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INTERACTIVE SCENARIO COMPUTER MODEL FOR DOSE RATES TO AIRCREWS IN FLIGHT THROUGH NUCLEAR DEBRIS CLOUDS

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

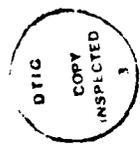
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INTERACTIVE SCENARIO COMPUTER MODEL FOR DOSE RATES TO AIRCREWS IN FLIGHT THROUGH NUCLEAR DEBRIS CLOUDS

INTRODUCTION

The dynamics of radioactive debris fallout from a nuclear weapons burst has been extensively modeled, and there are excellent codes to predict the distribution on the ground. These codes have been under development for the past 20-25 years. The WSEG-10 (1) and DELFIC (2) are notable models for this purpose. The DELFIC code based on numerical computation is the most extensively developed dynamic model and is used as the benchmark for all analytical work. A scenario of comparable strategic importance concerns the calculation of dose rates to aircraft crewmembers flying through nuclear debris clouds raised aloft by ground detonations. This scenario would occur, for example, in Airborne Command Post flights of the Strategic Air Command immediately following a nuclear attack.

The penetration of a nuclear dust cloud is hazardous to the aircraft and its crewmembers. Nuclear debris dust is also abrasive and destructive to jet engines. Gamma radiation from the dust will injure personnel as well as the avionics equipment. This report concerns an interactive computer model to assess the extent of the radiation hazard.

Early efforts by Patrick et al. (3) to model an airborne exposure scenario were based on empirical approximations to the nuclear detonation cloud dimensions and concentration parameters. This empirical model, however, could not account for wind parameters, other local atmospheric conditions, and of most concern, inhomogeneity of the cloud and the fractionated distribution of radioactivity. These parameters have a significant effect on the expected dose rates. A more recent model by Hickman (4) is based on WSEG-10, a revised fallout prediction model developed at the U.S. Air Force Institute of Technology. The WSEG-10 model developed by Bridgeman and Bigelow (5) takes into account fractionation, wind parameters, and some flight parameters. Yet it is still desirable to apply the full advantages of the DELFIC model in fly-through scenarios. Having a more detailed structure of the nuclear dust distribution in the atmosphere allows for the analysis of evasive flight trajectories, and loiter scenarios where the aircraft is scheduled to fly orbits in cloud fields. The user is also assured of the most accurate accounting of the ground zero (GZ) parameters, radioactive dust, winds aloft, and nuclear weapon parameters.

Implementation of the full capability of the DELFIC system has not heretofore been attempted for modeling the exposure of aircrewmembers in fly-through scenarios. The primary criticism is that the program is too expensive to run and that the model is difficult to learn. In spite of these circumstances we report the development for the first time of a completely interactive user-oriented model which has for its basis the benchmark DELFIC code. This user-oriented model has been achieved through an extensive adaptation of a related DELFIC based code CASSANDRA (6) to a time-shared Digital Equipment Corporation (DEC) model VAX 11/780 computer system. The

adaptation consisted in developing a large entry data array using the DEC Forms Management System (FMS) utility and in developing an appropriate nuclear scenario modeling theory. A complete interactive modeling session by an individual with any degree of computer experience can be accomplished in less than 20 min, assuming usual computer loads. The new facility can be a very useful aid to high level planners and modelers of nuclear encounter scenarios. Highly detailed analyses can be rapidly and efficiently performed. Studies of the effects of variation of any of a large number of parameters are possible. An example of the list of parameters that can be easily specified is given in Table 1.

TABLE 1. PARTIAL LIST OF PARAMETERS

| No. | Parameters |
|-----|---|
| 1. | Height of burst above GZ |
| 2. | Yield, fission fraction |
| 3. | Soil type |
| 4. | Particle distribution function |
| 5. | Particle solidification temperature |
| 6. | Wind layers |
| 7. | Atmosphere variables, humidity, pressure, etc. |
| 8. | GZ altitude |
| 9. | Any number of aircraft coordinates at any point in space relative to GZ and t_0 |
| 10. | Aircraft air mass exchange ratio |
| 11. | Cabin dimensions |

The following sections describe the theory, program structures and procedures, and some numerical examples of the interactive model.

THEORY

The nuclear scenario is illustrated in Figure 1. An aircraft is designated to be located at $V_i(x_i, y_i, z_i)$ and time (t_i) relative to GZ and t_0 . Note that this takes into account the aircraft velocity, and that time t_0 is when the detonation occurs. The critical required information is that of the dust concentration at each of the vertices V_i and points in between in the flight trajectory.

The extraction of dust concentration computations from the DELFIC source code is available in the CASSANDRA code (Cloud Snapshots of Dust Raised Aloft). This code developed by Showers and Crisco (6) at the US Army Armament Research and Development Command, Aberdeen Proving Ground, MD, is designed to use the detailed cloud rise module of the DELFIC system which provides cloud dynamic parameters from the initial time to stabilization. The CASSANDRA code also uses the DELFIC atmosphere model and particle fall procedures. The stabilized cloud is modeled as a stack of wafers of given particle sizes. These wafers are in turn transported by winds and deposited in agreement with DELFIC fall dynamics. The CASSANDRA code was developed to assess the threat caused by dust to reentry vehicles (RV) reentering the

atmosphere or antiballistic missiles (ABM) departing the environment of a nuclear detonation. The code ideally calculates dust concentrations for a given set of coordinates. It also calculates a user specified 2-D map of dust in a plane cutting through the cloud. With the availability of these calculations, it was then clear that fly-through scenario dose calculations could proceed.

