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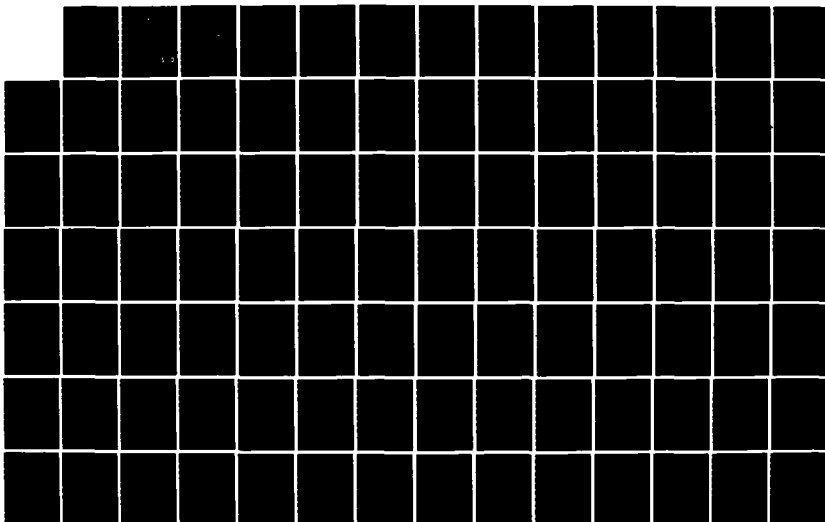
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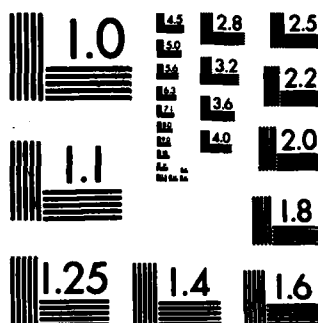
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INCORPORATION OF HOPKINS' VARIABLE WIND MODEL
INTO A POPULATION-DOSE FALLOUT CODE

THESIS

John W St. Ledger
Major, USAF

AFIT/GNE/ENP/85M-18

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INCORPORATION OF HOPKINS' VARIABLE WIND MODEL
INTO A POPULATION-DOSE FALLOUT CODE

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Nuclear Engineering

John W St. Ledger, B.S.

Major, USAF

March 1985

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Preface

The purpose of this study was to develop a variable wind fallout code that could be used to predict the radiation exposure and population insult due to a nuclear attack against the U.S. The operational codes currently used are constant wind models, and the code developed is based on Hopkins' two step technique for finding fallout from variable winds. The thesis was sponsored by the Air Force Operational Test Center at Kirtland AFB, New Mexico.

I would like to thank Tom Hopkins for his assistance in giving me his hotline locator code, the wind spectral coefficients, and for explaining how his model works. Also, I want to thank my thesis advisor, Dr. Bridgman, for his advice and encouragement. And finally, I thank my wife Mina, who did the hard work of running the house and taking care of our family, while I took eighteen months off for school.

John W St. Ledger

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Abstract

Hopkins' variable wind fallout model is used to predict the dose and population insult across the United States from a nuclear attack. The dose calculation is performed by two programs written in Fortran V for a CYBER 845 computer. Hopkins' hotline locator program was modified to reduce its run time, and it is used to locate the fallout hotline as trace particles are translated to the ground in a spatially varying wind field. The second program analytically smears fallout activity along the hotline. To reduce run time and to match the population model, the dose program uses a computational grid of one degree latitude by one degree longitude. A difference of cumulative normal functions gives the average dose across a grid cell. An analytical method was developed to treat multiple bursts against an area target as one cloud.

For the winds of 0000 Universal Time on 16 January 1982, a hypothetical attack against twenty five air bases and six Minuteman missile fields results in 26.9 million fallout deaths. This calculation used 407 seconds of computer time.

INCORPORATION OF HOPKINS' VARIABLE WIND MODEL
INTO A POPULATION-DOSE FALLOUT CODE

I. Introduction

Background

There are two general kinds of fallout code currently in use: discrete codes and smearing codes. Discrete codes, such as the Defense Land Fallout Interpretive Code (DELFIIC), produce "fallout footprints on the ground by numerical integration, employing discrete cells in space, time and particle size." (4:205) Smearing codes, such as WSEG-10 or the AFIT Smear Model, produce fallout footprints by analytic solutions to equations which approximate the fallout cloud location, size and activity arrival rate on the ground. While DELFIIC, as much as possible, uses physics to translate fallout to the ground, smearing codes generally use a mix of physics and empirical curve fits.

Hopkins has developed a two-step method to calculate fallout footprints which uses both discrete and smearing techniques (11:12). The first step is to locate the fallout hotline. Discrete trace particles are started at their initial heights using an empirical curve fit to DELFIIC stabilized particle size wafer heights (11:14-15). Using McDonald-Davies fall mechanics (4:212), the trace particles are translated by variable winds as they fall to the ground. Then, the curved hotline is approximated by straight lines connecting the ground locations of the trace particles (11:24). The second step is to analytically smear the activity along the hotline using a variable wind smearing equation

developed from the fundamental smearing equation(11:73-82).

Hopkins' two-step method has the advantages of both the discrete and the smearing techniques. Discrete codes, such as DELFIC, can use variable wind fields, but DELFIC would use a prohibitive amount of computer time to calculate the fallout from a nuclear attack. Smearing codes, such as WSEG-10, have the advantage of being fast running, but they use a constant or near constant wind field, which makes it difficult to realistically predict where the fallout will land far from a burst. By using discrete techniques and actual variable winds, Hopkins' hotline location method produces realistically curving hotlines, and can accurately predict fallout locations far from the burst. By smearing the activity along the hotline, run times are much faster than DELFIC, or other disk tossers, and can approach the run times for pure smearing codes.

Problem Statement

To incorporate Hopkins' variable wind model into a population-dose fallout code to predict fallout casualties due to a nuclear attack.

Scope and Assumptions

The goal of the thesis was program development. Results are presented for a hypothetical counterforce attack against the Minuteman missile fields and 25 air bases, using the winds of 0000 Universal Time on 16 January 1982. The programs were written in Fortran V for a CYBER 845 computer.

Effects due to weather, such as rain, and uneven terrain were not considered. Each nuclear explosion was considered as an independent event having no effect on the fallout distribution from any other

explosion. In the case of multiple explosions in one area, such as an attack on a Minuteman missile field, all fallout in the area was assumed to be translated by the winds affecting the center burst.

Approach and Organization

Hopkins' hotline locator code was modified to reduce its run time. The modified code uses a file of burst information and a file of wind spectral coefficients as input, and outputs hotline location to a file. The hotline output file can be used to draw a map showing hotline and fallout cloud locations or to calculate the dose across the United States. Using the hotline data and Wendel's US population model(21:5-9), the dose program calculates the fallout deaths due to an attack and outputs the total number of deaths and dose information for each one degree of latitude by one degree of longitude for the United States. The one degree by one degree mesh was used because it matches the mesh of Wendel's rural population model(21:6), it fulfills Air Force Operational Test Center (AFOTEC) requirements for dose information, and it uses less computer time than a smaller mesh.

Section II discusses the hotline locator program, its modifications, and shows the hotlines resulting from a hypothetical counterforce attack. Section III discusses the development of the dose program and the theory used in calculating the dose. Section IV contains the conclusions and recommendations for further study.

The appendices contain listings of the computer codes, maps showing the hotlines and fallout cloud locations, and the derivations for the algorithms used in the dose program.

II. Hopkins' Hotline Locator Program

Hopkins' model for locating fallout hotlines is fully described in reference 12. His computer code for calculating the hotline position was used with modifications to decrease its run time. The modified code with example input and output files is in Appendix F.

Program Description

The hotline locator program works by following trace particles as they fall through a 1976 US Standard Atmosphere(16) and are translated horizontally by variable winds. The line segments on the ground connecting the trace particle landing positions define the fallout hotline, and the trace particle times of arrival and wind shears are used to calculate fallout cloud dimensions. First, the trace particles' starting heights are determined by an empirical curve fit to DELFIC wafer starting heights(11:14-15). Then the atmosphere from the highest particle to the ground is divided into 24 (or twelve) equal layers, and each particle starting height is adjusted to the nearest level in the discretized atmosphere. The north-south/east-west wind components for the particle's starting height and location are multiplied by the time of fall through the first atmosphere layer to find the particle's starting location for the second layer. Then the winds and time of fall for each lower layer are used to translate the particle until it lands on the ground. After all trace particles are on the ground, the process is repeated for the next burst.

