Session Chairman: Gentlemen, thank all of you for participating in Session VI. We will now adjourn for lunch.

SESSION VII - METEOROLOGICAL ASPECTS OF AIR CLEANING

Afternoon - 23 October 1963

D. H. Slade, USWB, Chairman

Session Chairman: I am D. H. Slade from the United States Weather Bureau in Washington, and will be the chairman of Session VII which is primarily, but not entirely, meteorological. The first three papers deal with meteorology in one form or another, and there will be two papers after the mid-afternoon break which are essentially air cleaning papers. The procedure has been to leave the discussion until after a number of papers have been presented, so we will have the first three papers and then the discussion.

The role of a meteorologist in the nuclear energy industry is basically to predict the details of transport and diffusion of airborne materials from the source to what we might call the consumer. We are, therefore, intermediate in the chain between air cleaning personnel and the health physicist. You, we, and the health physicists have our own problems, which frequently seem rather far apart. We are a chain, however, and I think, as in a chain, we cannot consider our fields of interest as totally independent of each other.

I hope the papers presented in this session will give you some idea of the problems that meteorologists face.

It is my pleasure to present the first paper, the title of which is "Innovations and Developments in Air Pollution Studies." Much of the report was prepared by others in my group, if there are questions on some of this work which I am unable to answer, I will be happy to refer you to these people.

INNOVATIONS AND DEVELOPMENTS IN AIR POLLUTION STUDIES

David H. Slade
U. S. Weather Bureau

The Environmental Meteorological Research Project of the U. S. Weather Bureau, the group with which I am associated, has for the last fifteen years performed research and development in the fields of atmospheric pollution, diffusion and transport under the auspices of the AEC and the PHS. Our work has covered a wide range of studies from basic micrometeorological investigations through the development of practical techniques for immediate use. I would like to cover, in the few minutes allotted for this talk, some of the highlights of our current work.

THE "TETROON": CONSTANT LEVEL TETRAHEDRON BALLOON

A balloon ascends or descends according to whether its buoyancy force is greater or less than the weight of the balloon system. If the balloon is filled with a lighter-than-air gas and is constrained to keep a constant volume by a non-elastic envelope, for instance, then there is some given atmospheric density level at which the balloon will float in the absence of vertical motions. Slackness in the balloon and consequent loss of volume resulting from seepage of the gas or cooling of the balloon is overcome by super pressuring the balloon with respect to ambient flight pressure. Similarly, heating of this balloon system by the sun will not result in an increased volume. Such balloons, constructed of thin mylar plastic in the form of a tetrahedron, are called "tetroons" and have been used for the past five years in a number of atmospheric studies.

In the presence of atmospheric vertical motions, the tetroon will depart from its constant density surface and travel upward or downward at a rate that is felt to be a good approximation to the motion of the local environment.

In practice, the tetroon is tracked by a transponder-radar system. The radar scans in the vertical and horizontal until the transmitted radar pulse impinges on the transponder receiver. This received signal triggers the transponder transmitter, a unit weighing about five ounces which emits a signal fed directly into the video circuit of the radar. Using the WSR-57 radar, the standard Weather Bureau weather surveillance radar, transponder equipped tetroons have been tracked to almost 90 miles. The tetroon-transponder-radar system furnishes one of the simplest yet comprehensive methods of determining three-dimensional air motions over meso-scale distances yet developed for assessing both transport (trajectory) and turbulence (diffusion) data.

Perhaps the best way to illustrate uses of tetroons is by reference to the tetroon-derived data themselves. Figure 1 shows the trajectories of five typical flights followed by skin tracking (the transponder had not yet been developed). Flights 1 (1000 ft.), 2 (4200 ft.) and 3 (1600 ft.) were made during a nine-hour period while flights 4 and 5 were separated by about six hours. The utility of the tetroon-radar system for assessing atmospheric trajectories at a variety of levels is obvious. Such data could not be obtained from surface measuring systems while the conventional rawinsonde measurements would be incapable of presenting the detailed structure of wind speed and direction shown by the tetroon.

Typical of the turbulence type of statistic that may be obtained from tetroon position data are the mean spectra shown in Figure 2. The greatest speed variance in the top part of Figure 2 is associated with the low frequency oscillations which are probably "synoptic" or inertial in character. These variance data along with the mean wind speed, all obtainable from tetroon trajectories, may be used to directly compute the useful quantity, turbulence intensity.

Lateral variance and turbulence intensity statistics, taken from tetroon surface radar reflection readings at the NASA Wallops Island Site are compared in Table I with a variety of similar values determined analytically from weather

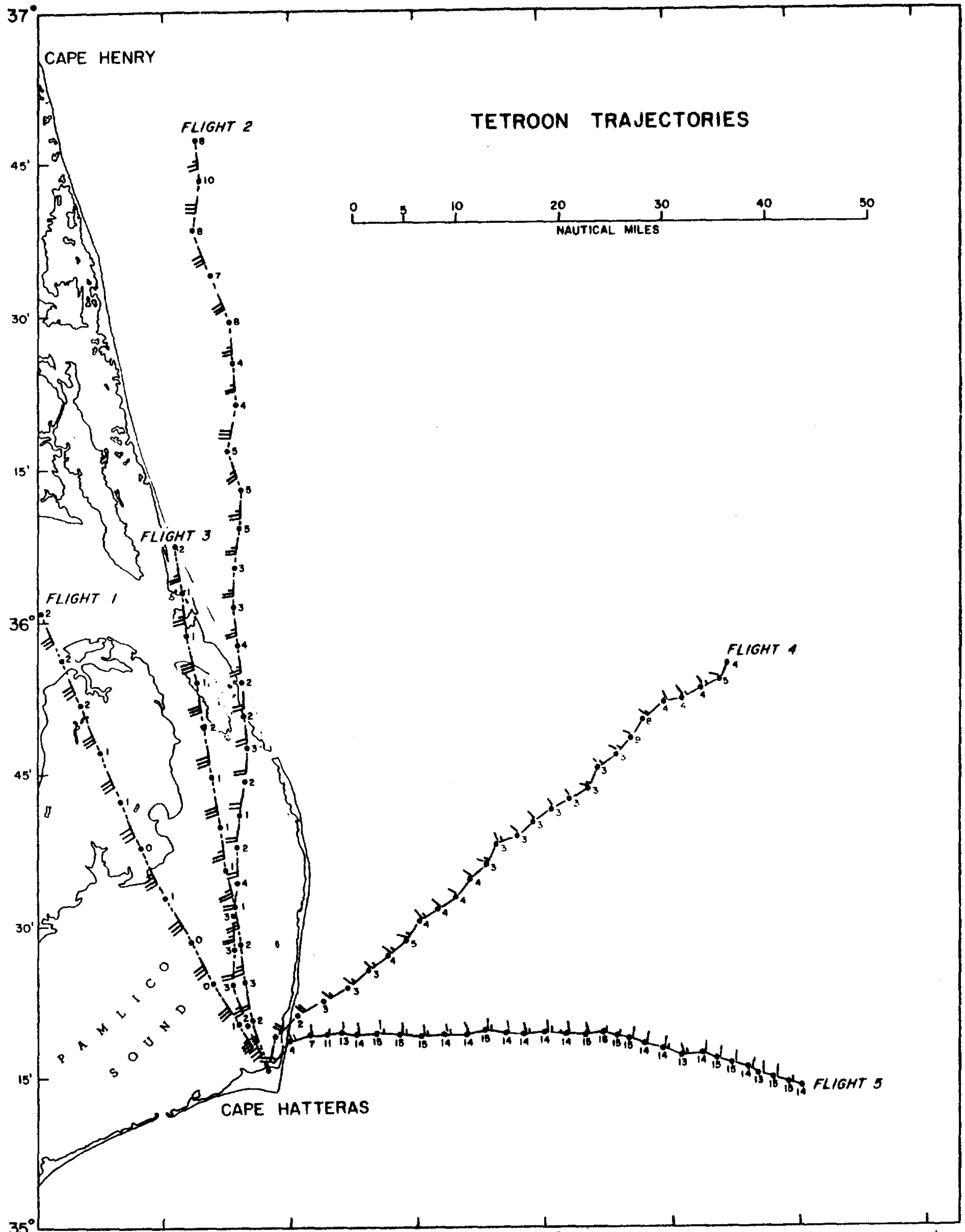

TETROON TRAJECTORIES
NAUTICAL MILES
0
5
10
20
30
40
50
CAPE HENRY
FLIGHT 1
FLIGHT 2
FLIGHT 3
FLIGHT 4
FLIGHT 5
PAMLICO SOUND
CAPE HATTERAS
37°
45'
30'
15'
36°
45'
30'
15'
35°
76°
45'
30'
15'
75°
45'
30'
15'

Figure I

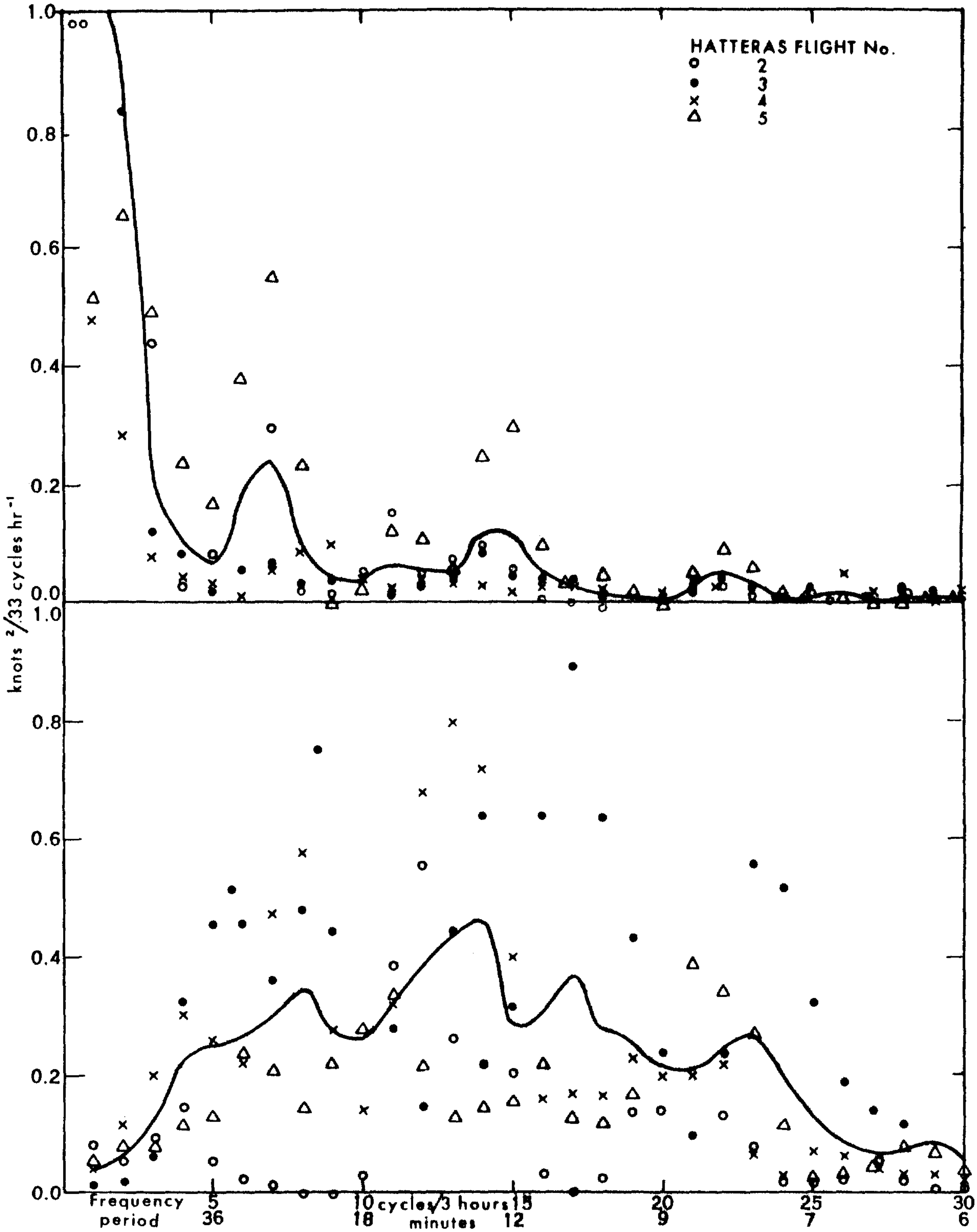

HATTERAS FLIGHT No.
2
3
4
5
1.0
0.8
0.6
0.4
0.2
0.0
knots ²/33 cycles hr⁻¹
Frequency
period
5
36
10 cycles/3 hours 15
18 minutes 12
20
9
25
7
30
6

Figure 2

charts or wind records.

TABLE I

Location	Height (Ft)	Variance $(Kt)^2$	Turbulence Intensity	Number of Evaluations
O'Neil, Neb	6	0.91	0.10	5
Idaho Falls	20	1.18	0.12	4
Brookhaven	75	4.56	0.15	2
Brookhaven	150	6.25	0.12	2
Idaho Falls	250	1.29	0.08	4
Brookhaven	300	5.87	0.11	2
England	1000-3000	0.18	0.03	8
Wallops (Flt. 7)	2500	0.15	0.03	4
Wallops (Flt. 3)	3000	0.31	0.03	3
Western Hemisph.	10,000	0.83	0.08	13
Western Hemisph.	18,000	1.72	0.07	4
Western Hemisph.	30,000	5.90	0.11	2

The order of magnitude difference in the variance may be real and ascribed to a real minimum in variance at this approximately 1 Km level (note the agreement with the "England" data due to Durst), may arise from the different definitions of length scale in Eulerian and Lagrangian wind measurements or may indicate the effect of low turbulence values for over-water trajectories.

Since the tetroon flights from Wallops Island and Cape Hatteras lay mostly over the water, it is not surprising that the paths showed comparatively little vertical turbulence. Because one of the chief uncertainties with respect to the analysis of tetroon data is the degree to which they respond to vertical air motions, a series of late summer tetroon flights were made in the desert near Las Vegas where daytime vertical turbulence would be expected to be quite intense. Figure 3 shows five early afternoon vertical trajectories. Oscillations of 5000 to 10,000 feet are common here compared to the few hundred to 1000 or 2000 feet vertical oscillations noted over the smoother ocean surface.

An interesting trajectory pattern may be noted if the tetroon circulation in the plane perpendicular to the mean path is plotted (Figure 4). The clockwise and counterclockwise circulation pattern, when superimposed on the mean wind, indicate the existence of helical flow patterns, a type of system noted

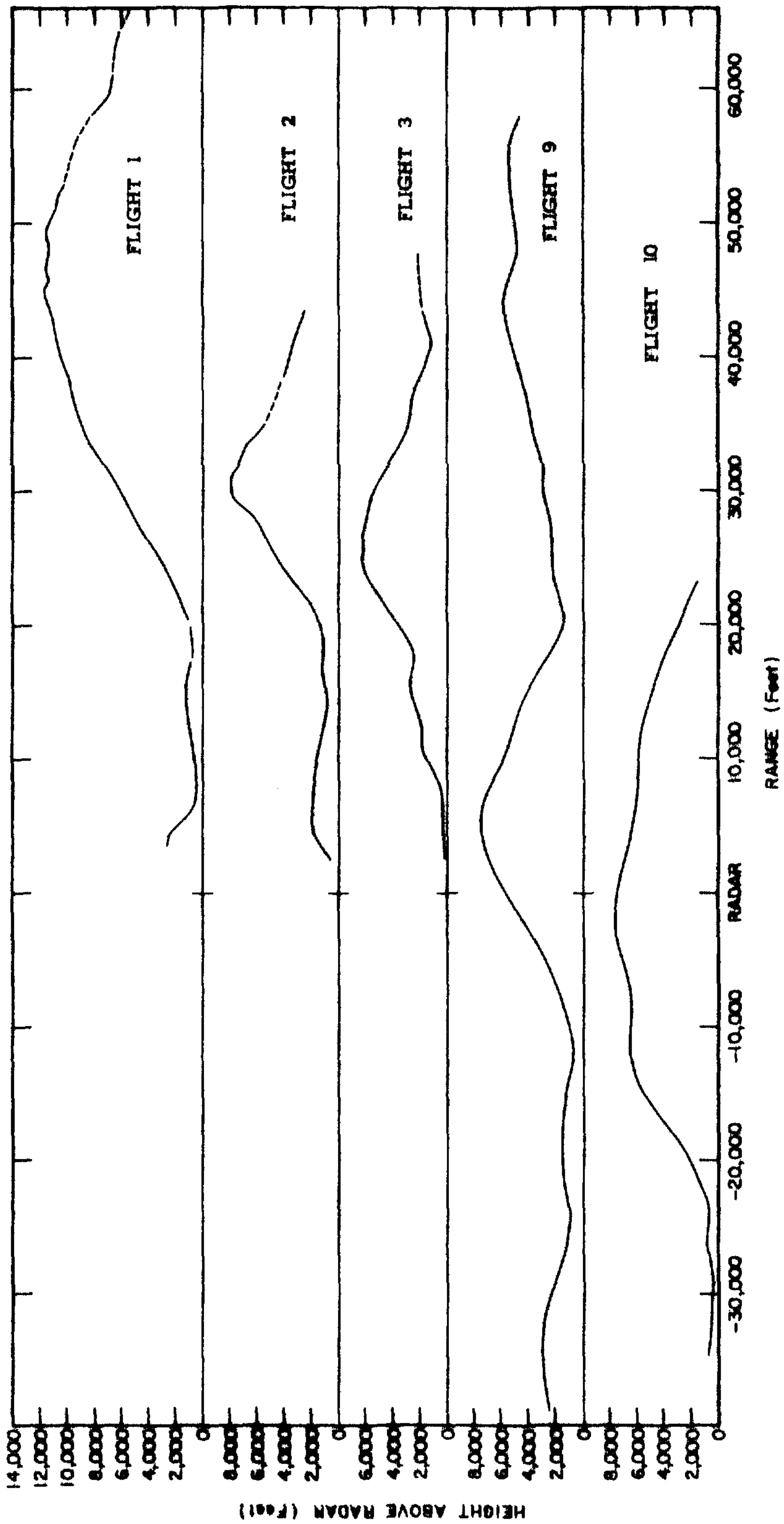

FLIGHT 1
FLIGHT 2
FLIGHT 3
FLIGHT 9
FLIGHT 10
HEIGHT ABOVE RADAR (Feet)
RANGE (Feet)
RADAR
-30,000
-20,000
-10,000
10,000
20,000
30,000
40,000
50,000
60,000

Figure 3

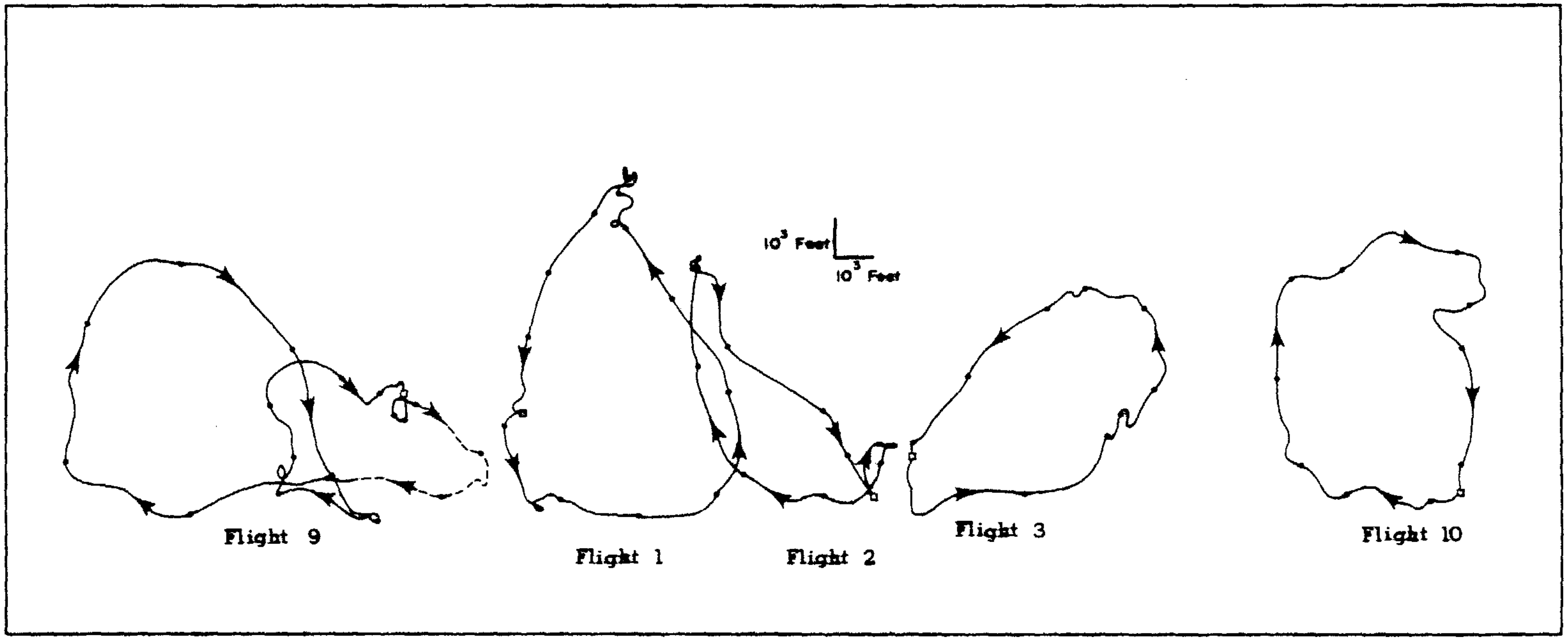

10³ Feet
10³ Feet
Flight 9
Flight 1
Flight 2
Flight 3
Flight 10

Figure 4

by other investigators. In general, this series of flights amply demonstrated that the heightened vertical motion activity over the daytime desert was quantitatively sensed by the tetroon flights.

The tetroon flights that have been described thus far utilized direct reflective or "skin" tracking. Many of the tetroons thus tracked were lost because of the impossibility of tracking by passive reflectors in the presence of ground clutter. The transponder described earlier was first used in an experiment near Cincinnati, Ohio in May of 1962. A maximum trajectory length of 54 miles and trajectories 10 to 20 miles long when the tetroon was floating very close to the ground amply demonstrated the superiority of this tracking method compared with tracking by passive reflection. While the number of flights was limited, the data were used to compute tetroon separation rates and mean square dispersion, shearing stress and eddy energy dissipation, all of which are quantities of great theoretical and practical interest and impossible, except by tetroon, to measure directly on this length scale and at typical tetroon altitudes.

The latest tetroon experiment was by far the largest by any system of reckoning. During a month interval, 88 tetroons were released from various points in the Los Angeles Basin and tracked by a radar mounted on Catalina Island. Totally, tetroons were tracked for over 400 hours with a longest track of 21 hours and a maximum distance of 88 miles. A detailed preliminary report on this project (Pack and Angell, 1963) is being published and will contain a bibliography of all previous papers on the subject.

