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INVESTIGATION OF WARM FOG PROPERTIES AND FOG MODIFICATION CONCEPTS

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16. Abstract Warm fog seeding experiments were performed in Elmira, New York to determine the potential of various sized and unsized hygroscopic chemicals for fog dissipation. Urea, disodium phosphate and sodium chloride were tested. Sized materials were most effective in causing fog dissipation but considerable leeway in sizing was tolerable. No firm conclusions were drawn with regard to the relative efficiencies of the three chemicals tested. The aerial seeding techniques employed were most effective during the latter stages of the life cycle of a fog. Wind measurements made at the field site established the presence of frequent and substantial turbulence in fog. This turbulence sometimes causes untreated fog to diffuse into cleared regions and degrades the effects of seeding.

The computer model developed earlier to simulate the effects of seeding natural fog with hygroscopic materials was expanded to include vertical turbulent diffusion. Agreement of the model predictions with experimental results at Elmira was demonstrated.

A four-week field investigation was conducted at the Seattle-Tacoma Airport to evaluate fog seeding operations performed by Aero-Dyne Corporation with polyelectrolytes. Only one fog of sufficient duration to permit

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Abstract (Cont'd)

seeding occurred. Detailed analysis of the data acquired showed that the occurrence and disappearance of the three patches of fog on that day were due to natural causes and that seeding was not responsible for the observed improvements in visibility.

Laboratory tests were performed to evaluate new chemicals as seeding agents and to study the effects of evaporation retardants on fog formation and persistence. None of the polyelectrolytes tested was effective in dissipating laboratory fog. Attempts to precoat natural nuclei with cetyl alcohol, an evaporation retardant, resulted in fogs that were much more persistent than control fogs, but firm conclusions relative to effects on fog formation could not be drawn.

An exploratory program was performed to determine the gross effects of disodium phosphate, urea, and sodium chloride on vegetation. Sodium chloride was most damaging to the vegetation. Urea produced increased vegetative growth but resulted in burning of leaf tips at the higher dosages. Disodium phosphate produced slightly more lush vegetation.

A brief experiment designed to dissipate stratus clouds was successfully performed in preparation for the 7 March 1970 total eclipse. Weather conditions did not require the use of this capability on the target date, however.

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We express our gratitude to Mr. Glenn S. Banfield, Airport Manager of the Chemung County Airport, Elmira, New York, for his cooperation and continuing assistance during the fog seeding experiments. Thanks are also due the members of the Elmira ground control, especially Mr. Jim Mengus, Chief Air Traffic Controller, for their special cooperation during our stay; and to Mr. William Garrecht, Chief of the Airways Facilities Section of the FAA, for his assistance in locating our instrumentation on restricted areas of the airport grounds. We are also indebted to Lieutenant Colonel Bob Leipold, USMC, for arranging to have a CH-46 helicopter available for a portion of the seeding program.

We express our gratitude to Mr. Bob Spicer, Assistant Manager of the Seattle-Tacoma Airport, for his willingness to allow us to perform our evaluation of the seeding trials of Aero-Dyne Corporation at the Sea-Tac Airport and to the members of the Sea-Tac ground control for their understanding tolerance of our presence on the airport grounds during periods of heavy traffic. We extend our thanks to the personnel of Aero-Dyne Corporation for the cooperative manner in which they assisted us in the seeding evaluation.

Finally, we wish to thank Dr. Helmut Weickmann of ESSA for his assistance in the planning and design of the seeding experiments for the 7 March 1970 total eclipse and also the members of the Research Flight Facility, ESSA, for their participation in the experiment.

I. INTRODUCTION

For the past seven years, Cornell Aeronautical Laboratory has been actively engaged in warm fog research. The primary goal of these studies has been to obtain a firm understanding of the physical and dynamic properties of fog with the expectation that this approach might lead to a practical concept for fog modification.

Initially, consideration was given to developing physical and dynamic fog models and to conducting experiments to determine more about the diffusional growth rates of droplets in a supersaturated environment. Instrumentation was developed for observing the natural nuclei in the atmosphere that are responsible for cloud and fog formation. Laboratory tests of suggested concepts for fog suppression were performed and measurements of microphysical characteristics of fog were obtained. Other laboratory tests were directed toward determining if the coalescence behavior of fog drops could be significantly altered.

As a result of these studies, a concept evolved for improving visibility in fog by seeding with hygroscopic nuclei of carefully controlled size. After considerable theoretical development, a series of laboratory tests were performed to determine if the concept could be applied on a larger scale, i.e. to natural fog. These tests demonstrated that visibility in laboratory fog could be dramatically improved by seeding with modest amounts of carefully sized NaCl.

Subsequently, field tests of the concept were performed on valley fogs in the vicinity of Elmira, New York during the late summer of 1968 and again during the fall of 1969.

The 1968 experiments have been previously described in other reports (e.g., see Kocmond and Eadie, 1969). Results of the more recent seeding experiments are presented in Section II of this report.

In addition to the field experiments of the past year our computer modeling effort was expanded and refined to include the effects of vertical turbulent transfer on warm fog modification. As in previous years, the model was used extensively to explore the potentialities and limitations of warm fog modification using sized hygroscopic seeding materials. Results of recent modeling studies are described in Section III of the text.

As part of this year's Fog Drops program, CAL was requested to evaluate a warm fog seeding operation at the Seattle-Tacoma Airport. Seeding operations were performed by the Aero-Dyne Corporation using polyelectrolytes as the seeding agents. Results of the evaluation are described in detail in Section IV.

Additional laboratory experiments were also performed to evaluate new chemicals as seeding agents and to study the effects of certain evaporation retardants on fog formation and dissipation. These studies were conducted in the 600 m^3 cloud chamber at the CAL-Ashford experimental site. The experiments are described in Section V.

For the past two or three years, there has been increasing concern relative to the effects of hygroscopic materials on plant ecology. An exploratory program was initiated at CAL to determine the gross effects of various seeding agents on vegetation. Three chemicals, sodium chloride, disodium phosphate, and urea, all of which were used in field experiments at Elmira, New York were regularly administered to test plots of rye grass at the CAL-Newstead site. The sensitivity of the vegetation to various dosages of the chemicals was examined and both short-term and long-term effects were studied. These results are described in Section VI.

Finally, as part of the Fog Drops program this year, CAL designed and participated in a cloud seeding experiment near Virginia Beach, Virginia. The purpose of the experiment was to dissipate stratus clouds for the 7 March 1970 total eclipse. The results of this study, which showed that seeding could be used effectively to dissipate supercooled stratus clouds, are described in the text and can be found in Section VII.

II. WARM FOG MODIFICATION EXPERIMENTS - ELMIRA, NEW YORK 1969

During the summer of 1969, twelve fully implemented seeding experiments were conducted at the Chemung County Airport, Elmira, New York. The experiments were designed to test the effectiveness of three hygroscopic seeding materials (urea, disodium phosphate and sodium chloride) as fog dispersal agents.

Previous field experiments (Kocmond and Eadie, 1969) have shown that visibility in dense natural fog can be significantly improved by seeding with carefully sized sodium chloride nuclei. The most recent experiments were conducted with the intent of testing new materials that were less corrosive than salt and also determining the importance of accurate sizing of material for fog dissipation.

Results of these tests are reported here.

A. Valley Fog Characteristics

Instrumentation used to collect data on the physical properties of valley fog included the following:

(1) A Piper Aztec aircraft equipped to measure drop sizes, liquid water content, temperature, dew point, and cloud nucleus concentration.

(2) A mobile research van carrying instrumentation for measuring drop sizes, drop concentration, liquid water content, and temperature in fog.

(3) A 55-foot telescoping tower equipped with high performance anemometry at 10 feet and 55 feet and temperature and dew point sensors at 3, 10, and 55 feet.

(4) Four transmissometers for measuring visibility in seeded and unseeded fog.

In Table I some physical characteristics of valley fog are tabulated for comparison with the radiation and advection fog models developed on this program (Jiusto, 1964). The data represent averages of measurements made in 17 fogs.

Table I

Comparison of Fog Characteristics

Fog Parameter	Radiation Fog	Advection Fog	Valley Fog Elmira, NY
Average Drop Diameter	10μ	20μ	17μ
Typical Drop Diameter Range	4-36μ	6-64μ	4-50μ
Liquid Water Content	110 mg m^{-3}	170 mg m^{-3}	150 mg m^{-3}
Droplet Concentration	200 cm^{-3}	40 cm^{-3}	55 cm^{-3}
Visibility	100 m	300 m	100-300 m
Vertical Depth	100-300 m	200-600 m	100-200 m

Perhaps the most striking feature of the valley fog data is the similarity of the average drop diameter, liquid water content, and drop concentration to that of the advection fog (coastal fog). Although it is known that the cloud nuclei concentration is in part responsible for shaping the drop size distribution in clouds and fog, it is interesting to note that the characteristics of the valley fogs, which are formed in a continental environment with high nucleus concentration, are very similar to those of the coastal fogs where the nucleus concentration is much less. Cloud nucleus observations made in the vicinity of the field site indicate that, on the average, about 500 nuclei/cm^3 are active at 0.1% supersaturation. Since the average computed drop concentration in the Elmira valley fog is about 55 cm^{-3}, this suggests that supersaturations in this type of fog are indeed slight. Observations of average drop diameter and droplet concentration made near the fog top were found to be much more typical of radiation fog and of continental aerosols.

In Figure 1, vertical profiles of three fog parameters are shown for average data obtained in 12 Elmira valley fogs. The data were obtained during takeoff and ascent of the CAL Piper Aztec after mature fog had developed. Drop concentration and liquid water content were computed from the measured drop distributions assuming a constant visibility (it is recognized that visibility

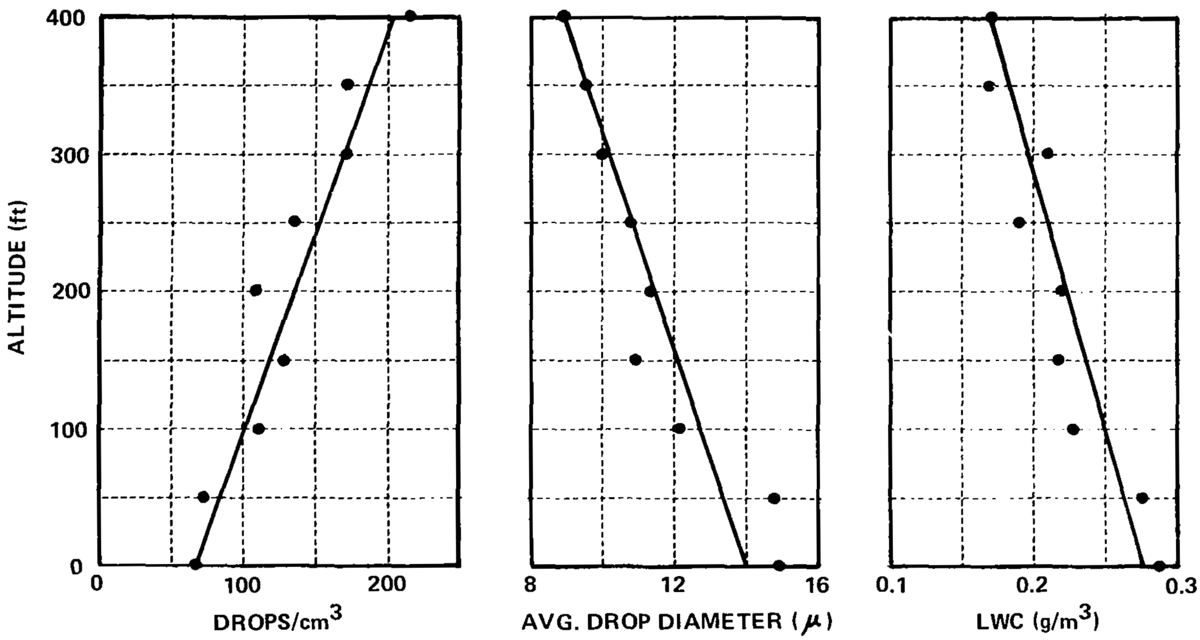


Figure 1 VERTICAL PROFILES OF VALLEY FOG PARAMETERS (AVERAGE DATA FROM 12 FOGS)

is not constant in fog; however, the results are intended to provide trends in the data rather than absolute measures). Note the steady decrease in average drop diameter as a function of height above fog base. Accompanying the decrease in drop size, however, is an increase in drop concentration.

Temperature profiles obtained shortly before fog formation at Elmira have shown that temperature inversions, frequently exceeding 1°C in 50 ft, exist in the lowest few hundred feet of air. Upon fog formation, however, the inversion breaks down within the fog and the temperature stratification through the fog becomes nearly neutral. After fog has formed, a capping inversion usually persists until the time of fog dissipation.

These observations are illustrated in Figures 2 and 3 in which temperature profiles are compared prior to, during, and after fog formation. The data shown in Figure 2 were obtained on 22 September 1969 from observations of temperature at three levels (3, 10, and 55 feet) on a telescoping tower. As shown, a temperature inversion of about 2°C existed over this altitude prior to fog formation. (On several occasions, inversions of as much as 3.5°C have been observed in the lowest 55 feet of the atmosphere. As fog began to form, this inversion broke down and the atmosphere became nearly isothermal over the altitudes in which temperatures were measured.) Once mature fog had developed, a temperature decrease of about 0.5°C became established within the lowest 55 feet of the fog.

Figure 3 shows a typical capping inversion that usually exists in valley fogs. The data were obtained from an aircraft sounding about three hours after fog had developed. Note the temperature decrease of about 1.5°C within the 450 ft depth of fog and also the extent of the inversion aloft which, in this case, amounted to about 10°C between 500 and 3000 feet.

Repeated observations of the formation of fog at the Elmira, New York field site suggest that mixing of the nearly saturated layers of air in the valley governs the fog formation process. Typically, as the ambient winds subside, drainage from the hills begins to predominate and surface winds in the valley become aligned with the orientation of the valley. Radiational cooling of the earth's surface and subsequent loss of heat from the lowest layers of air to the ground produce nearly saturated conditions close to the surface.

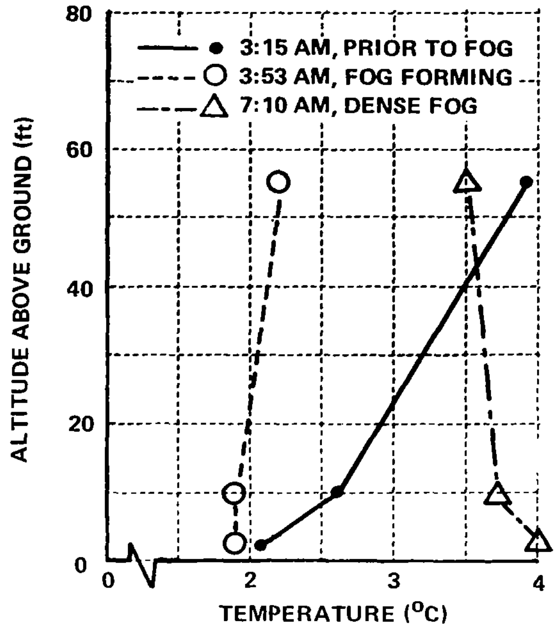


Figure 2 TEMPERATURE PROFILES THROUGH 55 FT PRIOR TO, DURING AND AFTER FOG FORMATION, 22 SEPT. '69

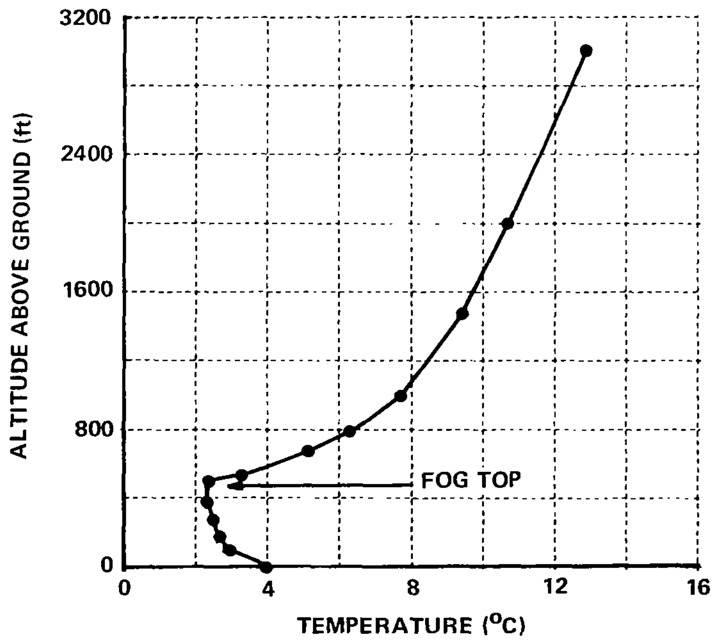


Figure 3 TEMPERATURE PROFILE THROUGH 3000 FT, 22 SEPT. '69, 7:10 AM

In the formation of valley fog, initial mixing usually occurs near the base of the hills and fog forms there. As drainage continues, the mixing process persists and the depth of the fog increases. Near the fog base, the drops are large and the liquid water content is highest, but the concentration of droplets is depleted because of sedimentation and fallout.

Near the fog top continued radiational cooling of the air results in slight supersaturations and additional fog formation. The continuous formation of new droplets with negligible terminal velocities accounts for the observed higher concentration of small drops near the fog top.

Observations of wind prior to and during fog formation suggest that mixing is indeed a principal factor in the formation and persistence of valley fog. After fog formation, the thermal stratification in the lower portions of the fog often becomes unstable. Under these conditions, appreciable turbulence may be present. For instance, after fog formation on 22 September 1969, the average standard deviation of the wind direction fluctuation measured at the 55 foot level was $\sigma_o \approx 9^o$ or .16 radians, based on ten-minute samples during stationary periods of the record between 5 and 8 a.m. Computer modeling studies have shown that turbulence of this intensity is very effective in causing the reformation of fog in a seeded region through mixing. This, of course, implies that careful planning and execution are necessary when attempting to modify fog that has fairly intense turbulent diffusion.

B. Fog Seeding Experiments

Fog seeding experiments were performed during the fall of 1969 to test the consequences of seeding natural valley fog with various specially sized and commercial grades of hygroscopic materials. Previous seeding trials during the late summer of 1968 demonstrated that visibility in natural fog could be significantly increased by seeding with NaCl nuclei of controlled sizes (NASA SP-212). The current tests were designed to test the effectiveness of disodium phosphate (Na_2HPO_4) and urea (NH_2CONH_2) in addition to the NaCl. A separate experiment was performed using cationic and anionic polyelectrolytes as seeding agents.

Seeding was accomplished using three twin engine Beech Baron aircraft that were specially equipped to disseminate dry seeding materials into fog. Each aircraft had a capacity of between 700 and 1000 lbs of seeding agent, depending on the density of the material. Commonly, the seeding procedure was to fly in formation so that the separation between aircraft was about 150 feet. Because of the configuration of the valley, seeding was usually done parallel to the wind and in a race track pattern. Our plan was to seed the fog a prescribed distance upwind of the airport and allow the seeded area to drift over the ground instrumentation. Dissemination rates varied; however, the usual procedure was to disseminate approximately 200 lbs of seeding material per mile. Assuming a plume width of approximately 50 meters and a length of 1.6 km this amounts to an area coverage of about one gram per square meter.

For a two-week period a CH-46 helicopter was also made available for the experiments. Here, the helicopter was flown over the seeded region in order to hasten the mixing of seeding material into the fog. A secondary objective was to rely on the mixing of dryer air from aloft with the fog beneath to aid in the dissipation process.

A total of 12 fully-implemented experiments were performed. Of these, five were conducted using commercial grade materials. These materials were tested to determine if visibility could be significantly improved in fog without requiring that the seeding agent be extremely carefully sized. From the analysis of data, the following points can be made relative to the 12 seeding experiments conducted this year:

(1) Three seedings resulted in visibility improvements in excess of one half mile. The materials used in these experiments were 15μ-40μ urea, 10μ-80μ urea and commercially available NaCl (Morton 200). The experiments were performed during the latter stages of the life cycle of the fog. In each case natural dissipation occurred between one and two hours after seeding.

(2) Four other experiments produced significant clearing; however, natural fog dissipation occurred in other parts of the valley within 30 minutes of seeding. These experiments, therefore, were not conclusive.

(3) Three seeding experiments produced negligible improvements in visibility. In each of these cases the fog did not dissipate naturally for several hours after seeding. The hygroscopic materials used in these experiments were sized NaCl, sized Na_2HPO_4, and unsized NaCl.

(4) Two helicopter experiments were performed. On one occasion in which the helicopter was used in conjunction with a sized Na_2HPO_4 seeding, no effects were observed. In the other experiment in which only the helicopter was used, significant clearing was achieved. However, the fog was patchy in character.

(5) In the single experiment in which polyelectrolytes were used, no improvement in visibility was noted after seeding. As in (3) above, natural fog dissipation did not occur until several hours after seeding.

(6) Analysis of wind records prior to and after fog formation indicate that there is frequent and substantial turbulence in valley fogs at the time of seeding. The result of this turbulence is to effectively dilute the seeded region with unmodified fog which in turn degrades the effects of seeding.

Discussion

Specific cases which highlight some of these conclusions are discussed below.

The first case was chosen to illustrate changes in the microphysical features of the fog that occur after seeding. In this example (27 August 1969) seeding was accomplished with 1000 lbs of 10-80μ urea; the measured fog depth was approximately 100 meters and the horizontal visibility at the time of seeding was 300 meters. The three aircraft completed seeding in approximately seven minutes and traversed an area of about 5×10^2 by 1.8×10^3 meters.

Figure 4 shows a comparison of drop size distributions about one minute prior to seeding; approximately 15 minutes after the start of seeding when visibility was at a maximum; and approximately 40 minutes after seeding was complete and visibility had again degraded to near its original value.

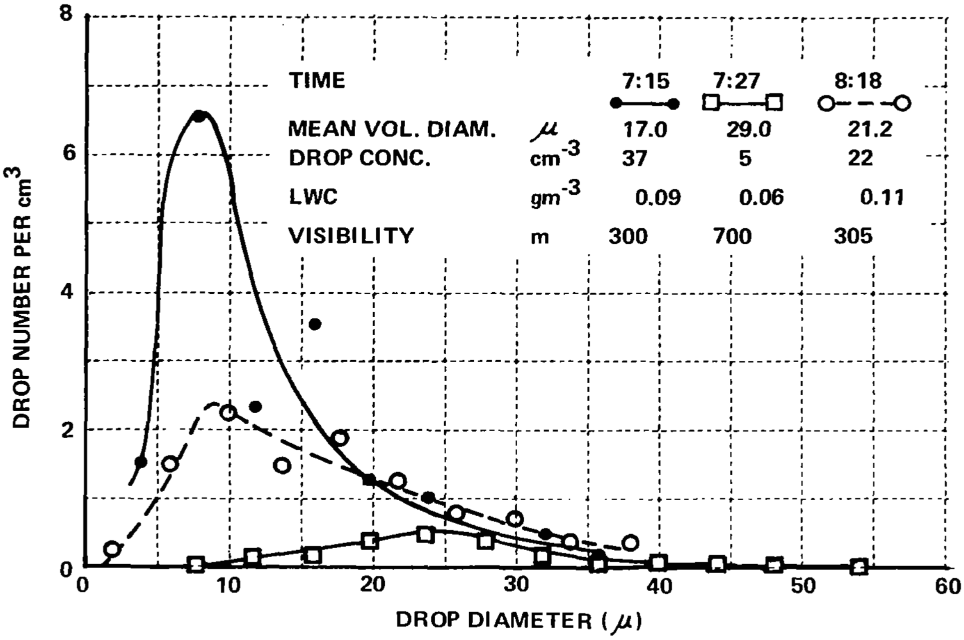


Figure 4 COMPARISON OF DROP SIZE DISTRIBUTIONS IN NATURAL AND SEEDED FOG - 27 AUG. '69

The shape of the distribution graphically illustrates the changes that occurred. Note, for example, that the mean volume diameter of the droplets increased from about 17μ prior to seeding to about 29μ in the seeded region and that the drop concentration decreased after seeding from 37 drops/cm^3 to 5 drops/cm^3. Accompanying the change in drop distribution was a decrease in liquid water content due to sedimentation and fallout of some of the solution drops formed on seeding nuclei. Visibility improved in the seeded region from 300 m to 700 m at this time. Later, after the seeded region moved away from our instrumentation and the airport, the visibility again degraded and the characteristics of the fog became more like that observed prior to seeding.

The second and third cases illustrate the effects of seeding a single fog at different times during its life cycle. In the first of the two experiments performed on September 23, 1969, seeding was accomplished with 2600 lbs of carefully sized 15-40μ diameter NaCl. The usual seeding plan of flying parallel to the prevailing wind and over the main runway was employed. At the time of this seeding, fog depth was approximately 150 meters and visibility was slightly less than 100 meters. Seeding was accomplished at about 7:00 a.m. LST, during a period when the fog was persistent and still building vertically. Wind speed and direction was 270° at 3 knots. The rather regular and smooth features of the fog top are shown in Figure 5 (this photo was taken a few moments before seeding began).

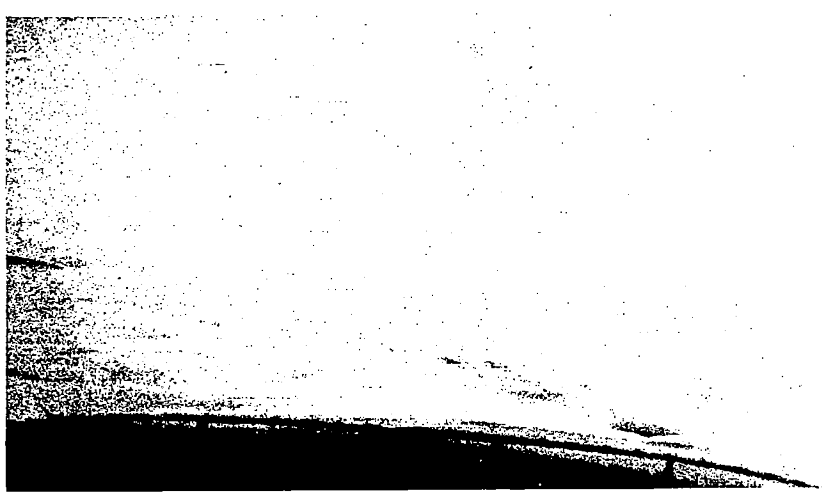


Figure 5 FOG TOP SHORTLY BEFORE SEEDING

In this experiment very little change in surface visibility was noted after seeding, even though the most carefully sized hygroscopic material was used. The series of photos taken from approximately 10,000 ft during this experiment show the results (Figure 6).

In the first and second photos, the three aircraft can be seen disseminating the hygroscopic particles into the fog. By the completion of the third pass, what appears to be an opening in the fog can be detected. The third photo shows that the slight clearing does not increase in size, but instead appears to be slowly disappearing. It is obvious, however, that a well-defined trench in the fog was produced from seeding.

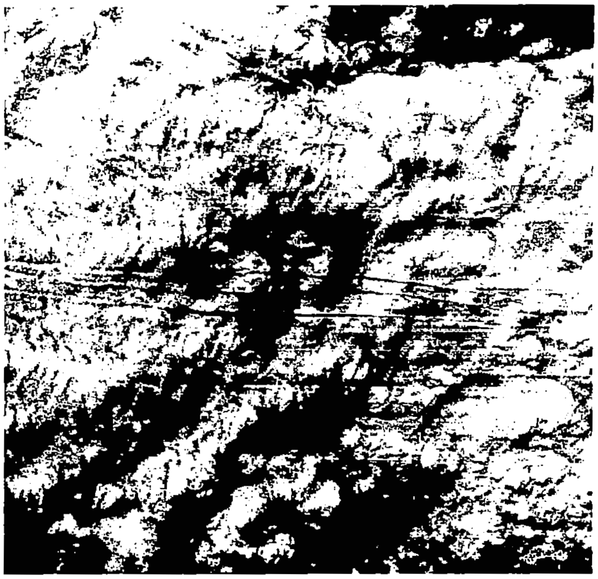
The last photo shows the fog just one minute later. The previously visible trench is now gone, and the fog features look essentially unchanged from those prior to seeding.

Although a heavy drizzle was noted on the ground, surface visibility was found to increase from 110 meters to only 160 meters after seeding. Once the drizzle stopped, visibility again returned to its previous low value.

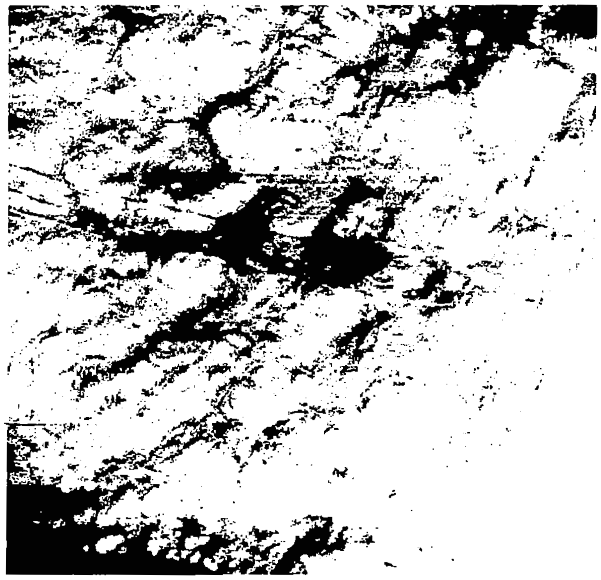
Before discussing the results of this experiment, we will consider the next case, which was performed on the same day approximately one and a half hours later.

