Results of Recent Field Programs in Atmospheric Diffusion[1]

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ABSTRACT

During the summer of 1959, the Green Glow program, consisting of 26 diffusion experiments during nocturnal inversions, was conducted at the Atomic Energy Commission's Hanford Site near Richland, Wash. The tracer, zinc sulfide, was released near ground level. Samplers were placed at 1.5 m above ground at 533 positions on six sampling arcs, the radii of which were 200 m, 800 m, 1.6 km, 3.2 km, 12.8 km, and 25.6 km. In addition to the ground sampling network, poles or towers were erected at 5 points, 8 deg apart, on each of the 4 inner arcs. Fifteen samplers were mounted on each pole or tower, the top level increasing from 27 m on the 200-m arc to 62 m on the 1.6-km and 3.2-km arcs.

General aspects of the experimental design and tracer technique are discussed along with terrain characteristics and meteorological conditions pertinent to these experiments. Experimental results are presented showing the increase in horizontal plume width and decrease of maximum exposure with distance from the source. An analysis of the area enclosed within a given exposure isopleth is summarized. The effect of significant wind direction shear on the vertical distributions of exposure is discussed. Results from the Green Glow experiments are compared with those from earlier diffusion experiments at O'Neill, Nebr., and later experiments at Hanford.

1. Introduction

In the summer of 1956, Project Prairie Grass, a cooperative effort under the direction of the Air Force, was conducted near O'Neill, Nebr. The objectives and results from this classical diffusion study are by now well known. The experiment not only provided some badly needed tools for engineering applications, but served a more basic purpose in that verification of the anisotropic character of the atmosphere was made which clearly underscored the folly of any arbitrary application of the diffusion equations.

During 1959, a second cooperative effort was undertaken by the Air Force Geophysics Research Directorate, the General Electric Company, the Air Weather Service, and the Texas A. and M. Research Foundation. This test series was conducted within the Hanford Reservation near Richland, Wash., and was nicknamed "Green Glow," in an obvious reference to the color of the fluorescent pigment which was used as a tracer. During 1960, many other diffusion experiments were conducted at Hanford, utilizing most of the facilities that were available during the 1959 Green Glow series. The 1960 tests which were conducted by the General Electric Company are collectively referred to as "the 30 series."

Project Prairie Grass consisted of some 70 experiments embracing a broad spectrum of atmospheric stabilities. The gas tracer, sulfur dioxide, was emitted continuously for 10-min periods from a source near the ground and the diffusive properties were observed along with the atmospheric characteristics out to distance of 800 m from the point of release. Green Glow on the other hand was comprised of 26 one-half-hour releases primarily designed to investigate diffusion to distances of 25,600 m (approximately 16 mi) from the source near the ground in atmospheres characterized by a thermal inversion near the surface. The surface over which the fluorescent-pigment tracer plume traveled was gently rolling and rather densely covered with a variety of desert vegetation of average height near one meter. This surface was very rough relative to that at O'Neill. The "30 series" tests were held on the same grid as those of Green Glow to distances of 3,200 m (about 2 mi). This series, which was comprised of 15 one-half hour releases, included 6 tests conducted during the daytime under lapse conditions.

This paper emphasizes some of the more recent findings of these series. Descriptions of the grids, sampling

