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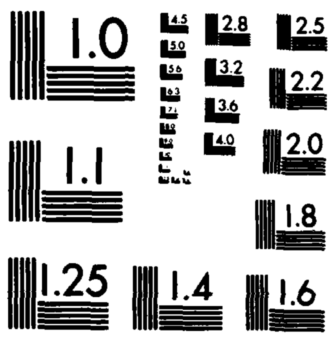

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FOR HEALTH & ENVIRONMENT

AD-A132 957

USAF SPACE SHUTTLE DISPERSION MODELLING

MARCH 1983

USAF Occupational and Environmental Health Laboratory
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

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William E Mabson
WILLIAM E. MABSON, Colonel, USAF, BSC
Commander

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Space Shuttle emits large quantities of hydrogen chloride (HCl) to the atmosphere during launch. The fate of the HCl is not well understood but includes ground deposition near the launch pad, acid washout, acid rainout, and gaseous HCl dispersion. A workshop was held at the USAF OEHL on 30 Nov to 2 Dec 1982 to discuss this phenomena and how to predict the effects which will occur during future Shuttle launches from Vandenberg AFB CA. Predictive dispersion model alternatives are presented. Recommendations include:

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Item 20 Continued

(1) Adapt the NASA model for VAFB operational use. (2) Continue work on more sophisticated models for risk assessments and to improve or eventually replace the simpler operational model. (3) Collect essential measurement data to evaluate and improve models, and (4) Form a steering committee to help insure an adequate predictive technique is operational for the first Shuttle launch from VAFB.

A

REPORT NO. 83-116EA195CDA

USAF OCCUPATIONAL AND ENVIRONMENTAL

HEALTH LABORATORY

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USAF SPACE SHUTTLE DISPERSION MODELLING

MARCH 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, the Headquarters Strategic Air Command (HQ SAC), Offutt AFB NE and Space Division in California. Recommendations in this report are aimed at the implementation of an acceptable launch oriented dispersion model 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 Kennedy Space Center, and at Vandenberg AFB for providing us with valuable information and assistance in our model evaluations. Special thanks are expressed to the panel members of the USAF Occupational and Environmental Health Laboratory Space Shuttle Dispersion Model Workshop. Their participation and expertise lead to a highly productive workshop which provided the basis for much of this report.

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 the missile system, and the transport and dispersion of material is a function of meteorological conditions at time of launch. There has long been concern for the environmental effects of exhaust materials produced by missile launches.

Comprehensive in situ monitoring networks have been established in an attempt to quantify these effects; however, these do not provide a predictive capability for when and where the environmental effects will occur. In addition, complex terrain, a myriad of variable meteorological conditions, and the large number of monitoring sites required to adequately define the effects sometimes lead to less than cost-effective results.

Dispersion modelling has been used to overcome several of the monitoring limitations and offers several advantages. First, dispersion modelling is not launch dependent. Data from simulated launch scenarios under a wide range of meteorological conditions can be produced and provide environmental risk assessments. Second, based on risk assessments, dispersion modelling can be used as a tool in the launch or no-launch decisions. Third, modelling can be used to define safe or potentially hazardous areas where restricted personnel access may be prudent. For these reasons, dispersion modelling has been selected for use to supplement monitoring efforts at Vandenberg AFB (VAFB).

The USAF Occupational and Environmental Health Laboratory (USAF OEHL) received a request to evaluate dispersion models for use at VAFB. The request was made from the USAF Hospital at Vandenberg Bioenvironmental Engineering Section (USAF Hospital Vandenberg/SGPB) through Strategic Air Command (SAC) with the concurrence of Headquarters Space Division (HQ SD). The USAF OEHL conducted a study of dispersion models and modelling programs which culminated in a Space Shuttle Dispersion Model Workshop held at USAF OEHL in December 1982. This report includes the results of the USAF OEHL study and the modelling workshop (Reference 1).