Program Modifications

Trace Particle Selection . Any number of trace particles can be used to define the hotline. The greater the number of trace particles, the more the hotline appears to be a continuous curved line. But doubling the number of trace particles will approximately double the run time.

The hotline program originally had 20 trace particles, and this was reduced to ten particles. The trace particle sizes currently used were picked to provide approximately equal length hotline segments for a one megaton burst. Twenty microns radius was picked as the smallest particle for several reasons. First, when local fallout is defined as the radioactivity that arrives within 24 hours(10:388), twenty microns generally represents the smallest particle of interest for single bursts in the 100 kiloton to five megaton range. Also, assuming a DELFIC default activity size distribution(4:211), 50 to 100 one megaton bursts must have the same hotline to cause a dose to infinity of 100 rads tissue near the twenty micron particle location. And finally, if the wind data used is considered as typical, then one megaton bursts in the eastern half of the US will deposit twenty micron and smaller particles in the Atlantic Ocean.

Atmosphere Layers . The modified hotline program uses twelve atmosphere layers, instead of the original 24 layers. Hopkins showed that using more than 24 layers in the atmosphere would not significantly increase the hotline accuracy, and that going from 24 to twelve layers resulted in about a four percent change in hotline location(12:32). Figure 1 shows two hotlines for a one megaton burst, one generated by using 24 atmosphere layers and the other from using twelve layers. As

HOTLINES FOR 12 AND 24 ATMOSPHERIC LAYERS

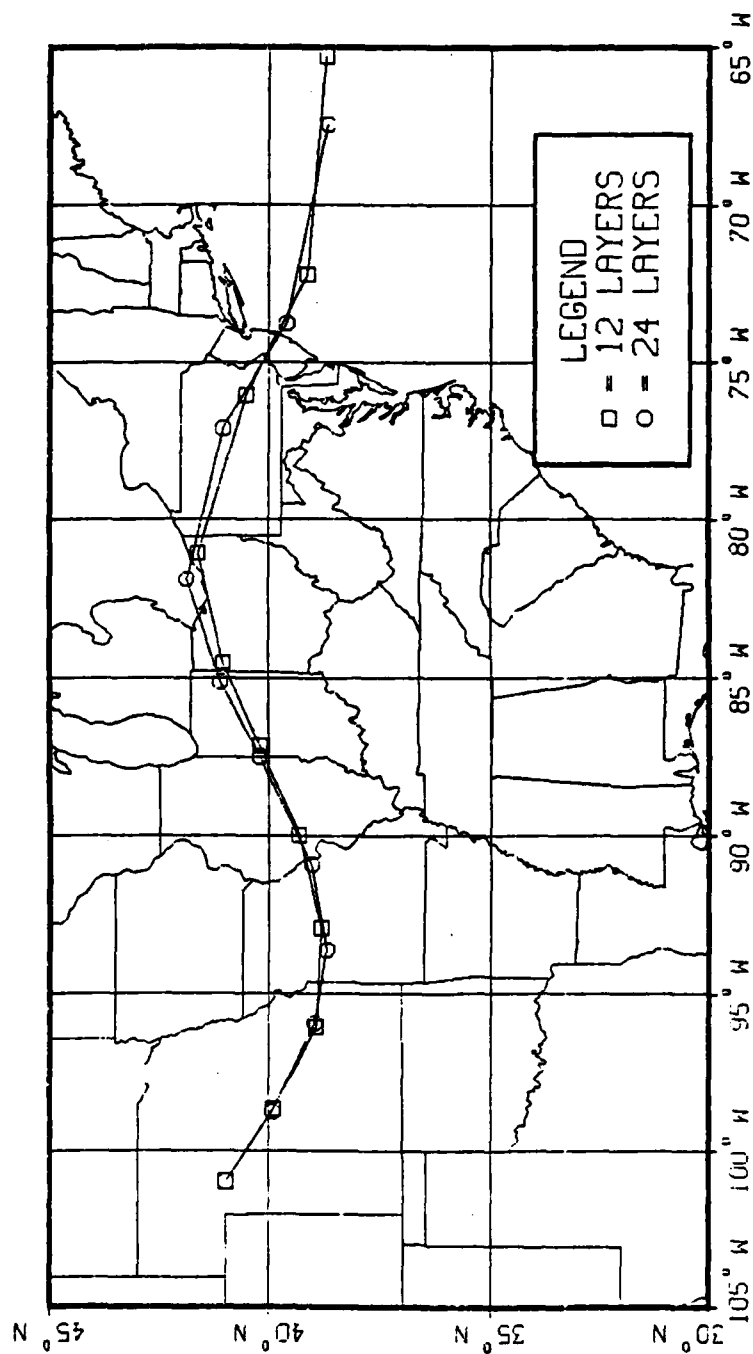


Figure 1

can be readily seen, there is a difference in the hotlines. However, this difference is not judged to be significant. The current hotline locator program does not allow the wind field to change with time, although a realistic wind field can change significantly over 24 hours. Therefore, the error introduced by using twelve atmosphere layers will probably be less than the error caused by using wind data from a fixed time. If climatological winds are used, such as the most probable winds for the month of January, then using 24 layers will produce more accurate probable hotlines at the expense of doubling the run time.

Spectral Coefficient Handling . The north-south/east-west wind components are calculated from spectral wind coefficients calculated by the National Meteorological Center(12:6). Using the spectral coefficients, it is possible to calculate the wind at any location on the Earth's surface for any of twelve different altitudes. The original hotline locator program read the desired coefficients from a data file each time a wind component was calculated, and it was discovered that the majority of the run time was used accessing the spectral coefficient data file. The hotline program was changed to read the coefficients into an array in working memory.

Attack Scenario

The modified hotline locator program was used to find the hotlines for a hypothetical counterforce attack consisting of 31 hotlines for 1125 one megaton bursts. The 25 air bases and six Minuteman fields attacked are listed in Table I. It was assumed that the wind translating the center burst of a missile field would translate all of the bursts in the field, and that there was no interaction between the bursts. All bursts

TABLE I

Air Base and Missile Field Target Locations
for Hypothetical Counterforce Attack(9:9;21:38)

Target	Number Bursts	Location	
1 Grand Forks	1	47.95N	97.40W
2 Hector	1	44.88N	93.22W
3 Minn-St. Paul	1	46.85N	92.18W
4 Duluth	1	56.85N	92.18W
5 KI Sawyer	1	46.35N	87.40W
6 Gen. Mitchell	1	42.95N	87.90W
7 Chicago-O'Hare	1	41.98N	87.90W
8 Kinchloe	1	46.23N	84.47W
9 Selfridge	1	42.60N	82.83W
10 Plattsburg	1	44.65N	73.47W
11 Offut	1	41.12N	95.90W
12 Lincoln	1	40.85N	96.77W
13 Salinas	1	33.78N	97.65W
14 Kansas City	1	39.30N	94.73W
15 Forbes	1	38.95N	95.67W
16 Whiteman	1	38.73N	93.55W
17 Lambert St. Louis	1	38.75N	90.37W
18 Roswell	1	33.30N	104.53W
19 McConnell	1	37.63N	97.27W
20 Natrona	1	42.92N	106.47W
21 Hill	1	41.12N	111.97W
22 Salt Lake City	1	40.78N	111.97W
23 Minot	1	48.42N	101.35W
24 Ellsworth	1	44.15N	103.10W
25 Maelstrom	1	47.50N	111.18W
26 Missile Field	220	47.50N	110.00W
27 Missile Field	165	48.50N	101.00W
28 Missile Field	220	48.50N	97.00W
29 Missile Field	165	44.50N	107.00W
30 Missile Field	165	41.50N	105.00W
31 Missile Field	165	38.50N	96.50W

were assumed to occur simultaneously.

The Whiteman AFB Minuteman field has 150 silos and fifteen control centers in an area of about 156 kilometers by 180 kilometers(6). This field was assumed to be representative of all Minuteman fields. The 200 silo fields were assumed to have dimensions of 180 km by 208 km, which gives the same silo density as the Whiteman field.

Results

The wind data used was for 0000 Universal Time on 16 January 1982. The unmodified hotline program used 1460 seconds to find one hotline. The modified version used 370 seconds to find the 31 hotlines shown in Figure 2.

There are six figures in Appendix A showing the fallout cloud locations in four hour intervals from four to 24 hours after the attack.

