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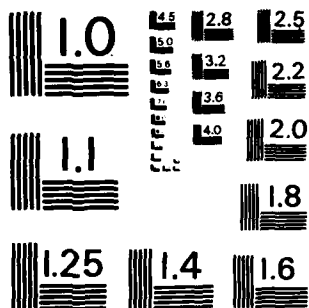
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USAF OEHL REPORT  
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AIR MONITORING TECHNIQUES FOR SPACE SHUTTLE  
LAUNCHES AT VANDENBERG AIR FORCE BASE  
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<b>Space Transportation System (STS) launches at Kennedy Space Center (KSC), Florida have produced a wide range of environmental phenomena. These phenomena have included far field hydrogen chloride (HCl) acid rainout and near field HCl gas revolatilization. The U.S. Air Force and the National Aeronautics and Space Administration (NASA) have conducted detailed scientific field and laboratory studies to define the effects of exhaust effluents.</b>		

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produced during Space Shuttle launches. Inferences can be drawn from the monitoring studies at KSC and applied to the first STS launch at Vandenberg AFB (VAFB). There are, however, significant differences in launch scenarios between KSC and VAFB that could alter or produce different environmental effects. These differences include terrain, meteorology, flame trench configuration, deluge water and vehicle configuration. These differences may produce unforeseen environmental effects during STS launches at VAFB and for this reason, a comprehensive monitoring program should be considered. This report recommends a monitoring program methodology which includes ground monitoring, aircraft monitoring and remote sensing for STS launches at VAFB.

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USAF OCCUPATIONAL AND ENVIRONMENTAL

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Air Monitoring Techniques for Space Shuttle

Launches at Vandenberg Air Force Base

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 VAFB, Headquarters Strategic Air Command (HQ SAC), Offutt AFB NE and Space Division (SD) in California. Recommendations in this report are provided to assist in the development of an integrated and comprehensive environmental monitoring program prior to the first Space Shuttle launch at Vandenberg AFB CA.

The authors wish to express their thanks to the many offices at Space Division, NASA at Marshall Space Flight Center, NASA at Langley Research Center, NASA at Kennedy Space Center, and at Vandenberg AFB for providing us with information which assisted us in preparing this report.

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## I. INTRODUCTION

A Final Environmental Impact Statement (FEIS) for the Space Shuttle at Vandenberg Air Force Base (VAFB) in California was published in January 1978 (Ref 1). The report listed possible adverse environmental effects associated with Shuttle launches. The FEIS also analyzed basic needs and requirements for environmental monitoring to insure Air Force compliance with federal, state and local environmental laws and regulations.

The USAF Occupational Environment and Health Laboratory (USAF OEHL) became involved in the environmental program for the Space Shuttle and other missile systems at VAFB in the late 1970s. In response to the general needs and requirements listed in the FEIS, an initial environmental monitoring program report for VAFB was published by the USAF OEHL in the fall of 1980 (Ref 2). The report defined a "first look" at what monitoring might be required at VAFB to monitor Shuttle environmental effects.

Space Transportation System One (STS-1) and STS-2 were launched in April and November 1982, respectively. In December 1982, the USAF OEHL received a request for assistance from the USAF Hospital Vandenberg Bioenvironmental Engineers (BEEs), through the BEE at the Strategic Air Command (SAC) and with the concurrence of Space Division (SD). They requested the USAF OEHL conduct a detailed evaluation of Space Shuttle environmental monitoring instrumentation and techniques and make recommendations for an environmental program at VAFB. A review and evaluation of monitoring instrumentation and techniques used to measure exhaust effluents from missile launches are published in a companion USAF OEHL Report (Ref 3). Information contained in the companion report provided the basis for identifying requirements and making specific recommendations for an environmental monitoring program in support of Space Shuttle operations at VAFB. Monitoring experience during STS-1 through STS-5 allowed this report to describe air monitoring for VAFB in more detail than the preceding FEIS and USAF OEHL baseline monitoring reports.

## II. BACKGROUND

The propulsion system of the STS consists of the main engines (ME) which use a hydrogen-oxygen mixture and two strap-on solid rocket boosters (SRB) that use atomized aluminum powder as the fuel and ammonium perchlorate as the oxidizer. Large quantities of hydrogen chloride (HCl) and aluminum oxide ( $Al_2O_3$ ) are propulsion by-products that are emitted into the atmosphere. Aluminum oxide is generally considered to be no more than a nuisance dust. Efforts have, therefore, focused on HCl. An HCl ceiling Threshold Limit Value (TLV) of 5 parts-per-million (ppm) has been established as an indicator level of toxic injury to humans (Ref 4). Space Shuttle launches are of greater interest than previous missiles since 2 1/2 times more HCl is emitted than from Titan III launches (Ref 5).

The launch of STS-1 produced some unexpected environmental effects not previously observed during other missile system launches. The launches of STS-2 through STS-5 confirmed that, although unique from other missile launches, these effects occurred at each launch. Figure 1 shows the

mechanisms involved in producing ground level occurrences of HCl. The addition of more than 600,000 gallons of sound and fire suppression water enhances near and far field HCl rainout. Near field measurements from STS-5 suggest some of the aqueous HCl may revolatilize for hours after a launch and form gaseous HCl concentrations of potential health concern for workers on or near the pad (Ref 6). Far field HCl effects can be produced from acid washout, acid rainout, or gaseous HCl concentrations. Acid washout occurs when rain from an overhead convective cloud scavenges HCl from the rocket exhaust ground cloud. In a heavy rain, one model predicts that nearly all of the HCl in the ground cloud (roughly 30 tons) could be deposited within 18 miles of the launch site (Ref 5). Spontaneous acid rainout, in the absence of a convective cloud, has been observed at all five STS launches to date. Gaseous HCl air parcels which diffuse to ground level have not been observed at the STS launches nor are generally predicted to occur in high enough concentrations downwind to be of health or environmental concern.