II. BACKGROUND

Missiles with solid rocket boosters emit large quantities of hydrogen chloride (HCl) and aluminum oxide (Al_2O_3) into the atmosphere. The fate of the HCl is not well understood and is the subject of on-going measurement and modelling efforts. Space Transport System (STS) launches are of greater interest than previous missiles since 2 1/2 times more HCl is emitted than from Titan III launches (Reference 2) and 300,000 gallons or more of deluge water enhances the acid deposition potential (Figure 1). Near field measurements from STS-5 suggest some of aqueous HCl may "revolatilize" for hours after a launch and form gaseous HCl concentrations of potential health concern for workers near the launch pad (Reference 3).

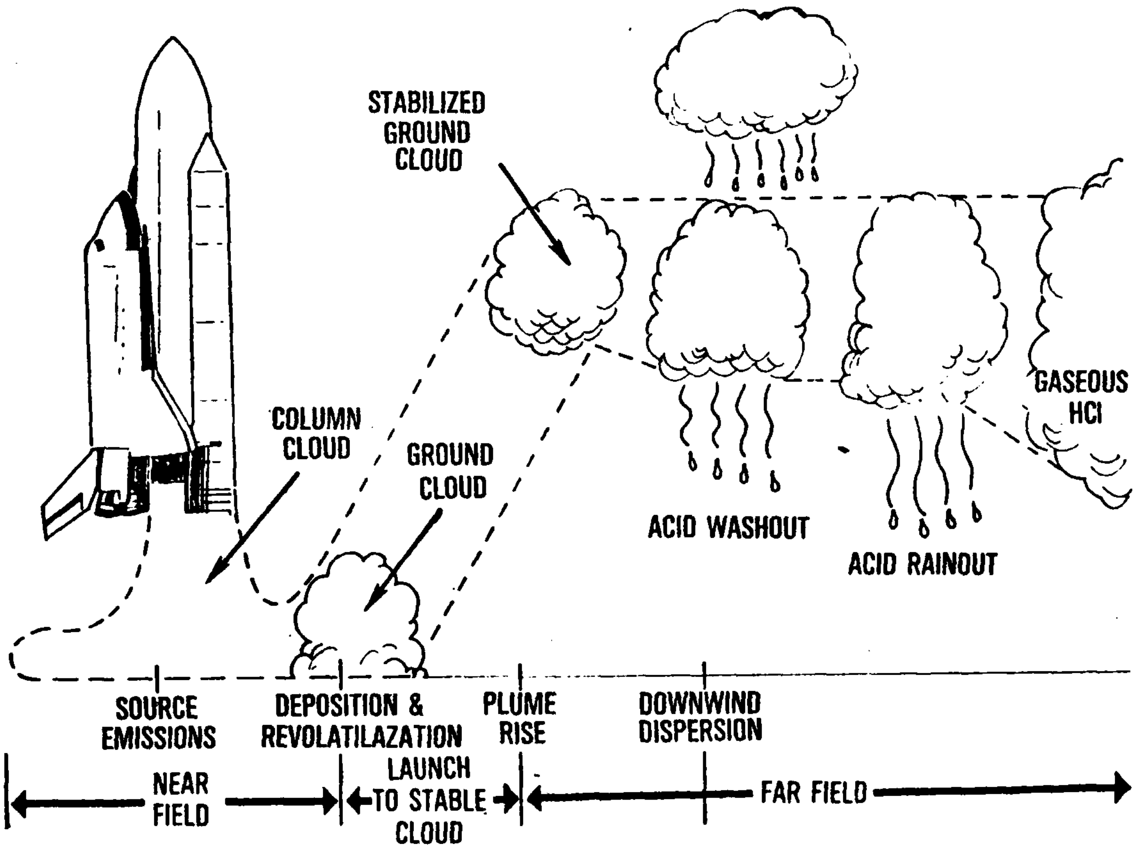

Figure 1. HCl Pathways

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 (Reference 4). Spontaneous acid rainout, in the absence of a convective cloud, has been observed at all five STS launches to date but is poorly handled by existing models. 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.