COUNTERFORCE ATTACK HOTLINES

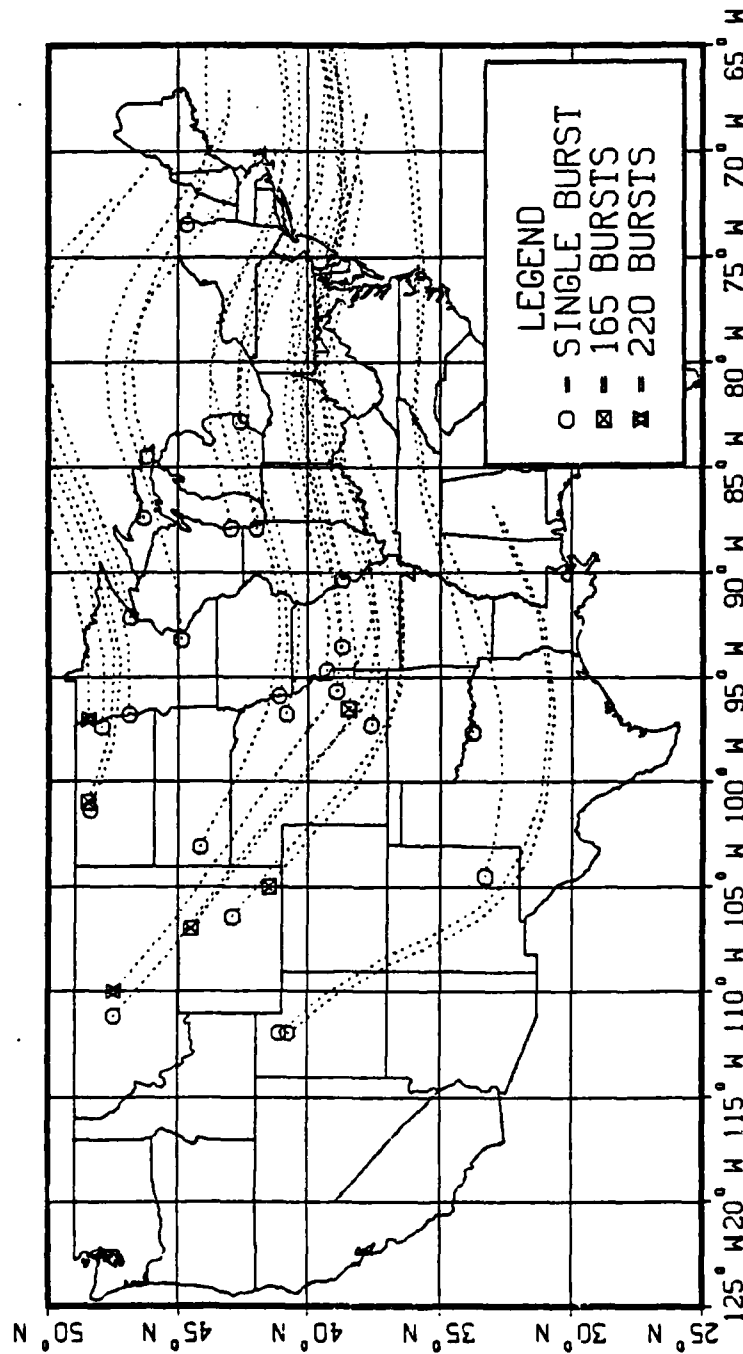


Figure 2

Markers at target locations. Dotted lines show fallout hotlines for each target.

III. Dose Program

The dose program finds the population exposure and dose across the United States. The program is based on Hopkins' variable wind smearing equation(11:73-82). The first decision made in program design was to pick the mesh size for calculating dose. It was determined that a grid size of one degree latitude by one degree longitude would satisfy AFOTEC requirements and simplify population insult calculations for the population model used. The relatively large mesh reduced run times. However, fallout cloud dimensions at early times are much smaller than the mesh size, and this causes the dose calculation to be sensitive to minor changes in the burst position. Therefore, a method was developed to find the average dose across a grid cell. An analytic method was also developed to calculate the dose from an area target without using superposition. WSEG-10 empirical formulas were used for cloud size and growth. However, the WSEG-10 formula for cloud growth due to wind shear had to be modified to give cloud standard deviations on the order of 200 kilometers at late times, as predicted by Bauer(18:Sec 6).

Variable Wind Smearing Equation

Hopkins' variable wind smearing equation is an expression for dose rates at points off of a curved hotline due to variable winds. The equation is:

$$\dot{D}_i(x,y) = \frac{K Y_f g(z_0) z_0}{\sqrt{2\pi} \sigma} e^{-\frac{1}{2} \left(\frac{xy - \bar{y}\bar{x}}{\sigma} \right)^2} \quad (1)$$

where

$\dot{D}_i(x,y)$ = the Unit Time Reference Dose Rate(10:391) at (x,y), with the

burst point defining the origin. (Roentgen/hour)

K = the source normalization constant

(Roentgen-kilometers squared/hour-kiloton)

Y_f = the weapon fission yield (kilotons)

$g(t_a)$ = the normalized fraction of radioactivity arriving on the ground at the time of arrival (per hour)

t_a = the time of arrival (hours)

X, Y = the hotline coordinates

with

$$r = (\sigma_x^2 Y^2 + \sigma_y^2 X^2)^{1/2} \quad (2)$$

and

σ_x, σ_y = the cloud standard deviation in the x and y directions.

Physically, Hopkins' smearing equation calculates the dose from a Gaussian cloud for points which are on a line perpendicular to the effective wind vector. Or, given the effective wind to a point on the hotline, Eq(1) calculates the dose rate for points in the crosswind direction. Appendix B has an explanation of the geometry of the smearing equation and its physical significance.

The source normalization constant typically has values of 2000 to 2950 R-mi sq/hr-kt(4:212;3:1). The dose program uses 2950 R-mi sq/hr-kt or 7452 rads-tissue-km sq/hr-kt.

The normalized fractional rate of arrival of radioactivity at the time of arrival is calculated from a method developed by Bridgman and Bigelow(4:210). The rate of arrival is:

$$g(t) = -A(r) \frac{dr}{dt} \quad (3)$$

where

$A(r)$ = the activity size distribution, or the fraction of activity
in particles of size r (per micron)

$\frac{dr}{dt}$ = the rate of change of particle radius arriving on the
ground (microns/hour)

The activity size distribution is assumed to be log normal, and r and dr/dt are calculated from a Laurent series fit using coefficients calculated by Colarco(4:214;7:67).

Dose at Arbitrary Coordinates

The hotline position is known from the hotline locator's output. But to find the dose at a cell center, it is necessary to find the hotline coordinates such that the cell center is in the crosswind direction. Figure 3 shows a hypothetical hotline, made up of hotline segments, and a cell center. The equation of the dotted line that contains the second hotline segment can be determined from the trace particle coordinates. It turns out that there are two points on the dotted line such that the cell center is in the crosswind direction. If either of these points is on the hotline segment, then those hotline coordinates are used in Eq(1) to calculate the dose at cell center. If both points are on the hotline segment, then the one with the earliest time of arrival is used to calculate the dose.

Appendix C has a derivation of the quadratic equation used to find the hotline coordinates, given a cell center location. The derivation also explains how the time of arrival and wind shears are calculated for hotline points between the trace particle positions.

AFOTEC wanted to know the dose rate for a mesh size of about 50 miles by 50 miles across the US. A one degree by one degree mesh is about 69 miles by 55 miles, so this mesh size satisfied AFOTEC requirements and was a convenient mesh size for calculating population dose. However, dose rates for this mesh size are sensitive to minor changes in burst position. That is, if the dose rate at a given cell center kills zero percent of the population, then moving the burst point ten or 15 kilometers could give a dose rate high enough to kill 100 percent of the cell population. Similarly, by assuming that the entire population of an SMSA resides at its centroid, a small change in burst position has a large effect on that population's dose.

To correct this problem, the dose program calculates the average dose across a cell or SMSA, and assumes that the population is evenly distributed across each cell or SMSA. The average dose can be found from a difference of cumulative normal functions. (See Appendix D) The average SMSA has about 4600 square kilometers(19:26), and the dose program assumes that each SMSA is a circle with a radius of 38 kilometers.