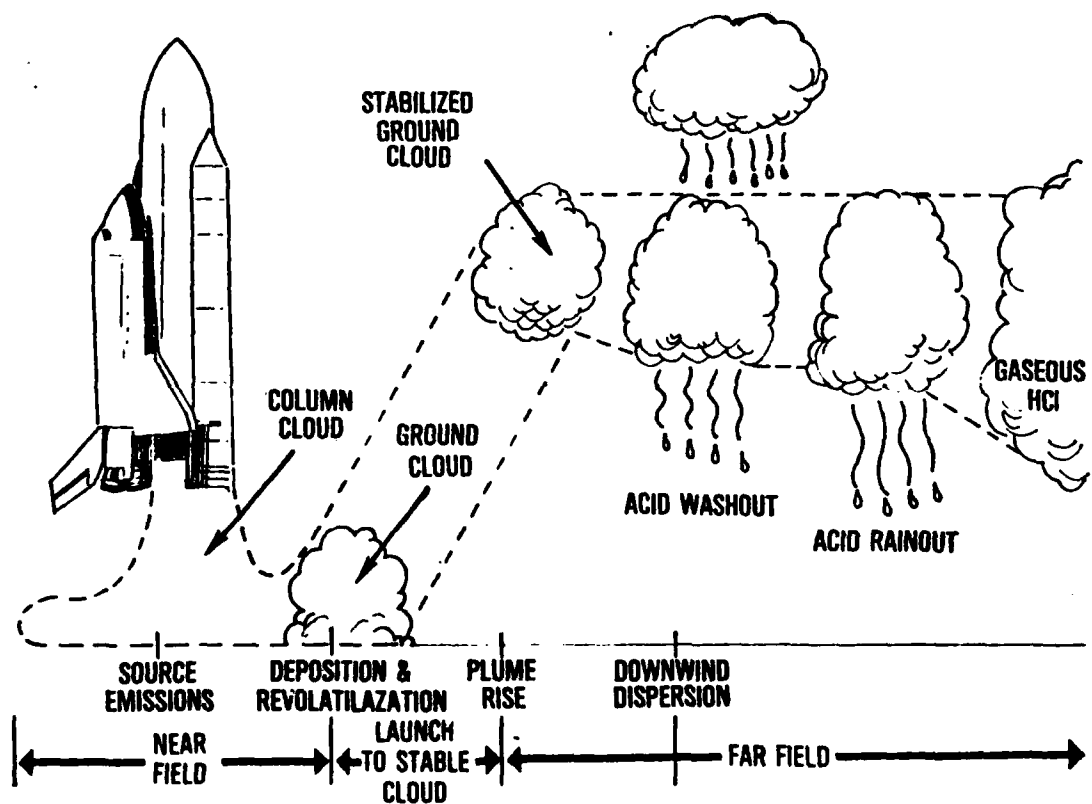


Figure 1. HCl Pathways (Ref 7)

Considerable monitoring of Shuttle exhaust effluents has been conducted at Kennedy Space Center (KSC). Monitoring instrumentation and techniques have been tested under launch conditions and many of the lessons learned at KSC can be applied to the monitoring program at Vandenberg. Significant differences

in launch scenarios do exist between KSC and VAFB. First, the terrain is different. Kennedy Space Center is relatively flat with an abundance of marshes and standing water. Vandenberg AFB is mountainous with high peaks and deep ravines. Second, the amount of deluge and fire suppression water used at VAFB may be as much as twice that used at KSC. More HCl acid deposition may be produced in the near field at VAFB. Third, at KSC, all SRB exhaust is vented out the north flame trench and ME exhaust out the south flame trench. At VAFB, the SRB exhaust is split with one engine venting north and one venting south. The ME exhaust is adjacent to the SRB trench to the south and will provide additional water for acid deposition. Flame trenches at VAFB are also narrower and have a larger inclination angle than KSC. Fourth, meteorology is different between the launch sites. VAFB frequently has high winds, but also has stronger and more persistent inversions and many more occurrences of fog. All these differences must be taken into consideration in the development of a comprehensive monitoring program at VAFB.

The USAF is committed to the protection of personnel and the surrounding environment from hazards associated with Space Shuttle launches at VAFB. Exhaust effluent monitoring is required so that mechanisms producing hazardous conditions can be better understood. A detailed understanding of environmental effects will allow protective or preventive measures to be taken if they are required.

### III. VAFB AIR MONITORING CONSIDERATIONS

There are several important purposes of air monitoring at STS launches. Monitoring details must be tailored to each specific purpose. Failure to adequately define monitoring technical objectives is a common reason why numerous monitoring efforts result in copious amounts of data but without the ability to settle the basic issues.

The three basic objectives of STS monitoring are to determine potential health effects, environmental effects, and atmospheric model predictive accuracy (Ref 7). Methods to evaluate models in order to know how much confidence to place in their predictions are discussed first. Launch specific monitoring to define potential health and environmental effects are discussed later followed by an estimate of overall monitoring program cost for VAFB.

#### A. Monitoring for Model Evaluation

Confidence in any predictive atmospheric model can only be derived from a careful evaluation of that model. An appropriate model, well applied, can be accurate to within a factor of 2 or 3 approximately 50% of the time (Ref 8). These accuracies may appear poor unless one considers that atmospheric dispersion over a ten-mile distance can reduce concentrations by a factor of 1,000 or even 10,000.

Some theoretical work has been done concerning model performance evaluations (Ref 9). A number of statistical techniques have been developed to evaluate model performance. They essentially assess the degree of agreement between a set of predicted and observed concentrations. Two graphical

examples are presented. Figure 2 shows a cumulative frequency distribution of over 10,000 predicted and observed values (Ref 10). It shows good agreement (within a factor of 2) at high concentrations but poor agreement at low concentrations where monitoring inaccuracy and other residual errors are important. Figure 3 shows a conceptual way of depicting the probability of model over- and underpredictions (Ref 10).

