NASA Contractor Report 3646

User's Manual for the REEDM (Rocket Exhaust Effluent Diffusion Model) Computer Program

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FOREWORD

This final report is submitted to the Atmospheric Sciences Division, Space Science Laboratory, Marshall Space Flight Center, in partial fulfillment of the requirements of Contract No. NAS8-34132.

This report contains a description of the models, model input parameters, user's instructions for the program, and worked example problems. A listing of the REEDM computer program is contained in NASA CR-3647.

The H. E. Cramer Company, Inc. is indebted to Mr. Joseph C. Sloan and Dr. Briscoe Stephens of the Atmospheric Sciences Division at MSFC for technical guidance and helpful suggestions in the development of the REEDM program and in the design of output formats. Mr. Norman Reavis, Atmospheric Sciences Division, MSFC, and Mr. Joseph Parker, KSC, assisted in the implementation of the program at MSFC and KSC.

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

NASA, and particularly Marshall Space Flight Center (MSFC), have pursued the development of computerized atmospheric dispersion models for predicting the behavior or rocket exhaust clouds in the troposphere since the mid 1960's. These models are routinely used to assess the environmental impact of exhaust products from rocket engines with respect to air quality standards, toxicity thresholds and potential bio-ecological effects and to evaluate requirements, of any, for launch constraints. The concept of using generalized multilayer dispersion models for these applications was first outlined in 1969 in Ref. 1 and the models have been continuously updated and improved since that time (Refs. 2-5). In 1973, a joint program for rocket exhaust prediction and launch monitoring was initiated by NASA for all Titan launches from Kennedy Space Center (KSC). In this program, MSFC had the responsibility of supplying dispersion predictions, Langley Research Center (LaRC) had responsibility for making concentration measurements of rocket exhaust products at the surface and aloft through the use of aircraft sampling techniques, and KSC provided local support for these activities. This program revealed the need for the development of real-time dispersion prediction capability (Refs. 4-6) and the results of the program provided measurements for use in verifying the accuracy of model predictions (Refs. 7-11) as well as providing a data base which could be used in making model improvements. The work under previous contracts and current work under Contract No. NAS8-34132 have culminated in the development of the REEDM computer code described in this user's manual. The REEDM code has been used to assess the environmental impact of Space Shuttle operations and to support the first launches of the Space Shuttle.

1.2 PURPOSE

The purpose of this report is to provide complete documentation for the following:

- Mathematical description of the atmospheric dispersion models, cloud-rise models and other mathematical formulas used in the current version of the REEDM code

- Vehicle and source parameters, other pertinent physical properties of the rocket exhaust cloud and meteorological layering techniques

- User's instructions for the REEDM computer program

1.3 ORGANIZATION OF THE MANUAL

The main body of the user's manual contains five sections. Section 2 contains a brief overview of the REEDM code. The cloud and plume rise models used in the code to position the cloud in space as it rises from the ground and the meteorological algorithms used to describe the state of the lower troposphere are described in Section 3. Section 4 contains a mathematical description of the atmospheric dispersion models implemented by the computer code. Section 5 describes the user operation of the REEDM computer program.

Appendix A of this manual contains example executions of the computer program. A program listing is presented in Volume 2 of this report.

SECTION 2
OVERVIEW OF THE NASA/MSFC REEDM PROGRAM

The burning of rocket engines during the first few seconds prior to and immediately following vehicle launches results in the formation of a large cloud of hot, buoyant exhaust products near the ground level which subsequently rises and entrains ambient air until the temperature and density of the cloud reach an approximate equilibrium with ambient conditions. By convention, this cloud is referred to as the ground-cloud. The rocket engines also leave an exhaust trial from normal launches which extends throughout the depth of the troposphere and beyond. The NASA/MSFC REEDM code is designed to calculate peak concentration, dosage and deposition (resulting from both gravitational settling and precipitation scavenging) downwind from normal launches and launch aborts for use in:

- Mission planning activities and environmental assessments
- Prelaunch forecasts of the environmental effects of launch operations
- Postlaunch environmental analysis

2.1 COMPONENTS OF THE REEDM COMPUTER PROGRAM

Figure 1 is a schematic diagram showing the major components of the REEDM computer program. Requisite meteorological inputs to the computer program are obtained from the vertical profiles of wind direction, wind speed, air temperature, atmospheric pressure and dew point or relative humidity between the earth's surface and 3000 m. This information is obtained during launch support activities from rawinsonde measurements routinely made at scheduled times throughout the pre-launch countdown and after the

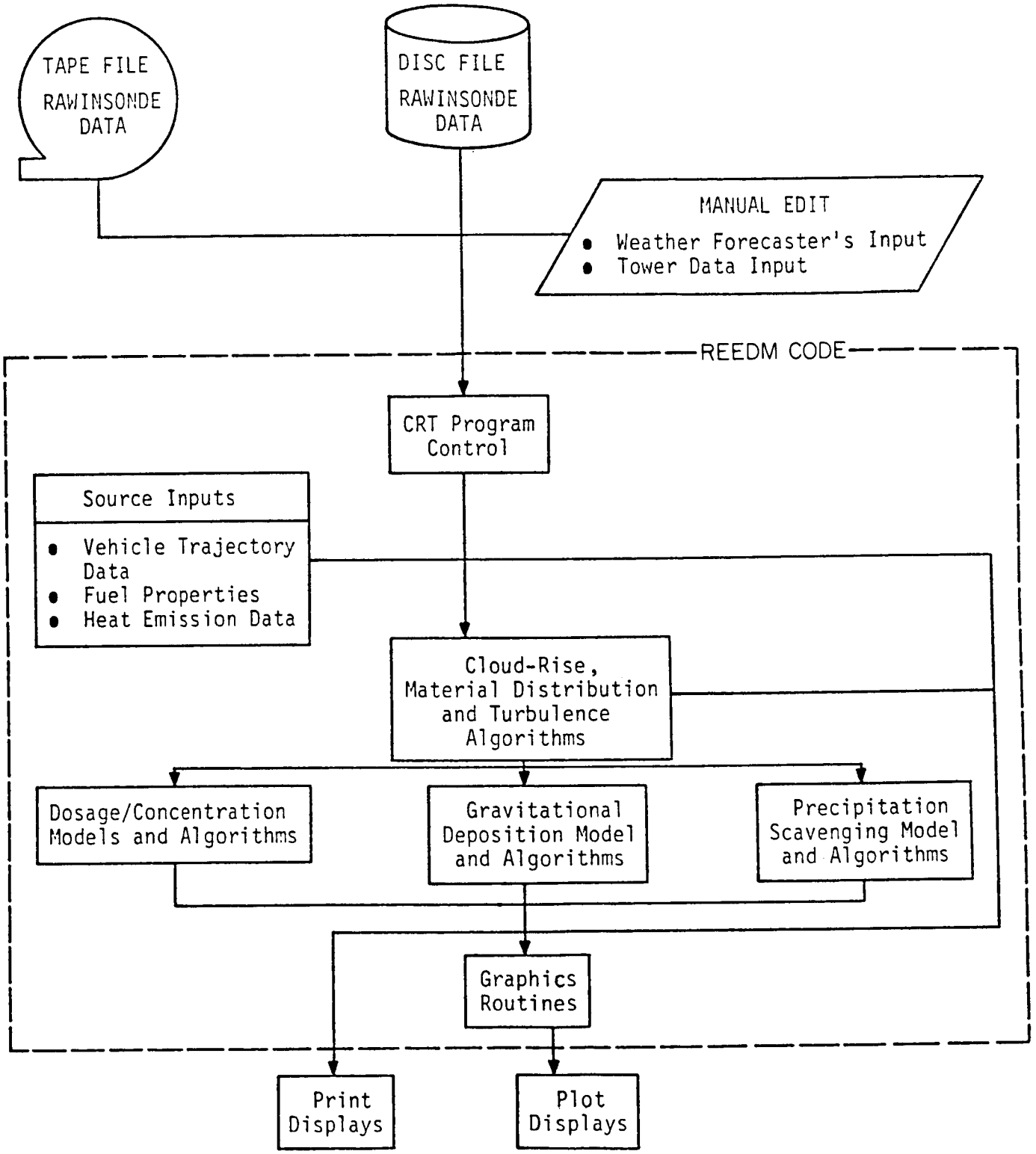


FIGURE 1. Schematic diagram illustrating major components of the REEDM computer program.

launch has occurred. The REEDM program accepts the rawinsonde data from either a disc or data tape file. As shown in Figure 1, the rawinsonde data file can be manually edited to provide for any changes in the vertical profiles that weather forecasters assigned to the launch support team expect to occur between the time of the latest available rawinsonde measurements and the projected time of launch. Similarly, the meteorological inputs for the layers near the surface may also be manually adjusted to reflect changes in the low-level data available from the Wind System. The Wind System is a series of 30-m towers located throughout Kennedy Space Center and one 152-m meteorological tower instrumented to measure wind direction, wind speed, turbulence and air temperature.

The REEDM program is controlled by operator input and internal management routines based on operator response to plain-language queries displayed on a CRT terminal. In Figure 1, this complex interactive function is simply designated by CRT Program Control. Once the operator has elected to perform calculations for the launch of a particular vehicle (for example, the Space Shuttle, Titan, or Delta Thor) and designated a normal launch or one of two launch-abort modes, the program automatically selects a proper set of source inputs for use in algorithms designed to calculate the following parameter values:

- Position in space of the rising ground cloud as a function of time after launch until the internal cloud temperature equals the ambient air temperature (cloud stabilization time)

- Dimensions of the ground cloud as a function of height

- Distribution of vehicle exhaust products within the cloud as a function of height

At this point, the rawinsonde meteorological data, cloud-rise, cloud dimension and exhaust-product distribution calculations are output to a printer

and, if desired by the operator, are also output to a plotted display of vertical profiles of wind direction, wind speed, temperature and virtual potential temperature as well as the dimensions of the stabilized cloud. The operator then has the option of modifying the default values selected and calculated by the program to represent the major meteorological layer structure parameters (the height of the base and top of an elevated inversion layer, for example) and the turbulence parameters that will be used in the dispersion calculations.

After the final selection of model input parameters has been made by the operator, the program performs the selected calculations (dosage/concentration, gravitational deposition, or deposition due to precipitation scavenging, etc.). When these calculations are completed, the results are printed and, at the operator's option, plotted. If the dosage/concentration option was selected, the print output includes peak concentration at 1-km intervals downwind from the launch pad, the cloud arrival and departure times at 1-km intervals downwind from the pad, and the total dosage and time-mean concentration for the period of interest at these distances. The operator has the option of requesting the REEDM program to plot these results versus distance from the pad and/or isopleths of these quantities on a map of KSC. The print output for the gravitational deposition model contains maximum ground-level deposition versus distance from the pad. If selected by the operator, plots are made of maximum gravitational deposition versus distance from the pad and of deposition isopleths on a map of KSC. Finally, if the operator chooses to calculate deposition due to precipitation scavenging, maximum deposition or maximum surface water pH is also printed and plotted.

Although not shown in Figure 1, there are three major run modes that an operator can choose for making calculations with the REEDM code (operational, research and production). The operational mode is designed for use during launch support operations and automatically calculates various user inputs. For example, in the operational mode, the REEDM code uses an algorithm to calculate appropriate turbulence parameters near the surface,

although an option is provided permitting the operator to modify the values. Either the values calculated by the REEDM code or the operator input values are then used to automatically construct a vertical profile of turbulence for the first 3000 m above the surface which is used in the dispersion calculations. When the research mode of the REEDM code is selected, more information is usually input by the operator. For example, the operator can specify values of the turbulence parameters at each height where rawinsonde data is available. Finally, the production mode of the REEDM code is used to process multiple rawinsonde soundings which are read from a tape or disc file. While the production mode can be run interactively from the CRT terminal, the primary purpose of the production mode is to facilitate batch processing of multiple cases without operator attention. The graphics package is not used with the production mode.

2.2 LAUNCH TYPES AND VEHICLE PARAMETERS

The REEDM code is designed to provide dispersion estimates for normal launches and two types of launch failures. For a normal launch, the assumption is made that all engines and the pad deluge system operate normally. In the case of a launch failure (single engine burn on pad), one solid engine of the Space Shuttle, Titan III and Delta vehicles is assumed to fail to ignite, causing the vehicle to remain on the pad in a hold-down configuration while the other solid engine is assumed to ignite and burn with the pad deluge system operating normally. In the other failure mode (slow burn on pad), an on-pad explosion is assumed to rupture the casings of the solid engines, scattering solid propellant over the area in the vicinity of the launch pad. The scattered solid propellant continues to burn over an extended period at a constant rate. It is assumed that the heat liberated by the explosion of liquid propellant (Space Shuttle and Delta Thor vehicles) does not contribute to plume rise because this heat is liberated over a very short time period compared to the burn time of the scattered solid propellant.

The fuel expenditure, heat content and burn time data currently used in the REEDM code are presented in Table 1 (Ref. 12). The fuel

TABLE 1. FUEL EXPENDITURE AND HEAT CONTENT DATA

Property	Vehicle Type			
	Space Shuttle	Titan III	Delta 2914	Delta 3914
(a) Normal Launch				
Fuel Expenditure Rate W (g s^{-1})	1.5219×10^7	5.4375×10^6	8.3607×10^5	1.0576×10^6
Effective Fuel Heat Content H (cal g^{-1})	1479.7	2021.1	1766.0	1449.9
(b) Single Engine Burn				
Fuel Expenditure Rate W (g s^{-1})	3.8451×10^6	2.7188×10^6	NA[1]	NA
Effective Fuel Heat Content H (cal g^{-1})	1062.4	1010.6	NA	NA
Burn Time t_B (s)	132.0	60.0	NA	NA
(c) Slow Burn				
Fuel Expenditure Rate W (g s^{-1})	9.8873×10^5	1.3594×10^6	2.7294×10^5	3.7073×10^5
Effective Fuel Heat Content H (cal g^{-1})	1000.0	1000.0	690.0	411.2
Burn Time t_B (s)	1027.0	240.0	69.0	126.0

[1] NA - Not applicable.

expenditure rates for normal launches were obtained by averaging the fuel expenditure rates for the engines over the approximate period from lift-off until the vehicle is about 3000 m above the surface. The fuel expenditure rates for the single engine burn are an average for the normal firing period of the engine. For the slow burn, the rates in the table are an average over the estimated total burn time of the scattered propellants. The effective fuel heat contents, which are used in calculating buoyant cloud rise for normal launches and plume rise for launch failures, include the effects of heat produced by afterburning as well as heat losses due to radiation.

Table 2 shows the exhaust cloud constituents, expressed as a fraction of the total weight of the exhaust products. These fractions have been adjusted to yield the weight of $HC\ell$, $A\ell_2O_3$, CO_2 and CO in the exhaust cloud when multiplied by the appropriate fuel expenditure rates in Table 1.

The cloud-rise and dispersion calculations for normal launches require specification of the time-height profile of the launch vehicle. The vehicle flight profile data for the first 3000 m above the surface were used to obtain a least-squares fit to the expression

$$T_k = az^b + c \tag{1}$$

where

T_k = time for the vehicle to reach the altitude z

The values thus obtained (Ref. 12) for the constants a, b and c in Equation (1) are given in Table 3.

TABLE 2. EXHAUST CLOUD CONSTITUENTS (FRACTION BY WEIGHT)

Constituent	Vehicle Type			
	Space Shuttle	Titan III	Delta 2914	Delta 3914
$HC\ell$	0.1146	0.1932	0.1218	0.1589
$A\ell_2O_3$	0.1828	0.2819	0.2214	0.1936
CO_2	0.2503	0.2665	0.2055	0.2783
CO	0.00042	0.0222	0.0156	0.0331

TABLE 3. VALUES OF THE CONSTANTS IN THE EXPRESSION FOR VEHICLE ALTITUDE VERSUS TIME[1]

Vehicle Type	Constant		
	a	b	c
Space Shuttle	0.652213	0.468085	0.375
Titan III	0.429580	0.518422	5.0
Delta 2914	0.922156	0.432703	0.54
Delta 3914	1.245756	0.418095	0

[1] See Equation (1).

2.3 METEOROLOGICAL LAYERS

As noted above, the primary meteorological input to the REEDM code is in the form of rawinsonde observations. Each level of information (standard, mandatory and significant levels) in the rawinsonde data stream (kth observation level) is used in the REEDM calculations to obtain the wind and temperature profiles. The REEDM code is currently constructed to perform dispersion calculations in two major, meteorologically-defined, layers. The base of the lower layer (L=1) is assumed to be at the earth's surface and top of the layer is assumed to be given by the base of an elevated inversion (top of the mixing layer). The boundaries of the upper layer (L=2), are set by the operator. For example, if calculations are desired of dosage/concentration at the altitude of a sampling aircraft flying in an elevated inversion, the boundaries of the upper layer are defined by the base and top of the elevated inversion. The boundaries of the layers must coincide with a height or level reported on the rawinsonde observation. If the user designates a height other than a kth height, the program automatically selects the kth height closest to the user input value.

The selection of the boundaries of the two major layers is critical to the outcome of the dispersion calculations. Both gases (vapor) and particulates ($A\ell_2O_3$) are assumed to be reflected toward the earth's surface at the tops of major boundaries. Vapor and particulates can be totally or partially reflected at the base of the lower layer according to a user-specified input for the fraction of material reflected (1=complete reflection, 0=no reflection). Material is never reflected at the base of the upper layer when gravitational settling or precipitation scavenging calculations are made, but gases are always reflected at the base of the upper layer. Thus, gases are assumed to be trapped in the upper layer for dosage/concentration calculations. The boundaries of these two major layers are also used in the determination of vertical turbulence profiles as explained below in Section 3. In the absence of user input of the layer boundaries, the height of the top of the lower layer is automatically set

by the program to the kth level closest to twice the cloud stabilization height (see Section 3 for the mathematical definition of cloud stabilization height). Also, the height of the base of the upper layer is set equal to the height of the top of the lower layer and the program sets the height of the top of the upper layer to the kth height closest to 3000 m. Rawinsonde measurements at heights greater than 3000 m are not read by the REEDM code. The layer heights are treated as defaults because the use of a kth height between the cloud stabilization height and twice the cloud stabilization height to represent the top of the lower layer maximizes the calculated ground-level vapor concentrations.

In general, program users should select the height of the base of an elevated inversion to represent the top of the lower layer. Because the top of the lower layer is defined in the program as the upper boundary of turbulent mixing, the user should select a height above which the temperature either increases or remains constant for at least to 50 to 100 m. At KSC, the transition zone between the afternoon sea breeze and the return flow aloft or the synoptic wind circulation may be characterized by large wind direction and wind speed shears. While this shear zone presents some problems in the interpretation of model calculated vapor concentrations/dosages, the transition zone likely does not present a barrier to vertical dispersion. Thus, the lowest layer should be placed above the transition zone, especially when ground-level concentrations/dosages are being calculated with the operational version of the REEDM code. Because the primary purpose of the REEDM code is to assist in estimating ground-level environmental effects produced by vehicle launches, the user should generally ignore surface-based inversions or elevated inversions with tops less than a few hundred meters above the surface in the selection of the top of the lowest layer.

The selection of the height of the base and top of the upper layer is also made from an interpretation of the rawinsonde observations. If, for example, the model is being used to estimate concentrations at the flight level of a sampling aircraft and this flight level is in an elevated inversion, the height of the base and top of the upper layer should corre-

spond to the base and top of the elevated inversion. Similarly, if the aircraft flight level is in a shear zone above the surface layer, the height of the base and top of the shear zone can be used as the base and top of the second layer. The program does not require that the base of the upper layer correspond to the top of the lower layer, except for washout deposition calculations, although the base of the upper layer cannot be less than the top of the lower layer.

SECTION 3

REEDM CLOUD AND PLUME RISE MODELS, SOURCE AND METEOROLOGICAL ALGORITHMS

3.1 REEDM CLOUD AND PLUME RISE MODEL

The determination of the stabilized height of the ground cloud for normal launches and of the plume generated by launch failures is an important factor in the dosage/concentration calculations because, in general, the maximum dosage/concentration calculated at the earth's surface is inversely proportional to the cube of the stabilized height. In the case of normal launches of solid-fueled vehicles or vehicles with large solid boosters, vehicle hold-down times are minimal and the vehicle residence times in the first several hundred meters are relatively short. The ground cloud is therefore comprised of buoyant gas emitted over a time period on the order of ten seconds. Experience to date shows that the buoyant rise of the ground cloud under these circumstances is best calculated using an instantaneous cloud-rise model. Limited experience in predicting the buoyant rise from the normal launch of Delta vehicles, with their large liquid-fueled first stage, indicates that an average of the rise predicted by a continuous plume-rise and instantaneous cloud-rise model is appropriate. No plume rise data are available for aborted launches of the vehicle types specified in the REEDM code. However, static tests of rocket engines indicate a continuous plume rise model is appropriate in these cases.

The buoyant rise models used in the REEDM program are based on the work of Briggs (Refs. 13 and 14).

3.1.1 Instantaneous Cloud-Rise Model

The time for the ground-cloud produced by the normal launch of the Space Shuttle and Titan vehicles to reach a height z_k in a stable atmosphere is given by

$$t_I = s^{-0.5} \arccos \left[1 - \left(\frac{s \gamma_x \gamma_y \gamma_z z_k^4}{4 F_I} \right) \right] \tag{2}$$

where t_I is constrained to be less than the cloud stabilization time t^* and

$$t^* = \pi s^{-0.5} \tag{3}$$

s = stability parameter

$$= \frac{g}{T} \frac{\Delta\Phi}{\Delta z}$$

g = gravitational accelleration (9.8 m s^{-2})

T = ambient air temperature (°K)

$\frac{\Delta\Phi}{\Delta z}$ = vertical gradient of virtual potential temperature

$\gamma_x, \gamma_y, \gamma_z$ = alongwind, crosswind and vertical entrainment coefficients

F_I = initial buoyancy term

$$= \frac{3 \, g \, H \, W \, t_R}{4 \, \pi \, c_p \, T} \tag{4}$$

H = effective fuel heat content (cal g^{-1})

W = fuel expenditure rate (g s^{-1})

t_R = time for the rocket to exceed the final cloud stabilization height z_I

$$= a \, z_I^{\,b} + c \tag{5}$$

ρ = air density (g m^{-3})

c_p = specific heat of air at constant pressure (0.24 cal g^{-1} $°K^{-1}$)

$$z_I = \left[\frac{8\ F_I}{\gamma_x\ \gamma_y\ \gamma_z\ s}\right]^{1/4} \tag{6}$$

According to the above formulas, the quantities z_I, t_R and the height over which $\Delta\Phi/\Delta z$ is measured are interrelated. The final cloud stabilization height z_I in Equation (6) must therefore be found by iteration. The iteration process begins by assuming that z_I lies in the first height interval (K=1) above the surface bounded by the rawinsonde observation heights k=1 and k=2 and solving Equation (6) for z_I with

$$\frac{\Delta\Phi}{\Delta z} = \frac{\Phi_2 - \Phi_1}{z_2 - z_1}$$

If z_I exceeds z_2, the iteration continues using the virtual potential temperature from the next highest kth observation level with the vertical gradient $\Delta\Phi/\Delta z$ estimated from the least squares approximation

$$\frac{\Delta\Phi}{\Delta z} = \frac{\sum_{i=1}^{k}\left\{\left[z_i - \left(\sum_{i=1}^{k} z_i/k\right)\right]\left[\Phi_i - \left(\sum_{i=1}^{k} \Phi_i/k\right)\right]\right\}}{\sum_{i=1}^{k}\left[z_i - \left(\sum_{i=1}^{k} z_{i/k}\right)\right]^2} \tag{7}$$

Providing that $z_I < 3000$ m, the program finds a value of z_I within an interval ($z_{i-1} \le z_I \le z_i$). At this point the program assumes that the gradient of virtual potential temperature in this height interval is linear and linearly interpolates to determine, within ±10 m, the value of z_I.

The above cloud-rise model was theoretically derived for a thermally stable atmosphere ($\Delta\Phi/\Delta z > 0$). A model based on similar considerations is easily derived for an adiabatic atmosphere. The cloud continues to rise over all time when the adiabatic model is used, although the rate tends to approach zero asymptotically at long times. Experience shows that the height at which the rate of rise determined from the adiabatic model becomes negligible for practical purposes can be predicted using a small value of $\Delta\Phi/\Delta z$ in the stable model. For this reason, the program sets $\Delta\Phi/\Delta z$ equal to 3.322×10^{-4} when the measured value of $\Delta\Phi/\Delta z$ is less than 3.322×10^{-4}. The program currently uses a default value of 0.64 for γ_x, γ_y, and γ_z.

3.1.2 Continuous Plume-Rise Model

The time for a continuous plume to reach the height z_R in a stable atmosphere is given by

$$t_c = s^{-0.5} \arccos\left[1 - \left(\frac{s\, u_c\, \gamma_x\, \gamma_y\, z_k^3}{3\, F_c}\right)\right] \tag{8}$$

where t_c is constrained to be less than t* given by Equation (3) and

F_c = buoyancy flux

$$= \frac{g\, H\, W}{\pi\, \rho\, c_p\, T} \tag{9}$$

$\bar{u}_c$ = height-weighted mean wind speed between the surface and the stabilization height z_c

$$z_c = \left(\frac{6\, F_c}{\bar{u}_c\, \gamma_x\, \gamma_y\, s}\right)^{1/3} \tag{10}$$

As in the case of the instantaneous cloud-rise model, Equation (10) must be solved by iteration because $\Delta\Phi/\Delta z$, z_c and $\bar{u}_c$ are interrelated. Also, the value of $\Delta\Phi/\Delta z$ is set equal to 3.322×10^{-4} degrees per meter when the value calculated from Equation (7) is less than 3.322×10^{-4} (adiabatic atmosphere). For the continuous plume-rise model, the program default value for γ_x and γ_y is 0.5.

3.2 SOURCE-DIMENSIONS, MATERIAL DISTRIBUTION, AND SPATIAL POSITION OF THE STABILIZED GROUND-CLOUD

The dispersion models are derived under the assumption that a vertical finite line source can be used to represent the source of material in each of the K layers defined by the rawinsonde measurement levels and that the alongwind (r_x), crosswind, (r_y) and vertical (r_z) radii of the cloud at the stabilization time t* are consistent with the cloud-rise model, e.g.:

$$\begin{aligned} r_x &= \gamma_x z_M \\ r_y &= \gamma_y z_M \\ r_z &= \gamma_z z_M \end{aligned} \tag{11}$$

where

$$z_M = \begin{Bmatrix} z_I \text{ ; instantaneous source} \\ z_c \text{ ; continuous source} \end{Bmatrix}$$

Under these assumptions, the alongwind radius of the cloud in the Kth layer is

$$R_{xK} = \left[r_x \left(1 - \frac{z_o^2}{r_z^2} \right) \right]^{1/2} \tag{13}$$

and the crosswind radius is

$$R_{yK} = \left[r_y \left(1 - \frac{z_o^2}{r_z^2} \right) \right]^{1/2} \tag{14}$$

where

$$z_o = \left| \bar{z} - z_M \right| \tag{15}$$

$$\bar{z} = (z_{TK} + z_{BK})/2 \tag{16}$$

z_{TK} = height of the top of the Kth layer

z_{BK} = height of the base of the Kth layer

3.2.1 Source Dimensions

The REEDM model allows the user to select either an elliptical or spherical shape to represent the form of the ground cloud. We strongly recommend that an elliptical shape be selected for normal launches and a spherical shape be selected for abnormal launches. For an elliptical shape, the source dimensions in the plane of the horizon are defined in terms of the standard deviations of the material distribution. For the source in the Kth layer, these dimensions are as follows:

Alongwind;

$$\sigma_{xo}\{K\} = \left\{ \begin{array}{lll} 0 & ; & 0 < \bar{z} \le (z_M - r_z) \\ R_{xK}/2.15 & ; & (z_M - r_z) < \bar{z} \le (z_M + r_z) \\ \sigma_{xm} & ; & (z_M + r_z) < \bar{z} \end{array} \right\} \tag{17}$$

Crosswind;

$$\sigma_{yo}\{K\} = \left\{ \begin{array}{lll} 0 & ; & 0 < \bar{z} \le (z_M - r_z) \\ R_{yK}/2.15 & ; & (z_M - r_z) < \bar{z} \le (z_M + r_z) \\ \sigma_{xm} & ; & (z_M + r_z) < \bar{z} \end{array} \right\} \tag{18}$$

where σ_{xm} is defaulted to 93 m for normal launches and to 0 m for abnormal launches. The assumptions are made in Equation (17) and (18) that the distribution of material in the plane of the horizon is bivariate Gaussian and that the concentration of exhaust products at one radius from the centroid is 10 percent of the concentration at the centroid.

For a spherical shape the corresponding dimensions in the horizontal plane are:

$$\sigma_{xo}\{K\} = \left\{ \begin{array}{lll} 50/2.15 & ; & 0 < \bar{z} \leq (z_M - r_z) \\ R_{yK}/2.15 & ; & (z_M - r_z) < \bar{z} \leq (z_M + r_z) \\ \sigma_{xm} & ; & (z_M + r_z) < \bar{z} \end{array} \right\} \tag{19}$$

$$\sigma_{yo}\{K\} = \left\{ \begin{array}{lll} 50/2.15 & ; & 0 < \bar{z} \leq (z_M - r_z) \\ R_{yK}/2.15 & ; & (z_M - r_z) < \bar{z} \leq (z_M + r_z) \\ \sigma_{xm} & ; & (z_M + r_z) < \bar{z} \end{array} \right\} \tag{20}$$

3.2.2 Material Distribution

For normal launches, the distribution of material within the ellipsoid with axes given by Equation (11) is assumed to be uniform in the vertical. Under this assumption, the amount of material F{K} in the Kth layer is given by

$$F\{K=k-1\} = \left\{ \begin{array}{lll} W(FM)\ t_k/V_k & ; & z_{TK} < z_M \\ W(FM)\left(\dfrac{t_R}{V_K} + \Delta t_k\right) & ; & z_M < z_{TK} \leq z_M\ (1 + \gamma_z) \\ W(FM)\ \Delta t_k & ; & z_M(1 + \gamma_z) < z_{TK} \end{array} \right\} \tag{21}$$

where

FM = fraction by weight of the exhaust cloud constituent from Table 2

$$\Delta t_k = a\left(z_{TK}^{b} - z_{BK}^{b}\right) \tag{22}$$

V_k = cloud volume in the Kth layer

$$= \pi\, r_x\, r_y \left\{ (z_{TK} - z_{BK}) - \left[\frac{(z_{TK} - z_M)^3 - (z_{BK} - z_M)^3}{3\, r_z^2} \right] \right\} \tag{23}$$

For launch failures, the program assumes that the material has a Gaussian distribution in the vertical about the stabilization height z_M. Thus,

$$F\{K=k-1\} = W(FM)\; t_B \left[P\{z_{TK}\} - P\{z_{BK}\} \right] \tag{24}$$

where

t_B = burn time from Table 1

$$P\{z\} = \frac{2.15}{\sqrt{2\pi}\, r_z} \int_{-\infty}^{z} \exp\left[-\frac{1}{2} \left(\frac{2.15(z-z_M)}{r_z} \right)^2 \right] dz \tag{25}$$

3.2.3 Spatial Position of the Stabilized Cloud

The spatial position in the plane of the horizon of the cloud in the Kth layer at the stabilization time t*, with respect to the origin at the launch pad, is assumed to be given by the following polar coordinates:

$$R_{CK} = \left\{ \left[x_K + \bar{u}_K (t^* - t_p) \sin \bar{\theta}_K \right]^2 + \left[y_K + \bar{u}_K (t^* - t_p) \cos \bar{\theta}_K \right]^2 \right\}^{1/2} \tag{26}$$

$$\theta_{CK} = \pi/2 - \tan^{-1} \left[\frac{y_K + \bar{u}_K (t^* - t_p) \sin \bar{\theta}_K)}{x_K + \bar{u}_K (t^* - t_p) \cos \bar{\theta}_K)} \right] \tag{27}$$

where

$$x_K = x_{K-1} - \xi_K \sin(\phi_{sK}) \tag{28}$$

$$y_K = y_{K-1} - \xi_K \cos(\phi_{sK}) \tag{29}$$

$$\bar{u}_K = \text{mean wind speed in the Kth layer}\left((u_{k+1} + u_k)/2\right)$$

$$t_p = \begin{cases} t_I\{z = z_{TK}\} & ; \text{ instantaneous cloud-rise model} \\ t_c\{z = z_{TK}\} & ; \text{ continuous cloud rise model} \end{cases} \tag{30}$$

$$\bar{\theta}_K = \text{mean wind direction in the Kth layer}$$

For layers below the Kth layer containing z_M,

$$\xi_K = t_p \bar{u}_K \tag{31}$$

$$\phi_{sK} = \bar{\theta}_K \tag{32}$$

For an instantaneous source, the value of ξ_K in the Kth layer containing z_M is

$$\xi_K = \left[\bar{u}_K \left(\frac{z_M - z_{BK}}{z_{TK} - z_{BK}}\right) + u_k\right]\left[t_R - t_{I,k}\right] \tag{33}$$

Similarly, for a continuous source,

$$\xi_K = \left\{\frac{t_R - t_{c,k}}{z_M}\right\}\left\{\left[\bar{u}_K \left(\frac{z_M - z_{TK}}{z_{TK} - z_{BK}}\right) + u_k\right]\left[z_M - z_{BK}\right] + \sum_{i=1}^{k}\left[z_{i+1} - z_i\right]\left[\frac{u_{i+1} + u_i}{2}\right]\right\} \tag{34}$$

The value of ϕ_{sK} is

$$\phi_{sK} = \frac{1}{2}\left[\left(\frac{\theta_{k+1} - \theta_k}{z_{TK} + z_{BK}}\right)\left(z_M - z_{BK}\right) + 2\,\theta_k\right] \tag{35}$$

for both the instantaneous and continuous sources.