One of the primary objectives of this experiment, beside the full scale test and demonstration of the technique, was to study the air flow in a region of considerable meteorological complexity, a region where the pollution problem is occasionally severe. The complexity is well illustrated by Figure 5 showing some of the tracks of tetroons released from Marineland, California during a two day period. This apparent chaos yields to standard statistical techniques such

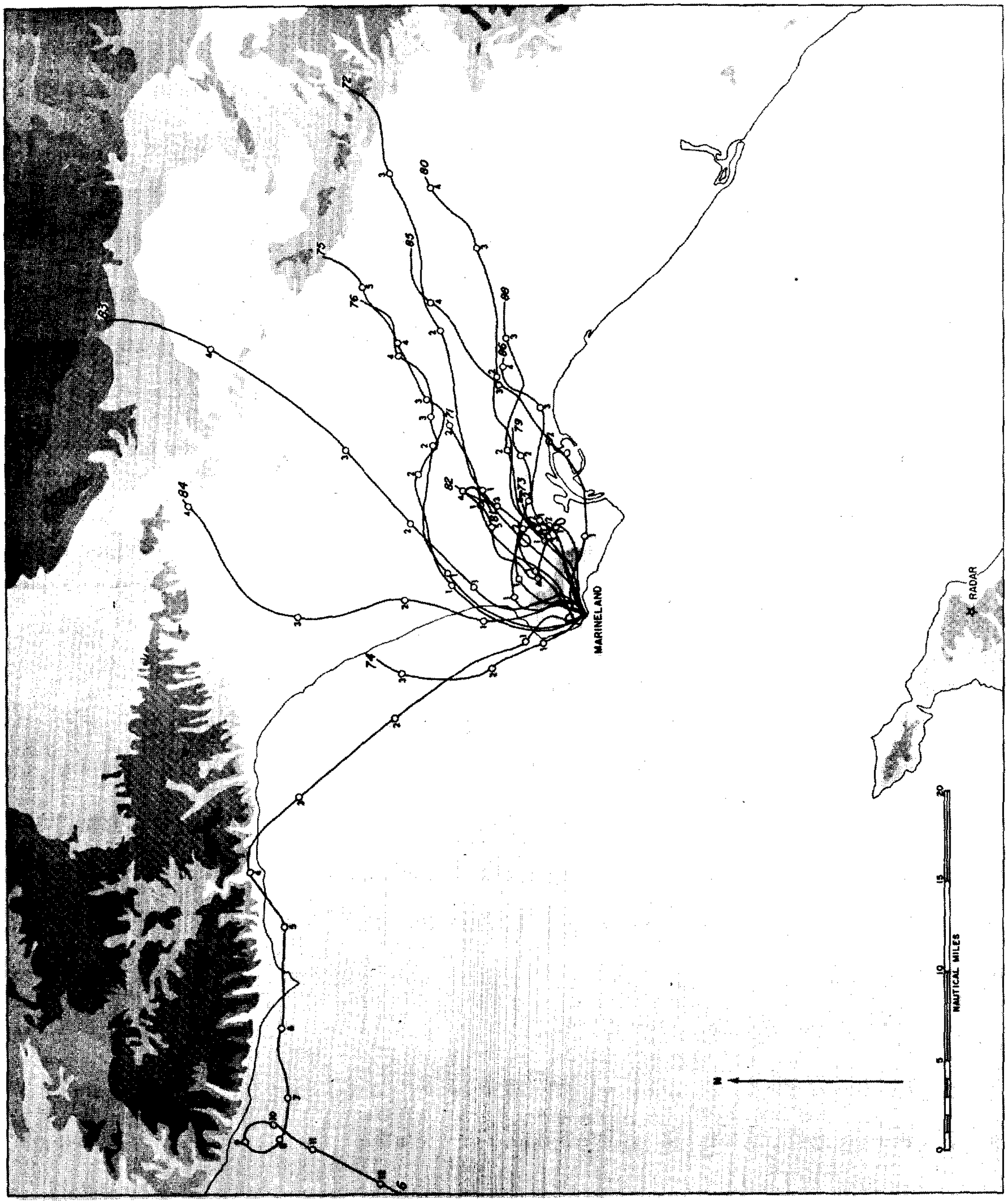


Figure 5

as those used in previous experiments to determine diffusion coefficients. Figure 6 shows the rate of continuous plume lateral spreading, a situation analogous to the lateral spreading of smoke from a chimney, derived from tetroon motion statistics. The power law relationship fits in almost perfectly with other data in the literature.

The response of tetroons to air motions in the vicinity of mountain barriers is shown in Figure 7. The paired flights 75 and 76 show, quite well, the difference in vertical motion over the water and land.

The future use of the tetroon system seems almost limitless. A program of routine daily release, similar to the routine sounding program of the upper atmosphere would furnish an as yet untapped reservoir of neverbefore observed data of direct use in a broad variety of meteorological sub-disciplines including air pollution, mesometeorology, numerical forecasting and aviation weather. The tetroon is an ideal vehicle for quantitatively observing a variety of aspects of the sea breeze. The tetroon may be "handed" from radar to radar with an increase of at least an order of magnitude in trajectory length. Investigations of severe weather furnish a fertile field for later generations of tetroon-transponder systems.

OTHER PROGRAMS

An interesting project currently being completed deals with the subject of wind persistence. It has been a common practice in hazards analyses for nuclear reactors, to assume that the wind direction will remain constant during the period of a release of radioactive products to the atmosphere. For postulated accidental releases, this period may be as long as a few days for the bulk of the activity to escape. Such an assumption is extremely conservative since it does not take account of the long period natural variability of the wind (the shorter period variability is essentially accounted for in the diffusion coefficients). A machine program has been developed which uses standard weather station wind observations, readily available for hundreds of locations within

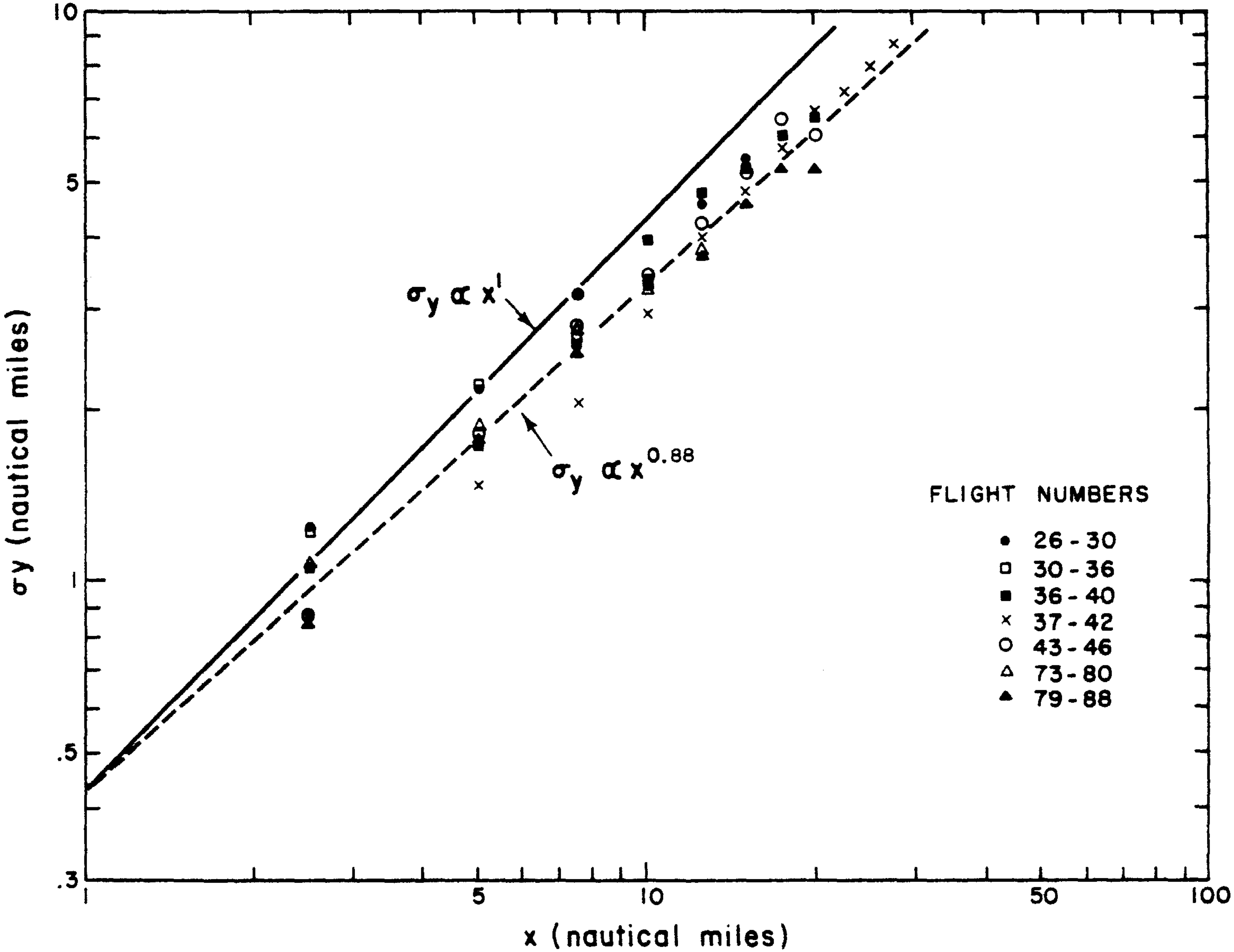
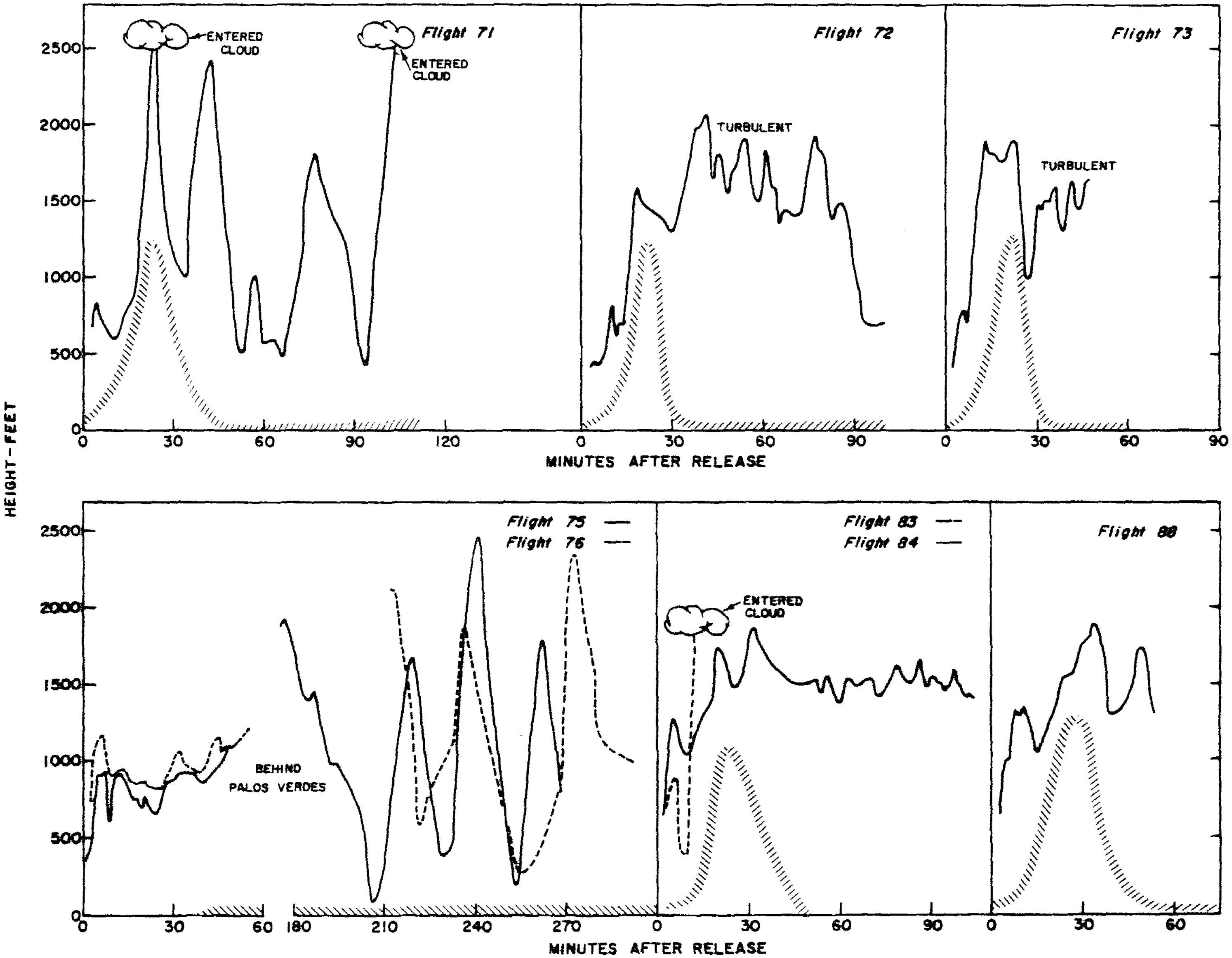

σy (nautical miles)
x (nautical miles)
10
5
1
.5
.3
1
5
10
50
100
σy ∝ x¹
σy ∝ x^0.88
FLIGHT NUMBERS
26 - 30
30 - 36
36 - 40
37 - 42
43 - 46
73 - 80
79 - 88

Figure 6



Flight 71
Flight 72
Flight 73
ENTERED CLOUD
ENTERED CLOUD
TURBULENT
TURBULENT
HEIGHT - FEET
MINUTES AFTER RELEASE
Flight 75
Flight 76
Flight 83
Flight 84
Flight 88
ENTERED CLOUD
BEHIND PALOS VERDES
MINUTES AFTER RELEASE

Figure 7

the United States, to estimate the tendency of the wind to remain within angular sectors of 22-1/2, 67-1/2 and 112-1/2 degrees (one, three and five compass points) for various lengths of time. Figure 8 shows a typical graph resulting from five summers of Corpus Christi wind data. This graph may be interpreted by recourse to a typical point, say on the 10% line, such as that enclosed within the small circle. This point indicates that 10% of the total number of times that the wind switched to the east it was observed to remain in that direction for at least five hours. Thus, the directions for which the 10%- as well as the 50%-line is high are the directions of greatest wind persistence. The upper row of points on the diagram represent the maximum number of hours for which the wind remained in the indicated direction. This program is being run for the four seasons at 64 locations in the United States for one, two and three direction sectors.

Another program developed for use with routinely obtained weather data was designed to translate this readily available information directly into a diffusion climatology. Originally developed by Turner (1961) and based on a series of diffusion coefficients recommended by Pasquill (1961), this FORTRAN program uses wind speed, cloud cover and sun elevation to furnish data that may be analyzed as in Figure 9 for Cape Canaveral in summer. The areas on the diagram are labelled in order of increasing stability with "A" representing very unstable conditions and "F" very stable. The total area represented by each letter is proportional to the total length of time that that stability condition occurred during the summer. By assigning numerical values of vertical and horizontal turbulence parameters to each stability category, a quantitative estimate of seasonal diffusion is obtained. The combination of the results of the two machine programs for a particular site with information on source strength and population distribution about the site results in a quantitative, objective first estimate appraisal of the hazard potential.

Our group has just completed construction of a quarter-meter path length

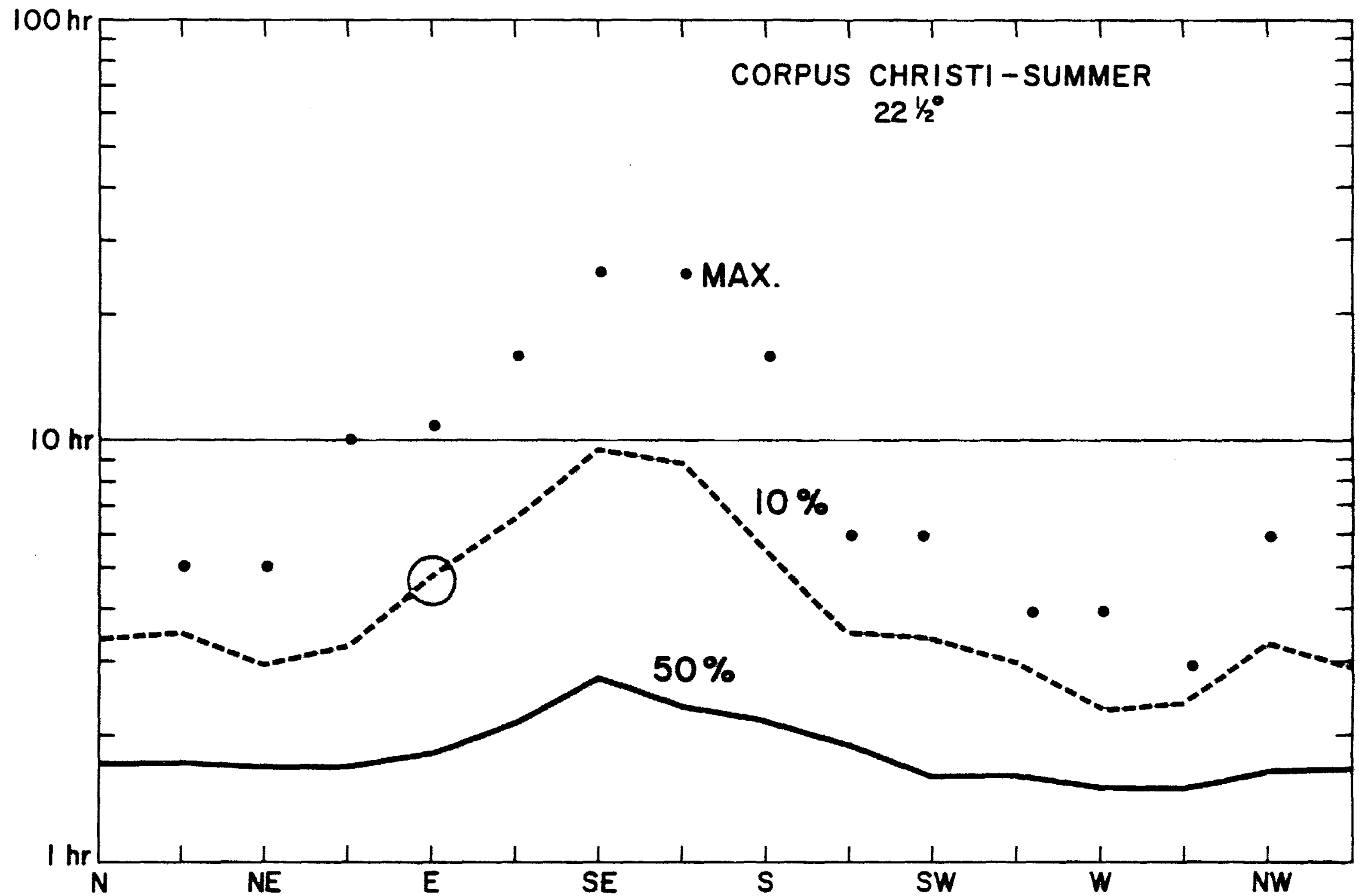

CORPUS CHRISTI - SUMMER
22 ½°
MAX.
10 %
50 %
100 hr
10 hr
1 hr
N
NE
E
SE
S
SW
W
NW

Figure 8

DIFFUSION INDEX FOR CAPE CANAVERAL
SUMMER (July, Aug. 1958 – June, July, Aug. 1959)

