SAVANNAH RIVER PLANT
STACK GAS DISPERSION AND MICROCLIMATE SURVEY

Prepared by

L. L. FALK
C. B. CAVE
W. R. CHALKER
J. A. GREENE
C. W. THORNGATE

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ABSTRACT

Atmospheric diffusion and microclimate studies at Savannah River are reported. A new simple method was developed enabling operating personnel to establish the downwind concentration and dispersion pattern of materials released from stacks. A statistical study of atmospheric temperature inversions was made because of their influence on atmospheric diffusion. The microclimate of the plant site is compared with Augusta.

E. I. du Pont de Nemours & Co. (Inc.)
Explosives Department - Atomic Energy Division
Savannah River Laboratory

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Reproduction of Memo, L. L. FALK to
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SAVANNAH RIVER PLANT

STACK GAS DISPERSION AND MICROCLIMATE STUDY

I - SUMMARY

A. PURPOSE OF STUDY

1. Determine the stack gas dispersion characteristics of the Savannah River Plant Site.
2. Develop a simple procedure for rapidly determining dispersion characteristics under a given weather condition with a minimum of equipment.
3. Characterize the microclimate of the plant site as it affects plant design, construction, and operation and determine the limits within which the long term climatological records of the Augusta Weather Bureau may be applied to the plant site.

B. RESULTS

1. Stack Gas Dispersion

- a. The dimensions of the ground-level dispersion pattern of stack effluents were related to simple measurements of wind speed and direction variations (See Fig. 7 and 8). A new diffusion equation was developed on the basis of observed data (See p. 18, Fig. 2 and Exhibit D).
- b. Working charts based on wind measurements were developed to permit rapid computation of the dimensions (Fig. 7, 8 and 9) and magnitude of average concentrations at ground level, accurate in most instances within a factor of two (Fig. 10).
- c. The ratio of peak, one-minute, to average, 1/2 to 1 hour, concentrations was related to wind variability (Refer to Fig. 12).

2. Dispersion Climatology

Savannah River wind records for one year and U. S. Weather Bureau observations of atmospheric temperature-height relationship at Atlanta and Charleston, taken at 10 a.m. and 10 p.m., for an 8-year period were analyzed and show:

- a. Inversions, i.e., low atmospheric turbulence, at ground level may be expected at Savannah River 35 to 40 per cent of the hours (Fig. 29), and at least on 2/3 to 3/4 of the nights of the year (Fig. 17). Strong turbulence may be expected about 20 per cent of the hours (Fig. 29).
 - b. The frequency of both rain and inversions based at ground surface is less than 5 per cent at 10 p.m. or at 10 a.m. (Refer to Fig. 20).
 - c. Inversion intensity as measured by the rate of temperature increase with height is less during rainy than non-rainy periods (Fig. 21 and 22).
 - d. Inversion intensity is inversely and nonlinearly related to inversion thickness. Very stable inversions are usually less than 300 ft. thick (Fig. 23).
 - e. There is reasonable agreement in the frequencies of inversions obtained from the U. S. Weather Bureau analysis and the frequency of inversions at Dunbarton as indicated by wind variability records (See Fig. 30).
 - f. Comparison of wind speed distributions for Dunbarton, 400 area and Augusta airport for July, 1952, show approximately twice as frequent an occurrence of wind speeds of 1 - 3 m.p.h. at 400 area than at the other two locations. Calm occurred 15 per cent of the time at 400, 11 per cent at Augusta and only 1 per cent at Dunbarton (Fig. 34).
3. Microclimatology - (See Letter, L. L. Falk to C. S. Robinson, Jan. 10, 1952 - Exhibit E)
- a. Plant locations of higher elevation show maximum dry bulb temperatures an average of 1-3° F. cooler than Augusta; at lower plant elevations, these average about the same as Augusta.
 - b. Higher plant elevations show minimum dry bulb temperatures an average of up to 2° F. cooler than Augusta; at lower elevations these average 2 to 4° F. cooler than Augusta.
 - c. Maximum wet bulb temperatures are essentially the same at the plant as at Augusta.

- d. The maximum continuous number of hours that a high wet bulb temperature persists is related to the departure of that temperature below the monthly maximum wet bulb. For example, the monthly maximum wet bulb generally persists for no more than two hours at a time, but a wet bulb within 1 or 2° F. of the monthly maximum may persist up to seven hours at one time.
- e. The number of hours of very high humidity (over 95 per cent) is approximately 25 per cent higher in the lower elevated portions of the plant site than in the higher portions.

C. CONCLUSIONS

1. A meteorological tower requiring operating personnel is not needed to estimate the rate of dispersion of stack gases.
2. Standard wind direction and wind speed recorders provide information necessary to completely express the dispersion pattern. Thus, operating supervisory personnel have a simple and readily available tool for determining the dispersion effects of stacks in their area. In agreement with basic operating philosophy, operating supervisory personnel can handle their problem and will have to rely on a specialist only when unusual conditions are encountered (See pp 23 - 32).
3. Since the microclimate of the site is so similar to the Augusta climate, a minimum of weather records need be kept for operating purposes.
4. Dispersion conditions in the 400 Area require continuous close monitoring because more air stagnation develops frequently (Fig. 34).
5. Weather conditions are satisfactory for using cooling towers, but not all locations in the area are equally good. Future specific installations should be carefully checked in this regard. A careful economic and engineering evaluation should be made before deciding on their use (See Exhibit E).

D. RECOMMENDATIONS

1. Install a wind instrument in each main operating area.
2. Maintain hygrothermographs only at Dunbarton Fire Tower and in the 400 Area unless additional data are required by Operations.
3. Train operating supervision in the procedure for computing dispersion patterns.

E. SIGNATURES

Prepared by:

X. R. Folke
Engineering Service Div.

Supervised by:

[Signature]
Group Supervisor

Approved by:

[Signature]
Chief Engineer

Submitted by:

[Signature]
Division Manager

II - DISCUSSION

A. INTRODUCTION

1. Purpose of Study

The basic problems forming the foundation for the present study revolve around:

- a. Evaluation of the dispersion characteristics describing the spread of a gas or finely divided dust upon discharge from a stack. Of particular interest are the concentrations or dosages at ground level of material released from stacks, the geometrical shape of the ground-level dispersion pattern, the adequacy with which present dispersion theories describe actuality, and the relationship of short-time (1-minute) peak concentrations to the average (1/2- to 1-hour) concentration at a point downwind.
- b. Development of a simple and rapid method for determining, within reasonable limits of accuracy, the magnitude and shape of a dispersion pattern from any stack based on easily obtainable information, such as a trace of a wind speed and direction recorder. The object here is to place at the disposal of operating personnel a method that requires a minimum knowledge of stack meteorology and will eliminate the need for complex installations such as a meteorological tower and the resultant maintenance of a large staff of trained meteorologists.
- c. Establishment of the characteristics of the micro-climatology of the Savannah River plant site as it affects plant design and operations. Involved here are comparisons of various site locations, particularly in terms of wind, temperature and humidity, (1) with Augusta for establishment of long term site climate records based on Augusta records; and (2) with one another to determine local variations.

2. Scope of Study

a. Budget and Cost

This study was organized on a budget of \$114,000 of which \$20,000 was allocated for materials and equipment. It was anticipated that less than two years would be required to organize and carry out the program. The actual material and equipment

cost was \$20,099 and the total cost is not expected to exceed \$118,000 including the issuance of this report.

b. Methodology

All meteorological equipment used was either purchased from manufacturers or borrowed from the U. S. Navy or U. S. Weather Bureau. Since the technique of the dispersion work was based on a recently developed method, certain equipment had to be built either by an outside contractor or by Savannah River Engineering Department Construction forces. Various facilities were also provided or constructed by the latter.

c. Personnel

Four meteorologists were assigned full time by the Engineering Service Division to conduct this study. The services of a consultant outside the Company were used to review progress, plan work, and assist in some of the theoretical and mathematical aspects of the program.

d. Closing of Study

Purchased equipment not expended at the end of the field program has been transferred to Atomic Energy Division, Explosives Department. Equipment borrowed from S.R.P. Construction and U. S. government Agencies was returned.

3. Scope of Report

This report contains the following:

- a. Brief review of dispersion theory.
- b. Description of methods used in the dispersion study and the methods for evaluating experimental dispersion tests.
- c. Development of aids for rapid evaluation by Operations personnel of dispersion of material from stacks.

- d. Development of a more precise dispersion equation.
- e. Presentation of wind and inversion analysis based on U. S. Weather Bureau records for Augusta or nearby stations.
- f. Development of wind, temperature and humidity relationships between Augusta and the plant site and within the plant site.

4. Acknowledgments

Dr. George S. Benton of Johns Hopkins University was employed as consultant for the study. Dr. Benton made valuable contributions by checking mathematical derivations, deriving methods of computing dispersion parameters, and deriving the modified version of the Bosanquet and Pearson equation to fit the observed data (Exhibit D).

The fine cooperation of the Engineering Department, Construction Division, Savannah River Plant, was of great assistance to the E.S.D. Group.

In addition, valuable information on the fluorescent particle technique or loans of certain equipment were obtained from the Chemical Department of Stanford University, U. S. Army Chemical Corps, U. S. Weather Bureau, and U. S. Navy.

B. ATMOSPHERIC DISPERSION

1. Status of Knowledge

a. History

It has been generally realized that dispersion of stack effluents is markedly affected by both weather and non-weather factors. Bosanquet and Pearson (Ref. 1) developed the first workable equation which set forth these factors and permitted an approximate estimation of the ground-level concentration of materials emitted from stacks. Sutton (Ref. 2) has more recently published similar formulas. The principal drawback to using these and similar equations for everyday use is that the atmospheric turbulence constants involved can be evaluated only with expensive equipment and long tedious calculations. Present practice in most air pollution problems involves computations of the equations assuming average constants for different conditions of atmospheric turbulence.

b. Available Theory

The formulas that have been developed attempt to define the shape of the atmospheric "cone" in which the stack gases are dispersed. This cone is ventilated at a constant rate according to the velocity of the wind. The cone's shape and volume are determined by the stack height, the length of dispersion along the longitudinal axis (the distance from the stack), the height of dispersion along the vertical axis, and the width of the dispersion along the axis at right angle to the direction of flow. Variations in deviations from a true cone are compensated for by different exponents and power functions. In the formulas that have been developed, the average concentration at ground level over a period of one hour or so varies directly as the emission rate of the material; inversely as the wind speed; inversely as the distance raised to a power of 1.5 to 2.0; and inversely as the exponent of the ratio of stack height to distance and the ratio of distance to one side of the axis of flow to distance downwind.

The equations most frequently in use are:

Bosanquet and Pearson

$$C = \frac{M}{\sqrt{2\pi} p q u x^2} e^{-d} \quad (1)$$

$$\text{where } d = \frac{h}{p x} + \frac{y^2}{2 q x^2}$$

Sutton

$$C = \frac{2M}{\pi C_y C_z u x^{2-n}} e^{-g} \quad (1a)$$

$$\text{where } g = \frac{1}{x^{2-n}} \left(\frac{h^2}{C_z^2} + \frac{y^2}{C_y^2} \right)$$

The symbols above are:

- C = ground-level concentration
- M = rate of emission of material from stack
- u = wind speed
- h = stack height
- x = distance downwind from stack
- y = crosswind distance to one side of downwind axis of dispersion cloud
- p = Bosanquet's vertical diffusion coefficient
- q = Bosanquet's horizontal diffusion coefficient
- C_z = Sutton's vertical diffusion coefficient
- C_y = Sutton's horizontal diffusion coefficient
- n = Sutton's turbulence index

The Bosanquet formula is simpler since it involves only two dispersion coefficients. Furthermore, the accurate determination of the value n requires complex instrumentation and the value of C is highly sensitive to n. Also, at the point of maximum downwind ground-level concentration, the equations of both Bosanquet and Pearson and Sutton reduce to forms differing only by a constant. In the work of this study Bosanquet's equation was selected as a starting point.

The diffusion coefficients represent the degree of turbulence. The significance of these two coefficients can be visualized as follows:

Turbulence in the atmosphere is made up of random movements of air superimposed upon the

general movement in a downwind direction as measured by the mean wind speed. The magnitude of the vertical turbulence is measured by p . Small vertical turbulence yields a small value of p , i.e., the vertical dimension of the "cone" of dispersion from a stack is small. One result is that the "cone" intersects the ground farther from the stack for smaller values of p than for larger values that are associated with strong turbulence. Thus, the maximum average ground-level concentration is farther from the stack for small turbulence and closer for strong turbulence. Horizontal turbulence is measured by q . When horizontal turbulence is small, q is small and the horizontal dimension of the "cone" of dispersion from a stack is small. When horizontal turbulence is great, both q and the horizontal dimension of the "cone" are relatively large. The result of this is that the horizontal angle of spread of a cloud of material from a stack is small (a few degrees) for low q and large (up to 100-120 degrees) when turbulence is great.

The extremes of turbulence are most likely encountered at low wind speeds on cloudless days and nights. Surface heating during the day creates strong turbulence while cooling of the ground at night creates an inversion with little turbulence.

2. Method Selected for Studying Dispersion from Stacks

There are numerous field techniques for studying dispersion of stack effluents. Most methods such as scattering of balloons, transfer of heat or moisture, and various measurements of turbulence characteristics are indirect approaches. Further theoretical treatment of the intermediate data obtained is required to obtain desired dispersion information. It was, therefore, decided to use a procedure which gives dispersion data directly.

The method selected was the release of a cloud of finely divided fluorescent particles, the concentrations or dosages of which could be quantitatively evaluated at downwind ground-level sampling points. The reasons for selecting this method are as follows:

- (1) it is a direct method.
- (2) the technique and instrumentation have been previously developed and evaluated.

- (3) simplicity.
- (4) ease in identifying the fluorescent tracer.
- (5) results are applicable to both gaseous and fine particle dispersion problems.
- (6) tracer is nontoxic at concentrations used.

A fuller discussion of these points is given in Exhibit A.

3. Equipment

The equipment purchased or built for the study of stack dispersion by the fluorescent particle tracer technique is described in detail in Exhibit A. In brief, these are:

a. Equipment for fluorescent particle dispersion

- (1) The fluorescent pigment - zinc cadmium sulfide.
- (2) A pigment dispenser - a device which converts a bulk of dry pigment into a cloud of finely divided individual particles and discharges the cloud into the atmosphere to form a source of known and nearly uniform rate.
- (3) Drum samplers - for sampling the air downwind from particle source to obtain variation of pigment concentration with time. Particles are collected by dry impingement upon a moving tape mounted on a rotating drum.
- (4) Filter samplers - evaluates the dosage of particles downwind by drawing air through a filter at known rate.
- (5) Millipore filters - used in filter samplers and are practically 100 per cent efficient in retaining fluorescent particles on the top surface of the filter.
- (6) Microscopic equipment - used to count fluorescent particles caught in drum and filter samplers.

b. Auxiliary equipment

- (1) Stack - an existing 100-ft. forest fire lookout tower at Dunbarton served as an elevated point for pigment dispersion.
- (2) Wind instruments - a permanent recording wind vane and anemometer was installed on top of the fire tower. A hot-wire anemometer was used during certain tests to obtain variations of wind speed with height.
- (3) Wiresonde - an instrument borrowed from the U. S. Navy to obtain variations of temperature and humidity with elevation.
- (4) Balloon - a 400 cu. ft. helium-filled balloon was used to elevate the sensing elements of the wiresonde and hot-wire anemometer instruments.

4. Procedure for Field Experiments (FE)

The duration of field experiments was generally 1/2 to 1 hour based on actual dispersion time of pigment. The preparation for and evaluation of each experiment, however, took several days. In Exhibit B are described in detail the various steps required to successfully carry out one test. These include:

- a. Scheduling of runs - these were at all times of day or night, clear or cloudy weather, except during rain, under various wind speed and turbulence conditions.
- b. Preparation and maintenance of equipment.
- c. Location of samplers downwind - up to one mile from the pigment dispensing point, approximately 50 stack heights. This gave complete coverage under strong turbulence conditions when the maximum ground-level concentrations were within 1000 ft. of the source. Under poor turbulence (inversions) coverage was complete as far downwind as 2 to 5 times the distance to the maximum ground-level concentrations.
- d. Determination of temperature, humidity, and wind relationships with height.
- e. Evaluation of concentrations and dosages from particle counts for each sampler.

- f. Determination of pigment particle rates of emission during the test.
- g. Computation of auxiliary meteorological information which include:
 - (1) Mean wind speed and direction during the test.
 - (2) Wind speed variability - the variation of wind speed at 10-second intervals about representative 10-minute mean wind speeds.
 - (3) Wind direction variability - the variation of wind direction at 10-second intervals about representative 10-minute mean wind directions.

5. Analysis of Field Experiments

Previous sections have shown the approach and methods used to obtain dispersion data directly. The following sections will show how these data have been analyzed and the relation between important diffusion coefficients and meteorological characteristics obtainable from simple wind recording instruments. This leads, finally, to the development of a simple system to permit rapid evaluation of the magnitude and shape of dispersion patterns.

a. Analysis of individual field experiments

When consideration is given to analysis of individual field experiments, a reasonable approach is to compute, from the observed data, dispersion coefficients which, when inserted into an existing theoretical equation, best fit that equation to the observed data. Thus, in effect, each field experiment becomes a single piece of data.

