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EFFLUENT SAMPLING OF TITAN III C VEHICLE EXHAUST

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16. Abstract

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Based on the measurements, comparisons with the model were made in three areas: (1) assumption of cloud geometry at stabilization; (2) prediction of cloud stabilization altitude; and (3) prediction of the path of cloud travel. In addition, the importance of elemental analyses of the particulate samples is illustrated. Average particle loadings as high as 400 $\mu g/m^3$ (normal background of 20 to 30 $\mu g/m^3$) were detected in the field, and were found from elemental analyses not to be from the rocket exhaust.

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SUMMARY

Downwind in situ ground-level measurements of the exhaust from a Titan III C launch vehicle were made during a normal launch at the Air Force Eastern Test Range, Florida. The measurement activity was conducted as part of an overall program to obtain field data for comparison with the National Aeronautics and Space Administration's (NASA) multilayer dispersion model currently being used by that agency to predict the behavior of rocket vehicle exhaust clouds. Because of the seaward path of the exhaust cloud, the proximity of the launch pad to the sea, and the issuance of small-craft advisories for the area, all measurements were confined to land, ranging from the launch pad to approximately 2 kilometers downwind from the pad. Measurement systems included detectors for hydrogen chloride (HCl), carbon dioxide (CO_2), and particulates (Al_2O_3). In addition, airborne and ground-based optical systems were employed to monitor exhaust-cloud rise, growth, and movement. These measurement systems, located along the ground track (45° azimuth from the launch pad) of the exhaust cloud, showed no effluents attributable to the launch. Some hydrogen chloride and aluminum oxide were detected in the surface-wind direction (15° azimuth) from the pad.

Based on the measurements, comparisons with the model were made in three areas: (1) assumption of cloud geometry at stabilization; (2) prediction of cloud stabilization altitude; and (3) prediction of the path of cloud travel. In addition, the importance of elemental analyses of the particulate samples is illustrated. Average particle loadings as high as 400 $\mu g/m^3$ (normal background of 20 to 30 $\mu g/m^3$) were detected in the field, and were found from elemental analyses not to be from the rocket exhaust.

INTRODUCTION

During the launch of a rocket vehicle, the initial exhaust (typically, the first 10 to 20 seconds) from the vehicle generates a ground cloud in the immediate vicinity of the launch pad. As a result of the heat content of this cloud, it rises to a stabilization altitude and drifts and diffuses with the prevailing winds. This stabilization altitude is typically 500 to 3000 meters depending upon the buoyancy (heat content) of the cloud and the height of the surface mixing layer. When the cloud reaches the stabilization altitude, it

is termed "a stabilized ground cloud" and is trapped between the Earth's surface and the top of the surface mixing layer. Initially, the cloud is composed of those species generated by the rocket-motor exhaust; however, as the cloud rises, stabilizes, and drifts with the wind, it entrains large quantities of atmospheric air. In response to the National Environmental Policy Act of 1969 and the concern for the fate of rocket-vehicle exhaust in the troposphere, NASA has developed a diffusion model (ref. 1) to predict the downwind dispersion and ground-level deposition of exhaust effluents from the stabilized ground cloud. NASA is concerned with the prediction of those meteorological conditions under which the deposition from the stabilized ground cloud may present a potential environmental impact, especially in the troposphere. The primary objective of this investigation was to obtain ground-level effluent measurements of the Titan III C ground cloud for the purpose of generating a data base for comparison with effluent predictions from the model. A secondary objective was to document the physical characteristics of the ground cloud from formation to dissipation. The measurement activity is one of many launch-vehicle monitorings being conducted by NASA.

This report summarizes the effluent measurements attained during the joint rocket-vehicle effluent-dispersion monitoring activity for the Titan III C (Test 9433) launch conducted by NASA, Marshall Space Flight Center (MSFC), Kennedy Space Center (KSC), and Langley Research Center (LaRC). The Titan III C was launched from the Air Force Eastern Test Range (AFETR) launch complex 40 (LC-40) on December 13, 1973, at 2357 UT (1857 EST).

The program included in situ ground-level measurements of the dispersion of the Titan III C exhaust effluent from 100 meters to approximately 2 kilometers from the launch point. Instrumentation consisted of measurement systems for hydrogen chloride, particulates, and carbon dioxide. In addition, airborne and ground-based optical systems were used to record the rise, growth, and dispersion of the ground effluent cloud. Preflight meteorological and dispersion predictions starting at T - 5 days and continuing up to T - 1 hour were used to site the instrumentation and to design the sampling activity. The postflight calculations (based on launch-time meteorology) of the dispersion of the ground cloud were made using the MSFC multilayer diffusion model (ref. 1) and are summarized herein.

The authors acknowledge the cooperation of the Kennedy Space Center, the United States Air Force, and their respective contractors during the measurement program.

ABBREVIATIONS

AFETR Air Force Eastern Test Range

EST Eastern Standard Time

KSC	Kennedy Space Center
LaRC	Langley Research Center
LC	launch complex
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
ppmv	parts per million by volume
S	secondary site
SRM	solid rocket motor
T	launch time
UT	universal time
μg	10^{-6} gram

PROGRAM DESCRIPTION

Launch Vehicle

The Titan III C launch vehicle was developed by the United States Air Force for space launches at the Air Force Eastern and Western test ranges. The launch vehicle consists of a three-stage core using a liquid-propellant propulsion system and two solid rocket motors (Stage 0) attached on opposite sides of the core. Stages I, II, and III are ignited at altitude (above surface mixing layer); only Stage 0 with the two solid rocket motors (SRM) contributes effluent to the ground cloud. Each solid rocket motor is approximately 3 meters (10 feet) in diameter, 26 meters (86 feet) tall, and weighs 2.2×10^5 kilograms (250 tons). The two solid rocket motors develop more than 7 meganewtons (2.4×10^6 pound-force) of thrust at lift-off. The solid propellant consists of an ammonium perchlorate oxidizer, an aluminized synthetic-rubber binder fuel, and various other additives to stabilize mass and to control the burning rate.

The exhaust effluent emitted by the Stage 0 solid rocket motors consists mainly of hydrogen chloride, aluminum oxide, and carbon monoxide. The quantity of vehicle exhaust contributing to the formation of the ground cloud is calculated on the basis of the

stabilization altitude of the cloud, the trajectory of the vehicle, and the burn rate of the motors. (See refs. 1 and 2.) Exhaust quantities are shown in table I for stabilization altitudes of 300 meters and 1400 meters.

Prelaunch Effluent Predictions

Prelaunch effluent predictions using the dispersion model (ref. 1) and meteorological forecasts, starting at T - 5 days and continuing to T - 1 hour, were used to design the effluent sampling experiment. Table II briefly summarizes the prelaunch predictions from T - 11 hours to T - 1 hour. Each set of predictions, as discussed in the next section, was used to design a particular phase of the effluent sampling experiment.

Location of Instruments

The azimuth and distance from the launch pad of each of the 16 ground sites used in this effluent sampling study are shown in figure 1 and table III. All sites except site AA were selected on the basis of prelaunch dispersion predictions. Site AA, a permanent site for all LC-40 launches, is located on the launch-complex perimeter road. Because of the location of LC-40, there was a high probability that the ground cloud would drift towards the ocean. In order to cover this possibility, two seacraft were obtained as sampling platforms. As shown in figure 2, the T - 11 hour prediction showed the effluent cloud moving towards the ocean. Based on this prediction, procedures were implemented to prepare the seacraft for a sampling mission. The final commitment of the seacraft sampling was withheld until after the T - 9 hour prediction. The T - 9 hour prediction also indicated a seaward track for the cloud and at approximately T - $8\frac{1}{2}$ hours, the final commitment of the seacraft to a sampling mission was made. However, at about T - 8 hours (prior to seacraft departure) small-craft advisories were posted for the AFETR area, preventing the use of the seacraft for the effluent sampling mission. These small-craft advisories remained in effect through the launch. The T - 9 hour prediction was also the basis of the selection of site locations for instrument sets S-1 to S-11. As the result of the predicted cloud path, the proximity of the launch pad to the ocean (fig. 2), and the aborted seacraft sampling mission, all instrument sites were restricted to a single road which paralleled the coastline. Sites could not be located at greater radial distances from the pad, and multiple instrument sets could only be used for covering potential shifts in the wind direction. (Normally all instrument sites would be within 30° of the predicted cloud path and at three radial distances from the launch pad.) Location instructions for these sites were given to the field teams at about T - 7 hours. The T - 6, T - 4, T - 2, and T - 1 hour predictions were nearly identical to the two earlier predictions, showing only slight variations in cloud direction of travel. These predictions were used in the following ways to finalize the effluent monitoring mission:

T - 6 hour prediction.- This prediction was used to select instrument sites CC to FF with location instructions being given to the field teams at approximately T - $4\frac{1}{2}$ hours. In addition, based on cloud speed and predicted effluent concentrations, an initial effluent sampling schedule was developed and communicated to the field teams at about T - 4 hours.

