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MARTIN MARIETTA

**A Computer Program for
Superpositioning Multiple UF₆
Plume Simulations to Determine
Health Effects**

D. D. Holt

This document has been approved for release
to the public by:

David B. Hilland *2/3/95*
Asst. Technical Information Officer Date
Oak Ridge K-25 Site

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DEPARTMENT OF ENERGY

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Martin Marietta Energy Systems, Inc., Engineering
Process Engineering

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Plume Simulations to Determine Health Effects

D. D. Holt

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Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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Foreword

This report is one of a series of reports documenting computer programs used for predicting health effects that might occur as a result of postulated accidental releases of UF_6 . The reports in this series are the following.

R. A. Just and W. R. Williams, "A Computer Program for Simulating the Atmospheric Dispersion of UF_6 and Other Reactive Gases Having Positive, Neutral, or Negative Buoyancy," K/D-5694, Martin Marietta Energy Systems, Oak Ridge, TN, April 1986.

W. R. Williams, "Computer Programs for Developing Source Terms for a UF_6 Dispersion Model to Simulate Postulated UF_6 Releases from Buildings," K/D-5695, Martin Marietta Energy Systems, Oak Ridge, TN, April 1986.

D. D. Holt, "A Computer Program for Superpositioning Multiple UF_6 Plume Simulations to Determine Health Effects," K/D-5696, Martin Marietta Energy Systems, Oak Ridge, TN, April 1986.

R. A. Just, "Report on Toxicological Studies Concerning Exposures to UF_6 and UF_6 Hydrolysis Products, K/D-5573, Revision 1, Martin Marietta Energy Systems, Oak Ridge, TN, July 1984.

Introduction

The MERGE program is a post-processor for the UF_6 atmospheric dispersion program (ADP) described in Ref. 1. It superimposes the results from several plume simulations and determines for given ground level locations on a grid the total dose and health effect of specified components, based on Ref. 2. The MERGE program utilizes a Gaussian dispersion model's results, an assumed Gaussian profile, and an approximation for transient behavior.

Approximation for Transient, Three-Dimensional Behavior

The model approximates steady-state, three-dimensional behavior by assuming the plume centerline concentration follows a Gaussian distribution which has the same average value (averaged over the plume cross section) as the concentration obtained from the UF_6 ADP. Figure 1 is a schematic of a Gaussian plume, showing vertical and crosswind diffusion patterns. A similar approximation is used to simulate transient behavior as depicted in Figure 2. If the release rate (input) is a square-wave function of time as shown in Figure 2A, then the mass flow rate (response) predicted by a mass-conservative, nondispersing model at a downwind point is this same squarewave centered at the travel time (which is equal to the downwind distance divided by the average plume horizontal velocity or x/v as shown in Figure 2B). A mass-conservative, Gaussian model includes dispersion and would predict the bell-shaped, dashed curve in Figure 2B which has the same area under the curve as the square wave. A nondispersing version of the model given by the UF_6 ADP would predict a square wave response similar to the mass-conservative, nondispersing model except that the height of the square would be different due to chemical reactions and other nonconservative processes (Figure 2C). The complete model approximates the transient response by forcing the mass-conservative, Gaussian response in the time domain (bell-shaped curve) onto this square wave as shown in Figure 2C. An input function that is not a square wave is approximated as a number

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Figure 1. Schematic of a Gaussian Plume Showing Vertical and Crosswind Diffusion Patterns.

Figure 2. Scheme for Approximating Transient Behavior

of different plumes (Figure 2D) and the response to each of these square waves is summed to arrive at the approximate transient response (dashed curve in Figure 2F).

An expression for the mass-conservative, Gaussian response to a square-wave input can be derived by suitably superpositioning and integrating instantaneous, elevated point sources as described by Gifford³. The expression is

$$C = 0.25Q_n(\pi\rho v A_y A_z)^{-1} \exp(-0.5 y^2/A_y^2) \{ \exp[-0.5(z-h)^2/A_z^2] + \exp[-0.5(z+h-2L)^2/A_z^2] \} \phi(x_t/A_x, x_T/A_x, x/A_x) \quad (1)$$

where

C is the mass fraction of component n .

