_0 = \left(\frac{20,000}{.01626} \right)^{.38095} = 209 \text{ m}$$

Part 2 - What is the concentration at a point one-half mile (805m)

downwind and ten meters to the right of the center of the puff? (Note: $r^2 = x^2 + y^2 + h^2 = 0 + (10)^2 + (25)^2$ and $\bar{u}t = 805 + 209 = 1014 \text{ m}$)

$$\chi = \frac{200,000}{\pi^{3/2} (.143)^3 (1014)^3 (2.00-0.25)^{1/2}} \exp \left[- \frac{100 + 625}{(.143)^2 (1014)^2 (2.00-0.25)} \right]$$

$$\chi = \frac{200,000}{1,264,670} e^{-.194} = .1303 \quad \text{or} \quad 1.303 \times 10^{-1} \text{ gm/m}^3$$

- c) The total integrated dosage at the ground downwind of an instantaneous elevated point source

The concentration of a passing cloud is not the only concern of people dealing with air pollution and exposure to radioactive material. In addition there is a great deal of interest in the total integrated dosage. This is the amount of material to which an object in a stationary position would be exposed during the passage of a cloud from an instantaneous point source. The formulae for total dosage are as follows:

$$TID = \frac{2Q}{\pi C^2 \bar{u} (\bar{u}t)^{2-n}} \exp \left[- \frac{h^2}{C^2 (\bar{u}t)^{2-n}} \right] \quad (8)$$

Note: the total integrated dosage equation for the instantaneous point source is the same as the continuous point source equation (equation #1) when the latter has no y-component, i.e., the measurement is made in the center of the plume, and $C_y = C_z$.

$$TID_{(max)} = \frac{2Q}{\pi e \bar{u} h^2} \quad (\text{same as equation \#3}) \quad (9)$$

$$d_{(max \text{ dosage})} = \left(\frac{h^2}{C^2} \right)^{\frac{1}{2-n}} \quad (\text{same as equation \#2}) \quad (10)$$

Using hypothetical problem #3 and remembering that the pertinent data were $n = .20$, wind speed = 15 mph, emission = 20,000 grams, tower height = 164 feet and $C_x = C_y = C_z = .273$, do the following problem:

Part 1 - What is the TID one mile (1609m) downwind of the source?

$$TID = \frac{2(20,000)}{\pi (.273)^2 6.7(1609)^{(2.0-0.2)}} \exp \left[- \frac{(50)^2}{(.273)^2 (1609)^{(2.0-0.2)}} \right]$$

$$TID = .0431 e^{-.05675} = .0407 \text{ or } 4.07 \times 10^{-2} \text{ gm/m}^3$$

Part 2 - What is the distance to the point where the TID is the maximum?

$$d_{(max \text{ dosage})} = \left[\frac{(50)^2}{(.273)^2} \right]^{\frac{1}{2.0-0.2}}$$

$$d_{(max \text{ dosage})} = (33557)^{.5556} = 327 \text{ m}$$

Part 3 - What is the concentration at TID_{max} ?

$$TID_{(max)} = \frac{2(20,000)}{\pi(2.718) 6.7(50)^2}$$

$$TID_{(max)} = \frac{40,000}{8.5389(16750)}$$

$$TID_{(max)} = \frac{40,000}{143027} = .280 \text{ or } 2.80 \times 10^{-1} \text{ gm/m}^3$$

Using hypothetical problem #5 and remembering that the pertinent data were $n = .20$, wind speed = 15 mph, emission = 180,000 grams, the release point was the top of the building (10m), the finite volume correction = 70m and $C_x = C_y = C_z = .325$, do the following problem:

Part 1 - What is the TID one-half mile (805m) downwind?
($ut = 805 + 70 = 875 \text{ m.}$)

$$TID = \frac{2(180,000)}{\pi(.325)^2 6.7(875)^{(2.0-0.2)}} \exp \left[- \frac{(10)^2}{(.325)^2 (875)^{(2.0-0.2)}} \right]$$

$$TID = \frac{360,000}{439,028} e^{-.00479} = .816 \text{ or } 8.16 \times 10^{-1} \text{ gm/m}^3$$

Part 2 - What is the distance to where the TID is the maximum?

$$d_{(max \text{ dosage})} = \left[\frac{(10)^2}{(.325)^2} \right]^{\frac{1}{2.0-0.2}}$$

$$d_{(\text{max dosage})} = (947)^{.5556} = 45 \text{ m}$$

Part 3 - What is the concentration at TID_{max} ?

$$TID_{(\text{max})} = \frac{2(180,000)}{\pi(2.718)6.7(10)^2}$$

$$TID_{(\text{max})} = \frac{360,000}{5721} = 62.9 \text{ gm/m}^3$$

Parts 2 and 3 have been included for illustrative purposes only; normally with an explosion $d_{(\text{max dosage})}$ and TID_{max} will be at or near the explosion.

5.3 Ground Deposition

So far problems involving transitory conditions have been discussed. The more permanent conditions (discounting radioactive decay) are the result of ground deposition. Since most reactors at NRTS are not operated when precipitation is falling, only the dry fall-out problems will be considered. For those interested in the wash-out problem the appropriate equation is presented below. This equation is analagous to the dry fall-out equation and by comparison one can readily see the manner in which the former operates. The dry fall-out and wash-out formulae are as follows:

Dry fall-out

$$\omega_{\text{dry-max}} = \frac{nQ}{2e(\pi)^{1/2}C_y(x)^{2-(n/2)}} \quad (11)$$

Wash-out

$$\omega_{\text{rain-max}} = \frac{Q}{e(\pi)^{1/2}C_y(x)^{2-(n/2)}} \quad (12)$$

Using hypothetical problem #1 and remembering that the pertinent data were $n = .20$, $C_y = .273$ and Q (the emission rate) was 20 grams each second, what is the maximum ground deposition rate one mile (1609 m) downwind?

$$\omega_{\text{dry-max}} = \frac{.20(20)}{2(2.718)(3.1416)^{1/2}(.273)(1609)^{2-\frac{.20}{2}}}$$

$$\omega_{\text{dry-max}} = \frac{4}{3,254,643} = .0000012290 \text{ or } 1.23 \times 10^{-6} \text{ gm/m}^2/\text{sec}$$

Multiplying this by the time (in seconds) would give the total deposition.

