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ENVIRONMENTAL MONITORING INSTRUMENTATION

AND MONITORING TECHNIQUES FOR

SPACE SHUTTLE LAUNCHES

JULY 1983

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WILLIAM E. MABSON, Colonel, USAF, BSC
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Space Shuttle emits undesired exhaust materials into the atmosphere during a launch including large quantities of hydrogen chloride (HCl). The fate of the HCl is not well understood but includes deposition and HCl gas revolatilization near the launch pad and downwind acid washout, acid rainout and HCl gas dispersion. The Air Force and NASA began monitoring missile exhaust effluents in the early 1970s. There has been an evolution in monitoring instrumentation, monitoring techniques and monitoring schemes developed jointly by the Air Force and NASA culminating in the efforts for Space Shuttle

DD FORM 1473 1 JAN 73   EDITION OF 1 NOV 65 IS OBSOLETE

launches at Kennedy Space Center. This report reviews and evaluates these efforts and recommends an integrated program of ground monitors, aircraft monitors and remote sensors to monitor Shuttle exhaust materials.

Report No. 83-216EQ195GEF

USAF OCCUPATIONAL AND ENVIRONMENTAL

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July 1983

Environmental Monitoring Instrumentation

and Monitoring Techniques for

Space Shuttle Launches

July 1983

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PREFACE

This report was prepared by the USAF Occupational and Environmental Health
Laboratory (USAF OEHL), Brooks AFB TX, for personnel at the USAF Hospital at
Vandenberg AFB CA, Headquarters Strategic Air Command (HQ SAC), Offutt AFB NE
and Space Division (SD) in California. Recommendations in this report are
aimed at the implementation of an integrated and comprehensive monitoring
program prior to the first Space Shuttle launch at Vandenberg AFB CA.

The authors wish to express their thanks to the many personnel at SD, NASA at
Marshall Space Flight Center (NASA MSFC), NASA at Langley Research Center
(NASA LaRC), NASA at Kennedy Space Center (NASA KSC), and at Vandenberg AFB
(VAFB) for providing us with valuable information and assistance in our
monitoring evaluations. We would also like to thank the USAF School of
Aerospace Medicine (USAFSAM) and other personnel of the USAF OEHL with special
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Capt Ed Bishop. Their participation, inputs and technical review assisted us
immensely in the preparation of this report.

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I. INTRODUCTION

The Space Shuttle and other missile systems emit undesired exhaust materials into the atmosphere during a launch. The amount of material injected into the atmosphere is dependent on both the missile system and the transport and dispersion of this material. There has long been concern for the potential environmental effects of exhaust materials.

Monitoring the exhaust effluents during missile launches has been conducted to define the materials emitted and to quantify the effects on the surrounding environment. Monitoring attempts have included ground monitoring, aircraft monitoring and remote sensing. All three have certain advantages and disadvantages. Ground monitoring requires numerous sampling sites to insure that a representative sample is obtained. Large scale monitoring schemes become more difficult as terrain becomes complex. Ground monitoring can be accomplished both in the near field and far field, under most meteorological conditions and types of terrain, and yield quantitative results that are directly related to environmental effects.

Aircraft monitoring offers the advantage of direct measurement of exhaust cloud's chemical and physical parameters. Information of this type can be applied to dispersion models used to calculate downwind environmental effects. Aircraft are restricted by meteorological conditions and terrain avoidance in complex terrain. Remote sensing can be used to supplement ground and aircraft monitoring and may replace them as technology improves. Strategically located remote sensing devices can measure exhaust cloud composition and the fallout material as it is deposited. Measurements can be made both near and far field under all types of meteorological conditions and types of terrain. The main disadvantage of remote sensing is that most systems are in the research and development stage. It will be many years before remote sensing advanced technology is fully developed. Until that time, an integrated program of ground monitoring, air monitoring and available remote sensing is required to adequately define the environmental effects produced during missile launches.

The USAF Occupational and Health Laboratory (USAF OEHL) became involved in the environmental program for the Space Transportation System (STS) and other missile systems at Vandenberg AFB (VAFB), California, in the late 1970s. An initial environmental monitoring report for VAFB was published in fall of 1980 (Ref 1). In December 1981, the USAF OEHL received a request for assistance from the USAF Hospital Vandenberg Bioenvironmental Engineers through the Strategic Air Command (SAC) and with the concurrence of Space Division (SD). They requested the USAF OEHL evaluate Space Shuttle environmental monitoring instrumentation and monitoring techniques and make recommendations for an environmental program at VAFB. This report is a historical review of instrumentation and techniques used to measure exhaust effluents, beginning at Kennedy Space Center and VAFB in the early 1970s up to and including the launch of STS-5 in Nov 82. The review includes laboratory and field studies as well as the results of ground monitoring, aircraft monitoring and remote sensing. A companion USAF OEHL report (Ref 2) provides a detailed description of monitoring instrumentation and monitoring techniques for Space Shuttle launches at VAFB.

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II. BACKGROUND

The USAF has established an environmental protection program to protect and enhance environmental quality (Ref 3). Air Force policy is to comply not only with Air Force directives relating to envirmental quality, but also with the spirit as well as the letter of the National Environmental Policy Act, all other federal environmental laws, executive orders, regulations, and with criteria and standards published by the Environmental Protection Agency (EPA). The intent of state, and local pollution abatement laws, regulations, criteria and standards also apply to Air Force policy.

Concern about pollutant emissions began in the 1950s as complaints increased about visible emissions and odor levels at civilian airports caused by aircraft powered by turbine engines. Investigations of these complaints eventually culminated in passage of the Clean Air Amendments of 1970. At this time, there was also concern voiced about exhaust emissions produced from the multitude of missile launch vehicles in the Army, Navy, Air Force and National Aeronautics and Space Administration (NASA) inventories.

The Air Force and NASA began monitoring exhaust effluents of missiles systems in the early 1970s. Of special concern were systems using solid fuels since large quantities of hydrogen chloride (HCl) and aluminum oxide (Al_2O_3) were emitted during these launches. Aluminum oxide is generally considered to be no more than a nuisance dust; however, an HCl ceiling exposure concentration of 5 parts-per-million (ppm) has been established to prevent toxic injury to humans (Ref 4). Space Shuttle launches are of greater interest than previous missile systems since 2 1/2 times more HCl is emitted (Ref 5).

There has been an evolution in monitoring instrumentation, monitoring techniques and monitoring schemes developed jointly by the Air Force and NASA culminating in the efforts for Space Shuttle launches at Kennedy Space Center (KSC). Some monitoring instrumentation and techniques used at KSC can also be used at VAFB. However, differences in terrain, meteorology, flame trench configuration and amounts of deluge water, between KSC and VAFB, may require research and development of more sophisticated monitoring devices to account for variations in environmental effects produced by the site specific launch scenarios. In addition, as science and technology advance, new and better monitoring systems may be available to replace those currently used.

In completing this report, the USAF OEHL has reviewed previous monitoring programs for a variety of missile systems and missile launches beginning in the early 1970s. Missile launches at VAFB, KSC, as well as the scale test model static test firings at Marshall Space Flight Center, have been used as a basis for our monitoring evaluations. The USAF OEHL has participated in laboratory and field studies in association with monitoring programs for Space Shuttle launches. This report is a review and evaluation of ground monitoring, aircraft monitoring and remote sensing instrumentation and techniques.

III. EVALUATION OF MONITORING METHODS

Numerous monitoring devices and monitoring techniques have been developed and used during the evolution of environmental monitoring programs for missile

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launches. Instrumentation ranges from extremely simple passive devices, which require little or no supporting equipment and with analysis that can be conducted by visual inspection, to more complex active monitoring systems which require an abundance of supporting equipment and detailed laboratory analysis. There are three general categories of monitoring methods used in our evaluation: ground monitoring, aircraft monitoring, remote sensing. However, some monitoring devices evaluated have been used in more than one general category.

A. Ground Monitoring

1. Coulometry. An instrument system was developed by the USAF School of Aerospace Medicine (USAFSAM) for both airborne and ground monitoring of HCl found in rocket exhaust (Ref 6). The detection concept was an adaption of a commercial microcoulometer which had been designed for measurement of chlorides in solution. Microulometric detection of HCl was based on automatic titration of the chloride ion as silver chloride precipitate. The continuous monitoring instrument consisted of a microcoulometer titration cell, electronic control console, recorder, integrator, air pump, and flowmeter. The heart of the system was the titration cell, which contained acetic acid electrolyte, and four electrodes: a sensing pair (silver vs silver acetate), and a generating pair (silver vs platinum). The concentration of silver ions in the cell was adjusted to 10^{-7} molar by applying a bias potential of 250 mV across the sensing electrode pair. Any change in silver concentration (by precipitation of AgCl) was detected by the sensing electrodes as a potential difference which led through the coulometer amplifier to generation of silver titrant at the generator electrode. The current required was recorded, via a precision series resistance, on a potentiometric recorder. The peak area provided the quantity of electricity, in coulombs, required for the reaction. Because Faraday's laws applied and the reaction was stoichiometric, the microcoulometer was a primary standard, and the quantity of chloride in the sample was easily calculated.

Application of the microcoulometric instrument to measure HCl in rocket exhaust posed special problems in inlet design. Because of the extreme reactivity of HCl, inlet passivation (conditioning) was necessary to prevent sample loss. Several inlet materials were tested for their passivation requirement. These materials included: glass, Pyrex[R] glass, Teflon[R], stainless steel, nylon. When subjected to a continuous sample of 5 ppm HCl, in nitrogen diluent, at a flow rate of 100 cc/min, Pyrex glass gave the fastest initial and 90% response time. Pyrex glass was thus selected for the inlet configuration. The conditioning time for Pyrex glass was found to be a strong function of sample humidity, and was related to sample flow rate and concentration. Integral sampling of moist or humid HCl samples, similar to those encountered in coastal launch environments, proved the most problematic. Moisture collection in the inlet tended to enhance sample loss by HCl absorption. The problem was partially alleviated by heating the inlet to prevent moisture formation. Tests of dry and moist samples showed that inlet heating to 50°C will reproduce 98% of the dry HCl response.

Before using the microcoulometer instrument in the field, it was compared to bubbler results using a continuous steady-state HCl source. Agreement of the two measuring techniques was within ±10%.

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The USAFSAM, at the request of NASA at Langley Research Center (NASA LaRC), used a microcoulometer instrument to measure the HCl for a number of launch vehicles at KSC and the 6.4% scale model Space Transportation System at NASA Marshall Space Flight Center (NASA MSFC). Microcoulometric measurement results are shown in Table 1.

Table 1. Microcoulometer Measurement Results

Date	Launch Vehicle	Location	No. Sites/ Total No. Sites	HCl Average Conc. (ppm)
Nov 72	Delta-Thor	NASA KSC	0/3	0[a]
Dec 73	Titan III	NASA KSC	0/2	0
Feb 74	Titan III	NASA KSC	0/3	0[a]
May 74	Titan III	NASA KSC	1/1	1.8
Dec 74	Titan III	NASA KSC	0/2	0[a]
May 75	Titan III	NASA KSC	0/2	0[a]
Aug 75	Titan III	NASA KSC	0/2	0[a]
Sep 75	Titan III	NASA KSC	2/2	4.0
Feb 75	6.4% STS	NASA KSC	1/1	<1.0
Mar 75	6.4% STS	NASA KSC	1/1	15.0<

[a] Ground cloud trajectory away from sampling site.

It is apparent from Table 1 that prepositioning a limited number of microcoulometers to measure ground cloud deposition caused problems. This difficulty is not just inherent to the microcoulometers but can occur in any monitoring scheme with any number of monitoring devices. The use of dispersion models to aid in site location can alleviate this problem. The microcoulometer observed HCl for two Titan III launches at KSC. During the May 74 launch, an average HCl concentration of 1.8 ppm was observed for 1.9 minutes at a position 3.3 miles off the coast of KSC. This calculates to a dosage of 205 parts-per-million-seconds (ppm-s). The observation occurred approximately 22 minutes after launch. An average HCl concentration of 4.0 ppm was observed for 2.0 minutes (480 ppm-s dosage) at a position 4.5 miles inland from Launch Complex-41 at KSC during a Sep 75 Titan III Launch. The observation occurred at 73 minutes postlaunch. Microcoulometers were located within 500 ft of the 6.4% scale model STS test stand during test firings in Feb-Mar 75. An average HCl concentration greater than 15.0 ppm was estimated using the microcoulometer since contact with the induced ground cloud caused the instrument to register off-scale readings.

In Aug-Sep 74, the USAFSAM participated in monitoring HCl in the ground cloud from static tests of small rocket motor firings at the Naval Weapons Center, China Lake CA. An instrument comparison study was conducted between microcoulometers, chemiluminescence HCl monitors from GEOMET Technologies, Inc., bubblers, silver nitrate indicator tubes and pH recorders.

Results of the comparison showed good repeatability between the two micro-coulometers used and good comparability between the microcoulometers and the GEOMET chemiluminescence HCl monitors.

In Sep 75, the USAFSAM provided HCl monitoring assistance to the University of California, Riverside (UCR) for the determination of HCl buildup in experimental growth chambers used to expose ornamental plants to various concentrations of missile exhaust products. HCl monitors included microcou-lometers, GEOMET chemiluminescence HCl monitors, and bubblers. Comparison of the measurement methods was done at five HCl concentrations in the plant expo-sure chamber. The results of the comparison showed agreement between the methods within the limits of experimental error.

The microcoulometric instrument has been tested as a laboratory and field instrument for measuring HCl from rocket exhaust effluents. It has the advantage of easy field calibration. Disadvantages include slow response time, small dynamic range (0.05 ppm detection limit to 15 ppm maximum concen-tration), inlet HCl absorption problems and equipment size. The microcoulo-meter is also sensitive to temperature, relative humidity and provides only dosage data. Approximate concentrations can be obtained by assuming a square-wave concentration-time profile.

The microcoulometric instrument was a very useful first generation HCl monitor; however, the instrument was cumbersome to deploy and has since been replaced by more sophisticated state-of-the-art HCl monitoring devices. We recommend no further laboratory or field testing of this technique and do not recommend its use for the STS launches at VAFB.

2. Chemiluminescence HCl Monitor. Chemiluminescent detection of HCl is based on exothermic oxidation of 5-amino-2,3-dihydro-1,4-phthalazine-dione (luminol) in alkaline solution by hypochlorous acid. The light generated by this reaction is linearly proportional to HCl concentrations in the incoming gas stream and is measured by a photomultiplier detector. Hypochlorous acid is formed from HCl by passing the incoming air stream through a tube coated with a solution of sodium bromate and sodium bromide. This mixture reacts with hydrogen chloride to produce hypochlorite and hypobromite which initiate luminol oxidation to generate light. The USAFSAM used three models of chemi-luminescence HCl analyzers in various studies (Ref 7). All were developed by GEOMET Technologies, Inc., Rockville, MD and embody the same luminol detection principle. The first instrument was designed primarily for laboratory use and contained two reaction cells, one for detection of HCl and the other for reference subtraction of interferent gases. Because of the relative bulk of the laboratory instrument, the USAFSAM contracted with GEOMET Technologies, Inc., in late 1974 to develop two improved chemiluminescence HCl analyzers for different field applications: ground and airborne monitoring. Airborne chemiluminescence HCl monitoring will be covered in Section III.C. A summary of available GEOMET monitoring results for rocket launches prior to the launch of STS-1 are shown in Table 2.

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**Table 2. GEOMET Chemiluminescence HCL
Ground Monitoring Results**

Date	Launch Vehicle	Location	No. Sites Hit Total No. Sites	Max HCl Conc. (ppm)	Max HCl Dosage (ppm-s)
May 74	Titan III	NASA KSC	1/1	Positive[a]	Positive[a]
Feb 75	6.4% STS	NASA MSFC	1/1	5.0	26.5
Mar 75	6.4% STS	NASA MSFC	1/1	40.0<	400.0
Aug 75	Titan III	NASA KSC	1/1	Positive[a]	Positive[a]
Dec 76	Titan III	VAFB	1/3	1.9	775.5
Mar 78	Titan III	VAFB	3/3	0.7	172.2
Jun 78	Titan III	VAFB	2/3	3.5	122.5

[a]Quantification not possible due to rapid electronic scaling.

The USAFSAM conducted a number of laboratory and field experiments using GEOMETs. Positive GEOMET readings were recorded 3.5 miles downwind of the Titan III launch site at KSC during a May 74 launch (Table 2). Positive readings were recorded for a similar launch 4.5 miles downwind in Aug 75. Accurate quantitation of the GEOMET signal could not be made due to the rapidity of the automatic electronic scaling which occurred. The USAFSAM used one GEOMET at the 6.4% STS static test firings at NASA MSFC in Feb and Mar 75. A concentration of 5 ppm and dosage of 26.5 ppm-s were recorded 500 ft downwind of the test stand in Feb 75. During the Mar 75 test, the test vehicle broke free of the test stand resulting in high HCl concentrations in the vicinity of the GEOMET. The GEOMET response went off-scale; however, estimates of greater than 40 ppm concentrations and greater than 400 ppm-s dosages were suggested. GEOMET monitoring assistance was provided to the UCR in the determination of HCl buildup and decay in experimental growth chambers used to expose ornamental plants to various concentrations of missile exhaust products. Results of this study demonstrated the accuracy and repeatability of GEOMETs under laboratory conditions. Additional studies at the NWC compared results of GEOMETs and microcoulometers during static test firings of small rockets. Results of the instrument comparison showed good agreement between the two instruments.

GEOMET measurements of HCl at VAFB were made by Western Space and Missile Center (WSMC) safety personnel with the assistance of the Air Force Rocket and Propulsion Laboratory (AFRPL). Data were obtained during three Titan III launches: Dec 76, Mar 78, Jun 78 (Table 2). Concentrations as high as 3.5 ppm and dosages as high as 172.2 ppm-s were recorded at a distance of 3500 ft from the launch site.

The USAF and NASA KSC used GEOMETs to monitor HCl produced from the launches of STS-1 through STS-5 (Ref 8). Figure 1 shows all GEOMET locations both on Pad 39A and at external locations for STS-1 through STS-5. Figure 2 is a breakdown of GEOMET sites on Pad 39A for the launches of STS-3 through STS-5. Table 3 is a summary of GEOMET HCl data for the STS launches.

