AEC
RESEARCH
and
DEVELOPMENT
REPORT

BNWL-235 1
4

PACIFIC NORTHWEST LABORATORY
ANNUAL REPORT FOR 1965
IN THE PHYSICAL SCIENCES
to the
USAEC Division of Biology and Medicine
VOLUME I: ATMOSPHERIC SCIENCES

MAY, 1966

IsaChem 60013 27121 NOV 3 1966
R L Nelsen 60919 302A NOV 8 1966

BATTELLE-NORTHWEST

BATTELLE MEMORIAL INSTITUTE / PACIFIC NORTHWEST LABORATORY

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

PRINTED BY/ FOR THE U. S. ATOMIC ENERGY COMMISSION

3 3679 00060 2351

BNWL-235 1

UC-48

Biology and Medicine

PACIFIC NORTHWEST LABORATORY
ANNUAL REPORT FOR 1965
IN THE PHYSICAL SCIENCES

to the
USAEC Division of Biology and Medicine
VOLUME 1: ATMOSPHERIC SCIENCES

By

Staff Members of
Environmental and Radiological Sciences Department
Atmospheric Sciences Section

Edited by
D. W. Pearce and J. K. Green

May, 1966

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

Printed in USA, Price \$2.00. Available from the
Clearinghouse for Federal Scientific and Technical Information,
National Bureau of Standards
U.S. Department of Commerce, Springfield, Virginia

TABLE OF CONTENTS

	<u>Page No.</u>
PRECIPITATION SCAVENGING STUDIES—R. J. Engelmann and D. I. Hagen	1
MIDAS COMPUTER PROGRAM FOR EVAPORATION OF FALLING DROPS—R. J. Engelmann. .	7
MIDAS COMPUTER PROGRAM FOR ISENTROPIC STREAM FUNCTIONS AND TRAJECTORIES— R. J. Engelmann and W. E. Davis	8
BATTELLE-NORTHWEST RADIO-TELEMETERED METEOROLOGICAL AND RADIATION OBSERVATION NETWORK—P. W. Nickola and E. H. Phinney	9
INSTRUMENTING OF THE QUEEN AIR AIRCRAFT FOR SAMPLING OF A ZINC SULFIDE ATMOSPHERE TRACER—P. W. Nickola.	11
PREDICTION OF EXPOSURES FROM AN ELEVATED SOURCE—C. E. Elderkin and W. T. Hinds	14
SPECTRAL DISTRIBUTION OF ATMOSPHERIC TURBULENCE—C. E. Elderkin	21

PACIFIC NORTHWEST LABORATORY
ANNUAL REPORT FOR 1965
IN THE PHYSICAL SCIENCES

VOLUME 1: ATMOSPHERIC SCIENCES

PRECIPITATION SCAVENGING STUDIES—R. J. Engelmann and D. I. Hagen

Washout coefficients for inorganic iodides present in process stack gases were measured in three snowfalls. The values of 4.1×10^{-5} , and $1.1 \times 10^{-4} \text{ sec}^{-1}$ were measured in columnar-crystal, snowfall rates of 0.4, 0.42, and 1.0 mm/hr, respectively. This indicates a linear relation to snowfall rate. In another test, in rainfall, organic iodides were scavenged with only about 1% of the inorganic iodides.

Introduction

A guide intended to assist workers in understanding and making quantitative predictions on scavenging was published in 1965. ⁽¹⁾ several sets of calculations were made for inclusion in that guide and are briefly reported here.

The measurement of washout coefficients (below-cloud scavenging) has continued under essentially the same experimental design as previously reported. ⁽²⁾

Three more tests in snow using Hanford process stack gases in January 1965, yielded washout coefficients for iodine gas. ⁽¹⁾ The test design was then modified to allow the use of nonradioactive tracers in tests off-site. In November and December of 1965, five tests using nonradioactive bromine and/or iodine gas were conducted from the Battelle-Northwest meteorological tower in rain, and an

additional test in rain called PUREX-4 utilized the process stack gases. In December, eight tests were conducted in light snow showers using a 40 ft tower erected on the dry bed of Rimrock Lake in the Cascade Mountains (Figure 1). These tests used iodine and bromine gases and iodide particles as tracers. At year's end, the rain and snow samples from the late 1965 tests were undergoing neutron activation analysis by the Radiological Chemistry Section.

Calculated Washout Coefficients for Iodine in Rain

The washout coefficient for a fully soluble gas may be calculated from

$$\Lambda = \int 2 \pi C N Y \text{Sh} \quad (1)$$

where C = electrostatic capacitance of the crystal

N = number of crystals per volume of air

Y = diffusivity of the gas in air

Sh = Sherwood, or mass transfer number for the falling crystal

FIGURE 1. Scavenging Test Site at Rimrock Lake, Showing 40 ft Tower, Tracer Plume, and Snowfall Collectors. (Photo courtesy of Nelson Bennet.)

and the integration is over all crystal types in the snow. For spheres, the capacitance is $D/2$, half of the diameter, and the equation reduces to the washout coefficient in rain,

$$\Lambda = \int_0^{\infty} \pi D N Y Sh dD. \quad (2)$$

From this formula, coefficients for gaseous inorganic iodine were calculated as a function of rainfall rate for various observed rain spectra. Coefficients for other soluble gases should be proportional to their diffusivities in air.

Figure 2 shows calculations for:

- The spectra fitted by Best to numerous observed rainfall data. The results shown here were identical to those of Chamberlain. (3)

- * Spectra observed in showers in India by Kelkar⁽⁴⁾ and in Washington by Engelmann, using water-sensitive paper.

- * Spectra observed at Corvallis, Oregon; Island Beach, New Jersey; and Majuro, Marshall Islands using a raindrop camera (data

provided by the Illinois State Water Survey).

Differences between these curves are thought to be due to differences in the small-drop portion of the spectra. Small drops have a small terminal velocity, and so have a large residence time in the gas cloud. Best's spectra overestimate the number of small drops, and so washout coefficients obtained from them are theoretically too high. Small drops are more easily missed in the reduction of data from film negatives than from water-sensitive paper. Therefore, it is believed that the India-Washington spectra more nearly represent the true state of gaseous

scavenging. There is, however, no assurance that the spectra from different locations are not sufficiently different to affect washout.

Additional calculations using spectra from Japan (data provided by Dr. Ichiro Imai) give curves for individual showers having essentially the same slopes as those curves in Figure 2, but the magnitude of washout for a given rainfall rate appears to have a strong dependence upon relative humidity. The small drop portion of the spectrum is sensitive to evaporation.

Measured Washout Coefficients for Iodine in Snow

Four washout tests using the minute amounts of ^{131}I present in

FIGURE 2. *predicted Washout Coefficients in Rain for I_2 , Using Selected Rain Spectra.*

some stack effluents at Hanford were reported previously. (2) This radioiodine is all in the vapor state and is about half inorganic (HI and I_2) and half organic iodides (apparently alkyl iodides). Rain and stack gas samples are counted by Radiological Chemistry. (5)

Washout Tests REDOX-4 of January 10, 1965, and REDOX-6 and -7 of January 23, 1965, were conducted in snows composed almost entirely of columnar crystals. These three tests were conducted using a different stack but the same techniques as in tests Purex-2 and -3 with agglomerated spatial dendrites reported last year.