Using hypothetical problem #4 and remembering that the pertinent data were $n = .25$, $C_y = .123$ and Q (the emission) was 100,000 grams, what is the maximum ground deposition at a position one-half mile (805m) downwind?

$$\omega_{\text{dry max}} = \frac{(25)100,000}{2(2.718) \pi^{1/2} (.123)(805)^{(2 - \frac{25}{2.00})}}$$

$$\omega_{\text{dry max}} = \frac{25,000}{332,776} = .0751 \text{ or } 7.51 \times 10^{-2} \text{ gm/m}^2$$

This is the total deposition from the passing puff.

5.4 Cloud width, $2y_0$, and cloud height, z_0

Meteorologists conducting experiments with continuous point sources are frequently interested in plume or cloud width ($2y_0$) and cloud height (z_0). The basic equations for determining these quantities are as follows:

Cloud width

$$2y_0 = 2 \left(\ln \frac{100}{p} \right)^{1/2} C_y x^{(2-n)/2} \quad (13)$$

Cloud height

$$z_0 = \left(\ln \frac{100}{p} \right)^{1/2} C_z x^{(2-n)/2} \quad (14)$$

It is obvious that $2y_0$ is just twice z_0 when $C_y = C_z$. Therefore only problems involving $2y_0$ will be demonstrated.

Using hypothetical problem #1 and remembering that the perti-

ment data were $n = .20$ and $C_y = C_z = .273$, determine the cloud width and height at a position one mile (1609 m) downwind where each is 10% of the axial concentration.

$$2y_0 = 2 \left(\ln \frac{100}{10} \right)^{1/2} .273 (1609)^{\frac{2.0-0.2}{2}}$$

$$2y_0 = 2 (1.5174) (209.92) = 637 \text{ m.}$$

Using hypothetical problem #2 and remembering that the pertinent data were $n = .25$ and $C_y = C_z = .123$, determine the cloud width and cloud height at a position one-half mile (805 m) downwind where each is 25% of the axial concentration.

$$2y_0 = 2 \left(\ln \frac{100}{25} \right)^{1/2} .123 (805)^{\frac{2.00-0.25}{2}}$$

$$2y_0 = 2 (1.1774) (42.9024) = 101 \text{ m.}$$

5.5 Effective Stack Height

In order not to complicate the preceding problems, we have assumed that the physical stack height was equal to the effective stack height; at NRTS this generally has been the case. However factors such as stack diameter, stack draft velocity, wind speed,

excess temperature of the stack gas and vertical gradient of air temperature can affect the effective stack height. The most frequently used formula for determining the effective stack height is that which was empirically determined by Davidson from Bryant's wind tunnel experiments. The Bryant-Davidson equation is

$$\Delta h = d \left(\frac{v_s}{u} \right)^{1.4} \left(1 + \frac{\Delta T}{T_s} \right) \quad (15)$$

Note: All the distance terms are in the English system and the temperatures are in similar units.

Hypothetical Problem #7 Gas emitted from a 164-foot stack with a 20-foot diameter has an excess temperature of 100°C over the atmospheric (ambient air) temperature of 27°C (absolute temperature = 300°). If the stack draft velocity is 100 fps and the mean wind speed is 15 mph (22 fps), what is the effective stack height?

$$\Delta h = 20 \left(\frac{100}{22} \right)^{1.4} \left(1 + \frac{100}{400} \right)$$

$$\Delta h = 20 (8.329) 1.25 = 208.2 \text{ feet}$$

Thus the effective stack height would be 372.2 feet.

Hypothetical Problem #8 Gas emitted from a 246-ft. stack with a 10-ft. diameter, has an excess temperature of 1200°C over the air tempera-

ture of 27°C (absolute temperature $\approx 300^{\circ}$). If the stack velocity is 85 fps and the average wind speed is 29 mph (42.5 fps), what is the effective stack height?

$$\Delta h = 10 \left(\frac{85}{42.5} \right)^{1.4} \left(1 + \frac{1200}{1500} \right)$$

$$\Delta h = 18 (2.639) = 47.5 \text{ feet}$$

Thus the effective height would be 293.5 feet.

VI. NOMOGRAMS

As seen in the previous section, numerical evaluations are time consuming and require some facility with mathematics (or a slide rule). Furthermore, since the equations are at best good approximations precise answers are not needed. Nomograms based on the diffusion equations give results which are as good as the results determined by numerical evaluation. These nomograms are especially good for field work in which first approximations have to be obtained quickly.

6.1 Atmospheric Diffusion Calculations

The first nomogram, that for atmospheric diffusion calculations, is shown in Figure 3, has many applications and is not as complicated as it appears to be. Although each scale is labelled, some confusion can be reduced by stating what each scale represents. Each scale equals the following quantity:

FIG. 3
NOMOGRAM FOR ATMOSPHERIC
DIFFUSION CALCULATIONS

Scale I = x (distance) or $\bar{u}t$ (speed x time) in meters

II = n (Sutton's non-dimensional stability parameter)

III = C^2 (diffusion coefficient squared) in $[(m)^{1/2}]^2$

IV = f (reference number)

V = h (height of source or plume) in meters

VI = r^2 (radial distance squared) in meters squared.

VII = f -reference for an infinite line source

VIII = f -reference for a continuous point source

IX = f -reference for an instantaneous point source

X = u (wind speed)

XI = χ/Q for an instantaneous point source in $\left(\frac{gm/m^3}{gm}\right)$

XII = χ/Q for a continuous point source in $\left(\frac{gm\ m^{-3}}{gm\ sec^{-1}}\right)$

XIII = χ/Q for an infinite line source in $\left(\frac{gm\ m^{-3}}{gm\ sec^{-1}\ m^{-1}}\right)$

Table IV states how the nomogram can be used to solve various problems.

Illustrative Example #1 The example illustrated on the nomogram

is taken from Meteorology And Atomic Energy, and is as follows:

Find the relative dilution, χ/Q , at a point on the ground beneath the axis of a plume, 1000 meters downwind from a continuously emitting stack which is 100 meters high. The parameters have the value $n = 0.5$, $C^2 = 0.2$ and $\bar{u} = 2$ m/sec.

1) Align a straightedge with $x = 1000$ meters (scale I) and $n = 0.5$ (scale II), locating a point on the reference scale R_1 (approximately equal to 143 on scale V).