Q_n is the release rate of Component n from the point source (the height of the square wave), lb/sec.

ρ is plume density, lb/ft³.

v is plume horizontal velocity, ft/sec.

A_x, A_y, A_z are plume dispersion parameters in the downwind, crosswind, and vertical directions, respectively, ft.

y is the crosswind distance from the release point, ft.

z is the plume centerline height above the reference elevation, ft.

h is the elevation above the reference elevation, ft.

L is the ground elevation above the reference elevation, ft.
(note that L can be negative)

ϕ is the transient response function to the square wave input.

x_t, x_T are the downwind distances from the release point traveled during times t and T , respectively, by a fictitious particle moving along the plume centerline, ft.

t is the time after the release, sec.

T is the duration of the release (the width of the square wave), sec.

x is the downwind location, ft.

The function ϕ is defined by

$$\begin{aligned}\phi(S_1, S_2, S_3) &= 0 \text{ for } S_1 < 0 \\ &= \operatorname{erf}\left(\frac{S_1 + S_3}{2}\right) + \operatorname{erf}\left(\frac{S_1 - S_3}{2}\right) \text{ for } 0 < S_1 < S_2 \\ &= \operatorname{erf}\left(\frac{S_1 + S_3}{2}\right) - \operatorname{erf}\left(\frac{S_1 + S_3 + S_2}{2}\right) \\ &\quad + \operatorname{erf}\left(\frac{S_1 - S_3}{2}\right) - \operatorname{erf}\left(\frac{S_1 - S_3 - S_2}{2}\right) \text{ for } S_1 > S_2\end{aligned}$$

where

$$S_1 = x_t/A_x$$

$$S_2 = x_T/A_x$$

$$S_3 = x/A_x$$

erf is the error function.

The function ϕ is a continuous function which has a value of zero for $S_1 < 0$ ($t < 0$), increases toward an asymptotic value of 2.0 for $0 < S_1 < S_2$ ($0 < t < T$), and decreases again toward an asymptotic value of zero for $S_1 > S_2$ ($t > T$) as shown in Figure 3. When $S_2 > S_1 > S_3 + 4$, the function is very close to the value of 2.0 and Equation (1) becomes equivalent to a steady-state Gaussian distribution. This situation approximately corresponds to $T > t > (x + 4A_x)/v$ and Equation (1) becomes

$$\begin{aligned}C &= 0.5Q_n (\pi\rho v A_y A_z)^{-1} \exp(-0.5 y^2/A_y) \{ \exp[-0.5(z-h)^2/A_z^2] \\ &\quad + \exp[-0.5(z+h-2L)^2/A_z^2] \}.\end{aligned}\quad (2)$$

When S_2 (or T) is small in comparison to S_1 (or t) and S_3 (or x/v), the increasing and decreasing portions to the function come together and the function becomes the dashed bell-shaped curve shown in Figure 3. This situation occurs when $S_1 > 0.01 > S_2$ which corresponds approximately to $t > 0.01 A_x/v > T$. As S_2 approaches zero ($T \rightarrow 0$), Equation (1) approaches the expression for an instantaneous (puff) source which is

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Figure 3. Typical Behavior of the ϕ Function

$$C = TQ_n (2\pi)^{-3/2} (\rho A_x A_y A_z)^{-1} \exp(-0.5 y^2/A_y^2) \{ \exp[-0.5(z-h)^2/A_z^2] \\ + \exp[-0.5(z+h-2L)^2/A_z^2] \} \{ \exp[-0.5(x_t - x_T + x)^2/A_x^2] \\ + \exp[-0.5(x_t - x_T - x)^2/A_x^2] \}. \quad (3)$$

The infinite time integral of ϕ can be evaluated analytically and the result is $2T$.