Tests 4 and 7 yielded essentially the same washout coefficient for about the same precipitation rate (Figure 3). The washout coefficient observed in Test 6 suggests a linear increase in the washout coefficient with the snowfall rate, as is expected when the snow crystal type and size do not vary.

It is assumed that the washout coefficient of inorganic iodine in process plant stack exhausts varies with snowfall rate as indicated in Figure 3. It is assumed that there is a family of lines, one for each crystal type, the position of each being determined by the snow crystal's type and size.

Inorganic forms of radioiodine in the same tests were scavenged with distinctly lower coefficients, there being insufficient washed out to allow the calculations. In rain scavenging test PUREX-4 of November 1965, still under analysis, the organic iodide was scavenged with

FIGURE 3. Washout Coefficients of Inorganic Iodine Vapor as a Function of Snowfall Rate for Columnar and Agglomerated Dendritic Crystals.

only about 1% of the rate for inorganic iodine. The results from the rain test suggest that these coefficients cannot be applied to free iodine and other gases from other sources.

Area Within a Washout Isopleth

In the special case of horizontally uniform precipitation over a continuous plume, the area affected by at least a particular washout rate (quantity per area per time) can be calculated. (6) Culkowsky (7) and Guthrie and Nichols (8) have calculated the maximum washout possible at one particular distance in a rain which starts as soon as (or earlier than) the plume release. But, when calculating maximum possible washout, it must be remembered that the length of release and the duration of washout are often not

the same. Washout rates at a distance from the source are greater when there is little intermediate precipitation.

If the precipitation extends upstream to the source, the deposition rate from a Gaussian plume at a distance x downstream and y from the plume axis is given by

$$\omega = \frac{AQ}{\bar{u} \sigma_Y \sqrt{2\pi}} \exp(-y^2/2 \sigma_Y^2) \exp(-\lambda x/\bar{u}) \quad (3)$$

where Q = rate of release

$\bar{u}$ = wind speed at plume height

σ_Y = crosswind standard deviation of the plume concentration.

In Equation (3), the two washout coefficients are not necessarily the same. The first applies to the current precipitation, and the second to the earlier precipitation extending back to the source. The area within a washout isopleth, according to Equation (3), has been obtained by

numerical integration, and these results are presented in Figures 4, 5, and 6, for three values of the stability parameter, $\sigma_\theta \bar{u}$, as a function of both the current and "upstream" washout coefficients. The stability parameter ($\sigma_\theta \bar{u}$) is the product of the mean wind speed and the deviation of the wind direction at plume height, in radians-meters/seconds, as defined by Fuquay, Simpson, and Hinds. (9)

As an example in the use of these figures, suppose that it had been snowing lightly for some time, but that the snow had now intensified considerably. The reader wishes to know the area within a particular washout isopleth for the current stability and precipitation. He chooses the figure appropriate to the existing value of $\sigma_\theta \bar{u}$, then on the left side of the graph finds the value of ω/Q of interest divided by the current washout, $\lambda/\bar{u}$. He then moves his pointer over to the curve labelled with the earlier washout, then down to the scale marked "area."

FIGURE 4. Area Within a Current Washout Isopleth for Various Earlier Washout Rates, Based on a Gaussian Plume Model and Plume Variance as a Function of $\sigma_\theta \bar{u}$.

FIGURE 5. Area Within a Current Washout Isopleth for Various Earlier Washout Rates, Based on a Gaussian Plume Model and Plume Variance as a Function of $\sigma_{\theta} \bar{u}$.

FIGURE 6. Area Within a Current Washout Isopleth for Various Earlier Washout Rates, Based on a Gaussian Plume Model and Plume Variance as a Function of $\sigma_{\theta} \bar{u}$.

He multiplies this by $\bar{u}$ to obtain the area of the washout isopleth in square meters.

As a matter of interest, the calculations have also been made for the plume described by

$$\sigma_Y = 0.2 x^{0.8} \quad (4)$$

(where σ_Y and x are in meters) and are shown in Figure 7. Equation (4)

is a kind of composite of experimental data for 30-min long releases at Hanford, Washington.

Comparison of the figures will show that the area is not only quite dependent upon the earlier washout coefficient, but also upon the stability parameter. Some study of the climatology of $\sigma_\theta \bar{u}$ versus $\Lambda/\bar{u}$ should therefore be made before the figures are used in hazards appraisals.

FIGURE 7. Area Within a Current Wash-out Isopleth for Various Earlier Wash-out Rates, Based on a Plume Standard Deviation as a Function of Distance.

MIDAS COMPUTER PROGRAM FOR EVAPORATION OF FALLING DROPS—R. J. Engelmann

It is occasionally necessary to evaluate evaporative losses to rain spectra taken at the ground, a correction for evaporation of a small drop captured during a scavenging test, or the growth or evaporation of cloud-size droplets containing solutes. The theory for these calculations has long been available, but the evaporative process is a

nonlinear problem in several equations.

A MIDAS (Modified Integral Digital Analog Simulator) computer program was developed,⁽¹⁰⁾ which gives as a function of time the drop diameter, temperature, vapor pressure, height, fall velocity, and horizontal drift distance for the input wind speed, temperature,

and humidity profile. The program accounts for reduced evaporation due to

soluble impurities. A graph of the height-drift distance calculated for a small droplet is shown in Figure 8.

FIGURE 8. *Evaporating Water Droplet Trajectory in Dry Air.*

MIDAS COMPUTER PROGRAM FOR ISENTROPIC STREAM FUNCTIONS AND TRAJECTORIES— R. J. Engelmann and W. E. Davis

A MIDAS computer program was developed to calculate the stream functions needed for long-range trajectory construction on constant-entropy surfaces. Such trajectories should be more accurate because air motions are approximately adiabatic (isentropic) and follow isentropic surfaces. Thus, they objectively account for elevation changes not included in conventional constant-level or constant-pressure trajectories.

The program uses as input the pressure versus temperature data, $T = T(p)$, observed with radiosonde weather balloons and routinely reported on weather teletype at 12-hr intervals, to solve the following set of equations for the stream function ψ ,

$$\frac{dp}{dz} = -p g/RT \quad (5)$$

$$\theta = T(1000/p)^{2/7} \quad (6)$$

$$T = T(\log P) \quad (7)$$

$$\psi_{\theta} = c_p T_{\theta} + g z_{\theta}. \quad (8)$$

where p , T , ϕ , c_p and R are the pressure, temperature, potential temperature, specific heat, and gas constant of the air, and z_θ and T_θ are the height and temperature of the θ isentropic surface.

Three trajectories were constructed to check the program and technique. The trajectories originated at Hanford at a low elevation

and extended significant distances before intersecting the ground boundary layer at various places in the Rocky Mountains. These compared favorably to constant altitude trajectories for the same dates, yielding the additional information of where a released material might return to the vicinity of the earth's surface.

BATTELLE-NORTHWEST RADIO-TELEMETERED METEOROLOGICAL AND RADIATION OBSERVATION NETWORK—P. W. Nickola and E. H. Phinney

Introduction

Previous reports(11, 12) have described the Battelle-Northwest radio-telemetered data gathering network. A subsequent report(13) describes most recent extensive technical modifications to various network components. These modifications primarily were to convert the remotest stations from self-contained DC electrical power to externally supplied 110 AC power operation. Other previously unreported modifications include the addition of temperature sensing instrumentation and read-out channels for certain stations.