TABLE IV

PROGRAM FOR SOLVING METEOROLOGICAL
DIFFUSION PROBLEMS ON FIG. 3

SOURCE TYPE	QUANTITY SOUGHT	SYMBOL	NECESSARY ALIGNMENTS (SYMBOLS REFER TO CORRESPONDING SCALES ON FIG. 3)	REMARKS
Instantaneous point source at the ground	Ground Concentration	$\chi_{(x,y)}$	R ₁ -II-I; R ₁ -IV-III; XI-IX-VI	Use $r^2 = x^2 + y^2$, scale VI
	Concentration at a height h	$\chi_{(x,y)}$	R ₁ -II-I; R ₁ -IV-III; XI-IX-VI	Use $r^2 = x^2 + y^2$ + h^2 , scale VI
Instantaneous elevated point source at a height h	Ground concentration	$\chi_{(x,y)}$	R ₁ -II-I; R ₁ -IV-III; XI-IX-VI	Use $r^2 = x^2 + y^2$ + h^2 , scale VI
	Distance of the maximum ground concentration	d_{max}	R ₂ -(t)IX-V; R ₁ -IV- III; R ₁ -II-I	
	Maximum ground concentration	χ_{max}	XI-(t)IX-V	
	Integrated ground concentration		R ₁ -II-I; R ₁ -IV-III; R ₂ -VIII-VI; XII-R ₂ -X	Cf. text
Continuous point source at the ground	Downwind concentration at height h	$\chi_{(x,0)}$	R ₁ -II-I; R ₁ -IV-III; R ₂ -VIII-V; XII-R ₂ -X	
	Ground concentration at lateral distance y from cloud axis	$\chi_{(x,y)}$	R ₁ -II-I; R ₁ -IV-III; R ₂ -VIII-V; XII-R ₂ -X	Use $h=y$, scale V
	Concentration at height h and lateral distance y	$\chi_{(x,y)}$	R ₁ -II-I; R ₁ -IV-III; R ₂ -VIII-VI; XII-R ₂ -X	Use $r^2 = y^2 + h^2$, scale VI

TABLE IV (CONTINUED)

PROGRAM FOR SOLVING METEOROLOGICAL
DIFFUSION PROBLEMS ON FIG. 3

SOURCE TYPE	QUANTITY SOUGHT	SYMBOL	NECESSARY ALIGNMENTS (SYMBOLS REFER TO CORRESPONDING SCALES ON FIG. 3)	REMARKS
Continuous elevated point source at a height h	Downwind ground concentration	$\chi_{(x,0)}$	$R_1-II-I; R_1-IV-III;$ $R_2-VIII-V; XII-R_2-X$	
	Ground concen- tration at lateral distance y from cloud axis	$\chi_{(x,y)}$	$R_1-II-I; R_1-IV-III;$ $R_2-VIII-VI; XII-R_2-X$	Use $r^2 = y^2 + h^2$, scale VI
	Maximum ground concentration	χ_{max}	$R_2-(t)VIII-V; XII-$ R_2-X	
	Distance of the maximum concen- tration	d_{max}	$R_2-(t)VIII-V; R_1-IV-$ $III; R_1-II-I$	
	Distance downwind a given concen- tration will occur	x	$XII-R_2-X; R_2-VIII-V;$ $R_1-IV-III; R_1-II-I$	Two values of f are defined by the 2nd alignment, which leads to two values of x
	Distance from cloud axis y a given concentra- tion will occur	y	$R_1-II-I; R_1-IV-III;$ $XII-R_2-X; R_2-VIII-VI$	Use $y^2 = r^2 - h^2$ to find y
	n , given the down- wind concentration	n	$XII-R_2-X; R_2-VIII-V;$ $R_1-IV-III; R_1-II-I$	
	n , given the con- centration at a lateral distance y from cloud axis	n	$XII-R_2-X; R_2-VIII-VI;$ $R_1-IV-III; R_1-II-I$	
	C^2 , given the down- wind concentration	C^2	$XII-R_2-X; R_2-VIII-V;$ $R_1-II-I; R_1-IV-III$	
	C^2 , given the con- centration at a lateral distance y from cloud axis	C^2	$XII-R_2-X; R_2-VIII-VI;$ $R_1-II-I; R_1-IV-III$	

2) Align R_1 with $C^2 = 0.2$ (scale III), locating a value of f , 6×10^3 , (scale IV).

3) Align the stack height, $h = 100$ m (scale V), with the value of f on scale VIII, locating a point on the reference scale R_2 (approximately equal to 1.3×10^{-5} on scale XI).

4) Align R_2 with $\bar{u} = 2$ (scale X), determining that $\chi/Q = 1 \times 10^{-5}$ (scale XII).

5) Multiply χ/Q by the emission rate, e.g., if the emission rate was 100 gm/sec, the concentration would be 1×10^{-3} gm/m³.

To aid field workers in developing a facility with this nomogram several more problems are included.

Hypothetical Problem #9 During the afternoon when there is a strong lapse rate ($n = .20$), the average wind is 6.7 mps and the rate of emission is 20 grams each second from a 50m stack. What is the concentration 1600m downwind and 6m to the right of the plume axis? Assume that the diffusion in the y- and z- directions is the same. Using $n = .20$, wind speed = 15 mph (6.7 mps) and the stack height of 50m with Table III a $C = .273$ ($C^2 = .0745$) is obtained. (Note: $r^2 = h^2 + y^2 = 2500 + 36 = 2536$)

1) Align the straightedge with $x = 1600$ m (scale I) and $n = 0.20$ (scale II), locating a point on the reference scale R_1 (approximately three-eighths inch above 25 on scale VI).

2) Align R_1 with $C^2 = 0.0745$ (scale III), locating a value of f , 4×10^4 (scale IV).

3) Align $r^2 = 2536$ (Note: This is not much different than $h = 50$ on scale V) on scale VI, with the value of f on scale VIII, locating a point on the reference scale R_2 (approximately equal to 9.5×10^{-6} on scale XI).

4) Align R_2 with $\bar{u} = 6.7$ (scale X), determining that $\chi/Q = 2.2 \times 10^{-6} \text{ gm/m}^3$ (approximately).

This problem is practically identical with hypothetical problem #1. If we multiply χ/Q by $Q(20)$, we get $\chi = 4.4 \times 10^{-5} \text{ gm/m}^3$. Comparing this result with that of problem #1, we see that the answers are approximately the same.

Hypothetical Problem #10 Use the data in problem #9 and solve it as an instantaneous point source.

The first two steps are the same as in problem #9

3) Align $r^2 = 2536$ on scale VI with the value of f on scale IX, thereby obtaining R_2 (approximately equal to 10^{+7} on scale VIII)

4) Using a pair of dividers it is seen that this point corresponds to 4×10^{-8} on scale XI (in an instantaneous point source problem there is no need to line up scale X with R_2)

5) Multiplying the result by $Q(20)$ we see that χ equals $8 \times 10^{-7} \text{ gm/m}^3$.