Substituting the mass flow rate from a downwind horizontal momentum balance ($\theta U p c_n$) for Q_n leads to the following expression for approximating the three-dimensional, transient behavior of the concentration:

$$C = [\theta c_n U / (4\pi A_y A_z v)] \exp(-0.5 y^2/A_y^2) \{ \exp[0.5(h-z)^2/A_z^2] \\ + \exp[-0.5(h+z-2L)^2/A_z^2] \} \phi(x_t/A_x, x_T/A_x, x/A_x) \quad (4)$$

where

θ is the plume's cross-sectional area, ft^2 .

c_n is the mass fraction of component n at a given downwind location as determined by the UF_6 ADP.

U is the plume's velocity, ft/sec .

Equation (4) is used to calculate concentration as a function of time at specific locations. The expression for the infinite-time integral of concentration (dose) at any location is similar to Equation (4) except the ϕ function is replaced by $2T$.

$$D = [\theta c_n U / (4\pi A_y A_z v)] \exp(-0.5 y^2/A_y^2) \{ \exp[-0.5(z-h)^2/A_z^2] \\ + \exp[-0.5(z+h-2L)^2/A_z^2] \} 2T \quad (5)$$

where

D is the infinite-time integral of C (dose), mass fraction-sec.

The dispersion coefficient in the downwind direction was not computed by UF_6 ADP. This is due to two facts. The first is that it did not require the downwind dispersion coefficient. The second is that generalized values for the downwind dispersion coefficient are not readily available (as opposed to the crosswind and vertical dispersion coefficients). Therefore, as a rough estimate, the downwind dispersion coefficient is set equal to the crosswind dispersion coefficient.⁴

Superpositioning Different Releases

It should be noted that Equations (4) and (5) apply best to a release for which the temperature, composition, and source geometry are constant with time during a finite time period after which the release stops. They are not applicable for cases in which the temperature, composition, flow rate, or release geometry vary with time or multiple releases occur simultaneously. However, the MERGE program utilizes a superpositioning model. This model is still only an approximate solution because it is based on solutions to linear rather than nonlinear differential equations. However, it is a better approximation than the comparable simple square wave used to obtain Equations (4) and (5).

To apply superpositioning, the time-varying release rate is approximated as a series of releases, each having a constant release rate. The UF_6 ADP is run separately for each release, and the concentration at a specified time and location (t , x , y , and z) is calculated using Equation (4). Due to computer storage and execution time limitations, the MERGE program uses the maximum concentration of a plume component for a given location (x , y , and z). The dose is computed correctly as given in Equation (5). The effect of this shortcut for computing concentration is that the overall concentration from the combining of plumes that differ when the releases start can be extremely conservative. In general, the values of the parameters in Equation (4) will be different for each single release. The concentrations at the specified time and location for each release are summed to arrive at the result from superpositioning (the concentrations of some plumes may be zero).

The superpositioning model can also be used to calculate the concentration or dose resulting from several constant-rate releases at different times from different locations. It should be noted that the superpositioning of multiple sources only considers dispersion effects and does not consider the effects of interactions between the individual plumes on the trajectory and growth of the combined plume. These

effects can be significant if the momentum and/or energy of the individual plumes are relatively large when they merge.

Determination of Plume Arrival and Departure

Computation of the release duration for a given downwind location can not be directly obtained from the ϕ function because the wind velocity is not constant with respect to height. The method used in MERGE computes for each location a start search time and a stop search time and then searches between the two times at that location for the plume times of arrival and departure. The time boundaries are computed by an algorithm which was generated as a result of experiments with the simulation of a variety of plume releases. Let

