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Evaporation and Dispersion of Hazardous Materials

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Final Report,
by 15 May 78-14 May 79

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June 1979

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This work was undertaken in order to develop a state-of-the-art predictive model for the evaporation and dispersion of hazardous liquids, especially hydrozine family fuels and propellants, which might be accidentally spilled. All of the several model elements have been assembled and combined in a FORTRAN computer program which will compute evaporation rates and limits of the hazardous region, that is, the maximum distance away from the centerline

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where a hazard would exist as well as the maximum distance down wind that a hazard would exist. Depending upon the input data supplied, the program will also predict the amount of water that would be required for sufficient dilution to eliminate the hazard, the effects of changing variables (as for example, the effects of changes in wind speed, or in air temperature or in atmospheric stability), and the effect of the passage of time (up to twenty-four hours) if weather conditions are updated hourly. In the latter case, allowances are made for composition changes in the remaining pool because of preferential evaporation of components, possible absorption of water from the atmosphere, and absorption of (and reaction with) carbon dioxide from the atmosphere. A number of computations were made in order to determine the effects of changes in the several input parameters. The results of these are presented in the form of correction factors which can be used to correct from certain "base cases", and thus provide for rapid field estimation when needed.

EVAPORATION AND DISPERSION OF HAZARDOUS MATERIALS

Final Report

Grant No. AFOSR 78-3559

by

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EVAPORATION AND DISPERSION OF HAZARDOUS MATERIALS

Introduction:

This work was undertaken in order to develop a state-of-the-art predictive model for the evaporation and dispersion of hazardous liquids, especially hydrozine family fuels and propellants, which might be accidentally spilled.

The importance of the problem has been adequately shown previously (1, 2). Some earlier work by Ille and Springer (3) approached the problem from the standpoint of pure materials. However, the materials of particular interest here are not always transported or used as pure materials, hence in this work it has been necessary to incorporate modifications of the earlier work (3) to include mixture behavior.

An additional consideration has been the incorporation of model elements relating to the reactions of the hazardous materials with the environment, especially water absorption from the air, carbon dioxide absorption from the air and decay of the evaporated material during its transport down wind.

Since the users of this predictive model will ordinarily wish to define the down-wind area wherein a hazard would exist in the case of a spill, the predictive scheme includes down wind dispersion and hazard corridor definition.

All of the several model elements have been assembled and combined in a FORTRAN computer program which will compute evaporation rates and limits of the hazardous region, that is, the maximum distance away from the centerline where a hazard would exist as well as the maximum distance down wind that a hazard would exist. Depending upon the input data supplied, the program will also predict the amount of water that would be required for sufficient dilution to eliminate the hazard, the effects of changing variables (as for example, the effects of changes in wind speed, or in air temperature or in atmospheric stability), and the effect of the passage of time

(up to twenty-four hours) if weather conditions are updated hourly. In the latter case, allowances are made for composition changes in the remaining pool because of preferential evaporation of components, possible absorption of water from the atmosphere, and absorption of (and reaction with) carbon dioxide from the atmosphere.

A number of computations were made in order to determine the effects of changes in the several input parameters. The results of these are presented in the form of correction factors which can be used to correct from certain "base cases", and thus provide for rapid field estimation when needed.

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Nature of the Hazardous Materials Considered:

There are three hazardous (toxic) materials of interest in this work; they being: hydrazine, H_2NNH_2; monomethyl hydrazine (MMH), H_2NNHCH_3; and unsymetrical dimethyl hydrazine (UDMH), $H_2NN(CH_3)_2$. Of these materials, as used by or transported by or for the U.S. Air Force only the MMH is in pure form. The UDMH is used as an equal parts (by mass) mixture with hydrazine. This mixture is sometimes referred to as "Aerozine 50". Hydrazine is also used in a water solution of 70 percent (by mass) hydrazine.

The vapor phase toxicity of these materials has been defined (4), and the Short Term Public Exposure limits (STPL) are given as 7.0 mg/m^3, 2.8 mg/m^3 and 38.2 mg/m^3 for hydrazine, MMH and UDMH respectively.

Hydrazine and both of the derivatives are miscible in all proportions with water. Not only are they miscible, they are extremely non-ideal and fit the definition of "hygroscopic", that is, they very readily take up water, and the equilibrium partial pressure of water vapor over the solutions is much lower than that predicted by Raoult's law. Some limited vapor-liquid equilibrium data have been published (5, 6), and neither the hydrazine and water system nor the UDMH-water system obey the Marqules equation (7, 8). This non-ideality is with respect to the liquid solutions. There are no indications of any particular non-ideality of the vapor mixtures.

The three hydrazine species each have somewhat different physical properties, with, in most cases, the properties of MMH being intermediate between those of hydrazine and UDMH. Most of the relevant physical properties of the pure liquids have been collected into a single publication (9).

Computational Methods:

The work of MacKay (10) was used to predict a mass transfer coefficient based on the vapor phase resistance. The basic equation is:

$$k_m = 0.0292\ Sc^{-0.67}\ u^{(2-n)/(2+n)}\ x^{(-n)/(2+n)} \qquad (1)$$

where:

k_m = mass transfer coefficient,

Sc = Schmidt No.

u = Wind velocity (at elevation of 10 m)

x = "Diameter" of Liquid Pool

(The pool "diameter" is actually the distance across the pool in the direction of the wind.)

n = wind velocity profile power

The Schmidt number is a common dimensionless number, encountered frequently in mass transfer and is given by:

$$Sc = \mu/\rho D$$

where:

μ = viscosity

ρ = density

D = diffusivity of diffusing component in air

The appropriate properties for the Schmidt number evaluation is the gas film adjacent to the liquid surface.

The evaporative flux, then is given by:

$$Q_m = k_m(C_1 - C_A) \qquad (2)$$

where:

Q_m = evaporative flux

C_1 = equilibrium concentration of diffusing material immediately adjacent to the liquid surface

C_A = concentration of diffusing component in the bulk air stream

For any concentration, $C = p/RT$ if the ideal gas low holds, where:

p = partial pressure of the component

R = universal gas constant

T = temperature

It was assumed that each transfering component will transfer in accordance with equation (2), since it is, essentially, a definition of the mass transfer coefficient. For an evaparating hydrazine, C_A, that is, the bulk concentration in the air, is zero at all times, and that the interface composition may be determined by assuming it to be an equilibrium concentration. For water, which may transfer in either direction, the bulk concentration varies with the humidity, while the interface composition will be an equilibrium value. For carbon dioxide, it was assumed that the composition was 0.03 percent in the air and was zero at the interface.

The Schmidt numbers as well as the equilibrium concentrations are functions of temperature, with the latter being very strong functions for each component (except carbon dioxide). The estimation methods are presented in Appendix A.

The temperature immediately adjacent to the liquid surface was assumed to be equal to the liquid pool temperature, while the mean temperature of the film (for Schmidt number evaluation) was assumed to be the mean of the liquid pool temperature and the bulk air temperature

The liquid pool temperature depends upon the relative rates of heat transfer to and from the pool. The transfer to the pool being radiant heating from sunshine, q_s, radiation from the atmosphere, q_a, convective heating from the air, q_h and convective heating from the ground surface, q_g. It is possible that q_h and/or q_g could be negative. The heat losses are reradiation from the pool to space q_r, and the latent heat of vaporizing materials, q_l.

The latent heat term is quite large, and is itself a strong temperature function since the evaporation rate is a strong temperature function. Therefore, it is reasonable to assume that the actual pool temperature is that which is in equili-

brium with the surroundings, that is, the rate of heat gain is equal to the rate of heat loss.

Thus:

$$q_s + q_a + q_h + q_g = q_r + q_l \qquad (3)$$

Except for q_s and q_a, each term in equation (3) is a function of the pool temperature, and so it is possible to deduce the pool temperature which would be the equilibrium temperature by finding that temperature which will satisfy equation (3).

The evaluation of q_s was done by an algorithm devised to determine the solar insolation rate on horizontal surfaces as a function of latitude, longitude, date, time, and cloud cover (11). The algorithm is rather lengthy and is not reproduced here. The absorptivity of the pool, a_p, was assumed to be 0.96 which compares well with water and a number of organic liquids (10, 12).

The atmospheric long wave length radiation, q_a, was evaluated as a function of the temperature of the air and the atmospheric emissivity, E_a, as given by Sax (13).

The convective transfer from (or to) the air was modelled after MacKay (10) which is a heat transfer analog of the same mass transfer coefficient given earlier as equation (1). The form for the analogous equation is:

$$h_a = k_m \rho C_p (Sc/Pr)^{0.67}$$

where:

ρ = density of the "film"

C_p = heat capacity of the "film"

P_r = Prandtle no., $C_p\mu/k$ of the "film"

k = thermal conductivity

The film properties were evaluated at the mean temperature and the mean composition of the interface (equilibrium composition at the pool temperature) and the bulk air condition.

The convective transfer between the ground and the pool was treated according to Schmidt and Silveston (14). This is the same algorithm used by Ille and Springer (3), although the liquid mixture properties had to be evaluated as composition functions as well as temperature functions. These properties estimations and others are presented in Appendix A.

The re-radiation from the pool is that of a radiator radiating to space. The liquid pool emissivity, E_p, is assumed to be 0.96 (12).

Finally, the latent heat of vaporization is the specific latent heat of each component times its evaporative flux. When the several terms of Equation (3) are rewritten as temperature functions, it becomes:

$$q_s T_a^4 \sigma E_a + h_a(T_a - T_p) + h_g(T_g - T_p) = T_p^4 \sigma + \sum_{i=1}^{m} \lambda_i Q_{m_i} \qquad (5)$$

where:

σ = Steffan-Boltzmann Constant

Each term of this equation is an energy flux.

Equation (5) may be solved for the pool temperature, T_p, if all the other terms are known. The solution requires an iterative method, but is readily found by the Newton-Raphson method.

The mass transfer flux, as given by Equation (2), is seen to be a function of the equilibrium concentration of transfering component. In Equation (2) this concentration is identified as C_1. For any component, i, this equilibrium composition is given by:

$$(C_1)_i = \gamma_i P_{vi} x_i / RT_p \qquad (6)$$

where:

γ = activity coefficient

Pv = vapor pressure

x = mole fraction of component in the liquid

The activity coefficient is predicted by methods indicated in Appendix A. Equation (6) was not applied to carbon dioxide, but rather, the equilibrium composition was set at zero.

The bulk phase composition, C_A, was set at zero for the hydrazines, a nominal value (fixed) was chosen for carbon dioxide, and the value for water was computed from the atmospheric conditions as given in Appendix A.

Overall, the computational procedure requires a pool temperature estimate. In all this work, the first estimate was taken to be the air temperature, Ta. Based upon this estimate, a set of appropriate physical properties was deduced, and an evaporative flux determined. Finally, with estimated properties and estimated flux, Equation (5) could be solved for the pool temperature.

An overall interation followed, based upon revised estimated pool temperatures until satisfactory agreement existed, at which time the corresponding evaporative flux was taken as the correct value, and the total evaporation rate was determined as the product of the flux times the pool area.

Dispersion calculations used the evaporation rate as the source strength for the hydrazine materials. The basic assumptions were that the source was a ground-level point source with no plume rise, and in case of two toxic materials present simultaneously (aerozine 50), the toxicity was considered additive, but not synergistic after the method of the American Conference of Industrial Hygenists (14).

Any reaction of the evaporated hydrazine as derivatives in air was treated as a first-order decay. The equations for dispersion are as given by Turner (15) and as used in Ille and Springer (3). The basic relation for centerline concentration for any distance x downwind is:

$$C_{(x,o)} = \frac{Q_m A_p}{\pi \sigma_y \sigma_z u} \exp - (k_r x/u) \qquad (7)$$

where:

k_r = atmospheric decay constant

A_p = pool area

σ_y = crosswind diffusion coefficient

σ_z = vertical diffusion coefficient

At any distance y away from the centerline, the concentration is given by:

$$C_{(x,y)} = C_{(x,o)} \exp - 1/2\left(\frac{y}{\sigma_y}\right)^2 \qquad (7,a)$$

The diffusion coefficients, σ_y and σ_z are functions of the downwind distance, x. The values used in this work are those given in Ille and Springer (3) and are as recommended by the Environmental Protection Agency.

For the case of more than one toxic material, the existence of a hazardous condition may be determined as follows for n toxic components:

$$\frac{C_T}{L_T} = \sum_{i=1}^{n} \frac{C_i}{L_i} \qquad (8)$$

where the ratio $\frac{C_T}{L_T}$ = Combined hazard ratio

L_i = Exposure limit for component i

C_i = Concentration of component i

If the value of $\frac{C_T}{L_T}$ is less than unity, the exposure limit is not exceeded.

In use, the dispersion calculation was carried out by evaluating Equations (7) and (7,a) at particular sets of x and y values for each toxic component, then evaluating Equation (8) to determine if a hazard existed. Practically, the downwind distance was successively incremented, and at each, the crosswind distance was incremented until the combined hazard ratio was less than unity. The computation was completed when the centerline (y = 0) concentrations (with successive downwind distances) showed a combined hazard ratio of less than unity.

Computational Results

The desired output of the computing program was an identification of the hazard corridor for a particular spill. It was considered that the hazard corridor was defined if the maximum downwind distance and the maximum crosswind distance of the hazard area were determined.

The computed output could have been used to determine the shape of the hazard area, but there are such a large number of variables in the conditions that it seemed appropriate to simply define a length (maximum downwind distance of hazard) and width (maximum crosswind distance of hazard).

The several variables, atmospheric conditions as well as spill dimensions were arbitrarily set for a "base case" for each of the propellant mixtures considered. Then, in order to determine the effects of the several variables independently, a series of computations were made wherein the selected variable was varied incrementally from the base case, and the results determined in the form of "correction factors". The correction factors derived from these calculations are plotted in the figures following. Tabulated values are presented in Appendix E.

Table I defines the "base case" conditions, and Table II shows the results of the base case calculation.

Table 1

DEFINITION OF BASE CASE SPILL CONDITIONS

Spill size:	36 m^3 (carload)
Spill area:	350 m^2
Spill diameter*:	20 m
Air temperature:	25°C
Ground temperature:	25°C
Wind speed:	3 m/s (6.7 miles/hr)
Stability class:	C
Relative humidity:	60%
Latitude:	30° North**, **Longitude:** 100° West**
Date:	266** (September 23), **Time:** 10:00 a.m.**
Cloud cover:	30%**

*Spill "diameter" is actually the distance across the pool in the direction of the wind.

**The date, time, location and cloud cover conditions result in an insolation (solar flux) of 440 w/m^2.

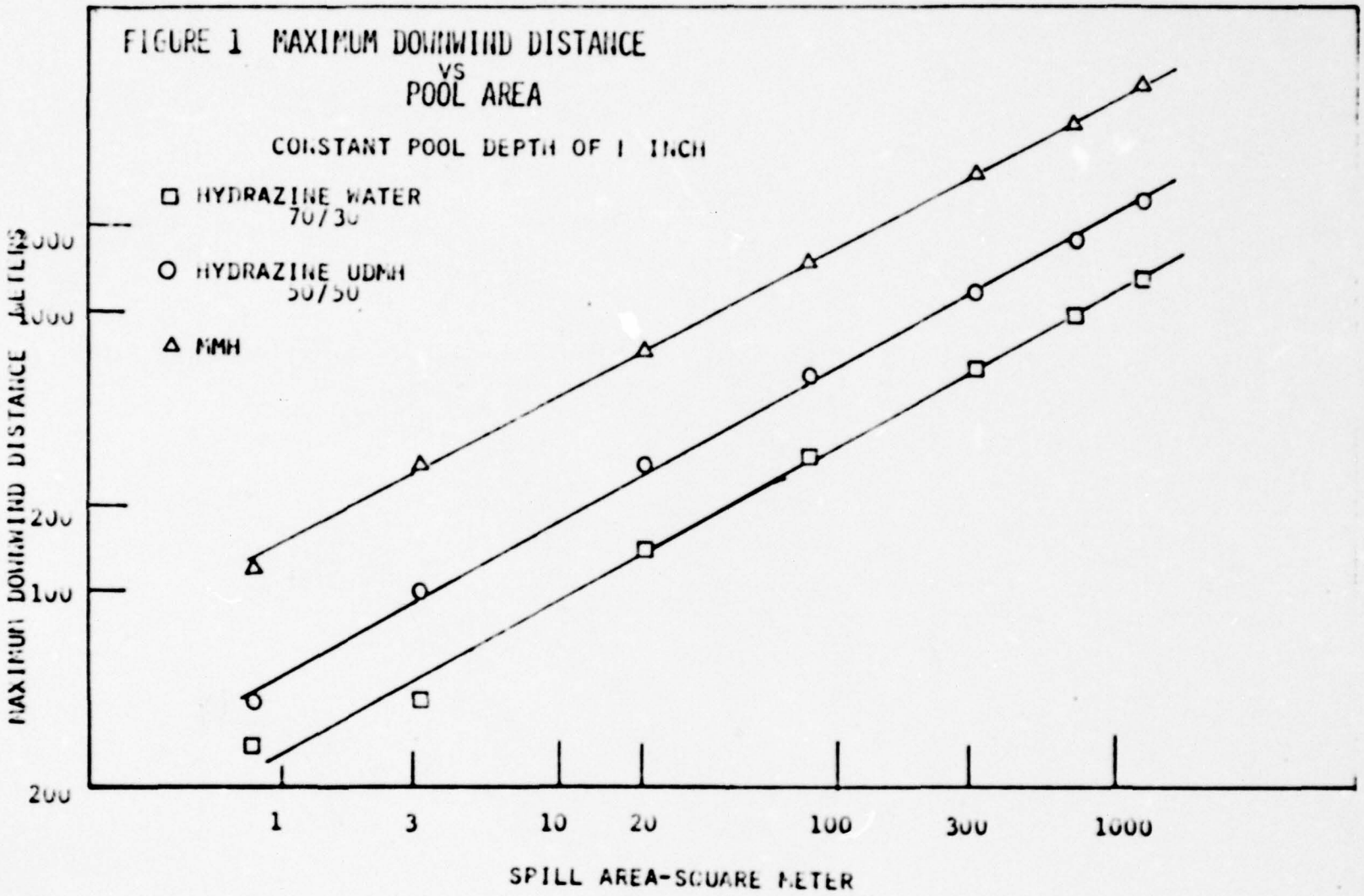
Table II

BASE CASE DISPERSION RESULTS

Mixture	Mass of Spill (kg)	Maximum Downwind Distance of Hazard (m)	Maximum Crosswind Distance of Hazard (m)	Amount of Water to Eliminate Hazard* (kg)
Hydrazine : water (70 : 30)	36070	360	35	216000
Hydrazine : UDMH (50 : 50)	32620	630	58	780000
MMH "pure"	31330	1630	138	4480000

*The amount of water which would be required to sufficiently dilute the spill so that it would no longer present a hazard was computed by assuming a hazard would no longer exist if the downwind distance of the hazard were no more than the pool diameter.