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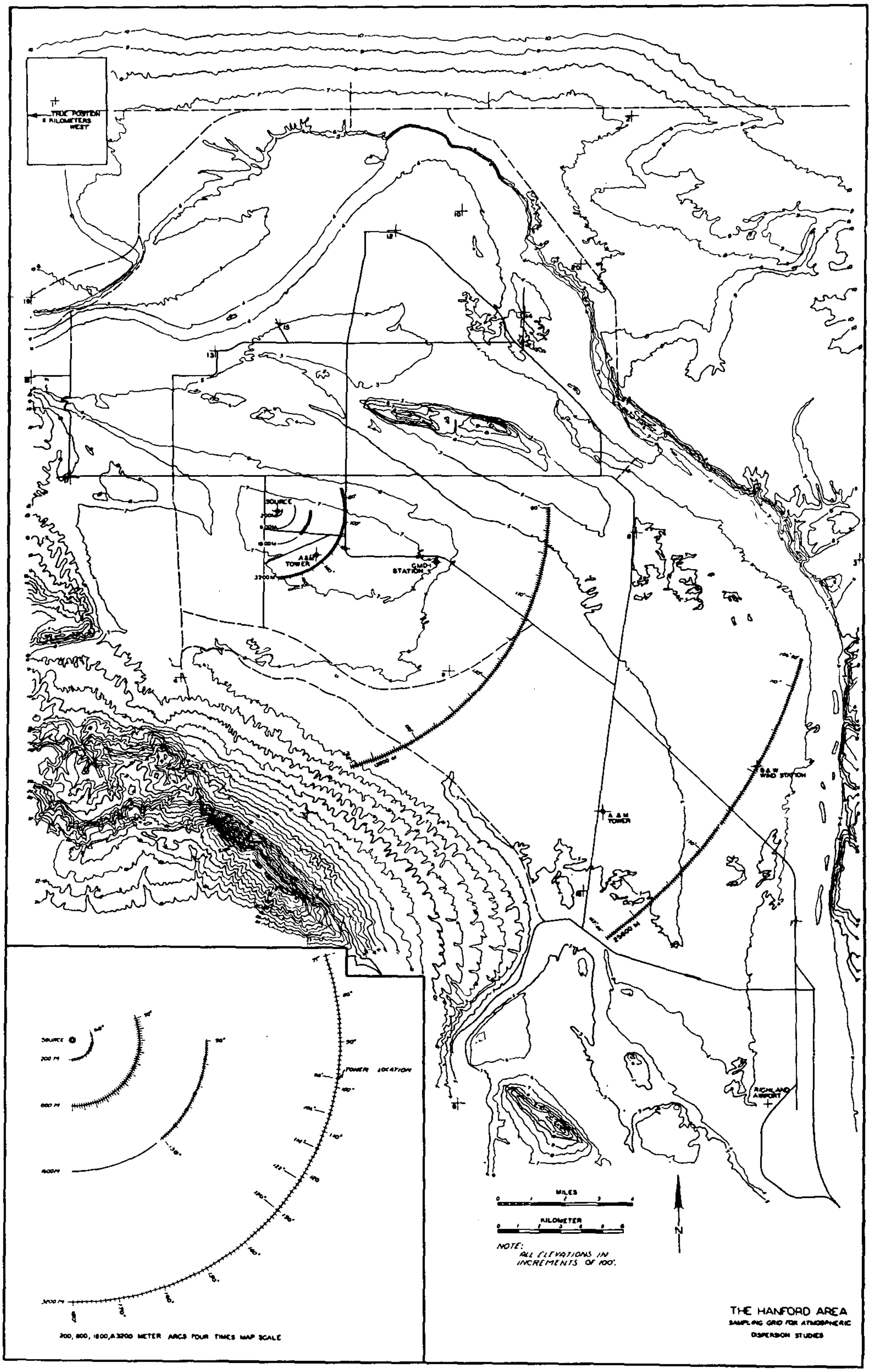


FIG. 1. The Hanford sampling grid and general topography.

and assaying techniques must necessarily be brief. The discussion is primarily directed toward a summary of the results obtained from the two Hanford series, comparing these where possible to the Prairie Grass summaries.