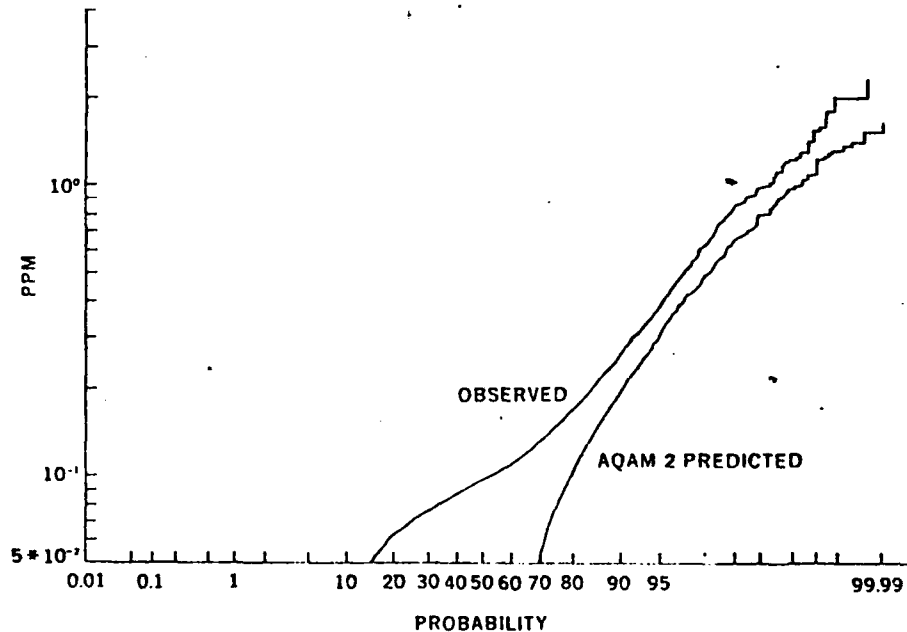


Figure 2. Cumulative Frequency Distribution of Observed and Predicted CO Values (Ref 10).

A comprehensive review of dispersion modelling indicates a strong need for applied model evaluations which critically compare model theory with observations (Ref 10). The key difficulty with such studies is that hundreds, if not thousands, of measurements over wide ranging atmospheric conditions are needed. Consequently, while statistical confidence levels for model analyses are sorely needed by decision makers, they are rarely available.

Less comprehensive model evaluations are still useful and can lead to general acceptance of a predictive model. A method to determine the minimum number of ground level monitors is presented in Appendix A. The numbers of monitoring sites in a network, positioned prior to launch, are a function of many factors. Plume spread, distance from launch, variance from predicted mean wind direction, acceptable observations errors (from being crosswind to the plume concentration centroid), number of downwind observations, and accessibility to the sites are all important. Typical atmospheric conditions result in a minimum of 36 required sites. Worst case atmospheric stabilities (narrow plume spread with time due to a stable atmosphere) suggest a minimum of 72 monitoring sites.

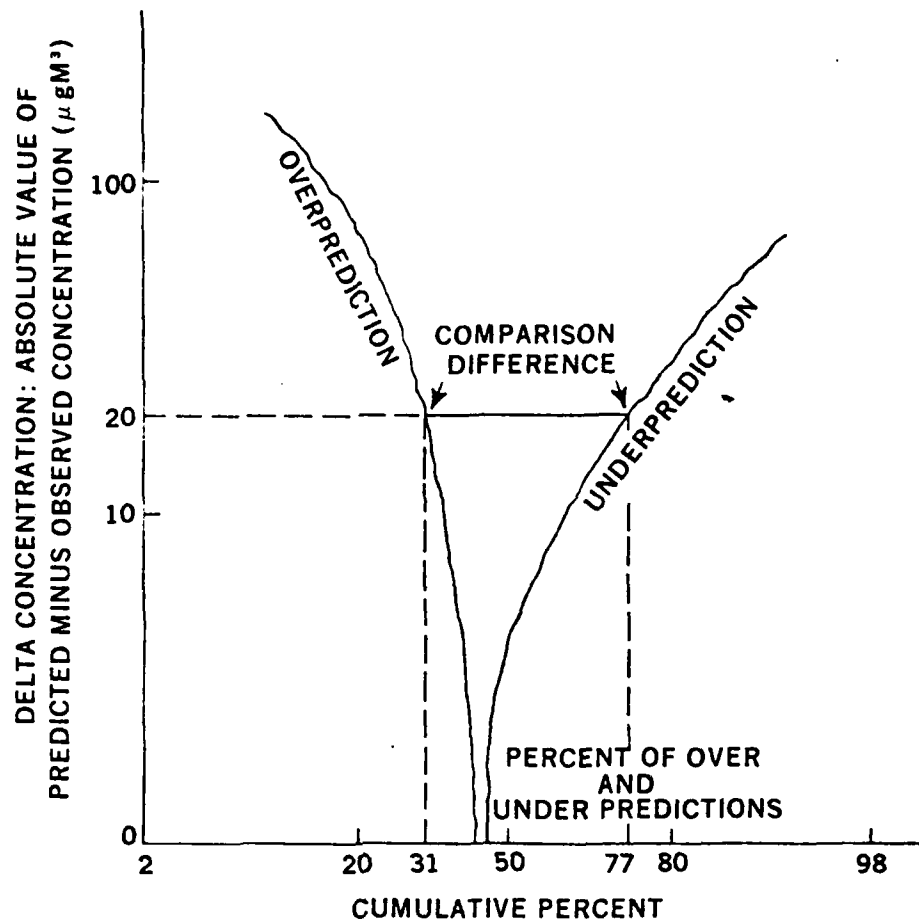


Figure 3. Cumulative Percent Frequency of Model Overprediction and Underprediction (Ref 10).

Only simple, passive monitoring devices in a ground level network at Vandenberg are feasible due to this large number of minimum sites and the road access difficulties. One or several mobile "rover vans" would allow for observations with more accurate instruments at sites determined from last minute model predictions.

Aircraft measurements during STS launches to date have proven more useful than ground measurements. Future measurements of STS launches can be supplemented by studies of Titan III launches or controlled tracer releases. The best combination of aircraft in situ measurements, ground level measurements, and remote measurements during the various launches remains an unresolved issue. While STS measurement and model evaluation costs will be high, the costs of not having an adequate predictive model may be much higher.

## B. Launch Specific Monitoring

1. Near Field Monitoring. Monitoring of two different phenomena in the near field is required: near field HCl acid deposition during launch, and revolatilization of HCl gas for hours after launch. Widespread acid deposition has been observed on the pad during every STS launch. A similar problem is expected at VAFB. Continuing studies of this phenomena at VAFB will provide a better scientific understanding of production mechanisms. Resulting data can be input into the dispersion models to improve their predictive capabilities. This work will also assist in the determination of the washdown water required during a launch.