Since neither the downwind nor crosswind distances are linear in pool area, plots of those distances as functions of pool area are shown in Figures 1 and 2. The figures 3 through 10 are correction factors to the data presented in Figures 1 and 2.


FIGURE 1 MAXIMUM DOWNWIND DISTANCE
VS
POOL AREA
CONSTANT POOL DEPTH OF 1 INCH
HYDRAZINE WATER
70/30
HYDRAZINE UDMH
50/50
MMH
MAXIMUM DOWNWIND DISTANCE METERS
2000
1000
200
100
200
1
3
10
20
100
300
1000
SPILL AREA-SQUARE METER

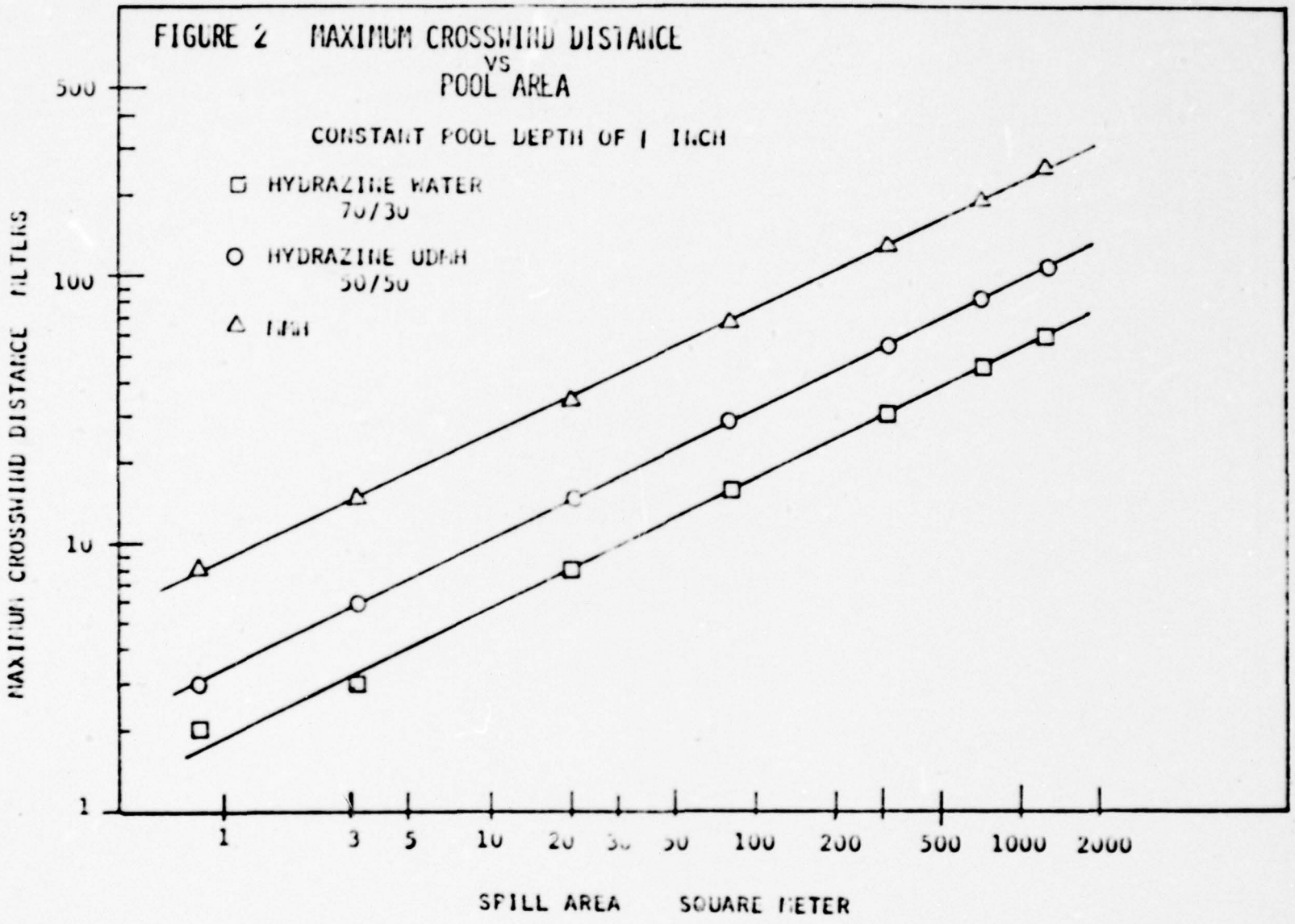

FIGURE 2 MAXIMUM CROSSWIND DISTANCE VS POOL AREA
CONSTANT POOL DEPTH OF 1 INCH
HYDRAZINE WATER 70/30
HYDRAZINE UDMH 50/50
UDMH
MAXIMUM CROSSWIND DISTANCE METERS
500
100
10
1
1
3
5
10
20
30
50
100
200
500
1000
2000
SPILL AREA SQUARE METER

FIGURE 3 CORRECTION FACTORS FOR AIR TEMPERATURE

(DOWNWIND AND CROSSWIND)

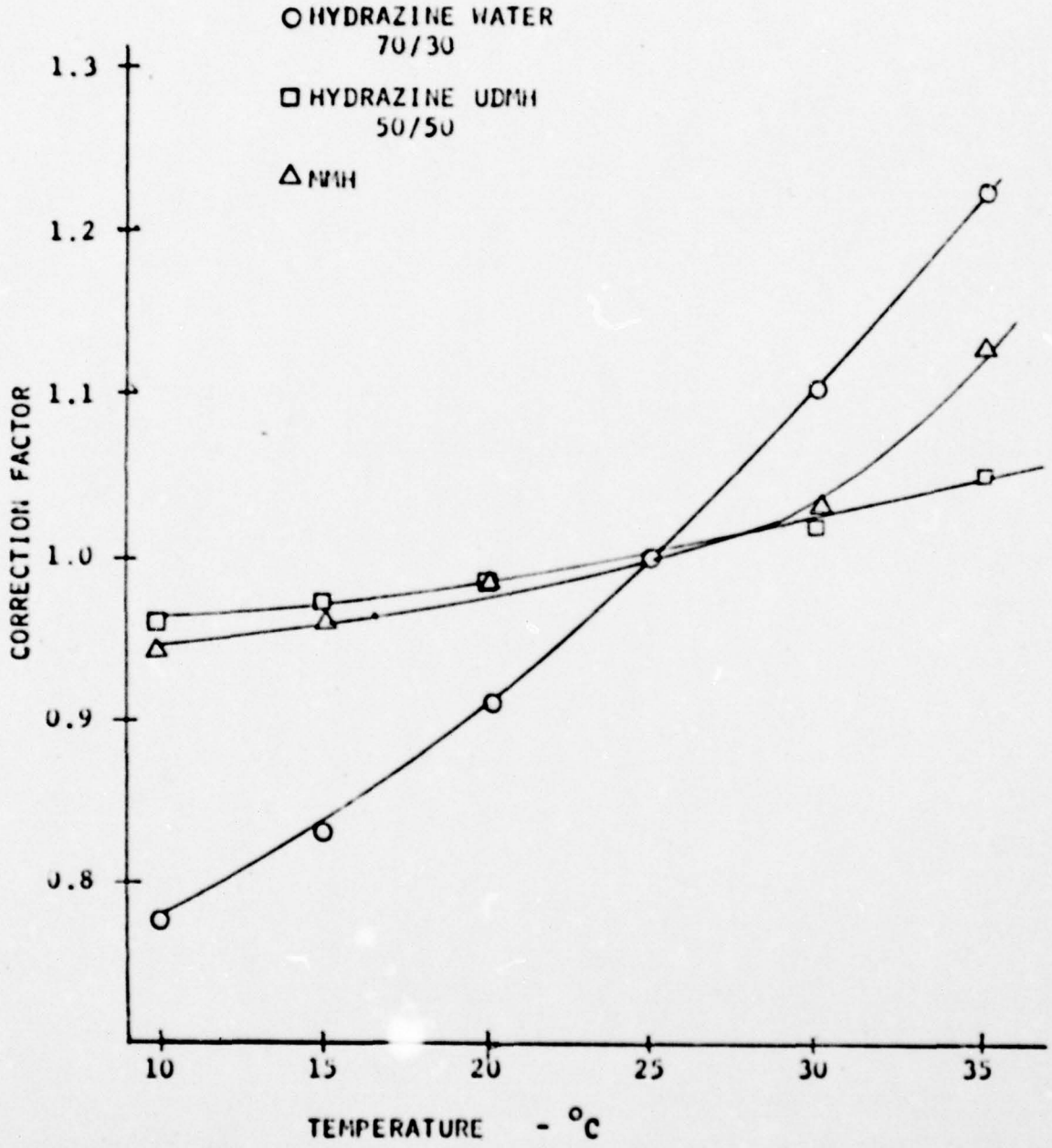


FIGURE 4 CORRECTION FACTORS FOR GROUND TEMPERATURE

(DOWNWIND AND CROSSWIND)

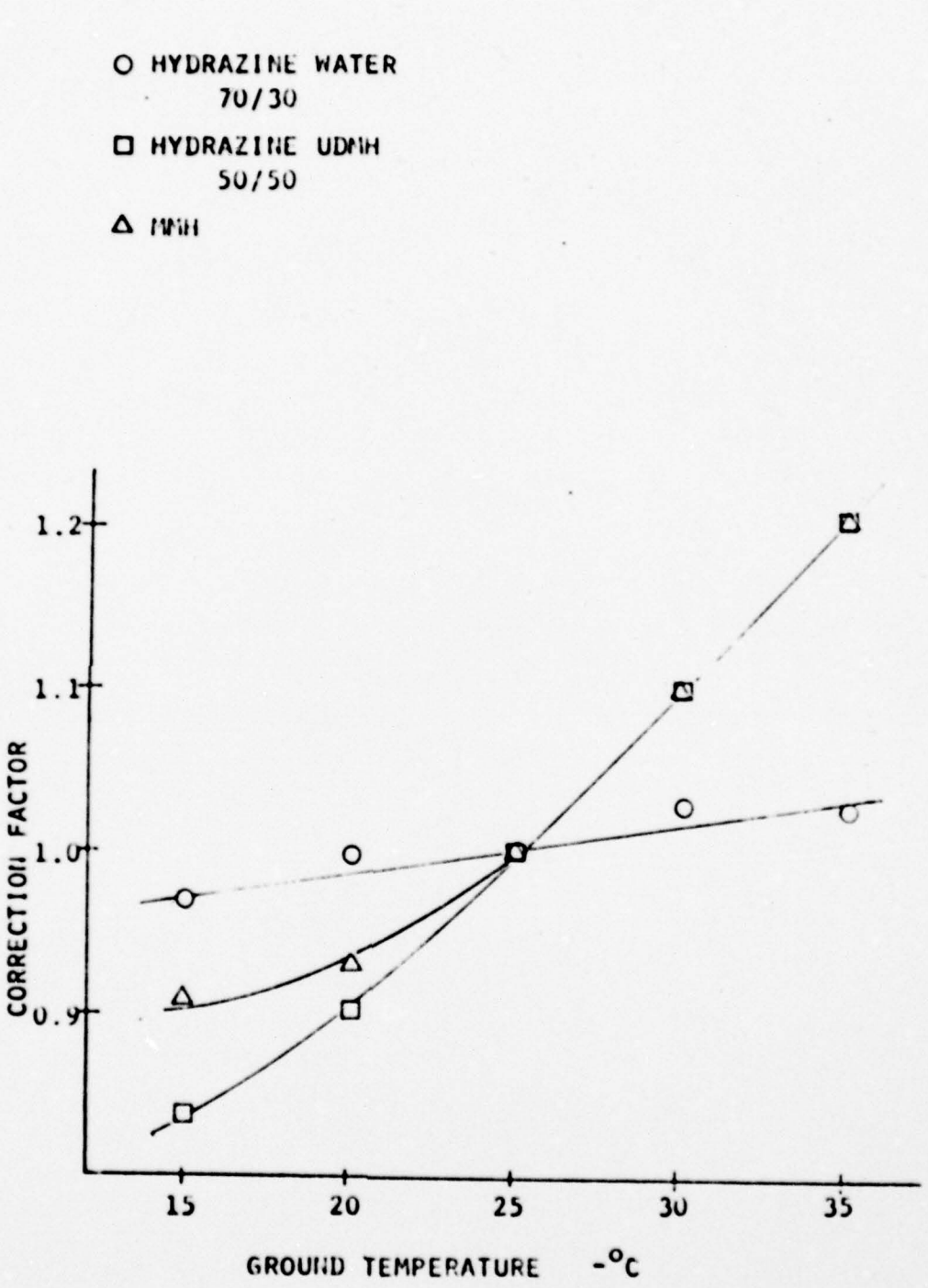


FIGURE 5 CORRECTION FACTORS FOR SOLAR FLUX

(BASE CASE FLUX = 440 W/M^2)

