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MSFC EXHAUST EFFLUENT DIFFUSION PREDICTIONS AND MEASUREMENTS FOR STS-1, STS-2, STS-3, AND STS-4

Compiled by

Robert E. Turner
Systems Dynamics Laboratory

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16. ABSTRACT

This report presents the results of the Marshall Space Flight Center (MSFC) air quality predictions and measurements made during the launches of the Space Shuttle on April 12, 1981 (STS-1), November 12, 1981 (STS-2), March 22, 1982 (STS-3), and June 27, 1982 (STS-4), from Kennedy Space Center (KSC), Florida. The report discusses the atmospheric conditions, the use of the NASA/MSFC REED code, and the resulting predictions and measurements.

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PREFACE

The purpose of this report is to provide complete documentation of the results of the Marshall Space Flight Center (MSFC) air quality predictions and measurements made during the Space Shuttle launches from Kennedy Space Center (KSC) on April 12, 1981 (STS-1), November 12, 1981 (STS-2), March 22, 1982 (STS-3), and June 27, 1982 (STS-4). This report discusses the atmospheric conditions, the use of the NASA/MSFC REED code, and the resulting predictions and measurements.

Additional information on operational environmental impacts involving potential effects on air quality can be found in the Environmental Impact Statement for the Kennedy Space Center, October 1979.

This report consists of the following sections:

Section A - MSFC Exhaust Effluent Diffusion Predictions and Measurements for STS-1

Section B - MSFC Exhaust Effluent Diffusion Predictions and Measurements for STS-2

Section C - MSFC Exhaust Effluent Diffusion Predictions and Measurements for STS-3

Section D - MSFC Exhaust Effluent Diffusion Predictions and Measurements for STS-4

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SECTION A - MSFC EXHAUST EFFLUENT DIFFUSION PREDICTIONS AND MEASUREMENTS FOR STS-1

BY

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TECHNICAL MEMORANDUM

SECTION A

MSFC EXHAUST EFFLUENT DIFFUSION PREDICTIONS AND MEASUREMENTS FOR STS-1

I. INTRODUCTION

This report presents the results of the Marshall Space Flight Center (MSFC) air quality predictions made during the first Space Shuttle launch (STS-1) from Kennedy Space Center (KSC) on April 12, 1981.

The National Aeronautics and Space Administration (NASA) has conducted and is conducting a prediction and measurement program to assess the potential environmental effects from aerospace operations. As a part of this joint Langley-Kennedy-Marshall (LaRC-KSC-MSFC) program, MSFC has developed both the NASA/MSFC Rocket Exhaust Effluent Diffusion (REED) code and the use of polymer electrets to measure exhaust effluents. Large-scale solid rocket launches have been monitored since the late 1960's to refine the model and to develop new measurement techniques for use in making environmental analyses of the air quality from the exhaust effluents from the Space Transportation System (STS) launches.

The Space Shuttle exhaust ground cloud results from the exhaust plume from the Space Shuttle Main Engines (SSME's) and the Solid Rocket Boosters (SRB's) initially impinging on the launch complex and flame trench. The initial ground cloud is formed from high-temperature combustion products (exit plane temperatures of approximately 2146 K) and vaporized flame trench water. The exhaust cloud rises to an altitude at which buoyant equilibrium with the ambient atmosphere is established. This occurs at an altitude of 1 to 2 km in a period of 5 to 10 min after launch. At this point, the kinematic transport phase commences. At stabilization, the exhaust cloud typically contains approximately 99 percent ambient air entrained during the cloud rise portion of its transport. The major rocket exhaust constituents are hydrogen chloride (HCL), carbon dioxide (CO_2), water vapor (H_2O), and aluminum oxide (Al_2O_3). Figure A-1 is a schematic representation of this process. The exhaust cloud rise to stabilization and the turbulent transport are intimately coupled to small-scale meteorological phenomena, rocket exhaust plume chemistry, and turbulent diffusion.

Some of the difficulties involved in carrying out launch prediction and monitoring activities will be considered. Since the transport process is intimately dependent on the meteorological conditions, they will be considered next.

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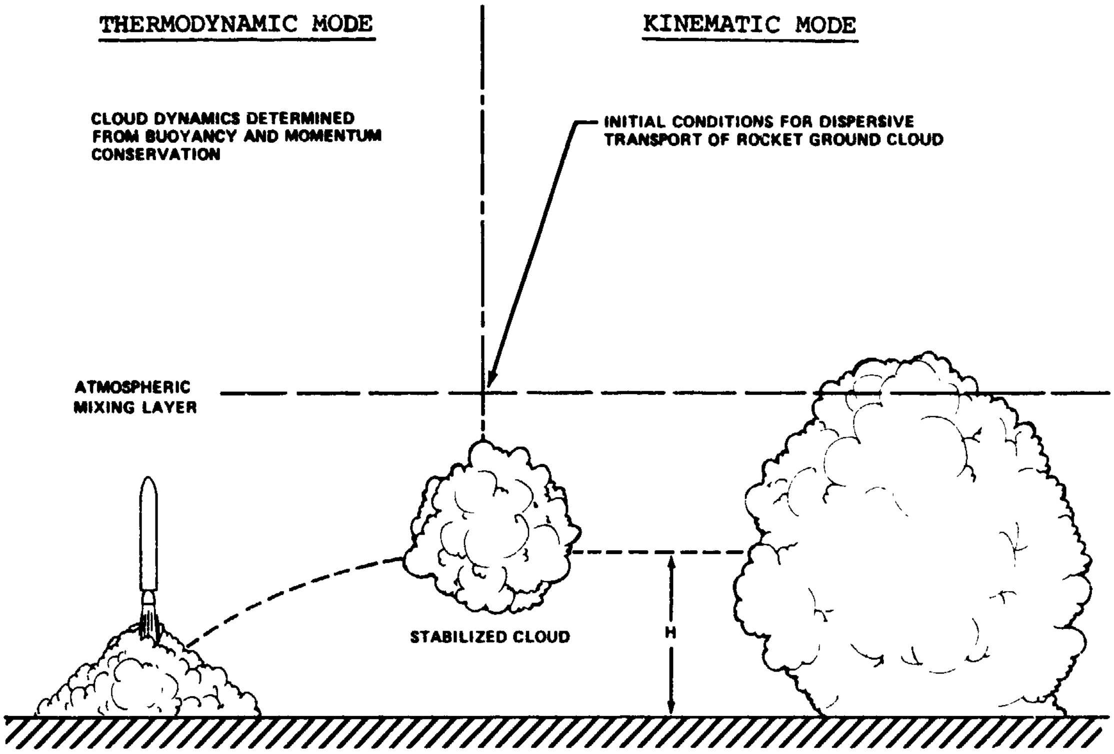

Figure A-1. Schematic of rocket exhaust ground cloud formation and transport.

II. METEOROLOGICAL CONDITIONS

Real-time atmospheric data and weather forecasts were provided by the Cape Canaveral Air Force Station Air Weather Service Detachment located in the Cape Range Control Center. Their data included vertical atmospheric soundings, synoptic weather charts, upper air charts, wind tower data, and other meteorological information. These data were then analyzed in terms of diffusion parameters by a MSFC atmospheric scientist in a small-scale parametric forecast.

Weather conditions at the time of launch were influenced by a large surface high-pressure system centered in the Atlantic Ocean (Fig. A-2). Aloft winds were generally southeasterly to approximately 1000 m (3500 ft), changing to easterly [up to 6?00 m (19 000 ft)] prior to switching to westerly above 6200 m (19 000 ft). At 8.5 hr prior to launch (L - 8.5 hr)[1], a MSFC forecast was made (Table A-1) as an input to the NASA/MSFC REED code, which was the basis for the diffusion prediction that determined the final deployment of the monitoring instrumentation.

At launch time (L - 0), the surface wind speed was 2 m s^{-1} and light to moderate (4 to 10 m s^{-1}) aloft over the initial 10 km (3048 ft) according to the atmospheric sounding (Table A-2).

1. L-time is clock time prior to or after launch, and T-time is a time in the count which is always equal to or less than L-time.

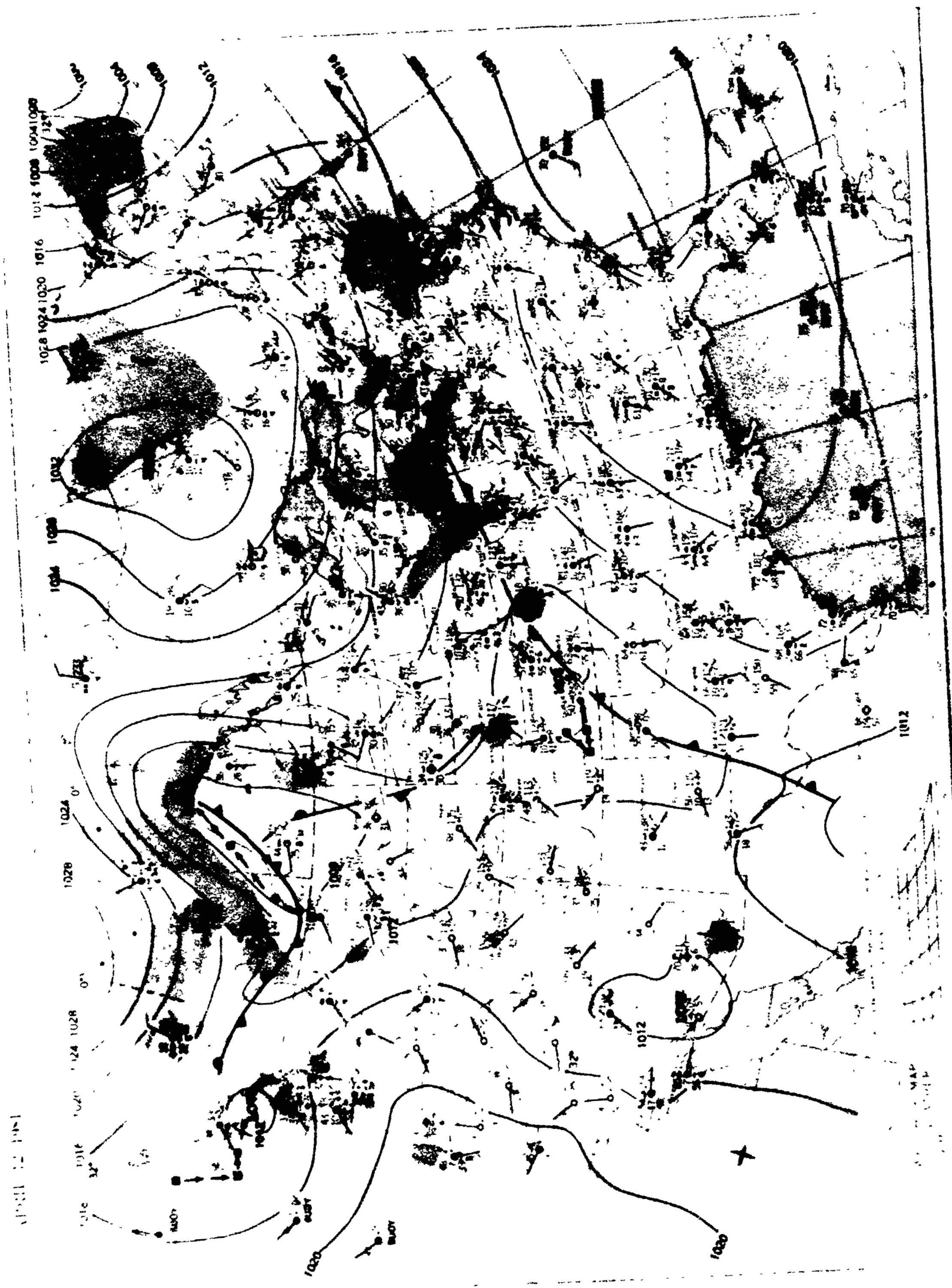

Figure A-2. Surface weather map at launch of STS-1.

TABLE A-1. PREDICTED PROFILE BASED ON FORECAST 8.5 hr PRIOR TO LAUNCH

********************* METEOROLOGICAL DATA *********************

RUN NUMBER: 1 USING METEOROLOGICAL DATA FILE: FD1212

TEST NBR 09100 L-8.30HR FD1212
FORECAST: J.C. SLOAN
CAPE CANAVERAL AFS, FLORIDA
ASCENT NBR 0151

TIME: 2230/EST DATE: 11 APR 1981

********************* FORECAST *********************

SURFACE DENSITY (GM/M**3): 1218.88

MET LEVEL NO.	ALTITUDE (FT)	ALTITUDE (M)	DIR. (DEG)	SPEED (M/S)	SPEED (KTS)	TEMP	PTEMP (DEG. C)	DPTEMP (DEG. C)	PRESS (MB.)	RH (%)	
1	16	4.9	120.0	3.09	6.00	15.0	14.58	0.0	1025.1	90.0	
2	1000	304.8	115.0	6.18	12.00	18.0	20.62	0.0	990.2	77.0	
3	1500	457.2	115.0	6.95	13.50	16.8	20.84	0.0	972.9	82.0	**
4	2000	609.6	115.0	7.72	15.00	15.5	21.09	0.0	955.6	87.0	
5	3000	914.4	115.0	6.18	12.00	14.0	22.45	0.0	922.0	85.0	
6	3500	1066.8	112.5	6.18	12.00	14.5	23.95	0.0	905.7	55.0	**
7	4000	1219.2	110.0	6.18	12.00	15.0	25.43	0.0	889.4	25.0	
8	5000	1524.0	100.0	6.18	12.00	15.0	28.36	0.0	858.0	16.0	
9	5500	1676.4	95.0	6.69	13.00	14.5	29.41	0.0	842.8	17.5	**
10	6000	1828.8	90.0	7.21	14.00	14.0	30.50	0.0	827.7	19.0	
11	7000	2133.6	80.0	7.21	14.00	13.5	33.23	0.0	798.3	23.0	
12	7500	2286.0	75.0	7.72	15.00	12.8	34.11	0.0	784.1	25.5	**
13	8000	2438.4	70.0	8.24	16.00	12.1	35.01	0.0	769.9	28.0	
14	9000	2743.2	70.0	9.27	18.00	10.0	35.95	0.0	742.4	30.0	
15	9500	2895.6	65.0	9.78	19.00	9.0	36.45	0.0	729.0	30.0	**
16	10000	3048.0	60.0	10.30	20.00	8.0	36.97	0.0	715.6	30.0	

** - INDICATES THAT DATA IS LINEARLY INTERPOLATED FROM INPUT METEOROLOGY

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TABLE A-2. ATMOSPHERIC SOUNDING MADE AT TIME OF LAUNCH

*** **************** METEOROLOGICAL DATA ***********************

RUN NUMBER: 1 USING METEOROLOGICAL DATA FILE: VD1212

TEST FOR 09100 T-0 DATA VD1212
RAWINSONDE RUN AN/GMD-1
CAPE CANAVERAL AFS, FLORIDA
ASCENT NBP 0154

TIME: 712 EST DATE: 12 APR 1981

******************** SOUNDING ********************

SURFACE DENSITY (GM/M**3): 1220.55

MET LEVEL NO.	ALTITUDE (FT)	ALTITUDE (M)	DIR. (DEG)	SPEED (M/S)	SPEED (KTS)	TEMP	PTEMP (DEG. C)	DPTEMP	PRESS (MB.)	RH (%)	
1	16	4.9	110.0	2.06	4.00	17.0	17.01	15.9	1023.4	93.0	
2	501	152.7	125.0	5.15	10.00	20.8	22.73	16.1	1006.0	74.5	
3	670	204.2	131.0	5.66	11.00	20.2	22.19	15.5	1000.0	75.0	
4	785	239.3	135.0	5.66	11.00	19.7	21.97	15.1	996.0	74.8	
5	1000	304.8	136.0	6.18	12.00	19.1	21.98	14.8	988.5	76.0	
6	1500	457.2	139.0	6.18	12.00	17.7	21.97	14.1	971.2	80.0	**
7	2000	609.6	142.0	6.18	12.00	16.2	21.97	13.5	954.0	84.0	
8	2114	644.3	143.0	6.18	12.00	15.9	22.01	13.3	950.0	85.0	
9	3000	914.4	136.0	4.64	9.00	14.1	22.73	11.7	920.4	86.0	
10	3256	992.4	131.0	4.12	8.00	13.6	22.96	11.3	912.0	86.1	
11	3618	1102.8	115.0	4.12	8.00	14.4	24.54	5.4	900.0	62.0	
12	4000	1219.2	99.0	4.12	8.00	15.1	25.95	-.6	887.9	37.0	
13	4122	1256.4	94.0	4.64	9.00	15.4	26.49	-2.5	884.0	29.5	
14	5000	1524.0	79.0	6.18	12.00	15.3	29.15	-2.2	856.6	30.0	
15	5205	1586.5	77.0	6.69	13.00	14.9	29.39	-2.4	850.0	30.0	
16	6000	1828.8	74.0	7.72	15.00	14.2	31.14	-2.7	826.3	31.0	
17	6552	1997.0	74.0	8.24	16.00	14.6	33.36	-2.3	810.0	31.8	
18	6884	2098.2	75.0	8.75	17.00	14.1	33.92	-2.2	800.0	32.0	
19	7000	2133.6	75.0	8.75	17.00	14.0	34.16	-2.2	797.0	33.0	
20	7500	2286.0	75.0	9.01	17.50	12.9	34.54	-2.8	782.8	33.5	**
21	8000	2438.4	75.0	9.27	18.00	11.8	34.95	-3.5	768.7	34.0	
22	8659	2639.3	74.0	9.78	19.00	10.6	35.81	-4.1	750.0	35.0	
23	9000	2743.2	73.0	9.78	19.00	10.1	36.31	-4.4	741.2	35.0	
24	9500	2895.6	72.0	9.78	19.00	9.0	36.73	-5.9	727.8	34.0	**
25	10000	3048.0	71.0	9.78	19.00	8.0	37.18	-7.5	714.4	33.0	

** - INDICATES THAT DATA IS LINEARLY INTERPOLATED FROM INPUT METEOROLOGY

Figure A-3 shows the GOES SMS-11 imagery of cloud cover. Figure A-4 is an enlargement of the KSC area which shows the STS-1 exhaust trail visible near the center of the photograph. Data from the wind tower array at KSC and Cape Canaveral Air Force Station are shown in Table A-3. Data from the NASA 150-m tower (tower 313) are used as an input in the NASA/MSFC REED code prediction.

III. ROCKET EXHAUST PREDICTIONS

A. STS-1 Exhaust Cloud

The first launch of the Shuttle produced an exhaust cloud that was very similar in size and concentrations to prelaunch estimations. Figures A-5 through A-9 show a temporal history of the exhaust cloud development, together with cloud dimensions. The camera site, approximately due west of Pad 39A, is one of three sites where sequential photographs were taken. Figure A-5 was taken 30 s after launch, and the column cloud and two flame trench clouds are evident. Figure A-6 shows the clouds at L + 90 s; the darker lower clouds are beginning to merge to form a single ground cloud. In Figure A-7 (L + 240 s), the clouds have merged and can no longer be distinguished as individual clouds. Figures A-8 and A-9 show the cloud at L + 330 s and L + 26 min, respectively.

The flame deflectors at the launch pad are designed to direct the SRT exhaust plume (which is composed principally of HCL, Al_2O_3, and steam) toward the north and the SSME exhaust plume (which is composed principally of water and steam) toward the south. An apparent chimney effect causes these two exhaust clouds to merge and form a single ground cloud. The LaRC aircraft used to make exhaust cloud concentration and particle measurements reported at least two more clouds formed at higher altitudes. The two separate exhaust clouds are visible in Figure A-9, which was taken at L + 26 min. The appearance of two separate clouds may mean that the clouds do not completely merge as indicated in Figure A-7.

B. Diffusion Predictions

The NASA/MSFC REED code [1] was utilized to make predictions of the transport of exhaust effluents. The objective was to determine the HCL concentration fields of the exhaust cloud in the transport layers. The predictions were used to support ground-level and aircraft measurements. The NASA/MSFC REED code includes three separate models to account for the atmospheric conditions, the thermodynamic, and the kinematic modes of the transport process. The code is outlined in Figure A-10.

Two sets of diffusion predictions were made for L - 0. The first was made based on a meteorological forecast at L - 8.5 hr (Table A-1) to support KSC's final deployment of air quality monitoring instrumentation. The center-line peak concentrations, 10-min average concentrations, and dosages for HCL along the ground cloud transit path are shown in Figure A-11. The HCL isopleths for this forecast are shown in Figure A-12. To correlate the surface measurements with the air quality predictions, the L - 0 sounding (Table A-2) was used in the NASA/MSFC REED code. The L - 0 HCL centerline concentrations and dosages are shown in Figure A-13, and HCL isopleths are shown in Figure A-14. The locations of the KSC dosimeter measurements are also shown in these figures.

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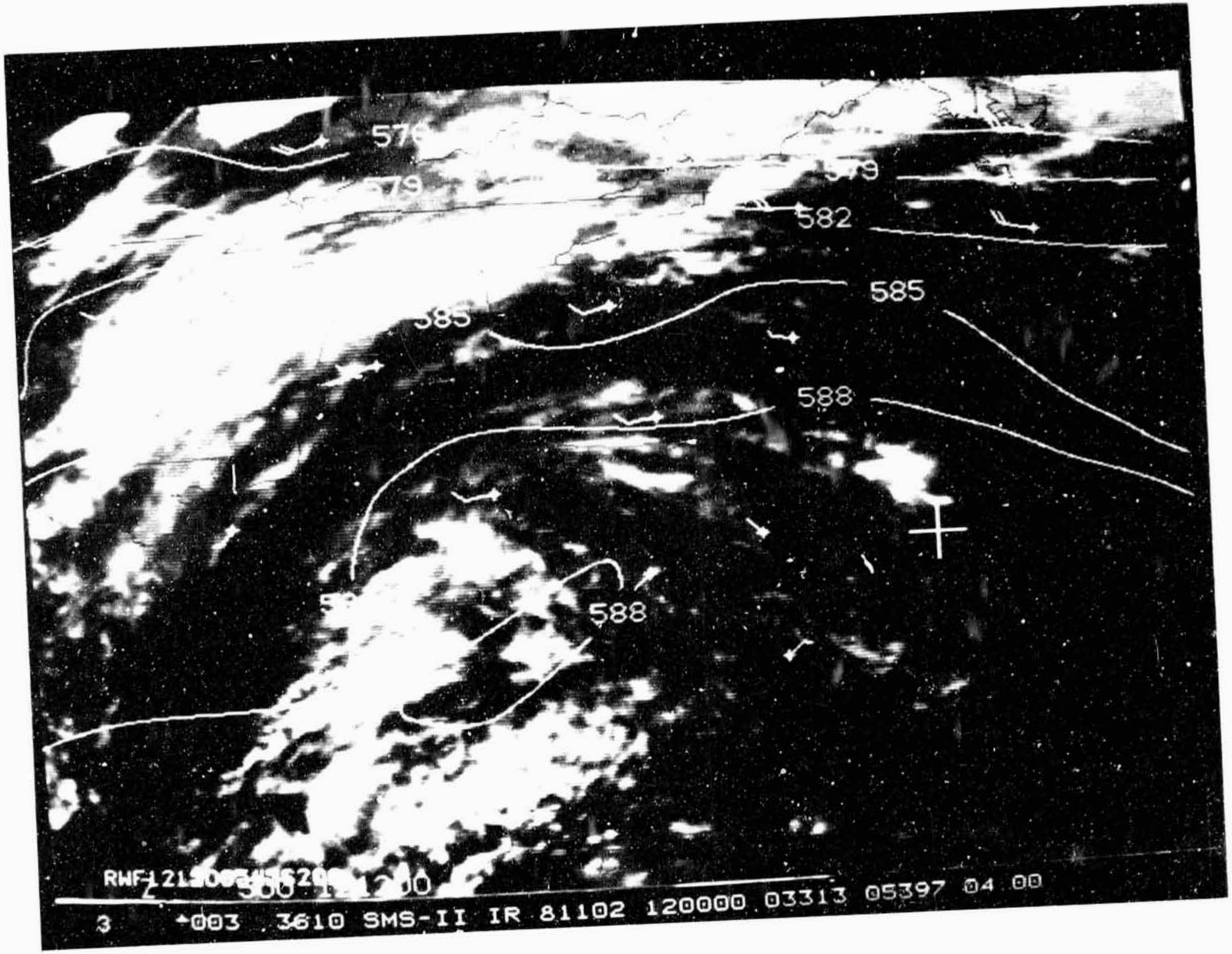

Figure A-3. GOES SMS-11 cloud cover imagery.

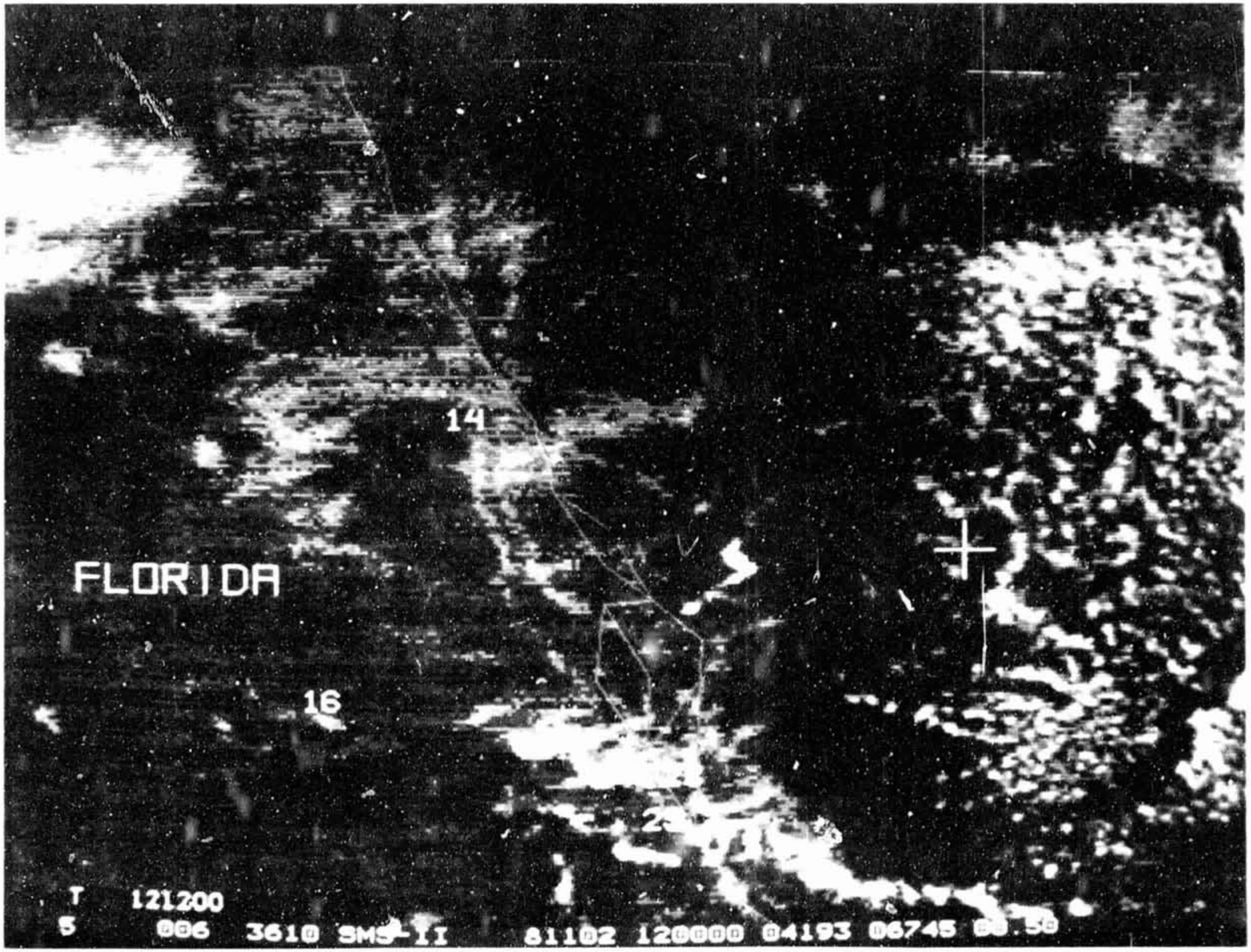

Figure A-4. Enlargement of KSC area from GOES SMS-11 cloud cover imagery.