A monitoring scheme similar to the one used at STS-5 is suggested. Copper plates, pH paper and graduated centrifuge tubes mounted on a secured tripod stand can be placed on a number of selected radials out from the launch point. Intervals of every 200 ft out from a circle 400 ft from the launch mount to a distance of 2000 ft are recommended. The location of each site will be dependent on surrounding structures and terrain. A sample plan based on experience at KSC is shown in Figure 4. A total of 75 near field monitoring sites is required for this plan. The copper plates can provide number and size distributions of the acid deposition and pH paper will indicate the acidity. Two graduated centrifuge tubes filled with distilled water (one totally exposed and one shielded from the acid rainout) can be used to determine both a chemical mass balance and a water balance. Analysis of these samples by ion chromatography will yield the best results.

The protection of personnel in the LCC during a launch and those entering the pad area postlaunch is of concern to the USAF. Revolatilization of HCl gas around the pad can occur in concentrations exceeding 38 ppm (Ref 6) for many hours after the launch. For this reason, continuous HCl monitors are recommended to give real-time HCl concentrations to decision makers for use in determining safe/hazardous areas and personnel protective equipment requirements. Continuous HCl monitoring sites are also shown in Figure 4. Six fixed continuous HCl monitors and one mobile monitor are adequate to cover the pad area. One monitor is located at each of the air intake vents to the LCC and one each on either side of the SRB flame trenches. The mobile unit can be used to find "hot spots" not definable by the six permanent monitors. There are commercially available continuous HCl monitors that can be used for this purpose. Tests of these monitors during STS launches at KSC can provide a basis for selection. We also suggest backup monitoring devices in the form of sequential midget impinger samplers at each of the fixed sites. Not only will they provide backup HCl data but also detailed chemical species analyses.

One of the most productive near field monitoring devices at STS launches at KSC has been the video monitors located on the pad. Video cassettes provide valuable permanent records of launch events and aid the interpretation of other ground monitoring data in the near field. We suggest a minimum of three video cameras on the pad for each launch at VAFB. Each should use professional 3/4 inch tape, 3 gun cameras, and clock timer signals down to 0.1 seconds.

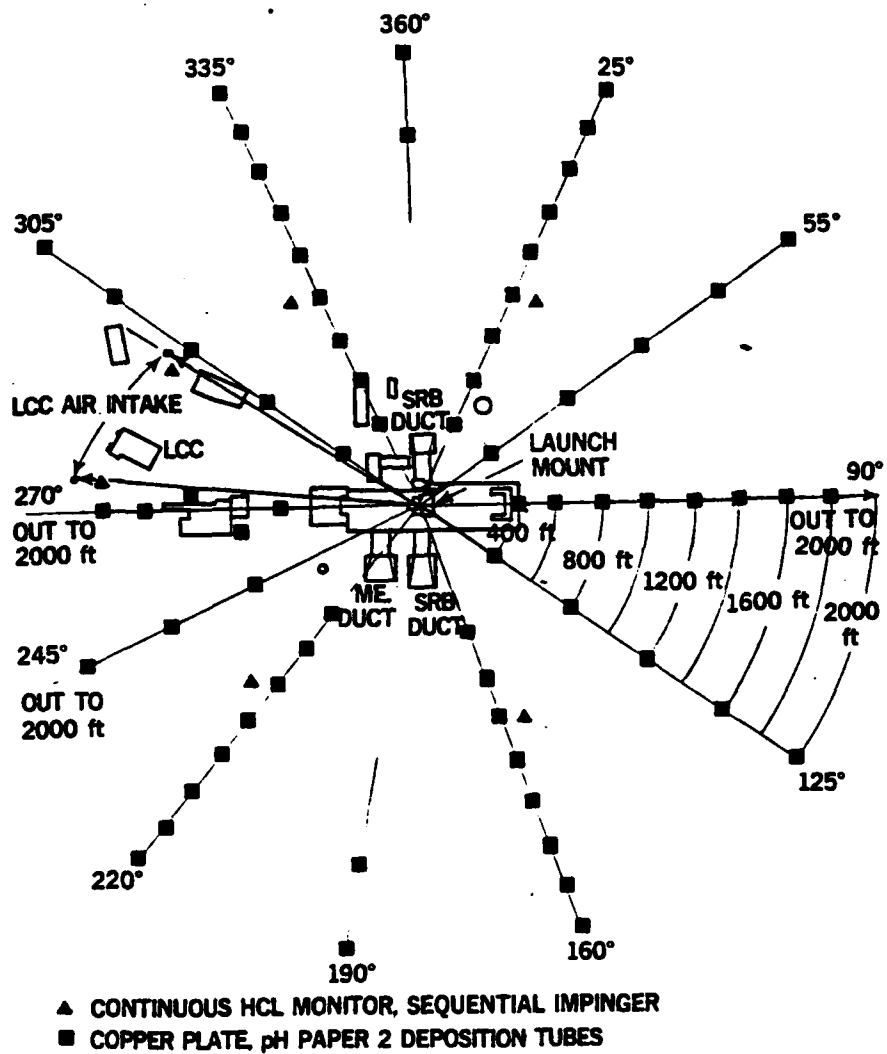


Figure 4. Near Field Monitoring Plan for SLC-6

2. Far Field Monitoring. Far field acid rainout has occurred beyond six miles at each STS launch at KSC. It is not known whether the VAFB differences in meteorology, terrain and flame trench configuration will enhance or diminish far field environmental effects. Far field ground monitoring is required to determine the extent of this problem. We suggest simple, cost-effective passive monitors mounted on a small light-weight platform. Each site should include a copper plate, pH paper and a passive dosimeter. The copper plate and pH paper will determine the acid deposition footprint as well as provide number and size distribution of the fallout and its acidity. A passive dosimeter will yield semiquantitative HCl concentrations and dosage data. A simple, light-weight, sample stand can be used to minimize site preparation times. A suggested design is shown in Figure 5. The pH paper, copper plate and passive dosimeters are positioned on the base plate of the sample insert, the cover plate is folded over the base plate to secure the samplers and then placed in a protective plastic bag. In this way, the monitoring devices can be prepared prior to use and rapidly deployed in the field before a launch. An aluminum rod with a lightweight aluminum sampling platform attached can be quickly driven into the ground and the sample insert easily attached.