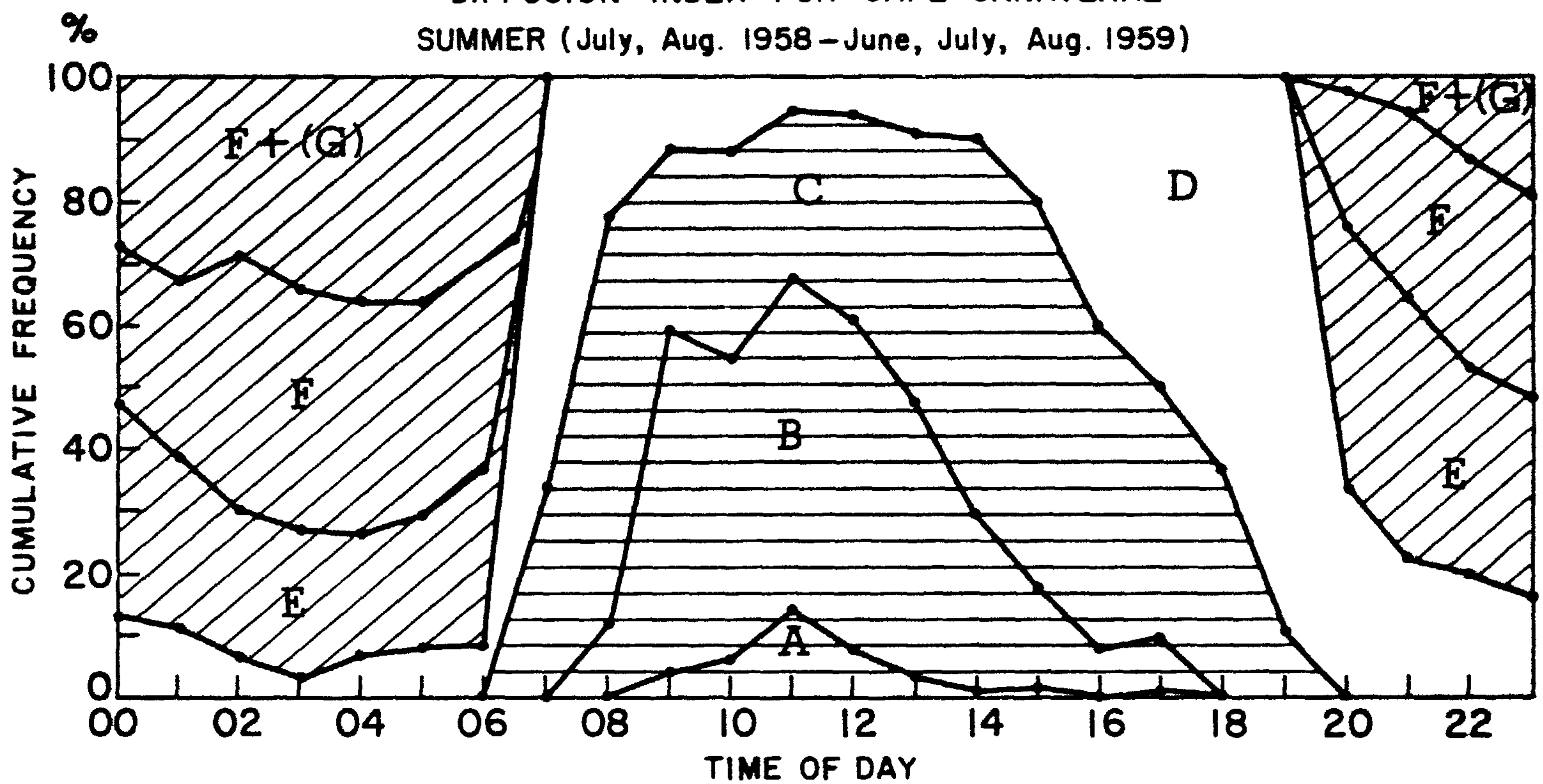


Figure 9

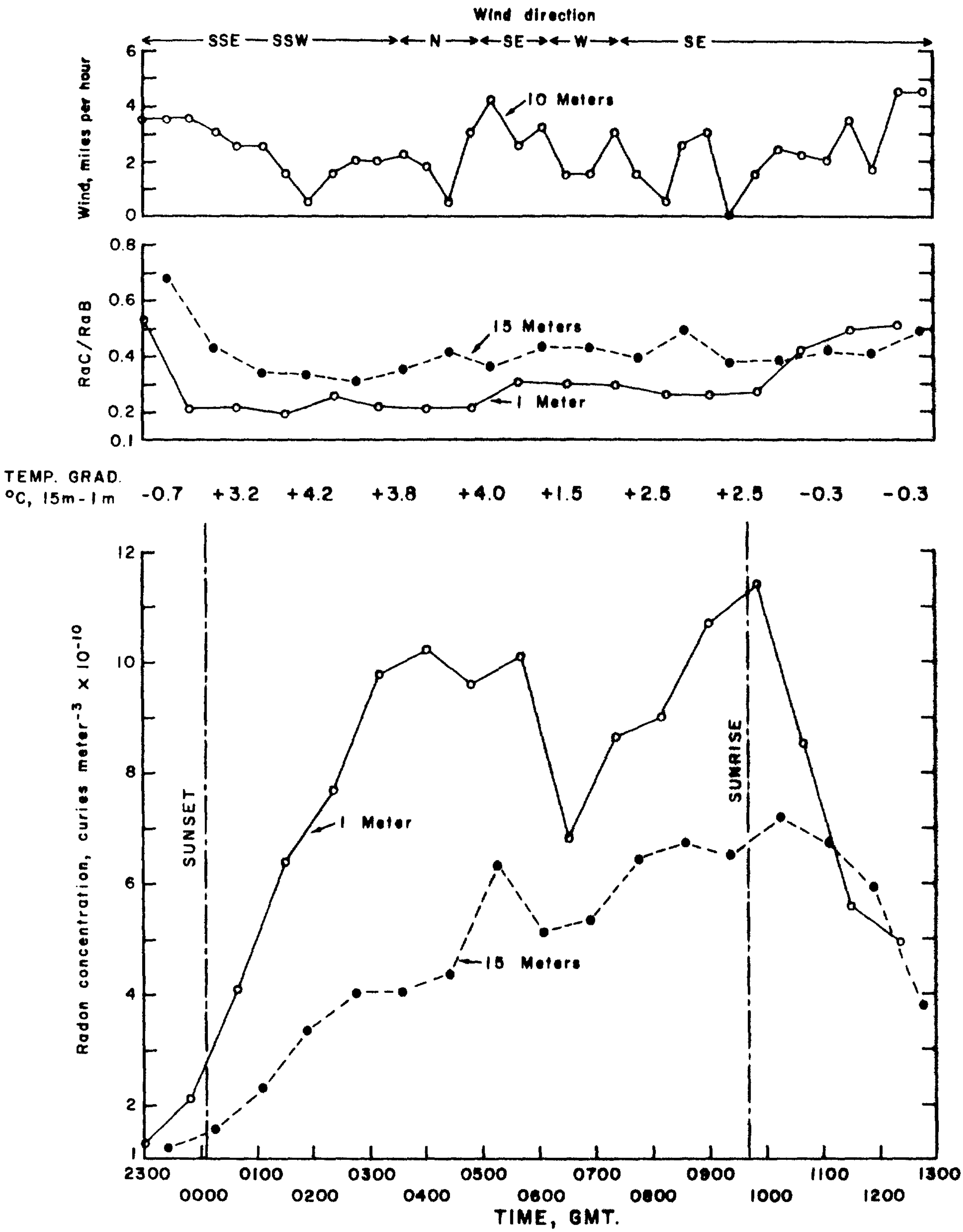
ultrasonic anemometer. As the name indicates, this instrument measures wind speed, in this case vertical wind speed fluctuations, by utilizing high frequency sound waves. The speed of sound across an open atmospheric path is altered by the component of air motion directed along the path and the mean path air temperature. Fluctuations in both air motions and air temperature cause corresponding fluctuations in the observed speed of sound. The path directed air velocity can be measured accurately by detecting the difference in phase shift between the two received sonic signals at opposite ends of the open path using two oppositely directed continuously transmitting sonic transducers as sources. The sum of the phase shifts would yield a measure of the path mean temperature. Due to problems concerning accurate measurement of the mean path temperature and the precise orientation of the sonic array, the fluctuation of vertical motion rather than the absolute value is being measured. The ultrasonic anemometer is inherently superior to conventional mechanical vertical motion systems because of its freedom from mechanical resonance effects. This advantage coupled with high response time and excellent sensitivity properties allow a reading rate more than ample for any conceivable meteorological use. The instrument has been tested and will shortly be used in micrometeorological data acquisition by our group.

Studies of the effects of meteorological variables on the vertical diffusion of the natural radioactive gas, radon, are currently being pursued at our office. The study of the vertical gradient of radon near the ground provides an excellent quantitative insight into vertical diffusion processes in this region of the atmosphere. The techniques is rather inexpensive and may be applied over any land surface.

It was decided that the radon daughter products would be the subject of the study rather than the radon parent. The reasons for this decision were that the daughters may be easily and economically collected by drawing known volumes of air containing the particulate-attached daughter products through common particulate filters and that the β activity of the daughters is measurable to a degree of accuracy commensurate with the accuracy needed in diffusion studies. A considerable amount of time has been spent in developing a unique calibration procedure which has the advantages of economy and comparative simplicity and further permits samples to be collected over time periods as short as twenty minutes. A complete description of this technique will be published in the near future (Hosler, Lockhart and Dewitt). It will suffice to say here that the procedure involves obtaining an estimate of the radon concentration from the radon daughter activity, which is then corrected for radioactive equilibrium departure between it and its daughters. Calibration and checks on the accuracy of these corrections are obtained from analysis of radon grab samples made at the time of the filtration runs.

Figure 10 shows, at the bottom, the concentration data at two levels in the atmosphere for a nighttime period. The typically observed increase in concentration after sunset is evident at both heights. Numerous experiments have shown that the vertical profile of radon concentration is closely related to the atmospheric thermal stability. The highest radon activity is normally observed just prior to sunrise and radon concentrations exceeding 5×10^{-9} curies meter $^{-3}$ have frequently occurred at our test site. Concentrations of 10^{-11} to 5×10^{-10} curies meter $^{-3}$ are normally observed during afternoon hours. Future plans call for gradient measurements over a 300-foot vertical interval and study of vertical diffusion over this layer.

Our group is currently involved in revision the publication "Meteorology and Atomic Energy" (1955). A vast amount of information has been developed in this field in the eight years since the publication of the first edition. Many of the theoretical developments and experimental verifications that form the basis of our present systems of diffusion estimation were in an embryonic state at that time. A publication date of mid 1964 is indicated at this time.



Wind direction
SSE
SSW
N
SE
W
SE
Wind, miles per hour
10 Meters
RaC/RaB
15 Meters
1 Meter
TEMP. GRAD.
°C, 15m-1m
-0.7
+3.2
+4.2
+3.8
+4.0
+1.5
+2.5
+2.5
-0.3
-0.3
Radon concentration, curies meter^{-3} x 10^{-10}
SUNSET
SUNRISE
1 Meter
15 Meters
2300
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
TIME, GMT.

Figure 10

ILLUSTRATIONS

REFERENCES

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Pasquill, F., 1961: The Estimation of the Dispersion of Windborne Material. METEOROLOGICAL MAGAZINE, 90, 33-49.

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DISCUSSION AND COMMENT

It is easy to characterize stability in the sense that I can answer it, but I don't think I can answer it simply. The typical region at the time of these experiments was one which was slightly unstable perhaps up to a few thousand feet, and above that was this very stable capping inversion. Therefore, one would say that probably in the lowest of the Theta-N it was probably below the inversion. It would be something in terms of whatever corresponds to slightly unstable by day and slightly stable by night.

However, I don't think those schemes were really designed to give information on these more complicated patterns that we seem to face so often in real life, but only for rough estimates. Also, the lines on the curves were based on many points, I believe, points derived during nighttime flights and daytime flights. I don't think I would really want to assign a category, at least, you couldn't do it with a lot of confidence.

Session Chairman: The next paper in Session VII is by Mr. James Fuquay, of Hanford Atomic Products Operation. It is entitled, "Comparison of Results of Atmospheric Diffusion Experiments with Calculations from Prediction Models."

COMPARISON OF RESULTS OF ATMOSPHERIC DIFFUSION EXPERIMENTS WITH CALCULATIONS FROM PREDICTION MODELS

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Hanford Laboratories
Hanford Atomic Products Operation
General Electric Company
Richland, Washington

ABSTRACT

Results of 340 diffusion experiments utilizing a ground source and encompassing a wide range of atmospheric stabilities are summarized. Peak exposures normalized for wind speed and source strength when plotted against the travel-time show stratification when stability and growth parameters are factored into the analysis. Differences in the results between sites are greatly reduced when diffusion is considered time dependent from those which result from the distance from source concept. In general, exposure limits for unstable, neutral, moderately stable and stable meteorological conditions are established, which are compared with the predictions from some of the diffusion models currently being applied. Whereas, the agreement between predicted and observed exposure values are good for diffusion in neutral and unstable atmospheres, there are significant differences noted in the stable case. These differences point to the need to investigate atmosphere mechanisms which have not been factored into the models. Results of the Hanford model, which attempts to account for depletion of the plume through deposition, are presented.

INTRODUCTION

In the last ten years, there has been a large amount of experimental data obtained from diffusion programs in the United States. The emphasis has been on studying the environmental contamination resulting from a continuous release of material near the ground. This appears to be as logical a starting point as any since the results of such experimentation serve to satisfy many of the demands of the atomic, chemical and space industries while at the same time present much fewer difficulties in the experimental design, requiring less equipment and expense than studies with an elevated source.

Major experimental programs which have contributed to the understanding of diffusion resulting from releases near the ground include Prairie Grass (O'Neill, Nebraska, 1956), Green Glow (Hanford, Washington, 1959), 30 Series (Hanford, 1960-1963), Ocean Breeze (Cape Canaveral, Florida, 1961-1962), Dry Gulch (Vandenberg Air Force Base, California, 1961-1962), National Reactor Testing Station Series (Arco, Idaho, 1960-1962) and the FRT-2 Series (Dugway, Utah, 1960). The total number of experiments has reached 340, all of which either have been documented or are presently being prepared for publication. There is now the opportunity to examine these data as a whole and to gain insight into any differences that there might be between them. In addition, these results can be compared with those obtained from prediction models which are now popularly employed.

A priori, differences might be expected between results at the various sites primarily because of differences in the tracers used, the physical characteristics of the surfaces and the climatological regimes. The first two considerations bear directly on the depletion of the cloud through deposition of material on the surface which it contacts, causing lower air dosages than would be expected if deposition were not occurring. The complexities of these interactions are not fully understood, and, at the present time, the models which attempt to account for them have not been adequately subjected to tests.

CONSOLIDATION OF DATA FROM MAJOR U.S. DISPERSION PROGRAMS

The data from the U.S. diffusion programs which represent a wide range of atmospheric stabilities where ground exposures were measured in some cases to distances of 20 miles from the source deserve further investigation in order that 1) evaluation of general diffusion models can be made or new models developed and 2) future experimental programs can be designed to provide definitive data based on inadequacies of past programs.

Table I summarizes those field programs with respect to tracer material and nature of the terrain which are discussed in this paper.

Figures 1, 2 and 3 summarize the results of these test series averaged in terms of the stability and the horizontal growth of the plume. On a logarithmic scale is plotted the normalized peak exposure (ordinate) having units of meters^{-2} and time of travel in seconds on the abscissa. Identification of the test series is designated by letters corresponding to those given in Table I, and curves associated with stable conditions are given as solid lines, whereas those conducted when the atmosphere was unstable are dashed. The number of experiments included in each curve is given in parenthesis. The very dark lines found on each of the three figures are the Hanford curves characterizing diffusion in very stable and very unstable conditions, and serve here to identify the relative positions of the curves in the separate figures. The Hanford curves have been further delineated

Variation of normalized exposure with time
for Prairie Grass and Hanford

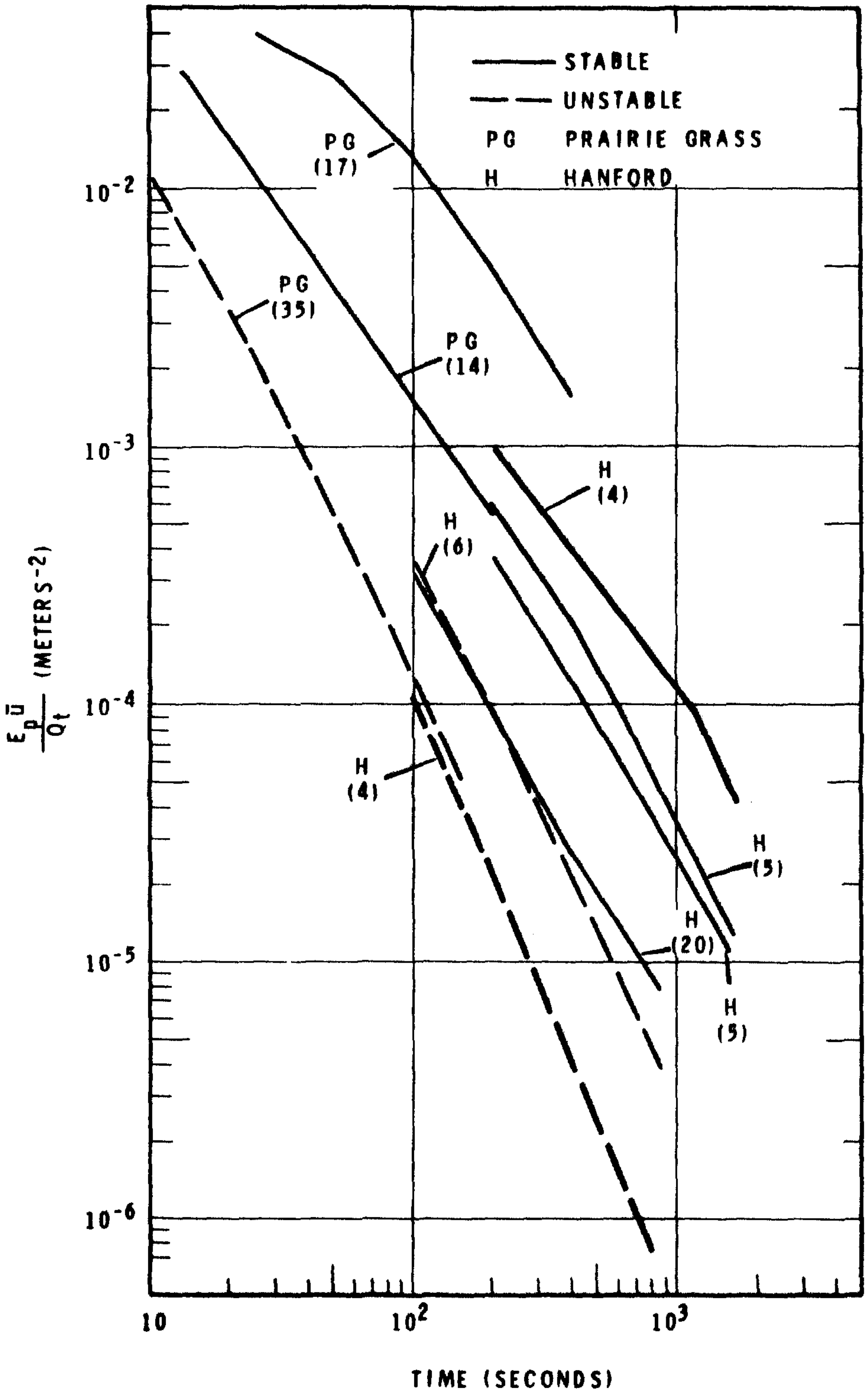

FIGURE 1

Variation of normalized exposure with time
for NRTS and Dugway, Utah

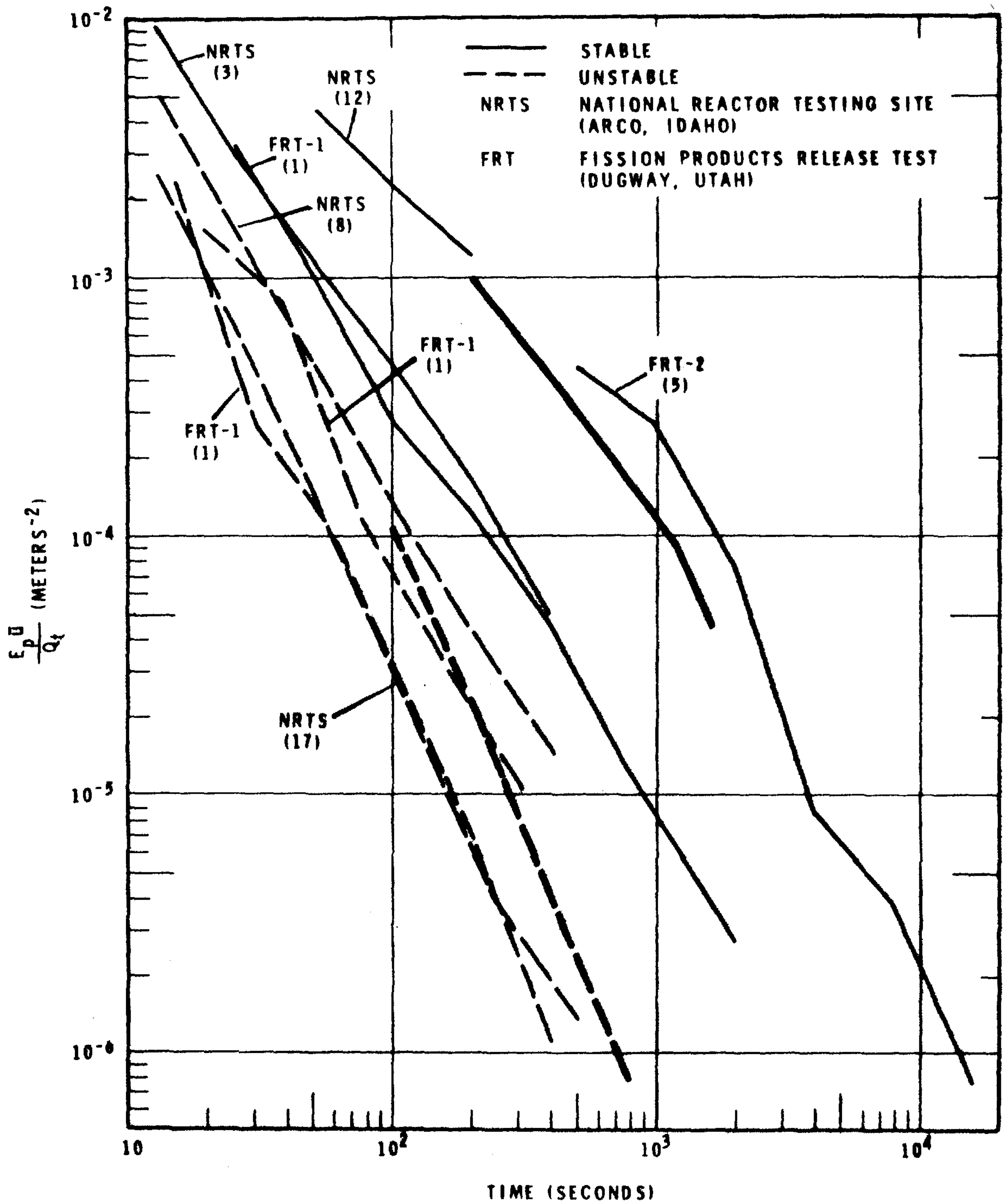

FIGURE 2

Variation of normalized exposure with time for
Cape Canaveral and Vandenberg Air Force Base

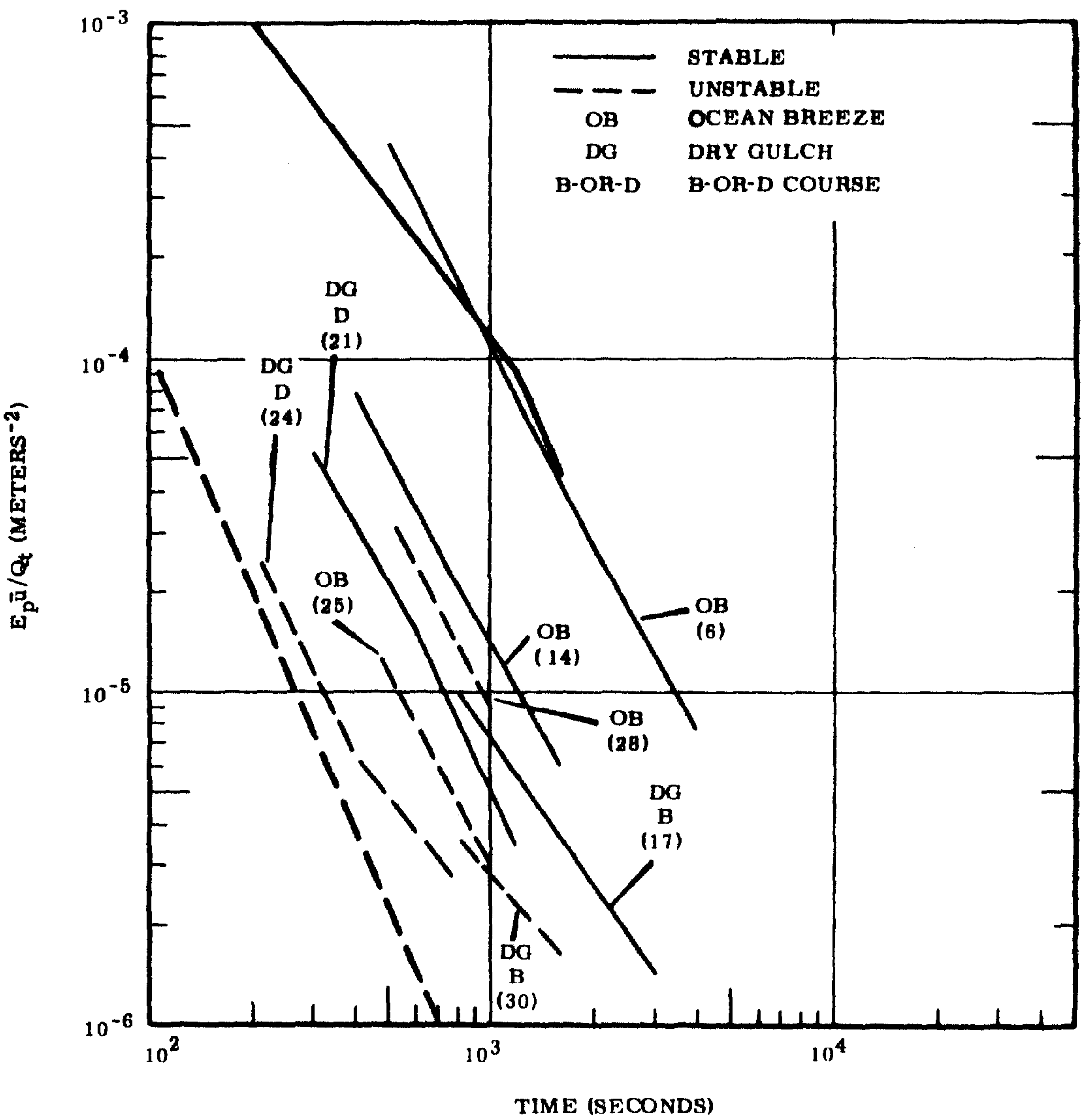

FIGURE 3

TABLE I

SUMMARY OF TEST SERVICES CHARACTERISTICS

Test Series	Tracer	Terrain	Vegetation	Location
Prairie Grass (PG)	Sulfur Dioxide	Flat	Mowed Grass	O'Neill, Neb.
Hanford (H)	Zinc Sulfide	Gently Rolling	1 m. Sage	Richland, Wash.
Ocean Breeze (OB)	Zinc Sulfide	Flat	1/2 m. Palmetto	Cape Canaveral, Fla.
*Dry Gulch (B) (DG-B)	Zinc Sulfide	Flat	1/2 m. Brush	Vandenberg, Calif.
Dry Gulch (D) (DG-D)	Zinc Sulfide	Rough Terrain	1/2 m. Brush	Vandenberg, Calif.
Fission Products Release I (FRT-1)	Zinc Sulfide and Fission Products	Gently Rolling	3/4 m. Desert Sage	Arco, Idaho
Nat. Reactor Test Station Series (NRTS)	Fluorescein	Gently Rolling	3/4 m. Desert Sage	Arco, Idaho
Fission Products Release II (FRT-2)	Iodine-131	Flat	Salt Flats	Dugway, Utah

*Two grids were used at Vandenberg. The brush was generally sparse, but was characterized by rough terrain. A few trees were located on both the B and D courses.

to point up the degrees of stability (i.e., very stable to slightly stable, etc.), thus accounting for six curves on figure 1 with the most stable conditions on the right and greatest instability represented by the dashed curve on the extreme left. Delineation of the curves were made on the basis of the stability (Richardson number) and surface wind direction variability ($\sigma_\theta \bar{u}$).