A Heated Exhaust Toxic Area Forecast (HETAF) dispersion model has been used successfully at VAFB for many years (Reference 5). However, due to simplifying assumptions it is very conservative and predicts more stringent evacuation and/or launch hold conditions than are believed necessary. The NASA Rocket Exhaust Effluent Dispersion (REED) model is more refined (Reference 6) and has qualitatively done well in launches STS-1 through STS-5. However, it does not have an acid rain prediction capability, account for VAFB terrain, or have dispersion coefficients representative of VAFB. While the need for dispersion model improvements for VAFB launches has been generally perceived for some time, a consensus position among involved Air Force offices does not exist. What is clear is that little time remains to make such model improvements prior to the first STS launch at VAFB (Figure 2).

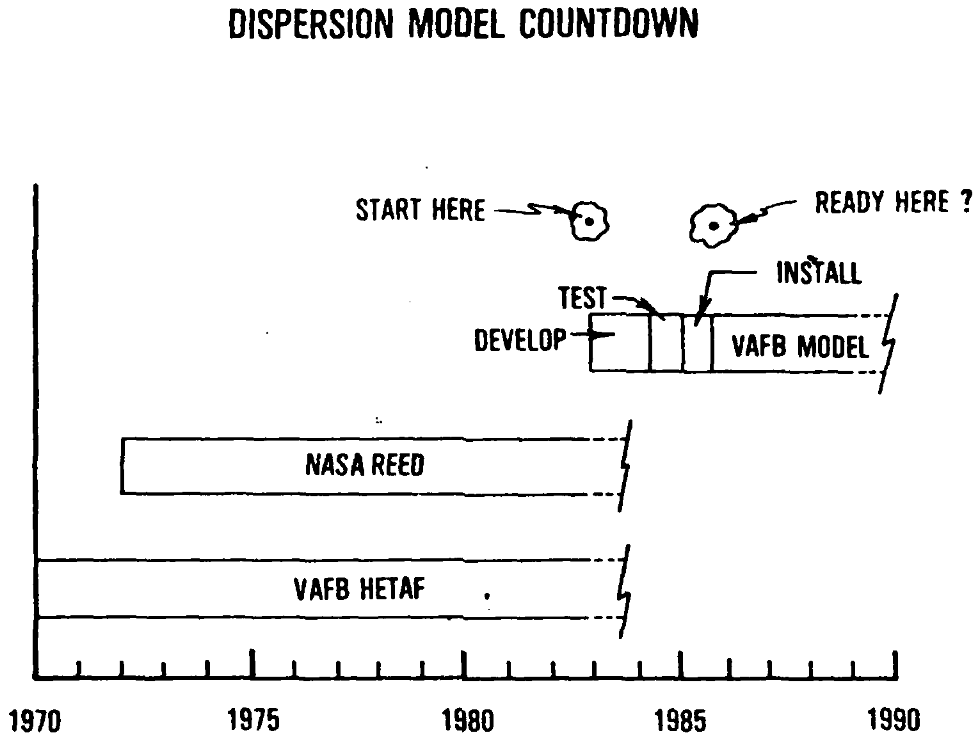

Figure 2. Dispersion Modelling Countdown for VAFB

III. DISCUSSION

A. USAF OEHL Space Shuttle Launch Dispersion Modelling Workshop

1. Workshop Objectives/Attendance

A workshop was held at the USAF OEHL, Brooks AFB TX, from 30 November to 2 December 1982. The purpose was to evaluate the need for atmospheric dispersion models and to recommend actions for model implementation prior to STS launches from Vandenberg AFB CA.

A goal of this workshop was to try to get consensus recommendations from the government meteorologists, scientists, and environmental engineers closely associated with recent efforts. Organizations and attendees are presented in Table 1. Recommendations will facilitate planning and

TABLE 1

Shuttle Modelling Workshop Attendees

Name	Organization
Lt Col Wooten	SD/DEV, Los Angeles CA
Major Reed	SD/SGX " " "
Capt Compton	SD/WE " " "
Lt Col Schneider	SD/YVA " " "
Capt Epperson	SD/YVAS, Los Angeles CA
Dr Bywater	Aerospace Corp., Los Angeles CA
Mr Dargitz	WSMC/SEY, Vandenberg AFB CA
Capt Roller	WSMC/WE, Vandenberg AFB CA
Mr Sloan	ESMC/DET 11 (2 WS), Patrick AFB FL
Mr Kunkel	AFGL/LYT, Hanscom Field MA
Dr Keller	NASA/MSFC, Huntsville AL
Lt Col Naugle	USAF OEHL/ECA, Brooks AFB TX
Capt Swoboda	USAF OEHL/ECA, Brooks AFB TX
Lt Col Ryan (Short Briefing to Attendees)	AFESC/RDV, Tyndall AFB FL

budgeting for environmental modelling efforts during STS activation and operations at VAFB. Workshop objectives were to:

a. define requirements and expectations for models,

b. review current STS model studies,

c. recommend model improvements for VAFB. Each of the three objectives will be described in the following sections.