APPLIES TO BOTH DOWNWIND AND TO CROSSWIND MAXIMUM DISTANCES

○ HYDRAZINE WATER 70/30

□ HYDRAZINE UDMH 50/50

△ MMH

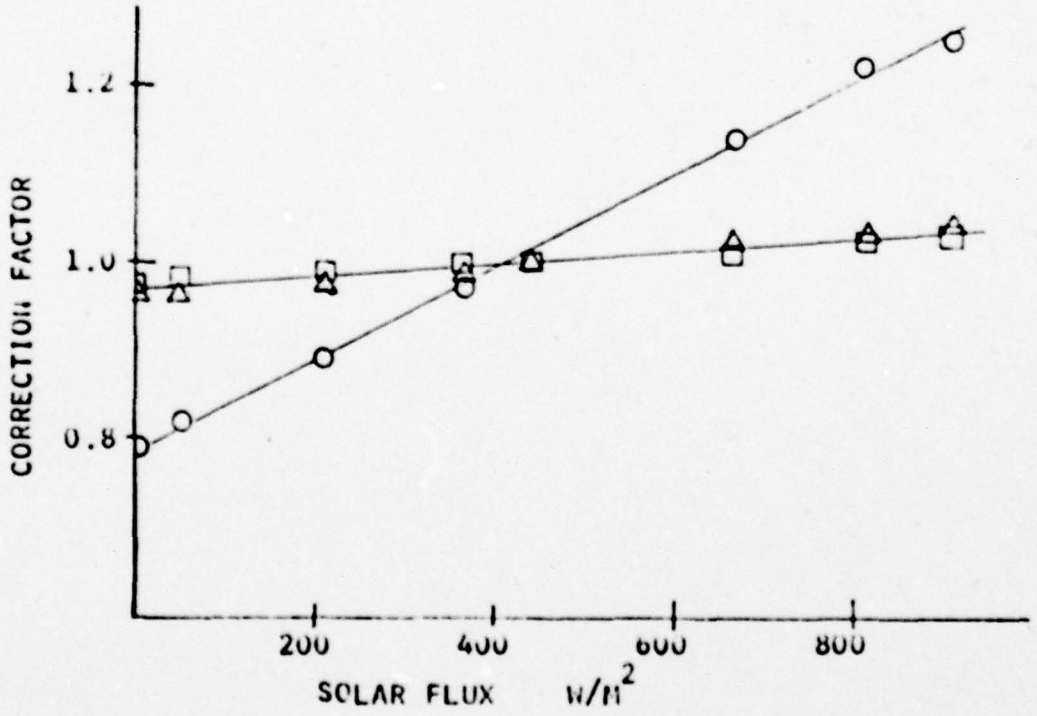


FIGURE 6
CORRECTION FACTOR FOR MAXIMUM DOWNWIND DISTANCE
VS
STABILITY CLASS

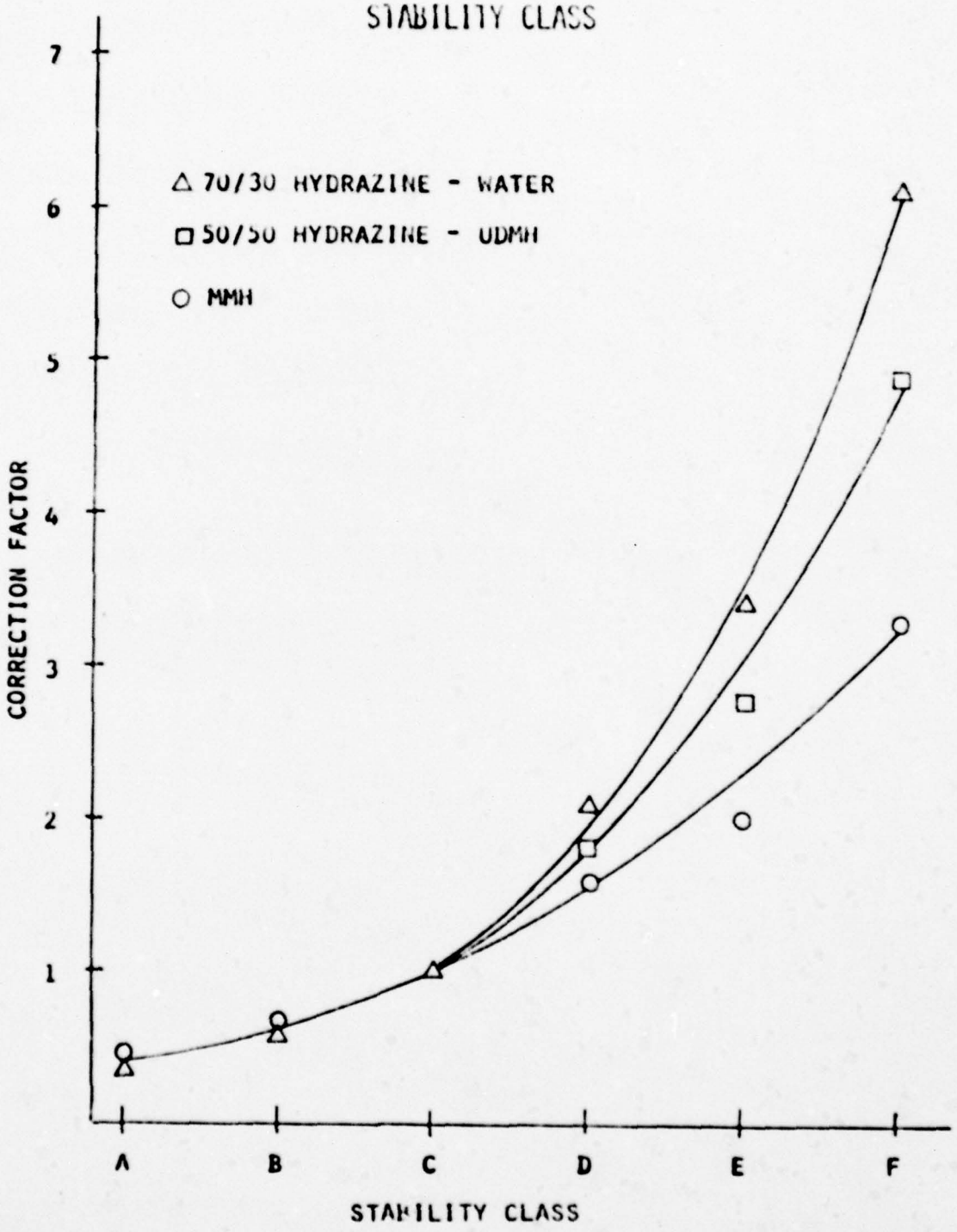


FIGURE 7 CROSSWIND CORRECTION FACTOR VS STABILITY CLASS

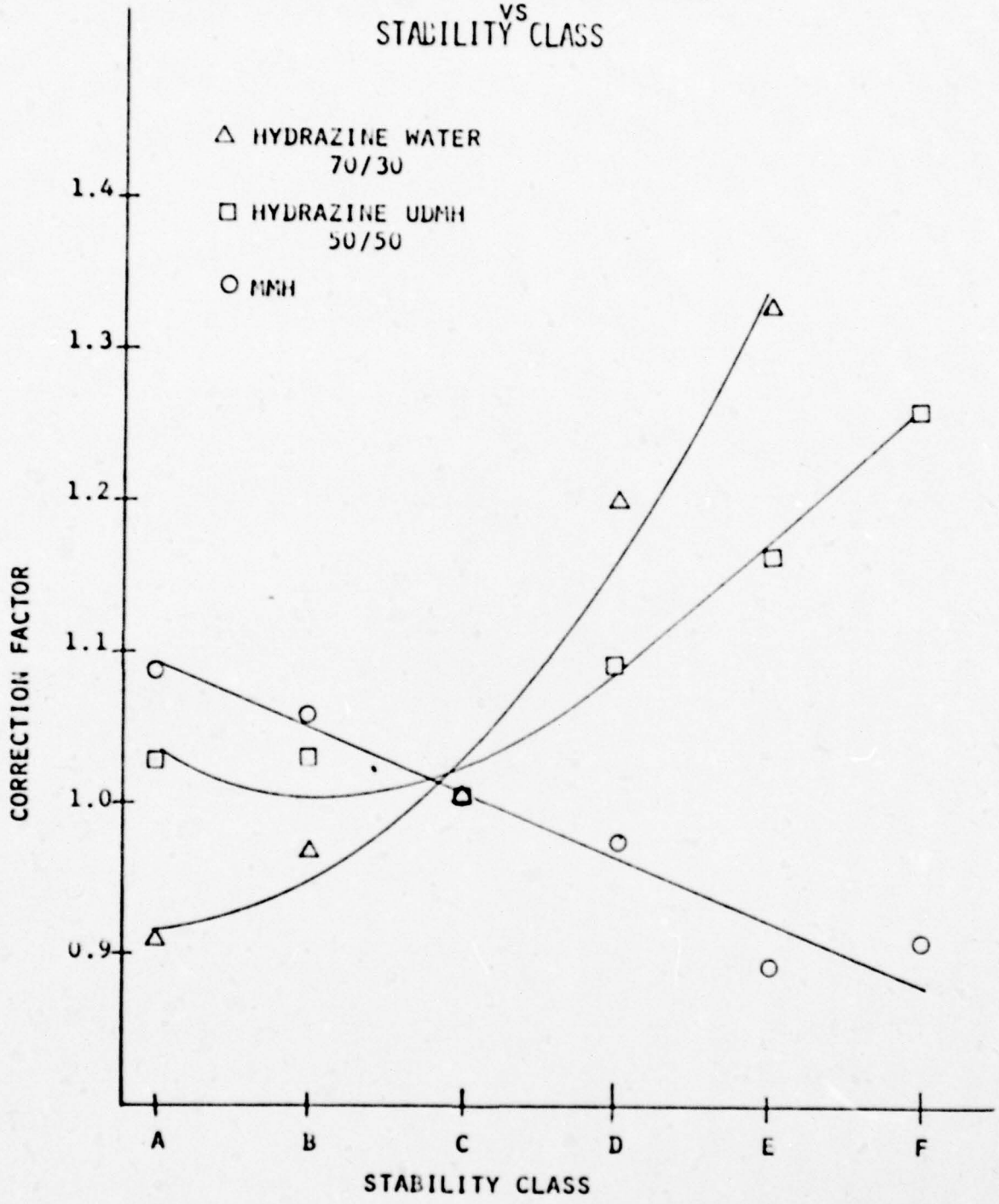


FIGURE 3 CORRECTION FACTORS FOR WIND VELOCITY

CURVE APPLIES FOR ALL MIXTURES, BOTH DOWNWIND AND CROSSWIND

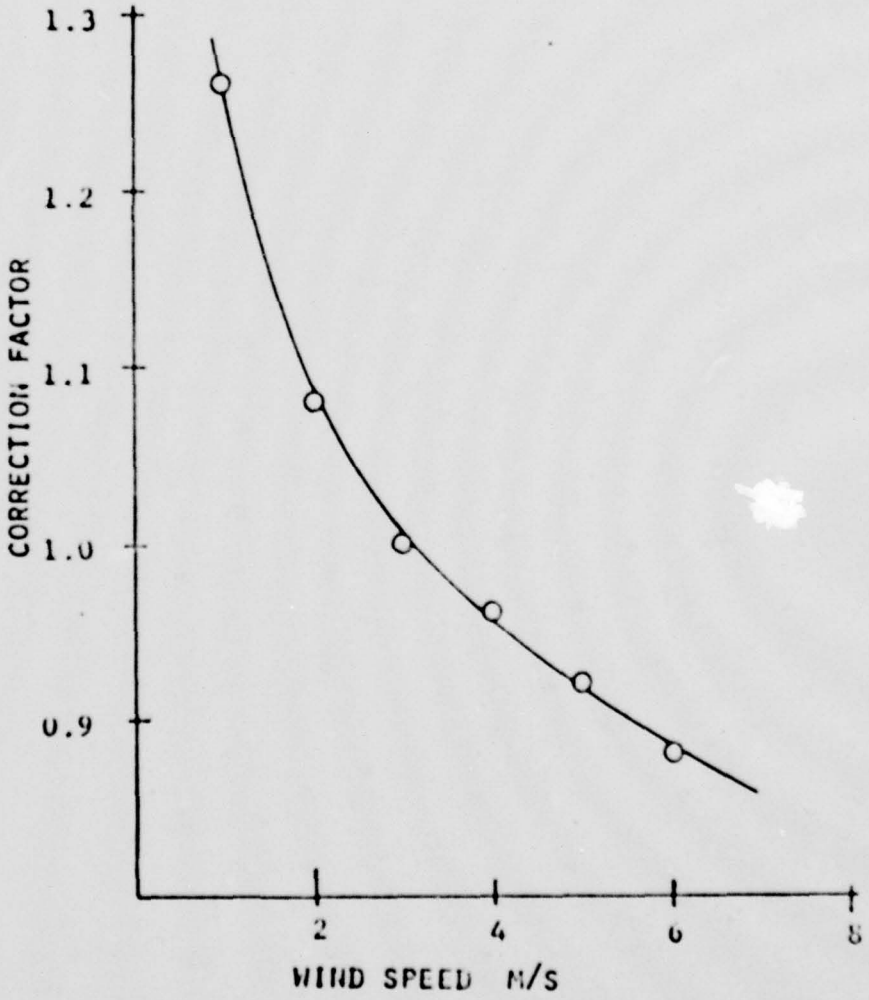


FIGURE 9 CORRECTION FACTORS FOR CLOUD COVER

(DOWNWIND AND CROSSWIND)

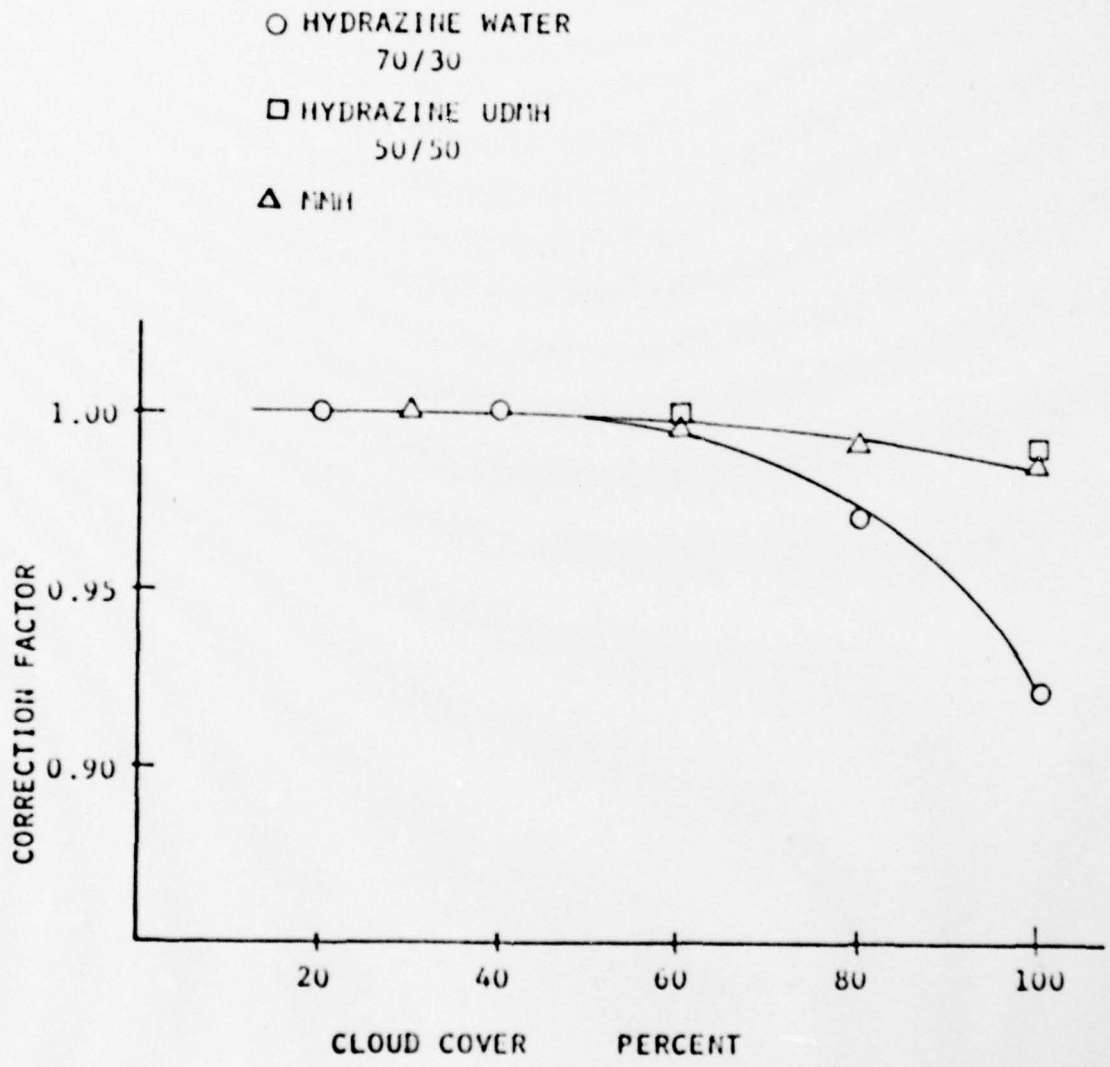
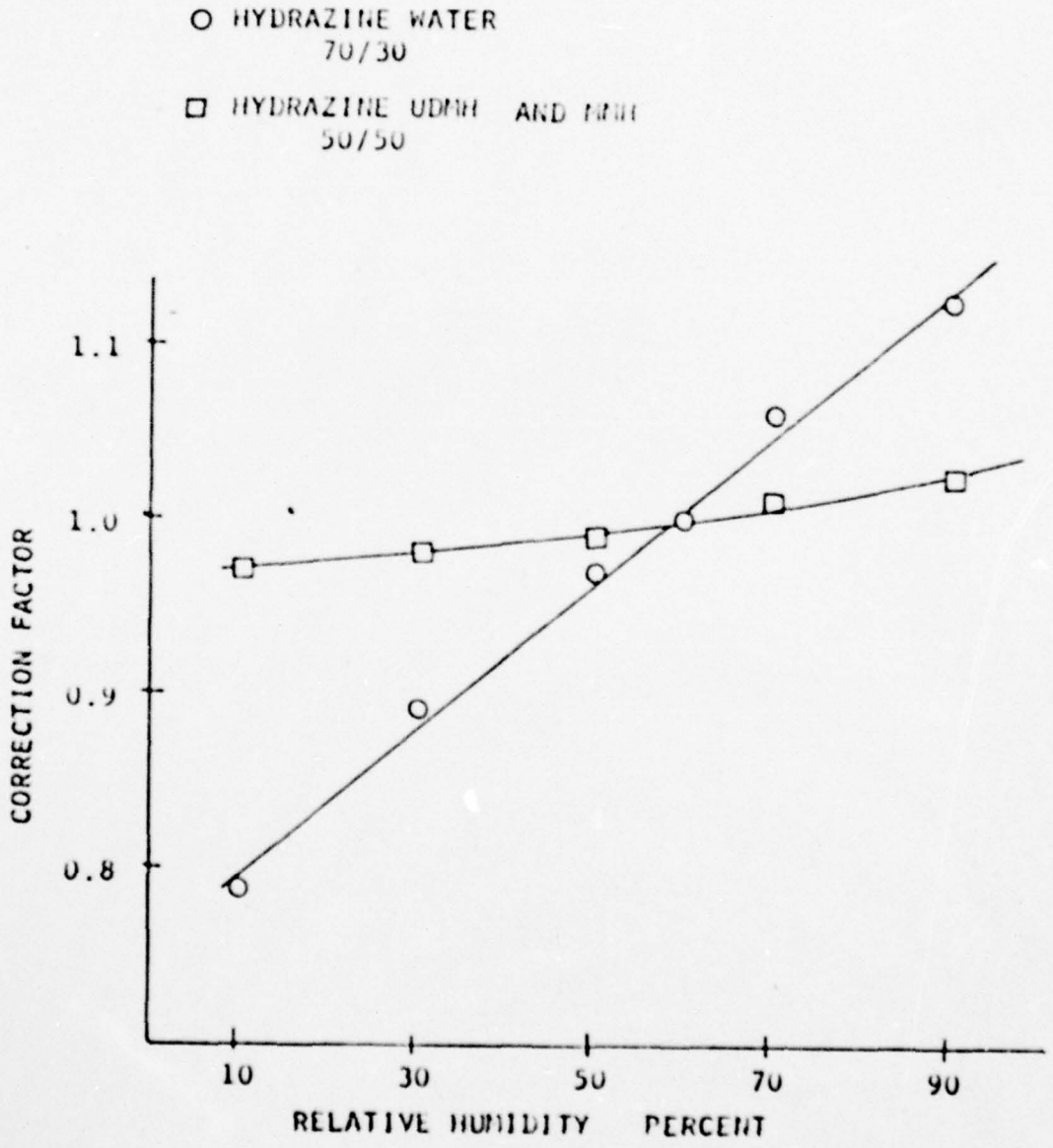


FIGURE 10 CORRECTION FACTORS FOR RELATIVE HUMIDITY
(DOWNWIND AND CROSSWIND)



Use of Pre-computed Results

In order to provide a method of rapid field estimation of the extent of a hazard corridor, the maximum distances of hazard presented in Figures 1 and 2 may be multiplied by one or more of the correction factors presented in the following Figures 3 through 10.

Comparisons between the computed result and the estimated result (using the correction factors) have indicated that the maximum difference between computed and estimated results would probably not exceed 20 percent, although all possibilities have not been explored. Also, for small spills, the use of distance increments of ten meters may introduce some additional rounding and truncating errors. An error of 25 percent, if that were the case, would not be an excessive error for such a computation, and could actually be safely ignored when it is compared to the possible error in the dispersion calculations. Turner (15) points out that the dispersion calculation result will be "within a factor of three" of the actual concentration when the terrain and circumstances agree reasonably well with the assumptions of the model.

An example of the use of the precomputed results follows:

Example case:

Spill of 250 kg of MMH with a spill area of 10 m^2

Rel. Humidity = 40%

Cloud Coverage = 0%

Wind Speed = 2 m/s

Stability Class = B

Air Temperature = 30°C

All other conditions similar to "Base Case".