Although using the average dose allows the use of a coarse mesh for the population, the results can be deceiving. Consider Figure 4, which shows a side view of the dose deposited across a cell, on a line through the cell center. Let the fallout be from a one megaton burst with 500 kilotons fission; let the effective wind be 50 kilometers per hour; let the time of arrival be three hours and the cloud standard deviation in the crosswind direction be six kilometers. Under the hotline, the time integrated dose to infinity is 1030 rads tissue. For someone living more than three standard deviations from the hotline, the dose is zero. The

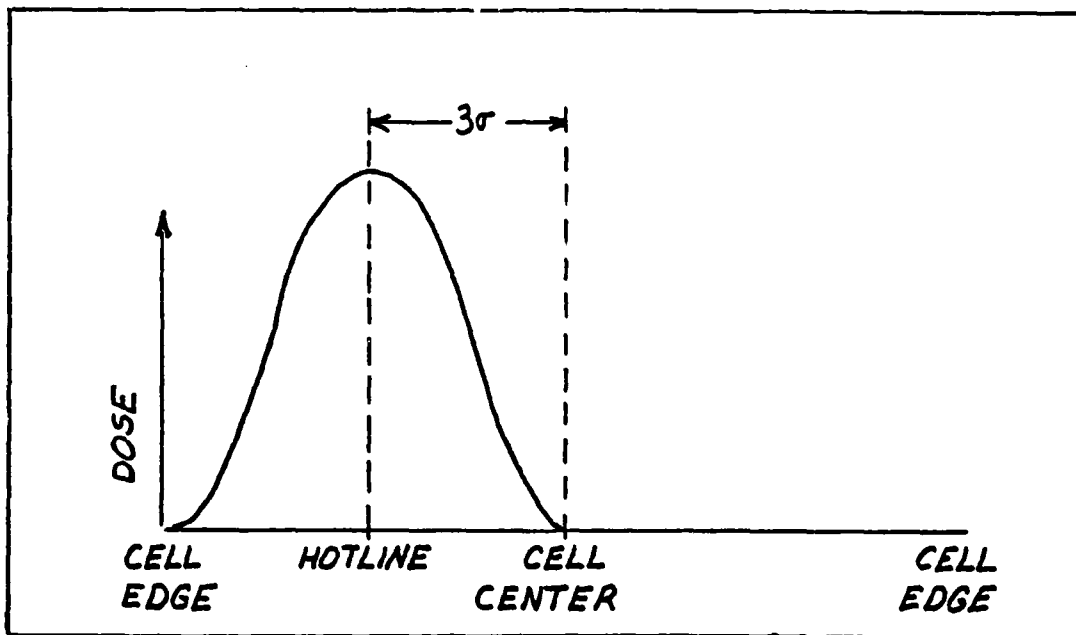


FIGURE 4 Dose Across a Cell

average dose across the cell is 140 rads tissue. In this case, the average dose is almost eight times less than some people receive. And the average dose predicts no casualties while over 98 percent of the people directly below the hotline will actually die. If several hotlines cross the cell, then the average dose will give a more accurate account of the deaths within the cell. Also, at later times when the cloud size is on the order of or larger than the cell size, the average dose will more accurately predict population deaths. There was insufficient time to do a complete analysis of the effects of using the average dose.

Multiple Bursts

When there is an attack on an area target, such as a Minuteman missile field, it is desirable to treat the fallout produced as one mega-cloud. This allows calculating the dose rate for a cell one time,

instead of superimposing the dose rates from several hundred bursts. Crandley developed and validated a multiple burst technique for a constant wind fallout code(8). Appendix E draws on Crandley's results and extends them to variable winds. There was insufficient time to derive and validate expressions for the average dose across a cell or city from an area of bursts. Therefore, as will be shown later, the area of bursts must be on the order of or larger than the cell size to achieve consistent dose rate calculations.

Probability of Death

The probability of death as a function of gamma radiation dose received, can be inferred to be a cumulative log normal distribution (See Figure 5) with: 170 rads tissue causing a one percent chance of death, 1200 rads tissue causing a 99 percent chance of death, and 450 rads tissue causing a 50 percent chance of death within 60 days(15:20-22). This probability distribution is valid for a dose received over a short time period of a few hours. The Way-Wigner decay formula is used to find the time integrated dose from the fallout time of arrival to infinity(20:1318). It was assumed that the dose to infinity was delivered in a short time period. The effects of alpha and beta radiation, and the effects of fallout ingestion were ignored.

Glasstone gives typical values for the dose protection factor afforded by various types of shelters(10:441). A protection factor of three was assumed to be a nominal value for the rural and urban population. The dose program uses the log normal distribution above, and a dose protection factor of three to calculate the probability of death.

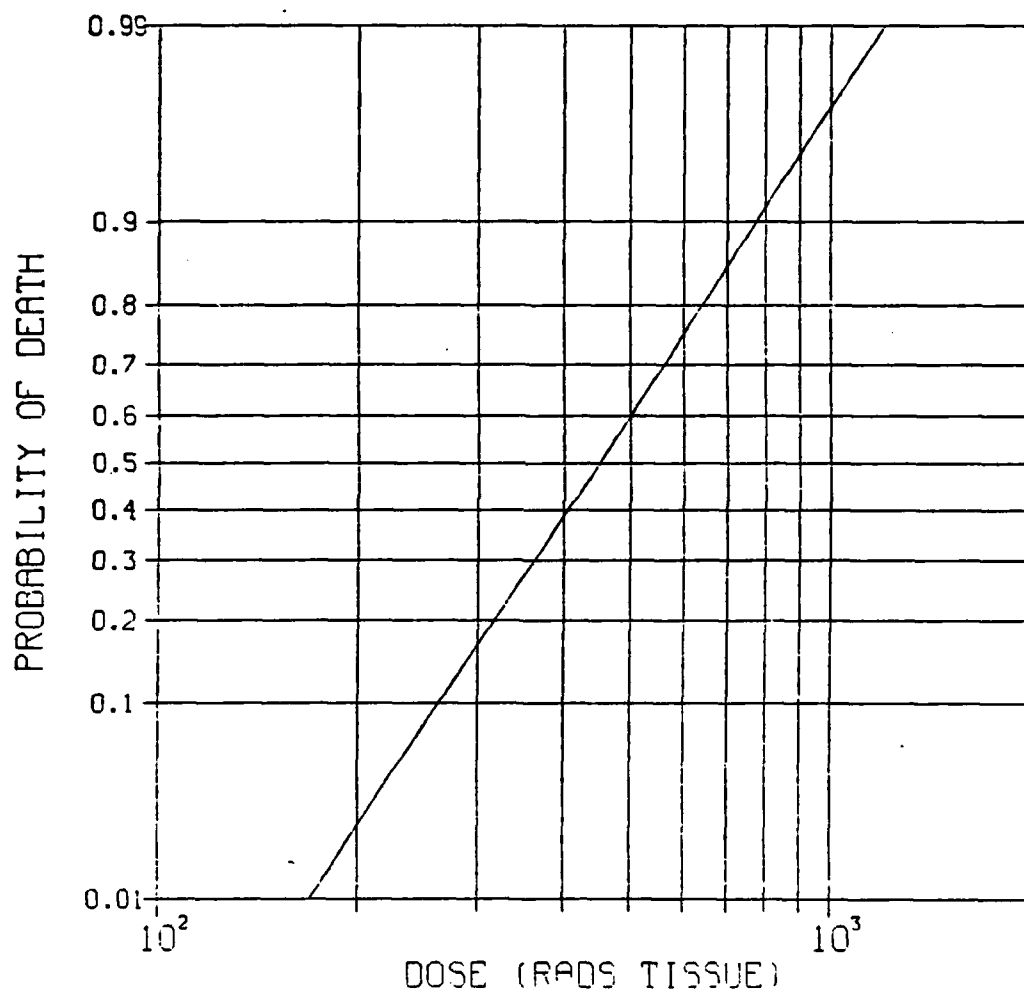


Figure 5

Probability of Death as a Function of Gamma Ray Dose

Wind Shear and Cloud Size

Wind shear acting on the fallout cloud as it translates through the atmosphere will cause the cloud to spread(12:49). The AFIT Smear Model uses the WSEG-10 formulation for the cloud standard deviation as a function of time(3:2):

$$\sigma = [\sigma_T^2 + (\sigma_z S t_a)^2]^{1/2} \quad (4)$$

where

σ = the cloud standard deviation in the x or y direction

t_a = the time of arrival

σ_z = the cloud's initial standard deviation in the vertical

S = the wind shear in the x or y direction

σ_T = a term for toroidal growth of the cloud at early times.

After three hours, for a one megaton burst, σ_T is a constant six kilometers.

