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Description of ARAC's Real-Time Modeling Support to the Mars Pathfinder and Cassini Missions

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DESCRIPTION OF ARAC'S REAL-TIME MODELING SUPPORT TO THE MARS PATHFINDER AND CASSINI MISSIONS

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1. INTRODUCTION

The Mars Pathfinder and Cassini missions, conducted by the National Aeronautics and Space Administration (NASA) to study Mars and Saturn, have radioactive materials on board both spacecraft to supply heat and electrical power. Although the risk of a release of radioactive material from either mission was very small, federal plans call for the Department of Energy (DOE) to provide emergency response support during the launch of any NASA mission involving radioactive materials.

For Mars Pathfinder and Cassini, DOE assigned the task of emergency response dispersion modeling to the Atmospheric Release Advisory Capability (ARAC) at the Lawrence Livermore National Laboratory (LLNL). The role of ARAC was to provide pre-launch guidance about where hazardous material would have gone if released, and in the event of an accident to provide refined calculations to help determine the magnitude of the release. This paper describes how ARAC carried out this mission.

2. DESCRIPTION OF MARS PATHFINDER AND CASSINI MISSIONS

The Mars Pathfinder mission, which launched from Cape Canaveral on 3 December 1996, landed the Mars Sojourner rover (Fig 1) on Mars on 4 July 1997. The rover has sent back a wealth of new information about Mars, including spectacular pictures of the planet's surface.

The Cassini mission, scheduled for launch in October 1997, will enter orbit around Saturn in July 2004. As it approaches Titan, Saturn's largest moon, Cassini will release the Huygens probe, which will descend through Titan's atmosphere. Cassini will orbit Saturn for four years.

3. NUCLEAR ASPECTS OF THE MISSIONS

Nuclear material was used for both these missions. For Mars Pathfinder, a small amount of Plutonium-238 (Pu-238) was used in three Radioisotope Heater Units (RHUs) to supply heat to the rover's electronic circuits. Also the rover's Alpha Proton X-Ray Spectrometer (APXS) contains Curium-244 (Cm-244). The APXS stimulated rock and soil targets with alpha particles emitted by the Cm-244 and recorded the resulting alpha, proton, and X-Ray spectra emitted from the sample to determine the composition of the targets. The total amount of nuclear material on board the spacecraft was 7.3 g of Pu-238 and .00093 g of Cm-244, but safety analyses predicted the release in the highly unlikely event of an accident would be only .0031 g of Pu-238 and .00054 g of Cm-244.

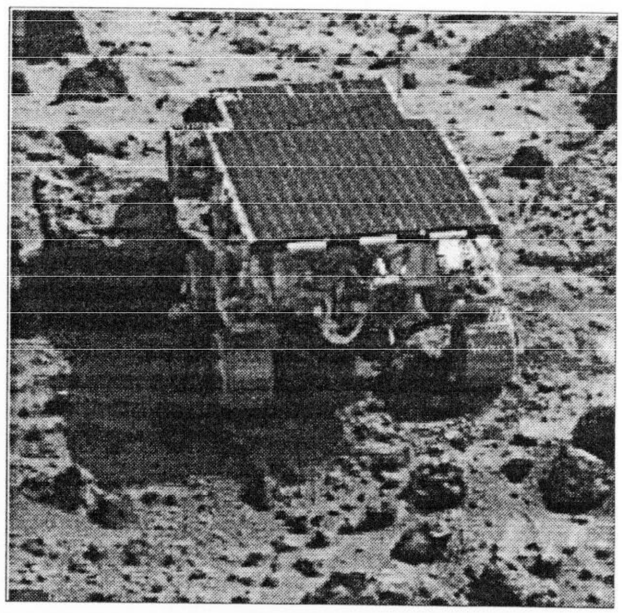

Figure 1. Rover on the surface of Mars.

Substantially more radioactive material was used for Cassini. Heat was supplied by 129 RHUs, each containing 2.56 g of Pu-238, and electrical power was supplied by three Radioisotope Thermoelectric Generators (RTGs), containing a total of 32,700 g of Pu-238. The RHUs and RTGs were extremely well built, designed to withstand almost any catastrophic event, so even in the event of an accident under most conditions no nuclear material would be

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released. In the rare cases where a release could occur, the total amount of released Pu-238 was predicted to be between .56 g and 360.14 g, depending on the accident scenario.