2. Model Requirements

About one-half day was devoted to this workshop objective to define when and why dispersion models are required for Space Shuttle operations. Results are shown in Table 2. Environmental measurements and models are so interrelated that the same, or similar, requirements list can be used to prioritize future efforts of both measurements and models. Motivations to use models beyond measurements are for future predictions and extrapolation of measurements at Kennedy Space Center FL (KSC) to specific launch configurations and atmospheric conditions at VAFB. The term "model," therefore, is used broadly and applies to parametric techniques using near field empirical measurements as well as downwind dispersion modelling.

Models are required during launch periods, T-24 hours up to T-0 hours, for actions involving launch risk assessments or area restrictions (Table 2). Model applications prior to launch are required for planning for facility design, securing personnel protective equipment, or for regulatory review. While much of this planning has already been done for VAFB, modifications may be made if suggested by on-going KSC measurements and model

TABLE 2

MODEL REQUIREMENTS

WHEN ?	PRIORITY HIGH	PRIORITY MED	PRIORITY LOW	WHY ?
• DURING LAUNCH				• ACTION
				(A) LAUNCH RISK ASSESSMENT
				PERSONNEL PROTECTION
	X			NEAR FIELD
	X			FAR FIELD
				ENVIRONMENTAL PROTECTION
		X		NEAR FIELD (EQUIPMENT)
	X			FAR FIELD (BIOLOGICAL)
	X			(B) AREA RESTRICTIONS
• PRIOR TO LAUNCH				• PLANNING
				(A) LAUNCH RISK ASSESSMENT
				PERSONNEL PROTECTION
	X			NEAR FIELD
	X			FAR FIELD
				ENVIRONMENTAL PROTECTION
		X		NEAR FIELD (EQUIPMENT)
		X		FAR FIELD (BIOLOGICAL)
		X		(B) REGULATORY REVIEW
• AFTER LAUNCH				• ASSESSMENTS
		X		(A) DAMAGE CLAIMS
				(B) SCIENTIFIC UNDERSTANDING
		X		ENV IMPACT ASSESSMENT
		X		MODEL IMPROVEMENTS

applications. Model studies are also required after launches. Assessments of the validity of damage claims are likely to be needed. A scientific understanding of model and measurement results is essential to establish the degree of confidence which should be placed on operational model predictions made during future launches.

The priorities for model uses shown in Table 2 represent a consensus derived from individual submissions of all attendees. The fact that no model use received a low priority indicates that a multifaceted-modelling program is required rather than one focused on a few key issues. Operational models to be used during launch periods were given a high priority due to the immediate action oriented needs of range safety personnel. More sophisticated models used prior and after launches were given a medium priority, but are also essential for understanding and improving the operational model results.

3. **Review of STS Models and Modelling Considerations.** The second workshop objective was to review recent efforts aimed at developing an

acceptable model for STS launches. The following is a synopsis of models and model considerations discussed at the workshop (Table 3).

TABLE 3

Model Review and Modelling Considerations

Model Alternatives		
- HETAF, IMPS, MADAM	Capt Roller	Western Space and Missle Center Weather
- NASA REED	Capt Swoboda	USAF Occupational and Environmental Health Laboratory
- Diffus	Mr Dargitz	Western Space and Missile Center Safety
- Deposition Theory	Dr Keller	NASA-Marshall
- Available Numerical	Dr Bywater	Aerospace Corporation
- Advanced Numerical	Mr Kunkel	Air Force Geophysics Laboratory
Modelling Considerations		
- STS #1 to #5 Model Results	Mr Sloan	Eastern Space and Missile Center Weather
- STS 6.4% Scale Test Firings	Capt Compton	Space Division Weather
- Model Evaluation Theory	Lt Col Naugle	USAF Occupational and Environmental Health Laboratory