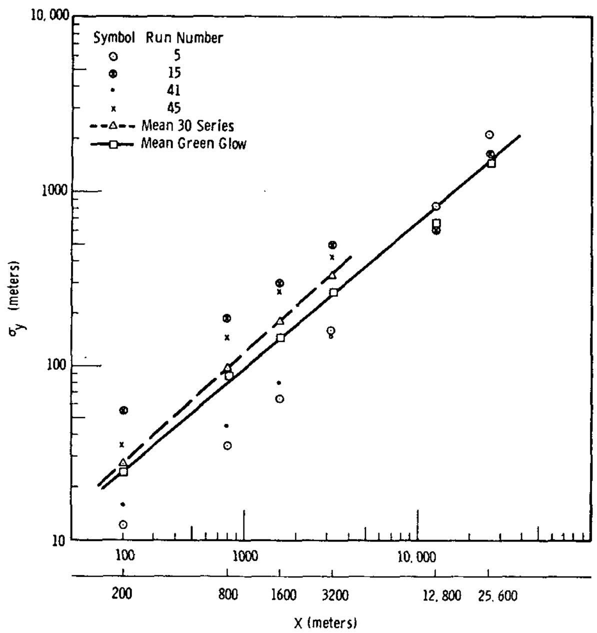
2. Description of the Green Glow site

The Green Glow experiments were conducted on the Atomic Energy Commission's Hanford reservation located in Southeastern Washington. The Hanford sampling grid and general topography are shown in Fig. 1. The field test area was in the relatively flat basin, sloping gently to the southeast from the Meteorology Tower. A pronounced nocturnal drainage wind from the northwest dominates the air flow pattern in the central portion of the valley. The release point for the fluorescent tracer material was located 100 m south of the Meteorology Tower, and the sampling grid was centered on that point. Samplers were placed at a height of 1.5 m above ground at 533 positions on six sampling arcs, the radii of which were 200 m, 800 m, 1.6 km, 3.2 km, 12.8 km, and 25.6 km. In addition to the ground sampling network, poles or towers were erected at five points, 8 deg apart, on each of the 4 inner arcs. Fifteen samplers were mounted on each pole or tower, the top level increasing from 27 m on the 200-m arc to 62 m on the 1.6-km and 3.2-km arcs. The flow rates through the filters increased from 0.15 liter per sec at 200 m to 2.0 liters per sec at 12.8 km and 25.6 km.

Meteorological equipment in support of these experiments included the 410-ft meteorological tower and the 65-ft portable mast near the source point, and two Texas A. and M. micrometeorological towers located 2.8 km and 21.3 km downwind of the source. In addition, a rawindsonde station was located about 8.0 km downwind for upper level wind and temperature observations and a radiotelemetering network relayed wind velocity data from several points over the test area.

3. Standard deviation of the cross-wind mass distribution

The mass of zinc sulfide collected on a given filter provides the basic data from which all other parameters in the analysis are derived. One of the basic statistics that evolves from the analysis is the time-mean plume width, usually designated by the standard deviation of the cross-wind mass distribution, σ_y (meters). This statistic can be evaluated for each arc and plotted against distance as shown in Fig. 2. The axes in this graph are logarithmic with σ_y (meters) represented on the ordinate and distance from the source X (meters) represented by values on the abscissa. The points on the graph are computations from selected runs from the Green Glow and "30 series" tests. These particular tests were selected to point up the apparent lack of correlation between the width of the plume and thermal stability. For example, Runs 5 and 15 from the Green Glow series are associated with very great thermal stability, but yet they represent the narrowest and broadest plumes, respectively, of the 26 tests of the series. Runs 41 and 45 were tests from the "30 series" conducted during very unstable daytime conditions



FGI. 2. Standard deviation of arcwise dosage distributions for selected experiments.