Several seeding passes from this experiment are shown in the photo sequence displayed in Figure 7. The fog at the time of seeding had a horizontal visibility of 140 meters and a vertical depth of about 150 meters. It is easily seen that the fog top is ragged and consists of many individual cells at the time seeding started. At the surface, observers noted that the fog appeared to be uniformly dense.

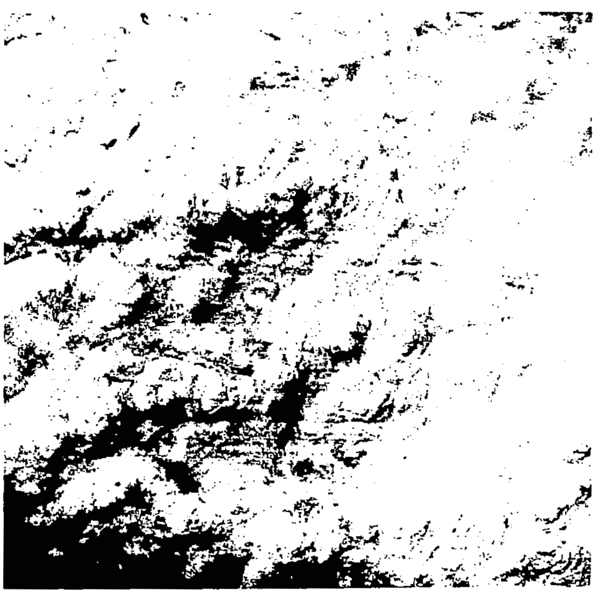
Five seeding passes were made with each aircraft. In this experiment 2100 lbs of Morton 200 NaCl was used. Shortly after seeding was completed, observers in the aircraft were able to detect the airport grounds through small openings in the fog. In the next-to-last photo, taken about ten minutes after the completion of seeding, many surface features are visible through the fog. It is obvious from this photo and the next that clearing is becoming widespread.



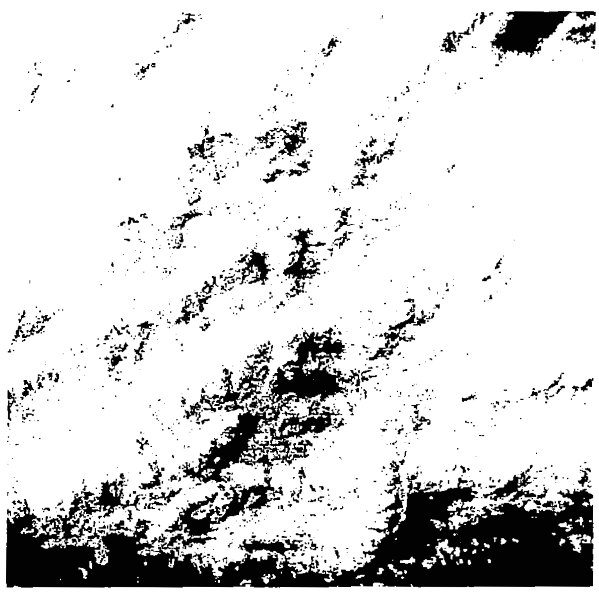
FIRST SEEDING PASS (NOTE TRAILING SALT PLUMES FROM THREE AIRCRAFT)



THIRD SEEDING PASS

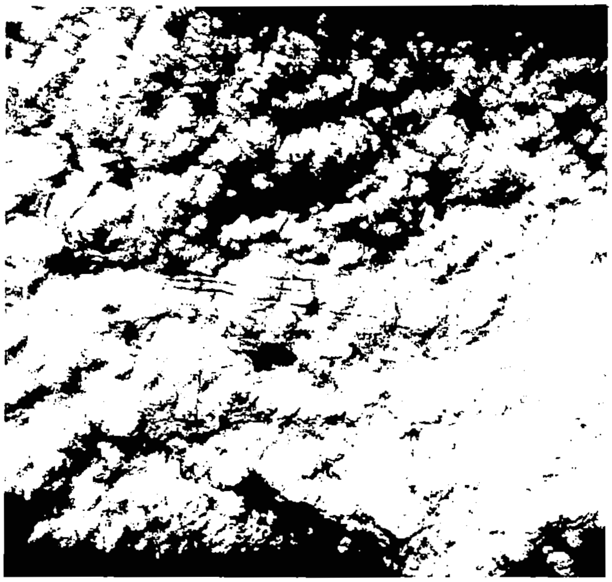


TRENCH IN FOG 10 MINUTES AFTER START OF SEEDING

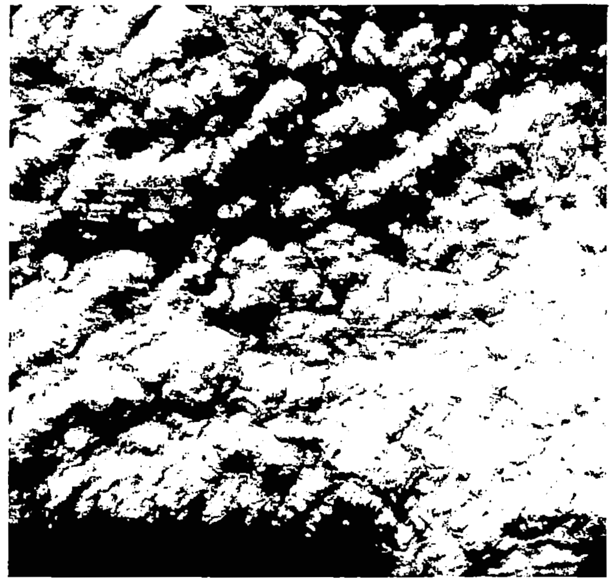


RAPID RETURN OF FOG TO PRE-SEEDED CONDITIONS

Figure 6 PHOTOGRAPHS TAKEN FROM 10,000 FEET WHICH SHOW THE EFFECTS OF SEEDING A PERSISTENT FOG WITH SIZED NaCl



FIRST SEEDING PASS



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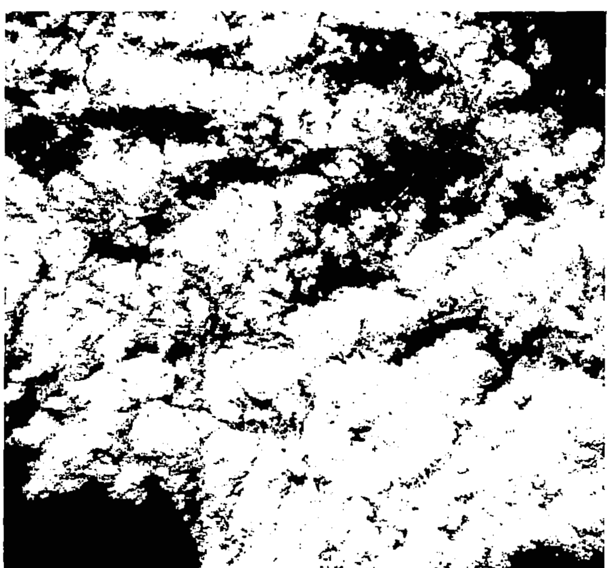
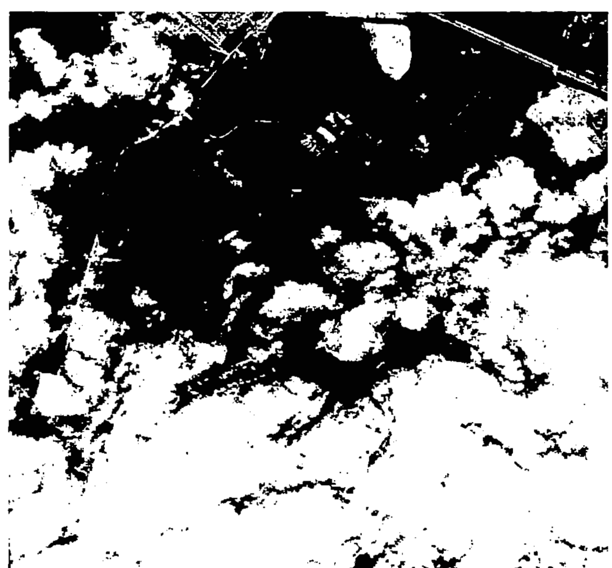


FOG TOP 10 MINUTES AFTER SEEDING



FOG TOP 20 MINUTES AFTER SEEDING

Figure 7 PHOTOGRAPHS TAKEN FROM 10,000 FEET WHICH SHOW THE EFFECTS OF SEEDING A SLOWLY DISSIPATING FOG WITH SIZED NaCl

Although the cleared area (particularly in the photograph taken 20 minutes after seeding) is considerably larger than the actual seeded volume, we believe that seeding in this case greatly enhanced the fog dissipation process. Observations and measurements of fog density upwind of the seeded area (but still on the airport grounds) showed that visibility remained below landing minimums for about 20 additional minutes and for a considerably longer period of time further up the valley.

There is little doubt that the initial breaks in the fog resulted directly from the changes in the microphysical characteristics of the fog after seeding. We believe that the growth of these open regions and the ultimate clearing of the valley in the vicinity of the airport was enhanced by radiation from the sun that entered the artificially cleared region and promoted "natural" fog dissipation.

It was considered instructive to model the conditions that existed prior to the first seeding in order to determine if the result that occurred could have been predicted. By using the observed fog characteristics and actual seeding rates, a useful test of the computer model would be provided.

The model fog was chosen to be 150 meters deep with a horizontal visibility equal to that observed in the actual fog, i.e., 100 meters. Seeding occurred at the fog top at a rate of 450 lbs per nautical mile. This rate of material dissemination was very nearly that achieved in the actual seeding experiment. From the thermal stratification observed in this fog, near neutral stability conditions were assumed and thought to be appropriate as an indication of the level of turbulence to be expected.

In Figure 8 the computed curves of visibility at the fog top are compared with computed surface visibility. The vertical visibility is also shown in the figure.

The data as displayed bear a remarkable resemblance to the visibilities that were actually observed at the surface. At the fog top where the prominent trench in the fog was noted and photographed after seeding (see photo No. 3 in Figure 6), the computed visibility was over 2000 meters.

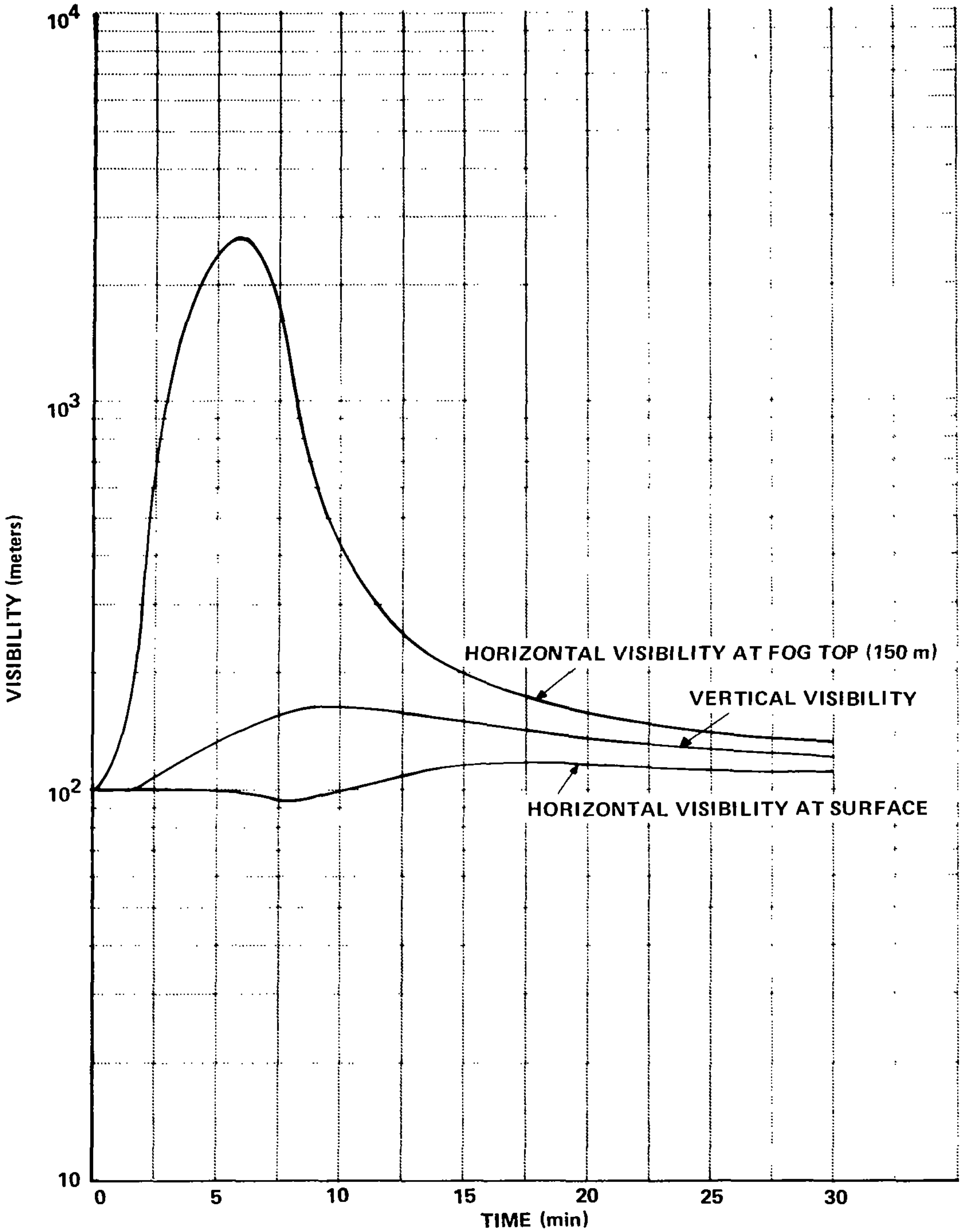


Figure 8 COMPUTED CURVES OF VISIBILITY VS TIME FOR AERIAL SEEDING WITH 450 LBS OF 15-40μ DIAMETER NaCl PER N.MI. UNDER NEAR-NEUTRAL STABILITY AND A FOUR KNOT WIND

The maximum computed vertical visibility was found to be a mere 160 meters, just barely enough to see through the fog if one were to look straight down from an aircraft.

From our analysis of the wind data and from the model predictions of the visibility conditions that prevailed after seeding, we are led to suspect that turbulent mixing was the principle factor responsible for the lack of significant visibility improvement at the ground in this experiment. After seeding, mixing rapidly diluted the seeded region with unmodified fog resulting in a treated volume that was essentially underseeded. It would be predicted, therefore, that during the persistent stages of the fog, turbulent mixing can largely modify and in some cases negate the effects of seeding with hygroscopic materials.

Later, when the second seeding occurred, the effects of mixing were not found to be detrimental. Apparently, in this experiment the scale and intensity of turbulence was considerably different (as indicated by the cellular structure of the fog top) from conditions that existed earlier in the day. Furthermore, the fog was no longer in the persistent and building stage and was obviously more susceptible to heating from the sun. Under these conditions, seeding was much more effective.

A final experiment to be discussed involved a polyelectrolyte seeding of dense fog. In this experiment (October 1, 1969) two seeding aircraft were employed. Both cationic (Calgon 823 C) and anionic (Calgon 823 A) materials were used. The horizontal visibility that existed in the fog prior to seeding was approximately 100 meters and the vertical depth was about 150 meters. Winds were approximately 6 knots from the west. The experimental plan was to seed the fog with 200 lbs of each chemical at a rate of about 35 lbs per nautical mile. From previous discussion with individuals familiar with polyelectrolyte seeding programs, we felt that this rate of material dissemination would be a reasonable approximation of the usual polyelectrolyte seeding rate.

Eleven seeding passes were completed during a 45-minute interval from 7:35 a.m. until about 8:10 a.m. The first jelly-like precipitation of material was observed at the surface about twenty minutes after the start of seeding. Fog visibility and liquid water content, however, remained very nearly the same as their previous values (i.e., 110 meters and 150 mg/m^3). At various times throughout the experiment, polyelectrolytic material was observed at the surface by observers, although fog visibility remained essentially unchanged. The maximum change in visibility that was noted after seeding was an increase from 100 meters to a final value of 130 meters. Unfortunately, in this experiment there were no usable slide data from which to generate drop-size distributions; all slides were overexposed. Transmissometers located on the airport grounds showed no improvement in visibility and aerial photographs showed no significant changes.

We have concluded from this experiment that there was no significant change in visibility that was due to seeding with polyelectrolytes. As previously noted, modification of fog during the persistent and building stages is extremely difficult, and hence, this single test cannot be considered conclusive.

It is important to state, however, that these results are in complete agreement with our previous laboratory experiments which have shown that polyelectrolytes in no way improve the visibility of laboratory fog.

C. Conclusions

These experiments have demonstrated that visibility in dense valley fog can be significantly improved by seeding with hygroscopic materials but that seeding must be tailored to the type of fog being considered. It appears that seeding can most efficiently be applied during the latter stages of the life cycle of a fog. That is, fogs can frequently be caused to dissipate more rapidly during the last hour or two prior to natural dissipation. The principal problem, of course, is one of properly evaluating the results under these circumstances.

To achieve significant modification of dense fogs in the earlier stages of their life cycle appears to require considerably more seeding material than was employed in these experiments. If, for example, the level of turbulence is excessive or if the liquid water content is particularly high or if the fog is accompanied by winds greater than 10 knots, it may be impractical to attempt seeding.

Sized materials were most effective in causing fog dissipation but considerable leeway in sizing was found to be tolerable. Because of the natural variability in the characteristics of these fogs it is not prudent to draw firm conclusions about the relative efficiencies of the three hygroscopic chemicals tested.

III. COMPUTER MODELING

During the past year, the computer modeling effort was expanded to further delineate the potentialities and limitations of warm fog modification by seeding with hygroscopic materials. The basic model employed in these investigations and its extension to include the effects of horizontal turbulent transfer have been described in some detail in an earlier report (Kocmond and Eadie, 1969). The primary accomplishment of this year's modeling effort has been the incorporation of the effects of vertical turbulent transfer into the model to provide a more realistic framework for assessing the influences of atmospheric turbulence on warm fog modification.

Wind measurements obtained in conjunction with fog modification experiments by CAL (see Section II) and by other organizations (Silverman and Smith, 1970) have established the existence of frequent and substantial turbulence in fog. Previous modeling investigations at CAL (Kocmond and Eadie, 1969) and elsewhere (Silverman, 1970; Silverman and Smith, 1970) have shown that even moderate turbulence may impose important constraints on fog dispersal operations. This report describes a further investigation of these constraints through the modeling of the effects of both horizontal and vertical turbulent transfer upon the modification produced by aerial seeding with hygroscopic materials.

A. Modeling of the Effects of Turbulent Diffusion

Atmospheric turbulence can influence the success of warm fog seeding in two ways: (a) by dispersing the seeding material and the solution droplets which form upon the particles of seeding material, and (b) by reducing gradients in fog properties produced by seeding. In order to simulate these effects, a Fickian diffusion modeling framework with a time and space independent diffusion coefficient was adopted. While this is a rather crude approximation to the processes of turbulent transfer in the atmosphere (see Sutton, 1953), it is commensurate with the present state of knowledge concerning turbulence in fogs and should suffice to provide first order estimates of the effects of turbulence on seeding effectiveness.

The simulation of influences of horizontal diffusion in the model is based on the widely used Gaussian model of turbulent diffusion. It is assumed that an aircraft disseminates an instantaneous line of seeding material on the top of a fog. It is further assumed that the lateral distribution of seeding material, or more properly the solution droplets which form upon the particles of seeding material, is Gaussian with a standard deviation $\sigma_y(t)$ which expands with time under the influence of turbulent diffusion according to the law

$$\sigma_y(t) = \sqrt{\sigma^2_{yo} + 2Dt} \quad , \tag{1}$$

where σ_{yo} is an assumed initial lateral standard deviation of the distribution of hygroscopic seeding material and D is the Fickian diffusion coefficient. It should be noted that Eq. (1) brings the exponent of the Gaussian distribution,

$$-\frac{1}{2}\left(\frac{Y}{\sigma_y(t)}\right)^2 = -\left(\frac{Y^2}{2\sigma^2_{yo} + 4Dt}\right) \quad , \tag{2}$$

into the proper form for Fickian diffusion (Sutton, 1953).

In order to minimize computational requirements, the computer model is again restricted to computing the fog modification at the centerline of the modified region where the modification is at a maximum. On the centerline of the Gaussian distribution, it can be shown (Kocmond and Eadie, 1969) that the concentration C_i of class i of solution drops varies with time according to the relation

$$\frac{dC_i}{dt} = -C_i \frac{d\,ln[\sigma_y(t)]}{dt} \tag{3}$$

where now

$$\frac{d\,ln[\sigma_y(t)]}{dt} = \frac{D}{\sigma^2_{yo} + 2Dt} \tag{4}$$

With the exception of the above modification of $\sigma_y(t)$ into a form appropriate for Fickian diffusion, the theoretical framework employed in modeling the influences of horizontal turbulent diffusion is identical to that described in detail in an earlier report (Kocmond and Eadie, 1969).

Similarly, the detailed simulation of the cloud physics processes in the model remains identical to that previously reported, with the exception of the description of vertical transfer. In order to model the effects of the sedimentation and vertical diffusion, and provide an accurate description of the vertical variation of visibility and other fog properties, the effects of seeding are computed at several equally spaced vertical levels in a model fog. In the earlier CAL model, the effects of sedimentation and fallout of solution drops were modeled by computing the height of each class of solution drops as a function of time and employing an interpolation scheme between vertical levels of the model to describe the condensational growth process. Sedimentation of the fog drops was neglected.

In the present model, vertical transfer is simulated through a set of partial differential equations describing the sedimentation and diffusion of the solution drops, and the diffusion of the fog drops and supersaturation (water vapor). Adding the contributions from the modeling of the cloud physics processes and horizontal turbulent diffusion, the differential equations of the model assume the following form:

$$\frac{\partial M_i}{\partial t} = \frac{\partial (W_i M_i)}{\partial z} + D \frac{\partial^2 M_i}{\partial z^2} + \left.\frac{\partial M_i}{\partial t}\right)_{HD} + C_i 4\pi r_i^2 \left.\frac{d r_i}{d t}\right)_G \quad (5)$$

$$\frac{\partial C_i}{\partial t} = \frac{\partial (W_i C_i)}{\partial z} + D \frac{\partial^2 C_i}{\partial z^2} + \left.\frac{\partial C_i}{\partial t}\right)_{HD} \quad (6)$$

$$\frac{\partial S_j}{\partial t} = D \frac{\partial^2 S_j}{\partial z^2} + \left.\frac{\partial S_j}{\partial t}\right)_{HD} + \left.\frac{\partial S_j}{\partial t}\right)_G \quad (7)$$

$$\frac{\partial r_k^3}{\partial t} = D \frac{\partial^2 r_k^3}{\partial z^2} + 3 r_k^2 \left[\left.\frac{\partial r_k}{\partial t}\right)_{HD} + \left.\frac{\partial r_k}{\partial t}\right)_G \right] \quad (8)$$

Here, C_i is the concentration, r_i is the radius, W_i is the terminal velocity, and $M_i = C_i \frac{4\pi}{3} r_i^3$ is the liquid water corresponding to class i of solution drops; S_j is the supersaturation at vertical level j, r_k is the radius of class k of fog drops and D is the diffusion coefficient. The subscripts HD and G denote the contributions from horizontal turbulent diffusion and condensational growth or evaporation, respectively.

In the computational procedure, the vertical transfer terms involving derivatives with respect to the vertical coordinate Z are approximated by centered differences on the equally spaced vertical grid levels of the model. The centered difference method was adopted for the sedimentation terms in preference to a more versatile upstream difference method to avoid the well-known pseudo-diffusive properties of the latter method (Molenkamp, 1968). No diffusion is permitted across the upper and lower boundaries of the grid system. Since moisture is conserved in the modeling of cloud physics and horizontal diffusion processes (Kocmond and Eadie, 1969), the fallout of the solution droplets through the lower boundary of the grid system is the only way that moisture can leave the system.

As in the previous model, a system of coupled differential equations of the type represented by equations (5) through (8) is integrated numerically by means of a variable-time step, fourth-order, predictor-corrector routine to establish the temporal evolution of supersaturation, size distributions of fog and solution drops, and related fog properties such as the visibility and liquid water content.

B. Results

The computer model as described above was employed to investigate the influences of turbulent diffusion upon the effectiveness of aerial fog seeding. It is assumed that a fixed wing aircraft lays down a single instantaneous line of hygroscopic seeding material at the top of a warm fog. The fog modification produced by seeding is computed at the centerline of the modified region.

In each of the following examples, the seeding material is 20 micron diameter NaCl particles. It is assumed that the initial lateral spread of the salt plume as a result of circulations produced by the seeding aircraft is $\sigma_{y0} = 10\,m$, corresponding to a total spread of 1 1/2 to 2 times the wing span of a small twin-engine seeding aircraft. It is further assumed that the seeding material is initially distributed uniformly through upper 20 m of the fog.

The model fog is assumed to be 100 m in depth, and the effectiveness of seeding is computed at eleven vertical levels spaced 10 m apart. Prior to seeding, the fog is approximated by a monodisperse distribution of 10 micron radius drops having a concentration of 62 drops cm^{-3}. It is assumed that these drops are formed on NaCl nuclei having a mass of 7.7×10^{-13} g. This monodisperse fog drop distribution produced a horizontal and a vertical visibility of 100 m, and a liquid water content of $0.26\ g\ m^{-3}$. The model fog is based on surface measurements in fairly severe fogs at the experimental site near Elmira, New York. For simplicity, it is assumed that these conditions apply throughout the depth of the fog, thereby neglecting any variations in the properties of the natural fog with height. The fog temperature is assumed to be $10^{\circ}C$.

This seeding situation was selected to be fairly representative of a number of aerial seeding experiments at the Elmira, New York field site, without entailing prohibitively large computational requirements. The field experiments, however, were based on multiple pass aerial seeding with a spacing on the order of 50 m between passes. The aerial seeding rates employed in the field experiments were typically on the order of 250 lbs per nautical mile, but ranged as high as 450 lbs per nautical mile on one occasion.

Based upon turbulence measurements in fog, Silverman and Smith (1970) estimated diffusion coefficients in the range 1 to 4 m^2/sec. Since these estimates are compatible (Lumley and Panofsky, 1964; Hanna, 1968) with the near-neutral conditions observed in well-developed valley fogs at the CAL field site, the values $D = 1$ and $4\ m^2/sec$ were employed in the computer model to establish a likely range of turbulence effects.

Figures 9 and 10 show computed changes in vertical visibility as a function of time after aerial seeding of the fog top for $D = 1$ and $4\ m^2/sec$, respectively. The computed vertical visibilities correspond to slant range visibilities through the fog from top to bottom and hence provide an integrated measure of visibility improvement throughout the 100 m depth of the model fog. The rates of lateral expansion of the seeding plumes are indicated by the standard deviations σ_y shown at the tops of Figures 9 and 10.

The visibility improvements produced by the 250 lbs per nautical mile seeding rate employed in the Elmira field tests are particularly disappointing for the $D = 4\ m^2/sec$ case. In the $D = 1\ m^2/sec$ case, on the other hand, the 250 lbs/nautical mile seeding rate produces rather significant clearing. The degradation in general seeding effectiveness produced by the larger value of the diffusion coefficient is obvious.

Not so obvious is the fact that the initial improvement in visibility produced by a given seeding rate is greater for $D = 4\ m^2/sec$ than for $D = 1\ m^2/sec$, even though the maximum visibility improvement is considerably less in the $D = 4\ m^2/sec$ case. This reflects the more rapid vertical transfer of seeding effects in the $D = 4\ m^2/sec$ case.

It is also important to point out that while greater and longer-lasting visibility improvements can be produced by employing higher seeding rates, it is seen from Figures 9 and 10 that the time required for maximum visibility improvement to be reached increases as the seeding rate increases, thereby increasing targeting problems. This results from the greater reductions in relative humidity that are produced by higher seeding rates, and accompanying reduced growth and slower fallout of the solution drops.