From Fig. 1, the downwind maximum is 250 m

From Fig 2, the crosswind maximum is 21 m

Air temperature correction, Fig. 3, is 1.03

Stability class correction: Fig. 6, Downwind, 0.6; Fig. 7, Crosswind, 0.97

Wind velocity correction, Fig. 8, is 1.08

Cloud cover correction, Fig. 9, is 1.00

Relative humidity correction, Fig. 10, is 0.98

Estimated values:

Downwind max. = 250 x 1.03 x 0.6 x 1.08 x 1.00 x 0.98 = 163 m

Crosswind max. = 27 x 1.03 x 0.97 x 1.08 x 1.00 x 0.98 = 29 m

The computed values for this case are:

Downwind max. = 170 m

Crosswind max = 28 m

Limitations of the Model:

While the model elements which have been assembled represent the state-of-the art in predicting evaporation, there are several areas of weakness among the components of the model. Each of these weaknesses are considered below, although in general it is not possible to evaluate the magnitude of error which would follow from possible inapplicability of assumptions or models.

Dispersion Estimates

As was mentioned in the preceeding, the dispersion estimation may have errors of substantial magnitude. Turner (15) suggests for level terrain, and for center-line concentrations close to the source, that the estimated value is within a factor of three, which seems to indicate a possible error of some 200 percent. Compared to this, the other errors in the model are not very significant.

Mass Transfer Model

The mass transfer model, Equation (1), taken from MacKay (10) is intended as a coefficient for a pure material evaporating, or if not pure, a well stirred mixture in the liquid pool. The reason is that the model assumes all the resistance of mass transfer is in the vapor film. It is probable, however, that a considerable liquid phase resistance will be present in most of the practical applications considered in this study; even, perhaps, the pure MMH, since it is hygroscopic and would develop a water rich layer immediately adjacent to the interface as water is absorbed from the atmosphere.

Although it would be difficult to quantify the effect of the error in this instance, it would be most significant for components which evaporate rapidly.

Equilibrium Concentrations

The binary and ternary system vapor-liquid equilibrium data are necessary for predicting the concentration driving force. All the vapor-liquid equilibrium

data which were available for this study were at one atmosphere total pressure of transported component, that is, at the bubble point (boiling point) of the materials. Actually, the partial pressures, and hence the temperatures, will be much lower than that of the data.

To use this data, it was assumed that the activity coefficients were functions only of composition. For the binary system of hydrazine and water, the relation of activity coefficient to composition could be treated as a polynomial. However, for the ternary system of hydrazine-UDMH-water, the binary data had to be fitted to an integrated form of the Gibbs-Duhem Equation, in this case, the Marqules Equation (7, 8) in order to use the ternary form. The binary data did not fit the Marqules Equation well, and so there must be some error in the ternary predictions.

In the case of the MMH-water system, there were no data available at all, and were estimated as being intermediate between the other two binaries, hydrazine-water and UDMH-water.

The error from these assumptions, especially for the system MMH-water could be as high as seventy-five percent.

Other Errors

Most of the remaining errors are in the properties evaluations, such as viscosity, density, thermal conductivity and so forth of the mixtures. These errors will be relatively insignificant because of the much larger uncertainties of the dispersion model, and perhaps, the equilibrium concentrations.

Generally these properties were computed by recognized correlations, and will give results with less than ten percent error.

APPENDIX A

Property Evaluations and Miscellaneous Computational Methods

I. Properties of Liquid Mixtures:

The liquid properties of interest in these computations were:

Density, ρ

Viscosity, μ

Thermal Conductivity, k

Heat Capacity, c_p

Coefficient of Thermal Expansion, β

The methods of computation, including the effect of temperature on the property were generally as recommended by Reid and Sherwood (16).

Density

For a liquid mixture, the volume was assumed to be additive, hence the density was the mass fraction weighted sum, thus:

$$\rho_m = \sum_{i=1}^{n} X_i \rho_i \qquad \text{(A-1)}$$

where: X_i = mass fraction of component i and

ρ_i = density of component i.

Individual expressions for the density of each component as a function of temperature were obtained as polynomials, either as presented directly or by reduction of published data.

For hydrazine (9)

$$\rho = 1230.78 - 0.62668(T) - 4.5284 \times 10^{-4}(T^2) \qquad \text{(A-1-a)}$$

For UDMH (9)

$$\rho = 1060.41 - 0.77507(T) - 4.8648 \times 10^{-4}(T^2) \qquad \text{(A-1-b)}$$

For MMH (9)

$$\rho = 1150.34 - 0.93949(T) \qquad \text{(A-1-c)}$$

For water (17)

$$\rho = 1054.4 - 0.19241(T) \qquad \text{(A-1-d)}$$

For the above expressions, the density ρ is in kg/m^3 and the temperature is in kelvins.

Viscosity

The liquid mixture viscosities were determined from methods presented by Reid and Sherwood (6).

$$\log[\log(10\mu_m)] = \rho_m\left[\frac{\Sigma x_i I_i}{\Sigma x_i M_i}\right] - 2.900 \qquad \text{(A-2)}$$

In this expression, μ_m = mixture viscosity in centipoise

ρ_m = mixture density in g/cm^3

x_i = mole fraction of component i

M_i = molecular weight of component i

I_i = viscosity constant for component i

for hydrazine, I = 84.8

for MMH, I = 140.4

for UDMH, I = 196.0

for water, I = 59.8

The temperature effect on viscosity was treated by the "Souder's Method" as given in Reid and Sherwood (16) and this is included in the foregoing equation for the viscosity of liquid mixtures.

Thermal Conductivity

Thermal Conductivity of the liquid mixtures was treated by mole fraction weighting, thus:

$$k_m = \sum_{i=1}^{n} k_i x_i \qquad \text{(A-3)}$$

where: k_i = thermal conductivity of component i

x_i = mole fraction of component i

The individual component conductivities were determined as temperature function polynomials, either as directly presented or by reduction of published data (9, 17).

For hydrazine: $k = 0.088142 + 2.742 \times 10^{-3}(T) - 4.677 \times 10^{-6}(T^2)$ (A-3-a)

For UDMH: $k = 0.28841 - 4.262 \times 10^{-4}(T)$ (A-3-b)

For MMH: $k = 0.14236 + 9.2048 \times 10^{-4}(T) - 1.9014 \times 10^{-6}(T^2)$ (A-3-c)

For water: $k = 0.3427 + 9.178 \times 10^{-4}(T)$ (A-3-d)

The thermal conductivities are in w/m·K when the temperature, T, is in Kelvins.

Heat Capacity

The heat capacity values of the liquid mixtures were computed as mass weighted averages, thus:

$$C_{p_m} = \sum_{i=1}^{m} C_{p_i} X_i \qquad \text{(A-4)}$$

where: C_{p_i} = heat capacity of component i

X_i = mass fraction of component i

The component heat capacities were computed from temperature polynomials, either as directly presented or as deduced by data reduction (9, 17)

For hydrazine: $C_p = 1234.8 + 8.4488(T) - 7.7651 \times 10^{-3}(T^2)$ (A-4-a)

For UDMH: $C_p = 1703.3 + 3.6978(T)$ (A-4-b)

For MMH: $C_p = 2731.3 - 0.072316(T) + 2.4745 \times 10^{-3}(T^2)$ (A-4-c)

For Water: $C_p = 2512 + 6.147(T)$ (A-4-d)

where: C_p = heat capacity, J/kg·K

T = temperature, K

Coefficient of Thermal Expansion

The coefficient of thermal expansion was computed by noting the change in density with temperature:

$$\beta = \frac{\rho_2^2 - \rho_1^2}{2(T_1 - T_2)\rho_1\rho_2} \qquad \text{(A-5)}$$

where: ρ_1, ρ_2 = liquid mixture density at temperatures of T_1 and T_2 respectively.

This function was computed each time needed by finding the density at two different temperatures in the temperature region of interest.

II. Properties of Vapor Mixtures:

The vapor properties necessary for computation of the properties of the air/liquid surface film included:

density

viscosity

heat capacity

thermal conductivity

diffusivity

Schmidt no.

For the hydrazines, the basic information on vapor phase viscosity, heat capacity and thermal conductivity was taken as polynomials from the source previously cited (9). For water, these properties were generally taken from Kern (17). Additionally, the vapor film properties are predominately those of air. Air properties were taken generally from Perry (12).

The density was computed by assuming the validity of the ideal gas law.

Viscosity

The vapor phase component viscosities, μ_v, were computed from the following expressions:

For hydrazine: $$\mu_v = \frac{1.425 \times 10^{-6}(T)^{1.5}}{(T + 569.478)} \qquad \text{(A-6-a)}$$

For UDMH: $$\mu_v = \frac{1.1155 \times 10^{-6}(T)^{1.5}}{(T + 493.24)} \qquad \text{(A-6-b)}$$

For MMH: $$\mu_v = \frac{1.2313 \times 10^{-6}(T)^{1.5}}{(T + 530.23)} \qquad \text{(A-6-c)}$$

For water: $$\mu_v = 33.333 \times 10^{-8}(T) - 1 \times 10^{-7} \quad \text{(A-6-d)}$$

For air: $$\mu_v = \frac{1.45 \times 10^{-6}(T)^{1.5}}{(T + 116)} \quad \text{(A-6-e)}$$

The mixture viscosity was then computed by the following:

$$\mu_{v_m} = \frac{\sum_{i=1}^{n} \mu_{v,i} y_i (M_i)^{.5}}{\sum_{i=1}^{n} y_i M_i^{.5}} \quad \text{(A-7)}$$

where: $\mu_{v,i}$ = vapor phase viscosity in kg/m·5

y_i = mole fraction of component i in vapor

M_i = molecular weight of component i

T = temperature in Kelvins

Heat Capacity

Vapor phase heat capacities were computed by polynomial expressions of the form $C_{p_i} = a_i + b_i T + C_i T^2$. For the components, the following constants were used:

Component	a	b	c
hydrazine	1493.7	3.3133	1.0209×10^{-3}
UDMH	264.43	4.548	-1.5146×10^{-3}
MMH	355.22	4.1338	-1.34725×10^{-3}
water	1656.9	0.61297	1.0657×10^{-3}
air	970.69	0.067864	1.6569×10^{-3}

The heat capacity of the mixture, then was:

$$C_{p_m} = \sum_{i=1}^{m} y_i C_{p_i} \quad \text{(A-8)}$$

The above constants give heat capacity values in J/kg·K when temperatures are in Kelvins.

Thermal Conductivity

The vapor phase thermal conductivity was estimated by methods recommended by Reid and Sherwood (16), as viscosity and heat capacity functions. The component thermal conductivities were computed by the Eucken approximation as given by Perry (12).

$$k_i = M_i(C_{p_i} + 10393/M_i) \qquad \text{(A-9)}$$

where M_i is the component molecular weight. For the mixture, the thermal conductivity was computed by:

$$k_m = \frac{\sum_{i=1}^{m} y_i k_i M_i^{1/3}}{\sum_{i=1}^{m} y_i M_i^{1/3}} \qquad \text{(A-10)}$$

Diffusivity and Schmidt Number

The values for diffusivity of each component in air, and the corresponding Schmidt number were computed by methods given by Sherwood, Pigford and Wilke (18). These were precalculated as temperature functions for all the components of interest, so in use, the component and the temperature was all that was necessary to compute a value for Schmidt number or the binary diffusivity. No allowance was made for the mixture having more than two components. Each diffusivity, each Schmidt number, and hence, each mass transfer coefficient was determined as if it were the only component being transfered.

III. Computation of Mass Transfer Flux in the Absence of Wind.

In order to account for a small mass transfer effect that would occur in the absence of wind, Equation (1) had to be modified since it can, as written, account only for the turbulent transport.

Sherwood, et.al. (18) present a relation for predicting flux at the surface of a sphere under molecular diffusion. This relation can be rearranged to

give a static mass transfer coefficient, k_s of:

$$k_s = \frac{DP}{RTrP_{BM}} \qquad \text{(A-11)}$$

where: D = diffusivity,

P = pressure,

R = gas constant,

T = temperature, and

r = radius of the sphere.

P_{BM} = mean effective pressure of inert

The pool surface was likened to the surface of a sphere, and the equivalent radius, in terms of the pool area was found. The resulting expression is:

$$k_s = \frac{DP}{P_{BM}}\sqrt{\frac{2\pi}{A_p}} \qquad \text{(A-12)}$$

where A_p is pool surface area. This expression for static transfer was added to the expression for turbulent transport given in Equation (1).

IV. Computation of Equilibrium Vapor Compositions

The basic equation used to compute vapor equilibrium composition was:

$$y_i = \gamma_i X_i P_{v,i}/P \qquad \text{(A-13)}$$

where: y_i = vapor phase mole fraction of component i

γ_i = activity coefficitnt of component i

X_i = Required phase mole fraction of component i

$P_{v,i}$ = vapor pressure of component i

P = total pressure

The activity coefficient is a function of the liquid phase composition. The equation used in this work was the three-suffix Marqules equation. For a binary mixture:

$$\log \gamma_1 = X_2^2[A_{12} - 2X_1(A_{21} - A_{12})] \qquad \text{(A-14,a)}$$

$$\log \gamma_2 = X_1^2[A_{21} - 2X_2(A_{12} - A_{21})] \qquad \text{(A-14,b)}$$

The coefficients for a ternary mixture can be deduced from the binary data if the constants A_{12}, A_{21}, A_{13}, A_{31}, A_{23} and A_{32} are known, in which case:

$$\log \gamma_1 = X_2^2[A_{12} - 2X_1(A_{21} - A_{12})] + X_3^2[A_{13} + 2X_1(A_{31} - A_{13})]$$
$$+ X_2X_3[1/2(A_{21} + A_{12} + A_{31} + A_{13} - A_{23} - A_{32})$$
$$+ X_1(A_{21} - A_{12} + A_{31} - A_{13}) + (X_2 - X_3)(A_{23} - A_{32})]$$

For γ_2, the subscripts are rotated, 1 becoming 2, 2 becoming 3 and 3 becoming 1. For γ_3, the subscripts are rotated once more.

Nomenclature

a = heat capacity constant

A_p = area of liquid pool

A_{12}, A_{21}, A_{13}, A_{31}, A_{23}, A_{32} = binary activity coefficient constants

h = heat capacity constant

C_A = vapor phase concentration in bulk air

C_1 = vapor phase concentration at interface

C_p = heat capacity at constant pressure

$C_{(x,y)}$ = ground level concentration resulting from dispersion

D = diffusivity

h_a = heat transfer coefficient between air and pool

h_g = heat transfer coefficient between ground and pool

I = viscosity estimation constant

k = thermal conductivity

k_m = mass transfer coefficient

k_r = reaction rate constant

m = number of components

n = wind velocity profile power

P = pressure

P_{BM} = mean pressure of non-diffusing components

P_v = vapor pressure

P_r = Prandtl No.

q_a = heat flux from atmospheric radiation

q_g = heat flux from convective exchange between pool and ground

q_n = heat flux from convective exchange between pool and air

q_l = latent heat of vaporizing or condensing materials, expressed as flux

q_r = reradiation heat flux from pool

q_s = solar flux

Q_m = evaporative flux

r = radius of sphere equir to pool

R = universal gas constant

Sc = Schmidt number

T = temperature

Ta = temperature of the air

Tg = temperature of the ground

Tp = temperature of the pool

u = wend velocity

X = distance across pool, also mole fraction in liquid

x = mass fraction in liquid

y = mole fraction in vapor, also distance away from centerline

β = coefficient of expansion

γ = activity coefficient

μ = viscosity

ρ = density

σ = Steffan-Baltzman

σ_y = crosswind diffusion coefficient

σ_z = vertical diffusion coefficient

Subscripts (except as otherwise noted above)

i = component i

l = liquid

m = mixture

v = vapor

APPENDIX B

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APPENDIX C

Description of the Computer Program

A computer program was written (see Appendix D) to estimate the evaporation flux and the ground level concentrations which result from the dispersion. Figure 11 shows a simplified flow diagram.

The essential feature of the model is that when the temperature of the pool has been satisfactorily estimated, the flux can be readily deduced. However, since the evaporation flux has a significant bearing on the pool temperature, an iterative solution is indicated.

The program makes an initial assumption that the pool temperature is the same as the air temperature. After this assumption, all the properties and coefficients are evaluated and the evaporative flux computed. When the flux is computed, the energy balance is solved for the pool temperature using the Newton-Raphson method. If the new solution for the pool temperature is used immediately as a revised estimate, then under some conditions the overall solution diverges. Therefore, a damping factor is used to obtain a new temperature assumption.

When the solution has converged satisfactorily, then the last value of the evaporative flux is taken as the correct value and the program proceeds to compute an evaporation rate.

The evaporation rate is assumed constant for one second, and the amount of each component transfering in the one second period is subtracted from the pool inventory, so a new pool composition may be computed.

After each one second of evaporation, a new composition is used. The computation proceeds by summing the one second amounts for 36 seconds (0.01 hour). The average rate over the 36 seconds is then used for the dispersion calculations as the source strength.

For each ten meters down wind, the dispersion subroutine computes the ground-level concentration at the centerline and at incremental distances away from the

centerline until the result shows the concentration to be below the hazard level. That is, the downwind distance is incremented by ten meters, then the crosswind distance is incremented and so forth, until finally the centerline concentration is found to be below the hazard level.

Various output information is available; the actual output can be whatever is desired.

Among the variables computed which would be of interest as output are:

Crosswind distance of the hazard as a function of downwind distance;

Maximum crosswind distance of the hazard;

Maximum downwind distance of the hazard;

Evaporation rate of each component;

Liquid pool composition.

All of the above are computed for each 0.01 hour

The input data required are:

The composition of the original spill, mass fraction of hydrazine, UDMH, water and MMH;

The mass (kg) of the spill, the "diameter" (downwind distance across the pool) of the pool (m) and the pool area (m^2);

The time zone (from Greenwich), latitude, longitude (degrees), date, (Julian day), time (24 hr, decimal hours), the air temperature (°C), ground temperature (°C), wind velocity at 10 m elevation (m/s), relative humidity (percent), cloud coverage (percent), and the stability class integer, (1, 2, 3, 4, 5, 6 for A, B, C, D, E, F, respectively).