4. ARAC SYSTEM

The ARAC mission is to provide timely and credible advisories for radiological (and other) hazardous releases to the atmosphere. Briefly, the ARAC system simulates the release of some material in the atmosphere and predicts its movement downwind. The system calculates the consequences to health of the release, based on known characteristics of the material.

ARAC has been designed to respond in near-real-time to releases anywhere worldwide. The flexible ARAC 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 NASA launches, ARAC's support is improved if equipment is deployed and plans are made before any potential release.

The ARAC 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 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.

ARAC 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. Examples from a simulated release made in real time before the Mars Pathfinder launch (Figs 2 and 3) show complicated patterns due to strong wind shear within the model domain. As discussed earlier, this simulation involved a very small amount of Pu-238 (0.0031 g); the corresponding consequence plots will be presented below.

The ARAC 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 and Dickerson, 1990). ARAC's system allows use of multiple sources of meteorological data, and ARAC used different types of meteorological data for Mars Pathfinder and Cassini, as discussed below.

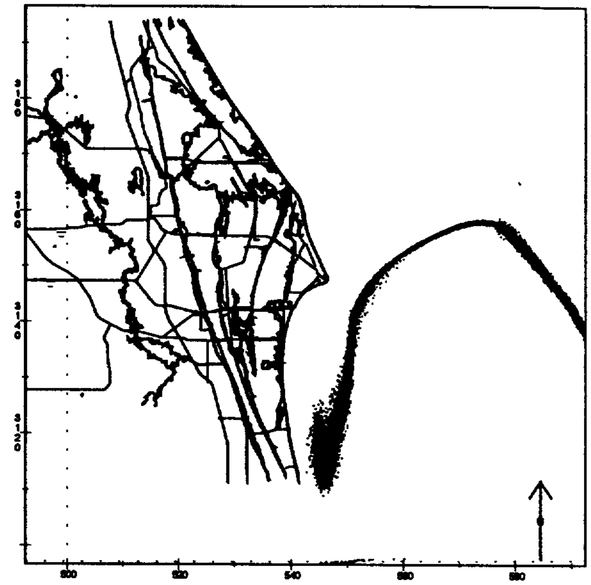

Figure 2. Overhead view of ARAC particle positions for Mars Pathfinder calculation, 2 hr after simulated release at 0658 UTC on 4 Dec 96. Abscissa and ordinate scales are Universal Transverse Mercator (UTM) distances, equivalent to km.

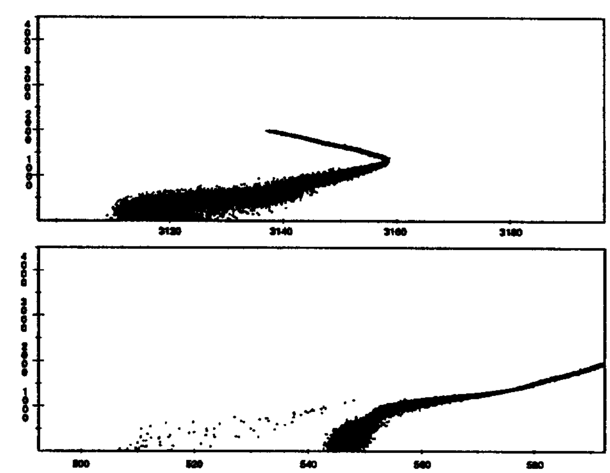

Figure 3. Side views of ARAC particles for Mars Pathfinder calculation, 2 hr after simulated release at 0658 UTC on 4 Dec 96. (Top) View from east to west. (Bottom) View from south to north. Vertical scale is m AGL.

5. HOW ARAC PLOTS WERE USED

ARAC generated pre-launch plots for both missions, and was prepared to perform additional calculations if there had been an actual release.

The purpose of the pre-launch plots was to provide guidance to NASA response officials about where a release would go if it occurred. They used this information to pre-deploy field measurement teams, who would have sampled the air and ground to define the radioactive cloud (where did it go, when did it get there, and how much was in it) had there been an a release.