For all K layers above z_M ($z_{BK} > z_M$),

$$R_{CK} = t_R \bar{u}_K \tag{36}$$

$$\theta_{CK} = \pi + \bar{\theta}_K \tag{37}$$

3.3 TURBULENCE PROFILE ALGORITHM

The REEDM dispersion model code uses profiles of the standard deviations of the azimuth wind angle σ'_A and elevation angle σ'_E as prime predictors of cloud growth. The program calculates default turbulence profiles, which can be adjusted by the program operator. The algorithm used to calculate the turbulence profiles begins by calculating a reference standard deviation of the wind azimuth angle $\sigma'_{AR}\{\tau_o=600s\}$, assumed representative of a measurement made over a ten-minute period at the lowest height available from the rawinsonde data input (4.9 m at KSC).

3.2.1 Calculation of the Default Value for $\sigma'_{AR}\{\tau_o=600s\}$

The calculation method (Ref. 12), based on the application of similarity relationships outlined in Ref. 15, assumes that

$$\sigma'_{AR}\{\tau_o=600s\} = \frac{\sigma_V\{600s\}}{\bar{u}} \simeq \frac{k_A \quad f\{B\}}{\ln\left(\frac{\bar{z}}{z_o}\right) - \quad \psi\{Ri\}} \quad ; \quad Ri \neq 0 \tag{38}$$

where

σ_V = standard deviation of the crosswind component of the wind

$\bar{u}$ = mean wind speed at the measurement height of σ_V

τ_o = reference time for the measurement of σ'_{AR} and σ_V

$f\{B\}$ = function of the bulk Richardson number B

$\bar{z}$ = geometric mean height of the layer of interest

z_o = roughness length (0.20 m used for KSC)

$\psi\{Ri\}$ = function of the Richardson number Ri

In the program, values of f{B} and $\psi\{Ri\}$ are obtained from the expressions

$$f\{B\} = \begin{cases} 2.7 & B<-0.008 \\ 2.7+112(.008+B) & ; \quad -0.008 \le B < -.00175 \\ 3.4-725.5(.00175+B) & ; \quad -.00175 \le B < .008 \\ 1.55+38.04(B+.0008) & ; \quad .0008 \le B < .029 \\ 2.35+5.43(B-.029) & ; \quad .029 \le B \end{cases} \tag{39}$$

and

$$\psi\{Ri\} = \begin{cases} 2\ \ell n\left[(1+\xi)/2\right] + \ell n\left[(1+\xi)^2/2\right] + 2\tan^{-1}\xi + \pi/2 & ; \quad Ri < 0 \\ 7Ri/(1-7Ri)^{1/4} & ; \quad Ri > 0 \end{cases} \tag{40}$$

where

$$\xi = (1-16Ri)^{1/4} \tag{41}$$

$$B = \frac{g\ \bar{z}^2}{T\ \bar{u}^2}\ \frac{\Delta\Phi}{\Delta\bar{z}} \tag{42}$$

$\frac{\Delta\Phi}{\Delta\bar{z}}$ = vertical gradient of potential temperature over the height $\bar{z}$

$$Ri = \left[-\frac{1}{14\ k_A\ \sqrt{B}} + \frac{1}{2}\sqrt{\frac{1}{49\ k_A^2\ B} + \frac{4(k_A+1)}{7\ k_A}}\right]^2 \quad ; \quad Ri > 0 \tag{43}$$

For Ri < 0, the following equation is solved by Newton's method to obtain Ri

$$0 = \frac{1-\xi^4}{16\xi^2\left[\ell n(z/z_o) + 0.50864 - 2[\ell n(1+\xi)] - \ell n(1+\xi^2) + 2\tan^{-1}\xi\right]^{-B}} \tag{44}$$

Finally, for Ri=0, $\sigma_{AR}\{\tau_o=600s\}$ is calculated from the relationship

$$\sigma_{AR}\{\tau_o=600s\} = \frac{48.816}{\ln\left(\frac{\bar{z}}{z_o}\right)} \quad ; \quad Ri = 0 \tag{45}$$

The program does not permit $\sigma'_{AR}\{\tau_o=600s\}$ to be greater than 0.524 radians (30 degrees).

3.3.2 Vertical Profiles of σ'_A and σ'_E

The dispersion models in the REEDM code use mean values of σ'_A and σ'_E in the two major layers (L=1,2). In the case where the operator enters values of σ'_A and σ'_E at each rawinsonde level, the program computes the height-weighted mean values from the expression

$$\bar{\sigma}'_L = \frac{\sum_{k=z_{BL}}^{z_{BK}} (z_{k+1} - z_k)\left[(\sigma'\{k+1\} + \sigma'\{k\})/2\right]}{z_{TL} - z_{BL}} \tag{46}$$

where

σ'_L = mean value of the standard deviation (σ'_A or σ'_E) in the Lth layer

z_{TL} = top of the Lth layer

z_{BL} = base of the Lth layer

When values of σ'_A and σ'_E are not entered at each k level, the program calculates the mean value of σ'_A under the assumption that σ'_A decreases with height in the surface mixing layer according to a power-law relationship (Refs. 16-18) given by

$$\sigma'_A\{z\} \approx \sigma'_A\{z=5m\}\left(\frac{z}{5}\right)^m \tag{47}$$

where m takes on negative values.

The mean value of $\bar{\sigma}'_A$ is defined as

$$\frac{\sigma'_A\{z=5\}}{(z_{TL}-5)\ 5^m}\int_5^{z_{TL}} z^m\,dz = \frac{\sigma'_A\{z=5\}\left[z_{TL}^{1+m}-5^{1+m}\right]}{(z_{TL}-5)\ 5^m\ (1+m)} \tag{48}$$

It can be shown that, for reasonable values of m, Equation (48) is closely approximated by the simple expression

$$\overline{\sigma'_A}\{L=1;\tau_o=600s\} = \frac{\sigma'_{AR}\{\tau_o=600s\}}{2} \tag{49}$$

and the value at $z=z_{TL}$ by

$$\sigma'_A\{z_{TL}=1;\tau_o=600s\} = \frac{\sigma'_{AR}\{\tau_o=600s\}}{2} \tag{50}$$

The assumption (Refs. 19 and 20) is also made that the value of σ'_A can be adjusted for the time required to form the source, in this case considered to be the cloud stabilization time t*, by means of the expressions

$$\sigma'_A\{L=1;\tau=t^*\} = \sigma'_A\{L=1;\tau_o=600s\}\left(\frac{t^*}{600}\right)^{0.2} \tag{51}$$

and

$$\sigma'_A\{z_{TL}=1;\tau=t^*\} = \sigma'_A\{z_{TL}=1;\tau_o=600s\}\left(\frac{t^*}{600}\right)^{0.2} \tag{52}$$

Also, because the surface layer is capped by an elevated inversion where turbulence levels are expected to be minimal, the program reduces the value of σ'_A at the top of the second layer to about 10^{-2} as indicated by

$$\sigma'_A\{z_{TL}=2,\tau=t^*\} = .01745\left(\frac{t^*}{600}\right)^{0.2} \tag{53}$$

If the program user has assigned the base of second layer coincident with the top of the lower layer, the mean effective value of σ'_A in the upper layer is defined by the program as

$$\sigma'_A\{L=2;\tau=t^*\} = \frac{\sigma'_A\{z_{TL}=2;\tau=t^*\} + \sigma'_A\{z_{TL}=1;\tau=t^*\}}{2} \tag{54}$$

When the user chooses to assign the base of the upper layer at some kth height above the top of the lower layer, the program assumes that σ'_A has decreased to 1 deg in the Kth level just above the top of the lower layer. Thus, the effective value of σ'_A in the upper layer (L=2) is

$$\sigma'_A\{L=2;\tau=t^*\} = .01745\left(\frac{t^*}{600}\right)^{0.2} \tag{55}$$

For the gravitational settling model described in Section 4.2 below where material is assumed to fall through all layers, the program uses height-weighted values of σ'_A between the surface and the source in the Kth layer as given by

$$\sigma'_{AK} = \frac{\sum_{i=1}^{K} \sigma'_{Ai} \quad (z_{i+1} - z_i)}{\sum_{i=1}^{K} (z_{i+1} - z_i)} \tag{56}$$

where σ'_{Ai} in the surface mixing layer ($z_i < z_{TL}$) is given by Equation (51). In the next upper layer, σ'_A is obtained by linear interpolation, using the values from Equation (52) and Equation (53), over the layer depth and by using Equation (53) at all greater heights.

Finally, the program assumes that turbulence over the layer depths of interest is approximately isotropic and thus that the mean effective value of σ'_E is equal to the mean effective value of σ'_A.

SECTION 4
REEDM DISPERSION MODELS

The dispersion models used in the REEDM code are based on Gaussian model concepts which experience has shown to be best suited for most practical applications. A detailed discussion of Gaussian modeling concepts and alternative approaches is found in Refs. 21 and 22. As pointed out in this discussion, (Ref. 22), the Gaussian approach, when properly used, "is peerless as a practical diffusion modeling tool. It is mathematically simple and flexible, it is in accord with much though not all of working diffusion theory, and it provides a reliable framework for the correlation of field diffusion trials as well as the results of both mathematical and physical diffusion modeling studies." In the REEDM dispersion model code, the exhaust material is assumed to be uniformly distributed in the vertical and to have a bivariate Gaussian distribution in the plane of the horizon at the point of cloud stabilization. It follows from these assumptions that the models are of the general form identified with Gaussian models for vertical line sources of finite extent.

4.1 DOSAGE AND CONCENTRATION MODELS

For convenience, the dosage and concentration formulas are written in a rectangular coordinate system with the origin at the ground beneath the cloud stabilization point in the Kth layer. The x axis is directed along the axis of the mean wind direction in the Lth layer and the y axis is directed crosswind or perpendicular to the mean wind direction. In the programs, the origin of the coordinate system is placed at the launch pad.

The dosage or time-integrated concentration at any point (x,y,z) in the Lth layer due to the source in the Kth layer is given by the expression

$$
\begin{aligned}
D_{L,K} = \frac{F\{K\}}{2\sqrt{2\pi}\,\sigma_{yL}(z_{TK} - z_{BK})} & \left\{ \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_{yL}}\right)^2 \right] \right\} \\
& \left\{ \sum_{j=1}^{N} f_j \left\{ \sum_{i=0}^{\infty} \left[\gamma_j^{\,i} \left[\operatorname{erf}\left(\frac{2i(z_{TL} - z_{BL}) - z_{BK} + z + V_j\, x/\bar{u}_L}{\sqrt{2}\,\sigma_{zL}} \right) \right.\right.\right.\right. \\
& \left. + \operatorname{erf}\left(\frac{-2i(z_{TL} - z_{BL}) + z_{TK} - z - V_j\, x/\bar{u}_L}{\sqrt{2}\,\sigma_{zL}} \right) \right] \\
& + \gamma_j^{\,i+1} \left[\operatorname{erf}\left(\frac{2i(z_{TL} - z_{BL}) - 2z_{BL} + z_{TK} + z - V_j\, x/\bar{u}_L}{\sqrt{2}\,\sigma_{zL}} \right) \right. \qquad (57) \\
& \left.\left. + \operatorname{erf}\left(\frac{-2i(z_{TL} - z_{BL}) + 2z_{BL} - z_{BK} - z + V_j\, x/\bar{u}_L}{\sqrt{2}\,\sigma_{zL}} \right) \right] \right] \\
& + \sum_{i=1}^{\infty} \left[\gamma_j^{\,i} \left[\operatorname{erf}\left(\frac{2i(z_{TL} - z_{BL}) + z_{TK} - z - V_j\, x/\bar{u}_L}{\sqrt{2}\,\sigma_{zL}} \right) \right.\right. \\
& \left. + \operatorname{erf}\left(\frac{-2i(z_{TL} - z_{BL}) - z_{BK} + z + V_j\, x/\bar{u}_L}{\sqrt{2}\,\sigma_{zL}} \right) \right]
\end{aligned}
$$

$$+ \gamma_j^{i+1} \left[\mathrm{erf}\left(\frac{2i(z_{TL} - z_{BL}) + 2z_{BL} - z_{BK} - z + V_j\, x/\bar{u}_L}{\sqrt{2}\,\sigma_{zL}} \right) \right.$$

(57)
(Continued)

$$\left. \left. + \mathrm{erf}\left(\frac{-2i(z_{TL} - z_{BL}) - 2z_{BL} + z_{TK} + z - \bar{V}_j\, x/u_L}{\sqrt{2}\,\sigma_{zL}} \right) \right] \right\} \Bigg\}$$

where, for convenience, 0° is set equal to unity and

f_j = fraction of material with velocity V_j

γ_j = partial reflection coefficient (1 for complete reflection and 0 for no reflection) for the jth size category

V_j = gravitational settling velocity for the jth size category

N = total number of size categories describing the size distribution of interest ($N \leq 10$ in the REEDM code)

σ_{zL} = standard deviation of the vertical distribution of material in the Lth layer due to the source in the Kth layer

$$= \sigma'_{EL} x_{rz} \left(\frac{x}{x_{rz}} \right)^{\beta} \tag{58}$$

x_{rz} = distance downwind from a vertical point source over which the vertical cloud expansion is linear (default value equals 100 m in the REEDM code).

β = coefficient of vertical cloud expansion (default value equals 1.0 in the REEDM code).

σ'_{EL} = effective value of σ'_E in the Lth layer (see Section 3.3)

σ_{yL} = standard deviation of the crosswind distribution of material in the Lth layer due to the source in the Kth layer

$$= \left\{ \left[\sigma'_{AL}\ x_{ry} \left(\frac{x + x_v - x_{ry}(1-\alpha)}{\alpha\ x_{ry}} \right)^{\alpha} \right]^2 + \left[\frac{\Delta\theta'_L x}{4.3} \right]^2 \right\}^{1/2} \tag{59}$$

x_{ry} = distance downwind from a virtual point source over which the crosswind cloud expansion is linear (default equals 100 m in the REEDM code)

x_v = virtual distance

$$= x_{ry} \left(\frac{\sigma_{yo}\{K\}}{\sigma'_{AL}\ x_{ry}} \right)^{1/\alpha} + x_{ry}\ (1-\alpha) \tag{60}$$

α = coefficient of crosswind cloud expansion (default equals 1 in the REEDM code)

σ'_{AL} = effective value of σ'_A in the Lth layer (see Section 3.3)

$$\Delta\theta'_L = \begin{cases} (\theta_{TL} - \theta_{BL})\ (\pi/180) & ;\ V_j = 0 \\ \Phi'_{j,k} & ;\ V_j \neq 0 \end{cases}$$

$\Phi'_{j,k}$ = effective wind-sheer angle in radians for particles (drops) in the jth size category (see Equation 75) below

$$\bar{u}_L = \begin{cases} \left(\frac{1}{z_{TL} - z_{BL}} \right) \sum_{k=z_{BL}}^{z_{TL}} (z_{k+1} - z_k)\ \bar{u}_k & ;\ V_j = 0 \\ \bar{u}_{j,k} & ;\ V_j \neq 0 \end{cases} \tag{62}$$

$\bar{u}_{j,k}$ = effective mean wind-speed for particles (drops) in the jth size category (see Equation (69) below)

The total contribution to a receptor position is calculated by summing the contributions from all sources, i.e. $D_L = \sum_k D_{L,K}$.

The peak concentration, or highest concentration which occurs as the exhaust cloud passes the point (x,y,z), is given by the expression

$$\chi_{P,K} = D_L \left(\frac{\bar{u}_L}{\sqrt{2\pi}\ \sigma_{xL}} \right) \tag{63}$$

where

σ_{xL} = standard deviation of the alongwind distribution of material in the Lth layer due to the source in the Kth layer

$$= \left[\left(\frac{L\{x\}}{4.3} \right)^2 + \sigma_{xo}^2\{K\} \right]^{1/2} \tag{64}$$

$L\{x\}$ = alongwind cloud length at the distance x

$$L\{x\} = \left\{ \begin{array}{ll} \dfrac{0.28\ \Delta\bar{u}_L\ x}{\bar{u}_L} & ;\ \Delta\bar{u}_L \geq 0 \\ \dfrac{0.28\,|\Delta\bar{u}_L|\,x}{\bar{u}_L} & ;\ \dfrac{\Delta\Phi}{\Delta z} < 0, \Delta\bar{u}_L < 0 \\ 0 & ;\ \dfrac{\Delta\Phi}{\Delta z} \geq 0, \Delta\bar{u}_L < 0 \end{array} \right\} \tag{65}$$

$$\Delta\bar{u}_L = \frac{\sum_{k=1}^{z_{TL}} (z_{k+1} - z_k)\ (\bar{u}_{k+1} - \bar{u}_k)}{z_{TL} - z_{BL}} \tag{66}$$

The peak time-mean concentration, or highest time-mean concentration to occur as the exhaust cloud passes the point (x,y,z), is

$$\chi_{P,K}\{T_A\} = \frac{D_L}{T_A}\left\{\mathrm{erf}\left(\frac{\bar{u}_L\ T_A}{2\sqrt{2}\ \sigma_{xL}}\right)\right\} \tag{67}$$

where

T_A = time in seconds over which the concentration is averaged

4.2 GRAVITATIONAL DEPOSITION MODEL

The weight of material per unit area deposited on the ground as a result of the gravitational settling of particles (drops) with velocity V_j from the source in the Kth layer is given by the expression

$$DEP_K = \frac{F\{K\}}{\sqrt{2\pi}\ \sigma_{yL}(z_{TK} - z_{BK})}\left\{\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_{yL}}\right)^2\right]\right\}$$

$$\left\{\sum_{j=1}^{N} f_j\ (1-\gamma_j)\left\{\frac{V_j}{2\bar{u}_{j,k}}\left[\mathrm{erf}\left(\frac{z_{TK}-V_j x/\bar{u}_{j,k}}{\sqrt{2}\ \sigma'_{EK}\ x}\right) - \mathrm{erf}\left(\frac{z_{BK}-V_j x/\bar{u}_{j,k}}{\sqrt{2}\ \sigma'_{EK}\ x}\right)\right]\right.\right. \tag{68}$$

$$\left. - \frac{\sigma'_{EK}}{\sqrt{2\pi}}\left[\exp\left(-\frac{1}{2}\left(\frac{z_{TK}-V_j x/\bar{u}_{j,k}}{\sigma'_{EK}x}\right)^2\right) - \exp\left(-\frac{1}{2}\left(\frac{z_{BK}-V_j x/\bar{u}_{j,k}}{\sigma'_{EK}x}\right)^2\right)\right]\right.$$

(Continued)

$$+ \sum_{i=1}^{\infty} \gamma_j^{\,i-1} \left\{ \frac{V_j}{2\bar{u}_{j,k}} \left[\mathrm{erf}\left(\frac{2iz_{TL} - z_{TK} + V_j x/\bar{u}_{j,k}}{\sqrt{2}\ \sigma'_{EK}\ x} \right) - \mathrm{erf}\left(\frac{2iz_{TL} - z_{BK} + V_j x/\bar{u}_{j,k}}{\sqrt{2}\ \sigma'_{EK}\ x} \right) \right] \right.$$

$$+ \frac{\sigma'_{EK}}{\sqrt{2\pi}} \left[\exp\left(-\frac{1}{2} \left(\frac{2iz_{TL} - z_{TK} + V_j x/\bar{u}_{j,k}}{\sigma'_{EK}\ x} \right)^2 \right) - \exp\left(-\frac{1}{2} \left(\frac{2iz_{TL} - z_{BK} + V_j x/\bar{u}_{j,k}}{\sigma'_{EK}\ x} \right)^2 \right) \right]$$

(68)
(Continued)

$$+ \gamma_j \left[\frac{V_j}{2\bar{u}_{j,k}} \left[\mathrm{erf}\left(\frac{2iz_{TL} + z_{TK} - V_j x/\bar{u}_{j,k}}{\sqrt{2}\ \sigma'_{EK}\ x} \right) - \mathrm{erf}\left(\frac{2iz_{TL} + z_{BK} - V_j x/\bar{u}_{j,k}}{\sqrt{2}\ \sigma'_{EK}\ x} \right) \right] \right.$$

$$\left. \left. \left. \frac{\sigma'_{EK}}{\sqrt{2\pi}} \left[\exp\left(-\frac{1}{2} \left(\frac{2iz_{TL} + z_{TK} - V_j x/\bar{u}_{j,k}}{\sigma'_{EK}\ x} \right)^2 \right) - \exp\left(-\frac{1}{2} \left(\frac{2iz_{TL} + z_{BK} - V_j x/\bar{u}_{j,k}}{\sigma'_{EK}\ x} \right)^2 \right) \right] \right] \right\} \right\} \right\}$$

where

$$\bar{u}_{j,k} = \frac{\left(X_{j,k}^2 + Y_{j,k}^2 \right)^{1/2}}{z_{TK}} V_j \tag{69}$$

$$X_{j,k} = \frac{-u_k}{V_j b_k} \left\{ \sin\left[b_k \left(\frac{\Delta z_K}{2} + z_k \right) - \sin\left(b_k z_k \right) \right] \right\}$$

$$+ \sum_{i=1}^{k-1} \left\{ \frac{u_i}{V_j b_i} \left[\sin\left(b_i z_{i+1} \right) - \sin\left(b_i z_i \right) \right] \right\} \tag{70}$$

$$Y_{j,k} = \frac{u_k}{V_j b_k} \left\{ \cos\left[\left(b_k \frac{\Delta z_K}{2} + z_k\right)\right] - \cos(b_k z_k) \right\} + \sum_{i=1}^{k-1} \left\{ \frac{u_i}{V_j b_i} \left[\cos(b_i z_{i+1}) - \cos(b_i z_i)\right] \right. \tag{71}$$

$$b_k = \Delta\theta'_k / \Delta z_k \tag{72}$$

$$\Delta\theta'_k = \begin{cases} (\pi/180)\ (\theta_{TK} - \theta_{BK}) & ; \quad \Delta\theta'_k \neq 0 \\ 2 \times 10^{-3} & ; \quad \Delta\theta'_k = 0 \end{cases} \tag{73}$$

$$\Delta z_k = z_{TK} - z_{BK} \tag{74}$$

The effective wind-shear angle (change in direction of particle trajectory) for a particle in the jth size category falling to the surface from the Kth layer is

$$\Phi'_{j,k} = \tan^{-1}\left(\frac{Y_{j,k}}{X_{j,k}}\right) \tag{75}$$

In Equation (68), x is directed along an axis parallel with the direction $((\overline{\pi+\theta'_k}) + \Phi'_{j,k})$ and y is crosswind to this direction. It should be noted that the deposition model given by Equation (68) assumes complete reflection of all material at the top of the L layers and partial reflection γ_j at the ground.

4.3 PRECIPITATION SCAVENGING MODEL

The weight of material from the Kth layer deposited on the ground as a result of washout by rain is given by

$$WK_K = \left\{ \frac{\Lambda\ F\{K\}}{\sqrt{2\pi}\ \sigma_{yL}\ \bar{u}_L} \quad \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_{yL}}\right)^2 \right] \right\} \left\{ \exp\left[-\Lambda\left(\frac{x}{u_L} - t_i\right)\right] \right\} \tag{76}$$

where

Λ = fraction of material removed per unit time

t_i = time precipitation begins

The principal assumptions made in deriving Equation (76) are:

(1) The rate of precipitation is steady over an area that is large compared to the horizontal dimension of the cloud of material

(2) The precipitation originates at a level above the top of the cloud so that hydrometeors pass vertically through the entire cloud

(3) The time duration of the precipitation is sufficiently long so that the entire alongwind length of the cloud passes over the point (x,y)

The program uses the following expression (Ref. 23) to obtain a value of Λ for HCℓ scavenging

$$\Lambda = 5.2 \times 10^{-4}\ R^{0.567}\ \text{sec}^{-1} \tag{77}$$

where

R = rainfall rate (in/hr)

The REEDM code also provides estimates of the maximum pH of ground-water collections of $HC\ell$ at (x,y) under the assumptions that the rain begins just as the cloud reaches the receptor location, the rain ends just as the cloud passes the receptor, and that the collection surface is impervious. Thus,

$$pH\{HC\ell\} = -\log_{10}\left[WD_K/(25.4\ R\ M\ D)\right] \tag{78}$$

where

D = rain duration (h)

M = molecular weight of $HC\ell$ (36.465 g $mole^{-1}$)

SECTION 5
REEDM COMPUTER PROGRAM OPERATION

This section provides the complete execution and data-preparation instructions for the REEDM computer program. The REEDM computer program is designed for use on a HEWLETT PACKARD HP1000 computer under the RTE IVB operating system. The REEDM program consists of a main program element REEDM and the following 12 segmented programs, all scheduled by the main program: REDAM, RDATM, RCLDM, RDHMM, RCONM, RCNOM, RPDPM, RGDPM, RGPDM, READM, RCIMM and RMMRM. The REEDM operating instructions in Section 5.1 assume the user has assembled and loaded the REEDM programs and has prepared a meteorological upper-air (rawinsonde) data file. If these tasks have not been completed, the user should refer to Sections 5.3 and 5.4 before proceeding.

5.1 GENERAL REEDM OPERATING INSTRUCTIONS

The REEDM computer program can be executed in a completely interactive environment, in a completely batch environment or in a combination of the two. The REEDM computer program is executed by typing

RU,REEDM,LU1,LU2,LU3,LU4,LU5

where

LU1 - Logical input number from which the REEDM program is to read the input data and control information. The number specified determines whether the program will execute in an interactive or batch environment. If the number entered (or default) is the logical unit number of an interactive device (CRT,TTY, etc.), the program assumes an interactive environment and solicits all input data and commands via displays to the

LU1 (Continued) - device specified by LU1. The default is obtained by typing a comma indicating an empty field. The default logical unit will then be the unit from which the RU,REEDM was entered. If the number entered for LU1 is the logical unit number of a non-interactive device (magnetic tape, card reader, paper tape, etc.) or a number equated with a disc file, the program assumes a batch environment. The program will be completely batch or will require some interactive user input, depending on the input data. All program interactive messages and displays are written to the unit from which the batch run was initiated, except when running under JOB. When running under JOB all program interactive messages and displays are written to the system log device. See Section 5.1.3 for special input values for LU1 used for generating meteorological and maximum centerline plot forms.

LU2 - Logical unit number for print output. The default printer unit (6) is obtained by typing a comma indicating an empty field.

LU3 - Logical unit number for meteorological profile plot output. The default unit (12) is obtained by typing a comma indicating an empty field.

LU4 - Logical unit number for maximum centerline (concentration, dosage, deposition) profile plot output. The default unit (20 at KSC, 12 at MSFC) is obtained by typing a comma indicating an empty field.

LU5 - Logical unit number for isopleth (concentration, dosage, deposition) plot output. The default unit (21 at KSC, 12 at MSFC) is obtained by typing a comma indicating an empty field.

If all LU numbers are to be defaulted, type only RU,REEDM omitting any trailing commas. Section 5.1.1 below specifies the operating instructions for an interactive environment, Section 5.1.2 for a batch environment and Section 5.1.3 for plot forms generation.

5.1.1 Interactive Processing

The REEDM computer program is executed in an interactive environment only when the logical unit number specified by LU1 is an interactive device (CRT,TTY,etc.). After the user types the RU,REEDM command, the REEDM program begins execution by displaying the following message:

```
*************************************************************
******     NASA/MSFC MULTIPLE LAYER TECHNIQUE - REEDM     ******
******            UPDATE ####    LOCATION KSC             ******
******     ENTER '-1' TO CHANGE PREVIOUS INPUT VALUE.     ******
******     ENTER '-9' TO START AT BEGINNING OF PROGRAM.   ******
******     ENTER '-9' AT BEGINNING TO ABORT PROGRAM.      ******
******     THE FIRST INPUT OPTION SHOWN IS THE DEFAULT.   ******
*************************************************************
```

where the value of #### is the update level of the copy of REEDM the user is executing. All segments of the REEDM program must have the same update reference number. The above display also reminds the user of certain conventions that will apply to most input requests throughout the operation of the program. Specifically, the following conventions apply to interactive processing:

- The first option shown is the default option unless stated otherwise in the explanation of the option. The default option is obtained by typing the SPACE key followed by the RETURN key. In the following text, the SPACE key will be denoted by ∇ and the RETURN key by C_R. Also, on those input devices with enhanced character features, the default will be highlighted by inverse video.

- Most options can be entered by typing the first character of the option name followed by C_R. However, for those options that have the same first characters, you must enter sufficient characters to make the entry unique or type the entire name of the option. On those input devices with enhanced character features, the characters that are entered to select an option are underlined.

- For most input options, the entry of a -9 followed by C_R will cause the REEDM program to restart. If the user is in a section of the program that will not respond to a -9, the user must continue to enter valid data until a display is reached that will respond to -9.

- For most input options, the entry of a -1 followed by C_R will cause the program to go back to the previous input option display. If the user is in a section of the program that will not respond to a -1, the user must either continue to enter valid data or enter a -9 or abort the REEDM program.

- For input options where multiple values are required, the values are positional and each must be separated by a comma. Two consecutive commas indicate an empty field with the respective variable remaining its previous (default) value. Do not type C_R until the entire string of values has been entered.

- The program will echo back all values and options entered, except YES or NO options.

The remainder of this section will show the REEDM prompt as a display asking for either data or for a response that will direct the program along optional paths. Each display is typed in boldface type with

a leading display number (record number). The display number is used for order and cross-referencing against batch data record numbers and is accompanied by a code in parenthesis (ORP;CWG). The letters O, R and/or P that appear prior to the semi-colon indicate if the display will occur under the Operational, Research or Production modes of operation. The letters C, W and/or G indicate if the display will occur for Concentration (dosage), Washout deposition or Gravitational deposition calculations. If the particular letter does not occur in parenthesis, the display does not occur for that mode of operation and/or that calculation. The program will prompt with only those displays that are required for the mode of operation and calculation quantity you select. The REEDM interactive display prompts are explained below in the order they appear to the user.

1. - (ORP;CWG)

ENTER RUN TYPE (OPERATIONAL, RESEARCH, PRODUCTION):

As explained in Section 2.1, the Operational (O) mode is designed for use during launch support operations and automatically calculates many of the user inputs. The Research (R) mode allows the user to specify a more complete array of inputs and provides more detailed output which is useful for case studies. The Production (P) mode is used to process multiple cases and is primarily executed in a batch environment as described in Section 5.1.2.

2. - (ORP;CWG)

ENTER METEOROLOGICAL DATA FILE NAME (RRSOND):

The REEDM program assumes the user has previously stored the meteorological upper-air (rawinsonde) data into a disc file. The default file name "RRSOND" is shown in parenthesis in Display 2 and is obtained by typing ∇C_R. The format and contents of the meteorological disc data file are specified in Section 5.3. For Production mode runs multiple cases

(data sets) may be stacked in this file. If the data file is on disc and the file name is "DATA##", the program will begin processing with the data-set number given by ##. The program counts the data sets from 00 to 99. For example, if the disc file name given to the program is "DATA07", the program will start processing with the eighth data set in the file. Also, if the data file is on tape and the file name given is "TAPE##", the program will begin processing with the tape data-set number given by ##. The program counts the data sets from 00 to 99. If tape is used, the program assumes the data are in the KSC65 format shown in Section 5.3 and are read from logical unit 8. Also, the user is required to position the tape to the correct file number prior to processing.

3. - (P;CWG)

ENTER NUMBER OF RUNS TO BE MADE (1):

This display only occurs for production mode runs and asks for the number of cases you wish to process. The default value is given in parenthesis. There must be this number of data cases stacked in the file specified in Display 2.

4. - (ORP;CWG)

ENTER MODEL TYPE (CONCENTRATION/DOS.,WASHOUT DEP.,GRAVITATIONAL DEP.):

The REEDM program contains three different dispersion model options. The user has the option of either calculating concentration, dosage and time average concentration (C), deposition due to washout by precipitation (W), or deposition due to gravitational settling (G).

