8.6 ENSURING ENVIRONMENTAL SAFETY FOR SPACE LAUNCH

B. F. Boyd[1], M. E.Fitzpatrick[1], C. R. Parks[2], P. N. Rosati[3] and R. W. Lamoreaux[3]

[1]45th Weather Squadron, Patrick Air Force Base, FL 32925, [2]ACTA, Inc., Cape Canaveral, FL 32920,
[3]45th Space Wing, Patrick Air Force Base, FL 32925

1. INTRODUCTION

The Air Force's 45th Weather Squadron (45 WS) provides comprehensive operational meteorological services to the Eastern Range (ER) and the Kennedy Space Center (KSC). These services include weather support for resource protection, pre-launch ground processing and day-of-launch operations for over 30 launches per year by the Department of Defense (DoD), National Aeronautics and Space Administration (NASA), and commercial launch customers. To ensure safety of government personnel and the civilian population, the Eastern Range Safety Office ingests weather data into physics models which, in turn, assess the risk of each operation. Additionally, for launches with radioactive material, the Lawrence Livermore National Laboratory (LLNL) provides radioactive fallout predictions.

Most weather support, in essence, is to assure safety of resources -- people and material. However, this paper addresses the team work required between the 45 WS, the 45th Space Wing (45 SW) Range Safety Office, and LLNL in the following areas:

(1) weather data required for the Range Safety model to forecast blast overpressure predictions in case of an accident;

(2) weather data input to models which in turn determine potential toxic hazard corridors for: ground processing operations, nominal launch operations, and catastrophic launch failures; and

(3) weather data input to models which in turn forecast potential radioactive fallout.

2. WEATHER SYSTEMS IN SUPPORT OF SAFETY

Range Safety assesses the risk of each operation at the ER. Performing risk assessments by ingesting weather data into safety models allows the Range Safety Office to ensure the safety of government personnel and the civilian population.

For the 45 WS to provide required data to the Range Safety Office, an extensive suite of instrumentation is deployed throughout the Cape Canaveral Air Force Station (CCAFS)/KSC area as described by Harms et al. (1998). The ER meteorological instrumentation includes: four independent lightning detection systems, an extensive upper-air system, hundreds of boundary layer sensors, two weather radars, and a direct GOES weather satellite receiver and display (Boyd, et al., 1999).

The current satellite receive and integrated display system, the Meteorological Interactive Data Display System (MIDDS), was installed in 1984/85 and first described by Erickson et al. (1985). Over the years it has undergone many modifications, but today is still a derivative of the University of Wisconsin Space Science and Engineering Center's (SSEC) Man-computer Interactive Data Access System (McIDAS). The original goal of MIDDS was to consolidate all meteorological data into a single data management and display system. Although that goal has yet to be fully reached, it remains valid today (Harms, et al., 2003).

2.1 Upper-Air Systems

A key system for safety support is the ER upper-air system, the Automated Meteorological Profiling System (AMPS), described by Divers et al. (2000) and Harms et al. (2003). AMPS is a balloon based sounding system using a differential code correlating Global Positioning Satellite (GPS) implementation for wind profiling. The AMPS can automatically produce wind and temperature profiles from multiple balloon flights in near real time. There are two flight elements. The high-resolution flight element (HRFE), for wind measurements only, is carried by a 2-meter Jimsphere. An inverse differential GPS approach is used for calculation of the wind and can produce a wind only profile to approximately 17 Km. The low resolution flight element (LRFE) uses standard balloons to loft a sonde that provides both wind and thermodynamic data to 25 Km or higher. The system is operated and maintained at CCAFS by the Range Technical Services Contractor. The frequency of upper-air observations varies from two or three LRFEs per day for routine forecasting needs, to a combination of 16 or more LRFEs and HRFEs in 24 hours to support a single launch. The AMPs was accepted operationally at the ER in 2004, but continues under development.

2.2 Boundary Layer Sensors

Boundary layer sensing at the ER is important for safety's risk assessments. Two systems provide data: a network of 44 meteorological towers with wind, temperature, and dew point sensors at various levels, and a network of five 915 MHz Doppler Radar Wind Profilers (DRWPs) with Radio Acoustic Sounding Systems (RASS) (Table 1 and Figure 1). Most towers are 16 to 18 m tall, with sensors at two levels. Three others are 67 m and one is 165 m with sensors at various heights. All report wind, temperature, and dew point, either each minute or every five minutes. The network of 915 MHz DRWPS as described by Lucci

---

**Corresponding Author*: Billie F. Boyd, 45 WS/SYA, 1201 Edward H. White II St, MS 7302, Patrick AFB, FL 32925-3238; e-mail: billie.boyd@patrick.af.mil

et al., 1998 and Harms et al., 1998 samples low-level winds from 120 m to 3 km every 10 minutes and produces virtual temperature profiles every 15 minutes.