If there had been an accident, ARAC would immediately have made new calculations based on the actual time of the accident, using or modifying the pre-defined release scenario as appropriate. As field measurement reports became available, this information would be input to the ARAC models, which would be re-run with adjustments so the predictions matched the measurements. In this way, ARAC would help determine the magnitude of the release.

6. ARAC PREPARATIONS FOR MARS PATHFINDER

For both missions, ARAC did not model the explosive cloud rise that would occur during an accident involving a rocket. Instead, ARAC used the results of previous NASA and DOE studies which predicted the configuration of the stabilized cloud following the dissipation of the immediate heat and buoyancy effects, and the distribution of the radioactive material in the cloud. Because the source terms were well-specified, the primary challenge for ARAC was to represent the complex wind patterns in the Cape area.

ARAC used two meteorological data sources for its Mars Pathfinder calculations: forecasted vertical wind profiles (which were remarkably accurate) generated by a forecaster of the U.S. Air Force's 45th Weather Squadron at Cape Canaveral Air Station (CCAS), and weather observations from the many sensors arrayed around the Cape (over 40 instrumented, multi-level meteorological towers, rawinsonde soundings, and a 50 MHz profiler). These observations are collected automatically by the CCAS Meteorological Interactive Data Display System (MIDDS). ARAC retrieved them using a dial-in modem connection and inserted them into its operational worldwide meteorological database, facilitating their use in its model system.

An important advance was needed in ARAC's system to use data from the multi-level meteorological towers at the Cape. Previously ARAC used only the lowest level from those reported at a tower. To use all the data available from the Cape, ARAC created new algorithms which use data from all levels from the full vertical extent of all towers.

No ARAC personnel or equipment were deployed to support the Mars Pathfinder mission. All calculations were carried out at LLNL, and plots showing ARAC pre-launch calculations were faxed to NASA response personnel at the Kennedy Space Center (KSC). All these calculations were based on a single pre-defined release scenario, so the only day-to-day changes were due to use of current meteorological data, plus small adjustments to accommodate the launch windows becoming a few minutes earlier each day.

7. ARAC PREPARATIONS FOR CASSINI

ARAC's preparations for Cassini were much more extensive because of the potential for a larger release. Four ARAC scientists deployed to Florida, along with three ARAC computer systems. All model calculations were done at 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.

As with Mars Pathfinder, ARAC used the full set of data from the MIDDS system for Cassini support. In addition to the data sources which had been in place during Mars Pathfinder, five new 915 MHz profilers were installed prior to Cassini. Thus ARAC had access to a very rich dataset, providing excellent resolution in the horizontal, vertical, and time. And, as before, the 45 WS supplied ARAC with forecasted soundings.

ARAC developed a new software package allowing display and editing of the tower, sounding, and profiler data retrieved from MIDDS. Using this package ARAC personnel performed quality control of the MIDDS data before their use in the ARAC models. The MIDDS data retrieval and all communications between LLNL and the deployed personnel and equipment were done over dedicated communications circuits provided by DOE's Remote Sensing Laboratory (RSL).

An important new ARAC capability for Cassini was provided by implementing the Navy Operational Regional Atmospheric Prediction System (NORAPS). NORAPS is a prognostic model developed by the Navy Research Laboratory, which has been used operationally for several years at the Fleet Numerical Meteorology and Oceanography Center and which was supplied to ARAC through an interagency support agreement. To use NORAPS to support Cassini, ARAC accelerated the work needed to bring

NORAPS into an operational state at LLNL. NORAPS runs provided high-resolution, time-varying meteorological data for the ARAC models described above.

ARAC therefore 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 ARAC collects routinely from the Air Force Global Weather Center. ARAC 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, ARAC used its existing, well-tested, validated models to support Cassini. As with Mars Pathfinder, all ARAC calculations were based on pre-defined release scenarios. However for Cassini ARAC modeled three separate release scenarios, representing accidents before the launch, during the first 5 sec after ignition, and from 5 to 143 sec after ignition.