As indicated previously, the Bosanquet and Pearson equation in Section B 1. above is simpler to use than the Sutton equation which has one additional turbulence coefficient. Three methods were developed to compute the coefficients p and q from the observed data. The derivation and application of these are given in detail in Exhibit C. The methods developed were:

- (1) Isopleth method - the dosage (concentration times exposure time) for each sampler in the field is plotted, smoothed lines of equal dosage are drawn, and the diffusion coefficients are computed graphically from the pattern obtained.
- (2) Ratio method - the ratios of the dosages for pairs of points in the dosage pattern permit solution for p and q independently. The trial and error nature of this method makes it lengthy.
- (3) Curve fitting method ("A" method) - this method involves the graphical solution for p and q based on relationships of the dosages observed in a dispersion pattern and is considerably more rapid than the Ratio method.

b. Dimensionless analysis of dispersion tests

Several field experiments must be compared on common basis. Dimensionless analysis affords a method for reducing all field experiments to a common basis for comparison regardless of the differences in pigment emission rate and meteorological conditions between individual tests. In this manner, all observed data can be presented in form for comparison with existing theoretical equations. Also, this type of analysis readily permits modification of existing equations to more nearly fit the observed data.

(1) Dimensionless form of Bosanquet and Pearson equation

When the Bosanquet and Pearson equation (eq. 1) is differentiated with respect to x , equated to zero and solved for x , the value of x_m , the distance to the point of maximum concentration is:

$$x_m = h/2p \quad (2)$$

Any distance, x , downwind along the axis of the dispersion cloud can be defined in the dimensionless form

$$x/x_m = R = \frac{2px}{h} \quad (3)$$

$$x = \frac{Rh}{2p} \quad (4)$$

Dosage, D , equals concentration multiplied by time, t , of exposure

$$D = Ct \quad (5)$$

Substituting equations (4) and (5) in eq. (1) yields

$$D = Ct = \frac{4Mt}{\sqrt{2\pi} u R^2 h^2} \left(\frac{p}{q}\right) e^{-2/R} \frac{-2y^2 p^2}{q^2 R^2 h^2} \quad (6)$$

The maximum ground-level dosage, D_m , occurs at $y = 0$ and $R = 1$. Thus, from equation (6),

$$D_m = \frac{4Mt}{\sqrt{2\pi} u h^2} \left(\frac{p}{q}\right) e^{-2} \quad (7)$$

When equation (6) is divided by equation (7), the ratio is obtained of the dosage anywhere in the dispersion pattern to the maximum dosage directly downwind at x_m :

$$D/D_m = \frac{1}{R^2 e^{-2}} e^{-2/R} \frac{-2(y)^2}{R^2(h)} \frac{(p)^2}{(q)^2} \quad (8)$$

Let $S = D/D_m$ and taking the natural logarithm of both sides of eq. (8) gives

$$\ln S = 2 - 2 \ln R - 2/R - \frac{2}{R^2} \frac{(y)^2}{(h)} \frac{(p)^2}{(q)} \quad (9)$$

Thus, when $y = 0$, i.e., along the downwind axis of the dispersion cloud,

$$\ln S = 2 - 2 \ln R - 2/R \quad (10)$$

which is completely dimensionless. This shows that the nondimensional shape of the downwind dosage curve along the axis of the cloud is not dependent upon the stack height nor upon the state of turbulence as measured by the coefficients p and q .

This is also true in the crosswind direction. At $R = 1$, equation (9) reduces to

$$\ln S = -2 \frac{(y)^2}{(h)} \frac{(p)^2}{(q)} \quad (11)$$

When $S = 0.1$, $\ln S = -2.30$ and y in eq. (11) becomes $y_{0.1}$, the distance from the center line along the line $x = x_m$ to the point where $D = 0.1 D_m$. Then

$$(p/q)^2 = 1.15 \left(\frac{h}{y_{0.1}} \right)^2 \quad (12)$$

Substituting eq. (12) into eq. (11) gives

$$\ln S = -2.30 \left(\frac{y}{y_{0.1}} \right)^2 \quad (13)$$

If $L = y/y_{0.1}$, i.e., the ratio of a crosswind distance y to the crosswind distance to the point where $S = 0.1$, both measured at $R = 1.0$, then

$$L^2 = \left(\frac{y}{y_{0.1}} \right)^2 = -0.434 \ln S = -\log S. \quad (14)$$

which, again, expresses crosswind dispersion in a dimensionless form. Since S is $\neq 1$, $-\log S \neq 0$.

The significance of equations (10 and (14) is this:

Regardless of stack height or turbulence, when stack dispersion according to Bosanquet and Pearson's formula is expressed in dimensionless form, the shape of the dispersion pattern will be the same. The dimensionless plot of the Bosanquet and Pearson equation is shown in Figure 1. The dimensionless units are S , R , and L .

(2) Dimensionless Treatment of Observed Data

A dimensionless plot was made of the downwind dosages observed for each field test with data sufficiently complete to determine with reasonable accuracy the values of x_m and D_m . Similarly the lateral (crosswind) distance from the axis to the points where $S = 0.1$ were plotted in a dimensionless form. A curve of best fit was drawn for both crosswind and downwind plots and both curves were utilized to make the dimensionless area plot shown in Figure 2. Figure 2 is based on observed data plus the reasonable assumptions of (a) a normal crosswind distribution along the y axis at $x = x_m$, and (b) lines for $1/S > 0.1$ have the same relative shape as the line $S = 0.1$.

Comparison of the observed area plot (Figure 2) with the theoretical plot (Figure 1) reveals significant differences in shape for values of R greater than 1.

- (a) The theoretical dosage becomes approximately twice the observed dosage as S approaches 0.1 ($R = 5$).
- (b) The differences in shapes can be interpreted as signifying that the horizontal diffusion coefficient, q , decreases with increased distance from the source while the vertical diffusion coefficient, p , increases with distance. The theoretical equation of Bosanquet and Pearson assumes p and q are constants for a given turbulence condition.

c. Form of New Equation

The Bosanquet and Pearson equation can be modified so that it will practically fit the observed dispersion patterns. The modified equation is

$$D = \frac{K M t}{\sqrt{2\pi} p_m q_m u x_m^2 R^{2.16}} e^{-\frac{h}{p_m x_m R^{1.44}} - \frac{y^2}{2 q_m^2 x_m^2 R^{1.44}}} \quad (15)$$

where $q_m = q$ at x_m

and $p_m = p$ at x_m

The plot of the lines $S = 0.1$ and 0.5 from this equation are shown as dashed lines on the observed dimensionless plot in Figure 2. Details of the derivation of this equation are given in Exhibit D. Fuller discussions of the variations of p and q with downwind distance are also shown in this Exhibit.

d. Information required to use dimensionless plot.

(1) Scale Factors

The dimensionless plot of observed dispersion patterns (Figure 2) is expressed in terms of three scale factors:

$$\begin{aligned} S &= D/D_m = \text{magnitude scale factor} \\ R &= x/x_m = \text{downwind scale factor} \\ L &= y/y_{0.1} = \text{crosswind scale factor} \end{aligned}$$

To define the actual shape of the dispersion pattern, it is necessary to know the downwind and crosswind scale factors, in particular x_m and $y_{0.1}$.

(a) Downwind scale factor, R.

As indicated previously (eq. 2), the distance to the maximum concentration point, x_m , is a function of the vertical diffusion coefficient, p , and the stack height, h . Therefore, a means for measuring p will immediately yield x_m for a given stack. It was found that the wind speed variability as measured by a recording anemometer could be related both to p as determined by methods outlined in

Exhibit C as well as to the observed distance to the maximum concentration. Examples of nighttime and daytime wind speed (and direction) traces are shown in Figures 13 and 15. The variation shown is due to changes in turbulence from low at night to strong in the day.

If σ_{us} is the standard deviation of the wind speeds at 10-second intervals about the mean speed, $\bar{u}$ for 10 minutes, then the line which best fits the observed data for the most completely sampled tests is

$$p = 0.57 \frac{\sigma_{us}}{\bar{u}} \quad (\text{See Figure 3}) \quad (16)$$

Figure 4 shows the relationship observed between x_m/h and $\sigma_{us}/\bar{u}$ and indicates the relationship

$$\frac{\sigma_{us}}{\bar{u}} \cdot \frac{x_m}{h} = 1.2 \quad (17)$$

Estimation of σ_{us} is somewhat difficult from usual wind speed recording instruments. The range of the wind speed variability, i.e., the average width of the recorded wind speed trace is relatively simple to determine for a short time interval such as 10 minutes. Examinations of wind speed records for various field experiments showed that the range, r_{us} , of 10-second wind speed variations for a 10-minute period was approximately 4 times the standard deviation, σ_{us} .

$$r_{us} = 4 \sigma_{us} \quad (18)$$

Therefore eq. (17) can be expressed as

$$\frac{r_{us}}{\bar{u}} \cdot \frac{x_m}{h} = 4.8 \quad (19)$$

Thus, the scale factor R can be determined from the wind speed trace in terms of stack heights, x/h and x_m/h .

(b) Crosswind scale factor

The evaluation of the crosswind factor, L , requires determination of $y_{0.1}$. This is related, in part, to the horizontal diffusion coefficient, q . Just as the variability of the wind speed is related to p , so the variability of the wind direction was found to be related to q as determined for the field experiments by methods outlined in Exhibit C.

If σ_{es} is the standard deviation of the wind direction at 10-second intervals about the mean direction for 10 minutes, the straight line which best fits the data for the most completely sampled tests is

$$q = 0.048 + 0.015\sigma_{es} \quad (20)$$

where σ_{es} is measured in degrees. (See Figure 5.)

According to eq. (12) derived from the Bosanquet and Pearson theory,

$$(p/q)^2 = 1.15 (h/y_{0.1})^2 \quad (12)$$

or

$$\left(\frac{y_{0.1}}{h}\right)(p/q) = 1.15 = k \quad (21)$$

Substituting eq. (16) and eq. (20) into (21) yields

$$\left(\frac{y_{0.1}}{h}\right)\left(\frac{0.57\sigma_{us}/\bar{u}}{0.048 + 0.015\sigma_{es}}\right) = k \quad (22)$$

or

$$\left(\frac{y_{0.1}}{h}\right)\left(\frac{38\sigma_{us}/\bar{u}}{3.2 + \sigma_{es}}\right) = k \quad (23)$$

The values of $y_{0.1}/h$, $\sigma_{us}/\bar{u}$ and σ_{es} for the field experiments of best sampler coverage of the dispersion field were substituted into eq. (23) to solve for k . The mean value of k computed for these

tests was 1.5 with 2/3 of the data between $k = 1.0$ and 2.0 . Thus,

$$\frac{y_{0.1}}{h} = 1.5 \frac{(3.2 + \sigma_{es})}{(38 \sigma_{us}/u)} \quad (24)$$

As in the case of σ_{us} , σ_{es} is relatively difficult to obtain rapidly from a wind direction trace. The range of 10-second wind direction variability, r_{es} , was related to the standard deviation, σ_{es} , by

$$r_{es} = 4\sigma_{es} \quad (25)$$

Therefore, eq. (24) becomes

$$\frac{y_{0.1}}{h} = 1.5 \frac{(12.8 + r_{es})}{(38 \sigma_{us}/u)} \quad (26)$$

or

$$\frac{y_{0.1}}{h} = \frac{12.8 + r_{es}}{25.3 \sigma_{us}/u} \quad (26a)$$

Eq. (26) allows solution of $y_{0.1}$ in stack heights and, therefore, determination of the crosswind scale factor, L , in terms of quantities available from the trace of a recording wind vane and anemometer.

(c) Magnitude scale factor

The magnitude scale factor, $S = D/D_m$, depends on evaluation of D_m , the value of the maximum downwind ground-level dosage (or concentration) at the centerline of the dispersion cloud ($x = x_m$, $y = 0$).

Equation (7) is the expression of Bosanquet and Pearson for this maximum dosage. In practically every field test, the observed dosages were higher than expected. The insertion of a constant, K , in eq. (7) is a means of fitting the equation to the data.

$$D_m = \frac{4KQt}{\sqrt{2\pi} u h^2} \frac{(p)}{(q)} e^{-2} \quad (27)$$

Computation of K for individual field experiments is demonstrated in Exhibit C.

Neither K nor p/q proved to be constants nor could a relationship be established between K , p/q and the meteorological characteristics, T_{es} or σ_{us}/u . By rearrangement of eq. (27), a new constant, K' , can be obtained

$$\frac{D_m h^2 u}{M_t} = K' = \frac{C_m h^2 u}{M} \quad (28)$$

The value of K' was computed for the experiments of best coverage of the dispersion pattern. An average value of 0.19 was obtained with 85 per cent of the values of K' within a factor of 2 of 0.19 and 95 per cent within a factor of 3. Thus, by using an average K' to compute D_m or C_m , accuracy within a factor of 2 can usually be expected.

6. Use by Operating Personnel

The following lists the principal information concerning stack dispersion of wastes which may be required, all or in part, by operating personnel.

- (1) The direction and speed of travel of stack gas.
- (2) The distance to the point of average maximum ground-level concentration or dosage.
- (3) The shape of the ground-level dispersion pattern.
- (4) The magnitude of the concentration or dosage at the point of maximum ground-level value.
- (5) The horizontal angle subtended by the largest crosswind dimension of the contamination pattern.
- (6) Relation of the short-time (e.g., one-minute) peak values of concentration to the average concentration (1/2- to 1-hour) at a given point in the dispersion field.

a. Direction and Speed of Travel

The direction followed by material emitted from a stack will be approximately that of the mean wind during the time of emission. It should be noted that wind direction is reported as the direction from which the wind is blowing, e.g., a north wind blows from the north toward the south. Therefore, gas from a source will move toward a direction opposite to that of the wind direction reported by a wind instrument. In certain of the fluorescent particle field experiments the axis of a dispersion cloud at ground level was noted to deviate as much as 10 to 15 degrees from the mean direction of the wind. This was due to deflection of the cloud by small elevations in terrain or by tendency of clouds, at ground level, to follow open fields rather than penetrate heavily wooded areas. This effect was particularly noted downwind from the point of maximum ground-level concentration or dosage.

The rate of travel of airborne contaminants can be estimated from the wind speed measured at the height of discharge. Actually, a better

estimate would be available from some mean wind speed measured between ground level and the height of discharge. This mean speed, in most cases, will be less than the speed at the discharge elevation. Figure 6 or Table I shows the time for air to travel various distances at various wind speeds. For example, in a 7 m.p.h. average wind, material dispersed from a stack will travel 2 miles downwind in 17 minutes.

b. Distance to Point of Maximum Ground-Level Concentration or Dosage

Eq. (19) shows that the distance, in stack heights, to the average maximum ground-level concentration (or dosage) can be determined from the quantity $r_{us}/\bar{u}$ taken from a wind speed trace. The value r_{us} is taken as the width of the wind speed trace over a 10-minute period: $\bar{u}$ is the mean wind speed for the same period. The distance x_m in feet is then determined by entering Figure 7 with $r_{us}/\bar{u}$ to stack height, h ; the value $x_m = x_s$ when $S = 1$. The example in Figure 7 is for $r_{us}/\bar{u} = 0.7$ and $h = 150$ ft. The value of $x_m = 1000$ ft.

c. Shape of Ground-Level Dispersion Pattern

The dimensionless shape of dispersion patterns is shown in Figure 2 based on observed data. Figures 7 and 8 are computing graphs to convert recorded wind information into pattern shape with dimensions in feet.

Figure 7, prepared from eq. (19) and Figure 2, is used to compute the downwind dispersion pattern along the line of mean wind direction. In previous section b., this chart was used to compute x_m , the distance to the maximum downwind dosage or concentration ($S = 1.0 = D/D_m$). Figure 8, prepared from eq. (26a) and Figure 2, permits determination of the crosswind shape of the dispersion pattern at $R = x/x_m = 1$. Figures 2, 7 and 8 enable us to draw contours defining the ground-level shape and relative magnitude of the dispersion cloud from a source for any turbulence condition indicated by a wind trace. All that is required are wind trace readings r_{us} , $\bar{u}$, r_{es} and the stack height h .

Let us assume, for example, that

$$\begin{aligned} r_{us}/\bar{u} &= 0.7 \\ r_{es} &= 10 \text{ degrees} \\ h &= 150 \text{ ft.} \end{aligned}$$

and that we wish to calculate the dimensions of the dispersion cloud defined by the ground-level concentration of $0.1 D_m$.