To calculate the irradiation dose required a scaling factor related to dust mass, the assumption of two radiation sources, the outside air (immersion dose rate), and internal dose due to dust ingested into the aircraft. Mathematically it is assumed that the aircraft is at a position vector \underline{r}_0 as shown in Figure 2 and that the irradiation due to cloud sources is locally homogeneous. The total dose rate is composed of two factors, i.e.,

$$\text{Total dose rate} = \text{immersion dose rate} + \text{onboard dose rate} \quad (1)$$

The immersion dose rate (DOSER) at a point (\underline{r}_0) and time (t) is given by

$$\text{DOSER}(\underline{r}_0, t) = t^{-1.2} K_1 \sum_{j=1}^{100} K(j) \int \frac{\rho(\underline{r}, t, j) \exp[-K_2(\underline{r} - \underline{r}_0)]}{4\pi|\underline{r} - \underline{r}_0|^2} dV \quad (2)$$

where the Way-Wigner (7) time dependence is assumed, t is in hours after detonation, and K_1 is a factor associated with the energy deposition of 1 MeV gamma ray photons, $K_1 = 4.88 \times 10^{-10}$ rad cm²/photon; see reference 8. The summation is over the particle size class j , assuming there are 100 values. $K(j)$ is the radioactivity associated with particle class j . The dust density $\rho(\underline{r}_0, t, j)$ also depends on the particle class j , location in the cloud space \underline{r}_0 and time t . For the purpose of computing the integral, the dust density is assumed uniform in the vicinity of the integrated region. Thus,

$$\text{DOSER}(\underline{r}_0, t) = t^{-1.2} K_1 \sum_{j=1}^{100} K(j) \rho(\underline{r}_0, t, j) \int \frac{\exp[-K_2(\underline{r} - \underline{r}_0)]}{4\pi|\underline{r} - \underline{r}_0|^2} dV \quad (3)$$

Assuming mathematically that the integral goes over infinite volume results in the integral having the value in spherical coordinates $\underline{R} = \underline{r} - \underline{r}_0$

$$I = \iiint \frac{\exp[-K_2 R]}{4\pi R^2} R^2 \sin \theta dR d\theta d\phi = 1/K_2 \quad (4)$$

K_2 is the atmospheric absorption, $6.767 \times 10^{-3} \text{ m}^{-1}$ (4). Thus,

$$\text{DOSER}(\underline{r}_0, t) = \frac{t^{-1.2} K_1}{K_2} \sum_{j=1}^{100} K(j) \rho(\underline{r}_0, t, j) \quad (5)$$

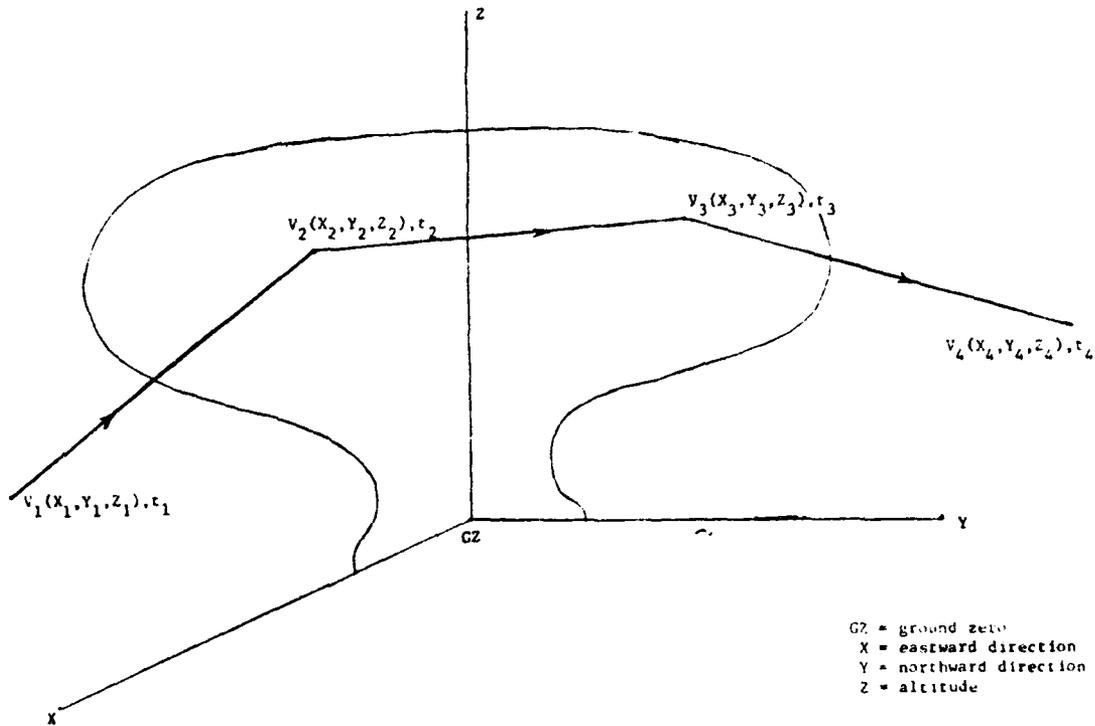


Figure 1. Nuclear fly-through scenario.