5. - (ORP;CWG)

ENTER LAUNCH TIME AND DATE (1000 EST 22 MAR 1982):

The REEDM program assumes the user has stored the default launch time and date in a file called ?LTIME on disc as a single line. The format must be the same as that shown inside the parenthesis in Display 5 (not including the parenthesis) and left-justified in the record. The program retrieves this time and date and displays it as the default time and date in Display 5. If the program cannot find file ?LTIME, a warning message is displayed and the program uses the current time and date for the default displayed in parenthesis. If you desire to enter another time and date or change any part of the default, the values are entered immediately below the corresponding time, day, month, etc. of the default display. Abbreviations for the month are - JAN, FEB, MAR, APR, MAY, JUN, JUL, AUG, SEP, OCT, NOV, DEC.

6. - (ORP;CWG)

ENTER LAUNCH VEHICLE (SHUTTLE,TITAN,DELTA2914,DELTA3914):

Vehicle data parameters are automatically provided for the SPACE SHUTTLE(S), TITAN III(T), DELTA 2914(D2) and the DELTA 3914(D3) vehicles. Only calculations for these vehicles can be processed by the REEDM program.

7. - (ORP;CWG)

ENTER LAUNCH TYPE (NORMAL,SINGLE ENGINE,CONFLAGRATION):

The three launch situations are given as -

NORMAL LAUNCH (N)

- Two solid engines and zero stage liquid engine ignite normally

NORMAL LAUNCH (N) (Cont.)

- Heat released prior to lift-off ignored in cloud rise calculation
- Heat vaporizes water from pad deluge system

SINGLE ENGINE BURN ON PAD (S)

- One solid engine ignites and burns
- Vehicle remains in hold-down configuration
- Pad deluge pad operates normally

CONFLAGRATION (C)

- On-pad explosion ruptures solid engine casings and propellant scatters in vicinity of pad
- Solid propellant burns at a constant rate over selected periods
- Liquid propellant does not contribute to heat released for cloud rise

8. - (ORP;CWG)

ENTER PROPELLANT TEMPERATURE (30 DAY AVG.) (20.87 DEG. C):

The vehicle propellant temperature in degrees Celsius is entered here. The default value shown is a 30 day average historical value for the month entered in Display 5. The default propellant temperatures are valid only for Kennedy Space Center, Florida.

9. - (ORP;CW)

ENTER ONE OR MORE SPECIES (HCL,AL2O3,CO2,CO):

This option is displayed for concentration (dosage) and washout deposition calculations only, except only $HC\ell$ and $A\ell_2O_3$ are displayed for washout deposition. Gravitational deposition calculations automatically assume the calculations are to be made for the deposition of $A\ell_2O_3$.

9.1 - (R;CWG)

ENTRAINMENT PARAMETERS GAMMAX=.64 GAMMAY=.64 GAMMAZ=.64 CHANGE (NO,YES):
THE PRODUCT OF GAMMAX*GAMMAY*GAMMAZ SHOULD EQUAL .64 CUBED

The default entrainment coefficients (see Equation 11) are shown as .64 for a normal launch. However, if either a single engine burn or conflagration is selected in Option 7 above, the default entrainment parameters will be shown as .5. If the user wishes to change these parameters, a "Y" is entered and the program will ask for the new values in the following displays.

9.2 - (R;CWG)

ENTER GAMMAX (.64):

Enter the alongwind entrainment coefficient. A value of .5 is displayed for abnormal launches.

9.3 - (R;CWG)

ENTER GAMMAY (.64):

Enter the crosswind entrainment coefficient. A value of .5 is displayed for abnormal launches.

9.4 - (R;CWG)

ENTER GAMMAZ (.64):

Enter the vertical entrainment coefficient. A value of .5 is displayed for abnormal launches.

10. - (ORP;CWG)

ENTER LAUNCH COMPLEX NUMBER (39A,39B,39C,40,41,17):

Enter the entire launch complex number. The default launch complex number depends on the type of vehicle entered in Display 6. If the vehicle is the SPACE SHUTTLE, the default is "39A". If the vehicle is the TITAN III, the default is "40". If the vehicle is the DELTA, the default is "17". The default for this display does not necessarily appear as the first option in parenthesis. The program will automatically determine the launch coordinates for each of the above 6 sites when plotting isopleths of concentration, dosage, or deposition.

11. - (ORP;C)

CALCULATIONS TO BE DONE AT (SURFACE,STABILIZATION,ANOTHER):

This display only appears for concentration/dosage calculations. Washout deposition and gravitational deposition are calculated only at the surface. Also, calculations of $A\ell_2O_3$ concentration, dosage are allowed only within 5 meters of the surface. An entry of "S" results in surface calculations, "ST" the cloud stabilization height and "A" requires the entry of the height in the following display.

11.1 - (ORP;C)

ENTER CALCULATION HEIGHT (METERS) (0.00 METERS):

This display appears only if "A" is entered in response to Display 11. The height entered must be less than the top boundary of the upper layer (L=2) or must be less than 5 meters if $A\ell_2O_3$ concentration/dosage are being calculated. The default height is given in parenthesis.

12. - (ORP;CWG)

ENTER CLOUD SHAPE (ELLIPTICAL, SPHERICAL):

This parameter determines the shape of the cloud and the distribution of source material. The default is Elliptical (E), specifying an elliptical shape and a uniform vertical distribution of source material in each Kth meteorological layer (see Section 3.2.2). The option allows a spherical (S) shape with a Gaussian vertical distribution of material within the cloud. As noted in Section 3.2.2, we suggest the (E) option be used for normal launches and the (S) option be used for abnormal launches.

12.1 - (R;C)

ENTER ABSORPTION COEFFICIENT FOR GASES ONLY (RNG:0 to 1,DEF.=NO ABS.=0):

Enter the fraction of material absorbed at the surface. The value entered here refers to the fraction of vapor material $HC\ell$, CO, CO_2) absorbed at the ground surface and/or the base of the upper mixing layer. The default value is no absorption or zero.

12.2 - (R;C)

ENTER DECAY COEFFICIENT (NO DECAY=0):

Enter the coefficient of time-dependent decay in units of sec^{-1}. The coefficient of time-dependent decay can be determined by the absolute value of $\ell n\ (0.5)/t$, where t is that time at which 1/2 of the material has been removed due to physical or chemical processes.

12.3 - (R;CWG)

This option permits the user to change the coefficients of crosswind α and vertical β cloud expansion from the default values to values other than unity. We suggest that α always be set equal to 1. The value of β can be set equal to 0.9 for abnormal launches, but should be set equal to 1 for normal launches. If the user desires to change the value, a "Y" is entered here and the new values of α and β are entered in the following displays.

12.4 - (R;CWG)

ENTER ALPHA:

Enter the user-selected coefficient of crosswind cloud expansion.

12.5 - (R;CWG)

ENTER BETA:

Enter the user-selected coefficient of vertical cloud expansion.

12.6 - (R;CWG)

DOWNWIND EXPANSION DISTANCES XRY=100.0 XRZ=100.0 CHANGE (NO,YES):

This option permits the user to change the alongwind distance in meters over which rectilinear cloud expansion in the crosswind and/or vertical directions occurs (see Equations 58, 59 and 60). If a change is desired, enter "Y" and enter the distance in the following displays.

12.7 - (R;CWG)

ENTER XRY:

Enter the alongwind distance in meters over which rectilinear cloud expansion in the crosswind direction occurs.

12.8 - (R;CWG)

ENTER XRZ:

Enter the alongwind distance in meters over which rectilinear cloud expansion in the vertical direction occurs.

12.9 - (R;C)

CONCENTRATION AVERAGING TIME (TIMAV=600.0 SEC.) CHANGE (NO,YES):

This option allows the user to change the time over which peak time-mean concentration is calculated (see Equation 67). The default value is shown in parenthesis. If a change is desired, enter "Y" and the new time is entered in the following display.

12.10 - (R;C)

ENTER TIMAV:

Enter the averaging time in seconds over which the peak time-mean concentration is to be calculated.

12.11 - (R;CG*)

```
 GRAVITATIONAL SETTLING CATEGORIES DATA
NUMBER OF SETTLING CATEGORIES =                                  10
TERMINAL FALL VELOCITY VALUES (METERS PER SECOND) =            .1078
     .1078,.1078,.1078,.1078,.1078,.1078,.1078,.1078,.1078,
REFLECTION COEFFICIENT VALUES =                               0.000
     0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,
FREQUENCY OF OCCURRENCE VALUES =                               .0002
     .0151,.1182,.1175,.1724,.2358,.3130,.4240,.5818,.7266,
 AVERAGE PARTICLE SIZE DIAMETERS (MICROMETERS) =             115.00
      230.,350.,440.,500.,555.,610.,675.,750.,870.,
 DO YOU WISH TO CHANGE THE GRAVITATIONAL SETTLING DATA (NO,YES):
```

The default values for parameters related to gravitational deposition and concentration of $A\ell_2O_3$ with gravitational deposition occurring are shown in the display. If the user desires to change any or all of these data, a "Y" is entered and the respective changes are entered in the following displays. Also, when calculating concentration, the program does not display or require the particle diameter.

12.12 - (R;CG)

ENTER THE NUMBER OF SETTLING CATEGORIES (MAXIMUM IS 10):

Enter the number of particle-size categories required to represent the material distribution. The default for this parameter is shown in Display 12.11.

---

* This display occurs for concentration only when the calculation is being made for $A\ell_2O_3$.

12.13 - (R;CG)

ENTER ## TERMINAL FALL VELOCITY VALUES (METERS PER SECOND):

Enter ## particle settling velocities in meters per second, where ## is the value entered in Display 12.12. Each value entered is separated from the following value by a comma. Type C_R at the end of the string of values. The defaults for these parameters are shown in Display 12.11. Also, if the user does not wish to change all values, a comma must be typed for each value skipped to indicate an empty field.

12.14 - (R;CG)

ENTER ## REFLECTION COEFFICIENT (NO REF. = 0) VALUES:

Enter ## particle reflection coefficients as fractions, where ## is the value entered in Display 12.12. Each value represents the fraction of the material in the respective particle-size category that is reflected (not absorbed) at the surface. Each value entered is separated from the following value by a comma. Type C_R at the end of the string of values. The defaults for these parameters are shown in Display 12.11. Also, if the user does not wish to change all values, a comma must be typed for each value skipped to indicate an empty field.

12.15 - (R;CG)

ENTER ## FREQUENCY OF OCCURRENCE VALUES (SUM MUST TOTAL 1.0):

Enter ## particle mass fractions where ## is the value entered in Display 12.12. Each value represents the fraction of the total material mass in the respective particle category. Each value entered is separated from the following value by a comma. Type C_R at the end of the string of values. The defaults for these parameters are shown in Display 12.11. Also, if the user does not wish to change all values, the user must type a comma for each value skipped to indicate an empty field.

12.16 - (R;G)

ENTER ## AVERAGE PARTICLE SIZE DIAMETERS (MICROMETERS):

Enter ## average particle-size diameters in micrometers, where ## is the value entered in Display 12.12. Each value represents the geometric mean diameter for the respective particle-size category. Each value entered is separated from the following value by a comma. Type C_R at the end of the string of values. The defaults for these parameters are shown in Display 12.11. Also, if the user does not wish to change all values, the user must type a comma for each value skipped to indicate an empty field.

13. - (ORP;W)

CALCULATE (MAXIMUM POSSIBLE,TIME-DEPENDENT) WASHOUT DEPOSITION?:

This display appears only for calculations of washout deposition. Maximum possible (M) produces the maximum possible deposition on the ground due to precipitation scavenging independent of the time when precipitation begins ($t_i=x/u_L$ in Equation 76.). Time dependent (T) washout deposition produces the deposition on the ground due to precipitation scavenging that begins at the time t_i specified in Display 15.

14. - (ORP;W)

ENTER RAINFALL RATE (HEAVY=0.3,MODERATE=0.2,LIGHT=0.1,ANOTHER):

This display appears only for washout deposition and asks for the rainfall rate in inches per hour. If the user wishes to specify the rainfall rate, enter an (A) and the rate is entered in the following display.

14.1 - (ORP;W)

ENTER RAINFALL RATE (INCHES PER HOUR):

Enter the rainfall rate in inches per hour.

14.2 - (R;W)

RAINFALL SCAVENGING COEFFICIENT (LAMBDA= 2.62743E-04) CHANGE (NO,YES):

The rainfall scavenging coefficient λ appearing in Equation 76 has units of s^{-1} and is determined from Equation 77 depending on the value of R in Display 14 or 14.1. The value of λ in parenthesis above (LAMBDA=2.62743E-4) is for heavy rain (R=0.3 in/hr in Display 14). If the user desires to use a value of λ other than the value calculated using Equation 77, a "Y" is typed and the desired value is entered in the following display.

14.3 - (R;W)

ENTER LAMBDA:

Enter the rainfall scavenging coefficient in units of s^{-1}.

15. (ORP;W)

TIME RAIN STARTS AFTER LAUNCH (TIME1=0.00 SECONDS) CHANGE (NO,YES):

This display appears only for time-dependent washout deposition. The default time of start of precipitation is displayed in parenthesis. If the user wishes to specify the start time, enter a "Y" and the time is then entered in the following display.

15.1 - (ORP;W)

ENTER TIM1 (SECONDS):

Enter the time in seconds after launch time at which precipitation begins.

16. - (ORP;W)

RAIN DURATION (DURAT= 1.00 HOURS) CHANGE (NO,YES):

This option allows the user to change the default value for the duration of precipitation shown in the parenthesis. If a change in the duration of precipitation is desired, enter a "Y" and enter the duration in the following display.

16.1 - (ORP;W)

ENTER DURAT (HOURS):

Enter the duration of precipitation in hours.

16.2 - (R;CWG)

PRINT DETAIL MODEL PARAMETERS? (NO,YES):

This option allows the user to select between a summary or detailed print-output and is available only in the research mode.

17. - (ORP;CWG)

DO YOU WISH TO PLOT THE METEOROLOGICAL PROFILE (YES,NO):

The meteorological data profile is used to assess the quality of the rawinsonde data and to determine the height of the layer boundaries to

be used in the dispersion calculations. The program plots vertical profiles of wind direction, wind speed, temperature and virtual potential temperature as well as the dimensions of the stabilized cloud as viewed from the launch pad along the mean wind direction in the lowest layer. Figure 2 shows an example meteorological profile plot produced by the program for 0712 Eastern Standard Time 12 April 1981. This example shows an elevated inversion based at approximately 990 meters and a surface based inversion with its top at about 150 m.

17.1 - (ORP;CWG)

```
MOUNT A METEOROLOGICAL PROFILE FORM ON PLOTTER LU##
                                SPACE - RETURN WHEN READY
                                ENTER F TO PLOT THE FORM:
```

This display appears only when "Y" is given in response to Display 17 above. The logical unit to which the program sends the plot is given by ## in Display 17.1. A meteorological profile form or blank paper must be mounted on the plotter and the plotter left in a ready state before a response is entered to this display. Forms generation for meteorological profiles is discussed further in Section 5.1.3.

18. - (ORP;CWG)

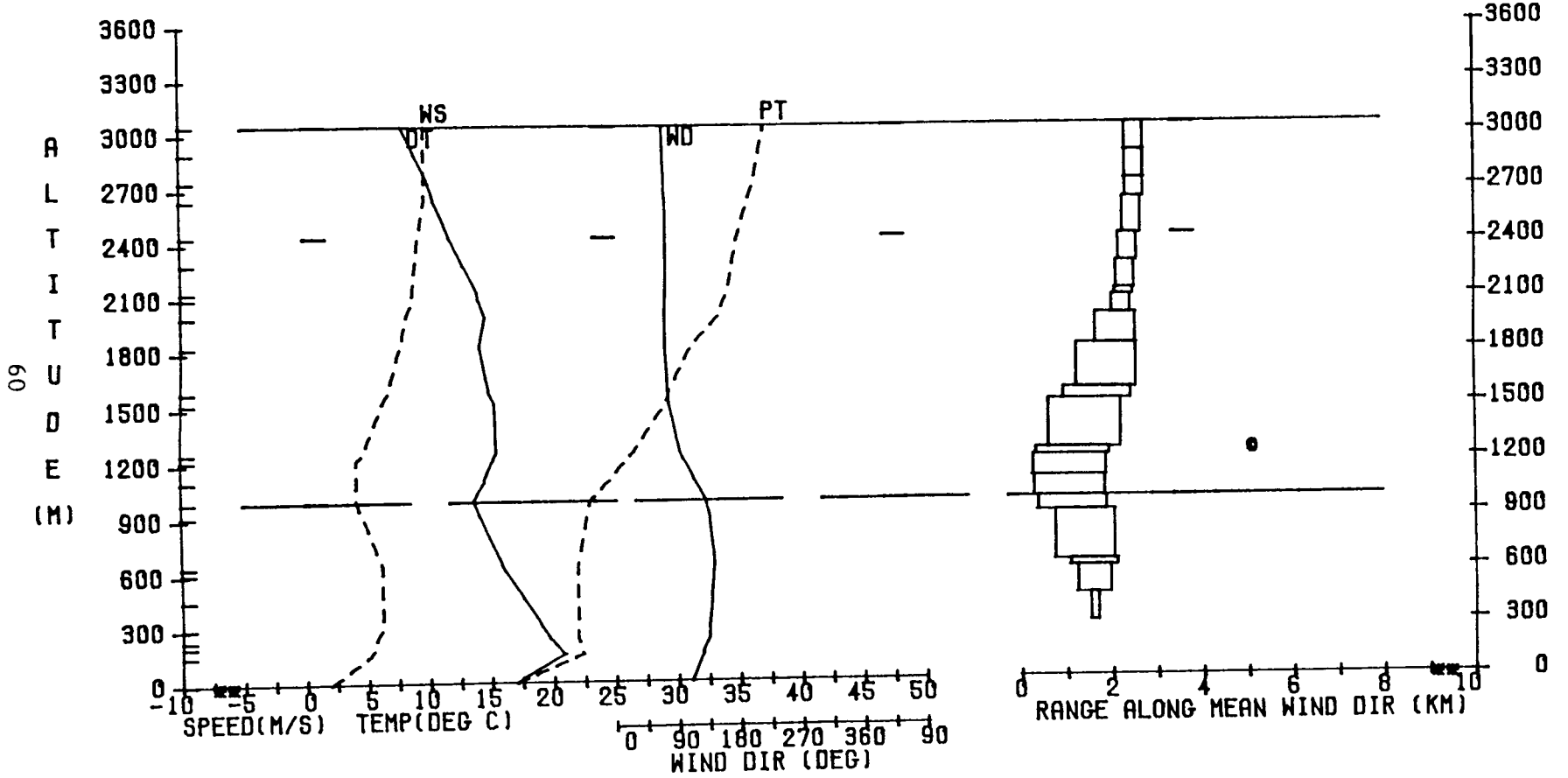
```
HEIGHT AT THE TOP  OF THE UPPER LAYER (METERS):          3048.00
HEIGHT AT THE BASE OF THE UPPER LAYER (METERS):          2438.40
HEIGHT AT THE TOP  OF THE LOWER LAYER (METERS):          2438.40
+ + + + + + + STABILIZATION HEIGHT + + + + + + +         1246.39
+ + + + + + + + CALCULATION HEIGHT + + + + + + +            0.00
HEIGHT AT THE BASE OF THE LOWER LAYER (METERS):             0.00
DO YOU WISH TO CHANGE (NEITHER,UPPER,LOWER) TRANSITION LAYER:
```

The REEDM program uses two major meteorologically defined layers as discussed in Section 2.3. The boundaries of these layers must coincide with heights reported in the rawinsonde data file. If the user selects any height other than those shown in Display 18 above, the program will automatically select the height from the rawinsonde data file closest to the value entered by the user in the following displays. The program sets the

DATE: 12 APR 1981 TIME: 0712 EST PLOTTED AT: HEC FROM FILE: VD1212

SURFACE PRESSURE: 1023.4MB DENSITY: 1220.6G/M^3 • - STAB HT: 1246.4M ** - CALC HT: 0.0M

	LAYER1 SURFACE	LAYER1 TOP	LAYER2 BOT	LAYER2 TOP
ALTITUDE (M)	0.0	992.4	992.4	3048.0
DRY TEMP (DEG C)	17.0	13.6	13.6	8.0
POT TEMP (DEG C)	17.0	23.0	23.0	37.2
WIND SPEED (M/S)	2.1	4.1	4.1	9.8
WIND DIR (DEG)	110.0	131.0	131.0	71.0



PLOTTED AT: *** 1044. 24 JUN 1982 ***

Figure 2. Meteorological profile plot produced by REEDM from KSC rawinsonde data for 0712 Eastern Standard Time, 12 April 1981.

base of the lower layer to 0 (surface) and defaults to twice the cloud stabilization height for the top of the lower layer. The program also uses the top of the lower layer as a default value for the base of the upper layer and sets the top of the upper layer to the highest rawinsonde measurement level read by the program (normally 3048 meters). These layer heights are used as defaults because a value for the height of the top of the lower layer between the stabilization height and twice the stabilization height maximizes ground-level vapor concentrations. However, the user is expected to alter the default values of the base and top of the major layers based on the print output of the rawinsonde data, the plot of the meteorological profile, or forecasts of meteorological conditions at launch time. The user should generally select the height of the base of an elevated inversion to represent the top of the lower layer and base of the upper layer. It should be noted that the primary function of selecting the top of the lower layer is to represent a boundary to turbulent mixing (see Section 3.3.2). For this reason, the temperature should begin to increase or remain constant above the selected height for at least 50 to 100 meters (see Figure 2). The primary purpose of the REEDM program is to assist users in estimating the environmental effects of vehicle launches. The user must, therefore, reflect on the expected effects of the selected layer heights on the calculated concentration/dosage levels. For this reason, the user should likely ignore surface-based inversions or elevated inversions with tops less than a few hundred meters above the surface in the selection of the top of the lower layer unless there is very strong evidence that the cloud above this layer will not penetrate to the surface. Also, if the model is being used to estimate concentrations at the flight level of sampling aircraft and this flight level is in an elevated inversion, the base and top of the upper layer should correspond to the base and top of the elevated inversion. If there is no elevated inversion, the user can specify a single layer by entering 0 for the top and bottom of the upper layer and changing the top of the lower layer to the height of the highest sounding level read by the program (usually 3048 m). Also, the user is cautioned to use all of the meteorological sounding data up to 3048 meters when calculating gravitational deposition and to limit the top of the upper layer to the height precipitation originates when calculating washout deposition.

18.1 - (ORP;CWG)

ENTER THE HEIGHT AT THE TOP OF THE LOWER LAYER (METERS):

The program will use the height from the rawinsonde data file closest to the value entered here. Upon entry of this value, the program will return to Display 18.

18.2 - (ORP;CWG)

DO YOU WISH TO CHANGE (TOP,BASE) HEIGHT OF THE UPPER LAYER:

Options to modify either the height of the top (T) or base (B) of the upper layer.

18.3 - (ORP;CWG)

ENTER THE HEIGHT AT THE BASE OF THE UPPER LAYER (METERS):

The program will use the height from the rawinsonde data file closest to the value entered here. Upon entry of this value, the program returns to Display 18. The program will not allow the entered height to be below the height at the top of the lower layer unless the value entered is 0 and the height at the top of the upper layer is also set to 0. Also, the program will not allow the height entered to be different from the height at the top of the lower layer when washout deposition is being calculated. If either of these restrictions are violated, the program will display "REEDM WARNING 020" (see Section 5.2) after an "N" is entered in Display 18 and will not allow you to continue.

18.4 - (ORG;CWG)

ENTER THE HEIGHT AT THE TOP OF THE UPPER LAYER (METERS):

The program will use the height from the rawinsonde data file closest to the value entered here. Upon entry of this value, the program

returns to Display 18. This height should be the height of the highest level from the rawinsonde data file (usually 3048 meters) read by the program when gravitational deposition or concentration ($A\ell_2O_3$) with gravitational deposition occurring is being calculated.

19. - (ORP;CWG)

ENTER SIGMA AZ, (ESTIMATED=13.82,ANOTHER):

The default turbulent intensity SIGMA AZ value shown in parenthesis is the program approximation to the standard deviation of the azimuth wind direction at a height of approximately 5 meters. This value (SIGMA AZ) corresponds to $\sigma'_{AR}\{\tau_o=600\}$ in Equation 38. The program follows the rules outlined in Section 3.3 for calculating and assigning SIGMA AZ values to the meteorological sounding levels. If the user is in the Operational or Research mode and does not intend to input SIGMA AZ at each sounding level (see Display 20.2 below), the program calculates the SIGMA AZ at each sounding level using the same rules specified in Section 3.3.2. (Equations (49)-(56) as if the program had selected $\sigma'_{AR}\{\tau_o=600\ s\}$. However, if the user is in the Research mode and intends to input SIGMA AZ at each sounding level in Display 20.2, the value entered here is used unmodified as the value at the base of the first meteorological sounding layer and the remaining values are entered in Display 20.2 below.

19.1 - (ORP;CWG)

ENTER SIGMA AZ (DEG):

Enter the standard deviation of the azimuth wind direction in degrees.

20. - (ORG;CWG)

ENTER SIGMA EL, (ESTIMATED=13.82,ANOTHER):

The default values of SIGMA EL shown in parenthesis is the default standard deviation of the wind elevation angle. The default value shown in parenthesis is identical to the value defaulted or input as SIGMA AZ in Display 19. This value of SIGMA EL is automatically treated similar to SIGMA AZ in the program. That is, the layer values used in the program are derived from this input using the same rules given by Equations (49) through (56) under the assumption that, after the rules have been followed, the turbulence over the layer depths of interest is isentropic. However, If the user is running in the Research mode and chooses to input SIGMA EL at each sounding level in Display 20.2 below, the value entered here is used unmodified as the value at the base of the first meteorological layer and the remaining values are entered in Display 20.2.

20.1 - (ORP;CWG)

ENTER SIGMA EL (DEG):

Enter the standard deviation of the wind elevation angle in degrees.

20.2 - (R;CWG)

DO YOU WISH TO INPUT SIGMA A & SIGMA E FOR EACH LEVEL? (NO,YES):

When SIGMA A AND SIGMA E values are entered for each meteorological sounding level, the program uses a height-weighted mean (similar to Equation (56)) to calculate the value used within each meteorological layer. If the user desires to enter the SIGMA A AND SIGMA E values, enter a "Y" here and enter the values for sounding level 2 through the top sounding level in Display 20.3. The program assumes the values for level 1 (surface) were entered in Displays 19 and 20 above.

20.3 - (R;CWG)

ENTER SIGMA A, SIGMA E (IN DEG) FOR LEVEL ## (20.000,20.000):

Enter the values for SIGMA A and SIGMA E respectively, in degrees and separated by a comma. The display gives the level number as ## and the default values shown in parenthesis. The program will repeat this display for each meteorological sounding level.

20.4 - (ORP;CWG)

DO YOU WISH TO CONTINUE WITH THE MODEL CALCULATIONS? (YES,NO):

This display is essentially a pause to enable the user to restart the program or continue with the maximum centerline calculations. If you continue with the model calculations, there is a delay while the model calculations are being performed. The program will display the distance at which calculations are being done, where the last distance displayed will be 29,000 meters.

21. - (OR;CWG)

DO YOU WISH TO PLOT MAXIMUM CENTERLINES? (YES,NO):

This option enables the user to plot maximum centerline profiles of concentration, dosage, time-mean concentrations, washout deposition or gravitational deposition.

21.1 - (OR;CWG)

```
MOUNT A CENTERLINE PROFILE FORM ON PLOTTER LU ##
                           SPACE - RETURN WHEN READY
                           ENTER F TO PLOT THE FORM:
```

Mount a maximum centerline profile form or blank paper (see Section 5.1.3) on the plotter with the logical unit number specified by ##

in the display. Make sure the plotter is ready to receive commands prior to entering ∇C_R if a form is mounted or prior to entering FC_R if a blank sheet of paper is mounted.

21.2 - (OR;CW)

PLOT MAXIMUM CENTERLINE VALUES FOR: (HCL,AL203,CO,CO2)

This display will appear only if there is more than one species specified by the user under Display 9.

21.3 - (OR;G)

PLOT DEPOSITION IN (MILLIGRAMS OR PARTICLES/M**2)

This display appears only when gravitational deposition is selected for calculation under Display 4.

21.4 - (OR;CWG)

DO YOU WISH TO PLOT CENTERLINE PROFILES FOR ANOTHER VARIABLE OR SPECIES? (YES,NO)

This option enables the user to replot the just completed profile, plot a maximum centerline concentration, dosage, time-mean concentration, washout deposition or gravitational deposition profile for another species or plot gravitational deposition in alternate units.

22. - (OR;CWG)

DO YOU WISH TO PLOT ISOPLETHS? (YES,NO):

This option allows the user to plot isopleth patterns of concentration, dosage, time-mean concentration, washout deposition or gravitational deposition.

22.1 - (OR;C)

PLOT ISOPLETHS OF: (CONCENTRATION,DOSAGE,TIME MEAN CONCENTRATION)

This option is displayed only if concentration has been calculated.

22.2 - (OR;CW)

PLOT ISOPLETHS FOR: (HCL,AL2O3,CO,CO2)

This option is displayed only if there is more than one species specified by the user under Display 9.

22.3 - (OR;W)

PLOT ISOPLETHS FOR SUM OF LAYERS OR LAYER 1 OR LAYER 2?:

Washout deposition on the ground is calculated as the contribution from layer 1 (lower layer), layer 2 (upper layer) and the total given as the sum of layers. This option allows the user to plot the contribution of each layer separately or the total deposition with the default as the total deposition (Sum of layers).

22.4 - (OR;G)

PLOT DEPOSITION IN (MILLIGRAMS OR PARTICLES/M**3)

This display appears only for gravitational deposition.

22.5 - (OR;G)

PLOT ISOPLETHS FOR SUM OF LAYERS OR FOR LOWER LAYER ONLY?

This display appears only for gravitational deposition and allows the plotting of the total ground level deposition or the contribution from

the lower layer only. The default is the total ground level deposition (Sum of layers).

22.6 - (OR;CWG)

```
MAXIMUM CONCENTRATION OF HCL = .9723     PPM
DEFAULT ISOPLETHS ARE:  .9723E-01 PPM
                        .2917     PPM
                        .4862     PPM
                        .6806     PPM
                        .8751     PPM

ENTER FIRST ISOPLETH VALUE (SPACE - RETURN FOR DEFAULTS)
```

This display shows the maximum value of the quantity (concentration) calculated by the program for the species (HCℓ) to be plotted. Also, default isopleth levels chosen by the program are shown. If the user chooses to use the defaults, ∇C_R is entered. However, if the user wishes to specify the isopleth levels, the first specified value (in the same units as shown in the display) is entered at this point. The second through tenth values are then entered in Display 22.7 below.

22.7 (OR;CWG)

```
ENTER SECOND ISOPLETH VALUE (SPACE - RETURN TO TERMINATE ISOPLETH INPUTS)
```

Upon entering the second isopleth value, the program will return to this display replacing the word SECOND by THIRD, THIRD by FOURTH, etc. until ∇C_R is entered or until ten values have been entered.

22.8 - (OR;CWG)

```
MOUNT LAND MAP ON PLOTTER LU ## FOR SITE XX, ENTER SPACE-RETURN WHEN READY
OR ENTER AN 'A', IF THE ALTERNATE MAP IS DESIRED?
OR AN 'S', IF YOU WISH TO SPECIFY THE LAUNCH SITE MAP LOCATION?:
```

Isopleth plotting is accomplished on preprepared maps of Kennedy Space Center. The maps are designated as either a LAND map or a SEA map

(the word LAND is replaced by the word SEA in Display 22.8). This display informs the user of which map to use for obtaining the best isopleth coverage. The display also informs the user to mount the map on the plotter with logical unit number given by ##. The launch-site number is given by XX. The user has the option of accepting the designated map by entering "∇", or forcing the program to use the alternate LAND/SEA map by entering "A", or of specifying the launch-site coordinates by entering "S".

22.9 - (OR;CWG)

```
ON A SCALE OF 0 to 9999 UNITS IN BOTH X AND
Y DIRECTIONS, ENTER THE LAUNCH LOCATION
(0,0 IS THE LOWER LEFT CORNER). X,Y?:
```

This display occurs only when the user selects the "S" option in Display 22.8 above. The program divides the plotter X (horizontal) and Y (vertical) directions into 9999 units each. The origin of the plot (0,0) is located at the lower left hand corner of the plot bed. Also, the X axis corresponds to the north to south axis of the preprepared Kennedy Space Center maps and the Y axis corresponds to the west to east axis of the maps. For example, to enter the launch coordinates of site 39A, the user enters X=4095 and Y=7300 for the land map or X=4200 and Y=1700 for the sea map. In addition for site 39B, the user should enter X=3518 and Y=6702 for the land map or X=3650 and Y=1123 for the sea map.