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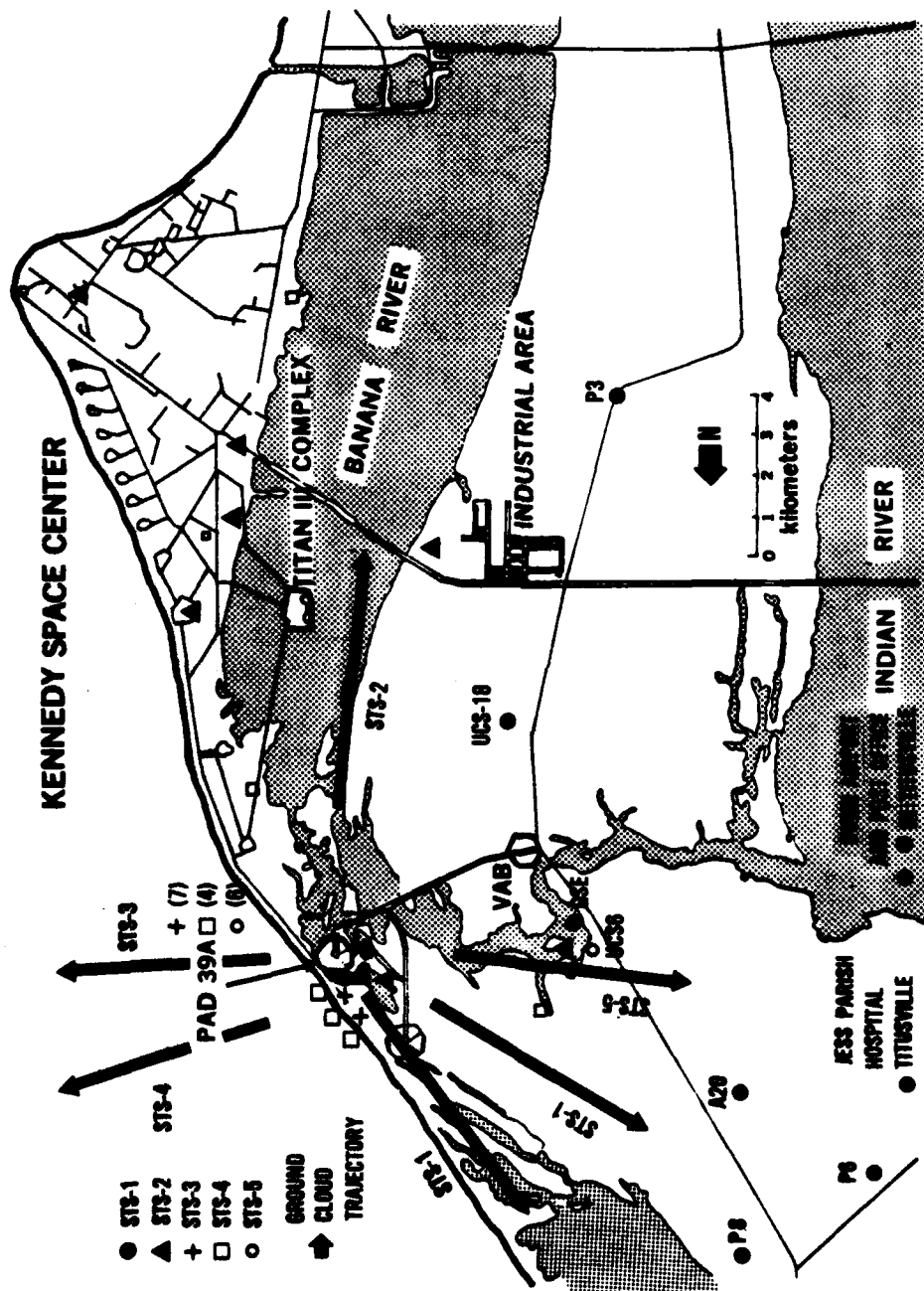
Figure 1. GEOMET Monitoring Sites for the Launches of STS-1 through STS-5
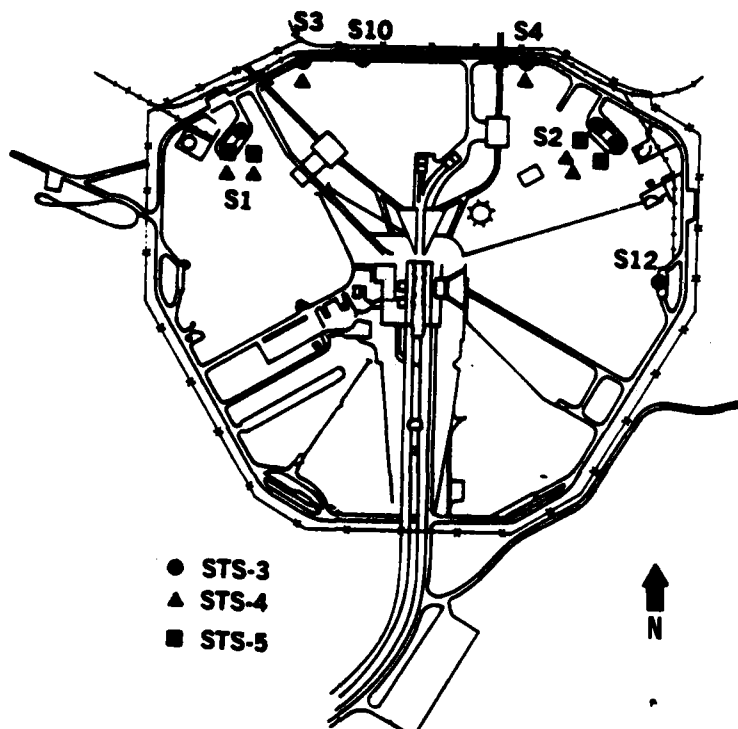
Figure 2. GEOMET Siting on Pad 39A at KSC for
the Launches of STS-3 through STS-5

Table 3. Summary of GEOMET HCl Data for the
Launches of STS-1 through STS-5 at KSC

Date	STS Launch	No. Sites Hit Total No. Sites	Location	Sample Inlet	Max Conc. (ppm)	Dosage (ppm-s)
Apr 81	1	1/12	Titusville	Std Tube	0.1[a]	–
Nov 81	2	0/10				
Mar 82	3	6/13	Coast Road	Std Tube	0.3	–
			S1	Std Tube	4.0	4,600
			S2	Std Tube	1.7	1,000
			S2	Filter	7.7	1,160
			S10	Std Tube	1.9	3,000
			S12	Std Tube	6.5	1,450
Jun 82	4	2/7	Coast Road	Std Tube	0.9	130
			S2	Std Tube	25.0[b]	10,000
Nov 82	5	4/8	UCS6	Std Tube	9.0	90
			S1	Std Tube	29.0	480
			S1	Filter	7.0	3,200
			S3	Std Tube	12.0	400

[a] Concentration peak could be background.
[b] Peak concentration recorded at L+2:30 hours.

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A total of 12 GEOMETs were deployed for STS-1. Only one GEOMET, north of Titusville and 20 miles from the launch site, recorded a response. Although an upper portion of the column cloud passed over this site, the response is attributed to background noise.

Ten GEOMETs were deployed for STS-2. No HCl was detected, apparently, since none were in the optimal position. An attempt was made to "chase" the ground cloud with a mobile GEOMET, but heavy traffic following the launch negated this effort.

Thirteen GEOMET chemiluminescent HCl monitors were deployed for STS-3; seven units on Pad 39A, three units on Pad 39B, and three units along the coast road north and east of Pad 39A. No HCl data were recorded on Pad 39B and only one of the three units positioned along the coast road recorded any significant levels of HCl. Of the seven GEOMETs positioned within the launch pad area, five recorded some HCl data. The two units that failed to record any data either lost power prior to launch or were not properly deployed. The maximum concentration measured was 7.7 ppm on the northeast camera pad (S2). This GEOMET was equipped with a special filter designed to provide a "total" HCl measurement capability. A second GEOMET positioned immediately adjacent to this unit, equipped with the standard sampling tube, measured a maximum concentration of 1.7 ppm. These units recorded a total dose of about 1160 ppm-s and 1000 ppm-s, respectively. The second highest concentration recorded was 6.5 ppm with a total dose of some 1450 ppm-s at position S12. A GEOMET positioned on the northwest camera pad (S1) appears to have recorded a peak concentration of 4 ppm and total dose of 4600 ppm-s. The signal trace from this unit is indicative of electronic instability. Background voltages vary rapidly over more than half of the scale covering two ranges from 0.05 ppm to 0.8 ppm. If this unit did record HCl data, the duration of the measurement was approximately 51 minutes. The recording may be a measure of increased electronic instability rather than an actual measurement of HCl. A GEOMET placed behind a concrete retaining wall in the drainage ditch near the perimeter fence (S10), in line with the Solid Rocket Booster flame trench, measured a peak concentration of 1.9 ppm and a dose of approximately 3000 ppm-s.

Seven GEOMETs were deployed for STS-4, four on Pad 39A (two each at S1 and S2) and three along the coast road northeast of the pad. At S1, one of the GEOMET strip chart recorders malfunctioned and the other GEOMET recorded no HCl. Neither of the two GEOMETs at S2 recorded any HCl immediately after launch, but a peak concentration of 25 ppm was recorded by one of the units approximately 2 1/2 hours after launch. The total dose recorded was about 10,000 ppm-s. This occurrence supported the postulation that HCl gas revolatilization from aqueous HCl thrown onto the ground around the pad during a launch does in fact occur. Of the three units positioned along the coast road, only one measured any HCl.

Eight GEOMET chemiluminescent HCl monitors were deployed for the launch of STS-5, six units within the pad area and two units downwind; one located on the southern shore of Banana Creek and one at UCS6. No HCl was measured at the Banana Creek location. The GEOMET positioned at over three miles downwind UCS6, however, recorded a peak concentration of 9 ppm and a

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dose of 90 ppm-s as the cloud passed directly overhead. Three of the six GEOMETs positioned within the launch pad area measured HCl with the highest concentration (29 ppm) recorded at the northwest camera pad (S1). The total dose registered was approximately 480 ppm-s. Two units placed on the northeast camera pad (S2) and one at S4 failed to measure any HCl.

Although the HCl data shown in Table 3 represent actual measurements, only data for STS-5 can be reported with any confidence. Operational and calibration problems encountered during STS-1 through STS-4 produced results that were erratic and difficult to interpret. For STS-5, the USAF OEHL provided a gas permeation oven in order to use chlorine (Cl_2) permeation tubes to calibrate the GEOMETs. This technique was more efficient and accurate than previously used aqueous HCl injection calibration techniques.

GEOMET chemiluminescence HCl analyzers were designed to measure gaseous HCl produced during rocket launches. Results of laboratory and field studies have demonstrated that they are accurate HCl gas measuring devices when properly calibrated. We believe they can be used effectively at VAFB when HCl gas revolatilization occurs on the pad after a shuttle launch. There is a divergence of scientific opinion as to if or how much aerosol HCl can be measured by the GEOMET configured with a standard inlet tube. The amount measured will be a function of aerosol/droplet size, length of inlet tube, side-wall diffusion and flow rate. No comprehensive study to determine the effectiveness of the GEOMET in HCl aerosol/droplet environments has been conducted. Attempts to modify the GEOMET to measure aerosol/droplet HCl were made for STS-4 and STS-5. An open-faced inline filter with sodium bromate/bromide-coated filter paper were substituted for the standard tube. Preliminary indications are that this modification will allow the GEOMET to measure HCl as an aerosol/droplet in solution but is less sensitive to gaseous HCl. Further study is required to determine if a combination of the standard tube and inline filter will transform the GEOMET into a total HCl monitor.

Continuous real-time HCl concentration data are required on the pad at VAFB for personnel protection as well as to increase scientific understanding. We recommend the GEOMET as a candidate "continuous" monitor for measuring near field revolatilized HCl gas produced by STS launches at VAFB.

If selected as a near field monitor, we endorse further development and testing for total HCl applications. We do not recommend the GEOMET for use in any large scale far field monitoring schemes due to high cost, excessive support manpower and equipment, and the complex terrain of VAFB.

3. Dosimeter Tubes. Measurement of gaseous HCl from rocket exhaust is much more difficult than monitoring HCl evolution from stationary sources. The rocket exhaust cloud is transient and a measuring instrument or collection device may only be exposed to HCl for several seconds. An instrument for measurement must respond accurately to a short HCl pulse and a collection device must collect sufficient sample for subsequent analytical assessment of HCl dosage.

The dosimeter tube was developed to satisfy these requirements. It utilizes a simple coated-tube collector which is returned for laboratory analysis after use (Ref 9). The technique consists of sodium carbonate-coated glass tubes through which sample air is drawn by a pump. HCl is absorbed on the coated surface and the tubes are capped and returned to the laboratory for analysis. Laboratory analysis involves rinsing the collector coating with a solution of potassium iodate in sulfuric acid and drawing the evolved gases into a chemiluminescence HCl monitor. The monitor operates on a two-phase luminol oxidation principle where photons of light are produced, read by a photometer and the resulting signal output quantifies the HCl which has been collected.

In the fall of 1978, NASA KSC began using dosimeter tubes to monitor rocket exhaust effluents (Ref 10). Representative results of dosimeter tube measurements for Titan III-C launches at VAFB and KSC and for the launches of STS-1 and STS-4 are at Appendix A. NASA KSC set out 47 single tube dosimeter stands for the launch of a Titan III-C in Dec 78. Location (Figure A-1) and results (Table A-1) are at Appendix A. Results of this test became suspect since there was little difference between tubes at sites which were directly beneath the ground cloud and those that were far removed. Dosages for many of the far field sites were in the 20-30 ppm-s range. In addition, no dosages were measured in the near field around Complex 40.

Dosimeter tubes were used to measure HCl produced by a Titan III-C at VAFB on 7 Feb 80. Sites and results are at Figure A-2 and Table A-2, respectively. The data again show that high dosages were obtained from tubes at sites far removed from the ground cloud trajectory. Dosages between paired tubes showed a wide variance. The highest dosage measured was more than 2 km upwind of the SLC-4 launch site. It was speculated, and confirmed by running background samples, that sodium chloride (NaCl) from sea salt spray was producing a positive interference in the tubes. A mechanism was required to eliminate this interference.

The front end inlet filter configuration shown in Figure 3 is added to the glass dosimeter tube to eliminate NaCl and any other particulate interferences. It consisted of a 10 cc syringe attached to the glass tube with a serum stopper. A free moving plastic cap was located within the syringe and acted as an impactor to remove particulate matter.

The new dosimeter tube configuration was tested during a Titan launch at VAFB in Jun 81 (Ref 11). Location of tubes and results are in Figure A-3 and Table A-3, respectively. Dosages obtained were lower than dosimeter results from previous tests without the syringe-impactor. Variability between paired tubes was also much better than previous tests. However, significant dosages were still seen at locations which were far removed from the ground cloud location. Since tubes within the ground cloud path measured higher dosages than those outside it, tubes with syringe-impactors were used for additional monitoring attempts.

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VACUUM PUMP CONNECTION →

DOSIMETER TUBE

SERUM STOPPER →

10 cc SYRINGE

PLASTIC CUP →
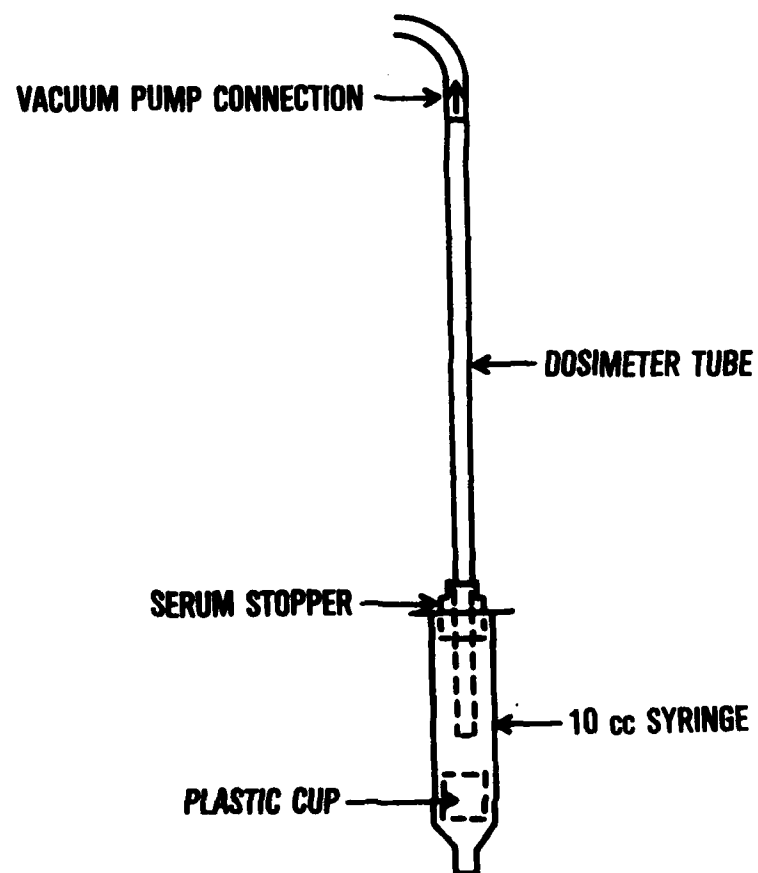
Figure 3. Dosimeter Tube with Syringe-Impactor
Front-End Inlet Configuration

Dosimeter tubes were deployed for the STS Flight Readiness Firing (FRF) in Feb 81 at KSC. No toxic atmospheric contaminants were expected because only the main engines, fueled with liquid hydrogen and liquid oxygen were tested. Deployment of dosimeter tubes with the other atmospheric moni- toring instrumentation served as a training exercise for NASA KSC personnel as well as to gather background data. Even with the syringe-impactor configura- tion and even though the SRBs were not tested, the dosimeter tubes measured up to 9 ppm-s, but, the mean dosage for the 40 tubes was less than one.

A monitoring network of 51 dosimeter sites (Figure A-4) was estab- lished for the launch of STS-1 in Apr 81 (Ref 12). The primary ground cloud moved northwest up the coast. A portion of the column cloud sheared off due west and was tracked by aircraft to Orlando. Dosimeter tube results showed many anomalies. Some tubes under the path of the primary ground cloud indi- cated high hits (maximum 32 ppm-s) and many nonhits (<1 ppm-s). Similar results were found at sites that were under the wind sheared column cloud. Tubes on the pad had indicated that only one site had a dosage higher than one. The highest overall dosage was located at a site greater than 10 km upwind. All values were lower than had been expected. Another problem was encountered during the launch. Thirty percent of dosimeter tube sampling trains with remotely activated pagers did not activate, thus limiting the amount of data available.

There was no improvement in quantitative data measured during STS-2 and STS-3 nor was equipment reliability much better. Air Force and NASA personnel decided to accomplish a detailed study of dosimeter tubes both in the laboratory and in the field. The joint study was conducted by GEOMET Technologies, Inc. (under contract to USAF OEHL), the USAF OEHL, and NASA KSC (Ref 13). Three tasks were proposed. First, determine the best front end filter configuration for eliminating sea salt spray and other particulate interferences. Second, test the best configuration at STS-4 to identify reliability and repeatability of the tubes. Third, determine the errors involved when using the best configuration and develop a correction factor matrix under varying atmospheric conditions.

Different tube configurations were tested in a preliminary study. The two best candidate configurations were the syringe-impactor and a high- molecular-weight polyethylene intake filter normally used to prevent particulate matter from entering the fluid feed lines of autoanalyzers. These two were tested under varying conditions of temperature and relative humidity (R.H.). Results are shown in Table 4.

It can be seen that the syringe-cup configuration did experience HCl losses under all conditions but recovered enough sample to analyze. The polyethylene filters totally absorbed all the sample under almost all condi- tions. Therefore, the syringe-impactor fitted dosimeter tubes were selected to be thoroughly tested during the launch of STS-4.

To insure that dosimeter tubes would be directly impacted by exhaust materials from the launch of STS-4, 51 tubes were sited within the perimeter fence of Pad 39A (Figure A-5). Thirteen were at the northwest elevated camera pad (S1), 16 at the northeast elevated camera pad (S2) and

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four each at P1-P8 along the perimeter fence. Results are depicted in Table A-5 and show a wide variability between adjacent tubes just as was experienced during all previous launches. In addition, dosages measured on the pad were much lower than one would expect in the toxic environment around the pad during a launch. Serious problems with the repeatability and reliability of tubes were confirmed.

Concurrent with the dosimeter tube field study at STS-4, GEOMET Technologies, Inc., conducted laboratory studies of the syringe-impactor configured dosimeter tubes. Tests were conducted under varying source strengths, exposure times, temperatures and relative humidities. It was found that the syringe-impactors absorb HCl and this absorption rate is a function of temperature and relative humidity but more importantly a function of HCl concentration.

Table 4. Dosimeter Tube Inlet Configuration Comparison

Temperature (°C)	Relative Humidity (%)	HCl Source (ppm)	Exposure Time (seconds)	Dose (ppm-s)	HCl Recovered (ppm-s)	
					Syringe Cup	Filter
			30	2.8	1.5	ND*
26	62	0.093	60	5.6	2.5	ND
			300	28.6	7.9	ND
			600	56.0	20.0	ND
			30	3.6	0.6	ND
27	75	0.12	60	7.2	3.9	ND
			300	36.0	15.0	0.5
			600	72.0	25.0	1.2
			30	5.1	2.9	ND
28	88	0.17	60	10.2	5.1	ND
			300	51.0	24.0	0.7
			600	102.0	61.0	ND

*ND indicates not detected.