Network Capabilities

We now have a rearranged grid consisting of stations both on and peripheral to the Hanford reservation. These stations are capable of reporting wind, temperature, and radiation data on an integrated real-time basis. The data are radio-telemetered to an accumulation and print-out facility located at the Battelle-Northwest central

meteorological station. Normal operation of the network consists of an automatic preprogrammed hourly poll of all stations. However, selected polling sequences down to 5-min intervals, or even individual station polls, are available on demand. Sufficient flexibility in the system will allow for additional network stations to be activated if required in the future.

Utilization

The data are integrated into our regular climatological data acquisition program. Additionally, they are used in various investigations aimed at further definition of local meso-scale circulation regimes. A most important use for the data is in hazards evaluation studies—they represent essential input for any meteorological analyses issued before, during, or after plant contingency operations. And, of course, the data are incorporated operationally and analytically in all of our diffusion experiments.

Performance Assay

Field checks of the validity of wind speeds and directions reported by the radio-telemetering system were performed. In a check on the validity of reported direction, the vanes at four outlying stations were fixed rigidly at a known direction for a period of several hours. The average direction reported at the central station Flexowriter was within 6° of the ideal fixed direction. The range in direction reported by the fixed vanes was 6° or less during each of the 48 reporting intervals.

In a second comparison, vanes were not fixed but were allowed to fluctuate normally. The agreement between directions reported by the telemetering station and a nearby sensor recording on a strip chart was within 10° 75% of the time. Much of the disagreement in the 25% remaining occurred in situations when there was a great deal of variance in wind direction. In this situation, the significance of a direction (whether the mean from the strip chart or the output from the telemetering resistance-capacitance circuit) is open to question.

Integrating wind speed sensors were mounted near several radio-telemetering speed sensors, and

the reported speeds were compared. With winds under 6 mph, the speeds reported by telemetering averaged 0.4 mph less than those on the nearby anemometers. In winds over 6 mph, the difference averaged 5%.

A comparison of speeds reported by a pair of telemetering stations situated within 20 ft of each other was investigated during a total of 176 hourly reporting intervals. During 170 of these hours, the absolute difference in reported speed was ≤ 1 mph. In three instances, the difference was 2 mph and in 1 instance, 3 mph. In the two remaining cases, the system malfunctioned and reported differences of 6 and 16 mph.

The preceding comparisons disclosed that the radio-telemetering system is capable of reporting valid data. Using these comparisons as a guide to its capabilities, all data reported by the system over a ten-day interval were scrutinized. Inasmuch as the technician responsible for the maintenance of the system was unaware that the performance test was being made, the data are considered representative of routine performance. The system was judged to be operating within specifications 95% of the time. A more comprehensive description of this entire evaluation can be found elsewhere. (14)

INSTRUMENTING OF THE QUEEN AIR AIRCRAFT FOR SAMPLING OF A ZINC SULFIDE ATMOSPHERIC TRACER—P. W. Nickola

In the summer of 1965, Battelle-Northwest obtained a Beechcraft "A-Queen Air 80" aircraft, shown in Figure 9. Shortly after its acquisition, the aircraft was instrumented with a zinc sulfide detection system to permit the use of the aircraft in atmospheric diffusion studies involving zinc sulfide tracer. The detection system was fabricated by a commercial firm⁽¹⁵⁾ but was based on similar samplers developed at Hanford. (16-19)

The detection heads for the system protrude from the nose cone of the aircraft, as is seen in the figure. In Figure 10 the nose cone has been removed for a better view of the two sensors.

Vacuum from a venturi mounted on the side of the aircraft draws air through one or the other of the protruding detector intakes at a rate of about 5 cfm. The sampled air is exposed to a mercury arc lamp in an irradiation chamber. If

there are any zinc sulfide tracer particles⁽²⁰⁾ in the air, they are caused to phosphoresce by the ultraviolet irradiation. The particles pass through a light trap and by a photomultiplier tube. The photomultiplier anode current, which has been demonstrated to be linearly related to tracer concentration, is recorded in the aircraft cabin.

In-cabin controls permit selection of one or the other detector head by means of a solenoid on the vacuum line. A selector switch on the recorder console permits a choice of full-scale inputs of from 4 to 1000 nA. The power for the system is supplied by an inverter that is powered by a generator driven by the airplane engine.

Calibration of the detection system was accomplished with the aircraft on the ground. Fluorescent tracer 2210 was emitted directly upwind of the aircraft at a distance of about 200 m. Wind speed during

FIGURE 10. *Zinc Sulfide Detection System Mounted on Nose of Aircraft.*

the calibration procedure was 25 mi/hr. Vacuum for the detector system was supplied by a vacuum pump. Sampler flow rate was controlled to 5.0 cfm.

About 4 ft from the zinc sulfide detection intakes (and at the same elevation above surface), a series of standard Hanford membrane filter units was exposed. These filters were inserted and removed manually from their vacuum source to correspond insofar as possible with the arrival and departure of tracer puffs as indicated by the airplane detection system. The filters were assayed on the Hanford Rankin counter ⁽²¹⁾ for mass of zinc sulfide. With a knowledge of the filter flow rate and

exposure interval, it was possible to compute a mean tracer concentration for the period of filter exposure. This mean concentration was compared to the mean signal level recorded on the airplane detection system for the same interval.

Results of the calibration run are plotted in Figure 11. A total of 26 concentration measurements was made for the more sensitive Unit 1; only 10 measurements were obtained for Unit 2. Primarily, because similar samplers previously calibrated had been shown to have a linear relationship for concentration versus photomultiplier output over more than three orders of magnitude, the slopes

FIGURE 11. Calibration Curves for Airborne Zinc Sulfide Detection System.

of the calibration curves were forced to unity on this logarithmic plot. Certainly the points for Unit No. 1 are not in serious disagreement with this restriction. Too few points were obtained for Unit No. 2 for satisfactory calibration, but due to its relative lack of sensitivity, it is at any rate considered only as the backup unit.

The curves are plotted with the mentioned slope restriction and in a manner such that there are the same number of points on either side of the curve. With these restric-

tions, the range of deviations of points from the Unit 1 curve is -100% to +154% of the graphed value. Two-thirds of the points fall within the range -65% to +124% of the curve value. For the 10 points for Unit 2, the extreme range is from -70 to +140% of the curve value. The calibration equation for Unit 1 is

$$C = (2.1 \times 10^{-6}) N$$

where C is concentration in grams per cubic meter and N is the photomultiplier output in nanoamperes. The equation for Unit 2 is

$$C = (2.1 \times 10^{-5}) N.$$

PREDICTION OF EXPOSURES FROM AN ELEVATED SOURCE—C. E. Elderkin and W. T. Hinds

A pair of equations relating plume width and height parameters (σ_y and σ_z , respectively) is developed,

$$\sigma_y = 0.87 \sigma_w t$$

$$\sigma_z = 0.87 \sigma_w t.$$

Travel time, rather than the more conventional distance, is used because of the rather small variation in vertical velocity in the test conditions discussed. It is shown that the position of the maximum exposure, theoretically predicted as $H/X_{max} = 0.87 \sigma_w / \bar{u}$, agrees well with observations, but the slope of observed data beyond 300 sec is proportional to $t^{-2.3}$ as opposed to the theoretically expected $t^{-2.0}$. Three techniques for predicting exposure from an elevated source are presented, depending upon the time and instrumentation available. The simplest and quickest uses average curves only; more sophisticated technique requires wind measurement at 50 ft. By averaging the wind direction over 20-sec intervals, a relation can be used to estimate plume width; using 160-sec averages of wind speed, an estimate of vertical velocity can be obtained. An alternative technique employing stability measurements and similarity relationships is used for obtaining σ_w . These values of σ_y and σ_w are then used as parameters in a nondimensional graph which is based on observed data averages rather than theoretical models. By using observed σ_y and σ_w values in the plot of

$$\frac{E_p \bar{u}}{Q_T} \frac{\sigma_y H^2}{\sigma_w} \text{ versus } \frac{a_w}{u} \frac{X}{H}$$

an estimation of exposure is possible to within 50% of observed values.