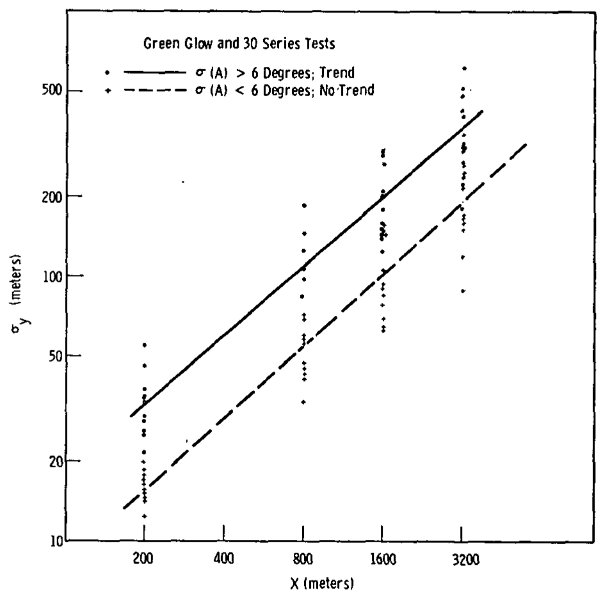


FIG. 3. Standard deviation of arcwise dosage distributions as related to the standard deviation of wind direction.

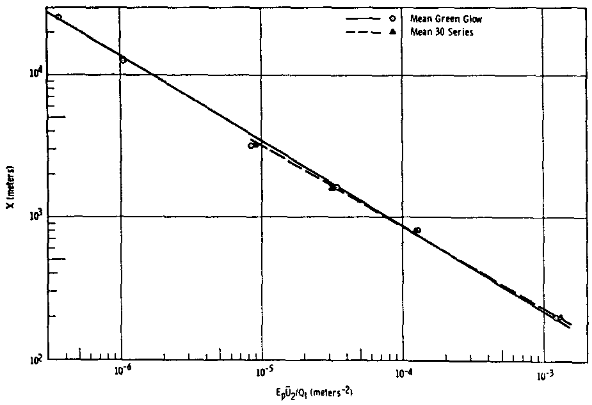


Fig. 4. Distance dependence of mean normalized peak exposure for the Green Glow and 30 Series experiments.

and here again are very narrow and broad plumes. The mean growth curves for both series are also shown and, in general, they approximate a power function with a slope near 0.85 although there is some evidence to support curvature in the region between 3200 m and 12,800 m where there was a marked elevation change with irregular topography.

Since the data clearly demonstrate that the knowledge of thermal stability alone is insufficient for prediction of the time-mean plume width, it is natural to next examine the serial analysis of the wind for the existence of trends and cycles. Fig. 3 shows the standard deviation plotted as before as function of the distance from the source. Here, however, some stratification of the data is obtained with the defining of two subclasses. The open circle points on the graph are Green Glow and "30 series" tests associated with winds characterized by meander or trend, whereas the plus points are runs that were conducted under fairly steady-state conditions. Analytically, this determination was made by computing the standard deviation of the 20-sec averages of the wind directions observed at 2 m through the one-half hour duration of the tests. The direction standard deviation, $\sigma(A)$ deg, of 6 deg appeared to differentiate fairly well between the two classes, giving about the same results as a subjective appraisal of the wind direction data.

4. Maximum centerline exposure

Another diffusion statistic that is useful in determining the spatial distribution of the tracer material is the dosage or exposure. Exposures (E, g sec m^{-3}) are determined by dividing the total amount of tracer collected on the sampler (mass in grams) by the flow rate through the sampler. Peak exposures (E_p) are simply the largest of all the exposures on each of the arcs for any particular experiment. So that all the experiments can be compared, the effects of the source strength, Q_T (grams) and wind speed, u (m sec^{-1}), were removed by computing the normalized quantity, $E_p u/Q_T$ (m^{-2}). Fig. 4, a graph whose coordinates are logarithmic, shows that the normalized exposure approximates a power function relation with respect to distance from the source. The two curves are the mean values of the Green Glow series, which include all stable experiments and the "30 series," which are comprised of 6 unstable and 9 stable tests. The slope of the best fit lines is approximately -1.80.