Table 1
Profiler Locations

Profiler	Name	Site	Comment
1	RWP 0001	Launch Complex 17 (South Cape)	Southern Most
2	RWP 0002	False Cape	Coastal, North Side of the Cape
3	RWP 0003	Kennedy Parkway (Merritt Island)	Intermediate Inland
4	RWP 0004	Mosquito Lagoon	Northern Most
5	RWP 0005	Tico Airport	Western Most

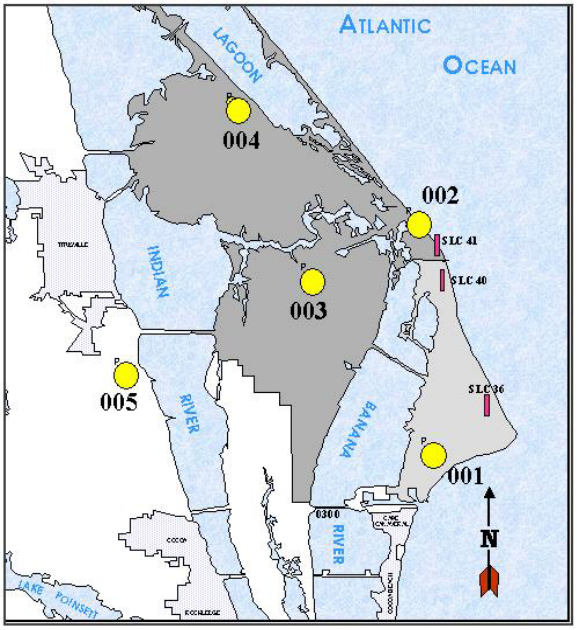

Figure 1. 915 MHz Doppler Radar Wind Profiler Locations

2.3 Other Systems

While the ER lightning systems, as described by Harms et al. (1997), may be the most unique of all local weather systems, they do not play a significant role in toxic or blast forecasting. Other weather systems, such as radar and Geostationary Operational Environmental Satellite (GOES) imagery, while not used directly, do aid in the final determination of the actual toxic forecasts. A case in point was the Titan IV B-41 launch countdown on 27 Feb 01 (Boyd et al., 2002). The 915 MHz Profilers were invaluable for providing toxic hazard support. They allowed for the minimization of spatial and temporal forecast uncertainties, which facilitated critical decisions regarding launch viewing from the NASA Causeway, while ensuring the safety of viewers. However, when the RWP0004 profiler showed northeasterly flow in the surface layer, which appeared to be inconsistent with the other profilers and not normal for the time of day; the GOES visible image at 1745Z (1245L), as shown in Figure 2, provided an explanation for this dissimilar northeasterly wind profile.

The tip of Cape Canaveral can be seen near the center of the image in Figure 2. There are cumulus clouds over the Florida peninsula; clear skies over the Atlantic Ocean to the south for about fifty miles from the coastline; and low clouds over the Atlantic Ocean to the north of the Cape. These low clouds east of Volusia County formed overnight from the outflow of showers off the tip of the Cape. The overnight showers moved out to sea from the Cape southward, but left a low cloud deck over the ocean waters to the north. As the CCAFS and KSC surface temperatures rose during the morning hours of the 27th, these low clouds moved onshore to the southwest which mitigated the rising surface temperatures. The Figure 2 visible image shows this low cloud mass over the Mosquito Lagoon. It is these low clouds moving in from the northeast at 1800Z that validated the RWP0004 northeasterly surface winds.

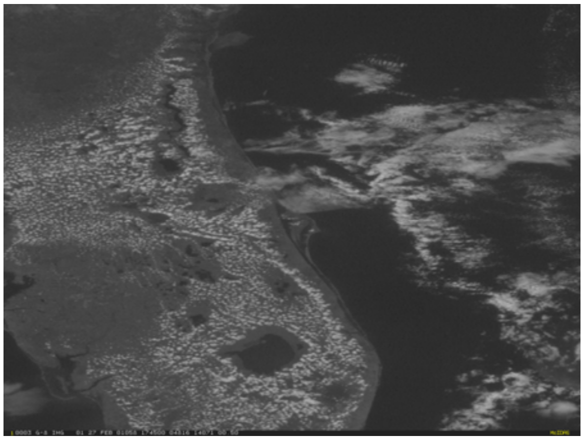

Figure 2. 27 Feb 01, 1745Z, Florida GOES Satellite Visible Image

The radar observed tracks generally provide verification of the predicted plume tracks. The WSR-88D weather radar was especially valuable in tracking the abort plume from the Delta II rocket failure on 17 January 1997 (Parks and Rosati, 2000).

National numerical weather model data (grids) are relayed by MIDDS to Range Safety. That data is in turn input to ER safety analysis models. Data from boundary layer and upper-air sensors are also input directly, or modified as “forecast data”. Range Safety personnel then run models for blast focusing and toxic corridors to make an assessment call to the Launch Decision Authority regarding safety of both on-base and off-base personnel.

3. BLAST DAMAGE ASSESSMENT

Early in the space program, intermediate range airblast effects for launch vehicles presented little or no risk to nearby areas. As population density and potential explosive yields increased, the risk associated with this hazard became more significant. The original solution was to impose very conservative launch limitations based on wind direction. To eliminate this overly conservative approach, the Blast Assessment Model was developed and put into operational use at the ER in 1981 to evaluate inadvertent detonation hazards as a function of meteorological conditions (Daniels and Overbeck, 1980, Boyd and Overbeck, 1987). From 1982 to 1994, the assumptions and estimates used in this program were further evaluated for accuracy. Research into TNT equivalencies of different failure modes for each vehicle, window breakage mechanics, shard impacts on personnel, and population data bases contributed to the development and refinement of the BLASTX model used on the ER and the BLASTC model used on the Western Range (WR). These BLAST risk analysis codes have now been extensively revised. In particular, the BLASTX and BLASTC codes have been combined into a common code called BLAST Distant Focusing Overpressure (BLASTDFO), which can be run for launches on the ER or the WR. However, the terrain data types and formats remain unique for the two ranges. New features include the ability to compute window breakage and risk – both on and off base, user capability to increase the number of Monte Carlo loops, and the ability to ingest vertical profiles of meteorological data forecast by the North American Mesoscale (NAM) model (previously Eta). A new tool called GlassDFO includes new models for dual pane and filmed windows. In addition, a new propellant explosive yield histogram generation tool has been developed to simulate vehicle impacts and predict explosive yields and associated probabilities.