- (1) Enter Figure 7 with $r_{us}/\bar{u}$ at 0.7 to $h = 150$ and across to the two lines of $S = 0.1$. The ground-level dosage (or concentration) is then 0.1 the maximum dosage (D_m or C_m) at 260 and 5200 ft. from the source measured along the mean downwind direction. Between 260 and 5200 ft., the dosage (D) is greater than $1/10 D_m$ and between the stack and 260 ft. as well as beyond 5200 ft., D is less than $1/10 D_m$. The values of downwind distance to other values of S between 0.1 and 1.0 can also be read and plotted.
- (2) Enter Figure 8 with $r_{us}/\bar{u}$ at 0.7 to r_{es} at 10 degrees, rise vertically to $h = 150$ and across to the line of $S = 0.1$. This yields a value of $y_{0.1} = 190$ ft., i.e., the crosswind distance to $S = 0.1$ at the downwind distance to the maximum concentration is 190 ft. on either side of the mean downwind direction.
- (3) The downwind distance to maximum concentration was determined to be 1000 ft. in section b. above.
- (4) Plot the data in (1) - (3) above and draw the $S = 0.1$ contour using Figure 2 as a pattern.

d. Alternate Method for Sections b. and c.

An alternate procedure for evaluating the shape and dimensions of the dispersion pattern involves the preparation of a series of charts of which Figure 9 is an example. This sample chart has been prepared from Figures 2, 7 and 8 for a value of wind direction variation range, r_{es} , of 30 degrees. Similar charts can be prepared for other values of r_{es} , for example, 10, 20, 30, 40, 50, 70 and 90 degrees. It is believed that

selection of the chart of r_{es} value closest to the observed value will give results of sufficient accuracy for most purposes.

The two tables on the charts give the distances in stack heights for values of S along the downwind line ($y=0$) and the crosswind line at x_m at various values of $r_{us}/\bar{u}$. Values of x and y for other points in the field can be computed by interpolation in the two tabulations.

The charts can be made even more useful by having an example of a wind trace of the appropriate r_{es} illustrated on the chart.

In practice, the operator would leaf through such a series of charts and select the one having r_{es} closest to that observed (by measurement of the wind direction trace width or by comparison with the sample trace on the chart). From the wind speed trace, $r_{us}/\bar{u}$ is quickly calculated. The chart is then entered at values of $r_{us}/\bar{u}$ and the downwind and crosswind distances to points of interest can be read off in stack heights. This can be converted to feet by multiplying by the stack height. A series of such charts can even be prepared for a particular stack in which case downwind and crosswind distances in the tables can be in feet (or miles).

To illustrate: An operator wants to know how far downwind will be the maximum average ground-level concentration and how much farther before the concentration decreases to $1/2$ the maximum. He notes that r_{es} is 30 degrees. The illustrated chart in Figure 9 would be selected. The wind speed variation r_{us} range is 5 m.p.h. and the wind speed, $\bar{u}$, averages 10 m.p.h.; therefore, $r_{us}/\bar{u}$ is 0.5. Entering Figure 9, he finds that the maximum concentration (at $S = 1.0$) is 9.5 stack heights downwind and decreases to $1/2$ ($S = 0.5$) farther downwind at 20 stack heights. If the stack is 200 feet high, then these distances are 1900 and 4000 ft., respectively. The actual concentration at these points is then computed by the method in the next section, e.

Also the operator may wish to know the farthest crosswind distance on either side of the dispersion pattern centerline that the ground-level concentration will decrease to 0.1 the maximum ($S = 0.1$).

According to the diagram in Figure 9, this point is at $R = 2.7$ and $L = 1.6$. The crosswind distance to $S = 0.1$ at $L = 1.0$ at $R = 1$ and for $r_{us}/\bar{u}$ of 0.5 is given in the table on the left as 3.4 stack heights. The distance to $L = 1.6$ at $R = 2.7$ is $1.6/1.0 \times 3.4 = 5.4$ stack heights or 1080 ft. for a 200 ft. stack.

e. Magnitude of Ground-Level Dispersion Pattern

The magnitude of the ground-level concentration at any point in a dispersion field is a function of the relative position in that field, the stack height, wind speed and discharge rate of stack effluent. Dosage is, in addition, a function of exposure time.

Eq. (28) enables calculation of dosage or concentration at the point of the maximum average ground-level value ($S = 1$). Eq. (28) resolves to

$$\frac{C_m}{M} = \frac{D_m}{Mt} = \frac{0.19}{h^2 \bar{u}} \quad (29)$$

Eq. (29) is plotted in Figure 10. The chart is entered with wind speed, across to the stack height and down to C_m/M or D_m/Mt . For example, at a wind speed of 10 m.p.h. and a 150-ft. stack, $C_m/M = D_m/Mt = 9.6 \times 10^{-9}$. To obtain C_m , it is necessary to know M , the emission rate of material from the stack. To obtain D_m , both M and exposure time, t , are required. In the example above, let us assume that 10 c.f.m. of gas G are being emitted. Then $C_m = 9.6 \times 10^{-9} \times 10 = 9.6 \times 10^{-8}$ cu. ft. of G per cu. ft. of air $= 9.6 \times 10^{-8} \times 10^6 = 0.096$ parts of G per million parts of air (p.p.m.).

The units of M should be in an appropriate unit per time. Then C_m will have dimensions of those same units per volume of air. Table II gives some appropriate conversion factors to multiply C_m/M to get C_m . To get dosage, multiply C_m by total time of exposure (or emission), t .

Once C_m (or D_m) is determined, other values of C or D in the dispersion field can be determined. In sections 5c and d above, the dispersion pattern

was drawn for lines of $S = C/C_m$ (or D/D_m): $C = C_m$ when $S = 1$. Thus, the value of a line of constant S equals SC_m (or SD_m) where S is less than 1 for all points of the dispersion pattern except at the maximum ground-level point at $x = x_m$, $y = 0$.

f. Horizontal Angle of Dispersion Cloud

In certain monitoring operations, it is necessary to know how wide will be the horizontal angle covered by the cloud as it moves downwind. Figure 2, the dimensionless plot of observed dispersion data, indicates that a line through the dispersion source, x and $y = 0$, is nearly tangent to the lines of equal S at a distance $x = x_m$. If the line $S = 0.1$ is defined as the outer limits of the dispersion cloud, the horizontal angle of cloud spread, α (alpha), is found to be

$$\begin{aligned}\alpha &= 2 \text{ arc tan } 4.5 q. \\ &= 2 \text{ times angle whose tangent is } 4.5 q.\end{aligned}\quad (30)$$

from the field experiments. Substituting eqs. (20) and (25) into (30) yields

$$\alpha = 2 \text{ arc tan } (0.22 + 0.017 r_{es}) \quad (31)$$

Figure 11 shows α for various values of r_{es} . As r_{es} approaches zero, α approaches 25 degrees. This seeming inconsistency is probably due to difficulties in measuring very narrow dispersion patterns. The dashed line would more nearly represent actual conditions.

The values of α (or $1/2\alpha$) can be entered in Figure 9 to increase the usage of that type of chart.

The use of this type of information can be seen in application to monitoring of planned or unplanned releases to the atmosphere. Let us assume that an unplanned release occurs from a stack. Examination of a wind direction trace shows the range of the direction, r_{es} , for the past 10 minutes to be 30 degrees. Reference to Figure 11 reveals that the horizontal angle of dispersion of the resultant plume to be about 72 degrees. Immediate action can then be taken to safeguard the area fanning out at least 35 degrees on either side of the direction toward which the wind is blowing. It must be

recognized that shifts in the average wind direction during such a release may change the direction of travel of a cloud and must be immediately considered in evaluating the horizontal angle of cloud spread. Also, particularly at low wind speeds, the dispersion path downwind may be somewhat distorted by near-by buildings or changes in terrain elevation.

g. Relation of Peak to Average Concentrations

The drum sampler data permit the calculation of the relation of the peak one-minute concentrations to the average concentrations during dispersion tests. In Table III are shown the ratios of the peak one-minute to average concentration (30 to 60 minutes) for those field experiments with adequate drum sampler data. From the values of $\sigma_{us}/\bar{u}$ and eq. (25) for these tests, Figure 12 was prepared. Here the ratio of peak to average concentration is plotted against $\sigma_{us}/\bar{u}$. The relationship is not clearcut but the curve plotted will serve as a guide to the relationship of this ratio to the wind speed variability criterion of turbulence. The peak to average ratio may also be affected by variations in the output of the pigment dispenser that appear as variations downwind which are being attributed to turbulence.

h. Sample Calculations

(1) Nighttime Sample

In Figure 13 is reproduced a wind trace observed about midnight. The problem is to determine:

- (a) The speed and direction of travel of material from the stack.
- (b) The distance downwind to the point of maximum average ground-level concentration.
- (c) The shape of the dispersion cloud as defined by the areas where the average concentrations are all greater than $1/10$ and $1/2$ that at the maximum.
- (d) The relation of peak to average concentrations.

Calculations

The wind direction trace in Figure 13 indicates, for the period marked by parallel black lines (this period arbitrarily chosen for example purposes only), that the mean wind direction was from about 15 degrees west of south (each small division is 5 degrees). Thus, material emitted from a stack will travel toward a direction about 15 degrees east of north.

The wind speed trace for the same period shows the average speed, $\bar{u}$, at about 12 m.p.h. (each division is 1 m.p.h.). According to Figure 6 or Table I, material emitted from a stack will take 5 minutes to travel 1 mile, 10 minutes to travel 2, etc.

The value $r_{us}/\bar{u}$ must be obtained to get the distance, to the point of maximum ground-level concentration. The distance between the two parallel lines of the wind speed trace is r_{us} . In this case, it is about 2.5 m.p.h. Thus, $r_{us}/\bar{u} = 2.5/12 = 0.21$. According to Figure 7, x_m for a 200-ft. stack is 4600 ft. downwind. Also the downwind distances where the concentration is 0.1 the maximum are 1100 feet and 23,000 feet. The distances to the 1/2 maximum concentration ($S = 0.5$) are 2400 and 10,000 ft.

To complete the dimensions of the dispersion pattern, the crosswind distance at x_m to the 0.1 maximum value must be determined. According to the wind direction trace in Figure 13, the range of direction, r_{es} , is 23 degrees. Enter Figure 8 with $r_{us}/\bar{u} = 0.21$ to a line of $r_{es} = 23$ (yielding a value of $y_{0.1}/h = 7.7$). The intersection of the line for stack height of 200 feet and the $y_{0.1}/h = 7.7$ line is off the chart. Therefore, it is necessary to either extend the chart or use a value of $y_{0.1}/h = 0.77$ ($1/10 \times 7.7$) and multiply the answer by 10. Using the latter technique, enter $y_{0.1}/h$ at 0.77 to the $h = 200$ ft. line, and move horizontally along $y_{0.1} = 153$ to the line of $S = 0.1$. The value of $y_s = 153$ (at $S = 0.1$). Multiplication by 10 yields $y_{0.1} = 1530$ ft. Following $y_{0.1} = 153$ only to $S = 0.5$ line, the crosswind distance at x_m to the 1/2 maximum concentration contour is found to be $86 \times 10 = 860$ ft. from the centerline of the dispersion pattern.

In Figure 14, the dimensions calculated above are plotted and $S = 0.1$ and 0.5 contours are drawn similar in relative shape to that on the dimensionless plot in Figure 2. Examination of Figure 14 shows that the point of maximum average ground-level concentration is almost 1 mile from the plant and the area enclosing the $1/10$ maximum is about 4 miles long and about 0.8 miles wide at the widest point $2\frac{1}{2}$ miles downwind.

Consultation of Figure 12 shows that peak concentrations (one-minute) will average 8-9 times the long-time average at a value of $r_{us}/\bar{u}$ of 0.21.

If it is assumed that 100 c.f.m. of gas G are being emitted from the stack, then Figure 10 shows that C_m/M for $\bar{u} = 12.5$ m.p.h. and $h = 200$ ft. is 4.3×10^{-9} . Then, according to Table II, $C_m = C_m/M \times M \times 10^6$ p.p.m. or $4.3 \times 10^{-9} \times 100 \times 10^6 = 0.43$ p.p.m. $S_{0.1} = 0.043$ and $S_{0.5} = 0.22$ p.p.m. was labeled in Figure 14.

(2) Daytime Sample

Figure 15 is a wind trace obtained under daytime conditions of greater turbulence. The stack height is again assumed 200 feet. For the period between the parallel lines,

Mean speed = 17 m.p.h.

Mean direction = 230 degrees (WSW).

Thus, the emitted material will move toward the ENE and reach (Figure 6) 1 mile in 3-4 minutes, 2 miles in 7 minutes, 5 miles in 18 minutes, etc.

Wind speed range, $r_{us} = 13$ m.p.h.

$r_{us}/\bar{u} = 0.77$

Wind direction range, $r_{es} = 85$ degrees

According to Figure 7, the downwind distance to the point of maximum average ground-level concentration for $h = 200$ feet is 1100 feet. The distances to $S_{0.1}$ are 280 and 5300 feet and to $S_{0.5}$ are 560 feet and 2400 feet.

From Figure 8, the crosswind distances to $S_{0.1}$ and $S_{0.5}$ are 1000 ft. and 560 ft. from the centerline of the dispersion pattern.

The calculated dimensions are plotted in Figure 16 and the contours are drawn using Figure 2 for the relative shapes.

Again, 100 c.f.m. of gas G are assumed to be emitted from the stack. Figure 10 shows that for $U = 17$ m.p.h. and $h = 200$ ft., C_m/M is 3.2×10^{-9} . Then, according to Table II, $C_m = C_m/M \times M \times 10^6$ p.p.m. or 0.32 p.p.m. $S_{0.1}$ is 0.032 and $S_{0.5}$ is 0.16 p.p.m. as labeled in Figure 16.

Figure 16 was plotted on the same scale as Figure 14 for comparison.

Figure 12 shows that peak concentrations (one-minute) may be as high as 17-18 times the long-time average for a value of r_{us}/U of 0.77.

7. Dispersion Climatology

The following sections on dispersion climatology deal with those weather factors of particular interest in dispersion of stack effluents. These include (a) frequencies of temperature inversions (low turbulence) based on U. S. Weather Bureau radiosonde ascents, (b) of classes of wind variability types measured at Dunbarton and (c) comparison of distributions of wind direction and speed at Augusta and the site.

a. General

(1) Inversion Analysis

The following section deals with inversion data for Augusta obtained by analysis of the U. S. Weather Bureau radiosonde observations at Atlanta and Charleston for the eight-year period, 1942-1949, inclusive. These two are the closest Weather Bureau Stations to Augusta that make routine radiosonde ascents twice daily.

The data were obtained for inversions of three types

- Type I - Inversions based at the ground.
- Type II - Inversions based above the ground but below 500 ft. - Low inversions.
- Type III - Inversions based above 500 ft. but below 1500 ft. - High inversions.

These types were tabulated by the Bureau according to:

- (1) Time of sounding - 10 a.m. or 10 p.m., E.S.T.
- (2) Average intensity of inversion - °C/kilometer.
- (3) Inversion thickness above the base, meters.
- (4) Occurrence or absence of rain observed near or at time of radiosonde observations.

- (5) Wind direction frequencies at time of inversions.
- (6) The above by months for both stations.

The tabulated data has been analyzed to bring out the following information:

- (a') Frequency for each month of the three types of inversions expected at Augusta at 10 a.m. and 10 p.m.
- (b') Frequency for each month of inversions with and without rain at 10 a.m. and 10 p.m.
- (c') Frequency of inversion intensity for winter and summer months at 10 p.m.
- (d') Relationship of inversion thickness to intensity at 10 p.m. for January and July.
- (e') Annual and monthly frequency of wind direction during inversions.

Since Augusta is approximately midway between Atlanta and Charleston, averaging of the data for the two stations was considered valid.

(a') Frequency of Inversion Types

Figure 17 is a plot, by months for both the 10 a.m. and 10 p.m. soundings (ascents), of the per cent of the observations showing the three types of inversions. Inversions based at the ground become established by 10 p.m. on 1/2 to 3/4 of the days while inversions with higher bases are less frequent at that hour, i.e., less than 15 per cent. On the other hand, ground (Type I) inversions are comparatively rare at 10 a.m., except during October through March when occurrence is 2 to 12 per cent of the days. The most predominant inversion at 10 a.m. is the high (Type III) inversion, based between 500 and 1500 ft. This is often the

result of "burning off" of ground or low inversions established during the night. This process of inversion breakup by surface heating is well established by 10 a.m. in winter and virtually complete by this time in summer; the latter is evidenced by low frequency of all types on summer mornings.

The frequency of both day and night inversions of various types are combined by months in Figure 18. From this tabulation, the probability of occurrence or absence of each type or all types of inversions at 10 a.m. and 10 p.m. can be obtained. For example, in January, the probability of having any inversion below 1500 ft. at either 10 a.m. or 10 p.m. is 0.66 and of having no inversions below 1500 ft. is 0.34. In July, the reverse is true; i.e., the probability of an inversion at 10 a.m. or 10 p.m. is only 0.31 and of having none below 1500 ft. is 0.69.

(b') Frequency of Rain and Inversions

In certain dispersion problems, particularly those dealing with particulate material, the frequency of rain with or without inversions occurring is of interest. Table IV shows the percentage of hours that rain was recorded at Augusta for 4-6 years of record. In November through March, the frequency of precipitation is about 50 per cent higher than during the remainder of the year.