Figs. 5 and 6 show $E_p u/Q_T$, the peak exposure on each arc normalized for the source strength and wind speed, vs. distance from the source for the unstable and stable cases. The range of $E_p u/Q_T$, as well as the median value, are shown for each distance. For unstable cases shown in Fig. 5, it is evident that Prairie Grass data and those unstable runs from "30 series" compare favorably, with the median value of "30 series" data being just slightly greater than the median of Prairie Grass. For stable cases, however, Fig. 6, the median value of Prairie Grass exceeds the median value of *Green Glow* data by a factor of 3.3 at a distance of 200 m and a factor of 3.9 at 800 m. This indicates that in the stable cases the diffusion at Hanford was greater than that at O'Neill in the horizontal, in the vertical, or in both. In addition, there are important differences in duration of release between the two sets of data. The 30-min stable releases at Hanford are most frequently affected by trends in the wind velocity, whereas the 10-min releases at O'Neill exhibited greater persistence. As a result, the normalized peak exposures for Prairie Grass would be expected to be greater than those obtained in the two Hanford series during stable conditions.

5. Cross-wind integrated exposure

In order to remove the effects of horizontal diffusion, the normalized cross-wind integrated exposure was plotted as a function of distance from the source as shown in Figs. 7 and 8. The cross-wind integrated exposure (CIE) represents the total amount of tracer which passed through the arc at the 1.5-m level. The normalized quantity, $[\mathrm{CIE}]u_2/Q_T(M^{-1})$ is equivalent to $(u_2/Q_T)\int E dy$, where y is measured along the arc. Fig. 7 shows that in unstable conditions the differences between the Prairie Grass and "30 series" results are small. But, as in the case of the normalized peak exposures for the stable case, Fig. 8 shows the median of the normalized cross-wind integrated exposure values at Prairie Grass to be greater than that of Green Glow by a factor of 2.0 for the 200-m arc and a factor of about 1.9 at the 800-m arc.

There are several factors that could bring about the higher exposures observed at O'Neill relative to those at Hanford. First of all, the differences in the climatological and physical characteristics of the two areas are great and might be expected to affect the rates of vertical diffusion that would result. For example, the greater mechanical turbulence produced by the brush covered Hanford area would bring about greater vertical diffusion resulting in lower exposures than would be observed over a smoother boundary such as that at O'Neill. Secondly, and related to the first argument, is the consideration of deposition of matter upon the surface as a mechanism for the removal of the tracer from the atmosphere. There has been some evidence that this factor is operative in the Hanford experiments and investigation is continuing on this problem. Also, there is evidence in both the Hanford and O'Neill data

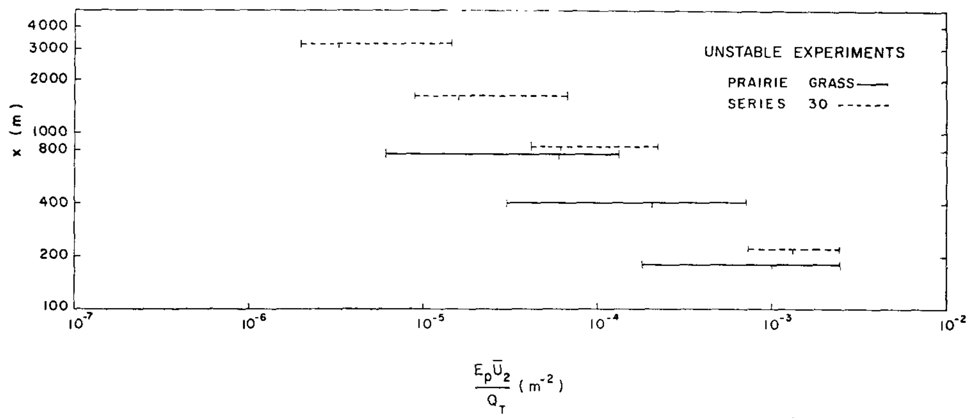


FIG. 5. Range and median values of normalized peak exposure: unstable experiments.