Typical values of wind shear used are on the order of one to two per hour, which gives a cloud standard deviation of 50 to 100 kilometers at late times for a one megaton burst. The hotline locator program calculates wind shear values of about one to 30 per hour, which in general agrees with the range of wind shear calculated by Norment for certain selected wind fields(17:57). Typical values of the hotline locator wind shear at late times for a one megaton burst, give cloud standard deviations of about 500 to 1000 kilometers. But Bauer has determined that the cloud standard deviation can be calculated from(18:Sec 6,39):

$$\sigma = (2 K_{yy} T)^{1/2} \quad (5)$$

where

k_{yy} = a latitude, altitude and time of year dependent variable

T = the time after burst.

With σ in kilometers, T in days and using a mean value for k_{yy} :

$$\sigma \approx 200 (T)^{1/2} \quad (6)$$

So at late times, the cloud standard deviation should be on the order of 200 kilometers.

Norment has developed a smear fallout code called DNAF-1. His empirical equation for horizontal cloud standard deviation is(17:41)

$$\sigma = [\sigma_0^2 + (\Delta z S t_a / 10)^2]^{1/2} \quad (7)$$

with

σ_0 = a term for growth not due to wind shear

Δz = the vertical thickness of the cloud

t_a = the time of arrival

S = the wind shear.

The dose program, following Norment, uses:

$$\sigma = [\sigma_T^2 + (\sigma_z S t_a / 10)^2]^{1/2} \quad (8)$$

to calculate the standard deviation. This "empirical fix" of the WSEG-10 formula gives cloud standard deviations of about 100 to 200 kilometers for typical values of wind shear and a 24 hour time of arrival, which approximates Bauer's prediction.

Program Validation

The dose program was used with a variety of hypothetical hotlines to check its operation. For instance, reflecting the hotline about the x or y axis results in the dose rates being reflected about the x or y axis. As a further test, a conservation check was made of the activity smeared on the ground. For single and multiple burst hotlines, the burst position was varied within a latitude longitude cell, and the program output was summed to find the total activity on the ground, as compared to the activity contained in 20 micron and larger particles.

When activity conservation was checked for a single burst with a one degree by one degree cell size, and dose averaging was not used, then anywhere from 20 to 180 percent of the available activity was on the ground. With dose averaging, 101 ± 13 percent (3 sigma deviation, 20 locations) of the activity was smeared on the ground. Without dose averaging, a cell size of ten km by ten km conserved activity, and the run time for one hotline increased from five to 50 seconds.

For multiple burst hotlines, dose conservation varied depending on the size of the burst area. Table II shows how dose conservation varied. It is recommended that an area of bursts have dimensions of at least 100 by 100 kilometers. Otherwise, the bursts should be treated by superposition.

Results

For an attack against the 25 air bases in Table I, the dose program used 30 seconds of central processor time and calculated 537,000 fallout deaths within 60 days of the attack. No single burst, by itself, had a

TABLE II
Activity Conservation for Multiple Bursts
Versus Size of Burst Area

Number of Bursts	Area Dimensions(km)	% Activity on the Ground
100	50 x 50	233(+ 121)
100	100 x 100	135(+ 38)
165	156 x 180	112(+ 10)
220	180 x 208	108(+ 11)
100	200 x 200	102(+ 13)

Deviations are three sigma for ten locations. Point cell values are used. That is, dose is not averaged across a cell.

dose rate high enough to cause any deaths, due to the effects of averaging the dose across a cell. So the deaths occurred in the areas where several hotlines overlap. (See Figure 2) For an attack using a one megaton surface burst against each Minuteman silo and control center, the dose program used 13 seconds and calculated 25.9 million deaths. A combined attack used 37 seconds and calculated 26.9 million deaths.

IV. Conclusions and Recommendations

The hotline locator and dose programs use a reasonable amount of computer time to calculate the dose and population insult across the United States. To calculate the hotlines and the dose from the hypothetical attack with 31 hotlines required 407 central processor seconds, on a CYBER 845. The technique of averaging the dose across a grid cell, allows the use of a large mesh and results in a faster run time but underestimates the fallout deaths for single bursts. Several hundred bursts in one area can be treated as a mega-cloud with one hotline. However, the dimensions of the area should be as large or larger than the cell size to conserve activity on the ground.

There are several areas in which the models or programs can be improved:

1. An investigation of the growth of fallout clouds due to wind shear needs to be performed to derive an accurate expression for cloud standard deviation.
2. The spectral coefficients used to calculate wind speed can also be used to calculate vertical wind speed in the atmosphere(13). The vertical winds should be added to the hotline locator program. Since Colarco's Laurent coefficients for $r(t)$ were developed assuming no vertical winds, this would require a different method be used to calculate $g(t)$.
3. An algorithm to find the average dose across a cell for multiple bursts should be added to the dose program.

4. When the fallout cloud dimensions are larger than the synoptic scale of the atmosphere (about 150 to 450 km), a cloud may tend to disperse into several smaller clouds which translate separately(13). An investigation should be done to determine how local fallout is affected by synoptic scale wind patterns.
5. The hotline locator program should be further modified to reduce its run time. The spectral wind coefficients for different times could then be interpolated to find hotlines in a spatially and temporally varying wind field, with a reasonable run time.

Appendix A

Fallout Cloud Locations Every Four Hours

Figures 6-11 show the fallout cloud locations from the counterforce attack in Table I. The marker locations show where the fallout clouds are touching the ground for every four hours after the attack. The markers show only where the clouds are touching the ground. Wind shear will cause the cloud position to change with altitude. The solid lines show where the fallout clouds have already passed, and the dotted lines show the future track of the clouds.