Introduction

Air pollution has been a problem of growing concern for many years; as industrialization continues, the acute cases sometimes approach the unbearable, and mild cases forewarn of worse to come. In an effort to understand and reduce air pollution problems, two aspects of pollution dispersion are subject to investigation at Battelle-Northwest. One, the more immediate concern, involves the description of the behavior of releases to the atmosphere from existing facilities. The second and lengthier study attempts a precise definition of pollution dispersion including such relevant factors as terrain, atmospheric conditions,

building geometry, neighboring structures, pollutant type, and so forth. The complete solution to the second part of the problem requires continued study, but current results allow useful and quite dependable answers to problems of the first type even though limitations must be considered.

We will present here prediction techniques based on data collected over several years of testing the dispersive capabilities of the atmosphere for sources removed from the surface. The results we have found allow reasonably rapid determination of the average ground level concentration of pollutants released from continuous sources about 200 ft high at Hanford in neutral and unstable conditions.

Various methods of estimating ground level exposures from elevated sources are discussed. One merely involves a knowledge or estimate of the source strength and the mean wind at the height of release. A second method requires additionally a continuous recording of the 50 ft wind and another requires a stability determination from mean wind speed and temperature measurements. Although these techniques were developed for use at Hanford, some general utility may be possible, at least in method if not in detail.

In the first section, the data and interpretations leading to this family of prediction techniques are briefly presented. Second, each of the procedures is explained. In the third section, restrictions placed on the techniques are emphasized, and the possibility of applying each technique at sites other than Hanford is examined.

The Data

Measurements of atmospheric diffusion at Hanford were made by releasing zinc sulfide particles at a height of 185 ft (56.4 m). Air samples were taken at some 600 positions on 9 arcs between 100 and 1600 m from the source. Each arc extended some 120° or more, so complete distributions were measured. Seventeen dispersion tests were conducted in neutral and unstable conditions with concurrent wind speeds, directions, and temperatures measured at 8 levels from the surface to 400 ft.

The mass of the particles on each sample was determined per unit

air flow through the sampler, yielding an exposure or dosage. When normalized to the total emission, the resulting ratio E/Q_T is the same as an average concentration per unit release rate.

Only the major points gained from this study will be mentioned here. First, a_Y , the standard deviation of the lateral plume distribution at the surface was found to be proportional to σ_v , the standard deviation of the lateral wind component fluctuations, calculated from wind speed and direction measured at 50 ft and to the 0.94 power of travel time, t . This dependence can be seen in Figure 12, from which it can also be seen that the data may be represented nearly as well by the simpler linear relation

$$a_Y = 0.87 \sigma_v t. \quad (1)$$

For neutral and unstable conditions, it is not unreasonable to expect, for short range dispersion, that the vertical spread of the plume,

FIGURE 12. *Normalized Plume Width versus Travel Time.*

σ_z , has the same form,

$$a_z = 0.87 \sigma_w t, \quad (2)$$

where σ_w is the standard deviation of the vertical velocity fluctuations. This contention is supported by the observation that, on the average, at the point downwind where the crosswind integrated exposure at the surface reaches a maximum, σ_z , given by Equation (2) is equal to the height of release. This is expected from a bivariate normal description of the plume,

$$\frac{E \bar{U}}{Q_T} = \frac{1}{\pi \sigma_y \sigma_z} \exp - 1/2 \left(\frac{y^2}{\sigma_y^2} + \frac{H^2}{\sigma_z^2} \right), \quad (3)$$

where $\bar{U}$ is the wind speed at the height of release H .

Figure 13 shows the agreement given by Equation (3), evaluated at the point of maximum, in the form $H/x_m = 0.87 \sigma_w / \bar{U}$. The experimental points for values of H/x_m compare well with the curve of $0.87 \sigma_w / \bar{U}$ where $\sigma_w / \bar{U}$ was determined at the 50 ft level from similarity relationships⁽²²⁾ as a

FIGURE 13. Normalized Vertical Diffusion versus Stability.

function of stability. The stability parameter z/L' , which has the advantage of being directly proportional to height, is related to the more familiar Richardson's number for unstable conditions through

$$z/L' = \frac{Ri}{(1 - 18 Ri)^{1/4}}. \quad (4)$$

Stability calculations were made from surface and 50 ft wind and temperature measurements. The single point in Figure 13 deviating markedly from the curve was for a very light wind unstable case where the estimation of stability was most likely poor.

An important feature of the test series was the relatively narrow range of σ_w values for the neutral and unstable conditions under which the tests were conducted. This occurred because σ_w is a function of both wind speed and stability, increasing for higher wind speeds as well as for greater instability. But, because high winds generally accompany more nearly neutral conditions and low wind speeds accompany unstable conditions, σ_w values, calculated from wind and temperature measurements for each test, were found to be in a relatively narrow range. By separating three of the tests from the remaining fifteen, two relatively narrow ranges of σ_v values are distinguished. Then, from the bivariate normal model given by Equation (3), we would expect, in view of Equations (1) and (2) that curves of normalized axial or peak exposures, $\frac{E_p \bar{U}}{Q_T}$, would be unified if plotted

as a function of travel time for each group of data where σ_w and σ_v were reasonably constant. This expectation is borne out as observed in Figure 14, where the average normalized axial exposure curve for the three tests with an average σ_v of 1.9 m/sec and an average σ_w of 0.74 m/sec are distinctly separate from the average of the remaining tests where σ_v averages 1.1 m/sec and σ_w averages 0.55 m/sec. The shaded areas indicate the envelope of the data in each group. The curve for the more turbulent cases is lower in normalized peak exposure because of the larger values of $\bar{\sigma}_v$ and $\bar{\sigma}_w$, and the time of maximum occurs somewhat earlier because of the slightly larger value of $\bar{\sigma}_w$. Such behavior is anticipated from Equation (3) when $y = 0$ and σ_y and σ_z are given by Equations (1) and (2), respectively, using the average σ_v and σ_w values mentioned above. In fact,

FIGURE 14. Normalized Axial Exposure versus Travel Time.

the bivariate normal model representations, also shown in Figure 14, are seen to agree quite well with the experimental results over the entire extent of the data. The approach of the elevated source exposures, at large travel times, to the ground source exposure curve, as expected from the bivariate normal model, is also verified in Figure 14 where the curve for the bulk of the elevated source data is seen to coincide ultimately with the ground source data curve for the same range of σ_v values in unstable conditions. However, the slope of the curves at these larger travel times is greater than expected from the bivariate normal model, decreasing more nearly proportionally to $t^{-2.3}$ than to $t^{-2.0}$ as in the model. Thus, the use of the bivariate normal model relations plotted in Figure 14 for travel times greater than about 300 sec might lead to significant over-estimations of concentration.