Figure 19 shows, by months, the frequency at 10 a.m. and 10 p.m. of all inversions based below 1500 ft. compared with the frequency of such inversions when rain over 0.01 in. fell sometime between 8 and 12 a.m. or p.m. At night (10 p.m.) rain and inversions occurred together between 2 and 6 per cent of the time (days)

while inversions occurred (with or without rain) between 60 and 82 per cent of the days. In the morning (10 a.m.), rain and inversions occurred together during the winter (November through March) between 6 and 10 per cent of the time (days) and between 1/2 and 3 per cent during the remainder of the year.

Figure 20 is similar to Figure 19 but only for ground (Type I) inversions. It was noted in Figure 17 that the ground inversion is predominant at 10 p.m. Figure 19 shows this also to be true during rainy periods. Figure 20, like Figure 17, shows that the ground inversion is not the predominant 10 a.m. sounding both for rainy and non-rainy periods.

(c*) Frequency of Inversion Intensity at 10 P.M.

The fluorescent particle field work has shown how turbulence influences the dispersion of material from a stack. The intensity of inversions has a direct effect on the degree of turbulence. The following analysis of the U.S. Weather Bureau inversion data develops the frequency of the occurrence of ground and low inversions of various intensities as measured by the rate of increase of temperature with height. Intensity has been expressed in °F./200 ft. and curves were prepared for ground and low inversions at 10 p.m. during winter (November - March) and summer (May - September). Ground inversion intensities during rainy periods was also evaluated.

Figure 21 shows the winter night inversion intensities. A value of 4.5° F./200 ft. was selected as the division between stable and very stable inversions. This is based on analysis of inversion types as selected from Savannah River Dunbarton

wind records and is discussed in section (2) below. Figure 20 shows that 88 per cent of the ground inversions established by 10 p.m. during winter are stable and 12 per cent very stable. During rainy periods, only stable ground inversions are established. This chart also shows that 97-98 per cent of the low inversions are stable and 2-3 per cent very stable.

In summer (Figure 22) at 10 p.m., only 2 to 3 per cent of the ground inversions are very stable, 97-98 per cent being stable. With rain, the intensity frequency of ground inversions is similar to the winter curve in Figure 21. Low inversion intensity frequency curves show less intense inversions in summer than in winter (less than one per cent are very stable).

(d') Inversion Intensity and Thickness

Figure 23 shows the average inversion thickness associated with intensities for ground inversions for 10 p.m. soundings for January and July. Curves for other months will lie between. Very stable inversions are comparatively thin. At 10 p.m., they are generally less than 300 ft. thick in winter and 150 ft. thick in summer. Stable inversions are thicker with thickness increasing as intensity decreases.

(e') Frequency of Wind Direction During Inversions

Wind direction frequencies during inversions have been computed on monthly and annual bases. It was first established that the average wind direction distribution for Atlanta and Charleston was reasonably representative of Augusta Weather Bureau records.

Figure 24 shows the annual distribution of wind directions associated with inversions of the three types. The predominant inversion associated with low or calm winds is based at the ground. Also, S and SW winds occur more frequently during ground inversions than any other direction. On the other hand, NW, N, NE and E winds are more frequent for high (Type III) inversions.

Figures 25, 26, 27 and 28 show similar plots on a monthly basis. In every month, when inversions are associated with calm, the inversions are based at the ground. The ground inversion is generally, except in September through January, associated with S and SW winds more than any other direction. This is particularly true in the months April through August. This is partly due to the fact that these wind directions are quite frequent in these months regardless of association with inversions. High inversions are relatively evenly distributed with wind direction in the months April through August but show greater association with NW, N, and NE winds the remainder of the year. No predominance of particular directions with low (Type II) inversions is apparent.

(2) Distribution of Wind Direction Variability Types at Dunbarton

It has been shown in previous sections dealing with fluorescent particle field experiments that variability of wind speed and direction is a measure of atmospheric turbulence and is related to dispersion of stack effluents.

The following classes were established from the relation of the range of wind direction variability and vertical temperature change as measured in field experiments:

<u>Class</u>	<u>Turbulence</u>	<u>Range of Wind Direction Variability, Deg.</u>
1	Very stable	less than 12
2	Stable	12-25
3	Neutral or unstable	25-70
4	Very unstable	greater than 70

Hourly wind records for approximately one year, June 1951 to June 1952, at Dunbarton were evaluated for the number of hours that the wind direction record fell into the above four classes.

Figure 29 shows the frequency of occurrence of the four classes for each month. The mean (annual) frequency of occurrence of the classes are:

Class 1	13.4%	of recorded hours
" 2	23.0%	" " "
" 3	44.6%	" " "
" 4	19.0%	" " "

The very stable turbulence class shows a greater frequency during the fall and early winter. The frequency of the stable Class 2 is somewhat higher in summer than in spring or fall. Neutral turbulence is less frequent in summer than during the remainder of the year, while very unstable (Class 4) is more frequent in summer. The latter is associated with longer days, greater insolation and less cloudiness during the summer.

The very stable and stable classes (1 and 2) roughly correspond to the inversion frequencies discussed in the above section on the U. S. Weather Bureau Inversion Analysis. In Figure 30 are plotted the monthly hourly frequencies of Classes 1 and 2, as well as the average frequency of the 10 a.m. and 10 p.m. inversions based at the surface taken from Figure 20. There is reasonable agreement between the two curves, particularly since the inversion record is longer (8 years) and are for only 2 hours of the day. It appears that generally between 35 and 40 per cent of the time, inversions (or stable and very stable turbulence) may be expected at the Savannah River Plant.

(3) Wind Distributions

The Dunbarton Fire Tower wind instrument established records for a little over one year and the location is representative of most of the plant operating areas, except the 400 Area. The following analyses of these records will compare wind data between the Dunbarton Tower and the U. S. Weather Bureau records at Augusta Airport. Some difference in the method of measuring hourly wind speed and direction at the two locations exists: the Dunbarton records were kept as mean hourly wind speed and direction while the Weather Bureau records represent the prevailing wind speed and direction at the time of observation, usually once per hour.

(a') Seasonal Wind Speed and Direction Patterns

Figures 31 and 32 show the wind direction distribution for Dunbarton and Augusta for summer, 1951 (June - August) and winter, 1951-52 (December-February), respectively. The distributions are for wind speed ranges: calm, 1-3 m.p.h., 4-12 m.p.h., and over 12 m.p.h.

In summer (Figure 31, Augusta shows a considerably higher frequency of calm periods than Dunbarton (9.3 vs. 0.2 per cent). The frequency of winds 1-3 m.p.h. is also higher at Augusta than at Dunbarton (27.3% vs. 14.4%). The predominant direction is southerly, with greater frequency of southwesterly winds at Dunbarton and southeasterly at Augusta. Winds in the 4-12 m.p.h. range are more frequent at Dunbarton than at Augusta (80.6% vs. 57.6%). South and southwest winds predominate at Dunbarton while southeast and southwest wind predominate at Augusta. For winds over 12 m.p.h., there appears little difference between the two stations.

In winter (Figure 32), there is again a considerably higher frequency of calm periods at Augusta (10.6 vs.

0.35 per cent). Winds of 1 to 3 m.p.h. are about one-fourth as frequent at Dunbarton as at Augusta, both showing lower frequencies in winter than in summer, particularly at Dunbarton. Easterly winds in this speed range are somewhat more frequent at Augusta; at Dunbarton, no direction is predominant. Winds in the 4-12 m.p.h. speed range are more frequent at Dunbarton than at Augusta (67.3 vs. 53.8 per cent) with southwest and west winds predominant. Northeast and east winds are relatively more frequent at Dunbarton than at Augusta. Winds in the speed range of over 12 m.p.h. are considerably more frequent in winter than in summer, both at Dunbarton and Augusta. These are also more frequent at Dunbarton in winter (26.7 per cent of the time).

(b') Low Wind Speed Frequency

Figure 33 shows the monthly frequency of low wind speeds (= 3 m.p.h.) at Augusta (9-year average for the old downtown Weather Bureau office), at Dunbarton (June, 1951 - July, 1952, inclusive) and at Augusta airport (June, 1951 - July, 1952, inclusive).

The Augusta airport location shows considerably higher frequencies of low winds than at Dunbarton or than would have been expected on the basis of the 9-year downtown average. This latter difference may be explained on the basis that: (1) the airport location is in a more stagnant area than downtown Augusta; (2) the airport anemometer is closer to ground level than the old downtown location on a building; and/or (3) the period June, 1951 - July, 1952 is anomalous. The value for July, 1952, at the 400 Area Patrol Hq. Building (low level anemometer) shows

considerably higher frequency of low winds than at the other locations. This is due to low elevation terrain and relatively heavily wooded areas in the general vicinity.

Seasonally, low winds may be expected most frequently in summer and fall, and least in late winter or spring.

b. Local Climatological Effects

Wind Distributions Within the Site

Wind data are available for July, 1952, to compare Dunbarton, 400 Area and Augusta. These data are plotted in Figure 34. Periods of calm were about 14 times more frequent in the 400 Area than at Dunbarton and about 50 per cent higher than at Augusta Airport. Periods of 1-3 m.p.h. winds were almost twice as frequent at 400 Area than at Dunbarton or Augusta, directions being predominantly southerly. Winds in the 4-12 m.p.h. range are less frequent in the 400 Area (43%) than at Dunbarton (74.7%) or Augusta (60.5%). Southerly and easterly directions prevail. Above 12 m.p.h., the 400 Area again shows least frequency, Augusta most. Easterly winds prevail.

The records at Dunbarton probably represent the wind conditions at most plant operating areas built on higher ground. The 400 Area is an exceptional location due to low elevation. The lower level (approximately 20-30 ft. above ground) of the 400 Area instrument as compared to the Dunbarton instrument (approximately 100 ft. above ground) will tend to increase the periods of lower wind speed. Nevertheless, the 400 Area is indicated as one with significantly more frequent periods of low winds leading to poorer dispersion of materials released to the atmosphere.

C. MICROCLIMATOLOGY OF PLANT SITE

Microclimate stations were established to determine (1) if any significant differences exist between site locations with respect to temperature and humidity that may benefit plant design or indicate potential air stagnation areas, and (2) the correlations, if any, required to relate U. S. Weather Bureau climate records for Augusta to the plant area.

The information in this section has already been reported in Memo: L. L. Falk to C. S. Robinson, Temperature and Humidity at Savannah River Plant, January 10, 1952. This memo is reproduced as Exhibit E.

Table I

TRAVEL TIME OF DISPERSED MATERIAL

Miles	1/2	1	2	3	5	10	15	20	25
Wind Speed m.p.h.	Approximate Time, Hrs.: Min., To Travel Indicate Miles								
1	0:30	1:00	2:00	3:00	5:00	10:00	15:00	20:00	25:00
2	0:15	0:30	1:00	1:30	2:30	5:00	7:30	10:00	12:30
4	0:08	0:15	0:30	0:45	1:15	2:30	3:45	5:00	6:15
6	0:05	0:10	0:20	0:30	0:50	1:40	2:30	3:20	4:10
8	0:04	0:08	0:15	0:25	0:40	1:15	1:55	2:30	3:10
10	0:03	0:06	0:12	0:20	0:30	1:00	1:30	2:00	2:30
12	0:02	0:05	0:10	0:15	0:25	0:50	1:15	1:40	2:00
14	0:02	0:04	0:08	0:13	0:20	0:45	1:00	1:15	1:50
16	0:02	0:04	0:07	0:11	0:20	0:40	1:00	1:15	1:45
20	0:01	0:03	0:06	0:09	0:15	0:30	0:45	1:00	1:15
25	0:01	0:02	0:05	0:07	0:12	0:25	0:35	0:50	1:00
30	0:01	0:02	0:04	0:06	0:10	0:20	0:30	0:40	0:50

Table II

CONVERSION FACTORS

<u>If M Measured in</u>	<u>Multiply C_m/M by</u>	<u>To Get C_m in</u>
cu.ft./min. (c.f.m.) ¹ c.f.m. ¹	$\frac{M}{M \times 10^6}$	cu.ft. of M/cu.ft. of air parts per million (p.p.m.) by volume
cu.ft./hr. (c.f.h.) ¹	$1.67 M \times 10^4$	p.p.m.
lb./min.	$\frac{3.59 M \times 10^8}{w}^*$	p.p.m. ²
lb./hr.	$\frac{6M \times 10^6}{w}$	p.p.m. ²
lb./min.	$4.54 M \times 10^5$	milligrams/cu.ft.
lb./min.	$1.60 M \times 10^7$	milligrams/cu.meter
lb./hr.	$7.58 M \times 10^3$	milligrams/cu.ft.
lb./hr.	$2.68 M \times 10^5$	milligrams/cu.meter
grams/min.	$M \times 10^3$	milligrams/cu.ft.
grams/min.	$3.53 M \times 10^4$	milligrams/cu.meter
grams/hr.	$16.7 M$	milligrams/cu.ft.
grams/hr.	$5.88 M \times 10^2$	milligrams/cu.meter
curies/min.	M	curies/cu.ft.
curies/min.	$M \times 10^6$	microcuries/cu.ft.
curies/min.	$3.53 M \times 10^{-5}$	curies/cm ³
curies/min.	$35.3 M$	microcuries/cm ³

*w = molecular weight of material of M emission rate.

1 At temperature and pressure of atmosphere.

2 At 0°C. (32°F.) and 760 mm. Hg. pressure. Multiply by $T/273$ and $760/p$ where T = absolute temperature of air (°K) and p = pressure in mm. Hg. to get p.p.m. at air temperature and pressure. If temperature is in Fahrenheit, use $\frac{\text{Temp.} + 460}{460}$.

460

Table III

RATIO OF ONE-MINUTE PEAK TO AVERAGE CONCENTRATIONS

<u>FIELD EXPERIMENT NO.</u>	<u>RATIO</u>
2	27
3	19
4	42
5	22
6	17
7	2.3
8	7.5
9	13
10	4
11	11
13	4.7
14	12
16	8
17	4.3
18	19
20	16
21	10
22	20
23	12
24	16
25	6

Table IV

PERCENTAGE OF HOURS REPORTING 0.01 IN. PRECIPITATION
OR MORE AT AUGUSTA

<u>Month</u>	<u>Years of Record</u>	<u>Per Cent of Hours</u>		
		<u>Mean</u>	<u>Lowest</u>	<u>Highest</u>
January	6	6.6	3.4	9.0
February	6	6.3	2.7	9.5
March	6	9.1	5.1	12.2
April	6	4.9	3.5	7.0
May	6	2.8	0.8	4.4
June	5	4.4	2.8	7.5
July	5	5.0	2.8	5.7
August	4	4.8	1.9	7.5
September	4	4.6	1.9	5.8
October	4	5.4	1.7	9.1
November	4	8.6	5.4	12.4
December	4	7.0	1.6	12.2

DIMENSIONLESS PLOT OF BOSANQUET AND PEARSON EQUATION

(ONLY HALF OF THE PATTERN IS SHOWN BE-
CAUSE IT IS SYMMETRICAL ABOUT THE LINE
 $L=0$)

DIMENSIONLESS PLOT OF OBSERVED DISPERSION PATTERNS

RELATION OF p AND $\sigma_{us}/\bar{u}$

$\sigma_{us}/\bar{u}$, RATIO OF WIND SPEED VARIATION
TO MEAN WIND SPEED

RELATION OF $\sigma_{us}/\bar{u}$ AND x_m/h

x_m/h , DISTANCE IN STACK HEIGHTS TO
POINT OF MAXIMUM DOWNWIND DOSAGE

RELATION OF q AND $\sigma_{\theta s}$

$\sigma_{\theta s}$, DEGREES, WIND DIRECTION VARIATION

TRAVEL TIME OF DISPERSED MATERIAL

DOWNWIND DIMENSIONS OF DISPERSION PATTERN

DISPERSION PATTERN DIMENSIONS FOR $r_{us} = 30$ DEGREES

$r_{us}/\bar{u}$							S
0.2	0.3	0.5	0.7	1.0	1.5	2.0	
DISTANCE CROSSWIND, STACK HEIGHTS							
8.5	5.6	3.4	2.4	1.7	1.2	0.9	0.1
6.1	4.1	2.5	1.7	1.2	0.8	0.6	0.3
4.7	3.3	1.9	1.4	1.0	0.65	0.5	0.5
3.5	2.3	1.4	1.0	0.7	0.5	0.35	0.7
1.9	1.2	0.7	0.5	0.4	0.25	0.2	0.9

$R = x/x_m$, RATIO OF DOWNWIND DISTANCE TO
DISTANCE TO MAXIMUM CONCENTRATION

$S = C/C_m = D/D_m$, RATIO OF CONCENTRATION TO
THAT AT POINT OF MAXIMUM

$r_{us}/\bar{u}$, RATIO OF WIND SPEED VARIATION RANGE
TO MEAN WIND SPEED

S	0.1	0.5	0.9	1.0	0.9	0.7	0.5	0.3	0.2	0.1
$r_{us}/\bar{u}$	DISTANCE DOWNWIND, STACK HEIGHTS									
0.2	6.0	12.4	17.0	24.0	30	40	53	71	87	120
0.3	4.0	8.2	12.0	16.0	20	27	35	48	58	81
0.5	2.4	4.7	7.1	9.5	11.8	15.8	20	28	34	48
0.7	1.7	3.5	5.1	6.8	8.5	11.3	15.0	20	25	35
1.0	1.2	2.5	3.6	4.8	6.0	8.0	10.5	14.2	17.5	24
1.5	0.7	1.6	2.3	3.1	3.7	5.2	6.7	9.2	11.5	15.7
2.0	0.6	1.2	1.8	2.4	3.0	4.0	5.3	7.2	8.7	12.0

COMPUTATION CHART FOR MAXIMUM AVERAGE GROUND-LEVEL CONCENTRATION

$C_m = D_m / t =$ MAXIMUM DOWNWIND CONCENTRATION
 $D_m = C_m t =$ MAXIMUM DOWNWIND DOSAGE
 $M =$ EMISSION RATE OF MATERIAL FROM A STACK

$\bar{U}$ = WIND SPEED, M.P.H.

h , STACK HEIGHT, FEET

RELATION OF r_{es} TO HORIZONTAL ANGLE OF DISPERSION CLOUD

SAMPLE OF NIGHTTIME WIND TRACE

WIND DIRECTION

DEGREES

WIND SPEED

M.P.H.