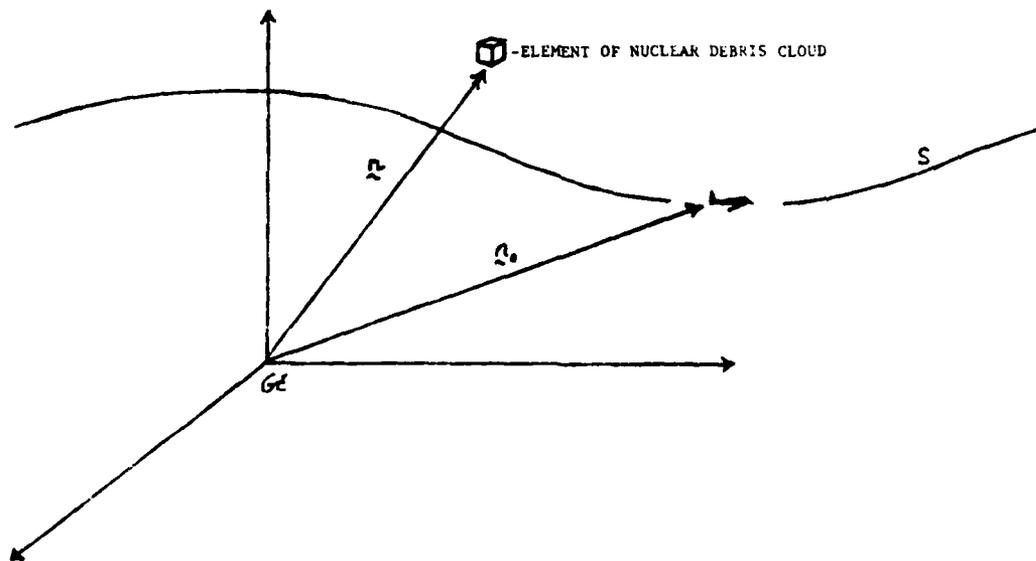


Figure 2. Geometry for dose rate computations.

The $K(j)$ parameter is developed as follows. Assume that the total radioactivity raised aloft is 530-gamma MCI/Mt of fission yield and is normally distributed over dust particle mass (size) (9). This takes into account fractionation as discussed by Bridgeman and Bigelow (5). Since the radioactivity is distributed with the total mass, and each of the 100 particle size classes carries equal mass, then the dose rate becomes

$$DOSE R(\rho_0, t) = \frac{t^{-1.2} K_1 A}{K_2 M} \sum_{j=1}^{100} \rho(\rho_0, t, j) \quad (6)$$

where A is the total radioactivity, $A = 7.06 \times 10^{22} Y \cdot F$ (photons/hour) where Y is the yield in kilotons, F is the fission fraction, and M is the total mass raised aloft (in grams). All these parameters are part of the DELFIC section of the model. Given a sufficient number of calculated points, then the total dose due to immersion can be computed by numerical integration of the dose rate along the flight trajectory given in Figure 2.

The loci of the points at which dust concentrations are to be computed are obtained in the present model by an equal space incrementation of the Euclidean distance between two user-specified points, i.e.,

$$\rho_i = \rho_1 + \frac{i}{N_{21}} (\rho_2 - \rho_1); \quad i = 1, 2, 3, \dots, N_{21} \quad (7)$$

where

$$N_{21} = \text{TRUNCATE} \left[\frac{|\rho_2 - \rho_1|}{\delta} \right] = \text{TRUNCATE} \left[\frac{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}{\delta} \right] \quad (8)$$

and δ is an incrementation parameter; from experience on dust concentration variations, $\delta = 0.006$ m is a good value. The time at the loci is similarly computed. The total dose is computed by numerically integrating the average dose rate between loci and the transit time in the locus-to-locus interval. It remains for the CASSANDRA section of the code to compute the 100 particle dust densities at each intermediate vertex point.

The dose rate due to the dust brought onboard is computed in a similar manner. In this case the dust brought onboard is based on a user specified aircraft parameter, the total air mass flow rate, and the outside dust density. The cabin pressurizing system compresses a given volume of outside air and with it carrying a certain amount of radioactive debris. The air volume compressed and brought in (AVINR) is given by

$$AVINR = 7.56(FR) / (ADZ) \quad (9)$$

where FR is the mass flow rate in pounds per minute and ADZ is the air density at Z altitude in grams per cubic centimeter. The ADZ is based on a polynomial fit to atmospheric data (10). The total dust mass (DBB) is equal to the product of the AVINR parameter with the dust concentration summed over

particle size class and the total time of flight between the initial locus and the point in question, i.e.,

$$DBB(i) = AVINR(i) \cdot \sum_{j=1}^{100} \rho(R_{ij}, t_j) (t_i - t_{j-1}) \quad (10)$$

With the total dust brought onboard thus computed, the dose rate to an aircrewmember is assumed to come from two sources: 1) the dust distributed throughout the cabin air volume, and 2) the dose rate from a potential air filter. The cabin is modeled as a right circular cylinder of (CL) centimeter length and (CR) centimeter radius. The distance of the aircrewmember from a filter is D centimeter; this is illustrated in Figure 3. To first approximation the model assumes a fraction (FR) of the dust goes into the cabin air and the remainder stays in the filter. The cabin air dust dose rate (CDUSTDR) at (1) is given by

$$CDUSTDR(i) = (FR) \cdot \frac{t_i^{-1.2} K_1 A}{M} \cdot \frac{DBB(i)}{CV} \int \frac{\exp[-k_3 r]}{4\pi r^2} dV \quad (11)$$

where $CV = \pi (CR)^2 CL$ (cabin volume). In cylindrical coordinates and making the approximation $\exp[-kr] = 1$ over the dimensions of the aircraft gives

$$CDUSTDR(i) = (FR) \cdot \frac{t_i^{-1.2} K_1 A}{M} \cdot \frac{DBB(i)}{4\pi CV} \int_0^{2\pi} \int_0^{CR} \int_0^{CL/2} \frac{n \, dn \, dz \, d\phi}{(z^2 + n^2)} \quad (12)$$

or $CDUSTDR(1) =$

$$(FR) \cdot \frac{t_i^{-1.2} K_1 A}{M} \cdot \frac{DBB(i)}{CV} \left[\frac{(CL) \log(4(CR)^2 + (CL)^2)}{4} + \tan^{-1}\left(\frac{CL}{2CR}\right) \cdot CR - \frac{CL \log CL^2}{4} \right] \quad (13)$$