Since the program computes the evaporation and dispersion for one hour, new weather data may be read in for succeeding hours up to 24.

Subroutines

The main program calls the following subroutines as required:

Subroutine SOILH: Returns ground-to-pool heat transfer coefficient as a function of the pool composition, amount, area, temperature and the soil temperature.

Subroutine SKY: Returns long wavelength radiation flux and the partial pressure of water vapor from the atmosphere as functions of the air temperature, relative humidity, and cloud cover.

Subroutine SOLAR: Returns solar flux intensity as a function of date, time, latitude, longitude and cloud cover.

Subroutine AIRH: Returns air to pool heat transfer coefficient as a function of mass transfer coefficients, Schmidt numbers, vapor composition, air temperature and pool temperature.

Subroutine SCMIT: Returns Schmidt numbers and diffusivities for the transfered components in air as functions of the temperature of the pool and of the air.

Subroutine GAMMA: Returns equilibrium partial pressures for all transfered components as functions of composition and temperature of the pool.

Subroutine DISPER: Computes and prints the results of dispersion calculations. The input is the evaporation rate, which is the source strength, and weather data.

Appendix D contains a listing of the program and a sample of the output.

Variables Used in Computer Program

Variable Name	Variable Description
XI1, XI2, XI3, XI4	initial composition mass % of hydrazine, UDMH, water, and MMH, respectively
MASS	mass of the propellant spill, kg
DIA	diameter of the propellant spill, meters (downwind distance)
AREA	area of the spill, m^2
DATE	Julian day (1 to 366)
TIME	time, hours after midnight (0to 24)
TA	air temperature, °C (sometimes K, internally)
TG	ground temperature, °C (sometimes K, internally)
U	wind speed, m/s
RHUM	relative humidity, percent
KLAS	atmospheric stability class, numerical, 1 = A, 2 = B, etc.
MPRINT	output printing scheme variable
DELT	time constant in seconds used in calculations
EMIS	pool emissivity
GN	ground roughness factor and temperature factor in the atmosphere
POOLAB	pool absorptivity
PT	atmospheric pressure, Pa
TIN	initial time in hours after midnight
X1, X2, X3, X4	mass fraction of hydrazine, UDMH, water, and MMH, respectively
TP	computed temperature of the liquid pool, K
TCC	turbulent contribution to the mass transfer coefficient, m/s

Variables Used in Computer Program (continued)

Variable Name	Variable Description
PBM1, PBM2, PBM3, PBM4, PBM5	mean partial pressures of non-diffusing material, Pa
TC1, TC2, TC3, TC4, TC5	mass transfer coefficient for hydrazine, UDMH, water MMH, and CO_2, respectively
HVAP1, HVAP2, HVAP3, HVAP4	heat of vaporization for hydrazine, UDMH, water, and MMH, respectively, J/kg.
TPT	temporary pool temperature calculated by using Raphson-Newton method
EVAP1, EVAP2, EVAP3, EVAP4	evaporation flux of hydrazine, UDMN, water, and MMH, respectively
CO2	Diffusing flux of CO_2 into the liquid pool, kg mole/$m^2 \cdot s$
QVAP	evaporative heat loss of the propellant pool, J/m^2 s
CONST	solar flux + radiative heat gain from atmosphere - evaporative heat loss, W/m^2
XM1, XM2, XM4	mole fraction in propellant spill of hydrazine, UDMH, and MMH, respectively
XJ1, XJ2, XJ3, XJ4	weight percent of hydrazine, UDMH, water, and MMH, respectively
SUM1, SUM2, SUM3, SUM4	algebraic sum of the evaporation rates of the respective components over a 36 second time interval, kg/s
AVG1, AVG2, AVG3, AVG4	average evaporation rate over a 36 second time interval for hydrazine, UDMH, water, and MMH, respectively, kg/s
XM	downwind distance, m
YM	crosswind distance, m
CCE	centerline concentration equivalent (dimensionless ratio)
CC1, CC2, CC4	centerline concentration in µg/m^3
CCY1, CCY2, CCY4	concentration at YM, µg/m^3
XMDEL	increment of downwind distance, m

Variables Used in Computer Program (continued)

Variable Name	Variable Description
RXK1, RXK2, RXK4	reaction rate constants (first order), sec^{-1}
Q1, Q2, Q4	emission rates of components, kg/s
XK	downwind distance, km
SIGZ	dispersion coefficient in vertical direction, m
SIGY	dispersion coefficient in horizontal direction, m
ILAST	counting integer, dimensionless
INCR	print frequency increment
TF	average film temperature, K
SC1, SC2, SC3, SC4, SC5	Schmidt number for hydrazine, UDMH, water, MMH, and carbon dioxide, respectively
DIFF1, DIFF2, DIFF3, DIFF4, DIFF5	Diffusivity of hydrazine, UDMH, water, MMH, and CO_2 respectively, in air, m^2/s
GAM(1), GAM(2), GAM(3), GAM(4)	activity coefficient for hydrazine, UDMH, water, and MMH, respectively
VP1, VP2, VP3, VP4	pure component vapor pressure for hydrazine, UDMH, water, and MMH, respectively, Pa
W1, W2, W3, W4	mass of hydrazine, UDMH, water, and MMH, respectively, kg
HG	heat transfer coefficient between the ground and the liquid pool, W/m^2 K
Q	total mass of the spill, kg
T	temperature used in temp dependent expressions, K
DN1, DN2, DN3, DN4	liquid density of hydrazine, UDMH, water, and MMH, respectively, kg/m^3
DNLM	density of the liquid mixture, kg/m^3
DNMTG, DNMTP	liquid density of the mixture at the ground and pool temperature, respectively, kg/m^3
BETA	expansion coefficient, K^{-1}

Variables Used in Computer Program (continued)

Variable Name	Variable Description
TM	film temperature at the soil-pool interface, K
DNM	density of the liquid mixture at the film temp, kg/m^3
TK1, TK2, TK3, TK4	thermal conductivity of liquid hydrazine, UDMH, water, and MMH, respectively, W/m K
QM	total number of moles in the liquid pool, kg mole
CP1, CP2, CP3, CP4	liquid heat capacity of hydrazine, UDMH, water, and MMH, respectively, in J/kg K
TKM	thermal conductivity of the liquid mixture, W/m K
CPM	heat capacity for the liquid mixture, J/kg K
VISM	viscosity of the liquid mixture, kg/ m s
PRL	Prandtl number for the liquid mixture
DP	pool depth in meters
DT	temperature difference between the pool and ground, K
GR	Grashoff number
RA	Rayleigh number
A, B, C	constants used in the generalized heat transfer coefficient correlation, also in atmospheric emissivity correlation
CLOUDS	cloud coverage in percent
PH2O	partial pressure of water in the atmosphere, Pa
SKYRAD	radiant energy absorbed by the pool, W/m^2
EA	atmospheric emissivity
LAT	latitude, degrees (+ north and - south)
LONG	longitude, degrees (+ west and - east)
TZN	time zone number (hours behind Greenwich mean time)
SOLR	intensity of the total solar radiation incident on pool surface, W/m^2

Variables Used in Computer Program (continued)

Variable Name	Variable Description
F1, F2, F3, F4, F5	variables related to solar radiation as functions of the date
Z, W	direction cosines of direct solar beam
SALT	solar altitude, radians
CCM	cloud cover modifier
IDN	intensity of direct normal solar radiation, BTU/hr ft^2
ID	intensity of solar radiation incident on pool surface, Btu/hr·ft^2
SKY	sky diffuse radiation incident on surface, Btu/hr·ft^2
P1, P2, P3, P4	equilibrium partial pressure of hydrazine, UDMH, water, and MMH, respectively, Pa
H	heat transfer coefficient between the liquid pool and the air, $W/m^2 \cdot K$
WM(1), WM(2), WM(3), WM(4), WM(5)	molecular weight of hydrazine, UDMH, water, MMH, and air, respectively
Y(1), Y(2), Y(3), Y(4), Y(5)	average mole fraction in the pool-air film of hydrazine, UDMH, water, MMH, and air, respectively
DNF	molar density of the vapor film, kg·mole/m^3
CP(1), CP(2), CP(3), CP(4), CP(5)	gaseous heat capacity of hydrazine, UDMH, water, MMH, and air, respectively in J/kg·K
CPM	average molar heat capacity of the vapor film, J/kg mole·K
VIS(1), VIS(2), VIS(3), VIS(4), VIS(5)	gaseous viscosity of hydrazine, UDMH, water, MMH, and air, respectively, kg/m·s
VISM	average viscosity of the vapor film, kg/m·s
TK(1), TK(2), TK(3), TK(4), TK(5)	gaseous thermal conductivity for hydrazine, UDMH, water, MMH, and air, respectively, W/m·K
TKM	thermal conductivity of the vapor film mixture, W/m·K
CPF	average heat capacity of the vapor film mixture, J/kg·K

Variables Used in Computer Program (continued)

Variable Name	Variable Description
TC	average mass transfer coefficient of the vapor film mixture, m/s
SC	average Schmidt number of the vapor film mixture
PR	Prandtl number of the vapor film mixture at the film temp

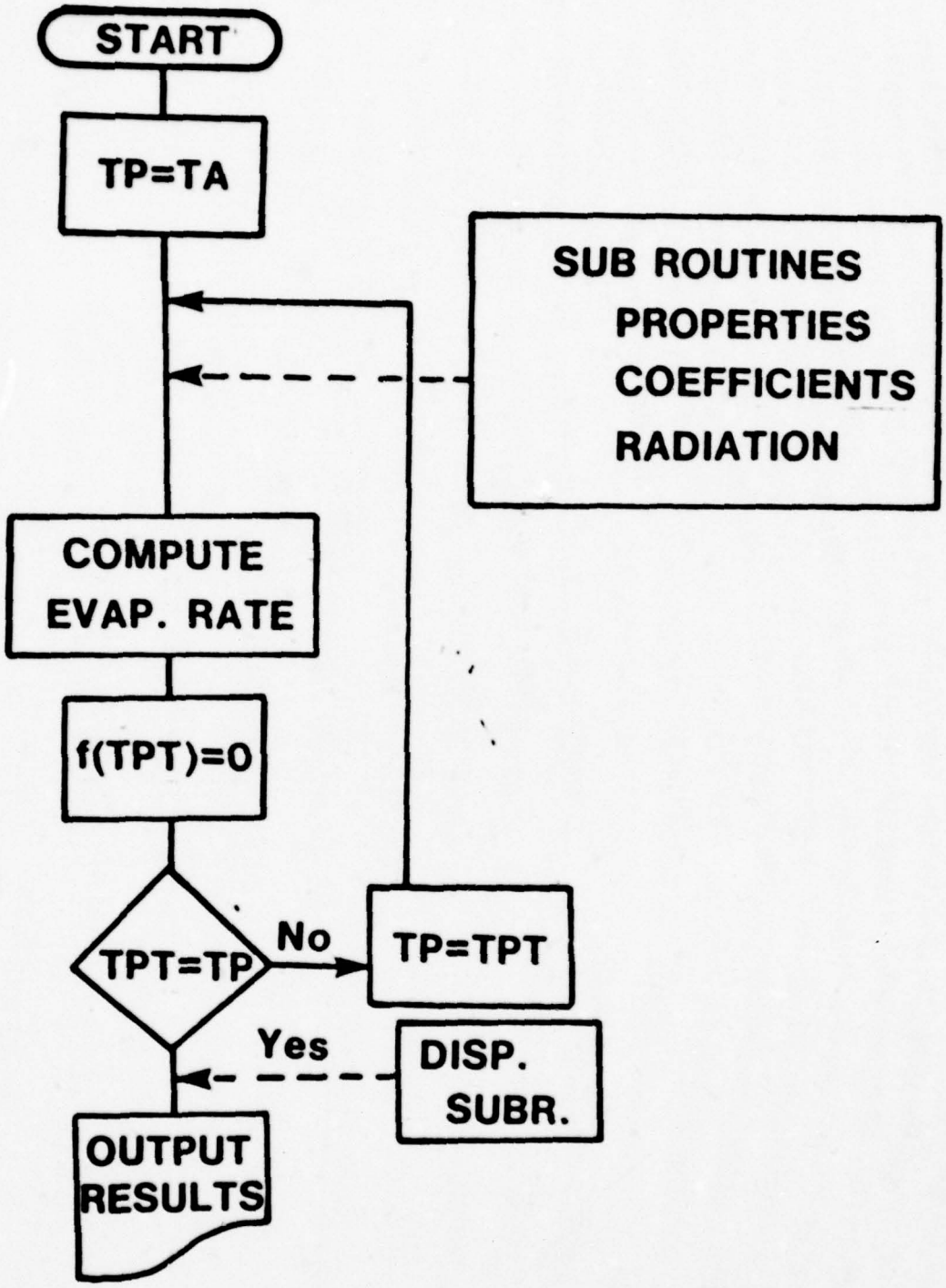


FIGURE 11 PROGRAM FLOW CHART

APPENDIX D

Printout of Computer Program and Typical Output

```
FORTRAN IV G LEVEL 21                MAIN                DATE = 79178        14/20/56            PAGE 0001

0001            REAL LAT,LONG,MASS
0002            DIMENSION A(4)
0003            DIMENSION FV1(34),FV2(34),FV3(34),FV4(36),AVG(4,10,10),DATE(6)
0004            READ(5,1100)I1,I2,I3,I4
0005         1100 FORMAT(4F10.3)
0006            READ(5,1) MASS,DTA,ADEA
0007            READ(5,1) TZN,LAT,LONG
0008            READ(5,2) DATE,TIME
0009          2 FORMAT(2F10.3)
0010            DO 10 I=1,24
0011            READ(5,10,END=28)TA,TG,U,RHUM,CLOUDS,KLAS
0012         10 FORMAT(5F10.3,I1)
0013          1 FORMAT(3F10.3)
0014            INTEGER A
0015            DATA A/'1','2','3','4','5','6'/
0016            DATA MMONIT/3/
0017            DATA DELT/30./
0018            DATA F/15.,20.,25.,30./
0019            DATA PI/3.1415/
0020            IF(KW.EQ.1) WRITE(6,4) MASS,DTA,ADEA
0021          4 FORMAT(1H1,4X,'INITIAL CHARACTERISTICS',62,'MASS =',F8.1,' KG',8X,
               >'DTA =',F5.1,' METERS',7X,'ADEA =',F4.1,' SQ METERS',/)
0022            IF(KW.EQ.1) WRITE(6,1005) TZN,LAT,LONG
0023       1005 FORMAT(4X,'TZN = ',F4.1,'     LATITUDE = ',F5.1,'     LONGITUDE =
               =',F5.1,/)
0024            IF(KW.EQ.1) WRITE(6,1004) DATE,TIME
0025       1004 FORMAT(4X,'DATE = ',F8.1,'     TIME = ',F5.2,/)
0026            IF(KW.NE.1) WRITE(6,30)
0027         30 FORMAT(1H1,///4X,'ATMOSPHERIC CONDITIONS',///)
0028            WRITE(6,7) U,RHUM,CLOUDS
0029          7 FORMAT(4X,'U =',F4.1,' METERS PER SECOND',5X,'REL HUMIDITY =
               =',F5.1,' PERCENT',5X,'CLOUD COVERAGE =',F5.1,' PERCENT',/)
0030            WRITE(6,3) TA,TG,KLAS
0031          3 FORMAT(4X,'TA =',F5.1,' C',10X,'TG =',F5.1,' C',11X,'STABILITY CLA
               >SS =',A1,/)
0032            IF(KW.EQ.1) WRITE(6,1000) I1,I2,I3,I4
0033       1000 FORMAT(4X,'INITIAL CONDITIONS',7X,'I1 =',F5.1,7X,'I2 =',F5.1,
               >7X,'I3 =',F5.1,7X,'I4 =',F5.1,///)
0034            IF(KW.EQ.1) WRITE(6,20) DELT
0035         20 FORMAT(4X,'TIME CONSTANT USED IN THIS CALCULATION =',F4.1,' SECONDS
               >',///)
0036            TT=TIME
0037            IF(((TIME+.01)-.GE.24.) TIME=0.
0038            TA=TA+273.2
0039            TG=TG+273.2
0040            IF(KW.NE.1) GO TO 33
0041            X1=I1/100
0042            X2=I2/100
0043            X3=I3/100
0044            X4=I4/100
0045         33 TOTA
0046            W1 = X1*MASS
0047            W2 = X2*MASS
0048            W3 = X3*MASS
0049            W4=X4*MASS
0050            WRITE(6,1007)
0051       1007 FORMAT(///29X,'EVAPORATION RATES, KG/SEC',22X,'COMPOSITION, WT %',
               >/)
```

```
                IF(X[N-1.EQ.0.) WRITE(6,1006)
                IF(X[N-1.NE.0.) WRITE(6,1066)
1066  FORMAT(1X,'TIME',  9X,'X',13X,'WATER',24X,'WATER',/)
1006  FORMAT(1X,'TIME',  9X,'X',9X,'HYDRAZINE',8X,'UDMH',9X,'WATER',12X,
     >'HYDRAZINE',7X,'UDMH',7X,'WATER',/)
                WRITE(6,1005)T,X
                DO 10 M=1,10
                DO 14 L=1,10
                DO 13 K=1,K1
                DO 8 J=1,100
                CALL SCHIFF(A,T0,SC1,SC2,SC3,SC4,SC5,DIFF1,DIFF2,DIFF3,DIFF4,DIFF5
               2)
                CALL GAMMA(V1,V2,V3,V4,T0,P1,P2,P3,P4)
                CALL SKY(T0,DH2O,CLOUDS,POOLAR,DH20,SKYDAD)
                Z1 = (Z-DH)/(Z+DH)
                Z2 = -(Z-DH)/(Z+DH)
                TCC=0.111E-A0(10.**(7400./(T0+460.)))*0.0[*0.0022
                DO=EXP(
                IF(P1.LE.0.) GO TO 20
                DO=DO*EXP(BLOG(PT/(PT-P1)))
                GO TO 21
           20   DO=DO*1
           21   IF(P2.LE.0.) GO TO 22
                DO=DO*EXP(BLOG(PT/(PT-P2)))
                GO TO 23
           22   DO=DO*1
           23   IF(P4.LE.0.) GO TO 24
                DO=DO*EXP(BLOG(PT/(PT-P4)))
                GO TO 25
           24   DO=DO*1
           25   IF(ABS(Z1-DH20).LE..001) GO TO 26
                DO=DO*EXP(BLOG((PT-DH20)/(PT-P1)))
                GO TO 27
           26   DO=DO*1.-DH20
           27   TC1=TCC/SC100.*7.0*DO*DIFF1/(.1000*ADF*00.*DODW1)
                TC2=TCC/SC200.*7.0*DO*DIFF2/(.1000*ADF*00.*DODW2)
                TC3=TCC/SC300.*7.0*DO*DIFF3/(.1000*ADF*00.*DODW3)
                TC4=TCC/SC400.*7.0*DO*DIFF4/(.1000*ADF*00.*DODW4)
                TC5=TCC/SC500.*7.0*DO*DIFF5/(.1000*ADF*00.*DODW5)
                CALL SCLAR(DATE,LAT,LONG,TIME,T2%,CLOUDS,SOLR)
                CALL SOILMTP(T0,V1,V2,V3,V4,ADFA,MG)
                CALL DIFW(T0,T8,P1,P2,P3,P4,DH20,SC1,SC2,SC3,SC4,TC1,TC2,TC3,
               2TC4,TC5)
                HYDR[1]=.36E+01*(EXP(-.7D)/355.)**.38
                HYDR2=.48E+01*(EXP(-.7D)/187.5)**.38
                HYDR3=.3E+01*(EXP(-.7D)/276.7)**.38
                HYDR4=.7E+01*(EXP(-.7D)/287.)**.38
                TDT = T0
                EVAP1=TC1*P1/(8314.*(T0+T))*12.05
                EVAP2=TC2*P2/(8314.*(T0+T))*44.1
                EVAP3=TC3*(P3-DH20)/(8314.*(T0+T))*18.02
                EVAP4=TC4*P4/(8314.*(T0+T))*64.08
                CO2=TCC*.0010*PT/(8314.*(T0+T))
                DVAP=EVAP1+HYDR1+EVAP2+HYDR2+EVAP3+HYDR3+EVAP4+HYDR4
                CO=STR*DVAP*.5*POOLAR-DVAP
                DO 5 I=1,30
                TDT=PT-((TC-TDT)*HC*(T8-TDT)*HC-EM[*5.05,ATF-(T0+TDT+460.+CONST)/
               2(-HC*HC-4.0*EM[*5.05,ATF-(T0+TDT+460.
```