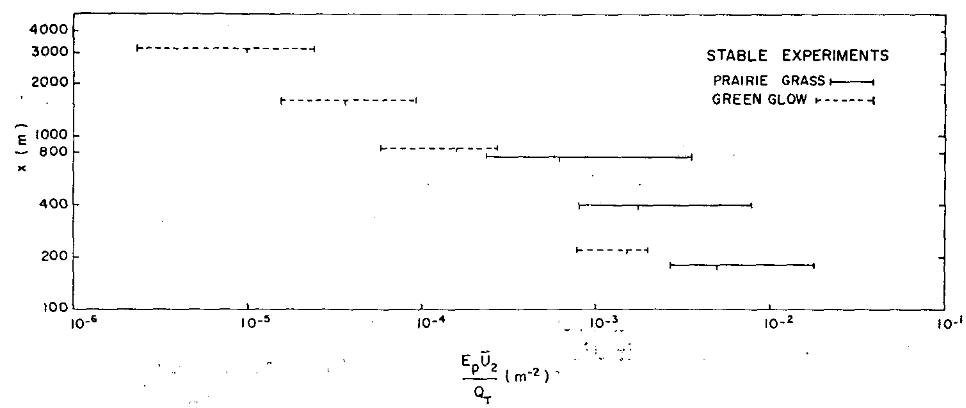


FIG. 6. Range and median]values of normalized peak exposure: stable experiments.

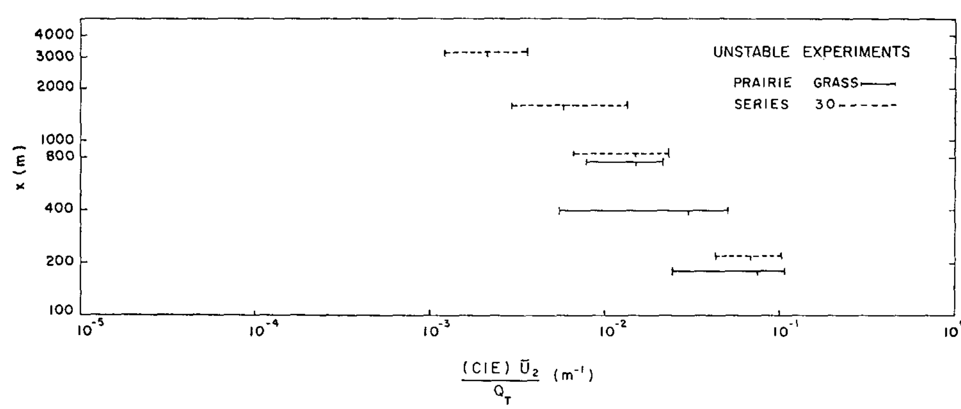


FIG. 7. Range and median values of normalized cross-wind integrated exposure: unstable experiments.

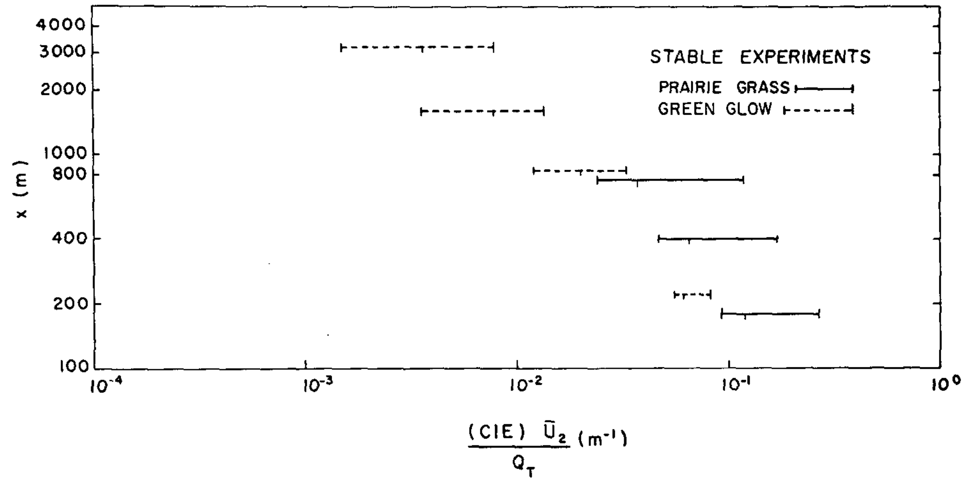


FIG. 8. Range and median values of normalized cross-wind integrated exposure: stable experiments.