3.1 Theory

Overpressure waves differ from ordinary acoustic waves because they travel supersonically through the air; but at sufficient distances from the source, where the blast overpressures have dissipated to levels below a few pounds per square inch (psi), their propagation is nearly identical to that of acoustic waves. Therefore, the same basic principles of physics, i.e. Snell's Law that describe the propagation of acoustic waves, are used in BLASTDFO to predict effects of blast waves at intermediate ranges.

Acoustic waves propagate through the atmosphere as wavefronts along ray paths determined by the local sonic velocity. Using the meteorological conditions encountered in the vicinity of the launch site, one can plot the ray paths for various acoustic source positions (launch pads) and azimuthal directions toward population centers located away from the launch site or rocket trajectory. Estimates of the relative attenuation or enhancement of blast overpressure (or acoustic energy) are based on the divergence or convergence of these ray paths at each affected site. The predicted overpressure is correlated with the expected damage to windows to provide an expected casualty (E_c) output.

3.2 Atmospheric Effects

Four atmospheric parameters (and in particular, how they change in the vertical) play major roles in acoustic wave propagation: wind, temperature, relative humidity, and pressure (Boyd et al., 2000). These parameters determine the local speed of sound and sonic velocity for the existing or modeled atmosphere. The speed of sound is the rate at which acoustic waves travel in still air, whereas the sonic velocity includes the directional effect of the wind. Under some conditions, the sonic velocity profile (the variation of sonic velocity with altitude) may create focusing of acoustic waves at specific regions on the ground. The relationship of the sonic velocity profile and the focusing of acoustic waves is based on Snell's Law. When the sonic velocity decreases with altitude, the wavefronts are refracted upward and the ray paths bend away from the ground. When the sonic velocity increases with altitude wavefronts are refracted downward and the ray paths bend toward the ground.

An infinite variety of sonic velocity profiles is possible – various types are illustrated in Figure 3. For an idealized case where the sonic velocity is constant at all altitudes (isotropic condition), an acoustic wave expands spherically away from a point source with the decrease in sound pressure level being inversely proportional to the range squared (at least to the first order). For a standard earth atmosphere, neglecting wind effects, the sonic velocity decreases with altitude (gradient condition) so the overpressure decreases more rapidly (higher attenuation) than for an isotropic atmosphere; the acoustic ray paths bend upward and little energy returns to ground. Under gradient conditions, airblast overpressure levels can be expected to be of little consequence at population centers, given the distance of those areas from the launch pads.

In many cases, for the real atmosphere, an inversion condition exists, where temperature, and hence, sonic velocity increases with altitude above ground. This is frequently true for early mornings. Near surface winds may also create inversion propagation conditions in the downwind direction. Within the inversion layer, the acoustic ray paths are refracted downward, back toward the ground; and, therefore the energy along the ground is dissipated more slowly (lower attenuation) than under the isotropic condition. Under inversion conditions, in the event of a large inadvertent detonation, strong blast overpressures may be expected at significantly greater distances from the launch pad.

The most severe condition for a significant blast wave overpressure occurs when a more complex sonic velocity profile (resulting from a combination of temperature and wind effects) causes ray paths that initially bend upward, to turn back toward the ground within a higher altitude inversion layer and create a caustic focusing region. The atmosphere acts as an acoustic lens, which focuses the acoustic wave energy at particular ground (or above-ground) locations. In this case, due to the simultaneous arrival of countless ray paths to the same point – the caustic – simple geometric ray theory predicts infinite amplification of the overpressure. In reality, infinite amplification never occurs (partly because of lateral and temporal variability in the atmospheric conditions caused by turbulence), but strong amplification in the focusing region is observed. The ray theory identifies where such focusing would occur, based on concentration of the ray paths, and provides the basis for the BLASTDFO assessment prediction model. The actual overpressure levels (amplification) predicted by the BLASTDFO model are based on empirical attenuation relationships derived from the airblast test program conducted at the Cape Canaveral Air Force Station.

Currently, for actual launch support many cases are run using a Monte Carlo technique. This technique takes into account vehicle failure probability and allows a risk management based approach to be used to assess the true danger from a potential explosion and the accompanying airblast overpressure.