Hypothetical Problem #11 About an hour before sunset when a slightly lapse condition exists ($n = .25$), the average wind speed is 9 mph (4 mps) and the rate of emission is 100 grams each second from a 246-foot (75m) stack. What is the concentration one-half mile

(805m) downwind and in the center of the plume? Assuming that the diffusion in the y- and z- directions is the same and using $n = .25$, the wind speed of 9 mph and the tower height of 75m, we see that C_y and C_z each equal .123 ($C^2 = .0151$).

1) Align the straightedge on 800 of scale I and on $n = .25$ of scale II thereby obtaining a reference point at 23.5×10^3 on scale VI (R_1).

2) Align this reference point with $C^2 = .0151$ on scale III; this gives $f = 1.8 \times 10^3$.

3) Align $h = 75m$ on scale V with f on scale VIII thereby obtaining R_2 (equal to 7×10^{-6} on scale XI).

4) Align $u = 4$ mps on scale X with R_2 and read χ/Q on scale XII (3×10^{-6}).

5) Multiply χ/Q by Q (100) and χ equals 3×10^{-4} .

The nomogram in Figure 3 can also be used for maximum concentration problems (cf. Table IV).

Hypothetical Problem #12 Use the data in problem #9 (Continuous Point Source).

Part 1 Determine $\chi_{(max)}$.

1) Place one end of the straightedge on $h = 50m$ (scale V) and the edge tangent (point of tangency or $f = 2.8 \times 10^3$) to scale VIII. Read R_2 (equal to 5.5×10^{-5} on scale XI).

2) Align the wind speed (6.7 mps) on scale X with R_2 and read the maximum χ/Q on scale XII (1.4×10^{-5}).

3) Multiply this χ/Q by Q (20), getting $\chi_{(max)} = 2.8 \times 10^{-4} \text{ gm/cm}^3$.

Part 2 Determine $d_{(max)}$.

1) Align f (or the point of tangency) determined in step 1 of part 1 with $C^2 = .0745$ on scale III. This gives an $R_1 = 21 \times 10^3$ on scale VI.

2) Align R_1 with $n = .2$ (scale II). The maximum distance indicated on scale I is approximately 330 meters.

Hypothetical Problem #13 Use the data in problem #9, assuming an instantaneous point source with an emission of 20 grams.

Part 1 Determine $\chi_{(max)}$

1) Place one end of the straightedge on $h = 50\text{m}$ (scale V) and the edge tangent (point of tangency or $f = 2.1 \times 10^3$) to scale IX. Read χ/Q (approximately equal to 1.2×10^{-6}) on scale XI.

2) Multiply χ/Q by Q (20) obtaining $\chi_{(max)} = 2.4 \times 10^{-5} \text{ gm/m}^3$.

Part 2 Determine $d_{(max)}$.

1) Align f (or the point of tangency) determined in step 1 of part 1 with $C^2 = .0745$ on scale III. This gives an $R_1 = 20.6 \times 10^3$ on scale VI.

2) Align R_1 with $n = .2$ (scale II). The maximum distance indicated on scale I is approximately 300 meters.

As indicated in Table IV, the nomogram for atmospheric diffusion calculations can be used for solving innumerable diffusion problems. Only the most important applications have been demonstrated and the person who has to work frequently with diffusion would do well to work all the various type problems he would encounter.

6.2 Maximum Concentrations from Continuous Point Source

Figure 4 is an alignment chart for finding $\chi_{(max)}$ from a continuous point source and is more convenient for the purpose than Figure 3. The procedure is as follows:

- 1) Align $\bar{u}$, scale I, with h , scale II.
- 2) Find a perpendicular to this line through Q (units per second), scale IV. If isotropic diffusion is assumed, the value of $\chi'_{(max)}$ which this locates on scale III is the required maximum concentration.
- 3) If nonisotropic diffusion is assumed or if the Brookhaven wind trace types are used (cf. Table II), align the point found on scale III with Cz/Cy , or a_m , scale V, and read $\chi_{(max)}$, scale VI. (Note: The Brookhaven standard values for a_m for type A, B, C and D wind traces have been indicated on scale V for convenience).

Illustrative example #2 The example on the nomogram is as follows:

Find $\chi_{(max)}$ when $\bar{u} = 3.8$ mps, $h = 34m$ and $Q = 1$ gm/sec.

- 1) Align $\bar{u}$ (scale I) = 3.8 with h (scale II) = 34m.
- 2) Draw the perpendicular to this line through $Q = 1$ on scale IV.

FIG. 4 NOMOGRAM FOR SOLVING SUTTON'S
EQUATION FOR MAXIMUM CONCENTRATION
FROM A CONTINUOUS POINT SOURCE

3) If isotropic diffusion is assumed the maximum concentration is at the intersection of the perpendicular and scale III (5×10^{-5} gm/sec). If nonisotropic diffusion is assumed and $C_z/C_y = 0.6$, then a line intersecting the point where the perpendicular in step 2 crosses scale III and 0.6 on scale V marks the maximum concentration on scale VI (3×10^{-5} in this case).

Using hypothetical problem #1 and remembering that the pertinent data were tower height = 50m, $\bar{u} = 6.7$ mps, $Q = 20$ gm/sec and $C_z = C_y$, determine $\chi_{(max)}$.

- 1) Align $\bar{u}$ (scale I) = 6.7 with h (scale II) = 50m.
- 2) Draw the perpendicular to this line through $Q = 20$ on scale IV.
- 3) Isotropic diffusion is assumed, therefore the maximum is at the intersection of the perpendicular and scale III (2.75×10^{-4} gm/sec). If nonisotropic diffusion is assumed and $C_z/C_y = 0.5$, then the line intersecting the point where the perpendicular in step 2 crosses scale III and 0.5 on scale V marks the maximum concentration on scale VI (1.5×10^{-4} in this case).

Using hypothetical problem #2 and remembering that the pertinent data were tower height = 75m, $\bar{u} = 4.0$ mps and $Q = 100$ gm/sec and $C_z = C_y$, determine $\chi_{(max)}$.

- 1) Align $\bar{u}$ (scale I) = 4.0 with h (scale II) = 75m.
- 2) Since 100 does not appear on scale IV reduce this quantity by an order of magnitude (making it 10). Draw the perpen-

dicular to the line in step 1 through $Q = 10$ on scale IV.