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Results of this study are graphically depicted in Figure 4.
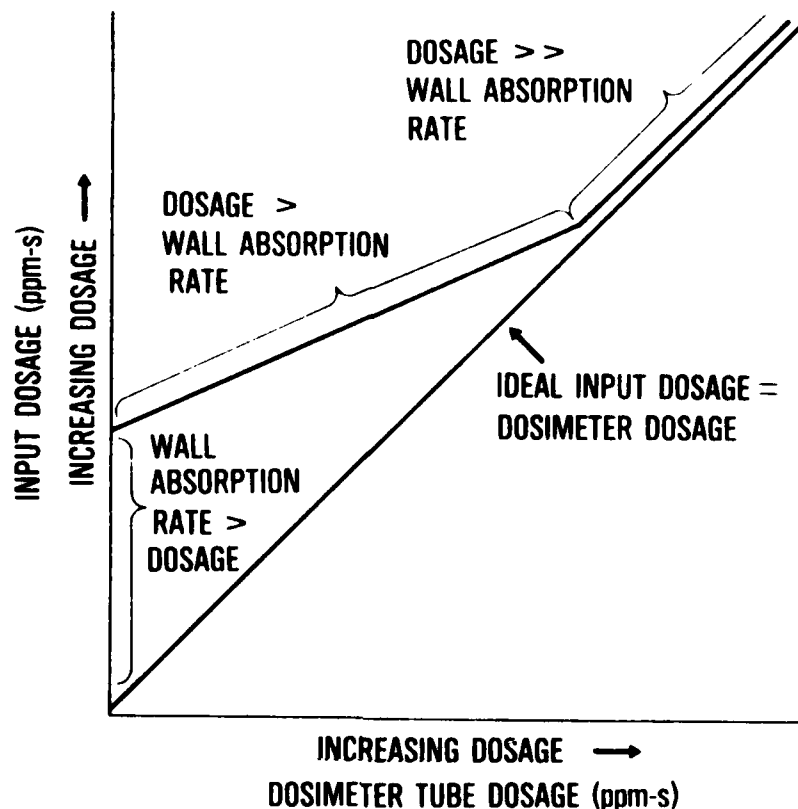
Figure 4. Effect of Inlet Wall Absorption on
HCl Recovered by Dosimeter Tubes

When the wall absorption rate of the syringe-impactor exceeds the
incoming dosage, the dosimeter tube will see no HCl. As the dosage begins to
exceed the wall absorption rate, HCl readings from the tubes can be made. The
syringe-impactors have a limited absorption capacity and once reached (dosage
much greater than wall absorption rate) the input and measured dosage corre-
late very well. The main problem with applying correction factors to dosim-
eter tube results is the fact that sample concentrations and exposure times
are required. Neither of these values are readily available in the field;
therefore, developing and applying correction factors is futile.

The history of dosimeter tubes has been tattered with continual
problems and uncertainties. Due to interferences, unknown absorption rates,
support equipment failures, unreliability, nonrepeatability and the complex
terrain at VAFB, the tubes are not recommended for use in an environmental
program in support of STS launches at VAFB.

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4. pH Indicators. A number of different techniques have been used to indicate the acidity of rocket exhaust effluents. These have included a simple colorimetric change of a surface substrate material (pH paper) to more complex techniques used to measure anions and cations of a sample. A partial list of techniques used for measuring the pH of rockets with solid propellants up to and including the launch of STS-5 is shown in Table 5.

Table 5. pH Indicators for Measuring Rocket Exhaust Effluents

Date	Launch Vehicle	Launch Location	pH Indicator	No. Sites Hit/ Total Sites	pH Range
Jan 75	6.4% STS	NASA MFSC	pH paper	12/12	2.0-4.5
Feb 75	6.4% STS	NASA MFSC	pH paper	7/26	1.0-4.0
Mar 75	6.4% STS	NASA MFSC	pH paper	13/13	2.0-4.0
Sep 75	Titan	NASA KSC	mineral oil[a]	9/9	1.0-3.0
May 77	Titan	NASA KSC	mineral oil[a]	16/16	3.0<[b]
Dec 78	Titan	NASA KSC	mineral oil[a]	3/16	2.0-3.0
Feb 81	STS FRF	NASA KSC	pH paper	0/31	N/A[c]
Feb 81	STS FRF	NASA KSC	Deposition Bucket[d]	0/40	N/A[c]
Apr 81	STS-1	NASA KSC	pH paper	?/30	Low[d]
Apr 81	STS-1	NASA KSC	Deposition Bucket[d]	15/46	4.6-7.2
Apr 81	STS-1	NASA KSC	mineral oil[a]	7/30	1.0-3.0
Nov 81	STS-2	NASA KSC	pH paper	19/40	$\leq$1.0-4.0
Mar 82	STS-3	NASA KSC	pH paper	17/51	$\leq$1.0-4.0
Jun 82	STS-4	NASA KSC	pH paper	15/33	$\leq$1.0-3.0
Nov 82	STS-5	NASA KSC	pH paper	29/32	$\leq$1.0-3.0

[a] pH estimate by measuring excess CL^- with microcoulometer
[b] Drizzle occurred over entire area and sample pH were same as background
[c] Main engine test only, no SRB effluents
[d] Determination of pH by conductivity and ion analysis

A study was conducted in Mar 75 by NASA LaRC to determine the interaction of HCl and water with the sandy soils of KSC following a Titan III launch (Ref 14). Soil slurries were titrated with 0.05 N HCl and the slurry buffering process was measured with a pH electrode. Results of this study showed that soil entrained in the ground cloud could neutralize 1-5% of the available HCl produced during a Titan launch. These results can be correlated to space Shuttle launches: only a small percent of HCl produced during an STS launch will be neutralized by entrained soil. This method of determining the pH of fallout material is not feasible for large scale monitoring since detailed knowledge of soil characteristics is required.

Arnold Engineering Development Center (AEDC) evaluated exhaust cloud monitoring instrumentation in controlled laboratory studies and at the STS 6.4% scale model test firings at MSFC (Ref 15). Bubblers used as gas scrubbers and pH paper were used for the laboratory evaluation. Three types

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of bubblers were tested in which pH electrodes were mounted to measure real time pH changes. It was found that Al_2O_3 particles ingested in the bubblers buffered the HCl solution, thus raising the pH. Several types of pH paper (pH = 0.0-11.0) were deployed throughout the test chamber. In all cases, these papers registered pH = 0.0 when exposed in the chamber for long durations.

Both bubblers and pH paper were used during the STS 6.4% scale model test firings. The pH determinations from the bubblers were used to calculate solution concentrations, however, this pH data are not available. Results of pH paper measurements for three 6.4% firings are shown in Table 5. AEDC tried, but was not able, to correlate HCl concentration (ppm) to colorimetric change of the pH paper. They suggested that pH papers might be usefully deployed over a large area downwind of a rocket launch to provide some indications of acid droplet and gaseous events. They recommended care be taken to record the pH as soon as possible after the launch since fading or discoloration of pH papers occurs and this can alter results.

NASA LaRC used water saturated mineral oil dishes to characterize rocket exhaust effluents (Ref 16). Results of pH measurements for three Titan launches and the launch of STS-1 are also shown in Table 5. A discussion of techniques used are in Section III.A.6.

Combinations of pH paper, mineral oil dishes and deposition buckets were deployed to measure the pH of effluents produced by the Space Shuttle during the FRF and the launches of STS-1 through STS-5 (Refs 12, 17, and 18). Results are depicted in Table 5. The pH paper proved to be the most valuable indicator of deposition acidity. It was found that for all launches, HCl acid aerosol/droplets/deposition with a pH = 1.0 or lower will occur both on the launch pad and to a distance exceeding 6 miles downwind.

Estimates have been made that deposition of pH = 0.4 or less can occur from Space Shuttle launches. There are a number of commercially available pH papers that indicate pH this low; however, tests of these papers at STS launches have not been successful. The problem is that the pH paper sampling sites must be established up to 12 hours prior to launch. High humidities which are dominant at VAFB and KSC, and early morning dew can cause the pH papers to become saturated and in many instances bleeding occurs. Results obtained under these circumstances are questionable. A survey by NASA KSC and the USAF OEHL for commercially available nonbleeding pH paper in the range of pH = 0.1-1.0 has not been successful. Development of a nonbleeding pH paper may be required.

The USAF OEHL attempted to develop an alternate method of determining pH in the 0.0-1.0 range. Laboratory tests consisted of dropping 1 μL droplets of HCl, in the range pH = 0.1-1.0, into a petri dish containing 20 mL of mineral oil. The droplets were retrieved from the mineral oil with a 10 cc syringe and deposited on pH paper. Even though the mineral oil acted as a buffer, accurate pH measurement could be accomplished in the lower pH range. The difficulty in using this technique in the field is that it requires at least 1 μL volume droplets which in many instances are not available. In addition, rapid analysis of the mineral oil dishes is required before the acid droplets coalesce, diffuse or are buffered by the mineral oil. This is usually not possible when large scale monitoring schemes are used.

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There are a number of pH indicators available for use in measuring the acidity of rocket effluents. Of these, pH paper is the most cost-effective especially when a large number of monitoring sites are required. Therefore, pH paper used in conjunction with other simple passive monitoring devices is recommended for near and far field monitoring at VAFB.

5. Copper Plates. The use of copper plates as passive monitors for measuring acid fallout originated during laboratory tests of simulated rocket launches conducted by AEDC (Ref 15). It was found that aluminum mirrors in dewpoint hygrometers became pitted when exposed to HCl droplets causing the hygrometer to malfunction. Based on this finding, glass slides which were vacuum coated with a thin layer of aluminum were positioned in the simulation chamber to record acid droplets which might settle on them. This technique proved successful, and the slides did record evidence of acid droplets. Analysis of deposition with a scanning electron microscrope (SEM) revealed the presence of aluminum and chlorine. Since the SEM instrument could not detect the lighter elements, including oxygen, it was impossible to determine whether the aluminum detected came from the substrate coating on the glass slide or from the aluminum oxide particles. To avoid this problem, a second set of glass slides was coated with copper, and, in the tests which followed, proved to be equally capable of recording acid droplet fallout. Copper coated glass slides used in the laboratory evolved into copper coated disc for the 6.4% scale model test firings at NASA MSFC and subsequently into the use of copper plates for Space Shuttle launches.

A summary of results of copper disc/plate measurements of rocket exhaust effluents is shown in Table 6.

Table 6. Copper Disc/Plate Indicators for
Measuring Rocket Exhaust Effluents

Date	Launch Vehicle	Location	Technique	No. Sites Hit/Total No. Sites	Comments
Aug 74	STS 6.4%	NASA MFSC	Copper Disc	0/13	None
Nov 74	STS 6.4%	NASA MFSC	Copper Disc	1/19	Acid Droplets
Jan 75	STS 6.4%	NASA MFSC	Copper Disc	1/8	Al_2O_3 Spheres
Jan 75	STS 6.4%	NASA MFSC	Copper Disc	5/6	Aerosols
Feb 75	STS 6.4%	NASA MFSC	Copper Disc	6/26	Aerosols
Mar 75	STS 6.4%	NASA MFSC	Copper Disc	8/8	Al_2O_3
Nov 81	STS-2	NASA KSC	Copper Plate	15/40	Acid Droplets
Mar 82	STS-3	NASA KSC	Copper Plate	17/51	Acid Droplets
Jun 82	STS-4	NASA KSC	Copper Plate	25/44	Acid Droplets
Nov 82	STS-5	NASA KSC	Copper Plate	7/51[a]	Acid Droplets

[a]Far field monitoring sites only

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The copper plates measurements for the launches of STS-1 through
STS-4 were so successful that plates were used in conjunction with pH paper to
measure acid fallout on pad 39A for the launch of STS-5 (Ref 18). The study
was conducted to provide information for determining the amount of washdown
water required at VAFB as well as a precursor to a rocket exhaust effluent
mass balance and water balance study for the launch of STS-6. The location of
the monitoring sites for the launch of STS-5 and results are shown in Figure 5.

WIND
E 9 KTS

■ pH=1.0, 100% COVERED
△ pH=1.0, 100-500 SPOTS
□ pH=3.0, 100-500 SPOTS
● COPPER PLATES ONLY, 100% COVERED
○ COPPER PLATES ONLY, 100-500 SPOTS
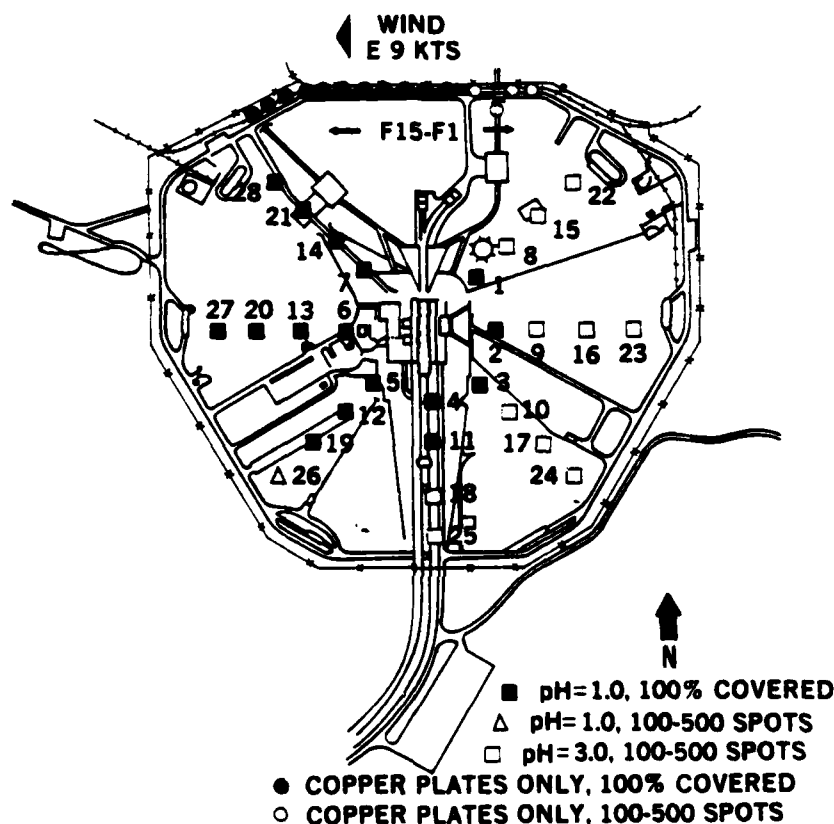
Figure 5. Copper Plate and pH Paper Observations
on Pad 39A for the Launch of STS-5

Copper plates and pH paper (pH = 1.0-7.0) were sited along seven
radials out from the pad at distances of 400 ft, 600 ft, 800 ft and 1,000 ft
from launch point. In addition, 15 single copper plates were attached to the
perimeter fence opposite the SRB flame trench. The study indicated that 100%
coverage of pH = 1.0 or lower deposition will occur out to a radius of 400 ft
around the pad regardless of wind direction. On the downwind side of the
pad, 100% coverage of pH = 1.0 deposition can extend out to and beyond 1,000
ft. On the upwind side of the pad, partial coverage of pH = 3.0 deposition
can occur out to 1,000 ft. In addition, 100% coverage of pH = 1.0 deposition
will occur opposite the SRB flame trench at a distance greater than 1,200 ft.

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A more comprehensive study will be conducted during the launch of STS-6 to better define the acid deposition distribution within and around Pad 39A.

Copper plates used to measure rocket exhaust effluent deposition offer many advantages. First, they are inexpensive and foolproof. All that is required is a 4 by 6 ft copper sheet which is commercially available for less than $100. One copper sheet will make 216, 4 by 4-inch, copper monitoring plates. Second, preparation of the plates is simple. All that is required is cutting the desired size of copper plate, buffing and chemically degreasing the plate. Third, the plates require no support equipment except for a supporting stand. Fourth, analysis can be accomplished by visual observation.

Results show that copper plates used as acid deposition indicators have been very successful in determining locations of acid deposition. Data that can be obtained from copper plates used during STS launches include: ground cloud deposition footprints, number distribution, size distribution and type of deposition (wet deposition, acid droplet, etc.). Copper plates used in conjunction with pH paper are a valuable cost-effective passive monitoring device. They can be used in large numbers with little cost and are not labor intensive. We recommend their use to identify the ground cloud acid footprint as well as near field acid deposition for initial Space Shuttle launches at VAFB.

6. **Mineral Oil Dishes.** Graduated petri dishes filled with mineral oil or a number of other substances have been used to capture and measure many types of atmospheric deposition. Particle and number size distributions can be obtained using this technique if evaporation, coagulation or diffusion do not occur. In addition, attempts have been made to identify droplet composition and to determine pH.

NASA LaRC used water-saturated mineral oil as a capturing medium for wet deposition from solid rocket exhaust clouds during nine Titan III launches and the launch of STS-1 (Ref 19). In general, wet deposition was found to be relatively sparse (100 to 1,000 drops/meter^2) and infrequent (4 out of 10 launches). Two of the Titan III launches had rainfall scavenging events (Sep 75 and Dec 77). Microcoulometry was the analytical technique used for chloride (Cl-) and atomic absorption used for sodium (Na). They measured excess chloride over and above diluted sea salt spray (NaCl) and found that excess Cl- was approximately equal to H$^+$; and therefore, the pH of the acid fallout (HCl) could thus be estimated using the following equation:

$$pH = -\log (H^+)$$

This approximation was substantiated by the use of pH paper at some of the monitoring sites. The results of their measurements are shown in Figure 6.
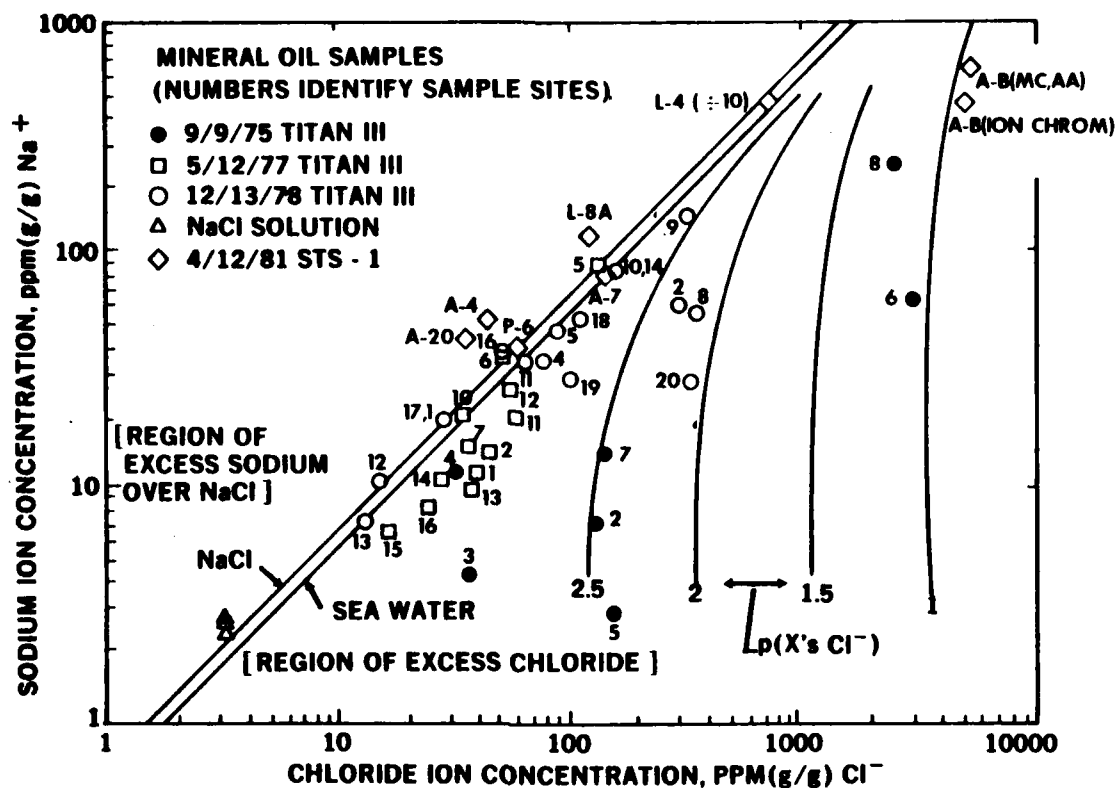
Figure 6. Composite Characterization of Chlorides Sodium
          and Excess Chloride Concentrations from Mineral
          Oil Samples Collected at KSC (Ref 16)

A region of excess chloride is shown to the right of the NaCl and seawater lines, and curves are parameterized in terms of equivalent pH of an idealized HCl plus diluted-seawater solution. Significant departures from the seawater line are evident in nine samples in which $1 \leq pH \leq 2.5$. Most of the remaining samples exhibited compositions closely resembling that of diluted seawater.

The USAF OEHL used graduated petri dishes filled with deionized water to identify and measure exhaust effluents on Pad 39A at STS-4. Analysis by titration showed no significant exhaust effluents above background levels. Problems with the sensitivity of the titration method was suspect and confirmed at STS-5 when ion chromatography was the analytical technique used for midget impinger samples (see Section III.A.8.). Ion chromatography, a very sensitive analytical technique identified the major exhaust materials. Future USAF OEHL efforts for STS launches will include the determination of a material mass balance on the pad using ion chromatography as the analytical technique.