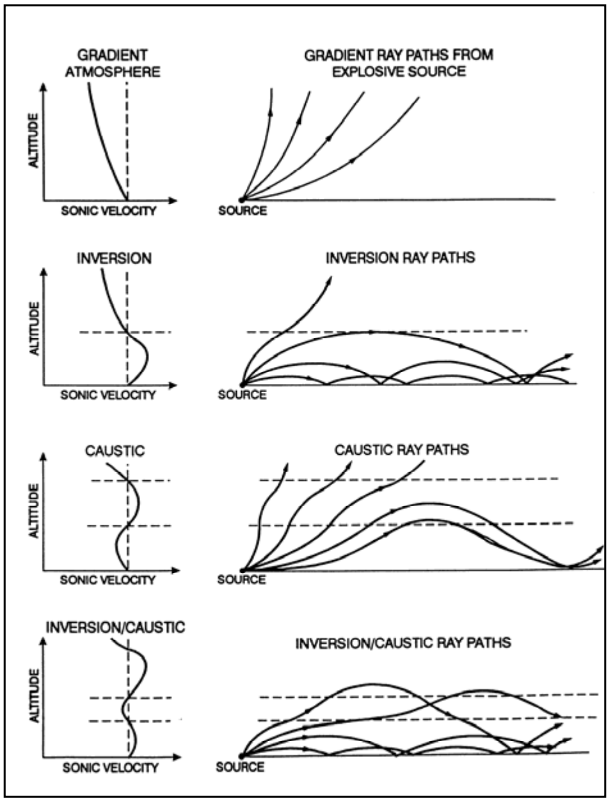

Figure 3. Types of Propagation Conditions

4. TOXIC HAZARD ASSESSMENT

Large vehicles such as the Air Force's Titan IV rocket and NASA's Space Shuttle are boosted by solid rocket motors which exhaust substantial amounts of hydrogen chloride (HCl) gas during a normal launch. The Titan IV also carried more than 400,000 pounds of liquid hypergol propellants, which could be released to the atmosphere in the event of a catastrophic failure. While more recent programs (Delta IV and Atlas V) do not employ large amounts of hypergolic propellant on their core vehicles, certain configurations do utilize solid rocket boosters during their ascent, which can also produce substantial concentrations of HCl in the event of a catastrophic launch abort. Ground operations involving fuel and oxidizer storage and transfer activities also pose a risk of toxic emissions. Restrictive federal and local guidelines force stringent human exposure limits for which accurate toxic hazard corridor (THC) predictions must be prepared to protect both on-base and off-base populations. These predictions support launch and ground operations, emergency response, and long-term planning (facility siting, launch availability studies, etc.). However, launch delays due to predicted THCs are increasingly becoming a concern. Any delay or postponement of a launch causes significant cost impacts.

4.1 Launch Day Toxic Modeling

A deterministic Gaussian-type model (Rocket Exhaust Effluent Diffusion Model (REEDM)) is currently used to predict THCs in support of launch operations (Parks et al., 1996). A new three-dimensional puff-type model known as RD3D (Range Dispersion Three-Dimensional) has been developed for Range Safety by ACTA, Inc. The new model is currently undergoing testing, with plans to have it replace REEDM in the 2006 time frame. Whichever model is used by Range Safety to produce a deterministic toxic plume, the model must be applied to large heated sources of toxic emissions such as nominal launch clouds, catastrophic failures which result in either a conflagration or deflagration, and inadvertent ignition of rocket propellants. The current code was first developed for the Air Force by the H. E. Cramer Company based on the NASA Multi-layer Diffusion Model (Boyd and Bowman, 1985). Key factors determining predicted values include cloud source terms, cloud rise and stabilization, cloud transport, cloud diffusion, atmospheric chemistry, and meteorological elements.

A deterministic model predicts vehicle-specific source term cloud characteristics for both nominal launch and catastrophic failure cases, without taking into account the probability of occurrence. Major toxic components of concern are HCl from solid rocket motors, during either a nominal launch or a low altitude failure, and hypergolic fuel and oxidizer components (various hydrazine's and nitrogen tetroxide (N_2O_4)) from a catastrophic failure. Cloud rise and stabilization are predicted by the deterministic code from initial cloud characteristics and the meteorological profiles of temperature, humidity, and wind. The altitude of the predicted cloud stabilization and the distribution of cloud mass about the stabilization height strongly influence the predicted ground-level concentrations. As presently run, REEDM uses a single mean wind vector within a vertical layer to predict the downwind trajectory of the stabilized cloud. This vector is calculated by averaging wind vectors from the measured wind profile. Atmospheric turbulence parameters based on climatology are used to predict the rate at which the elevated cloud components will diffuse down to ground level. The prediction of ground-level concentration isopleths, in parts-per-million (PPM), is highly dependent on the diffusion rate used by the model.

A standard rawinsonde data file, with its mandatory and significant level data, is processed to determine values at the surface (16 feet) and every 100, 500, or 1000 geometric feet to build an input file to REEDM.

4.2 Non-Launch Day Toxic Modeling

Toxic spills not heated by fire or explosion are referred to as cold spills, and can occur on non-launch days, particularly during propellant transfer operations in support of launch vehicle processing. Tools for cold spill hazard assessment at the ER are provided by the Meteorological and Range Safety Support (MARSS) system (Taylor et al., 1998). MARSS provides users with color graphics displays of meteorological and safety-related data and models for predicting concentrations and toxic corridors resulting from cold spills of various chemicals.

The Ocean Breeze/Dry Gulch (OB/DG) model in the MARSS system is one of two models used to assess cold spill diffusion at the ER. The other is the Hybrid Particle and Concentration Transport (HYPACT) model, a pollutant trajectory and concentration model. OB/DG is based on a least-squares multiple linear regression fit to tracer data collected in the Ocean Breeze (Cape Canaveral, FL), Dry Gulch (Vandenberg AFB, CA), and Prairie Grass (O'Neill, NE) experiments (Nou, 1963). The OB/DG equation is inverted to solve for the distances downwind to the exposure limits for the chemical released. Isopleths of ground-level concentrations corresponding to three concentration levels are then calculated by assuming a Gaussian distribution in the crosswind direction. A wedge-shaped toxic corridor is also calculated. The length of the corridor is estimated from the linear regression and adjusted for the appropriate atmospheric stability class. Its width is four times the standard deviation of wind direction (Taylor et al., 1998). Within the MARSS system, OB/DG information is embedded into a two-dimensional wind field grid to produce toxic hazard corridors for assessment of potential hazards, anomalous emissions, or planned nominal exhausts. Manual adjustments to the length and width of OB/DG outputs are often necessary to account for the various atmospheric stability classes, continuous versus puff releases, and the three-dimensional wind field.