T - 4 hour prediction.- This prediction was used to refine the sampling schedule developed from the T - 6 hour prediction. This sampling schedule was communicated to the field teams at about T - 3 hours in order that final instrument adjustment could be made just prior to the departure of the field teams from the launch danger area.

T - 2 hour prediction.- This prediction was used to develop the initial flight plan for the photographic aircraft and to furnish the ground optical-tracking teams with cloud direction, speed, and stabilization data. These data were communicated to the field units at about T - 1 hour, just prior to aircraft departure.

T - 1 hour prediction.- This was the last prediction on the cloud behavior, and hence was used to update the sampling schedules for the ground instrument sites, the aircraft flight plan, and that data required by the ground optical-tracking teams. These final updates were completed by approximately T - 15 minutes.

The postlaunch effluent predictions using the MSFC dispersion model and the actual launch-time meteorology are presented in the "Results" section of this report.

Measurement Systems

Effluent measurement systems.- All 16 ground sites were within the launch danger area (area that is cleared of all personnel during launch) and were remotely activated. The remote activation either turned sampling equipment on and off or only activated the instrument recorders. The equipment used at each site is listed in table IV. The sampling capabilities of each type of unit and any laboratory analysis required in analyzing the data are described in table V. References 3 to 5 describing the operation of the various instruments are given in column 1 of table V. All instruments are commercially available and well documented. Where possible the performance parameters given in table V are based on laboratory and field experience with each sampling unit. In lieu of this experience, manufacturer values are quoted. For the particle instrumentation, the range is stated in particle size rather than particle mass. Particle analysis was directed at: (1) the identification of chemical elements and their relative abundance using neutron activation analyses (ref. 5); (2) the determination of mass loading using gravimetric analysis; and (3) the determination of particle size using microscopic counting techniques. Appropriate background samples were taken prior to launch using selected instruments and are presented in the "Results" section.

Optical systems.- Two optical systems were used to document the formation, rise, growth, and downwind track of the ground cloud. The first optical system, consisting of three ground-based tracking cameras located as shown in figure 3, was used to track the centroid of the cloud from T - 0 until dissipation. Tracking was done visually by the camera operators and cloud photographs were taken at 10-second intervals. (The photographs were unsatisfactory because of the lack of lighting for the nighttime launch.) The tracking-camera readouts were used to calculate the location of the cloud centroid in three-dimensional space as a function of time. The three cameras were synchronized, giving the cloud location at 10-second intervals. The tracking-camera locations were selected so that the cloud, regardless of the direction of travel, was always in the field of view of at least two cameras. Figure 3 shows the field of view for these cameras. A second optical system consisting of an infrared imaging system was located in an aircraft at an altitude of 3 kilometers (10 000 feet). The imaging system was dual pass, imaging in the wavelength ranges of 2 to 5 microns and 8 to 14 microns. The flight path of the aircraft is shown in figure 4. This flight path was based on airborne visual-cloud sightings and/or ground-based directions.

RESULTS AND DISCUSSION

Postlaunch Effluent Calculations

Effluent dispersion calculations were made after the launch using the launch-time meteorological conditions so that the model could be compared with the effluent measurements and the observed cloud behavior. These effluent calculations were performed by MSFC using both model 3 and model 4 (see ref. 1 for a discussion of the differences between model 3 and model 4), and the meteorological sounding taken at T + 4 minutes. The basic difference between the two models is that model 3 assumes an ellipsoidal cloud shape at stabilization, whereas model 4 assumes a conically shaped cloud at stabilization. Figure 5 depicts this difference. In addition, model 4 divides the surface mixing layer into sublayers and distributes the exhaust effluents among the various sublayers. Model 3 does not subdivide the mixing layer. The result of these differences is that model 3 predicts lower effluent concentrations in the near field (from launch pad to cloud stabilization) than those predicted by model 4. Since all the effluent measurements were in the near field (0.1 to 2 kilometers from the pad), the emphasis of the measurement and model comparisons will be in the assessment of the validity of model 3 and model 4 in this near field. Sites EE and FF provide the measurement locations for this comparison as these sites were nearest the center line of the cloud path and had instrumentation sensitive enough for the comparison. Table VI summarizes the model 4 predictions for sites EE and FF. Noting the instrument capabilities at sites EE and FF (tables IV and V), the predicted hydrogen chloride and aluminum oxide effluent concentrations in table VI are

greater than the detection limit of the instrumentation at these sites. Model 3 predictions for sites EE and FF resulted in effluent concentrations below the detection limit of the instrumentation (gaseous species) and below normal ambient background concentrations (particles).

Effluent Measurements

Throughout the monitoring program, appropriate background sampling was conducted to define the ambient particle loading and hydrogen chloride concentration in the AFETR area. Background sampling occurred at T - 2 days, T = 0 day, and T + 1 day. Background particle loading was typically 20 to 30 $\mu g/m^3$ and ambient hydrogen chloride concentrations were always below 0.05 ppmv, the lower detection limit of the hydrogen chloride instrumentation. The data in the tables and figures have been corrected for background.

Table VII summarizes the effluent measurement results at sites S-1 to S-11. As shown, positive results were obtained at S-2 for hydrogen chloride and at S-1 to S-5 for particles. Nuclepore concentrations shown in the table are average mass weights per cubic meter of air sampled, whereas hydrogen chloride dosages are total integrated values for the entire sampling period. All nuclepore filters and substrates used were weighed before and after launch in a class 100 clean room, and then only after the sample had equilibrated to the clean-room environment. All bubbler analysis was by a coulometric technique resulting in a detection limit of 50 ppmv-sec for the bubbler configuration used. Tables VIII to X summarize the effluent measurements at sites CC, EE, and FF, respectively. Data from the Andersen and High Volume samplers at these sites are not shown in the tables, as an insufficient sample was obtained for analysis. The carbon dioxide detector (the only instrumentation at site DD) showed no increase in carbon dioxide as the result of the launch.

As shown in tables VIII, IX, and X, the only data showing an increase in the effluent background as the result of the launch were the nuclepore readings at sites EE and FF. These two readings are inconsistent with the lack of positive data from other instrumentation at these sites; but, as is shown later, the nuclepore loadings at sites EE and FF were not the result of the launch. Figure 6 is a plot of the nuclepore data obtained during the launch. The number in the parentheses is the particulate mass loading (above background) measured at the site in $\mu g/m^3$. Also shown are the nuclepore data obtained at site AA (LC-40). As shown in the figure, all but one sample (S-10) showing above the ambient particulate loading occurred downwind from LC-40. Each of the samples showing above the ambient particulate loading in figure 6 was subjected to neutron-activation analysis to identify the chemical elements present. Approximately 15 elements were considered in the analysis and the results for the two elements (aluminum and chlorine)

known to be major constituents of the exhaust effluent are shown in table XI. Also included in the table is the analysis of the background samples taken at AFETR. As can be seen from the table, the sample at AA (because of its proximity to the launch pad, it is expected to yield a good sampling of the exhaust effluent) is rich in aluminum and chlorine; the background samples have only trace amounts of aluminum and chlorine. As shown in table XI, after removing the background contributions, the samples at EE, FF, S-1, S-5, and S-10 had negligible amounts of aluminum and chlorine. The source of the increased mass loading observed in these samples is unknown, but it has been concluded that these samplings were not of the exhaust effluent cloud. The apparent inconsistencies discussed earlier in regard to the nuclepore samples at EE and FF have been resolved, and all measurements at EE and FF are consistent, showing no measured effluent as the result of the launch. Figure 7 is a plot of the aluminum content of the nuclepore samples in micrograms of aluminum per cubic meter of air sampled. From this plot, it is clear that only those sites downwind (surface wind) from the pad detected particles attributed to the launch. (Site S-2 was the only site where the presence of hydrogen chloride was indicated.) The source of the effluents measured at these sites is the dispersion of the pad debris and effluents by the surface wind. This dispersion is not analytically described by the model (an insignificant part of the overall problem) and thus measurement and model comparisons are not possible.