In order to test the accuracy of the finite difference approximations for the vertical transfer terms employed in the model, the vertical grid spacing was increased from 10 m to 20 m and the simulation for a 1000 lbs/nautical mile seeding rate and $D = 4\ m^2/sec$ was repeated. In Figure 11, the computed vertical visibilities are compared with those shown in Figure 10. It is seen that there is almost no discernable difference between the results

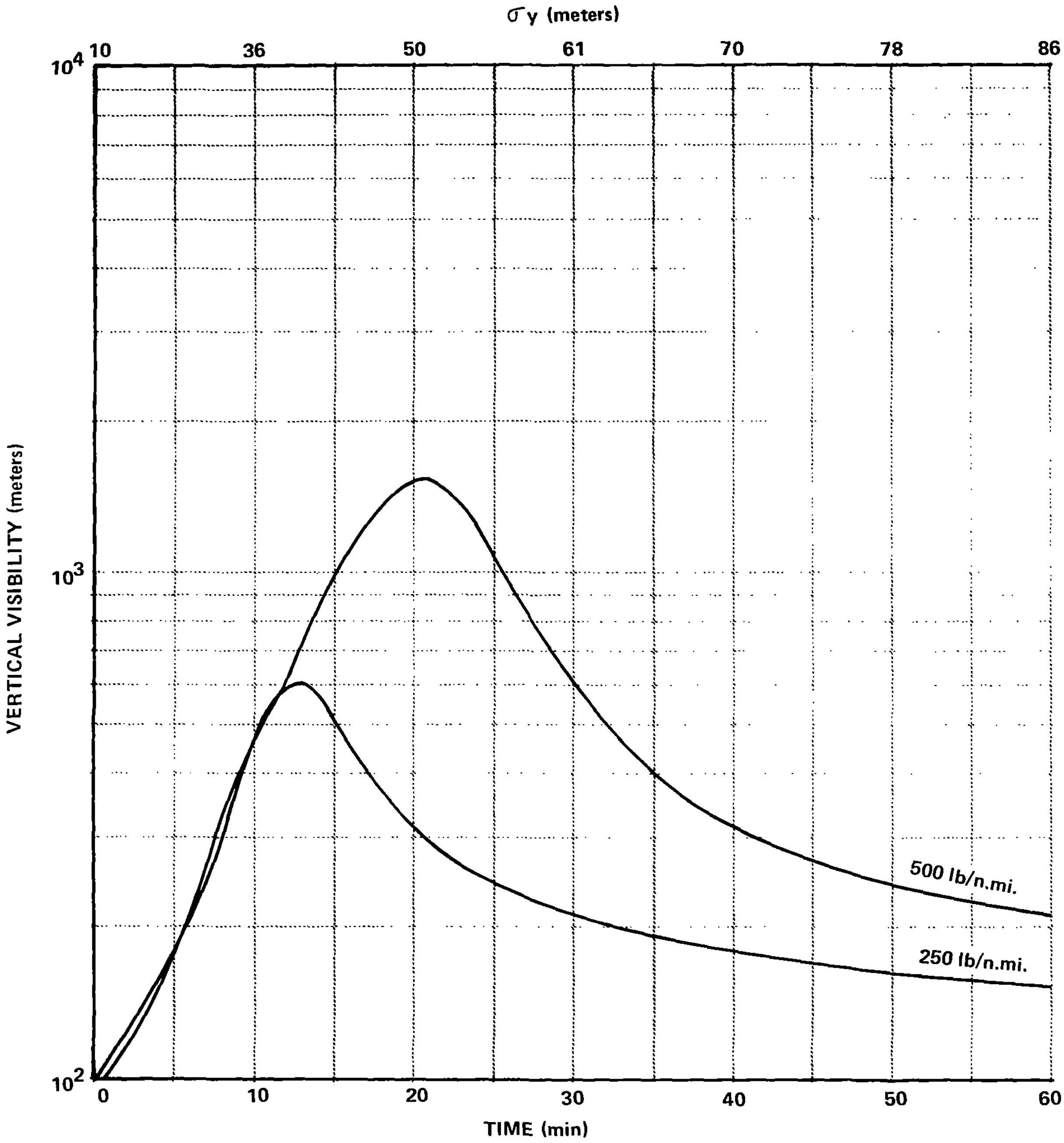


Figure 9 VERTICAL VISIBILITY VS TIME FOR D = 1 M^2/SEC

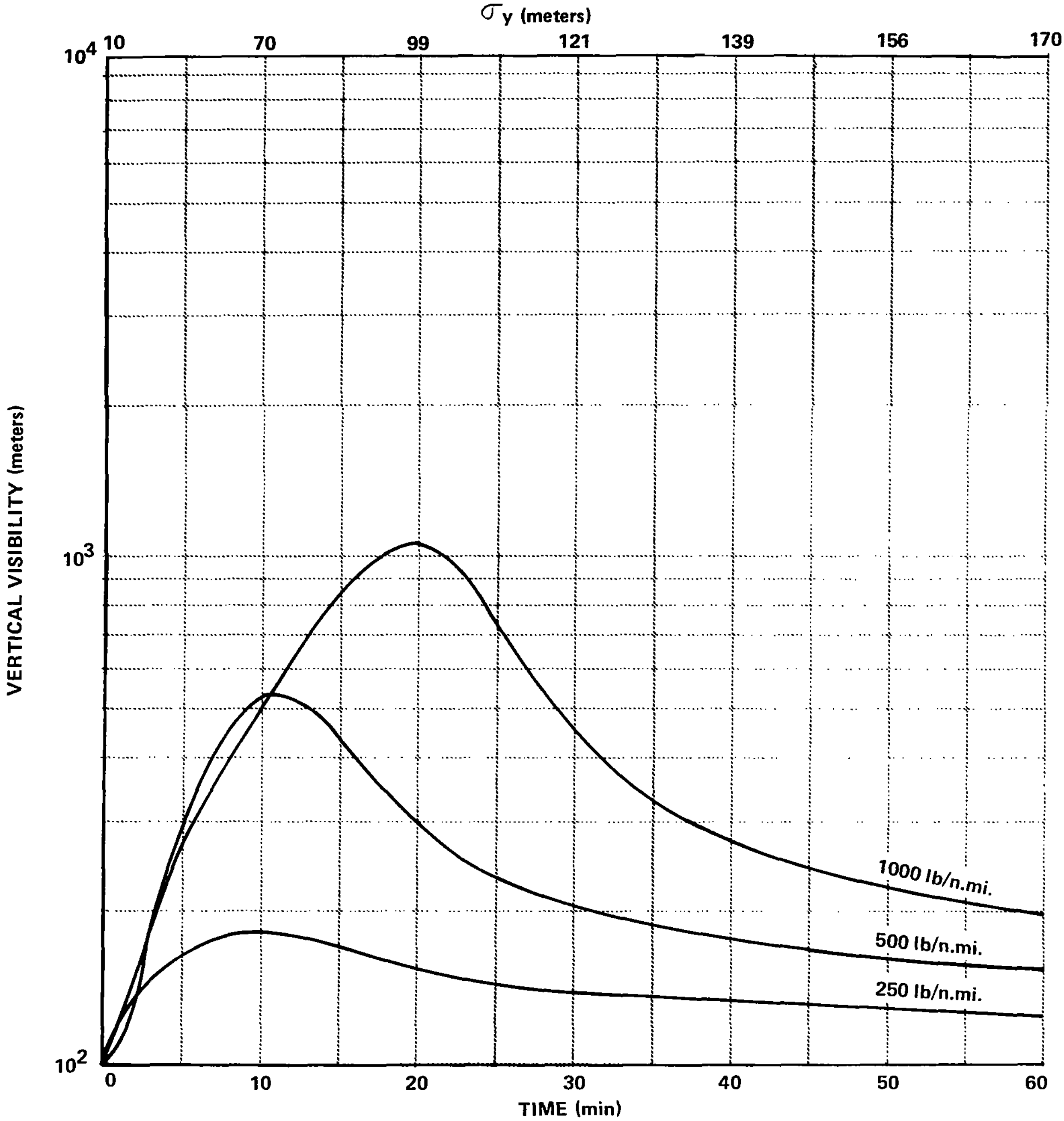


Figure 10 VERTICAL VISIBILITY VS TIME FOR D = 4 M^2/SEC

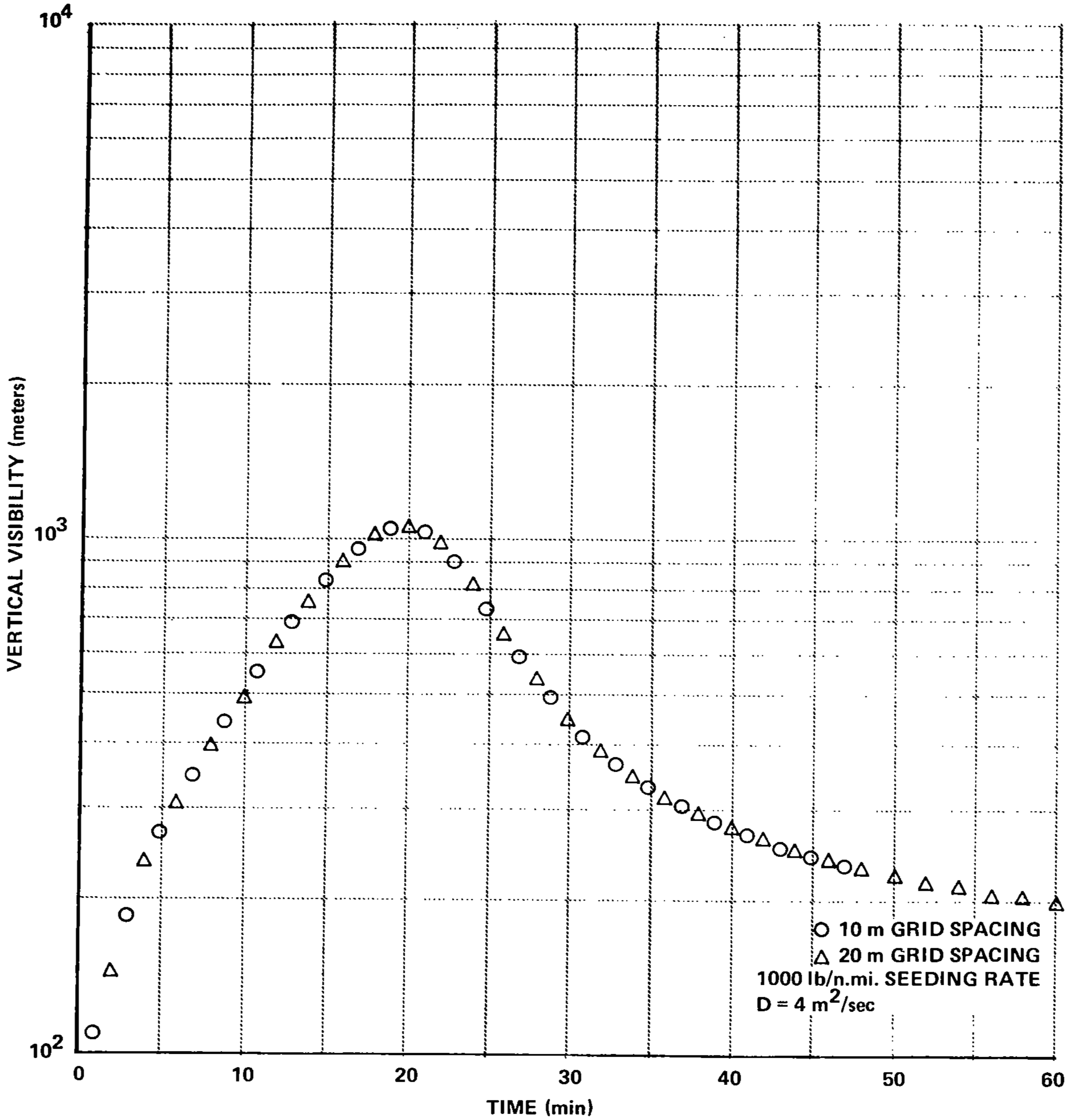


Figure 11 EFFECT OF VERTICAL GRID SPACING ON COMPUTED RESULTS

of the two simulations, indicating that the results which have been computed with a 10 m vertical grid spacing in the model fog are based upon an accurate approximation to the vertical transfer terms in differential equations (5) through (8).

In Figures 12 and 13, the horizontal visibility improvements at the surface are shown for $D = 1$ and $4\ m^2/sec$, respectively. All of the above discussion of vertical visibility curves applies equally well to these results. The greater initial improvements in visibility for the $D = 4\ m^2/sec$ case are even more accentuated in these surface visibilities. Indeed, for the 500 lbs/nautical mile seeding rate, the improvement in horizontal visibility at the surface is greater for the $D = 4\ m^2/sec$ case than for the $D = 1\ m^2/sec$ case for the first 15 minutes after seeding even though the maximum visibility improvement is much less in the $D = 4\ m^2/sec$ case.

Based upon the modeling results shown in Figures 9 to 13, it appears that while multiple pass seeding with a spacing between passes of 50 m is a satisfactory seeding technique in the $D = 1\ m^2/sec$ case, seeding rates on the order of twice those employed in the Elmira tests, or 500 lbs/nautical mile may be required to produce surface visibility improvements in excess of landing minimums (1/2 mile $\approx$ 800 m). In the $D = 4\ m^2/sec$ case, it appears that seeding rates on the order of 1000 lbs/nautical mile with a spacing between multiple passes of approximately 100 m would be a more appropriate technique. In either case, the average density of seeding material of the fog top would be approximately 2.5 grams/m^2.

In the $D = 4\ m^2/sec$ case, it is important to note the great similarity in the vertical visibility and surface visibility curves after a few minutes. This indicates that this level of turbulent diffusion is sufficient to rapidly produce vertical homogeneity in the fog modification throughout the 100 m depth of the fog.

In Figures 14 and 15, curves of the computed liquid water content at the surface are shown for $D = 1$ and $4\ m^2/sec$, respectively. In both cases, the liquid water content at the surface rises above its initial value of 260 mg/m^3 in the model fog before seeding, reaches a peak value four to seven minutes after seeding, falls to a minimum as the solution droplets fall

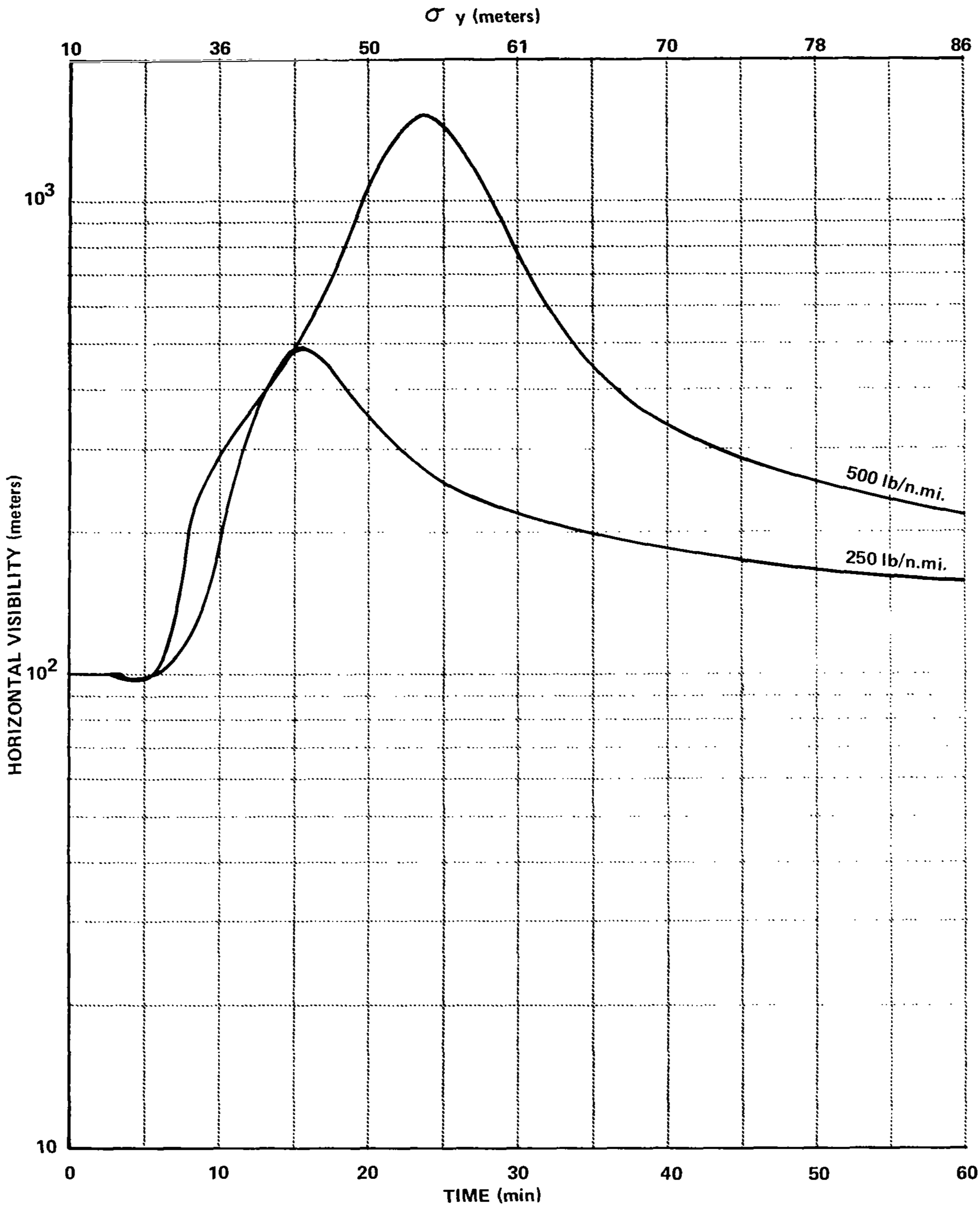


Figure 12 HORIZONTAL VISIBILITY AT THE SURFACE VS TIME FOR D = 1 M^2/SEC

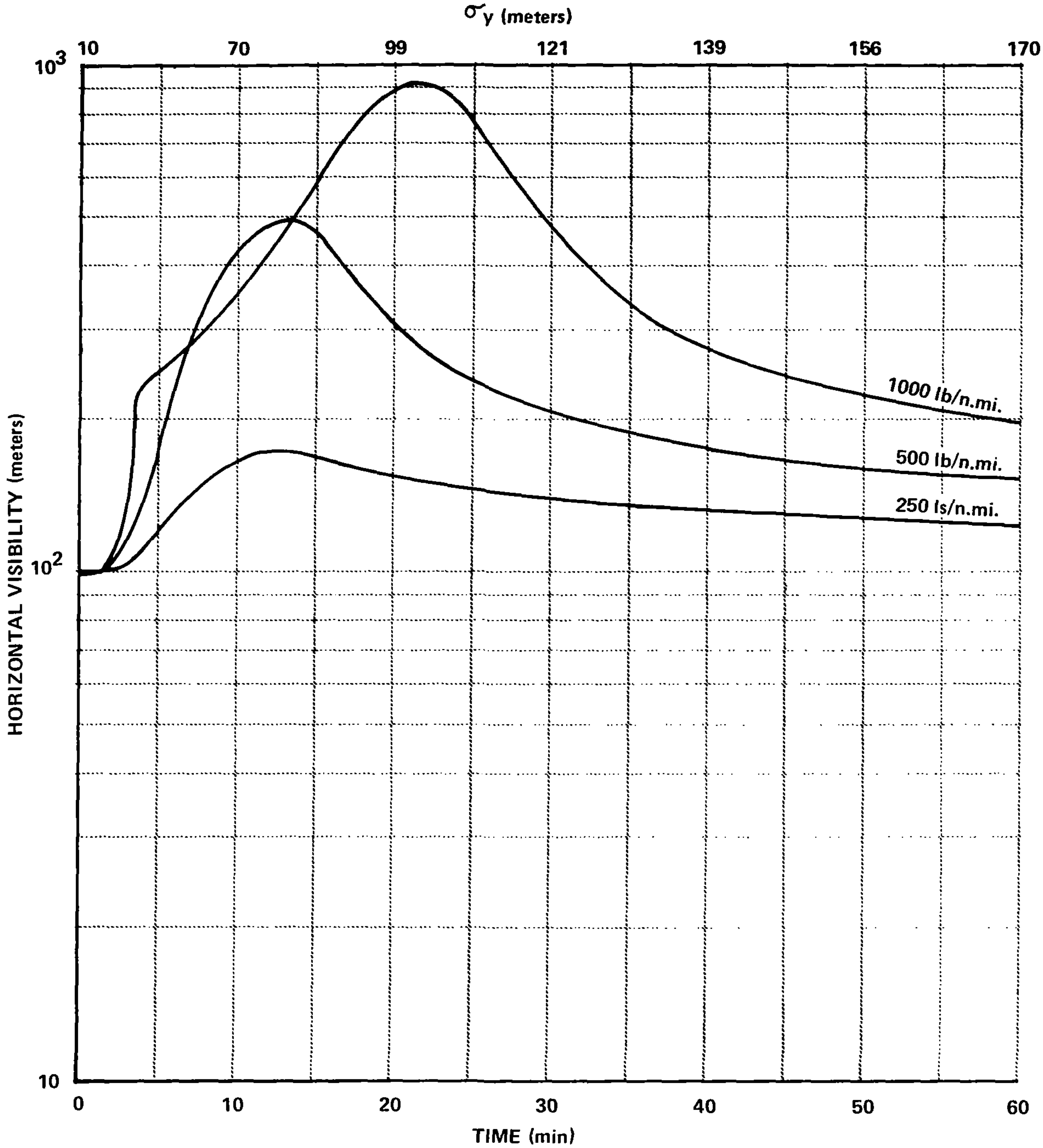


Figure 13 HORIZONTAL VISIBILITY AT THE SURFACE VS TIME FOR D = 4 M^2/SEC

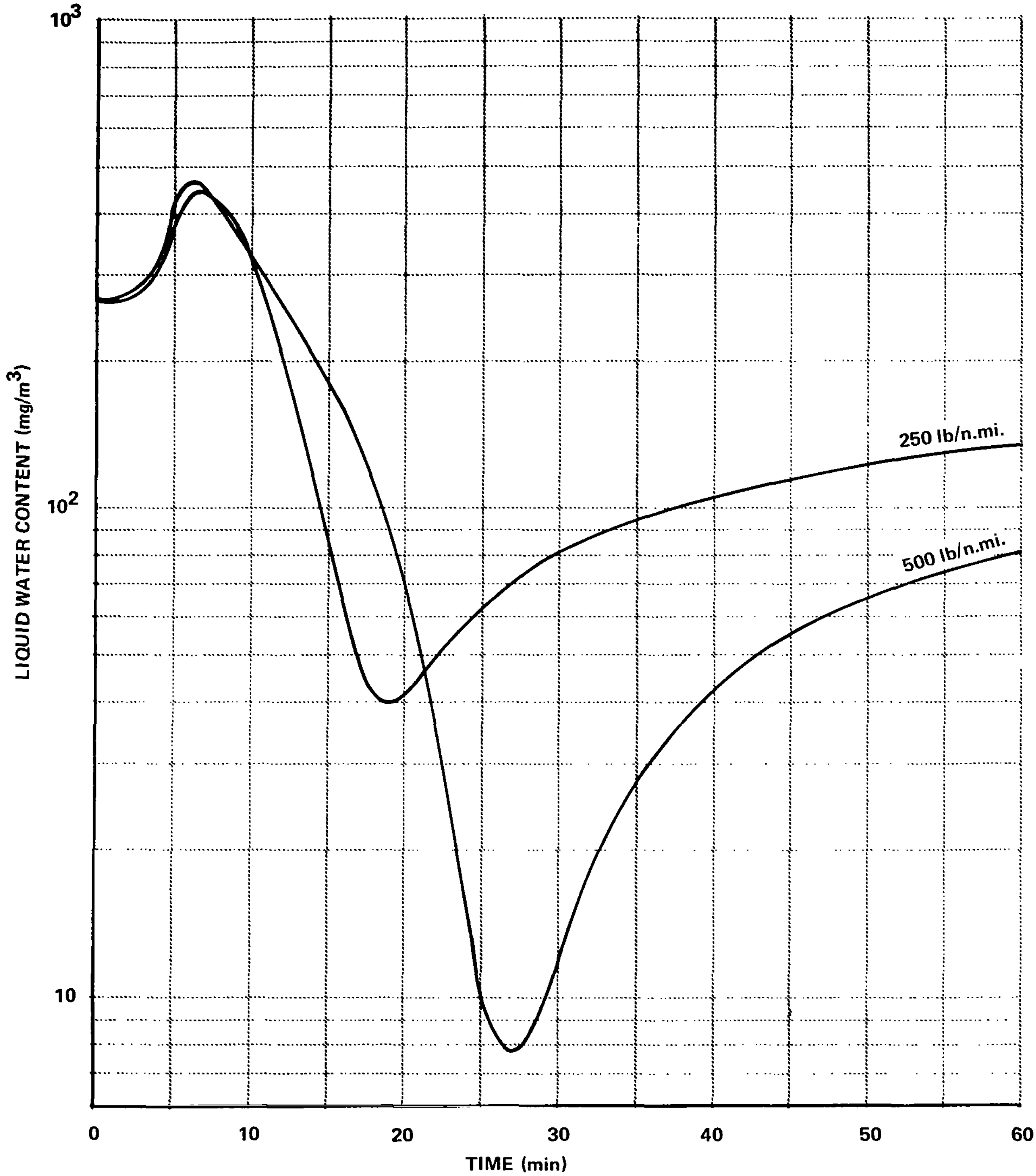


Figure 14 LIQUID WATER CONTENT AT SURFACE VS TIME FOR D = 1 M^2/SEC

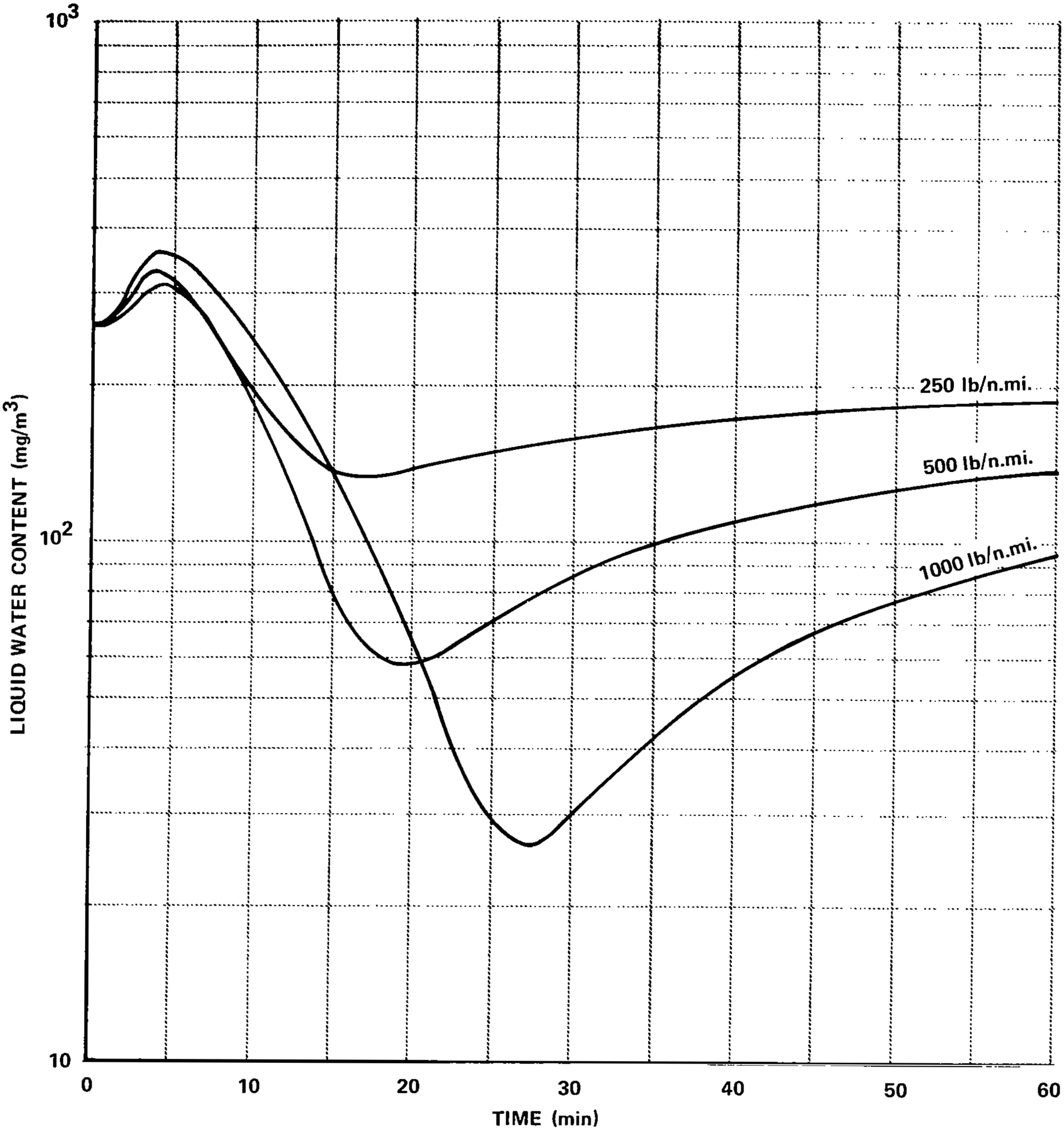


Figure 15 LIQUID WATER CONTENT AT SURFACE VS TIME FOR D = 4 M^2/SEC

out of the fog carrying most of the liquid water, and slowly returns to its initial value as fog reforms in the modified region under the influence of horizontal turbulent diffusion.

The initial peak in liquid water content is produced by the arrival of the major pulse of large solution drops at the surface after having extracted moisture from aloft in falling through the fog. It is interesting to note that the magnitude of this peak is only weakly related to the ensuing visibility improvement, a fact confirmed by the Elmira field tests, where substantial pulses of large solution droplets have been observed in seeding experiments where no significant visibility improvement was measured.

The magnitudes of the minimums in the computed liquid water curves have not been confirmed by the field observations, most likely because the extreme minimum is likely to be restricted to a very narrow zone and the liquid water observations generally represent seven-minute averages. Advection of the modified region beyond the observational network, generally precludes any experimental verification of the predicted rates of return of the surface liquid water content to unmodified values.