W_H = maximum wind speed in atmosphere

W_L = minimum wind speed in atmosphere

x = distance downwind

x_0 = plume release distance downwind

t = time

t_0 = start of plume release

Δt = duration of the plume release

T_B = start search time

T_E = stop search time

Then,

$$T_B = 0, \quad x - x_0 \leq 500 \text{ ft.} \quad (5a)$$

$$T_B = 0.9 (x - x_0)/W_H + t_0, \quad x - x_0 > 500 \text{ ft} \quad (5b)$$

$$T_E = 1.25 (x - x_0)/W_L + t_0 + t \quad (6)$$

Between T_B and T_E , the MERGE program considers the plume to arrive or depart when the approximation for transient behavior passes through a certain threshold value. The threshold value is the minimum of (1) 0.00005 times the steady-state value of the approximation for transient behavior, and (2) 0.001 times the maximum value of the approximation for transient behavior. These heuristic methods produce more conservative results (i.e., longer durations) when compared to the results from direct solution of the ϕ function for those problems having

constant wind profiles. The heuristic methods were developed from inspection of plumes from 0 to 25,000 feet. They are applicable beyond 25,000 feet, but the conservatism increases with increased downwind distance.

At this point, the MERGE program has computed the time of arrival, duration, and maximum concentration for the plume at the given location. The MERGE program then assumes a square wave distribution for component concentration with respect to time, rather than the approximation for transient behavior discussed earlier (see Figure 3). This is approximately correct for the near field, but can be overly conservative for the far field. But this assumption reduces drastically the amount of bookkeeping, storage, and execution time required by the MERGE program. The MERGE program then for a given point in time sums all the plume's concentrations at the current location. This method does have problems. Short spikes of peak concentration (e.g., 15 seconds duration) could increase the predicted health effects to more serious levels. Occurrence of such a spike is a modeling error resulting from the square wave approximation, since approximation for transient behavior would reduce the concentration in one plume as it raised the concentration in the other plume - not continue both at a maximum value. This method of computing concentration can be extremely conservative, but it is used only for concentration based health effects - such as the HF sublethal effects.

Toxicology

With the concentration computed as a function of time, the merge code can calculate the dose from the time of exposure, and durations of exposure to various concentration levels. The total exposure time for all locations can be shortened via an input option to simulate evacuation from the plume. With this information, the code can readily retrieve the predicted health effect. The health effects criteria are stored in subroutines which can be changed easily if data must be added

or replaced. The code then outputs the predicted health effect for the given location and continues computations for the remaining locations.

The toxicity of uranium and hydrogen fluoride used in the MERGE program are listed in Table 1. They follow the toxicity described by

Table 1. Legend of Symbols Used for Health Effects.

o	Below no health effects, but above FRC RPG (U)
a	Smell, no health effects (HF)
b	Possible mild health effects (U)
c	Smell, possible irritation (HF)
d	Renal injury (U)
e	Irritation, possible health effects (HF)
f	Renal injury, possible lethality (U)
g	Lethal (U, HF)

Just², which is shown in Figures 4 and 5, but the MERGE program's toxicity has four additions. First, the dashed lines in Figures 4 and 5 are assumed to be solid. Second, the irritation/possible health effects for hydrogen fluoride is assumed to occur after an exposure of 10 minutes that may or may not have been a continuous exposure. Third, the MERGE program is capable of determining the 10% lethal level of uranium (renal injury/possible lethality). The exposure for this health effect was also described by Just.⁵ Finally, the Federal Radiation Council's (FRC's) Radiation Protection Guide for exposure to soluble uranium outside restricted or occupational areas was also applied in the evaluation of the toxicity of uranium. The FRC's RPG is the concentration which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of concentrations as far below the RPG as practicable.⁶ The FRC's RPG was not used in the analysis of UF₆ releases for the SAR⁷.

Figure 4. Toxicity of Acute Exposures to Soluble Uranium

Figure 5. Toxicity of Acute Exposures to Hydrogen Fluoride

The 10% lethal level and the FRC's RPG were included in the MERGE program so that user can utilize them if desired.

Input Description

The input requirements for the MERGE program, as described in comment cards, are somewhat vague. This description characterizes the input requirements as it describes the input on a card by card basis.

Card one is the crosswind distance title card. This card is printed literally on the health effects printer plots. The contents of this card will be determined from the crosswind lattice lines of health effects (see cards five and six). This card is input so the computer will not need to compute its contents. The user must determine the location where the crosswind reference points should be located. The crosswind reference points should be expressed in thousands of feet or meters because of the heading stating that they are in such units.