An attempt has been made to treat the data from other sites in the same manner, and thus reducing the variance considerably. These curves should be viewed, however, with the knowledge that all the available data were not consistent; that is where Richardson numbers were available at some sites, stability ratios were available at others and, also, the parameter $\sigma_\theta \bar{u}$ was available (at the time of writing) only for the Hanford, NRTS and Prairie Grass data. Thus the generaliztions inferred from the figures should be valid, but modification using a consistent set of data for all series might eventually enhance these results. The data presently available support this premise and independent verification for the NRTS data has been made by Slade (private communication). Before proceeding with the relative comparisons, two important features inherent here require further amplification.

First, it will be noted that diffusion here is considered to be dependent on the time of travel, and not the distance from the source at which the sample was obtained. The travel time, t, was computed here from the ratio of the distance and the mean wind speed at the release height. This concept is consistent with the basic developments of G. I. Taylor and improves significantly the intersite comparisons. A good example of this point can be made by examining the average very stable curves for Prairie Grass and Hanford. Using the distance-concept, Prairie Grass data indicate an order of magnitude higher exposure than Hanford at 200 meters; yet, if the time-dependency is assumed, the difference is reduced to a factor of four with indications that the curves are converging as the travel-time increases.

The second significant feature of this summary, which has been briefly referred to, is that of classifying the curves with respect to the parameter $\sigma_\theta \bar{u}$, as well as some measure of the thermal stability. σ_θ here is the standard deviation of the wind directions observed over the period of emission, and $\bar{u}$ is the mean wind speed in that period. This is an Eulerian parameter which is analogous to the Lagrangian quantity $(\overline{v'^2})^{1/2}$. Fuquay, Simpson and Hinds (1963), using Hanford data, have shown that the horizontal growth, σ_y, is proportional to $(\sigma_\theta \bar{u})t^p$, where p is near unity for small t and approaches 1/2 for t in the vicinity of 1000 seconds--a result analogous to the theoretical development by Taylor. The classification of the Hanford curves presented here with respect to $\sigma_\theta \bar{u}$ are given in this paper.

Considering diffusion to be time-dependent and by using $\sigma_\theta \bar{u}$ as well as a stability parameter to classify the data, the exposure differences which are observed between test sites are considerably reduced from those inferred by other analyses. The agreement shown in figures 1, 2 and 3 is generally good for data from tests obtained under diversified conditions and involving differences in experimental technique. The very stable curves at all sites compare reasonably well as do the unstable, and if a finer resolution of data can be achieved by growth factors such as $(\sigma_\theta \bar{u})$, which is suggested here, the indications are that these empirical results are consistent. This is not to claim that the problems of general diffusion from ground source have been empirically solved, for this is clearly not the case. Channelled flow, for example, will yield results which deviate greatly from these averaged curves, making it clear that each problem should be analyzed with respect to its peculiarities. The studies at Vandenberg clearly demonstrate this. On the other hand, diffusion data which are presented here indicate that the differences which might be expected at these sites are on the average not great, giving some hope to developing models which are not severely contradicted by the experimental data presently available.

COMPARISON OF EXPERIMENTAL DATA WITH PREDICTION MODELS

Figure 4 further summarizes the data into groups that may be referred to as very stable, moderately stable, quasi-neutral and unstable. The limits of each of these classes correspond to the range of the data from the three preceding figures. The other curves given in the figure are the predictions of several of the models which are commonly applied at the present time. Of these, the Sutton diffusion model is the most well known. Cramer's curve, based on the Prairie Grass data, was one of the first to be developed from ground source experimental data, and is of interest particularly in the prediction of diffusion in stable atmospheres. Recently, Pasquill has presented a system for prediction based on a summary of experimental data and designed for ready application for those dealing with applied problems. Two of his curves characteristic of stable and unstable conditions are shown.

Comparison of experimental exposure data
with predictions from several models

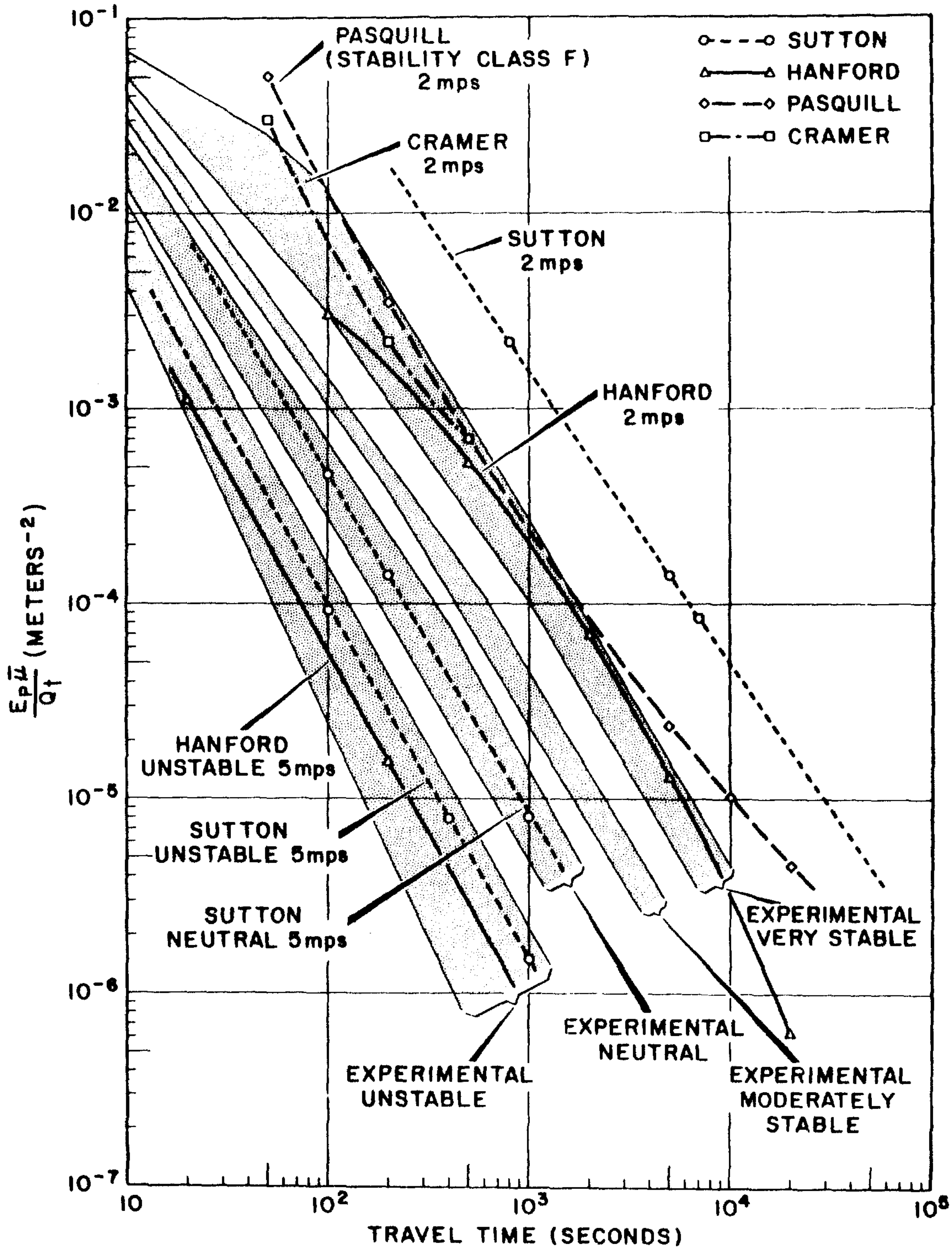

FIGURE 4

Finally, the Hanford curves are calculated from a model used at Hanford for several years, which attempts to account for the depletion of the cloud brought about by deposition on the surface. Obviously, these represent only some of the models which presently are available. Other models compare reasonably well with these and there is no major difference in the exposure values for short travel-times.

Figure 4 shows excellent agreement between the predictions of Sutton and Hanford for ground releases during neutral and unstable atmospheres. This is quite appropriate since the Hanford model for these conditions is Sutton's model with A. C. Chamberlain's modification to account for deposition and a Hanford innovation to extend the results to the unstable case.

It is in the prediction of ground source diffusion in stable cases that large differences between the models, the predictions resulting from them and the experimental data occur.

The models generally yield predictions of exposure which are higher than those which are observed during stable atmospheric conditions. For any travel-time, there is, at least, a one-order of magnitude difference between exposures which have been observed and those calculated. This differential appears to result primarily from the horizontal growth of the plume, so that the two experimental zones in Figure 4 represent narrow plumes (high exposures) and wide plumes (low exposures). Diffusion models yield predictions which more closely approximate the higher values. Better agreement between the observed and predicted values can be obtained by using higher values of the wind speed in the model. For example, the

Sutton predictions agree with the stable experimental data when the wind speed at the height of release is five meters per second. There is contradiction in such manipulation, however, for the atmosphere is rarely stable when the wind speed is this high near the ground. Wind data for the two-meter height obtained during the Prairie Grass and Hanford tests show that speeds of 2-3 mps are expected in moderately stable and very stable atmospheres and speeds in excess of 4 mps are quite rare.

SUMMARY AND CONCLUSIONS

The differences between observed and predicted exposures become very important at travel-times beyond 10^4 seconds. This corresponds to distances beyond 10 miles, which is the region in which greater demands for prediction are being made. Extrapolation of the Cramer, Sutton and Pasquill curves yield an order of magnitude difference at 10^4 seconds, and, because of their relative curvatures, this difference becomes greater as the travel-time increases. It is, therefore, important to exercise care in the extrapolation of any data which points up the need to re-evaluate these models which are generally applicable for short travel-times and determine whether extrapolation can be justified in light of the experimental data presently available. The Hanford curve results from a model which attempts to account for deposition. Although the agreement at short travel-times between the Hanford model on the one hand and the Cramer and Pasquill models on the other is good, the differences in curvature bring about great differences beyond ten miles. From the evidence at hand, the Hanford model appears to predict the exposures at the larger distances reasonably well although exhibiting the same conservatism characteristic of all the other models.

Demands are increasing today for predictions to distances 10 to 100 miles from the point of release. To meet such demands, it is attractive to rely on those models which have proved reliable for the short range estimates. However, particularly in the stable case, it appears that the extrapolation may not be justified, and it is suspected that atmospheric mechanisms which are not fully understood at the present time must be studied and their effects accounted for. The effect of depletion of the cloud due to deposition is accounted for as if the cloud were depleted at all heights. Yet, deposition is a boundary layer phenomenon, depleting the lower layers of the cloud and, perhaps, not altering the dosage distribution at higher levels. Consequently, one must appraise the applicability of the dispersion model in relation to the needs of the applied problem to be solved, and these weaknesses clearly identified, in order to stay within the bounds of scientific knowledge.

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Session Chairman: Thank you, Mr. Fuquay.

Meteorologists really have very much in the way of fancy instrumentation and gadgetry. I think the next paper deals with something that is quite fancy. Mr. W. M. Culkowski, of the Weather Bureau Research Station here at Oak Ridge, will give the paper entitled, "Theta-N System for Turbulence Measurements."

THETA-N SYSTEM FOR TURBULENCE MEASUREMENTS

Walter M. Culkowski

and

Duane H. Turner

Weather Bureau Research Station
Oak Ridge, Tennessee

ABSTRACT

Recent advances in applied optical instrumentation have permitted an extremely accurate, reliable, and versatile wind statistics system to be developed. Its basic principle is to obtain the differential of wind movement directly, then obtain other information by simple logic circuits. This system eliminates the ambiguities of conventional systems.

INTRODUCTORY REMARKS

In discussing analogue devices for dispersion estimates, at the Seventh Air Cleaning Conference, I alluded to a crude digital system by Humphrey and Wong [1] which showed some promise for future use in turbulence research. Although simple in principle, it was neither easy nor cheap to produce a working system which would be of sufficient improvement over other wind statistics systems to warrant serious consideration as a research or industrial tool. Now, however, utilizing recent developments in the computer field we have a capability of data reduction far in excess of our detecting abilities. Our original goal was one degree accuracy, but we can now record sensor movement to 1 minute of an arc. The absolute simplicity of the form of the output data makes it amenable to paper, or electronic tape recordings, strip chart recorders, or data reduction at the machine itself. There is no problem of calibration, and very little trouble from line voltage variations. In short, there is nothing about wind vectoring that this system cannot examine.

THE Θ-N CONCEPT

If the total travel (in degrees) of a wind vane per unit time is divided by the number of reversals of the wind direction per unit time, the result is the average travel of the vane per reversal.

$$M = \frac{1}{N} \sum \Delta\theta \qquad (1)$$

where

M = mean wind vane travel per oscillation

$\Delta\theta$ = degrees traveled per unit time

N = number of oscillations per unit time

The standard deviation of a Gaussian distribution is related to the modulus mean, M, by

$$\sigma = .3M \quad . \qquad (2)$$

With 25 or more oscillations, σ has a reliability coefficient of 95%. This criterion is easily met in daytime synoptic conditions within a few minutes.

THE SENSING SYSTEM

By employing a moiré [2] fringe of alternate light and dark sectors of a circle, the Optisyn [3] Corporation produces a high resolution shaft angle encoder. To be more precise, it produces a system of packages which convert changes in shaft angle into a series of right and left hand pulses which may then be operated on by simple sum and difference circuits. The unit at the Oak Ridge Weather Bureau Station is a 400 pulse per revolution model, although up to 20,000 pulses per revolution are available in this particular model. (I understand that shaft encoders are available with 1/100 of a second of an arc resolution, but these are of academic interest only as far as we are concerned.)

The first θ-N built at Oak Ridge is diagrammed in Figure 1. The Optisyn sensor sends out sine waves as the shaft rotates. The logic system determines whether the rotation is clockwise or counter-clockwise and shapes the resulting output into square waves on the appropriate (CW or CCW) channel. Wind vane travel (θ) information is picked directly off midway between the logic and photocell outputs, (for a more convenient impedance value) and the reversal (N) detector is placed on the outputs of the logic circuit. Both θ and N counters reduce the counts to numbers easily read from a strip chart. ($\Delta\theta$'s of 20,000 degrees/hour are not uncommon).

The dashed lines represent equipment to be added—a reversible, or ring, counter to indicate wind direction and the reference system for detecting accumulated position error.

For display purposes a second model was designed as shown in Figure 2. Basically, the functions are the same, but with a few refinements. By equations (1) and (2)

$$\sigma = \frac{.3}{N}\sum \Delta\theta = \frac{.6}{2N}\sum \Delta\theta \quad . \qquad (3)$$

Since our particular model has 400 counts per revolution,

$$\sigma = \frac{360°}{400°} \cdot \frac{.6}{2N}\sum \Delta\theta \qquad (3a)$$

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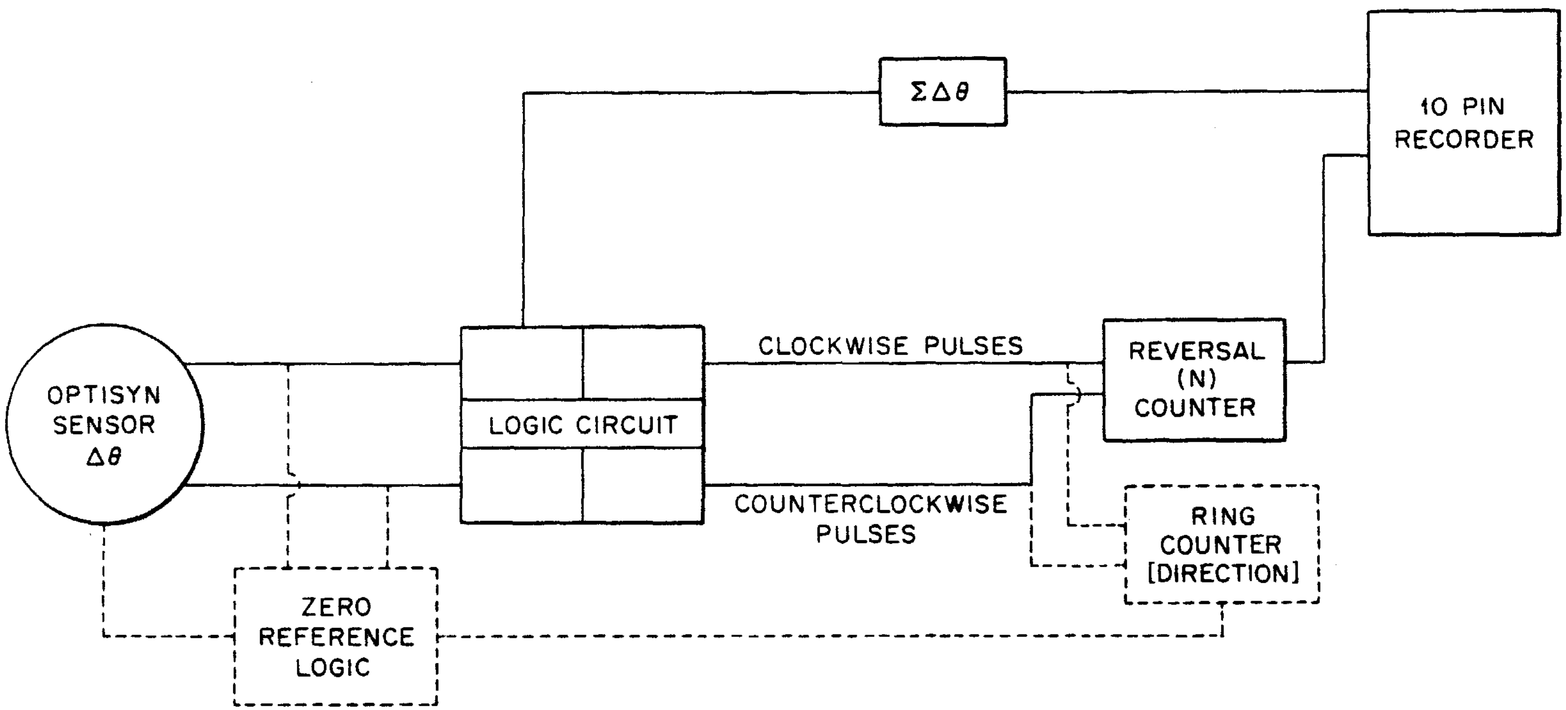

FIGURE 1

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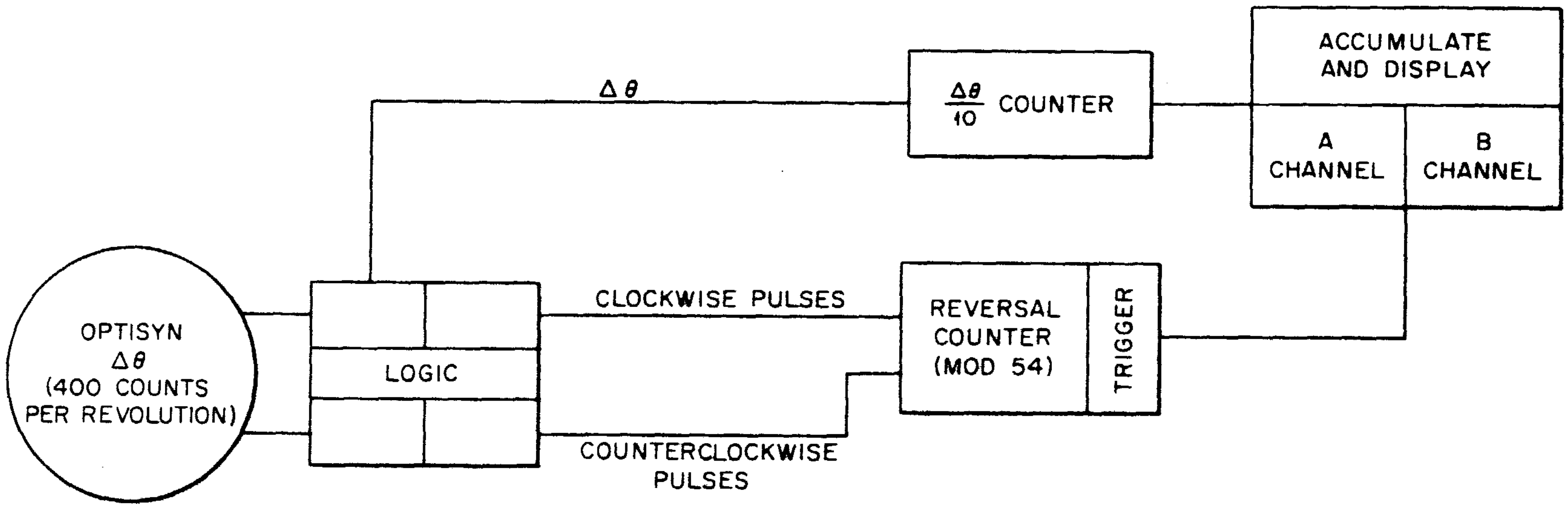

FIGURE 2

i.e.

$$\sigma = \frac{.27}{N} \sum \Delta\theta \qquad (3b)$$

thus if N = 27

$$\sigma = .01 \sum \Delta\theta \quad . \qquad (3c)$$

Therefore, if the readout is performed at the end of every 27 revolutions (54 reversals), the standard deviation can be read directly. To avoid decimals, the θ counter reduces the count by 100. Thus, the readout is in whole degrees. The display can be by "Nixie" (i.e. light) tubes or conventional counters. For our model we chose conventional counters. By a switching arrangement, one circuit "holds" the last count while another is counting. An indicator light shows which channel is "holding".