NIGHTTIME DISPERSION PATTERN

SAMPLE OF DAYTIME WIND TRACE

WIND DIRECTION

DEGREES

WIND SPEED

M.P.H.

DAYTIME DISPERSION PATTERN

FIG 15

AUGUSTA, GEORGIA: FREQUENCY OF INVERSIONS IN LOWEST 1,500 FEET

TYPE	ELEVATION OF BASE OF INVERSION
I	SURFACE
II	ABOVE SURFACE BUT BELOW 500 FEET
III	ABOVE 500 FEET BUT BELOW 1,500 FEET

MONTHS
DAY SOUNDING (10 A.M.)

MONTHS
NIGHT SOUNDING (10 P.M.)

FIGURE 17

AUGUSTA, GEORGIA PROBABILITY OF INVERSIONS IN THE LOWER 1,500 FEET

CLASSIFICATION OF INVERSIONS		
SYMBOL	TYPE	ELEVATION OF BASE
Ia	DAY	SURFACE
Ip	NIGHT
IIa	DAY	ABOVE SURFACE BUT BELOW 500'
IIp	NIGHT
IIIa	DAY	ABOVE 500' BUT BELOW 1,500'
IIIp	NIGHT	
NOTE: "O" INDICATES THE SUMMATION OF ALL INVERSION TYPES WITH LESS THAN 5% FREQUENCY		

**AUGUSTA, GEORGIA: FREQUENCY OF INVERSIONS BASED BELOW 1,500 FEET
AND FREQUENCY OF SUCH INVERSIONS WITH RAIN**

FIGURE 19

**AUGUSTA, GEORGIA: FREQUENCY OF SURFACE INVERSIONS
ASSOCIATED WITH RAIN AND FREQUENCY OF SURFACE
INVERSIONS WITHOUT REGARD TO RAIN**

FIGURE 20

**AUGUSTA, GEORGIA INTENSITY FREQUENCY OF INVERSIONS
WINTER MONTHS (NOV., DEC., JAN., FEB., MAR.)
NIGHT SOUNDING (10 P.M.)**

FIGURE 21

AUGUSTA, GEORGIA INTENSITY FREQUENCY OF INVERSIONS
SUMMER MONTHS (MAY, JUNE, JULY, AUG., SEPT.)
NIGHT SOUNDING (10 P.M.)

FIGURE 22

INVERSION THICKNESS VS. INTENSITY AUGUSTA, GEORGIA

INVERSIONS BASED AT SURFACE
NIGHT SOUNDINGS - 10 P.M.

AUGUSTA, GEORGIA WIND FREQUENCY DURING INVERSIONS BASED IN THE LOWER 1500 FEET

CLASSIFICATION OF INVERSIONS		
SYMBOL	TYPE	ELEVATION OF BASE
I	SURFACE
II	ABOVE SURFACE BUT BELOW 500 FEET
III	ABOVE 500 FEET BUT BELOW 1500 FEET

NOTE: TOPS OF BARS TOTAL 100% OF INVERSIONS.
DATA TAKEN FROM 1942-49 RECORDS AT
ATLANTA AND CHARLESTON.

6

AUGUSTA, GEORGIA WIND FREQUENCY DURING INVERSIONS BASED IN THE LOWER 1,500 FEET

TYPES OF INVERSIONS

- BASED AT SURFACE.
- BASED ABOVE SURFACE BUT BELOW 500 FEET.
- BASED ABOVE 500 FEET BUT BELOW 1,500 FEET.

AUGUSTA, GEORGIA WIND FREQUENCY DURING INVERSIONS BASED IN THE LOWER 1,500 FEET

TYPES OF INVERSIONS

- BASED AT SURFACE.
- BASED ABOVE SURFACE BUT BELOW 500 FEET.
- BASED ABOVE 500 FEET BUT BELOW 1,500 FEET.

AUGUSTA, GEORGIA WIND FREQUENCY DURING INVERSIONS BASED IN THE LOWER 1,500 FEET

TYPES OF INVERSIONS

- BASED AT SURFACE.
- BASED ABOVE SURFACE BUT BELOW 500 FEET.
- BASED ABOVE 500 FEET BUT BELOW 1,500 FEET.

AUGUSTA, GEORGIA WIND FREQUENCY DURING INVERSIONS BASED IN THE LOWER 1,500 FEET

TYPES OF INVERSIONS

- BASED AT SURFACE.
- BASED ABOVE SURFACE BUT BELOW 500 FEET.
- BASED ABOVE 500 FEET BUT BELOW 1,500.

FREQUENCIES OF WIND DIRECTION VARIABILITY CLASSES DUNBARTON FIRE TOWER JUNE 1951 - JUNE 1952

FIGURE 29

FIGURE 30

COMPARISON OF U. S. WEATHER BUREAU INVERSION ANALYSIS AND STABLE AND VERY STABLE WIND VARIABILITY CLASSES

FIGURE 31

COMPARISON OF DUNBARTON AND AUGUSTA
WIND DISTRIBUTION, SUMMER, 1951

FIGURE 32

COMPARISON OF DUNBARTON AND AUGUSTA WIND DISTRIBUTION, WINTER, 1951-1952

FIGURE 33

FREQUENCY OF LOW WIND SPEEDS AUGUSTA & SAVANNAH RIVER

- AUGUSTA AIRPORT (JUNE, 1951-JULY, 1952 INCLUSIVE)
- AUGUSTA - 9 YEAR AVERAGE
- - - - x DUNBARTON FIRE TOWER (JUNE, 1951-JULY, 1952 INCLUSIVE)

FIGURE 34

WIND DISTRIBUTION COMPARISON JULY, 1952

FLUORESCENT PARTICLE TECHNIQUE AND EQUIPMENT FOR DISPERSION TESTS

A. FLUORESCENT PARTICLE TECHNIQUE

1. Several reasons for selecting fluorescent particle technique are:

- a. Direct Method

The primary advantage in using the fluorescent particle technique stems from the fact that, being a tracer method, dispersion can be measured directly.

- b. Prior Development of Technique

Several direct methods were considered. However, information was most readily available on the fluorescent particle technique as successfully developed and applied by the Stanford University Chemical Department.

- c. Simplicity

The method of collection is straightforward; representative downwind sampling is readily accomplished. Collection is effected on a flat surface either by dry impingement on a moving tape or through membrane filters whereon all the particles collected are on the top surface.

The facilities required for assessing field samples by the particle technique are much less elaborate than the laboratory facilities required for assessing field samples using a chemical or radioactive tracer.

- d. Ease of Identifying Effluent

The fluorescent particle technique directly marks a portion of the atmosphere. Since this portion behaves similarly to any unmarked part, the measured dispersion characteristics of the marked portion may be assumed representative. Likewise, the particles fluoresce in such a manner that it is simple to distinguish them from any naturally occurring fluorescent particles. For this reason, problems of background are not of concern as they would be if radioactive tracers were used.

e. Applicable to Both Gaseous and Fine Particle Dispersion

The particles are small enough so that their terminal settling velocity is negligible compared to the eddy motions and wind velocity to which they are subject. Consequently, this technique has a reliable application to studies of the dispersion characteristics of both gases and finely divided particles.

f. Nontoxic

The fluorescent particles have no odor and the concentrations reached during field experiments are not toxic to personnel nor harmful to vegetation.

B. EQUIPMENT FOR DISPERSION TESTS

1. Basic Equipment

a. Pigment

The fluorescent pigment is zinc cadmium sulfide. Its color is yellow and density is 4.3.

It is manufactured by the New Jersey Zinc Sales Company under the trade name Horsehead Pigment 2266. When viewed under a microscope with ultraviolet illumination, the particles appear bright yellow or yellow-green on a black background.

b. Pigment Dispenser

The pigment dispenser is an instrument for converting bulk fluorescent pigment into a cloud of individual particles and discharging it to the air at a known rate. Fig. A-1 shows the assembled dispenser on top of the Dunbarton fire lookout tower which serves as an elevated emission point. In ascending order the parts are: blower mounted on legs, the feeder wheel and motor, the hopper, and the hopper cap with the agitator motor. Fig. A-2 is a top view of the blower (constructed from a Model 2 Model 29 Skill blower) and shows the funneling cone which directs the pigment into the blades below the coarse screen and prevents build-up of the pigment above the blower race. Air enters the blower through an outer annular space immediately below the top. This can also be seen in

Fig. A-1 above the legs which support the blower. Fig. A-3 pictures the lower or blower side of the feeder wheel section which fits over the top of the blower. The semi-circular teeth of the feeder wheel can be seen as well as the piano wire scraper which scoops out the pigment delivered from above. Fig. A-4 is a horizontal view of the feeder wheel mount with one side removed to expose the wheel. The M-shape recess on the plate cover shown at the left, reduces friction.

Fig. A-5 is a top or hopper-side view of the feeder wheel. The motor is a 27-volt d.c. aircraft motor that drives the wheel through a reducing gear. Fig. A-6 shows the pigment storage hopper, the cap and the agitator which, on rotating in the hopper, scrapes pigment from the sides of the hopper and prevents coning.

In operation, the pigment, hopper, agitator, and feeder wheel aggregate are weighed on a 20-kg. balance. The loss of weight after the dispensation permits calculation of the weight rate of emission of pigment.

c. Drum Samplers

The drum or tape sampler is a dry impactor used to determine the time variation of pigment concentration downwind. It consists of the following component parts: a 110-volt, 1,000-watt motor-generator power supply; a control box containing a vacuum pump and the electrical equipment for automatic control of the sampler head; and a sampler head containing a drum which will rotate. The assembled drum sampler is shown in Fig. A-7. The sampler head with the drum removed is shown in Fig. A-8 while Fig. A-9 pictures the gear train motor and limit switch of the sampler head. In operation, 3/4" Scotch tape, sticky on both sides, is placed on the periphery of the drum. The vacuum pump draws a sample of pigment through a nozzle and particles contained in the sample are impinged on the tape. Thus, as the drum rotates, a time variation of concentration is obtained.

d. Filters and Filter Samplers

The filter sampler evaluates the total dosage of particles at one location. The filtering material is a 1-in. disc of "Millipore" filter material, Hydrosol

type, manufactured by the Lovell Chemical Company. The filter discs are grid marked. Fig. A-10 shows the filter holder assembled and Fig. A-11 shows it in three parts disassembled: the filter disc, the body of the filter holder showing the stainless steel screen backing for the discs, and the circular top piece which holds the filter against the screen backing. The air filtration rate for these filters is approximately 1 to 3 liters per minute.

Fig. A-12 shows the first type of pump and motor used to draw air through the filters. These were replaced by lighter and more advanced design pictured in Figs. A-13 and A-14. The two heavy automobile batteries were replaced by two lighter motorcycle batteries and the large pump and motor were replaced by the very small pump and motor manufactured by the Gast Company.

e. Microscopic Equipment

The particles on both filters and tapes were assayed at 100 magnifications with a microscope and ultraviolet illumination from above the filters. The counting and particle sizing techniques are discussed more fully in Exhibit B.

2. Auxiliary Equipment

a. Stack

The Dunbarton Fire Tower served as a stack or elevated source of pigment emission. The tower's sloping roof was replaced by a flat working deck. The adaptation of this Fire Tower for the study represented a considerable savings since it was not necessary to construct a meteorological tower.

b. Wind Instruments

A recording 3-cup anemometer and wind vane (Instruments Corp.) was installed 8 ft. above the top of the reconstructed tower deck. During field tests, the recorder chart was operated at fast speed (3 in. per min.) to give more detailed wind data. Attempts were made to obtain wind profile data by elevating a non-directional Hasting hot-wire anemometer with a captive balloon but the analyzed results obtained were usually

uninformative. This was attributed to the fact that wind direction readings at different elevations were not simultaneous.

c. Wiresonde Equipment, Balloon and Shelters

Atmospheric temperature and humidity variations with height were obtained using a U. S. Navy AN/UMQ-3 Wiresonde. The sensory part of this instrument was raised by means of a Seyfang S-400 blimp balloon. Measurements were generally made up to 400 ft. The inflated balloon and Wiresonde equipment are illustrated in Fig. A-15.

The use of an abandoned garage converted into a balloon hanger eliminated the long and costly procedure of inflating and deflating the balloon on every field test day. The lengthy procedure of setting out the indicating units for Wiresonde and hot wire anemometer and stringing power cable to them was eliminated by building a small weatherproof building with collapsible sides in which the reels for the balloon and the indicating units were set up on a permanent basis. Power to this field house was supplied by buried extension cable.

EXHIBIT A
Figure A-1

**FIGURE A-1. ASSEMBLED DISPENSER
ON TOP OF FIRE TOWER**

EXHIBIT A
Figure A-2

**FIGURE A-2. TOP VIEW OF BLOWER SHOWING
FUNNELING CONE WITH BLOWER BLADES IN THE CENTER**

EXHIBIT A
Figures A-3 and A-4

FIGURE A-3. BOTTOM VIEW OF FEEDER WHEEL HOUSING SHOWING WHEEL TEETH AND SCRAPER

FIGURE A-4. SIDE VIEW OF OPENED FEEDER WHEEL HOUSING

EXHIBIT A
Figures A-5 and A-6

**FIGURE A-5. TOP VIEW OF FEEDER WHEEL HOUSING
SHOWING WHEEL, MOTOR, AND SCRAPER SPRING**

**FIGURE A-6. HOPPER AND CAP WITH
AGITATOR MOTOR AND GEARS**

EXHIBIT A
Figure A-7

**FIGURE A-7. DRUM SAMPLER ASSEMBLY
GENERATOR, CONTROL BOX, SAMPLER HEAD ON POST**

EXHIBIT A
Figure A-8

FIGURE A-8. SAMPLER HEAD WITH DRUM REMOVED

EXHIBIT A
Figure A-9

**FIGURE A-9. SAMPLER HEAD - GEAR
TRAIN, MOTOR AND LIMIT SWITCH**

EXHIBIT A
Figures A-10 and A-11

FIGURE A-10. FILTER HOLDER ASSEMBLED

**FIGURE A-11. FILTER HOLDER APART, WITH
MILLIPORE FILTER DISK**

EXHIBIT A
Figure A-12

**FIGURE A-12. FILTER SAMPLER BOX SHOWING
BATTERIES, LIEMAN PUMP AND FILTER HOLDER BOX**

EXHIBIT A
Figure A-13

**FIGURE A-13. ADVANCED DESIGN OF
FILTER SAMPLER ASSEMBLED IN FIELD**

EXHIBIT A
Figures A-14 and A-15

**FIGURE A-14. DETAILS OF ADVANCED FILTER
SAMPLER SHOWING GAS PUMP, BATTERIES AND
FILTER HOLDERS IN STORAGE SLOTS**

**FIGURE A-15. SEYFANG S-400 BLIMP BALLOON
AND WIRESONDE EQUIPMENT**

PROCEDURE FOR DISPERSION FIELD EXPERIMENTS

A. SCHEDULING OF EXPERIMENTS

While considerable detail was involved in the preparation for each experiment, the more important aspects were:

- a. Determination of battery strength and oil reserve.
- b. Measurement of the flow rate for the various air pumps.
- c. The cutting and insertion of millipore filters in the filter holders.
- d. The checking of the latest weather reports as impending rain or abrupt wind shifts make the field experiments difficult to carry out.

B. PREPARING PIGMENT DISPENSER

The feeder wheel housing unit was attached to the hopper section and the agitator inserted therein. A portion of pigment was placed in the hopper section and the aggregate accurately weighed to the nearest gram. After attaching the agitator cap, the entire unit was carried to the top of the tower where it was connected to the blower section. After the dispenser was positioned and the various electrical connections made, a brief operating check was made.