The modeling results which have been discussed were computed for a model fog which approximates a severe valley fog. It should be emphasized that the seeding rates required for effective dispersal of less severe fogs can be considerably smaller.

The simulations were also based on a seeding material composed of 20 micron diameter NaCl particles, a particle size which was felt to represent reasonable compromise between speed of clearance and seeding rate requirements for aerial seeding of the valley fogs at the Elmira field site. Other organizations (Silverman, 1970; Silverman and Smith, 1970) have employed NaCl particles in the 40 to 70 micron diameter range in fog seeding experiments, at the expense of seeding rates on the order of 3000 lbs/nautical mile, to promote coalescence and achieve rapid sedimentation.

In cases of light fog, where only a modest increase in visibility (e.g., a factor of two to three) is required to reach landing minimums, it may be possible to effectively employ rather small particles of seeding material, say, 5 microns diameter NaCl, with a great reduction in seeding rate requirements (Jiusto, 1969), provided turbulent mixing causes the seeding material to be distributed throughout the depth of the fog as rapidly as is indicated by our computations for $D = 4\ m^2/sec$. In such a situation, the necessary visibility improvement would be achieved through a favorable shift in the drop-size distribution, without relying on the additional visibility improvement which accompanies the precipitation of liquid water.

C. Conclusions

The computer modeling investigation has demonstrated that turbulent diffusion can impose important constraints on the effectiveness of warm fog dispersal by seeding with sized hygroscopic materials. Taking into account the wide variety of seeding situations encountered and seeding materials employed in the field tests, the visibility improvements predicted using turbulent diffusion coefficients determined from in-fog measurements appear to encompass the general range of seeding results observed in the 1968 and 1969 Elmira seeding experiments. At this stage, it is not clear whether the greater effectiveness of seeding observed in the latter stages of the life cycle of the valley fogs is primarily related to changes in turbulence characteristics or to augmentation of the natural dissipation processes.

The computer simulations suggest that the successful operational modification of warm fogs using hygroscopic materials is likely to require careful planning and execution based upon an assessment of the intensity and scale of turbulence present in a given seeding situation. There is a clear need for more observational data on the spatial and temporal variations in turbulent characteristics and other fog properties in a variety of warm fog situations. It is evident that computer modeling can provide a powerful framework for synthesizing such data and optimizing seeding techniques for many different seeding situations.

With the present CAL computer model, the essential features of warm fog seeding operations in the real atmosphere can be simulated with relatively modest computational cost. It is recommended that a series of numerical experiments should be carried out with this model to establish optimum seeding materials and seeding techniques as a function of some easily determined characteristics of an airport fog situation, such as fog depth, visibility, liquid water content, wind velocity, and wind fluctuations.

IV. EVALUATION OF FOG DISPERSAL OPERATIONS AT SEATTLE, WASHINGTON - FEBRUARY 1970

In recent years increased attention has been given to the use of polyelectrolytes* as effective fog dispersal agents. Detailed data on the physical changes of fog characteristics directly associated with operational polyelectrolyte seeding have never been published, however. At the request of both the FAA and ATA and with the full cooperation of the Seattle-Tacoma Airport authorities and the Aero-Dyne Corporation, which performed the seeding operations, NASA supported this Laboratory for a one-month field investigation of the effect of the operational seeding of fog with polyelectrolytes at Sea-Tac Airport.

The field investigation was performed between 15 February and 15 March, with field crews and equipment in readiness throughout the interval. Only one fog of sufficient duration to permit seeding occurred at the airport during that time. This chapter reports primarily of the results of our evaluation of that operation. All data obtained are presented for independent use by the scientific community.

On three occasions during the field trip, fog was observed at other locations in the Seattle-Tacoma vicinity and additional data were acquired with instrumentation housed in the CAL mobile van. These data are useful for characterizing fog in the region, and together with our observations of condensation nuclei activation spectra are summarized at the end of the chapter.

A. The Observational Network

A schematic representation of the Seattle-Tacoma Airport is presented in Figure 16. The numbered circles on the figure indicate the positions of the four CAL transmissometers and the two official airport transmissometers used in the investigation.

*long chain polymeric materials that contain ionizable groups chemically bonded to the polymer backbone, e.g. proteins

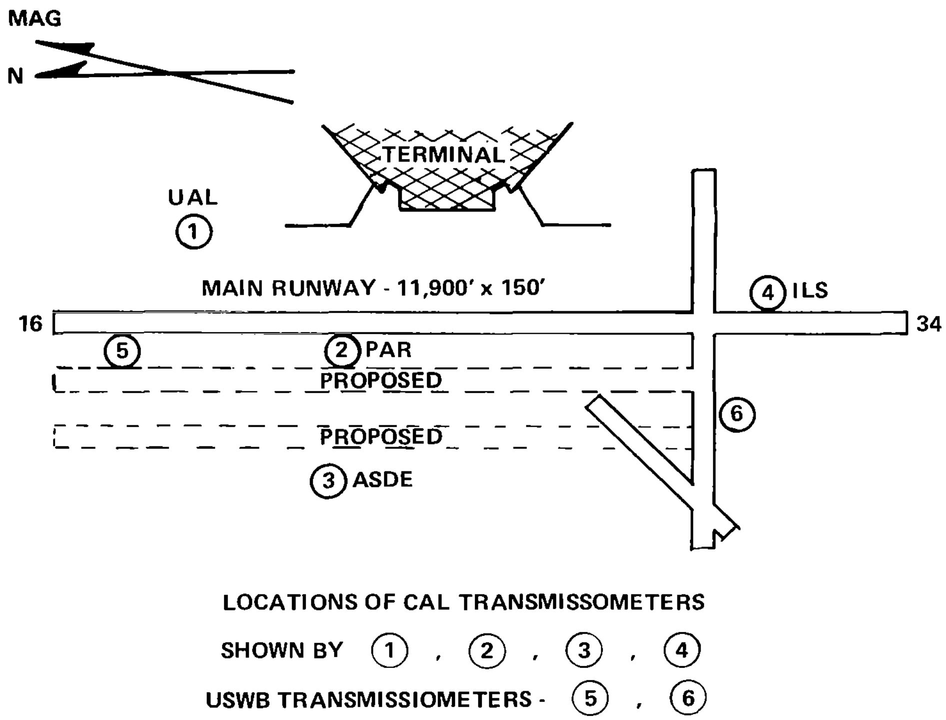


Figure 16 SCHEMATIC REPRESENTATION OF SEATTLE-TACOMA AIRPORT

In addition to the transmissometers, the following equipment was used in the evaluation. With the cooperation of the FAA, we installed three sets of Foxboro recording thermometers and hygrometers on the 100 ft high ASDE radar tower (position 3 in Figure 16). These instruments were located at 6 ft, 26 ft, and 86 ft on the tower. A Beckman-Whitley anemometer and wind vane provided continuous records of surface winds (about 7 ft elevation) from a location 100 ft east of the ASDE tower. Our mobile van, from which condensation nuclei, drop-size distribution, liquid water content and droplet concentration data were acquired, was located at the PAR site (position 2 in Figure 16). Official surface winds were obtained by the USWB from a 20 ft tower also located at that site.

B. Evaluation of the Seeding Operation of 20 February 1970

The fog which occurred on the morning of 20 February 1970 at the Seattle-Tacoma Airport formed and advected over the airport in four distinct patches beginning about 0300 LST. (The first patch, not shown in the data, occurred between 0250 and 0335.) Sea-Tac Airport is situated on a rise about 400 ft above sea level and to the east of Puget Sound and south-southwest of Lake Washington. Although the fog was greater than 500 ft deep and uniformly dense (as observed later) in the vicinity of Puget Sound, fog depth at the airport was estimated at only 150-200 ft. Visibility was extremely variable and rarely less than 1000 ft; the sky was at all times visible from the ground through the fog. Visibility obtained from the two airport transmissometers are shown in Figure 17 and from the four CAL transmissometers in Figure 18. The expression $V = \frac{3.912}{\beta}$ was used for determining visibility from CAL transmissometers, where β is the extinction coefficient.

The patchy nature of the fog is illustrated by the data presented in Figures 17 and 18. Local weather bureau personnel indicate that the trend of fog severity shown by these data, i.e., the heaviest fog at the north end of the airport and less severe conditions at the south end, is a general characteristic of the type of fog that occurs in the region. The fact that some patches of fog observed at the UAL (1) and PAR (2) sites were never observed at the ASDE (3), ILS (4) and Runway 34 (6) transmissometers is significant and must be recognized in data analysis.

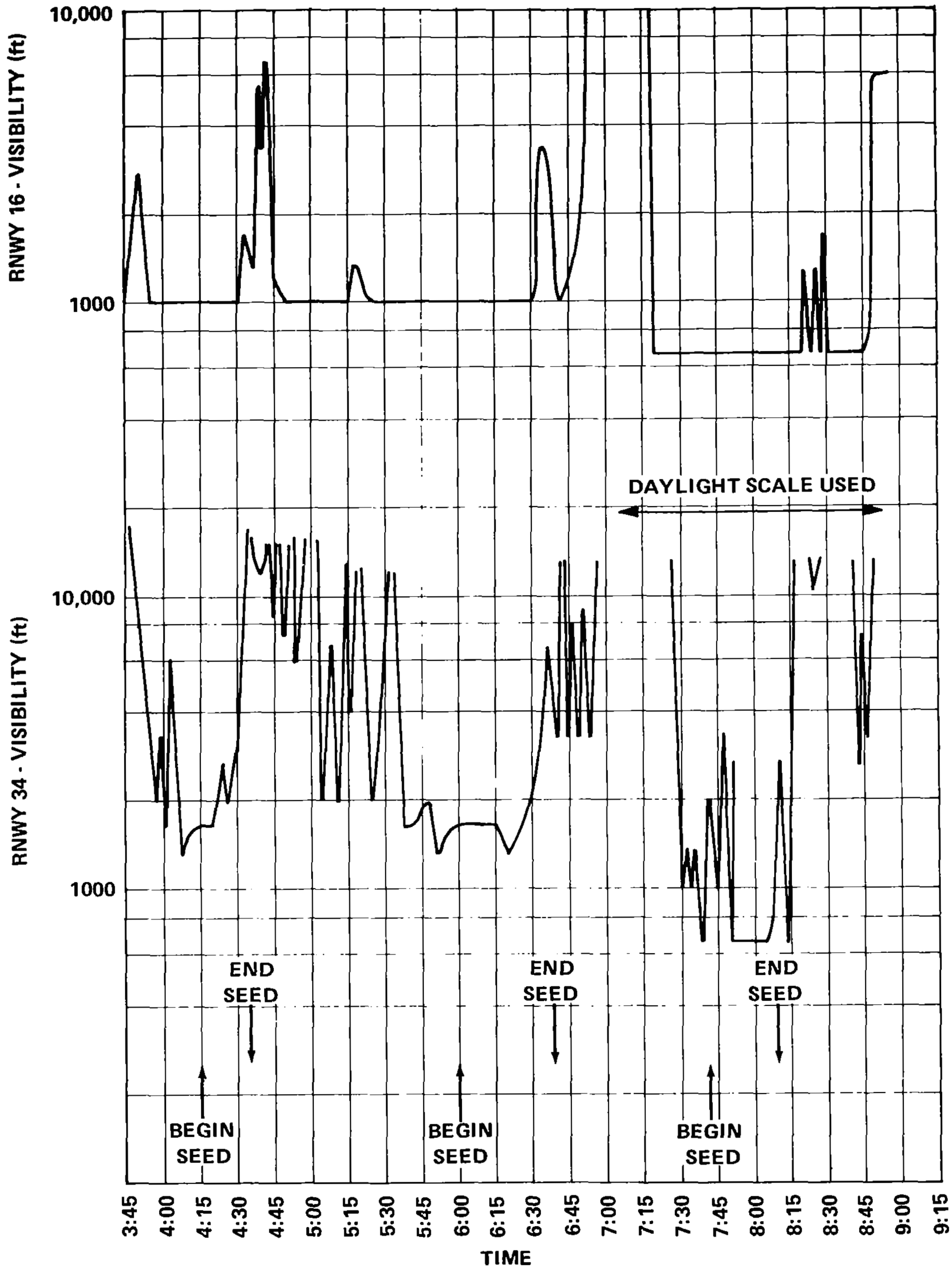


Figure 17 VISIBILITY FROM OFFICIAL SEA-TAC AIRPORT TRANSMISSOMETERS, 20 FEBRUARY 1970

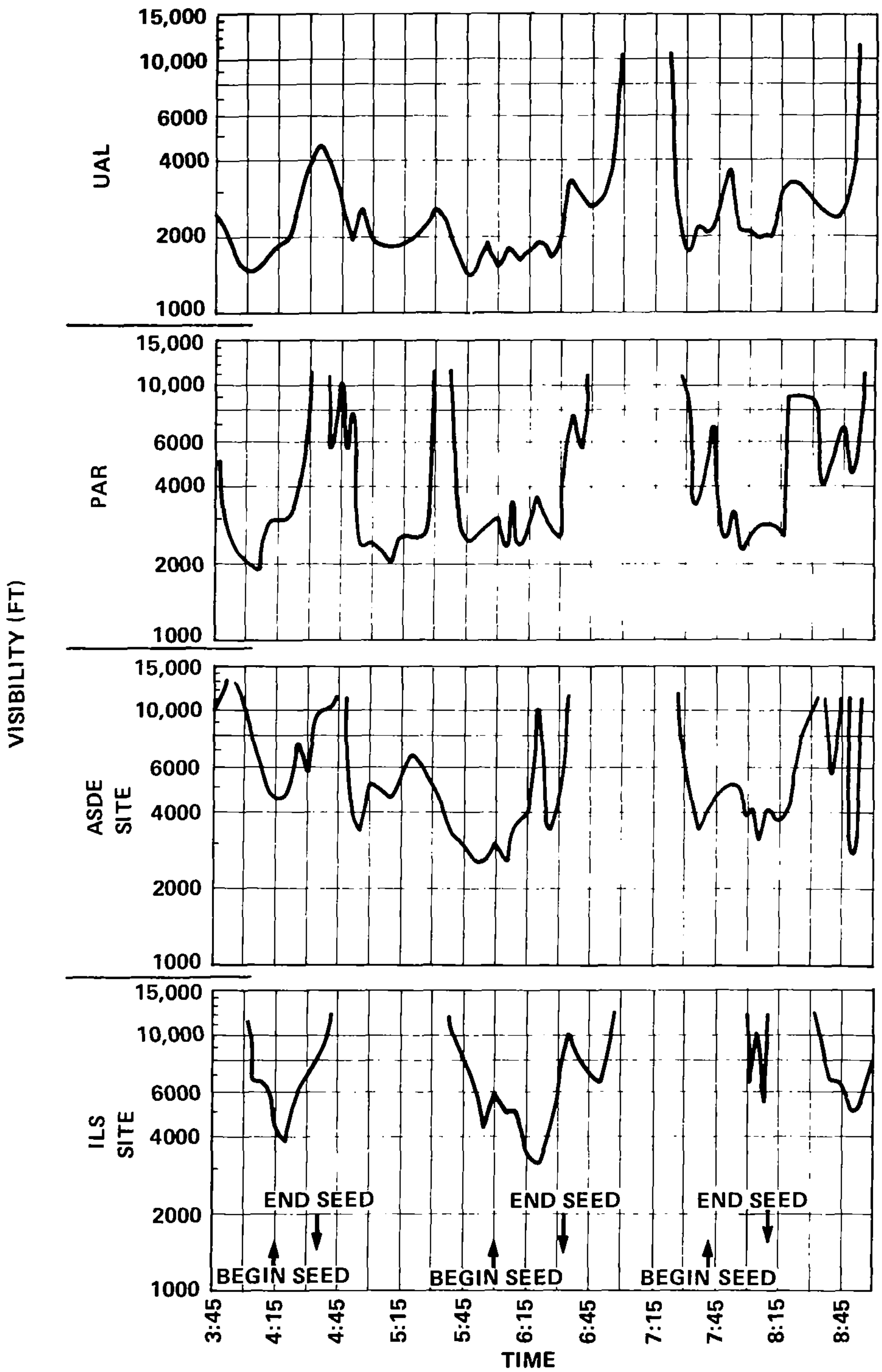


Figure 18 VISIBILITY FROM CAL TRANSMISSOMETERS - SEATTLE-TACOMA AIRPORT 20 FEBRUARY 1970

Three separate seedings were performed at the airport between 4:00 a.m. and 8:00 a.m. on 20 February 1970. The operational plan was to seed with polyelectrolytes (at a rate of about three lbs/mile) over Runway 16-34 until visibility improved to above landing minimums. The normal flight track used in the Sea-Tac operation calls for seeding from middle marker to middle marker over Runway 16-34. Because of unusually high winds (generally greater than ten knots) on 20 February the track was extended further north than usual and polyelectrolyte dispersal continued into an easterly turn. Navigation for the seeding operation was excellent; the seeding aircraft was observed almost directly over the runway by the CAL crew on all but 2 of the 19 passes flown and aggregates of the polyelectrolytes settled on the windshield of the van immediately after several of the passes.

Lacking other evidence the correlation between the end of seeding in each of the three runs and the improvements in visibility shown in Figure 17 might reasonably be taken as an indication of successful fog dispersal. Detailed analyses of the wind data, of the advection of the seeded region under the existing winds, of the changes of microphysical characteristics of the fog as seeding progressed and of the changes of the water vapor content in the atmosphere with time, demonstrate conclusively that the fog appearance and disappearance resulted from natural causes that were completely independent of the seeding operation. The correlation between seeding activities and fog dispersal, in this case at least, is due to the operational plan to seed until fog disappears and not to the action of the polyelectrolytes on the fog. It is inevitable that this kind of correlation will exist whenever such a plan is employed.

The data acquired by CAL on 20 February and the analyses of these data which led to the above conclusions are presented in the following subsections.

Analysis of Wind Data

The appearance and disappearance of fog at Sea-Tac Airport on 20 February was directly correlated with changes in wind direction and wind speed. Continuous wind direction data from the CAL instrumentation are plotted in Figure 19 together with discrete data points available from the official Weather Bureau instrumentation as recorded on WBAN forms. The intervals during which visibility at the Runway 34 transmissometer was below 2500 ft are shown by the heavy black line on the figure. A consistent difference in indicated wind directions of 15° to 20° is immediately apparent. Although the CAL instrument was calibrated to within $\pm 5^{\circ}$ on the day preceding this experiment, it is possible that the tripod on which the instrument was mounted was inadvertently rotated 15° to 20° sometime prior to the experiment. Instrumentation checks made the day before the experiment and after our return to Buffalo indicate that the instrument was linear to within $\pm 5^{\circ}$ on 20 February. In attempting to determine the source of the fog that advected over Sea-Tac we therefore shifted our data 15° clockwise to provide best agreement with Weather Bureau records. Our data were used to provide more detailed information on the times that wind direction changes occurred.

Continuous wind speed data obtained from our instrumentation and from Weather Bureau instrumentation are presented in Figure 20. Considering the half-mile separation between instruments, the agreement is quite good.

The data in Figure 19 show that the fog disappeared from the airport whenever the wind direction was more easterly than about 20°. When the wind direction was predominantly between 355° and 20° fog existed at the airport. From the map of the area shown in Figure 21, it is apparent that winds reaching the airport from 355° to 20° have a reasonably long fetch (five or more miles) over Lake Washington. When wind direction is more easterly than 20°, the fetch over the lake is negligibly small.

These data lead us to believe that the fog at Sea-Tac Airport formed in air that acquired moisture as it passed over Lake Washington and then advected over the airport. When the fetch over the lake was not long enough to permit significant moisture transfer, new fog ceased to form and the existing fog advected away from the airport. It is also possible that the air draining from the higher elevations east of the airport was sufficiently dry to

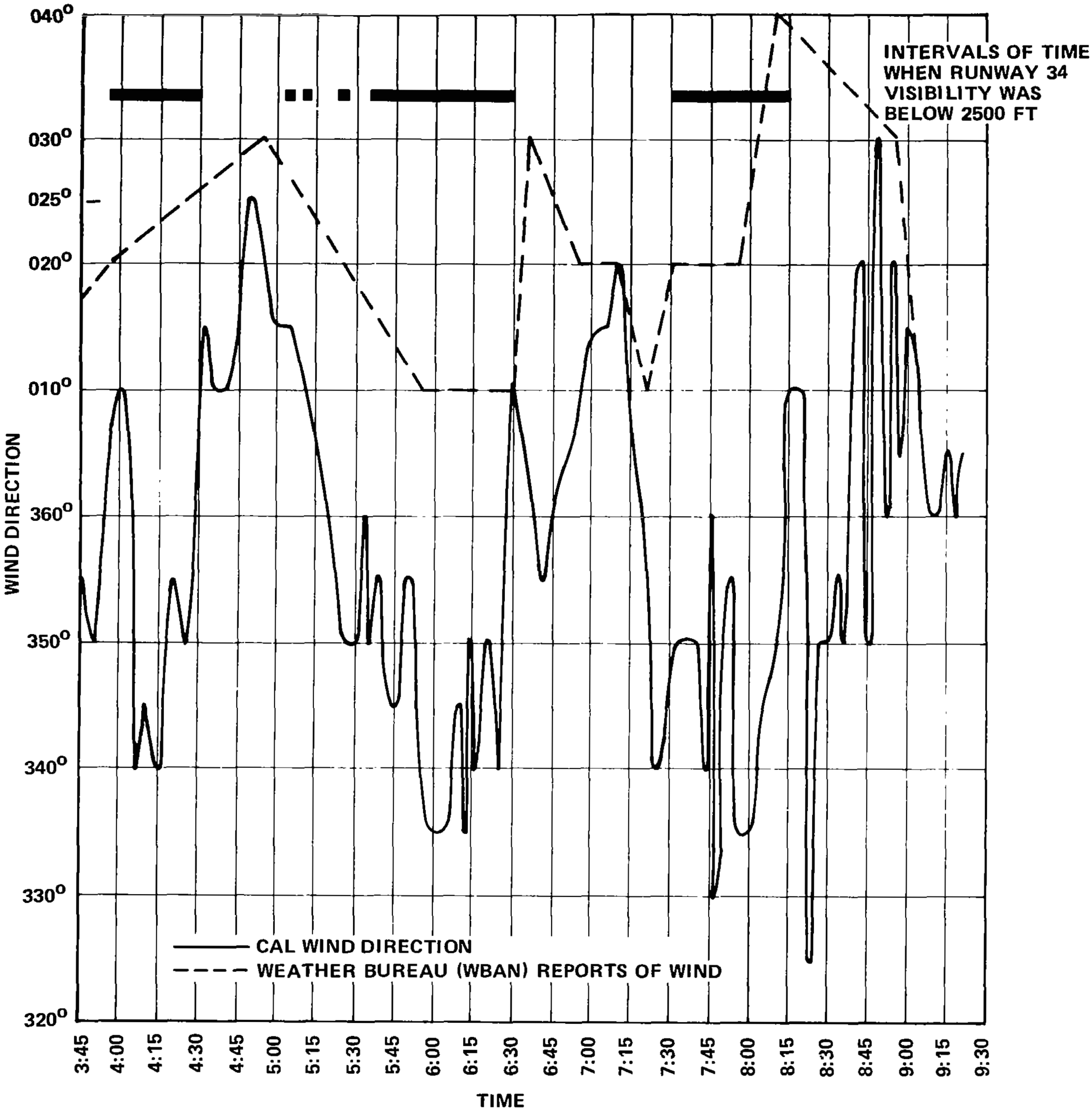


Figure 19 WIND DIRECTION (TRUE) 20 FEB. 1970

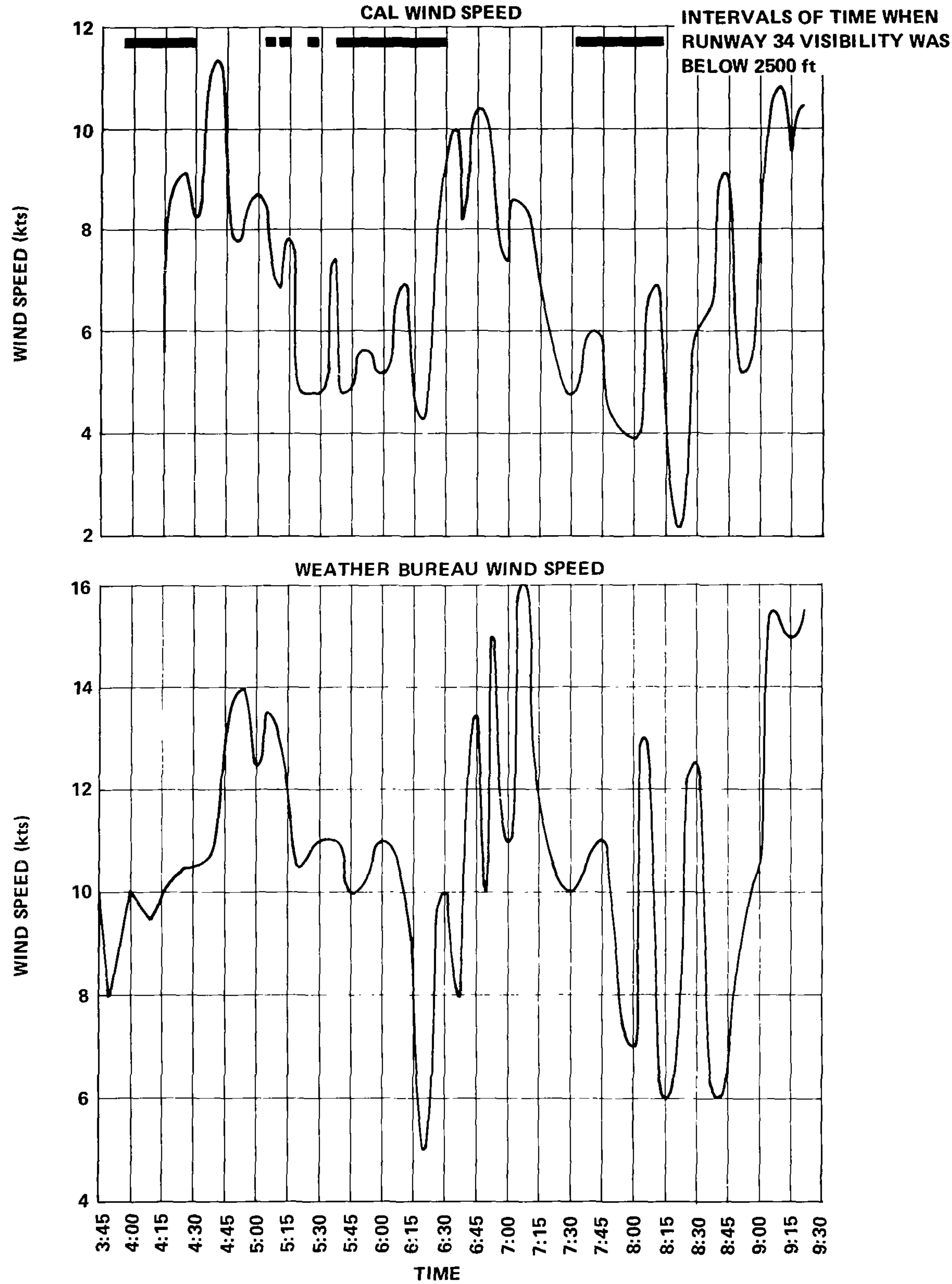


Figure 20 WIND SPEED AT SEA-TAC - 20 FEB. 1970

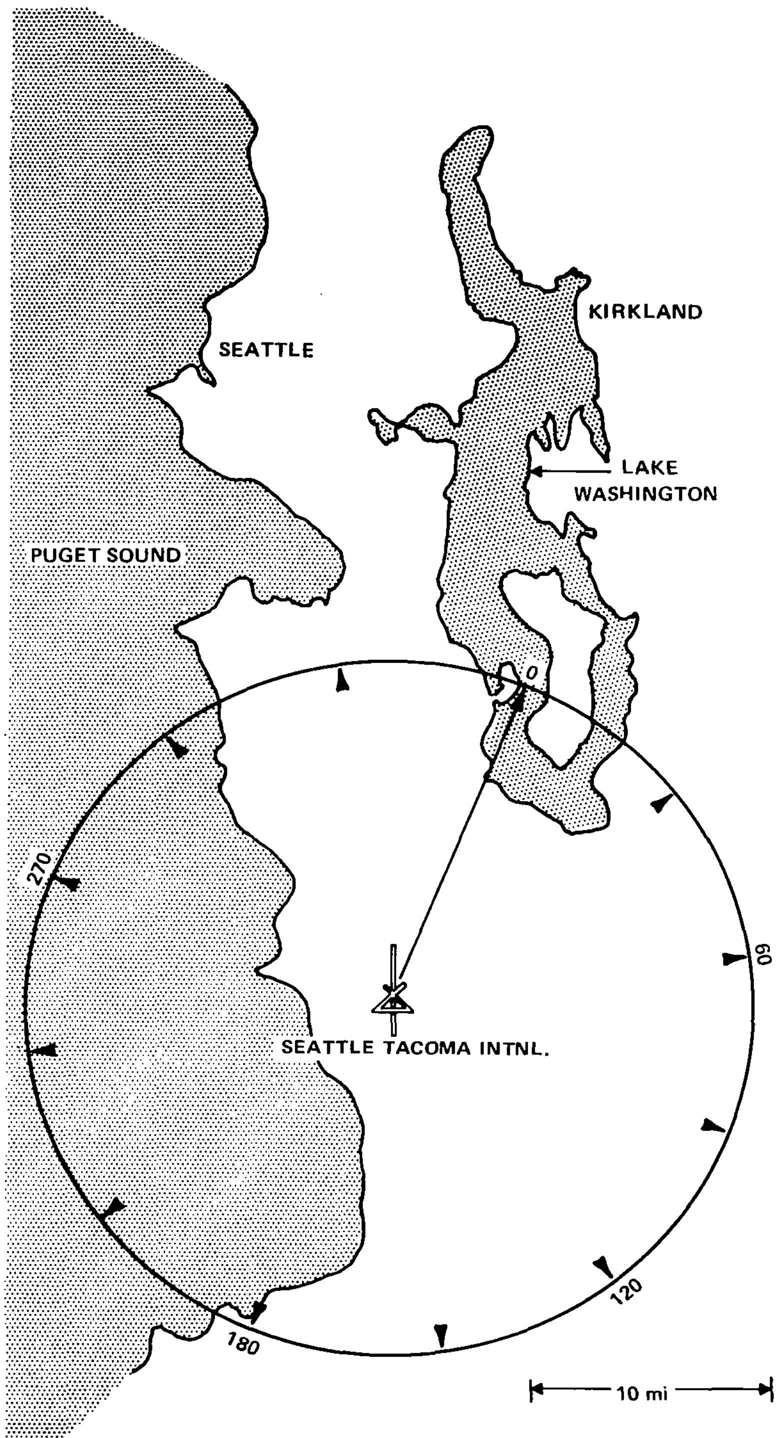


Figure 21 MAP SHOWING POSITION OF SEA-TAC AIRPORT IN RELATION TO PUGET SOUND AND LAKE WASHINGTON - AIRPORT RUNWAYS ARE NOT TO SCALE

prevent fog formation. The fact that the fog advected onto and away from the airport is indisputable from visual observations made by CAL personnel on 20 February.