DIGITAL TO ANALOGUE LINK

I'd like to stress here the basic difference between most wind systems and the present one. Other wind systems observe the direction first and then obtain the differential value. This system detects the differential, permitting other parameters to be obtained by integration. Thus, wind direction is obtained by

$$\theta = \int_0^\theta d\theta (\text{MOD } 360°) \quad . \qquad (4)$$

Naturally, a zero referencing circuit is necessary for establishing an "initial condition", but this is a simple matter.

Equation (4) could be treated either by digital or analogue techniques, preferably digital. An improtant set of turbulence data, however, depends on the second derivative of θ and this is best handled by analogue techniques [4]. Figure 3 illustrates a complete statistics system incorporating a straightforward digital to analogue link. One advantage of this circuit lies in the ability of the integrator to avoid the discontinuity at 360° = 0°. A special logic circuit would be necessary in Figure 3, for compatibility with the integrating networks. Pulses from the commercial system we now employ are 3×10^{-6} seconds in duration, a value far too low for this purpose.

SUMMARY

By employing a differential sensor, and integrating the movements of a wind vane, simple techniques for determining wind statistics are possible. The basic system is versatile, does not require periodic calibrating, avoids the voltage ambiguity inherent in conventional wind vane to analogue systems, and permits application of an unlimited variation of readout and data reduction systems.

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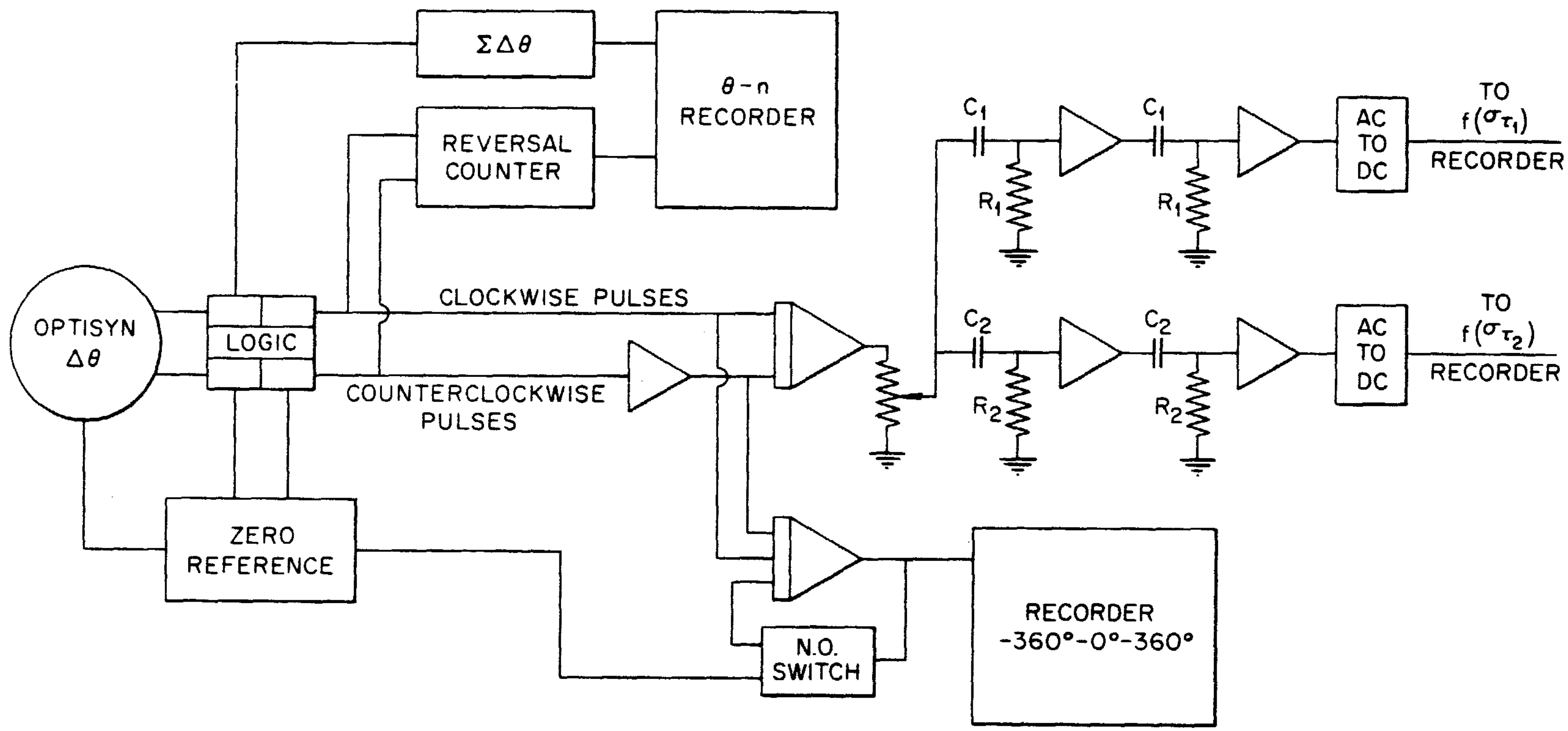

FIGURE 3

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FIGURES

Figure 1. Basic θ-N system.

Figure 2. θ-N system adapted for instant readout or display purposes.

Figure 3. Complete wind system for vectorial, statistical, and spectral investigations.

DISCUSSION AND COMMENT

The fixed source opposed to the light source has N light and alternate circles on one side on one band, and N-1 on the other, or N+1. As these rotate, a pattern of beats is produced. A very good analogy would be the way a wagon wheel looks in the movies. It sort of looks like it's going one way, and then it looks like it's going the other. Actually, it is the dark section beating against the speed of the film.

If you had just N and N+1 alternate light and dark sections, which you could do, you would have an alternate on and off system -- light-dark, light-dark, light-dark. By producing a moire fringe pattern, there is a continuous sign wave, which is a more amenable meteorologic circuit with a discriminating ability.

The basic unit costs roughly $700.00. There are other coders which can be bought for as little as $300. They operate either on a punch card principle, or a magnetic pick-off system, in an alternating system with a 10,000 cycle oscillation. The difference in the magnetic pickup of this data and the rotor determine the increment and direction traveled.

Session Chairman: The next paper is a duet by Mr. C. Hawley and Mr. E. G. Markee, USWB-IDO, entitled, "Controlled Environmental Radioiodine Tests." Mr. Hawley will present the first part and Mr. Markee will present the second.

STATEMENT BY MR. HAWLEY: Mr. Chairman, a word of explanation about our dual presentation. Originally, we were going to take the meteorological aspects, since this was an Air Cleaning Conference, and confine the remarks to the meteorological portion. As we were both going to be here we decided to wrap up the entire package including the biological aspects.

The CERT research project is a series of planned experiments whereby we intend to release radioiodine over pasture grounds and trace the meteorological behavior of the iodine through the milk cycle into the cow, feed this milk to human volunteers and thereby make a complete picture under actual field conditions. Hopefully, we will get some basic iodine behavior information which will be applicable to other programs but the point we are most interested in is the behavior of the iodine at the NRTS under our chronological and topographical regimes. We hope to get definitive information which we can apply to such things as reactor siting, safety analysis reports, and emergency actions following a large unplanned release of iodine.

This paper deals only with the preliminary experiments. Of course, we are looking for three basic relationships, or we are going to be; the relationship of air to vegetation, vegetation to milk, and milk to people. In order to do this, we had an ulterior motive in mind. As a part of the noxious weed control program in the desert, we wound up with approximately 2,000 acres of wheat grass which we would like to utilize. If we can prove that this will lend itself to this type of experimentation, we have a large, ready-made laboratory. The first experimentation may have left something to be desired. Currently, we are constructing an irrigation system, including a dairy barn, which we project will take care of us for about three years of experimentation whereby we can experiment with radioiodine and the various parameters; temperatures, pressures and heights, and, of course, distances. We hope to get some definitive particle sizing data.

I will turn the rostrum over to Mr. Markee, who will talk about the meteorology, and I will conclude the presentation.

CONTROLLED ENVIRONMENTAL RADIOIODINE TESTS (CERT)
AT THE NATIONAL REACTOR TESTING STATION*

Earl H. Markee, Jr., and C. A. Hawley, Jr.

SUMMARY

The CERT project consists of a series of planned releases of radioiodine over different vegetation and during various meteorological conditions, with the prime objective being to measure the amounts of radioiodine through the air-vegetation-cow-milk-human chain. This paper deals with the first, or preliminary, experiment in the CERT series at the National Reactor Testing Station (NRTS) in southeast Idaho. The preliminary experiment consisted basically of releasing radioiodine (iodine-131) gas over a natural Crested Wheatgrass pasture and using the contaminated grass for milk cow grazing. The resultant radioactive milk was fed to seven human volunteers. It was desired from this experiment to establish under known natural release conditions three basic relationships:

(1) The amounts of radioiodine in the air to those on the soil and vegetation,

(2) The amounts of radioiodine on the vegetation to those in the milk, and

(3) The quantities in the milk to those in the human thyroid after drinking the milk.

* The complete details of this CERT experiment will be published in the near future as IDO report number 12034.

Two 11.5 acre pasture areas with an initial grass density of 150 g/m^2 and an average height of 13 cm were established, one for contamination (hot) and one for control and background (cold), (Figure 1). Five iodine 131 generators which used the process of "swaging" the iodine 131 gas with nitrogen gas were oriented along a 150 m line normal to the expected prevailing wind, to simulate a short line source. The source line was 50 m upwind from the "hot" pasture. A dense sampling grid based on pre-test meteorological studies, was established to 300 m downwind (Figure 2). Background activities on soil and vegetation, as well as grass consumption and growth rates, were measured before and after the release. Milk production and activity levels were measured. The six cows used during the test were 1200-1600 pound fresh pure-bred Holsteins, obtained from Montana State College. Arrangements were made to maintain the cows on their normal feed supplements and the cows were acclimated to the natural grass and new surroundings for two weeks prior to placing them on the contaminated pasture. The cows were milked at 6 A.M. and 6 P.M. daily. Milk from the evening and morning milking of one cow was combined, pasteurized, counted, and consumed by seven volunteers over a 39-day period. Human thyroid activities were measured with a NaI crystal, 256 channel analyzer, in a low background whole-body counting vault.

A total of 970 millicuries of iodine-131 gas was released at 1500 MST on May 27, 1963 near ground level over a 30-minute period under moderately unstable meteorological conditions and an average wind speed of 6.6 mps. About 13% of the total released iodine was deposited on the grid, with 1.5% being actually on the grass (Figure 3). The Crested Wheatgrass covered about 15% of the total plot, the remaining surface being soil cover. Deposition velocities ranged from 0.4 to 0.8 cm/sec, with an average of 0.6 cm/sec. The activity on the carbon fall-out plates was found to be representative of the grass measurements.

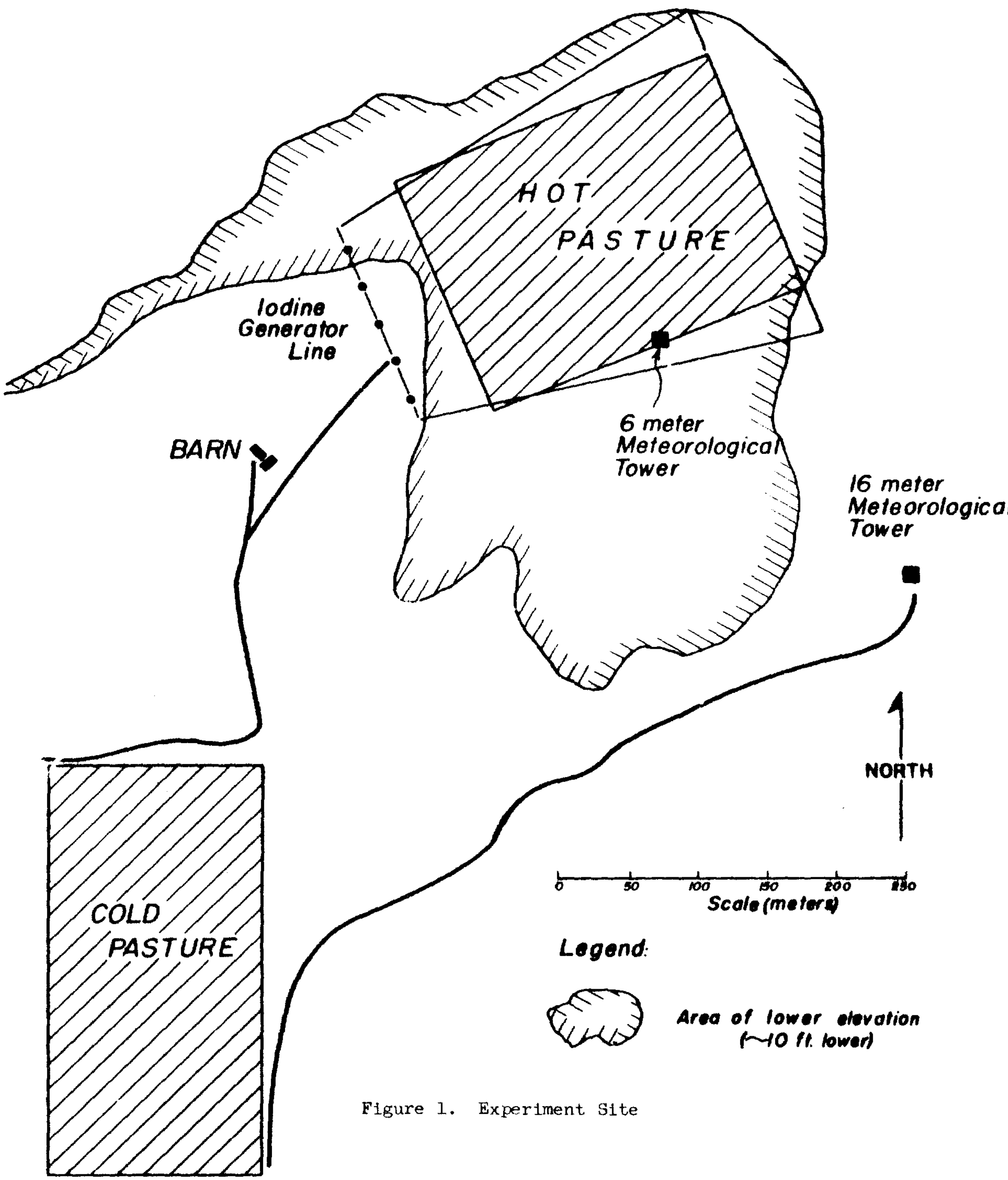
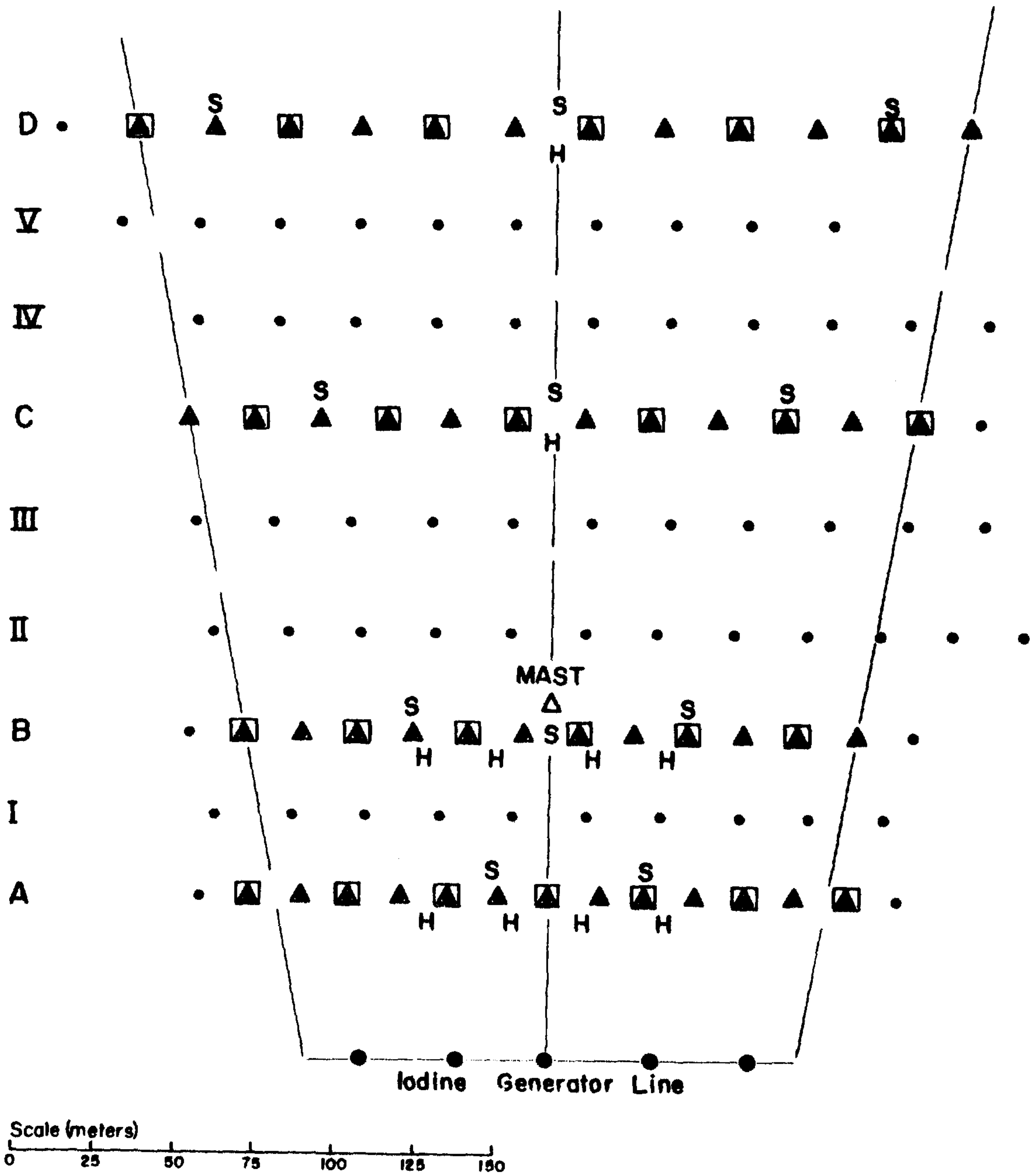


Figure 1. Experiment Site

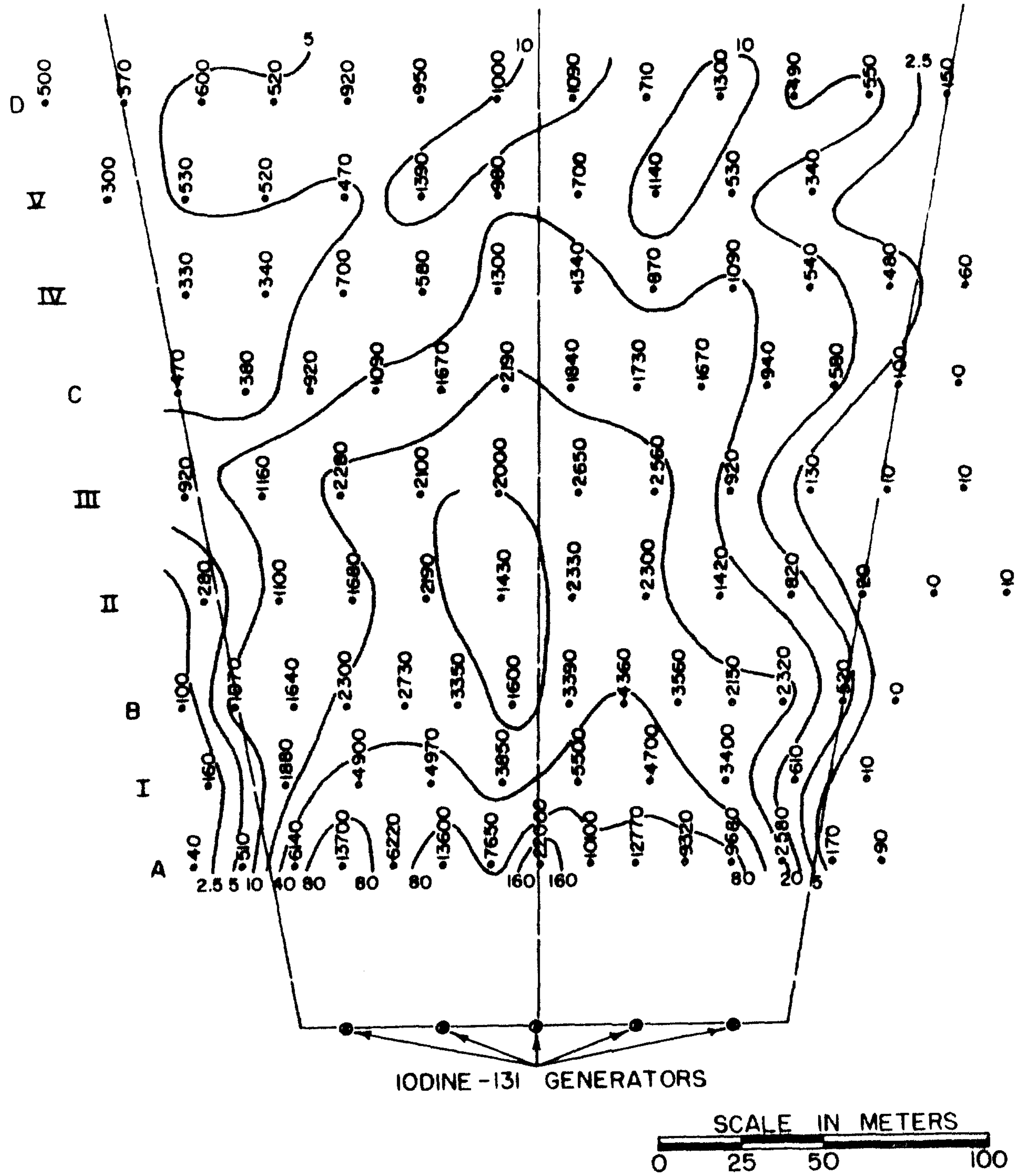


Legend:

- • Vegetation Samples
- Δ Air Samples (Hi-Vol)
- □ Fallout (Carbon, Sand, Sticky Paper)
- S Soil Samples
- H Hanford Samplers

Figure 2. Sampling Grid

Figure 3. Initial Grass Deposition (μμc/gram)



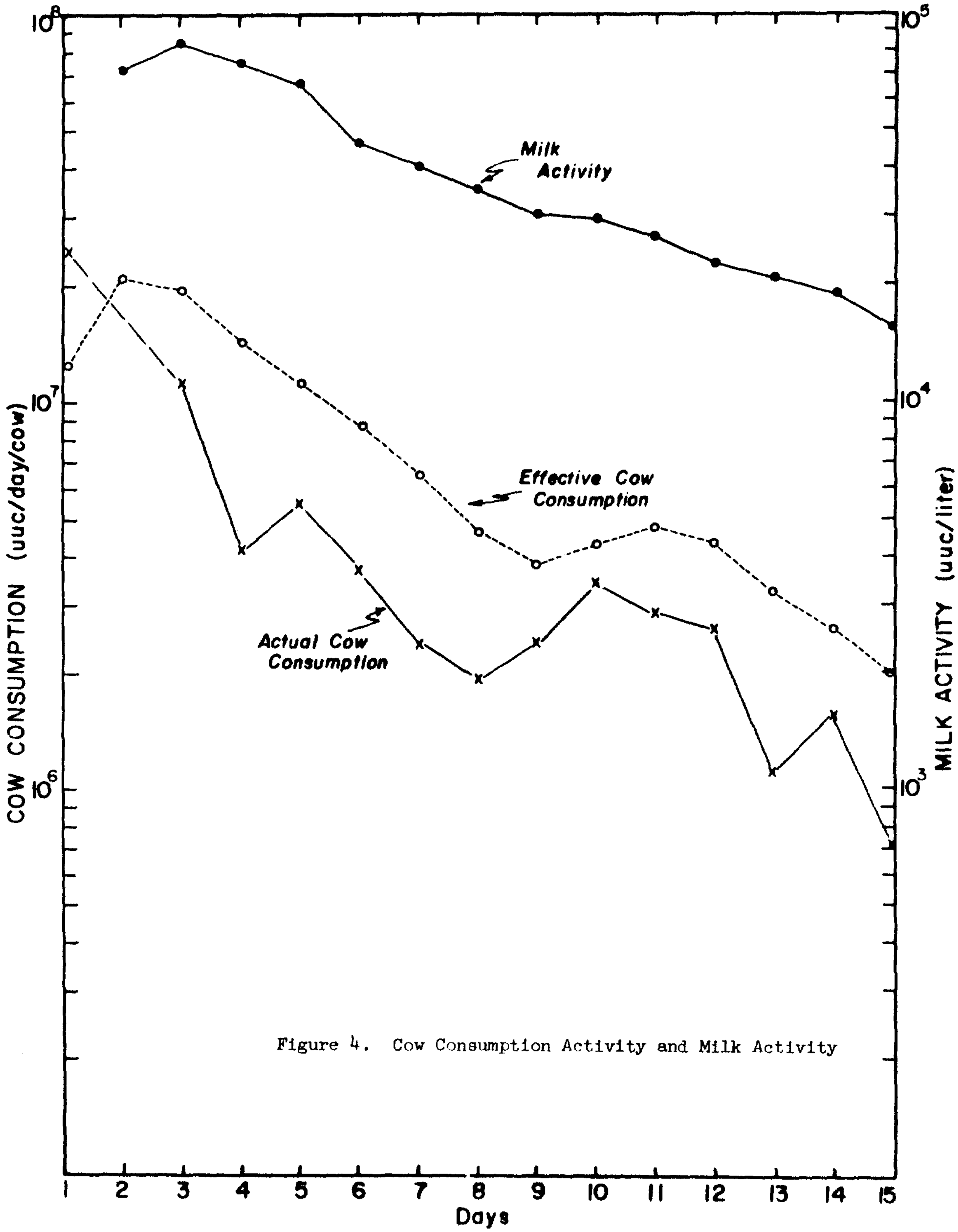


Figure 4. Cow Consumption Activity and Milk Activity

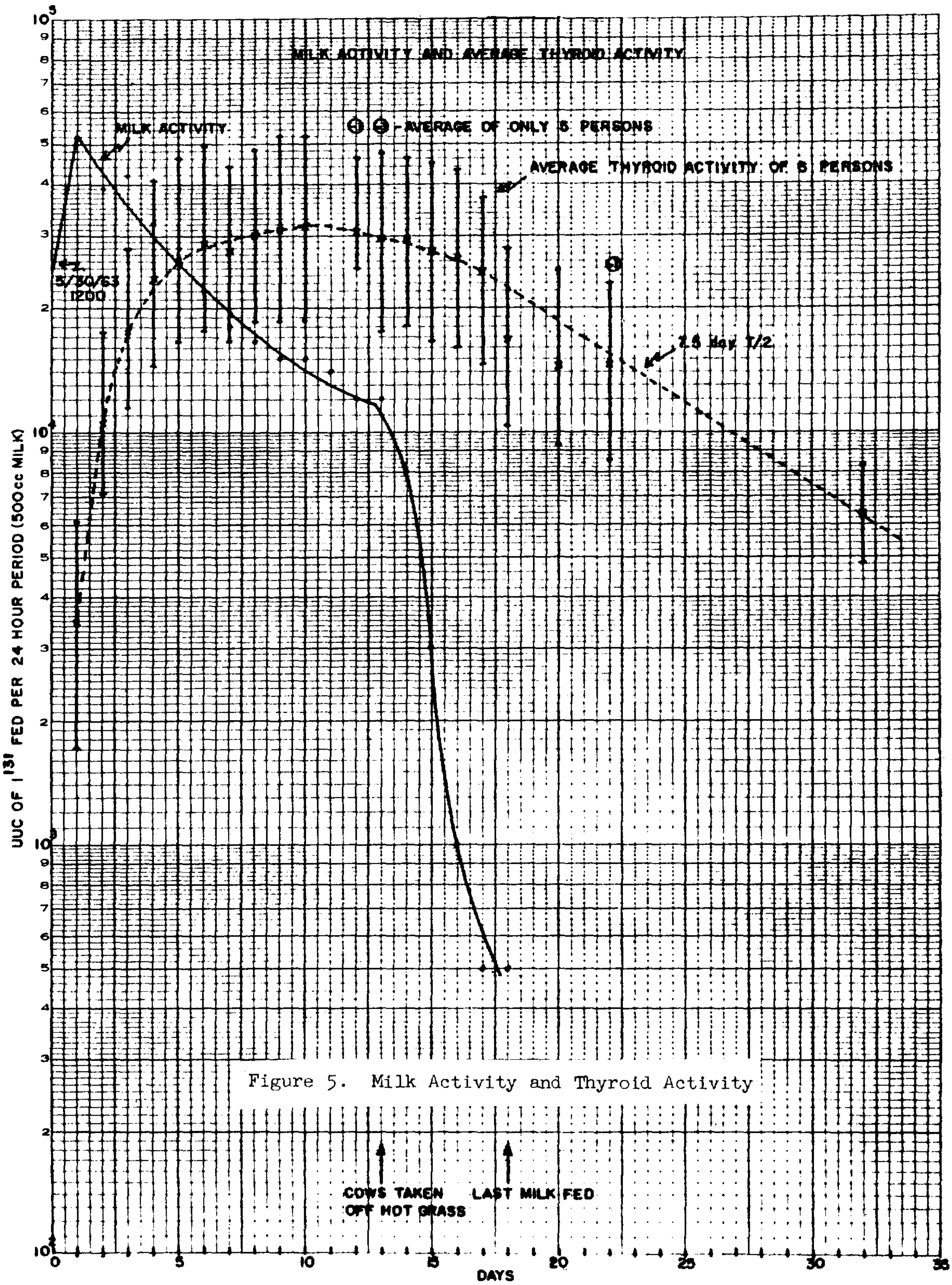


Figure 5. Milk Activity and Thyroid Activity

Controlled grazing which consisted of daily changes of 0.5 acre crosswind grazing strips progressing from 300 m downwind toward the source, enabled the quantitive measurement of grass consumption and activity. The effective half-life on grass was found to be 3.5 days. The comparison between grass activity and milk activity is shown in Figure 4. The effective cow consumption (Figure 4) represents the accumulation of activity within the cow from the current and previous days' grazing based on a one day "half-life" retention factor. The ratio of activities of grass and milk (pc/liter:pc/gm) was: 240 ± 35. The average thyroid uptake of ingested iodine-131 in milk was 19%. A model to predict thyroid activity levels was developed and shown to be quite accurate. The model is:

$$A_n = f \sum_{i=1}^{n} C_i \exp \left[-\lambda_E (T_n - T_{i-1}) \right]$$

A_n-Activity in thyroid at end of n'th time

f - Uptake factor (0.19)

C_i-Activity ingested at beginning of i'th time interval

λ_E-Effective decay constant (thyroid)

T_n-Total time elapsed

T_{i-1}-Time from 0 to end of (i-1) 'th interval

Thyroid doses to the volunteers averaged 0.39 Rad. A comparison of the milk and thyroid activities is shown in Figure 5.

The preliminary experiment showed that the basic experimental procedures were adequate. Further tests in the series will employ the same general procedures in investigating the behavior of radioiodines under various meteorological and physical conditions.

CONCLUDING STATEMENT BY MR. HAWLEY: I should have made it clear earlier that the prime objective of the preliminary experiment was to establish techniques that we can use when we get into the actual irrigated pasture system.

The cows were forced to graze in premeasured strips so that we could get a reasonable measurement of the actual amounts of grass the cows were eating. They were kept on the whole pasture long enough to get an idea as to how much grass would hold these cows for a one-day period. This was adjusted as the grass grew. This is the real trouble with this grass; at various times of the year it grows just like fury, and it was necessary to keep measuring and keep adjusting. We hope with the first test on our irrigated system, where we can actually control the grass measurements much better, we will be able to throw out this one variable. In this thing here, we treated all six of our cows.

We had six 1200 to 1600 pound pure-bred Holsteins, all of which were fresh, which were borrowed from Montana State College. So we took these six cows, and because there was never a factor of 2 discrepancy between the cows, we felt we could treat them as one animal, as far as the data goes. The cows were milked at 6:00 A.M. and 6:00 P.M.

Session Chairman: Thank you, gentlemen, for a most interesting presentation.

The next paper is a substitution which I don't think you will be able to find on your program. Mr. W. J. Megaw, of the United Kingdom Atomic Energy Authority at Harwell, and the topic of this paper is entitled, "The Efficiency of Membrane Filters."

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(Approved for Publication)

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THE EFFICIENCY OF MEMBRANE FILTERS

by

W.J. Megaw
R.D. Wiffen

ABSTRACT

Experiments are described in which the efficiency of type AA millipore filter was determined at a particle diameter of 0.02 microns, using aerosols of potassium permanganate and radioactive tungsten. No significant penetration of the filter was detected either by particle counting techniques using a Pollak counter or by radioactive methods. These results contradict those reported earlier by Fitzgerald and Detwiler. It is shown that the performance of the filter in this size range is not dependent on electrostatic effects and is predictable theoretically if it is assumed that diffusion is the sole filtration mechanism.

Larger particles which are still, however, smaller than the filter pores and for which diffusion processes are ineffective are also trapped with efficiencies of 100 per cent. Removal of the electrostatic charge of the filter does not alter its efficiency and it is concluded that such particles must be trapped by impaction in the filter pores.

Health Physics and Medical Division,
UKAEA Research Group,
Atomic Energy Research Establishment,
HARWELL

January, 1963

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1. Introduction

Membrane filters are porous membranes composed of cellulose esters and can be obtained with mean pore diameters ranging from 0.01 to 5 microns and with porosities as high as 85 per cent. Although they might be expected to act primarily as sieve type filters, they have the property of retaining particles which are very much smaller than the pore size and further of retaining all particles in a very shallow surface layer.

The filters are good electrical insulators, having a specific electrical resistance of about 10^{10} ohm-cm and a dielectric constant of 4.5 (Spurny and Polydorova, 1961). It has been generally accepted that the performance of the filter and, in particular, the surface layer effect, were due to electrostatic forces.

The efficiency of "Millipore"[1] membrane filters has been investigated by Fitzgerald and Detwiler (1957). They passed an aerosol of solid potassium permanganate through a millipore filter and sampled downstream of the test filter by means of another millipore filter. Silica replicas were then taken of the filters and examined by means of an electron microscope. The results of Fitzgerald and Detwiler, which are summarised in Table I indicate a maximum penetration of the grade AA filter (pore size 0.8 μ) at a particle diameter of 0.02 microns. The penetrations ranged from 25 per cent at a face velocity of 10 cm/sec to 56 per cent at a face velocity of 40 cm/sec. Corresponding penetrations of the type HA filter (pore size 0.45 microns) were 25 per cent and 76 per cent, respectively.

The curves given by Fitzgerald and Detwiler show that there is a greater penetration of the filter with the smaller pore size and also that maximum penetration occurs at a larger particle size for the filter with the smaller pores. To this extent they are surprising. They are contrary also to general experience in this laboratory, where for several years type AA millipore filters have been used routinely for the filtration of Aitken nuclei in the size range 0.01 to 0.1 microns in diameter, without any penetration ever having been detected. The method of measurement was such that a penetration of 0.1% would have been detected with ease.

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[1] Millipore Filter Corporation, Bedford, Massachusetts, U.S.A.

TABLE I

Penetration of Millipore filter by $KMnO_4$ aerosol

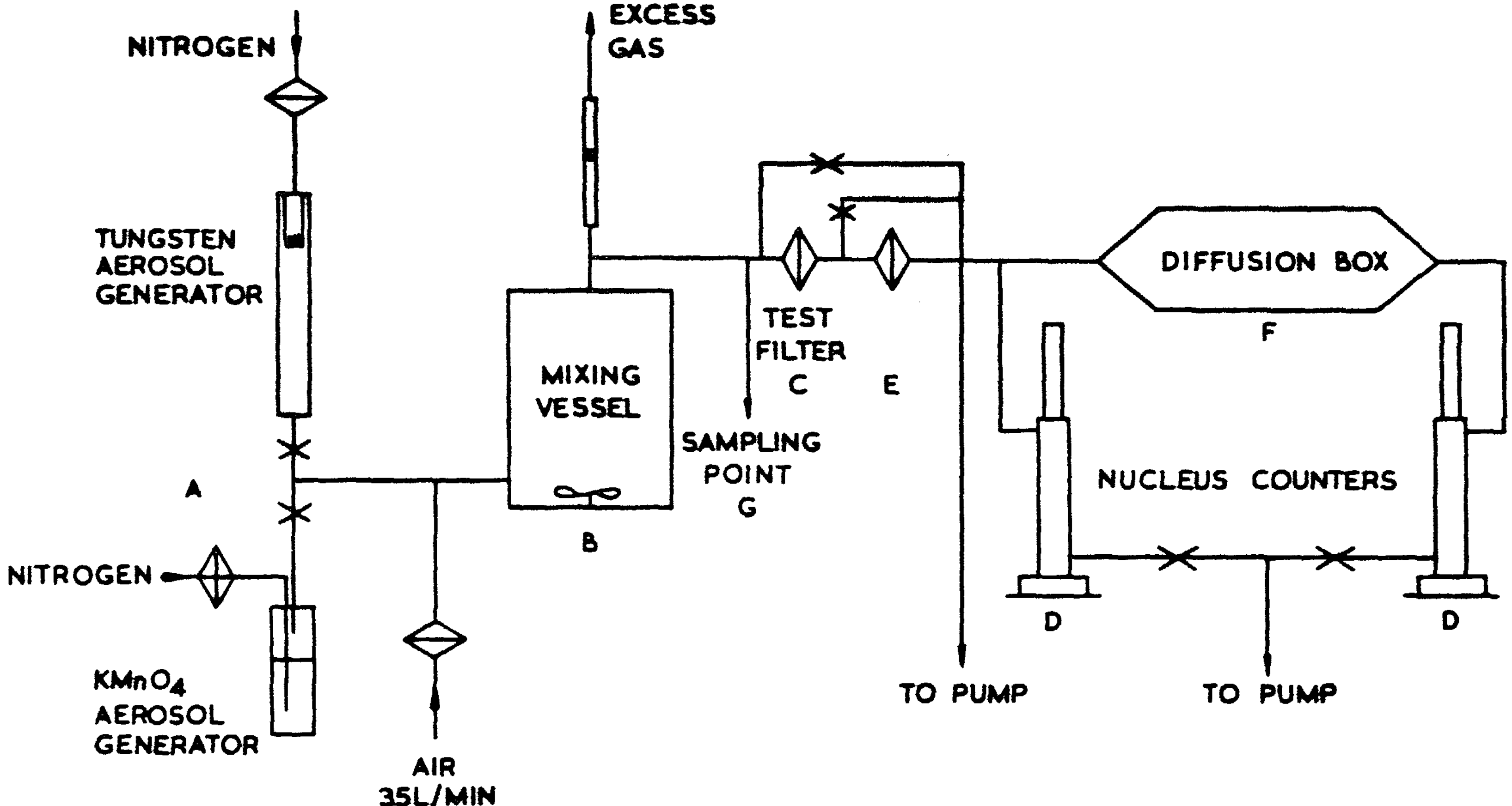
(Fitzgerald and Detwiler, 1957)

Particle Diameter Microns	Air Velocity cm/sec	Percent penetration of AA Millipore filter (pore size 0.8 μ)	Percent penetration of HA Millipore filter (pore size 0.45 μ)
5×10^{-2}	10 20 40	1 5 13	5 2 12
2×10^{-2}	10 20 40	25 35 56	25 35 76
8×10^{-3}	10 20 40	10 17 46-53	3 6 50

It was therefore considered desirable to perform further penetration tests on the type AA millipore filter. The experiments were carried out at particle sizes and face velocities as near as possible to those at which Fitzgerald and Detwiler found maximum penetration.

2. Experimental Method

A diagram of the arrangement of the apparatus is given as figure 1. The test aerosol was generated at A and passed through the chamber B, where it was diluted and dried, and then to the test filter C. The concentration of the aerosol could be measured by means of a nucleus counter at D. The nucleus counter used was similar to that described by Metnieks and Pollak (1959). At the overpressure used (160 mm Hg) the counter would have caused condensation on and hence detected particles down to a diameter of 2.5×10^{-7} cm. The useful concentration range of the instrument is from 50 to 300,000 particles per cm^3. A backing filter of the same type as the test filter was placed at E. The mean size of the aerosol could be determined by passing it through the diffusion box F, from which the diffusion coefficient could be determined by the method of Nolan and Guerrini (1935). Provision was made for sampling the aerosol at G by means of thermal and electrostatic precipitators so that the size distribution could be determined subsequently by electron microscopy.



AERE - R 4211

FIG. 1. ARRANGEMENT OF APPARATUS

2.1 Experiments with a potassium permanganate aerosol

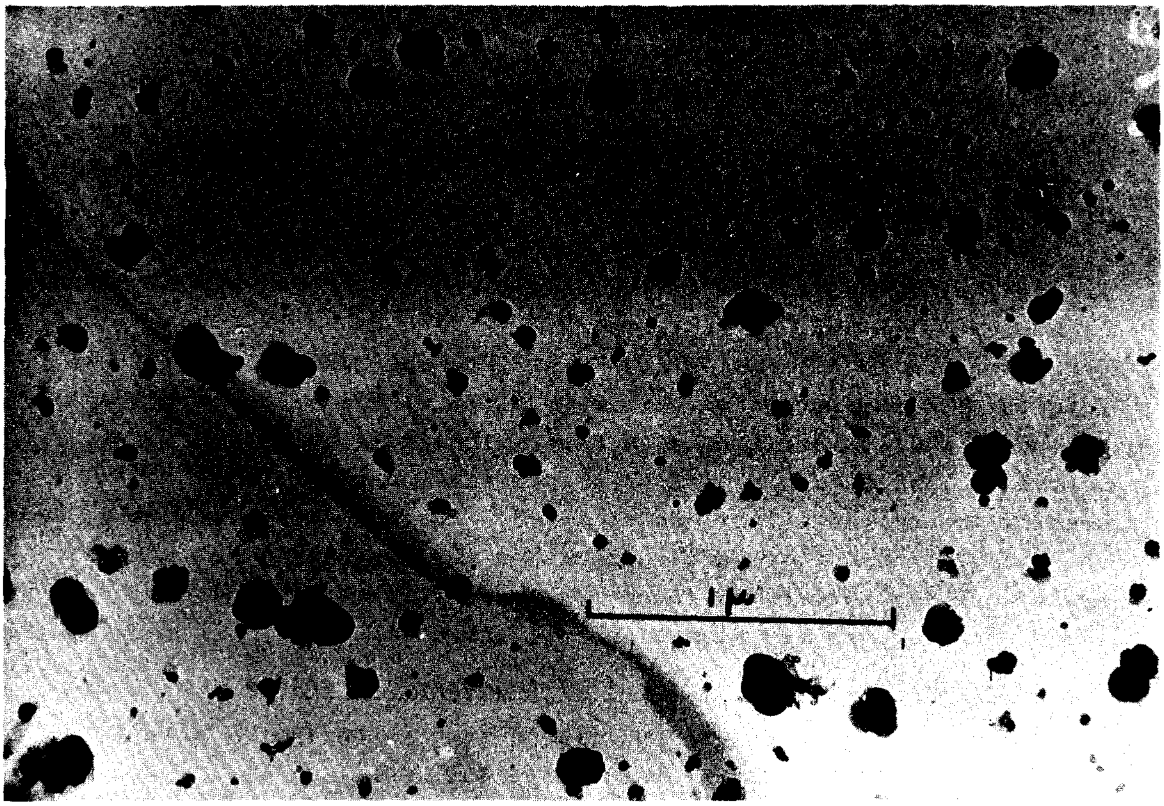
These preliminary experiments, using a similar aerosol to that of Fitzgerald and Detwiler, were undertaken to determine whether some property peculiar to the permanganate aerosol was responsible for the penetration of the millipore filter.