For example, suppose the distance between crosswind lattice lines is 250 feet and the health effects are computed 5000 feet on one side of the plume centerline. The card starts with two blanks, then 0 followed by three blanks, then 1 and three blanks, then 2 and so forth. This continues to the number 5. So the 0 will be centered on the centerline, it must be preceded by two blanks. One or both of the blanks are removed when the minimum crosswind distance is a negative number. For example, if the crosswind output is from -1000 to 5000 feet, the crosswind distance title card is as follows. First, a blank and -1. Then three blanks and 0 and the rest of the card is as described before.

Card two is the gross control card. The input needed is the number of plumes to be superpositioned, the number of downwind gross lattice lines, the number of crosswind gross lattice lines, an option to suppress printing of doses, an option to store the results (currently inoperative), and a units switch (English or metric). The gross lattice lines permit the MERGE program to produce output at points of interest or prevent output at points of noninterest. Note that the health effects output is not determined by the gross lattice lines alone. The

health effects are also output on the fine lattice lines, which are computed by the interval cards described later.

Card three is the gross downwind lattice lines cards. Output between two gross downwind lines distances is possible (see card four), but only on a linear scale.

Card four is the downwind interval card. There is always one item less on this card than on card 3. The input number is the number of divisions between the two gross downwind lattice lines. The division of the distance between the two gross lattice lines yields the fine downwind lattice lines for computation of health effects.

Cards five and six are similar to cards three and four, except they deal with crosswind lattice lines.

Card seven contains the elevation above reference elevation for health effects computations, the maximum exposure time, and the number of health effect components. The exposure time starts when the superimposed plumes first arrive at a given downwind location. The default is 28,800 sec (8 hr).

The next three cards are repeated for each health effect component. The first card requires the number of plume components which contain this health effect component and the name of the health effect component. Note that the toxicology subroutines in the MERGE program requires U be used for uranium and HF be used for hydrogen fluoride. The second card lists pairs of the plume component and plume component fraction which contain this health effect component. The third card lists the minimum concentration in g/m^3 and dose in g-s/m^3 to be printer plotted.

The final card is repeated for each plume. The card should have the device number of the plume's intermediate file, the strength of the plume, the duration of the plume, and the changes in start time, downwind distance, and crosswind distance relative to the plume's original start time, downwind location, and crosswind location. The plume's strength default is 1.0 and the duration default is the plume's original duration.

Explanation of Output

Most of the MERGE program's output is self-explanatory. The output requiring clarification is the summary after each printer plot of health effects. The areas are the printer plot's areas for each health effect. These areas are therefore a function of the grid spacing selected. Comparisons between two MERGE runs utilizing different grid spacings should be done with caution, if it is to be done at all. The areas are computed using rectangles which lie halfway between the fine lattice lines. When there are not two lattice lines for the rectangle to lie between (such as at the edge), then the rectangle is extrapolated from the last two lattice lines. The exception to this is no rectangle can proceed upwind of the first downwind lattice line.

The sum is the sum of all areas for this health effect or more severe health effects. The distance is the farthest downwind distance that this health effect occurs.

Sample Problem

Suppose one wanted the health effects—not the doses—of U and HF for 3000 m downwind, with output every 20 m for the first 100 m, every 150 m between 100 and 1000 m, and every 400 m thereafter. The crosswind distance of interest is 3000 m on either side of the release with output every 50 m from the centerline out to 1000 m and every 100 m beyond 1000 m from the centerline. (Variable spacing is discouraged in the crosswind direction for the sake of clarity, but it is illustrated here to demonstrate code capabilities.) Health effects for a maximum exposure of 8 hr at ground level are acceptable. The release is composed of two identical releases 402 m apart; one is 200 m to the right of the centerline while the other is 200 m to the left and 40 m downwind. The releases are based on output from the sample problem in the UF₆ ADP documentation.¹ The MERGE input for this sample problem is given in Table 2 and output is given in Table 3.