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PROGRAM IV G LEVEL 21                    MAIN                    DATE = 76178        14/28/56        PAGE 0003

0104                  IF(ABS(TOT-TOT1).LE. .001) GO TO 4
0107               5  TOT = TOT
0108               6  TOTOTW4
0109                  IF(ABS(TP-TOT).LE. .01) GO TO 8
0110               8  TP = TP + .3*(TOT-TP)
0111               9  PW1(I)=(1/32.05)/(W1/32.05*W2/64.)+W3/10.82*W6/64.88)
0112                  PW2(I)=(1/64.1 )/(W1/32.05*W2/64.)+W3/10.82*W6/64.88)
0113                  PW6(I)=(1/64.88)/(W1/32.05*W2/64.)+W3/10.82*W6/64.88)
0114                  W1=W1*AGFASCF(TO(FV1P1,PW1(I)*2032.05)
0115                  W2=W2*AGFASCF(TO(FV2P2,PW2(I)*2064.1)
0116                  W3 = W3*FV3P3*AGFASCF
0117                  W6=W6*AGFASCF(TO(FV6P6,PW6(I)*2064.88)
0118                  IF(W1).LE.0)W1=0
0119                  IF(W2.LE.0)W2=0
0120                  IF(W3.LE.0)W3=0
0121                  IF(W6.LE.0) W6=0
0122                  IF(L.NE.1) GO TO 32
0123                  FV1(I)=1/(W1+W2+W3+W6)*100.
0124                  FV2(I)=W2/(W1+W2+W3+W6)*100.
0125                  FV3(I)=W3/(W1+W2+W3+W6)*100.
0126                  FV6(I)=W6/(W1+W2+W3+W6)*100.
0127              32  FV1(I)=FV1P1
0128                  FV2(I)=FV2P2
0129                  FV3(I)=FV3P3
0130                  FV6(I)=FV6P6
0131                  TOT=TOT
0132             10   TIME = TIME + DT(I)/3600
0133                  SUM1=0
0134                  DO 11 K=1,NJ
0135             11   SUM1=SUM1+FV1(K)
0136                  AVG1(L)=SUM1/NJ
0137                  SUM2=0
0138                  DO 12 K=1,NJ
0139             12   SUM2=SUM2+FV2(K)
0140                  AVG2(L)=SUM2/NJ
0141                  SUM3=0
0142                  DO 13 K=1,NJ
0143             13   SUM3=SUM3+FV3(K)
0144                  AVG3(L)=SUM3/NJ
0145                  SUM6=0
0146                  DO 15 K=1,NJ
0147             15   SUM6=SUM6+FV6(K)
0148                  AVG6(L)=SUM6/NJ
0149             16   CONTINUE
0150                  JM=10
0151                  IF(MOD(INT,50).EQ.2) JM=1
0152                  DO 17 I=1,4
0153             17   PRINT 1,I,AVG1(I),JM,W1,W2,W3,W6
0154                  W1=W1*W2*W3*W6
0155                  W1=W1/W1
0156                  W2=W2/W1
0157                  W3=W3/W1
0158                  W6=W6/W1
0159                  PW1=100.*W1
0160                  PW2=100.*W2
0161                  PW3=100.*W3
0162                  PW6=100.*W6
0163                  IF(MOD(INT,50).EQ.0.AND. W.NE.1) GO TO 16
```

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FORTRAN IV G LEVEL 21                    MAIN                    DATE = 79174          14/39/56                PAGE 0004

0140                IF(NOPRINT.EQ.1.AND.ITA.EQ.6.)WRITE(6,1000)TIME,DATE(1),DATE(2),DAT
                   >E(3),A41,A42,A43
0142                IF(NOPRINT.EQ.1.AND.ITA.NE.6.)WRITE(6,1000)TIME,DATE(4),DATE(3),A44
                   >,A45
0144                IF(NOPRINT.EQ.2.AND.ITA.EQ.6.)WRITE(6,1000)TIN,DATE(1),DATE(2),DATE(3),
                   >A51,A52,A53
0147                IF(NOPRINT.EQ.2.AND.ITA.NE.6.)WRITE(6,1000)TIN,DATE(4),DATE(3),A54,
                   >A55
0148          1000 FORMAT(8X,F5.2,3X,F5.1,5X,F9.3,4X,F10.3,3X,F5.1,9X,F4.1,7X,F6.1,
                   >/)
0149          1000 FORMAT(8X,F5.2,3X,F9.3,4X,F10.3,2X,F5.1,9X,F5.1,/)
0150            1A CONTINUE
0151                IF(NOPRINT.EQ.1) WRITE(6,1001)TIME,WT
0152          1001 FORMAT(//8X,'MASS OF THE SPILL REMAINING AT TIME = ',F5.2,
                   >' IS ',F9.1,' KG',/)
0154                IF(NOPRINT.EQ.1) WRITE(6,1010) TIN
0156          1010 FORMAT(1H1//8X,'DISPERSION CHARACTERISTICS AT TIME = ',F5.2,/)
0156                IF(NOPRINT.EQ.2) WRITE(6,31) TIN
0174            31 FORMAT(//////8X,'DISPERSION CHARACTERISTICS AT TIME = ',F5.2,/)
0177                CALL DISPER(AVG(1,1,1),AVG(2,1,1),AVG(4,1,1),XLAS,U,ETA,AREA)
0178                IF(NOPRINT.EQ.1) WRITE(6,1020) TIME
0179          1020 FORMAT(//8X,'DISPERSION CHARACTERISTICS AT TIME = ',F5.2,/)
0180                IF(NOPRINT.EQ.1)CALL DISPER(AVG(1,10,10),AVG(2,10,10),AVG(4,10,10),
                   >XLAS,U,ETA,AREA)
0181            1B CONTINUE
0182            2B CONTINUE
0183                STOP
0184                END

 OPTIONS IN EFFECT*   ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 OPTIONS IN EFFECT*   NAME = MAIN    , LINECNT =     60
 STATISTICS*    SOURCE STATEMENTS =     184,PROGRAM SIZE =    8904
 STATISTICS*  NO DIAGNOSTICS GENERATED
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FORTRAN IV G LEVEL 21          SOIL                DATE = 76178          14/20/56          PAGE 0001
0001                 SUBROUTINE SOIL(WITD,TD,W1,W2,W3,W4,ABFA,HG)
0002                 IF(435(TD-TG),LE,0,01) GO TO 27
0003                 DEW1=W2+W3*W4
0004                 T = TD
0005                 GO TO 57
0006              40 T = TG
0007              47 PW1 = 1.31E,TG-,43444E7-6,85E4F-40TW02,
0008                 PW2 = 1.44E,41-,77E87E7-6,84E4F-40TW02,
0009                 PW4=1.54,34-,8394E4F
0010                 IF(T-491,170,71,71
0011              70 PW3 = 443,95
0012                 GO TO 72
0013              71 PW3 = 1.54,4--,1E94]4F
0014              72 PW=W1-1.E71*W2*EXP(W3*W4*W)/0
0015                 IF(T,EQ,TG) GO TO 49
0016                 DWTD = DW1W
0017                 GO TO 50
0018              49 DWTG = DW1W
0019                 ZW1 = DWTD*E02,-DWTG*E03,
0020                 BETA=0.1[(1.2*(TD-TG)*DW*TD*DW*TG)
0021                 DEW = (DW*TD + DW*TG)/2,
0022                 TW = (TD + TG)/2,
0023                 TW1=,E8[1+2,7+3E-3*TW-4,47F-40TW02,
0024                 TW2=,2*61-4,3E3F-40TW
0025                 TW3=,3*77*4,13E-4*TW
0026                 TW4=,1*77*3,28E-4*TW-1,8816F-40TW02,
0027                 PW=1/32,05*VP/44,1*W1/18,02*W4/44,08
0028                 P1=1/32,05/PW
0029                 P2=1/44,1/PW
0030                 P3=1/18,02/PW
0031                 P4=1/44,08/PW
0032                 TW=1.0+2.0*P2+3.0*P3+4.0*P4
0033                 PB1=1716,5*,44*10**2,765E-3*TW02,
0034                 PB2=1716,3 + 3,4*TW
0035                 PB3=513, + 4,1*TW
0036                 PB4=2711,2-,8733*TW,2,67E5F-3*TW02,
0037                 PB=1.0+P1*W2*P2+W3*P3+W4*P4)/P
0038                 W1=1.*P1*W2/PB,W3=P3*W3/PB,W4=P4*W4/PB
0039                 P1=10.**(1.*W1/1000,-3,0)
0040                 V1=W + (10,**(1)/1000,
0041                 P01 = 1.0*(1.+W1/TW)
0042                 P0 = P*(1.+W1/TW)
0043                 DT = ABS(TG-TD)
0044                 CD=3,*P0*T*SQRT(1.0/W02,+(1.-W/V1)**2,
0045                 PR = V*W02
0046                 IF(TG-TD) 41,41,71
0047              71 IF(PR-1700,) 41,41,42
                 C  CONVECTION REGIME
0048              41 B=1.
0049                 B=1.
0050                 C=1.
0051                 GO TO 45
0052              42 IF(PR-1000,) 43,43,44
                 C  FORCING REGIME
0053              43 B=.0912
0054                 B=.9
0055                 C=.9
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FORTRAN IV G LEVEL 21                    SOILH                    DATE = 79178          14/28/56          PAGE 0002

0042                    GO TO 25
0050              66 IF(RA-9999.,OPDLOO,21) 65,65,66
                  C     LAMINAR REGION
0059              65 A=.24
0060                 B=.75
0061                 C=.25
0062                 GO TO 25
0063              66 IF(RA-10000.,OPDLOO,21) 67,67,68
                  C     TRANSITION REGION
0096              67 A=.3
0068                 B=.14
0069                 C=.31
0070                 GO TO 25
                  C     TURBULENT REGION
0071              68 A=.1
0072                 B=.31
0073                 C=.34
0074              25 WRITE(IOOROPDLOOFOTAA/AA
0075                 RETURN
0076              27 WRITE.
0077                 RETURN
0078                 END

OPTIONS IN EFFECT*   ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
OPTIONS IN EFFECT*   NAME = SOILH    , LINECNT =     60
STATISTICS*    SOURCE STATEMENTS =       78,PROGRAM SIZE =     2904
STATISTICS*  NO DIAGNOSTICS GENERATED
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FORTRAN IV G LEVEL 21                    SKY                    DATE = 79178          16/20/56          PAGE 0001

0001                 SUBROUTINE SKY(TS,DHUM,CLOUDS,POOLS9,PH20,SKYRAD)
0002                 DIMENSION SKYRAD(100),TEMP(100),TEMP2(100),TEMP3(100),
0003                 IF(CLOUDS-20.) 120,120,121
0004           120   RA=.19
0005                 GO TO 124
0006           121   IF(CLOUDS-90.) 122,122,123
0007           122   RA=.13+.0006*(90.-CLOUDS)
0008                 GO TO 124
0009           123   RA=.07+(100.-CLOUDS)*.00195 =(100.-CLOUDS)**2.*.0000195
0010           124   CONTINUE
0011                 IF(CLOUDS-74.) 126,126,127
0012           126   RB=.79+.0010*CLOUDS
0013                 GO TO 128
0014           127   RB=.815+.0020*(CLOUDS-74.)
0015           128   FA = A + B*SQRT(.93/(1.+H2O*29.93/(1.+H2O*
0016                 SKYRAD = 5.67E-08*(T**4)*(RB-RA*
0017                 RETURN
0018                 END

OPTIONS IN EFFECT*   ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,MAP
OPTIONS IN EFFECT*   NAME = SKY       ,LINECNT =     60
STATISTICS*     SOURCE STATEMENTS =      18,PROGRAM SIZE =     988
STATISTICS* NO DIAGNOSTICS GENERATED
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```
FORTRAN IV G LEVEL 21          SOLAR          DATE = 79178      14/20/56          PAGE 0001

0001                SUBROUTINE SOLAR(F,LAT,LONG,T,TZN,CLOUDS,SOLR)
0002                REAL LAT,LONG,IDN,IO
0003                DIMENSION A0(5),A1(5),A2(5),A3(5),B1(5),B2(5),B3(5),F(5)
0004                DATA A0/.332,0,-.368,.66,-.1717,-.0005/
0005                DATA A1/-22.93,-.057,.36,.52,-.0344,-.041/
0006                DATA A2/-.298,0,.09,-.1.16,-.0033,-.0029/
0007                DATA A3/-.261,-.0015,-1.09,-.0026,-.0015/
0008                DATA B1/1.991,-.122,-.99,-.0067,-.0036/
0009                DATA B2/.003,-.154,-.18,0,-.0046/
0010                DATA B3/-.055,-.009,-.28,-.0009,-.0004/
0011                D = 0.01721417
0012                DO 13 I=1,5
0013             13 F(I)=A0(I)+A1(I)*COS(D0)+A2(I)*COS(2*D0)+A3(I)*COS(3*D0)+
                    B1(I)*SIN(D0)+B2(I)*SIN(2*D0)+B3(I)*SIN(3*D0)
0014                LAT = .01745329*LAT
0015                F(1) = .01745329*F(1)
0016                IF(ABS(TAN(LAT)*TAN(F(1))),GE,1.) GO TO 14
0017                HRD = ARCOS(-TAN(LAT)*TAN(F(1)))
0018                H = 15.*(T-12. + TZN + F(2) ) -LONG
0019                H = .01745329 * H
0020                IF ( ABS(H),GT,ABS(HRD) ) GO TO 14
                C   COMPUTE DIRECTION COSINES OF DIRECT SOLAR BEAM
0021                ZD = SIN(LAT)*SIN(F(1)) + COS(LAT)*COS(F(1))*COS(H)
0022                W = COS(F(1))*SIN(H)
                C   CALCULATE SOLAR ALTITUDE
0023                SALT = ARSIN(ZD)
                C   COMPUTE CLOUD COVER MODIFIER
0024                TC = CLOUDS/10.
0025                IF (SALT - .785398) 17,17,18
0026             17 CCM = .226+.0868*TC-.0178*TC**2 - .0045*TC**3.
0027                GO TO 23
0028             18 CCM=.934+.0338*TC+.0078*TC**2 - .0089*TC**3.
                C   COMPUTE INTENSITY OF DIRECT NORMAL SOLAR RADIATION
0029                IF(F(4)/7.,GE,10.) GO TO 16
0030             22 IDN = F(3)*EXP(F(5)*(F(4)/7)
                C   CALCULATE INTENSITY OF RADIATION INCIDENT ON SURFACE
0031                IF (Z-LE-0.) GO TO 20
0032                IO = IDN*D
0033                GO TO 21
0034             20 IO = 0.
                C   COMPUTE INTENSITY OF SKY DIFFUSE RADIATION
0035             21 SKY = CCM*IO
0036                SOLR = IO - SKY*ZD,15662
0037                GO TO 19
0038             16 SOLR = 0.
0039             19 CONTINUE
0040                LAT=57.295780*LAT
0041                RETURN
0042                END

OPTIONS IN EFFECT*   ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
OPTIONS IN EFFECT*   NAME = SOLAR      , LINECNT =     60
0000000016C0   SOURCE STATEMENTS =       42,PROGRAM SIZE =     0000
STATISTICS*  NO DIAGNOSTICS GENERATED
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FORTRAN IV G LEVEL 21                    AIRH                    DATE = 79178        14/20/56            PAGE 0001

0001                  SUBROUTINE AIRH(TP,T4,P1,P2,P3,P4,PH20,SC1,SC2,SC3,SC4,TC1,TC2,
                     *TC3,TC4,DT,M)
0002                  DIMENSION WW(5),TW(5),CP(5),VIS(5),Y(5)
0003                  DATA WW/32.,99.,68.,1.,18.,02.,44.,80.,28./
0004                  Y(1)=.5001/DT
0005                  Y(2)=.0003/DT
0006                  Y(3)=.50(P3-PH20)/DT
0007                  Y(4)=.5026/DT
0008                  Y(5)=1.-Y(1)-Y(2)-Y(3)-Y(4)
0009                  TF = .50(TP + T4)
0010                  DHF = 97/(43)6.60TF)
0011                  CP(1)=1.031,7.1,.9139E-1,.8200E-4*TF**2,
0012                  CP(2)=244.,63.6,.5490TF-1,.5164E-3*TF**2,
0013                  CP(3) = 1454.9 + .4139*TF + 1.0457E-3*TF**2,
0014                  CP(4)=355.,33.6,.1330TF-1,.3673E-4*TF**2,
0015                  CP(5)=470.,69.,.8479+6TF-1,.8949E-4*TF**2,
0016                  CPM=0
0017                  DO 88 I=1,5
0018               88 CPM=CPM+Y(I)*CP(I)/WW(I)
0019                  VIS(1)=1.425E-6*TF**.5/(TF+540.,4*TF)
0020                  VIS(2)=1.115E-6*TF**.5/(TF+693.,2*TF)
0021                  VIS(3)=1.3333E-6*TF-1.6-7
0022                  VIS(4)=1.231E-6*TF**.5/(TF+536.,2*TF)
0023                  VIS(5)=1.05E-6*TF**.5/(TF+110.,*TF
0024                  VISM=0
0025                  DO 87 I=1,5
0026               87 VISM=VISM+Y(I)*VIS(I)/WW(I)**.5
0027                  VISM=1/VISM
0028                  DO 86 I=1,5
0029               86 VISM=VISM+VIS(I)*WW(I)**.5
0030                  VISM=VISM/VISM
0031                  DO 98 I=1,5
0032               98 TW(I) = VIS(I)*(CP(I) + 1039./WW(I))
0033                  TWM=0
0034                  DO 91 I=1,5
0035               91 TWM=TWM+Y(I)*TW(I)*WW(I)**.5,3333
0036                  TWM=0
0037                  DO 92 I=1,5
0038               92 TWM=TWM+Y(I)*WW(I)**.3333