22.10 - (OR;CWG)

```
DO YOU WISH TO PLOT ISOPLETHS FOR ANOTHER VARIABLE
                OR SPECIES? (VARIABLE, SPECIES, NO):
```

This option allows the user to plot isopleths of any combination of variables or species. The word variable applies only to concentration, dosage and time-mean concentration. When calculating washout deposition or gravitational deposition, entering either a "V" or an "S" will allow plotting of an alternate species or alternate units.

23. - (ORP;CWG)

DO YOU WISH DISCRETE RECEPTOR CALCULATIONS? (YES,NO,LU# OF DATA FILE):

This option allows the user to calculate values of concentration, dosage, time-mean concentration or washout deposition or gravitational deposition at a specified location relative to the launch site. If the user wishes to enter the discrete receptors interactively, a "Y" is entered and the location is entered in Display 23.1. If the user desires to enter the receptors from a data file, the logical unit number previously equated with the receptor data file is entered at this point. The discrete receptor data file contains a maximum of 60 discrete receptors. Each discrete receptor is entered on a new line (record) in the following format -

RANGE(METERS),AZIMUTH(DEGREES),HEIGHT(METERS),COMMENTS

Type the range to the receptor in meters relative to the launch site followed by a comma. Type the azimuth bearing in degrees measured in the clockwise direction from 0 degrees north relative to the launch site. Also, if concentration/dosage is being calculated by the program, the user can specify the calculation height by entering a comma after the azimuth entry followed by the calculation height. Comment information may be entered in columns 31 through 50 and is printed along with the results of each receptor point. If you do not enter 60 points in the discrete receptor data file, the last image in the file must be a -1 beginning in column 1.

23.1 (ORP;CWG)

```
ENTER DISCRETE RECEPTOR LOCATION RELATIVE TO LAUNCH
PAD.  A 20 CHAR. COMMENT MAY BE ENTERED STARTING
UNDER THE ASTERISK.                                        *
RANGE(M),BEARING(DEG),HEIGHT(M):
```

The word HEIGHT does not appear for washout deposition or gravitational deposition calculations because these quantities can only be calculated at the surface. The range is entered in meters relative to the launch site and is followed by a comma. The bearing is entered in degrees and is measured relative to the launch site in a clockwise direction from 0 degrees north and is followed by a comma if the height is to be entered. Enter the calculation height in meters only for concentration calculations. If comment information (building number, etc.) is desired, begin the comment immediately under the asterisk that appears on your CRT screen or TTY page by entering spaces following the height or bearing. A maximum of 20 comment characters per discrete point are saved for print output. As each discrete receptor location is entered, there will be a short pause to calculate the quantity. The program will then display the calculation results on the CRT or TTY and print the results or save for later printing depending on previous options.

23.2 - (ORP;CWG)

DO YOU WISH TO ENTER ANOTHER DISCRETE RECEPTOR LOCATION?
(YES,NO):

This display appears only if the answer to display 23 was yes (Y) and allows you to return to enter up to 60 discrete receptors interactively.

24. - (OR;C)

DO YOU WISH RESULTS FOR ANOTHER CALCULATION HEIGHT (YES,NO):

This display asks whether or not the user wishes to calculate concentration at another height. If "Y" is entered, the program returns to display 11.1, then skips to Display 17. to continue processing.

25. - (OR;W)

DO YOU WISH TO CHANGE WASHOUT DEPOSITION
CALCULATION TYPE? (YES,NO):

This display asks whether the user wishes to change the washout deposition calculation from maximum to time-dependent or from time-dependent to maximum. If you enter a "Y", the program will return to Display 13.

26. - (ORP;CWG)

DO YOU WISH TO PROCESS ANOTHER METEOROLOGICAL CASE (YES,NO):

This is the last REEDM display and asks whether the user wishes to continue with another meteorological data case. If "N" is entered, the program terminates. If "Y" is entered, the program restarts at Display 1.

5.1.2 Batch Processing

The REEDM computer executes in batch environment when the input logical unit number specified by LU1 is a non-interactive device (card reader, magnetic tape, paper tape, disc file, etc.) . The program can be executed completely as a batch run or may require some interactive input depending on the user selected options. All messages and interactive displays are written to the logical unit from which the batch run was initiated, except when initiated from a JOB file. If the batch run is initiated from a JOB file, all messages and interactive displays are written to the system log device.

Upon execution of the REEDM program, the following display will be printed on the system log device or originating logical unit:

```
*************************************************************
******     NASA/MSFC MULTIPLE LAYER TECHNIQUE - REEDM     ******
******              UPDATE####      LOCATION HEC          ******
******     ENTER '-1' TO CHANGE PREVIOUS INPUT VALUE.     ******
******     ENTER '-9' TO START AT BEGINNING OF PROGRAM.   ******
******     ENTER '-9' AT BEGINNING TO ABORT PROGRAM.      ******
******     THE FIRST INPUT OPTION SHOWN IS THE DEFAULT    ******
*************************************************************
```

where the value of #### is the update level of the copy of REEDM you are executing. The reminders in the above display (a -1 returns to a previous display option and -9 restarts the program) are applicable in the batch environment only when the program solicits an interactive response and only -1 should be used. In the following text, each input option is shown with the respective record or reference number. These record numbers are the same as those given in Section 5.1.1 under Interactive Processing. In addition, each record number is accompanied by a code in parenthesis (OP;CWG). The letters O and P that appear prior to the semicolon indicate if the input option is required for the Operational and/or Production modes of operation. The letters C, W and/or G indicate if the option is required for concentration, washout deposition or gravitational deposition. An optional parameter must be present in the input data file if the record code for that parameter contains the letter (O, P, C, W or G) of an option chosen by the user. In setting up the input batch data file, the following conventions must be observed:

- The first option shown in the record description below is the default option, unless stated otherwise in the explanation of the option. The default option is obtained by entering ∇C_R (space return).

- For input options where multiple values are required, the values are positional and each must be separated by a comma. Two consecutive commas indicate an empty field with the respective variable being defaulted.

- Input options that require an interactive response are treated in the same manner as outlined in Section 5.1.1 under Interactive Processing.

- All input options and values typed into the input data file must begin in column 1 of each new record.

Enter the REEDM input control data in the following order:

1. - (OP;CWG)

Run Type - Enter "0" (default) for operational or "P" for production mode. Note that batch processing does not allow a research mode.

2. - (OP;CWG)

File Name - Enter the meteorological data sounding (rawinsonde) file name. A blank record defaults to the name "RRSOND". If the Production mode is selected, the user may stack up to 100 meteorological sounding cases in this file. The Operational mode only processes one case per program run. If the data are on disc, the format and contents must correspond to that given in Section 5.3. Also, if the disc file name is "DATA##", the program will begin processing with the data set number given by ##, where ## is counted from 00 to 99. If the data file name is "TAPE##", the program assumes magnetic tape data in the KSC65 format described in Section 5.3. The tape data are read from logical unit 8 beginning with the data set specified by ##, where ## is counted from 00 to 99. The user must position the tape to the correct file number prior to processing.

3. - (P;CWG)

Number of Runs - Under the Production mode only, enter the number of data cases to be processed from the file specified in Record 2. The default value is "1".

4. - (OP;CWG)

Model - Enter a "C" for concentration (default) dosage and time-mean concentration. Enter a "W" for washout deposition or a "G" for gravitational deposition.

5. - (OP;CWG)

Launch Date - Enter the launch time and date or leave a blank record for the default. The REEDM program assumes the user has stored the default launch time and date in a file called ?LTIME on disc as a single line. The format of the default time and date is the same as that used to enter the date here and is

HHHH∇EST∇DD∇MMM∇YYYY

where:

HHHH - the hour (1000)

EST - Eastern Standard Time, but may be entered as LST, PST, etc.

DD - the day (22)

MMM - the month, selected from - JAN, FEB, MAR, APR, MAY, JUN, JUL, AUG, SEP, OCT, NOV, DEC

YYYY - the year (1982)

∇ - space

5. - (OP;CWG) (Cont.)

If a blank is entered for this record and file ?LTIME does not exist, the program will default to the current time and date. Also, the month entered here determines the default propellant temperature value for Record 8.

6. - (OP;CWG)

Vehicle - Enter an "S" (default) for the SPACE SHUTTLE or "T" for the TITAN. Type "D2" for the DELTA2914 or "D3" for the DELTA3914.

7. - (OP;CWG)

Launch Type - Enter an "N" (default) for a Normal launch, an "S" for a Single engine burn or a "C" for a conflagration.

8. - (OP;CWG)

Propellant Temperature - Enter the propellant temperature in degrees Celsius. A blank record will result in the default value being selected from the following table, depending on the month entered in Record 5.

Default Propellant Temperature °C

Month			Month		
JAN	-	16.06	JUL	-	28.38
FEB	-	19.59	AUG	-	28.63
MAR	-	20.87	SEP	-	28.02
APR	-	23.43	OCT	-	26.29
MAY	-	25.74	NOV	-	22.86
JUN	-	27.67	DEC	-	18.68

These values are valid only for Kennedy Space Center, Florida.

9. - (OP;CW)

Species - Enter "H" (default) for $HC\ell$, "A" for $A\ell_2O_3$, "C" for CO and "C2" for CO_2. Note that this record is not entered for gravitational deposition and only "H" and/or "A" may be entered for washout deposition. Also, separate each entry by a comma.

10. - (OP;CWG)

Launch Complex - Enter "39A" for launch pad 39A, "39B" for launch pad 39B, "39C" for launch pad 39C, "40" for launch pad 40, "41" for launch pad 41 or "17" for launch pad 17. A blank record will use the default, depending on the launch vehicle. The defaults are:

SPACE SHUTTLE	-	39A
TITAN	-	40
DELTA	-	17

11. - (OP;C)

Calculation Height - Enter "S" (default) for surface, "ST" for the cloud stabilization height or the actual calculation height in meters. Note that this record is entered only for concentration runs.

12. - (OP;CWG)

Cloud Shape - Enter "E" (default) for elliptical or "S" for spherical shapes (see Section 3.2 for a description of the consequences of this option).

(Records 13 through 16 are only entered for washout deposition calculations).

13. - (OP;W)

Washout Deposition Type - Enter "M" (default) for calculations of Maximum possible washout deposition or "T" for Time-dependent washout deposition.

14. - (OP;W)

Rainfall Rate - Enter "H" (default) for Heavy (0.3 inches/hr.), "M" for Moderate (0.2 inches/hr.), "L" for Light (0.1 inches/hr.) or enter the rainfall rate in inches per hour.

15. - (OP;W)

Time - Enter the time in seconds after launch time that precipitation begins. This record is entered only if Record 13 contains a "T".

16. - (OP;W)

Duration - Enter the duration in hours of the precipitation. A blank record defaults to "1" hour.

(For Production mode runs, sets of records 17 through 20 and 23 must be entered. The number of sets depends on the number of runs specified in Record 3)

17. - (OP;CWG)

Plot Meteorological Profile - Enter "Y" (default) for yes, "N" for no or "F" for yes which specifies the profile form also be plotted. Meteorological profiles are plotted on the logical unit specified by LU3 in the run command.

18. - (OP;CWG)

Boundary Layering - Because the default boundary layer values are not known apriori, enter "Y" to display the default boundary layer values. Any other entry causes the program to use the default boundary layer values and go to Record 19. When a "Y" is entered, the program temporarily enters interactive processing. The program will then interactively prompt the user for the layer values in the same manner indicated under Display 18 through 18.4 under Interactive Processing, Section 5.1.1. At the end of interactive processing, the program continues with Record 19.

19. - (OP;CWG)

SIGMA(A) - Because the default SIGMA(A) value is not known apriori, enter "A" to display the default value and interactively modify it if desired. Any other value will cause the program to use the default value and go to Record 20.

20. - (OP;CWG)

SIGMA(E) - The default SIGMA(E) value is the same as that entered or defaulted for SIGMA(A). Enter "A" to display the default value and interactively modify it if desired. Any other value will cause the program to use the default value and go to Record 21.

(For a Production run, Records 21 and 22 are not entered)

21. - (O;CWG)

Plot Maximum Centerline - Enter "Y" (default) for yes, "N" for no or "F" for yes which specifies the maximum centerline form also be

21. - (O;CWG) (Cont.)

plotted. If "Y" or "F" is entered, the program enters interactive processing and will remain there during the plotting of all maximum centerline displays. The interactive prompt displays for maximum centerline plotting are shown in Display 21 through 21.4 under Interactive Processing, Section 5.1.1. All maximum centerline plots are plotted on the logical unit specified by LU4 in the run command.

22. - (O;CWG)

Plot Isopleths - Enter "Y" (default) for yes or "N" for no. If "Y" is entered, the program enters interactive processing and will remain there during all isopleth plotting. The interactive prompt displays for isopleths are shown in Display 22 through 22.10 under Interactive Processing, Section 5.1.1. All isopleth plots are plotted on the logical unit specified by LU5 in the run command.

23. - (OP;CWG)

Discrete Receptors - Enter "Y" (default) for yes, "N" for no or the logical unit number of the data file containing the discrete receptors. If "Y" is entered, the program enters interactive processing and prompts the user for the discrete receptors as shown in Displays 23.1 and 23.2 under Interactive Processing, Section 5.1.1. If a logical unit number is entered, the program will read all discrete receptor points from successive records from that unit in the following format

RANGE(M),AZIMUTH(DEG),HEIGHT(M),COMMENTS

Enter the range in meters to the receptor relative to the launch site. Enter the azimuth bearing in degrees

23. - (OP;CWG) (Cont.)

to the receptor, measured clockwise from 0 degrees north relative to the launch site. Enter the height in meters only if this is a concentration calculation. These three values are separated by commas and begin in column 1 of the record. A maximum of 20 characters of comment information may be entered beginning in column 31. There are a maximum of 60 discrete points possible and if you have less than 60 points, the last discrete point must be followed by a record containing "-1".

24. - (O;C)

Another Calculation Height - Enter "Y" if calculations for another height are desired or "N" if not. If "Y" is entered, the new height is entered in a record immediately following this record and a continued data file must be built starting with Record 17 above.

25. - (O;W)

Another Washout Deposition Type - Enter "Y" if an alternate washout deposition calculation type is desired (maximum possible or time-dependent) or "N" if not. If "Y" is entered, this record must be followed with a continued data file starting with Record 13, but omitting Records 14 and 16.

26. - (OP;CWG)

Another Case - Enter "Y" (default) if the program is to continue with another data case or file containing multiple cases. An "N" terminates the program. If "Y" is entered, the input data file must be continued from Record 1.

5.1.3 Plot Forms Generation

The REEDM computer program has the option of generating plot forms for the meteorological profiles and for the maximum centerline (concentration, dosage and deposition) profiles independent from the normal program operations. Prior to executing the program, prepare the plotter to receive the plot, as the REEDM program starts to plot immediately upon execution.

To generate meteorological profile forms type -

RU,REEDM,98,,LU3

where

LU3 - Logical unit number of the plotter you have prepared

At the completion of each plot form, the program will display back to your interactive unit

DO YOU WANT TO PLOT ANOTHER METEOROLOGICAL PROFILE FORM?
CHANGE PLOT PAPER BEFORE A YES (YES OR NO)

The default reply is YES and will continue to plot forms as long as you desire. A NO response terminates the REEDM program.

To generate maximum centerline profile forms type

RU,REEDM,99,,,LU4

where

LU4 - Logical unit number of the plotter you have prepared

At the completion of each plot form, the program will display back to your interactive unit .

```
DO YOU WANT TO PLOT ANOTHER CENTERLINE PROFILE FORM?
CHANGE PLOT PAPER BEFORE A YES (YES OR NO)
```

The default reply is YES and will continue to plot forms as long as you desire. A NO response terminates the REEDM program.

5.2 WARNING AND ERROR MESSAGES

This section contains a list of warning and error messages produced by REEDM.

Error Number	Message and Brief Description
001	*** REEDM ERROR 001,DATA INPUT ERROR,REC. XX.X The program cannot interpret the value or character you have entered for the input record specified by XX.X.
002	*** REEDM ERROR 002,CANNOT LOAD SEGMENT XXXXX The program is attempting to execute the program segment given by XXXXX and cannot locate it on the system disc. Find the named segment and restore (RP) it to the LG tracks or place it on the system disc before continuing.
003	*** REEDM ERROR 003, SEGMENT XXXXX HAS WRONG UPDATE NUMBER, MUST BE UPDATE NUMBER YYYY The program segment named by XXXXX must have the same update number as the main program, given by YYYY. The

Error Number	Message and Brief Description
003 (Cont.)	program has aborted the segment given by XXXXX and you must locate the correct segment update and restore it to the LG tracks or place it on the system disc before continuing.
004	*** REEDM ERROR 004, CANNOT FIND FILE XXXXX The meteorological data sounding (rawinsonde) file given by XXXXX cannot be located on any disc.
005	*** REEDM WARNING 005, CANNOT FIND FILE ?LTIME FOR LAUNCH TIME AND DATE, USING CURRENT TIME AND DATE The program assumes the launch time and date have been specified as a single record in file ?LTIME. If this file is not found, the program reverts to the time and date obtained from the computer. The format of the time and date record is TTTT∇SSS∇DD∇MMM∇YYYY where TTTT = the time (0730) SSS = EST, PST, etc. DD = the day (12) MMM = the month JAN, FEB, MAR, etc. YYYY = the year (1982) ∇ = a space or blank

Error Number	Message and Brief Description
006	*** REEDM WARNING 006, UNABLE TO OPEN FILE ?LTIME FOR LAUNCH TIME AND DATE, USING CURRENT TIME AND DATA The program has found file ?LTIME containing the launch time and date, but cannot open the file.
007	*** REEDM WARNING 007, FREQUENCY OF OCCURRENCE VALUES DO NOT SUM TO 1.0, TYPE N - RETURN TO NORMALIZE BY XXXXX OR SPACE-RETURN TO CONTINUE If the sum of the fractions of material of each drop size category does not sum to 1.0, check your data for an entry error. If you type SPACE-RETURN calculations will proceed using the specified fractions.
008	*** REEDM WARNING 008, A CALCULATION HEIGHT > 5 METERS WILL PRODUCE ERRONEOUS RESULTS FOR AL203 All $A\ell_2O_3$ calculations should be performed at or near the surface. Otherwise large wind direction shear in the sounding data could result in large errors in the calculations.
009	*** REEDM WARNING 009, INVALID MONTH ENTERED - PLEASE REENTER You have entered an incorrect abbreviation for the month. Enter the correct abbreviation from the following list: JAN,FEB,MAR,APR,MAY,JUN,JUL,AUG,SEP,OCT,NOV,DEC

Error Number	Message and Brief Description
010	*** REEDM WARNING 010, THE PRODUCT OF THE GAMMA'S IS INCORRECT, CONTINUE? (YES,NO):
	The product of the entrainment parameters, GAMMAX, GAMMAY AND GAMMAZ should equal approximately .26214 for a normal launch and the product of the parameters GAMMAX and GAMMAY should equal approximately .25 for an abnormal launch.
011	*** REEDM ERROR 011, OPEN ERROR YYY ON SOUNDING FILE XXXXX
	The parameter has found the meteorological data file (rawinsonde) specified by XXXXX, but cannot open the file due to error YYY. See your HP FMGR error message index for the meaning of YYY.
012	*** REEDM ERROR 012, READF ERROR YYY ON SOUNDING FILE XXXXX
	A read error has occurred in input data from file XXXXX. See your HP FMGR error message index for the meaning of YYY.
013	*** REEDM ERROR 013, CALCULATION HEIGHT IS ABOVE INPUT MET LEVELS
	The input calculation height is greater than the highest height of the rawinsonde data read by the program and no calculations can be performed.

Error Number	Message and Brief Description
014	*** REEDM ERROR 014, NO VALID SOUNDING LEVELS WERE FOUND ON FILE XXXXX The program cannot find any valid rawinsonde data in the file specified by XXXXX and no calculations can be performed.
015	*** REEDM ERROR 015, UNEXPECTED END OF FILE OCCURRED ON SOUNDING FILE XXXXX The program assumes the data file specified by XXXXX has been erroneously truncated. See Section 5.3 for the format and contents required for the meteorological data.
016	*** REEDM ERROR 016, SOUNDING DATA FILE XXXXX HAS LESS THAN FIVE VALID LEVELS The program requires at least 5 or greater sounding levels in the meteorological data. See Section 5.3 for the format and contents required for the meteorological data.
017	*** REEDM ERROR 017, NOT ENOUGH LAYERS, THE TOP OF THE LAST LAYER MUST BE GREATER THAN XXXXX The height of the stabilized cloud is above the highest height read by the program and calculations cannot be performed.
018	*** REEDM ERROR 018, (RCLDM) PLUME RISE ERROR FLAG EQUALS XX If the value of XX equals 1, the centroid height of the stabilized cloud is greater than the greatest height of

Error Number	Message and Brief Description
018 Cont.	the sounding read by the program and no calculations can be performed. If the value of XX equals 2, the program is trying to calculate a plume rise height at or below the lowest height read by the program and no calculations can be performed.
019	*** REEDM WARNING 019, -1 NOT APPLICABLE, PROG. ABORTS IF -1 TYPED AGAIN At this point the program cannot go back to the previous input option. A -9 will, in most cases, restart the program and another -1 will terminate the program.
020	*** REEDM WARNING 020, INVALID LAYERING - SPACE RETURN TO CONTINUE The layering you have chosen is invalid due to • Top of lower layer above bottom of upper layer for concentration or washout deposition • The bottom of the upper layer does not coincide with the top of the lower layer for washout deposition • The calculation height is outside the specified layer structure
021	*** REEDM WARNING 021, TOP OF UPPER LAYER LESS THAN TOP OF SOUNDING, CONTINUE? (NO,YES): The height you have chosen for the top of the upper layer is less than the top of the sounding and may underestimate the impact of gravitational deposition.

Error Number	Message and Brief Description
022	*** REEDM WARNING 022, GAP BETWEEN LAYERS MAY NOT PRODUCE REALISTIC GRAVITATIONAL SETTLING RESULTS, CONTINUE? (NO,YES) The bottom of the upper layer should coincide with the top of the upper layer for calculations of $A\ell_2O_3$ concentrations.
023	*** REEDM WARNING 023, PRECIPITATION DEPOSITION CALCULATED AT RANGE=XXXXX, AZIMUTH=YYYYY, MET. LAYER ZZ MAY BE OVERESTIMATED. This message is displayed for washout deposition when the time of the start of precipitation is greater than the time for the cloud to fully pass the calculation point.
024	*** REEDM WARNING 024, ZERO WIND SPEED AT LEVEL XX, PROG. SUBSTITUTES 1.0 M/S DIRECTION NOT MODIFIED MAY BE INCORRECT. The program has detected a wind speed value of 0 in data level XX. The program substitutes a value of 1 m/s for the calm wind speed, but does not modify the wind direction. Examine the data file for errors in wind speed and wind direction.
025	*** REEDM WARNING 025, EOF READ IN FILE XXXXXX, NNNN SHOULD BE LAST IMAGE, DATA MAY BE TRUNCATED. The last image of a disc rawinsonde data file should contain the characters NNNN in columns 1 through 4.

5.3 METEOROLOGICAL UPPER AIR SOUNDING DATA FILE FORMATS

This section specifies the format and contents of the meteorological upper-air sounding (rawinsonde) data. Section 5.3.1 gives the format and contents of data files to be read from disc. Section 5.3.2 gives the format and contents of data files to be read from magnetic tape. All magnetic tape data are read from logical unit 8.

5.3.1 Disc File Format

This section describes the format and contents of the upper-air meteorological disc data file. Each meteorological data file contains one or more sets of upper-air sounding data. Each set of data begins with the characters TEST in columns 1 through 4 of the first record an ends with the characters NNNN in columns 1 through 4 of the last record. All blank records are ignored by the program. The order, contents and format of each data set are given on the following pages.

5.3.2 Tape File KSC65 Format

This section describes the format and contents of the upper-air meteorological tape data file. Each meterological data file contains one or more sets of upper-air sounding data in the KSC65 format. Each data set begins with the characters TEST in columns 1 through 4 of the first record. All blank records are ignored by the program. The order, contents and format of each data set are given on the following pages.

5.4 ASSEMBLING AND LOADING THE REEDM PROGRAMS

This section describes the procedures required to assemble and load the REEDM programs. Section 5.4.1 provides complete assembly instructions and Section 5.4.2 provides the complete load instructions.

FORMAT AND CONTENTS OF DISC FILE DATA

RECORD	DATA CARD COLUMN
1	TEST NBR XXXXX T-0 DATA YYYYYY

The first record of each data set must begin with the characters TEST in columns 1 through 4. The characters XXXXX are replaced with the actual test number (09100) and the characters YYYYYY are replaced with the sounding designator (VD1212). The program uses this record (TE) to determine when it has read the first record of a sounding and otherwise uses it only for display purposes.

2	FORECAST RAWINSONDE RUN AN/GMD-1

The second record of each data set must begin with either RA or FØ in columns 1 and 2. The program uses these characters to determine if the data are measured rawinsonde or forecast data and uses the remainder of the record only for display purposes.

3	CAPE CANAVERAL AFS, FLORIDA

This record gives the location of the sounding and is used for display purposes only.

FORMAT AND CONTENTS OF DISC FILE DATA (CONT.)

RECORD	DATA CARD COLUMN 1–80
4	HHHHZ DD MMM YYYY

This record gives the rawinsonde or forecast time and date. The characters HHHH are replaced with the Z-time (1212), DD are replaced with the day (12), MMM are replaced with the month (APR) and YYYY are replaced with the year (1981).

RECORD	DATA CARD COLUMN 1–80
5	ASCENT NBR XXXX

This record gives the ascent number and is used for display purposes only. The characters XXXX are replaced with the ascent number (0154).

RECORD	DATA CARD COLUMN 1–80
6	ALT DIR SPD TEMP D/PT PRESS RH DENSITY
7	FT DEG KTS DEG C DEG C MBS PCT G/M3

Records 6 and 7 are optional and are used as data headings in the data set. The actual data values are entered beginning in record 8 underneath their respective data heading and in the appropriate units.

FORMAT AND CONTENTS OF DISC FILE DATA (CONT.)

RECORD	DATA CARD COLUMN				
	1 2 3 4 5 6 7 8 9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
8 through n	AAAAAA DDD	SSS TTT.T	XXX.X PPP	P.PP HHH	EEEE.EE

Records 8 through n give the sounding data at each successive 1000 foot interval, beginning with the surface observation.

AAAAAA - Height in feet entered as a whole number, right justified and filled with leading zeros (000016, 001000, etc.). The value must be filled with leading zeros, as the program keys on numeric characters to determine whether it has read a data record. The program rejects all soundings with a height less than 10 or greater than 10000 feet.

DDD - Wind direction in whole degrees, right justified (110). The program rejects all sounding levels with a wind direction greater than 360 degrees

SSS - Wind speed in whole knots, right justified (004). The program rejects all sounding levels with a wind speed greater than or equal to 99 (missing data)

TTT.T - Temperature in degrees Celsius, right justified (17.0). If this value is entered as a whole number (without decimal point), the program assumes the low order digit (column 20) is tenths. The program rejects all sounding levels with a temperature greater than or equal to 99 (missing data).

XXX.X - Dewpoint temperature in degrees Celsius, right justified (15.9). If this value is entered as a whole number (without decimal point), the program assumes the low order digit (column 26) is tenths. The program rejects all sounding levels with a dewpoint temperature greater than or equal to 99 (missing data)

PPPP.PP Pressure in millibars, right justified (1023.40). If this value is entered as a whole number (without decimal point), the program assumed the two low order digits (columns 33, 34) are tenths and hundreths. The program rejects all soundings with a pressure greater than or equal to 9999 (missing data).

FORMAT AND CONTENTS OF DISC FILE DATA (CONT.)

RECORD	DATA CARD COLUMN (1–80)
8 through n (cont.)	AAAAAA DDD SSS TTT.T XXX.X PPPP.PP HHH EEEE.EE

HHH - Relative humidity in whole percent, right justified (093). If the value entered for relative humidity is 999 (missing data), the program will calculate the relative humidity from the pressure and temperature data.

EEEE.EE - Density in grams per cubic meter, right justified (1220.55). The program only requires the surface density and assumes record 8 (surface or lowest sounding) contains a valid density. If this value is entered as a whole number, the program assumes the two low order digits (columns 51, 52) are tenths and hundreths.

RECORD	DATA CARD COLUMN
n + 1	TERMINATION XXXXX GEOPFT YYYYY MTRS GEOP ZZZZ MBS

This record gives the height and pressure of the final rawinsonde observation and is optional.

XXXXX - geopotential height in feet (98612)
YYYYY - geopotential height in meters (30057)
ZZZZ - pressure in millibars (11.9)

FORMAT AND CONTENTS OF DISC FILE DATA (CONT.)

RECORD	DATA CARD COLUMN
n + 2	TROPOPAUSE XXXXX FEET YYYYYY MB ZZZZZ C

This record gives the height of the tropopause and is optional

XXXXX - height in feet (42602)
YYYYYY - pressure in millibars (179.00)
ZZZZZ - temperature in degrees Celsius (-62.6)

n + 3	MANDATORY LEVELS

This record must have MA entered in columns 1 and 2 and informs the program that mandatory data levels follow.

n + 4	ALT FT DIR KTS TEMP D/PT PRESS RH
n + 5	GEØPØT

Records n+4 and n+5 are optional header records for the mandatory level data.

n + 6 through m	AAAAAA DDD SSS TTT.T XXX.X PPPP.P HHH

Records n+6 through m give the sounding data at each successive mandatory pressure level.

AAAAAA - Height in feet entered as a whole number, right justified and filled with leading zeros (000670).
DDD - Wind direction in whole degrees, right justified (131).

RECORD	DATA CARD COLUMN	
	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80	
n + 6 through m (cont.)	AAAAAA DDD SSS TTT.T XXX.X PPPP.P HHH	

SSS - Wind speed in whole knots, right justified (011)

TTT.T - Temperature in degrees Celsius, right justified (20.2). If this value is entered as a whole number, the program assumes the low order digit (column 20) is tenths.

XXX.X - Dewpoint temperature in degrees Celcius, right justified (15.5). If this value is entered as a whole number, the program assumes the low order digit (column 26) is tenths.

PPPP.P - Pressure in millibars, right justified (1000.0). If this value is entered as a whole number, the program assumes the low order digit (column 33) is tenths.

HHH - Relative humidity in whole percent, right justified (75). If the value entered for relative humidity is 999, the program will calculate the relative humidity from the pressure and temperature data.

RECORD	DATA CARD COLUMN
m + 1	SIGNIFICANT LEVELS
	This record must have SI entered in columns 1 and 2 and informs the program that data for significant levels follow.
m + 2	ALT FT DIR KTS TEMP D/PT PRESS
	Record m + 2 is an optional header record for the significant levels data.
m + 3 through ℓ	AAAAAA DDD SSS TTT.T XXX.X PPPP.PP
	Records m + 3 through ℓ give the sounding data at each remaining significant level.
	AAAAAA - Height in feet entered as a whole number, right justified and filled with leading zeros (000501).
	DDD - Wind direction in whole degrees, right justified (125).
	SSS - Wind speed in whole knots, right justified (010).
	TTT.T - Temperature in degrees Celsius, right justified (20.8). If this value is entered as a whole number, the program assumes the low order digit (column 20) is tenths.
	XXX.X - Dewpoint temperature in degrees Celsius, right justified (16.1). If this value is entered as a whole number, the program assumes the low order digit (column 26) is tenths.
	PPPP.PP - Pressure in millibars, right justified (1006.00). If this value is entered as a whole number, the program assumes the low order two digits (columns 33, 34) are tenths and hundreths.

FORMAT AND CONTENTS OF DISC FILE DATA (CONT.)

RECORD	DATA CARD COLUMN
$\ell + 1$	NNNN

Record ℓ+1 must contain NNNN in columns 1 through 4 and is used to indicate the end of the data set.

FORMAT AND CONTENTS OF TAPE FILE DATA

RECORD	DATA CARD COLUMN
1	TEST NBR XXXX
	The first record of each data set must begin with the characters TEST in columns 1 through 4. The characters XXXX are replaced with the actual test number and are used for display only.
2	RAWINSONDE RUN
	Optional record, used for display.
3	CAPE KENNEDY AFS FLA
	This record must have the characters CA entered in columns 1 and 2. The remaining information is used only for display. The program uses the characters CA to indicate the following record is the time and date record.
4	HHHHZ DD MMM YYYY
	This record gives the rawinsonde time and date. The characters HHHH are replaced with the Z-time (1715), DD are replaced with the day (01), MMM are replaced with the month (FEB) and YYYY are replaced with the year (1965).

FORMAT AND CONTENTS OF TAPE FILE DATA (Continued)

RECORD	DATA CARD COLUMN (1–80)
5	ASCENT NBR XXXX

This record gives the ascent number XXXX (0141) and is used only for display.

RECORD	DATA CARD COLUMN (1–80)
6	ALT FT. WDIR WKTS TEMP DEW PT. PRESS RH DEN

This record must have the characters AL entered in columns 1 and 2, the remaining information is used for heading labels only. The program uses the characters AL to indicate the following record begins the standard levels sounding data.