a. Heated Exhaust Toxic Area Forecast (HETAF). The HETAF model is a one-dimensional Gausian model that predicts the in-cloud centerline concentration of gaseous HCl at any given distance downwind of the stablized ground cloud location. Forecast concentrations at ground level are assumed to be equal to the concentration of the cloud above it and, since only centerline concentrations are calculated, the concentration is the same at all points perpendicular to the centerline and extending horizontally 3000 feet on either side of it. Terrain, vertical diffusion and physiochemical changes to the HCl are ignored. HETAF is a simplistic model developed for missile launches and is overly conservative. For this reason, launch holds based on HETAF predictions could occur when in reality there would be no need for concern.

b. Mesoscale Atmospheric Data Assimilation Model (MADAM). MADAM is a capability in the conceptual stage. The intent of a MADAM at VAFB is to improve the meteorological capability to define 4-D variations in the lower atmosphere. It is being designed to assimilate all available meteorological data and initially provide a 3-D diagnostic capability with the overall goal to provide a 3-D prognostic capability. When developed, MADAM will be a source of valuable input data to advanced dispersion models. The Mass Adjusted Three Dimensional Wind Field Model (MATHEW) can be used as an interim MADAM. MATHEW is a mass-adjusted, 3-D wind field model which was developed to provide wind fields for pollutant transport models. MATHEW takes into account local terrain and produces nondivergent 3-D winds at up to 30,000 grid points. Although theoretically appealing, MATHEW requires a computer with large storage capability.

c. Integrated Meteorological Processing System (IMPS). IMPS will provide a consolidation of all meteorological data at VAFB into a single state-of-the-art processing and display system. IMPS is scheduled to become operational in late 1985 and will contribute valuable input data to dispersion model(s) selected for VAFB.

d. NASA Rocket Exhaust Effluent Diffusion Model (NASA REEDM). The REEDM is a 3-D Gaussian model which calculates the following quantities downwind from normal and abnormal rocket launches: concentration and dosage patterns, time-mean concentration patterns, ground-level deposition due to gravitational settling or precipitation scavenging. Exhaust material is distributed in atmospheric layers by assuming the source is a vertical line source of finite extent. The REEDM makes no prediction of fallout in the near field since currently there is no predictive capability until ground cloud stabilization. The model can accept single station rawindsonde and tower data of field meteorological data such as IMPS or MADAM. The REEDM has been used with the White Sands Missile Range Terrain Model (EPAMS) to take into account complex terrain.

e. Diffus. Diffus is a 3-D numerical advection/diffusion model capable of simulating the time dependent distribution of rocket effluents in the atmosphere under many conditions. It has a numerical finite difference technique as well as a particle-in-cell technique. The model takes into account space and time-varying wind fields, surface roughness, wet and dry deposition, terrain and variable diffusion parameters. Large computers and long run times are required when operating Diffus.

f. Deposition Theory. One of the problems encountered during all Space Shuttle launches has been the acid rain fallout both on the pad and downwind. NASA at Marshall Space Flight Center has been involved in the theoretical treatment of possible mechanisms involved in this process. Atomization of deluge/fire suppression water, caused by mechanical turbulence of exhaust flows, is hypothesized as the only mechanism capable of producing droplets of large enough size to fall out immediately. A portion of these droplets are also entrained into the ground cloud where secondary mechanisms (condensation/coagulation) play a roll in the downwind acid rainout. Models currently have difficulty in treating acid rainout downwind and especially in the near field. To incorporate an acid rainout prediction capability in a model for VAFB, further study is required in the following areas: droplet number/size distribution, optimal deluge water, flame trench configuration effects, buoyant cloud rise, terrain effects, meteorology and transport mechanisms.

g. Available/Advanced Numerical Models. Although numerical models are theoretically appealing, their requirement for large computers and long run times make them currently unfeasible for the operational decision-maker. Available numerical models can be used to evaluate and improve the simpler operational models. Advanced numerical models offer the greatest promise for long range (earlier than T-24 hours) accurate predictions. Further numerical model development is required to better define the complexities of atmospheric diffusion in the areas of wind and turbulence fields, turbulent transport, influences of water vapor on buoyancy, contribution of latent heat to heat flux, and effects of uneven terrain.