4.3 Current Toxic Model Shortfalls and Improvement Efforts

An assessment of all dispersion models used at the ER/KSC was documented by Hosker et al. (1993). They noted that neither OB/DG nor REEDM can adequately deal with vertical changes in wind direction or speed, a major weakness in a complex flow region such as the KSC/CCAFS area. Likewise, OB/DG can not deal with the dense gas effects that may be important in the case of a large, fast release of N_2O_4. The source strength submodel of OB/DG uses evaporation rates empirically derived from actual spill measurements as a function of pool area and surface temperatures. However, these rates are fixed for a particular class of chemicals and factors such as surface temperature, wind, and individual chemical characteristics that affect evaporation rate, but may not be accounted for in other conditions. While the primary argument in favor of the OB/DG model is that some of the tracer data used in the model derivation were collected in the KSC/CCAFS area, this strength is also the model's main weakness because use of the model is limited to cases for which its data-based statistics are valid. The Ocean Breeze tracer data were mostly collected during daytime periods of unstable onshore flow. Under other conditions, such as stable flow at night, OB/DG may be inadequate. Also, the Ocean Breeze tracer measurements only extended to downwind distances of about 5 km. Extrapolating the OB/DG model beyond that distance would be risky.

The current deterministic model (REEDM) is a unique model based on relatively simple physics. It has a long development history with NASA and the Air Force. To help in assessing the model's strengths and weaknesses, the Atmospheric Turbulence and Diffusion Division of the National Oceanographic and Atmospheric Administration's (NOAA) Air Resources Laboratory (Eckmam et al., 1995) conducted studies of MARSS and REEDM version 7.05 (currently -- July 2005 – Range Safety is using REEDM version 7.13). The NOAA study concluded that the basic approach used by REEDM to model the diffusion of rocket-exhaust clouds is physically sound. However, specific features of the model were determined to have inconsistencies and shortcomings. The NOAA study also found MARSS to be at risk of under-estimating cold spill exposures. As a result of the NOAA findings, Range Safety acquired significant model improvements and new computer platforms for the Eastern Range Dispersion Assessment System (ERDAS). Additionally, modifications to REEDM led to the current Version 7.13 with the capability to ingest additional measured parameters, as they become available.

Some NOAA-reported deficiencies and Range Safety's corrective actions include:

(1) The approach which REEDM uses to account for vertical variations in atmospheric parameters such as wind speed and direction is overly simplistic. This was deficiency was corrected in version 7.07.

(2) The model does not properly account for the effects of turbulence on the alongwind diffusion of the ground cloud, and probably under estimates the effect of wind-speed shear on the alongwind diffusion. This was deficiency was also corrected in version 7.07.

(3) The empirical relations used by REEDM to estimate turbulence parameters (when no direct

measurements are available) are based on field measurements which may not be representative for all conditions at CCAFS. Turbulence measurements by wind profilers are being pursued, with hopes that delivery of the weather portion of the Range Standardization and Automation (RSA) project (Harms et al., 2003) will allow for this capability. RD3D code has been written to be able to ingest this data once it becomes available.

(4) REEDM tends to ignore low-level temperature inversions, because they are unlikely to have much effect on the buoyant cloud rise. However, these inversions can still be important, since they affect the vertical structure of the ambient turbulence. This problem was corrected in the RD3D model.

Beyond the NOAA findings, other factors limit REEDM's accuracy. Uncertainties in the chemical and physical interactions of the hypergols, important issues for the launch abort scenario, necessitated the embedding of the NASA Lewis Chemical Equilibrium Code into REEDM Version 7.07 and later versions. Gaps in knowledge of hydrazine and nitrogen dioxide (NO_2) chemistry and the affects of various air entrainments into the rising plume still exist, particularly in an abort plume environment.

A suite of models and upgraded hardware will replace REEDM and OB/DG on the Eastern Range. Hardware upgrades include the Eastern Range Dispersion Assessment System (ERDAS), formerly known as the Emergency Response Dose Assessment System described by Tremback et al. (1994). ERDAS, operational at CCAFS since 1999, is a system configured to produce routine mesoscale meteorological forecasts and enhanced dispersion estimates for the KSC/CCAFS region, and run the entire suite of Range Safety physics models used to assess toxic and blast hazards.

ERDAS includes two additional major software systems which are run and accessed through a graphical user interface. The first is the Regional Atmospheric Modeling System (RAMS), a three-dimensional, multiple-nested grid mesoscale numerical weather prediction model. The second is HYPACT. For modeling launch scenarios, HYPACT obtains the plume information (source term through cloud stabilization) from REEDM. HYPACT then diffuses the plume using the RAMS-predicted wind and potential temperature fields to advect and disperse the particles vertically and horizontally (Evans et al., 1996), and has at times been used as a replacement for OB/DG.

As mentioned earlier, another new development is the Range Dispersion Three-Dimensional Model (RD3D) developed for Range Safety by ACTA, Inc. RD3D is a deterministic puff-type model designed to simulate the formation, buoyant cloud rise, transport and diffusion from rocket launches and catastrophic failures, while incorporating the best features of REEDM and correcting the most significant deficiencies. The model uses meteorological data from rawinsondes, towers, radar profilers and ocean buoys to construct 3-dimensional diagnostic wind and turbulence fields that govern exhaust cloud dispersion. RD3D can be run with a single rawinsonde as input, but can also incorporate wind tower, wind profiler, and three-dimensional forecast data from models such as RAMS or the Fifth-Generation NCAR / Penn State Mesoscale Model (MM5), which will be available on ERDAS platforms once RSA has completed their weather product delivery. The model provides the capability to model rocket exhaust dispersion through a three-dimensional diagnostic wind field. RD3D has undergone extensive testing and is now being evaluated operationally. This model is planned to become the primary deterministic model for both launch day and non-launch day toxic modeling support, and will reside on the ERDAS operational platforms.