The filter dust dose rate (FDUSTDR) is simply the inverse distance dependence of the remaining dust at a distance D, i.e.,

$$FDUSTDR(i) = (1 - FR) \frac{t_i^{-1.2} K_1 A}{4\pi D^2} DBB(i) \quad (14)$$

These dust dose rates are integrated by taking the mean value of the rate between the two vertex points and multiplying by the time interval. In the computer program the air density at altitude Z(1) is computed from a polynomial fit to a standard atmosphere table. The computations involved

here and all of the input data requirements are all prompted by interactive subroutines as discussed in the next section.

Program Structure and Procedure

The system of computer subroutines and programs which comprise this interactive computer package is illustrated in Figure 4. The original CASSANDRA nomenclature is maintained for its respective programs; all other units are associated uniquely with this package which we term CASSIE. Extensive reporting features are introduced so that a file of all input data arrays is readily available. A set of these directories (Tables 2, 3, and 4) comprises the total system.

TABLE 2. DIRECTORY [CASSIE. SYSTEM]

| | | | |
|---------------|----------------|--------------|--------------|
| BOMB.COM;1 | DOSER.EXE;1 | CASSIE.OUT;1 | CLOUD.OUT;1 |
| DOSER.DAT;1 | DOSERDAT.EXE;1 | DUST.DAT;1 | M3DAT.EXE;1 |
| DOSER.OUT;1 | DOSERO.DAT;1 | M3DUST.FLB;1 | MPDQ.DAT;1 |
| DOSERN.DAT;1 | M3DUST.EXE;1 | MPDAT.EXE;1 | MPDQ.OUT;1 |
| M3DUST.DAT;1 | MEANDIAM.DAT;1 | MPDQ.LAB;1 | MPDQO.LAB;1 |
| M3DUSTO.DAT;1 | MPDQ.FLB;1 | MPDQO.DAT;1 | NEWVER.DAT;1 |
| MPDQ.EXE;1 | MPDQNEW.LAB;1 | MXEC.OUT;1 | |
| MPDQNEW.DAT;1 | MXEC.EXE;1 | | |
| MXEC.DAT;1 | VERTEXO.DAT;1 | | |
| VERTEX.DAT;1 | | | |

TABLE 3. DIRECTORY [CASSIE.SOURCES]

| | |
|-------------|----------------|
| MPDAT.FOR;1 | M3DUST.FOR;1 |
| MPDQ.FOR;1 | DOSERDAT.FOR;1 |
| DOSER.FOR;1 | MXEC.FOR;1 |
| M3DAT.FOR;1 | |

TABLE 4. DIRECTORY [CASSIE.MISC]

| | |
|-----------------|-------------------|
| CASSIESUB.EXE;1 | CASSIE.SUBJ.OBJ;2 |
| CASSIESUB.FOR;1 | EDTINI.EDT;1 |

The execution of all programs in this system (CASSIE) is controlled by a command procedure called BOMB.COM. It is started by typing "@BOMB" in response to the operating system prompt. Once the command procedure is entered, the user will no longer need to worry about any type of computer commands, and all keyboard entries will be in the form of answering questions or data entry. Upon starting the command procedure, the screen will clear and the menu given in Figure 5 will be displayed. The user will then be asked to enter a choice. If an invalid choice is entered, the user will be told and reprompted for a valid response.

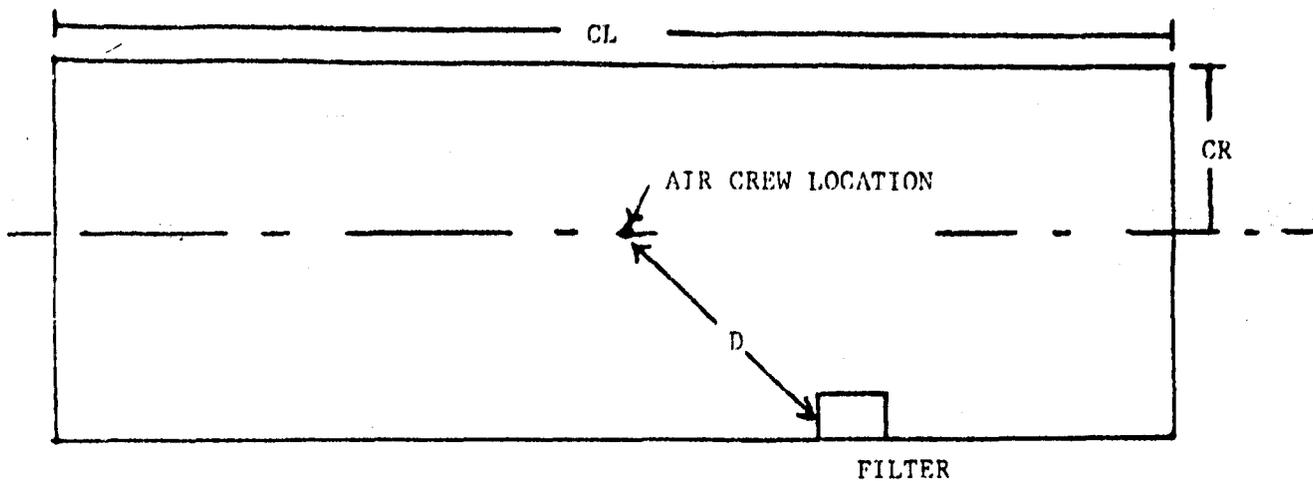


Figure 3. Cabin and filter dust dose rate model.