From the measurements presented it is concluded that no significant quantities of effluents were measured at site EE or FF. Therefore, it would appear that the higher concentrations predicted by model 4 did not exist; and, based on the near-field measurements, model 4 may not be a realistic description of the cloud geometry at stabilization. Model 4 is at least a factor of 15 times higher for the gaseous species and a factor of 60 to 100 times higher for the particles as compared to the detection limits of the instruments. Model 3 predicted concentrations below the detection limits of the instrumentation, and, while the data supports these predictions, no definitive statement can be made for the validation of model 3.

Optical Measurements of Cloud Behavior

The ground-based tracking cameras optically tracked the exhaust cloud for approximately 12 minutes before visual contact was lost. The results of this tracking are shown in figures 8 and 9. The ground location of the centroid of the ground cloud at a given time is given in figure 8. The bars at each data point represent the 1 sigma standard deviation in the position of the cloud centroid at that time. As shown by the figure, the cloud path was observed to be on an azimuth of approximately 45^{o} from the pad as predicted by MSFC. Sites EE and FF are plotted in figure 8. Figure 9 is a plot of the altitude of the cloud centroid as a function of time. Again, the bars reflect the measurement uncertainties. As shown, the cloud stabilized at approximately 1400 meters and reached

stabilization altitude at approximately 5 minutes after the launch. This result can be compared with a predicted stabilization altitude of 534 meters based on the MSFC model at the T - 4 minute meteorology. This discrepancy is probably the result of the magnitude of the heat of reaction assumed for the exhaust products in the cloud-rise equation. MSFC predictions assumed no plume afterburning $(CO - CO_2 + \text{heat})$ and thus a low heat of reaction; however, with afterburning a higher heat value is used in the cloud-rise equation, resulting in cloud stabilization altitudes similar to those experimentally observed. Using the 5-minute stabilization time and the data of figure 8, the cloud stabilized at approximately 3 kilometers from the pad. The MSFC model predicted a stabilization point of 1.5 kilometers from the pad. However, this discrepancy is probably the result of the error in predicting the stabilization altitude, since the predicted distance of cloud stabilization from the pad is highly dependent on the predicted stabilization altitude.

The optical system in the aircraft did not satisfactorily image the stabilized ground cloud. The problems were three-fold: (1) the infrared system was not able to satisfactorily isolate the cloud from the background; (2) the field of view of the system did not encompass the entire cloud; and (3) the exhaust effluent above the stabilized ground cloud could not be distinguished from the ground cloud. However, visual observations from the aircraft did confirm a cloud path of approximately 45° from the pad.

CONCLUDING REMARKS

As the result of the cloud path being over the ocean and the small-craft advisory issued for the Air Force Eastern Test Range (AFETR) area, effluent measurements were confined to the near-field region prior to cloud stabilization. These measurements do not provide a basis of comparison with the Marshall Space Flight Center (MSFC) model predictions in the prime area of interest (after cloud stabilization). However, comparison of the measurements and the model does give information on three aspects of the model: (1) the assumption of cloud geometry at stabilization; (2) the prediction of cloud stabilization altitude; and (3) the prediction of the path of cloud travel.

Two theoretical descriptions of the cloud geometry at stabilization exist at this time. These descriptions are termed model 3 and model 4. Model 3 assumes that the ground cloud rises in its entirety off the launch pad and moves downwind to stabilization with an ellipsoidal shape at stabilization. With this model geometry, surface effluent concentrations prior to cloud stabilization are small, typically below measurable levels. Significant ground-level deposition of effluents only occurs after cloud stabilization (typically 3 to 5 kilometers from launch pad) if this model geometry is correct. Model 4 assumes the ground cloud does not entirely rise off the pad; it rises and expands while still in contact with the ground, until at stabilization it is conical in shape, extending from

ground level to stabilization altitude. With this assumption of cloud geometry, measurable surface effluent concentrations should exist from the launch pad to stabilization and beyond. Since the near-field measurements (0.1 to 2 kilometers from pad) showed few effluents attributed to the launch, model 4 appears to be an incorrect description of the cloud geometry for the meteorological conditions experienced. Measurements during future launches will be required to determine the validity of model 3 and the relative merits of model 3 and model 4 for other meteorological conditions. A final decision as to the best representation of the cloud geometry at stabilization should be based on far-field (poststabilization) data.

The predicted cloud-stabilization altitude was approximately 530 meters as compared to a measured stabilization altitude of 1400 meters. This discrepancy is attributed to the magnitude of the heat-of-reaction (heat content of the cloud) term used in the cloud-rise equations. Assuming no plume afterburning (low heat of reaction) in the cloud-rise equations, the predicted cloud stabilization altitude was 530 meters; however, if afterburning was considered, the predicted stabilization altitude would be higher. Results from future launches will have to be considered before a definitive answer to the question if and to what magnitude should afterburning be considered in the heat-of-reaction term of the cloud-rise equations.

As shown by this investigation, the path of cloud travel was satisfactorily predicted. The analytical techniques employed by MSFC and the meteorological soundings used in these predictions were satisfactory for the meteorological conditions existing for this launch.

Besides the above-mentioned areas of information about the model, two additional points should be noted about refinements in future measurement programs. First, the importance of elemental analysis of particulate samples is well illustrated in this investigation. Particles in ambient air originate from many sources and it cannot be assumed that an increase in particle loading is necessarily the result of the launch. Elemental analysis, although time consuming and expensive, must be performed on selected samples to verify the source. It is recommended for future monitoring programs that the data-reduction plan for particulate samples includes elemental analysis. Secondly, in the selection of sampling seacraft, the possibility of rough sea conditions must be considered. Studies must be performed to identify those sea conditions under which valid measurements can be obtained and appropriate seacraft must be used to ensure a sampling mission for these sea conditions. Small-craft advisories do not necessarily cancel a seaborne sampling mission; thus, future seacraft must not be restricted by small-craft advisories.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., May 29, 1975.

REFERENCES

1. Dumbauld, R. K.; Bjorklund, J. R.; and Bowers, J. F.: NASA/MSFC Multilayer Diffusion Models and Computer Program for Operational Prediction of Toxic Fuel Hazards. NASA CR-129006, 1973.

2. Hart, William S.: Predictions of the Terminal Altitude and Size of Large Buoyant Clouds Generated by Rocket Launches. SAMSO-TR-70-207, U.S. Air Force, May 1970. (Available from DDC as AD 707 110.)

3. Gregory, Gerald L.; Hudgins, Charles H.; and Emerson, Burt R., Jr.: Evaluation of a Chemiluminescent Hydrogen Chloride and a NDIR Carbon Monoxide Detector for Environmental Monitoring. 1974 JANNAF Propulsion Meeting, Volume I, Part II, CPIA Publ. 260 (Contract N00017-72-C-4401), Appl. Phys. Lab., Johns Hopkins Univ., Dec. 1974, pp. 681-704.

4. Reyes, Robert J.; Miller, Richard L.; and Beatty, David C.: Monitoring of HCl From Solid Propellant Launch Vehicles. 1974 JANNAF Propulsion Meeting, Volume I, Part II, CPIA Publ. 260 (Contract N00017-72-C-4401), Appl. Phys. Lab., Johns Hopkins Univ., Dec. 1974, pp. 705-722.

5. Hulten, William C.; Storey, Richard W.; Gregory, Gerald L.; Woods, David C.; and Harris, Franklin S., Jr.: Effluent Sampling of Scout "D" and Delta Launch Vehicle Exhausts. NASA TM X-2987, 1974.

TABLE I.- TOTAL WEIGHT[a] (METRIC TONS) OF EXHAUST PRODUCTS FROM ZERO STAGE OF THE TITAN III

Effluent	Weight for cloud stabilization of altitude of 300 meters[b]	Weight for cloud stabilization altitude of 1400 meters[c]
HCl	9.5	19.9
H_2O	3.3	7.5
CO	12.9	25.9
CO_2	1.2	2.9
Al_2O_3	15.4	29.3

[a] Data assumes no plume afterburning.

[b] For the Titan launch vehicle and a cloud stabilization altitude of 300 meters, the first 10 seconds of zero stage burn contribute exhaust effluent to the stabilized ground cloud.