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TABLE A-3. DATA FROM CAPE CANAVERAL WIND TOWER ARRAY

WIND SYSTEM DATA 1130Z 12 APR 1981 30 MIN INTEGRATION

DIFFUSION DATA

	12 FT		54 FT			6 FT	LAPSE	VDLK30 DIR	5(1000)25		5 (100)25	
TOWER	DIR	SPD	DIR	SPD	GST	TMP	RATE	DEV	PPM	PPM	PPM	PPM
COASTAL												
112	162	02	152	05	07	64	6.2	5.1	56.8	25.0	17.5	7.7
110	124	04	144	07	09	67	3.5	1.9	44.9	19.8	13.9	6.1
108	136	02	131	05	07	62	6.7	4.3	59.4	26.2	18.4	8.1
005	131	06	123	08	10	71	0.0	1.1	28.8	12.7	8.9	3.9
003	129	05	132	08	10	70	1.4	1.9	32.0	14.1	9.9	4.4
001	081	05	090	07	09	71	1.7	1.2	34.8	15.3	10.8	4.7
BANANA												
313	233	00	143	04	05	52	16.8	15.4		58.2	40.8	18.0
311	149	02	140	03	04	64	5.6	.4	90.6	39.9	28.0	12.3
506	298	01	090	02	04	56	10,4	.3		95.2	66.8	29.4
403	108	02	113	06	07	60	10.1	.0			96.6	42.5
303												
INDIAN												
714	101	02	134	06	07	57	9.4	4.7	97.8	43.0	30.2	13.3
412												
509	100	01	116	04	05	55	13.1	.3			78.9	34.7
803	342	01	104	04	05	57	11.3	.0				48.4

METEOROLOGICAL DATA

ALT	TOWER 313					TOWER 110					TOWER 005				
FT	DIR	SPD	GST	TMP	DPT	DIR	SPD	GST	TMP	DPT	DIR	SPD	GST	TMP	D
495	150	10	12	70	55										
393	155	10	11												
292	141	09	10												
204	140	07	08	70	55	126	10	12			115	07	10		
162	146	06	08	71		142	10	11	71		121	07	10	70	
054	143	04	05	69	55	144	07	09	70	59	123	08	10	71	
012	233	00	01			124	04	06			131	06	08		
006	1024.0MBS			52	45				67	57				71	

Figure A-5. STS-1 exhaust cloud formation. Estimated cloud volume: 8.2×10^7 m^3; time: L + 30 s; length: 960 m (3150 ft); width: 274 m (900 ft).

Figure A-6. STS-1 exhaust cloud formation. Estimated cloud volume: 6.8×10^8 m^3; time: L + 90 s; length: 1143 m (3750 ft); width: 648 m (2125 ft).

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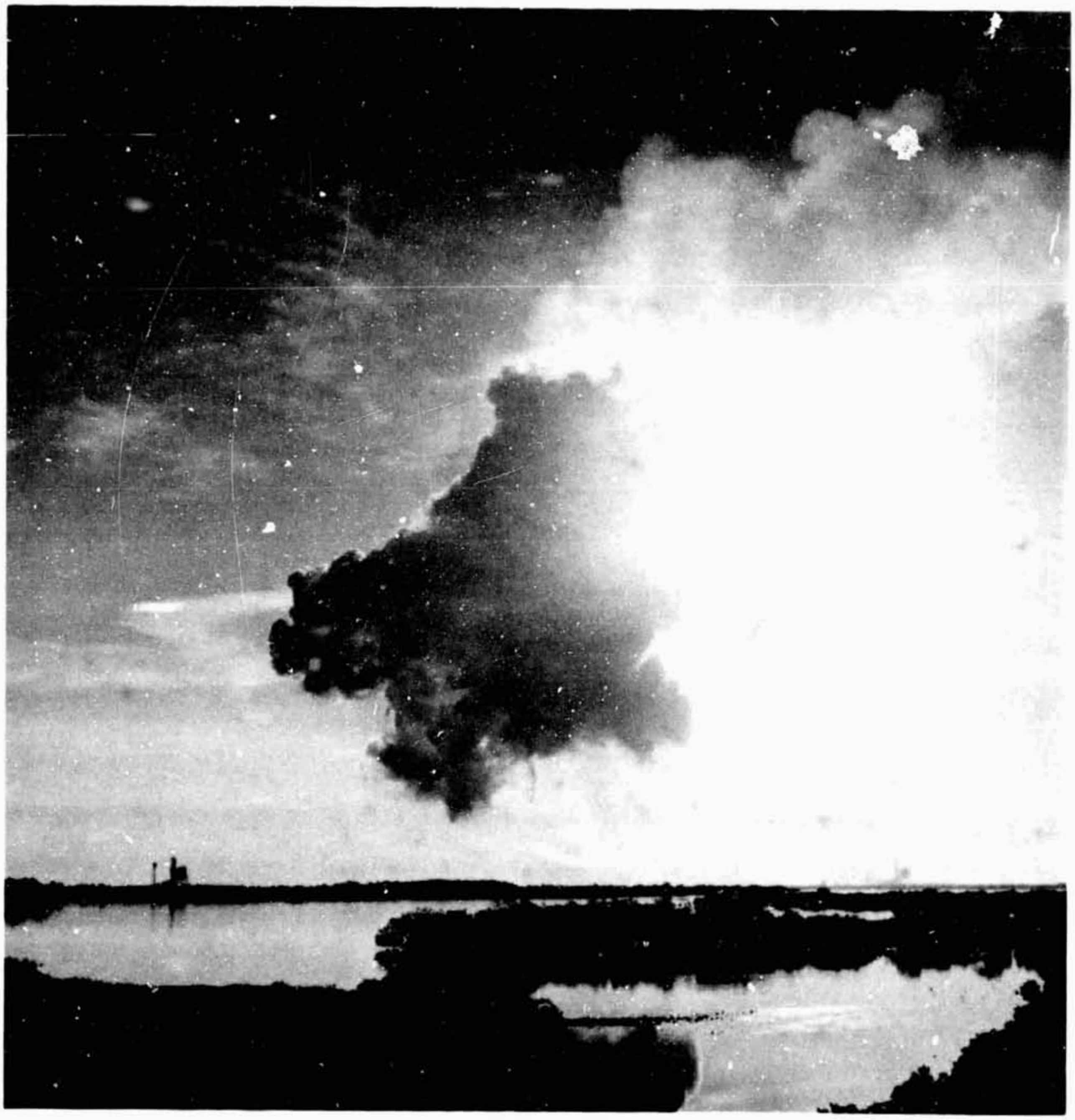

Figure A-7. STS-1 exhaust cloud formation. Estimated cloud volume: 1.2×10^9 m^3; time: L + 240 s; length: 1433 m (4700 ft); width: 1158 m (3800 ft).

Figure A-8. STS-1 exhaust cloud formation. Estimated cloud volume: $1.6 \times 10^9\ m^3$; time: L + 300 s; length: 1676 m (5500 ft); width: 1143 m (3750 ft).

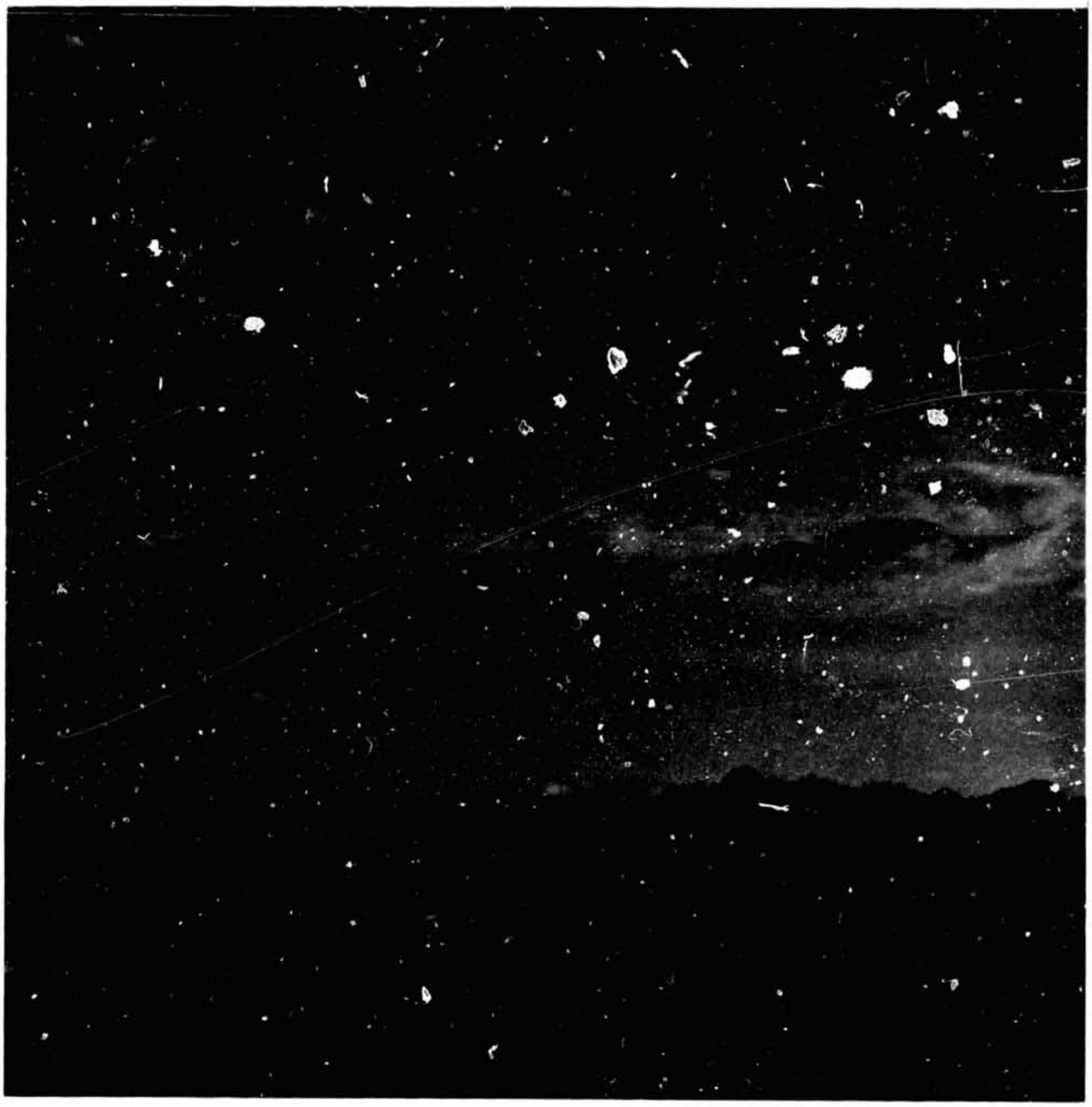

Figure A-9. STS-1 exhaust cloud formation; time: L + 26 min.

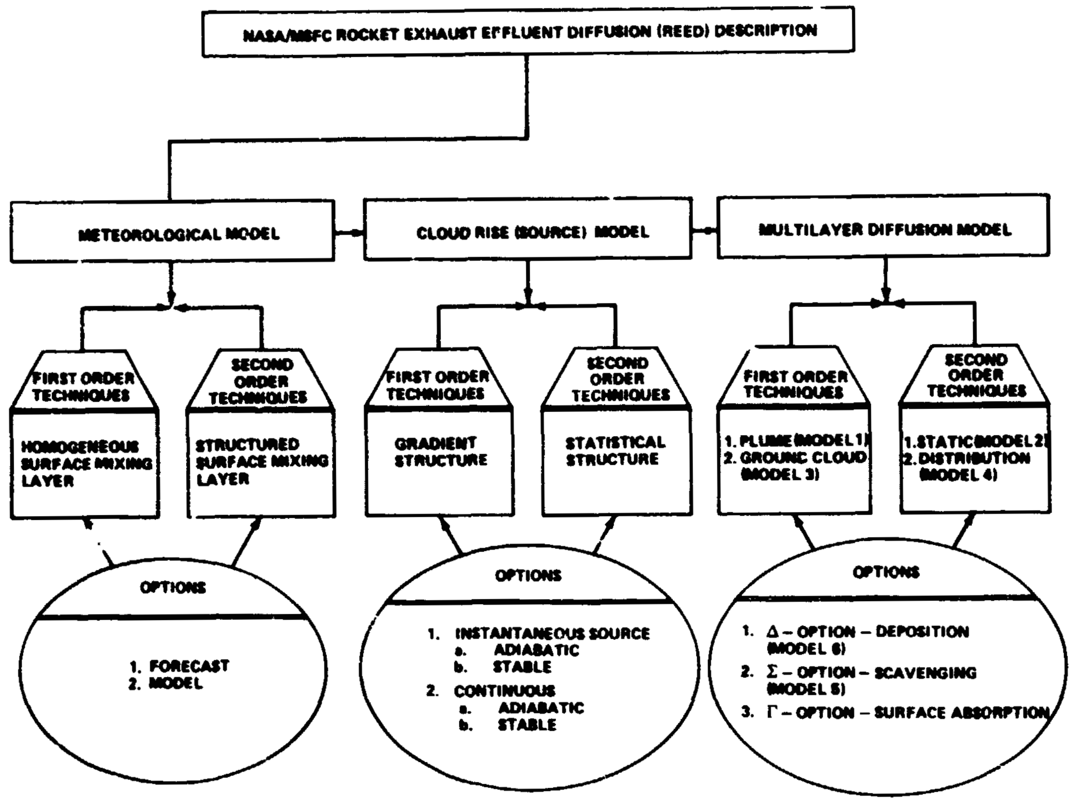

Figure A-10. NASA/MSFC REED code.

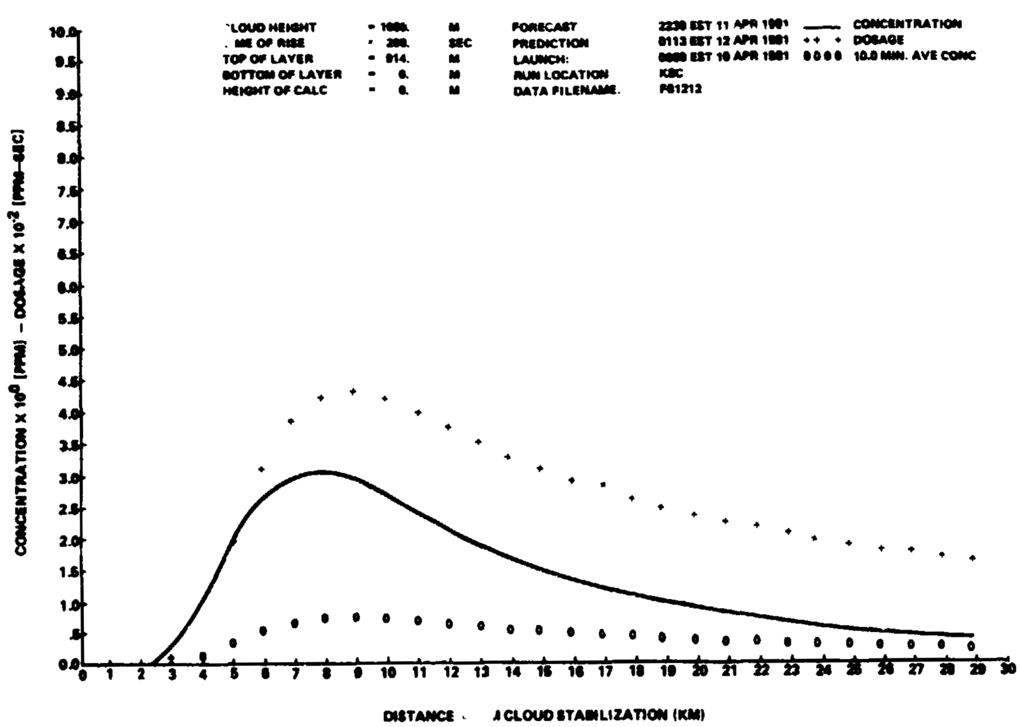

Figure A-11. Forecasted concentration and dosage for HCL.

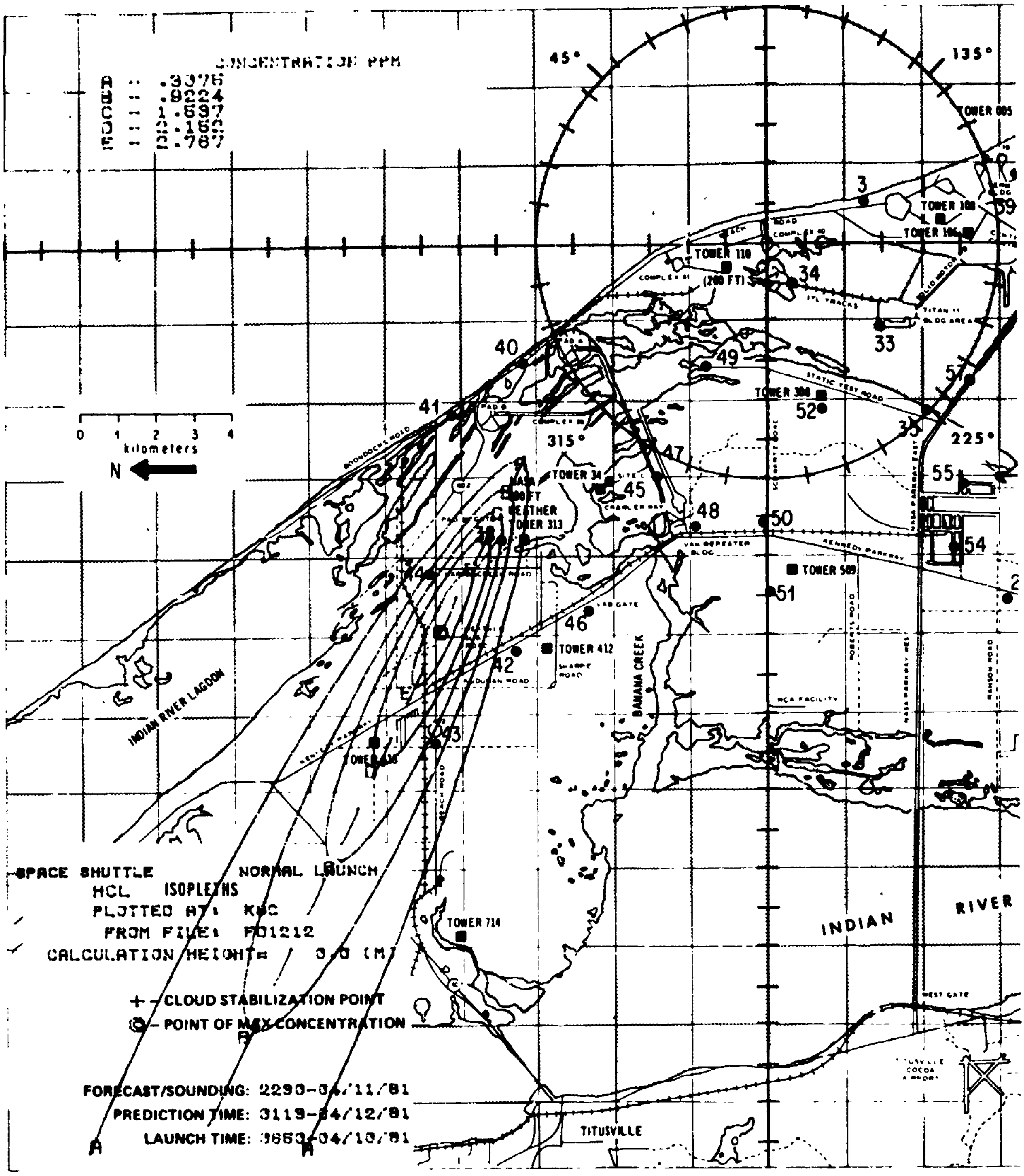

Figure A-12. Diffusion prediction based on 8.5-hr meteorological forecast.

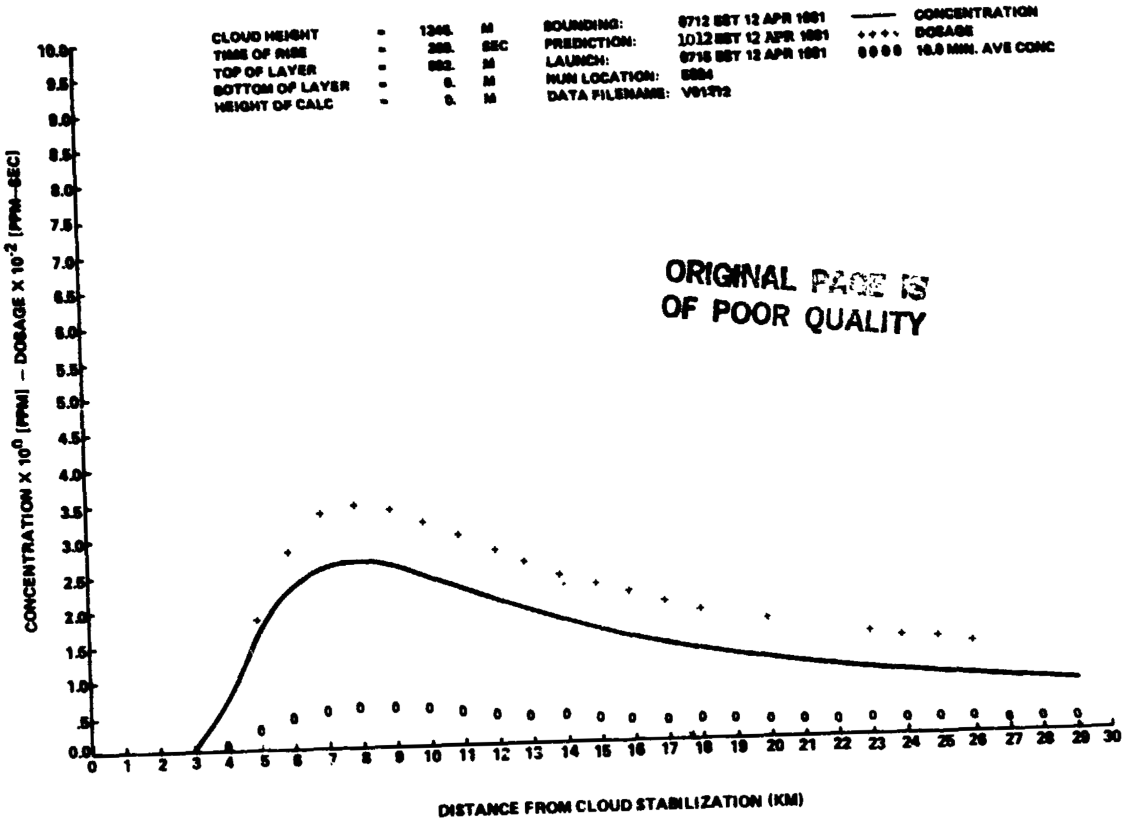

Figure A-13. Concentration and dosage for HCL using L - 0 sounding.

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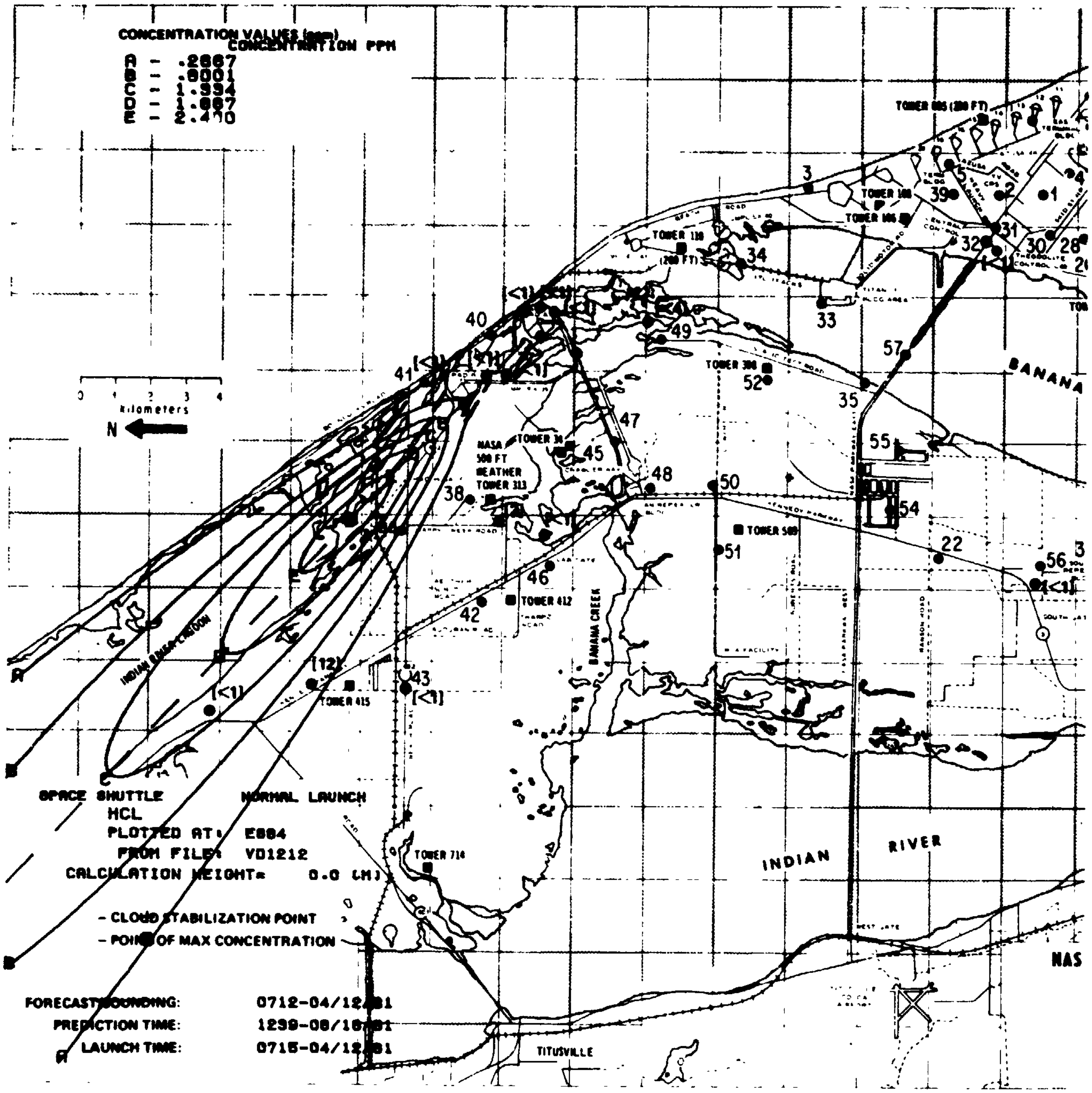

Figure A-14. Diffusion prediction based on atmospheric sounding taken at time of launch; [ ]: numbers in brackets indicate KSC's HCL dosimeters, ppm-s [2].