Analyses of the Advection of the Seeded Air Mass

Because of the cooperation of the Aero-Dyne Corporation in providing information on the seeding tracks flown and the time that each pass began, it was possible to compute the advection of the seeded air mass with reasonable accuracy. Aero-Dyne's basic plan for the seeding operation was to fly a seeding pattern that was almost directly over Runway 16-34 with seeding occurring between middle markers. Because of the need for airport navigational aids, corrections for east-west winds were necessarily limited but significant corrections for predominantly north-south winds could easily be made. To account for the strong north-northeast winds on 20 February the pattern was extended several miles to the north and seeding continued well into the right-hand turn following each seeding pass.

Given this information as well as the flight speed and the time of initiation of each seeding pass, it was possible to estimate the shape and location of the seeded air mass at the conclusion of each run. (A seeding run in this operation was defined as a group of seeding passes prior to fog disappearance.)

Since in our first analysis the principal disagreement between the location of the seeded air mass and the fog boundary occurred on the northern and eastern edges of the seeded region, we attempted in subsequent analyses to extend the seeded air mass as far north and east as permissible. We assumed therefore that the turn at the southern end of the track terminated directly over the middle marker to provide maximum flying time north of the airport. We assumed further that the seeding persisted through the entire easterly turn at the north end of the track and that a standard 3^{o}/sec turn was made. In addition, we assumed that flight speed was 180 mph, 40 mph faster than any estimates given to us by any of the personnel involved. Finally, we arbitrarily increased the time between initiation of passes to the nearest minute that was larger than the average time between passes for each run. When the average time between passes was less than five minutes, we used six minutes for the calculation.

Calculations were then made of the shape and position of the seeded air mass at the end of each seeding run. Official Weather Bureau wind data were used to compute advection of the seeded region and to determine its location at the time fog reappeared at the airport. To maximize our estimate of the size of the seeded region, we assumed that a diffusion rate that is equivalent to a 20° spread would have occurred in a plume from a point source.

Figure 22 shows the results of these calculations for Run 1, which consisted of five seeding passes beginning at 0415 LST and of durations ranging from two to five minutes. We assumed that the time between passes was six minutes. Fog reappeared at the Runway 34 transmissometer 61 minutes after completion of the seeding run. As shown in the figure, the nearest portion of the seeded region, even with these generous assumptions, was approximately eight miles downwind when fog reappeared. If the seeding had been responsible for the clearing, the fog should have reappeared when the seeded region advected away from the airport.

Nine passes were flown in the second seeding run, which extended from 0600 to 0638. With the exception of one pass that required seven minutes, all passes required less than five minutes. We based our calculations on a six-minute interval. The data are shown in Figure 23. When the fog reappeared on the active runway 52 minutes after the end of seeding, the nearest portion of the seeded air mass was four miles from the transmissometer.

The third run was flown between 0735 and 0809 with five passes ranging in duration from six to ten minutes. Calculations were based on an eight-minute interval. In this case, seeding was terminated six minutes before Runway 34 cleared. As shown in Figure 24, the nearest portion of the seeded air mass was 0.75 miles away when clearing occurred. Fog never returned that day.

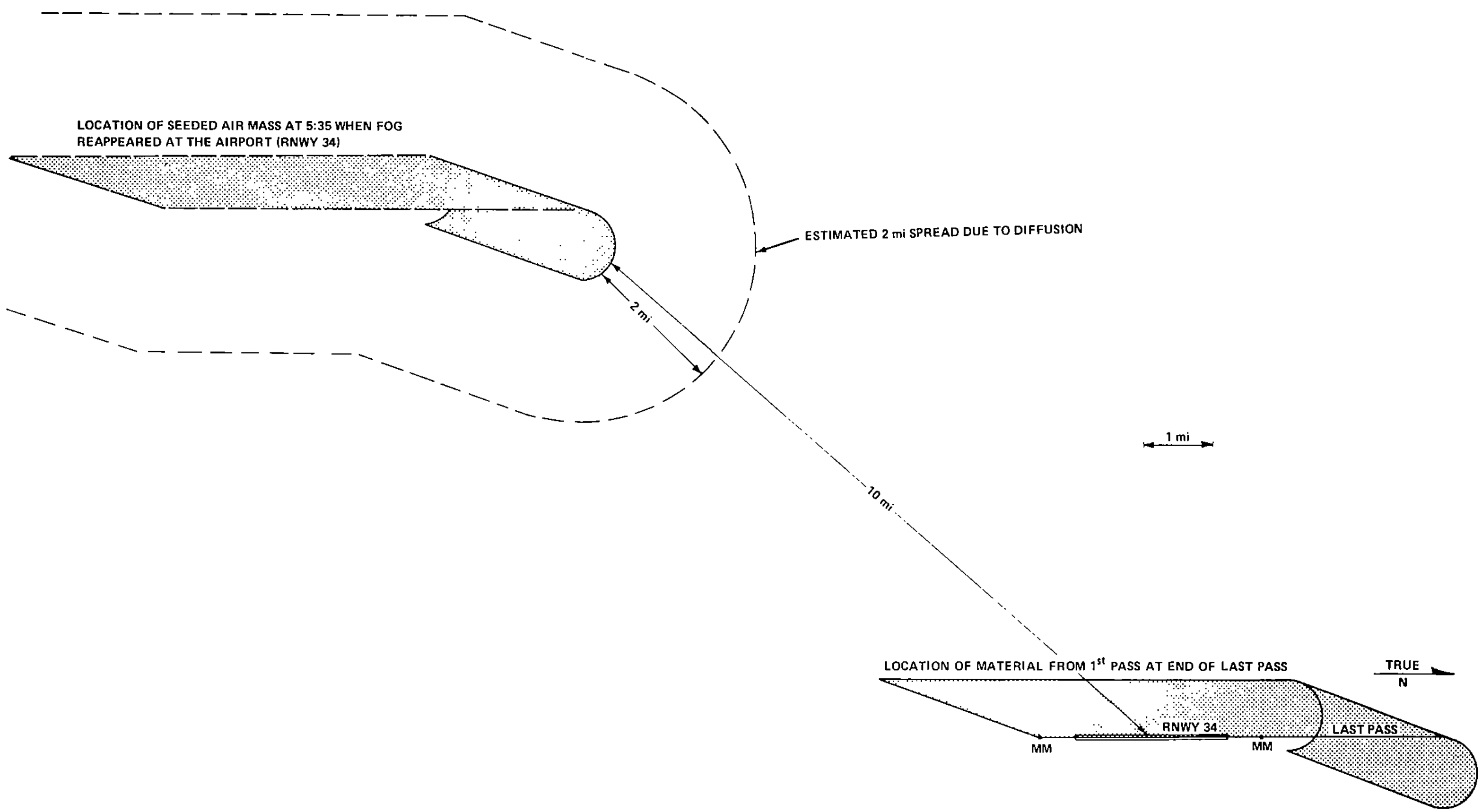


Figure 22 LOCATION OF SEEDED AIR MASS FROM RUN NO. 1 AT END OF SEEDING AND AT TIME FOG REAPPEARED ON RUNWAY 34

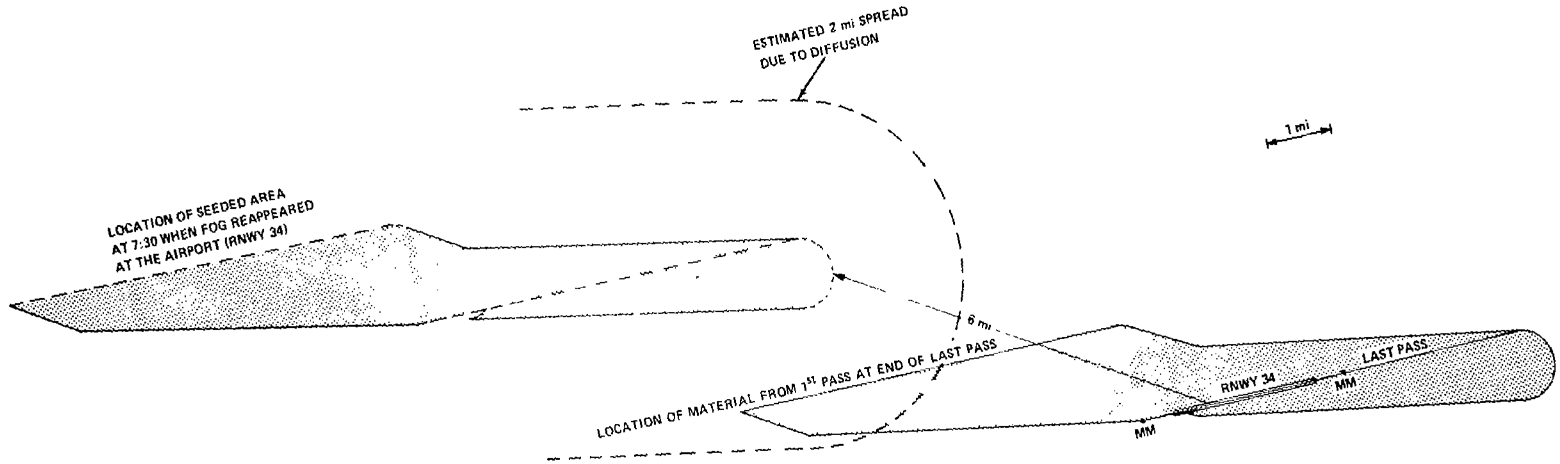


Figure 23 LOCATION OF SEEDED AIR MASS (RUN NO. 2) AT THE END OF SEEDING AND AT THE TIME FOG REAPPEARED AT RUNWAY 34

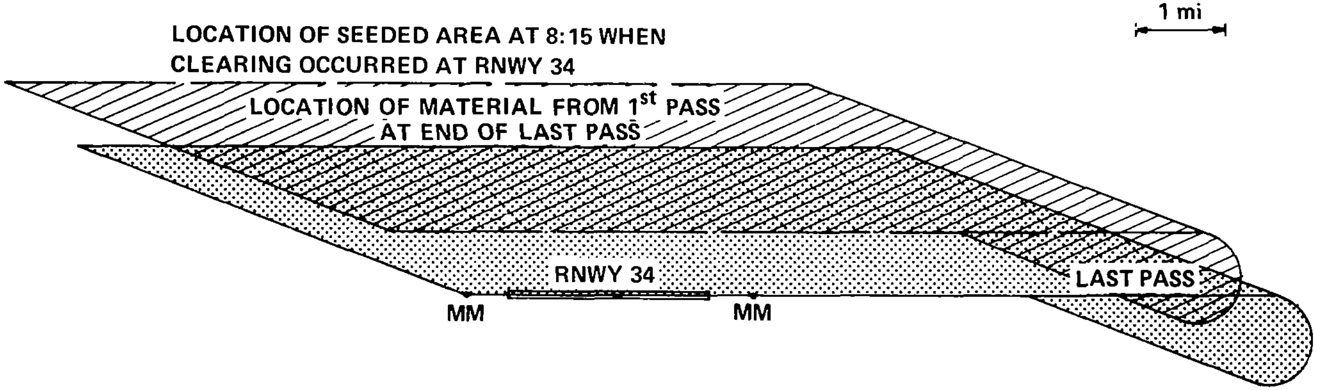


Figure 24 LOCATION OF SEEDED AIR MASS FROM RUN NO. 3 AT END OF SEEDING AND AT TIME FOG DISPERSED ON RUNWAY 34

It is apparent from this analysis that there was no correlation between the size and location of the seeded air mass and the size and location of the clear region at the time that fog reappeared at the airport. The fact that at the time of clearing the edge of the clear region was always near or within the seeded air mass was completely explained by the operational plan used; i.e., seed until fog disappears.

Analysis of the Microphysical Properties of the Seeded Fog

We are not aware of any technical descriptions of the hypothesis by which polyelectrolytes are expected to promote fog dispersal. According to reports in the press and to a number of private communications (e.g., Beckwith, 24 June 1970) polyelectrolytes promote coalescence of fog droplets that are already present in the atmosphere. By so doing, it is argued, the drop-size distribution is shifted from one containing a high concentration of small droplets before seeding to fewer, larger droplets after seeding. These larger droplets then settle to the ground to reduce LWC. According to Trabert's equation,

$$V = \frac{c}{\omega} \frac{\Sigma n_r r^3}{\Sigma n_r r^2} \sim K \frac{\bar{r}}{\omega}$$

both processes promote increases in visibility. In this equation c and K are constants, n_r is the number of droplets of radius r, ω is the liquid water content and $\bar{r}$ is the mean droplet radius.

The microphysical fog properties that were measured on 20 February are summarized in Figure 25. It should be recognized that these measurements were made at the PAR site (2 on Figure 9) and that while applicable in a general sense to visibility improvements determined from the Runway 34 transmissometer, detailed comparisons must be made with the PAR transmissometer record. This is necessary because of the patchy nature of the fog and because of the general trend that fog severity decreased from the northern to southern ends of the runway.

The fact that our instrumentation is capable of detecting the changes in microphysical properties that might be expected to accompany the observed visibility improvements is illustrated by data presented elsewhere in this

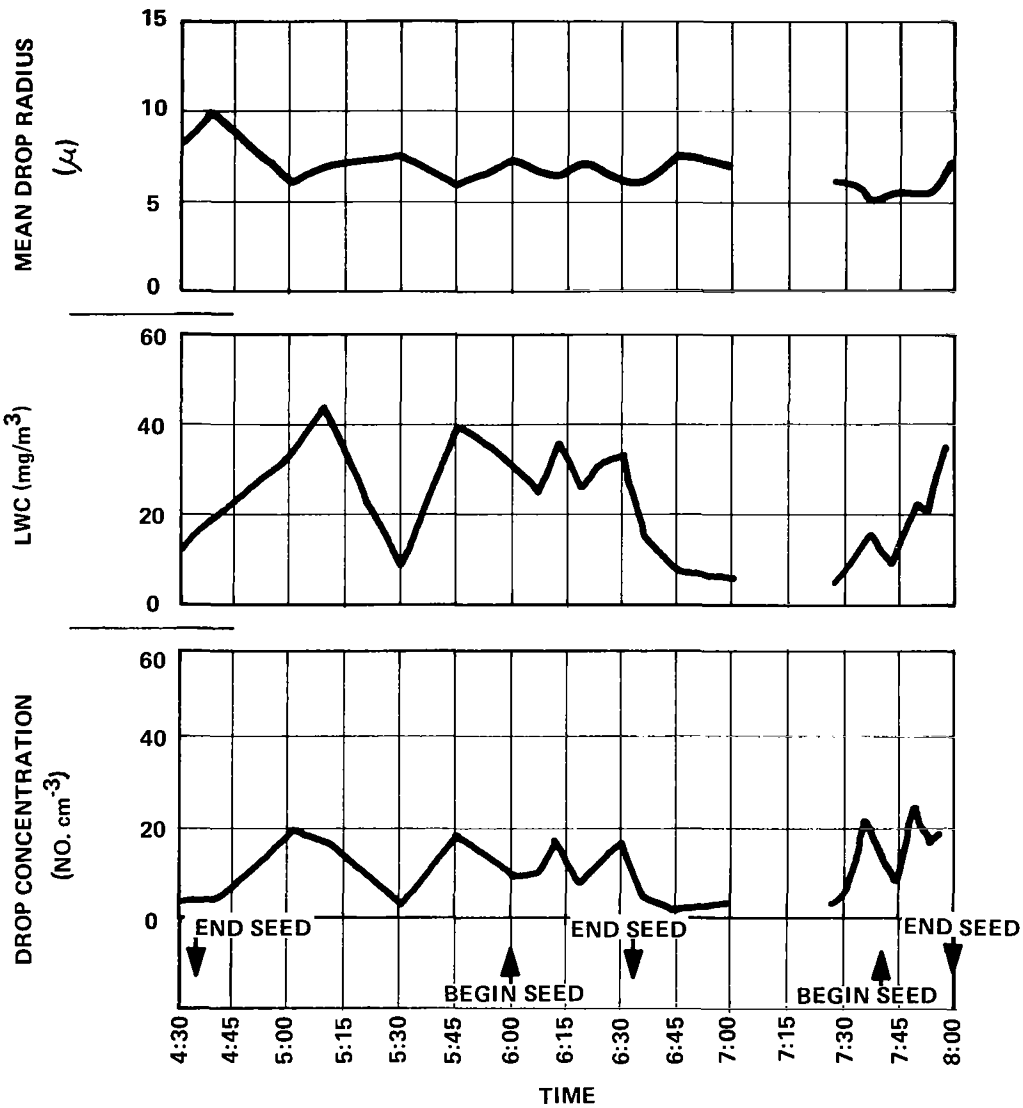


Figure 25 FOG MICROPHYSICS AS A FUNCTION OF TIME - 20 FEBRUARY 1970

report. That the equipment was located in the region that contained the seeding material is evident from Figures 22, 23, and 24 and from numerous observations of polyelectrolyte particles that had settled through the fog onto the windshield of our van. It is reasonable to expect, therefore, that the changes in microphysical properties produced by seeding should be evident in our data.

The gradual increases in LWC and droplet concentration between about 0440 and 0510 are associated with the local decrease in visibility at the PAR site; visibility did not decrease at the Runway 34 transmissometer. The changes in the mean values of the microphysical properties are opposite to those expected to occur following seeding according to the coalescence hypothesis. We will not elaborate on these data, however, because of the extremely local characteristics of the fog at the time that they were acquired.

Equipment malfunctions prevented acquisition of drop samples during the latter portion of run 3. Again, the trends in the data acquired are opposite to those expected from the coalescence hypothesis. A discussion of the trends in the drop-size distribution data for the seeding run is included later in this section. Conclusions based on variations of mean values of the microphysical properties of the fog can only be based on data that relate to run 2.

Quantitatively, a factor of five visibility improvement followed run 2 at the PAR site and an even greater improvement occurred at the Runway 34 transmissometer. If this improvement were produced solely by an increase of $\bar{r}$ in Trabert's equation, a factor of five increase in $\bar{r}$ should have been noted. No significant change occurred. The visibility improvement obviously resulted from the decreases in both LWC and drop concentration that are shown beginning at 0630 in Figure 25. To attempt to explain these decreases on the basis of a coalescence hypothesis but without a simultaneous increase in mean radius is contradictory.

The only applicable set of data on the mean microphysical characteristics of the fog, therefore, provide no support for the contention that seeding caused fog disappearance. Since detailed changes in drop-size distributions can occur without being reflected in mean quantities, it is worth examining the details of each distribution before drawing firm conclusions. The data acquired are presented in Figures 26 through 28.

Drop-size distributions which are associated with the local patch of fog that drifted across the PAR site in run 1 are shown in Figure 26. It is obvious that no significant change in drop sizes occurred. The only trend that can be noted is a gradual decrease in maximum observed radius from the time that the local patch of fog appeared until it was advected away from the airport.

Figure 27 shows the drop-size distributions obtained prior to, during, and after the second seeding experiment. As is clearly evident, the trend throughout the entire observation period (0546-0658 LST) is generally that of decreasing drop size and drop concentration and of narrowing drop distribution. Again, according to the hypothesis, the drop-size distribution would have first broadened and some drops that were larger than natural drops would have appeared. Later, it would be expected that the larger drops would precipitate out of the fog leaving a low concentration of small droplets which should remain virtually unchanged until unmodified fog again advected into the area. After seeding, however, the concentration of the smaller drops was found to decrease, while no significant change in size or concentration of the largest drops occurred.

The third seeding experiment was started at 0735 and continued through 0809 LST; data on fog microphysics were obtained from 0727 through 0753. The drop-size distributions for this period are shown in Figure 28. Note that, just as seeding began, the drop-size distribution narrowed and drop size decreased while drop concentration increased sharply. This is just the opposite of what would be expected if the seeding materials were beginning to act in the manner required to produce clearing.

From these data, it is apparent that the microphysical properties of the fog did not behave in the manner expected from the seeding hypothesis. More often than not, in fact, the behavior was exactly opposite to that expected

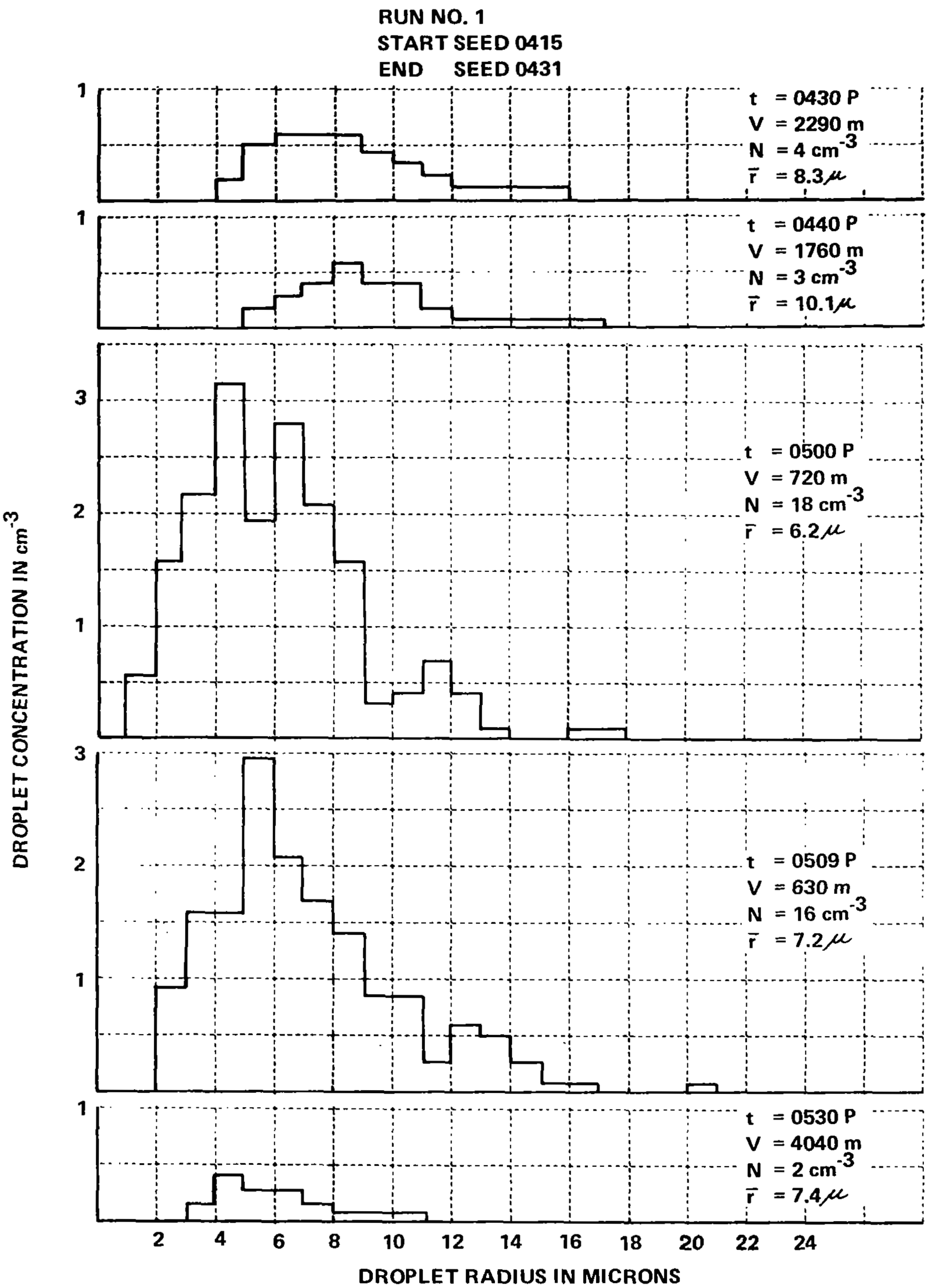


Figure 26 DROP SIZE DISTRIBUTIONS AT VARIOUS TIMES DURING AND AFTER RUN NO. 1
t = TIME, V = VISIBILITY, N = DROPLET CONCENTRATION, r = MEAN RADIUS

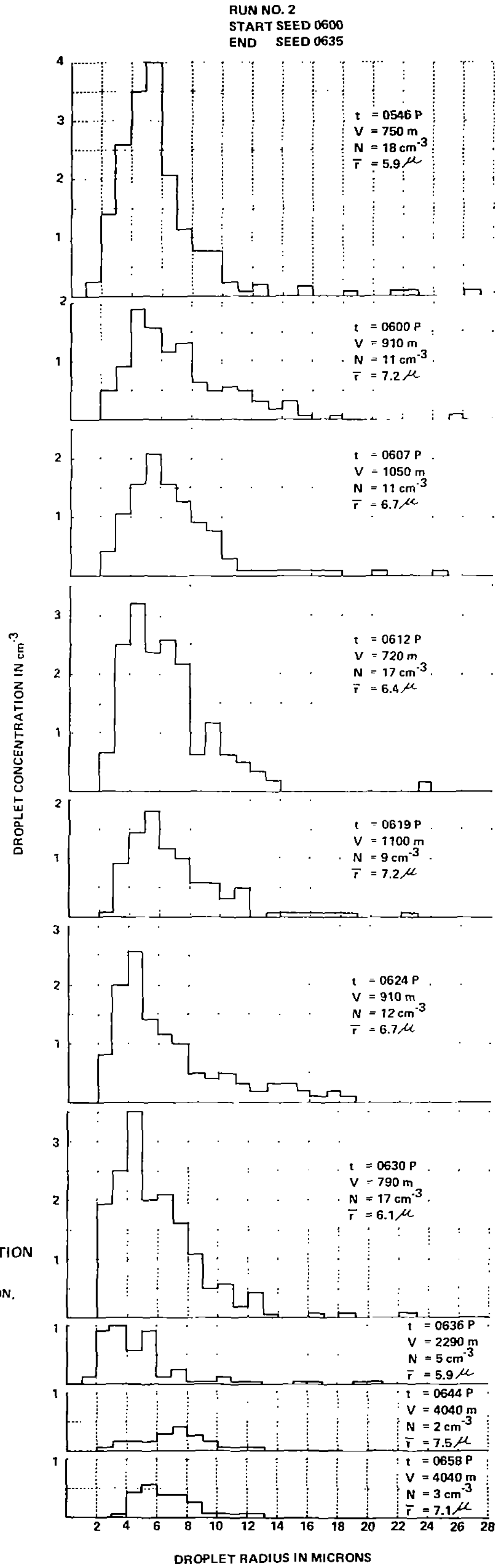


Figure 27 DROP SIZE DISTRIBUTIONS AS A FUNCTION OF TIME FOR RUN NO. 2

t = TIME, V = VISIBILITY, N = DROPLET CONCENTRATION, r = MEAN RADIUS

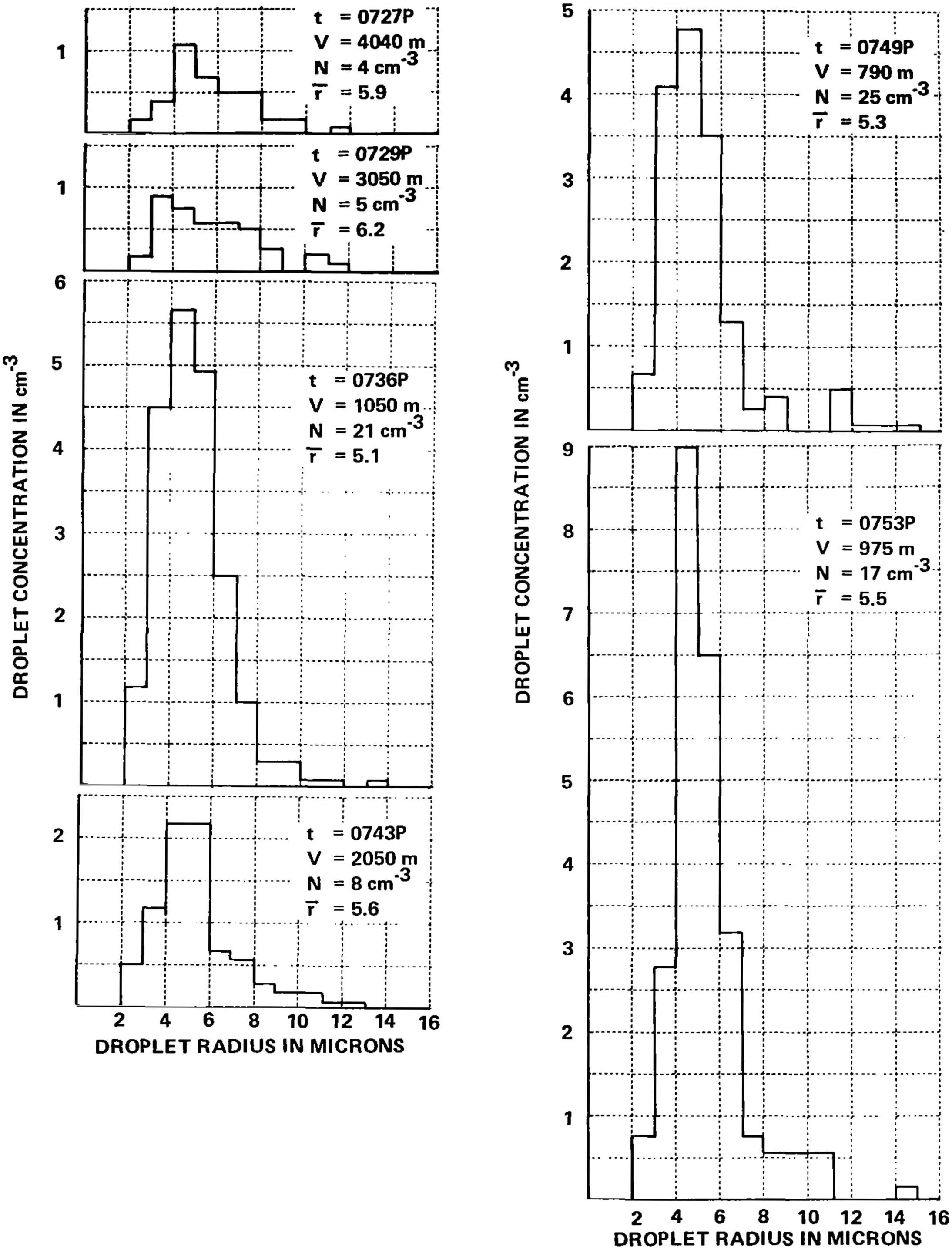


Figure 28 DROP SIZE DISTRIBUTIONS AS A FUNCTION OF TIME FOR RUN NO. 3
t = TIME, V = VISIBILITY, N = DROPLET CONCENTRATION, r = MEAN RADIUS

if the coalescence mechanism had been responsible for fog dissipation. We can only conclude, therefore, that the disappearance of fog at the airport was attributable to some cause other than that hypothesized for polyelectrolyte seeding operations.