0039                  TWM=1/TWM
0040                  VISM=0
0041                  DO 96 I=1,5
0042               96 VISM=VISM+Y(I)
0043                  TC=(Y(1)*TC1+Y(2)*TC2+Y(3)*TC3+Y(4)*TC4)/VISM
0044                  SC=(Y(1)*SC1+Y(2)*SC2+Y(3)*SC3+Y(4)*SC4)/VISM
0045                  CPM=0
0046                  DO 93 I=1,5
0047               93 CPM=CPM+Y(I)*WW(I)
0048                  CPM=CPM/TWM
0049                  PR = TC*VISM*CPM/(SC*PH)*.67
0050                  RETURN
0051                  END

OPTIONS IN EFFECT*   ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
OPTIONS IN EFFECT*   NAME = AIRH      , LINECNT =      60
STATISTICS*   SOURCE STATEMENTS =      51,PROGRAM SIZE =    2376
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FORTRAN IV G LEVEL 21          BIOM          DATE = 79178          14/29/56          PAGE 0002

*STATISTICS*  NO DIAGNOSTICS GENERATED
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```
FORTRAN IV G LEVEL 21                SCHIT                DATE = 79178        14/20/56        PAGE 0001

0001                SUBROUTINE SCHIT(TA,TP,SC1,SC2,SC3,SC4,SC5,DIFF1,DIFF2,DIFF3,DIFF4
                   >,DIFF5)
0002                TF = (TA+TP)*.5
0003                SC1 = .797834 + 0.000318E-00TF
0004                SC2 = 1.22974 + 7.05716E-00TF
0005                SC3 = .63788 + 0.00168*00TF
0006                SC4=.3765+3.787E-00TF
0007                SC5=.7435+4.10288-00TF
0008                DIFF1=-1.22937E-00+.98A7E-00TF*
0009                DIFF2=-7.95853+.0*.9784EE-00TF
0010                DIFF3=-1.954[3E-00+.1756AE-00TF
0011                DIFF4=0.5099E-003+.0336E-0070
0012                DIFF5=-1.15815E-00.97185-00TF
0013                RETURN
0014                END

OPTIONS IN EFFECT*   NAME = SCHIT    , LINECNT =      60
OPTIONS IN EFFECT*   SOURCE,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
STATISTICS*   SOURCE STATEMENTS =        14,PROGRAM SIZE =       886
*STATISTICS*  NO DIAGNOSTICS GENERATED
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```
FORTRAN IV G LEVEL 21                    GAMMA          DATE = 79178      14/20/56          PAGE 0001

0001                SUBROUTINE GAMMA(X),W2,W3,W4,T,P1,P2,P3,P4)
0002                DIMENSION A(3,3),P(6),Q(6),GAM(6)
0003                DATA A/0.,.41,-.45,.566,0.,.052,-1.675,-.65,0./
0004                DO W1/32.05 + W2/48.1 + W3/18.02 + W4/44.00
0005                P(1) = (W1/32.05)/D
0006                P(2) = W2/48.1)/D
0007                P(3) = (W3/18.02)/D
0008                P(4)=(W4/44.00)/D
0009                IF(P(4).EQ.0) GAM(4)=.1954
0010                IF(P(2).EQ.0) GO TO 5001
0011                J = 2
0012                K = 3
0013                DO 105 I=1,3
0014                Q(I)=A(J,I)*P(J)+(A(I,J)+2.0*(I)*(A(J,I)-A(I,J)))*P(K)*P(K)+(A(I,K)
                   2.0*(I)*(A(K,I)-A(I,K)))*P(J)*P(K)*(.50*(A(J,I)+A(I,J)+A(K,I)+
                   0(A(I,K)-A(J,K)-A(K,J))+P(I)*(A(J,I)-A(I,J)+A(K,I)-A(I,K))+
                   0(P(J)-P(K))*(A(I,K)-A(K,J)))
0015                JOE
0016                ***
0017          104 CONTINUE
0018                DO 103 I=1,3
0019          105 GAM(I) = 10.0**Q(I)
0020          103 VOF= ***1.00/T +.5679160T -4.9084E-5*T**2.
0021                V01 = 10.00(VOF-7.38113)
0022                V02 = 10.00(5.8604P-07F.00/T-148001./T**2.)
0023                V03 = 10.00(0.2)358-2334.87/T)
0024                P1 = P(1)*GAM(1)*V01*1000.
0025                P2 = P(2)*GAM(2)*V02*1000.
0026                P3 = P(3)*GAM(3)*V03*(1325./760.
0027                VP60=0*(A,3268-1186.63)/T-1E3337.6/T**2)
0028                P4=(P(4)*VP60)*1000.*GAM(4)
0029                RETURN
0030          5001 GAM(1)=1000.(1.187295-1.-.6007720*(3)*P(3)-.4970660*(3)**4-.3660940
                   2P(3)**2)
0031                GAM(3)=1000.(-.6000000.,5543*A02*(3)+.6P15(A02*(3)**3-.5387680*(3)**5)
0032                IF(P(2).EQ.0.) GAM(2)=0.
0033                IF(P(4).EQ.0) GO TO 103
0034                GAM(2)=1000.(3.3687600*(4)-.6607074.9804702*(4)*P(4)+4.8070028(4)**3
                   2-1.817320*(4)**6)
0035                ACT32=1000.(.834625-4-.1260202*(4)+.2064712*(4)*P(4)-.5164360*(4)**
                   2+.4387330*(4)**6)
0036                GAM(4)=.50(GAM(1)+GAM(2))
0037                GAM(3)=.50(ACT32+GAM(3))
0038                GO TO 103
0039                END

0000000 IN EFFECT: NOSOURCE,NOLIST,NODECK,LOAD,NOMAP
OPTIONS IN EFFECT:  NAME = GAMMA    , LINECNT =     60
*STATISTICS*  SOURCE STATEMENTS =      39,PROGRAM SIZE =     2644
*STATISTICS*  NO DIAGNOSTICS GENERATED
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```
FORTRAN IV G LEVEL 21                    DISPER                    DATE = 79178          16/20/56          PAGE 0001

0001                  SUBROUTINE DISPER(AVG1,AVG2,AVG4,CLAS,U,Z12,AREA)
0002                  DIMENSION XW(1000),YW(1000),CCF(1000),CC1(1000),CC2(1000),
                     >CC4(1000),CCX(1000),CCX2(1000),CCY4(1000)
0003                  DATA XMOL,PAR1,PAR2,PAR4/28.8,3.338-5,.240,.07
0005                  IF(Z12.NE.0) WRITE(6,630)
0006                630 FORMAT(//3X,'DOWNWIND',4X,'CENTERLINE',4X,'CENTERLINE',4X,'CENTERL
                     >INE',4X,'WAX. WID',/3X,'DISTANCE',4X,'EQUIV CONC',7X,'CONC HYD',
                     >7X,'CONC. (DWN)',8X,'HAZARD',/)
0004                  IF(Z12.EQ.0) WRITE(6,630)
0007                630 FORMAT(//3X,'DOWNWIND',7X,'CENTERLINE',8X,'CENTERLINE',8X,'MAX. WID
                     >TH',/3X,'DISTANCE',7X,'EQUIV CONC',7X,'ACTUAL CONC.',9X,'HAZARD',/)
0008                  QL=AVG1*AREA
0009                  Q2=AVG2*AREA
0010                  Q4=AVG4*AREA
0011                  DO 510 I=1,1000
0012                  XW(I)=XMOL*I
                C     COMPUTE DISPERSION COEFFICIENTS
0013                  SIGY=U(I)/1000.
0014                  GO TO (501,502,503,504,505,506),CLAS
                C     STABILITY CLASS A
0015                501 IF(XW.LE..1)SIGZ=.122,8888E00,9667
0016                  IF(XW.GT..1.AND.XW.LE..15) SIGZ=158,8888E00],0562
0017                  IF(XW.GT..15.AND.XW.LE..2) SIGZ=170,2222E00],0932
0018                  IF(XW.GT..2.AND.XW.LE..25) SIGZ=179,5238E00],1242
0019                  IF(XW.GT..25.AND.XW.LE..3) SIGZ=217,4193E00],2666
0020                  IF(XW.GT..3.AND.XW.LE..4) SIGZ=258,8889E00],4696
0021                  IF(XW.GT..4.AND.XW.LE..5)  SIGZ=314,7503E00],7283
0022                  IF(XW.GT..5.AND.XW.LT.3.1)) SIGZ=453,8543E00,1144
0023                   IF(XW.GE.3.1)) SIGZ=5000.
0024                  SIGY=465.120E*ATAN((24.167-2.5334*ALOG(XW))/57.29578)
0025                  GO TO 507
                C     STABILITY CLASS B
0026                502 IF(XW.LT..2) SIGZ=90.4770E00,93194
0027                  IF(XW.GT..2.AND.XW.LE..4) SIGZ=98.4839E00,98332
0028                  IF(XW.GT..4.AND.XW.LE.3.)  SIGZ=109.3*E00],0971
0029                  IF(XW.GT.3.) SIGZ=5000.
0030                  SIGY=465.720E*ATAN((18.333-1.8096*ALOG(XW))/57.29578)
0031                  GO TO 507
                C     STABILITY CLASS C
0032                503 SIGY=465.120E*ATAN((12.5-1.0857*ALOG(XW))/57.29578)
0033                  IF(XW.LT.123.) SIGZ=61.16]E00,91445
0034                  IF(XW.GE.123.) SIGZ=5000.
0035                  GO TO 507
                C     STABILITY CLASS D
0036                504 SIGY=465.120E*ATAN((8.333-.7238*ALOG(XW))/57.29578)
0037                  IF( XW.LT..3)  SIGZ=34,6598E00,84976
0038                  IF(XW.GE..3.AND.XW.LT.1.) SIGZ=32.0030E00,81064
0039                  IF(XW.GE.1..AND.XW.LT.3.) SIGZ=32.0030E00,84403
0040                  IF(XW.GE.3..AND.XW.LT.10.) SIGZ=33.5040E00,60404
0041                  IF(XW.GE.10..AND.XW.LT.30.) SIGZ=34.650E00,56589
0042                  IF(XW.GE.30.) SIGZ=44.0578E00,51179
0043                  GO TO 507
                C     STABILITY CLASS E
0044                505 SIGY=465.120E*ATAN((4.25-.5428*ALOG(XW))/57.29578)
0045                  IF(XW.LT..1) SIGZ=24.340E00,8364
0046                  IF(XW.GE..1.AND.XW.LT..3) SIGZ=23.1110E00,82954
0047                  IF(XW.GE..3.AND.XW.LT.1.) SIGZ=21.6280E00,7566
0048                  IF(XW.GE.1..AND.XW.LT.3.) SIGZ=21.6280E00,63077
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0040                IF(XX.GE.2..AND.XX.LT.4.) SIGY=22.53*XX**.57154
0041                IF(XX.GE.4..AND.XX.LT.10.) SIGY=24.703*XX**.50527
0042                IF(XX.GE.10..AND.XX.LT.20.) SIGY=24.97*XX**.44714
0043                IF(XX.GE.20..AND.XX.LE.40.) SIGY=25.42*XX**.37615
0044                IF(XX.GT.40.) SIGY=47.618*XX**.29592
0045                GO TO 507
                C   STABILITY CLASS E
0046              506 SIGY=ABS(.128*ATAN((4.1447-.341*ALOG(XX))/57.29578))
0047                IF(XX.LT. .3) SIGZ=15.209*XX**.81558
0048                IF(XX.GE..3.AND.XX.LT..7) SIGZ=14.457*XX**.78407
0049                IF(XX.GE. .7 .AND. XX.LT.1.) SIGZ=13.953*XX**.68465
0050                IF(XX.GE. 1. .AND. XX.LT.2.) SIGZ=13.953*XX**.63227
0051                IF(XX.GE.2. .AND. XX.LT.3.) SIGZ=14.823*XX**.54503
0052                IF(XX.GE.3. .AND. XX.LT. 7.) SIGZ=16.187*XX**.46449
0053                IF(XX.GE.7. .AND. XX.LT.15.) SIGZ=17.836*XX**.41507
0054                IF(XX.GE.15. .AND. XX.LT. 30.) SIGZ=22.651*XX**.32681
0055                IF (XX.GE.30. .AND. XX.LE.60.) SIGZ=27.074*XX**.27436
0056                IF(XX.GT. 60.) SIGZ = 34.219*XX**.21716
0057                GO TO 507
                C   COMPUTE CENTERLINE CONCENTRATIONS
0058              507 CC1(I)=QQ1(I)/(3.14159*SIGY*SIGZ)*EXP(-.5*(YM(I)/SIGY)**2)
0059                CC2(I)=QQ2(I)/(3.14159*SIGY*SIGZ)*EXP(-.5*(YM(I)/SIGY)**2)
0060                CC4(I)=QQ4(I)/(3.14159*SIGY*SIGZ)*EXP(-.5*(YM(I)/SIGY)**2)
                C   COMPUTE COMBINED HAZARD RATIO
0061                CCC(I)=CC1(I)/7.+CC2(I)/30.*2+CC4(I)/2.0
0062                IF(CCC(I).LT.1.) GO TO 550
                C   COMPUTE DISTANCE OF HAZARD CONDITION
0063                YM(I)=2.*ALOG(CCC(I))-.5*ALOG(
0064                IF(I.GT.1) GO TO 499
0065                IF(YM(I).GT.YM(I-1)) IMAX=I
0066              499 CC1(I)=CC1(I)*EXP(-.5*(YM(I)/SIGY)**2.)
0067                CC2(I)=CC2(I)*EXP(-.5*(YM(I)/SIGY)**2.)
0068                CC4(I)=CC4(I)*EXP(-.5*(YM(I)/SIGY)**2.)
0069              510 CONTINUE
0070              550 ILAST=I-1
0071                IMAX=IMAX*(ILAST/20.+.8)
0072                IF (ILAST.LE.20)ICOR=1
0073                DO 560 I=ICOR,ILAST,IMAX
0074                IF(XX(2.EQ.0.AND.CC4(I).EQ.0)WRITE(6,530)XM(I),CCC(I),CC1(I),YM(I)
0075                IF(XX(2.EQ.0.AND.CC4(I).NE.0)WRITE(6,530)XM(I),CCC(I),CC4(I),YM(I)
0076                IF(XX(2.NE.0)WRITE(6,530)XM(I),CCC(I),CC1(I),CC2(I),YM(I)
0077              560 CONTINUE
0078                I=ILAST
0079                IF(XX(2.EQ.0.AND.CC4(I).EQ.0)WRITE(6,530)XM(I),CCC(I),CC1(I),YM(I)
0080                IF(XX(2.EQ.0.AND.CC4(I).NE.0)WRITE(6,530)XM(I),CCC(I),CC4(I),YM(I)
0081                IF(XX(2.NE.0)WRITE(6,530)XM(I),CCC(I),CC1(I),CC2(I),YM(I)
0082                WRITE(6,600) YM(IMAX),XM(IMAX)
0083              600 FORMAT(/6X,'MAXIMUM CONCENTRATION DISTANCE',6X,'YMAX =',F6.0,2X,
                   1'XMAX =',F6.0/)
0084                RETURN
0085              620 FORMAT(8X,F6.0,8X,F6.2,8X,F6.2,8X,F6.2,8X,F6.0)
0086              630 FORMAT(8X,F6.0,8X,F6.2,10X,F6.2,11X,F6.0)
0087                END
```

```
 OPTIONS IN EFFECT*   ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
 OPTIONS IN EFFECT*   NAME = DISPER   , LINECNT =   60
 STATISTICS*   SOURCE STATEMENTS =    87,PROGRAM SIZE =    4308A
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FORTRAN IV G LEVEL 21          DISPER          DATE = 79178          16/20/56          PAGE 0003

 *STATISTICS*  NO DIAGNOSTICS GENERATED

 *STATISTICS*  NO DIAGNOSTICS THIS STEP
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FPR-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED WAP,LIST,LET
      DEFAULT OPTION(S) USED ---SIZE=(32256,32576)

                                        MODULE MAP

CONTROL SECTION                         ENTRY
    NAME     ORIGIN   LENGTH             NAME   LOCATION     NAME   LOCATION     NAME   LOCATION     NAME   LOCATION
  $AIN          58      25TE
  $CILH       2588      17A
  $$$         27A8      3AA
  $CLSP       3314      7EA
  AIPM        3836      94A
  $CMIT       4AC8      17A
  GAMMA       4C98      89C
  DISPFR      5124      A8B2
  IHCS$AC*    5976      18A
  IHCS$ECM*   FAFA      10F
  IHCS$CN*    FCCA      109
  IHCS$EP*    FEAA      192
  IHCFD$PR*   10040     183
  IHCFCMXM*   101CA     F62
  IHCCMM2*    11116     AC1
  IHCSTNCT*   117FA     266
  IHCFCVTH*   11AA0     1195
  IHCFFVTH*   12C1A     542
  IHCFF10S*   13140     F48
  IHCF10S2*   14088     55A
  IHCE00X*    140D8     628
  IHCUNOT*    14C3A     198
  IHCS$00T*   14F38     165
  IHCOMM*     15078     88F
  IHCFTOCM*   15928     28E
  IHCUSTPL*   15C1A     1E8

                                        ALOG10      F938   ALOG        F96A
                                        ARCOS       FAEA   ARSIN       FAFE
                                        COS         FCCA   SIN         FCE8
                                        EXP         FFAA
                                        FDUMP       10040
                                        IHCOMM      101CA  FDIOCS@     10296  INTSWTCH    1110E
                                        $$OPARD     11590
                                        OTAN        117FA  TAN         11A0E  QTAN        11980
                                        ARCOMM      11AA0  FCVADUTP    11B0A  FCVLOUTP    11B9A  FCV2OUTP    11CF4
                                        FCV1OUTP    12088  FCVFOUTP    125AA  FCVCOUTP    127C4  INT&SWCM    12AAB
                                        ARITHM      12C1A  ADJSWTCH    12FB4
                                        FIOCS@      13160  FIOCSREP    13166
                                        ERRMON      14A00  IHCFRRE     14A1B
                                        SORT        14F38
                                        DFBUG@      15078  DRIVFER     15756  BUFADR      16AFA
                                        IHCTRCM     15980  ERRTRA      15990
```