[c] For the Titan launch vehicle and a cloud stabilization altitude of 1400 meters, the first 21 seconds of zero stage burn contribute exhaust effluent to the stabilized ground cloud.

TABLE II.- SUMMARY OF MSFC EFFLUENT DISPERSION PREDICTIONS, MINUS COUNT

T-minus time, hours	Cloud stabilization altitude, meters	Cloud path from LC-40, degrees, true	Peak HCl concentration, ppmv	Location of peak from LC-40, kilometers
T - 11	890	52	1.3	7.8
T - 9	730	48	2.1	6.0
T - 6	720	49	1.9	6.0
T - 4	720	49	1.9	6.0
T - 2	720	49	1.9	6.0
T - 1	530	40	3	5.3

TABLE III.- MEASUREMENT SITE LOCATION RELATIVE TO LAUNCH COMPLEX 40

Site designation	Azimuth, degrees	Distance from LC-40, kilometers
S-1	5.7	1.8
S-2	10.2	1.6
S-3	15.0	1.3
S-4	27.3	1.1
S-5	41.8	.8
S-6	60.9	.6
S-7	90.0	.6
S-8	117.7	.7
S-9	131.0	.9
S-10	141.3	1.2
S-11	147.0	1.5
AA	80.0	.1
CC	95.0	.7
DD	13.4	1.4
EE	66.5	.8
FF	45.0	1.0

TABLE IV.- EQUIPMENT SITE PLAN

Site designation	Instrument	Species
S-1 to S-11	Bubbler	HCl
	pH paper	HCl
	Nuclepore filter	Particles
AA	pH paper	HCl
	Nuclepore filter	Particles
CC	Microcoulometer	HCl
	Bubbler	HCl
	pH paper	HCl
	Mass monitor	Particles
	Andersen	Particles
	Nuclepore filter	Particles
	High volume sampler	Particles
DD	Infrared gas analyzer	CO_2
EE	Chemiluminescent detector	HCl
	Bubbler	HCl
	pH paper	HCl
	Infrared gas analyzer	CO_2
	Mass monitor	Particles
	Andersen	Particles
	Nuclepore filter	Particles
	High volume sampler	Particles
FF	Microcoulometer	HCl
	Bubbler	HCl
	pH paper	HCl
	Mass monitor	Particles
	Andersen	Particles
	Nuclepore filter	Particles
	High volume sampler	Particles

TABLE V.- INSTRUMENT CAPABILITIES

Instrument/species	Range	Detection limit	Response to 90-percent reading	Required analysis
Chemiluminescent detector/HCl (ref. 3)	0.05 → 50 ppmv	0.05 ppmv	1 to 5 sec	None
Microcoulometer HCl (ref. 4)	0.1 → 20 ppmv	0.1 ppmv	1 to 5 sec	None
Bubbler/HCl (ref. 5)	Greater than 50 ppmv-sec	50 ppmv-sec	Not applicable	Coulometric
pH paper/HCl (ref. 5)	Qualitative	1 ppmv	Not applicable	None
Infrared gas analyzer CO_2 [a]	1 to 50 ppmv above ambient	1 ppmv above ambient	2.5 sec	None
Mass monitor particles (ref. 5)	0.1 < diameter < 10 μm	10 $\mu g/m^3$	Less than 5 sec	None
Andersen/particles (ref. 5)	0.43 < diameter < 11 μm	50 μg	Not applicable	Gravimetric, neutron activation
Nuclepore filter particles (ref. 5)	Diameter greater than 0.01 μm	10 μg	Not applicable	Gravimetric, neutron activation
High volume sampler/particles (ref. 5)	Diameter greater than 0.01 μm	200 μg	Not applicable	Gravimetric

[a] Instrument specifications based on manufacturer's data.

TABLE VI.- MODEL 4 PREDICTIONS: T + 4 MINUTE METEOROLOGY SITES EE AND FF

General predictions:

Cloud path, deg	46.5
Cloud ground speed, m/s	11.3
Cloud stabilization altitude, m	534

Effluent predictions, site EE (maximum concentrations):

HCl, ppmv	0.8
CO, ppmv	1.4
CO_2, ppmv	0.1
Al_2O_3, mg/m^3	1.8

Effluent predictions, site FF (maximum concentrations):

HCl, ppmv	1.7
CO, ppmv	3.0
CO_2, ppmv	0.2
Al_2O_3, mg/m^3	3.8

TABLE VII.- EFFLUENT RESULTS: SITES S-1 TO S-11

Site	Activation time, T + minutes	Total run time, minutes	Bubbler (HCl), ppmv-sec	pH paper color change	Nuclepore[a] (particles), $\mu g/m^3$
S-1	T + 1.5	43	<50	No change	26.5
S-2	T + 1.5	42	180	No change	282.0
S-3	T + 1.5	41	<50	No change	168.0
S-4	T + 1.5	40	<50	No change	127.0
S-5	T + 0.9	9	<50	No change	244.0
S-6	T + 0.9	38	<50	No change	----
S-7	T + 0.9	36	<50	No change	----
S-8	T + 1.2	9	<50	No change	----
S-9	T + 1.2	9	<50	No change	----
S-10	T + 1.2	9	<50	No change	126.0
S-11	T + 1.2	9	<50	No change	----

[a] Dash identifies nuclepore filters that had no weight increase as the result of the launch.

TABLE VIII.- EFFLUENT RESULTS: SITE CC

HCl:	
Microcoulometer, ppmv	<0.1
Bubbler, ppmv-sec	<50
pH paper	No change
Particles:	
Mass monitor	Ambient background only
Nuclepore filter	Ambient background only

TABLE IX.- EFFLUENT RESULTS: SITE EE

HCl:	
Chemiluminescent, ppmv	<0.05
Bubbler, ppmv-sec	<50
pH paper	No change
CO_2:	
Infrared, ppmv	<1 above ambient
Particles:	
Mass monitor	Ambient background only
Nuclepore, $\mu g/m^3$	67.5

TABLE X.- EFFLUENT RESULTS: SITE FF

HCl:	
Microcoulometer, ppmv	<0.1
Bubbler, ppmv-sec	<50
pH paper	No change
Particles:	
Mass monitor	Ambient background only
Nuclepore, $\mu g/m^3$	436

TABLE XI.- RESULTS OF NEUTRON-ACTIVATION ANALYSIS:

ALUMINUM AND CHLORINE

Sample designation	Mass loading,[b] $\mu g/m^3$	
	Aluminum	Chlorine
BS[a]	0.24	1.30
AA	896.6	73.6
EE	0	0
FF	0	0
S-1	.08	0
S-2	.68	.90
S-3	.67	1.38
S-4	4.28	.73
S-5	0	0
S-10	0	0

[a] BS – Background sample (average of 8 samples).

[b] For launch samples corrections for background contributions have been applied.