IV. ELECTRETS

A. Background

The NASA/MSFC electret is a small (quarter size) disk of a polymer (Fig. A-15) which is electrically charged. It has the property of attracting charged molecules. The exposed electrets are returned to the laboratory where X-ray spectroscopy is used to identify the charged particles present [3-4] and to provide a qualitative measure of the amount of chlorine (Cl) present.

Based on controlled experiments at rocket firings and Titan launches, it has been shown [5] that the electrets can provide an excellent footprint of solid exhaust effluents. Hence, the electrets provide a means of evaluating the effluents from the exhaust ground cloud.

B. NASA/MSFC Electret Measurements

Nineteen NASA/MSFC electrets were deployed for the STS-1 launch (Fig. A-16). The sites ranged in distance from 400 m to 24 km (Titusville, not shown on the map).

The spectrograph from site FIM8 (Fig. A-17) was used to establish a background since the ground cloud did not pass over that site. A typical spectrograph result for a site which the exhaust cloud did pass over is shown in Figure A-18. It clearly shows the Cl peak at 2.621 keV. Tables A-4 through A-12 give spectrograph peaks for the other sites where HCL was detected. It will be noted that these results compare well with the results obtained with the KSC dosimeters (Fig. A-13). Thus, it is reasonable to say that the air quality predictions and the electret measurements are in agreement and that they compare favorably with KSC and LaRC measurements and observations.

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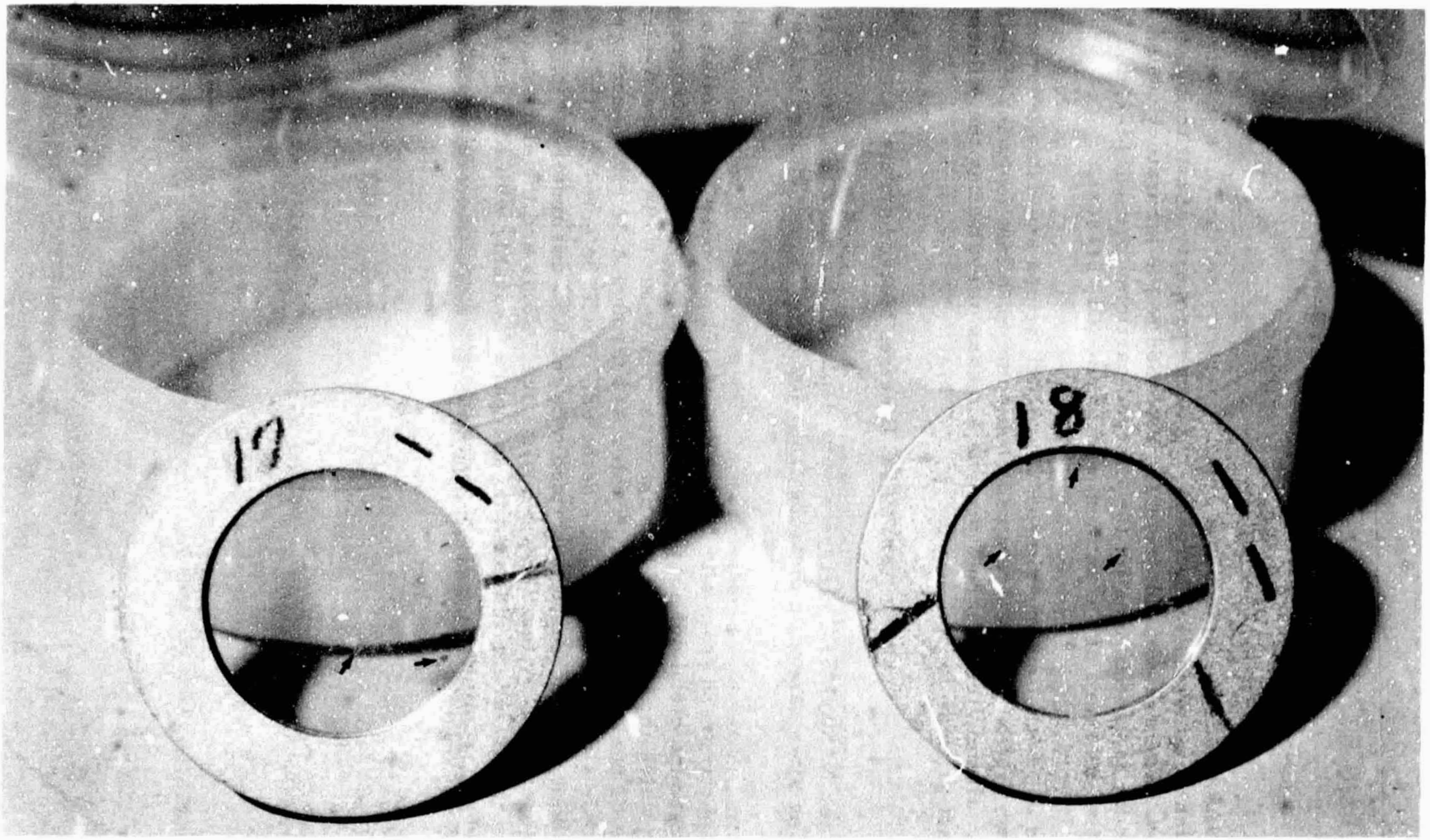

Figure A-15. The left electret which was positioned at site A8 shows a large reddish spot at about 4 o'clock. The right electret which was at site A9 has several spots at 12, 2 o'clock, and 10 o'clock. The spots indicate acidity.

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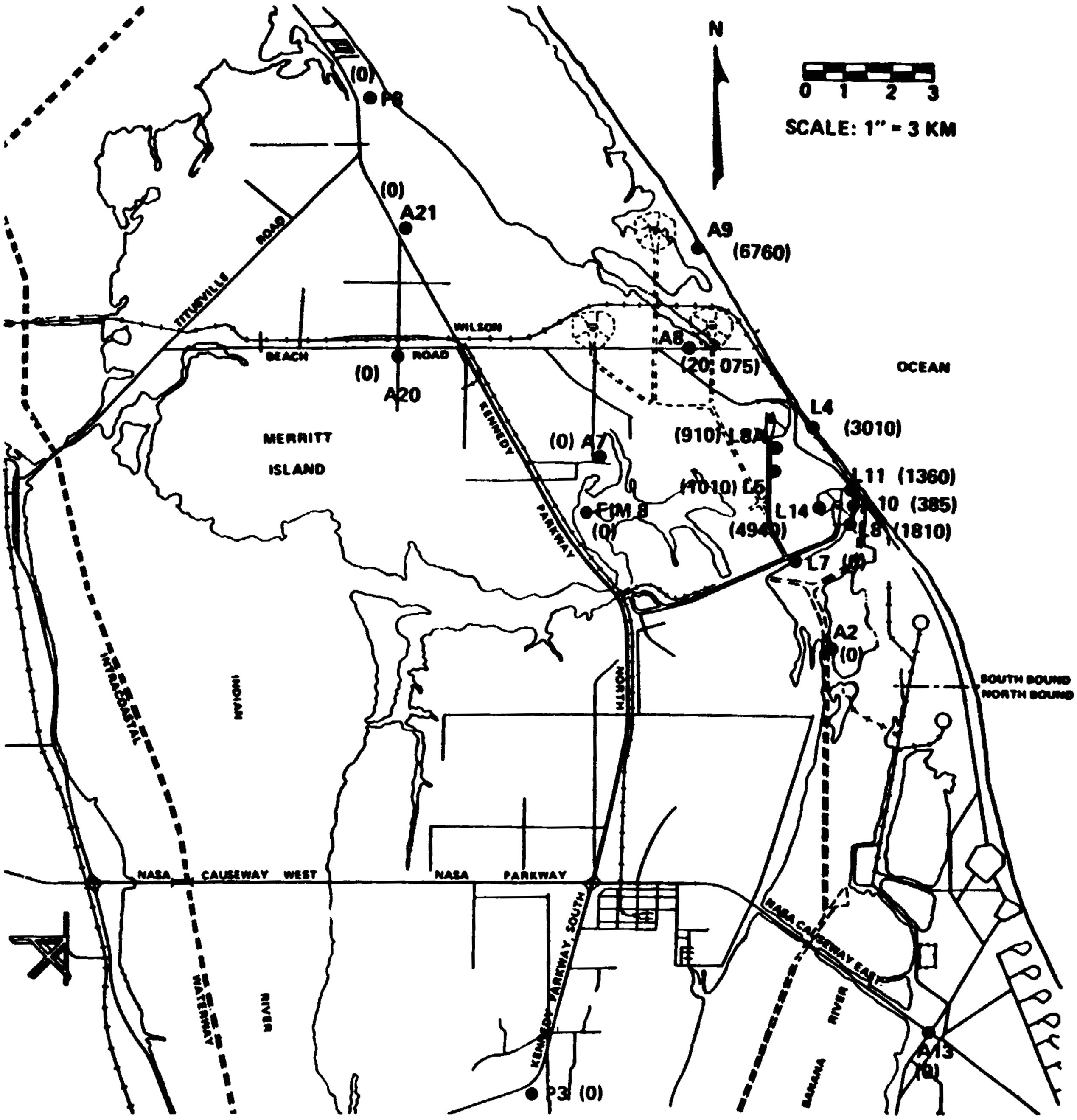

Figure A-16. Location of MSFC's electrets during STS-1 launch at Kennedy Space Center, Florida.

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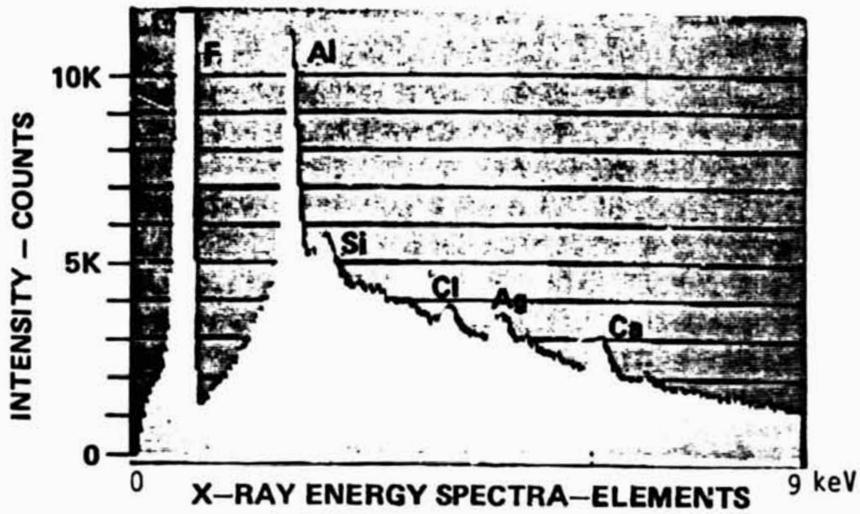

Figure A-17. Background energy spectra from site FIM8, STS-1.

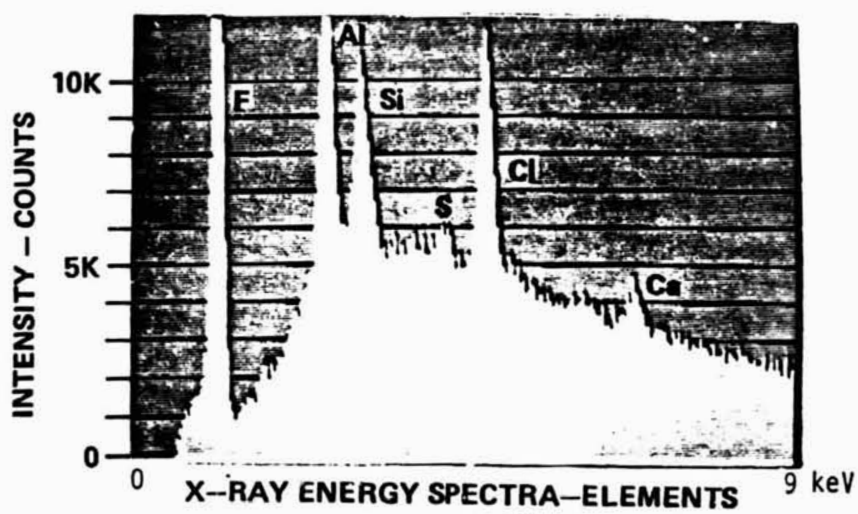

Figure A-18. X-ray energy spectra from site 8A, STS-1.

TABLE A-4. ELECTRET QUANTITATIVE RESULTS OBTAINED FROM X-RAY SPECTROSCOPY AT SITE A8 (5,130 m; Azimuth, 317° from Launch Pad 39A During STS-1)

Energy (keV)	Total Test Counts (1000 s)	Symbol	Background Counts
1.486	37,750	Al	13,840
1.739	1,800	Si	1,900
2.307	365	S	325
2.621	21,065	Cl	990
5.411	300	Cr	–
5.894	400	Mg	Trace
6.398	530	Fe	180

TABLE A-5. ELECTRET QUANTITATIVE RESULTS OBTAINED FROM X-RAY SPECTROSCOPY AT SITE A9 (7,360 m; Azimuth, 331° from Launch Pad 39A During STS-1)

Energy (keV)	Total Test Counts (1000 s)	Symbol	Background Counts
1.012	950	Zn	–
1.486	32,000	Al	13,840
1.739	2,450	Si	1,900
2.307	575	S	325
2.621	7,750	Cl	990
3.312	400	K	–
6.398	380	Fe	180

TABLE A-6. ELECTRET QUANTITATIVE RESULTS OBTAINED FROM X-RAY SPECTROSCOPY AT PAD L14 (439 m; Azimuth 247° from Launch Pad 39A During STS-1)

Energy (keV)	Total Test Counts (1000 s)	Symbol	Background Counts
1.041	800	Na	Trace
1.486	24,800	Al	13,840
2.307	630	S	325
2.621	5,930	Cl	990
3.690	1,980	Ca	2,130
5.894	260	Mg	Trace
6.398	1,016	Fe	180

TABLE A-7. ELECTRET QUANTITATIVE RESULTS OBTAINED FROM X-RAY SPECTROSCOPY AT PAD L8 (421 m; Azimuth 160° from Launch Pad 39A During STS-1)

Energy (keV)	Total Test Counts (1000 s)	Symbol	Background Counts
1.0412	625	Na	Trace
2.307	1,000	S	325
2.621	2,800	Cl	990
2.984	2,750	Ag	400
5.894	500	Mg	Trace

TABLE A-8. ELECTRET QUANTITATIVE RESULTS OBTAINED FROM X-RAY SPECTROSCOPY AT PAD L10
(458 m; Azimuth 78° from Launch Pad 39A During STS-1)

Energy (keV)	Total Test Counts (1000 s)	Symbol	Background Counts
1.041	350	Na	Trace
2.307	325	S	325
2.621	1,375	Cl	990
5.894	400	Mg	Trace

TABLE A-9. ELECTRET QUANTITATIVE RESULTS OBTAINED FROM X-RAY SPECTROSCOPY AT PAD L11
(421 m; Azimuth 14° from Launch Pad 39A During STS-1)

Energy (keV)	Total Test Counts (1000 s)	Symbol	Background Counts
1.0412	200	Na	Trace
2.307	500	S	325
2.621	2,350	Cl	990
3.312	100	K	–
5.411	Trace	Cr	–
5.894	500	Mg	Trace

TABLE A-10. ELECTRET QUANTITATIVE RESULTS OBTAINED FROM X-RAY SPECTROSCOPY AT PAD L4
(2,007 m; Azimuth 340° from Launch Pad 39A During STS-1)

Energy (keV)	Total Test Counts (1000 s)	Symbol	Background Counts
1.0412	1,000	Na	Trace
2.621	4,000	Cl	990

TABLE A-11. ELECTRET QUANTITATIVE RESULTS OBTAINED FROM X-RAY SPECTROSCOPY AT PAD L5
(1,784 m; Azimuth 255° from Launch Pad 39A During STS-1)

Energy (keV)	Total Test Counts (1000 s)	Symbol	Background Counts
1.0412	600	Na	Trace
1.739	2,400	Si	1,900
2.307	300	S	325
2.621	2,000	Cl	990
3.312	Trace	K	–
5.411	100	Cr	–
6.398	200	Fe	180

TABLE A-12. ELECTRET QUANTITATIVE RESULTS OBTAINED FROM X-RAY SPECTROSCOPY AT PAD L8A
(5,130 m; Azimuth 317° from Launch Pad 39A During STS-1)

Energy (keV)	Total Test Counts (1000 s)	Symbol	Background Counts
2.307	1,000	S	325
2.621	1,500	Cl	990
3.312	150	K	–
5.894	360	Mg	Trace

REFERENCES

1. Stephens, J. Briscoe, and Stewart, Roger B.: Rocket Exhaust Effluent Modeling for Tropospheric Air Quality and Environmental Assessments. NASA Technical Report R-473, June 1977.

2. A "Quick-Look" Report of Environmental Effects Resulting from STS-1. Technology Incorporated, Florida, April 17, 1981.

3. Pillai, P. K. C., and Shriver, Edward L.: Electrets and Their Applications in Contamination Studies. NASA Technical Report R-457, 1975.

4. Susko, Michael: Research in the Use of Electrets in Measuring Effluents from Rocket Exhaust of the Space Shuttle (6.4 Percent Scaled Model) and Viking I Launch. NASA Technical Paper 1073, November 1977.

5. Susko, Michael: Electrets Used to Measure Exhaust Cloud Effluents from Solid Rocket Motor (SRM) During Demonstration Model (DM-2) Static Test Firing. NASA Technical Memorandum TM-78171, April 1978.

SECTION B - MSFC EXHAUST EFFLUENT DIFFUSION PREDICTIONS AND MEASUREMENTS FOR STS-2

BY JOSEPH C. SLOAN, MICHAEL SUSKO, ROBERT E. TURNER, AND NORMAN H. REAVIS

SECTION B

MSFC EXHAUST EFFLUENT DIFFUSION PREDICTIONS AND MEASUREMENTS FOR STS-2

I. INTRODUCTION

This report presents the results of the Marshall Space Flight Center (MSFC) air quality predictions made during the second Space Shuttle launch (STS-2) from Kennedy Space Center (KSC) on November 12, 1981.

The NASA/MSFC Rocket Exhaust Effluent Diffusion (REED) code was utilized to make predictions of the transport and diffusion of rocket exhaust effluents as part of the continuing NASA environmental effects assessment program. Polymer electrets were also used to measure exhaust effluents.

The Space Shuttle exhaust ground cloud results from the exhaust plume from the Space Shuttle Main Engines (SSMEs) and the Solid Rocket Boosters (SRBs) initially impinging on the launch complex and flame trench. The initial ground cloud is formed from high-temperature combustion products (exit plane temperatures of approximately 2146 K) and vaporized flame trench water. The exhaust cloud rises to an altitude at which buoyant equilibrium with the ambient atmosphere is established. This occurs at an altitude of 1 to 2 km in a period of 5 to 10 min after launch. At this point, the kinematic transport phase commences. At stabilization, the exhaust cloud typically contains approximately 99 percent ambient air entrained during the cloud rise portion of its transport. The major rocket exhaust constituents are hydrogen chloride (HCL), carbon dioxide (CO_2), water vapor (H_2O), and aluminum oxide (Al_2O_3). Details of the REED code can be found in References 1 and 2.

II. METEOROLOGICAL CONDITIONS

Weather conditions at the time of launch were influenced by a large high-pressure system that covered the eastern half of the United States (Fig. B-1). A low-pressure system which had passed through Florida the preceding day was located in the Atlantic Ocean northeast of Cape Canaveral. At launch time, surface winds were moderate (7 to 8 m/sec) from the north-northwest. Aloft the winds gradually shifted to the north-northeast near 400 m, remained northeasterly to 1400 m, and then gradually shifted to a more northerly direction (Table B-1).

Figures B-2 through B-7 show the GOES-2 imagery of cloud cover over much of Florida and the Atlantic shortly after launch. The exhaust ground cloud can be seen in all of the pictures; however, the Shuttle contrail, or plume cloud, can be clearly identified in only the first two photographs. These photographs clearly show the cloud transport along the west bank of the Banana River and correspond well with the direction of motion observed on the ground.

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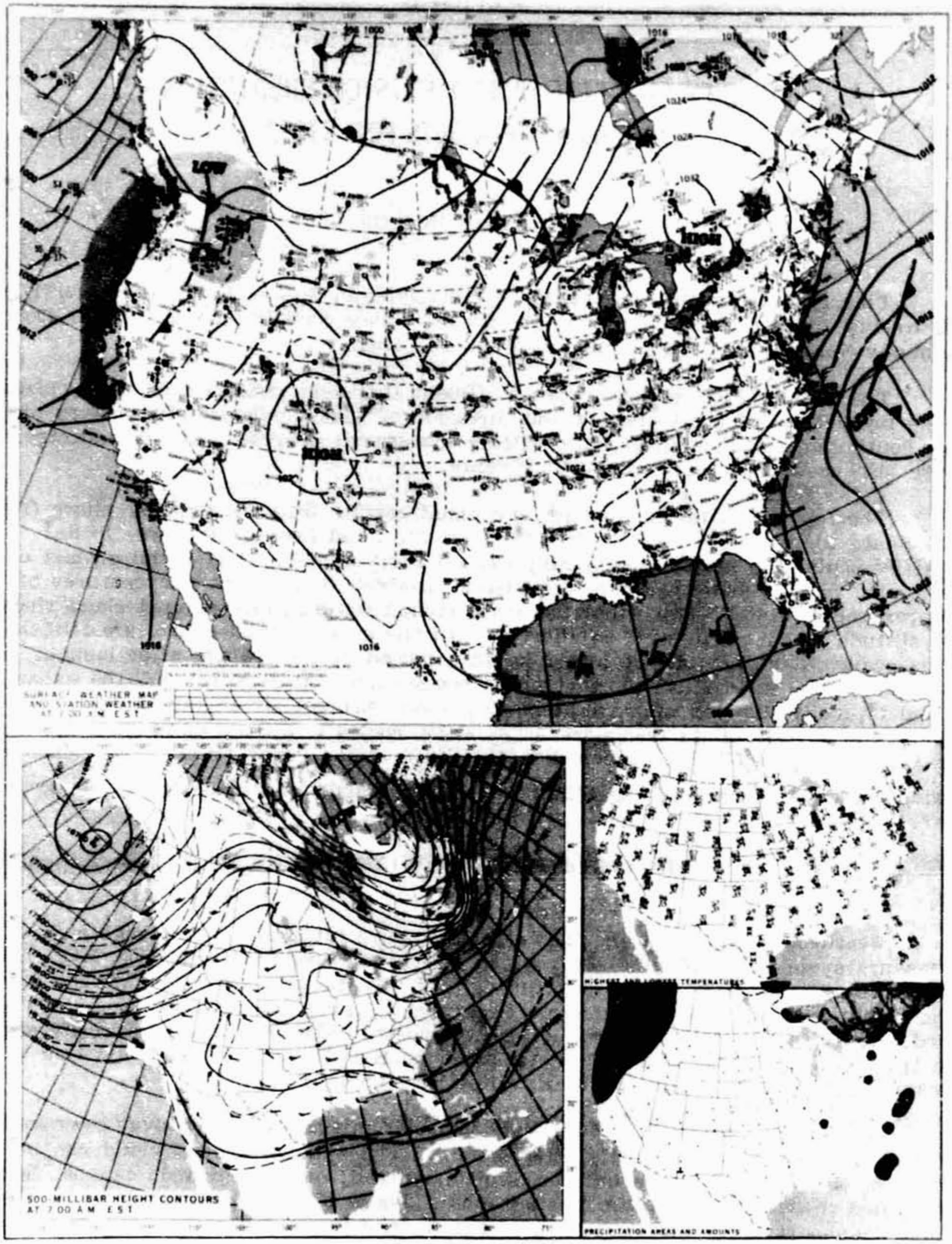

Figure B-1. Surface weather map at launch of STS-2.