RECORD	DATA CARD COLUMN (1–80)
7 through n	AAAAAAA DDD SSS TTT.T XXX.X PPP.P HHH EEE.E

Records 7 through n give the sounding data at standard levels at each successive 1000 feet, beginning with the surface observation.

AAAAAAA - Height in feet entered as a whole number, right justified.

DDD - Wind direction in whole degrees, right justified. The program rejects all sounding levels with a wind direction greater than 360 degrees.

SSS - Wind speed in whole knots, right justified. The program rejects all sounding levels with a wind speed greater than or equal to 99 (missing data)

TTT.T - Temperature in degrees Celsius, right justified. If this value is entered as a whole number (without decimal point), the program assumes the low order digit is tenths. The program rejects any sounding level with a temperature greater than or equal to 99 (missing data).

RECORD	DATA CARD COLUMN
	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
7 through n (cont.)	AAAAAAA ... DDD ... SSS ... TTT.T ... XXX.X ... PPPP.P ... HHH ... EEEE.E ...

XXX.X - Dewpoint temperature in degrees Celsius, right justified. If this value is entered as a whole number (without decimal point), the program assumes the lower order digit is tenths. The program rejects all sounding levels with a dewpoint temperature greater than or equal to 99 (missing data).

PPPP.P - Pressure in millibars, right justified. If this value is entered as a whole number (without decimal point), the program assumes the low order digit is tenths. The program rejects all sounding levels with a pressure greater than or equal to 9999 (missing data).

HHH - Relative humidity in whole percent, right justified. If the value entered for relative humidity is 999 (missing data), the program will calculate the relative humidity from the pressure and temperature data.

EEEE.E - Density in grams per cubic meter, right justified. The program only requires the surface density and assumes the first sounding record (7) contains a valid density. If this value is entered as a whole number (without decimal point), the program assumes the low order digit is tenths.

FORMAT AND CONTENTS OF TAPE FILE DATA (CONT.)

RECORD	DATA CARD COLUMN (1–80)
n + 1	TERMINATION ALT XXXXXX FT GEOPOTENTIAL

This record is used to terminate the standard levels data by the characters TE entered in Columns 1 and 2. XXXXXX gives the rawinsonde termination height and is optional.

n + 2	MANDATORY LEVELS

This record must have the characters ØR entered in columns 19 and 20. The program uses the characters ØR to indicate the mandatory sounding levels follow.

n + 3	ALT FT. WDIR WKTS TEMP DEW PT PRESS RH

This record is used as a data header only and is ignored by the program.

n + 4 through m	AAAAAAA DDD SSS TTT.T XXX.X PPPP.P HHH

Records n + 4 through m give the sounding data at mandatory pressure levels.

AAAAAAA - Height in feet entered as a whole number, right justified.

DDD - Wind direction in whole degrees, right justified. The program rejects all sounding levels with a wind direction greater than 360 degrees.

FORMAT AND CONTENTS OF TAPE FILE DATA (CONT.)

RECORD	DATA CARD COLUMN	
n + 4 through m (cont.)	AAAAAAA DDD SSS TTT.T XXX.X PPP.P HHH	
	SSS	- Wind speed in whole knots, right justified. The program rejects all sounding levels with a wind speed greater than or equal to 99 (missing data).
	TTT.T	- Temperature in degrees Celsius, right justified. If this value is entered as a whole number (without decimal point), the program assumes the low order digit is tenths. The program rejects any sounding level with a temperature greater than or equal to 99 (missing data).
	XXX.X	- Dewpoint temperature in degrees Celsius, right justified. If this value is entered as a whole number (wihout decimal point), the program assumes the low order digit is tenths. The program rejects all spunding levels with a dewpoint temperature greater than or equal to 99 (missing data).
	PPPP.P	- Pressure in millibars, right justified. If this value is entered as a whole number (without decimal point), the program assumes the low order digit is tenths. The program rejects all sounding levels with a pressure greater than or equal to 999 (missing data).
	HHH	- Relative humidity in whole percent, right justified. If the value entered for relative humidity is 999 (missing data), the program will calculate the relative humidity from the pressure and temperature data.

5.4.1 Assembling REEDM

The REEDM computer program source code consists of a main module &REEDM plus 20 segment and subroutine models &READM, &REDAM, &RDATM, &RDATN, &RCLDM, &RCLDN, &RMMRM, &RMMRN, &RDHMM, &RCONM, &RCNOM, &RCONN, &RPDPM, &RPDPN, &RGDPM, &RGPDM, &RGDPN, &RSUBM, &RCIMM, &RCIMN. All modules ending in M, except &RSUBM consist of a segment entry program and associated subroutines. All modules ending in N plus &RSUBM contain only subroutines. Figure 3 shows an HP1000 transfer file used to assemble all of the REEDM modules. The transfer file is executed by entering, under file manager (FMGR) -

:TR,\RMAS,1G,2G,3G,4G

where

1G = print output logical unit number

2G = a minus symbol ("-") if relocatable modules are to be created or omitted if not.

3G = number of lines per page for the list device. Default is 56 if omitted

4G = enter an L or Q for a complete source listing or omit for a summary listing

The above globals 1G through 4G correspond to the second through fifth parameters passed to the FTN4 program. See your HP1000 Fortran manual under executing FTN4 for a more complete description of these parameters. Figure 3 shows that the transfer fill purges all of the REEDM relocatable modules (% files). Also, Figure 3 assumes the file security code is "NA" and all files reside on disc logical unit "-9".

```
:*****************************************************************
:*                          UPDATE:  8213  SOURCE:  02 APR 82
:*
:*                    :TR,\RMAS,1G,2G,3G,4G
:*     THIS TRANSFER FILE COMPILES ALL OF THE REEDM PROGRAM SOURCE
:*     FILES.  FIRST ALL OF THE RELOCATABLE FILES ARE PURGED.  THEN THE
:*     SOURCE FILES ARE COMPILED WHERE THE USER MAY PASS THE FTN4
:*     PARAMETER OPTIONS IN GLOBAL PARAMETERS ONE THROUGH FOUR.  THESE
:*     GLOBALS CORRESPOND TO THE SECOND THROUGH FIFTH OPTIONS OF THE
:*     FTN4 PROGRAM.  FOR EXAMPLE, :TR,\RMAS,6,-,,L  COMPILES ALL OF THE
:*     REEDM SOURCE FILES, SENDING THE PRINT OUTPUT TO LOGICAL UNIT 6,
:*     CREATING RELOCATABLE FILES, NAMES BEGINING WITH THE % CHARACTER
:*     (THE "-" OPTION), AND CREATING A SOURCE LISTING (THE "L" OPTION).
:*
:*****************************************************************
:PU,%REEDM:NA:-9
:PU,%READM:NA:-9
:PU,%REDAM:NA:-9
:PU,%RDATM:NA:-9
:PU,%RDATN:NA:-9
:PU,%RCLDM:NA:-9
:PU,%RCLDN:NA:-9
:PU,%RMMRM:NA:-9
:PU,%RMMRN:NA:-9
:PU,%RDHMM:NA:-9
:PU,%RCONM:NA:-9
:PU,%RCNOM:NA:-9
:PU,%RCONN:NA:-9
:PU,%RPDPM:NA:-9
:PU,%RPDPN:NA:-9
:PU,%RGDPM:NA:-9
:PU,%RGPDM:NA:-9
:PU,%RGDPN:NA:-9
:PU,%RSUBM:NA:-9
:PU,%RCIMM:NA:-9
:PU,%RCIMN:NA:-9
:RU,FTN4,&REEDM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&READM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&REDAM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RDATM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RDATN:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RCLDM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RCLDN:NA:-9,1G,2G,3G,4G
```

FIGURE 3. Example HP1000 transfer file used to assemble the REEDM source modules (&) into relocatable modules (%).

```
:RU,FTN4,&RMMRM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RMMRN:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RDHMM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RCONM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RCNOM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RCONN:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RPDPM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RPDPN:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RGDPM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RGPDM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RGDPN:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RSUBM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RCIMM:NA:-9,1G,2G,3G,4G
:RU,FTN4,&RCIMN:NA:-9,1G,2G,3G,4G
::
```

Figure 3. (Continued)

5.4.2 Loading REEDM

The REEDM absolute program consists of the main program REEDM plus 12 segments; READM, REDAM, RDATM, RCLDM, RDHMM, RCONM, RCNOM, RPDPM, RGDPM, RGPDM, RMMRM AND RCIMM. The REEDM program and segments require a minimum of 24 consecutive LG tracks to load. Figure 4 shows an example HP1000 transfer file used to load the REEDM program. The transfer file is executed by entering, under file manager (FMGR)

:TR,\RMLD,1G

where

1G = Print output logical unit number

Figure 4 shows the loader (LOADR) is to obtain all of the load commands from disc file LREEDM, shown in Figure 5. Also, Figure 4 shows an additional transfer to file \RMOF, shown in Figure 6, used to remove any old copies of REEDM from the LG tracks prior to executing LOADR. Upon completion of the loading of REEDM, the user may execute REEDM and/or may save the absolute programs on disc. Figure 7 shows a transfer file \RMRP used to restore the REEDM program from disc to the LG tracks or save the REEDM programs from the LG tracks to disc or to purge the saved REEDM absolute programs from disc. This transfer file is executed by entering under file manager (FMGR)

:TR,\RMRP,1G,2G,3G

where

1G = PU to purge the absolute REEDM programs. RP to restore the absolute REEDM programs from disc to the LG tracks. This is not necessary if the absolute programs have been saved on a system disc. SP to save the REEDM programs from the LG tracks to disc.

```
:*********************************************************************
:*                          UPDATE:  8213  SOURCE:  02 APR 82
:*
:*                     :TR,\RMLD,1G
:*     THIS TRANSFER FILE LOADS THE REEDM PROGRAMS FOR EXECUTION.
:*     FIRST, ALL REEDM PROGRAMS ARE PERMANENTLY REMOVED FROM THE
:*     SYSTEM.  THEN THE LOADR PROGRAM IS RUN FOR EACH OF THE
:*     REEDM PROGRAMS.  THE USER MAY PASS THE LOGICAL UNIT NUMBER
:*     FOR LISTING THE LOADR MAPS.  FOR EXAMPLE,
:*     :TR,\RMLD,6  LOADS THE REEDM PROGRAMS, AND LISTS THE
:*     LOAD MAP ON LOGICAL UNIT 6.
:*
:*********************************************************************
:CA,2,1G
:,\RMOF,8
:IF,2G,NE,8,1
:CA,2,1
:RU,LOADR,LREEDM,,2G
:TR,-1,0,0,0
::
```

FIGURE 4. Example HP1000 transfer file for loading the relocatable modules (%) into an absolute program using commands from file LREEDM.

```
OP,LB          "LREEDM - REEDM UPDATE 8213, 02 APR 82 - LOADR COMMANDS"
RE,%REEDM
SE
RE,%READM
SE
RE,%REDAM
SE
RE,%RDATM
RE,%RDATN
SE
RE,%RCLDM
RE,%RCLDN
SE
RE,%RMMRM
RE,%RMMRN
SE
RE,%RDHMM
SE
LI,%RSUBM
RE,%RCONM
RE,%RCONN
SL
SE
LI,%RSUBM
RE,%RCNOM
RE,%RCONN
SL
SE
LI,%RSUBM
RE,%RPDPM
RE,%RPDPN
SL
SE
LI,%RSUBM
RE,%RGDPM
RE,%RGDPN
SL
SE
LI,%RSUBM
RE,%RGPDM
RE,%RGDPN
SL
SE
RE,%RCIMM
RE,%RCIMN
SE
EN
```

FIGURE 5. LOADR command sequence used in loading the REEDM programs.

```
:*********************************************************************
:*                          UPDATE:  8213  SOURCE:  02 APR 82
:*
:*                         :TR,\RMOF,1G
:*     THIS TRANSFER FILE "OFs" ALL REEDM PROGRAMS.  THE USER HAS THE
:*     OPTION TO EITHER ABORT ALL ACTIVE REED PROGRAMS, OR TO
:*     PERMANENTLY REMOVE ALL REEDM PROGRAMS FROM THE SYSTEM BY
:*     RESPECTIVELY PASSING A "1" OR AN "8" IN THE FIRST GLOBAL
:*     PARAMETER.  FOR EXAMPLE, :TR,\RMOF,1  ABORTS ALL ACTIVE
:*     REEDM PROGRAMS.
:*
:*********************************************************************
:IF,1G,NE,,1
:SE,1
:SYOF,REEDM,1G
:SYOF,READM,1G
:SYOF,REDAM,1G
:SYOF,RDATM,1G
:SYOF,RCLDM,1G
:SYOF,RMMRM,1G
:SYOF,RDHMM,1G
:SYOF,RCONM,1G
:SYOF,RCNOM,1G
:SYOF,RPDPM,1G
:SYOF,RGDPM,1G
:SYOF,RGPDM,1G
:SYOF,RCIMM,1G
::
```

FIGURE 6. Example HP1000 transfer file used to abort the REEDM programs, if 1G equals 1 or abort and remove the REEDM programs from the LG tracks, if 1G equals 8.

2G = The logical unit number of the disc on which the programs reside or will reside.

3G = This global is used only when 1G equals RP and if set to NP, the REEDM plot programs are not restored to the LG tracks. This option is used to minimize LG track usage when no plotting is desired.

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APPENDIX A

EXAMPLE REEDM PROGRAM CALCULATIONS

Example REEDM calculations have been made for concentration/dosage, washout-deposition and gravitational deposition for a normal launch of the Space Shuttle vehicle to illustrate the output format of REEDM calculations. The meteorological data used in the calculations are described in Section A.1. The results of the calculations, including the computer printout, are described in Section A.2.

A.1 METEOROLOGICAL DATA

Ground-level concentration/dosage, washout deposition and gravitational deposition calculations were made from meteorological data obtained from rawinsonde observations made at Cape Kennedy, Florida for the launch of the Space Shuttle on 12 November 1981. Figure A-1 shows the meteorological data file as read by the REEDM program. The line numbers on the left of Figure A-1 have been inscribed on the figure to illustrate the record number and are not part of the data file. Only data up to and including 10,000 ft. (3048 m) are used by the REEDM program. Figure A-2 shows a meteorological profile plot of the wind speed, wind direction, temperature and potential temperature made by the REEDM program using this data set.

A.2 REEDM CALCULATION RESULTS

Five example executions (4 interactive operational, 1 batch production) of the REEDM program are shown in this section, all made using the meteorological data shown in Section A.1. REEDM output listings in this section have been slightly modified for ease of documentation. Figure A-3 shows the program output for HCℓ concentration, dosage and 10-minute time-mean concentration for the normal launch of the Space Shuttle vehicle.

```
RECORD                    CONTENTS
NUMBER                (BEGINS IN COL. 1)
------                ------------------

 01.   TEST NBR 09101  T MINUS 0          RRSOND (VK1215)
 02.   RAWINSONDE RUN AN/GMD-1
 03.   CAPE CANAVERAL AFS, FLORIDA
 04.   1515Z  12 NOV 1981
 05.   ASCENT NBR   0434
 06.
 07.
 08.     ALT  DIR SPD  TEMP  D/PT  PRESS   RH ABHUM DENSITY I/R V/S   SHEAR
 09.      FT  DEG KTS DEG C DEG C   MBS   PCT  G/M3   G/M3   N  KTS /SEC DEG
 10.
 11.
 12.   000016 337 015  22.4  16.0 1016.90 067 13.35 1190.43 345 672 .000 000
 13.   001000 351 020  18.5  14.0 0982.28 075 11.89 1166.15 331 668 .022 041
 14.   002000 004 019  15.2  13.0 0947.92 087 11.25 1138.51 322 664 .008 096
 15.   003000 019 018  13.2  11.6 0914.45 090 10.36 1106.42 310 661 .008 116
 16.   004000 016 016  12.2  -2.3 0881.91 039 04.18 1074.10 265 659 .003 224
 17.   005000 004 014  11.7  -3.4 0850.42 035 03.64 1038.03 254 659 .006 242
 18.   006000 351 010   9.5  -3.1 0819.92 041 03.73 1008.36 248 656 .007 218
 19.   007000 358 010   7.4  -6.1 0790.28 038 03.07 0979.62 237 653 .002 108
 20.   008000 006 012   6.0  -8.2 0761.54 035 02.56 0949.01 227 652 .005 036
 21.   009000 000 015   6.4 -16.9 0733.78 018 01.34 0913.69 212 652 .006 337
 22.   010000 354 017   5.6 -17.8 0707.01 017 01.17 0883.01 204 651 .004 309
 23.   011000 346 017   4.6 -18.5 0681.13 017 01.10 0853.61 197 650 .004 258
 24.   012000 337 018   3.1 -19.5 0656.11 017 01.02 0826.90 191 648 .005 268
 25.   013000 333 020    .4 -21.2 0631.81 018 00.89 0804.07 185 645 .004 301
 26.   014000 334 022  -2.1 -23.2 0608.21 018 00.75 0781.14 179 642 .004 337
 27.   015000 335 023  -3.9 -25.3 0585.31 017 00.63 0756.90 173 640 .001 012
 28.   016000 331 022  -6.7 -27.1 0563.08 018 00.54 0736.00 167 636 .002 209
 29.   017000 322 022  -9.4 -29.3 0541.46 018 00.44 0715.06 162 633 .006 245
 30.   018000 313 023 -12.1 -31.1 0520.47 019 00.37 0694.48 157 630 .006 241
 31.   019000 305 024 -15.1 -33.2 0500.08 019 00.31 0674.86 152 626 .006 241
 32.   020000 302 028 -17.0 -35.1 0480.32 019 00.26 0653.22 147 624 .007 282
 33.   TERMINATION       88745 GEOPFT  27049 MTRS GEOP   18.5 MBS
 34.   TROPOPAUSE   48472  FEET   131.87 MB  -63.1 C   99.9 C   49N
```

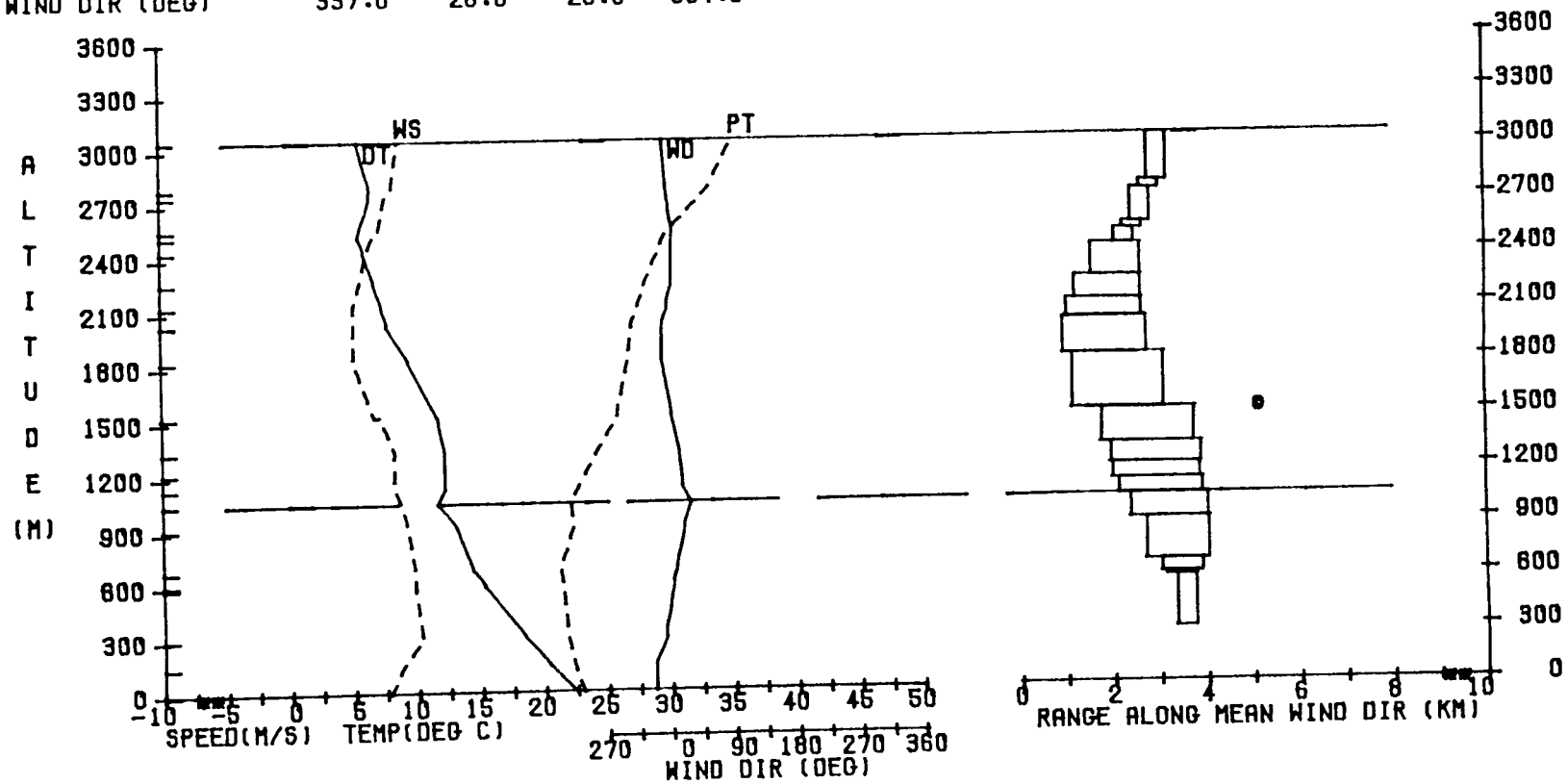
FIGURE A-1. REEDM example run meteorological data file, taken from rawinsonde observation at Cape Kennedy, Florida 12 November 1981.

RECORD NUMBER	CONTENTS (BEGINS IN COL. 1)
35.	MANDATORY LEVELS
36.	ALT FT DIR KTS TEMP D/PT PRESS RH
37.	GEOPOT
38.	
39.	
40.	000493 337 017 20.4 14.7 1000.0 070
41.	001936 003 019 15.4 13.1 0950.0 086
42.	003435 028 017 11.7 11.7 0900.0 100
43.	005005 004 013 11.6 -3.3 0850.0 035
44.	006658 352 010 7.8 -3.3 0800.0 045
45.	008396 006 014 5.7 -9.4 0750.0 034
46.	010248 352 017 5.3 -18.0 0700.0 017
47.	012224 335 018 2.3 -20.0 0650.0 017
48.	014324 334 022 -2.8 -24.0 0600.0 018
49.	016565 326 022 -8.4 -28.5 0550.0 018
50.	018960 305 024 -15.1 -33.2 0500.0 019
51.	SIGNIFICANT LEVELS
52.	ALT FT DIR KTS TEMP D/PT PRESS I/R
53.	
54.	
55.	000016 310 015 22.4 16.0 1016.90 345
56.	002235 008 019 14.4 12.5 0939.99 319
57.	003441 028 017 11.7 11.7 0899.98 308
58.	003718 018 016 12.2 2.2 0890.98 275
59.	004375 013 016 12.2 -8.2 0869.98 252
60.	006670 352 010 7.8 -3.3 0799.98 244
61.	007425 005 011 6.8 -9.7 0777.97 230
62.	008269 007 013 5.6 -7.6 0753.97 226
63.	009140 359 016 6.5 -18.7 0729.97 209
64.	011563 340 017 4.4 -18.8 0666.97 193
65.	019310 303 025 -16.0 -33.9 0493.90 151
66.	
67.	NNNN

FIGURE A-1. (Continued)

DATE: 12 NOV 1981 TIME: 1015 EST PLOTTED AT: HEC FROM FILE: RRSOND
SURFACE PRESSURE: 1016.9MB DENSITY: 1190.4G/M^3 ● - STAB HT: 1525.5M ■■ - CALC HT: 0.0M

	LAYER1 SURFACE	LAYER1 TOP	LAYER2 BOT	LAYER2 TOP
ALTITUDE (M)	0.0	1047.0	1047.0	3048.0
DRY TEMP (DEG C)	22.4	11.7	11.7	5.6
POT TEMP (DEG C)	23.0	22.2	22.2	35.1
WIND SPEED (M/S)	7.7	8.8	8.8	8.8
WIND DIR (DEG)	337.0	28.0	28.0	354.0



PLOTTED AT: ■■■ 254. 1 JUL 1982 ■■■

FIGURE A-2. Meteorological profile plot of wind speed, wind direction, temperature and potential temperature, taken from rawinsonde observations at Cape Kennedy, Florida, 12 November 1981.

This output was produced from an interactive run where all parameters except the layer-height parameters were defaulted. The layer parameters were changed to reflect the layer structure shown in Figure A-2. Figure A-2 shows the base of an upper-air inversion at 1047 meters. Thus the top of the lower layer and bottom of the upper layer were set to 1047 meters and the top of the upper layer was set to 3048 meters (maximum height used by program). The first page of Figure A-3 (page A-6) shows the launch time and date, the time and date of the program execution, and the REEDM model options selected for the execution of the program. The second page of Figure A-3 (page A-7) shows the meteorological data (from Figure A-1) used by the program. Page 3 of Figure A-3 (page A-8) shows calculated cloud rise, cloud stabilization and turbulence data calculated by the program. Pages 4 through 6 of Figure 3 (pages A-9 through A-11) show the maximum centerline HCℓ ground-level concentration (maximum of .901 PPM at 10017.4 m, 183.4°relative to launch pad 39A), dosage (maximum of 73.605 PPM seconds at 10025.7 m, 184.1° relative to launch pad 39A), and 10 minute time mean concentration (maximum of .123 PPM at 10025.7 m, 184.1° relative to launch pad 39A) at various distances along the cloud trajectory downwind from the launch pad. The cloud arrival and departure times at each range and bearing from the pad are also given. The layer heights in which the calculations apply are listed at the top of pages 4 through 6 of the listing. Figure A-4 is a plot of maximum ground-level HCℓ concentrations and dosages along the cloud centerline as a function of distance from the pad from calculations shown in Figure A-3. Figure A-5 shows HCℓ concentration isopleths plotted by the computer program on the (land) map of Kennedy Space Center for the meteorological and source inputs shown in Figure A-3.

Figure A-6 shows the output of an identical run to that shown in Figure A-3, except the calculations have been made for $A\ell_2O_3$ rather than HCℓ. The program output shows maximum ground-level centerline concentration, dosage and 10-minute time-mean concentration due to the $A\ell_2O_3$ in the Space Shuttle exhaust cloud. Figure A-7 shows a plot of the maximum ground-level centerline $A\ell_2O_3$ concentration and dosage along the centerline of the cloud

```
*************************************************************************
****************                                         ****************
**************** NASA/MSFC MULTIPLE LAYER TECHNIQUE - REEDM ****************
****************  UPDATE 8213    LOCATION HEC                ****************
****************                                         ****************
*************************************************************************


                    SPACE SHUTTLE        NORMAL LAUNCH

                LAUNCH TIME:        915 EST DATE: 12 NOV 1981
                TIME OF EXECUTION:  247 EST DATE:  1 JUL 1982

******************              MODEL OPTIONS             ******************

 MODEL                                                  CONCENTRATION/DOSAGE
 METEOROLOGICAL DATA SOUNDING                                          RRSOND
 RUN TYPE                                                         OPERATIONAL
 LAUNCH VEHICLE                                                 SPACE SHUTTLE
 LAUNCH TYPE                                                           NORMAL
 LAUNCH COMPLEX NUMBER                                                    39A
 SPECIES                                                                  HCL
 CLOUD SHAPE                                                       ELLIPTICAL
 CALCULATION HEIGHT                                                   SURFACE
 PROPELLANT TEMPERATURE (DEG. C)                                        22.86
**********************          METEOROLOGICAL DATA          **********************

    RUN NUMBER:   1           USING METEOROLOGICAL DATA FILE: RRSOND

     TEST NBR 09101  T MINUS 0           RRSOND (VK1215)
     RAWINSONDE RUN AN/GMD-1
     CAPE CANAVERAL AFS, FLORIDA
     ASCENT NBR   0434
    TIME: 1015 EST    DATE: 12 NOV 1981
```

FIGURE A-3. REEDM program output listing for an operational, interactive run producing ground level-concentration, dosage and 10-minute time mean concentration of HCℓ.