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Advantages of mineral oil dishes are their simplicity, ease of operation and low cost. Disadvantages include evaporation, coagulation and diffusion of the sample. In addition, detailed analysis of the sample may require sophisticated techniques. The capturing medium may buffer the sample to some degree and could be incompatible with some of the analytical techniques thereby limiting its usefulness.

7. Electrets. An electret is a dielectric with a permanent surface charge which gives them properties similar to magnets. They have been used as simple passive monitoring devices for attracting charged particles and ions to their surfaces. Analysis is accomplished by X-Ray Energy Dispersive Spectroscopy (XEDS) where electron counts of the different elements present on the surface of the specimen are determined. XEDS can also determine in terms of atomic weight the amount of a given element.

Electrets have been used successfully in collecting rocket exhaust effluents. Included in these studies are attempts to both qualify and quantify the effluents from the STS Solid Rocket Boosters (SRB). In January 1978, electrets were used during the static test firing of an SRB at the Thiokol static test site near Brigham City UT (Ref 20). Results of the electret measurements were compared to Thiokol fixed flow samplers which collected a sample on paper filters. The electret measured rocket effluents at locations where none was detected by the filters. It was concluded that electrets could be used as a complementary monitoring device to determine exhaust effluents at locations downwind of the firing; however, quantitative capabilities were unknown.

Experimental data for electrets were obained from 18 static test firings of the 6.4% scale model of STS at NASA MSFC, and chamber tests at AEDC (Ref 21). Field tests compared electret HCl results with other monitoring devices including: GEOMET chemiluminescence HCl detector, bubbler, millipore filter, and coulometer. Electrets showed high HCl electron counts which corresponded very well when other devices measured high levels of HCl. Likewise, when low measurements were obtained from the other monitoring devices correspondingly low electron count from the electrets were found. Chamber tests at AEDC confirmed these results.

A joint study was conducted by NASA MSFC and the USAF OEHL at the launch of STS-5 (Ref 22). Eight electrets were set out during the launch (Figure 7). Paired electrets were located at the northwest elevated camera pad (S1), the northeast elevated camera pad (S2), both within the perimeter fence of Pad 39A; and at the Universal Camera Site 6 (USC6) approximately 3 1/2 miles due west of the pad. Single electrets were placed at S3 and S4. The USAF OEHL took midget impinger samples (Section III.A.8.) at S1, S2, S5 and UCS-6 for this HCl comparison study. Results are shown in Table 7. In an attempt to calibrate electrets with a reliable HCl monitoring device, a ratio of HCl dosage measured by the midget impingers and mean HCl electron count measured by the electrets was formed at sites where both were located during the launch (S1, S2, UCS6). A ratio of approximately 22 ppm-s/electron count occurred at three sites with totally different exhaust effluent exposures (Table 7). Site S1 was directly downwind and heavily hit by the effluents on the pad. S2 was upwind of the main burn area opposite the SRB flame trench
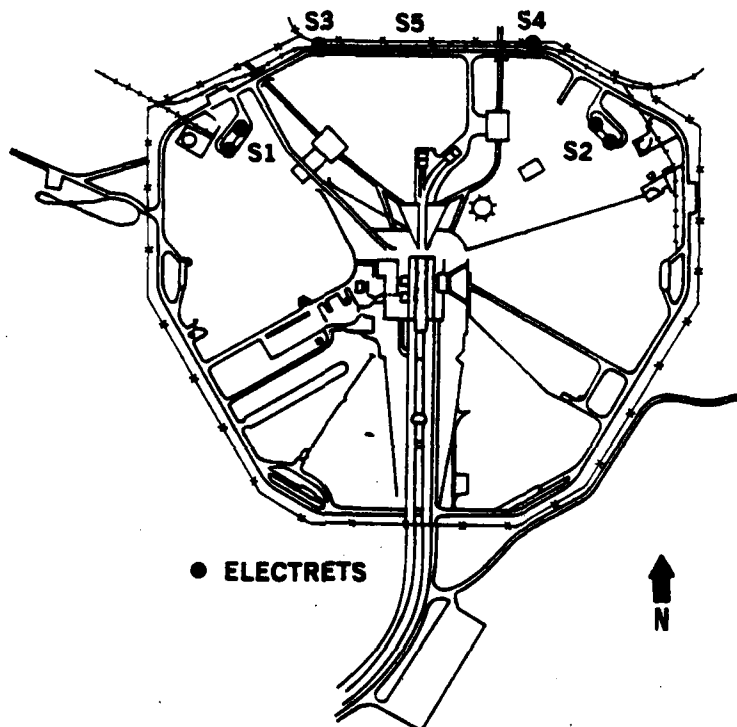
Figure 7. Electret Sampling Sites at STS-5

and was exposed to less HCl. The far field site at UCS6 was directly impacted by deposition from the ground cloud but received even less exposure than either site on the pad. At S3, although no impinger data were available, a high HCl electron count occurred as would be expected since the site was in and on the downwind side of the SRB grassy burn area. Similarly, S4 was between S2 and S3 just upwind of the burn area and had a lower count than S3 and a higher count than S2.

Table 7. Electret and Midget Impinger HCl Comparison Study at STS-5

Site	Electret (HCl electron count)[a]	Midget Impinger (HCl dosage ppm-s)[a]	HCL Dosage (ppm-s) ÷ Mean HCl electron count
S1	8,150 6,650	149,712	20.23
S2	650 750	15,390	21.99
S3	5,750	No Impinger	
S4	1,125	No Impinger	
S5	No Electret	562,494	
UCS6	50	1,116	22.32

[a]Background Chloride Subtracted

The strong correlation observed must be tempered by the fact that a limited number of data points were obtained during STS-5. Further studies are in progress to determine if electrets can be calibrated with sufficient confidence to use them alone to measure HCl or other specie dosages during shuttle launches.

Electrets may be desirable for use at VAFB because of their small size, light weight, low cost, long life and minimal support equipment. If they can be calibrated, monitoring STS exhaust effluents in the complex terrain of VAFB may be possible.

8. Bubblers/Impingers. A number of glass or plastic bubblers/impingers are available as sampling devices (Ref 23). These contain water or some other absorbing media to capture pollutant substances when air is passed through them. Essentially, a measured amount of absorbing liquid is placed in a sample bottle, which also contains the bubbler. As air is drawn through the bubbler/impinger, the contaminant is retained in the liquid. Analysis is usually accomplished in the laboratory by a number of available methods.

Bubblers have been used in the evaluation of other detectors used to measure HCl from rocket effluents. The USAFSAM used them as standards in the evaluation of microcoulometric instrumentation (Ref 6). Comparison studies were conducted both in the laboratory and in the field for a Delta Thor launch (1972) and Titan launches at KSC and VAFB beginning in 1973. Bubblers were also used in monitoring HCl in the ground exhaust cloud from static tests of small rocket motor firings at the Naval Weapons Center, China Lake CA (1974) and in HCl plant exposure studies at the UCR in 1975 (Ref 7).

Bubblers were used to measure HCl produced during test firings of the 6.4% scale model of the STS at MSFC in 1974 and 1975 (Ref 15). Results of the tests are shown in Table 8.

Table 8. Bubbler Results for Test Firings of the 6.4% Scale Model Space Transportation System at MSFC

Date	Launch Vehicle	Location	No. Sites/ Total No. Sites	Maximum HCl Dosage (ppm-s)
Aug 74	6.4% STS	MFSC	0/3	Zero
Nov 74	6.4% STS	MFSC	0/3	Zero
Jan 75	6.4% STS	MFSC	0/3	Zero
Jan 75	6.4% STS	MFSC	1/2	57
Feb 75	6.4% STS	MFSC	1/2	9,000
Mar 75	6.4% STS	MFSC	2/2	662

During the first three test firings, the ground cloud did not intercept the bubbler sampling sites but did for the latter three. A measured dosage of 9,000 ppm-s occurred from a bubbler approximately 200 ft away from the test pad in a Feb 75 test. These field tests, in addition to laboratory chamber studies, suggest that bubblers are a valuable monitoring device that will yield HCl dosages within ±10% of ambient levels.

Samples were collected for hydrogen chloride gas and aerosol using midget impingers during the launches of STS-4 and STS-5. The absorbing media was 15-20 mL of either 0.1 N sodium hydroxide or distilled water. Air was pulled through the impinger using a vacuum pump with flow regulated to a nominal value of 0.85 Lpm with a 21 gauge syringe needle operating as a critical orifice. An 0.8 μm filter cassette was used between the impinger and syringe needle to keep from plugging. Twelve sets of two impingers in series (six sets with sodium hydroxide and six sets with distilled water) were set up on the northwest elevated camera pad opposite the SRB flame trench on Pad 39A at KSC for the launch of STS-4. Seven sets (four containing sodium hydroxide and three with distilled water) were set up on the northeast elevated camera pad. The sampling train at each site was remotely activated at L-0:05 minutes and turned off at L+0:38 minutes. Analysis of samples was performed using a standard titration technique for the chloride ion which has minimum level of detection of .04 mg/sample. Analysis of samples showed no HCl above the detection limits of the titration techniques, and it is possible that the impingers were not activated.

The sampling train for the impingers was identical for STS-5 as it was for STS-4 except that distilled water was used as the absorbing medium in all the impingers (Ref 18). Ion chromatography was the analytical technique used which has level of detection 200 times more sensitive than the titration method. Locations of impinger sampling sites on the pad are shown in Figure 8 and far field sites in Figure 9. Results of both shown in Table 9.
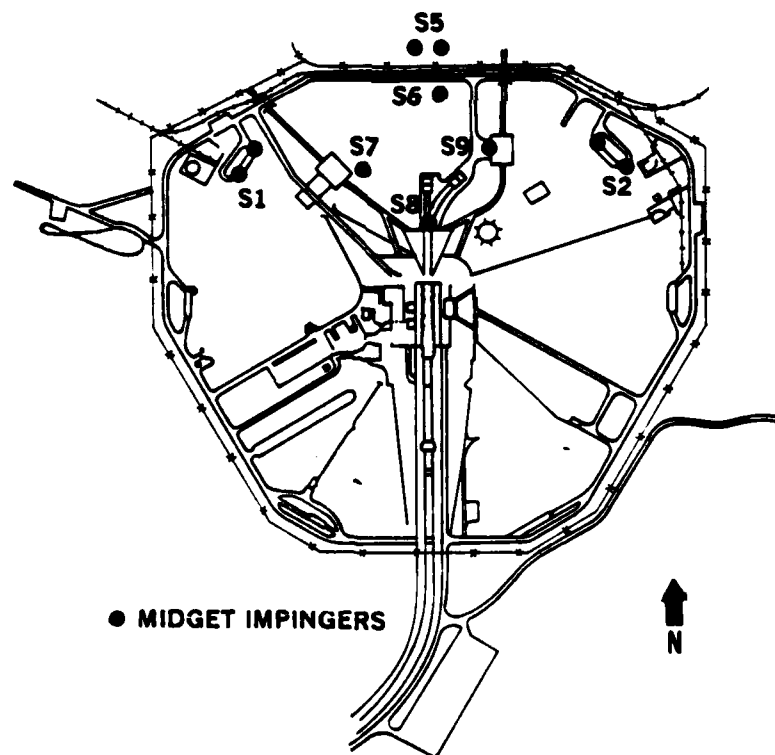
● MIDGET IMPINGERS

Figure 8. USAF OEHL Midget Impinger Sampling Sites
on Pad 39A at KSC for the Launch of STS-5
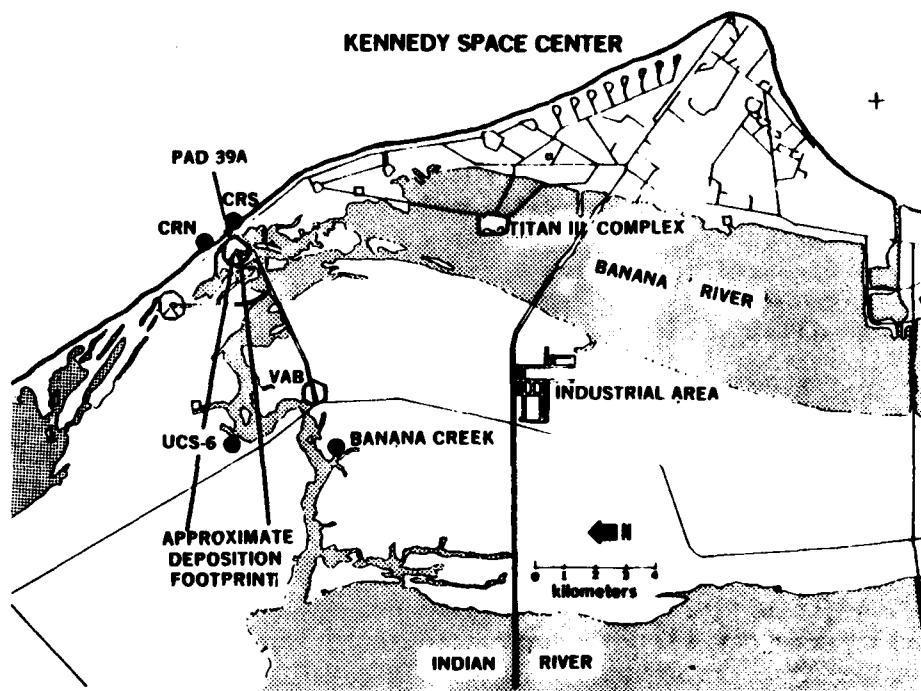
Figure 9. Far Field Midget Impinger Sampling
Sites for the Launch of STS-5 at KSC

        The table depicts total HCl and aluminum (Al), and the time
weighted average (TWA) concentrations for HCl and Al. Also included in the
table is the total HCl dosage in parts per million second (ppm-s) computed by
multiplying the average concentration by the sampling time. The concentra-
tions shown are time averaged and, therefore, higher peak concentrations could
have occurred during the sampling period. High HCl and Al were observed at S1
(downwind of the SRB exhaust) and S5 (directly hit by SRB exhaust) in the ini-
tial 10 minutes postlaunch. High average concentrations persisted for 3 to 4
hours after launch while Al concentrations decreased. At both S1 and S5, high
HCl average concentrations exceeded the Threshold Limit Value (TLV) ceiling
concentration of 5 ppm. This value should not to be exceeded by a worker in a
workplace environment. High HCl concentrations observed on the pad are proba-
bly associated with HCl gas revolatilization from the grassy burn area oppo-
site the SRB flame trench. The drop in aluminum concentrations after the
first 10 minutes after launch may occur because the heavier aluminum particles
fall out and resulting concentrations are associated with wind blown Al. Both
S1 and S5 exhibited high HCl dosages with S5 accumulating over 500,000 ppm-s
within the 4 hours after launch. S2 was upwind of the grassy burn area but
experienced TWA concentrations between 2.0-3.0 ppm from launch to 90 minutes
after launch. Aluminum concentrations were high for the first 10 mintues
after launch and dropped off significantly thereafter. Of the sites estab-
lished in the grassy burn area, S7 recorded average HCl concentrations greater
than 3.0 ppm for the periods L+4:00 to L+6:30 hours. Far field sites had
average HCl concentrations in the 0.1-0.3 ppm range.

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Table 9. Analysis of the USAF OEHL Impinger Samples for the Launch of STS-5 at KSC

Location	Site	Sampling Time (min)	Total HCl (µg)	HCl Conc. TWA (ppm)[a]	Total HCl Dosage (ppm-s)	Total Al (µg)	Al Conc. (mg/m³)[a]
W Pad (Launch)	S1	10	315	23.8	10,280	13.4	1.5
W Pad (Post)	S1	198	2,997	11.4	135,432	24.4	0.2
E Pad (Launch)	S2	10[b]	39	2.9	1,740	9.0	1.0
E Pad (Post)	S2	91[b]	305	2.5	13,650	5.4	0.1
Knollenberg (Launch)	S5	10[b]	372	28.1	16,860	16.6	1.8
Knollenberg (Post)	S5	241[b]	12,437	38.9	562,494	140.0	0.7
SRB	S6	209	217	0.7	8,778	26.8	0.1
SRB	S7	154	697	3.3	30,492	28.0	0.2
SRB	S8	78	16	0.2	936	23.8	0.3
SRB	S9	82	7	0.1	492	20.0	0.3
Coast Road South	CRS	82	37	0.3	1,476	12.6	0.2
Coast Road Noth	CRN	219	27	0.1	1,314	20.6	0.1
Universal Camera Site Six	UCS6	93	28	0.2	1,116	19.4	0.2
Banana Creek		142	44	0.2	1,704	23.2	0.2

[a]Postcalibration of the sample flow limiting orifices suggest that actual concentrations could have been even higher than shown in above table.

[b]Sampling times questionable.

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The USAF OEHL will repeat the midget impinger study for STS-6. In addition, sequential impinger samplers will be added to try to better define the time history of HCl gas revolatilization around the pad area.

Bubblers have been used very successfully to collect rocket exhaust effluents and measurements obtained from these samples have been used as a standard reference when evaluating other monitoring devices. They are active sampling devices that require pumps and supporting electrical power. Dosages and average concentrations can be obtained from bubbler samples; however, analysis must be accomplished in the laboratory rather than in the field thereby precluding instantaneous data. They should not be used in cases where real-time data are required. We recommend bubblers as intermediate level sampling devices between simple passive monitors and the more complex active continuous monitors. We do not recommend their use in large scale monitoring schemes since they are somewhat labor intensive. This is especially true in the complex terrain at VAFB.

9. Tenax^R GC Tubes. Organic contaminants were suspected to be present on Pad 39A after the launches of STS-1 through STS-4. To determine the extent of this potential problem, the USAF OEHL used Tenax GC tubes, a gas chromatographic column packing, to trap contaminants other than HCl. Air was pulled through the Tenax GC tubes using a vacuum pump with flow regulated to a nominal value of 0.85 Lpm with a 21 gauge syringe needle operating as a critical orifice. An 0.8 μm filter cassette was used between the tube and syringe to prevent clogging of the syringe needle. Analysis of the Tenax GC tubes, by the USAF School of Aerospace Medicine (USAFSAM), was performed using capillary column gas chromatography with species identification by mass spectroscopy. Locations of Tenax GC tubes sampling sites for the launch of STS-5 are the same as impinger sites (Figs 9 and 10). Analyses of Tenax GC samples are shown in Appendix B. Very low concentrations of organic compounds were found at all locations. Although some organics identified were directly related to associated STS operations, none of the organic compounds approached the TLV prescribed by the American Conference of Governmental Industrial Hygienists (ACGIH). Other substances found in trace amounts would be anticipated as they occur in the natural environment. It is concluded that organic contaminants produced by the Space Shuttle are of no health concern to individuals entering the pad postlaunch. No further organic material studies are contemplated for STS launches at KSC nor are any now recommended for VAFB.

10. Charcoal Tubes. Charcoal adsorption tubes were used to trap other possible organic contaminants at the launch of STS-5. The USAF OEHL placed two charcoal tubes in series at the near field and far field sites shown in Figures 8 and 9. Selected tubes were analyzed by the Utah Biomedical Test Laboratory (UBTL), Salt Lake City UT, under contract to the USAF OEHL. Only selected tubes in series were separated and analyzed by gas chromatography using NIOSH Method P&CAM 127 with the following modifications. First, charcoal tube samples were desorbed in 2.0 mL of carbon disulfide. Second, gas chromatography was accomplished using a Hewlett-Packard Model 5711A equipped with a flame ionization detector. Third, the column was a 30 mm x 0.31 mm fused silica capillary-coated internally with 1.0 μm DB-1. Fourth, oven temperatures were programmed from 50°C to 200°C at a rate of 8°C per minute. Analysis of selected tubes is shown in Table 10.

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**Table 10.   Analysis of Selected Charcoal Adsorption
Tubes at the Launch of STS-5 at KSC**

Location	Site	Tube	Sampling Time (Hours:Minutes)	Analysis (mg/sample)[a]
W Pad (Launch)	S1	Front	L-0:05 to L+0:10	<0.01
W Pad (Launch)	S1	Back	L-0:05 to L+0:10	<0.01
W Pad (Post)	S1	Front	L+0:10 to L+3:28	<0.01
W Pad (Post)	S1	Back	L+0:10 to L+3:28	<0.01
Knollenberg (Post)	S5	Front	L+0:10 to L+4:11	<0.01
Knollenberg (Post)	S5	Back	L+0:10 to L+4:11	<0.01
Universal Camera Site 6	UCS6	Front	L+0:10 to L+1:41	<0.01
Universal Camera Site 6	UCS6	Back	L+0:10 to L+1:41	<0.01
SRB	S7	Front	L+4:37 to L+7:01	<0.01
SRB	S7	Back	L+4:37 to L+7:01	<0.01

[a]Gas chromatograph/flame ionization detection analysis in mg/sample
relative to the response of n-hexane.