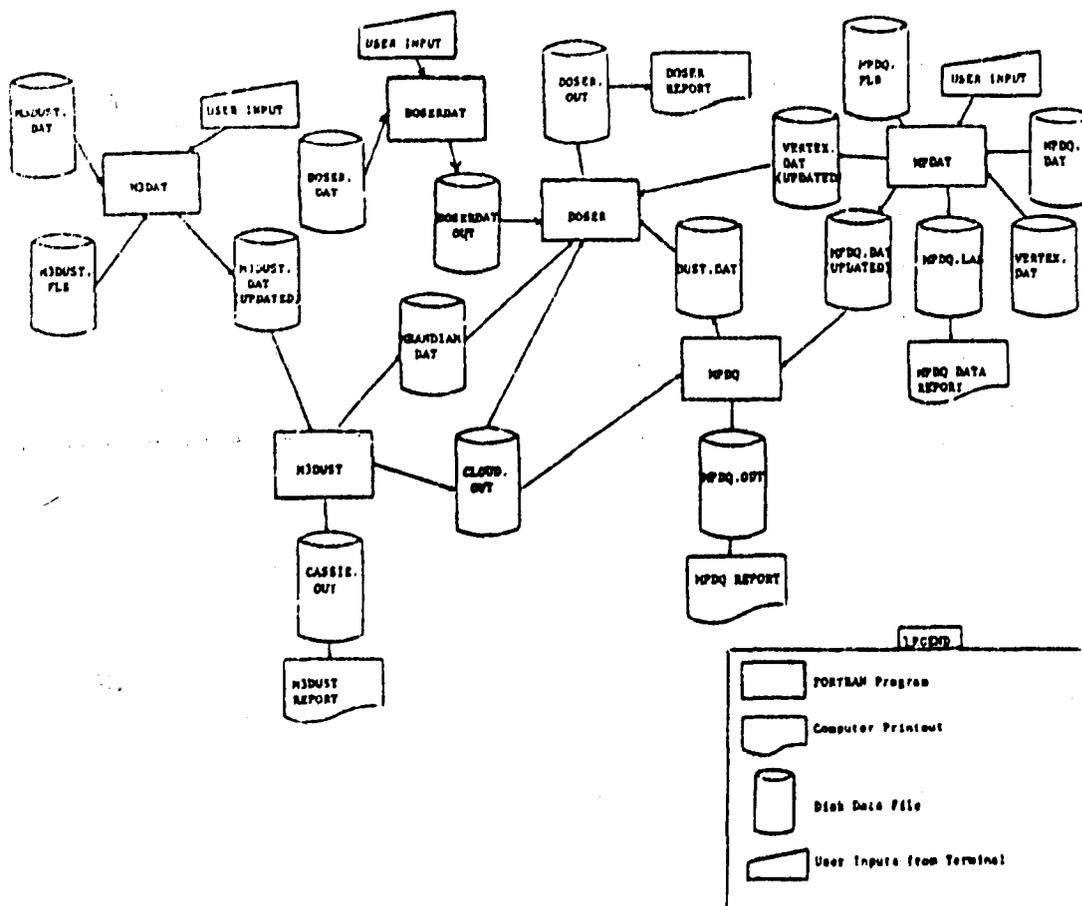


Figure 4. System flow chart of CASSANDRA.

MAIN MENU

You have the following options from which to choose:

- 1) Create the input data for M3DUST
- 2) Run M3DUST
- 3) Create the input data for MPDQ
- 4) Run MPDQ
- 5) Create the input data for DOSER
- 6) Compute the dose rates
- 7) Exit this procedure

Figure 5. Cassie nuclear scenario menu display.

When the chosen program terminates normally, the message "Normal program termination." will appear on the terminal. After a normal program termination, the message "Please wait..." will appear on the terminal. During a brief pause that follows, the command procedure will be doing some internal housekeeping chores. These include: (1) Renaming old versions of files that were updated during program execution. This is accomplished to restore the old version of the file in the event that the new version of the file is incorrect. (2) Purging any excess versions of files. When the housekeeping is completed, the menu will be redisplayed so that the user may enter the next option. Options (1), (3), (5), and (6) are unique to the CASSIE system and are described:

Options 1 and 3: Creating input data for the cloud rise and dust concentration modules

Data creation for these modules is accomplished through the use of the Digital Equipment Corporation's FMS. Through the use of this utility, a user can easily enter or modify program data. The FMS allows the user to enter data via a computer "form". The following general information applies to all aspects of data entry during terminal session:

1. Data fields are delimited with square brackets ("[" and "]").
2. Pressing the (RETURN) key will move the cursor forward to the next field.
3. Pressing the (BACKSPACE) key will move the cursor to the previous field.
4. Pressing the (PF2) key on the VT100 terminal will provide a help

message for the field that the cursor is on. Pressing the (PF2) key again will provide additional help information, if available.

5. Pressing the (PF4) key on the VT100 terminal while running the MPDAT program will produce a hard copy printout of the "form" as it appears on the terminal screen, data included.

6. Pressing the (LINEFEED) key will delete all data in a field.

7. Some fields are validated after entry to insure that a valid response is entered. In the event that an entry is invalid, a message will appear and the user will need to reenter a value for that field.