C. SAMPLER LOCATION

The area about the tower (dispersing point) was staked out in polar diagram fashion with markers at 5° intervals along concentric circles with radii at 625 ft., 1250 ft., 1875 ft., and 2500 ft. At 5000 ft. the intervals were 15°. The first responsibility was selection of the area and the sampling points therein to yield data completely defining the cloud. The factors considered in making such a selection included a forecast of the most probable wind direction for the next 30 to 60 minutes, and the degree of turbulence and wind speed to judge the angular spread of the samplers and to estimate at what distance from the tower or stack to place the samplers.

D. USE OF AUXILIARY EQUIPMENT

1. Wiresonde and Hot-Wire Anemometer Ascents

During each dispersion field experiment, the temperature-height relationship was determined using the U. S. Navy AN/UMQ-3 wiresonde elevated at 25 to 100 ft. intervals from the surface up to 400 ft. and back to the surface. Occasionally and concurrently, the wind speed profile was determined using the hot-wire anemometer.

2. Wind Record

While the field experiment was in progress, the wind recorder was operated at fast speed (3 in. of recorder paper per minute). This magnification of the wind record provided for greater detailed analysis of wind variations.

E. SAMPLER COLLECTION

Upon completion of an experiment, the sampler pumps were turned off and the millipore filter holders detached and stored. After return to the laboratory, the millipore filters were mounted on glass slides, with appropriate identification, for analysis under the microscope.

F. COUNTING PROCEDURE

The millipore filters, and the drum sampler tapes mounted on glass slides were magnified 100 times for counting purposes. An ultraviolet light source was used to make the fluorescent particles visible. A ruled reticule or grid for ease in counting was located within the eye piece of the microscope. This square represented one square millimeter of area on the filter at a magnification of 100. Hereafter, the area delineated by this grid will be referred to as one field. The effective collecting area of each filter was in excess of 200 mm.² (200 fields). To count the number of particles in this, many fields for 26 separate filters (number representing one field experiment) would obviously have been quite a task, normally not warranted.

Standard procedure in making microscopic counts, and the one used here, is to determine the number of particles in a series of random fields. The observed counts were summed and a mean value per field was obtained which, with appropriate conversion factors, gave the count for the entire filter. The question arose as to how many such fields had to be counted to

obtain a reliable mean value. The reliability desired was a percentage error of about 10% for the mean value. The problem was analyzed statistically. Four sets of 20 fields were counted and a standard deviation computed. Next, the per cent standard deviation or coefficient of variation, C_v , was obtained,

$$C_v = \sigma/N, \quad (B-1)$$

where

σ = Standard deviation,

N = Mean number of particles per 20 fields.

This technique was repeated a number of times and a series of coefficients of variation obtained corresponding to the mean number of particles per 20 fields.

The coefficient of variation was plotted against the mean number of particles per 20 fields (20 mm.²); also, a scale was provided for the mean number of particles per field. Thus, if the number of particles in a field were obtained, the graph would be entered to obtain a C_v value. The desired standard error is 10%. Thus, using the equation

$$\text{Standard error or precision} = \frac{C_v}{\sqrt{w}} \quad (B-2)$$

where

w = the number of units of 20 fields,

one solved for w and obtained the number of units of 20 fields that it would be necessary to count to determine a mean value per field of sufficient reliability. In practice, a table was devised to indicate the number of fields to count. The procedure was to count the number of particles for a few fields. Assume, e.g., that the values are in the range 5-15 particles per field. The table used an average value of the coefficient of variation for various particle ranges; for the range cited above this coefficient was 14%. For a standard error of 10%, the table gave the solution of the equation for w , in this case, 2 units of 20 or a total of 40 fields to count.

The counting procedure for the drum sampler tapes was similar to the filter sampler technique except that counting was along the length of tape. The width of the strip of collected particles was less than 0.5 mm.

The filter sampler count represents the total of the particles collected for the period of the dispersion run, whereas, the drum sampler tapes record particle concentration variations with time.

G. PARTICLE SIZING

The equipment employed in particle sizing was the same as that used in the counting procedure, except that a magnification of 430 was used. The ruled grid of known dimensions was used to measure the diameter of the individual particles. In this way, 500 particles per filter were sized and a size distribution obtained. From this distribution, a mean mass diameter for the particles was ascertained. A series of twelve field experiments were chosen covering all hours of the day, a variety of meteorological conditions, and stretching over a period of a month. For each of these field experiments, three filter samples, at different ranges from the stack, were sized. A probability distribution of particle size embodying the data of all 36 filters is given in Fig. B-1. The median diameter is about 1 micron and the mean mass diameter is 2.35 microns. Comparison of individual filters showed no significant difference between tests due to meteorological conditions or distance from the source.

H. DETERMINATION OF DOSAGE AND RELATION TO CONCENTRATION

The dosage for a particular filter sample was obtained by dividing its total particle count by the corresponding flow rate of the pump used in obtaining that sample. Based on these dosages and the filter positions, the dispersion dosage field was obtained. The relationship between dosage and concentration was direct and only involved a time factor, i.e., dosage was equal to average concentration multiplied by the time of the pigment dispersion.

I. DETERMINATION OF SOURCE STRENGTH

The weight of the dispersed material was determined by accurately weighing, on a beam balance, the loaded hopper and other portions of the dispenser before and after dispensation. From the total weight of dispensed material and the mean mass diameter of the particles, the source strength in particles per minute, or the total number of particles emitted, was ascertained.

J. COMPUTATION OF METEOROLOGICAL DATA

1. Lapse Rate of Temperature from Wiresonde

A plot of the wiresonde data depicted the vertical distribution of temperature (up to 400 ft.) which existed during the field run. The lapse rate or gradient of temperature was defined as the change of temperature with height. Lapse rates for two such air layers were computed: the change in temperature from the surface to 100 ft. and from 100 to 200 ft.

Stability conditions have been divided into the following four classifications:

- a. A temperature increase with height = $4.5^{\circ}\text{F.}/200\text{ ft.}$ - very stable.
- b. A temperature increase with height in range 0 to $4.5^{\circ}/200\text{ ft.}$ - stable.
- c. A temperature decrease with height in range 0 to $-3.0^{\circ}/200\text{ ft.}$ - neutral or slightly unstable.
- d. A temperature decrease with height = $-3^{\circ}\text{F.}/200\text{ ft.}$ - very unstable.

While the boundaries for these stability criteria were somewhat arbitrary, they were based on approximate relationships between the lapse rate of temperature and the variability of the wind direction. For example, if the temperatures at the surface and at 200 ft. were 14 and 9°F. , respectively, the lapse rate would be -5°F. per 200 ft. A lapse rate of this magnitude is considered highly unstable (large vertical turbulence) and characterizes good dispersion conditions. The condition where temperature increases with height is referred to as an inversion, i.e., the lapse rate is positive, such a case is highly stable (little turbulence) and characterizes poor dispersion conditions. Thus, a knowledge of the lapse rate of temperature yields information on the magnitude or extent of dispersion.

2. Wind-Height Relationship from Hot-Wire Anemometer

A profile of wind speed versus height was obtained by means of a Hastings nondirectional hot-wire anemometer sent aloft with the blimp balloon for a few field experiments.

This data was used to obtain one of the parameters appearing in the dispersion equations of Sutton. However, actually, simultaneous measurements of wind speed at different heights were required, so that the results obtained by raising the anemometer by balloon did not appear to yield significant results.

3. Wind Data

a. Mean Wind

During an experiment, the recorder for the anemometer on the dispensing tower was run at fast speed (3 in. of recorder paper equals 1 minute). This allowed detailed analysis of the wind record. The means of the wind direction and speed, $\bar{\theta}$ and $\bar{u}$, respectively, were obtained from wind direction and speed averaged for minute intervals for the duration of the run.

b. Measures of Wind Variability

There are several statistical measures of variability of data. The most common is the standard deviation, σ , (root mean square). For the wind speed, for example, this is defined as

$$\sigma_u = \sqrt{\frac{\sum (u - \bar{u})^2}{n}} \quad (B-3)$$

where n is the number of observations.

Standard deviations were computed for wind speeds and direction measured at 10-second intervals for a 10-minute period. Three such 10-minute intervals were usually selected for each field experiment.

FIGURE B-1

EXHIBIT C

ANALYSIS OF INDIVIDUAL FIELD EXPERIMENTS

A. INTRODUCTION1. Possible Approaches

When consideration was given to the analysis of individual field experiments, it became apparent that the most systematic approach was computation of the dispersion coefficients to fit a reasonable equation to observed data.

a. Choice of Existing Theories

Although no exact theory of atmospheric diffusion exists, approximate equations for diffusion in the lower atmosphere have been developed. The most widely accepted are those by Bosanquet and Pearson and by Sutton. The former authors assume that the effective diffusivity is proportional to the height above ground. Their solution for the diffusion of gases from a continuous point source is given as eq. (1), (page 10).

Sutton perhaps gives a more fundamental solution of the differential equation but assumes the statistical theory of turbulence and the form of the correlation coefficient to be correct. Sutton makes an additional refinement by introducing into his equation, a pure number, n , to account for various atmospheric stability conditions. Sutton's equation for the diffusion of gases from a continuous point source is given as eq. (1a), (page 10).

The equations of both authors refer to the concentration of the gas at some point at ground level. In practice here both of these equations are multiplied through by time, t , to give solutions in terms of dosage, $D = Ct$.

b. Selection of Theory to be Used

(1) Bosanquet and Pearson

When the Bosanquet and Pearson equation eq. (1), (page 10) is differentiated, the value of x_m is obtained:

$$x_m = h/2p$$

(eq. 2)

If eq. (2) is substituted into eq. (1), the value of $D_m = C_{mt}$ is obtained:

$$D_m = \frac{4Mt}{e^{2uh^2}} \cdot \frac{p}{q} \cdot e^{-\frac{2y^2p^2}{h^2q^2}} \quad (C-1)$$

If $a = y/h$ and $b = p/q$ (the ratio of the dispersion coefficients) and $4/(e^2/2\pi) = 0.216$,

$$D_m = \frac{0.216 Mt}{uh^2} \left[be^{-2a^2b^2} \right] \quad (C-2)$$

(2) Sutton

When Sutton's equation eq. (1a), (page 10) is differentiated, the value of x_m obtained is:

$$x_m = \left[\frac{h^2}{C_z^2} \right]^{1/(2-n)} \quad (C-3)$$

If eq. (C-3) is substituted into eq. (1a), the value of $D_m = C_{mt}$ is:

$$D_m = \frac{2Mt}{\pi euh^2} \cdot \frac{C_z}{C_y} \cdot e^{-\frac{y^2C_z^2}{h^2C_y^2}} \quad (C-4)$$

If, again, $a = y/h$ and $b = C_z/C_y$ (ratio of dispersion coefficients) and $2/e\pi = 0.234$ then,

$$D_m = \frac{0.234 MT}{uh^2} \left[be^{-a^2b^2} \right] \quad (C-5)$$

It is now obvious in comparing equations (C-2) and (C-5) that the equations of these authorities differ, at the point of maximum dosage, only with respect to constants.

Graphical methods for evaluating dispersion coefficients can be developed more readily for Bosanquet and Pearson's equation. Therefore, this equation, modified by K (see page 22), was chosen as the framework for computing dispersion coefficients from experimental data.

2. Sample Field Experiment

Field experiment (FE) 63 is used to illustrate the various analyses which were adopted to solve the diffusion equation for the dispersion coefficients. The basic field samples data for this experiment are shown in Table C-I.

B. DETERMINATION OF DISPERSION CHARACTERISTICS

1. Isopleth Method

a. Introduction

For a given field experiment the dosages at the various sampling points are plotted on a polar diagram and isopleths or lines of equal dosage are drawn to delineate the ground-level dosage pattern. This pattern is used to graphically determine the various dispersion characteristics and is shown in Figure C-1 for FE 63.

b. Determination of Coefficient p.

Equation (2) relates p and the downwind distance, x_m , of the maximum average ground-level dosage (or concentration). In Figure C-1, the value of x_m is 500 ft. The effective stack height, h, is 90 ft. (elevation of source of pigment minus elevation of point of maximum dosage). Equation (2) yields a value of $p = 0.09$.

c. Determination of Coefficient q

At the point of maximum dosage, $a = y/h = 0$ since $y = 0$. Then equation (C-1), with K added, reduces to:

$$D_m = \frac{4Kmtb}{\sqrt{2\pi} e^{2uh^2}} \quad (C-6)$$

If $y_{0.1}$ is the distance measured crosswind from the point of maximum dosage, D_m , to the point where $D_{0.1} = 0.1 D_m$, and $a_{0.1}$ is the value of $y_{0.1}/h$, then:

$$D_{0.1} = \frac{4Kmt}{\sqrt{2\pi} e^{2uh^2}} \left[b e^{-2b^2 a_{0.1}^2} \right] \quad (C-7)$$

If eq. (C-7) is divided by eq. (C-6),

$$D_{0.1}/D_m = 0.1 = \frac{1}{-2b^2 a_{0.1}^2}$$

(C-8)

or, taking natural logs,

$$ba_{0.1} = 1.1$$

(C-9)

Equation (C-9) plots as a straight line on log paper with b and $a_{0.1}$ as coordinates. A similar equation for Sutton's equation is:

$$ba_{0.1} = 1.6$$

(C-10)

Both equations (C-9) and (C-10) are plotted in Figure C-2.

The value of $b = p/q$ can now be determined. In the sample FE 63 plot, Figure C-1, $a_{0.1}$ is determined by measuring the distance in the y direction from $y_{0.1}$ on one side of the x direction to $y_{0.1}$ on the other side of the x direction; dividing by 2 (an average value of $y_{0.1}$; and by the value of effective stack height, h , used in the determination of p . In the case of FE 63, $y_{0.1} = 470/2 = 235$ ft. Then $a_{0.1} = 235/90 = 2.6$ stack heights. From Figure C-2, $b = 0.41$.

Since $b = p/q$ and $p = 0.09$, then $q = 0.22$.

d. Evaluation of K

Equation (C-6) can be solved for K by:

$$K = \frac{D_m h^2 u e^2 \sqrt{2\pi}}{4 M t b} = \frac{4.64 D_m h^2 u^2}{M t b} \quad (C-11)$$

For FE 63:

$D_m = 46,000$ particle (min.)/cu.ft. (est. from Figure C-1)

$h = 90$ ft.

$u = 1,240$ ft./min. (mean wind speed during dispersion)

$t = 45$ min. pigment dispersion time

$M = 3.67 \times 10^{10}$ particles/min. dispersion rate

$b = 0.41$

Then $K = 3.9$

Note that all values above are (and must be) in consistent dimensions.

2. Ratio Method

In this method the ratio of two dosages expressed by the Bosanquet and Pearson equation at points (x_1, y_1) and (x_2, y_2) is obtained. The resulting equation can be solved for p and q independently.

In practice this technique requires that a center line be found for each arc on which sampling data were taken. A mean center line for all the arcs must then be obtained which involved a lengthy cut and try technique. Furthermore ratios must be taken between most of the sampling points having a significant dosage. This is necessary as the solution of both p and q depend on the value of the slope of a straight line plot. The solution of the equation resulting from taking the ratio of the dosage equation at two points gives only one point on the graph for determining this slope. The lengthy and involved computational techniques required, outweigh the few advantages, e.g., p and q can be evaluated independently. For these reasons the method was abandoned, when the cross and downwind curve fitting method described below was devised.

3. Cross- and Downwind Curve Fitting ("A") Method

a. Introduction

The "A" method was devised as an alternate to the Isopleth and Ratio methods. In the exponent of the Bosanquet and Pearson equation (1) (page 10),

$$y^2/x^2 = \tan^2 \chi \quad (C-12)$$

where χ is the angle subtended at the source between a line drawn to a point in the dispersion pattern and the line of the x distance (the centerline of the dispersion pattern). If eq. (C-12) is substituted into eq. (1) and the logarithm to base 10 is taken, then:

$$A = \log \frac{Dux^2}{Mt} + \frac{\tan^2 \chi}{2q^2} \cdot \log e = \log \frac{K}{y^2 \pi p q} - \frac{h \log e}{px} \quad (C-13)$$

The value of K is used as in the Isopleth method.

If it is assumed that p and q are constants, then for any value of x , "A" is constant in the crosswind direction (the right side of eq. (C-13) is constant). Theoretically, if, for a given

distance from a source, all crosswind values of Dux^2/Mt are plotted on a vertical (ordinate) logarithmic scale and lines are drawn through each point at an angle from the vertical such that the tangent of that angle is equal to $\tan^2 \theta$ for that point, then all these lines should intersect at a single point. The horizontal abscissa scale of the diagram is proportional to $(\log e)/2q^2$. Thus the single intersection point yields q on the abscissa and "A" on the ordinate (the antilog of the value read horizontally to the $\log(Dux^2/Mt)$ scale. Such a diagram referred to above will be called an (A, θ) diagram and is illustrated for FE 63 in Figure C-3 for the arc of data 625 ft. from the stack (Figure C-1). At least 3 points on an arc are required to graphically obtain an "A" value for that arc.