The two charcoal tubes in series at UCS6 exhibited a very small
peak that eluted before carbon disulfide and was less than 0.01 mg per sample
compared to the response of n-hexane. There was no component present at a
concentration greater than 0.01 mg per sample for all other tubes analyzed.

The results of the midget impingers, Tenax GC tubes and charcoal
tubes indicate no other toxic species except for HCl associated with a STS
launch. We, therefore, recommend no further Tenax GC tube or charcoal adsorp-
tion tube studies be conducted at KSC or at VAFB.

11.   Particle Measuring System. The Air Force Geophysics Lab (AFGL)
was requested and funded by NASA to obtain microphysical data on the particle
and droplet size distribution in the solid booster exhaust cloud produced from
the launches of STS-3 and STS-4 (Ref 24). Three Particle Measuring Systems
(PMS) 1-D probes were obtained. The Axial Scattering Spectrometer Probe
(ASSP) uses the amplitude of scattered laser light to measure the size of
particles between 2 and 30 μ. The 1-D Cloud and Precipitation probes use
shadows of the drops on arrays of light sensitive diodes to obtain the maxi-
mum width of the drops as they pass through the collimated laser beam. Size
ranges for the cloud and precipitation probes are 20 to 300 μ and 300 to 4500
μ respectively. Size distributions from the three probes are recorded on
magnetic tape. In order to get liquid water concentrations as well as size
distributions, it is necessary to know the volume of the cloud sampled. This
is obtained by multiplying the sample area for each probe by the wind speed.

The PMS 1-D probes were mounted on an elevated platform at a
height of approximately 15 ft about 1200 ft directly opposite the SRB flame
trench. Fast response wind measuring instrumentation and a black and white TV
camera were also mounted on the platform.

An electrical power loss during the launch of STS-3 resulted in no data. To alleviate this problem for STS-4, electric power was provided to the site by a cable. Two methods of activating the equipment were used. The primary system consisted of a radio paging system activated by a signal from the Range Control Center. The backup system was a mechanical timer which was set to turn the equipment on prior to launch. Even though the paging system had checked out on all tests prior to the launch and activated other equipment at other locations for the launch, it failed to turn on the equipment at this site. The equipment was activated by the backup timer; however, power at the site was lost 85 seconds after launch. Initial reports indicated that the cable was burned through and it was surmised that hydrochloric acid ate through some of the cracks in the cable.

During the 85 seconds power was available, the ASSP malfunctioned. This probe operated for a short period of time at the beginning of the launch and it is uncertain if the malfunction was caused by the exhaust effluents passing through the probe. Upon return to the laboratory, the optics of the 1-D Cloud Probe were loose. It is suspected that this occurred as a result of high acoustical vibrations associated with the launch. The 1-D Precipitation Probe could not be operated in bench tests during the postlaunch inspection at AFGL until mirrors had been cleaned of exhaust and deluge contamination. Even after cleaning, noise interference occurred. There is uncertainty in the little data obtained from the PMS 1-D probes. It appears that the probes were overwhelmed by dirt, grass and exhaust debris as the SRB effluents directly impacted the site.

Particle and droplet size/number distributions are important parameters required by any dispersion model. Ideally, the distributions should be obtained once the horizontal momentum of the exhaust effluents desists and the buoyancy of the induced cloud begins to dominate. Aircraft with particle sizing instrumentation have been used but usually cannot penetrate the ground cloud until it has stabilized. Therefore, a data gap exists from time of launch until ground cloud stabilization. Remote sensing would ideally fill this void, but the technology will not be available for a number of years. The importance of measuring the particle and droplet size/ number distributions of the exhaust effluents as they are emitted horizontally from the SRB flame trench is still a question. The cost ($30K) of a study such as this becomes prohibitive when no usable data are collected. Monitoring problems would be increased at VAFB because both SRB flame trenches would require instrumentation.

Two attempts (STS-3 and STS-4) have been made to measure particle and droplet size/number distributions of the exhaust effluents emitted from the SRB flame trench during Shuttle launches. Minimal usable data have been obtained. The instrumentation used has not operated in the hostile environment existing on the pad during a launch. We do not recommend using PMS 1-D probes for ground measurements of STS launches at VAFB. Instead, we recommend using PMS 2-D probes on aircraft to measure size/number distributions of the Shuttle induced ground cloud for at least the first STS launch at VAFB. This information will provide valuable input to the dispersion models used and will describe the differences in distributions between KSC and VAFB for subsequent model modifications.

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12. **Biological Monitoring.** Factors that affect photosynthesis produce changes in chlorophyll variable fluorescence (Kautsky effect) and can be measured easily with a filter fluorometer as variable rate fluorescence with dark adapted intact leaves. Rapid changes in the yield of chlorophyll fluorescence occur within the first 15-30 seconds of illumination in all photosynthetic plants. The change in fluorescence is an indication of the rate of electron flow through the chloroplast electron transport system.

The electron transport is measured using a plant fluorometer, a portable DC battery-operated unit suitable for measurements in the field. It is connected to a portable DC battery-operated strip chart recorder. A 2 cm segment of leaf, top leaf side up, is placed in a leaf holder; the fluorometer probe is inserted on top of the leaf segment; the leaf segment is dark adapted for 2 min; the leaf segment is illuminated at 670 nm and simultaneously resulting fluorescence at wavelengths greater than 710 nm is detected and recorded on the strip chart over 10 or more seconds. The induction kinetics of chlorophyll fluorescence vary considerably between the upper and lower side of the same leaf. Thus, it is necessary to use the same side of the leaf in all instances.

The change of chlorophyll fluorescence has been successfully used to measure the effects of several environmental pollutants, such as polychlorinated biphenyl, lead, ozone, triazine, and bottom sediment of a municipal water reservoir.

A technique for using the fluorometer for field studies has been developed and tested by the University of Missouri Environmental Trace Substances Research Center. Each day, leaves of approximately the same age are collected from several plants at each location being investigated. Collections from each location are made at approximately the same time each day and meteorological conditions noted, especially light conditions. The leaves are placed in plastic bags containing moist cotton or absorbent paper. These are then placed in a dark container, preferably cool, and returned to the laboratory or any facility where the fluorometer readings can be made. Kept cool and in the dark, the leaves may be stored for several hours. Readings may, however, be taken as soon as the leaves are dark adapted for a period of about 5 minutes.

Specimens from each location are read in sequence. For example, a control reading is recorded followed by samples 1, 2, 3, etc., and then back to control. Usually 10-15 readings are taken from random leaves from each location. Sequential readings are taken because 2-3 hours may elapse before samples from the entire collection are read and in this way readings from any one location are spread over the entire recording period. If two people are available, one preparing and handling the specimens while the other operates the fluorometer, the strip-chart recorder and makes notations on the resulting graph, it is possible to process a leaf sample in about 1 minute. Thus large numbers of recordings may be obtained in a relatively short period. Variable fluorescence may then be determined from the charts at any convenient time.

Preliminary evaluations of the Plant Productivity Fluorometer as a biological monitoring system of STS launches were conducted following STS-5.

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Measurements were made in the field on leaves suffering heavy, moderate, light, and scattered (no more than one deposition droplet per plant) acid deposition within the ground cloud footprint, as well as real-time controls. Table 11 shows the means ($\pm$ s.e.m.) of six replicates of each impact category listed above (reported as % absorption units).

Table 11. Variable Chlorophyll Fluorescence of Leaves Impacted by Hydrogen Chloride after the Launch of STS-5 at KSC

Acid Damage	Mean[a] Chlorophyll Fluorescence
Control	0.253[b] $\pm$ .004[c]
Scattered hits	0.237 $\pm$ .003
Slight damage	0.222 $\pm$ .005
Moderate damage	0.200 $\pm$ .007
Heavy damage	0.167 $\pm$ .018

[a] Mean of six replicates
[b] Reported as % absorption units
[c] $\pm$ standard error of the mean

This preliminary evaluation, as well as private investigations, indicates that the plant productivity fluorometer is a simple, inexpensive, passive system for environmental monitoring. Future STS monitoring efforts are being designed to further evaluate this system and correlate the findings with HCl, water and mineral mass balance studies. The eventual goal is the practical field application of this system for near- and far-field monitoring of both short- and long-term environmental effects of STS launches.

B. Developmental Ambient Monitoring Instrumentation

The USAF OEHL contracted Radian Corporation, Austin TX, to conduct a literature review of the availability of current hydrogen chloride detection instrumentation for monitoring STS launches. Table 12 shows the results of this literature survey. The first five HCl measurement approaches that follow are from the Radian Corporation survey. Following these descriptions are a number of additional HCl monitoring techniques/devices which have been reviewed by the USAF OEHL in our search for monitoring instrumentation to measure exhaust effluents during STS launches. Further testing and evaluation of these techniques/devices should be the subject of future laboratory and field studies.

1. Chemiluminescence HCl. The GEOMET chemiluminescence HCl analyzer was discussed in Section III.A.2. Advantages of the GEOMET are that it is continuous, a dynamic concentration range of 0.01-100 ppm, and has been extensively tested in the laboratory and in the field during rocket launches including the STS. Further development may be required to overcome the GEOMET's inability to measure certain size HCl aerosols/ droplets.

Table 12. Comparison of Five HCl Measurement Approaches

Instrument Parameter	GEOMET 401S	GEOMET PDT	CMI-QCM	NIOSH P&CAM 310	MIRAN 1A
Instrumental approach	monitor	dosimeter	monitor	dosimeter	monitor
Active or passive	active	passive	active	active	active
HCl concentration or dose	concentration	dose	concentration	dose	concentration
Method of collection	$Br\,Br^-O_3$	$AgNO_3$	R_3N amine	silica gel	flow through cell
Method of detection	chemiluminescence	fluorescence	QCM	ion chromatography	NDIR (nondispersive infrared)
HCl vapor	yes	yes	yes	yes	yes
HCl particulate	yes	yes	yes	yes	no
Sensitivity	<0.01 ppm	30 ppm-sec	<0.01 ppm*	200 ppm-sec*	3 ppm*
Capacity	100 ppm	2,000 ppm-sec*	*	2,000 ppm-sec	*
Accuracy	±2%	*	±10%	±5%	±10%
Response time	<1 sec	NA	<1 min	NA	<1 min
Interference by NaCl	no	no	no	possible*	no
Other interferences	acid gases oxidants	acid gases *	NH_3 acid gases *	Cl_2	alkanes alcohols *
Power required	115 VAC 250 watts	none	115 VAC 50 watts	battery	115 VAC or battery
Ambient temperature	0-80°C	*	0-70°C	0-40°C	0-40°C
Ambient humidity	10-95% RH	*	<80% RH	*	*
Weight of field unit	25 lb	<0.5 lb	15 lb	2 lb	30 lb
Cost per field unit	$8,400	<$20	$4,000-6,000	$500	$10,000
Development required	~$0	$75,000	$250,000	$25,000	$100,000

*Instrument parameters that require determination instrument

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2. **Passive Dosimeter.** Passive dosimeter techniques (PDT) are in the development stage. One HCl PDT by GEOMET Technologies, Inc., that shows promise is based on fluorescence methodology. Such a dosimeter would contain the chemistry to either produce or quench a fluorophore on exposure to HCl. In addition to obvious advantages of no power requirement, low cost, negligible weight and easy deployment, such dosimeters could be rapidly scanned visually under ultraviolet light to determine which units had been exposed to HCl. An experienced observer could make a reasonably accurate estimate of the HCl dose on exposed units from the surface fluorescence. Subsequent elution of the fluorophore and fluorescence measurement of the eluent would quantify the dosage. The primary disadvantage of the PDT is it is a concept in the development stage and, as such, has inherent unknowns.

3. **Piezoelectric Quartz Crystal Microbalance.** The coated piezoelectric quartz crystal microbalance (QCM) technology consists of a vibrating quartz crystal which has been coated with a trapping membrane that selectively interacts with the chemical compound of interest. Different amounts of the chemical compound are measured by detecting changes in the crystal's vibrating frequency. The cumulative amount of the chemical is determined by the accumulation of the changes in frequency, which is amplified and detected by sophisticated electronics. Low levels of HCl in the atmosphere can be accurately determined with a QCM appropriately coated with an amine. The sensitivity of the QCM is such that HCl in parts per billion (ppb) levels in the atmosphere can be detected and can do so in real-time. Disadvantages of this technique include HCl saturation, replacement and/or refurbishment of quartz crystals, high instrument cost, high development cost and sophisticated electronic support equipment.

4. **NIOSH P&CAM 310.** One of the standard National Institute for Occupational Safety and Health (NIOSH) physical and chemical analytical methods (P&CAM) for HCl is P&CAM 310 (Ref 25). The method consists of silica gel tube collection, eluent desorption and analysis by ion chromatography. The advantage of using this technique is that it is a proven method accepted as a standard for measuring HCl. The disadvantage is that it does not provide real-time HCl concentrations but only HCl dosages and time-weighted concentrations which are available after laboratory analysis. This method will be field tested by the USAF OEHL at the launch of STS-6.

5. **Nondispersive Infrared.** A nondispersive infrared (NDIR) technique for measuring HCl is commercially available. The MIRAN series of portable ambient air analyzers are available from the Foxboro Company. These gas analyzers measure the amount of infrared light absorbed by the gas being analyzed at selected infrared wavelengths. Measurement is accomplished by a portable single-beam IR spectrometer providing an immediate, continuous indication of concentration. These analyzers are lightweight, portable and have been designed for field use. Disadvantages of this type of instrumentation are the inability to measure HCl aerosols, long response times, interferences, the high cost per field unit and cost of further research and development.

6. Millipore Filters. A millipore filter consists of a plastic membrane with a cellulose backing pad. The membrane and pad are housed in a disposable plastic container. The backing pad is an effective absorber of HCl. When the pad is subsequently macerated in distilled water, the HCl is released into the solution and the pH can be measured. The accuracy of the HCl concentration measurements using this device is defined by the various measurements that must be made including time of exposure, flow rate through the filter, quantity of water used in the analysis, and the hydrogen ion concentration. Assuming reasonable uncertainties for each of these measurements yields a net uncertainty of $\pm15\%$ in the HCl concentrations (Ref 15). The effects of HCl aerosol/droplets on measurement integrity are not known.

7. Cascade Impactors. Cascade impactors can be used to determine the size range of airborne particles. Their operation is based on the principle that when a high velocity particulate-laden air stream strikes a flat surface at a 90-degree angle, the sudden change in direction and momentum causes the particulate to impact on a plate. A series of impingement plates are mounted to collect particles of different size. The particles in each plate can be analyzed for total weight, particle count and chemical composition. Determination of average HCl concentrations is difficult and is based on sample exposure time and flow rate. Measurement uncertainties exist in an HCl aerosol/droplet environment.

8. Continuous Gas Filter Correlation Analyzer. Rockwell International has submitted an unsolicited technical proposal for a modified, continuous gas filter correlation (GFC) analyzer for measurement of HCl. Their proposed measurement process is separated into three distinct stages: quantitative sampling of mixed HCl gas and aerosols/droplets from ambient air, conversion of the aerosol/droplet fraction of the sample to HCl gas, actual measurement of total HCl. In order to capture a representative HCl sample, an inlet probe must be designed. Inlet probe considerations include: aerodynamic configuration, composition, flow rates, and geometry. The conversion of HCl aerosols/droplets to HCl gas will be accomplished by heating the sample above its vaporization temperature in a special conditioning chamber. Measurement of resulting HCl from the conditioning chamber will be made with a commercially available GFC analyzer. The operating principle of this GFC analyzer is described in the following paragraph.

Infrared radiation is passed through a rotating gas filter wheel which contains both HCl and N_2 gas cells. The radiation passing through the HCl cell has the HCl absorption wavelength subtracted out. The radiation passing through the N_2 cell remains sensitive to HCl. The two alternating beams of infrared energy resulting from the "chopping" action of the wheel enter a multipass optical chamber where they are reflected back and forth many times. Sample gas is drawn through the optical chamber. If there is no HCl present in the sample, then there will be no attenuation of the infrared radiation from either side of the GFC wheel. If any attenuation occurs from gases other than HCl, the attenuation will be equal on both sides for a net change of zero. If HCl is present in the sample, the beam generated by the HCl side of the wheel will experience no further attenuation while the beam generated by the N_2 side of the wheel will be attenuated. This attenuation creates an imbalance of the alternating beams received by the detector.

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The imbalance is proportional to the concentration of HCl in the sample. The reference and sample signals from the detector are amplified, compared and linearized by the analyzer electronics. The analyzer output can then be connected to the appropriate output and data recording devices. Research and development of this system to include a working prototype minus electronic support equipment will cost less than 50K and can be completed in approximately six months.

9. HCl Measurements by Iodide/Iodate Trapping. In the Rockwell International unsolicited proposal, a second measurement technique is suggested. This technique uses a bubbler sampling system to capture total HCl in an absorbing solution containing a combination of iodate (IO_3) and iodide (I). HCl reaction with the absorbing solution produces stable triodine ions (I_3). A starch indicator, which causes an intense blue color, is added and the absorbance of the solution is then measured in the visible light spectrum. The concentration of I_3 and, therefore, HCl is measured with a colorimetric autoanalyzer. This technique is in the conception stages only. Cost for research and development is on the order of 40K and can be completed in approximately six months.

10. Continuous Toxic Gas Monitor. An MDA Scientific, Inc., Model 7020 Hydrogen Chloride Monitor is a shelf item that may be used as a continuous HCl gas monitor on the SLC-6 pad area at VAFB. The Model 7020 is measurement specific to HCl and uses a specially formulated paper type detection system. During operation, the dedicated tape moves through a controlled sampling stream at a constant rate of speed. One-half the tape is exposed to the sampled air and develops a stain with an intensity proportional to the concentration of the in the air; the unexposed portion remains unstained.

The tape is continuously illuminated by a set of matched fibre optics. Reference and measurement cells sense the amount of light reflected by the stained and unstained portions of the tape and produce a differential output signal which is converted by the 7020's electronic module to a concentration reading. The minimum detectable concentration is 1.5 ppm with a maximum limit of 20 ppm (can be modified to 40 ppm). A single tape provides up to one week of unattended monitoring. For continuous monitoring of a number of sampling sites, the MDA PSM-8 Multipoint Monitoring System is available. Up to eight points located at up to 400 ft from the PSM-8 can be monitored simultaneously. An MDA Model 7020 Hydrogen Chloride Monitor with supporting instrumentation and protective enclosure is available for less than 7K. Further evaluations of the MDA Model 7020 are in process.

11. Hazardous Vapor Monitor. The Xontech, Inc., Model GC-810 Hazardous Vapor Monitor is a portable, automatic gas chromatograph capable of automatically sampling ambient air and detecting up to four species and their respective concentrations. Air is drawn into a gas sample loop with an internal pump. A microprocessor controls the pump, and injects the sample into a temperature controlled sample column and detector. The microprocessor searches for the peaks, integrates the area under the peaks and reports the data in peak area and retention time, or concentration and retention time. The system was designed to measure trace volatile compounds in the ppb range

in ambient air. Xontech, Inc., is currently modifying the system to become HCl specific. Further laboratory and field testing of this system is required.

C. Aircraft Monitoring. Exhaust plumes produced during rocket launches have been monitored by aircraft since the early 1970s. Aircraft monitoring emphasis was shifted to Titan III rocket launches at the inception of the STS program since the Shuttle SRBs use 2 1/2 times the same solid fuel as a Titan III. The following sections outline the history of aircraft monitoring of rocket exhaust plumes up to and including STS-5 and potential aircraft monitoring studies for STS launches at VAFB.

1. Aircraft Monitoring of Rocket Exhaust Plumes. Table 13 highlights the various agencies involved in aircraft monitoring as well as instrumentation used at each launch prior to STS-1. The USAFSAM mounted HCl monitoring instrumentation on board a USAF UHIN helicopter for three Titan III launches at VAFB (Nov 73, Oct 74, Jun 75). Instrumentation included a microcoulometer, GEOMET chemiluminescence HCl analyzer and pH paper (Refs 6 and 7). All instrumentation have been described in previous sections. Maximum HCl concentrations listed in the table showed a wide range (1.8-30.0 ppm) and can be attributed to different meteorological conditions, ground cloud geometry and the location of helicopter cloud penetrations.