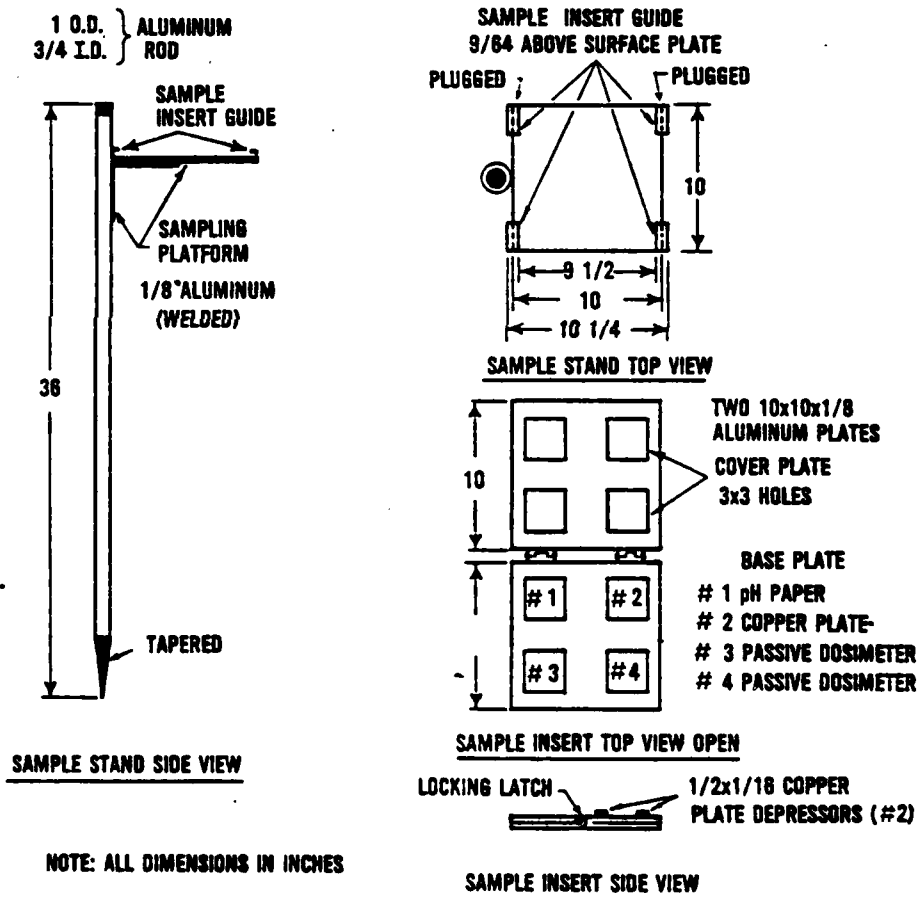


Figure 5. Far Field Sampling Stand

The complex terrain surrounding SLC-6 at VAFB makes far field monitoring difficult. Due to meteorological wind variability, we suggest monitoring sites in a 60 degree sector (plus and minus 30 degrees from the predicted trajectory of the ground cloud) extending out to the base boundaries. The number and spacing of monitoring sites can be easily determined as described in Appendix A. Spacing and the number of sampling sites required for distances out to 15 km are shown in Table A-1.

The values in the table represent the ideal spacing and number of sites required to adequately monitor the downwind deposition. We suggest selecting permanent monitoring sites on 1, 3, 5, 7, and 9 km arcs on the land masses surrounding SLC-6. Once selected, the sites that fall within the 60 degree sector for any launch can be monitored. This would require approximately 36 sets of monitoring instrumentation for neutral atmospheric conditions and a potential of 72 for stable atmospheric conditions. The many peaks and canyons surrounding SLC-6 will cause less than ideal siting of monitoring stations. Figure 6 shows the improved and dirt roadways on south VAFB. It can be seen that, even through ideal siting is not possible, an adequate monitoring scheme can be accomplished. Siting will be dependent on the ground cloud trajectory and condition of surrounding roads.

Far field video documentation of the STS induced ground cloud can provide data that would be otherwise unavailable. Ground cloud growth, dispersion and deposition data can all be kept as a permanent record when video equipment is used. We support the use of at least three far field television cameras during a launch.

3. Aircraft Monitoring. Ground monitoring of the STS exhaust effluents is difficult in the complex terrain at VAFB. Monitoring is especially restricted when the ground cloud trajectory is out to sea. In addition, ground samplers measure fallout materials and tell little about the cloud itself. Aircraft monitoring can be used to fill this void. Aircraft data have been obtained at the launches of STS-1, 2, 3 and 5. Much data have been collected and are still being analyzed. Differences between the KSC and VAFB launch scenarios will lead to many uncertainties in the STS ground cloud at VAFB. Aircraft monitoring is required to define the specific characteristics of the ground cloud under these different conditions. A thorough aircraft measurement program should be initiated for the first few shuttle launches at VAFB. We suggest a detailed scientific investigation of the ground cloud's physical and chemical properties. This endeavor is not inexpensive, but is necessary to provide a better scientific understanding of the ground cloud which will result in improved predictions capabilities of the diffusion models. A second and simpler aircraft monitoring activity should be conducted for each launch at VAFB. Downlooking LIDAR measurements from an aircraft platform can provide large scale growth and dispersion characteristics of the ground cloud. These data are not available in the aircraft penetrations of the ground cloud mentioned above. The effects of the land-sea interface and the impact of complex terrain can be identified with a LIDAR measurement of this type.