Analysis of Dew Point Data

Dew point data were obtained from the 6 ft, 26 ft, and 86 ft levels of the ASDE tower throughout the experiment at Sea-Tac. The data obtained between 0200 P and 0915 P on 20 February are presented in Figure 29. Intervals during which Runway 34 was below 2500 ft are indicated by the heavy lines on the figure. It is immediately apparent from the correlation between the presence of fog and fluctuations in dew point that fog disappearance was accompanied by a reduction in dew point of two to three degrees F.

The hypothesis on which seeding is based does not include a mechanism for the removal of water from the vapor phase. Furthermore, tests of the polyelectrolytes used in this experiment (provided by Aero-Dyne) in our 600 m^3 cloud chamber revealed that the materials indeed do not remove water from the vapor phase. Yet, the measured reductions in dew point correspond to decreases of specific humidity by approximately 0.5 grams per cubic meter. At the seeding rate used, 3 lb per mile, it would have been necessary for the polyelectrolytes to remove water vapor from the air at a rate exceeding 10^3 grams of water per gram of polyelectrolyte in order to account for the decrease in dew point of the seeded region alone. To account for the entire clear region, it would have been necessary to remove more than 10^4 grams of water per gram of polyelectrolyte. The removal of water from the vapor phase alone would have produced more than 0.01 inch of rain at the surface. Absolutely no rain was observed.

It is obvious from these data that the seeding operation could not have and did not cause the observed reduction in dew point. Yet, the observed reduction in water vapor from the atmosphere exceeded the total liquid water in the fog by more than a factor of ten. The only conclusion that is consistent with these data is that fog disappeared from the airport because of natural processes that involved the flow of drier air over the airport. This conclusion is completely consistent with the conclusion reached from the analysis of wind data.

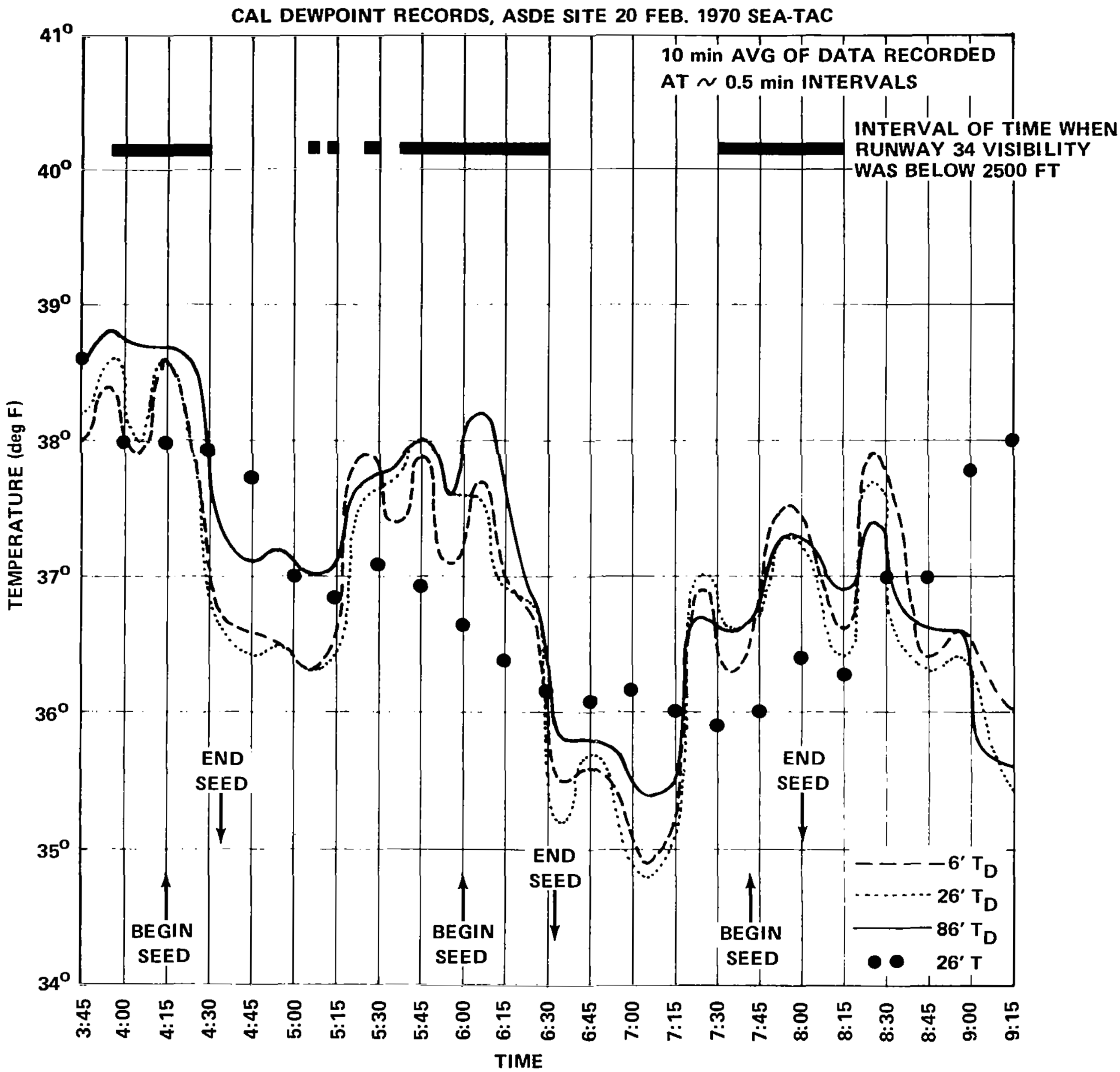


Figure 29 TEMPERATURE AT 26 FT AND DEWPOINT AT THREE LEVELS AS A FUNCTION OF TIME AT SEA-TAC - 20 FEB. 1970

Conclusions and Recommendations

In the preceding technical discussion we have shown that following each of the three seeding runs the sizes and locations of the clear zones that occurred at Sea-Tac on 20 February 1970 were in no way correlated with the sizes and locations of the portions of the atmosphere that were seeded with polyelectrolytes except as a result of the operational requirement to seed until fog disappears. We have shown that neither the mean nor the detailed behavior of the microphysical properties of the fog was consistent with the seeding hypothesis. We have shown also that the disappearance of fog on each of the three occasions was accompanied by a large decrease in dew point that cannot be attributed to the seeding operation. From these data we must conclude that the disappearance of fog was due to natural causes and not to the seeding operation.

Finally, we have shown that the occurrence and disappearance of fog was strongly correlated with shifts in wind direction. Whenever the wind had a long fetch over Lake Washington, fog advected over the airport. Whenever there was a short fetch over the lake, fog disappeared at the airport. We believe that these changes in wind direction were responsible for the observed changes in dew point and visibility at the airport.

The conclusion that the disappearance of fog at Sea-Tac on 20 February was not caused by seeding is not sufficient reason to conclude that polyelectrolytes are not effective fog dispersal agents. The conclusion, however, when coupled with the results of our field experiment with polyelectrolytes (reported in Section II of this document) and with the consistently negative results obtained in the 600 m^3 cloud chamber experiments, which are discussed in Section V, leads us to suspect that the materials may be ineffective. In order to draw a firm conclusion one way or the other, thoroughly implemented evaluation experiments such as reported here must be repeated on a number of occasions. We strongly urge that such evaluations be included with the operational seeding programs being planned for the immediate future.

V. LABORATORY EXPERIMENTS

Additional laboratory experiments were performed during the past year to evaluate new chemicals as seeding agents and also to study the effects of certain evaporation retardants on the fog formation and dissipation processes. The latter preliminary experiments were performed to determine if natural condensation nuclei could be "poisoned" with cetyl alcohol in order to inhibit their participation in the formation of fog. Firm conclusions regarding the poisoning effect of cetyl alcohol were not generated from these experiments; however, the data lead us to suspect that there is indeed a retardation of droplet growth on treated natural nuclei. Verification of this conclusion must await additional laboratory tests.

A. Test Procedure

Two types of experiments were conducted in the 600 m^3 cloud chamber shown in Figure 30. The facility consists of a cylindrical chamber which can be pressurized or evacuated at controlled rates. Consequently, nearly adiabatic expansions are produced and, under appropriate initial humidity conditions, fog forms. Laboratory fogs produced in this manner have been found to possess physical characteristics (i.e., visibility, drop-size distribution, drop concentration and liquid water content) that are representative of natural fogs. Conditions typical of either inland or coastal fogs can be produced by altering the processes of fog formation and persistence in the chamber.

In the first type of experiment, the procedure used to evaluate a seeding agent was to produce one fog for use as a control and observe its characteristics as a function of time. A second fog was then produced in an identical manner and seeded with a predetermined amount of the selected chemical. In both the control and seeded fog, a slow secondary expansion was initiated to cause the fog to persist. Seeding nuclei were dispersed into the fog from the chamber top and allowed to settle through the fog volume.

For additional discussion of the laboratory fog formation process and experimental procedures, see NASA SP-212.

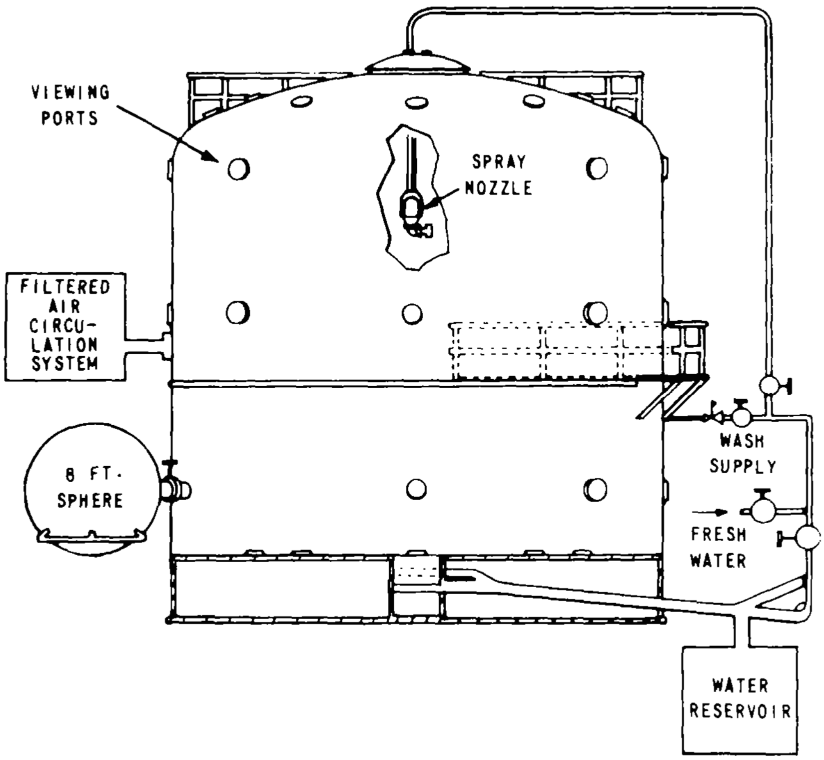


Figure 30 THE $600m^3$ TEST CHAMBER AT ASHFORD, NEW YORK

In the second kind of experiment, somewhat different procedures were adopted. These experiments were designed to test the effects of seeding laboratory fog with controlled amounts of cetyl alcohol vapors. The objectives were twofold: (1) it was desirable to know if fog formation in the seeded fog was significantly slower than that observed in the control fog, and (2) we wanted to determine if fog persistence was greatly increased after seeding with the evaporation retardants.

B. Summary of Results

Cetyl Alcohol Seeding Experiments

Previous experiments conducted at this laboratory (Pilié, 1966) have shown that it is possible to retard the growth of droplets on individual sodium chloride nuclei by first treating the nuclei with hexadecanol (cetyl alcohol). An important conclusion from those experiments was that condensation on treated nuclei could be retarded but not prevented from occurring.

It has been suggested (Jiusto, 1964) that if it were possible to treat some of the natural nuclei upon which fog droplets grow, then other, untreated nuclei might effectively compete for the available water vapor. The result would be a fog consisting of fewer, but larger, droplets that would scatter less light and have improved visibility characteristics. Field experiments in Australia (Bigg, et al., 1968), which were designed to inhibit fog formation by seeding with long-chain alcohols, suggested that the alcohol smoke was effective in preventing fog. There was no certain evidence, however, that the observed results would not have happened naturally.

More recently, experiments were undertaken at this laboratory to determine if fog formation and persistence could be significantly altered by seeding artificial fog with controlled amounts of cetyl alcohol vapor. The procedure for evaluating the effects of surface active agents on laboratory fog was as follows: after forming fog in the 600 m^3 cloud chamber, controlled amounts of cetyl alcohol vapor were introduced into the chamber. The vapor, upon entering the chamber and contacting the cool environment, immediately condensed to form tiny particles having a size range of 0.5 to 1μ. The cetyl alcohol haze was allowed to reside in the fog for several minutes during which time the fog droplets became coated with monomolecular films of the surface active agent.

The fog was then caused to rapidly dissipate by repressurizing the 600 m^3 volume. In this way, we hypothesized, the evaporating treated droplets would coat the natural condensation nuclei with a layer of cetyl alcohol. After several minutes, a slow expansion was produced in order to re-form the fog on treated nuclei. The visibility characteristics of the treated fog were compared with control fogs produced in an identical manner.

As a final step in the evaluation, the natural fog was allowed to dissipate naturally.

By following the above procedure, artificial fog formation and dissipation could be studied, and in so doing, the overall effect of treating nuclei with evaporation retardants could be examined. Visibility was recorded continuously during the experiments and fog microphysics data were obtained at various times during the life cycle of the fogs.

In Figure 31, visibility curves are shown for a control fog and a fog seeded with 2 gm of cetyl alcohol (a linear surface active agent that is effective as an evaporation retardant). It is apparent from the figure that after seeding and repressurization (t = 12 minutes) evaporation of the treated droplets is greatly retarded. Note from the data that several minutes after the start of the secondary fog forming expansion (t = 15 minutes) that visibility in the treated fog continued to improve slowly, indicating that evaporation of treated droplets had not been arrested and, as a corollary, that sufficient supersaturation had not been achieved to produce droplet growth. Once adequate cooling occurred and supersaturation increased, growth proceeded on the droplets and fog intensified (e.g., t = 20 minutes).

At t = 40 minutes the expansion was terminated and the fog was allowed to dissipate naturally. The stabilization of the fog for later times is evident from the data shown in the figure.

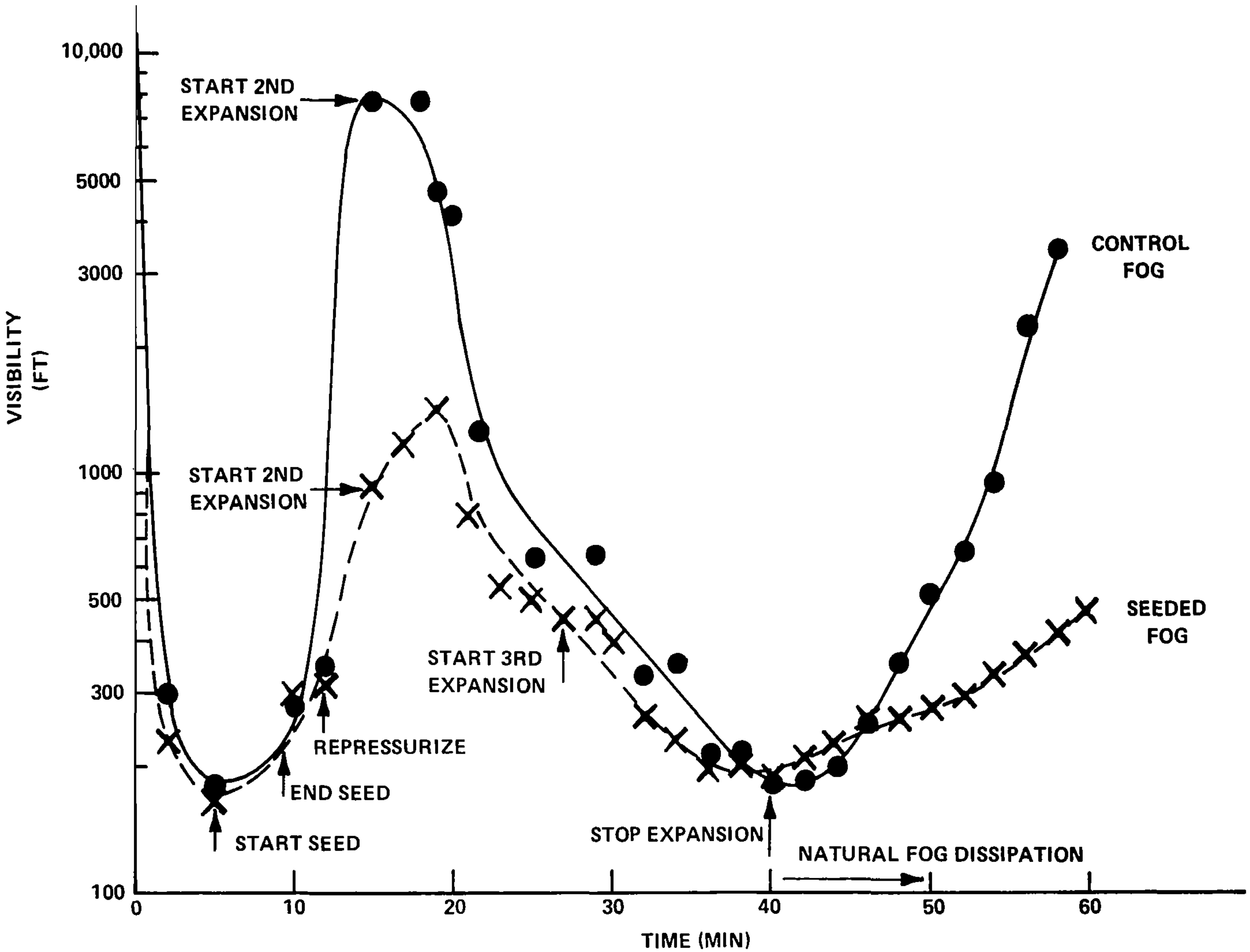


Figure 31 VISIBILITY AS A FUNCTION OF TIME FOR A CONTROL FOG AND A FOG SEEDED WITH 2 gms CETYL ALCOHOL

Drop-size distributions for the control and seeded fogs are shown at several times (specifically, t = 5, 25, 40, and 50 minutes) during the experiments (Figures 32 and 33). At t = 5 minutes, prior to seeding, the shape of the distributions are nearly identical. Differences in the concentration of droplets observed at this time are not highly significant. At t = 25 minutes, i.e., after seeding, repressurization and initiation of the secondary fog forming expansion, the distributions of the seeded and control fogs are much different in both shape and drop concentration. The seeded fog at this time is comprised of high concentrations of very small droplets suggesting that growth on treated droplets was substantially retarded. Because of the very high concentration of small droplets, the visibility in the seeded fog is actually worse than in the control fog at this time.

At t = 40 minutes the distributions are similar and the visibilities are nearly identical. The seeded fog is skewed somewhat toward smaller sizes again indicating retarded growth; however, the differences between distribution are not great.

At t = 50 minutes, approximately ten minutes after the expansion was stopped and fog was allowed to dissipate naturally, the differences in visibility, drop size and drop concentration are large. The effective manner in which the cetyl alcohol stabilized the fog is obvious from a comparison of the number of droplets and the shape of the distribution at this time. Somewhat later, i.e., t = 60 minutes, the visibility data in Figure 31 show even greater differences, again attesting to the stabilization effect of the cetyl alcohol.

It might reasonably be argued at this point that residual haze in the form of high concentrations of cetyl alcohol particles could restrict the visibility to the values shown and that treated fog droplets may not have been responsible for the observed low visibility. In order to help determine if this were true, a second experiment was run (after thorough flushing of the chamber) using 2 gm of oleyl alcohol: a non-linear surface active agent that is nearly identical to cetyl alcohol but which does not inhibit evaporation (slight differences in the structure of the oleyl alcohol molecule account for this behavior). The results of the visibility data are shown in Figure 34.

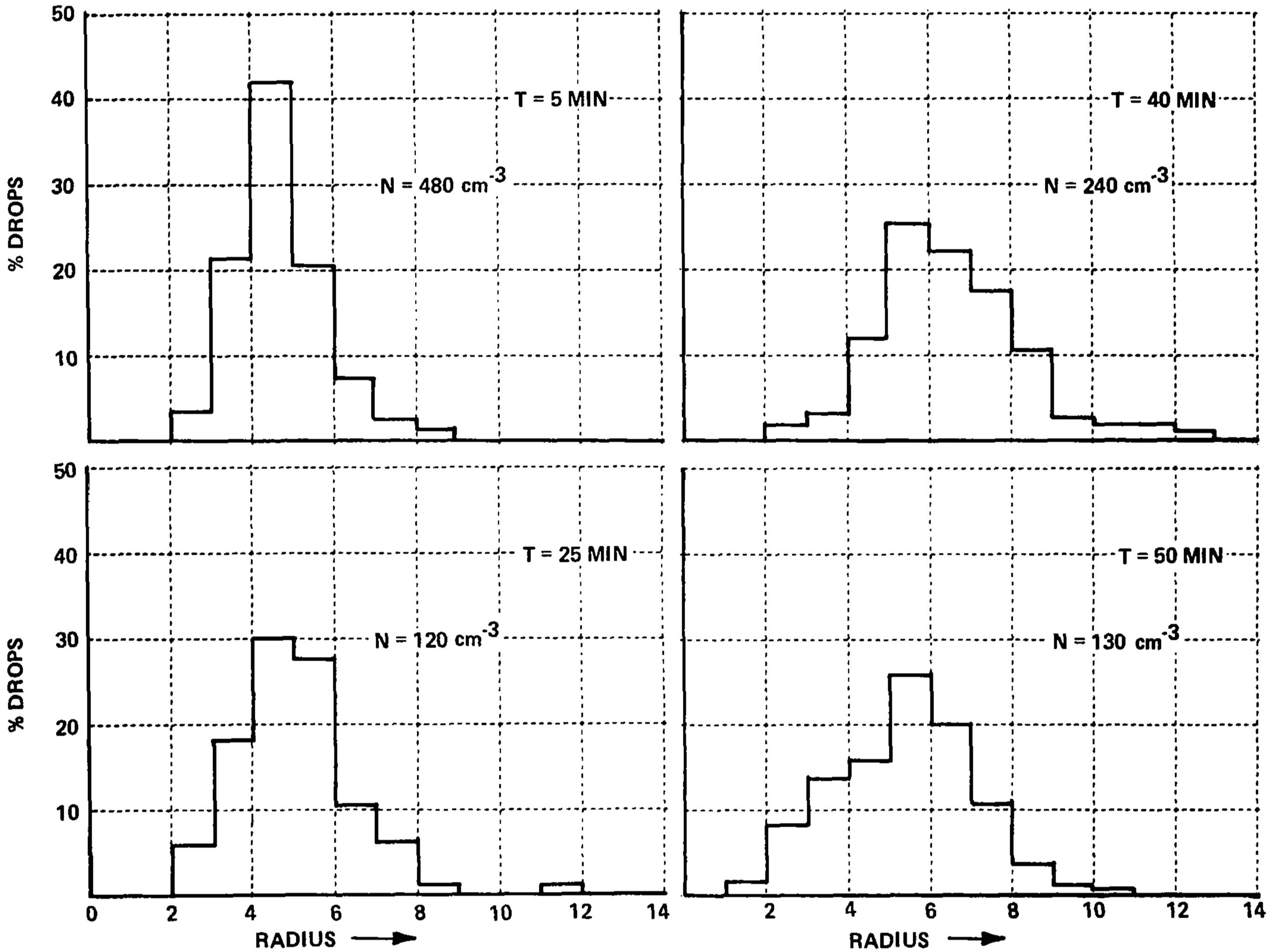


Figure 32 DROP SIZE DISTRIBUTIONS AND DROP CONCENTRATIONS (N) AT VARIOUS TIMES FOR A CONTROL FOG

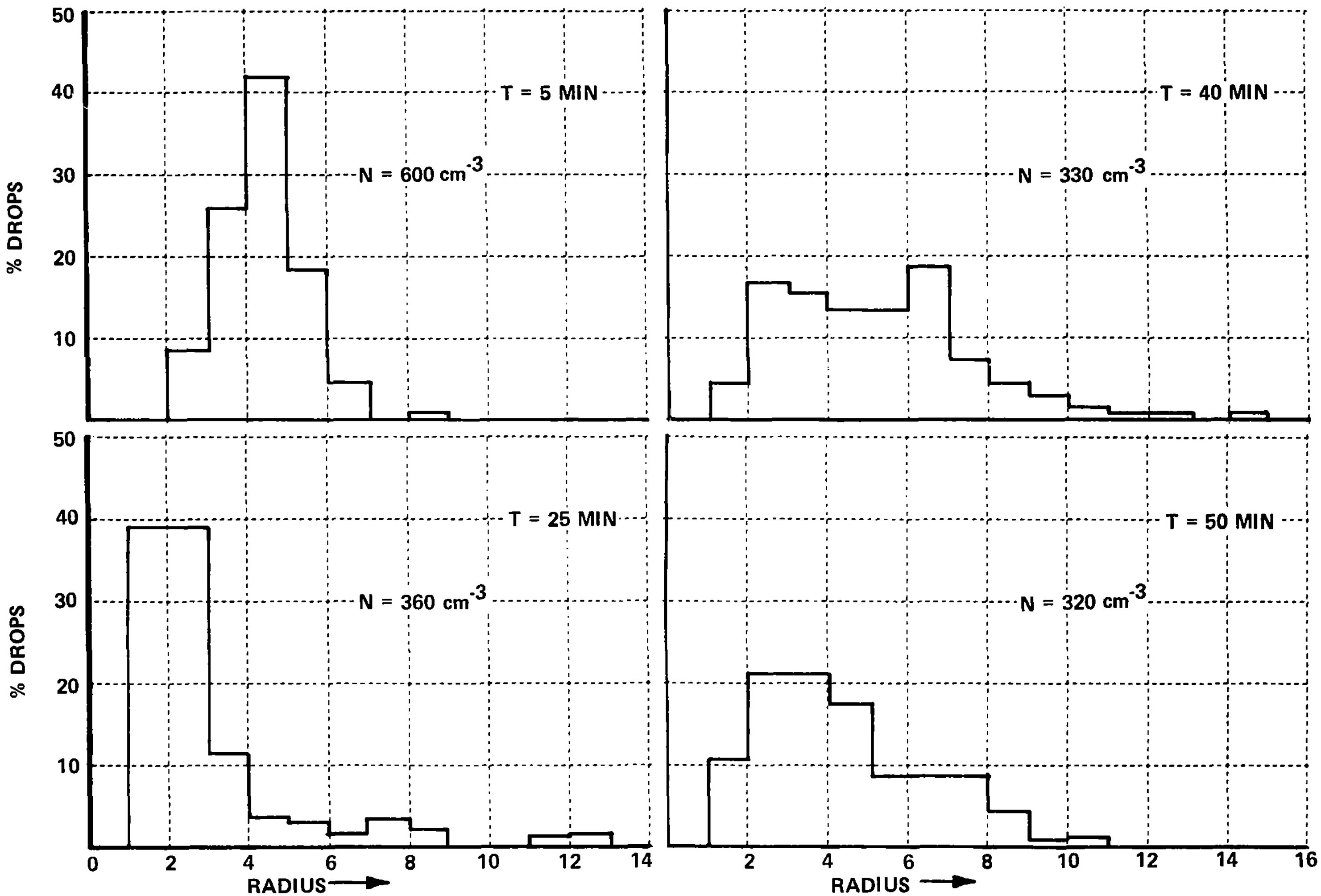


Figure 33 DROP SIZE DISTRIBUTIONS AND DROP CONCENTRATIONS (N) AT VARIOUS TIMES FOR A LABORATORY FOG SEEDED WITH 2 gms CETYL ALCOHOL