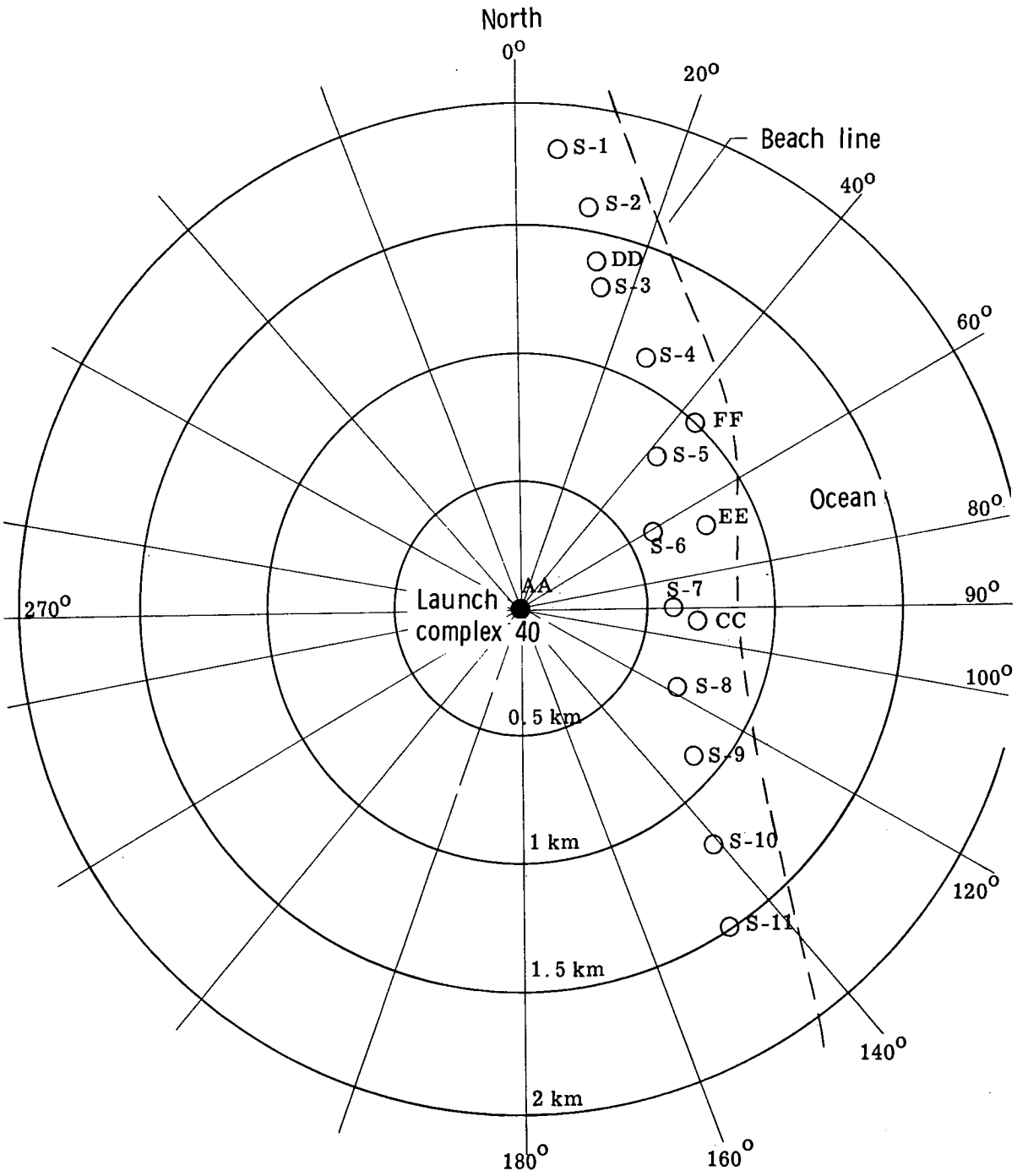

Figure 1.- Instrument site location.

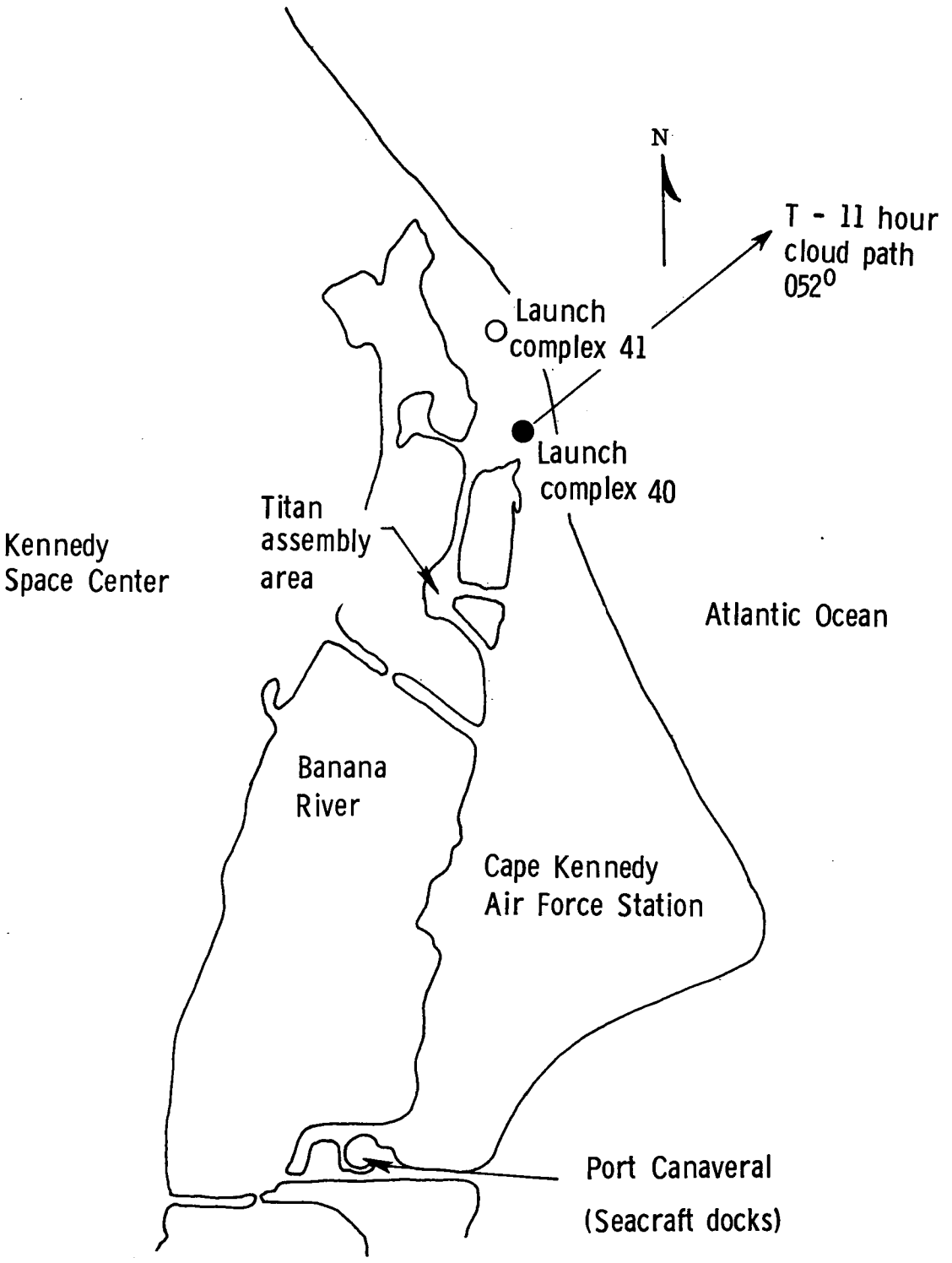

Figure 2.- Predicted cloud path. T - 11 hour calculation.