CLOUD LOCATIONS T= 4 HOURS

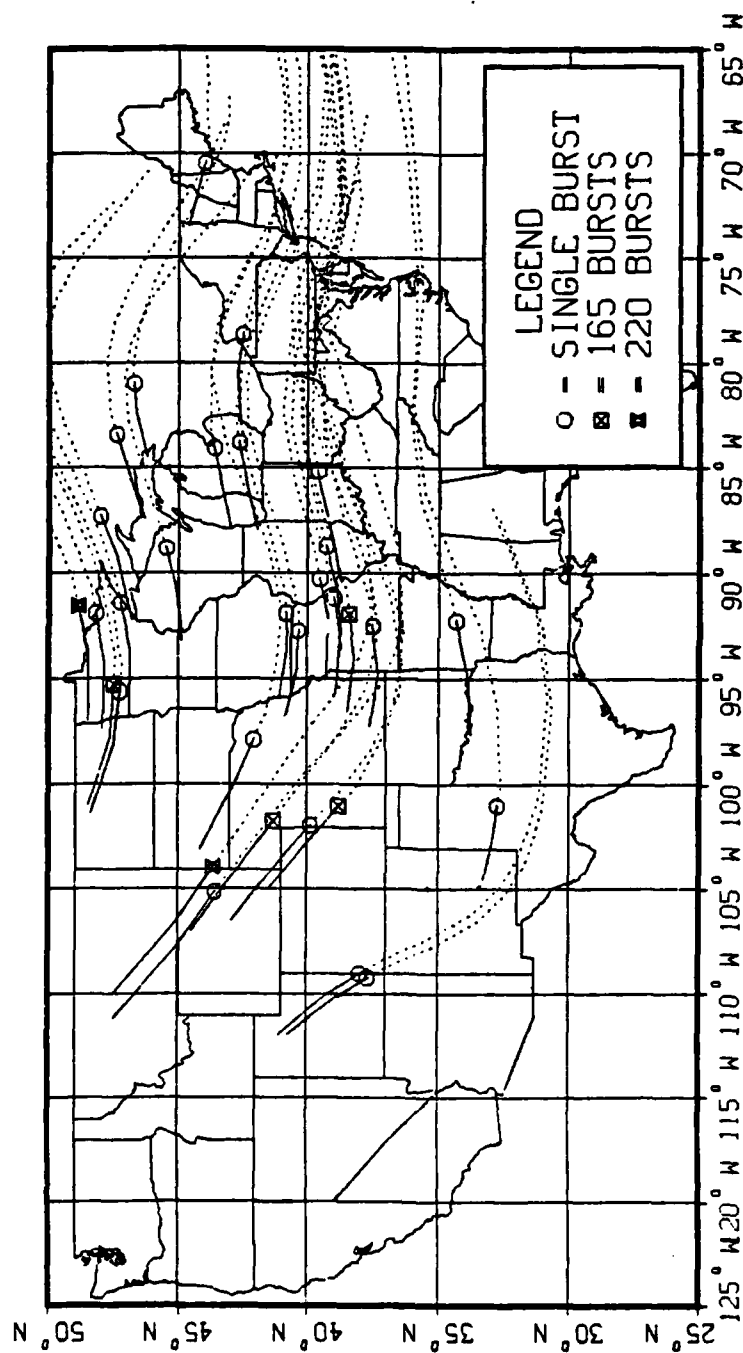


Figure 6

CLOUD LOCATIONS T= 8 HOURS

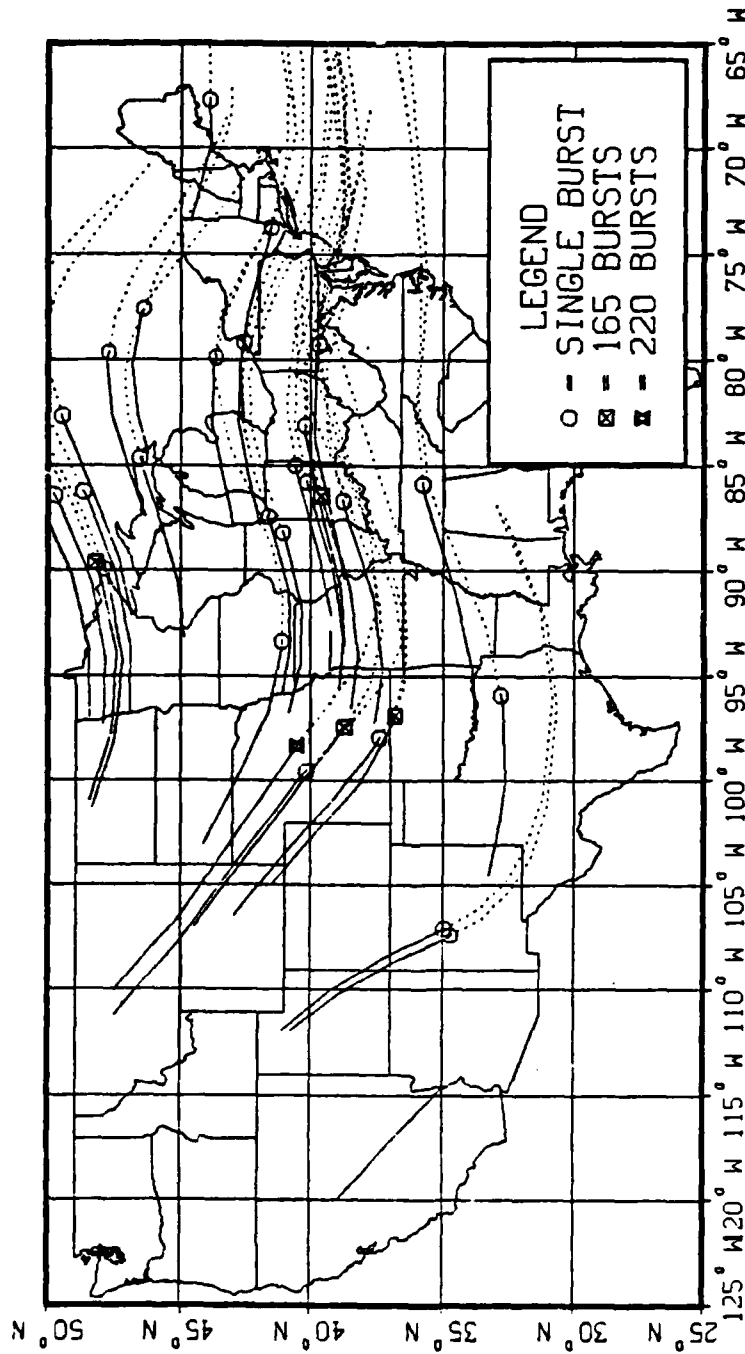


Figure 7

CLOUD LOCATIONS T=12 HOURS

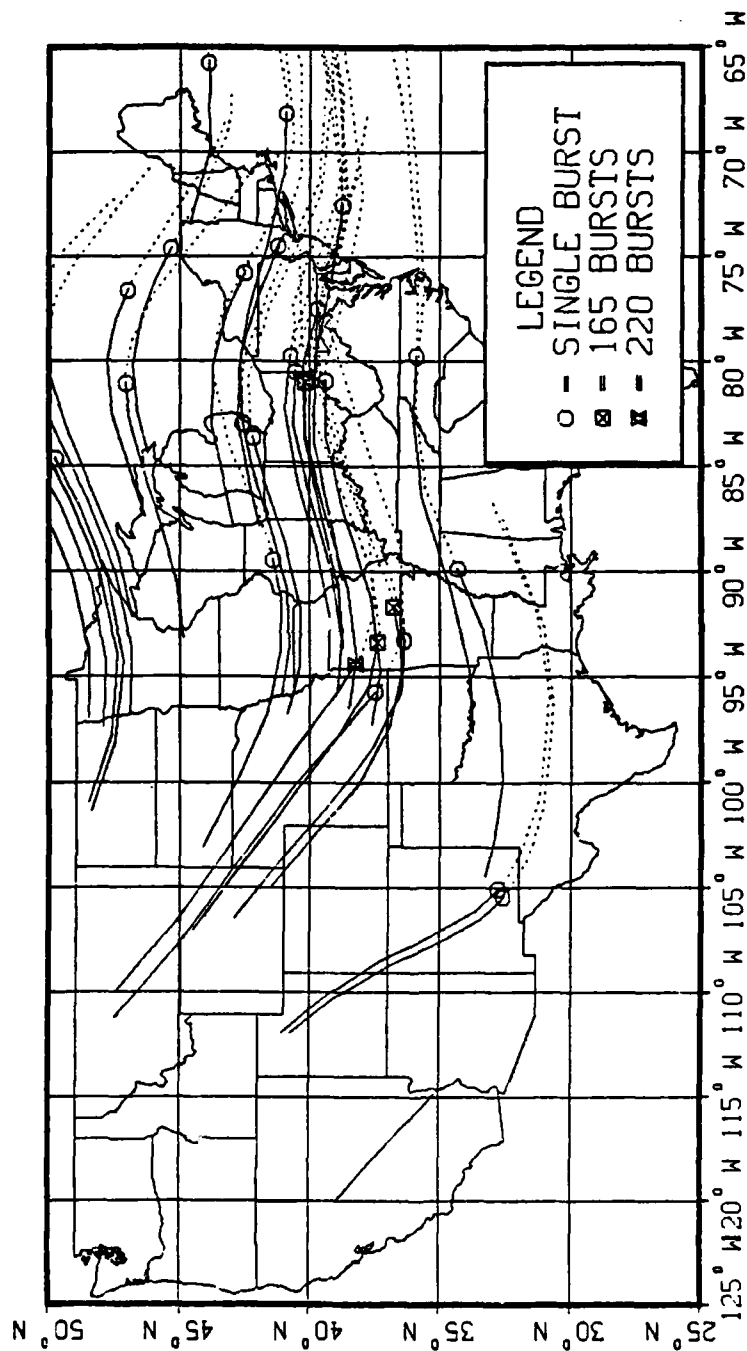


Figure 8

CLOUD LOCATIONS T=16 HOURS

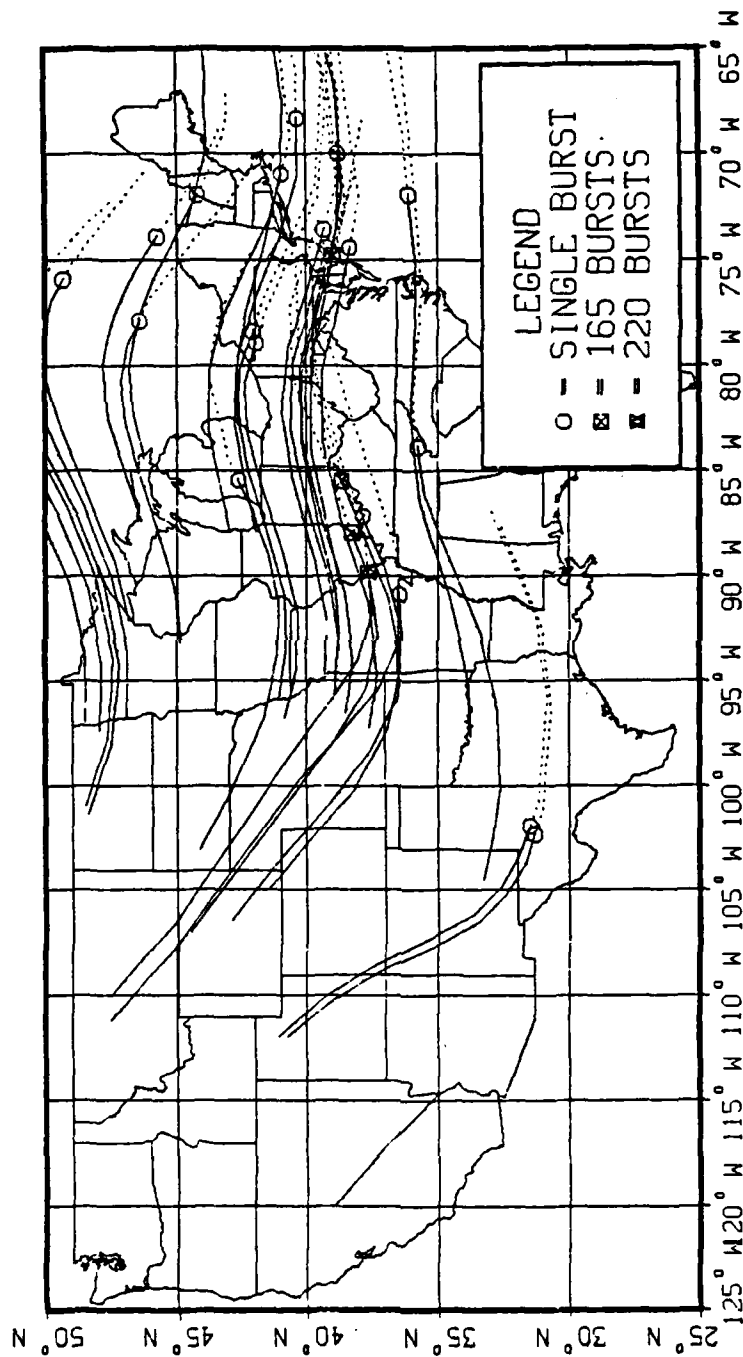


Figure 9

CLOUD LOCATIONS T=20 HOURS