The data entry programs were designed to be easy to use for a user of any level of computer expertise. Help messages are provided to help the user to determine what is being requested. Information related to the help messages for use in setting up Options 1 and 3 is derived from the sample data cards of Reference 6.

Data Flow In The CASSIE System

The interrelationship of files and programs in the CASSIE system is given in Figure 4. Data for the M3DUST program is created through the use of the data entry program M3DAT. Inputs to this program are the existing M3DUST data file (M3DUST.DAT) and user inputs from the terminal. The library that contains the computer "forms" used for data entry is M3DUST.FLB. Output from the data creation program is M3DUST.DAT, an updated version of the original data file.

Data for the MPDQ program is created through the use of the data entry program MPDAT. Inputs to this program are the existing MPDQ data file (MPDQ.DAT), a work file (VERTEX.DAT), and user inputs from the terminal. The library that contains the computer "forms" used for data entry is MPDQ.FLB. The VERTEX.DAT work file contains user-specified vertices that were used to create the current input data file for MPDQ. Outputs from the data creation program are an updated VERTEX.DAT, an updated MPDQ.DAT, and a descriptive file of the newly created inputted data. This file is named MPDQ.LAB and contains the input data along with a description of the data item. It can be printed out by using the appropriate print command.

Program M3DUST uses as input the data file M3DUST.DAT and creates as output MEANDIAM.DAT, CASSIE.OUT, and CLOUD.OUT. CASSIE.OUT is the report file from M3DUST and can be printed out. CLOUD.OUT is a binary file and CANNOT be printed. Its purpose is to serve as input to program MPDQ, and it contains the DELFIC cloud rise information for the computed cloud.

The input data files for program MDPQ are CLOUD.OUT (created by M3DUST) and the MPDQ data file MPDQ.DAT. Outputs are DUST.DAT and MPDQ.OUT. MPDQ.OUT can be printed on the system printer to obtain a hard copy of the MPDQ report.

Options 5 and 6: Calculating the dose rates

Dose rates are computed through the use of program DOSER. This program uses as input DUST.DAT, CLOUD.OUT, VERTEX.DAT, and DOSERDAT.OUT. VERTEX.DAT contains the user-specified input vertices. DUST.DAT is created when the MPDQ variable COMBIN is equal to 1. This file contains the dust amounts for

a given point in space. The file is separated into sections, and the number of sections is dependent upon the number of vertex points used. Within each section, the data points represent the dust amounts for each particle size class, with the first point in the section corresponding to the first particle size class, and the last point corresponding to the last particle size class. Option 5 calls program DOSERDAT which requires user inputs related to aircraft characteristics. Outputs from DOSER is finally the report file DOSER.OUT which can be printed to receive the hard-copy report. This is the final output product of the interactive session.

CASSIESUBS is a file of subroutines used by both MPDQ and M3DUST. The file of source codes for the subroutines can be found in [CASSIE.SOURCES] while the compiled subroutines are kept in [CASSIE.MISC] (see Tables 2, 3, and 4). The computer "forms" used by M3DAT and MPDAT to input data are contained in the form libraries M3DUST.FLB (M3DAT forms) and MPDQ.FLB (MPDAT forms).

Numerical Example

The model can be easily exercised to examine a scenario associated with a 1-Mt yield over sandy soil conditions mimicking the Dial Pack ground zero conditions and atmosphere (6). For the example treated here the aircraft is assumed to fly through at an altitude of 13,500 m with two stipulated vectors, 40 km west of GZ at $t_+ = 784$ s and 40 km east of GZ at $t_+ = 1234$ s. Figure 6 shows the MPDQ west-east dust concentration looking north through the X-Z plane. An aircraft figure is drawn to indicate the relative position at $t_+ = 1031$ s. The dose rates were computed using typical parameters for a KC-135 aircraft. A printout of the DOSER.OUT file which contains this dose rate data is given in Figure 7. Note that the immersion dose rate as the aircraft leaves the cloud drops off, whereas the onboard radioactivity, although small, still remains. To examine the significance of time on the dose rates, Figure 8 gives the same scenario with fly through at $t_+ = 1$ h = 3600 s. Note that the dose rates have fallen off sharply. These results appear to depart somewhat at later times when compared to previous models (see References 3 and 4).

As there are a very large number of possible scenario parameters, the ease in which this model may be adapted can lead to numerous analyses. One example not discussed is the use of GZ wind parameters. Orbits in clouds can be specified by prescribing segmented sections.