TABLE B-1. ATMOSPHERIC SOUNDING AT TIME OF STS-2 LAUNCH

********************** METEOROLOGICAL DATA **********************

RUN NUMBER: 1 USING METEOROLOGICAL DATA FILE: VK1215

TEST NBR 09101 T MINUS 0 VK1215
RAWINSONDE RUN AN/GMD-1
CAPE CANAVERAL AFS, FLORIDA
ASCENT NBR 0434

TIME: 1015 EST DATE: 12 NOV 1981

********************** SOUNDING **********************

SURFACE DENSITY (GM/M**3): 1190.43

MET LEVEL NO.	ALTITUDE (FT)	ALTITUDE (M)	DIR. (DEG)	SPEED (M/S)	SPEED (KTS)	TEMP	PTEMP (DEG. C)	DPTEMP (DEG. C)	PRESS (MB.)	RH (%)
1	16	4.9	337.0	7.72	15.00	22.4	22.98	16.0	1016.9	67.0
2	493	150.3	337.0	8.75	17.00	20.4	22.28	14.7	1000.0	70.0
3	1000	304.8	351.0	10.30	20.00	18.5	21.83	14.0	982.3	75.0
4	1936	590.1	3.0	9.78	19.00	15.4	21.46	13.1	950.0	86.0
5	2000	609.6	4.0	9.78	19.00	15.2	21.45	13.0	947.9	87.0
6	2235	681.2	8.0	9.78	19.00	14.4	21.29	12.5	940.0	88.4
7	3000	914.4	19.0	9.27	18.00	13.2	22.35	11.6	914.4	90.0
8	3435	1047.0	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
9	3441	1048.8	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
10	3718	1133.2	18.0	8.24	16.00	12.2	22.76	2.2	891.0	50.8
11	4000	1219.2	16.0	8.24	16.00	12.2	23.42	-2.3	881.9	39.0
12	4375	1333.5	13.0	8.24	16.00	12.2	24.32	-8.2	870.0	23.7
13	5000	1524.0	4.0	7.21	14.00	11.7	25.95	-3.4	850.4	35.0
14	5005	1525.5	4.0	6.69	13.00	11.6	25.88	-3.3	850.0	35.0
15	6000	1828.8	351.0	5.15	10.00	9.5	26.81	-3.1	819.9	41.0
16	6658	2029.4	352.0	5.15	10.00	7.8	27.13	-3.3	800.0	45.0
17	6670	2033.0	352.0	5.15	10.00	7.8	27.14	-3.3	800.0	46.1
18	7000	2133.6	358.0	5.15	10.00	7.4	27.64	-6.1	790.3	38.0
19	7425	2263.1	5.0	5.66	11.00	6.8	28.24	-9.7	778.0	30.5
20	8000	2438.4	6.0	6.18	12.00	6.0	29.28	-8.2	761.5	35.0
21	8269	2520.4	7.0	6.69	13.00	5.6	29.76	-7.6	754.0	39.0
22	8396	2559.1	6.0	7.21	14.00	5.7	30.27	-9.4	750.0	34.0
23	9000	2743.2	0.0	7.72	15.00	6.4	32.74	-17.	733.8	18.0
24	9140	2785.9	359.0	8.24	16.00	6.5	33.27	-19.	730.0	15.3
25	10000	3048.0	354.0	8.75	17.00	5.6	35.13	-18.	707.0	17.0

** - INDICATES THAT DATA IS LINEARLY INTERPOLATED FROM INPUT METEOROLOGY

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Figure B-2. GOES-2 cloud cover imagery, 1510 GMT.

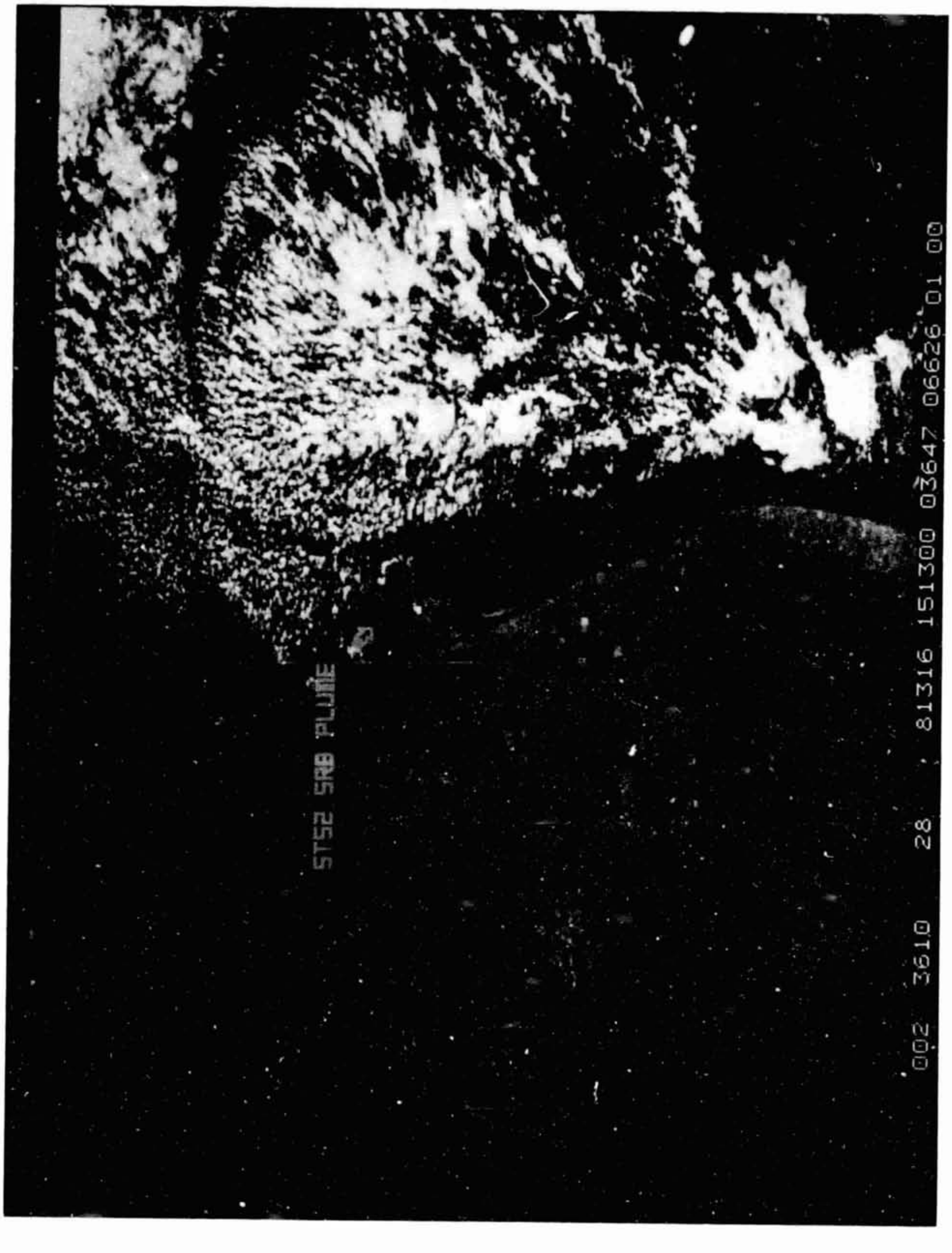

Figure B-3. GOES-2 cloud cover imagery, 1513 GMT.

Figure B-4. GOES-2 cloud cover imagery, 1520 GMT.

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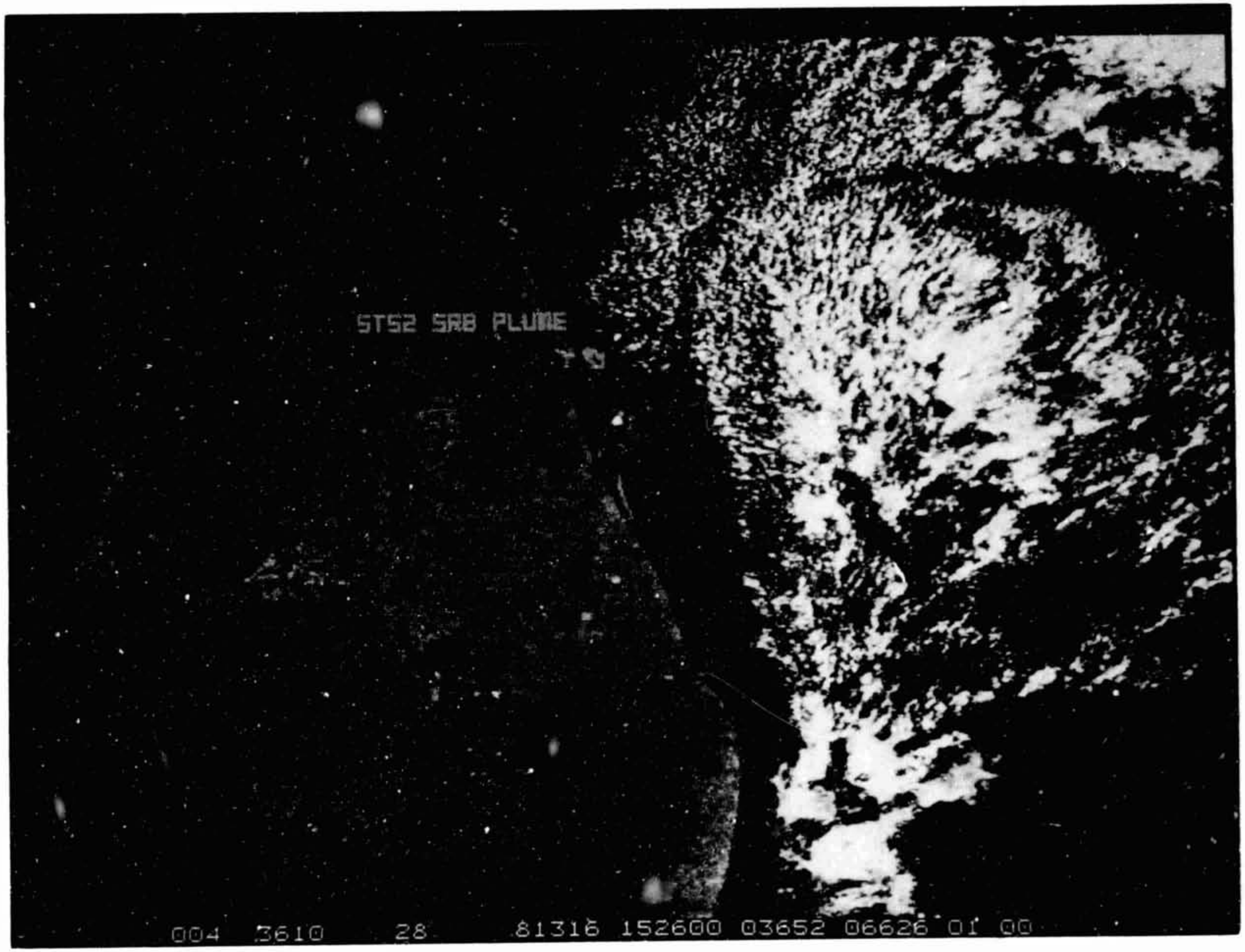

Figure B-5. GOES-2 cloud cover imagery, 1526 GMT.

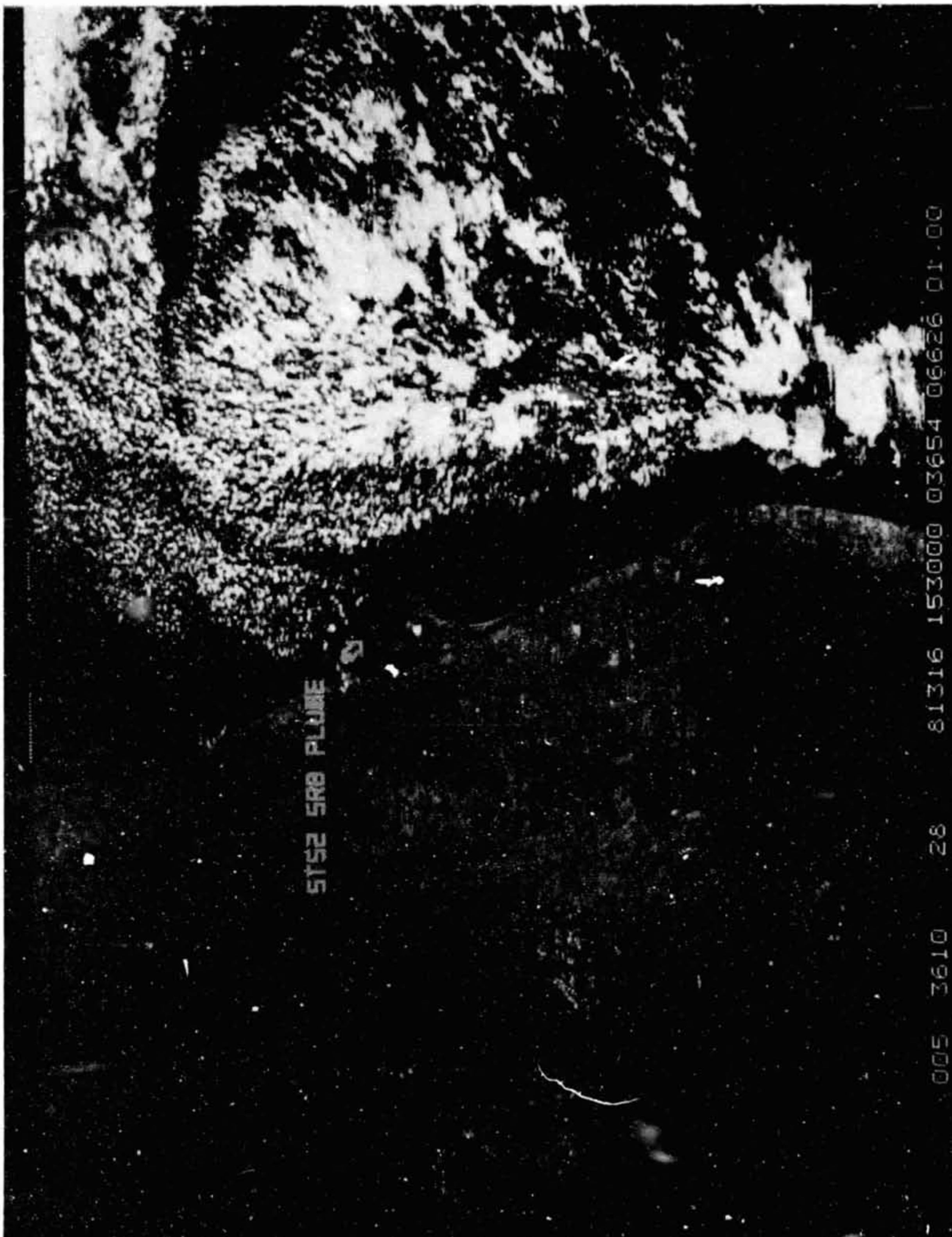

Figure B-6. GOES-2 cloud cover imagery, 1530 GMT.

Figure B-7. GOES-2 cloud cover imagery, 1533 GMT.

III. ROCKET EXHAUST PREDICTIONS

A. STS-2 Exhaust Cloud

The exhaust cloud produced by the launch of the second Shuttle was similar in size to the one produced by the first Shuttle launch. Figures B-8 through B-13 show a partial temporal history of the exhaust cloud development and transport through photographs taken at a camera site approximately 3 miles west of the launch pad. Figure B-8, which was taken approximately 45 sec after launch, shows the SSME cloud on the right side of the picture. This cloud is composed principally of water or steam, and some rainout is visible beneath the cloud. Figure B-9 was taken at 105 sec; the SSME cloud on the right has almost completely evaporated in the dry ambient air. Figure B-10, taken at 165 sec; shows that the plume and flame trench cloud have not merged and effluent rainout is clearly visible beneath both clouds. In Figure B-11, taken at L + 285 sec, the two clouds have merged and effluent rainout is still occurring. At L + 465 sec (Fig. B-12), the cloud has elongated along the transport direction, with rainout still occurring. At L + 11 min (Fig. B-13), the cloud has elongated further and the vertical extent has decreased as convective activity diminished, and the cloud approaches ambient conditions.

B. Diffusion Predictions

The NASA/MSFC REED code was utilized to make predictions of the transport and diffusion of ground cloud exhaust effluents in prelaunch and in postlaunch monitoring and measurement activities. Prelaunch atmospheric soundings and forecasts are used to make diffusion predictions that are used in environmental monitoring activities. The L - 0 sounding was used to make the diffusion predictions shown in Figures B-14 and B-15. Figure B-14 is a plot of the HCL concentration prediction contours. Contour values are shown on the map and are well below any of the critical values established by Government or industry. Figure B-15 presents a plot of particle gravitational deposition in milligrams per square meter; these are well below any critical values.

IV. ELECTRETS

A. Background

Electrets of polymers have been used successfully in measuring rocket exhaust effluents, as discussed in References 3 through 5. Electrets are made of Teflon-polytetrafluorethylene (C_2F_4). They are dielectrics with a permanent surface charge that gives them properties analogous to magnets, attracting charged particles and ions to their surfaces. The multi-element analysis aspect of the electret is of great value when contamination must be monitored. Details of the procedures and equipment used to make electrets can be found in References 3 and 4.

The particles collected in tests that have been conducted either have a positive or negative charge and are attracted to the electret's surface. These collected particles or ions on the electrets are then analyzed by taking an X-ray spectrograph of the sample. The electrets are evaluated by taking the total Cl counts (N_o) obtained

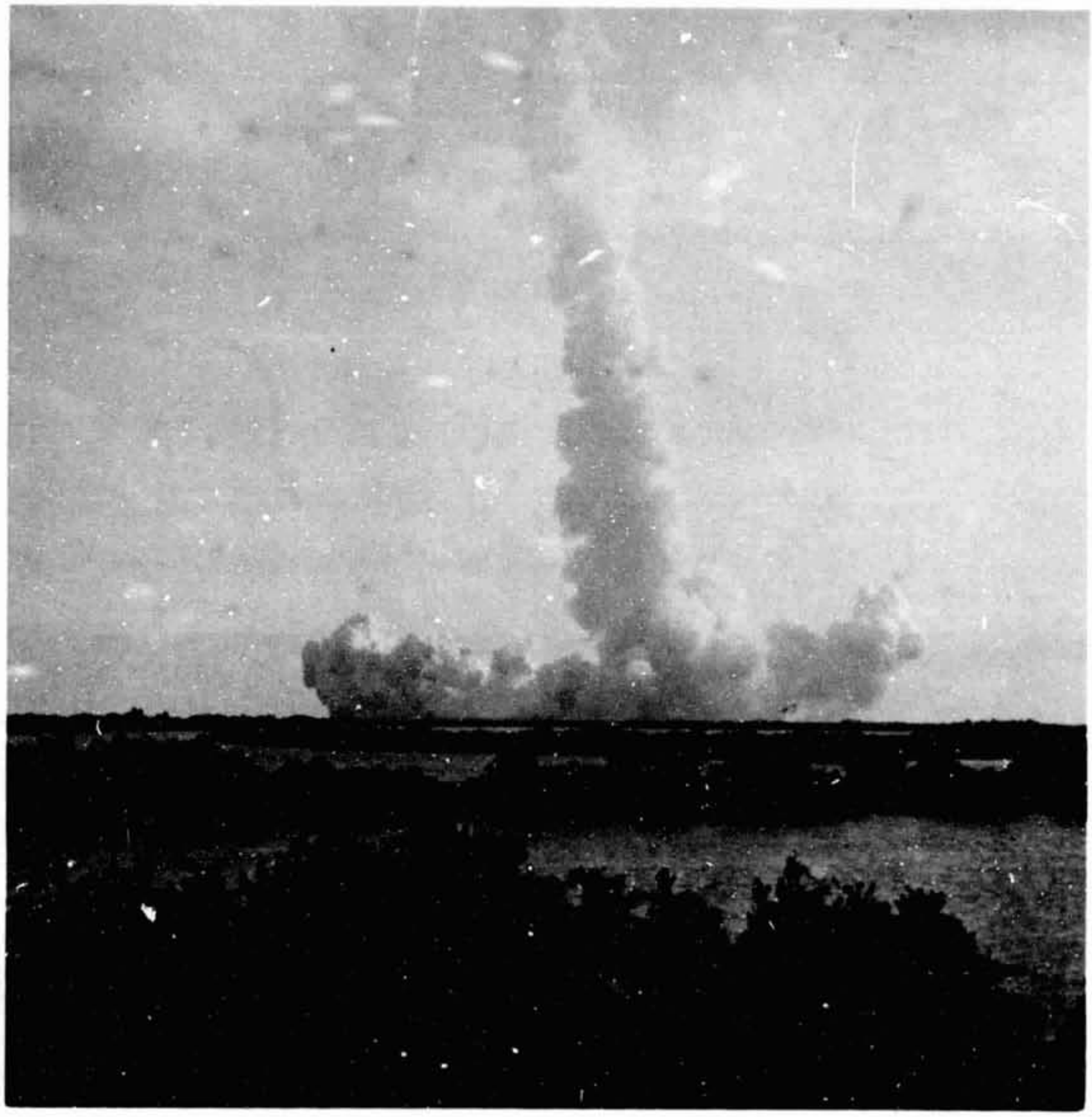

Figure B-8. STS-2 exhaust cloud formation; time: L + ∿ 45 sec.

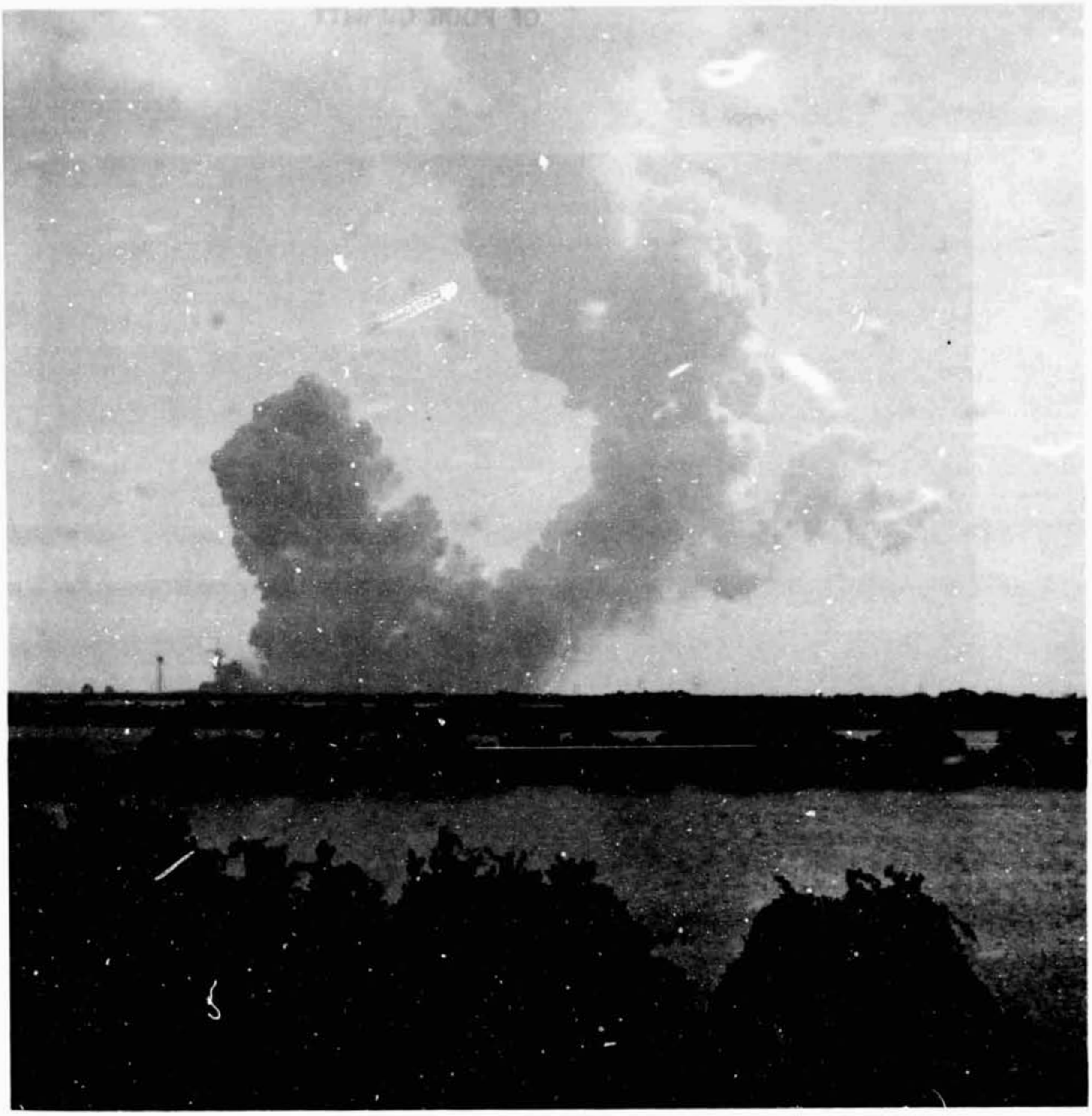

Figure B-9. STS-2 exhaust cloud formation; time: L + ∿ 105 sec.

Figure B-10. STS-2 exhaust cloud formation; time: L + ∿ 165 sec.

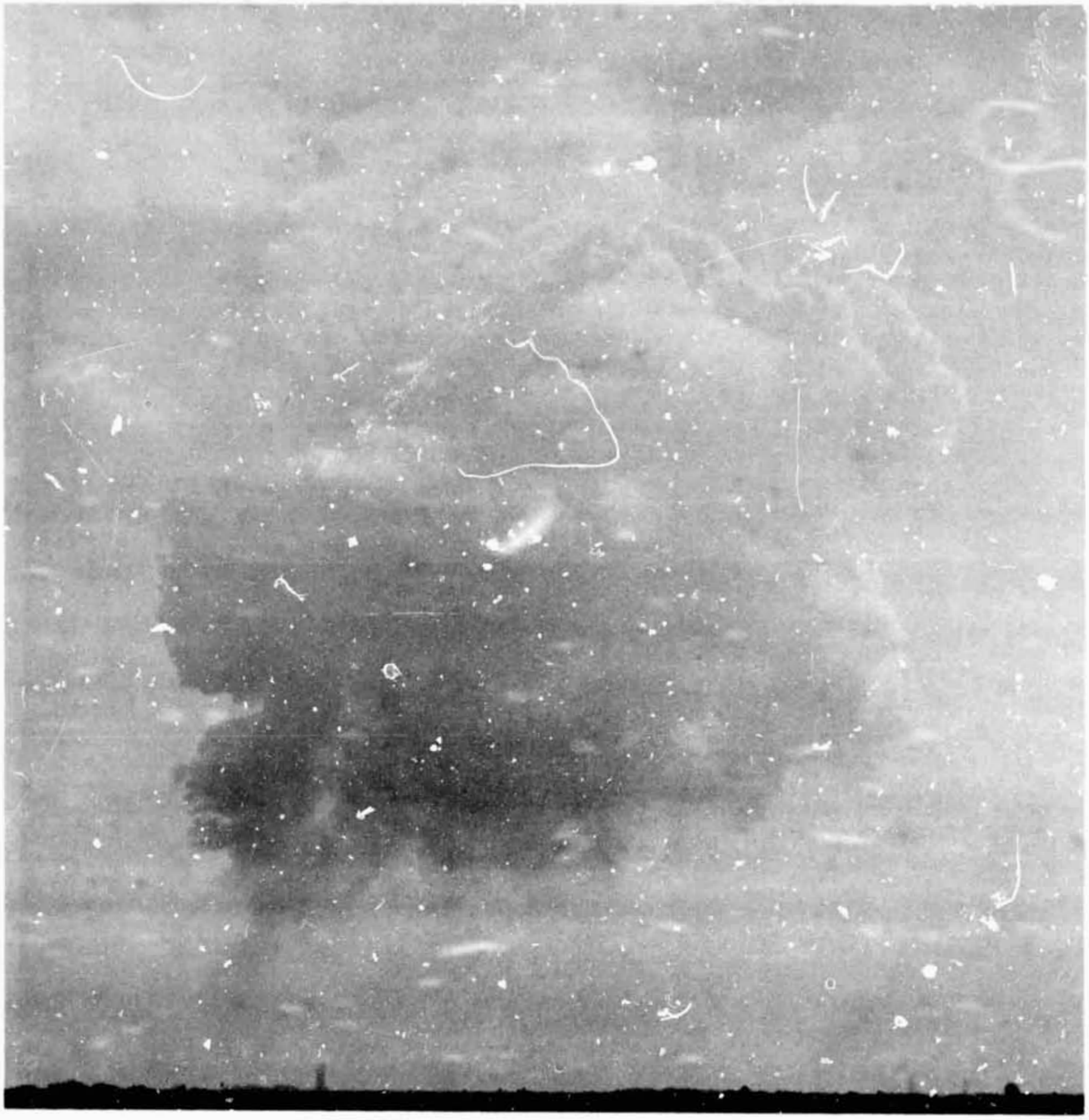

Figure B-11. STS-2 exhaust cloud formation; time: L + ∿ 285 sec.