h. STS-1 to STS-5 Model Results. The NASA REEDM was used as the operational model at KSC for the launches of STS-1 through STS-5. During STS-1, the lower ground cloud was predicted to move northwest of the pad up the Indian River Lagoon. Predicted and actual trajectory of the ground cloud were very close. Little monitoring data were available to confirm predicted peak deposition locations. At STS-2, the ground cloud moved south down the Banana River as predicted by the REED Model. Predictions and actual locations of maximum deposition were almost identical. Ground cloud trajectories were easterly (out to sea) for STS-3 and STS-4 which were predicted by the model. No deposition data were available. The stabilized ground cloud moved due west (inland) for STS-5 as forecast by the model; however, the area of maximum deposition was approximately one-half the distance suggested by the model. Overall, REEDM performed very well during the first five shuttle launches. Modifications in the model for use at VAFB to include revised turbulence parameters and cloud rise algorithms, the addition of an acid rain prediction capability, and the incorporation of terrain features will enhance REEDM performance.

i. STS 6.4% Scale Model Test Firings. STS launches are somewhat restricted in regards to what types of scientific studies can be accomplished. In order to quantify the cloud physical and chemical properties of the STS ground cloud, it may be required to find additional targets of opportunity beside shuttle launches. The 6.4% scale model test firings conducted at NASA Marshall Space Flight Center offer such opportunities. These firings are scaled down versions of an actual launch using proportionate main liquid engines and solid rocket booster engines in the exact launch pad configuration at VAFB. The workshop panel voiced concern for the the difficulty in scaling results from the 6.4% firings to an actual shuttle launch. The consensus was that, even though scaling would be a problem, valuable information could be obtained by studying these test firings. Of prime interest would be the effects of varying deluge water on cloud rise and near field/far field acid rainout. In addition, these firings would act as excellent tests for evaluating exhaust effluent monitoring instrumentation.

j. Model Evaluation Theory

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 about 50% of the time (Reference 7). 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 (Reference 8). A comprehensive review of dispersion modelling however, indicates a strong need for applied model evaluations which critically compare model theory with observations (Reference 9). 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 rigorous model evaluations are still useful and can lead to general acceptance of a predictive model. 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. STS Mission Abort/Termination Modelling

The Space Shuttle Orbiter carries onboard a number of fuels and oxidizers that if released to the atmosphere could cause a toxic hazard. Some of these include: monomethylhydrazine to fuel the Orbital Maneuvering System (OMS) and Reaction Control System (RCS), hydrazine to fuel the Auxiliary Power Units (APU), and nitrogen tetroxide which is used as an oxidizer for both the OMS and RCS. Accidental venting of these fuels could occur under a number of different scenarios. First, the orbiter is in the launch configuration on the pad and the mission is aborted. Off-loading of fuels and oxidizers could result in an accidental release. Second, a successful lift-off has occurred, but the orbiter aborts prior to achieving orbit and makes an emergency landing with or without mishap. Third, orbit is obtained and the mission is shortened or completed and the orbiter lands on earth with or without incident. The amount of fuels and oxidizers remaining onboard the orbiter is dependent on the different scenarios above.

The problem of accidental releases of orbiter fuels and oxidizers has been addressed and models are available to predict hazards associated with toxic chemical releases. The Atmospheric Sciences Laboratory (ASL) of the U.S. Army Electronic Research and Development Command has developed several near real-time computer programs which depict the hazard corridors which would result from the accidental release of toxic chemicals. These programs are collectively known as Toxic Corridor Prediction (TOXCOP) programs. One of these programs, Space Transportation System Toxic Corridor Prediction (STSTCP), was developed specifically for orbiter landings. It is Gaussian, requires simple meteorological input data, and runs on a desk-top calculator in less than a minute. The output of STSTCP is a toxic area corridor prediction for a toxic chemical release which will be hazardous to personnel.