3) Isotropic diffusion is assumed, therefore the maximum is at the intersection of the perpendicular and scale III (1.03×10^{-4} gm/sec). Remembering that we shifted down one order of magnitude on scale IV, we have to raise this answer an order of magnitude (therefore it is 1.03×10^{-3}). If non-isotropic diffusion is assumed and $C_z/C_y = 0.2$, then the line intersecting the point where the perpendicular in step 2 crosses scale III and 0.2 on scale V marks the maximum concentration on scale VI (2.1×10^{-4} after the order of magnitude correction has been made).

6.3 Plume Spread

Figure 5 is an alignment chart for determining the width and height of a plume at a given distance from the source. The procedure is as follows:

- 1) Align x , scale I, with n , scale II, locating a point on R.
- 2) Align this point with C or C^2 , scale III.
- 3) Find a perpendicular to the line in step 2 and passing through P (percentage of central plume concentration), scale IV, and read $2y_0$ and/or z_0 on scale V and/or scale VI.

Illustrative example #3 The example on the nomogram is as follows:

Given $x = 500\text{m}$, $n = 0.5$, $C^2 = 0.1$, $P = 10$, determine $2y_0$ and z_0 .
Following the steps indicated above, it is seen that $2y_0 = 100\text{m}$ and $z_0 = 50\text{m}$.

FIG. 5 NOMOGRAM FOR SOLVING SUTTON'S
CLOUD HEIGHT & WIDTH EQUATIONS

Using hypothetical problem #1 and remembering that the pertinent data were $n = .20$ and $C_y = C_z = .273$, determine $2y_0$ and z_0 at a position one mile (1609m) downwind where each is 10% of the axial concentration.

- 1) Align 1609 on scale I with .2 on scale II, locating a point on R.
- 2) Align the point on R with $C = .273$ on scale III.
- 3) Align a perpendicular to the line in step 2 through $P = 10$ (scale IV) locating a point on scales V and VI ($2y_0 = 560m$ and $z_0 = 280m$).

Using hypothetical problem #2 and remembering that the pertinent data were $n = .25$ and $C_y = C_z = .123$ determine $2y_0$ and z_0 at a position one-half mile (805m) downwind where each is 25% of the axial concentration.

- 1) Align 805 on scale I with .25 on scale II, locating a point on R.
- 2) Align the point on R with $C = .123$ on scale III.
- 3) Align a perpendicular to the line in step 2 through $P = 25$ (scale IV) locating a point on scales V and VI ($2y_0 = 100m$ and $z_0 = 50m$).

Appendix

TABLE V

FEET TO METERS AND METERS TO FEET

1 foot = 0.3048 meters 1 mile = 1609 meters				1 meter = 3.281 feet 1 kilometer = 0.621 statute miles			
FEET	METERS	FEET	METERS	METERS	FEET	METERS	FEET
1	0.3	50	15.2	1	3.3	50	164.0
2	0.6	60	18.3	2	6.6	60	196.9
3	0.9	70	21.3	3	9.8	70	229.7
4	1.2	80	24.4	4	13.1	80	262.5
5	1.5	90	27.4	5	16.4	90	295.3
6	1.8	100	30.5	6	19.7	100	328.1
7	2.1	120	36.6	7	23.0	110	360.9
8	2.4	140	42.7	8	26.3	120	393.7
9	2.7	150	45.7	9	29.5	130	426.5
10	3.1	160	48.8	10	32.8	140	459.3
11	3.4	180	54.9	11	36.1	150	492.1
12	3.7	200	61.0	12	39.4	160	524.9
13	4.0	220	67.1	13	42.7	170	557.7
14	4.3	240	73.2	14	45.9	180	590.6
15	4.6	250	76.2	15	49.2	190	623.4
16	4.9	260	79.3	16	52.5	200	656.2
17	5.2	280	85.3	17	55.8	300	984.3
18	5.5	300	91.4	18	59.1	400	1312.3
19	5.8	320	97.5	19	62.3	500	1640.4
20	6.1	340	103.6	20	65.6	600	1968.5
25	7.6	350	106.7	25	82.0	700	2296.6
30	9.1	360	109.7	30	98.4	800	2624.7
35	10.7	380	115.8	35	114.8	900	2952.8
40	12.2	400	121.9	40	131.2	1000	3280.8
45	13.7	500	152.4	45	147.6	1500	4921.3
MILES		METERS		METERS		MILES	
1/4		402		2000		1.24	
1/2		805		2500		1.55	
3/4		1207		3000		1.86	
1		1609		4000		2.49	
2		3219		5000		3.11	
5		8047		10,000		6.21	
10		16093		15,000		9.32	
15		24140		20,000		12.43	
20		32187		25,000		15.53	
30		48280		30,000		18.64	

TABLE VI

- a) miles per hour to meters per second and feet per second
 b) meters per second to miles per hour and feet per second
 c) feet per second to miles per hour and meters per second

(a)			(b)			(c)		
mph	mps	fps	mps	mph	fps	fps	mph	mps
1	0.4	1.5	1	2.2	3.3	1	0.7	0.3
2	0.9	2.9	2	4.5	6.6	2	1.4	0.6
3	1.3	4.4	3	6.7	9.8	3	2.0	0.9
4	1.8	5.9	4	8.9	13.1	4	2.7	1.2
5	2.2	7.3	5	11.2	16.4	5	3.4	1.5
6	2.7	8.8	6	13.4	19.7	6	4.1	1.8
7	3.1	10.3	7	15.7	23.0	7	4.8	2.1
8	3.6	11.7	8	17.9	26.2	8	5.5	2.4
9	4.0	13.2	9	20.1	29.5	9	6.1	2.7
10	4.5	14.7	10	22.4	32.8	10	6.8	3.0
11	4.9	16.1	11	24.6	36.1	11	7.5	3.4
12	5.4	17.6	12	26.8	39.4	12	8.2	3.7
13	5.8	19.1	13	29.1	42.7	13	8.9	4.0
14	6.3	20.5	14	31.3	45.9	14	9.5	4.3
15	6.7	22.0	15	33.6	49.2	15	10.2	4.6
16	7.2	23.5	16	35.8	52.5	16	10.9	4.9
17	7.6	24.9	17	38.0	55.8	17	11.6	5.2
18	8.0	26.4	18	40.3	59.1	18	12.3	5.5
19	8.5	27.9	19	42.5	62.3	19	13.0	5.8
20	8.9	29.3	20	44.7	65.6	20	13.6	6.1
21	9.4	30.8	21	47.0	68.9	21	14.3	6.4
22	9.8	32.3	22	49.2	72.2	22	15.0	6.7
23	10.3	33.7	23	51.4	75.5	23	15.7	7.0
24	10.7	35.2	24	53.7	78.7	24	16.4	7.3
25	11.2	36.7	25	55.9	82.0	25	17.0	7.6
26	11.6	38.1	26	58.2	85.3	30	20.5	9.1
27	12.1	39.6	27	60.4	88.6	35	23.9	10.7
28	12.5	41.1	28	62.6	91.9	40	27.3	12.2
29	13.0	42.5	29	64.9	95.1	45	30.7	13.7
30	13.4	44.0	30	67.1	98.4	50	34.1	15.2
31	13.9	45.5	1 mps = 2.2369 mph = 3.2808 fps 1 mph = 1.4667 fps = 0.4470 mps 1 fps = 0.6818 mph = 0.3048 mps			55	37.5	16.8
32	14.3	46.9				60	40.9	18.3
33	14.8	48.4				65	44.3	19.8
34	15.2	49.9				70	47.7	21.3
35	15.6	51.3				75	51.1	22.9
40	17.9	58.7				80	54.5	24.4
45	20.1	66.0				85	58.0	25.9
50	22.4	72.3				90	61.4	27.4
55	24.6	80.7				95	64.8	29.0
60	26.8	88.0				100	68.2	30.5