4.4 Toxic Launch Commit Criteria (LCC)

Toxic Launch Commit Criteria (LCC), in accordance with public safety risk management policies established by Federal law, were developed using a probabilistic model known as the Launch Accident Toxic Risk Assessment (LATRA) model. LATRA was developed for Range Safety (See et al., 1995) to perform numerous Monte Carlo runs within a single LATRA run, considering the consequences of numerous launch failure modes of various probabilities and uncertainties in weather inputs and demographic factors. LATRA computes casualties as a function of occurrence probability as well as the integrated casualty expectation. LATRA identifies downwind population data by susceptibility group, sheltering capability, and toxic hazard exposure response functions (ERFs) by health effect severity level for each type of susceptible population. Sensitive population subgroups include children, the aged, and those with respiratory disorders such as bronchitis. Expected numbers of affected individuals are generated by three health effect severity levels (mild, moderate, and severe) for both healthy and sensitive populations. This computation enables toxic risk assessment to be managed along with other sources of risk, such as from blast overpressures and debris impacts.

The 45 SW's on-base toxic LCC is based solely on deterministic model runs since base personnel can be directed into certified shelters. The 45 SW policy details procedures to ensure all CCAFS personnel are protected from possible exposure to hazardous material contained in the exhaust plume or catastrophic launch abort debris cloud from a vehicle launched from either CCAFS or KSC. Range Safety will either shelter on-base personnel in approved launch shelters, or direct them to move away from a Potential Hazard Corridor, if established on-base toxic LCC are exceeded. This procedure significantly minimizes launch scrubs due to a violation of the on-base toxic criteria. The policy mandates employee education, sheltering/evacuating personnel and visitors, and notification prior to, during, and after launches.

The 45 SW's off-base toxic LCC are based on not exceeding a constant (average) risk level over the varying population densities within Brevard County. The risk agreed to between Eastern Range Safety and the

Local Emergency Planning Committee, Brevard Emergency Management Center (BEMC) is based on the conservative presumption that the public notifications of the toxic hazard control process between 45 SW and BEMC will result in incomplete sheltering of personnel during a launch accident.

As stated in paragraph 2.3, National numerical weather model data (grids) are relayed by MIDDS to Range Safety. That data is in turn input to ER safety analysis models. Data from boundary layer and upper-air sensors are also input directly, or modified as “forecast data”. Range Safety personnel then run models for toxic and blast overpressure to make an assessment call to the Launch Decision Authority regarding safety of both on-base and off-base personnel.

5. RADIOACTIVE FALLOUT SUPPORT

Missions to the outer planets cannot rely on solar power, and thus require radioactive material for power and/or heat. Use of radioactive material onboard requires additional levels of safety oversight from the earliest planning through launch countdown. Prelaunch planning for this type of mission is accomplished via the Interagency Nuclear Safety Review Panel (INSRP), on which both the 45 SW Range Safety and the 45 WS serve. The day-of-launch radiological release support is the responsibility of the Department of Energy (DoE) and is accomplished by DoE’s designated representative with the assistance of Department of Defense’s (DoD) 45 WS (Boyd et al., 1998).

One recent interplanetary mission was Cassini, launched aboard a Titan-IVB/Centaur at 4:43 a.m. EDT, 15 October 1997. This began a 6.7-year journey (Figure 4) which arrived July 2004 at Saturn for a four-year scientific exploration. Radiological support for that mission was accomplished by the LLNL with the help of the 45 WS (Boyd et al., 2004).

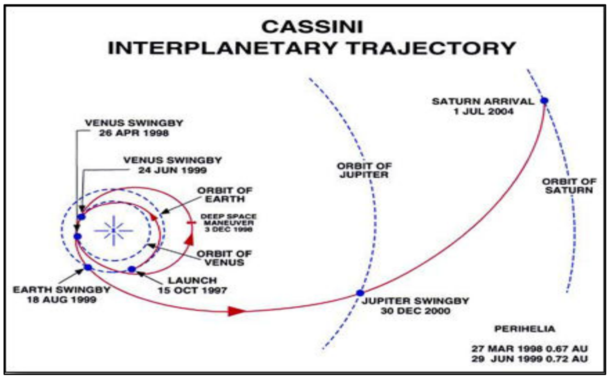

Figure 4. Cassini Trajectory

All space launches with radioactive material onboard require Environmental Impact Statements (by the National Environmental Act and NASA policy). For the Cassini mission, NASA completed the Environmental Impact Statement in June 1995 and a supplement in June 1997. Consistent with long-standing Presidential policy, the DoE prepared a comprehensive Safety Analysis Report over a seven-year period. The INSRP confirmed the safety analysis conducted for the mission was comprehensive and thorough. The INSRP is a Presidential appointed panel, with representatives from DoE, NASA, DoD, the Environmental Protection Agency (EPA), and a technical advisor from the Nuclear Regulatory Commission.

5.1 National Atmospheric Release Advisory Center (NARAC)

Lawrence Livermore’s NARAC mission is to provide timely and credible advisories for radiological (and other) hazardous releases to the atmosphere. The NARAC system simulates the release of some material in the atmosphere and predicts its movement downwind. The system calculates the consequences to health due to the release, based on known characteristics of the material (Pace, 1998).

NARAC has been designed to respond in near-real-time to releases anywhere worldwide. The flexible NARAC system has been used for many types of actual or exercise events (nuclear power plants, weapons, volcanoes, missile launches, oil fires, and many others). For non-routine applications, such as support to space launches, NARAC’s support is improved if equipment is deployed and plans are made before any potential release.

The NARAC system (Sullivan et al., 1993) uses topographical and meteorological data to generate a time-varying series of three-dimensional mass adjusted wind fields, which are used to drive the Atmospheric Diffusion Particle-In-Cell (ADPIC) Lagrangian particle dispersion model. ADPIC is a three-dimensional model which accounts for the effects of spatial and temporal variation of mean wind and turbulence, gravitational settling, dry and wet deposition, and initial plume buoyancy and momentum.