NASA LaRC conducted aircraft monitoring of nine Titan III exhaust plumes at KSC between Dec 74 to Nov 79 (Refs 16, 26, 27). NASA LaRC mounted monitoring instrumentation on a twin engine Cessna 402. Instrumentation included a GEOMET chemiluminescence HCl analyzer, a 10-stage quartz crystal microbalance impactor and a GFC device all of which were described in previous sections. The GEOMET was used to measure total HCl (aqueous and gaseous) and the GFC was used to measure gaseous HCl. The aqueous component was inferred by subtraction of the gaseous component from the total HCl measured. In addition, a Forward Scattering Spectrometer Probe (FSSP) and an integrating nephelometer were used on the aircraft. An FSSP measures the number of suspended aerosols as a function of aerosol diameter over a specific size range. Individual aerosol nuclei (solid and liquid) are counted and sized when they pass through the focused portion of a laser beam. As each aerosol passes through the sampling volume, it scatters light from the incident laser beam. The light scattered in the near-forward direction is directed onto a photodiode which generates a pulse. There is one pulse for each nucleus that passes through the beam. The magnitude of the pulse depends on the amount of light scattered by the aerosol which is related to the size of the aerosol. The FSSP data are presented as the number of aerosols sampled in a given size interval divided by the total number sampled in all size ranges, expressed in percent. The integrating nephelometer measures the light scattering coefficient of suspended particulates. The inlet is heated so that the nephelometer is insensitive to most liquid aerosols. Because of mass concentration versus light scattering coefficient assumptions, the nephelometer provides only an approximation of mass concentration in the rocket exhaust cloud. The nephelometer is useful in the determination of aircraft cloud penetration and exit. Monitoring of the nine Titan III launches were made during different times of the year under a variety of meteorological conditions. Maximum HCl concentrations observed varied from 3.8 ppm to approximately 40 ppm. It is not clear

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Table 13. Aircraft Monitoring Results of Rocket Exhaust Plumes

Date	Launch Vehicle	Location	Aircraft Platform	Organization	Instrumentation	Maximum HCl Conc. (ppm) Total	Gas
Nov 73	Titan III	VAFB	UHIN	USAFSAM	Coulometer	11.7	
Oct 74	Titan III	VAFB	UHIN	USAFSAM	Coulometer, pH Paper	30.0	
Dec 73	Titan III	KSC	Cessna 402	NASA LaRC	GEOMET, Nephelometer, Forward Scattering Spectrometer, Quartz Crystal Microbalance	40.0	
Jun 75	Titan III	VAFB	UHIN	USAFSAM	Coulometer, GEOMET, pH Paper	1.8	
Aug 75	Titan III	KSC	Cessna 402	NASA LaRC	Same as Dec 74	5.0	
Sep 75	Titan III	KSC	Cessna 402	NASA LaRC	Same as Dec 74	7.5	
May 77	Titan III	KSC	Cessna 402	NASA LaRC	Same as Dec 74	9.9	
Aug 77	Titan III	KSC	Cessna 402	NASA LaRC	Same as Dec 74	20.0	
Sep 77	Titan III	KSC	Cessna 402	NASA LaRC	Same as Dec 74	18.0	
Mar 78	Titan III	KSC	Cessna 402	NASA LaRC	Same as Dec 74 plus GFC	18.0	2.5
Nov 78	Atlas/Centaur	KSC	B-23	U of Washington	CCN, Ice Nuclei, Nucleopore, Rotating Membrane Filter, Nephelometer pH Paper	No HCl Data	
Dec 78	Titan III	KSC	B-23	U of Washington	Same as Nov 78	No HCl Data	
Dec 78	Titan III	KSC	Cessna 402	NASA LaRC	Same as Dec 74 plus GFC	16.0	1.6
Nov 79	Titan III	KSC	Cessna 402	NASA LaRC	Same as Dec 74 plus GFC	3.8	0.4

whether this wide variation was caused by meteorological conditions, location
of cloud penetrations or experimental variability. The CFC device was added
to the Cessna 402 monitoring equipment for the Mar 78, Dec 78, and Nov 79
Titan III launches. Maximum gaseous concentrations for the launches were 2.5
ppm (passes 5 and 6), 1.6 ppm (pass 1) and 0.4 ppm (pass 1), respectively, as
compared to the total HCl measurements of 18.0 ppm (pass 4), 16.0 ppm (pass 1)
and 3.8 ppm (pass 1).

A team of University of Washington scientists conducted airborne
monitoring studies of rocket plumes during a Nov 78 launch of an Atlas/Centaur
Rocket, and a Titan III launch in Dec 78 (Refs 28, 29). Monitoring instrumen-
tation was mounted on the University's airborne atmospheric research facility
which is a Douglas B-23 aircraft heavily laden with sophisticated cloud physi-
cal and chemical monitoring devices. The instrumentation included 39 individu-
ual state-of-the-art monitoring devices to comprehensively define the meteoro-
logical, physical and chemical characteristics of the induced ground clouds.
However, no specific HCl data were obtained during the two launches.

Aircraft monitoring results of HCl for STS launches at KSC are
shown in Table 14. NASA LaRC used the twin-engined Cessna 402 to monitor the
ground cloud produced during the launch of STS-1, STS-2, and STS-5 (Refs 30,
31). The same monitoring instrumentation used during Titan launches was used
at STS-1 and this equipment, in addition to a Knollenberg particle sizing
probe, was used at STS-2 and STS-5. Maximum total HCl concentrations ranged
from a low of 5.0 ppm at STS-2 to an preliminary estimate of 78 ppm at STS-5.
It is uncertain whether the differences observed are a function of meteorolog-
ical conditions, location and time of aircraft cloud penetrations or experi-
mental error.

NASA MSFC, in conjunction with the National Oceanic and Atmos-
pheric Administration (NOAA), used a NOAA Orion WP-3D aircraft to measure
ground cloud physical and chemical parameters at the launch of STS-3. Data
reduction is continuing at NASA MSFC and was not available at this writing.

2. Available Systems. Selection of an aircraft monitoring system for
STS launches at VAFB will be dependent on a number of factors. First, the
complex terrain surrounding SLC-6 to the east and the Pacific Ocean to the
west make large scale ground monitoring schemes difficult to implement. For
this reason, aircraft monitoring is required to supplement ground monitors.
Second, the type of aircraft monitoring needed to adequately define all
characteristics of the ground cloud is a significant factor. One aircraft
alone may not be capable of the multifaceted monitoring required. Aircraft
instrumented with sophisticated equipment to measure cloud meteorological,
physical and chemical parameters must make continuous cloud penetrations to
obtain a time history and spatial distribution of the cloud parameters. An
aircraft system of this type may not be suitable to measure the lateral/
vertical dispersion of the ground cloud and the effects of terrain and the
land/sea interface on dispersion. Monitoring of this type would be enhanced
by a downward looking remote sensing system. Third, it is uncertain how many
aircraft monitoring attempts during STS launches at VAFB will be needed to
define the parameters necessary to enhance dispersion model prediction capa-
bilities. Certain aircraft monitoring endeavors will be required for every

Table 14. Aircraft Monitoring Results of the STS-1 through STS-5 Ground Cloud at KSC

Date	STS Launch	Aircraft Platform	Organization	Instrumentation	Maximum HCl Conc. (ppm) Total	Gas
Apr 81	1	Cessna 402	NASA LaRC	GEOMET, GFC, Nephelometer, Forward Scattering Spectrometer, Quartz Crystal Microbalance	17.0	4.0
Nov 81	2	Cessna 402	NASA LaRC	Same as STS-1 plus 2-D Knollenberg Particle Sizing Probe	5.0	DNA[a]
Apr 82	3	NOAA Orion WP-3D	NASA MSFC NOAA	2-D Knollenberg Particle Sizing Probe, Formvar replicator, pH, Vertical Winds, Temp, Dew Point, Pressure, Liquid Water, Content, CCN, Ice Nuclei, Electric Fields, Radar, Video	DNA[a]	
Jun 82	4	No Aircraft Monitoring				
Nov 82	5	Cessna 402	NASA LaRC	Same as STS-1 plus Knollenberg Particle Sizing Probe	78[b]	DNA[a]

[a]Data Not Available
[b]Preliminary Result

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launch and others for only the first few. Fourth, the operation of any airborne sampling system necessitates the involvement of a large number personnel from a variety of disciplines to handle all aspects of the effort (Ref 32). These aspects include: system design and fabrication, calibration and quality assurance, data analysis, data processing, aircraft operations, coordination of air monitoring field operations. All must be included in developing a monitoring program for VAFB.

Aircraft monitoring for rocket exhaust plumes can be grouped into three general categories: meteorological monitoring, ground cloud growth and dispersion monitoring, species monitoring. An overlap exists between these three general categories, and in some instances, one aircraft can combine monitoring required in different categories. The following paragraphs define the general aircraft monitoring categories and describe examples of aircraft systems capable of accomplishing the monitoring.

a. Meteorological monitoring is conducted to define the changing microscale cloud physical and chemical properties of the ground cloud as it is carried downwind. Data acquired in meteorological monitoring are needed for input into deposition and dispersion models to enhance prediction capabilities. The only accurate method of obtaining these cloud parameters is by repeated aircraft penetrations through the ground cloud. An aircraft used in this role should have the minimum capability to sample for: temperature, dewpoint temperature, air turbulence (horizontal and vertical wind shear), liquid water content, cloud condensation nuclei (CCN), ice nuclei (IN), gases, particulates and aerosols.

There are many different laboratory techniques and instrumentation that can be used to measure these meteorological parameters. Some of the instrumentation are commercially available and some are one-of-a-kind laboratory prototypes. It is suggested that redundant monitoring systems be used whenever possible so data are not lost due to equipment malfunction. In addition to the above instrumentation, complete navigational instrumentation should be available on the aircraft to fix the time/space coordinates of the aircraft for each sampling pass. Accurate time/space coordinates will assist in the data reduction phase of aircraft monitoring and insure accurate analysis of the meteorological parameters of the ground cloud.

The Cloud and Aerosol Research Group of the University of Washington used their B-23 research aircraft to measure the rocket plumes during an Atlas/Centaur launch and a Titan III launch at KSC (Refs 28, 29). Thirty-nine different monitoring devices were used to quantitatively describe the major meteorological parameters as well as the major particle and trace gas constituents. NASA MSFC and NOAA used the NOAA Orien WP-3D aircraft to measure similar meteorological parameters of the STS-3 ground cloud. We suggest aircraft monitoring, similar to the attempts listed above, for the first few STS launches at VAFB. The cost of airborne meteorological monitoring is in the 75K-125K range.

b. Ground cloud growth and dispersion monitoring require a different type of aircraft monitoring scenario than meteorological monitoring. The purpose of growth and dispersion monitoring is to observe the dynamics of

ground cloud formation and to observe the volumetric changes with time. Dispersing characteristics as a function of complex terrain, land/sea interface and meteorological conditions can be tracked and recorded. Analysis of these data can be compared to dispersion model outputs and model modifications can be made to account for any differences encountered. Growth and dispersion monitoring is qualitative in nature but when added to the quantitative aircraft meteorological monitoring, it will provide a complete picture of ground cloud mechanics.

A two-frequency Light Detection and Ranging (LIDAR) system has been developed by the Environmental Protection Agency. It consists of a neodydium-Yag laser transmitter, a 36 cm Newtonian telescope receiver and an electronics package capable of providing real-time, on board data displays and data storage for later analysis. The beam is dispersed to insure that the laser energy density on the ground is consistent with eye safety. This LIDAR system, mounted on an aircraft, can be flown over the STS ground cloud and can measure growth and dispersion characteristics as the cloud moves downwind. We suggest remote sensing of ground cloud growth and dispersion for each STS launch at VAFB. The cost of an airborne monitoring system of this type is in the 15K-25K range.

c. Species monitoring of an STS ground cloud consists or airborne instrumentation designed to measure specific cloud constituents such as HCl. Repeated cloud penetrations are required to identify the time history and spatial extent of the designated gas, aerosol or particulate. Airborne instrumentation is dependent on the species in question. Species monitoring can be accomplished in conjunction with airborne meteorological monitoring for the first few STS launches at VAFB and alone when meteorological monitoring is concluded.

NASA LaRC used a twin-engined Cessna to measure HCl and Al_2O_3 particulates in rocket plumes during Titan launches and the launches of STS-1, 2 and 5 (Refs 30, 31). The USAFSAM used a UHIN helicopter platform to measure HCl during Titan launches at VAFB (Refs 6, 7). Either airborne species monitoring platform is acceptable; however, a helicopter platform may provide more flexibility than fixed-wing aircraft in the complex terrain of VAFB. The cost of an airborne species monitoring program is estimated between 15K-25K per STS launch.

D. Remote Sensing

1. Development of Remote Sensing Systems. A Joint Army-Navy-NASA-Air Force (JANNAF) Safety and Environmental Protection Subcommittee (S&EPS) workshop entitled "Remote Detection of Hazardous Materials" was held at the National Bureau of Standards in Gaithersburg, Maryland on 20-22 July 1982. The workshop brought together the foremost scientists in the field of remote sensing to present new developments. Presentations included both active and passive remote sensing systems.

Passive remote sensors detect incoming radiation whether it is direct or reflected radiation (Ref 33). They can be used at ground locations or mounted aboard aircraft or satellites. Advantages include low complexity,

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low weight and low power. Disadvantages include spatial resolution, inter-
ferences, molecular absorption/emission factors and the requirement to accu-
rately know the meteorological parameters and their effect on the sensors.
The generic types of passive remote sensors in use or under development are
shown in Table 15.

Table 15. Passive Remote Sensors

Sensor	Status/Platform
Optical Filter Radiometer	Extensive Experience/Satellite, Aircraft
Grating Spectrometer	Limited Experience/Satellite
Correlation Grating Spectrometer	Limited Experience/Aircraft, Ground
Gas Filter Correlation Radiometer	Extensive Experience/Aircraft, Ground
Interferometer	Extensive Experience/Satellite, Aircraft, Ground
Fabre-Perot Interferometer	Limited Experience/Controlled Laboratory Tests
Laser Heterodyne Techniques	Limited Experience/Ground

Remote sensing programs for atmospheric pollutants began at the
Environmental Protection Agency (EPA) in the late 1960s (Ref 34). Major
initial systems were designed to measure specific types of environmental
pollutants such as a mobile LIDAR system for stack plume opacity measurements
and a mobile infrared spectrometer system for quantification of gaseous air
pollutants. Passive and active remote sensing sytems in use or in the devel-
opmental stage at EPA include: Opacity LIDAR, Laser-Doppler Velocimeter
(LDV), GFC Systems, Ultraviolet Television (UVTV) Systems, Infrared Television
(IRTV) Systems, Remote Optical Sensing of Emissions (ROSE) System, Dual-
Wavelength LIDAR Systems.

Advances in technology have brought LIDARs to the forefront of
remote sensor systems. The most promising LIDAR system for monitoring the STS
ground cloud is the Differential Absorption LIDAR (DIAL). DIAL systems are
being developed to measure the atmospheric distribution of pollutants. This
system determines gas concentrations by measuring the differences in absorp-
tion of back-scattered laser light; one wavelength in the absorbing spectrum
of the reference gas and one wavelength in a nonabsorbing region of the refer-
ence gas. Ultraviolet and visible wavelength DIAL systems are range-resolved
which means concentrations are available at individual points within a plume
or gaseous cloud. Infrared DIAL systems provide concentration data which are
integrated over the entire optical length of the emitted beam. DIAL systems
are currently gas specific and, therefore, cannot be used to differentiate
types of gaseous constituents within the sample. DIAL users require knowledge
of the species to be sampled so that the system can be tuned to the specific
gas. Tunable DIAL instrumentation is under development and this technology
will provide a gas species detection capability as well as a quantitative
measurement capability.

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The lack of advanced technology is the primary limiting factor in further LIDAR development and, therefore, field operating systems. There are many design and material deficiencies that must be overcome including: interference gases and aerosols, water vapor absorption, calibration techniques, multiphased tuning, path lengths, detector noise, signal to background noise, range resolution, operational range, gas and aerosol absorption coefficients. As technology advances, more field usable LIDAR remote sensing systems will become available.

2. Remote Sensing for STS Launches. There has been limited testing of remote sensing systems during STS launches at KSC. Computer Genetics Corporation Wakefield, Massachusetts, under contract to NASA, conducted LIDAR measurements during the launch of STS-2 and STS-3 (Refs 35, 36). There were four objectives to the study. First, demonstrate LIDAR remote sensing techniques to track and scan the exhaust ground cloud to obtain high density, three-dimensional measurements of cloud size, nature, behavior and fallout under a variety of meteorological conditions which were previously unobtainable with existing in situ measurement techniques. Second, provide a research data base for performance extrapolation through the "phase in" of additional LIDAR techniques to determine size and distribution of particulates, discriminate water vapor from liquid states and measure HCl cross sections. Third, improve field data acquisition and data processing techniques and overall instrumentation performance. Fourth, develop optimized specifications for dedicated systems.

The LIDAR system employed was located in a mobile van approximately 3 1/2 miles directly west of Pad 39A. During STS-2, the LIDAR began lasing at L-0:03 seconds and continued for 528 seconds. A total of 1467 laser pulses were fired into the ground cloud. Each laser pulse produced 480 volumetric data points resulting in 704,160 range resolved data points. Real-time observations on an analog display during the launch showed substantially higher ambient noise levels than prelaunch data and, therefore, low ground cloud signal components. Overexposure of the photomultiplier tube from the exhaust flame was deduced as the cause of this problem. The low signal to noise of the ground cloud precluded data reduction using standard available software. NASA declined the proposal for software modification in lieu of running a similar LIDAR test at STS-3.

The LIDAR system was again deployed at STS-3 in the same location as STS-2. To eliminate any possibility of overexposing the LIDAR photomultiplier tube to the exhaust flame, a procedure was developed so that the LIDAR scanned away from Pad 39A until the Shuttle was out of the field of view. At L+0:00 the LIDAR began automatic scanning, but an error in scanning software resulted in a delay of approximately 40 seconds. The ground cloud was first monitored at L+0:54 seconds and scanning continued for almost 30 minutes. A total of 3560 laser pulses were fired into the ground cloud generating 1,708,800 range resolved LIDAR measurements. Data reduction included two-dimensional cloud cross sections in a scattergraph form.

The LIDAR study of STS ground clouds showed that remote sensing instrumentation is feasible for scanning, tracking and mapping the exhaust effluents during an STS launch. This capability could provide usable documentation of cloud transport dispersion and potential deposition locations.

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At a minimum, currently available LIDAR technology could be routinely used to archive exhaust cloud behavior or as input data to dispersion models. Additional development and field testing are required to obtain remote measurements of other parameters of importance to ground cloud studies and dispersion modelling. These include particle size and number distributions, species identification and quantification, and the discrimination of gas, aerosol and droplet chemical phases.

The ideal laser remote sensing system for monitoring and measuring the exhaust effluents produced during an STS launch appears to be a differential absorption LIDAR (DIAL) that is tunable and range resolved. The Air Force Engineering and Service Center (AFESC) is chartered as the Air Force lead laboratory for environmental quality research and development. They have initiated a program for the development of remote sensing to satisfy a myriad of Air Force needs. The objective of the program is to provide remote measurement systems for atmospheric pollutants and toxic gases including missile fuels, chemical warfare agents, regulated pollutants, aircraft emissions and rocket emissions. The goals of the program are to conduct detector system evaluations in 1982 and have an all encompassing DIAL system in 1986. Timing of these phases will be dependent on available technology. As the systems are developed, STS launches at either KSC or VAFB will make ideal field test beds for the instrumentation. Close coordination of all agencies involved should be maintained so that LIDARs can be tested at missile launch targets of opportunity as soon as the systems are developed.