TABLE VII

COMPUTED COEFFICIENTS C (h, n, u) FOR
25m AND 100m STACK HEIGHTS
(Based on method suggested by Barad and Hilst)

WIND SPEED (mph)	SUPERADIABATIC $n = 0.2$ STACK HEIGHT		ADIABATIC TO ISOTHERMAL $n = 0.25$ STACK HEIGHT		ISOTHERMAL AND SLIGHT INVERSION* $n = 0.33$ STACK HEIGHT		STRONG INVERSION** $n = 0.50$ STACK HEIGHT	
	$h = 25m$	$h = 100m$	$h = 25m$	$h = 100m$	$h = 25m$	$h = 100m$	$h = 25m$	$h = 100m$
1	.380	.309	.195	.150	.093	.078	.044	.038
2	.354	.290	.173	.141	.084	.071	.038	.034
3	.341	.278	.165	.135	.079	.067	.035	.032
4	.332	.270	.160	.131	.076	.064	.033	.030
5	.325	.264	.155	.127	.073	.061	.030	.029
6	.319	.259	.151	.124	.070	.059	.029	.027
7	.314	.256	.148	.121	.068	.057	.028	.026
8	.311	.252	.145	.119	.067	.056	.026	.025
9	.307	.249	.143	.118	.066	.055	.025	.024
10	.304	.247	.141	.116	.065	.055	.024	.023
11	.300	.244	.140	.115	.064	.054	.024	.022
12	.298	.242	.138	.114	.063	.053	.023	.021
13	.295	.240	.137	.113	.062	.052	.023	.021
14	.293	.238	.135	.112	.061	.052	.022	.020
15	.291	.237	.134	.111	.060	.051	.022	.020
16	.289	.235	.133	.110	.060	.050	.022	.020
17	.288	.234	.132	.109	.059	.050	.021	.020
18	.286	.233	.131	.108	.059	.049	.021	.020
19	.284	.231	.130	.107	.058	.049	.021	.019
20	.283	.230	.129	.106	.058	.049	.020	.019
25	.277	.226	.126	.103	.056	.047	.020	.018
30	.272	.222	.123	.101	.054	.046	.020	.017
35	.268	.218	.121	.099	.053	.045	.019	.016
40	.264	.215	.119	.098	.052	.043	.018	.016
45	.260	.212	.117	.096	.051	.042	.017	.015
50	.257	.209	.115	.094	.050	.041	.017	.015

* $\leq 2.5^\circ\text{F}/100\text{ feet}$

** $> 2.5^\circ\text{F}/100\text{ feet}$

GLOSSARY

- adiabatic (dry) or adiabatic lapse rate - describes a rate of temperature decrease with height of 1°C per 100 meters or $.54^{\circ}\text{F}$ per 100 feet.
- anisotropic (nonisotropic) - exhibiting different properties when tested along axes in different directions (cf. isotropic).
- backing - (applied to the wind) - the wind direction changes in a counterclockwise manner, e.g., from the north to northwest (cf. veering).
- coning - describes an effluent plume that is shaped like a cone with the axis horizontal.
- convection - the process whereby a circulation is created and maintained within a layer of the atmosphere, due either to surface heating of the bottom of the layer or to cooling at its top, and consisting in the sinking of relatively heavy air and the consequent forcing up of air which, volume for volume and under the same pressure, is relatively light (cf. convective turbulence).
- convective turbulence - irregular motion of parts of the atmosphere caused by convection (cf. convection, mechanical turbulence, thermal turbulence).
- diffusion - the process by which an effluent spreads out in its environment, usually the atmosphere.
- diffusion coefficients - numerical values expressing the rate of diffusion along each of three mutually perpendicular axes - downwind, crosswind and vertical.
- discontinuity - a zone or layer in the atmosphere within which there is a comparatively rapid transition of any of the meteorological elements from one value to another, e.g., a frontal zone is a discontinuity between two air masses, and is noted by changes in temperature, density, humidity, wind speed and direction.
- eddy - the more or less circular motion of the wind produced by an obstruction in the path of the wind or by convection.
- fanning - describes an effluent plume that is very smooth, almost laminar; it diffuses very little in the vertical.
- fumigation - describes an effluent plume that is marked by strong downdrafts. Large concentrations of effluent are brought to the ground along the effluent stream, as nocturnal inversion is dissipated by the morning sun.

inversion - the condition which exists in the atmosphere when the temperature increases rather than decreases with height through a layer of air (an inversion at the earth's surface is due most commonly to radiational cooling of the lower levels, which does not affect the air above.)

weak inversion (terminology used at NRTS) - is taken to mean an inversion when the temperature increase with height is between isothermal and 2.5°F per 100 feet.

strong inversion (terminology used at NRTS) - is taken to mean an inversion when the temperature increase with height is greater than 2.5°F per 100 feet.

isothermal - the condition which exists in the atmosphere when the temperature does not change with height.

isotropic - having the same properties in all directions (cf. anisotropic).

lapse (temperature) - the decrease of temperature with height in the free atmosphere.

weak lapse (terminology used at NRTS) - a decrease of temperature with height between isothermal (0.0°F per 100 feet) and adiabatic (0.54°F per 100 feet) inclusive.