NARAC personnel use horizontal and vertical cross-sections through the plume along with other displays to study and evaluate the structure of the plume, in order to decide whether the models are working optimally. The NARAC models have been extensively evaluated during many field tracer studies, and the results show the system is highly accurate when the source term is well known and the meteorological conditions are well represented (Foster, et al., 1990).

5.2 NARAC Cassini Support

For the Cassini launch, four NARAC scientists deployed to Florida, along with three NARAC computer systems (Pace, 1998). All model calculations were done at the Lawrence Livermore National Laboratory (LLNL), but the on-site personnel assisted in interpretation of the model results and acted as interfaces to the staff at LLNL, describing current conditions and channeling requests for support. To use all the data available from the ER/KSC area, NARAC developed procedures to retrieve the data from MIDDS automatically several times each hour, and created a new software package allowing display and editing of the tower, balloon, and profiler data retrieved from MIDDS. Using this package, NARAC personnel performed quality control of the MIDDS data before their use in the NARAC models. The MIDDS data retrieval and all communications between LLNL and the deployed personnel and equipment were done over dedicated communications circuits. The 45 WS also supplied NARAC with forecasted upper air data (soundings). The full set of data from the MIDDS system provided excellent spatial (horizontal and vertical) and temporal resolution.

For Cassini, NARAC made its first operational use of its own execution of the Navy Operational Regional Atmospheric Prediction System (NORAPS), a prognostic model. NORAPS was developed by the Naval Research Laboratory, has been used operationally for several years at the Fleet Numerical Meteorology and Oceanography Center, and was supplied to NARAC through an interagency support agreement.

NARAC had access to four types of meteorological data: forecasted soundings; MIDDS reports of local sensors; NORAPS output; and surface and upper air observations from the region, which NARAC collected from the Air Force Weather Agency. NARAC has automated procedures to retrieve, store, and use each of these types, and can run its models with these sources individually or in any combination. Except for changes to accommodate the new meteorological data sources, NARAC used its existing, well-tested, validated models to support Cassini (Pace, 1998).

6. SUMMARY

To ensure safety of government personnel and the civilian population, the Range Safety Office of the 45th Space Wing (45 SW) must assess the safety risk of each operation at the Eastern Range. A key element is weather data ingested into the safety models for risk assessments. A summary of current weather systems and data provided to Range Safety, and the models/techniques used by Range Safety to make those assessments have been presented. The Air Force's 45 SW weather and safety personnel continue to improve methods that ensure maximum safety while maintaining a fast paced launch schedule.

7. REFERENCES

Boyd, B. F., and C. R. Bowman, Jr., 1985: Diffusion Modeling In Support Of the Space Shuttle. JANNAF Safety & Environmental Protection Subcommittee Meeting, Monterey, CA, 4-8 Nov 85 (CPIA Publication 436), pp 227-234.

________ and K. B. Overbeck, 1987: Forecasting Atmospheric Sonic Propagation at the Eastern Range, Paper 87-0012, *AIAA 25th Aerospace Sciences Meeting & Exhibit*, Reno, NV.

________, J. W. Weems, D. E. Harms, R. M. Lucci, M. E. Fitzpatrick, & J. C. Pace, 1998: Specialized Weather Support for Space Launch of Nuclear-Powered Payloads, Joint Army-Navy-NASA-Air Force (JANNAF) S&EP Meeting, Houston, TX, 21-24 Apr 98, CPIA Pub 674, Vol I, Apr 98, 537-545.

________, D. E. Harms, M. E. Fitzpatrick, R. P. Stout, P. N. Rosati, D. D. Berlinrut, C. R. Parks, and K. B. Overbeck, 1999: Weather Support To Range Safety, Joint Army-Navy-NASA-Air Force (JANNAF) S&EPS Meeting, 26-30 Apr 99, San Diego, CA, CPIA Pub 687, Vol I, 59-69.

________, D. E. Harms, P. N. Rosati, C. R. Parks, and K. B. Overbeck 2000: Weather Support To Range Safety For Forecasting Atmospheric Sonic Propagation, Ninth Conference on Aviation, Range, and Aerospace Meteorology, 11-15 Sep 00, Orlando, FL, 432-437.

________, D. E. Harms, K. A. Winters, P. N. Rosati, C. R. Parks, and K. B. Overbeck, 2002: Boundary Layer Influences on Forecasting Toxic Corridors at the Eastern Range in Support of Space Launch, Tenth Conference on Aviation, Range, and Aerospace Meteorology, 13-16 May, Portland, Oregon, 182 – 185.

________, J. W. Weems, and W. P. Roeder, 2004: Weather Support for the Cassini Mission to Saturn,11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA, 4-8 Oct 04, Paper P7.1.

Daniels, R. D. and K. Overbeck, 1980: Development of a Blast Damage Assessment Model, J. H. Wiggins Co. Technical Report No 80-1351, March 1980.

Divers, R.P., A.Z. Chandler, P. Viens, K. Bzdusek, G. Herman, R. Hoover, and T. Mitchell, 2000: Automated Meteorological Profiling System (AMPS) Description, Ninth Conference on Aviation, Range, and Aerospace Meteorology, Orlando, FL, 11-15 Sep 00, Paper 8.1.

Eckman, R. M., C. J. Nappo, and K. S. Rao, 1995: Rocket Exhaust Effluent Diffusion Model (REEDM) Verification and Sensitivity Study. NOAA Technical Memorandum, ATE AL (Draft).

Erickson, J. E., B. F. Boyd, and J. W. Oliver, 1985: Meteorological Interactive Data Display System (MIDDS) Data Base, Preprints International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, Los Angeles, CA, Amer. Meteor. Soc., pp 173-175.