SURFACE DENSITY (GM/M**3): 1190.43

MET LEVEL NO.	ALTITUDE (FT)	(M)	DIR. (DEG)	SPEED (M/S)	(KTS)	TEMP	PTEMP (DEG. C)	DPTEMP	PRESS (MB.)	RH (%)
1	16	4.9	337.0	7.72	15.00	22.4	22.98	16.0	1016.9	67.0
2	493	150.3	337.0	8.75	17.00	20.4	22.28	14.7	1000.0	70.0
3	1000	304.8	351.0	10.30	20.00	18.5	21.83	14.0	982.3	75.0
4	1936	590.1	3.0	9.78	19.00	15.4	21.46	13.1	950.0	86.0
5	2000	609.6	4.0	9.78	19.00	15.2	21.45	13.0	947.9	87.0
6	2235	681.2	8.0	9.78	19.00	14.4	21.29	12.5	940.0	88.4
7	3000	914.4	19.0	9.27	18.00	13.2	22.35	11.6	914.4	90.0
8	3435	1047.0	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
9	3441	1048.8	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
10	3718	1133.2	18.0	8.24	16.00	12.2	22.76	2.2	891.0	50.8
11	4000	1219.2	16.0	8.24	16.00	12.2	23.42	-2.3	881.9	39.0
12	4375	1333.5	13.0	8.24	16.00	12.2	24.32	-8.2	870.0	23.7
13	5000	1524.0	4.0	7.21	14.00	11.7	25.95	-3.4	850.4	35.0
14	5005	1525.5	4.0	6.69	13.00	11.6	25.88	-3.3	850.0	35.0
15	6000	1828.8	351.0	5.15	10.00	9.5	26.81	-3.1	819.9	41.0
16	6658	2029.4	352.0	5.15	10.00	7.8	27.13	-3.3	800.0	45.0
17	6670	2033.0	352.0	5.15	10.00	7.8	27.14	-3.3	800.0	46.1
18	7000	2133.6	358.0	5.15	10.00	7.4	27.64	-6.1	790.3	38.0
19	7425	2263.1	5.0	5.66	11.00	6.8	28.24	-9.7	778.0	30.5
20	8000	2438.4	6.0	6.18	12.00	6.0	29.28	-8.2	761.5	35.0
21	8269	2520.4	7.0	6.69	13.00	5.6	29.76	-7.6	754.0	39.0
22	8396	2559.1	6.0	7.21	14.00	5.7	30.27	-9.4	750.0	34.0
23	9000	2743.2	0.0	7.72	15.00	6.4	32.74	-16.	733.8	18.0
24	9140	2785.9	359.0	8.24	16.00	6.5	33.27	-18.	730.0	15.3
25	10000	3048.0	354.0	8.75	17.00	5.6	35.13	-17.	707.0	17.0

** - INDICATES THAT DATA IS LINEARLY INTERPOLATED FROM INPUT METEOROLOGY

FIGURE A-3. (Continued)

********** EXHAUST CLOUD **********

MET. LAYER NO.	TOP OF LAYER (METERS)	CLOUD RISE TIME (SECONDS)	RANGE FROM PAD (METERS)	AZIMUTH BEARING FROM PAD (METERS)
1	150.3	3.9	0.0	0.0
2	304.8	13.5	0.0	0.0
3	590.1	43.7	3527.3	176.5
4	609.6	46.3	3442.2	182.2
5	681.2	56.4	3438.8	184.4
6	914.4	95.3	3347.8	190.6
7	1047.0	121.5	3184.5	197.7
8	1048.8	121.9	3106.7	200.5
9	1133.2	140.1	3067.8	197.2
10	1219.2	160.1	3028.1	193.6
11	1333.5	194.1	3031.5	192.3
12	1524.0	285.5	2950.9	189.8
13	1525.5	331.6	2896.9	189.1
14	1828.8	352.8 *	2891.4	189.1
15	2029.4	352.8 *	1817.1	171.5
16	2033.0	352.8 *	1817.1	172.0
17	2133.6	352.8 *	1817.1	175.0
18	2263.1	352.8 *	1908.0	181.5
19	2438.4	352.8 *	2089.7	185.5
20	2520.4	352.8 *	2271.4	186.5
21	2559.1	352.8 *	2453.1	186.5
22	2743.2	352.8 *	2634.8	183.0
23	2785.9	352.8 *	2816.5	179.5
24	3048.0	352.8 *	2998.3	176.5

* - INDICATES CLOUD STABILIZATION TIME WAS USED
** - RANGE FROM PAD IS AT CLOUD STABILIZATION TIME

********** CLOUD STABILIZATION **********

CALCULATION HEIGHT	(METERS)	0.00
STABILIZATION HEIGHT	(METERS)	1525.52
STABILIZATION TIME	(SECS)	352.84
FIRST MIXING LAYER HEIGHT:	(METERS)	TOP = 1046.99
		BASE= 0.00
SECOND SELECTED LAYER HEIGHT:	(METERS)	TOP = 3048.00
		BASE= 1046.99
SIGMAR(AZ) AT THE SURFACE	(DEGREES)	13.6138
SIGMER(EL) AT THE SURFACE	(DEGREES)	13.6138

FIGURE A-3. (Continued)

```
*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************         CONCENTRATION/DOSAGE MODEL      ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS      ****************
```

FOR HCL AT A HEIGHT OF 0.00 METERS
DOWNWIND FROM A SPACE SHUTTLE NORMAL LAUNCH
CALCULATIONS APPLY TO THE LAYER BETWEEN 0.00 AND 1046.99 METERS

THE METEOROLOGICAL DATA IS FROM 1015 EST 12 NOV 1981
LAUNCH TIME IS 915 EST 12 NOV 1981
TIME OF EXECUTION IS 247 EST 1 JUL 1982

RANGE FROM PAD (METERS)	BEARING FROM PAD (DEGREES)	PEAK CONCEN-TRATION (PPM)	CLOUD ARRIVAL TIME (MIN)	CLOUD DEPARTURE TIME (MIN)
5003.600	177.805	.027	2.853	9.636
6005.456	182.420	.210	4.510	11.623
7016.485	183.906	.543	6.167	13.610
8017.253	183.738	.783	7.822	15.598
9023.207	184.088	.889	9.477	17.585
10017.361	183.352	.901	11.131	19.573
11020.912	183.508	.861	12.783	21.560
12017.078	183.033	.799	14.435	23.548
13013.943	182.631	.734	16.087	25.535
14011.359	182.285	.673	17.737	27.523
15018.668	182.835	.618	19.387	29.510
16016.621	182.589	.571	21.036	31.497
17014.836	182.371	.530	22.685	33.485
18013.270	182.177	.493	24.333	35.472
19011.887	182.004	.461	25.981	37.460
20010.660	181.848	.433	27.628	39.447
21009.566	181.707	.407	29.275	41.435
22008.594	181.579	.384	30.921	43.422
23007.715	181.462	.363	32.567	45.409
24006.930	181.355	.344	34.213	47.397
25006.219	181.256	.327	35.858	49.384
26005.574	181.165	.311	37.503	51.372
27005.000	181.080	.296	39.148	53.359
28004.469	181.002	.283	40.793	55.347
29003.992	180.929	.270	42.437	57.334

	RANGE	BEARING
.901 IS THE MAXIMUM PEAK CONCENTRATION	10017.4	183.4

FIGURE A-3. (Continued)

```
*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************         CONCENTRATION/DOSAGE MODEL      ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS      ****************

                  FOR  HCL   AT A HEIGHT OF     0.00 METERS
             DOWNWIND FROM A  SPACE SHUTTLE        NORMAL LAUNCH
   CALCULATIONS APPLY TO THE LAYER BETWEEN    0.00 AND 1046.99 METERS

        THE METEOROLOGICAL DATA IS FROM  1015 EST  12 NOV 1981
                    LAUNCH TIME IS        915 EST  12 NOV 1981
             TIME OF EXECUTION IS         247 EST   1 JUL 1982
```

RANGE FROM PAD (METERS)	BEARING FROM PAD (DEGREES)	TOTAL DOSAGE (PPM SEC)	CLOUD ARRIVAL TIME (MIN)	CLOUD DEPARTURE TIME (MIN)
5002.480	178.174	.720	2.853	9.636
6017.630	184.365	12.695	4.510	11.623
7027.479	185.047	39.661	6.167	13.610
8030.907	185.007	61.136	7.822	15.598
9023.207	184.088	71.557	9.477	17.585
10025.654	184.078	73.605	11.131	19.573
11020.912	183.508	70.921	12.783	21.560
12017.078	183.033	66.219	14.435	23.548
13023.785	183.441	61.114	16.087	25.535
14021.031	183.117	56.281	17.737	27.523
15018.668	182.835	51.963	19.387	29.510
16016.621	182.589	48.187	21.036	31.497
17014.836	182.371	44.895	22.685	33.485
18013.270	182.177	42.014	24.333	35.472
19011.887	182.004	39.477	25.981	37.460
20010.660	181.848	37.227	27.628	39.447
21009.566	181.707	35.218	29.275	41.435
22008.594	181.579	33.414	30.921	43.422
23007.715	181.462	31.784	32.567	45.409
24006.930	181.355	30.306	34.213	47.397
25006.219	181.256	28.959	35.858	49.384
26005.574	181.165	27.726	37.503	51.372
27005.000	181.080	26.593	39.148	53.359
28004.469	181.002	25.549	40.793	55.347
29016.262	181.896	24.585	42.437	57.334

	RANGE	BEARING
73.605 IS THE MAXIMUM TOTAL DOSAGE	10025.7	184.1

FIGURE A-3. (Continued)

```
*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************         CONCENTRATION/DOSAGE MODEL      ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS      ****************
```

FOR HCL AT A HEIGHT OF 0.00 METERS
DOWNWIND FROM A SPACE SHUTTLE NORMAL LAUNCH
CALCULATIONS APPLY TO THE LAYER BETWEEN 0.00 AND 1046.99 METERS

THE METEOROLOGICAL DATA IS FROM 1015 EST 12 NOV 1981
LAUNCH TIME IS 915 EST 12 NOV 1981
TIME OF EXECUTION IS 247 EST 1 JUL 1982

RANGE FROM PAD (METERS)	BEARING FROM PAD (DEGREES)	10.0 MIN. MEAN CONCEN-TRATION (PPM)	CLOUD ARRIVAL TIME (MIN)	CLOUD DEPARTURE TIME (MIN)
5002.480	178.174	.001	2.853	9.636
6017.630	184.365	.021	4.510	11.623
7027.479	185.047	.066	6.167	13.610
8030.907	185.007	.102	7.822	15.598
9023.207	184.088	.119	9.477	17.585
10025.654	184.078	.123	11.131	19.573
11020.912	183.508	.118	12.783	21.560
12017.078	183.033	.110	14.435	23.548
13023.785	183.441	.102	16.087	25.535
14021.031	183.117	.094	17.737	27.523
15018.668	182.835	.087	19.387	29.510
16016.621	182.589	.080	21.036	31.497
17014.836	182.371	.075	22.685	33.485
18013.270	182.177	.070	24.333	35.472
19011.887	182.004	.066	25.981	37.460
20010.660	181.848	.062	27.628	39.447
21009.566	181.707	.059	29.275	41.435
22008.594	181.579	.056	30.921	43.422
23007.715	181.462	.053	32.567	45.409
24006.930	181.355	.051	34.213	47.397
25006.219	181.256	.048	35.858	49.384
26005.574	181.165	.046	37.503	51.372
27005.000	181.080	.044	39.148	53.359
28004.469	181.002	.043	40.793	55.347
29016.262	181.896	.041	42.437	57.334

	RANGE	BEARING
.123 IS THE MAXIMUM 10.0 MIN. MEAN CONCENTRATION	10025.7	184.1

FIGURE A-3. (Continued)

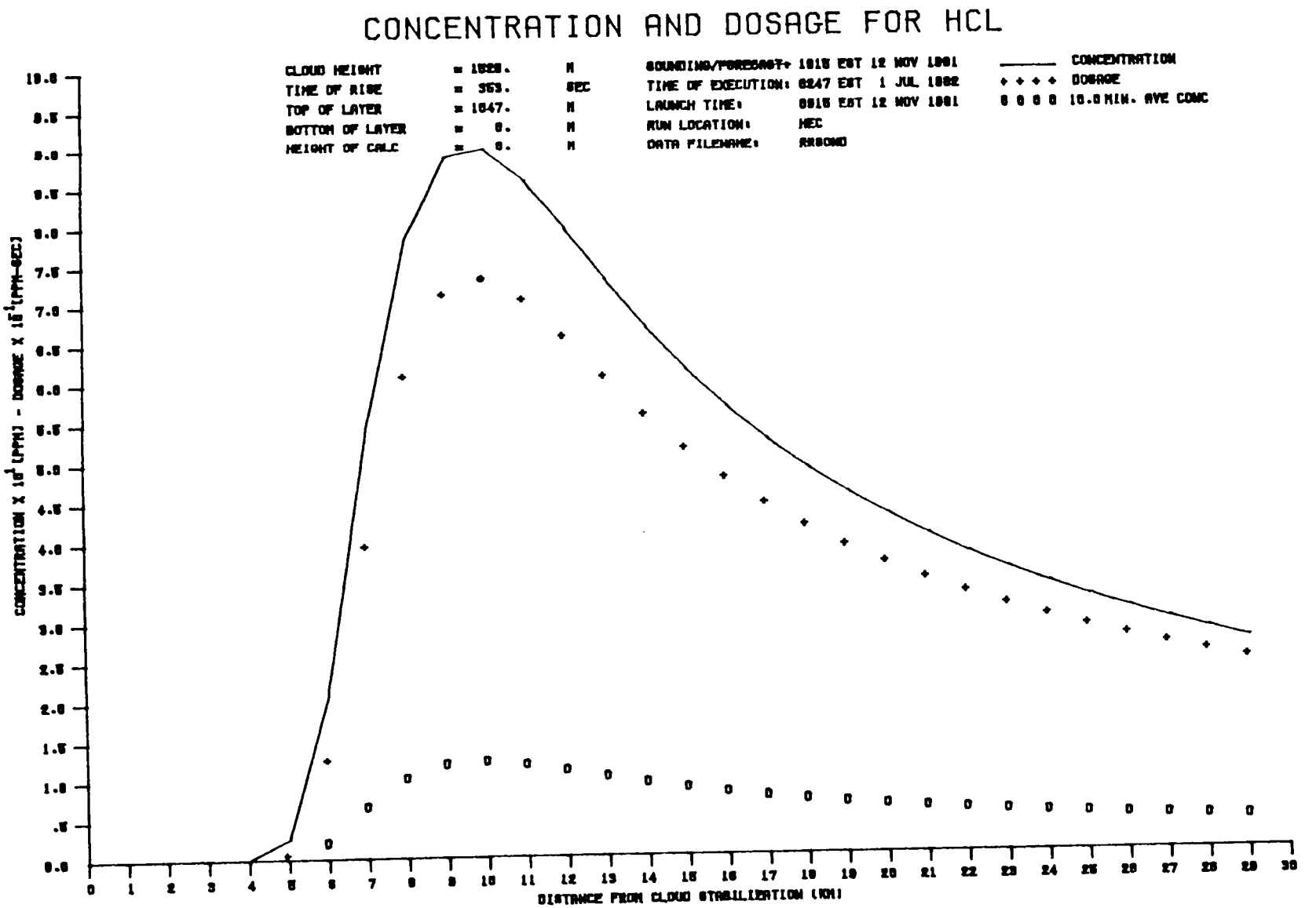


FIGURE A-4. Maximum centerline profile plot of ground-level concentration, dosage and 10-minute time mean concentration of HCℓ.

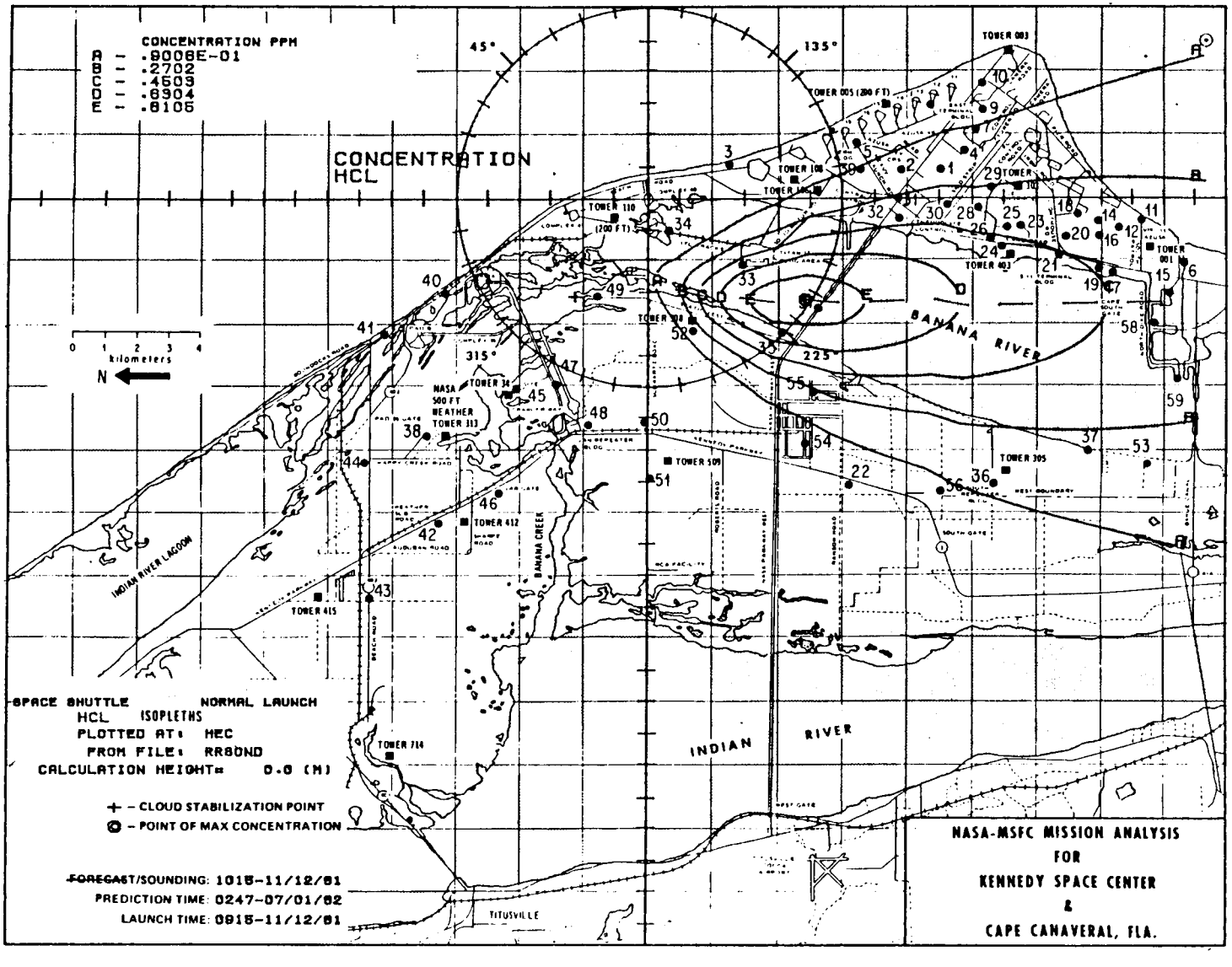


Figure A-5. Ground level HCℓ concentration isopleth plot using the "LAND" map of Kennedy Space Center.

```
*********************************************************************
****************                                     ****************
**************** NASA/MSFC MULTIPLE LAYER TECHNIQUE - REEDM ****************
****************  UPDATE 8213    LOCATION HEC             ****************
****************                                     ****************
*********************************************************************


                    SPACE SHUTTLE        NORMAL LAUNCH

                LAUNCH TIME:        915 EST DATE: 12 NOV 1981
                TIME OF EXECUTION:  312 EST DATE:  1 JUL 1982

******************              MODEL OPTIONS             ******************

 MODEL                                                  CONCENTRATION/DOSAGE
 METEOROLOGICAL DATA SOUNDING                                          RRSOND
 RUN TYPE                                                         OPERATIONAL
 LAUNCH VEHICLE                                                 SPACE SHUTTLE
 LAUNCH TYPE                                                           NORMAL
 LAUNCH COMPLEX NUMBER                                                    39A
 SPECIES                                                                AL2O3
 CLOUD SHAPE                                                       ELLIPTICAL
 CALCULATION HEIGHT                                                   SURFACE
 PROPELLANT TEMPERATURE (DEG. C)                                        22.86
**********************          METEOROLOGICAL DATA          **********************

    RUN NUMBER:   1          USING METEOROLOGICAL DATA FILE: RRSOND

     TEST NBR 09101  T MINUS 0          RRSOND (VK1215)
     RAWINSONDE RUN AN/GMD-1
     CAPE CANAVERAL AFS, FLORIDA
     ASCENT NBR   0434
    TIME: 1015 EST    DATE: 12 NOV 1981
```

FIGURE A-6. REEDM program output listing for an operation, interactive run producing ground-level concentration, dosage and 10-minute time mean concentration of $A\ell_2O_3$.

********** SOUNDING **********

SURFACE DENSITY (GM/M**3): 1190.43

MET LEVEL NO.	ALTITUDE (FT)	ALTITUDE (M)	DIR. (DEG)	SPEED (M/S)	SPEED (KTS)	TEMP	PTEMP (DEG. C)	DPTEMP (DEG. C)	PRESS (MB.)	RH (%)
1	16	4.9	337.0	7.72	15.00	22.4	22.98	16.0	1016.9	67.0
2	493	150.3	337.0	8.75	17.00	20.4	22.28	14.7	1000.0	70.0
3	1000	304.8	351.0	10.30	20.00	18.5	21.83	14.0	982.3	75.0
4	1936	590.1	3.0	9.78	19.00	15.4	21.46	13.1	950.0	86.0
5	2000	609.6	4.0	9.78	19.00	15.2	21.45	13.0	947.9	87.0
6	2235	681.2	8.0	9.78	19.00	14.4	21.29	12.5	940.0	88.4
7	3000	914.4	19.0	9.27	18.00	13.2	22.35	11.6	914.4	90.0
8	3435	1047.0	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
9	3441	1048.8	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
10	3718	1133.2	18.0	8.24	16.00	12.2	22.76	2.2	891.0	50.8
11	4000	1219.2	16.0	8.24	16.00	12.2	23.42	-2.3	881.9	39.0
12	4375	1333.5	13.0	8.24	16.00	12.2	24.32	-8.2	870.0	23.7
13	5000	1524.0	4.0	7.21	14.00	11.7	25.95	-3.4	850.4	35.0
14	5005	1525.5	4.0	6.69	13.00	11.6	25.88	-3.3	850.0	35.0
15	6000	1828.8	351.0	5.15	10.00	9.5	26.81	-3.1	819.9	41.0
16	6658	2029.4	352.0	5.15	10.00	7.8	27.13	-3.3	800.0	45.0
17	6670	2033.0	352.0	5.15	10.00	7.8	27.14	-3.3	800.0	46.1
18	7000	2133.6	358.0	5.15	10.00	7.4	27.64	-6.1	790.3	38.0
19	7425	2263.1	5.0	5.66	11.00	6.8	28.24	-9.7	778.0	30.5
20	8000	2438.4	6.0	6.18	12.00	6.0	29.28	-8.2	761.5	35.0
21	8269	2520.4	7.0	6.69	13.00	5.6	29.76	-7.6	754.0	39.0
22	8396	2559.1	6.0	7.21	14.00	5.7	30.27	-9.4	750.0	34.0
23	9000	2743.2	0.0	7.72	15.00	6.4	32.74	-16.	733.8	18.0
24	9140	2785.9	359.0	8.24	16.00	6.5	33.27	-18.	730.0	15.3
25	10000	3048.0	354.0	8.75	17.00	5.6	35.13	-17.	707.0	17.0

** - INDICATES THAT DATA IS LINEARLY INTERPOLATED FROM INPUT METEOROLOGY

FIGURE A-6. (Continued)

********** EXHAUST CLOUD **********

MET. LAYER NO.	TOP OF LAYER (METERS)	CLOUD RISE TIME (SECONDS)	RANGE FROM PAD (METERS)	AZIMUTH BEARING FROM PAD (METERS)
1	150.3	3.9	0.0	0.0
2	304.8	13.5	0.0	0.0
3	590.1	43.7	3527.3	176.5
4	609.6	46.3	3442.2	182.2
5	681.2	56.4	3438.8	184.4
6	914.4	95.3	3347.8	190.6
7	1047.0	121.5	3184.5	197.7
8	1048.8	121.9	3106.7	200.5
9	1133.2	140.1	3067.8	197.2
10	1219.2	160.1	3028.1	193.6
11	1333.5	194.1	3031.5	192.3
12	1524.0	285.5	2950.9	189.8
13	1525.5	331.6	2896.9	189.1
14	1828.8	352.8 *	2891.4	189.1
15	2029.4	352.8 *	1817.1	171.5
16	2033.0	352.8 *	1817.1	172.0
17	2133.6	352.8 *	1817.1	175.0
18	2263.1	352.8 *	1908.0	181.5
19	2438.4	352.8 *	2089.7	185.5
20	2520.4	352.8 *	2271.4	186.5
21	2559.1	352.8 *	2453.1	186.5
22	2743.2	352.8 *	2634.8	183.0
23	2785.9	352.8 *	2816.5	179.5
24	3048.0	352.8 *	2998.3	176.5

* - INDICATES CLOUD STABILIZATION TIME WAS USED
** - RANGE FROM PAD IS AT CLOUD STABILIZATION TIME

********** CLOUD STABILIZATION **********

CALCULATION HEIGHT	(METERS)	0.00
STABILIZATION HEIGHT	(METERS)	1525.52
STABILIZATION TIME	(SECS)	352.84
FIRST MIXING LAYER HEIGHT:	(METERS)	TOP = 1046.99
		BASE= 0.00
SECOND SELECTED LAYER HEIGHT:	(METERS)	TOP = 3048.00
		BASE= 0.00
SIGMAR(AZ) AT THE SURFACE	(DEGREES)	13.6138
SIGMER(EL) AT THE SURFACE	(DEGREES)	13.6138

FIGURE A-6. (Continued)

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*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************         CONCENTRATION/DOSAGE MODEL      ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS     ****************
```

FOR AL203 AT A HEIGHT OF 0.00 METERS
DOWNWIND FROM A SPACE SHUTTLE NORMAL LAUNCH
CALCULATIONS APPLY TO THE LAYER BETWEEN 0.00 AND 3048.00 METERS

THE METEOROLOGICAL DATA IS FROM 1015 EST 12 NOV 1981
LAUNCH TIME IS 915 EST 12 NOV 1981
TIME OF EXECUTION IS 312 EST 1 JUL 1982

RANGE FROM PAD (METERS)	BEARING FROM PAD (DEGREES)	PEAK CONCEN-TRATION (MILLI G/M**3)	CLOUD ARRIVAL TIME (MIN)	CLOUD DEPARTURE TIME (MIN)
5000.000	173.058	.175	3.025	17.733
6000.000	178.560	.949	4.310	20.008
7000.000	180.182	2.624	6.010	22.878
8000.000	180.466	4.074	7.769	25.833
9000.000	179.910	5.061	9.558	28.861
10000.000	179.411	5.619	11.375	32.024
11000.000	178.815	5.855	13.246	35.255
12000.000	178.220	5.864	15.122	38.489
13000.000	177.717	5.727	16.965	41.726
14000.000	177.015	5.501	18.783	45.192
15000.000	176.365	5.230	20.615	48.827
16000.000	175.756	4.946	22.420	52.512
17000.000	174.904	4.668	24.236	56.248
18000.000	174.077	4.416	26.058	60.023
19000.000	172.706	4.206	27.866	63.783
20000.000	171.062	4.060	29.654	67.489
21000.000	169.711	3.980	31.431	71.181
22000.000	168.655	3.946	33.195	74.832
23000.000	167.895	3.937	34.955	78.452
24000.000	167.436	3.941	36.712	82.069
25000.000	166.989	3.947	38.470	85.663
26000.000	166.842	3.953	40.222	89.275
27000.000	166.415	3.954	41.978	92.868
28000.000	166.287	3.949	43.725	96.475
29000.000	166.170	3.937	45.479	100.066

	RANGE	BEARING
5.864 IS THE MAXIMUM PEAK CONCENTRATION	12000.0	178.2

FIGURE A-6. (Continued)

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*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************         CONCENTRATION/DOSAGE MODEL      ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS       ****************
```

FOR AL203 AT A HEIGHT OF 0.00 METERS
DOWNWIND FROM A SPACE SHUTTLE NORMAL LAUNCH
CALCULATIONS APPLY TO THE LAYER BETWEEN 0.00 AND 3048.00 METERS

THE METEOROLOGICAL DATA IS FROM 1015 EST 12 NOV 1981
LAUNCH TIME IS 915 EST 12 NOV 1981
TIME OF EXECUTION IS 312 EST 1 JUL 1982

RANGE FROM PAD (METERS)	BEARING FROM PAD (DEGREES)	TOTAL DOSAGE (MILLI G SEC/M**3)	CLOUD ARRIVAL TIME (MIN)	CLOUD DEPARTURE TIME (MIN)
5000.000	173.058	4.762	3.025	17.733
6000.000	181.191	64.772	4.310	20.008
7000.000	181.496	213.777	6.010	22.878
8000.000	181.178	366.094	7.769	25.833
9000.000	180.663	486.893	9.558	28.861
10000.000	180.017	570.951	11.375	32.024
11000.000	179.073	622.251	13.246	35.255
12000.000	178.220	646.812	15.122	38.489
13000.000	177.449	651.922	16.965	41.726
14000.000	176.745	643.754	18.783	45.192
15000.000	175.817	627.288	20.615	48.827
16000.000	174.928	606.860	22.420	52.512
17000.000	173.790	585.815	24.236	56.248
18000.000	172.394	566.986	26.058	60.023
19000.000	171.013	551.807	27.866	63.783
20000.000	169.927	539.774	29.654	67.489
21000.000	168.855	529.757	31.431	71.181
22000.000	168.082	520.643	33.195	74.832
23000.000	167.607	512.015	34.955	78.452
24000.000	167.147	503.390	36.712	82.069
25000.000	166.989	494.659	38.470	85.663
26000.000	166.551	485.810	40.222	89.275
27000.000	166.415	476.728	41.978	92.868
28000.000	165.994	467.396	43.725	96.475
29000.000	165.876	458.079	45.479	100.066

651.922 IS THE MAXIMUM TOTAL DOSAGE

RANGE	BEARING
13000.0	177.4

FIGURE A-6. (Continued.

```
*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************         CONCENTRATION/DOSAGE MODEL      ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS      ****************
```

FOR AL203 AT A HEIGHT OF 0.00 METERS
DOWNWIND FROM A SPACE SHUTTLE NORMAL LAUNCH
CALCULATIONS APPLY TO THE LAYER BETWEEN 0.00 AND 3048.00 METERS

THE METEOROLOGICAL DATA IS FROM 1015 EST 12 NOV 1981
LAUNCH TIME IS 915 EST 12 NOV 1981
TIME OF EXECUTION IS 312 EST 1 JUL 1982

RANGE FROM PAD (METERS)	BEARING FROM PAD (DEGREES)	10.0 MIN. MEAN CONCEN-TRATION (MILLI G/M**3)	CLOUD ARRIVAL TIME (MIN)	CLOUD DEPARTURE TIME (MIN)
5000.000	173.058	.008	3.025	17.733
6000.000	181.191	.108	4.310	20.008
7000.000	181.496	.356	6.010	22.878
8000.000	181.178	.610	7.769	25.833
9000.000	180.663	.811	9.558	28.861
10000.000	180.017	.952	11.375	32.024
11000.000	179.073	1.037	13.246	35.255
12000.000	178.220	1.078	15.122	38.489
13000.000	177.449	1.087	16.965	41.726
14000.000	176.745	1.073	18.783	45.192
15000.000	175.817	1.045	20.615	48.827
16000.000	174.928	1.011	22.420	52.512
17000.000	173.790	.976	24.236	56.248
18000.000	172.394	.945	26.058	60.023
19000.000	171.013	.920	27.866	63.783
20000.000	169.927	.900	29.654	67.489
21000.000	168.855	.883	31.431	71.181
22000.000	168.082	.868	33.195	74.832
23000.000	167.607	.853	34.955	78.452
24000.000	167.147	.839	36.712	82.069
25000.000	166.989	.824	38.470	85.663
26000.000	166.551	.810	40.222	89.275
27000.000	166.415	.795	41.978	92.868
28000.000	165.994	.779	43.725	96.475
29000.000	165.876	.763	45.479	100.066

	RANGE	BEARING
1.087 IS THE MAXIMUM 10.0 MIN. MEAN CONCENTRATION	13000.0	177.4

FIGURE A-6. (Continued)

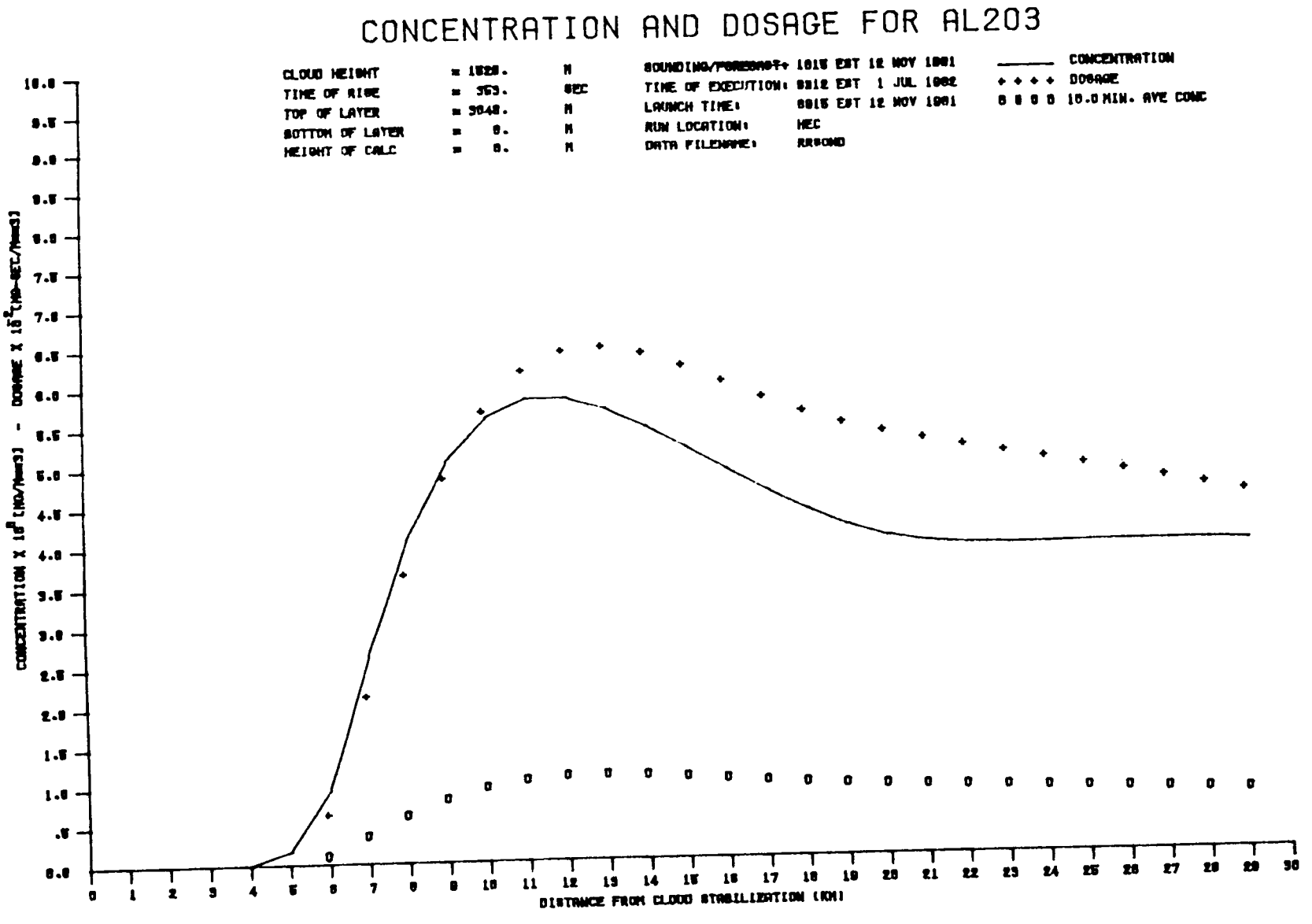

FIGURE A-7. Maximum centerline profile plot of ground-level concentration, dosage and 10-minute time mean concentration of $A\ell_2O_3$.