For short range predictions, then, the results of the test series indicate that concentrations can be estimated quite well from experimental curves, obtained from an average of a well-unified group of tests, and exhibiting a dependence on σ_v and σ_w .

Because of the conditions under which the tests were conducted, the data were best organized as a function of travel time to present a large unified sample so that the functional form of the exposure curve could best be studied. However, it is often more convenient

for estimating dispersion to have the exposure curves expressed as a function of distance. Figure 15 presents the average normalized peak exposures for near neutral and unstable conditions plotted versus distance. Again, the shading indicates the envelope of the data for each group where nine of the experiments fell into the near neutral class and eight were in the unstable group.

FIGURE 15. Normalized Axial Exposure versus Distance.

Prediction Techniques

For unstable and neutral conditions, where the linear plume growth rate appears to be a good approximation, at least for positioning the peak of the experimental curve, the key to predicting concentration accurately is the estimation of σ_v and σ_w . However,

vertical velocity fluctuations are not routinely measured at Battelle-Northwest and, in some instances where dispersion measurements are required, lateral fluctuation data or even mean wind speeds may not be available. Consequently, various alternate techniques for estimating dispersion are employed, depending on the available meteorological information and the lead time given for solving the problem.

When lack of meteorological data or time does not permit calculation of turbulence parameters, σ_v and σ_w , the average experimental curves of normalized peak exposure in Figure 15 are used, with estimates of source strength and mean wind speed, to determine dispersion from an elevated source. For cloudy and windy situations, the curve for near neutral conditions is used and for sunny, convective situations the curve for unstable conditions is used. The lateral plume spread at the surface is estimated by using $\sigma_v = 0.137x$ for near neutral conditions and $\sigma_Y = 0.325x$ for unstable conditions, closely approximating the average measured σ_Y curves for the same two groups of tests separating the exposure data.

When a recording of the wind measured at 50 ft is available and some analysis time is permitted, 20-sec average readings of wind speed and direction are taken over a period appropriate to the scale of the problem. Then, the standard deviation of the wind direction fluctuations, a , is calculated in

addition to the mean wind speed and an estimate of σ_v is made through the relation $\sigma_v \approx \sigma_u U$. The standard deviation for the vertical velocity is estimated by assuming that the energy in the high frequency end of the wind speed spectrum is proportional to the vertical velocity variance. This calculation is made by removing the low frequency energy with a 160 sec running mean. The variance about the running mean is calculated, and the resulting standard deviation of the high frequency wind speed fluctuations is related to σ_w through the expression

$$\sigma_w = 0.67 \sigma_u H_i \quad (5)$$

This relation was found from Equation (3), evaluated at the point where the crosswind integrated exposure reaches a maximum at the surface, and the dependence demonstrated in Figure 16 of H/t_m on $\sigma_u H_i$, where t_m is the measured travel time to the maximum.

An alternate technique for estimating σ_w is to use Figure 13 with measurements of mean wind speed and temperature. The Richardson's numbers for the 12.3 m level is calculated from the wind speed and temperature differences from 3 to 50 ft. Then, from Equation (4), z/L' can be determined and projected to the 50 ft level, the height where turbulence and trans-

FIGURE 16. Vertical Diffusion as a Function of High Frequency Longitudinal Wind Fluctuations.

port parameters are considered most characteristic of the dispersion to the surface from a source near 200 ft. Then, the appropriate σ_w can be found from Figure 13.

Once σ_v and σ_w have been estimated, the normalized curve of Figure 17 gives the distribution of peak concentrations at the surface. The prediction curve is simply the experimental curve for the bulk of the data, normalized with the source height and the average σ_v and σ_w values for that group of data removing their dependence as anticipated from the bivariate normal relationship. The bivariate normal model, as expressed in Equation (3), could likewise be used with Equations (1) and (2), and estimates not deviating greatly from the curve of Figure 17 would be obtained. However, such use should be limited, as is the curve, to travel times of about 300 sec.

FIGURE 17. Predicted Curve for Normalized Axial Exposure as a Function of Normalized Distance.

Restrictions and Conclusions

Probably the most important restriction attached to these data and their resulting prediction schemes is the source height. Only one height, 56 m, was used during the series of tests; and, since source height is of fundamental importance, extrapolation to differing source heights must be done cautiously. Some idea of how much extrapolation is possible can be gained by comparing Battelle-Northwest data with those from another site. Islitzer⁽²³⁾ reported the results of a similar series of tests at the National Reactor Testing Station, a site with terrain and vegetation similar to that at Hanford. The release height for the NRTS tests was 45 m, and the distance to the maximum was given in the paper as a function of σ_ϕ , the standard deviation of the vertical angle fluctuations. From this dependence and the linear growth assumption used with the bivariate normal model, Islitzer found

$$\sigma_z = 0.81 \sigma_\phi x$$

for nonstable conditions. Since σ_ϕ is approximately equal to $\sigma_w/\bar{U}$, the above expression is essentially the same as Equation (2), differing only slightly in the proportionality constant. The agreement indicates that the techniques outlined in this discussion might be applicable for a limited range of source heights around 200 ft.

Care must be taken in applying the Hanford results to other sites. Some of the details which are inputs for the prediction schemes

may well be unique to Hanford. One example is the poorly defined dependence on stability shown by a_v at Hanford. In addition, since σ_w is proportional to friction velocity, u^* , it is to be expected that sites with a different roughness will also have different values of σ_w and correspondingly different vertical diffusion rates. This could be a serious cause of error if Hanford's average results (over sagebrush) are applied unaltered to other areas. Heavily built-up areas, with many structures, are, of course, complex to analyze and considerable deviation from Hanford results might well be expected. In addition, the spectrum of turbulence, which is intimately related to the method used for defining σ_u H_i , may be quite different from one site to the next. Since diffusion is so dependent on all these entities, due care is a necessity.

The stability conditions covered by the tests summarized in "The Data" section extend from neutral

to unstable and care must be taken that no stable layers exist near the source. If any stable layers do exist, the subsequent suppression of vertical velocity causes drastic alterations in vertical diffusion and placement of maximum exposures. Furthermore, the tests were conducted in near stationary conditions and the results should only be applied under the same restrictions.

Nevertheless, given the necessary simple instrumentation and reasonably uniform surroundings, the techniques outlined here should yield satisfactory estimations of pollution in a number of common meteorological situations. Furthermore, since the bivariate normal model produces good results, and the meteorological parameters required to use the model for short-range diffusion estimates have been noted, this framework of prediction techniques may be useful in reducing the data gathering effort required to define the diffusion characteristics of a particular site.

SPECTRAL DISTRIBUTION OF ATMOSPHERIC TURBULENCE—C. E. Elderkin

Analysis of turbulence data, collected at Hanford over the past 2 years at heights of 3.0, 6.1, 12.2 and 87 m in a variety of meteorological situations, has been completed. The resulting power spectral distributions for the longitudinal and vertical component are presented. The similarity of the spectral distributions, dependent on wave number and height, is distinctly observed. Deviation from similar behavior, as a result of stability effects, is also noted.

Measurements of the turbulent fluctuations of the wind components were made at various heights and

for a number of wind speed and stability conditions during the past 2 years with a fast response,

heated thermocouple anemometer. The instrument outputs were recorded with a magnetic tape recorder. The continuous signals were later reproduced from the magnetic tape into an Ease 1132 analog computer for analysis. The computer was programmed to transform coordinates and remove mean values, allowing the u' , v' , and w' fluctuations to be re-recorded on magnetic tape. Other analog computer programs were then used to analyze these turbulence components, determining variances, covariances, power spectra, and cospectra.