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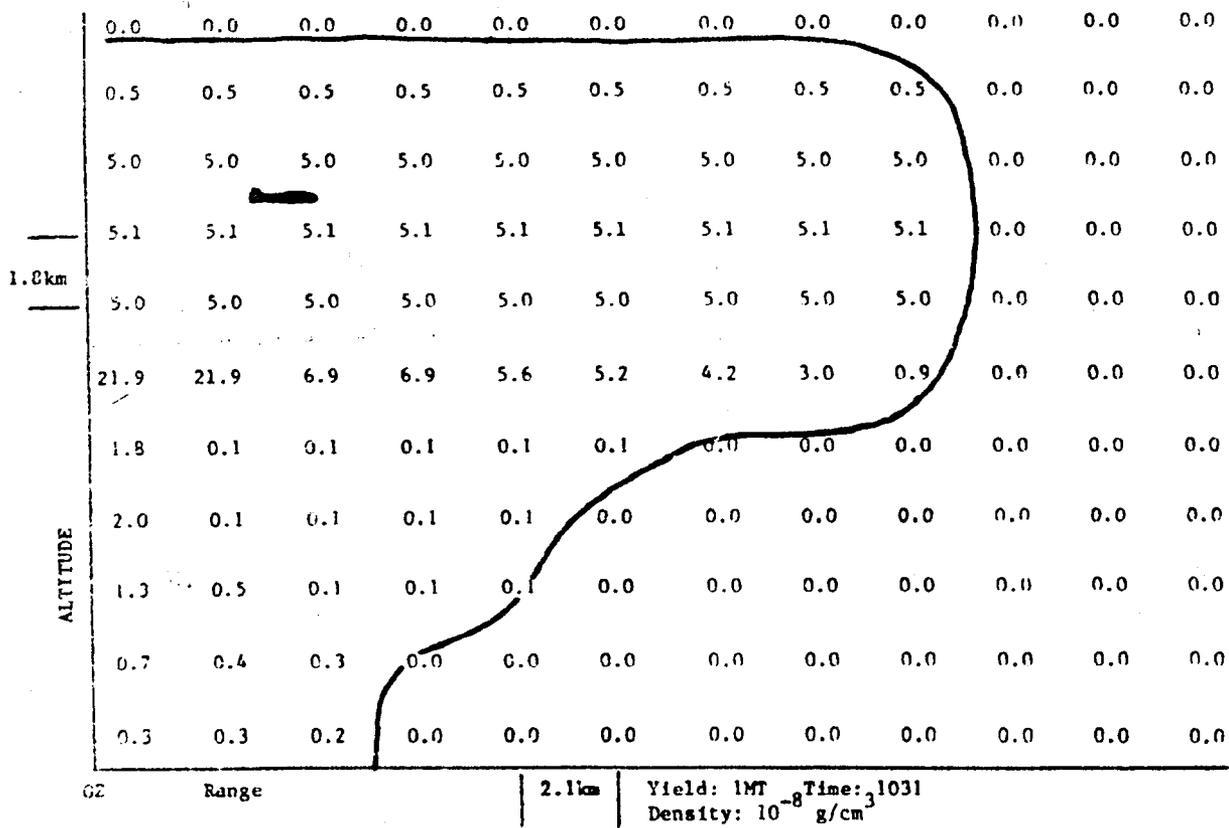


Figure 6. MPDQ west-east dust concentration.

| VERTEX NO. | X | Y | Z | T | IMMERSION DOSE RATE (RAD/HR) | CABIN DUST DOSE RATE (RAD/HR) | FILTER DUST DOSE RATE (RAD/HR) |
|------------|--------------|-------------|-------------|-------------|------------------------------|-------------------------------|--------------------------------|
| 1 | -0.40000E+05 | 0.00000E+00 | 0.13500E+05 | 0.78400E+03 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 2 | -0.36000E+05 | 0.00000E+00 | 0.13503E+05 | 0.80650E+03 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 3 | -0.32000E+05 | 0.00000E+00 | 0.13500E+05 | 0.82900E+03 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 4 | -0.28000E+05 | 0.00000E+00 | 0.13503E+05 | 0.85150E+03 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 5 | -0.24000E+05 | 0.00000E+00 | 0.13500E+05 | 0.87400E+03 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 6 | -0.20000E+05 | 0.00000E+00 | 0.13500E+05 | 0.89650E+03 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 7 | -0.16000E+05 | 0.00000E+00 | 0.13500E+05 | 0.91900E+03 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 8 | -0.12000E+05 | 0.00000E+00 | 0.13500E+05 | 0.94150E+03 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 9 | -0.08000E+05 | 0.00000E+00 | 0.13500E+05 | 0.96400E+03 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 10 | -0.04000E+05 | 0.00000E+00 | 0.13503E+05 | 0.98650E+03 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 11 | 0.00000E+00 | 0.00000E+00 | 0.13500E+05 | 0.10090E+04 | 0.109491E+03 | 0.126741E+01 | 0.998048E+00 |
| 12 | 0.00000E+04 | 0.00000E+00 | 0.13500E+05 | 0.10313E+04 | 0.105124E+03 | 0.146459E+01 | 0.115432E+01 |
| 13 | 0.00000E+04 | 0.00000E+00 | 0.13500E+05 | 0.10540E+04 | 0.094966E+02 | 0.164530E+01 | 0.129666E+01 |
| 14 | 0.12000E+05 | 0.00000E+00 | 0.13500E+05 | 0.10765E+04 | 0.0941350E+02 | 0.181042E+01 | 0.142680E+01 |
| 15 | 0.16000E+05 | 0.00000E+00 | 0.13500E+05 | 0.10990E+04 | 0.0902135E+02 | 0.196112E+01 | 0.15537E+01 |
| 16 | 0.20000E+05 | 0.00000E+00 | 0.13500E+05 | 0.11215E+04 | 0.000000E+00 | 0.191401E+01 | 0.150843E+01 |
| 17 | 0.24000E+05 | 0.00000E+00 | 0.13500E+05 | 0.11440E+04 | 0.000000E+00 | 0.186892E+01 | 0.147290E+01 |
| 18 | 0.28000E+05 | 0.00000E+00 | 0.13500E+05 | 0.11665E+04 | 0.000000E+00 | 0.182575E+01 | 0.143898E+01 |
| 19 | 0.32000E+05 | 0.00000E+00 | 0.13500E+05 | 0.11890E+04 | 0.000000E+00 | 0.178437E+01 | 0.140626E+01 |
| 20 | 0.36000E+05 | 0.00000E+00 | 0.13500E+05 | 0.12115E+04 | 0.000000E+00 | 0.174467E+01 | 0.137498E+01 |
| 21 | 0.40000E+05 | 0.00000E+00 | 0.13500E+05 | 0.12340E+04 | 0.000000E+00 | 0.170657E+01 | 0.134495E+01 |