Table 2. Sample Problem Input for the MERGE Program.

THE THIRD CARD FOLLOWING THIS IS THE FIRST INPUT CARD

1	2	3	4	5	6	7	8
1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890
-3	-2	-1	-0.5	0	0.5	1	2
	2	4	4ND	NO	METR		
	0.	100.	1000.	3000.			
	5	6	5				
-3000.	-1000.	1000.	3000.				
	10	40	10				
	0.0	0.0	2				

2 U
 UF6 .676 UOF .773
 8.9E-6 23.4
 1 HF
 HF 1.000
 .001 3180.
 7 1.0 0.0 0.0 0.0 -200.0
 7 1.0 0.0 0.0 40.0 200.0

1	2	3	4	5	6	7	8
1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890

THE THIRD CARD PRECEEDING THIS IS THE LAST INPUT CARD

Table 3. Sample Problem Output from the MERGE Program.

NO. OF PLUMES = 2
 NO. OF X GROSS LATTICE LINES = 4
 NO. OF Y GROSS LATTICE LINES = 4
 PRINT DOSES OPTION = NO
 NEW FILE OPTION = NO
 UNITS = METR

X GROSS LATTICE LINES:
 0.0 100.0 1000.0 3000.0

NO. OF INCREMENTS BETWEEN X GROSS LATTICE LINES:
 5 6 5

NO. OF Y GROSS LATTICE LINES:
 -3000.0 -1000.0 1000.0 3000.0

NO. OF INCREMENTS BETWEEN Y GROSS LATTICE LINES:
 10 40 10

ELEVATION = 0.
 MAX EXPOSURE TIME = 28800.
 NO. OF COMPONENTS = 2

NO. OF CONTRIBUTING COMPONENTS = 2
 NAME OF DESIRED COMPONENT = U

CONTRIBUTING COMPONENT	WEIGHT
UF6	0.676
UDF	0.773

NO. OF CONTRIBUTING COMPONENTS = 1
 NAME OF DESIRED COMPONENT = HF

CONTRIBUTING COMPONENT	WEIGHT
HF	1.000

Table 3. (Cont'd.)

PLUME'S SAMPLE PROBLEM, TITLE CARD

INPUT FILE NO. = 7
 FACTOR = 1.
 RELEASE DURATION = 600.00
 DELTA TIME = 0.00
 DELTA X = 0.00
 DELTA Y = -200.00

START TIME = 0.00
 START X = 0.00
 START Y = -200.00
 START Z = 16.40
 LOW WIND = 7.0963
 HIGH WIND = 24.7862

X	ARRIVAL	DURATION	U CONCENTRATION	HF CONCENTRATION
0.000000E+00	0.000000E+00	5.3550984E+02	0.000000E+00	0.000000E+00
2.000000E+01	1.5052844E+00	5.9910324E+02	1.4023747E-02	4.7137034E-03
4.000000E+01	1.5105688E+00	6.0120653E+02	4.6260007E-01	1.5548887E-01
6.000000E+01	1.5158532E+00	6.0330978E+02	7.9377280E-01	2.6679161E-01
8.000000E+01	1.5211376E+00	6.0541287E+02	1.0185061E+00	3.4230074E-01
1.000000E+02	3.0528441E+00	6.0446286E+02	1.1709272E+00	3.9348531E-01
2.500000E+02	7.8302758E+00	6.1232761E+02	9.5443442E-01	3.2030536E-01
4.000000E+02	1.4451194E+01	6.1658467E+02	5.6671967E-01	1.8993910E-01
5.500000E+02	2.1566206E+01	6.1901323E+02	3.7854385E-01	1.2673159E-01
7.000000E+02	2.8660218E+01	6.2262196E+02	2.7569450E-01	9.2212503E-02
8.500000E+02	3.5806264E+01	6.2602251E+02	2.1298230E-01	7.1178339E-02
1.000000E+03	4.3004344E+01	6.2921507E+02	1.7151540E-01	5.7277842E-02
1.400000E+03	5.9548902E+01	6.3787257E+02	1.0974229E-01	3.6586757E-02
1.800000E+03	7.6232217E+01	6.4695539E+02	7.8901224E-02	2.6267353E-02
2.200000E+03	9.3054288E+01	6.5478865E+02	6.0811816E-02	2.0219868E-02
2.600000E+03	1.1001511E+02	6.6332502E+02	4.9073533E-02	1.6298532E-02
3.000000E+03	1.2509436E+02	6.7277067E+02	4.0910388E-02	1.3573299E-02