The results of the analysis for the vertical and longitudinal component power spectra have been organized and are presented here. Wave length was normalized to height, since eddy sizes are expected to be proportional to height, and the spectral estimates were normalized to total variance. The product of frequency and normalized spectral density, $n S(n)/\sigma^2$, were plotted against the logarithm of the normalized wave number, $nz/\bar{U}$. Then, the area between wave numbers represents the fraction of the total turbulent energy contributed by that range of wave numbers, the total variance being the integral over all wave numbers of the spectral density, or,

$$\sigma^2 = \int_{-\infty}^{\infty} n S(n) d(\ln nz/\bar{U}). \quad (1)$$

Turbulent energy is introduced and removed by a number of mechanisms as described by the turbulent energy budget equation, (22)

$$\begin{aligned} \frac{de}{dt} = & u_*^2 \frac{d\bar{U}}{dz} + \frac{g}{T_0} \bar{w\theta} - \epsilon \\ & - \frac{d}{dz} (\bar{we}) - \frac{d}{dz} (\bar{pw}) \end{aligned} \quad (2)$$

where the change in turbulent energy, de/dt , results from the production of mechanical energy removed from the mean flow, the buoyant energy introduced into or removed from the vertical component, dissipation of turbulent energy at high wave numbers and the transport of turbulent energy into a region through the divergence of the flux of turbulent energy and the divergence of the correlation between vertical velocity and pressure fluctuations. With strong instability or stability, the buoyant energy term is expected to influence the shape of the spectra significantly, but, in neutral conditions and near the ground where the mean wind speed shear is great, i.e., in the "forced convection region," the mechanical energy production term is dominant in shaping the spectra. In particular, at high wave numbers where turbulence is isotropic, but viscosity is not yet effective, Kolmogoroff's inertial subrange (24) is described by

$$n S(n) = a \epsilon \kappa^{-2/3} \quad (3)$$

where wave number, κ , is estimated by $n/\bar{U}$. Then, in near neutral and equilibrium conditions, Equation (2) becomes $\epsilon = u_*^3/kz$, in view of the

$$\frac{n S(n)}{u_*^2} = a k^{-2/3} \left(\frac{nz}{\bar{U}} \right)^{-2/3}. \quad (4)$$

If the variances are proportional to u_*^2 , we can expect to find

$$\frac{n S_u(n)}{\sigma_u^2} = \frac{a \kappa^{-2/3}}{B^2} \left(\frac{nz}{\bar{U}} \right)^{-2/3} \quad (5)$$

at the high wave number end of the measured spectral distributions. Here, if the spectrum for the longitudinal component is being considered, the value of the universal constant, a , is generally felt to be about 0.138 when κ is in cycles per meter. For the vertical component spectrum, $\frac{4}{3}a$ should be used in Equations (3), (4), and (5). The value of B , the proportionality constant between the wind fluctuation standard deviation and the friction velocity, differs among components and varies somewhat with stability. In neutral conditions, for the vertical component, the constant is considered to be around 1.05 to 1.33; a value of 1.33 was found in the present study. For the longitudinal component, the constant, B , generally about 2.5, was found to be 2.90 in the present study.

The spectra for the longitudinal component were plotted in the manner suggested in the previous discussion, with the normalized spectral density, $n S_u(n)/\sigma_u^2$ on the ordinate and $nz/\bar{U}$, the ratio of height to wave length, plotted logarithmically on the abscissa. The tests were grouped according to stability, Figure 18 showing the spectra for neutral conditions, Figure 19 for unstable conditions, and Figure 20 for the stable cases. In addition, the cases above the forced convection region

were plotted separately in Figure 21 where test 9-1 was a stable test and the remainder were conducted in unstable conditions.

The similar character of the spectra, plotted in this manner, is to be noted. Differences are observed between stability groups, however. For all stabilities, peaks in the longitudinal component spectra reached maximum normalized values near 0.2 and were found at an $nz/\bar{U}$ value of about 0.01 to 0.04 cycle. For stable cases, an additional peak was found at about $nz/\bar{U} = 0.1$ cycle. The stable data were shifted at the upper end of the spectrum to slightly higher wave numbers than the data for neutral and unstable conditions.

One test, 9-1, in stable conditions at 12.2 m, conducted above the region dominated by the mechanical energy production, demonstrates a marked deviation from the similar form exhibited by the other data. The spectra for both the horizontal and vertical components for this single test were shifted to much higher $nz/\bar{U}$. This is to be expected, since, at greater heights where buoyancy effects dominate, the height above the surface should no longer determine the scale of the turbulence for the stable case, but some stability length, small compared with z , such as Monin and Obukhov's parameter, L' , would control the size of the eddies.

The spectra for the longitudinal component are also shown with the logarithm of $n S_u(n)/\sigma_u^2$ plotted

FIGURE 18. Longitudinal Component Spectra: Neutral Tests.

FIGURE 19. Longitudinal Component Spectra: Unstable Tests.

FIGURE 20. Longitudinal Component Spectra: Stable Tests.

FIGURE 21. Longitudinal Component Spectra: Tests Above 12 m.

versus the logarithm of $nz/\bar{U}$ in Figures 22 through 25. The universal form of Equation (5) for the inertial subrange is also shown in Figures 22 and 23, and the reasonably good verification of the inertial subrange is observed for neutral conditions, Equation (5) appearing about 20% low when the value $a = 0.138$ is used. Better agreement is seen with the unstable data. In Figure 25, the observed correspondence of the unstable cases above the forced convection region with those below, throughout the inertial subrange, could not have been anticipated from Equation (5). It is particularly surprising to find reasonable correspondence over most of the spectrum for Test 13-1 at 87 m where a small positive correlation was found between the vertical and longitudinal components

and u^* is obviously no longer constant with height. For stable cases, the lower end of the inertial sub-range appears to be at about $nz/\bar{U} = 0.1$ cycle while, for neutral and unstable conditions, the minus five-thirds law seems to extend to considerable lower wave numbers, about 0.1 to 0.2 cycle.

The outstanding exception to this is test 9-1, the stable test at 12.2 m, where the power spectrum is generally displaced to higher wave numbers of $nz/\bar{U}$, but the minus five-thirds law extends down to the peak of $nz/\bar{U} = 0.2$ cycle.

The spectra for the vertical component are shown in Figures 26 through 33, where normalized spectral density, $n S_w(n)/\sigma_w^2$, is plotted versus the logarithm of $nz/\bar{U}$ in Figures 26 through 29 and the logarithms of each are plotted in

FIGURE 22. Longitudinal Component Spectra: Neutral Tests.

FIGURE 23. Longitudinal Component Spectra: *Unstable Tests*.

FIGURE 24. Longitudinal Component Spectra: *Stable Tests*.

FIGURE 25. Longitudinal Component Spectra: Tests Above 12 m.

FIGURE 26. Vertical Component Spectra: Neutral Tests.

FIGURE 27. Vertical Component Spectra: Unstable Tests.

FIGURE 28. Vertical Component Spectra: Stable Tests.