4. Remote Sensing. Ground or aircraft remote sensing can supplement ground sampling and aircraft monitoring. As advanced technology becomes

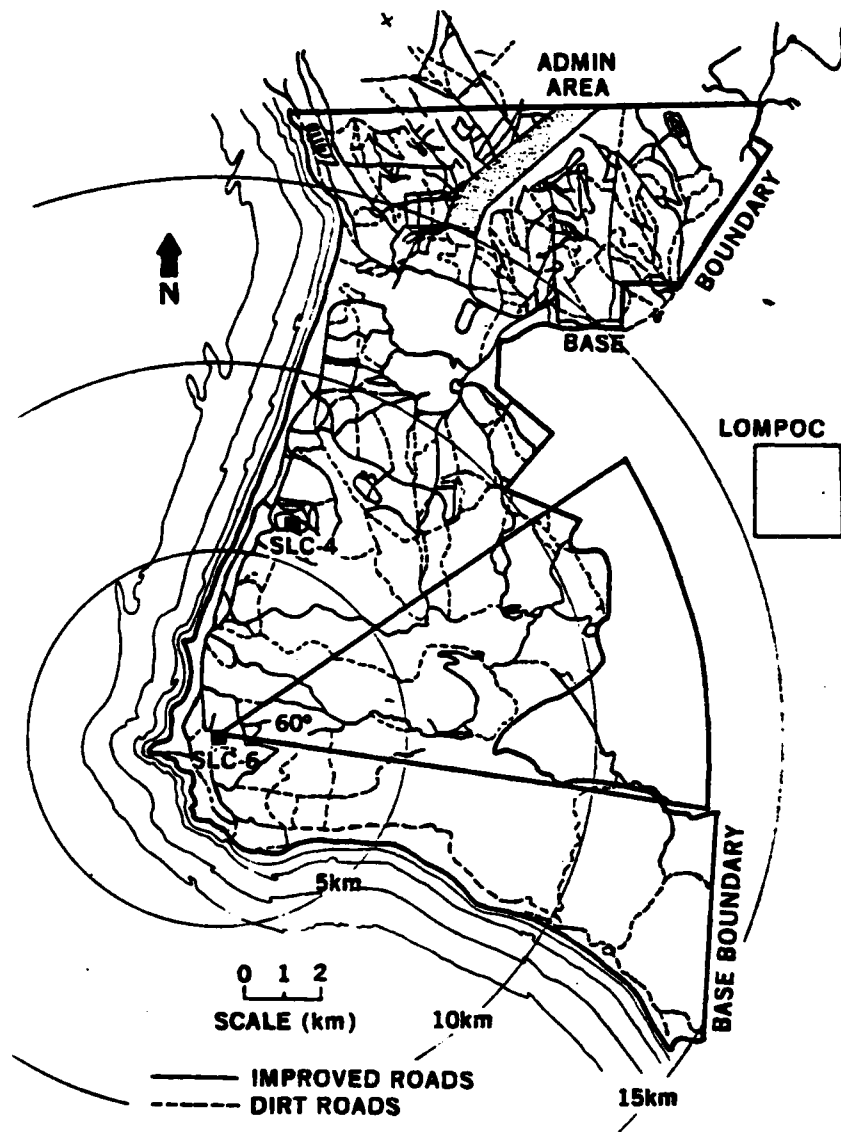


Figure 6. Accessible Roadways on South VAFB.

available, remote sensing has the potential to replace ground and aircraft monitoring. The ideal remote sensing device may be a differential absorption LIDAR (DIAL) that is multiphased and range resolved. The multiphased feature allows it to identify, differentiate, and quantify different chemical species. A range resolved LIDAR will provide concentration data at specific points in the cloud rather than an integrated value over an optical path length that is now available. Technology for an ideal remote sensing instrument is not currently available but extensive research and development are being conducted by DOD agencies and in commercial industry. The Air Force Engineering and Services Center (AFESC) is pursuing several LIDAR projects. As technology becomes available, the STS launches at VAFB would be excellent targets of opportunity to test prototype instrumentation. Close coordination should be maintained with AFESC and commercial industry to insure that a remote sensing system is made available for field testing at VAFB as soon as technologically feasible.

C. VAFB Monitoring Program Costs Estimates. Establishing a baseline cost estimate for a comprehensive monitoring program is difficult. Table 1 is an approximate cost of initiating a monitoring program at VAFB and operational costs incurred during the first STS launch. Some instrumentation are shelf items (pH paper, sequential sampler, tripod stand) and costs are available. Other devices have not been specifically identified (continuous HCl monitor, passive dosimeter) and selection of such instrumentation will determine the costs. Finally, selection of some monitoring instrumentation will depend on the degree of sophistication selected (video, aircraft monitoring, remote sensing). The costs for site establishment and storage of equipment are not included in the table because it is assumed that this will be accomplished by Air Force resources. Analysis of laboratory samples are costed as if contracted to a commercial laboratory (although USAF laboratory analysis is possible). Commercial contracting of remote sensing and aircraft monitoring is assumed for this cost comparison.

#### IV. CONCLUSIONS

Experience has shown that STS launches produce a wide range of varying environmental effects. Even with comprehensive theoretical studies, STS launch simulations, and monitoring attempts of other missile systems, the launch of STS-1 resulted in unforeseen environmental phenomena. These phenomena were highlighted by the far field HCl acid rain and the revolatilization of HCl gas on the pad. Inferences can be drawn from these results and applied to the first STS launch at VAFB. The USAF and NASA have conducted detailed scientific field studies of environmental effects of exhaust effluents during the launches of STS-1 through STS-5. The results of these endeavors have yet to address all environmental concerns; therefore, studies will likely continue at future STS flights at KSC. In addition, there are many differences in launch scenarios between KSC and VAFB including: meteorology, terrain, flame trench configuration, deluge/firex/washdown water, proximity of support personnel/equipment/facilities. With the environmental effects uncertainties that still exist at KSC, coupled with the many differences in launch scenarios between KSC and VAFB, the probability is high that unforeseen environmental

Table 1. Estimated Monitoring Program Costs through the First Space Shuttle Launch at Vandenberg AFB