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Figure B-12. STS-2 exhaust cloud formation; time: L + ∿ 465 sec.

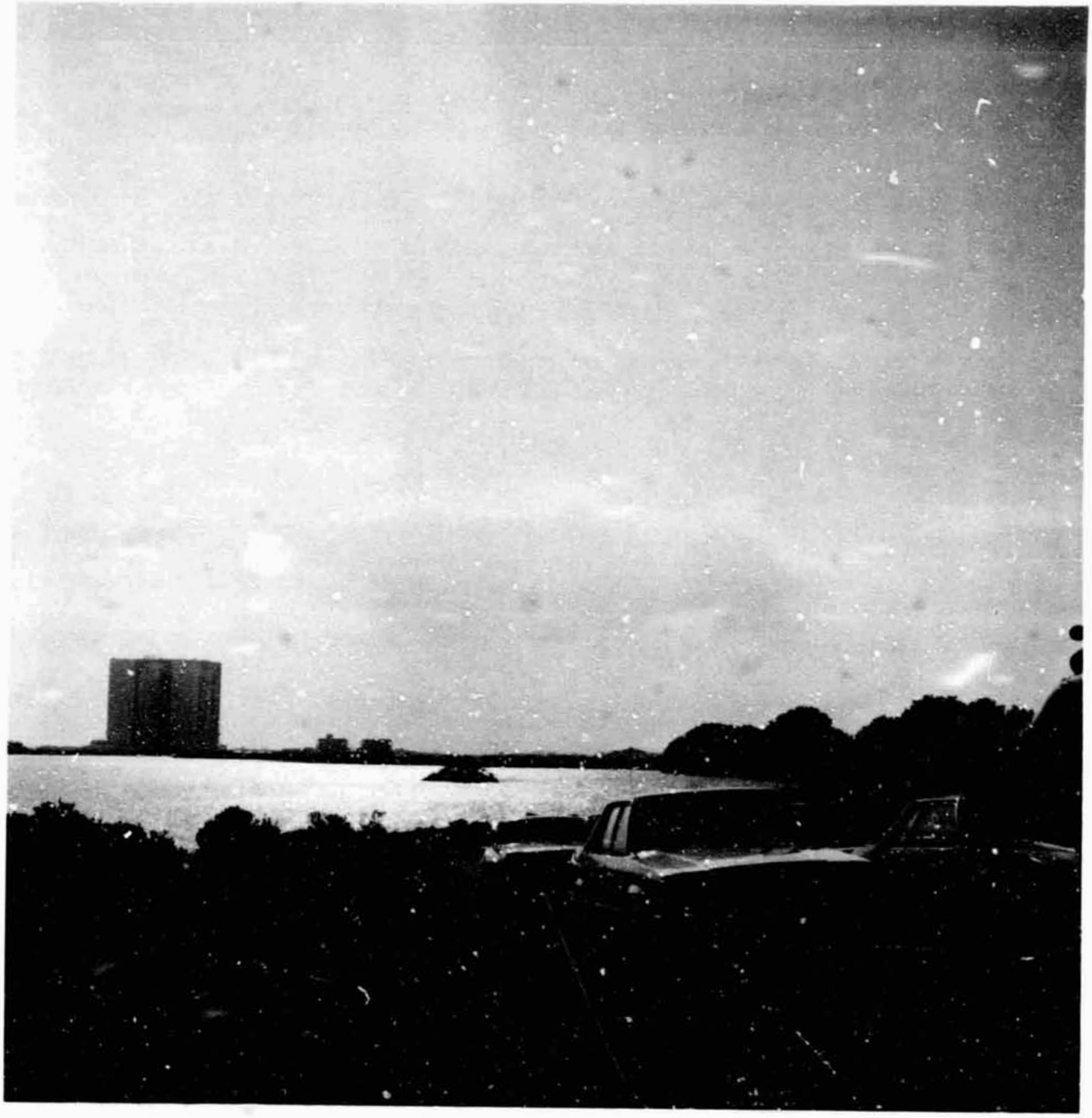

Figure B-13. STS-2 exhaust cloud formation; time: L + ∿ 11 min.

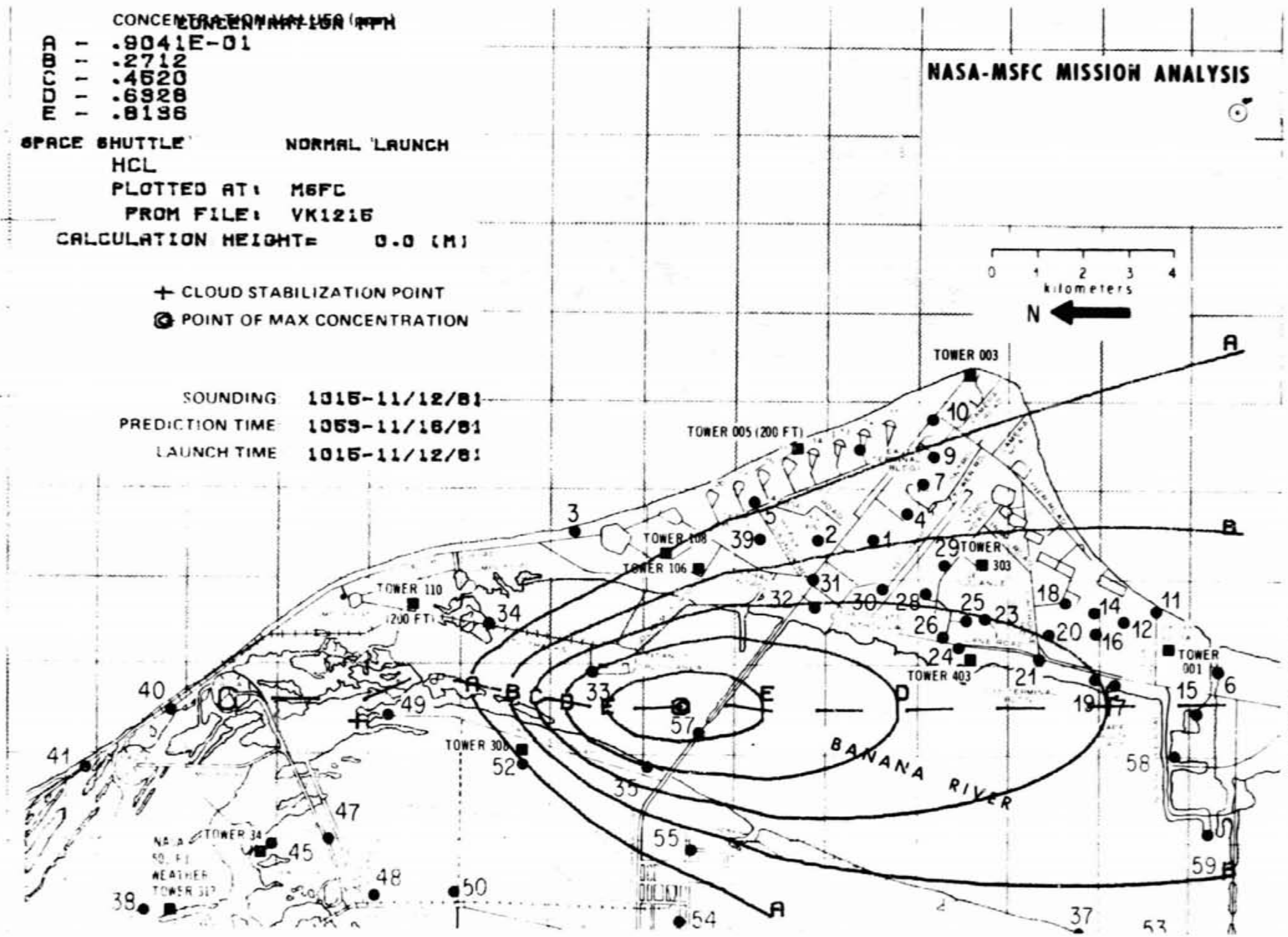

Figure B-14. Diffusion prediction for HCL at L - 0.

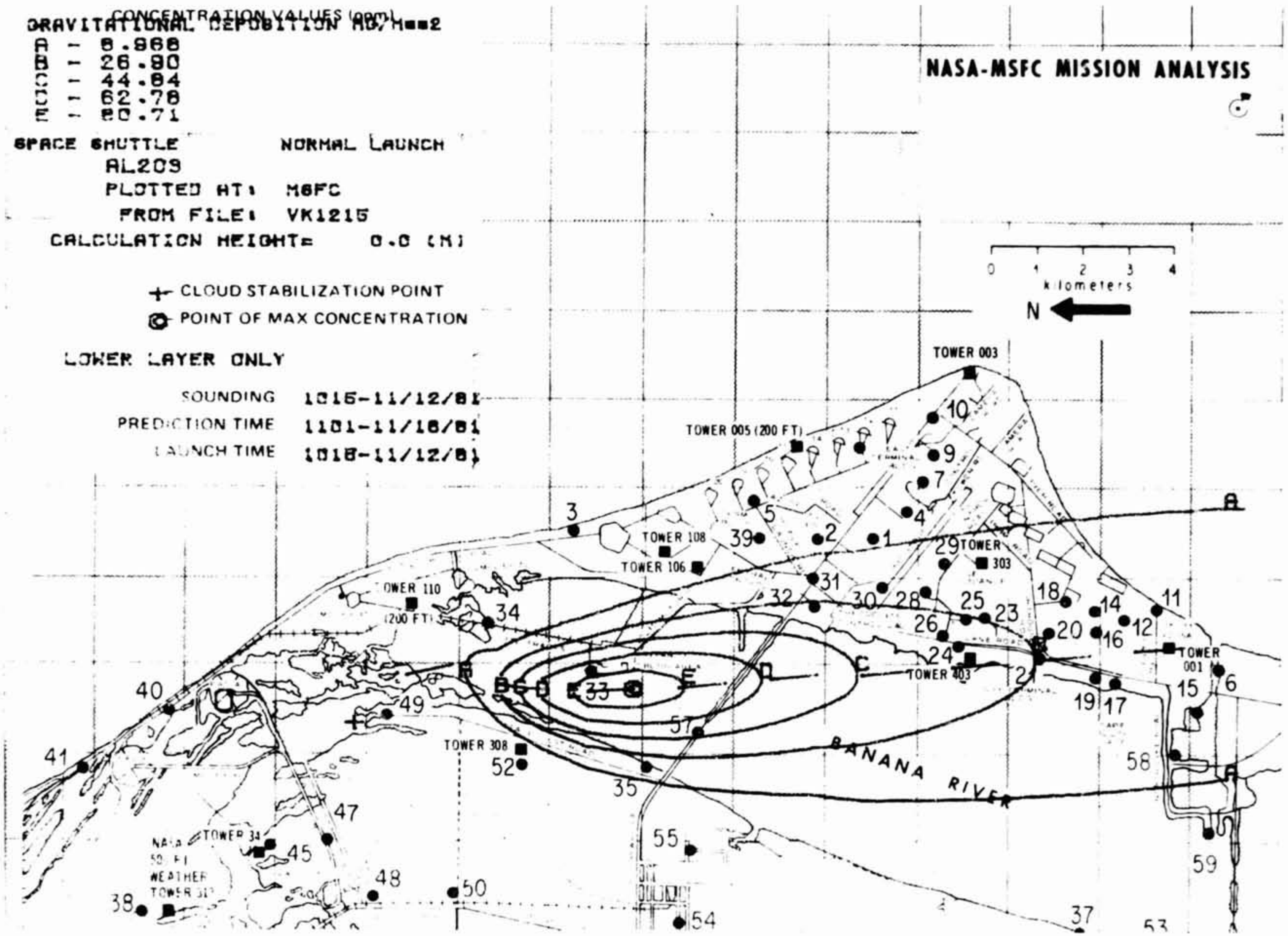

Figure B-15. Diffusion prediction for Al_2O_3 at L - 0.

from the surface of the electret after exposure to pollution as a measure of the quantity of material collected by X-ray energy spectroscopy (XES) analysis. From XES analysis of the effluents collected on the electrets from the ground cloud of STS-2, multi-element analyses are made in the X-ray energy range from 0.707 to 30 keV ± 0.170 keV (i.e., fluorine to silver). References 6 and 7 give details on X-ray energy microscopy and practical application of scanning electron microscopy.

B. MSFC's Electret Measurements at Launch Complex 39A

Samples were taken by the MSFC electrets at 13 locations extending from the immediate launch area (400 m) to approximately 2160 m. Figure B-16 illustrates the deployment of the electrets around launch complex 39A at KSC. The XES measurements are shown in Tables B-2 through B-14 of the Appendix. Figure B-17 illustrates qualitatively the difference in energy spectra of the background electret obtained at site UCS-6 2000 m and 270 degrees from the launch pad and an electret exposed to the STS-2 ground cloud at site L8, 420 m and 160 degrees from launch pad 39A. The two electrets were positioned 2 m above the ground and 1 m apart. One electret was perpendicular to the ground and the other horizontal to the ground. The intent was to determine the particle fallout on the horizontal electret positioned parallel to the Earth and to determine the ion measurement on the vertical electret. The data from XES clearly show that when the electret is in the direct flow of the ground cloud (vertical), it gathers more of the exhaust particles and ions as measured by XES.

Surface measurements by MSFC's electrets of the rocket exhaust ground clouds which traveled in a southerly direction from launch complex 39A were obtained at sites L8 (420 m and 160 degrees from launch pad 39A, Table B-3), L10 (450 m and 78 degrees from launch pad 39A, Table B-4), and L1 (1580 m and 120 degrees from launch pad 39A, Table B-5). At site 11 the observed electret Cl counts (N_o) from XES analysis [all counts are corrected for background (N_b)] were 13,750' and 13,750 , where the prime (') indicates electrets which were positioned vertical to the ground. Also, the counts (N_o) of aluminum were 35,675 for the vertical and the horizontal electrets. As shown in Tables B-2 through B-14, the counts from XES for aluminum are generally below 500. At site L8, the counts for Cl were 8750' and 1750$^-$ and for Al, 8675' and 3175$^-$. At site L10, the Cl counts were 675' and 4750$^-$, while the Al counts were 0. At site L1, the Cl counts were 7750' and 9750$^-$, while the Al counts were 75 for both horizontal and vertical electrets.

Figures B-18 through B-21, taken by the photomicroscope, illustrate the vertical and horizontal electrets exposed to the Space Shuttle's ground cloud at site 11 (420 m and 14 degrees from the launch pad). The Cl count was 13,750 for Cl and 35,675 for Al for both the vertical and horizontal electrets.

For comparative purposes, Figures B-22 and B-23 illustrate an electret exposed not in the direct flow of the ground cloud; 800 counts of Cl and 300 for Al were obtained. The microscope photographs of electret (Z^-) at site L14 (400 m and 247 degrees from the launch pad) are shown.

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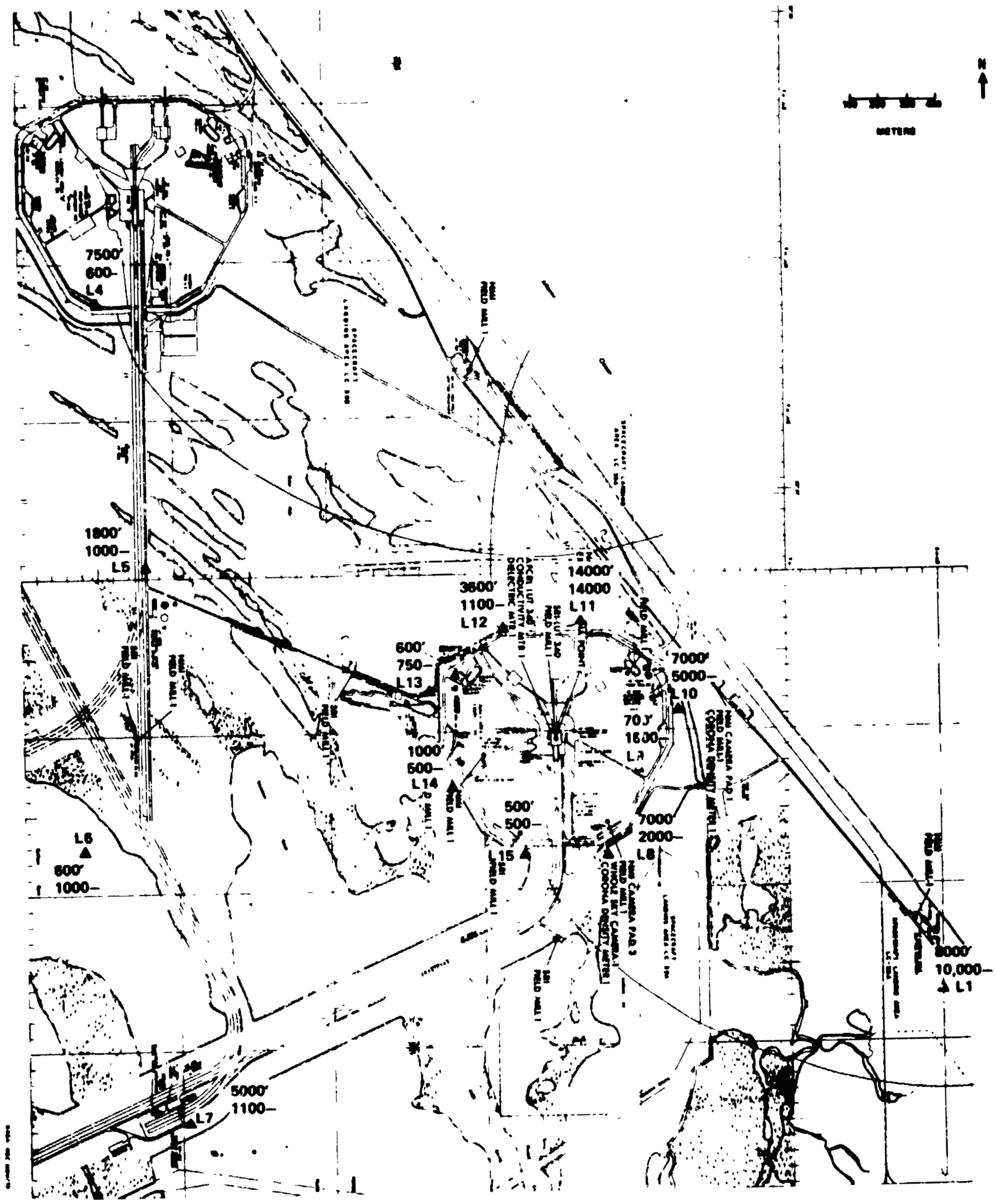
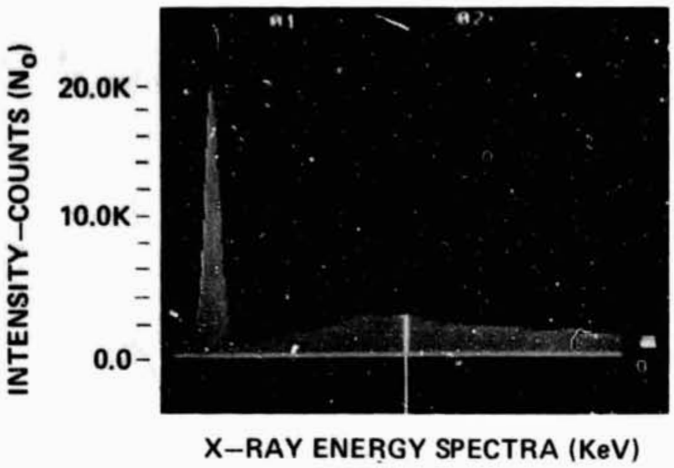


Figure B-16. Deployment of electrets at various sites at launch complex 39A, Kennedy Space Center, Florida, during launch of STS-2, November 12, 1981. Prime (') indicates electrets placed normal to the ground; dash marks (-) indicate parallel ground measurements are in counts (N_0) of Cl obtained from X-ray energy spectroscopy (XES) analysis.



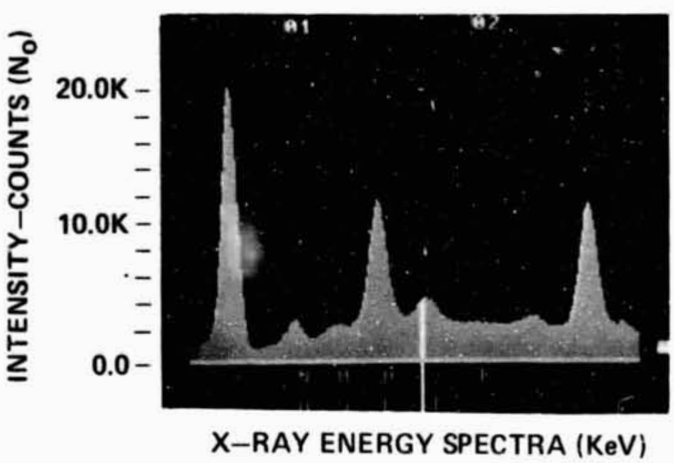


Figure B-17. Comparison of background energy spectra obtained by XES at site UCS-6, prior to launch (top figure) with spectra fror. site L8 after launch of STS-2 illustrating the two peaks of Cl and Al.

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Figure B-18. Microscopic photo of electret (3') at site 11 (7.9X).

Figure B-19. Closeup microscopic photo of electret (3') at site 11 (31X).

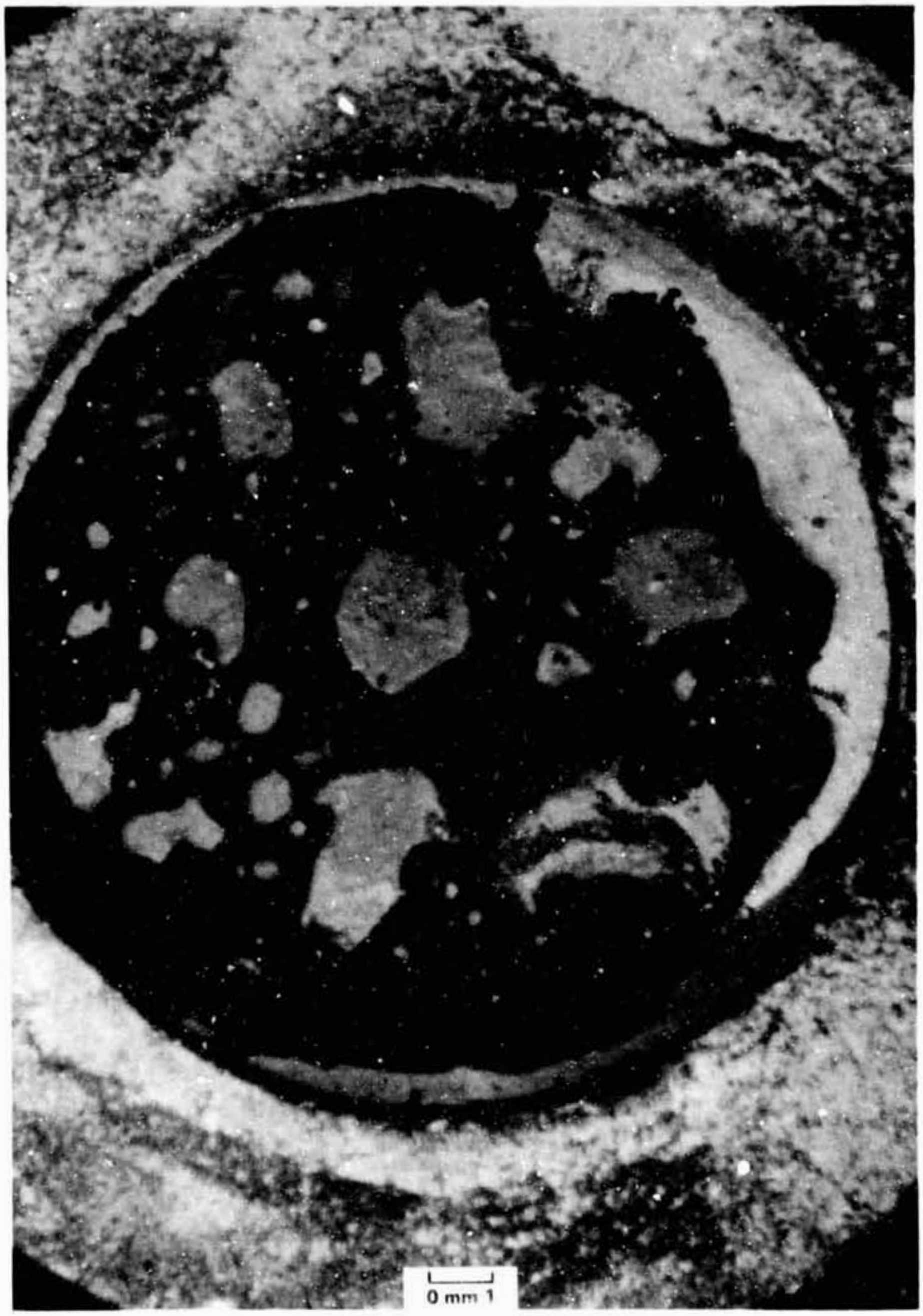

Figure B-20. Microscopic photo of electret (4^-) at site 11 (7.9X).