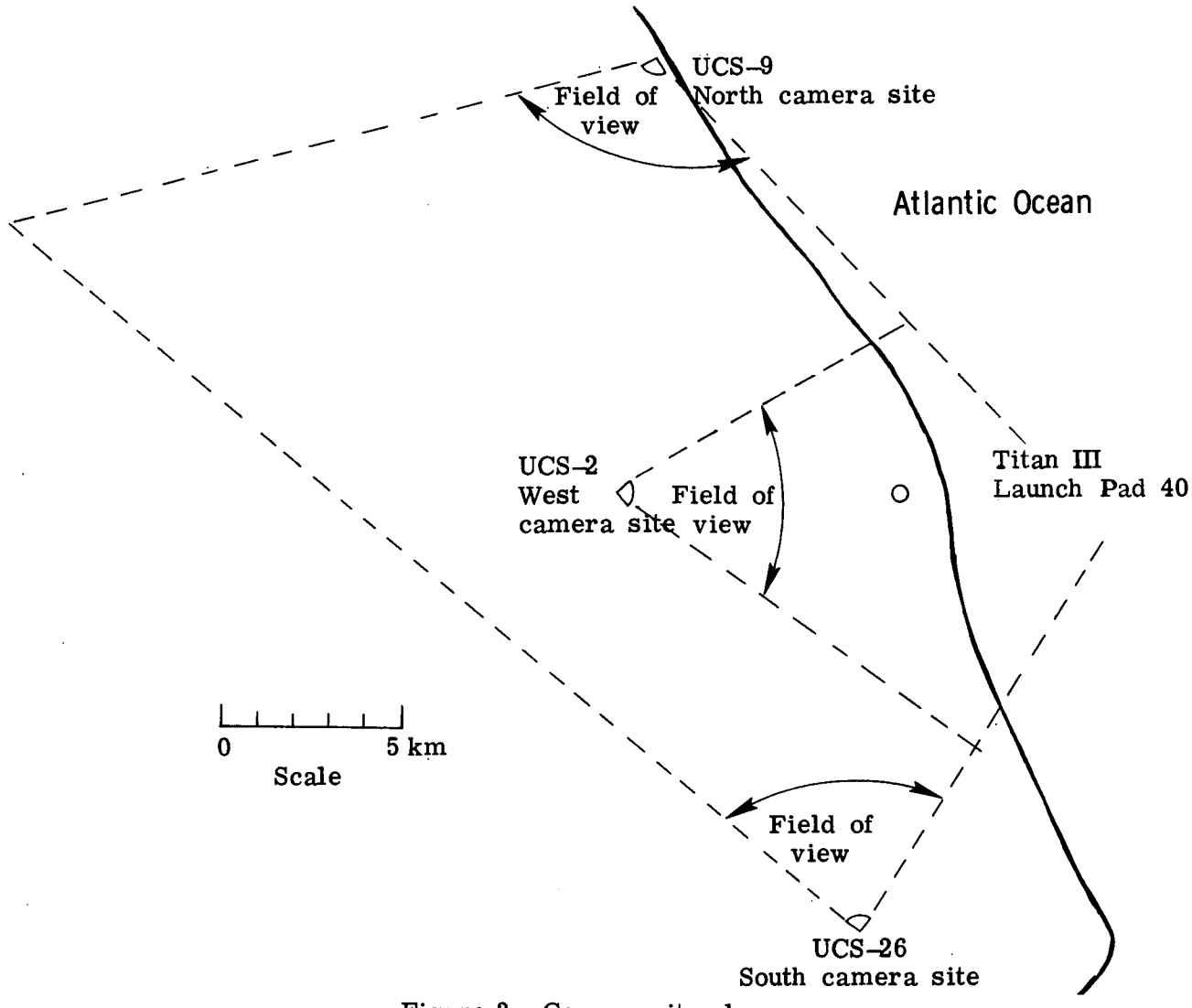

Figure 3.- Camera site plan.

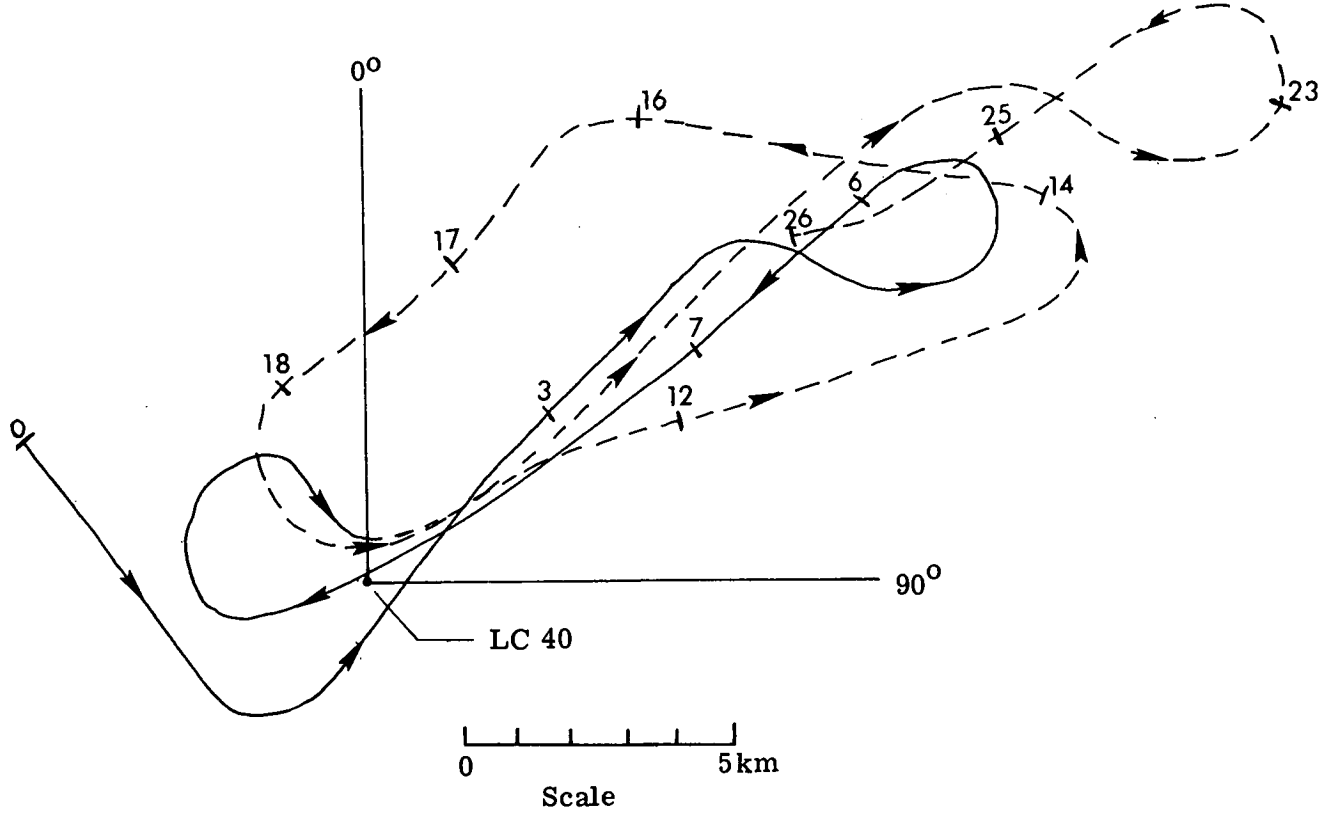

Figure 4.- Aircraft flight path. T = 0 to T + 26 minutes. (Numbers indicate time T + minutes.)

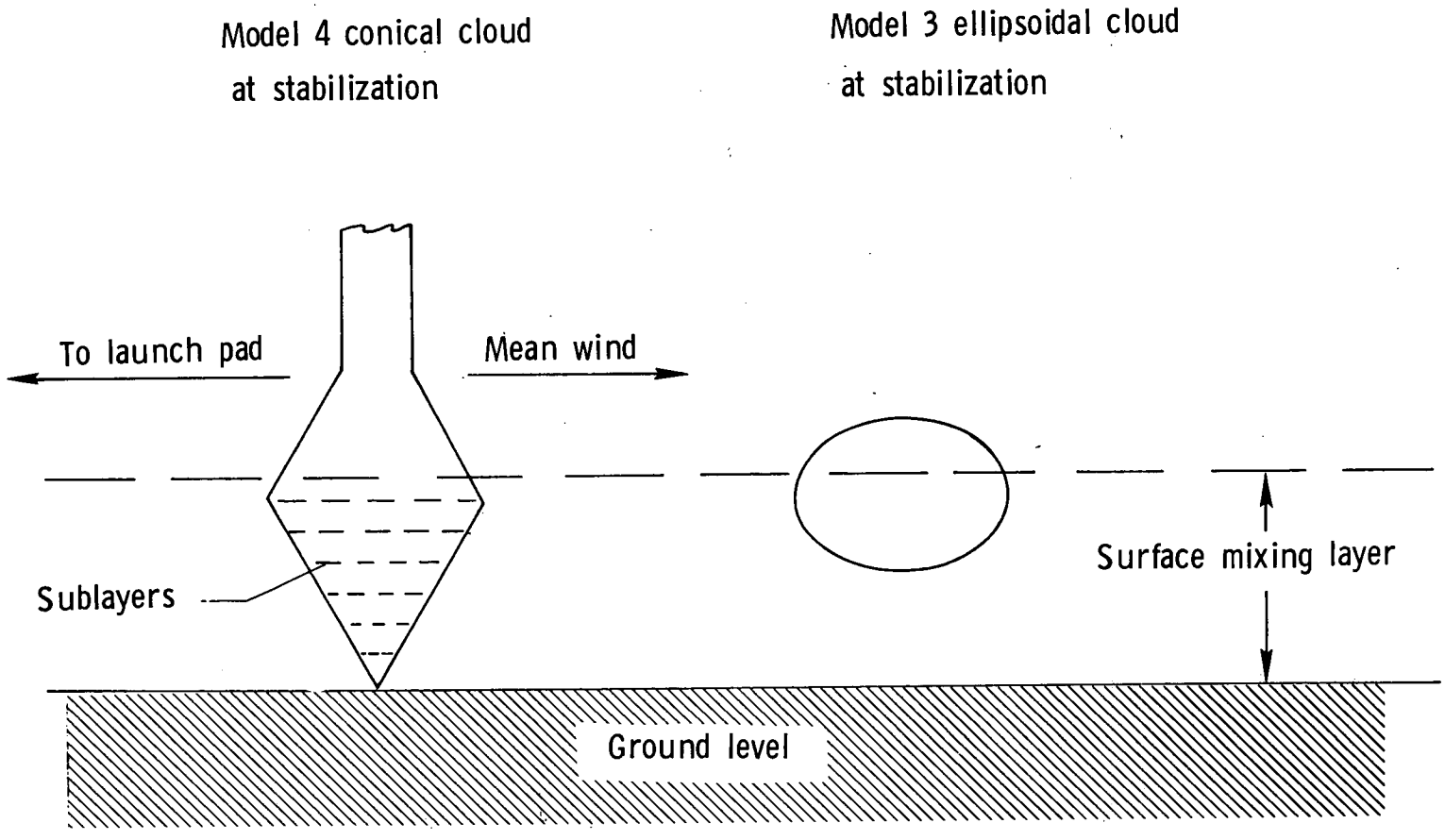

Figure 5.- Stabilized ground cloud geometries used in the multilayer diffusion model.