Monitoring Technique or Instrument	Number Required	Initial Cost		Assigned <sup>a</sup> Cost (\$)	Cost Per Launch		Analytical Cost/Unit (\$)	Subtotal Cost (\$)
		Cost/Unit (\$)	Subtotal Cost (\$)		Direct Cost/Unit (\$)	Cost/Unit (\$)		
1. Near Field								
A. Continuous HCl Monitor	7	10,000	70,000	7,000	0	0	20	7,140, <sup>b</sup>
B. Sequential Sampler	6	1,500	9,000	900	0	0	20	720 <sup>b</sup>
C. Copper Plates	75	0	0	0	1	1	0	75
D. pH Paper	75	0	0	0	1	1	0	75
E. Deposition Tubes	150	7	1,050	105	0	0	5	855
F. Tripod Stands	75	100	7,500	750	0	0	0	750
G. Ring Clamps	150	7	1,050	105	0	0	0	105
H. Video System	3	4,300	12,900	1,290	0	0	100	
2. Far Field								
A. Sampling Stand	36	100	3,600	360	0	0	0	360
B. pH Paper	36	0	0	0	1	1	0	36
C. Copper Plates	36	0	0	0	1	1	0	36
D. Passive Dosimeter	36	0	0	0	25	25	0	900
E. Video System	3	14,000	14,000	4,200	0	0	100	
3. Aircraft								
A. Cloud Physical and Chemical	1	0	0	0	100,000	100,000	0 <sup>c</sup>	100,000
B. Cloud Tracking	1	0	0	0	15,000	15,000	0 <sup>c</sup>	15,000
4. Remote Sensing								
	1	0	0	0	50,000	50,000	0 <sup>c</sup>	50,000
<b>Total</b>			<b>147,100</b>				<b>Total Cost</b>	
			<b>147,100</b>				<b>Per Launch</b>	<b>176,052</b>

<sup>a</sup>Initial cost of equipment amortized over ten launches

<sup>b</sup>24 tubes per sequential sampler analyzed at \$5 per sample

<sup>c</sup>Analytical cost included in direct cost per unit

effects will also occur at VAFB. These circumstances suggest that a comprehensive monitoring program be established at VAFB with greatest emphasis on the first several launches.

The protection of personnel, the environment, and support equipment/facilities are all of concern to the USAF. For these reasons, a monitoring program to include ground monitoring, aircraft monitoring and remote sensing of STS exhaust effluents should be initiated at VAFB. A myriad of monitoring instrumentation and monitoring techniques have been and are being developed. This allows a wide range of possible alternatives in establishing a program at VAFB. The purpose of this report was to evaluate existing monitoring techniques and make recommendations for a monitoring program at VAFB. A summary of our findings follow.

Near field monitoring is required because of the HCl deposition that occurs on the pad during the launch and the HCl gas revolatilization that occurs for many hours postlaunch (Ref 6). Continuous real-time HCl monitors are available and should be used to identify the hazards associated with HCl gas revolatilization for the protection of personnel in the LCC and those entering the pad after a launch. Supporting HCl detection devices such as sequential midget impingers or solid sorbent tubes can be used to provide backup HCl data. These monitoring devices can determine the time history and spatial extent of HCl gas revolatilization and can be chemically analyzed for other species. A monitoring scheme of simple, cost-effective copper plates and pH paper will define the spatial extent of acid aerosol/rain deposited in the pad area. Mass and water balance instrumentation used in conjunction with the copper plates and pH paper will provide valuable data to improve dispersion models as well as to determine the amount of washdown water required. Video and photographic documentation are necessary for data interpretation and an accurate record of launch events and postlaunch findings.

Far field monitoring poses a special problem. Such monitoring is required, based on the results from STS-1 through STS-5 which showed acid deposition occurring at distances out to and exceeding six miles. The complex terrain surrounding SLC-6 at VAFB make far field monitoring exceedingly difficult. Nevertheless, simple, light-weight, cost-effective monitoring sites can be established alongside the accessible roadways on VAFB. These sites should be placed in a downwind direction based on most current dispersion model prediction of the ground cloud trajectory. Each site should include pH paper, copper plate and simple passive dosimeter device all mounted on a small light-weight stand. These sites will provide the ground cloud deposition footprint, particle/droplet number and size distributions and semiquantitative analysis of HCl concentration and dosage. Video equipment should be sited at advantageous positions in order to track the movement and dispersion of the STS induced ground cloud. Video results are important for understanding and improving dispersion models and for documentation in case litigation occurs.

Aircraft measurements can provide detailed ground cloud physical and chemical data. Due to the many differences between KSC and VAFB, a comprehensive study of the first few shuttle launches at VAFB is required. This data could be used to enhance dispersion model performance that would assist in predicting environmental impacts for future launches. Downward looking

LIDAR on a small aircraft could provide vertical and horizontal resolution of the ground cloud. Ground cloud behavior in complex terrain under different meteorological conditions could be observed and incorporated into the dispersion models. This technology is available, relatively inexpensive and should be conducted at all launches. Aircraft measurements would complement ground monitoring studies.

Complex terrain problems that hinder ground monitoring and adverse weather which hinders aircraft measurements can be circumvented as sophisticated LIDAR technology becomes available. The Air Force should consider using available LIDAR instrumentation for launch targets of opportunity such as Titan III, MX, and STS launches at KSC. Support for research and development of LIDAR programs at the AFESC and in commercial industry is recommended. LIDARs will eventually be able to provide ground cloud and fallout concentration data from a ground location or aircraft platform. The LIDAR can initially supplement ground and aircraft measurements and may eventually replace them.

Ground monitoring, aircraft monitoring and remote sensing should all play a significant role in the total monitoring program at VAFB. An STS monitoring workshop should be convened to merge these three separate efforts into one integrated program. The workshop attendees should include all agencies involved in STS environmental monitoring at VAFB. Topics would include the development of a specific STS monitoring plan and associated monitoring protocol. Selection of available monitoring instrumentation or determination of research and development of specific monitoring devices or techniques should be decided at the workshop. Results of this workshop should lead to an integrated monitoring program being available prior to the first STS launch at VAFB.