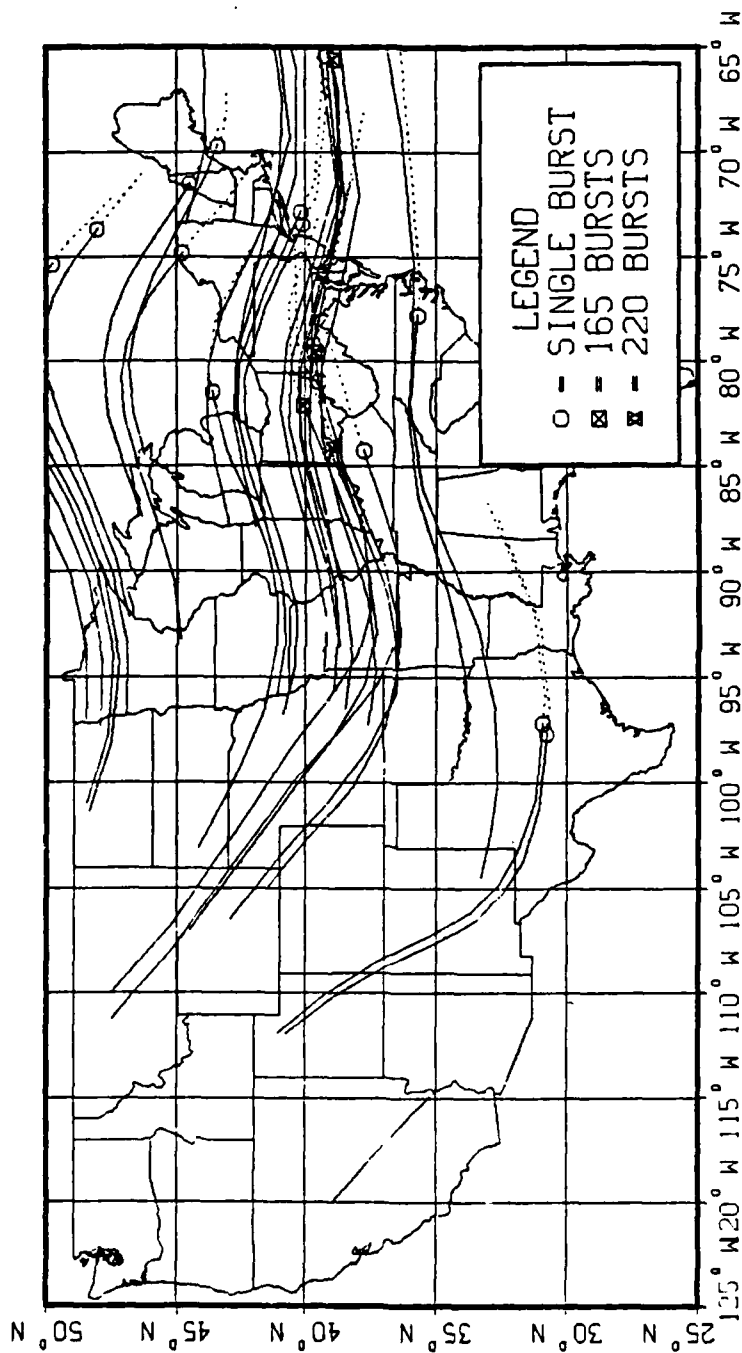


Figure 10

CLOUD LOCATIONS T=24 HOURS

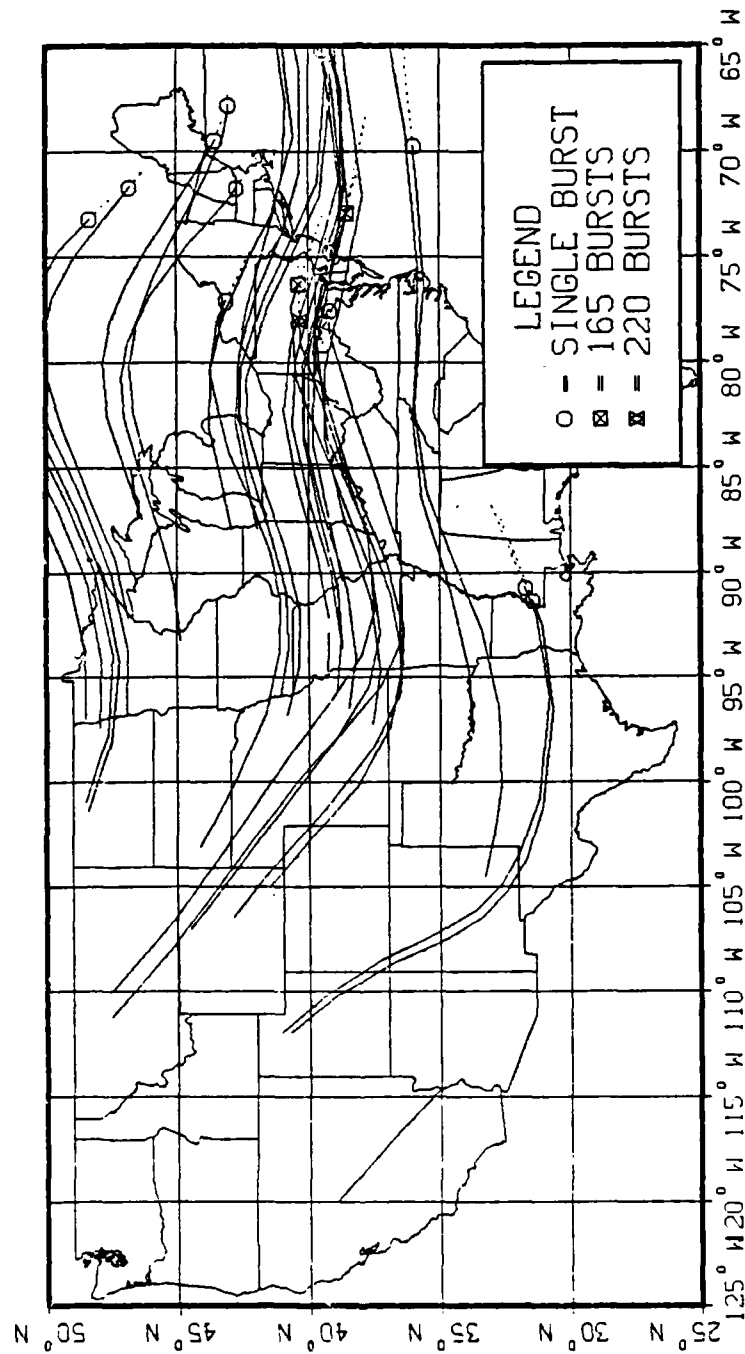


Figure 11

Appendix B

Physical Interpretation of Hopkins' Variable

Wind Smearing Equation

The physical significance of Hopkins' variable wind smearing equation was first shown by Bridgman(2). This discussion generally follows his explanation.