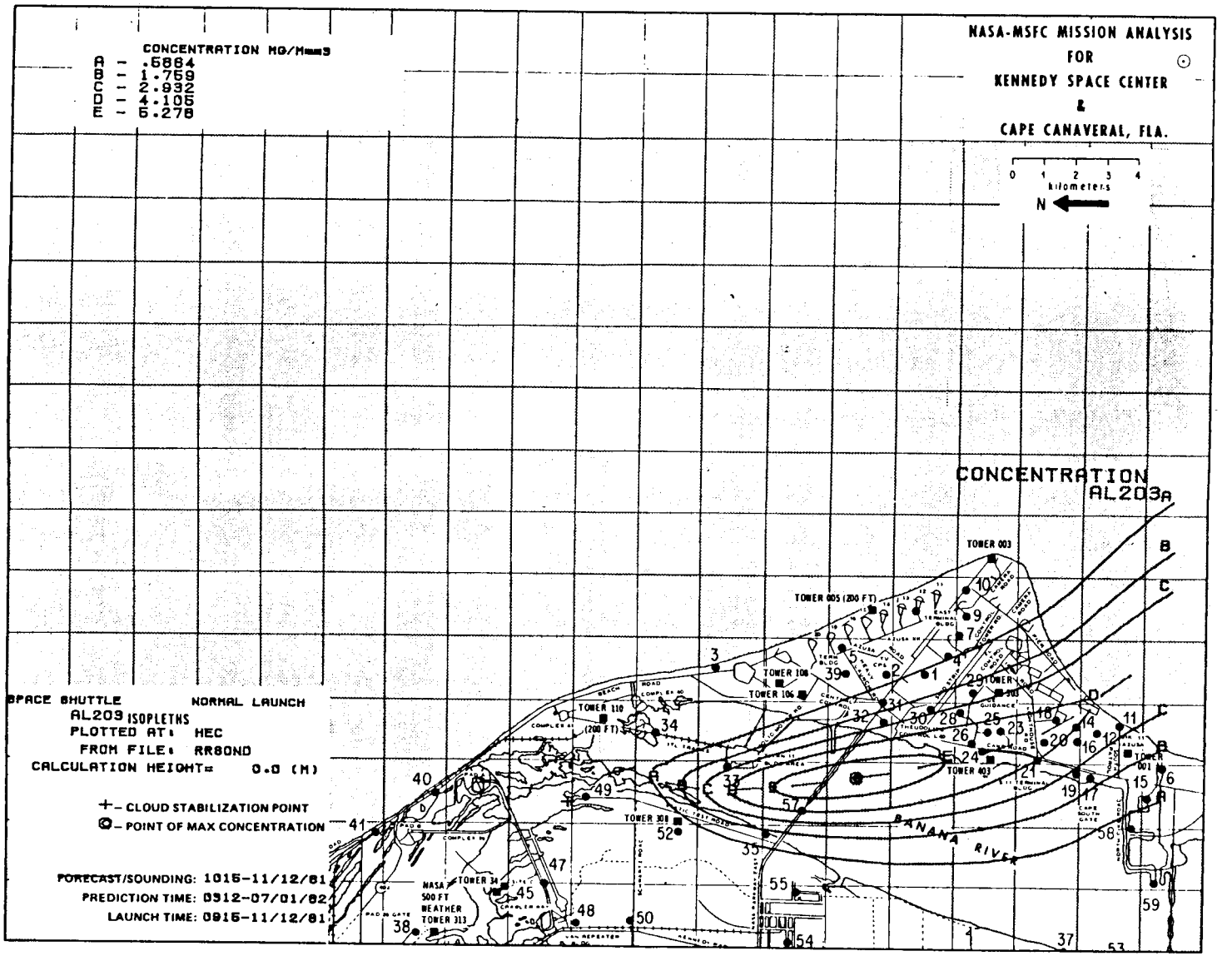

Figure A-8. Ground level $A\ell_2O_3$ concentration isopleth plot using the "SEA" map of Kennedy Space Center.

trajectory. Figure A-8 shows isopleths of $A\ell_2O_3$ concentration plotted on the land map of Kennedy Space Center.

Figure A-9 shows the program output for maximum possible ground-level pH of ground water due to $HC\ell$ washout deposition for the Space Shuttle launch. It should be noted that this is an example calculation and no washout deposition actually occurred during this launch. Again all input parameters except the layer-height parameters were defaulted after the washout deposition calculation was selected by the user. This listing differs from the previous listings shown in Figure A-3 and A-6 above in that the maximum ground-water pH due to washout deposition from the bottom layer and due to $HC\ell$ washout from the top layer are printed in addition to the total maximum ground-water pH caused by precipitation falling through both layers. The assumptions made regarding these calculations are described in Section 4.3 of the main body of this manual. Figure A-10 shows plots of maximum centerline ground-water pH due to washout deposition and isopleths of maximum ground-water pH due to washout deposition are shown in Figure A-11.

Figure A-12 shows the REEDM program output for gravitational deposition of $A\ell_2O_3$ contained in the exhaust cloud. Again, all input parameters except the layer-height parameters were defaulted after the selection of gravitational deposition by the user. Page 4 of Figure A-12 shows the maximum centerline $A\ell_2O_3$ deposition due to deposition of $A\ell_2O_3$ from the lower layer and page 5 shows the total ground-level $A\ell_2O_3$ deposition due to gravitational settling of $A\ell_2O_3$ from both the lower and upper layers. Figure A-13 shows plots of maximum centerline ground-level $A\ell_2O_3$ deposition due to gravitational settling and isopleths of $A\ell_2O_3$ deposition plotted on the (land) map of Kennedy Space Center are shown in Figure A-14.

Figure A-15 shows the input control data file for a batch, production type run and for the same inputs used in the interactive run shown in Figure A-3. The numbers on the left of Figure A-15 are added to indicate the record number and are not part of the data file. Also,

```
*************************************************************************
****************                                         ****************
**************** NASA/MSFC MULTIPLE LAYER TECHNIQUE - REEDM ****************
****************  UPDATE 8213    LOCATION HEC                ****************
****************                                         ****************
*************************************************************************


                    SPACE SHUTTLE        NORMAL LAUNCH

                LAUNCH TIME:        915 EST DATE: 12 NOV 1981
                TIME OF EXECUTION:  338 EST DATE:  1 JUL 1982

******************              MODEL OPTIONS              ******************

 MODEL                                                     WASHOUT DEPOSITION
 METEOROLOGICAL DATA SOUNDING                                            RRSOND
 RUN TYPE                                                       OPERATIONAL
 LAUNCH VEHICLE                                               SPACE SHUTTLE
 LAUNCH TYPE                                                           NORMAL
 LAUNCH COMPLEX NUMBER                                                    39A
 SPECIES                                                                  HCL
 CLOUD SHAPE                                                       ELLIPTICAL
 PROPELLANT TEMPERATURE (DEG. C)                                        22.86
 WASHOUT DEPOSITION IS                                          MAXIMUM POSSIBLE
 RAINFALL RATE (INCHES PER HOUR)                                          .30
 RAIN DURATION (HOURS)                                                   1.00
**********************          METEOROLOGICAL DATA          **********************

    RUN NUMBER:   1          USING METEOROLOGICAL DATA FILE: RRSOND

     TEST NBR 09101  T MINUS 0          RRSOND (VK1215)
     RAWINSONDE RUN AN/GMD-1
     CAPE CANAVERAL AFS, FLORIDA
     ASCENT NBR   0434
    TIME: 1015 EST    DATE: 12 NOV 1981
```

FIGURE A-9. REEDM program output listing for an operation, interactive run producing maximum centerline ground-water pH due to washout deposition.

SURFACE DENSITY (GM/M**3): 1190.43

MET LEVEL NO.	ALTITUDE (FT)	ALTITUDE (M)	DIR. (DEG)	SPEED (M/S)	SPEED (KTS)	TEMP	PTEMP (DEG. C)	DPTEMP (DEG. C)	PRESS (MB.)	RH (%)
1	16	4.9	337.0	7.72	15.00	22.4	22.98	16.0	1016.9	67.0
2	493	150.3	337.0	8.75	17.00	20.4	22.28	14.7	1000.0	70.0
3	1000	304.8	351.0	10.30	20.00	18.5	21.83	14.0	982.3	75.0
4	1936	590.1	3.0	9.78	19.00	15.4	21.46	13.1	950.0	86.0
5	2000	609.6	4.0	9.78	19.00	15.2	21.45	13.0	947.9	87.0
6	2235	681.2	8.0	9.78	19.00	14.4	21.29	12.5	940.0	88.4
7	3000	914.4	19.0	9.27	18.00	13.2	22.35	11.6	914.4	90.0
8	3435	1047.0	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
9	3441	1048.8	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
10	3718	1133.2	18.0	8.24	16.00	12.2	22.76	2.2	891.0	50.8
11	4000	1219.2	16.0	8.24	16.00	12.2	23.42	-2.3	881.9	39.0
12	4375	1333.5	13.0	8.24	16.00	12.2	24.32	-8.2	870.0	23.7
13	5000	1524.0	4.0	7.21	14.00	11.7	25.95	-3.4	850.4	35.0
14	5005	1525.5	4.0	6.69	13.00	11.6	25.88	-3.3	850.0	35.0
15	6000	1828.8	351.0	5.15	10.00	9.5	26.81	-3.1	819.9	41.0
16	6658	2029.4	352.0	5.15	10.00	7.8	27.13	-3.3	800.0	45.0
17	6670	2033.0	352.0	5.15	10.00	7.8	27.14	-3.3	800.0	46.1
18	7000	2133.6	358.0	5.15	10.00	7.4	27.64	-6.1	790.3	38.0
19	7425	2263.1	5.0	5.66	11.00	6.8	28.24	-9.7	778.0	30.5
20	8000	2438.4	6.0	6.18	12.00	6.0	29.28	-8.2	761.5	35.0
21	8269	2520.4	7.0	6.69	13.00	5.6	29.76	-7.6	754.0	39.0
22	8396	2559.1	6.0	7.21	14.00	5.7	30.27	-9.4	750.0	34.0
23	9000	2743.2	0.0	7.72	15.00	6.4	32.74	-16.	733.8	18.0
24	9140	2785.9	359.0	8.24	16.00	6.5	33.27	-18.	730.0	15.3
25	10000	3048.0	354.0	8.75	17.00	5.6	35.13	-17.	707.0	17.0

** - INDICATES THAT DATA IS LINEARLY INTERPOLATED FROM INPUT METEOROLOGY

FIGURE A-9. (Continued.

********** EXHAUST CLOUD **********

MET. LAYER NO.	TOP OF LAYER (METERS)	CLOUD RISE TIME (SECONDS)	RANGE FROM PAD (METERS)	AZIMUTH BEARING FROM PAD (METERS)
1	150.3	3.9	0.0	0.0
2	304.8	13.5	0.0	0.0
3	590.1	43.7	3527.3	176.5
4	609.6	46.3	3442.2	182.2
5	681.2	56.4	3438.8	184.4
6	914.4	95.3	3347.8	190.6
7	1047.0	121.5	3184.5	197.7
8	1048.8	121.9	3106.7	200.5
9	1133.2	140.1	3067.8	197.2
10	1219.2	160.1	3028.1	193.6
11	1333.5	194.1	3031.5	192.3
12	1524.0	285.5	2950.9	189.8
13	1525.5	331.6	2896.9	189.1
14	1828.8	352.8 *	2891.4	189.1
15	2029.4	352.8 *	1817.1	171.5
16	2033.0	352.8 *	1817.1	172.0
17	2133.6	352.8 *	1817.1	175.0
18	2263.1	352.8 *	1908.0	181.5
19	2438.4	352.8 *	2089.7	185.5
20	2520.4	352.8 *	2271.4	186.5
21	2559.1	352.8 *	2453.1	186.5
22	2743.2	352.8 *	2634.8	183.0
23	2785.9	352.8 *	2816.5	179.5
24	3048.0	352.8 *	2998.3	176.5

* - INDICATES CLOUD STABILIZATION TIME WAS USED
** - RANGE FROM PAD IS AT CLOUD STABILIZATION TIME

********** CLOUD STABILIZATION **********

CALCULATION HEIGHT	(METERS)	0.00
STABILIZATION HEIGHT	(METERS)	1525.52
STABILIZATION TIME	(SECS)	352.84
FIRST MIXING LAYER HEIGHT:	(METERS)	TOP = 1046.99
		BASE= 0.00
SECOND SELECTED LAYER HEIGHT:	(METERS)	TOP = 3048.00
		BASE= 1046.99
SIGMAR(AZ) AT THE SURFACE	(DEGREES)	13.6138
SIGMER(EL) AT THE SURFACE	(DEGREES)	13.6138

FIGURE A-9. (Continued)

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*****************************************************************************
****************                                                 ****************
****************   REEDM  UPDATE 8213  LOCATION HEC              ****************
****************          WASHOUT DEPOSITION MODEL               ****************
****************                                                 ****************
*****************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS           ****************

                        FOR  HCL  AT GROUND-LEVEL
             DOWNWIND FROM A  SPACE SHUTTLE        NORMAL LAUNCH
   CALCULATIONS APPLY TO THE LAYER BETWEEN    0.0 AND 1047.0 METERS

        THE METEOROLOGICAL DATA IS FROM 1015 EST  12 NOV 1981
                   LAUNCH TIME IS       915 EST  12 NOV 1981
             TIME OF EXECUTION IS       338 EST   1 JUL 1982
```

RANGE (METERS)	BEARING (DEGREES)	MAXIMUM POSSIBLE WASHOUT DEPOSITION (PH)
4045.401	188.570	1.949
5037.863	187.007	2.075
6031.291	185.817	2.187
7027.479	185.047	2.283
8023.588	184.373	2.363
9023.207	184.088	2.433
10017.361	183.352	2.494
11020.912	183.508	2.548
12017.078	183.033	2.597
13013.943	182.631	2.641
14011.359	182.285	2.682
15018.668	182.835	2.720
16016.621	182.589	2.755
17014.836	182.371	2.788
18013.270	182.177	2.819
19011.887	182.004	2.848
20010.660	181.849	2.876
21009.566	181.707	2.902
22008.594	181.579	2.928
23007.715	181.462	2.952
24006.930	181.355	2.975
25006.219	181.256	2.998
26005.574	181.165	3.019
27005.000	181.080	3.040
28004.469	181.002	3.061
29003.992	180.929	3.080

	RANGE	BEARING
1.949 IS THE PEAK WASHOUT DEPOSITION	4045.401	188.570

FIGURE A-9. (Continued)

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*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************          WASHOUT DEPOSITION MODEL       ****************
****************                                         ****************
*************************************************************************
****************       MAXIMUM CENTERLINE CALCULATIONS   ****************
                          FOR  HCL  AT GROUND-LEVEL
              DOWNWIND FROM A  SPACE SHUTTLE        NORMAL LAUNCH
   CALCULATIONS APPLY TO THE LAYER BETWEEN 1047.0 AND 3048.0 METERS

        THE METEOROLOGICAL DATA IS FROM 1015 EST  12 NOV 1981
                   LAUNCH TIME IS       915 EST  12 NOV 1981
              TIME OF EXECUTION IS      338 EST   1 JUL 1982
```

RANGE (METERS)	BEARING (DEGREES)	MAXIMUM POSSIBLE WASHOUT DEPOSITION (PH)
2009.809	176.985	1.615
3000.336	183.505	.929
4001.344	181.163	1.011
5000.693	181.694	1.063
6000.082	182.350	1.127
7000.000	182.633	1.187
8000.026	182.795	1.241
9000.016	182.753	1.290
10000.000	182.645	1.335
11000.012	182.732	1.377
12000.187	182.967	1.415
13000.148	182.922	1.450
14000.201	182.954	1.483
15000.000	182.640	1.514
16000.041	182.777	1.542
17000.242	182.955	1.569
18000.027	182.747	1.595
19000.332	182.985	1.619
20000.094	182.822	1.642
21000.004	182.674	1.664
22000.352	182.971	1.685
23000.145	182.851	1.705
24000.031	182.740	1.724
25000.004	182.639	1.742
26000.453	182.986	1.760
27000.266	182.901	1.777
28000.133	182.822	1.793
29000.047	182.749	1.808

	RANGE	BEARING
.929 IS THE PEAK WASHOUT DEPOSITION	3000.336	183.505

FIGURE A-9. (Continued)

```
*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************          WASHOUT DEPOSITION MODEL       ****************
****************                                         ****************
*************************************************************************
****************       MAXIMUM CENTERLINE CALCULATIONS   ****************
                          FOR  HCL  AT GROUND-LEVEL
              DOWNWIND FROM A  SPACE SHUTTLE        NORMAL LAUNCH
   CALCULATIONS APPLY TO THE LAYER BETWEEN    0.0 AND 3048.0 METERS

        THE METEOROLOGICAL DATA IS FROM 1015 EST  12 NOV 1981
                   LAUNCH TIME IS       915 EST  12 NOV 1981
              TIME OF EXECUTION IS      338 EST   1 JUL 1982
```

RANGE (METERS)	BEARING (DEGREES)	MAXIMUM POSSIBLE WASHOUT DEPOSITION (PH)
2009.809	176.985	1.615
3000.336	183.505	.929
4001.344	181.163	1.011
5000.693	181.694	1.063
6000.082	182.350	1.127
7000.000	182.633	1.187
8000.026	182.795	1.241
9000.016	182.753	1.290
10000.000	182.645	1.335
11000.012	182.732	1.377
12000.187	182.967	1.415
13000.148	182.922	1.450
14000.201	182.954	1.483
15000.000	182.640	1.514
16000.041	182.777	1.542
17000.242	182.955	1.569
18000.027	182.747	1.595
19000.332	182.985	1.619
20000.094	182.822	1.642
21000.004	182.674	1.664
22000.352	182.971	1.685
23000.145	182.851	1.705
24000.031	182.740	1.724
25000.004	182.639	1.742
26000.453	182.986	1.760
27000.266	182.901	1.777
28000.133	182.822	1.793
29000.047	182.749	1.808

	RANGE	BEARING
.929 IS THE PEAK WASHOUT DEPOSITION	3000.336	183.505

FIGURE A-9. (Continued)

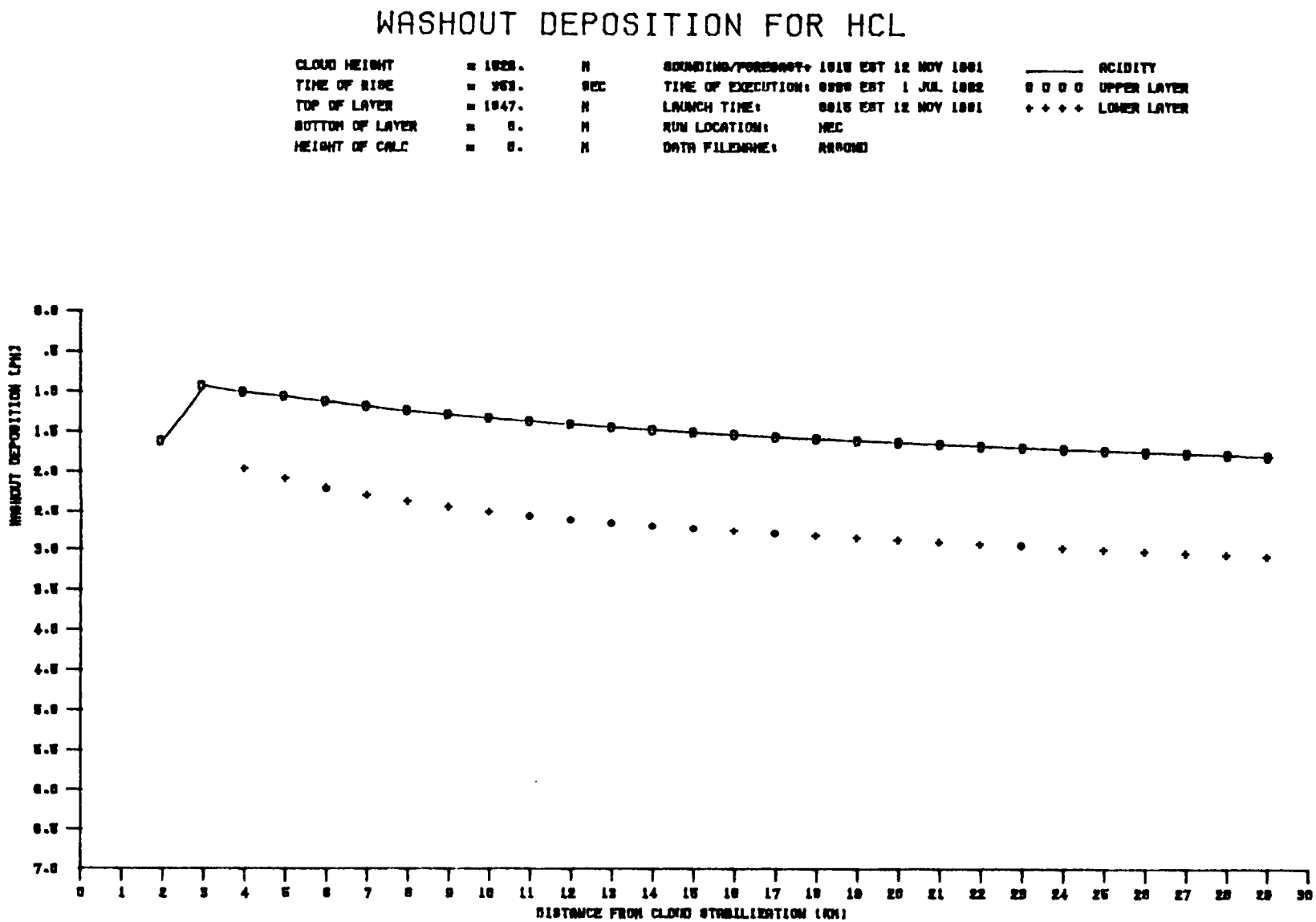

FIGURE A-10. Maximum centerline profile of ground-level maximum possible washout deposition of HCℓ.

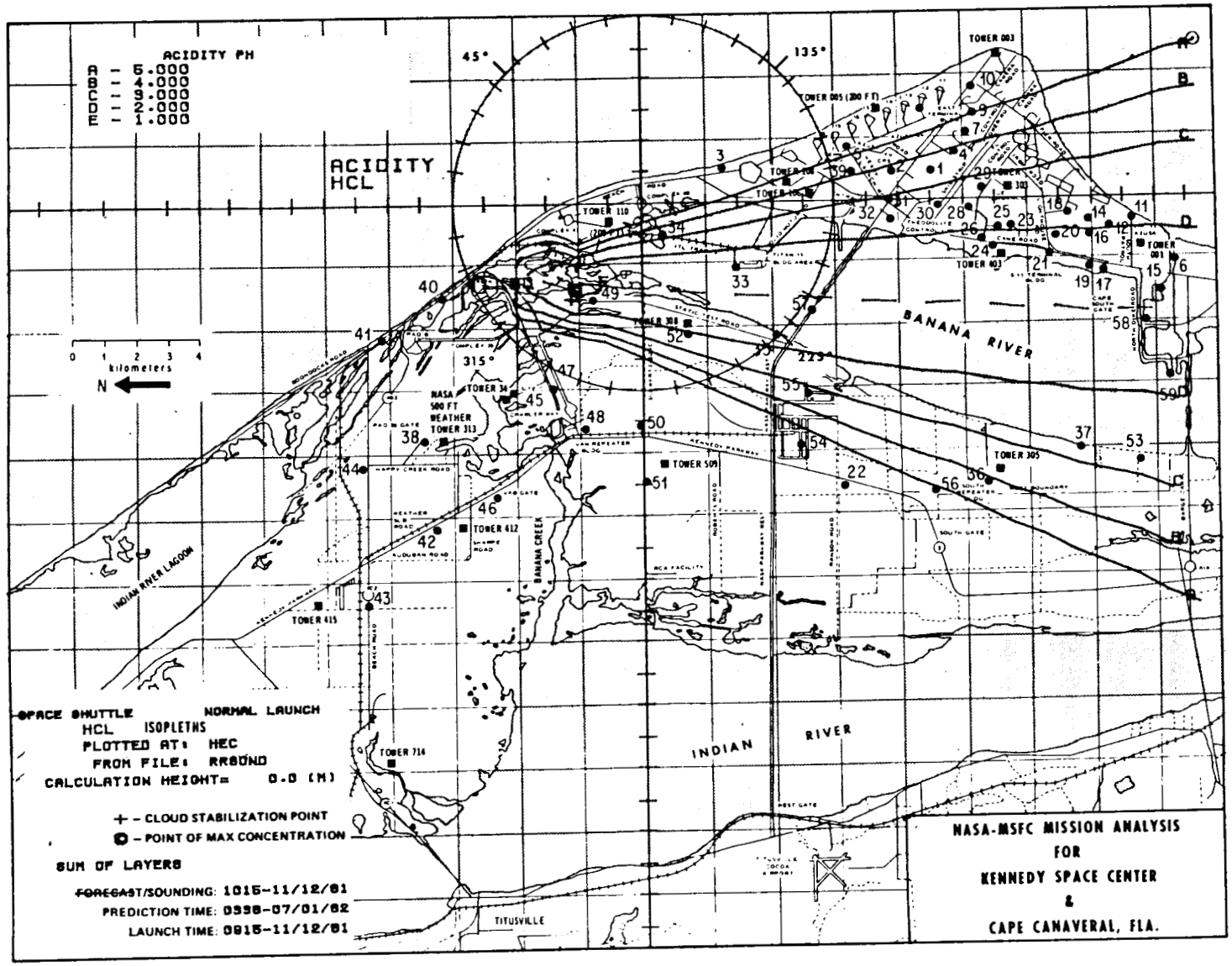

Figure A-11. Isopleth of maximum ground-water pH due to washout deposition using the "LAND" map of Kennedy Space Center.

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*************************************************************************
****************                                         ****************
**************** NASA/MSFC MULTIPLE LAYER TECHNIQUE - REEDM ****************
****************  UPDATE 8213    LOCATION HEC                ****************
****************                                         ****************
*************************************************************************


                    SPACE SHUTTLE        NORMAL LAUNCH

                LAUNCH TIME:        915 EST DATE: 12 NOV 1981
                TIME OF EXECUTION:  359 EST DATE:  1 JUL 1982

******************             MODEL OPTIONS             ******************

 MODEL                                                GRAVITATIONAL DEPOSITION
 METEOROLOGICAL DATA SOUNDING                                          RRSOND
 RUN TYPE                                                         OPERATIONAL
 LAUNCH VEHICLE                                                 SPACE SHUTTLE
 LAUNCH TYPE                                                           NORMAL
 LAUNCH COMPLEX NUMBER                                                    39A
 CLOUD SHAPE                                                       ELLIPTICAL
 PROPELLANT TEMPERATURE (DEG. C)                                        22.86
**********************          METEOROLOGICAL DATA          **********************

    RUN NUMBER:   1           USING METEOROLOGICAL DATA FILE: RRSOND

     TEST NBR 09101  T MINUS 0          RRSOND (VK1215)
     RAWINSONDE RUN AN/GMD-1
     CAPE CANAVERAL AFS, FLORIDA
     ASCENT NBR   0434
    TIME: 1015 EST    DATE: 12 NOV 1981
```

FIGURE A-12. REEDM program output listing for an operational, interactive run producing ground-level gravitational deposition of $A\ell_2O_3$.

SURFACE DENSITY (GM/M**3): 1190.43

MET LEVEL NO.	ALTITUDE (FT)	ALTITUDE (M)	DIR. (DEG)	SPEED (M/S)	SPEED (KTS)	TEMP	PTEMP (DEG. C)	DPTEMP (DEG. C)	PRESS (MB.)	RH (%)
1	16	4.9	337.0	7.72	15.00	22.4	22.98	16.0	1016.9	67.0
2	493	150.3	337.0	8.75	17.00	20.4	22.28	14.7	1000.0	70.0
3	1000	304.8	351.0	10.30	20.00	18.5	21.83	14.0	982.3	75.0
4	1936	590.1	3.0	9.78	19.00	15.4	21.46	13.1	950.0	86.0
5	2000	609.6	4.0	9.78	19.00	15.2	21.45	13.0	947.9	87.0
6	2235	681.2	8.0	9.78	19.00	14.4	21.29	12.5	940.0	88.4
7	3000	914.4	19.0	9.27	18.00	13.2	22.35	11.6	914.4	90.0
8	3435	1047.0	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
9	3441	1048.8	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
10	3718	1133.2	18.0	8.24	16.00	12.2	22.76	2.2	891.0	50.8
11	4000	1219.2	16.0	8.24	16.00	12.2	23.42	-2.3	881.9	39.0
12	4375	1333.5	13.0	8.24	16.00	12.2	24.32	-8.2	870.0	23.7
13	5000	1524.0	4.0	7.21	14.00	11.7	25.95	-3.4	850.4	35.0
14	5005	1525.5	4.0	6.69	13.00	11.6	25.88	-3.3	850.0	35.0
15	6000	1828.8	351.0	5.15	10.00	9.5	26.81	-3.1	819.9	41.0
16	6658	2029.4	352.0	5.15	10.00	7.8	27.13	-3.3	800.0	45.0
17	6670	2033.0	352.0	5.15	10.00	7.8	27.14	-3.3	800.0	46.1
18	7000	2133.6	358.0	5.15	10.00	7.4	27.64	-6.1	790.3	38.0
19	7425	2263.1	5.0	5.66	11.00	6.8	28.24	-9.7	778.0	30.5
20	8000	2438.4	6.0	6.18	12.00	6.0	29.28	-8.2	761.5	35.0
21	8269	2520.4	7.0	6.69	13.00	5.6	29.76	-7.6	754.0	39.0
22	8396	2559.1	6.0	7.21	14.00	5.7	30.27	-9.4	750.0	34.0
23	9000	2743.2	0.0	7.72	15.00	6.4	32.74	-16.	733.8	18.0
24	9140	2785.9	359.0	8.24	16.00	6.5	33.27	-18.	730.0	15.3
25	10000	3048.0	354.0	8.75	17.00	5.6	35.13	-17.	707.0	17.0

** - INDICATES THAT DATA IS LINEARLY INTERPOLATED FROM INPUT METEOROLOGY

FIGURE A-12. (Continued)

********** EXHAUST CLOUD **********

MET. LAYER NO.	TOP OF LAYER (METERS)	CLOUD RISE TIME (SECONDS)	RANGE FROM PAD (METERS)	AZIMUTH BEARING FROM PAD (METERS)
1	150.3	3.9	0.0	0.0
2	304.8	13.5	0.0	0.0
3	590.1	43.7	3527.3	176.5
4	609.6	46.3	3442.2	182.2
5	681.2	56.4	3438.8	184.4
6	914.4	95.3	3347.8	190.6
7	1047.0	121.5	3184.5	197.7
8	1048.8	121.9	3106.7	200.5
9	1133.2	140.1	3067.8	197.2
10	1219.2	160.1	3028.1	193.6
11	1333.5	194.1	3031.5	192.3
12	1524.0	285.5	2950.9	189.8
13	1525.5	331.6	2896.9	189.1
14	1828.8	352.8 *	2891.4	189.1
15	2029.4	352.8 *	1817.1	171.5
16	2033.0	352.8 *	1817.1	172.0
17	2133.6	352.8 *	1817.1	175.0
18	2263.1	352.8 *	1908.0	181.5
19	2438.4	352.8 *	2089.7	185.5
20	2520.4	352.8 *	2271.4	186.5
21	2559.1	352.8 *	2453.1	186.5
22	2743.2	352.8 *	2634.8	183.0
23	2785.9	352.8 *	2816.5	179.5
24	3048.0	352.8 *	2998.3	176.5

* - INDICATES CLOUD STABILIZATION TIME WAS USED
** - RANGE FROM PAD IS AT CLOUD STABILIZATION TIME

********** CLOUD STABILIZATION **********

CALCULATION HEIGHT	(METERS)	0.00
STABILIZATION HEIGHT	(METERS)	1525.52
STABILIZATION TIME	(SECS)	352.84
FIRST MIXING LAYER HEIGHT:	(METERS)	TOP = 1046.99
		BASE= 0.00
SECOND SELECTED LAYER HEIGHT:	(METERS)	TOP = 3048.00
		BASE= 0.00
SIGMAR(AZ) AT THE SURFACE	(DEGREES)	13.6138
SIGMER(EL) AT THE SURFACE	(DEGREES)	13.6138

FIGURE A-12. (Continued)

```
*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************       GRAVITATIONAL DEPOSITION MODEL    ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS   ****************
```

FOR AL203 AT GROUND-LEVEL
DOWNWIND FROM A SPACE SHUTTLE NORMAL LAUNCH
CALCULATIONS APPLY TO THE LAYER BETWEEN THE SURFACE AND 1046.99 METERS

THE METEOROLOGICAL DATA IS FROM 1015 EST 12 NOV 1981
LAUNCH TIME IS 915 EST 12 NOV 1981
TIME OF EXECUTION IS 359 EST 1 JUL 1982

RANGE (METERS)	BEARING (DEGREES)	- GRAVITATIONAL DEPOSITION - (MILLIGRAMS/ (SQ. METER)	(PARTICLES/ (SQ. METER)
5000.000	173.289	11.686	1.11468E+02
6000.000	181.659	160.417	1.53011E+03
7000.000	181.648	378.115	3.60657E+03
8000.000	181.532	472.799	4.50970E+03
9000.000	180.799	471.537	4.49766E+03
10000.000	180.322	425.281	4.05645E+03
11000.000	180.032	365.686	3.48802E+03
12000.000	179.463	307.447	2.93252E+03
13000.000	178.982	256.219	2.44389E+03
14000.000	178.569	213.233	2.03388E+03
15000.000	178.656	178.147	1.69922E+03
16000.000	178.350	149.408	1.42509E+03
17000.000	178.080	126.021	1.20203E+03
18000.000	177.840	106.953	1.02015E+03
19000.000	177.625	91.340	8.71225E+02
20000.000	177.432	78.488	7.48638E+02
21000.000	177.258	67.846	6.47138E+02
22000.000	177.099	58.982	5.62586E+02
23000.000	176.954	51.552	4.91721E+02
24000.000	176.821	45.288	4.31973E+02
25000.000	176.699	39.977	3.81309E+02
26000.000	176.586	35.447	3.38108E+02
27000.000	176.482	31.565	3.01073E+02
28000.000	176.875	28.238	2.69345E+02
29000.000	176.786	25.343	2.41728E+02

	RANGE	BEARING
472.799 IS THE PEAK GRAVITATIONAL DEPOSITION	8000.000	181.532

FIGURE A-12. (Continued)