strong lapse (terminology used at NRTS) - a decrease of temperature with height greater than adiabatic.

lapse rate - the rate of decrease of temperature with elevation.

lofting - describes an effluent plume that is flat on the bottom but exhibits spreading on the topside and to the sides.

looping - describes an effluent plume that appears to loop in the vertical.

mechanical turbulence - irregular motion of the wind caused by an obstacle in the wind stream.

momentum transfer - the transport of velocity from rapidly moving to slower moving layers of the air which will tend to equalize the differences in velocity between various layers in the free atmosphere. At NRTS this phenomenon frequently accounts for the change of winds experienced in the late morning or afternoon.

neutral - the use of this term should be avoided. Meteorologically it is defined as adiabatic (dry) but non-meteorologists frequently use it to mean isothermal conditions or conditions between isothermal and adiabatic.

radiation (non-radioactive) - the process by which energy is transferred through space or through a material medium from one place to another in the form of electromagnetic waves. In meteorology and climatology, radiation from the sun, earth and atmosphere, and the absorption of radiation by the earth and atmosphere, are of fundamental importance.

stability - a state of vertical equilibrium in which the vertical distribution of temperature is such that an element of air will resist displacement from the level at which it is in equilibrium with its environment.

stable - so placed as to resist forces tending to cause motion or displacement.

superadiabatic (lapse rate) - a rate of temperature decrease with height greater than 1°C per 100m (0.54°F per 100 ft). When such a lapse rate prevails the atmosphere is said to be unstable and there will be considerable overturning of the air.

thermal - an ascending air current caused by the heating of a surface.

thermal turbulence - irregular motion of the wind induced by heating, generally heating of the surface beneath the winds.

turbulence - irregular motion of the wind which is made up of a number of small eddies that travel with the general air current, superimposed on it. The tendency of turbulence is to create a uniform vertical distribution of atmospheric properties; turbulence accounts for the transfer of momentum.

unstable - that condition in the atmosphere in which vertical movement is prevalent. This generally occurs when a superadiabatic lapse rate prevails.

veering - the shifting of the wind in a clockwise direction (cf. backing).

wind - air in natural motion relative to the surface of the earth. Direction-wise it is always spoken of as the direction from which the air is flowing. Thus a north wind comes out of the north and moves to the south and any effluent released from a stack would be carried to the south.

ADDITIONAL PROBLEMS

To further develop facility with diffusion calculations one would do well to determine solutions for all of the following problems. As previously indicated slide rule accuracy is sufficient. Answers to these problems are on pages 58 and 59.

In all problems, unless otherwise stated, assume isotropic diffusion and that the stack height and effective height are synonymous.

Continuous Point Source (Problems 1 through 4)

1) During the afternoon when there is a strong lapse condition ($n = .20$) the average wind speed is 25 mph and the rate of emission of effluent is 50 grams each second from a 164-foot stack. Determine the concentration one mile downwind in the center of the plume, the concentration at and the position of $d_{(max)}$.

2) Just before sunset when there is a weak lapse condition ($n = .25$), the average wind speed is 20 mph and the rate of emission of effluent is 300 grams each second from an 82-foot stack. Determine the concentration at a point one-quarter mile downwind and 20 feet to the right of the plume axis, the concentration at and the position of $d_{(max)}$.

3) In the early evening when there is a weak inversion ($n = .33$), the average wind speed is 10 mph and the rate of emission of effluent is 250 grams each second from a 328-foot stack. Determine the concentration three miles downwind in the center of the plume, the concentration at and the position of $d_{(max)}$.

4) During the night when there is a strong inversion ($n = .50$), the average wind speed is 5 mph and the rate of emission of effluent is 1000 grams each second from a 246-foot stack. Determine the concentration twenty miles downwind in the center of the plume, the concentration at and the position of $d_{(max)}$.

Instantaneous Point Source (Problems 5 through 8)

5) During the afternoon when there is a strong lapse condition ($n = .20$), the average wind speed is 30 mph and a single puff of effluent containing 200,000 grams is emitted from a 328-foot stack. Determine the concentration one-half mile downwind in the center of the cloud, the concentration at and the position of $d_{(max)}$.

6) Just before sunset when there is a weak lapse condition ($n = .25$) the average wind speed is 15 mph and a single puff of effluent containing 300,000 grams is emitted from a 246-foot stack. Determine the concentration one mile downwind and 20 feet to the right of the cloud center, the concentration at and the position of $d_{(max)}$.

7) In the early evening when there is a weak inversion ($n = .33$), the average wind speed is 9 mph and a single puff of effluent containing 400,000 grams is emitted from a 164-foot stack. Determine the concentration four miles downwind in the center of the cloud, the concentration at and the position of $d_{(max)}$.

8) During the night when there is a strong inversion ($n = .50$), the average wind speed is 5 mph and a single puff of effluent containing 500,000 grams is emitted from an 82-foot stack. Determine

the concentration ten miles downwind in the center of the cloud,
the concentration at and the position of $d_{(max)}$.

Instantaneous Point Source, Requiring a finite volume correction
(Problems 9 and 10)

9) A reactor in a building 50 meters by 50 meters and 25 meters high explodes and knocks out all the walls of the building. The prevailing relevant meteorological conditions are 1) an evening with a weak inversion ($n = .33$) and 2) a wind speed of 8 mph. There is a release of 250,000 grams. Assuming that the release point is the top of the building, determine the finite volume correction and the concentration two miles downwind in the center of the cloud.

10) A reactor in a building 50 meters by 50 meters and 50 meters high explodes and knocks out all of the walls of the building. The prevailing relevant meteorological conditions are 1) a night with a strong inversion ($n = .50$) and 2) a wind speed of 3 mph. There is a release of 500,000 grams. Assuming that the release point is the top of the building, determine the finite volume correction and the concentration five miles downwind in the center of the cloud.

Total Integrated Dosage (Problems 11 and 12)

11) In the early evening when there is a weak inversion ($n = .33$), the average wind speed is 8 mph and a puff of effluent containing 100,000 grams is emitted from a 328-foot. Determine the total integrated dosage ten miles downwind in the center of the cloud, the concentration at and the position of $d_{(max)}$.

12) During a night when there is a strong inversion ($n = .50$), the average wind speed is 3 mph and a puff of effluent containing

200,000 grams is emitted from a 164-foot stack. Determine the total integrated dosage 20 miles downwind in the center of the plume, the concentration at and the position of $d_{(max)}$.