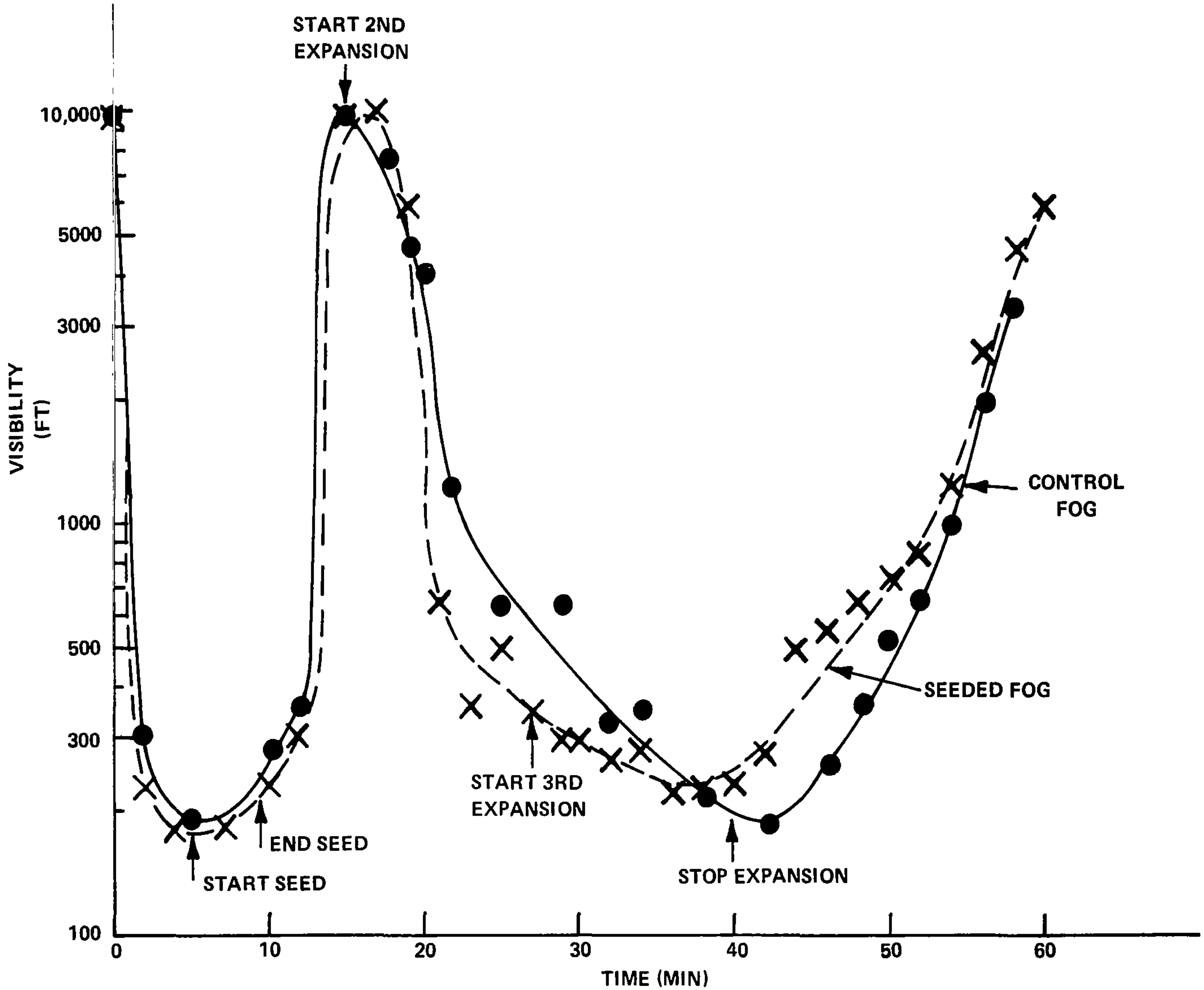


Figure 34 VISIBILITY AS A FUNCTION OF TIME FOR A CONTROL FOG AND A FOG SEEDED WITH 2 gms OLEYL ALCOHOL

It is obvious from this figure that haze was not responsible for restricting visibility. Note, for example, that after seeding (t = 5 minutes) and repressurization (t = 12 minutes) the treated fog droplets completely evaporated and visibility returned to a value equal to that of the control fog. In fact, the entire sequence of events shown in this figure for the seeded and control fogs are very similar. One can only conclude, therefore, that seeding with an equivalent amount of oleyl alcohol produces no significant changes in the visibility characteristics of the laboratory fog and that the production of high concentrations of cetyl alcohol in the previous experiment were not in themselves responsible for the low visibility that was observed.

The drop-size data for the oleyl alcohol seeding (Figure 35) bear this out. The data, when compared with the results shown in Figure 32, show no real differences that are important, except for the slight shift in the distribution toward smaller sizes at t = 25 minutes. The fairly high computed concentration of droplets in the seeded fog at this time is a result of the low visibility that was observed and used in the computation. Comparisons at t = 40 minutes and especially t = 50 minutes show very close correlation with the control fog.

C. Discussion of Results

These data show that laboratory fog dissipation can be greatly retarded by seeding with controlled amounts of evaporation retardants such as cetyl alcohol. The data also suggest that droplet growth on treated nuclei is retarded, but that under the conditions of these experiments, fog formation was not significantly altered by the seeding.

It is not known what percentage of fog droplets were actually treated in these experiments. The fact that fog dissipation was greatly retarded indicates that many droplets were coated with a monomolecular film of the chemical.

In future tests, drop samples will be acquired at other key times, such as t = 8, 10, 14, and 16 minutes of each experiment. The changes in the drop spectra and drop concentration at these times can then be used to more accurately describe the processes involved in seeded vs non-seeded fog formation and persistence. Additional experiments with more complete

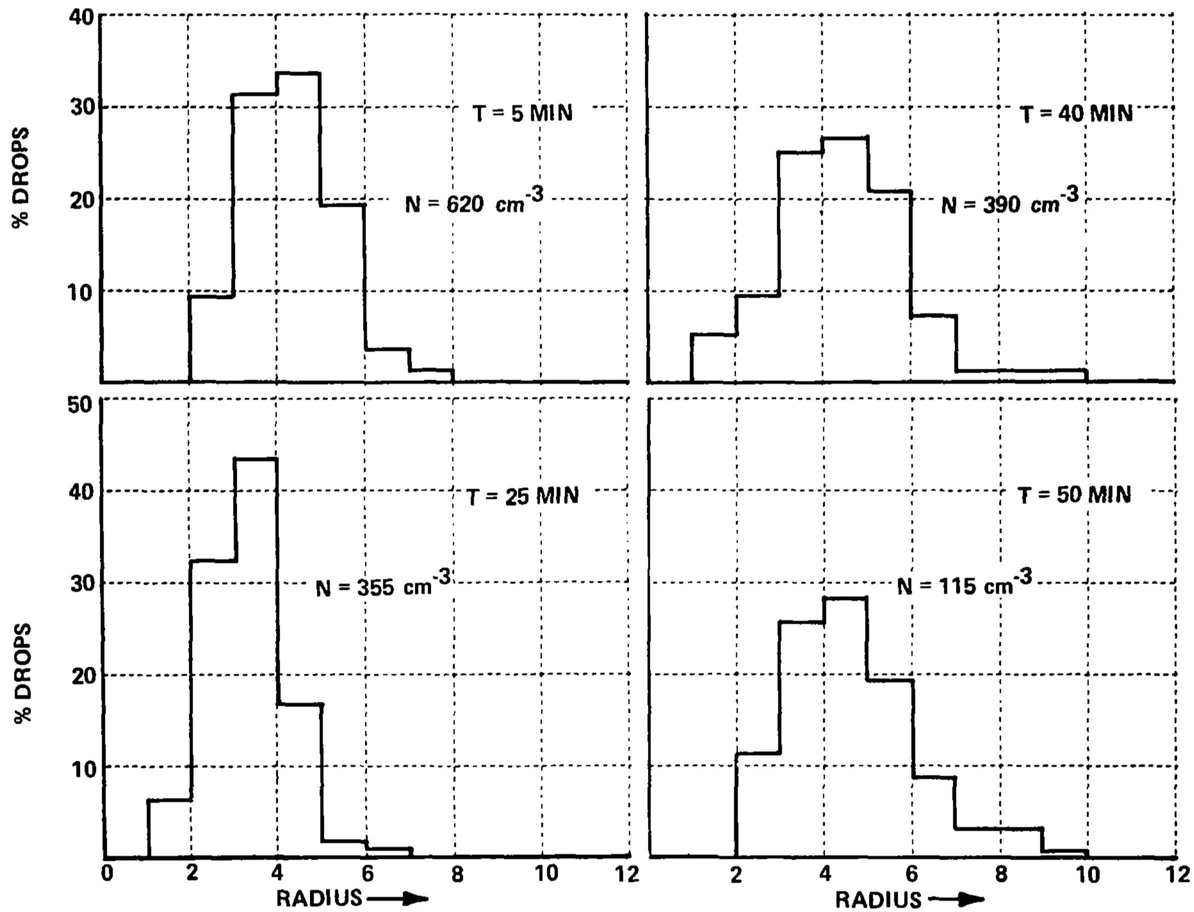


Figure 35 DROP SIZE DISTRIBUTIONS AND DROP CONCENTRATIONS (N) AT VARIOUS TIMES FOR A LABORATORY FOG SEEDED WITH 2 gms OLEYL ALCOHOL

data-taking are also needed to verify conclusions relative to the retardation of droplet growth on natural nuclei and/or droplets treated with cetyl alcohol. It can be concluded from these experiments, however, that seeding with relatively small amounts of cetyl alcohol greatly increased the persistence of laboratory fog and probably altered the growth rate of treated droplets. Experiments designed to verify the latter observation are planned for the coming year.

Polyelectrolyte Seeding Experiments

Additional experiments were performed during the past year to determine if any polyelectrolytic chemicals could be found that would produce significant clearing of laboratory fog. The complete list of all chemicals tested on this project is shown in Table II. In Appendix A, chemical information about each of the chemicals is tabulated.

In the current tests, cationic, anionic and nonionic materials were tested as well as carefully sized and also unsized materials. As shown, none of the materials produced significant clearing of laboratory fog. Differences in the amount of seeding material did not appear to alter the results that were achieved.

Several seeding agents used by Aero-Dyne Corporation in field experiments at Seattle, Washington were also tested in our 600 m^3 chamber. The materials were Hercules Skylite, Reten 205 and Calgon 822-A. Two other materials provided by Aero-Dyne were found to have identical infrared spectra to chemicals previously tested and were therefore not reexamined in the laboratory.

Pertinent data on fog microphysics were collected throughout the experiments. In previous tests, the data have been analyzed to determine if the polyelectrolytes produced changes in the drop sizes, liquid water content or drop concentration that could lead to visibility improvements in the fog. The data, however, have consistently shown that there are no significant changes in the microphysical properties of the fog that can be attributed to seeding. A discussion of visibility data and changes in fog

Table II

POLYELECTROLYTE SEEDING EXPERIMENTS

Seeding Agent	Seeding Mass	Particle Size (μ)	Maximum Visibility Improvement Factor
Dow Poly "B'	5.0 g	20-44	1.3
Dow Poly 'B'	15.0 g	20-44	1.3
Dow Separan AP 30	5.0 g	20-44	1.2
Calgon 822 A	5.0 g	unsized	1.2
Calgon 823 A	0.5 g	unsized	1.2
Calgon 823 C	0.5 g	unsized	none
Hercules Reten 205	5.0 g	unsized	1.2
Hercules Reten 210	5.0 g	10-20	1.5
Hercules CMC-12MB	5.0 g	10-20	2.3
Hercules EHEC-755	5.0 g	10-20	none
Hercules Reten A-1	5.0 g	10-20	none
Hercules 'Skylite'	5.0 g	unsized	none
Hoechst 3	5.0 g	unsized	1.2
Hoechst 4	5.0 g	unsized	none
Hoechst 5	5.0 g	unsized	none
Hoechst 6	5.0 g	unsized	1.2
Hoechst 7	5.0 g	unsized	1.6
Hoechst 8	150 ml	unsized	none
Hoechst 10	150 ml	unsized	none
Nalco LN-767-193A	5.0 g	10-20	1.8
Nalco LN-767-193B	5.0 g	20-44	1.5
Nalco LN-767-193D	5.0 g	20-44	1.7
Nalco LN-767-193C	75.0 g	unsized	none
Ganex V-904	15.0 g	44-125	1.5
PEI-1000	liquid	unsized	none

microphysics has been presented in previous reports (see, e.g., NASA SP-212) and will, therefore, not be included here. It is sufficient to point out at this time that data from recent polyelectrolyte seeding experiments are in no way different from previous results.

VI. PRELIMINARY STUDY OF THE GROSS EFFECTS OF SEEDING AGENTS ON VEGETATION

A. Introduction

An exploratory program was initiated to assess the effects of fog seeding agents on vegetation. Three chemicals considered as candidates for fog seeding and tested on this program were sodium chloride (NaCl), disodium phosphate (Na_2HPO_4) and urea ($CO(NH_2)_2$).

The average amount of chemical deposited on ground or leaf surfaces from one seeding of a fog is estimated to be 1 g m^{-2}. The probable necessity of seeding a fog a number of times during one day and of seeding more than one day a week was taken into account in planning treatment rates. Therefore, treatments of 1, 3, 9, and 15 g m^{-2} were used. A dosage of 15 g m^{-2} twice a week corresponds to 30 fog seedings per week.* The range from an equivalent of 1 seeding per week to 30 seedings per week insured that a broad spectrum of seeding rates would be included.

It is known that vegetation types differ in their sensitivity to salt concentrations in the soil and salts applied directly to leaf surfaces. Many fruit species, for example, will exhibit leaf injury from irrigation waters containing as little as 70-100 ppm sodium chloride, whereas some forage and field crops can accumulate sodium chloride up to 5 or 10% dry leaf weight without developing leaf injury symptoms ("Salt Tolerance of Plants," 1964). One of the criteria was, therefore, the use of vegetation having at least moderate sensitivity to salts.

Since it was rather late in the growing season for the seeding of most crops, it was necessary to choose a plant type which would germinate, grow quickly and be frost-tolerant. The principal crop selected for study based upon the above criteria was rye grain which is fast-growing, frost-tolerant, and moderately tolerant of salts ("Diagnosis and Improvement of

*In this experiment 30 seedings are simulated in two days. In reality, 30 seedings would be spread more uniformly through the week and contact concentrations less severe.

Saline and Alkali Soils," 1954). When the plots were laid out, birdsfoot trefoil was observed to comprise a substantial proportion of the existing vegetation. Since birdsfoot trefoil is somewhat more sensitive to salts and is an important legume forage, it was decided that treatment of this existing trefoil would provide an auxiliary study.

The area in which experiments were conducted is located at the CAL, Newstead, New York property, about 20 miles east of Buffalo. A field about 115 m x 82 m was plowed, disked, and seeded with rye grain at a rate of 300 lbs/acre. A 10-10-10 fertilizer was applied at the rate of 200 lbs/acre. The field was nearly level, sloping less than 1% from south to north. Soil texture, drainage characteristics and horizonation were uniform enough for the entire field to be classified as the same pedologic soil type (Appleton Silt loam). The overall drainage class according to USDA soil survey standards is "somewhat poorly drained." Drainage was slightly better at the south end of the field.

Textures in the A horizon and B horizon were loam to silt loam. There was evidence of some eluviation of clay from the A horizon into the B horizon.

Experimentation was done in the field. Consequently, while there was good control on the amount and timing of chemical dosages and the type of vegetation treated, control could not be effected on important variables such as rainfall and temperature. Limited control of soil conditions was achieved by choosing sites which were essentially of the same pedologic soil types. Still, there are variations in the physical and chemical properties of the soil which are not distinguished in pedologic classifications. While some inferences can be made from the results of the experiments, they cannot be applied to a broad spectrum of environmental scenarios. Further experimentation encompassing differing temperature and moisture regimes with vegetation and soil types is needed.

B. Experimental Program

Within the seeded field four rye grain plots were chosen for treatments. These plots were located where the growth of rye grain appeared to be most uniform. The general locations of these plots within the seeded area are shown in Figure 36. Plots LA and LB were treated once a week and plots HA and HB were treated twice a week. The auxiliary legume plot in the north end of the field designated as LC was treated once a week. Individual treatment within each of the plots seeded with rye grain are shown in Figure 37. Individual treatments on the trefoil are shown in Figure 38. The control blocks were the basis for qualitative and quantitative comparison between treated and untreated areas.

Two-gallon hand-operated pump sprayers were used to apply saturated solutions of the chemicals to the test plots. The sprayers were calibrated such that the volume of liquid delivered per second was known. The time span in seconds could be calculated from the amount needed for each treatment and the delivery rate. Calibration was checked before each treatment to insure good control.

The spraying schedule commenced on September 23, about two weeks after germination of the rye grain crop. The dates on which spraying was done and the cumulative dosages on each of the treated blocks are given in Tables III and IV.

C. Agent Evaluation

Evaluation of treatments was performed on both a qualitative and quantitative basis. Qualitative evaluation was done by visual observation of plant damage and apparent stunted or increased growth. In addition, many color and black and white photographs were taken to document visual observations. Some of the black and white photographs are reproduced in this report. It was impractical to include the color photographs, however. These color prints are available for examination at Cornell Aeronautical Laboratory, Inc. (CAL). A listing of the prints on file at CAL is contained in Appendix B.

At the conclusion of the treatments, measurements of above ground biomass were made. One set of measurements was made within two weeks of completion of the spraying schedule (October 1969). A second set of

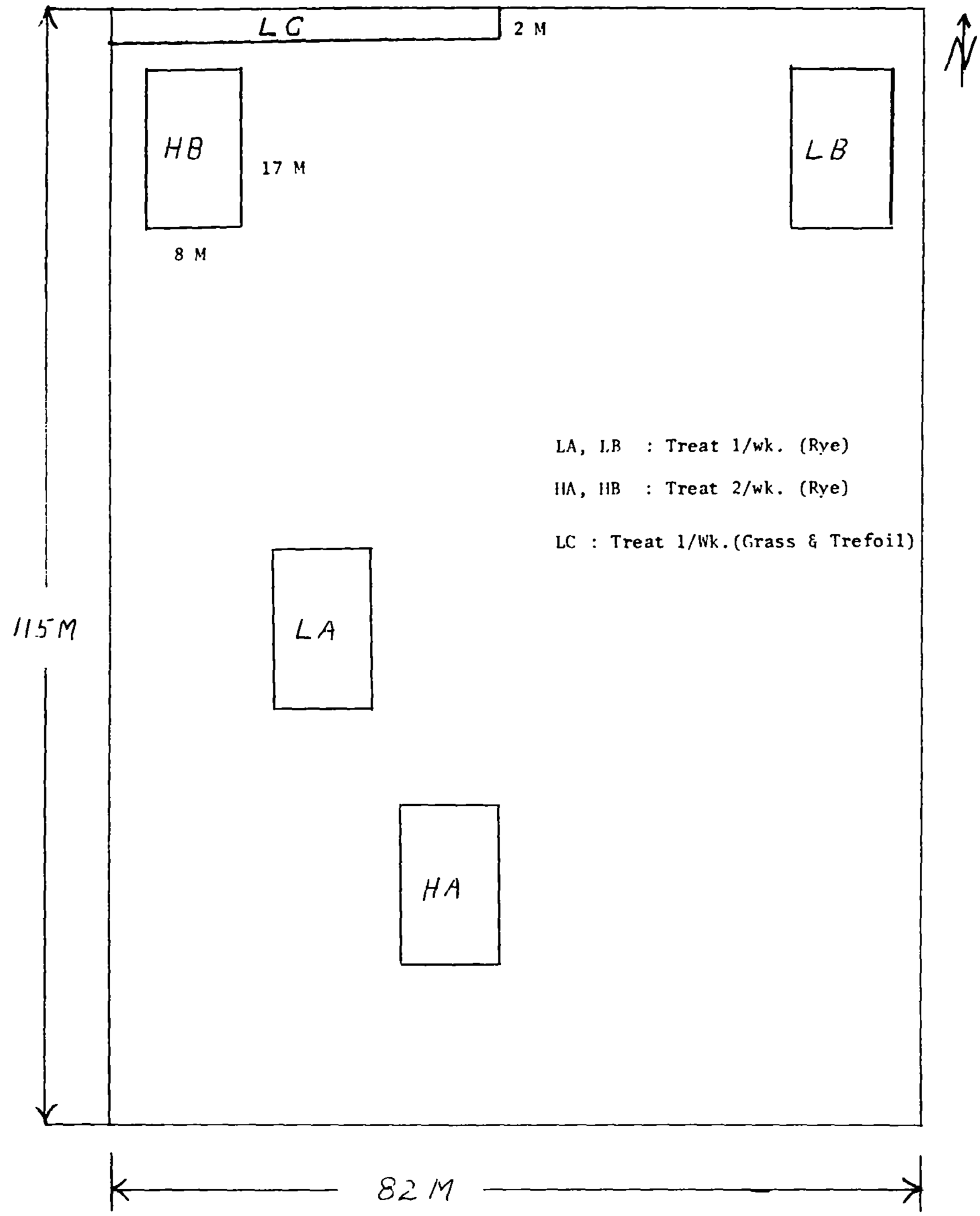


FIGURE 36
GENERAL LOCATION OF PLOTS AT NEWSTEAD SITE

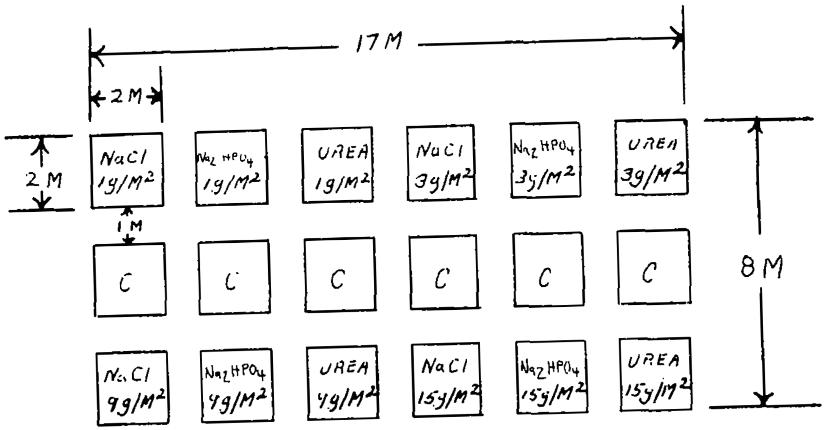


FIGURE 37

TREATMENTS ON RYE GRAIN (LA, LB, HA, HB)

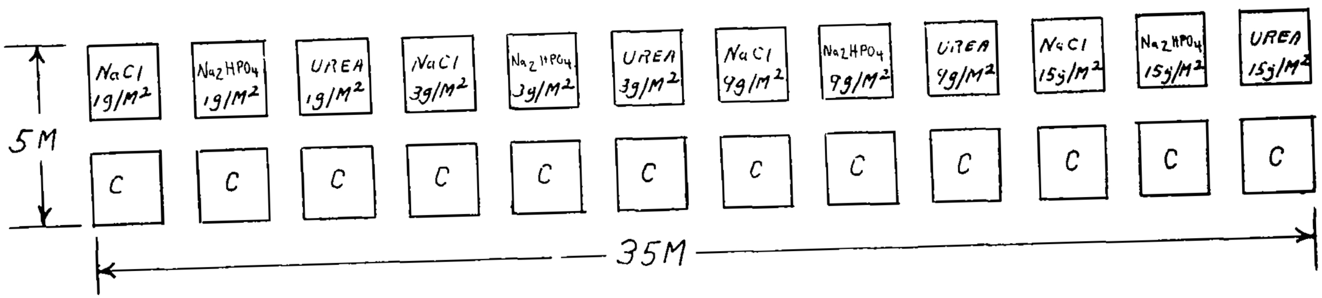


FIGURE 38

TREATMENTS ON BIRDSFOOT TREFOIL (LC)

TABLE III

CUMULATIVE DOSAGES, PLOTS LA, LB (RYE GRAIN) and PLOT LC (TREFOIL)

	Date	9/23	9/30	10/9	10/17
	1 gm/m^2	1 gm/m^2	2 gm/m^2	3 gm/m^2	4 gm/m^2
Sodium	3 gm	3	6	9	12
Chloride	9 gm	9	18	27	36
	15 gm	15	30	45	60
	1 gm	1	2	3	4
Disodium	3 gm	3	6	9	12
Phosphate	9 gm	9	18	27	36
	15 gm	15	30	45	60
	1 gm	1	2	3	4
	3 gm	3	6	9	12
Urea	9 gm	9	18	27	36
	15 gm	15	30	45	60

TABLE IV

CUMULATIVE DOSAGES, PLOTS HA, HB (RYE GRAIN)

	Date	9/23	9/26	9/30	10/6	10/9	10/14	10/17
	1 gm/m^2	1 gm/m^2	2 gm/m^2	3 gm/m^2	4 gm/m^2	5 gm/m^2	6 gm/m^2	7 gm/m^2
Sodium	3 gm	3	6	9	12	15	18	21
Chloride	9 gm	9	18	27	36	45	54	63
	15 gm	15	30	45	60	75	90	105
	1 gm	1	2	3	4	5	6	7
Disodium	3 gm	3	6	9	12	15	18	21
Phosphate	9 gm	9	18	27	36	45	54	63
	15	15	30	45	60	75	90	105
	1 gm	1	2	3	4	5	6	7
	3 gm	3	6	9	12	15	18	21
Urea	9 gm	9	18	27	36	45	54	63
	15 gm	15	30	45	60	75	90	105

biomass measurements was made when the rye crop contained mature grain (June 1970). The later biomass weighings are therefore indicative of the long-term effects which the various treatments had on the rye crop.

Qualitative Evaluation of Treatments

Qualitative comparisons were always made with reference to adjacent control plots since damage can be caused by factors other than the treatments (e.g., insect damage, nutrient deficiency, plant diseases, etc.).

An account of the visual observations is given here according to the chronology in which they were observed. Initial treatment was begun on September 23 about two weeks after germination of the rye grain. Since weather conditions probably had quite significant influences on vegetation responses to treatments, it was desirable to have some record of these conditions. Table V is a record of daily temperatures and rainfall at Buffalo Airport, located about 13 miles west of the test site. These records are believed to be representative of the conditions which existed at the test site for the duration of the experiment.

The initial treatments resulted in visible white salt coatings on foliage at high levels (i.e., 9 g m^{-2}, 15 g m^{-2}). A high proportion of the applied salts was probably washed off the foliage by a substantial rainfall on September 24 (0.64 inches recorded at Buffalo Airport). On September 26, no visual damage of the rye grain or trefoil was observed, but slight bleaching of wild strawberry and clover leaf tips which grew as weed plants was observed. A color photograph of this damage is on file at CAL.

On September 30, some necrosis of leaf tips on both HA and LA plots of rye grain and trefoil was observed at high dosages (9, 15 g m^{-2}). Urea appeared to do most damage at this stage, disodium phosphate practically none, and sodium chloride intermediate. On October 3, stimulation of growth was evident from urea treatments although necrosis of leaf tips was still evident. Slight burning of rye with disodium phosphate was noticed, but trefoil appeared unaffected by it. The most apparent damage was evident on trefoil with high dosages of sodium chloride.