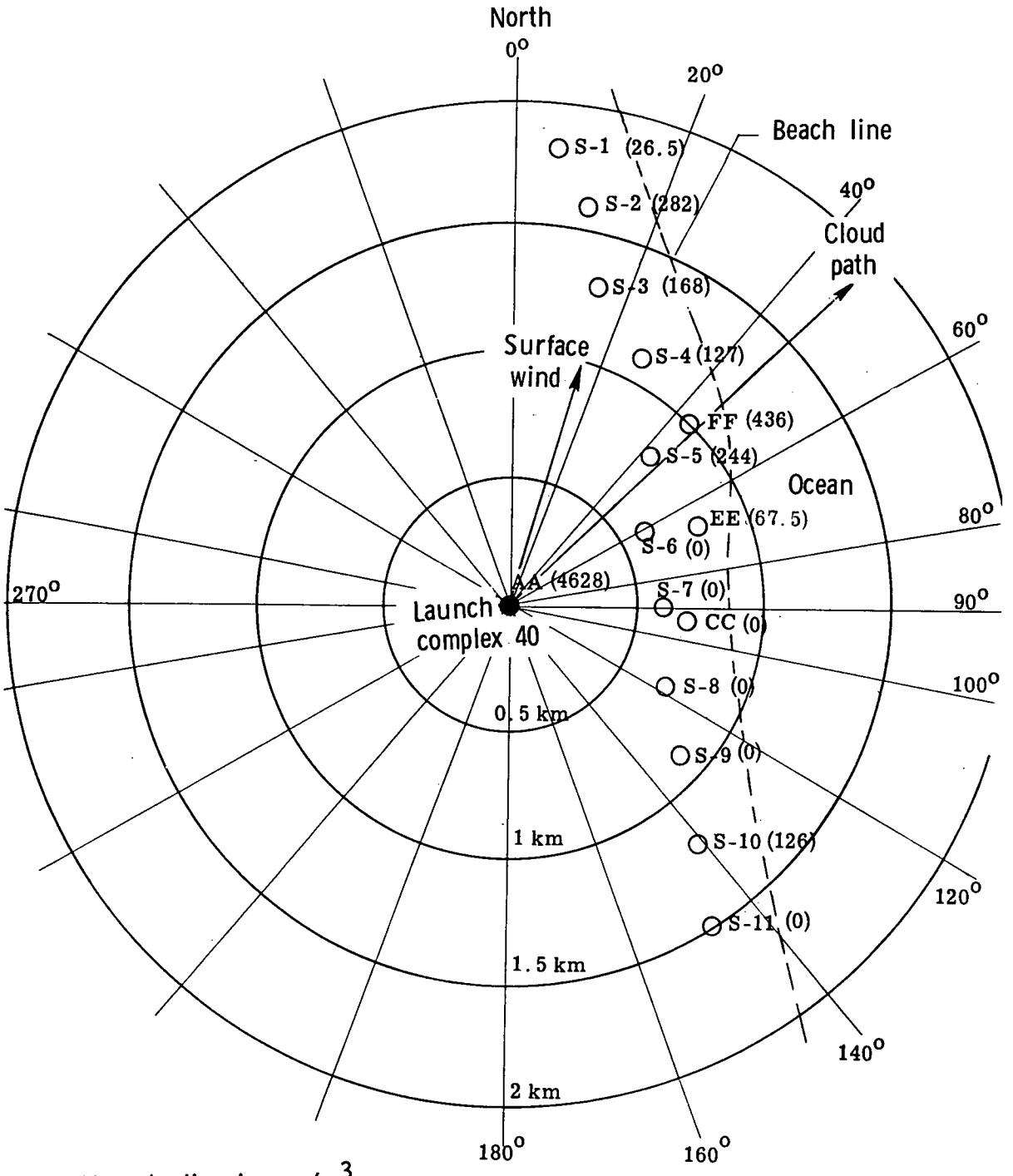

Figure 6.- Nuclepore results.

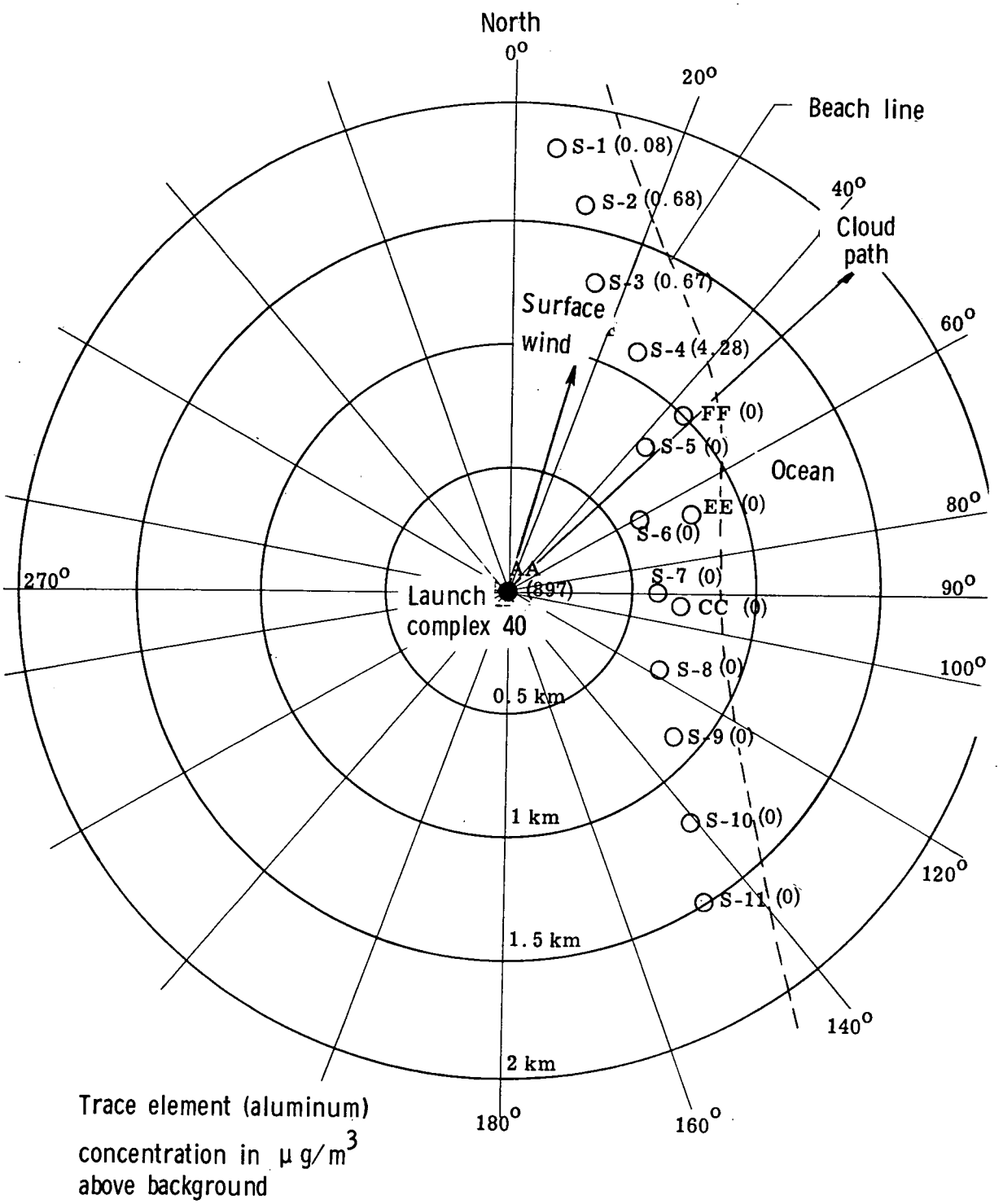

Figure 7.- Nuclepore results for aluminum.