The aerosol was generated by atomising a 0.1% solution of potassium permanganate. An electron micrograph of a sample of the aerosol obtained by electrostatic precipitation is shown in figure 2, and the particle size distribution obtained from this micrograph is given in figure 3. The geometric mean particle diameter by count was 0.024 microns and the geometric standard deviation, 3.0. The diffusion coefficient of the aerosol as determined by the method of Nolan and Guerrini, was 8.23×10^{-5} cm^2 sec^{-1}, corresponding to a 'mean' particle diameter of 0.026 microns. The results of measurements of the penetration of this aerosol through a type AA millipore filter at a face velocity of 40 cm sec^{-1} are listed in Table II. In nine separate tests no significant penetration of the filter was detected. Periodic tests were also made on less efficient filters as a check on the downstream detection system. The penetrations found for these filters were of the order expected and are also listed in Table II.

2.2 Experiments with a radioactive tungsten aerosol

The method of particle counting using the Pollak counter is extremely sensitive and has the additional advantage that the sensitivity is independent of particle size. It is however, rather indirect and it would have been useful, as a check, to compare electron micrographs of simultaneous samples taken from upstream and downstream of the filter. The efficiency of the type AA filter was so high, however, that it was not possible to obtain a downstream sample. A second series of experiments was therefore undertaken in which a radioactive aerosol was used. A sample was taken on a second AA millipore filter downstream of the test filter and the radioactivity of the two filters compared. This method of testing a filter by using an identical filter to take a downstream sample was used by Fitzgerald and Detwiler and is valid for a particular size range provided that penetration of the filter in that range is less than 100 per cent and is independent of aerosol concentration.

A tungsten wire was irradiated in the Harwell reactor Bepo for 30 minutes at a flux of 10^{12} neutrons cm^{-2} sec^{-1} and the aerosol



AERE - R 4211 FIG. 2
POTASSIUM PERMANGANATE AEROSOL

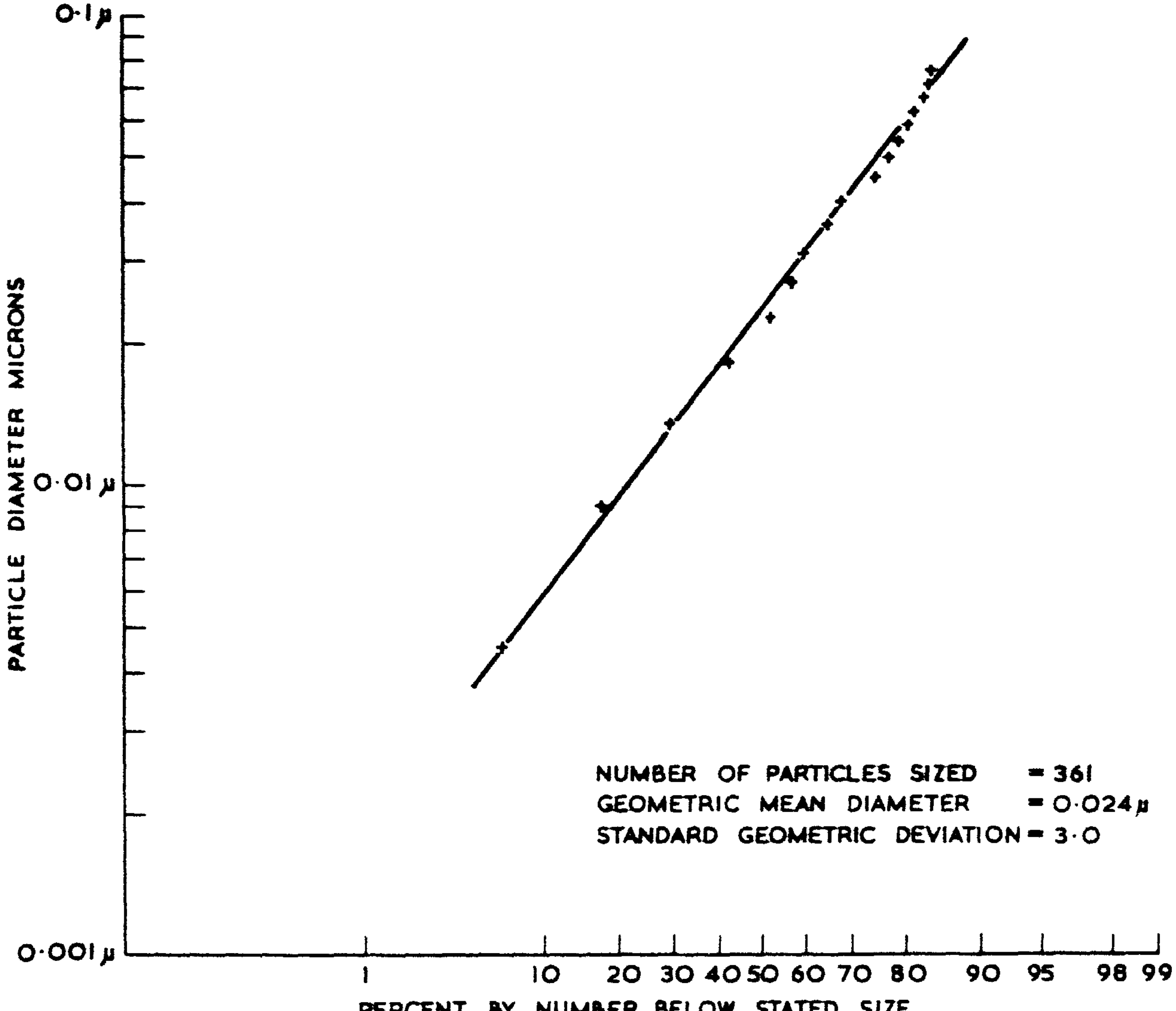


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FIG. 3. PARTICLE SIZE DISTRIBUTION OF $KMnO_4$ AEROSOL

TABLE II

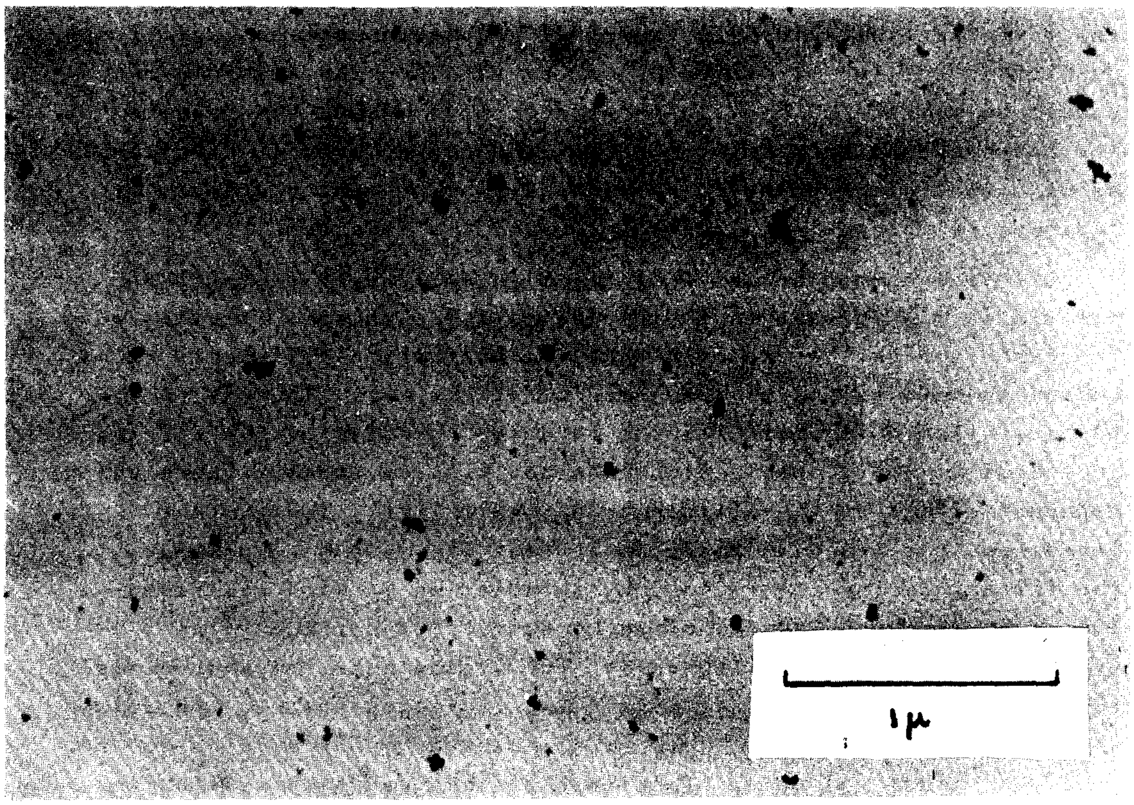
Tests with $KMnO_4$ aerosol

Date of Test	Type of Filter	Face velocity cm sec^{-1}	Pressure drop cmHg	Mean particle diameter as determined by diffusion box microns	Particle Concentration cm^{-3} measured with Pollak counter	
					Upstream of Test Filter	Downstream of Test Filter
29/12/60	Millipore AA	40	9.0		$> 3 \times 10^5$	< 10
		40	9.0		$> 3 \times 10^5$	< 10
30/12/60	Millipore AA	40	9.6	0.026	2.5×10^5	0(4 tests)
	Whatman 541	40	1.8	0.026	3.0×10^5	2.7×10^5 (2 tests)
2/1/61	Millipore AA	40	9.2	0.039	2.0×10^5	0(3 tests)
	*GFA paper	40	4.2	0.034	2.0×10^5	425 (3 tests)

*GFA paper is a high efficiency glass fibre paper manufactured by H. Reeve Angel and Co. Ltd., 9 Bridewell Place, London, E.C.4.

generated by heating the wire to a temperature of 1000-1200°C in a current of filtered nitrogen. The size of the particles was measured by means of a diffusion box as previously described, and could be adjusted to the required diameter of 0.02 microns by altering the temperature of the wire and the velocity of the gas flow past it. An electron micrograph of a sample of a particular aerosol taken with a thermal precipitator is given in figure 4, and its particle size distribution in figure 5. The geometric mean diameter by count is 0.0165 microns. The 'mean' particle diameter indicated by the diffusion box was 0.017 microns. The results of the tests are summarised in Table III and again show no significant penetration of the millipore filter by the tungsten aerosol. It should be remembered that in the radioactive method the results are proportional to mass of material and not numbers of particles as with the Pollak counter, and that in the present instance the radioactive method is therefore probably the less sensitive.

It is a common belief that the high efficiency of membrane filters is due in part to their electrostatic charge. If this were the case it might be expected that the filtration efficiency would depend to some extent on the humidity of the air. In some of the tests mentioned in Table III the relative humidity of the air was increased to 90-100 per cent by the addition of steam. There was no apparent effect on the efficiency of the filter. Two further tests were performed in which an attempt was made to discharge the filter, during filtration, by irradiating it with electrons from a Kr^{85} source mounted close to the filter surface. The arrangement is shown in figure 6. The strength of the source was 10 mc and a rough calculation gave the radiation dose to the filter as several rad hr^{-1}. The dose rate measured by a radiation monitor type 1349 was 1 rad hr^{-1}. The tests on the irradiated filter were carried out using both relatively dry air and very humid air. No penetration of the filter was detected. The experimental conditions and results are summarised in Table IV.



AERE - R 4211 FIG. 4
TUNGSTEN AEROSOL

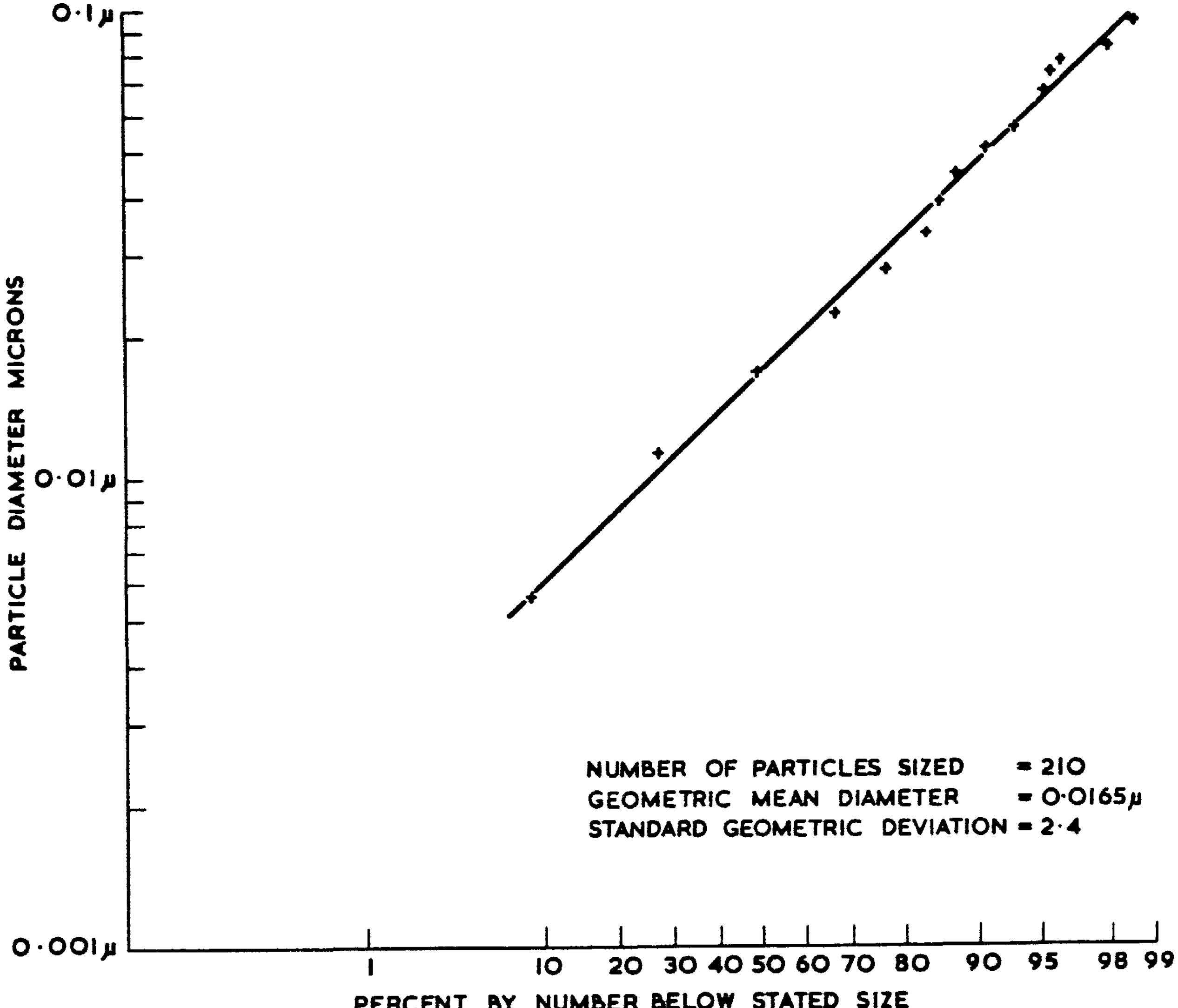


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FIG. 5. PARTICLE SIZE DISTRIBUTION OF TUNGSTEN AEROSOL

TABLE III

Tests with radioactive tungsten aerosol

Date of Test	Type of Filter	Face Velocity cm sec^{-1}	Pressure drop cmHg	Mean Diameter (microns) by diffusion box	Particle Concentration cm^{-3} measured with Pollak counter		Radioactivity of Filters d.p.m.		Relative Humidity %	Duration of Test mins.
					Upstream of Test Filter	Downstream of Test Filter	Test Filter	Backing Filter*		
28/8/62	AA Millipore	40	10.8	0.010	8.4×10^4	0	7.4×10^4	0 ± 1	15-20	40
31/8/62	"	40	11.4	0.017	2.7×10^4	0	7.1×10^3	0 ± 0.7	15	60
6/9/62	"	40	12.1	0.020	8.1×10^4	0	1.8×10^7	0 ± 0.9	15-20	100
14/9/62	"	40	12.0	0.017	4.4×10^4	0	1.04×10^5	0 ± 0.5	75	140
20/9/62	"	40	12.0	0.008	2.18×10^5	0	1.58×10^5	0 ± 1.0	15-20	120
21/9/62	"	40	12.1	-	-	-	6.8×10^4	0 ± 0.4	90	70
24/9/62	"	40	12.0	0.008	2.06×10^5	0	7.8×10^4	0 ± 0.5	96-98	300
25/9/62	"	40	11.5	0.009	2.38×10^5	0(10 tests)	-	-	98	60
25/9/62	"	40	11.5	0.020	7.2×10^4	0(10 tests)	-	-	98	60

* The limit of accuracy quoted is one standard deviation.

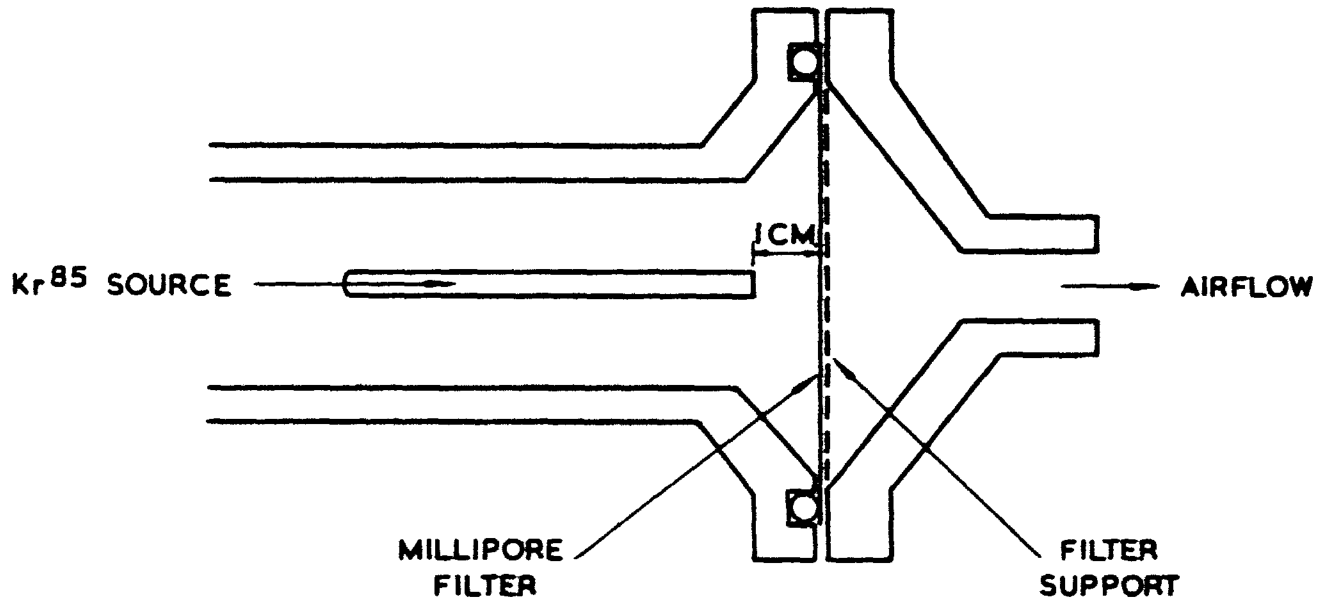

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FIG.6. ARRANGEMENT FOR IRRADIATION OF MILLIPORE FILTER

TABLE IV

Tests on irradiated filter using radioactive tungsten aerosol

Date of Test	Type of Filter	Face Velocity cm sec^{-1}	Pressure drop cmHg	Mean Diameter (microns) by Diffusion box	Particle Concentration cm^{-3} measured with Pollak counter		Radioactivity of Filters d.p.m.		Relative Humidity %	Duration of Test Mins.
					Upstream of Test Filter	Downstream of Test Filter	Test Filter	Backing Filter		
3/10/62	Millipore AA	40	11.5	0.020	3.1×10^4	0(5 tests)	-	-	20	20
4/10/62	"	40	11.2	0.010	1.6×10^5	0(3 tests)	3.28×10^5	0	98	25
4/10/62	G.F.A.	40	3.1	0.010	1.6×10^5	140 (2 tests)			98	
4/10/62	G.F.A.	40	3.1	0.017	2.16×10^4	80			98	

3. Discussion of results

The results given above show clearly that there is no appreciable penetration of type AA millipore filter by particles of diameter 0.02 microns at a face velocity of 40 cm sec^{-1}. These are the conditions for which Fitzgerald and Detwiler (1957) report penetrations of 50-100 per cent. The possibility that the disagreement is due to differences in the humidity of the gas or removal of the electrostatic charge on the filters in one or other of the experiments has been eliminated by tests with air at a relative humidity of 98-100 per cent and by removal of the electrostatic charge on the filter by irradiating it by electrons from a Krypton-85 source. No penetration of the filter was detected in either case. Fitzgerald and Detwiler collected the particles passing the test filter on a second millipore (type HA) filter, made a silica replica of this filter and evaluated it with an electron microscope. They do not give examples of the electron microphotographs in their 1957 paper. Examples are however given in an earlier (1955) paper in which millipore filters were used to evaluate other types of filter. In these photographs the unexposed (control) millipore filter is quite different in appearance from both the test filter and the downstream filter and in addition, even allowing for losses in reproduction the analysis of the photographs would appear to be difficult. It is noteworthy that Borasky and Mastel (1956) in a comparison of methods of sampling for electron microscopy conclude that the silica replication technique is the least reliable of the methods they considered.

The efficiency of the membrane filter can be estimated on theoretical grounds if the following assumptions are made:-

(1) the pores in the filter material are cylindrical holes in the direction of flow,

(2) retention of particles occurs only by diffusion of particles to the walls of the pores,

(3) particles are not re-entrained after deposition.

Then, by the equation for diffusion in a circular tube given by Fuchs (1955), we have,

$$\frac{n}{n_o} = 0.82\ e^{-3.66\mu} + 0.097\ e^{-22.2\mu} + 0.0135\ e^{-53\mu}$$

where $\mu = \frac{Dx}{R^2 \bar{u}}$ and $\frac{n}{n_o}$ is the fraction of particles of diffusion coefficient D penetrating a tube of radius R and length x at a velocity of $\bar{u}$. This equation is very similar to Gormley and Kennedy's (1948) form of Townsend's (1899) equation which has been shown by Chamberlain and Dyson (1956) to describe accurately the diffusion of thorium B atoms to the walls of a cylindrical tube.

By applying the equation the fraction of incident particles penetrating a given thickness of filter can be calculated and this has been done for a selection of particle sizes in Table V.

TABLE V

Calculated penetration of type AA millipore filter assuming that retention of particles is by diffusion to pore walls only

(a) penetration to a depth of 10 microns

(b) penetration of whole filter (150 microns)

Particle diameter microns	Diffusion constant $cm^2\ sec^{-1}$	Face Velocity $cm\ sec^{-1}$	Velocity in filter pores* $cm\ sec^{-1}$	Percentage penetration	
				(a) to depth of 10 microns	(b) of whole filter (150 microns)
0.005	1.9×10^{-3}	40	50	-	-
0.01	5×10^{-4}			1.0×10^{-8}	-
0.02	1.3×10^{-4}			0.21	-
0.03	6.6×10^{-5}			4.0	-
0.04	3.5×10^{-5}			16.5	1.24×10^{-10}
0.05	2.75×10^{-5}			28.6	1.35×10^{-6}
0.06	1.65×10^{-5}			39.6	2.24×10^{-4}
0.08	1×10^{-5}			52.3	0.034
0.10	6.7×10^{-6}			61.8	0.45

*estimated from face velocity assuming a porosity of 80%.