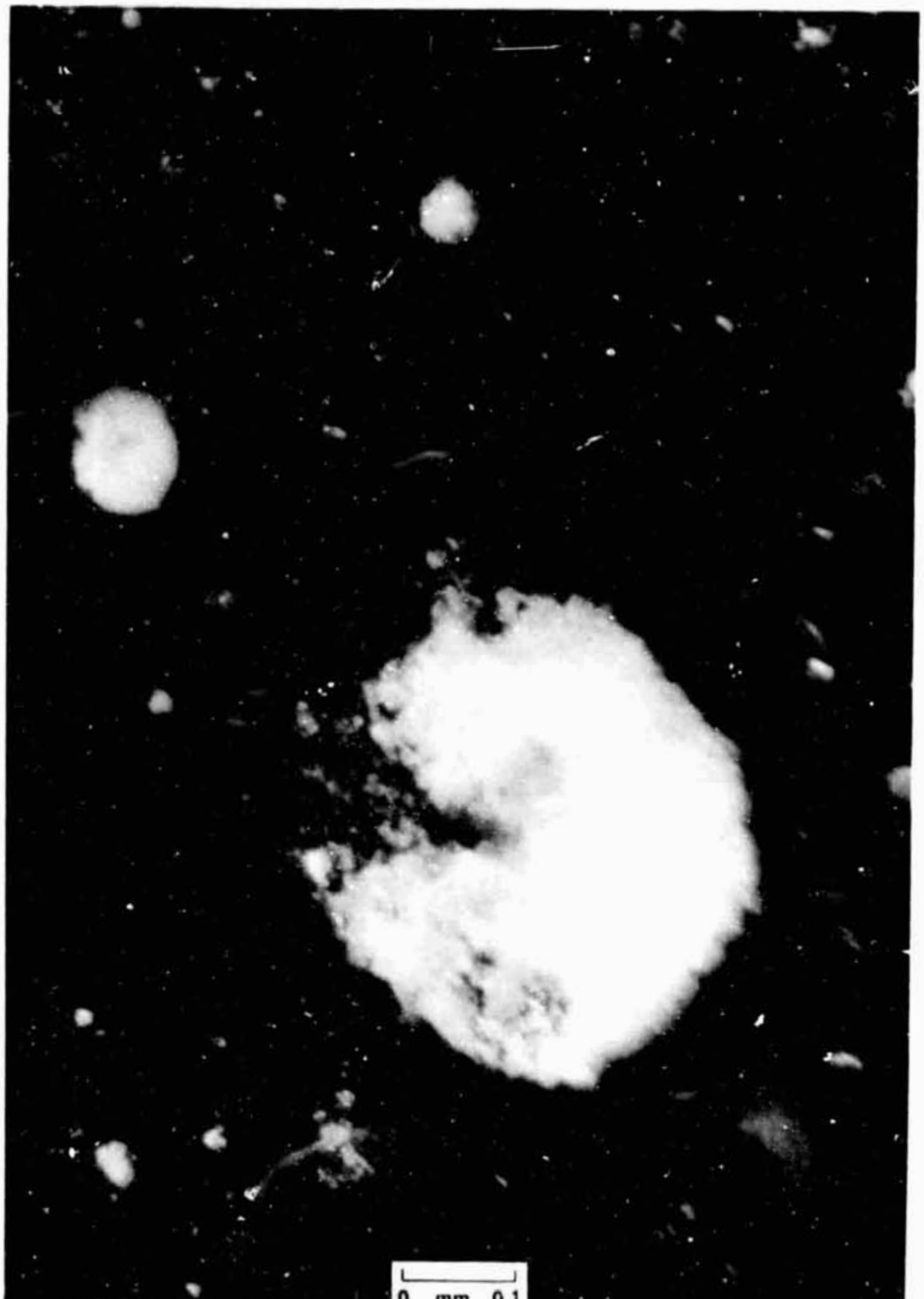

Figure B-21. Closeup microscopic photo of electret (4") at site 11 (157X).

Figure B-22. Microscopic photo of electret (6⁻) at site L13 (7.9X).

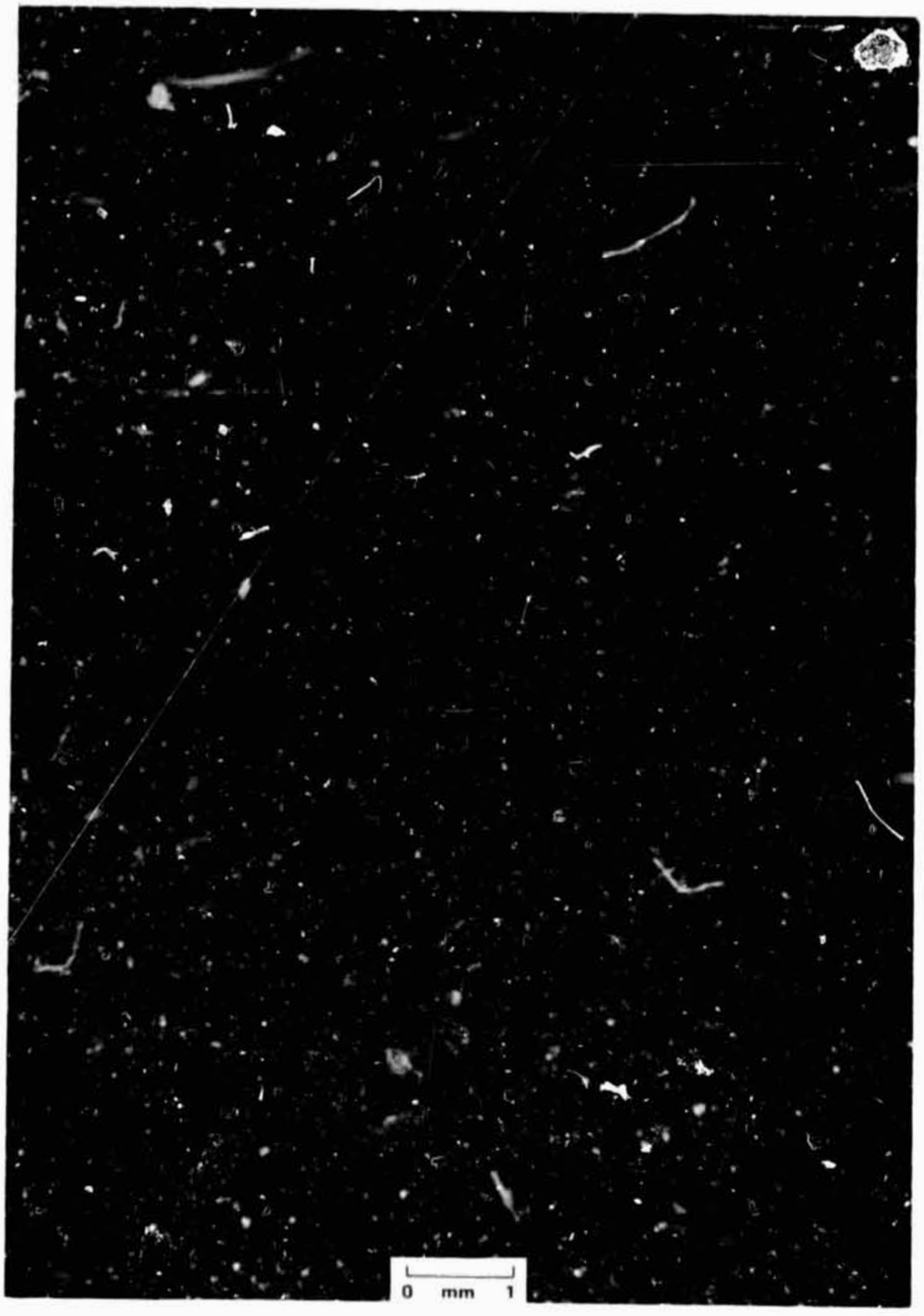

Figure B-23. Closeup microscopic photo of electret (6) at site L13 (75X).

C. Summary

The electrets are an important complementary aerosol measurement device. The multi-element analysis aspect of the electret is of great value when contamination must be monitored, as in the Space Shuttle launches, where measurements of hydrogen chloride, carbon dioxide, and aluminum oxide particles are to be monitored. An XES analysis illustrates the comparative contribution of each element in the fallout from the ground cloud.

APPENDIX

XES ANALYSES OF ELECTRETS

TABLE B-2. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L11, POSITIONED 420 m AND 14 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	21,000' 18,600⁻	19,000
1.0412	Na	500' 200⁻	
1.253	Mg		
1.497	Al	36,000' 36,000⁻	325
1.749	Si	8,000' 7,000⁻	325
2.013	P	500' 800⁻	
2.306	S	200' 300⁻	50
2.626	Cl	14,000' 14,000⁻	250
3.317	K	1,300' 1,500⁻	
3.660	Ca	150' 250⁻	
5.411	Cr	1,250' 1.120⁻	100
6.398	Fe	240' 200⁻	125
7.477	Ni	200⁻	
8.040	Cu	200⁻	
8.637	Zn	130' 200⁻	

TABLE B-3. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L8, POSITIONED 420 m AND 160 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	19,000' 19,000^{-}	19,000
1.0412	Na	1,400' 200^{-}	
1.253	Mg	250^{-}	
1.497	Al	9,000' 3,500^{-}	325
1.749	Si	1,400' 1,000^{-}	325
2.013	P		
2.306	S	600' 250^{-}	50
2.626	Cl	9,000' 2,000^{-}	250
3.317	K	250'	
3.660	Ca	600' 200^{-}	
5.411	Cr	60^{-}	100
6.398	Fe	350' 200^{-}	125
7.477	Ni	30'	
8.040	Cu	30' 30^{-}	
8.637	Zn		

TABLE B-4. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L10, POSITIONED 450 m AND 78 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	19,000' 19,000⁻	19,000
1.0412	Na	1,200' 1,000⁻	
1.253	Mg	700' 200⁻	
1.497	Al	300' 400⁻	325
1.749	Si	1,300' 1,300⁻	325
2.013	P		
2.306	S	800' 600⁻	50
2.626	Cl	7,000' 5,000⁻	250
3.317	K	250' 300⁻	
3.660	Ca	250' 250⁻	
5.411	Cr	60' 60⁻	100
6.398	Fe	180' 180⁻	125
7.477	Ni	30⁻	
8.040	Cu	40⁻	
8.637	Zn		

TABLE B-5. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L1, POSITIONED 1580 m AND 120 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	20,000′ 19,000⁻	19,000
1.0412	Na	2,000′ 1,800⁻	
1.253	Mg	400′ 600⁻	
1.497	Al	400′ 400⁻	325
1.749	Si	1,300′ 1,500⁻	325
2.013	P		
2.306	S	800′ 1,000⁻	50
2.626	Cl	8,000′ 10,000⁻	250
3.317	K	260′ 250⁻	
3.660	Ca	400′ 400⁻	
5.411	Cr		100
6.398	Fe	190′ 150⁻	125
7.477	Ni	30′	
8.040	Cu		
8.637	Zn		

TABLE B-6. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L14, POSITIONED 400 m AND 247 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	20,000' 20,000⁻	19,000
1.0412	Na	100' 100⁻	
1.253	Mg		
1.497	Al	150' 300⁻	325
1.749	Si	1,000' 1,000⁻	325
2.013	P		
2.306	S	100' 150⁻	50
2.626	Cl	1,000' 800⁻	250
3.317	K		
3.660	Ca		
5.411	Cr	60' 90⁻	100
6.398	Fe	180' 130⁻	125
7.477	Ni		
8.040	Cu	30' 30⁻	
8.637	Zn		

TABLE B-7. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L13, POSITIONED 480 m AND 293 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	20,000' 19,000-	19,000
1.0412	Na	70-	
1.253	Mg		
1.497	Al	250' 250-	325
1.749	Si	900' 900-	325
2.013	P	100' 100-	
2.306	S	600' 750-	50
2.626	Cl		250
3.317	K		
3.660	Ca		
5.411	Cr	120' 100-	100
6.398	Fe	160' 140-	125
7.477	Ni	50-	
8.040	Cu	30' 40-	
8.637	Zn		

TABLE B-8. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L15, POSITIONED 420 m AND 200 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	19,500' 20,000⁻	19,000
1.0412	Na	100⁻	
1.253	Mg		
1.497	Al	500' 500⁻	325
1.749	Si	1,100' 1,000⁻	325
2.013	P		
2.306	S	100' 200⁻	50
2.626	Cl	500' 500⁻	250
3.317	K		
3.660	Ca		
5.411	Cr	120' 60⁻	100
6.398	Fe	200' 120⁻	125
7.477	Ni	30'	
8.040	Cu	30'	
8.637	Zn		

TABLE B-9. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L12, POSITIONED 420 m AND 334 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	21,000' 20,000⁻	19,000
1.0412	Na	600' 130⁻	
1.253	Mg		
1.497	Al	500' 400⁻	325
1.749	Si	1,000' 1,300⁻	325
2.013	P		
2.306	S	500' 250⁻	50
2.626	Cl	3,600' 1,100⁻	250
3.317	K		
3.660	Ca	150' 60⁻	
5.411	Cr	170' 130⁻	100
6.398	Fe	150' 150⁻	125
7.477	Ni		
8.040	Cu		
8.637	Zn		

TABLE B-10. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L9, POSITIONED 400 m AND 115 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	20,000' 19,000⁻	19,000
1.0412	Na	250	
1.253	Mg		
1.497	Al	350' 350⁻	325
1.749	Si	1,000' 1,000⁻	325
2.013	P		
2.306	S	100' 200⁻	50
2.626	Cl	700' 1,800⁻	250
3.317	K		
3.660	Ca	100⁻	
5.411	Cr	30' 30⁻	100
6.398	Fe	150' 150⁻	125
7.477	Ni		
8.040	Cu	30' 30⁻	
8.637	Zn		

TABLE B-11. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L5, POSITIONED 1680 m AND 290 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	19,000' 19,000⁻	19,000
1.0412	Na	250' 100⁻	
1.253	Mg		
1.497	Al	400' 300⁻	325
1.749	Si	1,300' 1,000⁻	325
2.013	P	200' 100⁻	
2.303	S	350' 100⁻	50
2.626	Cl	1,800' 1,000⁻	250
3.317	K	1,000⁻	
3.660	Ca	150' 90⁻	
5.411	Cr	120' 60⁻	100
6.398	Fe	240' 150⁻	125
7.477	Ni	40⁻	
8.040	Cu	40⁻	
8.637	Zn		

TABLE B-12. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L4, POSITIONED 2160 m AND 311 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	19,000' 19,000⁻	19,000
1.0412	Na	1,200' 100⁻	
1.253	Mg	200'	
1.497	Al	250' 400⁻	325
1.749	Si	1,300' 1,100⁻	325
2.013	P		
2.306	S	600' 200⁻	50
2.626	Cl	7,500' 600⁻	250
3.317	K	300'	
3.660	Ca	300' 120⁻	
5.411	Cr	60'	100
6.398	Fe	130' 140⁻	125
7.477	Ni	30⁻	
8.040	Cu	30' 50⁻	
8.637	Zn		

TABLE B-13. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L6, POSITIONED 1680 m AND 258 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS. - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	19,000' 19,000$^-$	19,000
1.0412	Na	60' 100$^-$	
1.253	Mg		
1.497	Al	250' 300$^-$	325
1.749	Si	1,000' 1,200$^-$	325
2.013	P	100'	
2.306	S	100' 70$^-$	50
2.626	Cl	600' 1,000$^-$	250
3.317	K	60	
3.660	Ca	60' 180$^-$	
5.411	Cr		100
6.398	Fe	180' 140$^-$	125
7.477	Ni	40$^-$	
8.040	Cu	30' 60$^-$	
8.637	Zn		

TABLE B-14. X-RAY ENERGY SPECTROSCOPY ANALYSIS OF ELECTRET AT SITE L7, POSITIONED 1800 m AND 226 degrees FROM LAUNCH COMPLEX 39A DURING STS-2'S LAUNCH FROM KSC (' PRIME, INDICATES VERTICAL POSITIONED ELECTRETS, - DASH, INDICATES HORIZONTAL POSITIONED ELECTRETS)

X-Ray Energy (keV)	Symbol	Total Test Counts (N_o)	Background Counts (N_o)
0.707	F	19,000' 19,000-	19,000
1.0412	Na	1,100' 200-	
1.253	Mg	250'	
1.497	Al	400' 300-	325
1.749	Si	1,300' 1,000-	325
2.013	P	200' 150-	
2.306	S	600' 400-	50
2.626	Cl	5,000' 1,100-	250
3.317	K	250' 60-	
3.660	Ca	250' 60-	
5.411	Cr	60-	100
6.398	Fe	150' 150-	125
7.477	Ni	30-	
8.040	Cu	40-	
8.637	Zn		

REFERENCES

1. Stephens, J. Briscoe, and Stewart, Roger B.: Rocket Exhaust Effluent Modeling for Tropospheric Air Quality and Environmental Assessments. NASA Technical Report R-473, June 1977.

2. Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development, 1982 Revision (Compiled by Robert E. Turner and C. Kelly Hill), Section XVI. NASA Technical Memorandum 82473, June 1982.

3. Pillai, P. K. C., and Shriver, Edward L.: Electrets and Their Applications in Contamination Studies. NASA Technical Report R-457, 1975.

4. Susko, Michael: Research in the Use of Electrets in Measuring Effluents from Rocket Exhaust of the Space Shuttle (6.4 Percent Scaled Model) and Viking I Launch. NASA Technical Paper 1073, November 1977

5. Susko, Michael: Electrets Used to Measure Exhaust Cloud Effluents from Solid Rocket Motor (SRM) During Demonstration Model (DM-2) Static Test Firing. NASA Technical Memorandum 78171, April 1978.

6. Waldseth, Rolf: X-R Energy Spectrometry. Kevex Corporation, Burlingame, California, June 197[illegible]

7. Goldstein, Joseph L., and Yakowitz, Harvey: Practical Scanning Electron Microscopy. Plenum Press, New York, 1975.

SECTION C - MSFC EXHAUST EFFLUENT DIFFUSION PREDICTIONS AND MEASUREMENTS FOR STS-3

BY JOSEPH C. SLOAN AND ROBERT E. TURNER

SECTION C

MSFC EXHAUST EFFLUENT DIFFUSION PREDICTIONS AND MEASUREMENTS FOR STS-3

I. INTRODUCTION

This report present the results of the Marshall Space Flight Center (MSFC) air quality predictions made during the third Space Shuttle launch (STS-3) from Kennedy Space Center on March 22, 1982.

The NASA/MSFC Rocket Exhaust Effluent Diffusion (REED) code was utilized to make predictions of the transport and diffusion of rocket exhaust effluents as part of the continuing NASA environmental effects assessment program. Details of the REED code can be found in the Reference.

II. METEOROLOGICAL CONDITIONS

Weather conditions at the time of launch were influenced by a high-pressure ridge that was drifting slowly eastward and by a cold front that was approaching from the north (Fig. C-1). Low-level winds aloft were west, southwesterly to westerly with the approach of the frontal trough from the north. Surface winds over the Cape were southwesterly during the early morning countdown and after launch; however, just prior to launch, winds in the pad area switched to easterly with the startup of the Sea Breeze. Easterly flow was recorded on all pad anemometers both at the surface and 275-ft levels. This intrusion of easterly winds could explain reports of the exhaust cloud appearing to hover in the pad area before moving out to sea.

GOES east imagery of cloud cover in Figures C-2 and C-3 shows the scattered stratocumulus and cirrus clouds that were present during launch. The Shuttle contrail or plume cloud is clearly visible in the photograph; however, the exhaust ground cloud cannot be identified.

III. ROCKET EXHAUST PREDICTIONS

A. STS-3 Exhaust Cloud

The exhaust cloud produced by the launch of STS-3 penetrated and mixed with low-level clouds that were present in the launch area, which made it difficult to estimate cloud size and configuration. Figures C-4 through C-9 show a temporal history of the exhaust cloud development and transport in photographs taken at a site located west of the launch pad. As in previous exhaust clouds, rainout occurs shortly after launch and can be seen in some of the photographs.

B. Diffusion Predictions

As in previous launches, the NASA/REED code was utilized to make predictions of the transport and diffusion of exhaust cloud effluents. The L = 0 radiosonde sounding shown in Figure C-10 was used to obtain the HCL concentrations and gravitational deposition values which are shown in Figures C-11 and C-12. Again, these values were below any of the critical values that have been established by government or industry.

REFERENCE

Stephens, J. B. and Stewart, R. B.: Rocket Exhaust Effluent Modeling for the Tropospheric Air Quality and Environmental Assessments. NASA Technical Report R-473, June 1977.

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Figure C-1. Surface weather map at launch of STS-3.

Figure C-2. GOES SMS cloud cover imagery.

Figure C-3. GOES SMS cloud cover imagery.

Figure C-4. STS-3 exhaust cloud formation;
time: L + approximately 60 sec.

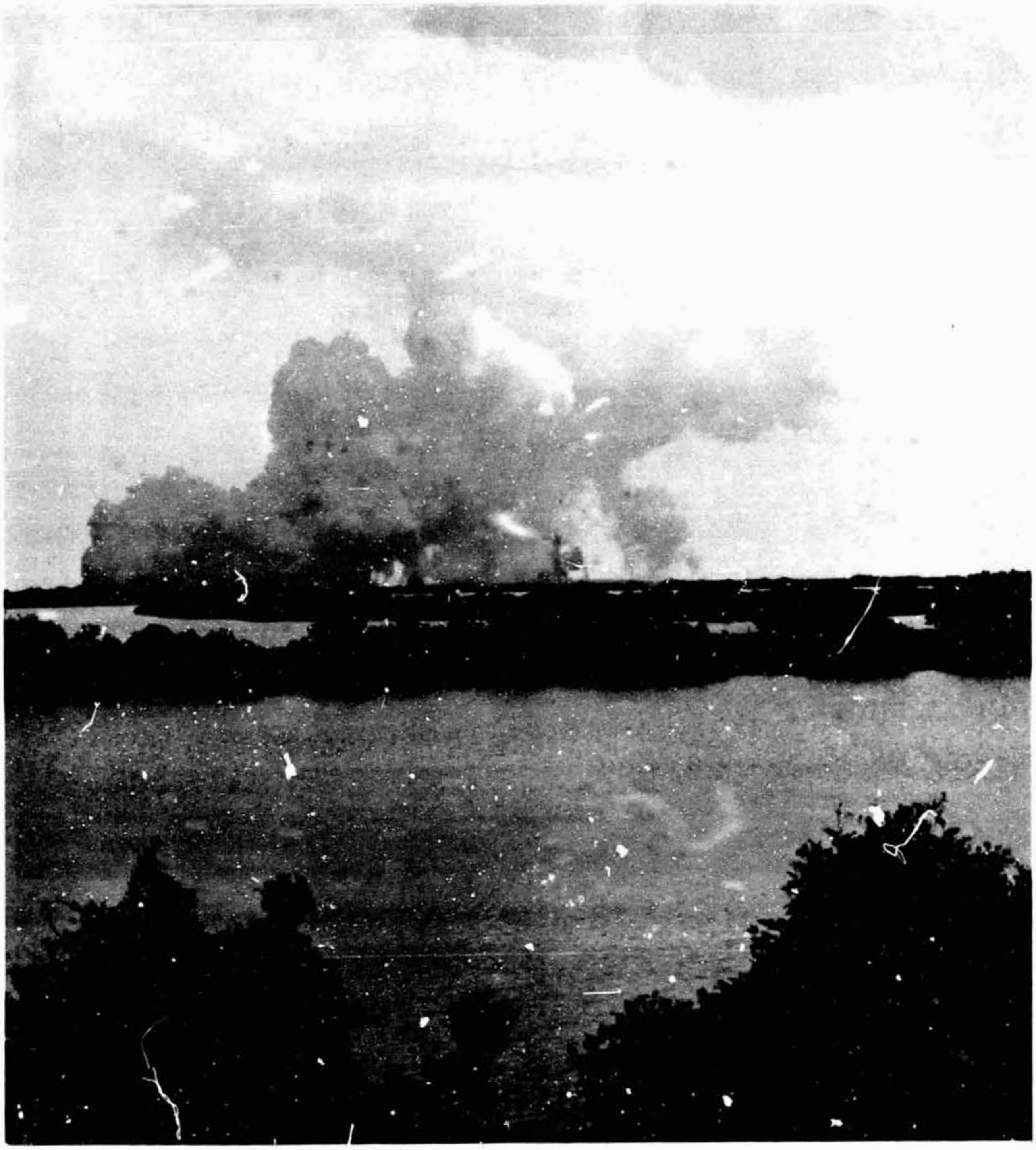

Figure C-5. STS-3 exhaust cloud formation;
time: L + approximately 120 sec.

Figure C-6. STS-3 exhaust cloud formation;
time: L + approximately 210 sec.