The Ocean Breeze Dry Gulch Diffusion Programs (Reference 10) are a set of empirically derived diffusion equations. The Dry Gulch Program is used by Vandenberg AFB staff meteorologists to predict potentially toxic areas as the result of a chemical spill or release. This program requires minimal input data and runs on a desktop calculator.

Another method for identifying hazardous areas associated with toxic chemical releases from the orbiter is outlined in Air Weather Service Technical Report 80/003, Calculating Toxic Corridors. This method uses four techniques which are dependent on input data available. Calculations can be completed manually or with the aid of a desk-top calculator.

The problem of an orbiter mishap or an unscheduled release of toxic chemicals is real. Any of the above models can adequately predict hazardous areas. Consideration should be given to having these models available at orbiter primary, alternate and emergency landing sites and also available to operational decision makers in the event that an orbiter mishap occurs at some remote location.

IV. RECOMMENDATIONS

A. Use NASA REEDM at VAFB

The first recommendation is to use the NASA REEDM for operational predictions during STS launches at VAFB. It is a big improvement over the HETAF model currently used. Source emissions, plume rise equations, a nonuniform vertical dispersion, multiple layers of the stabilized ground cloud, and dry deposition in addition to gaseous HCl predictions are all handled more precisely with the REEDM (Table 4).

While the model has qualitatively performed well, observations at STS-1 through STS-5 launches have not been scientifically compared to model predictions. Plume rise equation results should be compared to photographs

TABLE 4

Use NASA REED Model at VAFB (Recommendation 1)

- Incorporate STS-1 to STS-5 Observations
  - -- Plume Rise
  - -- Wet Deposition
  - -- Air $ Ground Measurements
- Adapt to VAFB
  - -- Local Diffusion Coefficients
  - -- Terrain
  - -- Deposition in Fog, Inversions, Shore Effects
- Perform Risk Assessment
  - -- Reasonable "Worst Case" Conditions

and videotapes. Wet deposition in the form of acid rain has been observed in every STS launch; yet the model was never designed to make such predictions. Near field deposition must be considered. Aircraft and ground measurements need to be compared to model results.

Adaptation of the REEDM to VAFB conditions will be required before it can be considered operational. Specific diffusion coefficients have to be determined. The rugged terrain at VAFB must be addressed, either with simple correction factors or with estimates of errors which result from neglecting terrain. The impact of special conditions such as fog, local inversions, and sea/land breeze effects on personnel and the environment should be modelled.

Additional model applications in the form of a preliminary (prior to a risk assessment with sophisticated models) risk assessment are recommended. Model runs with reasonable "worst case" meteorological conditions from Recommendation 3 may allow a deemphasis of issues such as far field gaseous HCl concentrations if such issues can be shown to be insignificant. Risk assessments with operational models and eventually sophisticated models should result in:

1. The probabilities of a cloud drifting over downwind personnel and environmental receptors of interest.

2. The likelihood of damage given those trajectories.

B. Continue Research on More Sophisticated Models

Models of greater sophistication are recommended to improve or eventually replace the REEDM (Table 5). A one or perhaps three dimensional convective model should be combined with empirical measurements to predict near field deposition and plume rise. Results are important for the revolatilization of gaseous HCl concerns which have recently been indicated.

Numerical models have fewer inherent simplifying assumptions than Gaussion models and promise improved accuracy in complex wind fields such as

TABLE 5

Use Sophisticated Models to Improve (or replace) Operational Model (Recommendation 2)

- 1-D or 3-D Convective Model for Near Field Deposition and Plume Rise

- Apply Available Numerical Models
  - -- Evaluate Operational Model
  - -- Determine Diffusion Coefficients
  - -- Perform Risk Assessment

- Develop Advanced Numerical Models
  - -- Start with Boundary Layer Models
  - -- Improve Forecasting Potential

at VAFB. Even though computer difficulties and meteorological data limitations may not allow use of numerical models during launch operational applications, these complex models are useful for prior and after launch applications. Numerical models which are currently available should be used to help determine the diffusion coefficients and evaluate the simpler operational models. They should be applied with reasonable "worst case" meteorological conditions for risk assessments which are more precise than possible with simpler models.