Ground Deposition (Problems 13 and 14)

13) In the early evening when there is a weak inversion ($n = .33$) the average wind speed is 6 mph and the emission rate from a 328-foot stack is 100 grams each second. What is the maximum deposition rate five miles downwind?

14) During a night when there is a strong inversion ($n = .50$) the average wind speed is 3 mph and the emission rate from 164-foot stack is 500 grams each second. What is the maximum ground deposition ten miles downwind?

Cloud Width and Cloud Height (Problems 15 and 16)

15) In the early evening when there is a weak inversion ($n = .33$) the average wind speed is 6 mph and the emission rate from a 246-foot stack is 1000 grams each second. Determine the cloud width and height two miles downwind where each is 10% of the axial concentration.

16) During the night when there is a strong inversion ($n = .50$), the average wind speed is 2 mph and the emission rate from an 82-foot stack is 1000 grams each second. Determine the cloud width and height at a position ten miles downwind where each is 25% of the axial concentration.

Effective Stack Height (Problems 17 and 18)

17) Gas emitted from an 82-foot stack with a 10-foot diameter

has an excess temperature of 560°C over the ambient air temperature of 7°C . If the stack draft velocity is 220 fps and the mean wind speed is 30 mph, what is the effective stack height?

18) Gas emitted from a 100-foot stack with a 20-foot diameter has an excess temperature of 1200°C over the ambient air temperature of 27°C . If the stack draft velocity is 410 fps and the mean wind speed is 14 mph, what is the effective stack height?

$d_{(\max)}$ (Problem 19)

19) Given the following data, a continuously emitting source and a wind speed of 10 mph, fill in the following table:

		$d_{(\max)}$ (m)			
$ht_{(m)}$	n	.20	.25	.33	.50
25					
50					
75					
100					

$\chi_{(\max)}$ (Problem 20)

20) Given the following data, an emission rate of 1 gram each second and a wind speed of 10 mph, fill in the following table:

		$\chi_{(\max)}$ (gm/m ³)			
$ht_{(m)}$	n	.20	.25	.33	.50
25					
50					
75					
100					

ANSWERS

1	a) $\chi = 6.73 \times 10^{-5} \text{ gm/m}^3$
b) $\chi_{(\text{max})} = 4.18 \times 10^{-4} \text{ gm/m}^3$
c) $d_{(\text{max})} = 347 \text{ m}$	8	a) $\chi = 8.11 \times 10^{-1} \text{ gm/m}^3$
b) $\chi_{(\text{max})} = 4.712 \text{ gm/m}^3$
c) $d_{(\text{max})} = 5987 \text{ m}$
2	a) $\chi = 1.18 \times 10^{-2} \text{ gm/m}^3$
b) $\chi_{(\text{max})} = 1.26 \times 10^{-2} \text{ gm/m}^3$
c) $d_{(\text{max})} = 412 \text{ m}$	9	a) $(\bar{u}t)_0 = 1389 \text{ m}$
b) $\chi = 9.32 \times 10^{-2} \text{ gm/m}^3$
3	a) $\chi = 8.04 \times 10^{-4} \text{ gm/m}^3$
b) $\chi_{(\text{max})} = 1.301 \times 10^{-3} \text{ gm/m}^3$
c) $d_{(\text{max})} = 8004 \text{ m}$	10	a) $(\bar{u}t)_0 = 10607 \text{ m}$
b) $\chi = 2.403 \times 10^{-1} \text{ gm/m}^3$
4	a) $\chi = 1.871 \times 10^{-2} \text{ gm/m}^3$
b) $\chi_{(\text{max})} = 1.893 \times 10^{-2} \text{ gm/m}^3$
c) $d_{(\text{max})} = 35,500 \text{ m}$	11	a) $\text{TID} = 3.939 \times 10^{-1} \text{ gm/m}^3$
b) $\chi_{(\text{TID max})} = 6.506 \times 10^{-1} \text{ gm/m}^3$
c) $d_{(\text{max dosage})} = 7841 \text{ m}$
5	a) $\chi = 1.424 \times 10^{-2} \text{ gm/m}^3$
b) $\chi_{(\text{max})} = 2.945 \times 10^{-2} \text{ gm/m}^3$
c) $d_{(\text{max})} = 709 \text{ m}$	12	a) $\text{TID} = 10.09 \text{ gm/m}^3$
b) $\chi_{(\text{TID max})} = 14.41 \text{ gm/m}^3$
c) $d_{(\text{max dosage})} = 16731 \text{ m}$
6	a) $\chi = 4.75 \times 10^{-2} \text{ gm/m}^3$
b) $\chi_{(\text{max})} = 1.047 \times 10^{-1} \text{ gm/m}^3$
c) $d_{(\text{max})} = 1307 \text{ m}$	13	$\omega_{\text{dry max}} = 3.95 \times 10^{-6} \text{ gm/m}^2/\text{sec}$
7	a) $\chi = 6.54 \times 10^{-2} \text{ gm/m}^3$
b) $\chi_{(\text{max})} = 4.712 \times 10^{-1} \text{ gm/m}^3$
c) $d_{(\text{max})} = 2374 \text{ m}$	14	$\omega_{\text{dry max}} = 3.32 \times 10^{-5} \text{ gm/m}^2/\text{sec}$
		15	$2y_0 = 162 \text{ m}$
$z_0 = 81 \text{ m}$
		16	$2y_0 = 128 \text{ m}$
$z_0 = 64 \text{ m}$

ANSWERS (CONTINUED)

17 $\Delta h = 159$ feet; effective stack height = 241 feet.

18 $\Delta h = 2386$ feet; effective stack height = 2486 feet.

19

$\frac{n}{ht(m)}$		$d_{(max)}(m)$			
	.20	.25	.33	.50	
25	133	371	1247	10564	
50	312	894	3147	28175	
75	542	1555	5439	48380	
100	789	2259	8012	71003	

20

$\frac{n}{ht(m)}$		$\chi_{(max)}(gm/m^3)$			
	.20	.25	.33	.50	
25	8.33×10^{-5}	8.33×10^{-5}	8.33×10^{-5}	8.33×10^{-5}	
50	2.082×10^{-5}	2.082×10^{-5}	2.082×10^{-5}	2.082×10^{-5}	
75	9.25×10^{-6}	9.25×10^{-6}	9.25×10^{-6}	9.25×10^{-6}	
100	5.20×10^{-6}	5.20×10^{-6}	5.20×10^{-6}	5.20×10^{-6}	

As indicated by the formula, a change in the n-value has no effect on $\chi_{(max)}$.

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