Evans, R. J., C. J. Tremback, and W. A. Lyons, 1996: The Implementation and Evaluation of the Emergency Response Dose Assessment System (ERDAS) AT Cape Canaveral Air Station/Kennedy Space Center, Preprints, Ninth Joint Conf. on the Applications of Air Pollution Meteorology with the AMA, Atlanta, GA, Amer. Meteor. Soc., pp 193-197.

Foster, K. T. and M. H. Dickerson, 1990: An Updated Summary of MATHEW/ADPIC Model Evaluation Studies, UCRL-JC-104134, Lawrence Livermore National Laboratory, Livermore, CA.

Harms, D. E., B. F. Boyd, R. M. Lucci, M. S. Hinson, and M. W. Maier, 1997: Systems Used to Evaluate the Natural and Triggered Lightning Threat to the Eastern Range and Kennedy Space Center, Preprints 28th Conference on Radar Meteorology, Austin, TX, Amer. Meteor. Soc., 240-241.

________, B. F. Boyd, R. M. Lucci, and M. W. Maier, 1998: Weather Systems Supporting Launch Operations at the Eastern Range, Paper 98-0744, AIAA 36th Aerospace Sciences Meeting and Exhibit, Reno, NV.

________, D., B. Boyd, F. Flinn, J. Madura, T. Wilfong, and P. Conant, 2003: Weather Systems Upgrades to Support Space Launch at the Eastern Range and the Kennedy Space Center, 12th Symposium on Meteorological Observations and Instrumentation, 9-13 Feb 03, Long Beach, CA, Paper 7.1, 9 pp.

Hosker, R. P., Jr., K. S. Rao, R. M. Eckman, J. T. McQueen, and G. E. Start, 1993: An Assessment of the Dispersion Models in the MARSS System Used at the Kennedy Space Center, NOAA Technical Memorandum, ERL AL-205, 91 pp.

Lucci, R. M., D. E. Harms, and B. F. Boyd, 1998: Current and Future Wind Profilers In Support Of the Spacelift Mission at the Eastern Range and Kennedy Space Center. Extended Abstracts, Fourth International Symposium on Tropospheric Profiling: Needs and Technologies, Snowmass, CO, 20-25 Sep 98, pp 206-208.

Madura, J. T., B. F. Boyd, W. H. Bauman, and M. E. Adams, 1991: Lower Tropospheric Measurements Required to Improve Weather Forecasts for Cape Canaveral AFS and Kennedy Space Center Florida, Extended Abstracts, Lower Tropospheric Profiling: Needs and Technologies, Boulder, CO, 10-13 Sep 91, pp 119-120.

Nou, J. V., 1963: Development of the Diffusion Prediction Equation, Chapter I in Haugen, D. A., and J. H. Taylor (eds.) 1963: The Ocean Breeze and Dry Gulch Diffusion Programs, Vol. II, USAF Cambridge Research Laboratories, Report 63-791 (II), AD 427-687, 1-21.

Pace, J. C., 1998: Description of ARAC's real-time modeling support to the Mars Pathfinder and Cassini missions, 10th Joint Conference on the Applications of Air Pollution Meteorology with the A&WMA, Phoenix, AZ, 11-16 Jan 98, 44-48.

Parks, C. R. and P. N. Roseti, 2000: Tracking Rocket Nominal Launch and Abort Plumes Using WSR-88D Doppler Radar, Ninth Conference on Aviation, Range, and Aerospace Meteorology, AMS, 11-15 Sep 00, Orlando, FL, pp 563-568.

________, K. Overbeck, R. Evans, B. Boyd, D. Berlinrut, and R. Nyman, 1996: Forecasting Toxic Hazards in Support of Space and Missile Operations at the Eastern Range, 5th Intnl. Conf. on Atmospheric Sciences and Applications to Air Quality, Seattle, WA, 18-20 Jun 96.

See, A. M., J. M. Hudson, and L. P. Philpson, 1995: LATRA FY95 Development, Technical Report No. 95-314/69-02, ACTA, Inc., Torrance, CA.

Sullivan, T. J., J. S. Ellis, C. S. Foster, K. T. Foster, R. L. Baskett, J. S. Nasstrom, and W. W. Schalk, 1993: Atmospheric Release Advisory Capability: Real-time modeling of airborne hazardous material, Bull. Amer. Meteor. Soc., 74: 2343-2361.

Taylor, G. E., R. A. Schumann, 1986: A description of the Meteorological and Range Safety Support (MARSS) system. Preprints, Proc. of Fifth Joint Conf. on Applications of Air Pollution Meteorology, Chapel Hill, NC, Amer. Meteor. Soc., pp 133-136.

________, M. K. Atchison, C. R. Parks, E. L. Rhodes, and B. F. Boyd, 1989: The Kennedy Space Center Atmospheric Boundary Layer Experiment (KABLE), JANNAF Safety and Environmental Protection Subcommittee Meeting, Brooks AFB, TX, 3-6 Apr 89, CIPA Pub 508, pp 75-83.

Taylor, R. W., R. M. Lucci, S. C. Jacobs, D. E. Harms, and A. A. Guiffrida, 1998: Meteorological Support to Assure Safe Access to Space, 35th Space Congress at Cocoa Beach, FL, 28 Apr-1 May 98, pp 103-109.

Tremback, C. J., W. A. Lyons, W. P. Thorson, and R. L. Walco, 1994: An Emergency Response and Local Weather Forecasting Software System. Preprints, 8th Joint Conference on Air Pollution Meteorology with AMA, Nashville, TN, Amer. Meteor. Soc., pp 219-223.