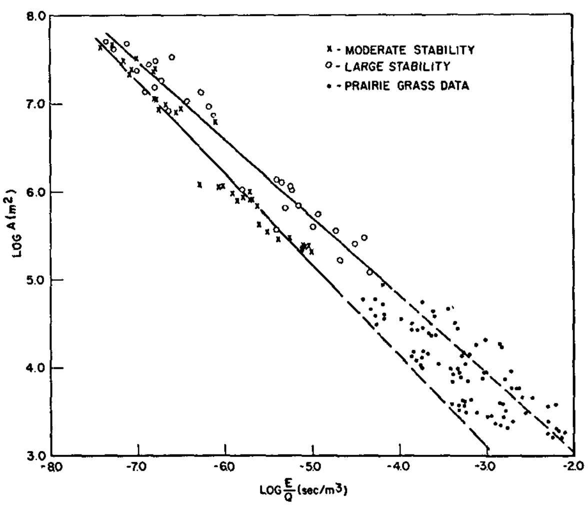


FIG. 9. Area inclosed by a given exposure isopleth: stable experiments.

that the surface of maximum (peak) exposure does not pass at the sampler height of 1.5 m, but actually passes above or below this height. In the Prairie Grass data, the maximum generally occurs below 1.5 m, whereas, in the Hanford data, the maximum is above this height. Part of this effect is due to the difference in source height. The difference in height of maximum will affect the comparisons that are made at the 1.5-m height. The fact that the integrated cross-wind exposures still show differences between the two locations indicates that the previously mentioned factors affecting the vertical diffusion are important.

6. Area-dosage relationship

The Prairie Grass and Hanford data have provided yet another useful tool in dealing with applied problems concerned with area-dosage relationships. Fig. 9 graphically summarizes some of the results obtained by Elliott and Nickola (1961). The Green Glow data are represented by crosses for moderate stability, open circles for strong stability, and Prairie Grass data by dots. It is quite evident here that the area enclosed within any given isopleth of exposure is related to that value of exposure raised to a power. The slope of the best fit line for all Green Glow data is -0.95, whereas, for stable Prairie Grass data it was -0.91. Further, differentiation has been made between very stable and moderately stable tests, showing that in general larger areas in the horizontal will be affected when the atmosphere is most stable as shown by the two regression lines. Very stable conditions were those in which a temperature inversion of 1.5F existed between 2 and 16 m height. Moderately stable conditions are defined as those in which the temperature difference over this interval was less than +1.5F, but greater than 0F.

7. Wind shear effects

Diffusion in stable atmospheres has long been recognized as being affected by other mechanisms not found in the neutral and lapse conditions. As a result, serious miscalculations can be made by attempting to apply models specifically developed for the neutral and lapse states to those of the stable regimes. One very noticeable property associated with stability is the wind direction shear with height that results in greater horizontal diffusion and a sloping axis of the maximum in the vertical. Barad and Fuquay (1962) have recently suggested a generalized model which treats the mass distribution as being bivariate normal and have demonstrated that the model realistically describes one of the Green Glow experiments which exhibited strong vertical shear. The parameters which define the distribution are a direct consequence of the cross-correlations of the velocity fluctuations and, therefore, have a fundamental basis. Investigation is continuing with this model utilizing other experimental data.

8. Conclusions

It is significant that data obtained from Prairie Grass, Green Glow, and "30 series" tests have provided information that is useful for estimates of plume growth and dilution to distance out to 16 miles. But, also, these series have brought to light some differences which apparently result from physical differences in the test sites, climatology, and experimental techniques. There is need for further investigation of the vertical diffusion and its relationship to meteorological variables, and finally it remains ultimately to incorporate all of the significant variables into a model that realistically describes diffusion over a wide range of stabilities. The significance of some factors has yet to be determined, leaving yet many areas of research to be explored.

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