## V. RECOMMENDATIONS

The following recommendations for air monitoring techniques in support of Space Shuttle launches at VAFB are based on monitoring experiences at KSC and the instrument evaluation in the companion USAF OEHL report, and analyses in this work:

- A. Conduct Near Field (SLC-6) Monitoring
  - 1. Continuous real-time HCl monitors
  - 2. Supporting HCl detection devices
  - 3. Mass and water balance instrumentation
  - 4. pH paper and copper plates
  - 5. Photographic and video documentation
- B. Conduct Far Field Monitoring
  - 1. pH paper

2. Copper plates
  3. Passive HCl dosimeters
  4. Photographic and video documentation
- C. Utilize Aircraft Monitoring
1. Detailed physical and chemical study
  2. Ground cloud dispersion characteristics
  3. Photographic and video documentation
- D. Evaluate Remote Sensing Technology
1. Air Force Engineering and Service Center (after R&D)
  2. Commercially available airborne LIDAR (ready now)
- E. Hold a VAFB STS Monitoring Workshop
1. Specific STS Monitoring plan
  2. Monitoring protocol
  3. Monitoring instrumentation selection
  4. Monitoring R&D
  5. Targets of opportunity to test instrumentation

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Appendix A

Air Monitoring Network Methodology

## Air Monitoring Network Methodology

Air monitoring at ground level must include a carefully selected network of sites positioned before launch. Sites which are too widely spaced are likely to detect concentrations far less than the maximum or be missed entirely. Detection of high concentrations at several downwind distances is important so that model predictions can be evaluated against more than one observation. A method is presented in this appendix which will allow computations of maximum spacing between monitoring sites.

The maximum crosswind distance between monitoring sites in a network is a function of the rate of plume spread, downwind distance from launch, and acceptable concentration differences between true peak concentrations ( $\chi_1$ ) and observed concentrations ( $\chi_2$ ) likely to be crosswind of the true peaks (Fig A-1). The unknown distance between monitors (M) is represented by twice the crosswind distance (y) from the plume centerline.

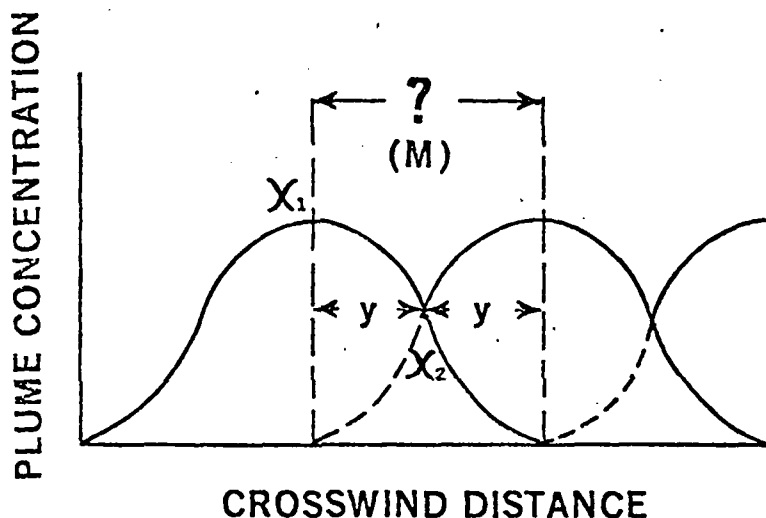


Figure A-1. Assumed Plume Concentration Cross Section.

The commonly used Gaussian distribution for a puff source is assumed to have the functional form.

$$\chi_{i+1}(x,y,0,0) = \frac{2Q_T}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z} \exp \left[ -\frac{1}{2} \left( \frac{x-ut}{\sigma_x} \right)^2 \right] \exp \left[ -\frac{1}{2} \left( \frac{y}{\sigma_y} \right)^2 \right]$$

(Ref 11)

Maximum concentrations occur when downwind distance ( ) = wind velocity (u) x time (t) and the first exponential multiplier reduces to 1.0. Assume that observed concentrations need to be at least half the true peak concentration (  $\geq 0.5$  ), then the above equation further reduces to:

$$0.5 = \exp \left[ -\frac{1}{2} \frac{y}{\sigma_y} \right]^2$$

$$\text{Then: } (\ln 0.5) \sigma_y^2 = -\frac{1}{2} y^2$$

$$\text{and: } y = -2 (\ln 0.5) (\sigma_y)^2^{1/2}$$

Therefore the distance between monitors (M) for distances from launch (x) is:

$$M_x = 2y = 2 \cdot 1.39 \sigma_y^2^{1/2}$$

$$M_x = 2.36 \sigma_y$$

Solutions for above are presented in Table A-1 where  $\sigma_y = f(x)$  is obtained from Turner's workbook (Ref 11) for neutral (D) conditions.

Table A-1. Number of Monitoring Sites and Spacing Required on a 60° Arc at Varying Distances Under Neutral (D) Atmospheric Stability.

Distance (km)	$\sigma_y^1$ (m)	Site Spacing <sup>2</sup> (m)	Arc Length <sup>3</sup> (m)	No. of Sites Required on 60° Arc <sup>4</sup>
0.5	35	83	532	6
1	70	165	1,046	6
2	130	306	2,092	7
3	190	448	3,139	7
4	250	588	4,185	7
5	300	708	5,232	7
6	350	826	6,278	8
7	400	944	7,324	8
8	450	1062	8,371	8
9	500	1180	9,417	8
10	550	1297	10,464	8
11	600	1416	11,510	8
12	650	1534	12,556	8
13	700	1652	13,603	8
14	750	1770	14,649	8
15	800	1888	15,696	8

<sup>1</sup>Horizontal dispersion coefficient under neutral (D) atmospheric stability (Ref 11, p 8)

$$^2\text{Site spacing} = M_x = 2[1.39\sigma_y^2]^{1/2} = 2.36 \sigma_y$$

<sup>3</sup>Arc length = S = rθ (θ in radians)  
 1° = π/180 radians = .01744 radians  
 60° = 1.0464 radians  
 60° Arc length = S<sub>60</sub> = r (1.0464)

<sup>4</sup>Number of sights required on each 60° arc = N<sub>60</sub>

$$N_{60} = \frac{S}{M_x}$$

If observations can be limited to a 60° Arc at distances of 1, 3, 5, 7 and 9 km downwind, the minimum number of monitoring sites from Table A-1 is 36. Similar computations based on stable (F) atmospheric conditions decrease the plume spread and halve the maximum distance between required sites. This means that a minimum of 72 ground monitoring sites would be needed in stable atmospheric conditions.

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