IV. SUMMARY AND CONCLUSIONS

Our review and evaluation of environmental monitoring instrumentation and monitoring techniques for Space Shuttle launches have identified three separate areas of monitoring required to adequately define and measure the environmental effects of the exhaust effluents. These areas are ground monitoring, aircraft monitoring and remote sensing. Although separate, the areas are not mutually exclusive and, in some instances, the same or similar instruments can be used. Only ground monitoring can measure effluents and resulting deposition in the near field during the first few minutes after launch. Far field ground monitoring can measure downwind fallout and quantify results where environmental effects are of greatest concern (i.e., on the ground). Ground monitoring can be conducted under all meteorological conditions; however, large numbers of monitoring sites are required to insure adequate area coverage. Aircraft monitoring can be used for direct measurement within the induced ground cloud which is not possible with ground monitoring. Cloud chemical and physical parameters which are important inputs to dispersion models can be obtained with aircraft monitoring. Because of flight safety, aircraft sampling will not be possible in low visibility conditions. Remote sensing systems can supplement ground and air monitoring. Cloud dimensions and trajectories, chemical constituents and their component concentrations, and areas of fallout materials will be available as advanced remote sensing technology becomes available. An integrated program of ground monitoring, aircraft monitoring and available remote sensing is required to measure the many different exhaust effluent parameters produced during Space Shuttle launches.

Environmental air monitoring methods can be grouped according to three characteristics: type of monitoring system, support equipment required, and analytical technique. Two types of monitoring systems are passive and active. Passive monitors sample only the ambient air surrounding the monitor and are based on the principles of diffusion, gravitational settling, or impaction (caused by the forces of the exhaust effluents as they are emitted from the launch site). Examples of passive monitors are copper plates, pH paper, mineral oil dishes and electrets. An active monitor draws ambient air samples into or passed a sampling probe where it is then measured. Bubblers, GEOMET chemiluminescence HCl analyzers and microcoulometers are considered active monitoring devices. The second distinguishing characteristic of monitoring methods is support equipment required. The range of support equipment is from simple sampling stands, used to mount passive devices, up to complex electronics for active systems. One key consideration is electrical power requirements. Electrical power can be made available at sites in the immediate vicinity around the launch pad but is impractical for sites at remote locations. The third characteristic used to differentiate monitoring methods is analytical technique. Analysis of some devices can be accomplished in the field by visual inspection and others require sophisticated laboratory facilities and equipment.

Selection of appropriate monitoring instrumentation to measure the various STS exhaust effluents at VAFB is important and will depend on the area of monitoring, pollutant to be analyzed, and instrument characteristics. Cost, as in any monitoring program, is always an important factor. In addition, durability of monitoring instrumentation is a key consideration. Instruments selected for near field ground monitoring will have to survive the initial launch blast and the toxic environment surrounding the pad after launch. Far field monitoring instrumentation will not only have to be durable but compact and lightweight to facilitate site establishment in the complex terrain surrounding SLC-6 at VAFB.

Establishing a workable monitoring program requires first, hypothesizing potential environmental effects; second, data accumulation and analysis to determine the scope of the environmental problem; third, competitive laboratory and field testing of monitoring instruments; fourth, selection of monitoring instruments; fifth, establishing a viable monitoring program; sixth, continuing data accumulation, analysis and quality control. Prior to the launch of STS-1, the Air Force and NASA conducted laboratory and field tests during STS launch simulations and other missile systems with similar fuels in order to anticipate potential environmental effects. During the first five STS launches exhaust effluent data were obtained and analyzed. In addition, various monitoring techniques were attempted to determine the best means of monitoring exhaust effluents. Some techniques have been found to adequately measure certain exhaust effluent. Certain techniques have been found to be obsolete and others require further research and development. The basis for a workable monitoring program has been established by the Air Force and NASA. The program has evolved from earlier programs involving other missile systems up to and including STS-5 and will continue to evolve as appropriate instrumentation is selected and additional data collected. Lessons learned during monitoring attempts at KSC will assist the Air Force in preparing a viable monitoring program prior to the first STS launch at VAFB.

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V. RECOMMENDATIONS

In this study we reviewed and evaluated monitoring methods to measure exhaust effluents produced during Space Shuttle launches. The basis for our recommendations include a literature review of past monitoring programs, observations and experience in monitoring at the first five STS launches at KSC, and USAF OEHL bench level instrument evaluations.

A. Continuous HCl gas analyzers are required in the near field surrounding SLC-6 at VAFB to measure revolatilized HCl gas after a launch. Protection of personnel entering the pad postlaunch and personnel located in the LCC is the key consideration. Specific instrumentation has not been selected but prime candidates are: chemiluminescence HCl analyzer, gas filter correlation, bubblers, nondispersive infrared technique, continuous toxic gas monitor, hazardous vapor monitor.

B. Simple monitoring devices used to measure HCl acid fallout, mass balance, acid spray patterns and water balance are required in the near field. Dispersion model input data, effects of varying deluge water, washdown water, and protection of facilities and equipment are reasons for this type monitoring. We recommend the use of copper plates and pH paper with either bubblers, millipore filters or electrets.

C. Far field monitoring to determine deposition patterns and amount of fallout material is needed to evaluate health consequences and environmental concerns. Copper plates and pH paper should be used with one or more type of passive monitor. Candidate passive monitors are electrets, passive dosimeter techniques and millipore filters. Monitoring site selection should be based on dispersion model predictions of ground cloud trajectories and deposition patterns.

D. A recommendation is made that the AFESC conduct laboratory and field tests of continuous HCl gas analyzers for near field monitoring, and passive systems for far field monitoring prior to final selection of instrumentation.

E. Organic materials have been found not to be hazardous to personnel and the environment during and after launch. We recommend no further testing for organic materials be conducted. This allows efforts to be focused on HCl health and environmental concerns.

F. Aircraft in situ monitoring to evaluate ground cloud chemistry and physics is needed for input to dispersion models and to increase scientific understanding of mechanisms involved in ground cloud formation and dispersion. We recommend Air Weather Service, the AFGL and NASA at MSFC determine instrumentation required.

G. We also recommend aircraft remote monitoring to measure cloud formation geometry and dispersion characteristics as affected by terrain and meteorological conditions. These data are needed to evaluate dispersion model performance and environmental risk assessments. An EPA aircraft with a LIDAR mounted is the prime candidate for this monitoring.

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H. Ground remote systems which can measure HCl may eventually make aircraft systems unnecessary. The AFESC has long range plans for such a remote sensing system. We recommend that when such systems are technologically developed they be field tested at Space Shuttle launches at KSC or VAFB.

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Appendix A

Dosimeter Tube Monitoring Results
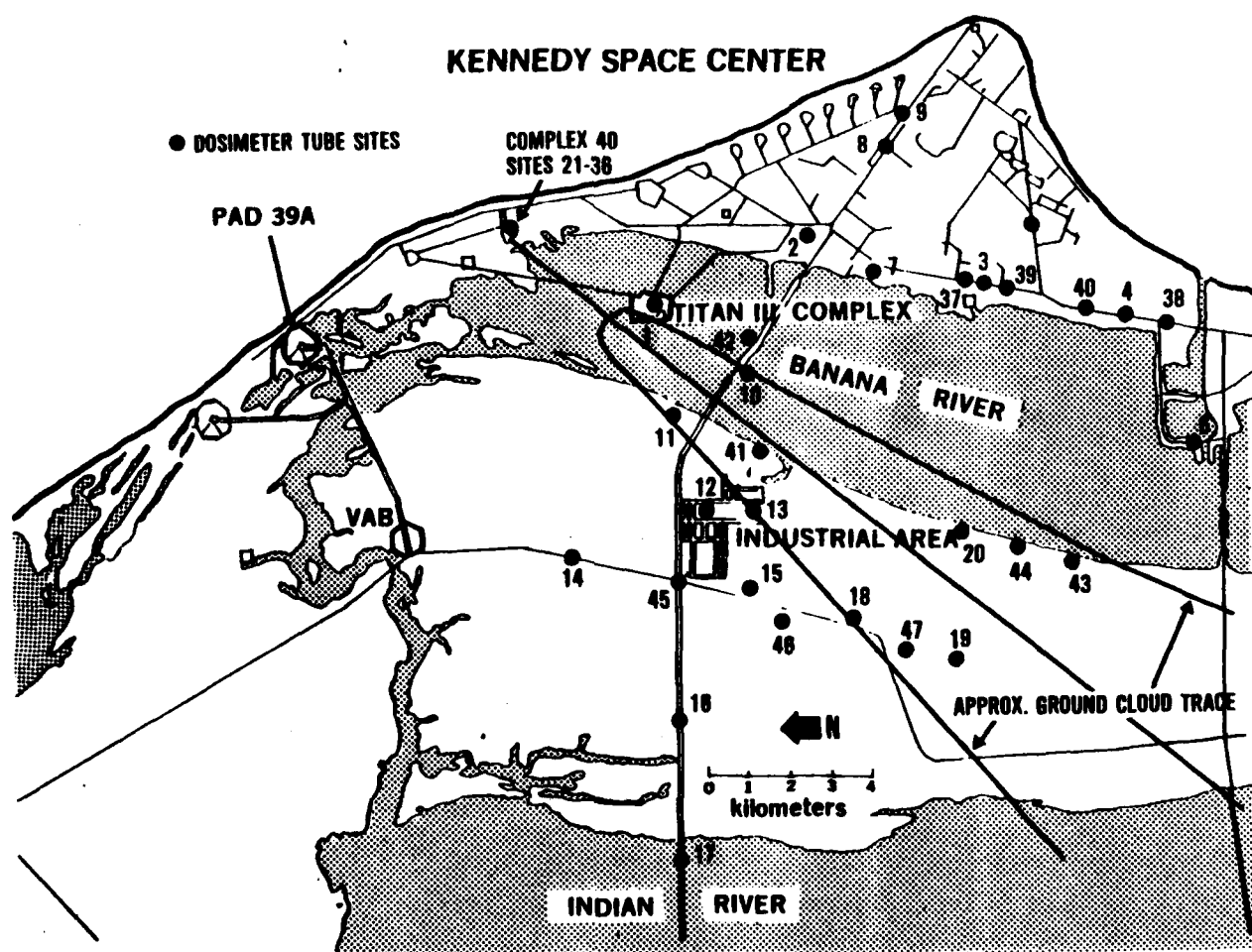
Figure A-1. Dosimeter Tube Siting for a Titan III-C
Launch on 13 Dec 78 at KSC

Table A-1. Dosimeter Tube Analysis For the Launch of
Titan III-C at KSC on 13 Dec 78 (Ref 10)

Site	HCl Dosage (ppm-s)[a]	Site	HCl Dosage (ppm-s)[a]
1	1.8	25	0
2	6.7	26	0
3	20	27	0
4	19	28	0
5	16	29	0
6	20	30	0
7	17	31	0
8	4	32	0
9	2	33	0
10	19	34	0
11	22	35	0
12	29	36	0
13	30	37	20
14	7	38	19
15	28	39	20
16	21	40	19
17	18	41	30
18	27	42	19
19	25	43	22
20	26	44	24
21	0	45	26
22	0	46	28
23	0	47	28
24	0		

[a]Zero values represent below detection limits
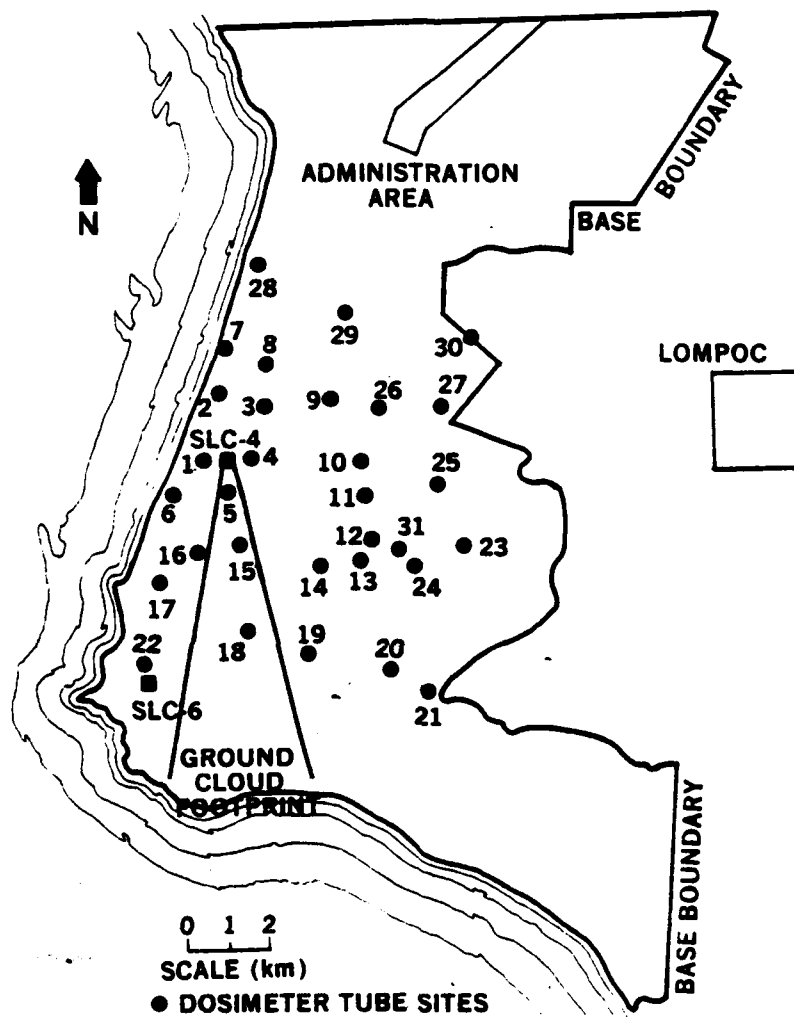
Figure A-2. Dosimeter Tube Siting for a Titan III
Launch on 7 Feb 80 at VAFB

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**Table A-2. Dosimeter Tube Analysis for the Titan III
Launch at Vandenberg AFB on 7 Feb 80 (Ref 11)**

Site Number	Dosage (ppm-s)		Site Number	Dosage (ppm-s)	
	Tube #1	Tube #2		Tube #1	Tube #2
1*	8	6	17**	35	90
2	65	63	18*	10	10
3	52	21	19**	5	6
4**	18	10	20	7	5
5**	120	105	21	3	3
6**	130	120	22**	8	10
7	110	320	23	7	4
8	4	4	24	3	95
9	9	270	25	4	5
10	7	8	26	4	22
11	190	6	27	4	108
12	5	280	28	75	24
13	7	8	29	4	5
14**	160	250	30	68	27
15*	6	9	31	3	10
16*	32	27			

*Site Directly in Cloud Path
**Site in Vicinity of Cloud Path
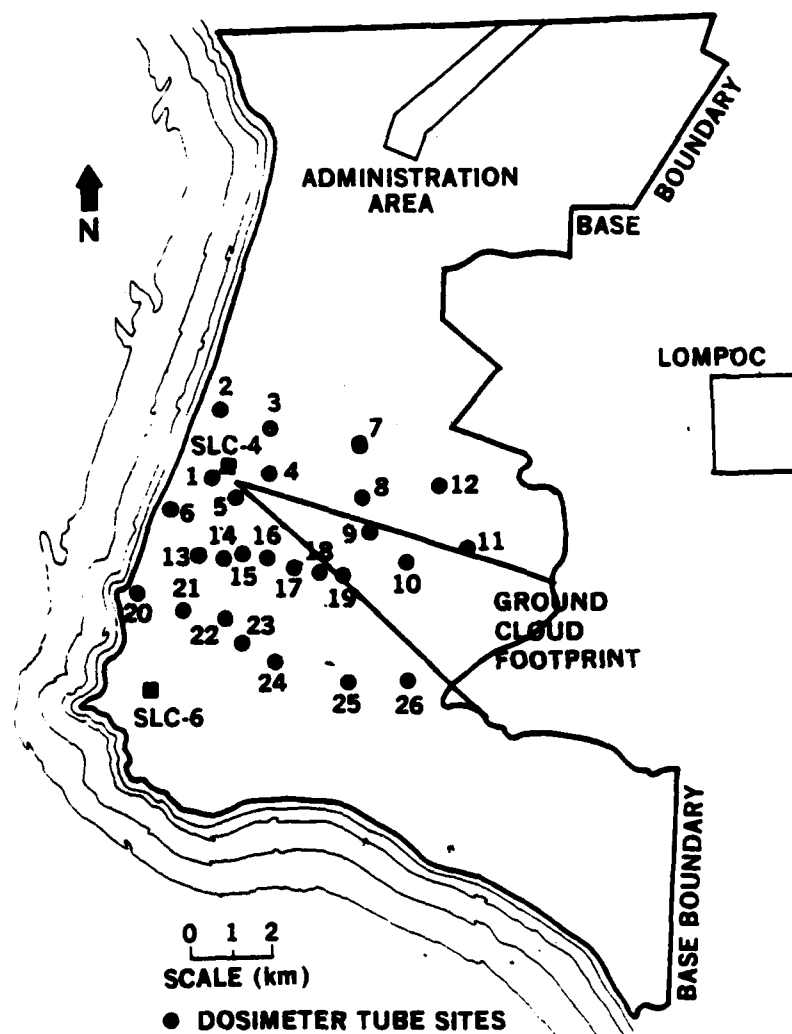
Figure A-3. Dosimeter Tube Siting for a Titan III
Launch on 18 Jun 80 at KSC

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**Table A-3. Analysis for Modified Dosimeter During a Titan III
Launch at VAFB on 18 Jun 80 (Ref 11)**

Site Number	Dosage (ppm-s) Tube #1	Tube #2	Site Number	Dosage (ppm-s) Tube #1	Tube #2
1	1	1	14	1	2
2	1	1	15	6	4
3	2	1	16	2	2
4	1	1	17	7	8
5	12	9	18	6	11
6	1	1	19	2	2
7	1	4	20	2	2
8	3	2	21	1	2
9	2	4	22	1	1
10	1	<1	23	2	3
11	34	2	24	Not Activated	
12	3	3	25	100*	2
13	2	2	26	100*	4

*Tubes Contaminated

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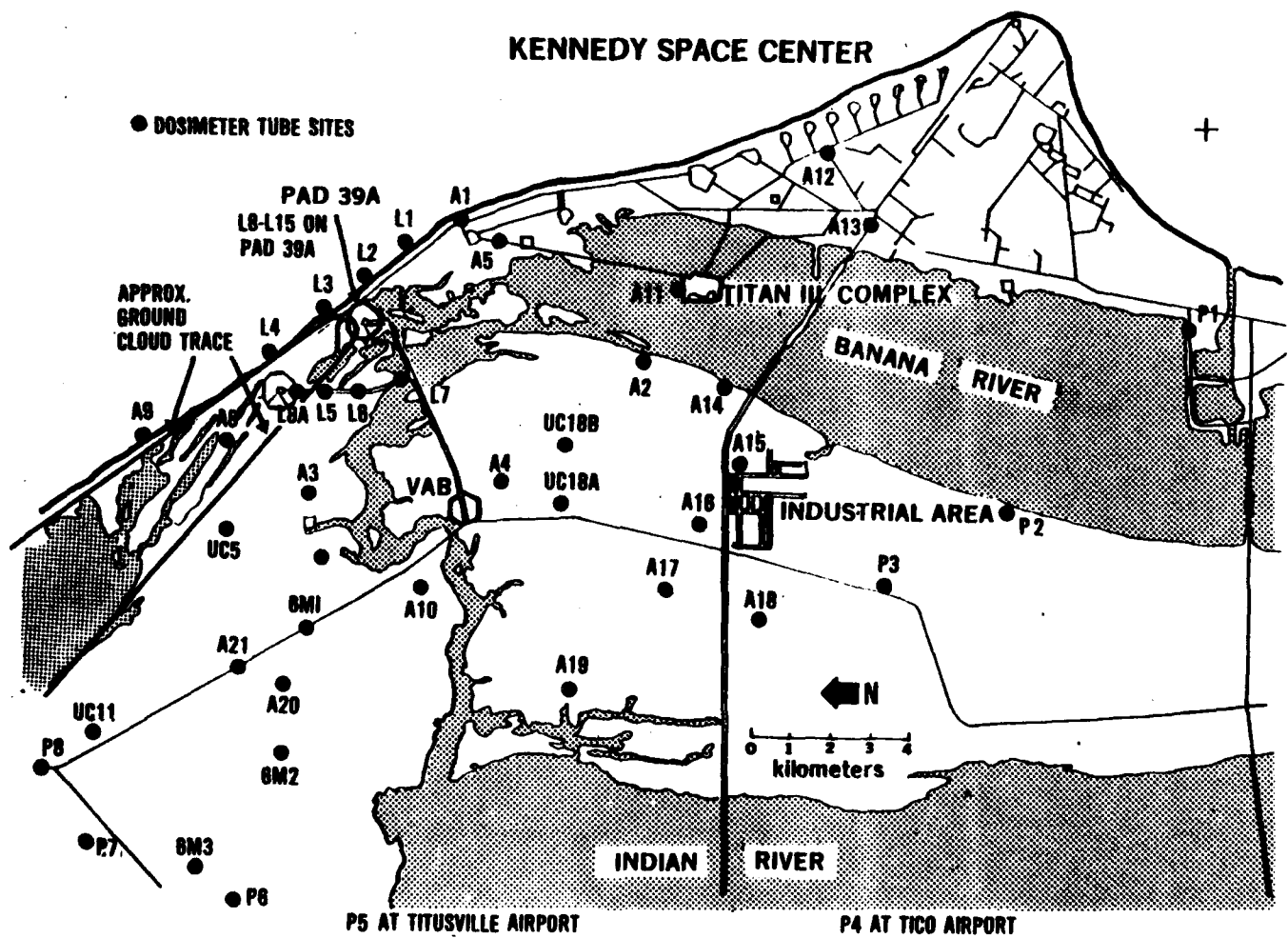
Figure A-4. Dosimeter Tube Siting for the Launch of STS-1 on 12 Apr 81 at KSC