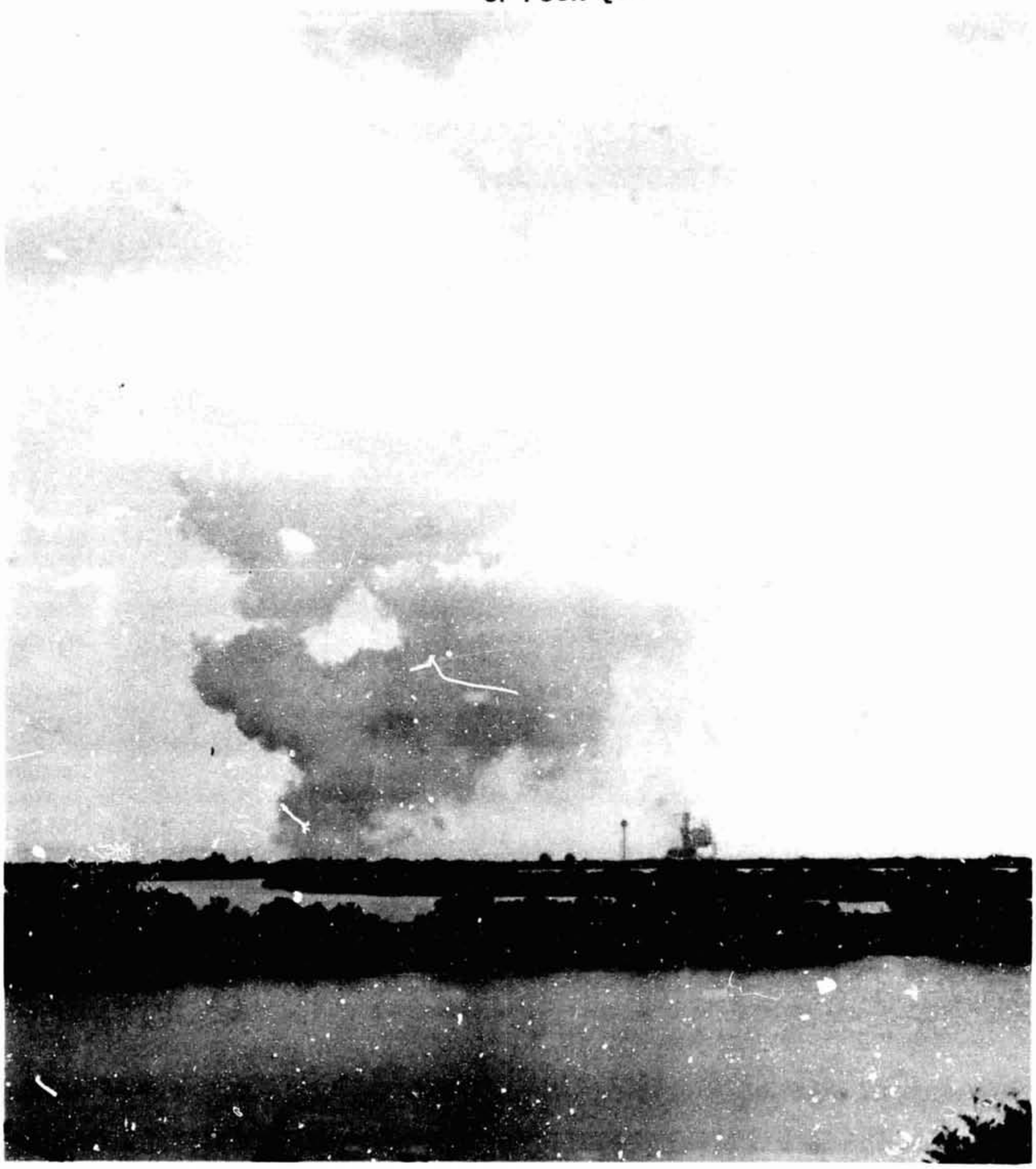

Figure C-7. STS-3 exhaust cloud formation;
time: L + approximately 330 sec.

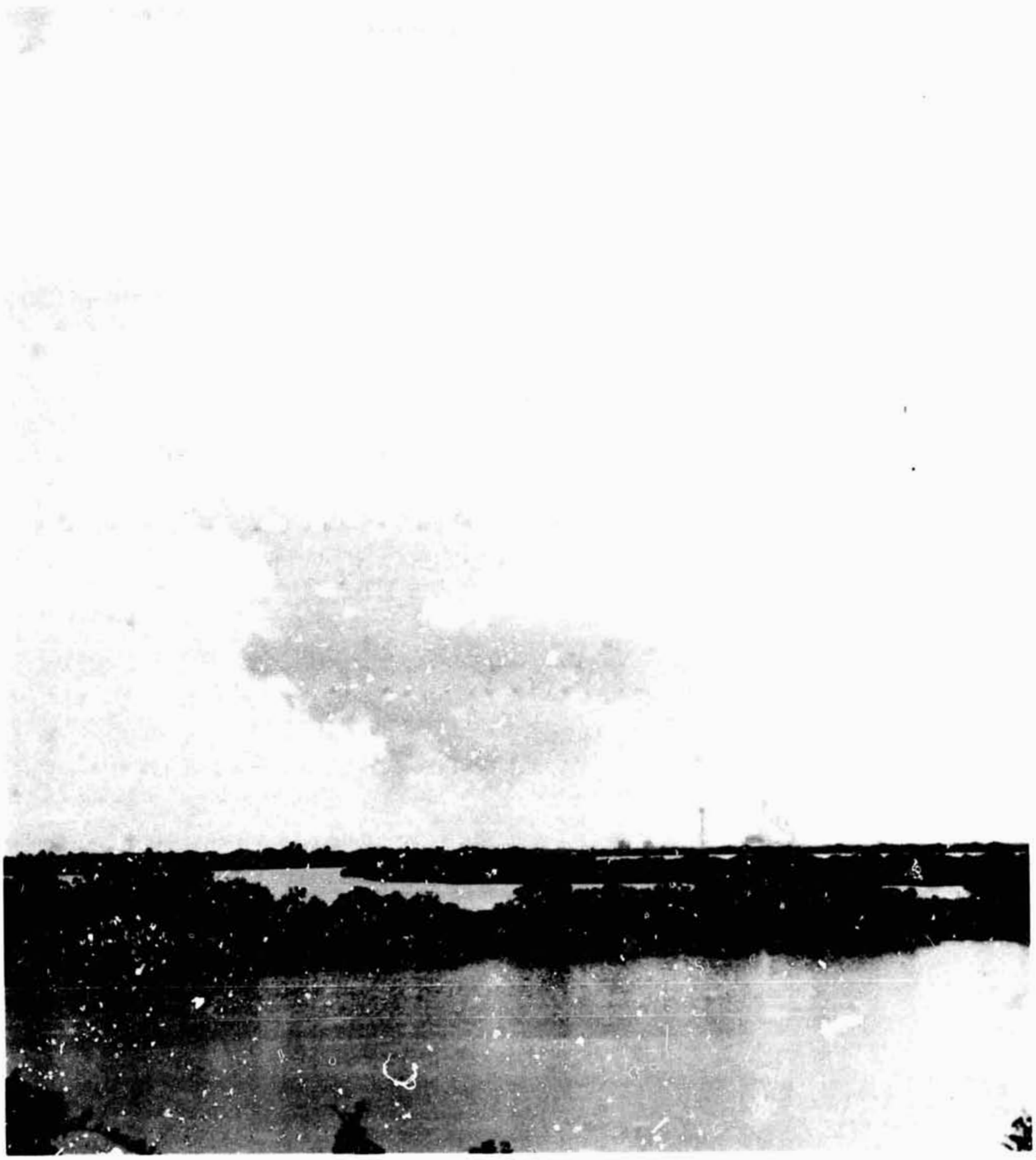

Figure C-8. STS-3 exhaust cloud formation;
time: L + approximately 420 sec.

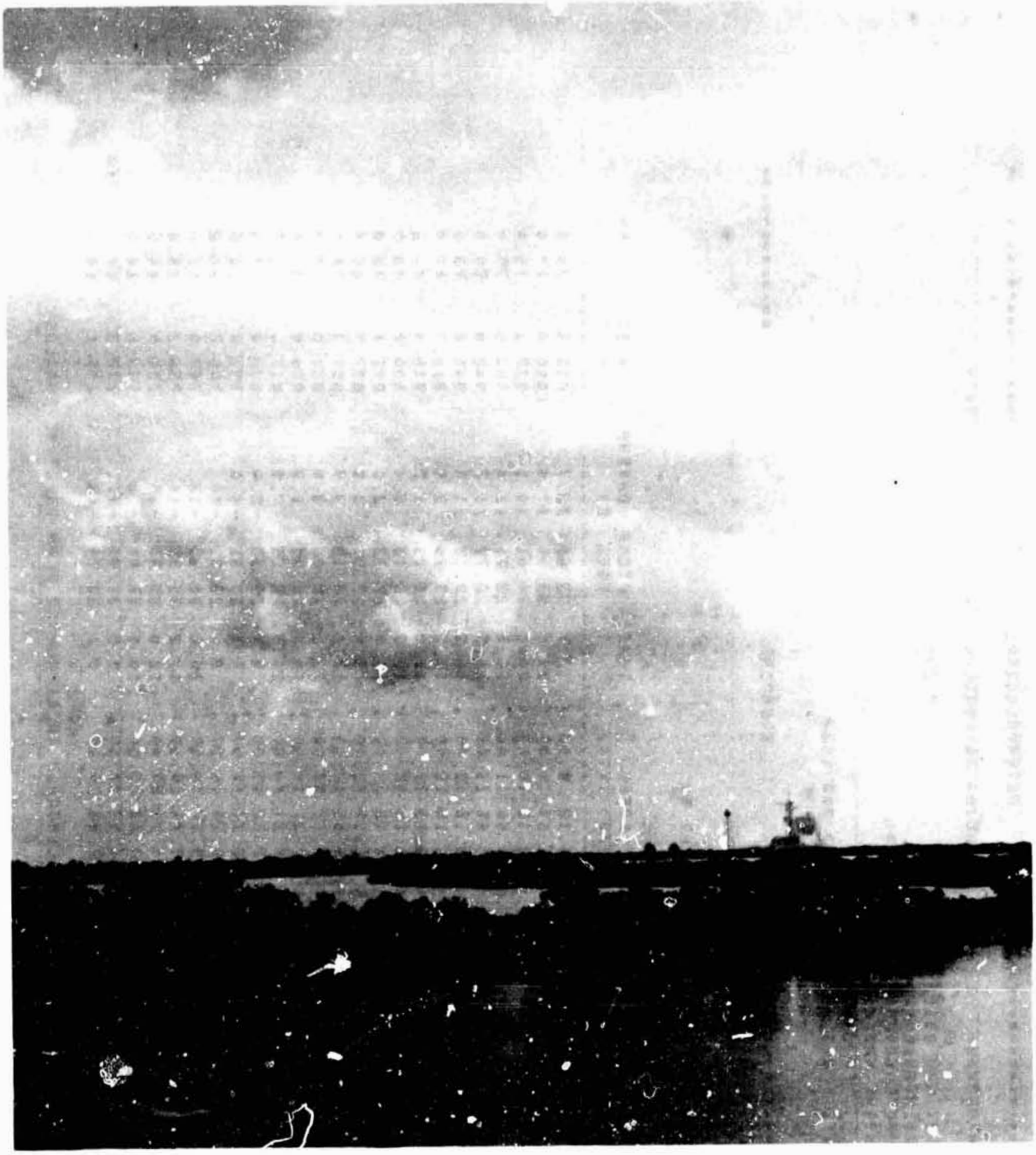

Figure C-9. STS-3 exhaust cloud formation;
time: L + approximately 540 sec.

***************************** METEOROLOGICAL DATA *****************************

RUN NUMBER: 1 USING METEOROLOGICAL DATA FILE: UC2214

TEST NBR 09102 ONI U:2214
RAWINSONDE NSS/NSS
CAPE CANAVERAL AFS, FLORIDA
ASCENT NBR 0125

TIME: 845 EST DATE: 22 MAR 1982

***************************** SOUNDING *****************************

SURFACE DENSITY (GM/M**3): 1187 52

MET LEVEL NO	ALTITUDE (FT)	ALTITUDE (M)	DIR (DEG)	SPEED (M/S)	SPEED (KTS)	TEMP* *	PTEMP (DEG C)	DPTEMP (DEG C)	PRESS (MB)	RH (%)	
1	16	4.9	260.0	4.12	8.00	22.7	23.68	18.7	1016.6	78.0	
2	486	148.1	267.0	4.64	9.00	21.6	23.84	17.4	1000.0	77.0	
3	1000	304.8	272.0	5.15	10.00	20.4	24.01	16.1	982.2	76.0	
4	1938	590.7	272.0	5.66	11.00	16.7	22.79	12.0	950.0	79.0	
5	2000	609.6	272.0	5.66	11.00	16.5	22.77	11.7	948.0	80.0	
6	2078	633.4	272.0	[illegible]	12.00	16.2	22.52	11.4	945.4	73.3	
7	3000	914.4	270.0	6.18	12.00	15.2	23.70	2.9	914.7	47.0	
8	3130	954.0	270.0	6.18	12.00	15.1	23.86	1.7	910.4	40.6	
9	3446	1050.3	271.0	6.18	12.00	15.3	25.13	2.4	900.0	43.0	
10	4000	1219.2	271.0	6.18	12.00	15.7	27.33	3.6	882.4	45.0	
11	4144	1263.1	271.0	6.18	12.00	15.8	27.90	3.9	877.9	45.5	
12	5000	1524.0	269.0	6.69	13.00	13.4	28.18	3.9	851.3	57.0	
13	5037	1535.1	268.0	6.69	13.00	13.2	28.08	3.9	850.0	57.0	
14	6000	1828.8	262.0	7.21	14.00	10.6	28.21	1.3	820.9	57.0	
15	6112	1862.9	262.0	7.21	14.00	10.3	28.15	.9	817.6	52.7	
16	6694	2040.3	260.0	7.72	15.00	9.7	29.15	-5.4	800.0	39.0	
17	7000	2133.6	259.0	8.24	16.00	9.4	29.61	-8.6	791.4	30.0	
18	7159	2182.1	259.0	8.24	16.00	9.2	29.81	-10.	786.8	24.8	
19	8000	2438.4	252.0	9.27	18.00	10.3	34.15	-13.	763.0	17.0	
20	8243	2512.5	251.0	9.78	19.00	11.2	35.35	-14.	756.2	15.4	
21	8453	2576.5	248.0	10.30	20.00	11.0	35.83	-15.	750.0	14.0	
22	9000	2743.2	242.0	10.82	21.00	10.5	37.01	-16.	735.6	14.0	
23	9500	2895.6	239.5	11.59	22.50	9.8	37.86	-17.	722.3	14.0	**
24	10000	3048.0	237.0	12.36	24.00	9.1	38.74	-18.	709.1	14.0	

** - INDICATES THAT DATA IS LINEARLY INTERPOLATED FROM INPUT METEOROLGY

Figure C-10. STS-3 radiosonde sounding made at time of launch; time: L = 0.

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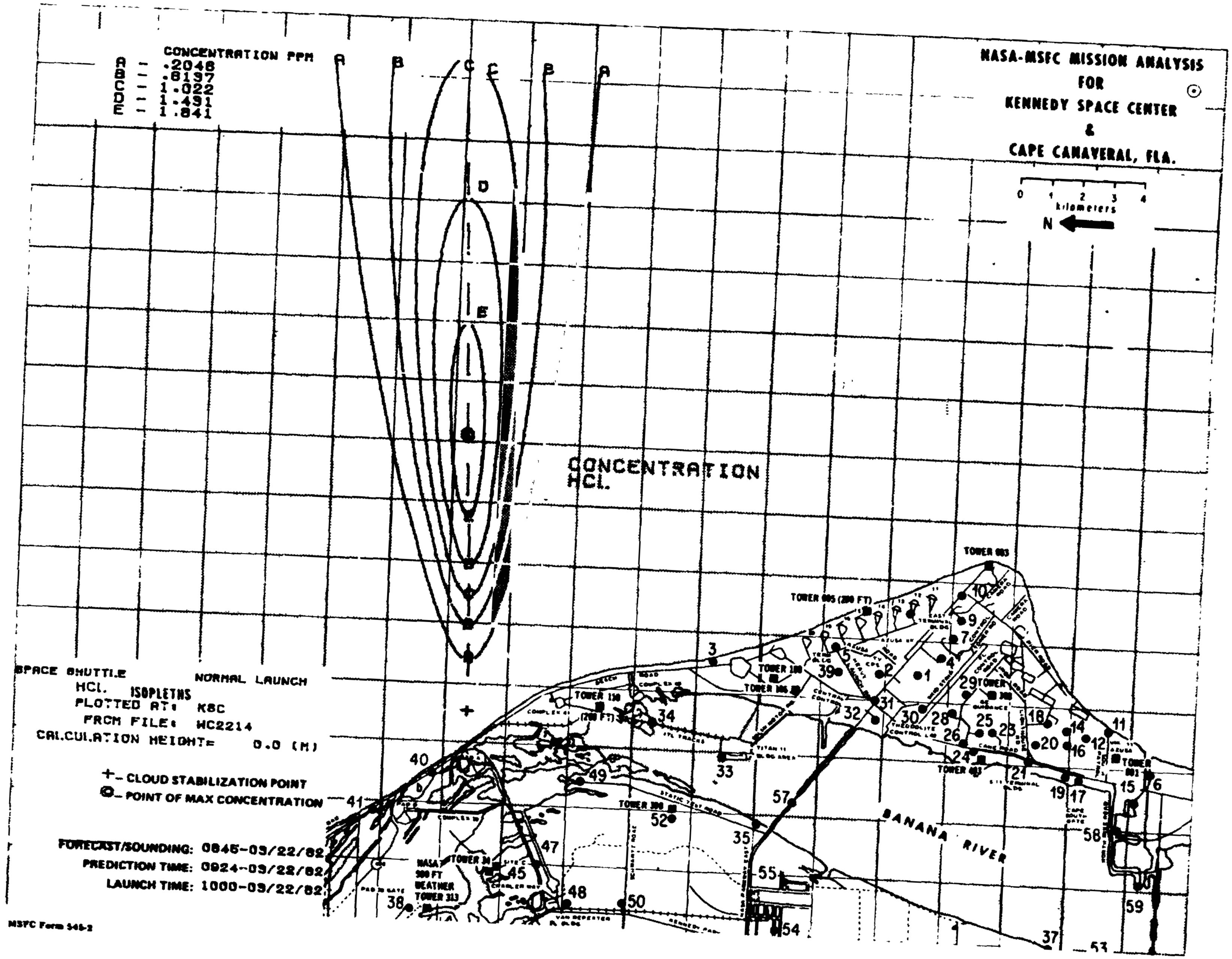

Figure C-11. Diffusion prediction for HCL; time: L = 0.

C-2

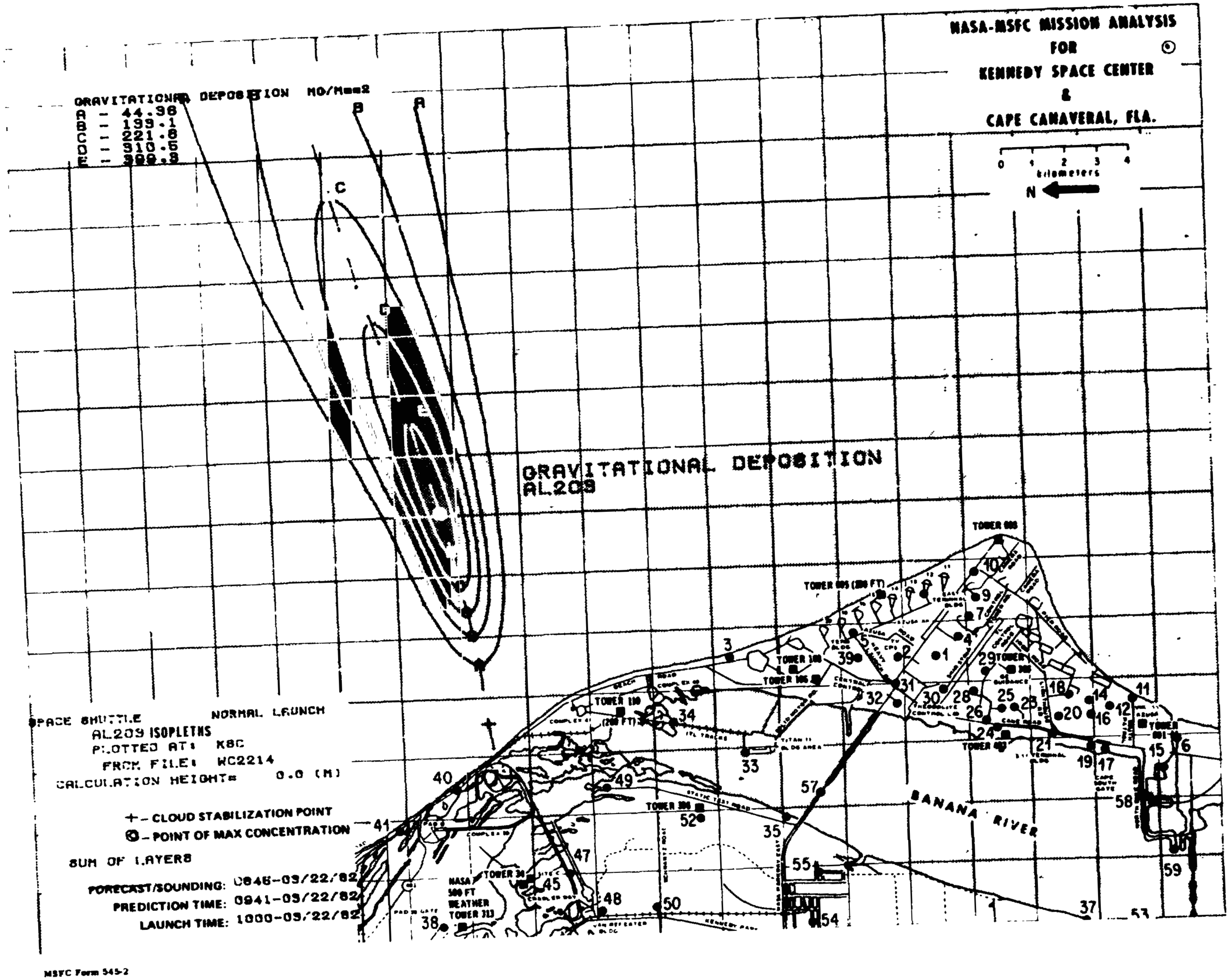

Figure C-12. Gravitational deposition; time: L = 0.

SECTION D - MSFC EXHAUST EFFLUENT DIFFUSION PREDICTIONS AND MEASUREMENTS FOR STS-4

BY JOSEPH C. SLOAN AND ROBERT E. TURNER

SECTION D

MSFC EXHAUST EFFLUENT DIFFUSION PREDICTIONS AND MEASUREMENTS FOR STS-4

I. INTRODUCTION

This report presents the results of the Marshall Space Flight Center (MSFC) air quality predictions made during the fourth Space Shuttle launch (STS-4) from Kennedy Space Center (KSC) on June 27, 1982.

The NASA/MSFC Rocket Exhaust Effluent Diffusion (REED) code was utilized to make predictions of the transport and diffusion of rocket exhaust effluents as part of the continuing NASA environmental effects assessment program. Details of the REED code can be found in the Reference.

II. METEOROLOGICAL CONDITIONS

Weather conditions at the time of launch were influenced by a high pressure system that was centered off the Atlantic Coast and extended southwestward across the Florida peninsula into the Gulf of Mexico (Fig. D-1). Winds at the surface were from the south-southeast at the surface shifting to southwesterly above 3000 ft remaining southwesterly through the exhaust cloud transport layers.

III. ROCKET EXHAUST PREDICTIONS

A. STS-4 Exhaust Cloud

As in previous launches exhaust cloud rainout begins shortly after launch and appears to be partially caused by the deluge water that mixes with the exhaust effluents (Figs. D-3 through D-9). Atmospheric conditions that were present at the time of launch may have enhanced convective and entrainment activity in the cloud and a first look seems to confirm this; however, it will take a more detailed approach to verify this fact. After 14 min, the exhaust cloud cannot be distinguished from the ambient cumulus clouds that were present in the pad area (Fig. D-10).

B. Diffusion Predictions

The NASA/REED code was utilized to make predictions of the transport and diffusion of exhaust cloud effluents by using the L=0 radiosonde sounding shown in Figure D-2. HCL concentrations and gravitational deposition values are shown in Figures D-11 and D-12 and are below any of the critical values that have been established by government or industry.

REFERENCE

Stephens, J. Briscoe and Stewart, Roger B.: Rocket Exhaust Effluent Modeling for the Tropospheric Air Quality and Environmental Assessments. NASA Technical Report R-473, June 1977.

SUNDAY, JUNE 27, 1982

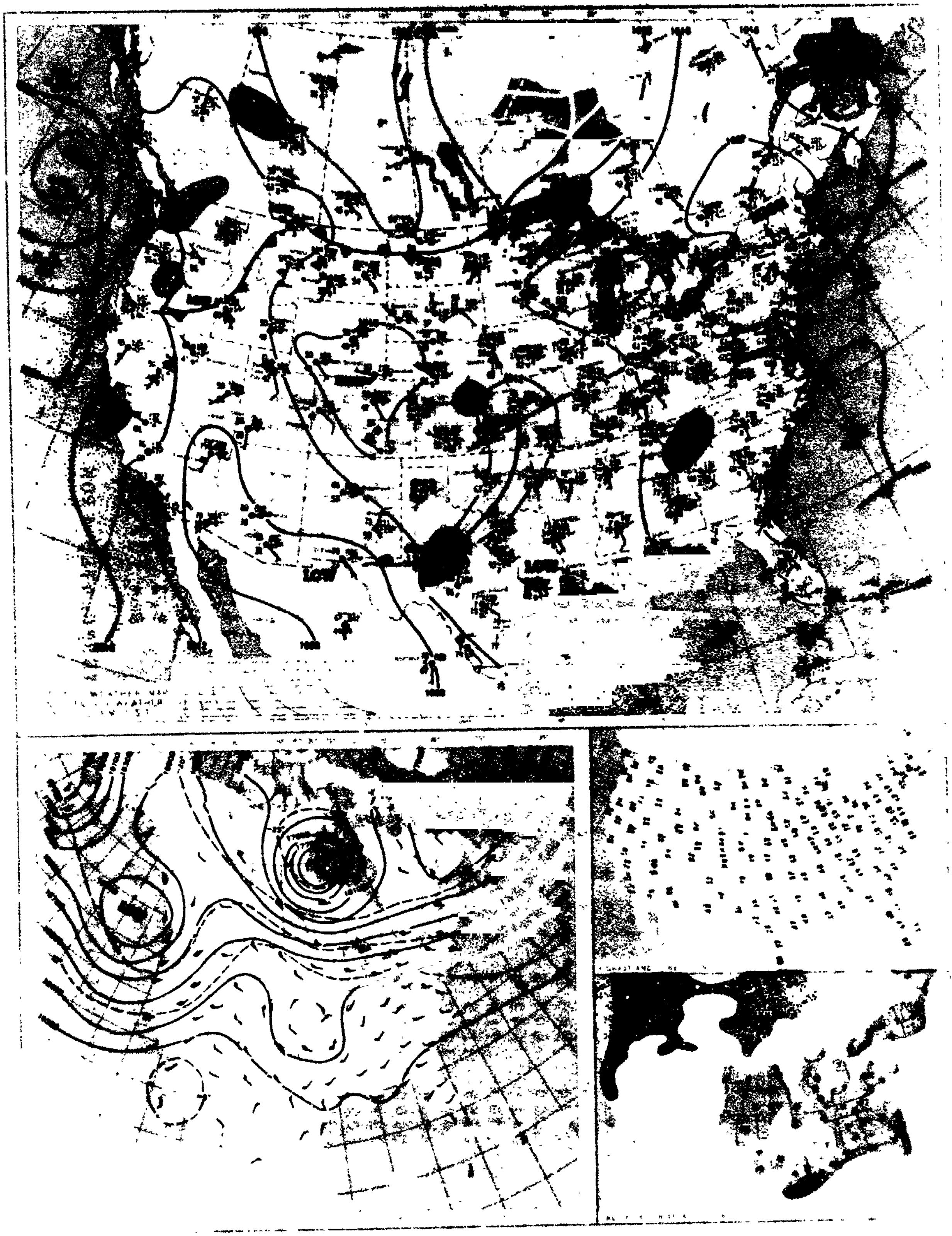

Figure D-1. Surface weather map at launch of STS-4.