FIGURE 29. *Vertical Component Spectra:
Tests Above 12 m.*

Figures 30 through 33. The universal character of the turbulence for this component can also be seen with only a few exceptions noted. Again, these occur principally in the measurements above the forced convection region shown in Figures 29 and 33. The maxima for all vertical component spectra occur at a considerably higher value of $nz/\bar{U}$ than for the longitudinal component, appearing generally at about $nz/\bar{U} = 0.4$ cycle with the peak normalized

spectral estimates averaging about 0.2. These values and the same spectral shape hold within the forced convection region for neutral and unstable conditions with a suggestion of a slight shift to higher wave numbers for stable cases, below 12 m. The lower limit for the minus five-thirds law occurs at about $nz/\bar{U} = 1.2$ cycles, for stable conditions; otherwise it extends to about 0.7 to 1. cycle.

Again, Equation (5) is shown for neutral and unstable conditions in Figures 30 and 31. Reasonably good agreement is again obtained using the value $a = 0.138$ and, in this case, the additional required factor of $4/3$.

Spectral peaks in unstable conditions within the forced convection region resulting from the direct introduction of convective turbulent energy into the vertical component are notably absent except for test 11-2, the most unstable case at 6 m where a few estimates suggest convective energy. This is contrasted in Figure 29 with the definite convective peak for Test 12-2, the unstable case at 12.2 m, noted in the $nz/\bar{U}$ range below 0.06 cycle. Test 13-1, the unstable test at 87 m, likewise indicates convective energy with the lowest two spectral estimates at about $nz/\bar{U} = 0.15$ cycle. Test 12-1, first thought to be a neutral case for the 12.2 m height, also shows a peak, similar to the other convective peaks, at a lower wave number than that introduced by the mechanical turbulence, in this case at $nz/\bar{U} = 0.13$ cycle. This test, though conducted under cover of a heavy overcast, was carried out on a summer day with a very light wind and a calculation of Richardson's number revealed that convective energy was, indeed, present. As expected, the convective peaks do not appear to scale according to height. In terms of frequency,

the 12.2 m unstable case, Test 12-2, has convective energy through the lower end of the sampled spectrum, below 2.3 cycles/min. The 87 m unstable case has convective energy apparent below 0.9 cycle/min and the light wind speed case at 12.2 m, Test 12-1, shows convective energy below 1.4 cycles/min. Again, the correspondence of the spectra for unstable cases above the forced convection region with those below, throughout the inertial subrange, in spite of the inapplicability of Equation (5) should be mentioned as should the occurrence of a "mechanical energy production peak" for all these cases at about the same $nz/\bar{U}$ value.

The vertical component spectrum for the test in stable conditions at 12.2 m was found, as with the longitudinal component, to be displaced to higher wave numbers as shown in Figure 33. The inertial subrange is seen from the spectral distribution to begin at about $nz/\bar{U} = 3.0$ cycles.

The findings of similarity in the vertical spectra agree with results of other investigators^{(25), (26)} as does the correspondence with the minus five-thirds law at large wave numbers for the vertical component, extending to somewhat lower wave numbers for the longitudinal component.⁽²⁷⁻²⁹⁾ However, the similarity found in the longitudinal spectra has not been generally recognized from previous investigations.

FIGURE 30. Vertical Component Spectra:
Neutral Tests.

FIGURE 31. Vertical Component Spectra:
Unstable Tests.

FIGURE 32. Vertical Component Spectra:
Stable Tests.

FIGURE 33. Vertical Component Spectra:
Tests Above 12 m.

REFERENCES

1. R. J. Engelmann. The Calculation of Precipitation Scavenging, BNWL-77. July 1965.
2. R. J. Engelmann. "Precipitation Scavenging Studies," Hanford Radiological Sciences Research and Development Annual Report for 1964, BNWL-36, pp. 1.54-1.59. 1965.
3. A. C. Chamberlain. Aspects of Travel and Deposition of Aerosol and Vapour Clouds, AERE-HP/R-1261. Harwell. 1953.
4. V. N. Kelkar. "Size Distribution of Raindrops - Part I," Ind. J. Meteor. Geophys., vol. 10, pp. 125-136. 1959.
5. R. W. Perkins. "Washout Studies Using Natural Tracers from Radio-Chemical Separations Plant Stacks." Hanford Radiological Sciences Research and Development Annual Report for 1964. BNWL-36, pp. 3.99-3.101. 1965.
6. United States Weather Bureau. Meteorology and Atomic Energy. U. S. Government Printing Office. 1955.
7. W. M. Culkowski. Deposition and Washout computations Based on the Generalized Gaussian Plume Model, ORO-599. Weather Bureau Research Station, Oak Ridge. 1963.
8. C. E. Guthrie and J. P. Nichols. Theoretical Possibilities and Consequences of Major Accidents in U²³⁵ and Pu²³⁹ Fuel Fabrication & Radioisotope Processing Plants, ORNL-3441. Oak Ridge National Laboratory. 1964.
9. J. J. Fuquay, C. L. Simpson, and W. T. Hinds. "Prediction of Environmental Exposures from Sources Near the Ground Based on Hanford Experimental Data." J. Appl. Met., vol. 3, pp. 761-770. 1964.
10. R. J. Engelmann. MIDAS Computation of Waterdrop Evaporation, BNWL-74. July 1965.
11. M. L. Barad and J. J. Fuquay (Editors!). "The Green Glow Diffusion Program." Geophysical Research Papers No. 73, Air Force Cambridge Research Laboratories, Geophysics Research Directorate, Cambridge, Massachusetts, HW-71400, vol. 1, pp. 69-71. 1962.
12. G. E. Driver. Instruction Manual Radio-Telemetering Network Data Station, HW-63467. January 1960.
13. C. A. Ratcliffe and E. M. Sheen. Radio-Telemetering Network Data Stations Instruction Manual, HW-83854. September 24, 1964.
14. P. W. Nickola. Unpublished Report. Battelle-Northwest, Richland, Washington. 1965.
15. E. Bollay Associates, Inc., Boulder, Colorado.
16. P. W. Nickola and M. F. Scoggins. "Atmospheric Tracer Technology: Real Time Sampler." Hanford Radiological Sciences Research and Development Annual Report for 1963, HW-81746, pp. 1.47-1.48. January 1964.
17. P. W. Nickola, M. O. Rankin, M. F. Scoggins and E. M. Sheen. A Device for Recording Air Concentrations of Zinc Sulfide Fluorescent Pigment on a Real Time Scale, HW-SA-3317. January 10, 1964.
18. P. W. Nickola. "A Sampler for Recording the Concentration of Airborne Zinc Sulfide on a Real Time Scale." Hanford Radiological Sciences Research and Development Annual Report for 1964, BNWL-36, pp. 1.59-1.64. January 1965.
19. J. J. Fuquay. Progress in Atmospheric Physics: A Summary of Hanford Laboratories Work on this Program under General Electric, 1959-1964, HW-83602, pp. 6-10. September 1964.