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Table A-4. Dosimeter Tube Analysis for the
Launch of STS-1 on 12 Apr 81

Site	Remote Pager Activated	Dosage (ppm-s)	Site	Remote Pager Activated	Dosage (ppm-s)
L1	Yes	<1	A12	Yes	8
L2	Yes	<1	A13	Manual	<1
L3	Yes	<1	A14	Yes	16
L4	No	<1	A15	Yes	<1
L5	Yes	<1	A16	Yes	<1
L6	Yes	<1	A17	No	<1
L7	Yes	<1	A18	Yes	4
L8	No	<1	A19	Manual	3
L8A	No	<1	A20	Manual	1
L9	Yes	<1	A21	Yes	12
L10	Yes	<1	P1	Manual	1
L11	Yes	<1	P2	No	<1
L12	Yes	<1	P3	Manual	1700
L13	Yes	<1	P4	Manual	<1
L14	No	8	P5	Manual	<1
L15	No	<1	P6	Yes	8
A1	Yes	6	P7	Yes	3
A2	No	4	P8	Manual	<1
A3	Yes	16	6M1	Manual	2
A4	Yes	7	6M2	Yes	16
A5	Yes	2	6M3	Manual	4
A7	Manual	2	UC5	Manual	1
A8	No	<1	UC11	Manual	<1
A9	Manual	32	UC18A	Manual	<1
A10	Yes	6	UC18B	Manual	<1
A11	Yes	4			
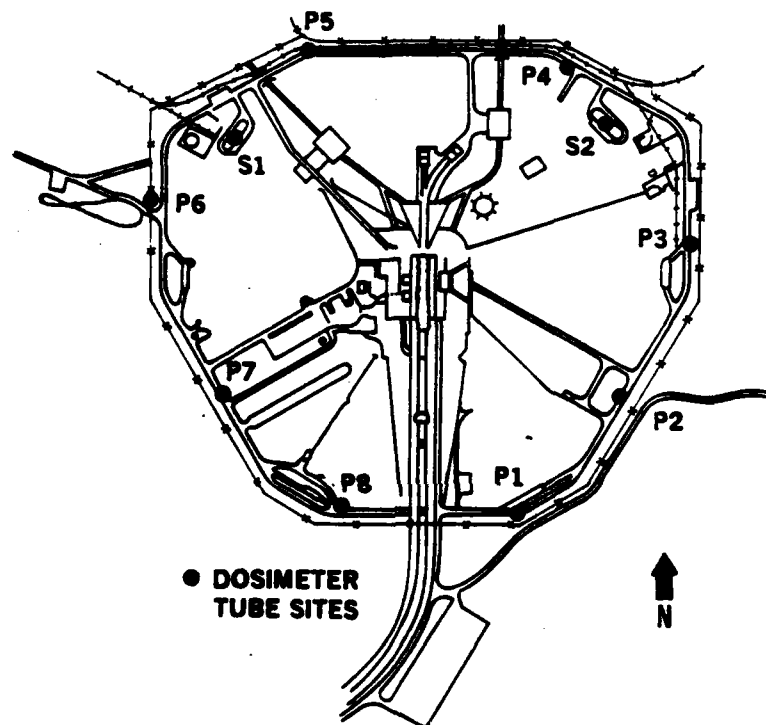
Figure A-5.   Dosimeter Tube Siting on Pad 39A at
             KSC for the Launch of STS-4 at KSC

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Table A-5. STS-4 Dosimeter Tube Analysis

Sample Point	High HCl Dosage (ppm-s)	Low HCl Dosage (ppm-s)	Mean HCl Dosage (ppm-s)	Standard Deviation
S1	44.0	<0.1	15.9	14.5
S2	3.0	<0.1	0.9	1.0
P1	1.8	<0.1	0.6	0.8
P2	2.7	<0.1	0.8	1.3
P3	2.4	<0.1	0.8	1.1
P4	1.2	<0.1	0.6	0.6
P5	LOST	LOST	LOST	
P6	9.0	<0.1	4.6	3.9
P7	26.0	<0.1	10.5	11.0
P8	34.0	17.0	25.5	8.3

Appendix B

Tenax^R GC Analysis for the Launch of STS-5

Table B-1. Tenax[R] GC Analysis at the Northwest Elevated
Camera Pad (S1) for L+0:00 to L+0:10 Hours
During the Launch of STS-5 at KSC

Compound	Analysis ($\mu g/m^3$)
Butane, 2-Methyl	4.49
Methane, Trichlorofluoro (R-11)	16.88
Pentane	17.21
Methane, Dichloro	.60
2-Propanone	11.86
Pentane, 2-Methyl	8.56
Pentane, 3-Methyl	4.85
Hexane	4.12
1-Butanol	3.47
Ethane, 1,1-Dichloro-1-Nitro	.54
Benzene	7.16
1-Pentanol, 2,2-Dimethyl	8.31
Hexane, 3-Methyl	1.71
Heptane	8.03
Cyclohexane, Methyl	21.30
Hexane, 2,4-Dimethyl	9.36
1-Heptene, 5-Methyl	18.28
Benzene, 1,3-Dimethyl	14.92
1,3,5,7-Cyclooctatetraene	32.00
Heptane, 2,4-Dimethyl	.42
Octane, 2,7-Dimethyl	7.31
Octane, 2,4,6-Trimethyl	20.31
Hexane, 2,2,4-Trimethyl	13.64
Unknown (7)	31.06

Table B-2. Tenax[R] GC Analysis at the Northwest Elevated Camera Pad (S1) for L+0:10 to L+3:28 Hours During the Launch of STS-5 at KSC

Compound	Analysis ($\mu g/m^3$)
Cyclobutane	.45
Aziridine	.02
Methane, Trichlorofluoro (R-11)	.40
Pentane	.48
Cyclopropane, 1,1-Dimethyl	.10
Methane, Dichloro	.03
Acetaldehyde	.20
Butane, 2,3-Dimethyl	.12
Pentane, 3-Methyl	.05
Hexane	.10
Cyclohexane	.04
Ethane, 1,1-Dichloro-1-Nitro	.03
Benzene	.34
1-Pentanol, 4-Methyl	.01
Hexane, 3-Methyl	.09
Heptane	.04
Cyclohexane, Methyl	.28
Benzene, Methyl	1.22
Hexane, 2,3,4-Trimethyl	.06
Benzene, 1,3-Dimethyl	.18
Unknown (4)	.31

Table B-3. Tenax[R] GC Analysis at the Northeast Elevated Camera Pad (S2) for L+0:00 to L+0:10 Hours During the Launch of STS-5 at KSC

Compound	Analysis ($\mu g/m^3$)
Butane, 2-Methyl	5.59
Methane, Trichlorofluoro (R-11)	32.77
Pentane	30.85
Carbon Disulfide	7.18
Ethane, 1,1,2-Trichloro-1,2,2-Trifluoro (R-113)	5.22
Methane, Dichloro	2.14
2-Propanol	108.44
Pentane, 2,2,3-Methyl	2.87
2-Pentanone, 3-Methyl	40.46
Cyclohexane	9.64
Ethane, 1,1,1-Trichloro (R-140)	.94
Benzene	8.36
Cyclopentane, 1,3-Dimethyl-(cis)	17.58
Heptane	5.56
Cyclohexane, Methyl	38.76
Octane, 2,7-Dimethyl	2.78
Benzene, Methyl	169.58
Cyclohexane, 1,2-Dimethyl - (Trans)	45.33
Cyclohexane, 1,2-Dimethyl - (cis)	11.44
Heptane, 3-Methyl	13.96
Benzene, 1,3-Dimethyl	14.88
1,3,5,7-Cyclooctatetraene	33.05
Octane, 2,2,6-Trimethyl	8.88
Benzene, 1,2,3-Trimethyl	4.03
Octane, 2,6,6-Trimethyl	66.03
Hexane, 2,2,4-Trimethyl	69.47
Pentane, 3-Ethyl-2,2-Dimethyl	1.81
1-Decene, 8-Methyl	2.13
Unknown (11)	112.63

Table B-4. Tenax[R] GC Analysis at the Northeast Elevated Camera Pad (S2) for L+0:10 to L+1:41 Hours During the Launch of STS-5 at KSC

Compound	Analysis ($\mu g/m^3$)
Methane, Trichlorofluoro (R-11)	.15
Pentane	.08
Ethane, 1,1,2-Trichloro-1,2,2-Trifluoro (R-113)	.08
Acetaldehyde	1.28
2-Pentanone, 3-Methyl	.32
Ethane, 1,1-Dichloro-1-Nitro	.30
Benzene	.08
Furan, 2-Propyl	.19
Cyclohexane, Methyl	.27
Benzene, Methyl	.42
Hexane, 3-Methyl	.43
Ethane, Tetrachloro	.12
Benzene, 1,3-Dimethyl	.39
1,3,5,7-Cyclooctatetraene	1.19
Heptane, 2,4-Dimethyl	.09
Benzaldehyde	3.74
Octane, 2,2,6-Trimethyl	2.36
Hexane, 2,2,5-Trimethyl	1.84
Ethanone, 1-Phenyl	3.82
Nonanal	.04
Decanal	.38
Tridecane	.04
Unknowns (6)	11.25

Table B-5. Tenax[R] GC Analysis at the Knollenberg Site (S5) for L+0:00 to L+0:10 Hours During the Launch of STS-5 at KSC

Compound	Analysis ($\mu g/m^3$)
Methane, Trichlorofluoro	.59
Butane, 2-Chloro-3-Methyl	1.16
Acetaldehyde	3.42
Hexane	1.00
Benzene	4.00
Cyclopentane, Methyl	.23
Cyclohexane, Methyl	1.41
Benzene, Methyl	5.53
Ethene, Tetrachloro	.71
Cyclopentene, 1-Ethenyl-3-Methylene	2.87
1,3,5,7-Cyclooctatetraene	1.66
Unknown (8)	22.37

Table B-6. Tenax[R] GC Analysis at the Knollenberg
Site (S5) for L+0:10 to L+4:11 Hours
During the Launch of STS-5 at KSC

Compound	Analysis $(\mu g/m^3)$
Butane, 2-Methyl	.10
Methane, Trichlorofluoro (R-11)	.45
Pentane	.71
Carbon Disulfide	.02
2-Propanone	5.02
Pentane, 3-Methyl	.09
Butanal	.3
Hexane, 3-Methyl	.43
Benzene	.20
1-Butanol	.74
2-Propenoic Acid, 2-Methyl-, Methyl Ester	.19
Formic Acid, Butyl Ester	.81
2-Picoline, 6-Nitro	3.56
Hexane, 3,3,4-Trimethyl	.10
Benzene, 1,3-Dimethyl	.19
1,3,5,7-Cyclooctatetraene	.32
Ethanol, 2-Butoxy	29.96
Pentane, 2,2,3,4-Tetramethyl	.67
Benzoic Acid, 2-Hydroxy, Methyl Ester	1.50
Isooctanol	.02
Decane, 1-Chloro	.15
Phenol, 2,6-bis(1,1-Dimethylethyl)-4-Methyl	.74
Unknown (3)	.57

Table B-7. Tenax[R] GC Analysis at Site S6 in the SRB
Flame Trench for L+4:22 to L+6:51 Hours
During the Launch of STS-5 at KSC

Compound	Analysis (μg/m³)
Methane, Trichlorofluoro (R-11)	.04
Pentane	.09
2-Propanone	1.45
Acetaldehyde	.02
Benzene	.18
Furan, 2-Propyl	.07
2-Fropendic Acid, 2-Methyl, Methyl Ester	.05
Benzene, Methyl	.11
Pentane, 2,3,3-Trimethyl	.11
Benzene, 1,2-Dimethyl	.20
Benzene, Ethyl	.06
Heptane, 2,4-Dimethyl	.08
Ethanol, 2-Butoly	5.09
Pentane, 3,3-Dimethyl	.79
Hexane, 2,2,4-Trimethyl	.45
Ethanone, 1-Phenyl	.35
1-Hexanol, 4-Methyl	.40
Cyclopropane, Octyl	.18
2-Decen-1-OL	.42
Tridecane	.05
1-Heptanol, 2,4-Dimethyl	.17
Nonane, 1-Chloro	.54
Undecane, 2,4-Dimethyl	.26
Tridecane, 6-Methyl	.12
Unknown (8)	4.38

Table B-8. Tenax^R GC Analysis at Site S7 in the SRB
Flame Trench for L+5:46 to L+6:58 Hours
During the Launch of STS-5 at KSC

Compound	Analysis ($\mu g/m^3$)
Acetaldehyde	.12
Benzene	.20
Benzene, 1,3-Dimethyl	.19
Benzene, 1,4-Dimethyl	.02
Dentane, 2,3,3-Trimethyl	.03
Ethane, 1,1-Dichloro-1,2,2,2-Tetrafluoro (R-114)	.20
Unknown (3)	.15

Table B-9. Tenax^R GC Analysis at Site S8 in the SRB
Flame Trench for L+5:47 to L+7:05 Hours
During the Launch of STS-5 at KSC

Compound	Analysis ($\mu g/m^3$)
Methane, Trichlorofluoro (R-11)	.19
Pentane	.12
Acetaldehyde	.42
Ethanol, 2-Methoxy-Acetate	.34
2-Butanone	.18
Benzene	.08
2-Propenoic Acid, 2-Methyl-, Methyl Ester	.57
Benzene, Methyl	6.36
Hexane, 3,3-Dimethyl	.07
Benzaldehyde	1.08
Ethanone, 1-Phenyl	.70
Undecane, 2-Methyl	1.83
Ethane, 1,1-Dichloro-1,2,2,2-Tetrafluoro (R-114)	.50
Undecane, 4,7-Dimethyl	14.21
Unknown (3)	

Table B-10. Tenax[R] GC Analysis at Site S9 in the SRB
Flame Trench for L+4:47 to L+7:21 Hours
During the Launch of STS-5 at KSC

Compound	Analysis ($\mu g/m^3$)
Methane, Trichlorofluoro (R-11)	1.09
Pentane	1.11
Pentanal	2.03
Butane, 2,2,3,3-Tetramethyl	.25
Pentane, 2,4-Dimethyl	.07
2-Butanone	.66
Benzene	.97
2-Propenoic Acid, 2-Methyl, Methyl Ester	1.62
Benzene, Methyl	6.07
Heptane, 2,4-Dimethyl	.38
Benzene, 1,3-Dimethyl	1.84
Benzene, Ethyl	.50
Hexane, 3,3-Dimethyl	.26
Benzene (1-Methylethyl)	.23
Benzaldehyde	2.39
Undecane, 4,7-Dimethyl	1.52
Heptane, 4-Ethyl-2,2,6,6-Tetramethyl	.03
Ethanone, 1-Phenyl	1.02
Benzoic Acid, 2-Hydizoxy-, Methyl Ester	12.79
1-Decene, 2,4-Dimethyl	1.19
Nonane, 1-Chloro	.54
Phenol, 2,6-bis (1,1-Dimethylethyl)-4-Ethyl	.78
Unknown (7)	5.50

Table B-11. Tenax[R] GC Analysis at the Coast Road South
(CRS) Site for L+0:00 to L+1:22 Hours
During the Launch of STS-5 at KSC

Compound	Analysis ($\mu g/m^3$)
Acetaldehyde	.20
Benzene	.45
Formic Acid, Butyl Ester	.05
Cyclobnanone, 2,2,3-Trimethyl	.46
Pentane, 2,2,3,4-Tetramethyl	.66
Heptane, 2,4-Dimethyl	.15
Benzaldehyde	4.46
Ethanone, 1-Phenyl	4.00
1-Decene, 2,4-Dimethyl	.04
Octane, 2,4,6-Trimethyl	.08
Decane, 2-Methyl	.75
Unknown (10)	5.56

Table B-12. Tenax[R] GC Analysis at the Coast Road North (CRN) Site for L+0:00 to L+3:39 Hours During the Launch of STS-5 at KSC

Compound	Analysis ($\mu g/m^3$)
Pentanal	4.59
Pentane, 2-Methyl	.57
Pentane, 3-Methyl	.44
Hexane	.10
1-Hexanol	.18
Ethane, 1,1-Dichloro-1-Nitro	.17
Benzene	.48
Hexane, 2-Methyl	.93
Hexane, 3-Methyl	1.00
Pentane, 2,2,3-Trimethyl	1.11
Heptane	.22
3-Pentanone, 2-Methyl	.08
Benzene, Methyl	4.07
Hexane, 2,3,4-Trimethyl	2.35
Oxtane	.60
Benzene, 1,3-Dimethyl	5.22
Benzene, Ethyl	4.45
Heptane, 2,4-Dimethyl	.49
Benzene, 1-Ethyl-2-Methyl	2.57
Benzaldehyde	1.90
Benzene, 1,2,3-Trimethyl	2.20
Benzene, 1-Methyl-4-Propyl	1.93
Ethanone, 1-Phenyl	2.34
Benzene, 1,2,4,5-Ttramethyl	.47
1-Decene, 2,4-Dimethyl	1.80
Naphihalene, 2-Methyl	.11
1-Pentanol, 4-Methyl-2-Propyl	.16
Undecane, 4,8-Dimethyl	.31
Decane, 2,6,8-Trimethyl	2.00
Undecane, 2,4-Dimethyl	.31
Unknown (6)	1.46

Table B-13. Tenax^R GC Analysis at the Universal Camera
Site Six (UCS6) for L+0:00 to L+1:33 Hours
During the Launch of STS-5 at KSC

Compound	Analysis (μg/m³)
Butane, 2-Methyl	.35
2-Propanone	2.44
Pentane, 2,2,4-Trimethyl	.16
2-Butanone	.37
Benzene	.06
2-Butanone, 3-Methyl	.08
1-Butanol	.82
Benzene, Methyl	2.96
Octane	.26
Benzene, 1,3-Dimethyl	3.99
Benzene, Ethyl	.90
Ethanol, 2-Butoxy	29.40
Pentane, 2,2,3,4-Tetramethyl	.23
Hexane, 2,2,4-Trimethyl	.26
Ethanone, 1-Phenyl	.47
1-Hexanol, 4-Methyl	.97
1-Decene, 2,4-Dimethyl	1.58
Unknown (1)	.20

Table B-14. Tenax^R GC Analysis at the Banana Creek
Site for L+0:00 to L+2:22 Hours
During the Launch of STS-5 at KSC

Compound	Analysis (μg/m³)
Butane, 2-Methyl	.07
1-Butanol, 3-Methyl	.04
Acetaldehyde	.17
Butane, 2,3-Dimethyl	.10
Pentane, 3-Methyl	.06
1-Pentanol, 4-Methyl	.18
Benzene	.31
Cyclobutene, 2-Propenylidene	.12
Ethene, Tetrachloro	.28
Benzene, 1,3-Dimethyl	.89
1,3,5,7-Cyclooctatetraene	.38
Heptane, 2,4-Dimethyl	.12
Ethanol, 2-Butoxy	18.26
Octane, 6-Ethyl-2-Methyl	.11
Octane, 2,3,6-Trimethyl	.19
Ethanone, 1-Phenyl	1.49
Decanal	.27
Unknown (2)	.99

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