SPECIFIC ACTIVITY DISTRIBUTION FUNCTION PARAMETERS
 Yield (kt) = 0.10000E+04
 Fixation Fraction = 0.50000
 Total cloud mass (g) = 0.40059E+13

| | X | Y | Z | T |
|--------------------------------|--------------|---------|-------------|------------|
| Initial | -40000.00000 | 0.00000 | 13500.00000 | 784.00000 |
| Final | 40000.00000 | 0.00000 | 13500.00000 | 1234.00000 |
| Total Flight Immersion Dose: | | | | 6.25275 |
| Total Flight Cabin Dust Dose: | | | | 0.13037 |
| Total Flight Filter Dust Dose: | | | | 0.10291 |

Figure 7. Dose rates.

| VERTEX NO. | X | Y | Z | T | IMMERSION DOSE RATE (RAD/HR) | CABIN DUST DOSE RATE (RAD/HR) | FILTER DUST DOSE RATE (RAD/HR) |
|------------|--------------|-------------|-------------|-------------|------------------------------|-------------------------------|--------------------------------|
| 1 | -9.10000E+05 | 0.00000E+00 | 0.13500E+05 | 0.36000E+04 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 2 | -9.36000E+05 | 0.00000E+00 | 0.13500E+05 | 0.36225E+04 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 3 | -9.32000E+05 | 0.00000E+00 | 0.13500E+05 | 0.36450E+04 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 4 | -9.28000E+05 | 0.00000E+00 | 0.13500E+05 | 0.36675E+04 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 5 | -9.24000E+05 | 0.00000E+00 | 0.13500E+05 | 0.36900E+04 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 6 | -9.20000E+05 | 0.00000E+00 | 0.13500E+05 | 0.37125E+04 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
| 7 | -9.16000E+05 | 0.00000E+00 | 0.13500E+05 | 0.37350E+04 | 0.118844E+02 | 0.101944E-01 | 0.382627E-01 |
| 8 | -9.12000E+05 | 0.00000E+00 | 0.13500E+05 | 0.37575E+04 | 0.183579E+02 | 0.312113E-01 | 0.737931E-01 |
| 9 | -9.08000E+05 | 0.00000E+00 | 0.13500E+05 | 0.37800E+04 | 0.996267E+01 | 0.455464E-01 | 0.107681E+00 |
| 10 | -9.04000E+05 | 0.00000E+00 | 0.13500E+05 | 0.38025E+04 | 0.957325E+01 | 0.592078E-01 | 0.139986E+00 |
| 11 | -9.00000E+05 | 0.00000E+00 | 0.13500E+05 | 0.38250E+04 | 0.887139E+01 | 0.717526E-01 | 0.169646E+00 |
| 12 | -8.96000E+05 | 0.00000E+00 | 0.13500E+05 | 0.38475E+04 | 0.849566E+01 | 0.836677E-01 | 0.197902E+00 |
| 13 | -8.92000E+05 | 0.00000E+00 | 0.13500E+05 | 0.38700E+04 | 0.807000E+01 | 0.947474E-01 | 0.224486E+00 |
| 14 | -8.88000E+05 | 0.00000E+00 | 0.13500E+05 | 0.38925E+04 | 0.775764E+01 | 0.105624E+00 | 0.249727E+00 |
| 15 | -8.84000E+05 | 0.00000E+00 | 0.13500E+05 | 0.39150E+04 | 0.770417E+01 | 0.116157E+00 | 0.274618E+00 |
| 16 | -8.80000E+05 | 0.00000E+00 | 0.13500E+05 | 0.39375E+04 | 0.000000E+00 | 0.123356E+00 | 0.272736E+00 |
| 17 | -8.76000E+05 | 0.00000E+00 | 0.13500E+05 | 0.39600E+04 | 0.000000E+00 | 0.114570E+00 | 0.270074E+00 |
| 18 | -8.72000E+05 | 0.00000E+00 | 0.13500E+05 | 0.39825E+04 | 0.000000E+00 | 0.113793E+00 | 0.268042E+00 |
| 19 | -8.68000E+05 | 0.00000E+00 | 0.13500E+05 | 0.40050E+04 | 0.000000E+00 | 0.113027E+00 | 0.267229E+00 |
| 20 | -8.64000E+05 | 0.00000E+00 | 0.13500E+05 | 0.40275E+04 | 0.000000E+00 | 0.112269E+00 | 0.266452E+00 |
| 21 | -8.60000E+05 | 0.00000E+00 | 0.13500E+05 | 0.40500E+04 | 0.000000E+00 | 0.111511E+00 | 0.265670E+00 |

SPECIFIC ACTIVITY DISTRIBUTION FUNCTION PARAMETERS
Yield (KT) = 0.10000E+04
Fission Fraction = 0.90000
Total cloud mass (g) = 0.40058E+12

| | X | SPECIFIED FLIGHT VECTORS | | T |
|--------------------------------|--------------|--------------------------|-------------|------------|
| | | Y | Z | |
| Initial | -40000.00000 | 0.00000 | 13500.00000 | 3600.00000 |
| Final | 40000.00000 | 0.00000 | 13500.00000 | 4050.00000 |
| Total Flight Immersion Dose: | | 0.33208 | | |
| Total Flight Cabin Dust Dose: | | 0.00781 | | |
| Total Flight Filter Dust Dose: | | 0.01846 | | |

Figure 8. Fly-through scenario dose rate.

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