Advanced numerical models promise greater predictive accuracy than with current techniques. Advances in computers and remote meteorological sensing equipment may eventually make these complex techniques practical. Improvements in forecasting as well as model accuracy are benefits which should be sought in future research efforts.

C. Collect Additional Data for Models

Since all of the models considered are heavily dependent on empirical parameters, accurate collection of measurement data is critical to model performance. Much of these data are valuable alone and independent from models. Five data collection task areas are recommended (Table 6) and described in sequence.

TABLE 6

Collect Additional Data for Models (Recommendation 3)

- Engineering Calculations and Observations
  - HCl and Al_2O_3 Deposition
  - HCl Revolatilization

- Particle Size and Number Distribution
  - Air and Ground Measurements
  - Near and Far Field Measurements

- Risk Assessment
  - Worst Case Meteorological Conditions at VAFB
  - Normal and Abnormal Launch Scenarios

- Improve Meteorological Data Base at VAFB
  - Diurnal Variations at Space Launch Complex Six
  - LIDAR and Acoustic Sounder Instrumentation

- STS Simulation Studies for Model Evaluation
  - Tracer Gases
  - Titan III Missile Launches
  - 6.4% Model Tests at NASA-Marshall

Engineering calculations and observations are needed for initial model inputs. A surprise finding of the December 1982 conference at KSC was that a mass balance of HCl and water is not known to exist. The original assumption that all HCl exists as a gas in the downwind ground cloud is clearly not correct. However, neither the quantity of HCl nor the water deposited around the launch pad have been quantified. Calculations of HCl removal mechanisms (even preliminary ones) such as atomization, nucleation, condensation, wet deposition, and rainout should be produced and circulated for critical peer review.

Particle size distributions as a function of time, distance, and meteorological parameters are important to model the acid aerosol/rain phenomenon. Ground measurement efforts should be improved and integrated with aircraft measurements.

A meteorological data set of reasonable "worst case" conditions needs to be assembled from existing VAFB data (Table 6). The information can be applied both with and without complex terrain input data for risk assessments using both operational and available numerical models. Both types of model applications can then be used to identify shortcomings in the current data so that needed improvements in the meteorological system at VAFB can be incorporated in a cost-effective manner. A study of this nature would also highlight the potential deposition problems at VAFB and assist in the development of a comprehensive monitoring plan.

Downwind measurements are important for model performance evaluations to establish confidence or improve dispersion models. Aircraft, remote sensing, and ground measurements are all recommended since each method has both advantages and disadvantages. Aircraft measurements produce the most quantitative data as a function of distance, but only at cloud heights. Remote sensing of wind fields and atmospheric concentrations offers great promise, but is limited in range and requires further development and testing. Ground monitoring is best for damage evaluations, especially for acid rainout.

Events such as the 6.4% scale model tests at NASA-Marshall or Titan III launches at VAFB can be treated as targets of opportunity to measure parameters for direct use or for model input. The scale model tests should continue to be used to test measurement techniques and to study the effect of deluge water spray quantities on plume buoyancy and acid rainout. Measurements at Titan III launches should be initiated for personnel training and preliminary model evaluations prior to the first STS launch.

D. Form of a Steering Committee. Due to the limited time to get an acceptable model for the first STS launch at VAFB scheduled for October 1985, a steering committee is recommended to review and take appropriate action on all recommended modelling efforts (Table 7). This committee should meet semiannually to insure ample progress on all efforts. After a review of progress in each task, action should be taken to redirect efforts if needed. An important function of this group would be to identify "data gaps" where empirical measurements are needed for model inputs.

TABLE 7

Form a Steering Committee (Recommendation 4)

- Semiannual Meetings
- Review Modelling Efforts
- Action on Alternatives
- Identify "Data Gaps"

V. SUMMARY

Models are required for reasons as outlined in Table 2. Many candidate approaches were explored for use with Space Shuttle launches as described in Section A.3. Recommendations from the dispersion model workshop are summarized from Tables 4 through 7 as follows:

A. Use NASA REEDM with improvements for VAFB.

B. Continue research on more sophisticated model to improve or replace the NASA REEDM.

C. Collect additional data for models.

D. Formation of a steering committee for modelling efforts.

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