It is apparent from Table V that, neglecting other modes of filtration, diffusion to the pore walls would ensure a one hundred per-cent efficiency of the filter up to a particle diameter at least of 0.05 microns and would also account in this size range, for the observed fact (e.g. Kubie, Jech and Spurny, 1961) that membrane filters retain all particles in a very shallow surface layer.

The experimental results have also confirmed that in the size around 0.02 microns diameter the filtration efficiency of membrane filters is not dependent on any electrostatic effect. As the particle size increases retention by diffusion to the pore walls becomes less effective and at a particle diameter of 0.4 microns penetration of the filter would be about 70 per cent if diffusion was the sole mechanism of filtration. As the particle size increases however, filtration by impaction in the filter pores, which are in reality probably rather tortuous, becomes increasingly important. Additional tests with a methylene blue aerosol also showed no detectable penetration when the filter was irradiated. The geometric mean diameter of this aerosol was about 0.05 microns, but two per cent of the concentration of 10^6 particles cm^{-3} were greater than 0.4 microns in diameter. It is apparent that in this size range also the filtration efficiency of the millipore filter does not depend on electrostatic forces.

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DISCUSSION AND COMMENT

Session Chairman: Perhaps we had better discuss Mr. Megaw's presentation at this moment.

HACL Comment: We have a filter in this country that was charged by passing air through it. It had polyvinyl rubber fibers. We had some tests with this as to discharge, and so on. We have measured the Millipores, as you know, in a Faraday cage and have found a fair net charge on them. But, if you take off the charge you do not see any difference in performance. So, I think your conclusions are correct. I was not familiar with the K. Spurny reference. I do not know how recent that is.

Comment: The Spurny work was all done in the past year.

Question: If these results were obtained from the AA filters, what would you expect with HA?

Comment: Well, they have that much smaller pore size, so I think they must be that much better. I think someone has shown recently that people tend to use Millipore filters that are far too good for what they want. Quite often you can get very good performance with a filter with perhaps a 3 or 4 micron pore size, with consequent saving in pressure drop.

I don't suppose it is worth mentioning, but I cheated a little bit in that we once actually did find some penetration through a Millipore filter. This was when we were trying to use it to get a narrow cut of particle size, to get an almost homogeneous aerosol of about one or two microns. Technically, if you want to do it, you light a cigarette and hold it quite close to the paper. We did get some penetration, but we certainly ascribe this penetration to constant condensation from gaseous material in the cigarette smoke after it has passed through the filter because of the tremendous pressure drop there.

Question: Do you suppose the Fitzgerald and Detwiler discrepancy here, which is a rather major one, is attributable to the holder of the filter papers and that this is really a leakage around the seams?

Comment: That might be so. I have been discussing this by letter with Fitzgerald for the last two years. I am going up to see him next week and talk to him. Perhaps only one of us will come away from there, I don't know.

Session Chairman: Thank you, Mr. Megaw.

Mr. Brion of the French Atomic Energy Commission will give the next paper after a very short break, the title of which is "Filter Efficiency and Clogging."

FILTER EFFICIENCY AND CLOGGING

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Service de Controle des Radiations et de Génie Radioactif
Centre d'Etudes Nucléaires de
Fontenay-aux-Roses (Seine)-FRANCE-

ABSTRACT

It is generally admitted that filter efficiency increases with clogging. Experiments, conducted with three kinds of aerosol show that efficiency may decrease with clogging, especially when filtering oily aerosols.

INTRODUCTION

When working, an air filter undergoes alterations. The most noticeable effect is the resistance increase which is often given to point out clogging. Efficiency is generally considered as unaffected or improved by clogging.

In order to precise that point, we have undertaken some experiments which are described in this paper.

TEST RIG

A spherical chamber - see fig. 1 - contains a test aerosol. Two filter holders, one with a clogged sample, the other with a new one, are connected to the chamber. Air is drawn through each filter, alternately, by the circulating pump of a particle counter.

TEST AEROSOLS

Three kinds of aerosol have been used:

A. smoke generated by a smoke-producer called "smoking rope."
B. local atmospheric aerosol.
C. smoke generated by a smoke-producer called "milk sugar smoke-producer."

Photomicrographs of aerosol A and C are given fig. 2 and fig. 3, respectively. Aerosol A appears as structureless particles - when ignited, the "smoking rope" produces tars which look like oils on a filter -. On the opposite, aerosol C consists of cubic crystals of ClK.

Measured with the "Royco" particle counter, aerosols A, B and C appear with a maximum number of 0.3-0.4 micron diameter particles and a major particle diameter of 1.2 micron.

FILTER SAMPLES

Most experiments have been made with alfa paper filter, giving 3 per cent methylene blue penetration. Few other experiments with another filter, giving 25 per cent methylene blue penetration, have led to similar results.

Effective area of samples was four square centimeters - 0.62 sq. in.

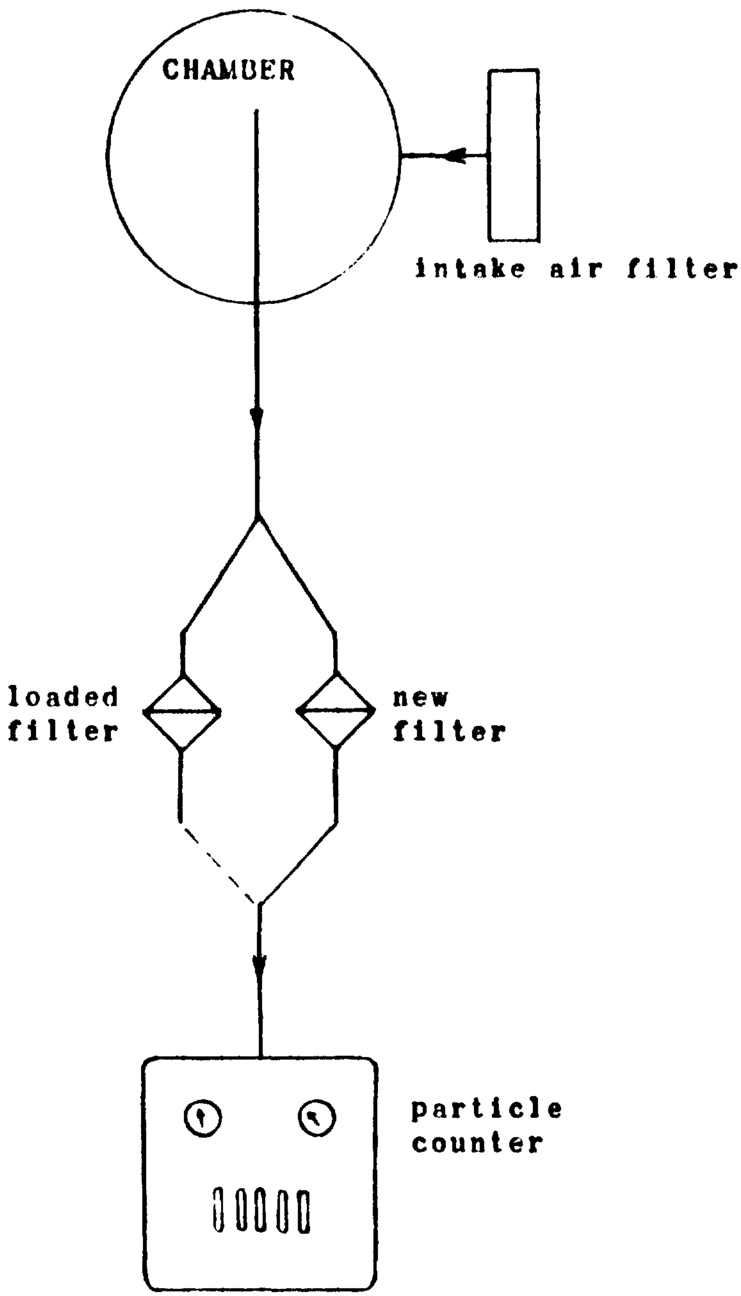


Fig. 1 - TEST RIG DIAGRAM

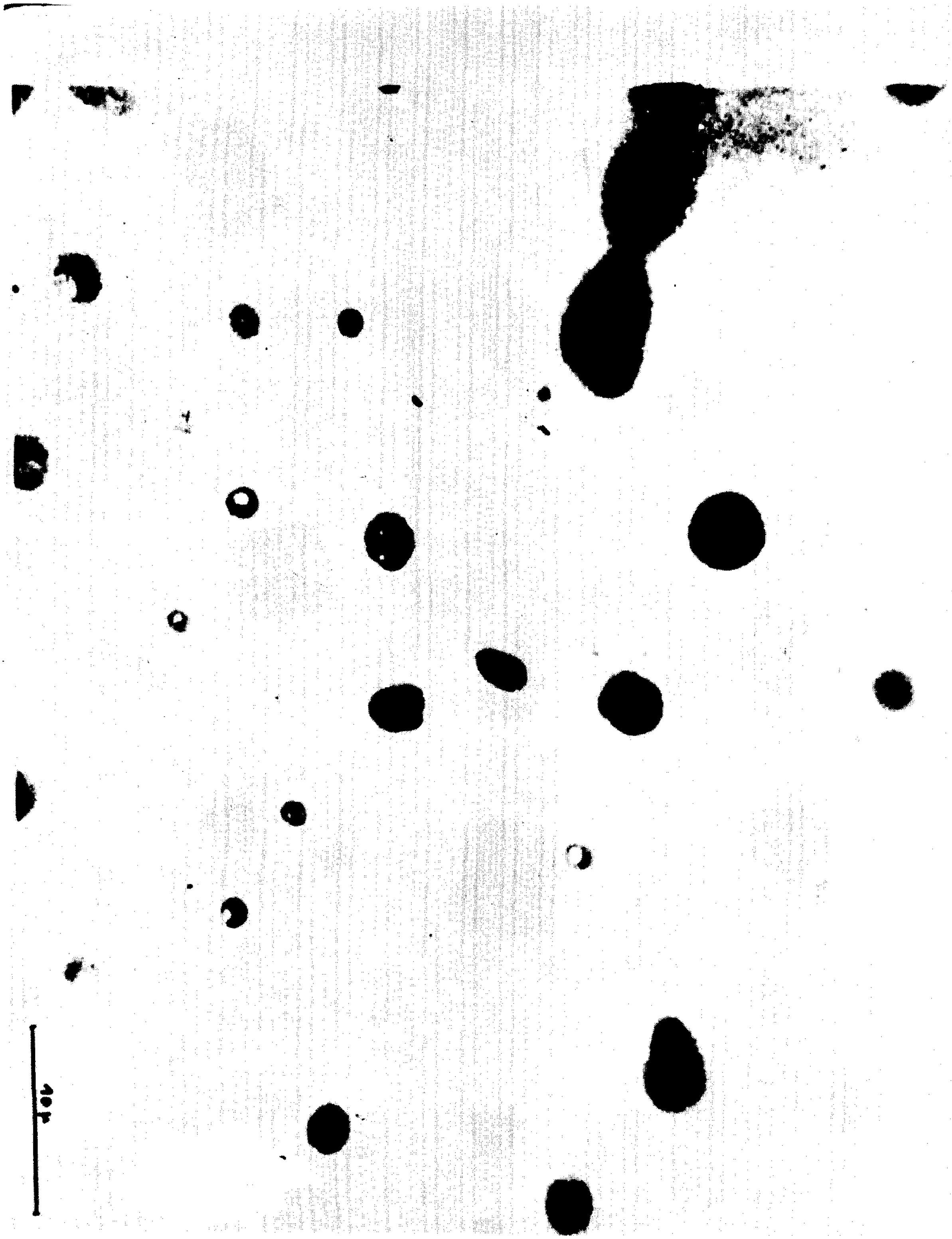


Figure 2

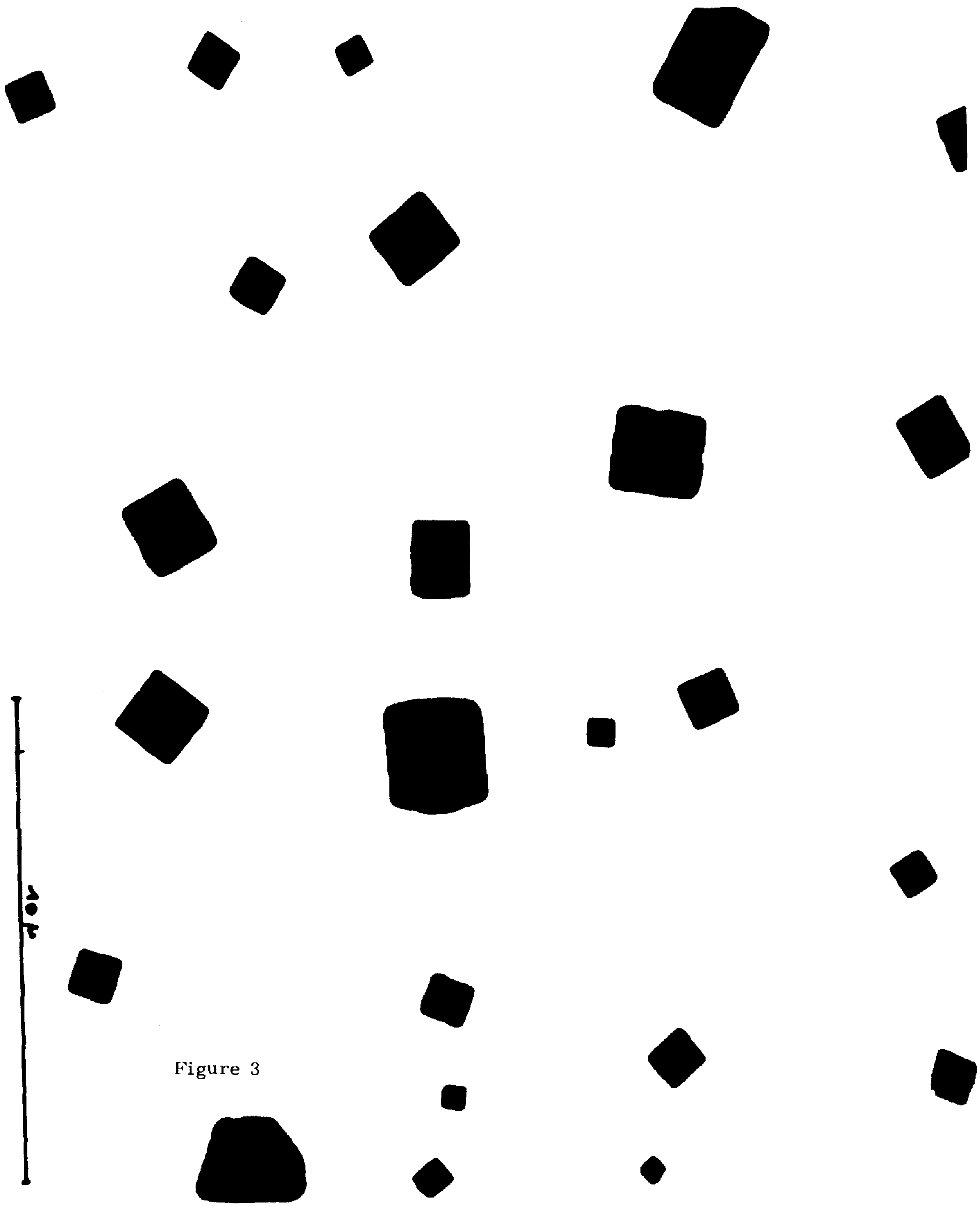
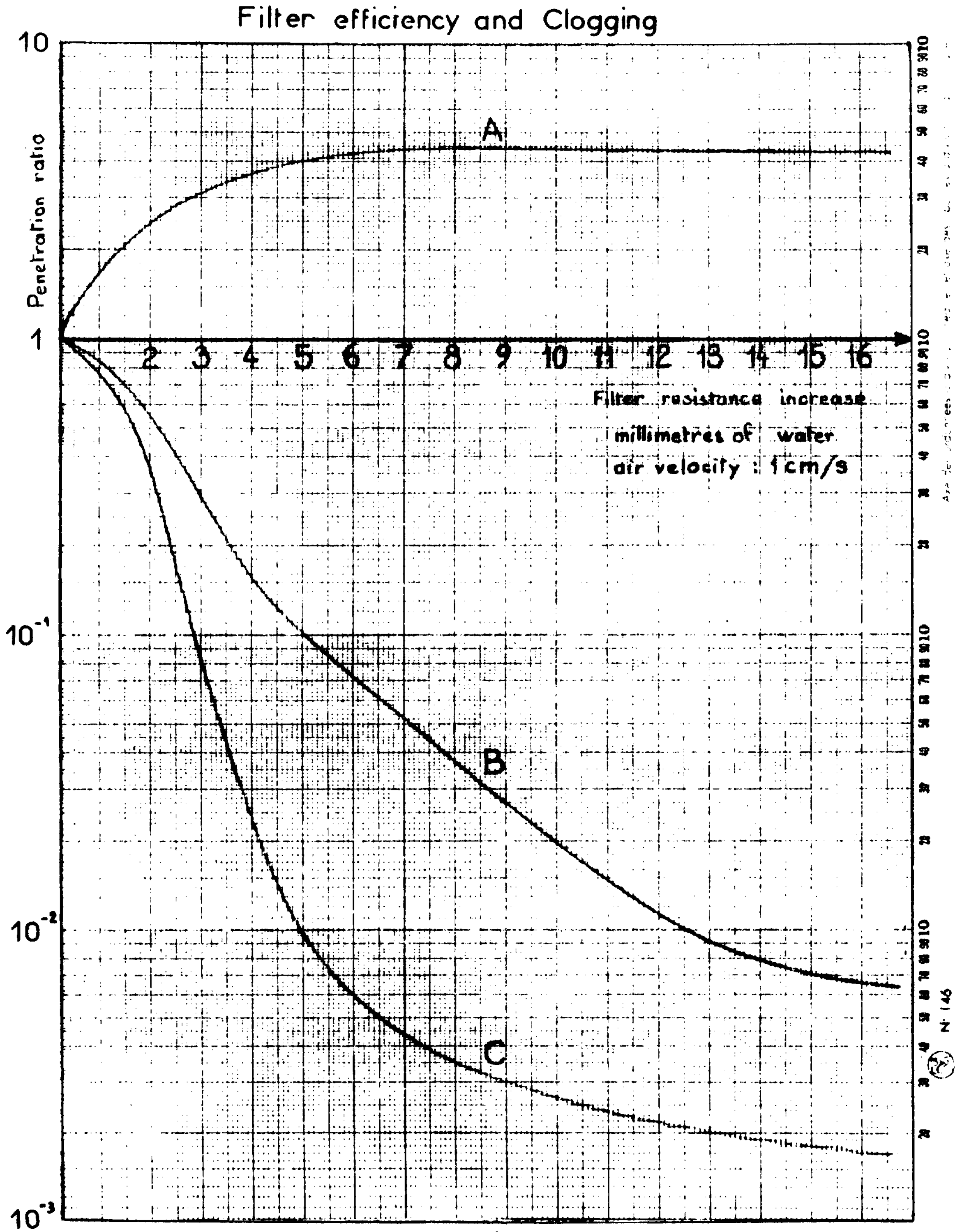


Figure 3



Filter efficiency and Clogging
10
1
10^{-1}
10^{-2}
10^{-3}
Penetration ratio
A
B
C
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Filter resistance increase
millimetres of water
air velocity : 1 cm/s

Figure 4

EXPERIMENTS

Filter samples have been loaded up to different rates with the various aerosols. Loading was achieved with an air velocity of fifty centimeters per second - 100 Feet/min.

Penetration tests have been carried out with aerosol A in the chamber, and few checking tests with aerosol C have given similar results.

The particle counter was alternately connected to the new filter sample and to the loaded one. It counted the particles coming through the filters, within the size range 0.3 - 1 micron.

Air velocity was one centimeter per second - 2 feet/min. - which is the normal value for these filters.

RESULTS

Fig. 4 curves show the connection between efficiency, expressed by the ratio of the loaded filter penetration and the new filter penetration, and clogging, pointed out by the resistance increase in millimeters of water - 0.04 inch of water.

One can see that clogging with aerosols B and C increase efficiency up to one hundred times and more, whereas clogging with aerosol A decrease efficiency down to three or four times.

CONCLUSION

On the opposite of most dusts, some aerosols may lower filtration efficiency when loading filters. It seems that filter structure is damaged by a physical and/or a chemical action produced from tarry or oily aerosols. It might be of interest to know whether DOP aerosol, used for filter tests, is able of such an action.

Comment: If you have any questions, I would advise you to speak slowly, or, if there is someone who is able to translate, I should be very glad to answer.

Session Chairman: We will withhold any questions, for now.

I have been informed that we have with us Mr. Wim Walrave of the Netherlands who may have a paper to present or may want to discuss off-the-cuff what they are doing in his country. Is this the case?

Comment: It is not the case. Thank you

Session Chairman: In which case, we will then ask if there are any questions on the three papers which have been presented?

Comment: I might mention that the Department of Agriculture in Maryland, has been studying decontamination of farmland and has been using some techniques that we might want to look into.

Session Chairman: If there are no other questions, this is not quite the end of Session VII. We have a movie Dr. Silverman will narrate entitled, "High Expansion Foam Test." He might want to say a few words about that.

COMMENTS BY DR. SILVERMAN: I hope you haven't been waiting with bated breath for this movie, because it is an attempt to answer some questions that were raised when we proposed the foam technique for containment studies. Of course, some of the more skeptical architects and engineers asked, "Well, how high can you push a column of foam?"

We said, "With a 1000-to-1 ratio, we ought to push it almost as high as a column of air." Well, it turns out that if you want to prove this, you have to go through with what I might say is valid experimental proof. So, we looked for a facility where we could perform the experiment. Thanks to the Atomic Energy Commission's decision to drop the EOCR, we found a building at Idaho in the Central Facilities area, and were able to get the Safety Group at the Idaho Operations, who had a High-X foam generator on a truck, to run this series of tests for us.

This test followed Murphy's Law, I'm sorry to say, because one of the things that happened was that we told them we would like to have them put a stabilizer in the foam. This was fine. They would be glad to do it, and the company shipped out the stabilizer without the solvent, so it had lumps in it and we got a wet foam.

It wasn't too bad. The tower you will see here in the film is about 72 feet high and the major part of the cross-section is about 19 feet by 16 feet. The volume is about 30,000 cubic feet, and it should have taken three minutes to fill the tower. Instead, it took twenty minutes to reach the 51-foot level, and then the fan, which only has a static of three inches, began to overload.

We are indebted to Mr. Richard Beers of the Idaho Safety Group for running this test, and since you might find the movie a little monotonous, so I have asked them to run it at sound speed even though it was taken at silent speed.