TABLE V

WEATHER RECORDS* - BUFFALO MUNICIPAL AIRPORT - Sept. 23-Oct. 17, 1969

Date		TEMPERATURE (F^o) Average	Maximum	Minimum	RAINFALL (in.)
Sept.	23	63	75	51	T **
	24	58	65	51	.64
	25	52	54	49	T
	26	56	63	49	0
	27	56	61	51	0
	28	52	58	45	.01
	29	52	60	44	0
	30	59	66	51	0
Oct.	1	59	72	46	0
	2	65	70	59	.31
	3	59	66	51	1.00
	4	50	55	45	0
	5	55	70	40	0
	6	59	69	48	0
	7	61	67	54	.19
	8	56	66	46	.01
	9	53	65	41	0
	10	63	76	49	0
	11	69	80	58	.03
	12	60	66	53	0
	13	67	82	52	.04
	14	54	64	43	.06
	15	46	56	36	0
	16	50	62	38	.09
	17	49	53	44	T

* From Local Climatological Data, U.S. Dept. of Commerce, ESSA, Environmental Data Service

** Less than .01 inches.

By October 6, damage to trefoil from sodium chloride and urea at 15 g m^{-2} was quite evident. Color photographs of this damage are on file at CAL. However, damage to trefoil from these chemicals was less at 9 g m^{-2} and only slight at 3 g m^{-2}. Cumulative dosage on trefoil at this point was 2 g m^{-2}, 6 g m^{-2}, 18 g m^{-2}, and 30 g m^{-2}. Stimulation of rye grain growth with urea was very evident at the 3, 9, and 15 g m^{-2} levels. Semi-weekly sodium chloride treatments had apparently stunted the growth of rye grain to some extent.

One interesting observation was that the early damage to wild strawberries and clover had not increased appreciably.

By October 9, the damage to both rye and trefoil at high dosages did not appear greater than on October 6. A rainfall on October 7, one day after treatment on October 6, may have washed a high percentage of applied chemicals from the foliage. As with previous observations, damage from disodium phosphate was least evident.

On October 14, the birdsfoot trefoil appeared to be severly damaged from sodium chloride and urea treatments at the 9 and 15 g m^{-2} levels (cumulative dosages were now 3, 9, 27, and 45 g m^{-2} on the trefoil). Damage to rye grain, although not as severe, had increased considerably from October 9 when sodium chloride and urea were used at high dosage rates (9, 15 g m^{-2}). Although necrosis of leaf tips on both trefoil and rye grain from disodium phosphate was still relatively slight, it appeared that growth was somewhat stunted at higher dosages. The period from October 9 to October 14 was the warmest interval during the experiment and may have increased the rate of water movement from plant tissue to salt coatings, thus causing increased plasmolysis of leaf surfaces (exosmosis).

On October 15, a number of color pictures were taken to show comparative effects of the cumulative treatments. These photographs are also on file at CAL. Most of the trefoil treated with sodium chloride at a cumulative dosage of 27 g m^{-2} exhibited severe damage, whereas effects from disodium phosphate were only slightly evident. Comparison of the effects of cumulative dosages of 54 g m^{-2} of sodium chloride, disodium phosphate, and urea on rye grain indicate that necrosis and stunting is most evident from the sodium chloride treatment. Although some leaf tip burning was caused by the urea treatment, the promotion of a dense vigorous stand was evident.

It was decided to end the treatments on October 17 so that samples could be taken from the seeded and control plots before bad weather set in. Samples were taken from three of the four rye grain plots (LA, HA, and HB), but continuous bad weather precluded taking samples from the remaining rye grain plot (LB) or the trefoil plot (LC). Two samples consisting of the above ground foliage were taken from each treatment along with a number of samples from control plots. Each sample was obtained from a 1 ft^2 area. The undried samples were weighed to the nearest gram soon after harvest. These weights are recorded in columns (1) and (2) of Tables VI, VII, and VIII.

In the spring of 1970, periodic visits were made to the test plots to observe any residual effects of the chemical agents on new vegetative growth. From visual observation, it appeared that there was little residual effect of any of the chemicals on birdsfoot trefoil vegetative growth.

There was little observable difference between the appearance of rye grass control plots and plots treated once or twice a week at 1 and 3 g m^{-2} for all chemicals. However, there were observable differences on rye plots which received dosages of salt or urea the previous fall at rates of 9 and 15 g m^{-2} either once or twice a week. The salt-treated plots contained shorter, less densely spaced plants than the controls, whereas the urea-treated plots contained a denser, taller stand. The seed heads on the urea were also larger and more abundant than the control while many of the seed heads on the high dosage salt plots (9, 15 g m^{-2}) were smaller and contained fewer seeds. There did not appear to be any differences between the plots treated with disodium phosphate at 9 and 15 g m^{-2} and control plots. Figure 39 shows the rye grain harvested from plots treated once a week (LA) and twice a week (HA) with sodium chloride, urea, and disodium phosphate. The stunting effect of the salt treatments and invigorating effect of urea treatments are evident. The effects were more pronounced on plots treated twice a week as expected.

TABLE VI

BIOMASS ON PLOT LA*

	(1) Rep.A	(2) Rep.B	(3) $\overline{X}_t$	(4) $\overline{X}_t - \overline{X}_c$	(5) Level of Significance
Na Cl-1	67 g	63 g	65 g	+5 g	60%
-3	46	36	41	-19	80%
-9	34	32	33	-27	90%
-15	33	38	36	-24	80%
Urea -1	61	65	63	+3	NS**
-3	83	73	78	+18	80%
-9	102	103	103	+43	95%
-15	208	258	233	+173	90%
Na_2HPO_4-1	58	87	73	+13	60%
-3	47	40	44	-16	80%
-9	55	49	52	-8	60%
-15	45	44	45	-15	80%

* Average biomass ($\overline{X}_c$) of 10 control samples was 60 g with a variance (σ_c^2) of 313.

** Less than 50% level.

TABLE VII

BIOMASS ON PLOT HA*

	(1) Rep.A	(2) Rep.B	(3) $\overline{X}_t$ (Av.)	(4) $\overline{X}_t - \overline{X}_c$	(5) Level of Significance
Na Cl-1	55 g	69 g	62 g	-5 g	NS **
-3	32	46	39	-28	80%
-9	35	42	39	-28	90%
-15	24	31	28	-39	95%
UREA-1	77	85	81	+14	70%
-3	204	204	204	+137	99%
-9	59	93	76	+11	60%
-15	148	138	143	+76	99%
Na_2HPO_4-1	38	34	36	-31	90%
-3	51	70	61	-6	60%
-9	30	32	31	-36	95%
-15	45	54	50	-17	80%

* The average biomass ($\overline{X}_c$) of 6 control samples was 67 grams with a variance (σ_c^2) of 316.

** Less than 50% level.

TABLE VIII

BIOMASS ON PLOT HB*

	(1) Rep.A	(2) Rep.B	(3) $\overline{X}_t$	(4) $\overline{X}_t - \overline{X}_c$	(5) Level of Significance
NaCl-1	82 g	87 g	85 g	-144 g	90%
-3	124	154	139	-90	80%
-9	62	105	84	-145	95%
-15	119	97	108	-121	90%
Urea-1	169	108	139	-90	80%
-3	376	326	351	+122	90%
-9	219	385	302	+73	70%
-15	237	244	241	+12	NS **
Na_2HPO_4	105	92	99	-130	90%
-3	210	220	215	-14	NS
-9	141	107	124	-105	80%
-15	199	240	220	-9	NS

* The average biomass ($\overline{X}_c$) of 6 control samples was 229 g. with a variance (σ^2) of 5182.

** Less than 50% level

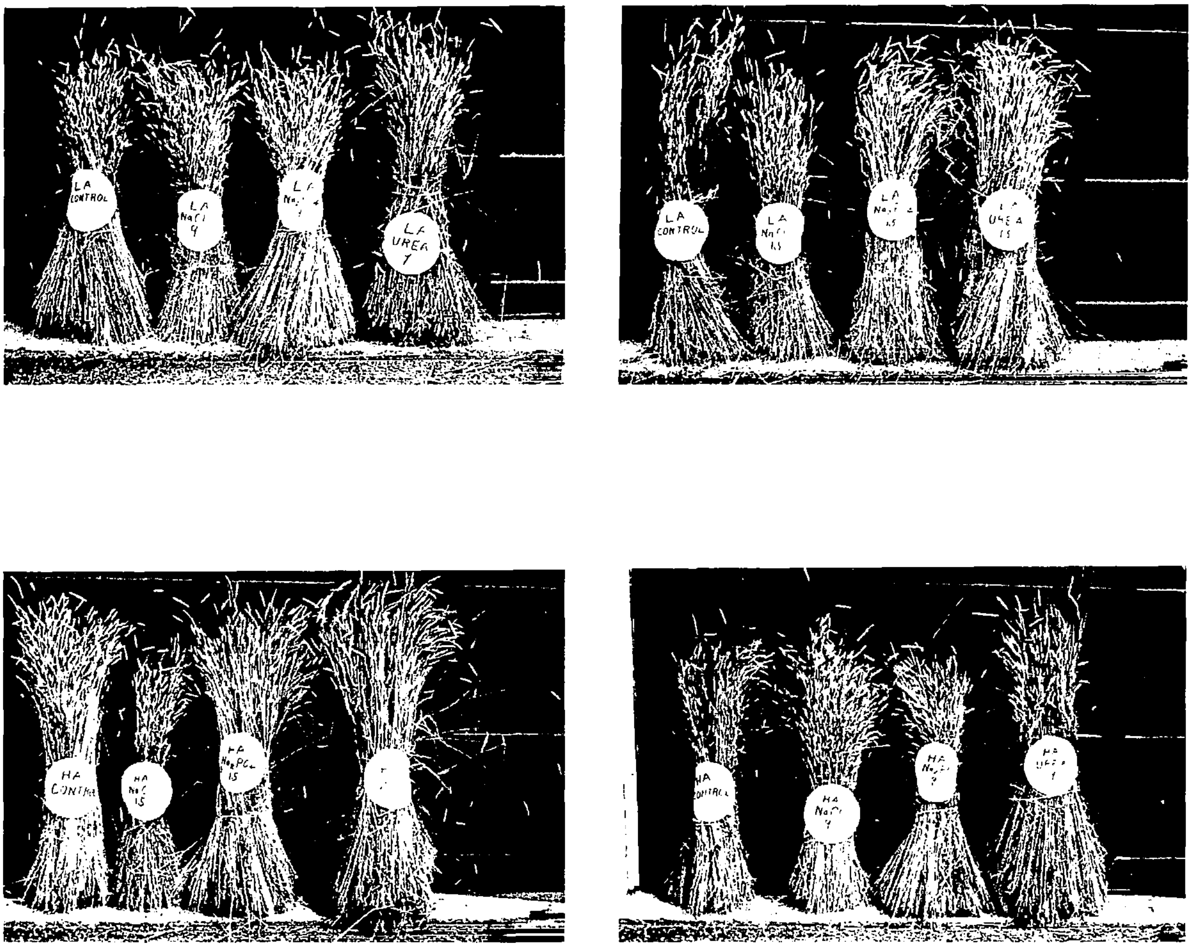


Figure 39 RYE GRAIN HARVESTED FROM TREATED AND CONTROL PLOTS - LA = TREATMENTS (gm^{-2}) ONCE PER WEEK, HA = TREATMENTS (gm^{-2}) TWICE WEEKLY

Quantitative Evaluation of Treatments

Differences in biomass yields between treatment samples and control samples collected upon the completion of the treatments in October 1969 are given in column (4) of Tables VI, VII and VIII. Percentage differences are given in Table IX. The significance of the difference between the means of the controls and the treatments is given in column (5) of Tables VI, VII, and VIII. Tests were made of the hypothesis that the means of two normal distributions are equal when the standard deviations are unknown and not necessarily equal (Bowker and Lieberman, 1959). The test statistic (t') is:

$$t' = \frac{\overline{X}_c - \overline{X}_t}{\sqrt{s_c^2/n_c + s_t^2/n_t}}$$

where X_c = average biomass of controls

X_t = average biomass of treatments

s_c^2 = variance of controls

s_t^2 = variance of treatments

n_c = number of controls

n_t = number of treatments

Degrees of freedom (v) is:

$$v = \frac{\left(s_c^2/n_c + s_t^2/n_t\right)^2}{\left(s_c^2/n_c\right)^2/\left(n_c+1\right) + \left(s_t^2/n_t\right)^2/\left(n_t+1\right)} - 2$$

The criteria for rejection of the hypothesis that $\mu_c = \mu_t$

was $t' \geqq t_{\alpha;V}$ when $\mu_c > \mu_t$

and $t' \leqq -t_{\alpha;V}$ when $\mu_c < \mu_t$

TABLE IX

PERCENTAGE DIFFERENCES IN BIOMASS BETWEEN TREATMENTS AND CONTROLS *

	HA	HB	LA
NaCl-1	-7%	-63%	+8%
-3	-42	-39	-31
-9	-42	-63	-45
-15	-58	-53	-40
UREA-1	+20	-39	+5
-3	+204	+53	+30
-9	+16	+32	+71
-15	+113	+5	+228
Na_2HPO_4-1	-46	-56	+21
-3	-9	-6	-26
-9	-53	-46	-13
-15	-25	-4	-25

$$* \ \% \text{ Increase or decrease} = \frac{\text{average control biomass} - \text{average treatment biomass}}{\text{average control biomass}} \times 100$$

where μ_c = mean of controls

μ_t = mean of treatments

V = degrees of freedom

$t\alpha$ = percentage points of the distribution

In June 1970 the rye grain crop reached maturity. At this time vegetation from the 9 and 15 g m^{-2} plots was harvested and above ground biomass measurements made. These data are given in Table X and graphed in Figure 40. Although the 1 and 3 g m^{-2} plots were not harvested, the curves shown in Figure 40 are probably realistic in that treatments at 1 and 3 g m^{-2} with any of the agents once or twice a week resulted in no visual ultimate biomass differences between treatments and controls.

Biomass measurements indicate that at about 9 g m^{-2} significant residual effects resulted from treating rye grain with sodium chloride, urea, and perhaps disodium phosphate. At 15 g m^{-2} these effects became more pronounced.

D. Discussion

In this discussion it is useful to distinguish between "short-term effects" and "long-range effects." In this context, short-term effects refer to the visual damage observed on leaf surfaces during the fall of 1969 and biomass measurements made in October 1969. Long-range effects refer to observations made in the spring of 1970 and biomass measurements made in June 1970. Short-term effects and long-range effects will be discussed in that order.

Short-term Effects

Qualitative observations and photographs described previously are firm evidence that there are pronounced short-term effects by the chemicals used under the test conditions. Necrosis of leaf tissue from sodium chloride, urea, and to a lesser extent, disodium phosphate is undeniable. Greater short-term damage to trefoil rather than rye grain is apparent when sodium chloride and urea are used. The degree of bleaching and necrosis appeared

TABLE X

Rye Grain Plot Harvests (6/29/70)

	Treatment (gm^{-2})	Biomass (gms)	% of Control
	Control	4204	100
	NaCl-15	2845	68
Plot	Na_2HPO_4-15	4933	117
	UREA-15	8050	191
IIA	Control	3133	100
	NaCl-9	3162	101
	Na_2HPO_4-9	3272	103
	UREA-9	5720	163
	Control	3690	100
	NaCl-15	3338	90
	Na_2HPO_4-15	4048	110
	UREA-15	6166	167
	Control	4103	100
	NaCl-9	3544	89
	Na_2HPO_4-9	3889	96
	UREA-9	5879	135

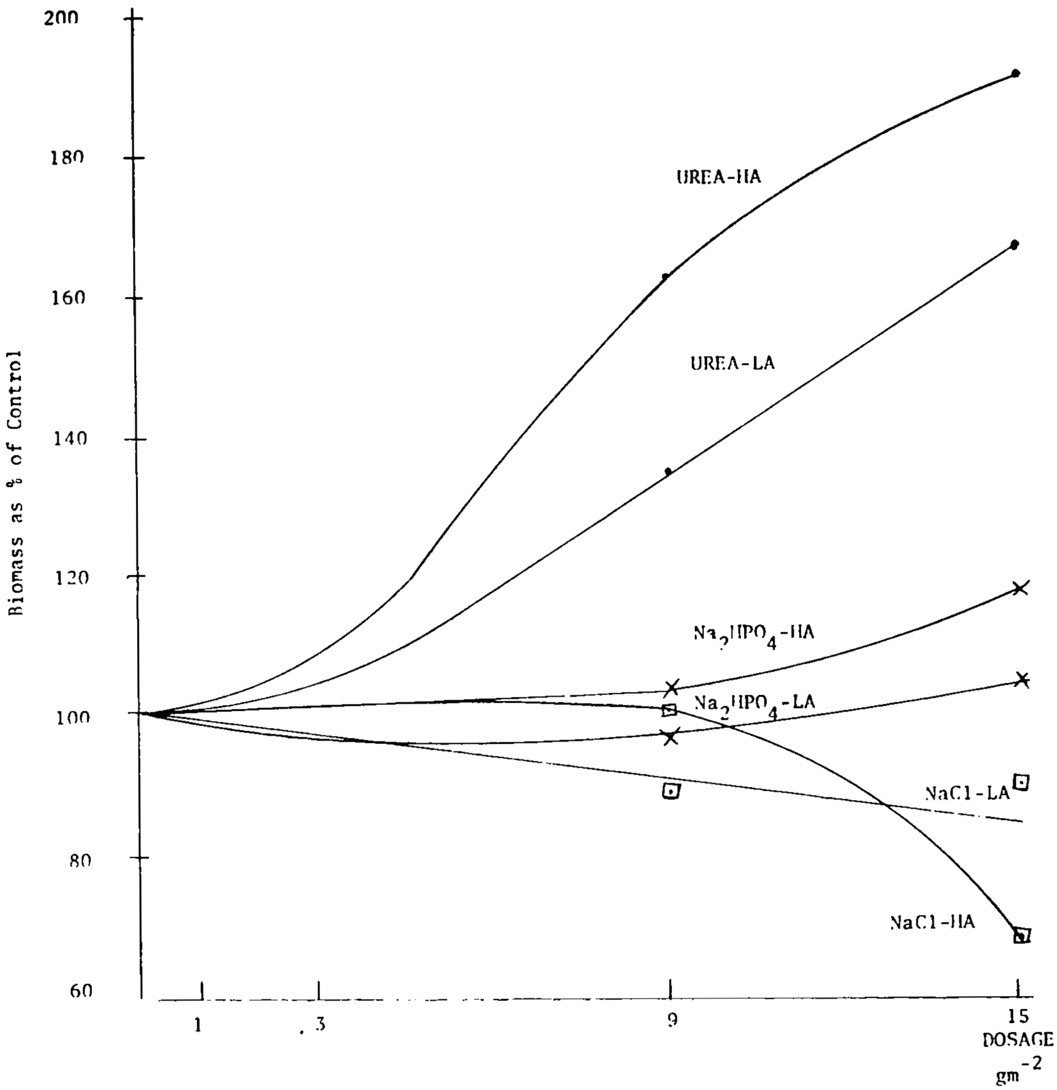


FIGURE 40

Biomass Yields as Percent of Control Plots to increase the most when dosage was increased from 3 to 9 g m^{-2}. Tissue damage and stunting of growth was most evident from sodium chloride. Urea obviously stimulated growth despite appreciable burning of leaf surfaces at higher dosages.

Quantitative measurements of above-ground biomass generally upheld field observations as shown in Tables VI through IX.

Table IX shows that 11 of 12 treatments with sodium chloride decreased biomass, 11 of 12 treatments with urea increased biomass, and 11 of 12 treatments with disodium phosphate decreased biomass. The significances of the differences in biomass effected by the treatments was not always great, as indicated in column (5) of Tables VI, VII, and VIII. The variability in the initial stand may have obscured some of the treatment effects. Plant densities after initial germination were not uniform throughout each plot. The greater effect of sodium chloride in suppressing growth was shown in the data analysis wherein 6 of the 12 sodium chloride treatments were significant at the 90% level. Only 3 of the disodium phosphate treatments were significant at this level. Visual effects from disodium phosphate were far less evident also.

The data show no consistent increases or decreases in biomass either from increased dosage of the individual chemicals or from once (LA) or twice a week (HA, HB) treatments. The limited control over experimental conditions does not allow the observation of meaningful differences.

Long-range Effects

As mentioned earlier, from visual observations there appeared to be no significant long-term effects of the agents on the growth of birdsfoot trefoil. The application of all agents at low dosages (i.e., 1, 3 g m^{-2}) appeared to have no long-term effects on the growth and yield of rye grain. However, at higher dosages (i.e., 9, 15 g m^{-2}), salt, disodium phosphate, and urea influenced the ultimate biomass yields as shown in Figure 40. There is little doubt that the fallout of urea from fog seedings in the long run would increase vegetative growth even if used at frequent high dosages.

Conversely, it appears that salt applied at dosages greater than about 9 g m^{-2} over a period of a number of weeks would result in ultimate decreases in yields of some crops.

The variation in response of different plant species to chemical treatment was evident. Birdsfoot trefoil which experienced greater immediate damage than rye grass to large doses appeared to recover and resume normal growth, whereas rye grain which was more tolerant initially experienced greater ultimate effects.

It must be cautioned that the results of this research cannot be extrapolated to temperature and moisture regimes differing greatly from those experienced during the conduct of these experiment. It is probable that under higher temperature, drier conditions or a combination of high temperature-dry conditions, effects of the various agents would be more detrimental.

E. Recommendations for Future Study

The long-term influence of salt on rye grain was rather surprising since it was expected that the highly soluble salt would be leached from the root zone by heavy winter snowfalls and early spring rains. A buildup of nitrogen in the soil was expected since soil microorganisms are known to accumulate nitrogen which later becomes available for plant assimilation. Accumulation of phosphate in the soil was expected since phosphate is known to quickly combine with minerals and organic colloids present in soil.

Consequently, soil samples were collected from all plots and will be analyzed for accumulation of chemicals applied in the fall of 1969. Accumulation of sodium or chlorine would be undesirable whereas accumulation of phosphorus and nitrogen would be desirable since these are essential plant nutrients.

There are a number of other experiments which would be beneficial. It is known that new seedlings are more sensitive to salts. Therefore, it may be necessary to treat some plots with candidate chemicals prior to or shortly after germination. It would also be useful to conduct experiments when temperatures are somewhat higher than those experienced during this series of tests. Responses to chemicals under drier conditions need further study also. Experiments should also be conducted on woody plant species which are commonly found in areas adjacent to airports. There are many species of commonly occurring hardwoods on the CAL, Newstead, Ashford, or Bethany properties which could be used in an experimental program.

Strict control of the amount of chemical sprayed on each block was realized in the experiments conducted this summer. However, no attempts were made to insure that droplet sizes simulated those that occur in real fog seedings. There is little doubt that many of the droplets from the sprayer tanks were considerably larger than those in actual seedings. The smaller drops in actual seedings may provide more even distribution of chemicals and consequently less severe local leaf tip burning. It is recommended that a spraying system be developed which will closely simulate actual droplet size distributions. This work can be best conducted in a greenhouse to eliminate uncontrollable influences from the natural environment.

VII. CLOUD DISSIPATION FOR THE TOTAL ECLIPSE OF MARCH 7, 1970

The occurrence of stratus clouds during a total eclipse poses an obvious threat to the optical data that scientists can acquire during such an event. At the request of NASA, Cornell Aeronautical Laboratory conducted a brief study to determine if cloud seeding procedures could effectively be used (if they were needed) to dissipate supercooled stratus clouds over a fairly well-defined area. The target area of interest for the March 7, 1970 total eclipse was Langley Field and the Back Bay National Wildlife Refuge located at the seashore approximately ten miles south of Virginia Beach, Virginia.

After brief consideration of the technical problems associated with the seeding plan, we pointed out that CAL was not properly equipped to perform this operation alone. The target areas were separated by too large a distance to permit the seeding operation to be carried out by one aircraft. Furthermore, the greatest probability of success would be achieved by seeding with larger quantities of dry ice than CAL could handle in its Aztec.

We suggested, therefore, that arrangements be made with Dr. Helmut Weickmann, Director of ESSA's Atmospheric Physics and Chemistry Laboratory to use one of ESSA's Research Flight Facility DC-6 aircraft for dry ice seeding at one site and that, if desirable, the CAL Aztec could be used for silver iodide seeding (at a reduced probability of success, depending on cloud temperature) at the second site. Agreement was reached to follow this plan and for CAL to coordinate technical activities directly with Dr. Weickmann.

According to the experimental plan that was established, the two aircraft and field crews met at Langley on 5 March and reviewed planned activities with air traffic control and meteorological personnel at the field. Plans were made for a dry run during the afternoon of 6 March. The DC-6 was to attempt to clear the Langley site using 2000 lb of dry ice and the Aztec to clear the Wildlife Refuge site using 2400 grams of AgI dispensed from

24 pyrotechnic flares (provided cloud temperatures were below -7°C). If warmer temperatures existed at cloud level, the Aztec would fly its complete seeding pattern but burn only two flares to check equipment.

On 6 March a persistent stratocumulus layer existed over the area with bases at 3000 ft, T = -1°C and tops at 4600 ft, T = -5°C. Measured winds (using DC-6 equipment) were from 326° to 344° at 17 to 22 knots at cloud level. Based on previous seeding experiments (Eadie, 1970), tracks were established 40 minutes upwind (about 15 nm) from the target area. ESSA seeded with 2000 lbs of dry ice dispersed between 1250 and 1409 local time and opened a clear hole approximately 10 nm long and 8 nm wide in the cloud. Probably because of a wind measurement error, the opening passed approximately 5 nm east of the target area. The Aztec seeded with two flares over a six-minute interval. A glaciated region in the cloud tops was observed but as expected at these warm cloud temperatures, a clear hole in the cloud did not develop.

It was decided on the basis of this dry run that, should clouds develop on 7 March, the DC-6 would initiate its flight early and seed a test pattern beginning one hour before nominal target time for the eclipse operation. Drift of the hole opened by the test pattern would be observed and the seeding track for the eclipse operation would be selected on the basis of observed drift rather than observed winds. As it happened, the weather on 7 March was clear with unlimited visibility and ceiling. The seeding operation was therefore not required.

On the basis of the experiment the previous day, we recommend that plans for operational cloud dissipation be included at locations where optical measurements are to be made of an eclipse, provided, of course, that climatological data for that region indicate that the probability of clouds is high. We recommend further that the seeding track be selected on the basis of observed drift of a test hole in the clouds. If possible, dry ice should be used as the nucleating agent. The length of the seeding tracks used in the dry run experiment (12 nm) appear to have been suitable for the conditions of that experiment. We recommend shorter track lengths be avoided if operationally feasible.

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APPENDIX A

Chemical information supplied by the manufacturer of each seeding agent tested is provided below:

1.	Dow Polyelectrolyte 'B'	Cross-linked polyacrylamide-potassium polyacrylate copolymer
2.	Dow Separan AP 30	80% polyacrylamide-sodium polyacrylate copolymer
3.	Calgon 822 A	Anionic polyelectrolyte (polyacrylamide acid form)
4.	Calgon 823 C	Cationic polyelectrolyte (polyacrylamide basic form)
5.	Hercules Reten 205	Polyacrylamide
6.	Hercules Reten 210	Cationic polyelectrolyte
7.	Hercules CMC-12MB	Sodium carboxymethyl cellulose
8.	Hercules EHEC-755	Ethyl hydroxyethyl cellulose
9.	Hercules Reten A-1	Anionic polyelectrolyte (polyacrylamide)
10.	Hercules Skylite	Polyacrylamide (basic)
11.	Hoechst 3	Polyvinyl compound of polyvinyl acidic amide
12.	Hoechst 4	Polyacrylamide
13.	Hoechst 5	Polyacrylic acid
14.	Hoechst 6	Polyvinyl acetate
15.	Hoechst 7	Polyvinyl alcohol
16.	Hoechst 8	Polyaddition product of PO + EO
17.	Hoechst 10	Polyaddition product of PO + EA
18.	NALCO LN-767-193A	High m.w. non-ionic acrylamide
19.	NALCO LN-767-193B	Anionic polymer - sodium salt of polyacrylamide
20.	NALCO LN-767-193D	Anionic polymer - sodium salt of carboxylic acid
21.	NALCO LN-767-193C	Cationic polymer - quarternary amine
22.	Ganex V-904	Polyvinylpyrolidone
23.	PEI-1120	High m.w. polymer formed from the polymerization of ethylenimine

APPENDIX B

Listing of Color Photographs*

File No.	Date	Treatment	Cumulative Treatment	Observation
1	9/30/69	Urea 15 g m^{-2}	30 g m^{-2}	Slight bleaching of wild strawberry and clover leaf tips
2	10/6/69	Urea 15 g m^{-2}	30 g m^{-2}	Bleaching of birdsfoot trefoil leaves
3	10/6/69	NaCl 15 g m^{-2}	30 g m^{-2}	Bleaching of birdsfoot trefoil leaves
4	10/6/69	NaCl 15 g m^{-2}	27 g m^{-2}	Stunted rye grass
		Urea 15 g m^{-2}	45 g m^{-2}	Vigorous rye grass growth
5	10/15/69	NaCl 9 g m^{-2}	27 g m^{-2}	Necrosis of birdsfoot trefoil leaves
6	10/15/69	Na_2HPO_4 9 g m^{-2}	27 g m^{-2}	Trefoil unaffected
7	10/15/69	NaCl 9 g m^{-2}	54 g m^{-2}	Sparse rye grass growth and necrosis of leaf tips
8	10/15/69	Na_2HPO_4 9 g m^{-2}	54 g m^{-2}	Rye grass growth affected very little

*Color prints and negatives on file at CAL

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