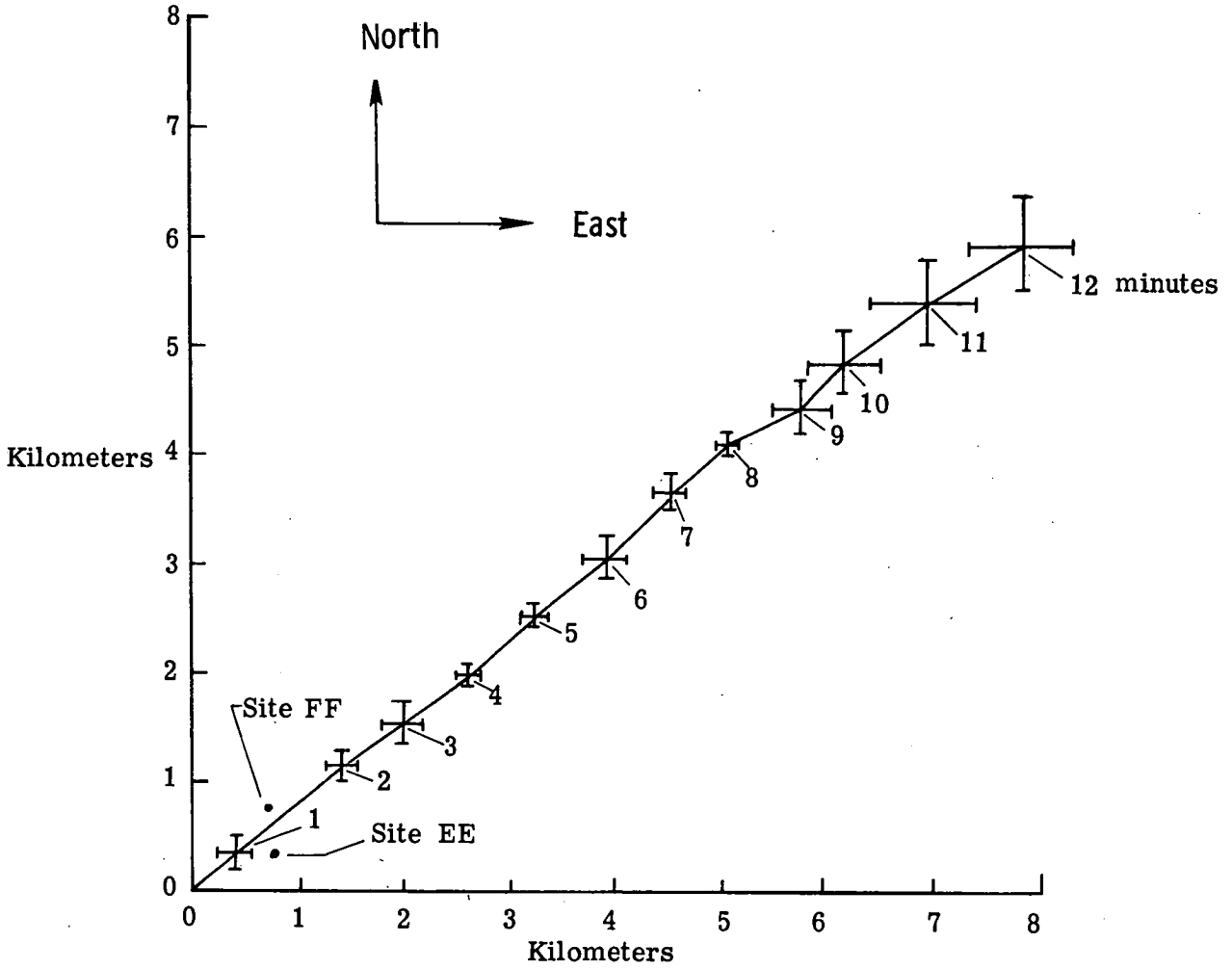

Figure 8.- Ground track of stabilized ground cloud.

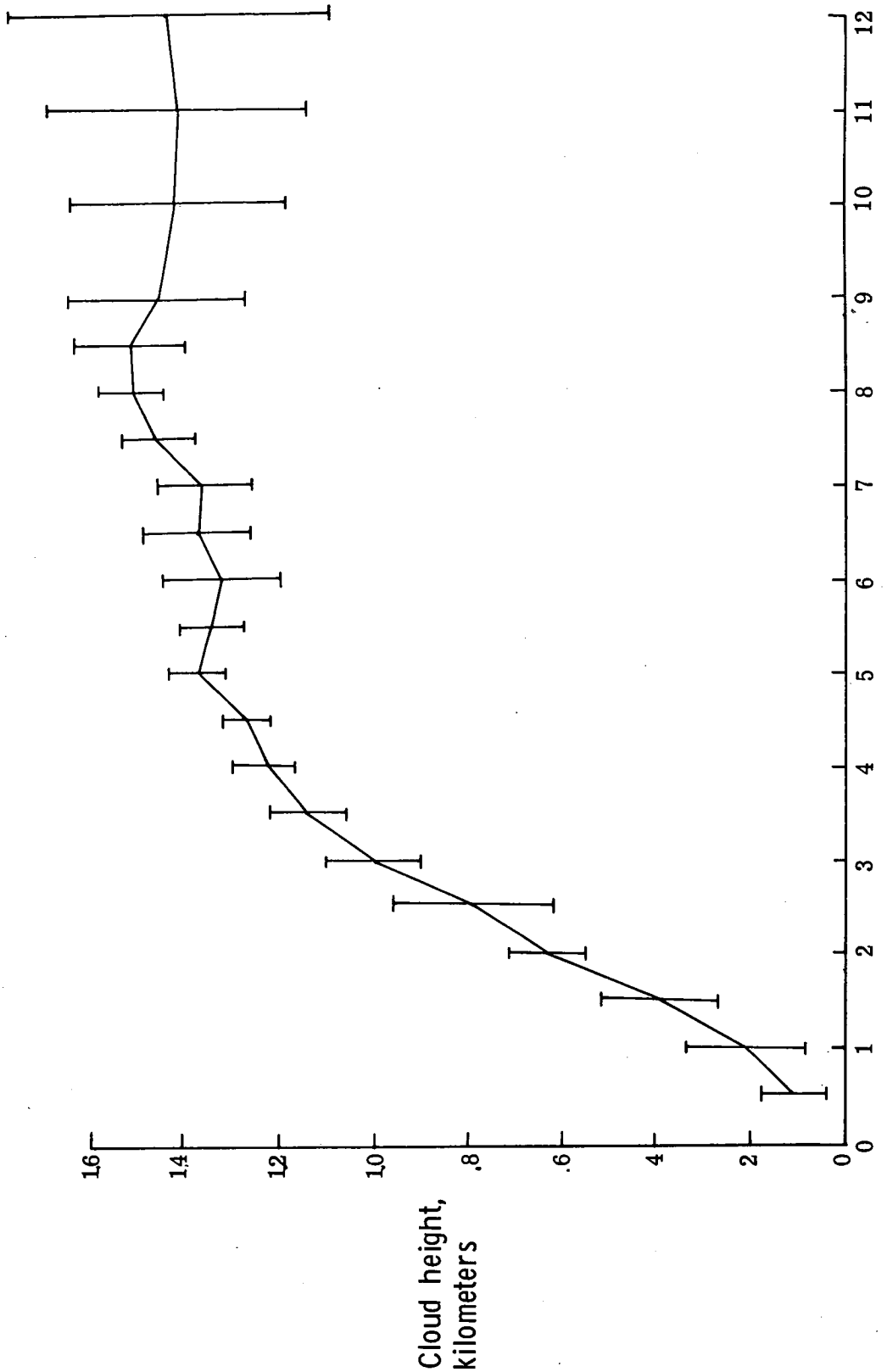

Figure 9.- Altitude track of stabilized ground cloud.

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