Table 3. (Cont'd.)

PLUME'S SAMPLE PROBLEM, TITLE CARD

INPUT FILE NO. = 7
 FACTOR = 1.
 RELEASE DURATION = 600.00
 DELTA TIME = 0.00
 DELTA X = 40.00
 DELTA Y = 200.00

START TIME = 0.00
 START X = 40.00
 START Y = 200.00
 START Z = 16.40
 LOW WIND = 7.0963
 HIGH WIND = 24.7862

X	ARRIVAL	DURATION	U CONCENTRATION	HF CONCENTRATION
0.000000E+00	0.000000E+00	5.3550984E+02	0.000000E+00	0.000000E+00
2.000000E+01	0.000000E+00	5.3550984E+02	0.000000E+00	0.000000E+00
4.000000E+01	0.000000E+00	5.3550984E+02	0.000000E+00	0.000000E+00
6.000000E+01	1.5052844E+00	6.0060833E+02	6.0719298E-01	2.0408689E-01
8.000000E+01	1.5105688E+00	6.0271709E+02	8.8795664E-01	2.9843998E-01
1.000000E+02	1.5158332E+00	6.0482563E+02	1.0824292E+00	3.6377055E-01
2.500000E+02	3.1109726E+00	6.1441704E+02	9.9822114E-01	3.3503918E-01
4.000000E+02	9.5707165E+00	6.1890607E+02	5.8855375E-01	1.9727646E-01
5.500000E+02	1.8518389E+01	6.2108622E+02	3.8971471E-01	1.3048226E-01
7.000000E+02	2.5579447E+01	6.2318625E+02	2.8218301E-01	9.4389500E-02
8.500000E+02	3.2692538E+01	6.2666715E+02	2.1712047E-01	7.2565926E-02
1.000000E+03	3.9857663E+01	6.2993935E+02	1.7434157E-01	5.8224998E-02
1.400000E+03	5.8061791E+01	6.3706980E+02	1.1101751E-01	3.7013637E-02
1.800000E+03	7.4738167E+01	6.4628371E+02	7.9604430E-02	2.6502534E-02
2.200000E+03	9.1553300E+01	6.5424917E+02	6.1249650E-02	2.0366182E-02
2.600000E+03	1.0656317E+02	6.6485345E+02	4.9369147E-02	1.6397252E-02
3.000000E+03	1.2358643E+02	6.7247406E+02	4.1121853E-02	1.3643874E-02

Table 3. (Cont'd.)

PLUME'S SAMPLE PROBLEM, TITLE CARD

EVACUATION COMPLETE TIME • 28800.