According to eq. (C-13), if "A" is plotted against h/x for each arc, the slope of the straight line obtained defines p . Also, when this line is extended to $h/x = 0$

$$A_{h/x=0} = \log \frac{K}{2pq} \quad (C-14)$$

and K can be evaluated.

b. Determination of q

Data for the 625-ft. arc for FE 63 will be used to illustrate this technique.

(1) Dux^2/Mt

From the dosage data for the samples on this arc (Table C-I), and values of

$M = 3.67 \times 10^{10}$ particles/min.	) Original
$u = 1,240$ ft./min.	) test
$t = 45$ min.	) data
$x = 625$ ft.	

values of Dux^2/Mt were computed and plotted on the vertical log scale of Figure C-3.

(2) θ Scale

For each point on the Dux^2/Mt , a series of angles are laid off from the vertical whose tangents equal $\tan^2 \theta$ for a series of corresponding to several possible centerlines for the arc. Examination of the dosage

values on the 625 ft. arc in Table C-I shows that the centerline of the dispersion pattern is probably between 50 and 60 degrees.

Assume that the centerline is 55 degrees, then for sampler 74, $\gamma = 15^\circ$; for sampler 66, $\gamma = 5^\circ$; for sampler 36 $\gamma = 5^\circ$; etc.

Therefore, in Figure C-3, a short arc is plotted for each point for a range of angles that will sufficiently cover the most likely centerline. The actual angles plotted are angles whose tangent is $\tan^2 \gamma$ multiplied by a factor determined by the dimension of the horizontal q scale and the dimensions and number of cycles in the logarithmic scale.

(3) Evaluation of q

Considering 50 to 60 deg. as the range of the centerline, the next step is to graphically solve for a centerline common to all five of the sampling points on the 625-ft. arc. In the example, the lines on the (A, γ) diagram come closest to intersecting at one point when the centerline of the dispersion field on this arc is 57 degrees.

The value of q is selected corresponding to a vertical line giving the closest grouping (in the vertical) of the lines in Figure C-3; in this instance a value of $q = 0.173$ is indicated.

The value of "A" for each sampler can be read on the "A" scale opposite the intersection of the selected vertical q value line and each line drawn from the Dux^2/Mt scale.

c. Determination of p

Determination of p by the "A" method requires that q be a constant as downwind distance increases. Therefore, each arc of samplers in Table C-I must be worked out for "A" values such that the same value of q is obtained on all arcs studied. This requires a certain amount of trial-and-error with all charts like Figure C-3.

Once "A" values are obtained for all available data, they are plotted against h/x as in Figure C-4. A line is then drawn that best fits (by eye) the points. Values of "A" for samplers with greater dosage values should be given more weight than those with lower values.

The slope,

$$(h/x)/A$$

is then computed and p determined by:

$$p = \frac{h/x}{A} \cdot \log e$$

In FE 63, the value of $p = 0.082$.

d. Determination of K

The line drawn in Figure C-4 is extended to $h/x = 0$ and the corresponding value of $A_{h/x=0}$ is read. Then, with the determined values of p and q , K is determined from eq. (C-14). For FE 63,

$$A_{h/x=0} = 1.94$$

Then,

$$K = \sqrt{2\pi} pq \left[10^{1.94} \right] = 3.41$$

TABLE C-I

DATA SHEET FOR FIELD EXPERIMENT NO. 63

Filter No.	Distance from Source, ft.	Angle ¹ Degrees	Pump Flow Rate c.f.m.	Total Particle Count	Dosage ² Particles (min.)/cu.ft.
17	150	50	0.066	460	6,970
47	315	25	0.075	45	600
21	315	50	0.082	2,610	31,800
27	315	75	0.075	780	10,400
57	625	20	0.068	-	-
22	625	29	0.080	48	600
74	625	40	0.089	1,075	12,100
66	625	50	0.073	2,870	39,300
36	625	60	0.068	2,790	41,000
38	625	75	0.080	680	8,500
85	1,250	20	0.086	-	-
45	1,250	30	0.082	18	220
79	1,250	40	0.089	324	3,640
19	1,250	50	0.075	1,320	17,600
83	1,250	60	0.075	2,400	32,000
60	1,250	75	0.082	124	1,510
53	1,875	20	0.080	-	-
37	1,875	30	0.071	-	-
61	1,875	40	0.071	54	760
72	1,875	50	0.073	612	8,380
56	1,875	60	0.080	1,430	17,900
52	1,875	75	0.057	28	491
14	2,500	15	0.066	-	-
15	2,500	30	0.068	2	29
25	2,500	45	0.080	132	1,650
67	2,500	60	0.093	788	8,470

1 Degrees from north. East = 90 degrees.

2 Dosage = concentration x time = total particle count ÷ pump flow rate.

AREAL DOSAGE PLOT FOR FIELD EXPERIMENT 63

MAY 20, 1952 1016-1101 E.S.T.

NUMBERS IN DIAGRAM ARE DOSAGES IN PARTICLES X MINUTES
CU. FT.

◆ ESTIMATED LOCATION OF MAXIMUM DOSAGE POINT.

RELATION OF a AND b

DETERMINATION OF q BY THE "A" METHOD

FE 63

625 FT. FROM STACK

DETERMINATION OF p BY "A" METHOD FE 63

DERIVATION OF NEW EQUATIONA. INTRODUCTION

According to eq. (8), the Bosanquet and Pearson equation can be expressed in the form

$$S = D/D_m = \frac{1}{R^2 e^{-2}} e^{-2/R} - \frac{2}{R^2} \left(\frac{y}{h}\right)^2 \left(\frac{p}{q}\right)^2 \quad (8)$$

Substituting eq. (12),

$$\left(\frac{p}{q}\right)^2 = 1.15 \left(\frac{h}{y_{0.1}}\right)^2 \quad (12)$$

into eq. (8) yields

$$S = \frac{1}{R^2} e^{2 - 2/R} - \frac{L^2}{R^2 \log e} \quad (D-1)$$

since $2.30 = \frac{1}{\log e}$, and $L = y/y_{0.1}$

It can also be shown by similar manipulations that Sutton's dispersion equation can be written in a similar dimensionless form except that his dispersion characteristic, n , enters:

$$S = \frac{1}{R^{2-n}} e^{1 - \frac{1}{R^{2-n}}} \left[1 + \frac{L^2}{\log e} \right] \quad (D-2)$$

Both the equations of Bosanquet and Pearson and of Sutton belong to the same family of curves. A more general dimensionless equation can be written as

$$S = \frac{1}{R^{c_0}} e^{c_1 - \frac{c_1}{R^{c_2}}} - \frac{L^2}{R^{c_3} \log e} \quad (D-3)$$

where c_0 , c_1 , c_2 , and c_3 are constants to be determined. This equation belongs to the same family as eq. (D-1).

The constants are not all independent. The condition must be imposed that at $R = 1$,

$$\frac{S}{R} = 0$$

Therefore,

$$c_0 = c_1 c_2$$

and

$$S = \frac{1}{R c_1 c_2} e^{c_1} - \frac{c_1}{R c_2} - \frac{L^2}{R c_3 \log e} \quad (D-4)$$

Eq. (D-4) is identical with eq. (D-1) when $c_1 = 2$, $c_2 = 1$ and $c_3 = 2$. It is identical with eq. (D-2) when $c_1 = 1$, $c_2 = 2-n$ and $c_3 = 2-n$.

Both eqs. (D-1) and (D-2) call for normal distribution of dosage on crosswind plots (i.e., normal distribution of S as a function of $y/y_{0.1}$ for any constant R). The crosswind dispersion characteristic q is actually a measure of the standard deviation of this normal distribution. For Bosanquet and Pearson's equation, the standard deviation is a constant $= \sqrt{2}/2$. In Sutton's equation, on the other hand, the standard deviation varies as $\sqrt{2} R^{-0.05/2}$ and, therefore, decreases slowly with distance.

B. DETERMINATION OF c CONSTANTS

1. Determination of c_3

In Exhibit C, the "A" method for analyzing individual field experiments was described. It was pointed out that a value of q was determined which fit as well as possible the significant data for the entire dispersion test. Upon re-examination of those field experiments with good sampling coverage, q was determined for each sampling arc distance and the variation of q with distance from the source determined. The results of these calculations are shown in Fig. D-1 where q/q_m is plotted against R ; q_m is the value of q at $R = 1$. The vertical lines represent the variations about the average curve (solid curve).

The constant, c_3 , can be evaluated by analyzing how the standard deviation of the normal curve of crosswind profiles varies with R . In Fig. D-1, the dashed line fits the equation

$$q/q_m = R^{-0.28}$$

which is the equivalent of stating that the standard deviation varies as $1/2 R^{-0.28/2}$. This curve fits the observed variation of q/q_m with R reasonably well and corresponds to a value of $c_3 = 1.44$ in eq. (D-3).

2. Determination of c_1

As noted above, Bosanquet and Pearson set $c_2 = 2$ and Sutton sets it equal to 1. If value of p are plotted against the distance to the maximum concentration in stack heights, x_m/h , these are related to c_1 by

$$c_1 = \frac{h}{px_m}$$

In Fig. (D-2) are plotted the values of p determined by the "A" method (see Exhibit C) against values of x_m/h taken from area plots of this data. The line drawn to the data yields a value of $c_1 = 1.5$.

This value of c_1 is midway between values of c_1 from Bosanquet and Pearson and from Sutton.

3. Determination of c_2

The value of c_2 can be obtained from a plot of "A" values vs. R . This has been done in Fig. D-3 with q varying with R .

"A" apparently passes through a peak at somewhere near $R = 3$ or 4, i.e.,

$$\frac{\partial A}{\partial R} = 0$$

Setting $c_1 = 1.5$ and $c_3 = 1.44$,

$$A = \text{constant} - (1.5c_2 - 2) \log R - \frac{1.5 \log e}{Rc_2}$$

$$\frac{\partial A}{\partial R} = -\frac{(1.5c_2 - 2)}{R} + \frac{1.5c_2 \log e}{Rc_2^2 + 1}$$

Equating to zero:

$$(1.5c_2 - 2) Rc_2^2 = 0.434 (1.5c_2)$$

$$R = 3.4$$

$$c_2 = 1.44 = c_3$$

It is convenient to have $c_2 = c_3$.

C. FINAL FORMS OF NEW EQUATION

The general dimensionless eq. (D-4) can now be written

$$S = \frac{1}{Rc_1c_2} e^{c_1 - \frac{c_1}{Rc_2} - \frac{L^2}{Rc_2 \log e}} \quad (D-5)$$

since $c_2 = c_3$

$$\text{or } S = \frac{1}{Rc_1c_2} e^{c_1 - \frac{1}{Rc_2} \left[c_1 + \frac{L^2}{\log e} \right]} \quad (D-6)$$

Inserting values of c_1 and c_2 , equation (D-6) becomes:

$$S = \frac{1}{R^{2.16}} e^{1.5 - \frac{1}{R^{1.44}} \left[1.5 + \frac{L^2}{\log e} \right]} \quad (D-7)$$

Expressed dimensionally, the new form of the dispersion equation becomes

$$D = \frac{K M t}{\sqrt{2\pi} p_m q_m u x_m^2 R^{2.16}} e^{-\frac{h}{p_m x_m R^{1.44}} - \frac{y^2}{2 q_m^2 x_m^2 R^{1.44}}} \quad (D-8)$$

Same as (15)

where

$$q/q_m = R^{-0.28} \quad (D-9)$$

and

$$p/p_m = R^{0.44} \quad (D-10)$$

According to eq. (D-9), q decreases with distance. This may be viewed as a reflection of the absence of large-scale turbulence in the horizontal plane. On the other hand, eq. (D-10) indicates that p would be expected to increase with distance since large scale vertical turbulence does exist.

It should be pointed out that above equations are well substantiated for unstable dispersion conditions where data well beyond $R = 1$ were available. In the case of stable (low turbulence) conditions, data beyond $R = 1$ or 2 were not available so that some caution must be exercised in applying the new equation far beyond $R = 1$ or 2.

RELATION OF q AND R

EXHIBIT D
FIGURE D-1

RELATION OF p AND x_m/h

RELATION OF "A" AND R

NUMBERS REFER TO FIELD EXPERIMENTS

Exhibit E

CC: J. E. Cole, Explosives, Wilm.
J. B. Tinker, Explosives, Wilm. E-1
M. B. Kershaw, Engi. Design, Wilm.
E. B. Showell-C. A. Gosline,
ESD, Wilm.

MEMORANDUM

January 10, 1952.

C. S. Robinson (4)
Design Division
Wilmington

TEMPERATURE AND HUMIDITY AT SAVANNAH RIVER PLANT

Attached is a report of the climatological findings to date at the Savannah River Plant as reflected in the temperature and humidity data collected. The period covered is essentially the spring, summer and fall of 1951.

Even though the climate data have been collected for less than one year, certain conclusions appeared reasonable. Generally speaking, the site is cooler in the summer and warmer in the winter than Augusta. The possibility of using cooling towers is slightly more favorable than thought at the time of site selection.

Further: (a) the site is 1-3° F. cooler (dry bulb) than Augusta at the higher elevations in summer but is similar to Augusta in the fall; (b) the lower elevations are slightly cooler (up to 1° F.); (c) the higher wet bulb temperatures are similar to those of Augusta; (d) Valley slope locations are less desirable for atmospheric waste disposal and cooling towers and (e) high elevations appear best for cooling tower locations.

ENGINEERING SERVICE DIVISION

/s/ L. L. Falk

L. L. Falk

LLF:mhw:tr

CLIMATOLOGICAL COMPARISONS OF TEMPERATURE AND HUMIDITY AT SAVANNAH RIVER PLANT

I Summary

A. Purpose

Microclimate stations have been established at the Savannah River Plant to determine (1) if any significant differences exist between site locations with respect to temperature and humidity which would benefit plant design or indicate potential stagnation areas and (2) the corrections, if any, required to relate U. S. Weather Bureau climate records for Augusta to the plant area.

B. Methods

The four microclimate stations were established on the plant area in March and June, 1951, at (1) Dunbarton Fire Tower, elev. 325 ft. above MSL, (2) between 400 and CMX, elev., 130 ft., (3) TCA slope, elev. 200 ft., (4) 200-F, elev. 300 ft. Dry bulb temperature and relative humidity are recorded at each. Similar data are available for the U. S. Weather Bureau Station at the Augusta airport (Bush Field) and maximum and minimum dry bulb temperature is available daily from a downtown Augusta location.

Comparisons of maximum and minimum dry bulb, maximum wet bulb, maximum hours of continuous consecutive duration of high wet bulb temperature, times of onset and end of high relative humidity (above an arbitrary value), and periods of very high relative humidity (95 per cent or greater) have been made for the various locations.

C. Results

1. The maximum dry bulb averages 1-2 degrees F. cooler at Dunbarton and TCA slope than at the Augusta airport in summer and are essentially the same during the fall. The 200-F area is similar to Dunbarton but of less degree. The 400 Area shows no clearcut difference from the airport, sometimes being warmer, sometimes cooler. The city shows an average 1/2 to 2 degrees warmer than the airport.

2. The minimum dry bulb at Dunbarton and 200-F averages about the same as the airport during summer but averages 1 to 3 degrees F higher during the spring and fall. The TCA slope

and 400-D have 1-2 degrees lower minimums than the airport in summer, but are about the same or slightly higher in spring and fall. The city shows an average minimum dry bulb 2-3 degrees higher than the airport.

3. The maximum wet bulb temperature averages within 1 degree of being the same as that at the airport. No wet bulb data is available at the city location.

4. On an average basis, the longest single continuous period that the maximum monthly wet bulb will prevail is 2 hours. Similarly, the longest single continuous period that the wet bulb temperature will be within 2 degrees of the maximum is 7 hours.

5. Comparison of times of onset of high humidity indicate that around sunset the TCA slope is subjected to higher humidities about 1-3 hours (average) sooner than at Dunbarton in spring and fall and from 1/4 to 1 hour sooner in the summer. The other site stations show similar patterns compared to Dunbarton but of less difference.

6. No clearcut difference between stations in the ending time of the high humidity conditions were noted.

7. The number of hours of very high humidities (95 per cent or more) is about 25 per cent higher at 400 and TCA slope than at the higher stations, Dunbarton and 200-F, during the months July through November. Up to 1/3 of the hours (not including rain or shower periods) in the summer months have 95 per cent relative humidities or higher (at ground level).

D. Conclusions

In spite of the fact that the climate work at the site has not yet accumulated a full year's data, certain conclusions appear reasonable. They are:

1. At the higher plant locations, the dry bulb temperatures will be 1° F. to 3° F. cooler than the long-term records at Augusta;

2. At the lower plant locations, the dry bulb will be the same, on up to 1° F. cooler than Augusta;

3. The maxima wet bulb temperatures are similar to those in Augusta;

4. Frequent high humidities at night cause the minimum, dry bulb and minimum wet bulb temperature to be much alike;

5. Valley slope locations, such as Upper Three Runs, are most subject to high humidities, drainage effects, and air stagnation, and will be least desirable for both atmospheric waste disposal and cooling towers;

6. High site elevations appear to be the best for cooling tower location;

7. Cooling tower hold-up or equalization basins can be designed on basis that maximum wet bulb temperature in any month will not prevail at any one time for more than 2 consecutive hours, nor within 2 degrees of the maximum for more than 7 consecutive hours.