8. ARAC PRODUCTS

The ARAC products for Mars Pathfinder pre-launch support were 50-Year Committed Effected Dose Equivalent (CEDE), Total Ground Deposition, and Instantaneous Air Concentration plots, all valid at 30 min intervals out to 4 hr after a simulated release during each day's launch window. The reason for generating plots valid at these intervals was to illustrate the evolution of the release, allowing better response by emergency responders. However, this meant that more plots were sent than were needed for pre-launch support tasks.

For Mars Pathfinder, ARAC generated plots 24 hr, 3 hr, and 30 min before the launch window. Examples of these plots are at Figs 4 and 5, showing the CEDE and deposition plots valid 4 hr after a simulated release at the time of the launch. *The predicted activity levels are extremely low.* On the CEDE plot, the area extending south from the Cape shows areas with dose levels between 0.1 and 1.0 mRem in 50 years. For comparison, normal background radiation from terrestrial sources and cosmic rays is about 30-100 mRem per year. The deposition plot shows values about an order of magnitude smaller than the existing worldwide Pu-238 deposition levels.

For Cassini, ARAC also generated plots 24 hr, 3 hr, and 30 min before the launch window. ARAC modeled each of the three release scenarios at each product generation time, and sent the CEDE and deposition plots for each scenario to NASA using a Geographical Information System operated by RSL.

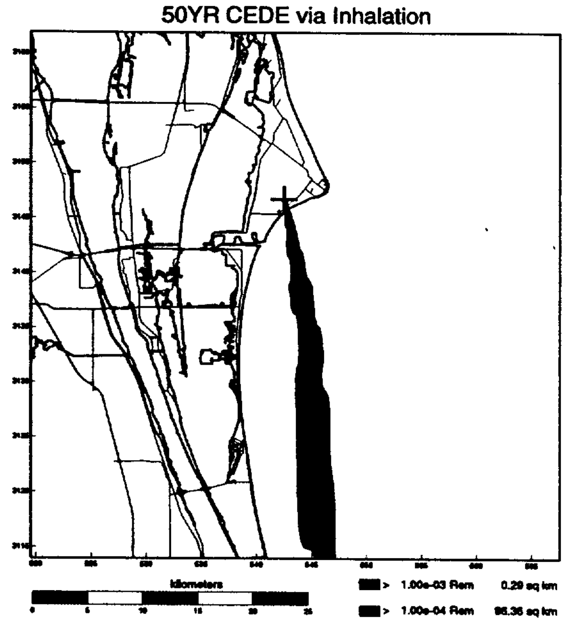

Figure 4. Cumulative Effective Dose Equivalent plot valid 4 hr after simulated Mars Pathfinder release at 0658 UTC on 4 Dec 96. Values are well below background.

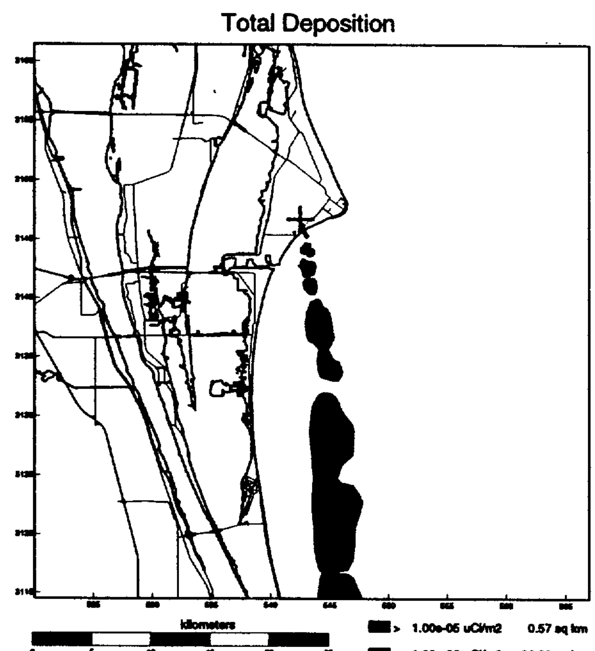

Figure 5. Ground Deposition plot valid 4 hr after simulated Mars Pathfinder release at 0658 UTC on 4 Dec 96. Values are well below background.