X (IN)	ARRIVAL (S)	DEPARTURE (S)	DURATION (S)
0.000000E+00	0.000000E+00	6.000000E+02	6.000000E+02
2.000000E+01	0.000000E+00	6.0060853E+02	6.0060853E+02
4.000000E+01	0.000000E+00	6.0271709E+02	6.0271709E+02
6.000000E+01	1.5052844E+00	6.0482563E+02	6.0332034E+02
8.000000E+01	1.5105688E+00	6.0693401E+02	6.0542345E+02
1.000000E+02	1.5158532E+00	6.0751570E+02	6.0599985E+02
2.500000E+02	3.1109726E+00	6.2015789E+02	6.1704692E+02
4.000000E+02	9.5707165E+00	6.3103587E+02	6.2146515E+02
5.500000E+02	1.8518389E+01	6.4057944E+02	6.2206105E+02
7.000000E+02	2.5579447E+01	6.5128217E+02	6.2570273E+02
8.500000E+02	3.2692538E+01	6.6182877E+02	6.2913624E+02
1.000000E+03	3.9857663E+01	6.7221941E+02	6.3236175E+02
1.400000E+03	5.8061791E+01	6.9742147E+02	6.3935968E+02
1.800000E+03	7.4738167E+01	7.2318761E+02	6.4844944E+02
2.200000E+03	9.1533300E+01	7.4784294E+02	6.5628964E+02
2.600000E+03	1.0656317E+02	7.7334013E+02	6.6677695E+02
3.000000E+03	1.2358643E+02	7.9786503E+02	6.7427859E+02

Table 3. (Cont'd.)

Table 3. (Cont'd.)

PLUME'S SAMPLE PROBLEM, TITLE CARD

GROUND-LEVEL HEALTH EFFECTS, U
 MAXIMUM EXPOSURE TIME = 674. S
 EVACUATION COMPLETE TIME = 28800. S

	HE	SUM (M**2)	AREA (M**2)	DIST (M)
a	1.6465500E+07	1.1045000E+07	3.0000000E+03	
b	5.4205000E+06	3.1155000E+06	3.0000000E+03	
d	2.3050000E+06	2.3050000E+06	1.8000000E+03	
f	0.0000000E+00	0.0000000E+00	0.0000000E+00	
g	0.0000000E+00	0.0000000E+00	0.0000000E+00	

Table 3. (Cont'd.)

PLUME'S SAMPLE PROBLEM, TITLE CARD

GROUND-LEVEL HEALTH EFFECTS, HF
MAXIMUM EXPOSURE TIME = 674. S
EVACUATION COMPLETE TIME = 28800. S

Table 3. (Cont'd.)

PLUME'S SAMPLE PROBLEM, TITLE CARD

GROUND-LEVEL HEALTH EFFECTS, HF
 MAXIMUM EXPOSURE TIME = 674. S
 EVACUATION COMPLETE TIME = 28800. S

	HE	SUM (M**2)	AREA (M**2)	DIST (M)
a	1.3348000E+07	1.5400000E+06	3.0000000E+03	
c	1.1808000E+07	3.9407500E+06	3.0000000E+03	
e	7.8672500E+06	7.8672500E+06	3.0000000E+03	
g	0.0000000E+00	0.0000000E+00	0.0000000E+00	

References

1. Just, R. A. and Williams, W. R., "A Computer Program for Simulating the Atmospheric Dispersion of UF_6 and Other Reactive Gases Having Positive, Neutral, or Negative Buoyancy," K/D-5694, Martin Marietta Energy Systems, Inc., Oak Ridge, TN, April 1986.
2. Just, R. A., "Generic Report on Health Effects for the U. S. Gaseous Diffusion Plants," K/D-5604, Section VIII, Part 1, Martin Marietta Energy Systems, Inc., Oak Ridge, TN, March 1985.
3. Gifford, F. A., Jr., "An Outline of Theories of Diffusion in the Lower Layer of the Atmosphere," Chapter 3 in D. H. Slade (ed.), "Meteorology and Atomic Energy," U.S. AEC Report TID-24190, July 1968.
4. Turner, D. B., "Workbook of Atmospheric Dispersion Estimates," Public Health Service Publications 999-AP 26 (1967, Rev. 1969).
5. Private communication with R. A. Just, March 22, 1985.
6. Harley, J. H., "Radiation Hazards," Section 5A in N.I. Sax (ed. 1, "Dangerous Properties of Industrial Materials, Fifth Edition", Van Nostrand Reinhold Co., New York, NY, 1979.
7. Helfrich, M. V., Holt, D. D., and Williams, W. R., "An Analysis of UF_6 Releases from Gaseous Diffusion Plants for the SAR," March 25, 1985.

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