E. Recommendations

1. Base cooling tower design on the Augusta wet bulb records;

2. At lower plant elevations, base plant design utilizing dry bulb data on the Augusta dry bulb records;

3. At higher plant elevations, base plant design utilizing dry bulb data on temperatures 2 degrees cooler than the Augusta records would indicate.

4. If possible, place cooling towers on high ground and avoid valley locations.

5. If possible, prefer high ground for atmospheric waste disposal.

II Discussion

A. Methods

Recording hygrothermographs (dry bulb and relative humidity) have been placed at the following locations.

- Sta. 1 Dunbarton Fire Tower. March, 1951. Elevation, approximately 325 ft.
- Sta. 2 400-D. Between 400 and CMX Areas. March, 1951. Elevation, approximately 130 ft.
- Sta. 3 Temporary Construction Administration. About 1/4 mile SE of T-1 on the slope toward Upper Three Runs. Established March, 1951. Elevation, approximately 200 ft.
- Sta. 4 200-F. About 1/2 mile S of 200-F area fence. Established late June, 1951. Elevation approximately 300 ft.

Daily U. S. Weather Bureau records are available from which temperature and humidity information is obtained for the present station location at the Augusta airport (Bush Field). Daily maximum and minimum dry bulb temperature records are also available from a downtown Augusta location atop the Augusta Herald building.

From the data available from the above, the following comparative analyses have been made to date:

1. Comparison of daily maximum and minimum dry bulb temperatures of site locations and the Augusta city location with Augusta airport.
2. Comparison of daily maximum wet bulb temperature of site locations with Augusta city stations.
3. The maximum continuous duration (longest single consecutive period) of high wet bulb temperatures at the Dunbarton Fire Tower location. This has already been reported in a letter, L. L. Falk to C. S. Robinson, November 20, 1951 and will also be included in this report.
4. Comparison of the mean differences of the times of onset and end of high humidities between each site location and Dunbarton.

5. Comparison of the number of hours at each site location of the number of hours of very high humidity (= 95%) for non-rainy days and nonshower periods between site locations.

B. Results

1. Maximum and Minimum Dry Bulb Comparisons.

Figures E-1 and E-2 graphically show the monthly differences of maximum and minimum dry bulb, respectively, between site locations and downtown Augusta, and Augusta Airport (Bush Field). The average difference, the standard deviation and the extremes of difference (range) between the daily maximum or minimum dry bulb between the indicated stations and the airport are shown.

a. Maximum Dry Bulb (Figure E-1).

The site locations of Dunbarton, 200-F and the TCA slope are generally cooler at the maximum than the Augusta airport. The greatest average differences were noted in mid-summer (June and July) at each location. The differences in the fall months (Oct. and Nov.) are not considered particularly significant.

The average difference between the maximums at the 400-D area and Augusta airport varied from month to month, showing no particular trend. The city of Augusta is consistently warmer, on the average, than its airport, the greatest difference occurring in the late summer.

Considering all stations, the average standard deviation of differences in the maximum dry bulb is about 1.5° F. Thus two-thirds of the days, the difference between two maximum dry bulbs will be $\pm 1.5^{\circ}$ F. of the average difference.

On the basis of elevation, the results appear to fall into line with that expected, except for the TC slope, which shows lower maximum temperatures than would have been anticipated.

b. Minimum Dry Bulb (Figure E-2).

A somewhat altered picture of the variation among locations is presented from minimum dry bulb comparisons.

The Dunbarton and 200-F areas show similar patterns when compared to the airport, i.e., essentially the same average minimum in the summer months, but warmer in the spring and fall at the site locations.

The TCA slope and the 400-D areas show similar patterns with lower minimums than the airport from May through October. It should be noted that the pattern of the dry bulb average difference for Dunbarton and 200-F change when going from maximum to minimum dry bulb comparisons (Fig. E-1 to Fig. E-2) but remains essentially the same for the TCA slope.

The minimum at the 400-D station is generally cooler than at the airport from May through September.

The minimum for the city is, on the average, warmer than the airport, but less so in summer than in spring and fall.

The mean standard deviation for these differences is about 2° F.

Again, the TCA slope appears to be out of line with comparative results generally expected on the basis of elevation alone.

2. Comparison of Daily Maximum Wet Bulb.

The daily range of wet bulb temperature is less than that for the dry bulb; for this reason, differences in maximum wet bulb temperature between stations will be less than for dry bulb.

No cleancut patterns exist in the wet bulb differences as was noted in the dry bulb. (See Fig. E-3.) Dunbarton appears to be generally about 1/2 to 1 degree cooler than Augusta airport on the average. 200 area and the TCA slope are generally slightly warmer. The 400 area is approximately the same. It would appear that from the standpoint of temperature distribution of the higher wet bulb temperatures of the day, that the average difference between stations is less than 1° F. On individual days, however, differences of as much as 6 to 7 degrees have been noted.

3. Longest Single Consecutive Period of High Wet Bulb (Monthly)

Figure E-6 shows the longest single period (duration) of high wet bulb temperatures at Dunbarton. The month-by-month

data (April through October) are shown to the right and the average slope of the curves is shown on the left. The highest temperature on each monthly curve is the maximum wet bulb temperature recorded during the month.

To demonstrate the use of the average curve at the left of the graph, assume that the maximum wet bulb temperature in any month is 75° F. The graph shows that the longest consecutive period in the month that the maximum will prevail is 2 hours. The average longest period that the wet bulb will be 73° or more ($75^{\circ} - 2^{\circ}$) will be nearly 7 hours. The longest that it will be 71° or greater ($75^{\circ} - 4^{\circ}$), will be 12 hours in that month. This does not mean that 71° or more cannot occur any number of times, but not for a continuous period of more than 12 hours.

4. Differences of Times of Onset and End of High Humidity

An arbitrary definition for high humidity was established for this comparison. It is the average of the average relative humidities at night (0130, 0730 and 1930 EST) taken from the Augusta climatic record. These arbitrary averages computed for each month and above which high humidity conditions are considered to prevail, are as follows:

April	67%
May	69
June	74
July	79
August	82
September	79
October	76
November	75

From the hygrothermograph traces, the times of onset and end of high humidity conditions at each site station was determined and those of 200-F, TCA slope and 400-D were compared with Dunbarton. Thus a comparison of whether high humidity set in or ended earlier or later at Dunbarton than at each other station could be determined monthly on an average basis.

The results of such a study are shown in Figure E-4. The comparison of onset of high humidities are shown at the left and that of end at the right. (Complete April and May data for 400-D are lacking due to delay in obtaining a spare humidity broken by insects.) Both the monthly average difference and the maximum and minimum differences (range of data) are plotted.

Certain features of the graph should be noted. (a) The onset of high humidity generally occurs, on the average (solid bars), last at Dunbarton although on certain individual days onset may occur sooner or later (the light bars) at any station. (b) The end of high humidity usually occurs slightly sooner at Dunbarton. (c) The average onset patterns for 200-F vs. DFT and 400-D vs. DFT are essentially the same. The average for all the data available at each is 35-40 minutes earlier onset at 200-F and 400-D than at Dunbarton. (d) The overall average of onset is almost twice as early (80 minutes) at TCA than at Dunbarton. (e) The seasonal pattern of onset shows greater variations in the spring and fall than in summer. (f) The difference in the end time of high humidities at each station is comparatively small, the average being less than 30 minutes difference.

It would appear that, although there is a 170-ft. difference in elevation between 200-F and 400-D, that the rate of increase of relative humidity (generally at night) is similar and is more rapid than at Dunbarton. The rate is even faster on the TCA slope, an indication of air drainage effect into the Upper Three Runs valley.

5. Comparison of Hours of Very High Humidity

A comparison was made of the number of hours at each station each month when the relative humidity was 95 per cent or greater and excluding rain or showery periods.

A plot of this data is shown in Figure E-5. On a seasonal basis, the greatest frequency of very high humidities is in the summer when the relative humidity will exceed 95 per cent about one-third of the non-rain time. The difference among the locations should be noted. The TCA slope, except during June, shows the greatest incidence of very high humidity. Dunbarton, as a rule shows the lowest. The next highest elevation, 200-F, is quite similar, except for November, to Dunbarton. The 400-D area shows an intermediate frequency, at times being similar to Dunbarton and 200-F, sometimes nearer the TCA slope values, and still other times being at an intermediate value.

It would appear that the generally longer periods of very high humidities at TCA and 400-F are due to air stagnation at night with resultant and more rapid decreases of temperature by radiation and increase of relative humidity.

DIFFERENCE IN DAILY MAXIMUM DRY BULB TEMPERATURES BETWEEN SRP STATIONS, CITY OF AUGUSTA AND AUGUSTA AIRPORT.

T= MAXIMUM DRY BULB
TEMPERATURE, °F. AT:
A = AUGUSTA AIRPORT
200 = 200-F AREA
TC = TEMPORARY
ADMINISTRATION
AREA
400 = 400-D AREA
CITY = CITY OF AUGUSTA
D = DUNBARTON FIRE
TOWER AREA

EXHIBIT E
FIGURE E-1

DIFFERENCE IN DAILY MINIMUM DRY BULB TEMPERATURES BETWEEN SRP STATIONS, CITY OF AUGUSTA AND AUGUSTA AIRPORT

DIFFERENCE IN DAILY MAXIMUM WET BULB BETWEEN SITE STATIONS AND AUGUSTA AIRPORT (BUSH FIELD)

T=MAXIMUM WET BULB
TEMPERATURE, °F.

at:

- A =AUGUSTA AIRPORT
- 200 =200-F AREA
- TCA =TEMPORARY CONSTRUCTION ADMINISTRATION
- 400 =400-D AREA
- D =DUNBARTON TOWER AREA

EXHIBIT E
FIGURE E-3

PERSISTENCE OF HIGH HUMIDITIES AT DUNBARTON ABOVE THE AVERAGE
AUGUSTA RELATIVE HUMIDITY FOR 0130, 0730, & 1930 E.S.T.

EXHIBIT E
FIGURE E-4

COMPARISON OF HOURS PER MONTH AT EACH SITE DURING WHICH
THE RELATIVE HUMIDITY WAS 95% OR GREATER

EXHIBIT E
FIGURE E-5

PLANT

EXHIBIT E
FIGURE E-6

SYMBOLS AND TERMSA. SYMBOLS

- $a = y/h$, crosswind distance expressed in stack heights at the downwind distance, x_m , of the point of average maximum ground-level concentration (or dosage) (see Exhibit C).
- A , a quantity, the downwind variation of which is a function of p , the vertical diffusion coefficient (see eq. C-10, Exhibit C).
- $b = p/q$, the ratio of the vertical to horizontal dispersion coefficients.
- c_0, c_1, c_2, c_3 constants transforming Bosanquet and Pearson and Sutton's dimensionless diffusion equations to a general equation. Observed data show that $c_0 = c_1$, $c_2 = 2.10$, $c_1 = 1.5$ and $c_2 = c_3 = 1.44$ (see eq. D-3, Exhibit D).
- C , ground-level concentration of material emitted from a stack or elevated source. (Units: Quantity or volume per volume of air.)
- C_m , maximum average ground-level concentration.
- C_v , coefficient of variation of an observed set of data (see eq. B-1, Exhibit B).
- C_y , horizontal diffusion coefficient in Sutton's equation. (Units: length to power $n/2$.)
- C_z , vertical diffusion coefficient in Sutton's equation. (Units: same as C_y .)
- d = exponent in Bosanquet and Pearson's equation.
- $D = Ct$, ground-level dosage, i.e., ground-level concentration multiplied by time of exposure or dispersion. (Units: same as for C times time.)
- D_m , maximum ground-level dosage for the same period of exposure.
- e , base of natural logarithms.

- g, exponent in Sutton's equation.
- G, a material emitted from a stack source.
- h = the height of a stack. (Units: length.)
- k = 1.5, a constant defined in equation (21), (22) and (23).
- K, a constant inserted in Bosanquet and Pearson's equation to account for differences in the magnitude of dosage or concentration obtained between theoretical calculations and observed data.
- K', constant similar to K and defined in eq. (28). Average value = 0.19.
- L = $y/y_{0.1}$, the crosswind scale factor measured at downwind distance, x_m .
- M, rate of emission of material from a stack (quantity or volume per unit of time).
- n, a turbulence characteristic in Sutton's equation.
- N, mean number of fluorescent particles per 20 microscope fields (see eq. (B-1), Exhibit B).
- p, vertical diffusion coefficient in Bosanquet and Pearson's equation.
- q, horizontal diffusion coefficient in Bosanquet and Pearson's equation.
- r, range of variation of wind speed or direction.
- r_{us} , range of variation of wind speed observed at 10-second intervals for a period of 10 minutes. (Units: length/time.)
- r_{es} , range of variations of wind direction observed at 10-second intervals for a period of 10 minutes. (Units: degrees.)
- R = x/x_m , the downwind scale factor.
- S = D/D_m , the magnitude scale factor.
- t, time (minutes or hours).

- u , wind speed. (Units: length/time.)
- $\bar{u}$, mean wind speed. (Units: length/time.)
- w , the number of units of 20 fields counted in determining the number of fluorescent particles caught by a filter (see eq. (B-2), Exhibit B).
- x , distance downwind from a stack measured along the centerline of a dispersion pattern. (Units: length.)
- x_m , downwind distance to the point of maximum average ground-level concentration (or dosage).
- x_s , downwind distance to the point where the average ground-level concentration (or dosage) is a fraction S of the maximum average ground-level concentration (or dosage).
- y , crosswind distance measured at right angles to the centerline of the dispersion pattern. (Units: length.)
- y_s , crosswind distance measured at right angles to the centerline of the dispersion pattern to the point where the average ground-level concentration (or dosage) is a fraction S of the maximum average ground-level concentration (or dosage).
- $y_{0.1}$, the value of y_s when $S = 0.1$.
- α (alpha), the horizontal angle of dispersion of a cloud of material. This is defined as the widest angle subtended at the source by the outer limits of the dispersion pattern. The outer limit is taken here when the average concentration (or dosage) is $1/10$ the maximum average ground-level concentration (or dosage). (Units: degrees.)
- γ (gamma), the angular difference measured at the source, between any point in a dispersion pattern and the centerline of the dispersion pattern. For small angles, $\tan \gamma = y/x$.
- $\bar{\theta}$ (theta), mean wind direction.
- σ (sigma), standard deviation of a distribution (root-mean-square).
- τ_{us} , standard deviation of wind speed at 10-second intervals about a mean wind speed for a 10-minute period.

es. standard deviation of wind direction at 10-second intervals about a mean wind direction for a 10-minute period.

8. TERMS

1. Anemometer - an instrument for measuring wind speed. These usually consist of multiple cups which rotate with the wind. The rate of rotation is a measure of wind speed.
2. Concentration and Dosage - Concentration is the quantity of atmospheric contaminant per unit volume or weight of air. This may be in dimensions, such as mg./liter, mg./cu. meter, etc., or dimensionless, such as parts per million (p.p.m.). i.e., cu. ft. of a gas per million cu. ft. of air. Average concentration is the average over a comparatively long period such as 1/2 to one hour. This average is made up of short periods of varying concentration. The peak concentration is the highest short-period concentration observed during the long period and is taken in this work to be the highest concentration observed for one minute. The maximum average concentration is the maximum concentration found for the longer period. Dosage is concentration integrated over the time of exposure.
3. Atmospheric Diffusion - A process whereby material emitted from a source is dispersed, diluted and brought down to ground level by atmospheric forces of turbulence.
4. Dispersion - A term used in this report to describe the process of discharging a cloud of finely divided fluorescent particles into the atmosphere.
5. Ground-Level Dispersion Pattern - The pattern of concentration or dosages of material from a source as measured near the ground (5 ft.).
6. Inversion - A state of the atmosphere such that the dry bulb temperature increases with height. The intensity of an inversion is measured by the rate of increase of temperature with height, i.e., the faster the temperature increases, the more intense the inversion. Inversion thickness is the vertical distance between the lower and upper limits of an inversion.
7. Microclimatology - The study of variations in climate over comparatively limited areas of a few square miles as compared with macroclimatology which deals with climate over large areas (such as regions of a country or hemisphere).

8. Millipore Filters - The trade name of filters (manufactured by Lovell Chemical Co.) which are practically 100 per cent efficient in holding particles of submicron size. The particles caught are held on the top surface of the filter where they can be visually observed.
9. Radiosonde - A radio-transmitting sensing instrument raised into the atmosphere by a free balloon to obtain temperature, pressure and moisture data.
10. Turbulence - The random motion of the atmosphere caused by temperature differences and movement over terrain.
11. Wiresonde - An instrument raised into the atmosphere by a captive balloon that measures temperature and relative humidity by resistance circuits.

IV REFERENCES

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