```
*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************       GRAVITATIONAL DEPOSITION MODEL    ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS   ****************
```

FOR AL203 AT GROUND-LEVEL
DOWNWIND FROM A SPACE SHUTTLE NORMAL LAUNCH
CALCULATIONS APPLY TO THE LAYER BETWEEN THE SURFACE AND 3048.00 METERS

THE METEOROLOGICAL DATA IS FROM 1015 EST 12 NOV 1981
LAUNCH TIME IS 915 EST 12 NOV 1981
TIME OF EXECUTION IS 359 EST 1 JUL 1982

RANGE (METERS)	BEARING (DEGREES)	- GRAVITATIONAL DEPOSITION - (MILLIGRAMS/ (SQ. METER)	(PARTICLES/ (SQ. METER)
5000.000	173.300	11.690	1.11500E+02
6000.000	181.776	166.675	1.58980E+03
7000.000	182.153	435.197	4.15103E+03
8000.000	181.679	623.862	5.95058E+03
9000.000	180.892	714.718	6.81718E+03
10000.000	180.034	735.040	7.01102E+03
11000.000	179.073	712.055	6.79178E+03
12000.000	178.220	666.093	6.35339E+03
13000.000	177.449	610.374	5.82192E+03
14000.000	176.745	552.705	5.27186E+03
15000.000	175.544	497.844	4.74857E+03
16000.000	174.652	448.692	4.27975E+03
17000.000	173.234	406.801	3.88018E+03
18000.000	171.553	372.702	3.55494E+03
19000.000	170.166	345.187	3.29249E+03
20000.000	169.075	322.420	3.07534E+03
21000.000	168.285	302.953	2.88966E+03
22000.000	167.795	285.841	2.72644E+03
23000.000	167.319	270.477	2.57989E+03
24000.000	166.859	256.503	2.44660E+03
25000.000	166.700	243.655	2.32405E+03
26000.000	166.260	231.796	2.21093E+03
27000.000	166.123	220.795	2.10600E+03
28000.000	165.994	210.519	2.00799E+03
29000.000	165.876	200.897	1.91621E+03

	RANGE	BEARING
735.040 IS THE PEAK GRAVITATIONAL DEPOSITION	10000.000	180.034

FIGURE A-12. (Continued)

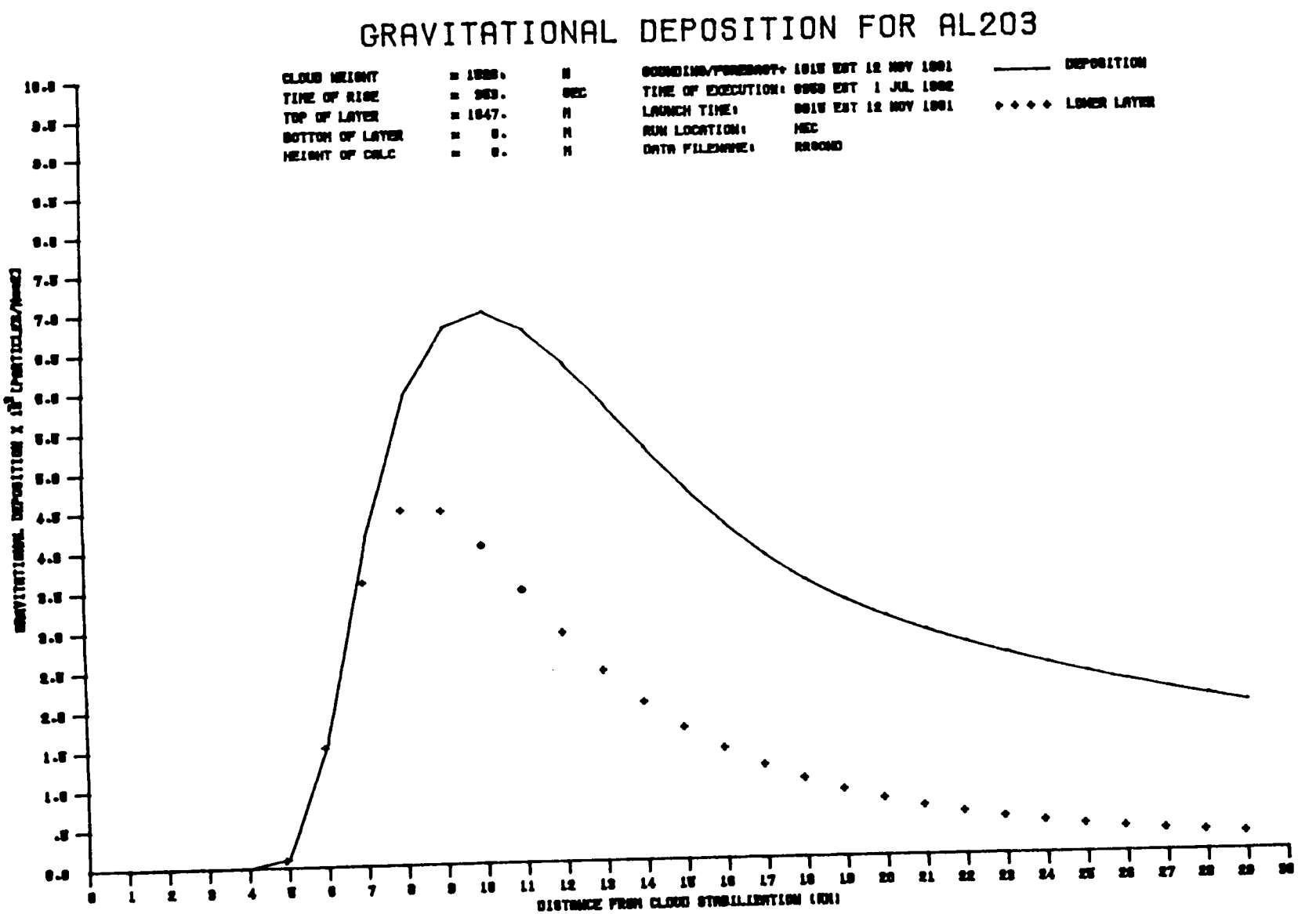

FIGURE A-13. Maximum centerline profile plot of ground level gravitational deposition of $A\ell_2O_3$.

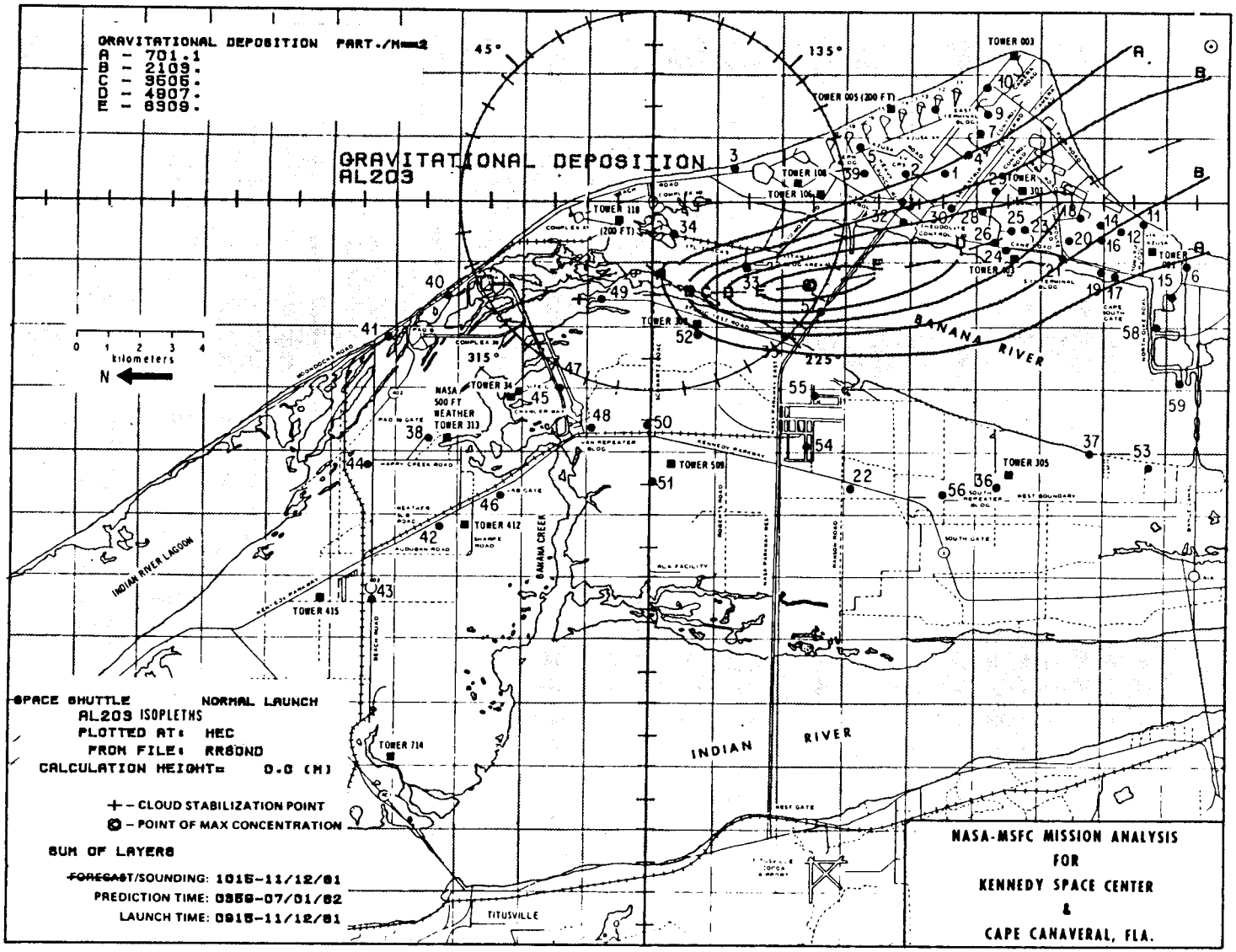

Figure A-14. Ground level $A\ell_2O_3$ gravitational deposition isopleth plot using the "LAND" map of Kennedy Space Center.

RECORD NUMBER	COMMAND (BEGINS IN COL. 1)
01.	PRODUCTION
02.	RRSOND
03.	1
04.	CONCENTRATION
05.	0915 EST 12 NOV 1981
06.	SHUTTLE
07.	NORMAL
08.	22.86
09.	HCL
10.	39A
11.	SURFACE
12.	ELLIPTICAL
17.	YES
18.	YES
18.	NO
20.	NO
23.	NO
24.	NO
26.	NO

FIGURE A-15. REEDM input control data for a batch production run producing ground-level concentration, dosage and 10-minute time mean concentration of HCℓ.

entries for the input options are completely spelled out for illustration purposes which is not necessary for the actual program operation (normal is a 1 to 2 character abbreviation or default). Record 17 contains "YES" for plotting of the meteorological profile. The program enters the interactive mode for plotting purposes which requires user response and will subsequently enter the batch mode prior to record 18. Record 18 contains "YES" for the modification of the layer structure at which time the program again enters the interactive mode and requires user response. A height of 1047 m was entered for the top of the lower layer and bottom of the upper layer and 3048 m was entered for the top of the upper layer. The program then reenters the batch mode for the duration of the run. Figure A-16 shows the output for this production run. This output listing contains more detail than the interactive run shown in Figure A-3 because production runs default to a detailed listing and operational runs default to a summary listing.

```
*************************************************************************
****************                                         ****************
**************** NASA/MSFC MULTIPLE LAYER TECHNIQUE - REEDM ****************
****************  UPDATE 8213    LOCATION HEC                ****************
****************                                         ****************
*************************************************************************


                    SPACE SHUTTLE        NORMAL LAUNCH

                LAUNCH TIME:        915 EST DATE: 12 NOV 1981
                TIME OF EXECUTION:  424 EST DATE:  1 JUL 1982

******************              MODEL OPTIONS             ******************

 MODEL                                                  CONCENTRATION/DOSAGE
 METEOROLOGICAL DATA SOUNDING                                          RRSOND
 RUN TYPE                                                           PRODUCTION
 LAUNCH VEHICLE                                                  SPACE SHUTTLE
 LAUNCH TYPE                                                            NORMAL
 LAUNCH COMPLEX NUMBER                                                     39A
 SPECIES                                                                   HCL
 CLOUD SHAPE                                                        ELLIPTICAL
 CALCULATION HEIGHT (METERS)                                              0.00
 PROPELLANT TEMPERATURE (DEG. C)                                         22.86

******************              MODEL PARAMETERS          ******************

 CONCENTRATION AVERAGING TIME (SEC.)                                     600.00
 DECAY COEFFICIENT                                                       0.0000
 ABSORPTION COEFFICIENT (RNG: 0 TO 1,NO ABSORPTION=0)                    0.0000
 DIFFUSION COEFFICIENTS                                   LATERAL        1.0000
                                                          VERTICAL       1.0000
 VEHICLE ENTRAINMENT PARAMETERS                           ALONGWIND       .6400
                                                          CROSSWIND       .6400
                                                          VERTICAL        .6400
 DOWNWIND EXPANSION DISTANCE (METERS)                     LATERAL        100.00
                                                          VERTICAL       100.00
**********************          METEOROLOGICAL DATA          **********************

    RUN NUMBER:   1          USING METEOROLOGICAL DATA FILE: RRSOND

     TEST NBR 09101  T MINUS 0          RRSOND (VK1215)
     RAWINSONDE RUN AN/GMD-1
     CAPE CANAVERAL AFS, FLORIDA
     ASCENT NBR   0434
    TIME: 1015 EST    DATE: 12 NOV 1981
```

FIGURE A-16. REEDM program output listing for a production, batch run producing ground-level concentration, dosage and 10-minite time mean concentration of HCℓ.

********** SOUNDING **********

SURFACE DENSITY (GM/M**3): 1190.43

MET LEVEL NO.	ALTITUDE (FT)	ALTITUDE (M)	DIR. (DEG)	SPEED (M/S)	SPEED (KTS)	TEMP	PTEMP (DEG. C)	DPTEMP (DEG. C)	PRESS (MB.)	RH (%)
1	16	4.9	337.0	7.72	15.00	22.4	22.98	16.0	1016.9	67.0
2	493	150.3	337.0	8.75	17.00	20.4	22.28	14.7	1000.0	70.0
3	1000	304.8	351.0	10.30	20.00	18.5	21.83	14.0	982.3	75.0
4	1936	590.1	3.0	9.78	19.00	15.4	21.46	13.1	950.0	86.0
5	2000	609.6	4.0	9.78	19.00	15.2	21.45	13.0	947.9	87.0
6	2235	681.2	8.0	9.78	19.00	14.4	21.29	12.5	940.0	88.4
7	3000	914.4	19.0	9.27	18.00	13.2	22.35	11.6	914.4	90.0
8	3435	1047.0	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
9	3441	1048.8	28.0	8.75	17.00	11.7	22.19	11.7	900.0	100.
10	3718	1133.2	18.0	8.24	16.00	12.2	22.76	2.2	891.0	50.8
11	4000	1219.2	16.0	8.24	16.00	12.2	23.42	-2.3	881.9	39.0
12	4375	1333.5	13.0	8.24	16.00	12.2	24.32	-8.2	870.0	23.7
13	5000	1524.0	4.0	7.21	14.00	11.7	25.95	-3.4	850.4	35.0
14	5005	1525.5	4.0	6.69	13.00	11.6	25.88	-3.3	850.0	35.0
15	6000	1828.8	351.0	5.15	10.00	9.5	26.81	-3.1	819.9	41.0
16	6658	2029.4	352.0	5.15	10.00	7.8	27.13	-3.3	800.0	45.0
17	6670	2033.0	352.0	5.15	10.00	7.8	27.14	-3.3	800.0	46.1
18	7000	2133.6	358.0	5.15	10.00	7.4	27.64	-6.1	790.3	38.0
19	7425	2263.1	5.0	5.66	11.00	6.8	28.24	-9.7	778.0	30.5
20	8000	2438.4	6.0	6.18	12.00	6.0	29.28	-8.2	761.5	35.0
21	8269	2520.4	7.0	6.69	13.00	5.6	29.76	-7.6	754.0	39.0
22	8396	2559.1	6.0	7.21	14.00	5.7	30.27	-9.4	750.0	34.0
23	9000	2743.2	0.0	7.72	15.00	6.4	32.74	-16.	733.8	18.0
24	9140	2785.9	359.0	8.24	16.00	6.5	33.27	-18.	730.0	15.3
25	10000	3048.0	354.0	8.75	17.00	5.6	35.13	-17.	707.0	17.0

** - INDICATES THAT DATA IS LINEARLY INTERPOLATED FROM INPUT METEOROLOGY

********** PLUME RISE DATA **********

EXHAUST RATE OF MATERIAL:	(GRAMS/SEC)		.1526714E+08
TOTAL MATERIAL OUTPUT:	(GRAMS)		.1251174E+10
HEAT OUTPUT PER GRAM:	(CALORIES)		1479.7000
VEHICLE RISE TIME PARAMETERS:	(TK=(A*Z**B)+C)	A=	.6522
		B=	.4681
		C=	.3750
SPECIFIC HEAT OF AIR:	(K CAL./GRAM)		.2400
VERTICAL GRADIENT OF POTENTIAL TEMP. TO STABILIZATION HEIGHT:	(DEG. K/M)		.0024

FIGURE A-16. (Continued)

MET. LAYER NO.	TOP OF LAYER (METERS)	CLOUD RISE TIME (SECONDS)	RANGE** FROM PAD (METERS)	BEARING FROM PAD (METERS)	LAYER SOURCE STRENGTH (GRAMS)
1	150.3	3.9	0.0	0.0	0.0000
2	304.8	13.5	0.0	0.0	0.0000
3	590.1	43.7	3527.3	176.5	.40697E+06
4	609.6	46.3	3442.2	182.2	.47471E+06
5	681.2	56.4	3438.8	184.4	.32251E+07
6	914.4	95.3	3347.8	190.6	.24692E+08
7	1047.0	121.5	3184.5	197.7	.21939E+08
8	1048.8	121.9	3106.7	200.5	.33505E+06
9	1133.2	140.1	3067.8	197.2	.16294E+08
10	1219.2	160.1	3028.1	193.6	.18038E+08
11	1333.5	194.1	3031.5	192.3	.25703E+08
12	1524.0	285.5	2950.9	189.8	.45283E+08
13	1525.5	331.6	2896.9	189.1	.36708E+06
14	1828.8	352.8 *	2891.4	189.1	.97955E+08
15	2029.4	352.8 *	1817.1	171.5	.56604E+08
16	2033.0	352.8 *	1817.1	172.0	.94127E+06
17	2133.6	352.8 *	1817.1	175.0	.24345E+08
18	2263.1	352.8 *	1908.0	181.5	.26409E+08
19	2438.4	352.8 *	2089.7	185.5	.25093E+08
20	2520.4	352.8 *	2271.4	186.5	.69526E+07
21	2559.1	352.8 *	2453.1	186.5	.27876E+07
22	2743.2	352.8 *	2634.8	183.0	.12960E+08
23	2785.9	352.8 *	2816.5	179.5	.29373E+07
24	3048.0	352.8 *	2998.3	176.5	.17541E+08

FIGURE A-16. (Continued)

********** EXHAUST CLOUD **********

CLOUD HALF-LENGTH (METERS)	CLOUD HALF-WIDTH (METERS)	SIGXO (METERS)	SIGYO (METERS)	SIGAP (DEGREES)	SIGEP (DEGREES)
0.0	0.0	0.0	0.0	6.8	6.8
0.0	0.0	0.0	0.0	6.8	6.8
198.8	198.8	92.5	92.5	6.8	6.8
310.4	310.4	144.4	144.4	6.8	6.8
422.7	422.7	196.6	196.6	6.8	6.8
650.9	650.9	302.7	302.7	6.8	6.8
810.2	810.2	376.8	376.8	5.0	5.0
851.5	851.5	396.1	396.1	1.0	1.0
874.3	874.3	406.7	406.7	1.0	1.0
911.7	911.7	424.1	424.1	1.0	1.0
944.0	944.0	439.1	439.1	1.0	1.0
971.5	971.5	451.9	451.9	1.0	1.0
976.3	976.3	454.1	454.1	1.0	1.0
964.5	964.5	448.6	448.6	1.0	1.0
889.0	889.0	413.5	413.5	1.0	1.0
835.2	835.2	388.5	388.5	1.0	1.0
801.3	801.3	372.7	372.7	1.0	1.0
707.5	707.5	329.1	329.1	1.0	1.0
521.7	521.7	242.7	242.7	1.0	1.0
208.2	208.2	96.9	96.9	1.0	1.0
200.0	200.0	93.0	93.0	1.0	1.0
200.0	200.0	93.0	93.0	1.0	1.0
200.0	200.0	93.0	93.0	1.0	1.0
200.0	200.0	93.0	93.0	1.0	1.0

* - INDICATES CLOUD STABILIZATION TIME WAS USED
** - RANGE FROM PAD IS AT CLOUD STABILIZATION TIME

********** CLOUD STABILIZATION **********

CALCULATION HEIGHT	(METERS)	0.00
STABILIZATION HEIGHT	(METERS)	1525.52
STABILIZATION TIME	(SECS)	352.84
FIRST MIXING LAYER HEIGHT:	(METERS)	TOP = 1046.99
		BASE= 0.00
SECOND SELECTED LAYER HEIGHT:	(METERS)	TOP = 3048.00
		BASE= 1046.99
SIGMAR(AZ) AT THE SURFACE	(DEGREES)	13.6138
SIGMER(EL) AT THE SURFACE	(DEGREES)	13.6138

FIGURE A-16. (Continued)

********** CALCULATED INPUT METEOROLOGICAL LAYER PARAMETERS **********

MET. LAYER NO.	WIND SPEED (M/SEC)	WIND SPEED SHEAR (M/SEC)	WIND DIRECTION (DEG)	WIND DIRECTION SHEAR	SIGMA OF AZI ANG (DEG)	SIGMA OF ELE ANG (DEG)
1	8.48	1.03	337.00	0.00	6.1212	6.1212
2	9.53	1.55	344.00	14.00	6.1212	6.1212
3	10.04	.51	357.00	12.00	6.1212	6.1212
4	9.78	0.00	3.50	1.00	6.1212	6.1212
5	9.78	0.00	6.00	4.00	6.1212	6.1212
6	9.53	-.51	13.50	11.00	6.1212	6.1212
7	9.01	.52	23.50	9.00	6.1212	6.1212
8	8.75	0.00	28.00	0.00	2.7167	2.7167
9	8.50	-.51	23.00	-10.00	1.0000	1.0000
10	8.24	0.00	17.00	-2.00	1.0000	1.0000
11	8.24	0.00	14.50	-3.00	1.0000	1.0000
12	7.73	-1.03	8.50	-9.00	1.0000	1.0000
13	6.95	.52	4.00	0.00	1.0000	1.0000
14	5.92	-1.55	357.50	13.00	1.0000	1.0000
15	5.15	0.00	351.50	1.00	1.0000	1.0000
16	5.15	0.00	352.00	0.00	1.0000	1.0000
17	5.15	0.00	355.00	6.00	1.0000	1.0000
18	5.41	.52	1.50	7.00	1.0000	1.0000
19	5.92	.52	5.50	1.00	1.0000	1.0000
20	6.44	.51	6.50	1.00	1.0000	1.0000
21	6.95	.52	6.50	-1.00	1.0000	1.0000
22	7.47	.51	3.00	-6.00	1.0000	1.0000
23	7.98	.52	359.50	1.00	1.0000	1.0000
24	8.50	.51	356.50	-5.00	1.0000	1.0000

FIGURE A-16. (Continued)

********** CALCULATED TRANSITION LAYER PARAMETERS **********

TRANSITION LAYER NUMBER: 1

VALUE AT	HEIGHT (METERS)	TEMP. (DEG K)	WIND SPEED (M/SEC)	WIND SPEED SHEAR	WIND DIR. (DEG)	WIND DIR. SHEAR	SIGMA AZI. (DEG)	SIGMA ELE. (DEG)
TOP:	1046.99	295.35	8.75		28.00		4.5342	4.5342
LAYER:			9.44	.76	359.98	52.60	6.1212	6.1212
BOTTOM:	0.00	296.14	7.72		337.00		6.1212	6.1212

TRANSITION LAYER NUMBER: 2

VALUE AT	HEIGHT (METERS)	TEMP. (DEG K)	WIND SPEED (M/SEC)	WIND SPEED SHEAR	WIND DIR. (DEG)	WIND DIR. SHEAR	SIGMA AZI. (DEG)	SIGMA ELE. (DEG)
TOP:	3048.00	308.29	8.75		354.00		.8993	.8993
LAYER:			6.85	-.99	2.65	-23.58	2.7167	2.7167
BOTTOM:	1046.99	295.35	8.75		28.00		4.5342	4.5342

FIGURE A-16. (Continued)

```
*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************         CONCENTRATION/DOSAGE MODEL      ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS      ****************
```

FOR HCL AT A HEIGHT OF 0.00 METERS
DOWNWIND FROM A SPACE SHUTTLE NORMAL LAUNCH
CALCULATIONS APPLY TO THE LAYER BETWEEN 0.00 AND 1046.99 METERS

THE METEOROLOGICAL DATA IS FROM 1015 EST 12 NOV 1981
LAUNCH TIME IS 915 EST 12 NOV 1981
TIME OF EXECUTION IS 424 EST 1 JUL 1982

RANGE FROM PAD (METERS)	BEARING FROM PAD (DEGREES)	PEAK CONCEN-TRATION (PPM)	CLOUD ARRIVAL TIME (MIN)	CLOUD DEPARTURE TIME (MIN)
5003.600	177.805	.027	2.853	7.162
6005.456	182.420	.210	4.510	9.012
7016.485	183.906	.543	6.167	10.862
8017.253	183.738	.783	7.822	12.713
9023.207	184.088	.889	9.477	14.563
10017.361	183.352	.901	11.131	16.415
11020.912	183.508	.861	12.783	18.266
12017.078	183.033	.799	14.435	20.118
13013.943	182.631	.734	16.087	21.970
14011.359	182.285	.673	17.737	23.822
15018.668	182.835	.618	19.387	25.674
16016.621	182.589	.571	21.036	27.527
17014.836	182.371	.530	22.685	29.380
18013.270	182.177	.493	24.333	31.234
19011.887	182.004	.461	25.981	33.087
20010.660	181.848	.433	27.628	34.941
21009.566	181.707	.407	29.275	36.795
22008.594	181.579	.384	30.921	38.650
23007.715	181.462	.363	32.567	40.504
24006.930	181.355	.344	34.213	42.443
25006.219	181.256	.327	35.858	44.430
26005.574	181.165	.311	37.503	46.418
27005.000	181.080	.296	39.148	48.405
28004.469	181.002	.283	40.793	50.393
29003.992	180.929	.270	42.437	52.380

	RANGE	BEARING
.901 IS THE MAXIMUM PEAK CONCENTRATION	10017.4	183.4

FIGURE A-16. (Continued)

```
*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************         CONCENTRATION/DOSAGE MODEL      ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS      ****************
```

FOR HCL AT A HEIGHT OF 0.00 METERS
DOWNWIND FROM A SPACE SHUTTLE NORMAL LAUNCH
CALCULATIONS APPLY TO THE LAYER BETWEEN 0.00 AND 1046.99 METERS

THE METEOROLOGICAL DATA IS FROM 1015 EST 12 NOV 1981
LAUNCH TIME IS 915 EST 12 NOV 1981
TIME OF EXECUTION IS 424 EST 1 JUL 1982

RANGE FROM PAD (METERS)	BEARING FROM PAD (DEGREES)	TOTAL DOSAGE (PPM SEC)	CLOUD ARRIVAL TIME (MIN)	CLOUD DEPARTURE TIME (MIN)
5002.480	178.174	.720	2.853	7.162
6017.630	184.365	12.695	4.510	9.012
7027.479	185.047	39.661	6.167	10.862
8030.907	185.007	61.136	7.822	12.713
9023.207	184.088	71.557	9.477	14.563
10025.654	184.078	73.605	11.131	16.415
11020.912	183.508	70.921	12.783	18.266
12017.078	183.033	66.219	14.435	20.118
13023.785	183.441	61.114	16.087	21.970
14021.031	183.117	56.281	17.737	23.822
15018.668	182.835	51.963	19.387	25.674
16016.621	182.589	48.187	21.036	27.527
17014.836	182.371	44.895	22.685	29.380
18013.270	182.177	42.014	24.333	31.234
19011.887	182.004	39.477	25.981	33.087
20010.660	181.848	37.227	27.628	34.941
21009.566	181.707	35.218	29.275	36.795
22008.594	181.579	33.414	30.921	38.650
23007.715	181.462	31.784	32.567	40.504
24006.930	181.355	30.306	34.213	42.443
25006.219	181.256	28.959	35.858	44.430
26005.574	181.165	27.726	37.503	46.418
27005.000	181.080	26.593	39.148	48.405
28004.469	181.002	25.549	40.793	50.393
29016.262	181.896	24.585	42.437	52.380

	RANGE	BEARING
73.605 IS THE MAXIMUM TOTAL DOSAGE	10025.7	184.1

FIGURE A-16. (Continued)

```
*************************************************************************
****************                                         ****************
****************   REEDM  UPDATE 8213  LOCATION HEC      ****************
****************         CONCENTRATION/DOSAGE MODEL      ****************
****************                                         ****************
*************************************************************************

****************       MAXIMUM CENTERLINE CALCULATIONS      ****************

                 FOR  HCL   AT A HEIGHT OF     0.00 METERS
            DOWNWIND FROM A  SPACE SHUTTLE        NORMAL LAUNCH
   CALCULATIONS APPLY TO THE LAYER BETWEEN    0.00 AND 1046.99 METERS

        THE METEOROLOGICAL DATA IS FROM  1015 EST  12 NOV 1981
                   LAUNCH TIME IS         915 EST  12 NOV 1981
             TIME OF EXECUTION IS         424 EST   1 JUL 1982
```

RANGE FROM PAD (METERS)	BEARING FROM PAD (DEGREES)	10.0 MIN. MEAN CONCEN-TRATION (PPM)	CLOUD ARRIVAL TIME (MIN)	CLOUD DEPARTURE TIME (MIN)
5002.480	178.174	.001	2.853	7.162
6017.630	184.365	.021	4.510	9.012
7027.479	185.047	.066	6.167	10.862
8030.907	185.007	.102	7.822	12.713
9023.207	184.088	.119	9.477	14.563
10025.654	184.078	.123	11.131	16.415
11020.912	183.508	.118	12.783	18.266
12017.078	183.033	.110	14.435	20.118
13023.785	183.441	.102	16.087	21.970
14021.031	183.117	.094	17.737	23.822
15018.668	182.835	.087	19.387	25.674
16016.621	182.589	.080	21.036	27.527
17014.836	182.371	.075	22.685	29.380
18013.270	182.177	.070	24.333	31.234
19011.887	182.004	.066	25.981	33.087
20010.660	181.848	.062	27.628	34.941
21009.566	181.707	.059	29.275	36.795
22008.594	181.579	.056	30.921	38.650
23007.715	181.462	.053	32.567	40.504
24006.930	181.355	.051	34.213	42.443
25006.219	181.256	.048	35.858	44.430
26005.574	181.165	.046	37.503	46.418
27005.000	181.080	.044	39.148	48.405
28004.469	181.002	.043	40.793	50.393
29016.262	181.896	.041	42.437	52.380

	RANGE	BEARING
.123 IS THE MAXIMUM 10.0 MIN. MEAN CONCENTRATION	10025.7	184.1

FIGURE A-16. (Continued)

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Final Report

16. ABSTRACT

The purpose of this report is to provide complete documentation of the REEDM Computer Program used to predict concentrations, dosages, and depositions downwind from normal and abnormal launches of rocket vehicles at NASA's Kennedy Space Center. The report consists of:

- A mathematical description of the atmospheric dispersion models, cloud-rise models and other formulas used in the REEDM model.
- Vehicle and source parameters, other pertinent physical properties of the rocket exhaust cloud, and meteorological layering techniques.
- User's instructions for the REEDM computer program.
- Worked example problems.

A computer listing of the REEDM program is contained in NASA CR-3647.

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