ENTRY ADDRESS 00
TOTAL LENGTH 15E08

AAAAMAIN DOES NOT EXIST BUT HAS BEEN ADDED TO DATA SET

SPILL CHARACTERISTICS: MASS = 34070.0 KG DIA = 20.0 METERS AREA = 350.0 SQ METERS

ZPN = 4.0 LATITUDE = 37.0 LONGITUDE = 100.0

DATE = 244.0 TIME = 10.00

U = 3.0 METERS PER SECOND REL HUMIDITY = 40.0 PERCENT CLOUD COVERAGE = 30.0 PERCENT

TA = 25.0 C TG = 25.0 C STABILITY CLASS C

INITIAL COMPOSITIONS: A1 = 70.0 A2 = 0.0 A3 = 30.0 A4 = 0.0

TIME CONSTANT USED IN THIS CALCULATION =30.0 SECONDS

	EVAPORATION RATES, KG/SEC			COMPOSITION, WT %		
TIME, MIN	HYDRAZINE	UDMH	WATER	HYDRAZINE	UDMH	WATER
10.00	8.671E-01	0.0	-8.255E-01	70.0	0.0	30.0

DISPERSION CHARACTERISTICS AT TIME = 10.00

DOWNWIND DISTANCE	CENTERLINE EQUIV CONC	CENTERLINE ACTUAL CONC.	HAZ. WIDTH HAZARD
20.	212.79	1689.50	9.
40.	99.23	616.44	15.
60.	58.06	194.62	20.
80.	36.52	115.44	24.
100.	10.96	76.49	27.
120.	7.93	54.96	30.
140.	5.98	41.30	32.
160.	4.52	32.31	34.
180.	3.72	26.52	35.
200.	3.04	21.64	35.
220.	2.57	18.08	35.
240.	2.19	15.34	35.
260.	1.98	13.24	34.
280.	1.85	11.58	32.
300.	1.65	10.19	30.
320.	1.29	9.04	24.
340.	1.16	8.00	21.
360.	1.06	7.20	11.
380.	1.06	7.29	11.

PLUME CROSSWIND DISTANCES: YMAX = 35. AT X = 218.

ATMOSPHERIC CONDITIONS

U = 3.0 METERS PER SECOND RFL HUMIDITY = 50.0 PERCENT CLOUD COVERAGE = 30.0 PERCENT

TA = 27.0 C TG = 27.0 C STABILITY CLASS C

	EVAPORATION RATES, KG/SEC			COMPOSITION, WT %		
TIME, HR	HYDRAZINE	UDMH	WATER	HYDRAZINE	UDMH	WATER
11.00	0.9729-01	0.0	-0.1329-01	69.6	0.0	30.4

DISPERSION CHARACTERISTICS AT TIME = 11.00

DOWNWIND DISTANCE	CENTERLINE EQUIV CONC	CENTERLINE ACTUAL CONC.	MAX. WIDTH HAZARD
20.	274.38	1935.69	9.
40.	74.97	528.88	14.
60.	34.04	240.23	21.
80.	21.47	151.37	25.
100.	14.76	99.44	29.
120.	10.18	71.36	32.
140.	7.37	51.47	34.
160.	6.00	41.99	36.
180.	4.93	33.81	38.
200.	3.98	27.84	39.
220.	3.36	23.39	40.
240.	2.95	19.93	40.
260.	2.66	17.71	40.
280.	2.19	15.42	40.
300.	1.99	13.33	39.
320.	1.88	11.35	37.
340.	1.78	10.51	35.
360.	1.35	9.47	31.
380.	1.29	8.57	27.
400.	1.11	7.88	21.
420.	1.02	7.13	9.
420.	1.02	7.13	9.

MAXIMUM CROSSWIND DISTANCE: YMAX = 40. AT X = 250.

ATMOSPHERIC CONDITIONS

U = 3.0 METERS PER SECOND REL HUMIDITY = 60.0 PERCENT CLOUD COVERAGE = 30.0 PERCENT

TA = 29.0 C TG = 30.0 C STABILITY CLASS B

	EVAPORATION RATES, KG/SEC			COMPOSITION, WT %		
TIME, MIN	HYDRAZINE	UDMH	WATER	HYDRAZINE	UDMH	WATER
12.00	0.9618-01	0.0	-0.743E-02	69.2	0.0	30.8

DISPERSION CHARACTERISTICS AT TIME = 12.00

DOWNWIND DISTANCE	CENTERLINE EQUIV CONC	CENTERLINE ACTUAL CONC.	MAX. WIDTH HAZARD
20.	134.24	993.83	14.
40.	37.62	246.71	22.
60.	17.08	135.18	28.
80.	10.53	77.42	34.
100.	6.97	48.78	38.
120.	4.98	34.88	41.
140.	3.75	26.36	43.
160.	2.93	20.62	43.
180.	2.36	16.62	43.
200.	1.96	13.77	43.
220.	1.62	11.38	39.
240.	1.34	9.44	36.
260.	1.18	8.28	27.
280.	1.03	7.26	12.
300.	1.03	7.20	12.

MAXIMUM CROSSWIND DISTANCE: YMAX = 43. AT X = 200.

ATMOSPHERIC CONDITIONS

U = 3.0 METERS PER SECOND REL HUMIDITY = 65.0 PERCENT CLOUD COVERAGE = 30.0 PERCENT

TA = 30.0 C TG = 32.0 C STABILITY CLASS B

	EVAPORATION RATES, KG/SEC			COMPOSITION, WT %		
TIME, MIN	HYDRAZINE	UDMH	WATER	HYDRAZINE	UDMH	WATER
13.00	0.947E-01	0.0	0.691E-02	68.9	0.0	31.1

DISPERSION CHARACTERISTICS AT TIME = 13.00

DOWNWIND DISTANCE	CENTERLINE EQUIV CONC	CENTERLINE ACTUAL CONC.	MAX. WIDTH HAZARD
20.	137.27	960.88	14.
40.	38.18	266.27	23.
60.	18.53	129.71	29.
80.	11.53	76.14	34.
100.	7.83	69.14	38.
120.	5.83	35.11	41.
140.	3.78	26.43	43.
160.	3.05	20.47	45.
180.	3.18	14.44	47.
200.	2.75	14.38	48.
220.	1.93	11.44	39.
240.	1.38	9.71	35.
260.	1.18	8.34	27.
280.	1.06	7.35	13.
280.	1.06	7.35	13.

MAXIMUM CROSSWIND DISTANCE: YMAX = 43. AT X = 200.

ATMOSPHERIC CONDITIONS

U = 3.0 METERS PER SECOND REL HUMIDITY = 42.0 PERCENT CLOUD COVERAGE = 30.0 PERCENT

Ta = 31.0 C Ts = 34.0 C STABILITY CLASS B

	EVAPORATION RATES, KG/SEC			COMPOSITION, WT %		
TIME, MN	HYDRAZINE	UDMH	WATER	HYDRAZINE	UDMH	WATER
14.00	9.911E-01	0.0	-9.696E-02	68.5	0.0	31.5

DISPERSION CHARACTERISTICS AT TIME = 14.00

DOWNWIND DISTANCE	CENTERLINE EQUIV CONC	CENTERLINE ACTUAL CONC.	MAX. WIDTH HAZARD
20.	137.00	921.00	14.
40.	34.51	264.63	22.
60.	17.32	131.24	28.
80.	10.10	71.11	34.
100.	6.75	47.25	38.
120.	4.92	33.77	40.
140.	3.81	25.62	42.
160.	3.04	19.88	43.
180.	2.60	16.88	43.
200.	1.99	13.82	42.
220.	1.57	11.00	38.
240.	1.33	9.33	32.
260.	1.15	8.02	24.
270.	1.07	7.47	17.

MAXIMUM CROSSWIND DISTANCE: YMAX = 42. AT X = 200.

ATMOSPHERIC CONDITIONS

U = 3.0 METERS PER SECOND REL HUMIDITY = 62.0 PERCENT CLOUD COVERAGE = 30.0 PERCENT

TA = 31.0 C TG = 54.0 C STABILITY CLASS B

TIME, MIN	EVAPORATION RATES, KG/SEC HYDRAZINE	UDMH	WATER	COMPOSITION, WT % HYDRAZINE	UDMH	WATER
15.00	0.7295E-01	0.0	-0.1545E-01	68.2	0.0	31.8

DISPERSION CHARACTERISTICS AT TIME = 15.00

DOWNWIND DISTANCE	CENTERLINE DOSAGE	CENTERLINE ACTUAL CONC.	HAZARD WIDTH
10.	379.01	2467.30	0.
20.	105.15	734.87	13.
30.	49.47	347.47	18.
40.	29.16	204.38	22.
50.	19.32	135.37	25.
60.	13.89	96.68	28.
70.	10.38	72.68	30.
80.	8.13	56.81	32.
90.	6.53	45.72	34.
100.	5.36	37.46	35.
110.	4.51	31.58	36.
120.	3.86	26.98	37.
130.	3.37	23.51	38.
140.	2.99	20.95	38.
150.	2.68	18.81	38.
160.	2.43	16.97	38.
170.	2.22	15.54	37.
180.	2.03	14.18	36.
190.	1.87	13.09	35.
200.	1.73	12.06	34.
210.	1.61	11.21	33.
220.	1.50	10.47	31.
230.	1.40	9.77	29.
240.	1.31	9.16	27.
250.	1.23	8.60	25.
260.	1.16	8.11	23.
270.	1.09	7.66	21.
280.	1.04	7.26	19.
290.	1.00	6.91	17.
300.	0.96	6.59	15.

MAXIMUM CROSSWIND DISTANCE: WMAX = 38. AT X = 160.

APPENDIX E

Computed Results and Correction Factors

Table E-1

MAXIMUM CROSSWIND AND DOWNWIND DISTANCES AS A FUNCTION OF SPILL AREA WITH POOL DEPTH CONSTANT AT 1 INCH (2.54 cm)

		(70/30) Hydrazine : Water			(50/50) Hydrazine : UDMH			100% MMH		
Dia (m)	Area (m^2)	Mass (kg)	Crosswind Distance	Downwind Distance	Mass (kg)	Crosswind Distance	Downwind Distance	Mass (kg)	Crosswind Distance	Downwind Distance
1	0.79	20	2	14	18	3	20	17.4	8	60
2	3.14	80	3	20	72	6	50	69.5	15	140
5	20	500	8	70	452	15	140	434	35	360
10	79	2000	16	150	1810	29	290	1735	68	750
20	314	8000	31	310	7230	55	590	6940	131	1540
30	710	18000	46	480	16300	82	910	15600	193	2350
40	1260	32000	60	650	28900	107	1230	27800	253	3180

*Base weather conditions and locale:

TZN = 6
DATE = 266 Julian day
WIND SPEED = 3 m/sec
CLOUD COVERAGE = 30 percent
AIR TEMPERATURE = 25°C
GROUND TEMPERATURE = 25°C
LATITUDE = 37°N
LONGITUDE = 100°W
TIME = 10.00
REL. HUMIDITY = 60 percent
STABILITY CLASS: C

Table E-2

SORRECTION FACTORS FOR SOLAR FLUX

(Base Case: SOLR = 440 w/m^2)

Solar Flux	Hydrazine : Water (70/30)		Hydrazine : UDMH (50/50)		MMH (100%)	
(w/m^2)	downwind	crosswind	downwind	crosswind	downwind	crosswind
0	0.78	0.80	0.96	0.98	0.96	0.96
49	0.81	0.83	0.98	0.98	0.96	0.96
209	0.89	0.89	0.98	1.00	0.98	0.97
365	0.97	0.97	0.99	1.00	0.99	0.99
440	1.00	1.00	1.00	1.00	1.00	1.00
666	1.14	1.11	1.01	1.02	1.02	1.02
811	1.22	1.20	1.02	1.03	1.05	1.03
909	1.25	1.23	1.04	1.03	1.06	1.05
941	1.28	1.26	1.04	1.05	1.07	1.05
953	1.28	1.26	1.04	1.05	1.07	1.06

Table E-3

CORRECTION FACTORS FOR STABILITY CLASS

Stability Class	Hydrazine : Water (70/30)		Hydrazine : UDMH (50/50)		MMH (100%)	
	downwind	crosswind	downwind	crosswind	downwind	crosswind
A	0.44	1.09	0.43	1.03	0.33	0.91
B	0.64	1.06	0.63	1.03	0.58	0.97
C	1.00	1.00	1.00	1.00	1.00	1.00
D	1.58	0.97	1.79	1.09	2.11	1.20
E	1.97	0.89	2.75	1.16	3.40	1.33
F	3.28	0.91	4.87	1.26	6.13	1.56

Table E-4

CORRECTION FACTORS FOR WIND VELOCITY

Wind Speed (m/s)	Hydrazine : Water (70/30)		Hydrazine : UDMH (50/50)		MMH (100%)	
	downwind	crosswind	downwind	crosswind	downwind	crosswind
1	1.31	1.29	1.21	1.19	1.28	1.25
2	1.11	1.11	1.06	1.07	1.07	1.07
3	1.00	1.00	1.00	1.00	1.00	1.00
4	0.94	0.97	0.95	0.97	0.94	0.96
5	0.92	0.91	0.90	0.93	0.91	0.92
6	0.86	0.89	0.87	0.90	0.88	0.90

Table E-5

CORRECTION FACTORS FOR AIR TEMPERATURE

Air Temperature (°C)	Hydrazine : Water (70/30)		Hydrazine : UDMH (50/50)		MMH (100%)	
	downwind	crosswind	downwind	crosswind	downwind	crosswind
35	1.25	1.20	1.05	1.04	1.13	1.12
30	1.12	1.09	1.02	1.02	1.03	1.03
25	1.00	1.00	1.00	1.00	1.00	1.00
20	0.91	0.91	0.98	0.99	0.98	0.98
15	0.81	0.85	0.97	0.98	0.96	0.96
10	0.77	0.78	0.96	0.97	0.94	0.95

Table E-6

CORRECTION FACTORS FOR GROUND TEMPERATURE

Ground Temperature (°C)	Hydrazine : Water (70/30)		Hydrazine : UDMH (50/50)		MMH (100%)	
	downwind	crosswind	downwind	crosswind	downwind	crosswind
15	0.97	1.00	0.83	0.84	0.91	0.93
20	1.00	1.00	0.90	0.91	0.92	0.93
25	1.00	1.00	1.00	1.00	1.00	1.00
30	1.03	1.03	1.10	1.10	1.10	1.10
35	1.03	1.03	1.21	1.21	1.21	1.20

Table E-7

CORRECTION FACTORS FOR CLOUD COVERAGE

Cloud Coverage (%)	Hydrazine : Water (70/30)		Hydrazine : UDMH (50/50)		MMH (100%)	
	downwind	crosswind	downwind	crosswind	downwind	crosswind
20	1.00	1.00	1.00	1.00	1.00	1.00
30	1.00	1.00	1.00	1.00	1.00	1.00
40	1.00	1.00	1.00	1.00	1.00	1.00
60	1.00	1.00	1.00	1.00	0.99	1.00
80	0.97	0.97	0.98	1.00	0.99	0.99
100	0.92	0.91	0.98	1.00	0.98	0.99

Table E-8

CORRECTION FACTORS FOR RELATIVE HUMIDITY

Relative Humidity (%)	Hydrazine : Water (70/30)		Hydrazine : UDMH (50/50)		MMH (100%)	
	downwind	crosswind	downwind	crosswind	downwind	crosswind
10	0.78	0.80	0.97	0.98	0.95	0.96
30	0.89	0.89	0.98	0.98	0.97	0.98
50	0.97	0.97	0.98	1.00	0.99	0.99
60	1.00	1.00	1.00	1.00	1.00	1.00
70	1.06	1.06	1.00	1.02	1.01	1.01
90	1.14	1.11	1.02	1.02	1.03	1.03