20. Zinc Sulfide (ZnS) Fluorescent Pigment 2210, manufactured by U. S. Radium Corporation, Morristown, New Jersey.
21. M. L. Barad and J. J. Fuquay (Editors). "The Green Glow Diffusion Program." Geophysical Research Papers No. 73, Air Force Cambridge Research Laboratories, Geophysics Research Directorate, Cambridge, Massachusetts, HW-71400, vol. 1, pp. 48-55. 1962.
22. J. L. Lumley and H. A. Panofsky. The structure of Atmospheric Turbulence. Interscience Publishers, New York. 1964.
23. N. F. Islitser. "Short-Range Atmospheric Dispersion Measurements from an Elevated Source." J. Meteorology, vol. 18, pp. 443-450. 1961.
24. A. N. Kalmogorov. "The Local Structure of Turbulence in Incompressible Viscous Fluid for very Large Reynolds Numbers." Doklady ANSSSR 30, p. 301. 1941.
25. H. A. Panofsky and R. A. McCormick. "The Spectrum of Vertical Velocity near the Surface." Quarterly Journal of Royal Meteorological Society, vol. 86, p. 495. 1960.
26. A. S. Gurvich. "Frequency Spectra and Distribution Functions of Vertical Wind Components." Izvestia ANSSSR, Geophysics Series 1960, No. 7, p. 1042. 1960 (a).
27. P. B. MacCready, Jr. "The Inertial Subrange of Atmospheric Turbulence." J. Geophys. Research, vol. 67, p. 1051. 1962 (b).
28. P. B. MacCready, Jr. "Turbulence Measurements by Sailplane." J. Geophys. Research, vol. 67, p. 1041. 1962 (a).
29. S. Pond, R. W. Stewart and R. W. Burling. "Turbulence Spectra in Wind over Waves." J. Atmospheric Sciences, vol. 20, p. 319. 1963.

DISTRIBUTIONNumber of CopiesNumber of Copies

325 Division of Technical
Information Extension

1 AIF Task Force
MPR Associates, Inc.
815 Connecticut Ave., N.W.
Washington, D.C. 20006

1 Air Force Cambridge
Research Laboratory
Bellford, Massachusetts
D. A. Hargen

1 Atomic Energy of Canada
Limited
Chalk River, Ontario
C. A. Mawson

2 Atomic Energy Estab-
lishment Trombay
Bombay 73, India
P. N. Krishnamoorthy
K. T. Thomas

2 Atomic Energy Research
Establishment
Harwell, Berks, England
R. H. Burns
E. Glueckauf

1 Australian A.E.C.
Post Office Coogee
New South Wales,
Australia
A. W. R. Wilson

1 Brookhaven National
Laboratory
L. P. Hatch

1 Center for Nuclear
Studies
P. O. Box 6, Fontenay-
aux-Roses
(Seine) France
A. de Calmes

2 Center for Nuclear
Studies
P. O. Box 2, Saclay
Gif-sur-Yvette (S & O),
France
F. Duhamel
A. Menoux

2 Douglas United Nuclear
T. W. Ambrose
P. C. Jerman

2 duPont Company
Aiken, South Carolina
W. B. Scott

1 duPont Company
Wilmington, Delaware
V. R. Thayer

1 ENEA (OECD) Health and
Safety Office
38, Blvd. Suchet,
Paris XVI, France
E. Wallauschek

2 Eurochemic Library
Mol, Belgium

2 General Electric Company
M. C. Leveritt
R. T. Trumbull

1 General Electric Company
Advanced Technology
Laboratories
1 River Road, Schenectady
5, New York
J. W. Healy-Consultant
Technical Hazards

1 Geological Survey of
the United Kingdom
Water Division
Stevenson Buchan,
Chief Geologist

2 Geological Survey of
The United States
Washington 25, D.C.
M. King Hubbert
C. V. Theis

1 George Washington
University
Washington, D.C.
C. R. Naeser

1 Geotechnical Corporation
Box 28277, Dallas 28,
Texas
W. B. Heroy

1 Gesellschaft Kernfor-
schung mbH
Karlsruhe 5
West Germany
Dr. H. Krause

DISTRIBUTION (Contd)

Number of CopiesNumber of Copies

2	<u>Hanford Occupational Health Foundation</u> W. D. Norwood P. A. Fuqua	1	<u>University of Arizona</u> Tucson, Arizona Department of Geology E. S. Simpson
2	<u>International Atomic Energy Agency</u> Vienna 1, Kaerntnerring 11, Austria H. Seligman J. Servant	1	<u>University of California</u> Berkeley, California Department of Civil Engineering W. J. Kaufman
3	<u>Isochem, Inc.</u> R. E. Tomlinson F. Hill D. J. Brown	1	<u>University of Illinois</u> Department of Agronomy M. B. Russell
1	<u>Johns Hopkins University</u> Baltimore, Maryland W. A. Patrick	1	<u>University of North Carolina</u> Chapel Hill, N. C. Department of Chemistry H. C. Thomas
2	<u>Lawrence Radiation Laboratory</u> Livermore, California G. H. Higgins J. B. Knox	1	<u>University of Wisconsin</u> Department of Chemistry H. Gladys Swope
2	<u>National Institute of Radiological Sciences</u> 250, Kurosuna-Cho, Chiba-shi, Japan M. Saiki M. Suzuki	9	<u>U. S. Atomic Energy Commission</u> Washington, D.C. Division of Biology and Medicine N. F. Barr H. D. Bruner W. D. Claus C. L. Dunham, Dir. H. Hollister A. W. Klement S. A. Lough J. R. Totter J. N. Wolfe
2	<u>N. V. Belchim</u> 200 Boeretang Mol, Belgium Paul Dejonghe Leo H. Baetsle	1	Division of Naval Reactors R. S. Brodski
9	<u>Richland Operations Office</u> J. T. Christy J. P. Derouin P. G. Hosted C. L. Robinson R. K. Sharp (2) Technical Information Library (2) R. D. Wildman	1	Division of Production W. L. Lennemann
2	<u>Oak Ridge National Laboratory</u> K. Z. Morgan E. G. Struxness	1	Division of Reactor Development W. G. Belter
		1	Health and Safety Laboratory New York City John Harley, Dir.
		1	<u>U. S. Atomic Energy Commission Savannah River Operations Office</u> K. K. Brown

DISTRIBUTION (Contd)

Number of CopiesNumber of Copies

1 U. S. Public Health
Service
 Division of Health
 Mobilization
 Washington, D. C.
 J. J. Lang
 Research Branch

1 World Health Organization
 Geneva, Switzerland
 R. L. Dodson, M.D.

117 Battelle-Northwest
 G. J. Alkire
 F. W. Albaugh
 W. J. Bair
 C. A. Bennett
 R. J. Brouns
 L. J. Chockie
 W. J. Clarke
 R. F. Dickerson
 R. L. Dillon (2)
 W. L. Dotson
 C. E. Elderkin
 R. J. Englemann
 S. L. Fawcett
 E. H. Finney
 R. F. Foster
 P. A. Fuqua
 J. J. Fuquay (50)
 J. K. Green (5)
 W. A. Haney
 J. F. Honstead
 F. P. Hungate
 E. R. Irish

Battelle-Northwest (Cont.)

R. T. Jaske
 R. L. Junkins
 D. R. Kalkwarf
 A. R. Keene
 H. A. Kornberg
 C. R. Lagergren
 K. H. Larson
 R. E. Nakatani
 C. E. Newton
 J. M. Nielsen
 R. F. Palmer
 H. M. Parker
 R. S. Paul
 D. W. Pearce
 R. W. Perkins
 I. C. Roberts
 W. C. Roesch (6)
 L. C. Schwendiman
 W. G. Spear
 C. L. Simpson (50)
 A. J. Stevens
 M. F. Sullivan
 R. C. Thompson
 C. R. Tipton, Jr.
 E. E. Voiland
 M. T. Walling
 W. E. Wilson
 D. C. Worlton
 Biology Library (2)
 Technical Information
 Files (5)
 Technical Publica-
 tions (2)