TIME: 1010 EST   DATE: 27 JUN 1982

********************** SOUNDING **********************

SURFACE DENSITY (GM/M**3): 1164.06

MET LEVEL NO	ALTITUDE (FT)	ALTITUDE (M)	DIR (DEG)	SPEED (M/S)	SPEED (KTS)	TEMP	PTEMP (DEG. C)	DPTEMP (DEG. C)	PRESS (MB.)	RH (%)	
1	16	4.9	160.0	3.61	7.00	28.9	30.60	24.7	1021.0	78.0	
2	624	190.2	186.0	3.09	6.00	27.3	30.52	22.8	1000.0	77.0	
3	1000	304.8	198.0	3.09	6.00	26.4	30.61	21.9	987.2	77.0	
4	1774	540.7	209.0	3.09	6.00	24.8	31.09	20.4	961.3	76.6	
5	2000	609.6	212.0	3.09	6.00	24.3	31.29	19.5	953.8	79.0	
6	2111	643.4	213.0	3.09	6.00	24.0	31.25	19.1	950.0	78.0	
7	3000	914.4	223.0	3.09	6.00	22.1	31.67	16.7	921.2	75.0	
8	3659	1115.3	230.0	3.09	6.00	20.9	32.47	16.2	900.0	79.0	
9	4000	1219.2	233.0	2.57	5.00	20.1	32.59	15.4	889.5	79.0	
10	4500	1371.6	238.0	2.32	4.50	19.0	32.83	14.2	874.0	78.0	**
11	5000	1524.0	243.0	2.06	4.00	17.9	33.10	13.0	858.6	77.0	
12	5275	1607.8	247.0	2.06	4.00	17.4	33.39	12.2	850.0	76.0	
13	6000	1828.8	257.0	1.55	3.00	16.3	34.20	9.8	828.6	69.0	
14	6968	2123.8	259.0	2.06	4.00	14.2	34.81	6.6	800.0	65.0	
15	7000	2133.6	259.0	2.06	4.00	14.1	34.76	6.6	799.4	65.0	
16	7500	2286.0	256.0	2.32	4.50	13.0	35.13	5.5	785.3	64.5	**
17	8000	2438.4	253.0	2.57	5.00	12.0	35.53	4.4	771.1	64.0	
18	8269	2520.4	252.0	2.57	5.00	11.5	35.75	3.9	763.6	60.3	
19	8746	2665.8	250.0	3.09	6.00	10.6	36.39	3.0	750.0	64.0	
20	9000	2743.2	249.0	3.61	7.00	10.2	36.69	2.5	743.5	63.0	
21	9500	2895.6	250.5	4.12	8.00	9.3	37.28	1.8	730.2	63.5	**
22	10000	3048.0	252.0	4.64	9.00	8.4	37.90	1.0	716.8	64.0	

** - INDICATES THAT DATA IS LINEARLY INTERPOLATED FROM INPUT METEOROLOGY

Figure D-2. STS-4 radiosonde sounding made at time of launch: time L=0.

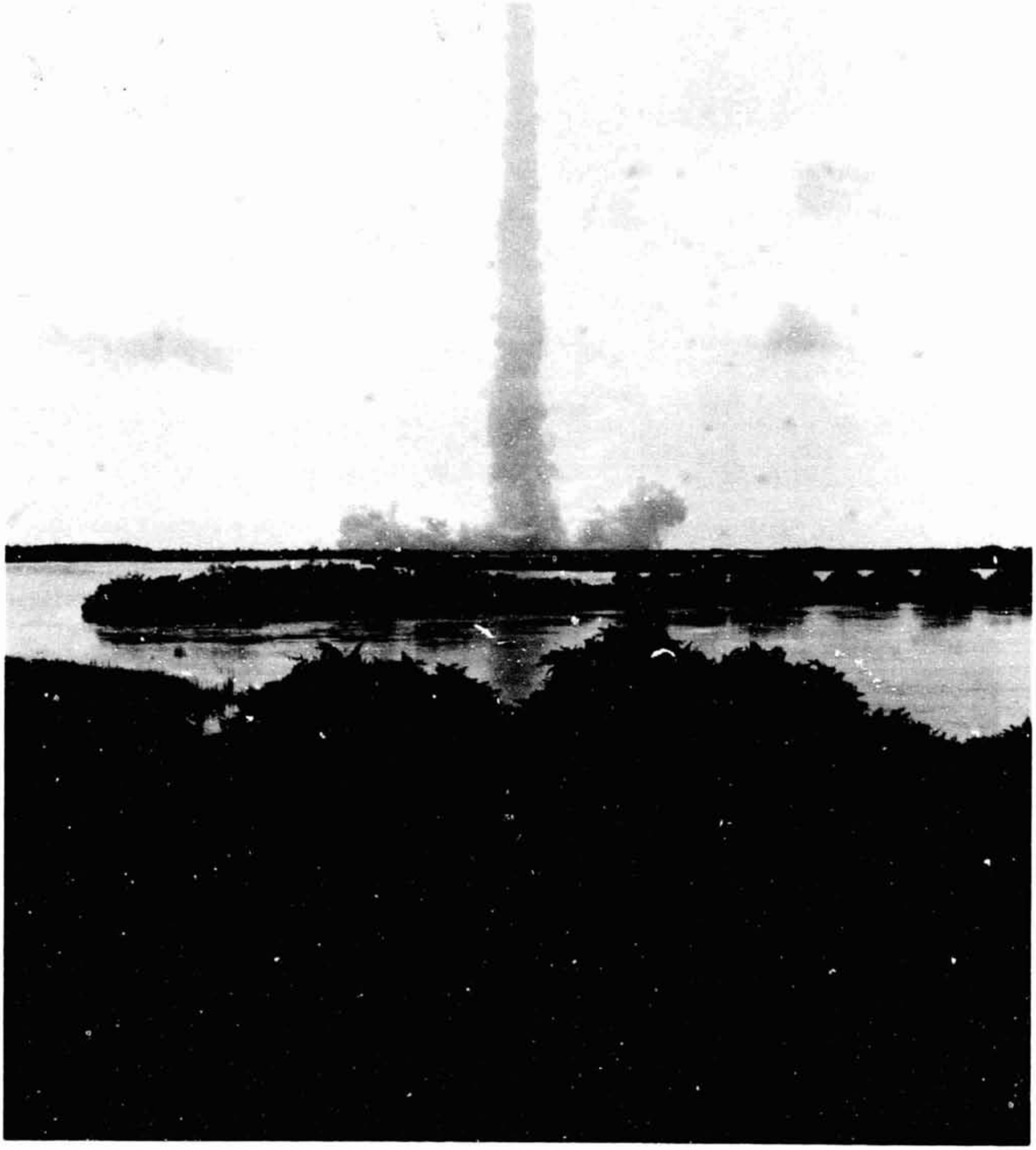

Figure D-3. STS-4 exhaust cloud formation; time L + approximately 30 sec.

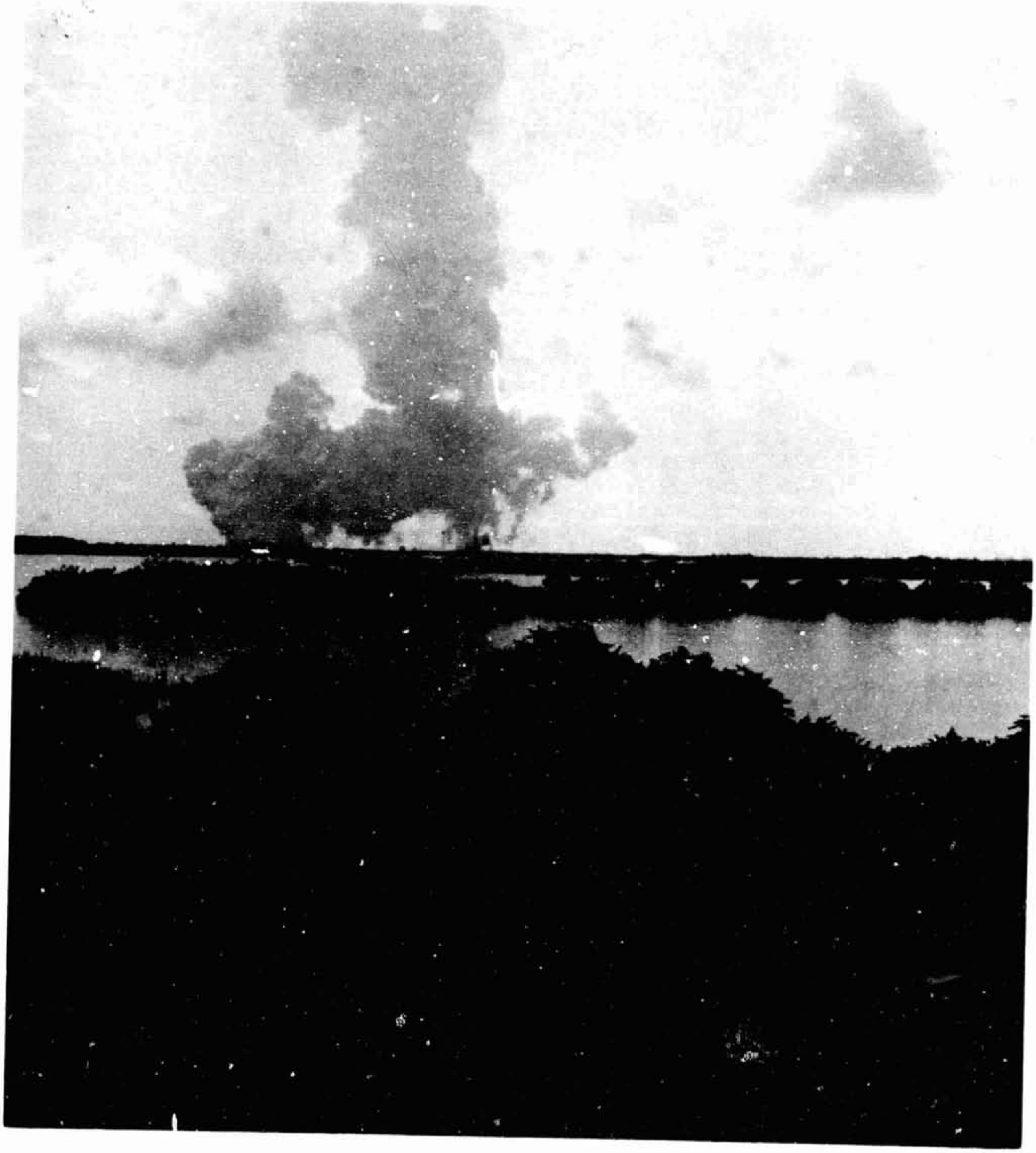

Figure D-4. STS-4 exhaust cloud formation: time L + approximately 60 sec.

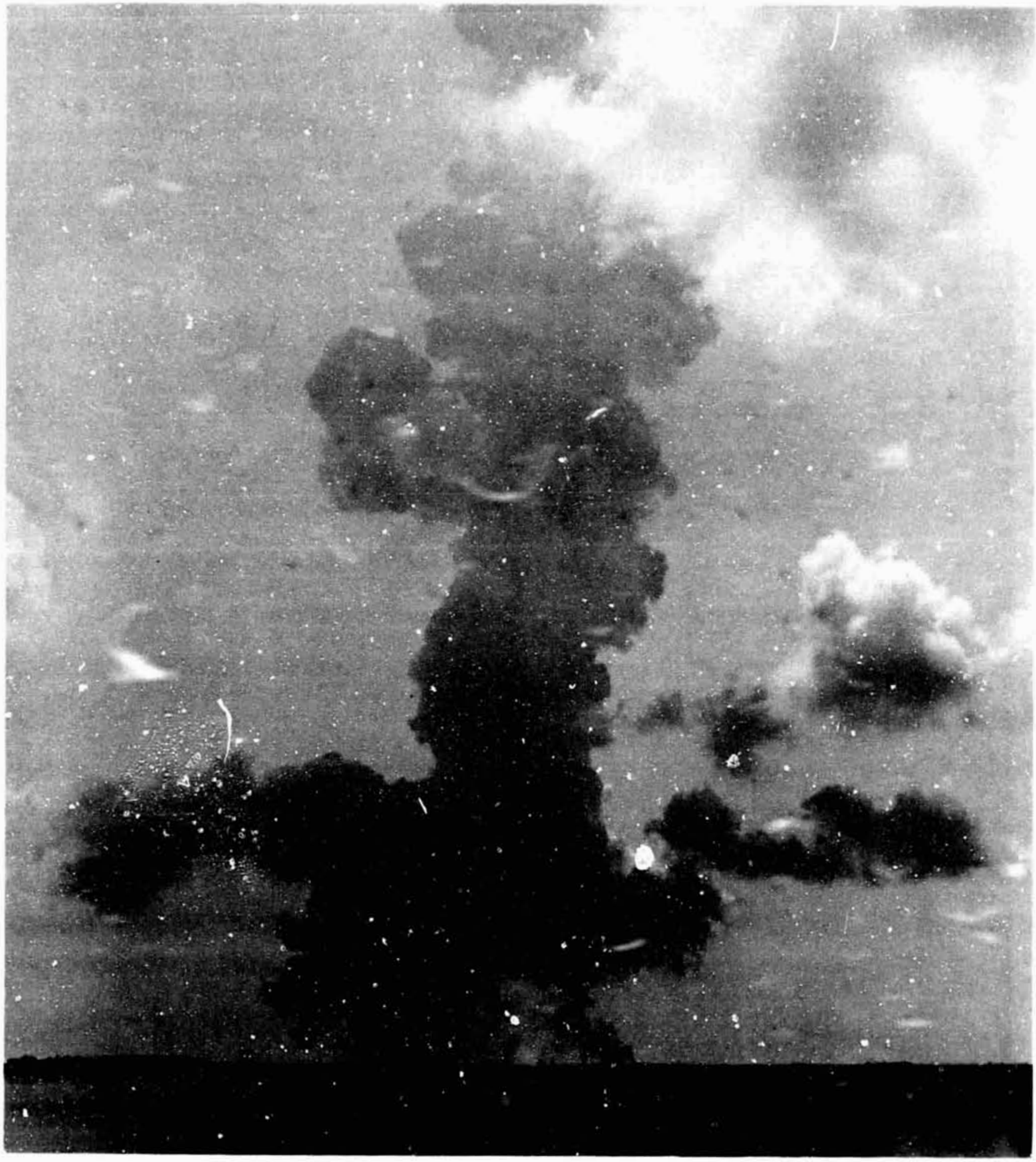

Figure D-5. STS-4 exhaust cloud formation; time L + approximately 150 sec.

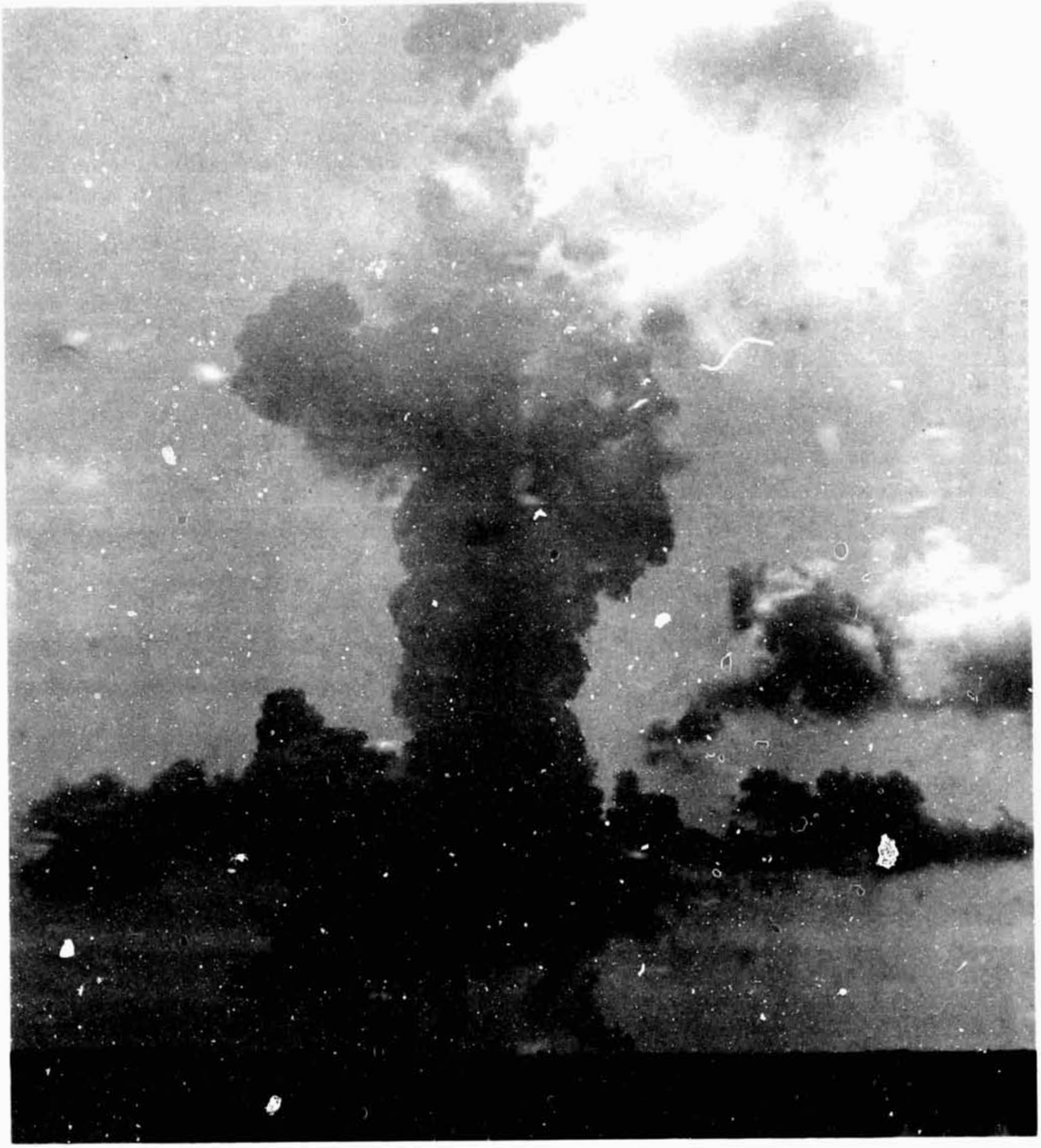

Figure D-6. STS-4 exhaust cloud formation; time L + approximately 210 sec.

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Figure D-7. STS-4 exhaust cloud formation; time L + approximately 390 sec.

Figure D-8. STS-4 exhaust cloud formation; time L + approximately 570 sec.

Figure D-9. STS-4 exhaust cloud formation; time L + approximately 600 sec.

Figure D-10. STS-4 exhaust cloud formation; time L + approximately 14 min.

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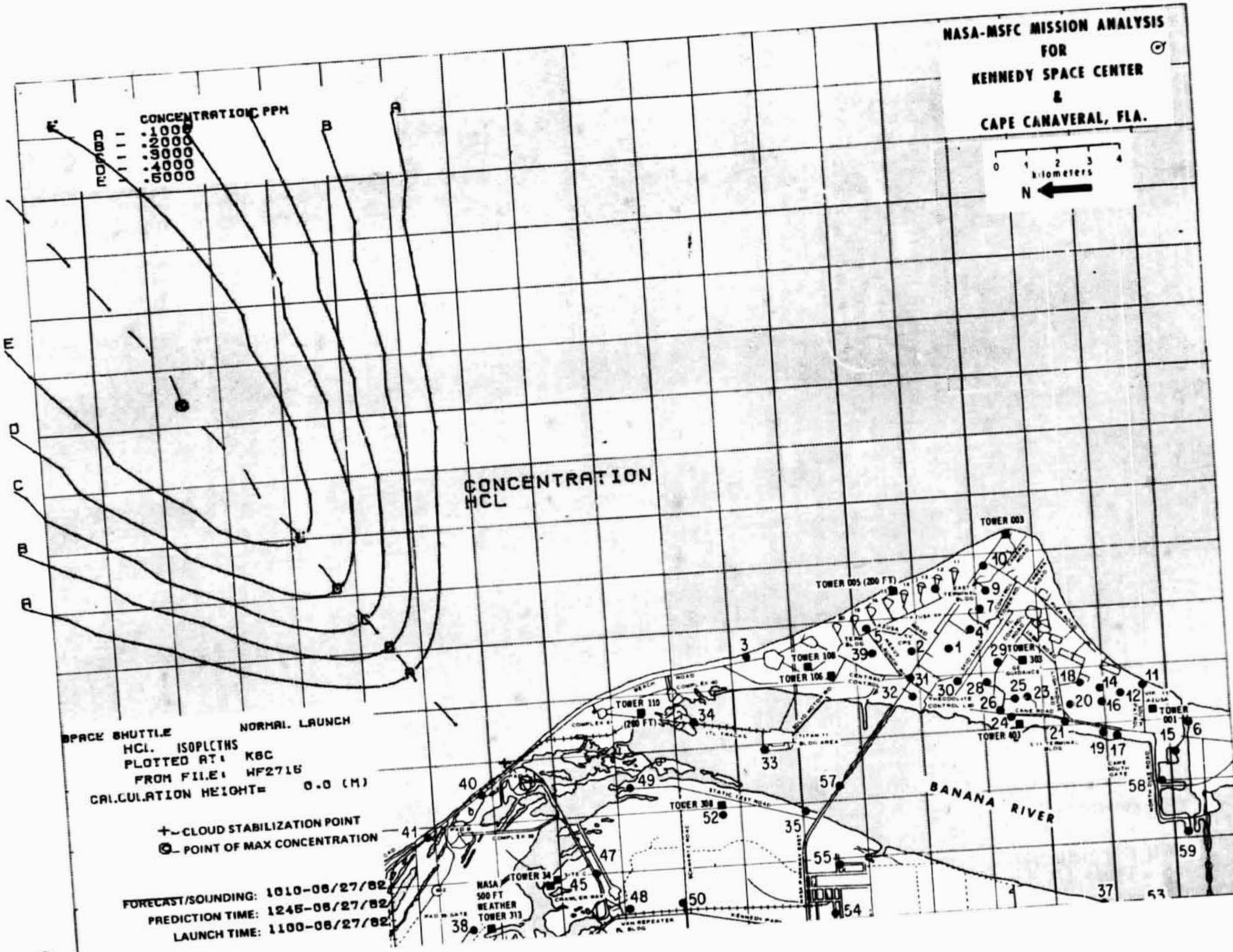

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Figure D-11. Diffusion prediction for HCL; time L=0.

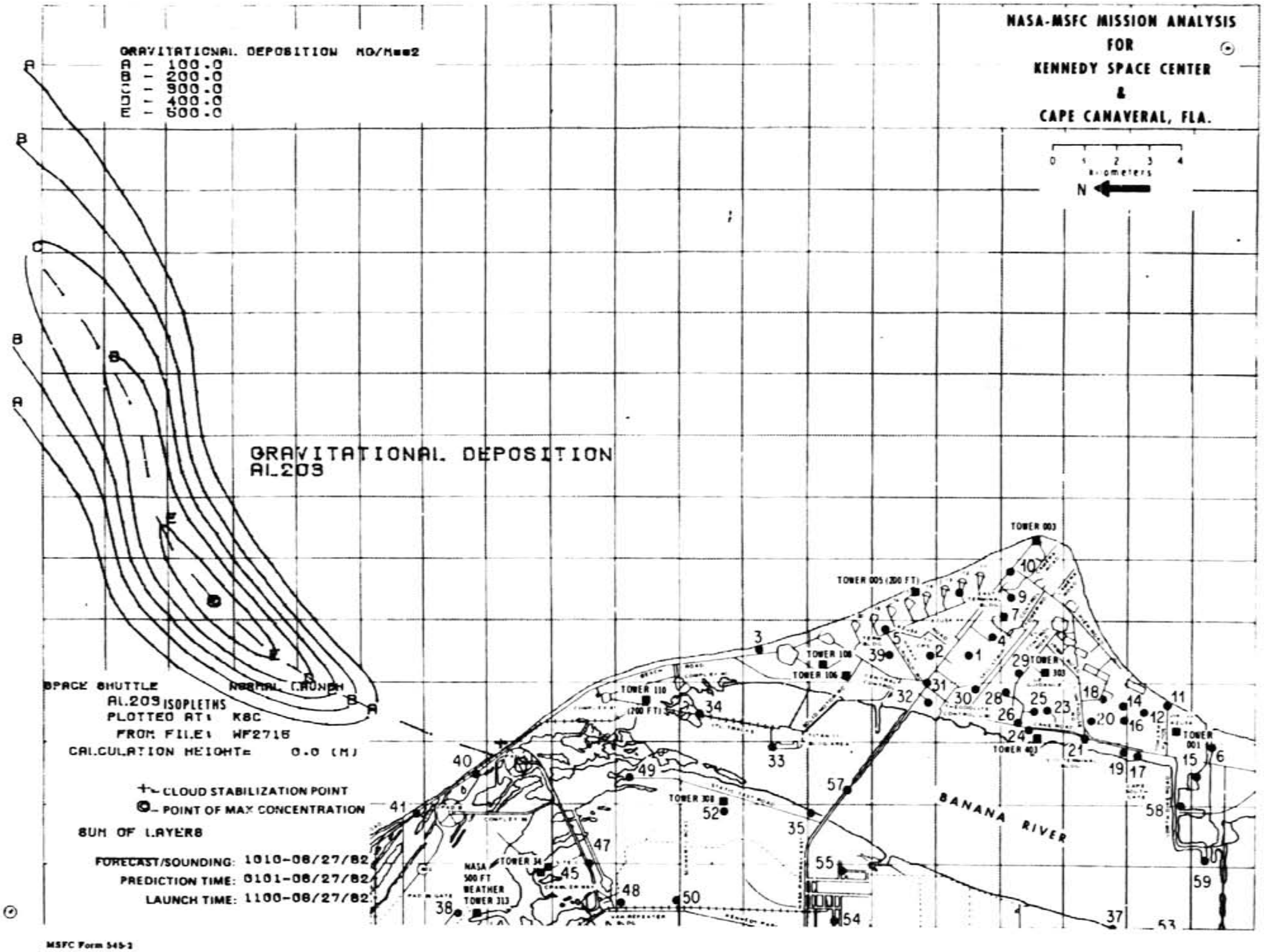

Figure D-12. Gravitational deposition; time L=0.

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