Consider Hopkins' variable wind smearing equation written in terms of velocities, rather than hotline coordinates(11:83):

$$\dot{D}_i(x,y) = \frac{K Y_f g(t_a)}{\sqrt{2\pi}(\sigma_x^2 V_y^2 + \sigma_y^2 V_x^2)^{1/2}} \exp\left[-\frac{1}{2} \frac{(x V_y - y V_x)^2}{\sigma_x^2 V_y^2 + \sigma_y^2 V_x^2}\right] \quad (B-1)$$

where

$\dot{D}_i(x,y)$ = the Unit Time Reference Dose Rate at (x,y)

K = the source normalization constant

Y_f = the fission yield

$g(t_a)$ = the fractional rate of arrival of radioactivity at
the time of arrival

V_x = the effective wind velocity in the x direction, or X/t_a

V_y = the effective wind velocity in the y direction, or Y/t_a

σ_x, σ_y = the cloud standard deviations in the x,y directions

Figure 12 shows the elliptical two dimensional Gaussian cloud located at (X,Y). Now, define the effective wind vector as:

$$\vec{V}_e = V_x \hat{i} + V_y \hat{j} \quad (B-2)$$

therefore

$$V_e = |\vec{V}_e| = (V_x^2 + V_y^2)^{1/2} \quad (B-3)$$

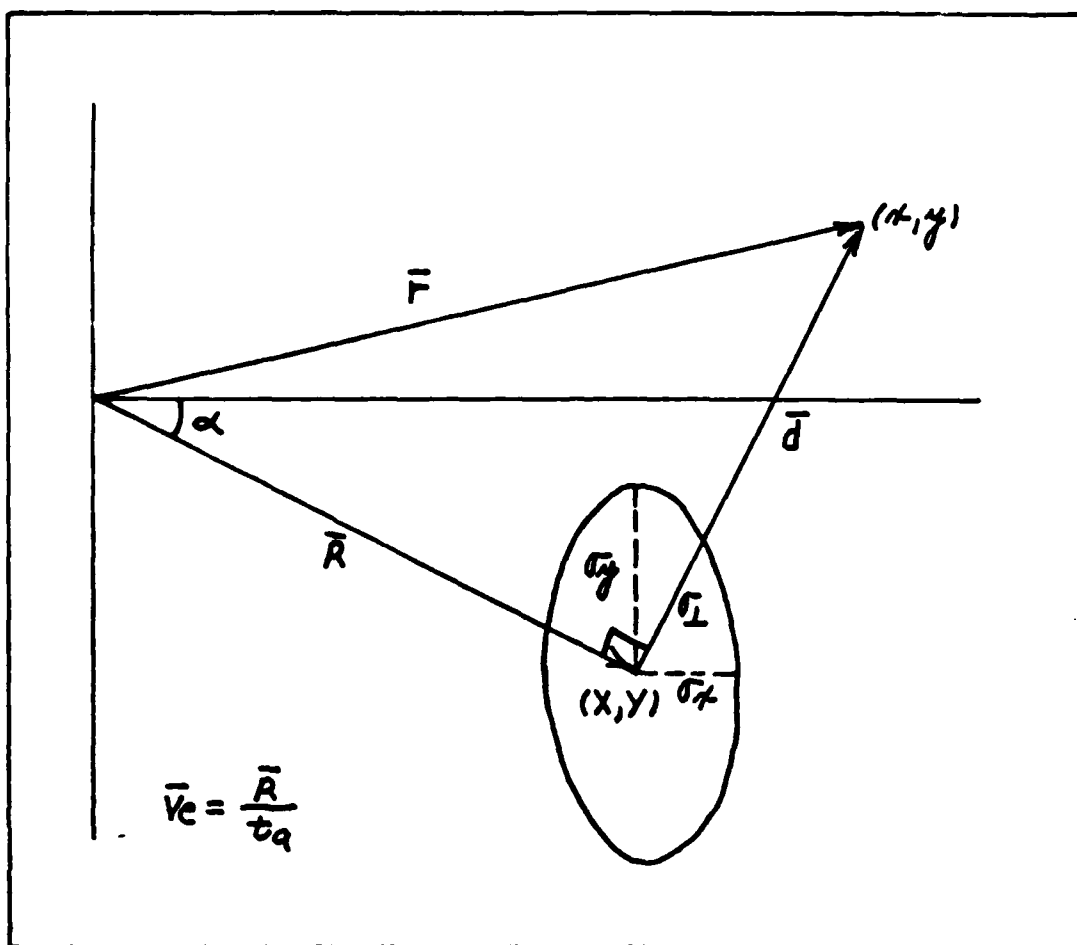


Figure 12

Two Dimensional Gaussian Fallout Cloud

Define the effective wind vector angle α as:

$$\alpha = \tan^{-1}(Y/X) \quad (B-4)$$

Then, the cloud standard deviation vector in the crosswind direction is:

$$\bar{\sigma} = -\sigma_x \sin \alpha \hat{i} + \sigma_y \cos \alpha \hat{j} \quad (B-5)$$

so that

$$\sigma_L = |\vec{\sigma}| = (\sigma_x^2 \sin^2 \alpha + \sigma_y^2 \cos^2 \alpha)^{1/2} \quad (B-6)$$

Now, from Eq(B-1) consider the term

$$\frac{1}{(\sigma_x^2 V_y^2 + \sigma_y^2 V_x^2)^{1/2}} \quad (B-7)$$

$$= \frac{1}{V_c (\sigma_x^2 \frac{V_y^2}{V_c^2} + \sigma_y^2 \frac{V_x^2}{V_c^2})^{1/2}} \quad (B-8)$$

$$= \frac{1}{V_c (\sigma_x^2 \sin^2 \alpha + \sigma_y^2 \cos^2 \alpha)^{1/2}} \quad (B-9)$$

$$= \frac{1}{V_c \sigma_L} \quad (B-10)$$

Now, consider the exponential term in Eq(B-1)

$$\frac{x V_y - y V_x}{(\sigma_x^2 V_y^2 + \sigma_y^2 V_x^2)^{1/2}} \quad (B-11)$$

$$= \frac{x V_y/V_c - y V_x/V_c}{(\sigma_x^2 V_y^2/V_c^2 + \sigma_y^2 V_x^2/V_c^2)^{1/2}} \quad (B-12)$$

$$= \frac{x \sin \alpha - y \cos \alpha}{\sigma_L} \quad (B-13)$$

From Figure 12, the unit vector $\hat{n}$ in the crosswind direction from (x,y) to (X,Y) is:

$$\hat{n} = \sin \alpha \hat{i} - \cos \alpha \hat{j} \quad (B-14)$$

Defining the position vector (x,y)

$$\vec{r} = x\hat{i} + y\hat{j} \quad (B-15)$$

we see that Eq(B-13) becomes:

$$\frac{\vec{r} \cdot \hat{n}}{\sigma_L} \quad (B-16)$$

Notice that

$$\vec{r} = \vec{R} + \vec{d} \quad (B-17)$$

$$\vec{r} \cdot \hat{n} = \vec{d} \cdot \hat{n} = |\vec{d}| \quad (B-18)$$

Therefore, Eq(B-16) is the number of standard deviations between (X,Y) and (x,y), when (x,y) is in the crosswind direction defined by the effective wind vector to the hotline.

Substituting (B-18), (B-16) and (B-10) into Eq(B-1) gives:

$$\dot{D}_1(x,y) = \frac{K Y_L g(z_0)}{V_c} \frac{1}{\sqrt{2\pi} \sigma_L} e^{-\frac{1}{2} \left(\frac{d}{\sigma_L} \right)^2} \quad (B-19)$$

which is exactly equivalent to the smearing equation for a constant wind in the x direction(4:215)

$$\dot{D}_1(x,y) = \frac{K Y_L g(z_0)}{V_x} \frac{1}{\sqrt{2\pi} \sigma_y} e^{-\frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2} \quad (B-20)$$

where y is now the distance in the crosswind direction, and V_x is the effective wind.

Appendix C

Dose at Arbitrary Coordinates

Given any arbitrary coordinates (x,y) and the hotline coordinates, with the wind shear and time of arrival for each trace particle, this method will find: the hotline coordinates which define the effective wind vector, the time of arrival and the wind shear.

Figure 13 shows the i th hotline segment of a hotline, a known point (x,y) , and the unknown hotline coordinates (X,Y) .

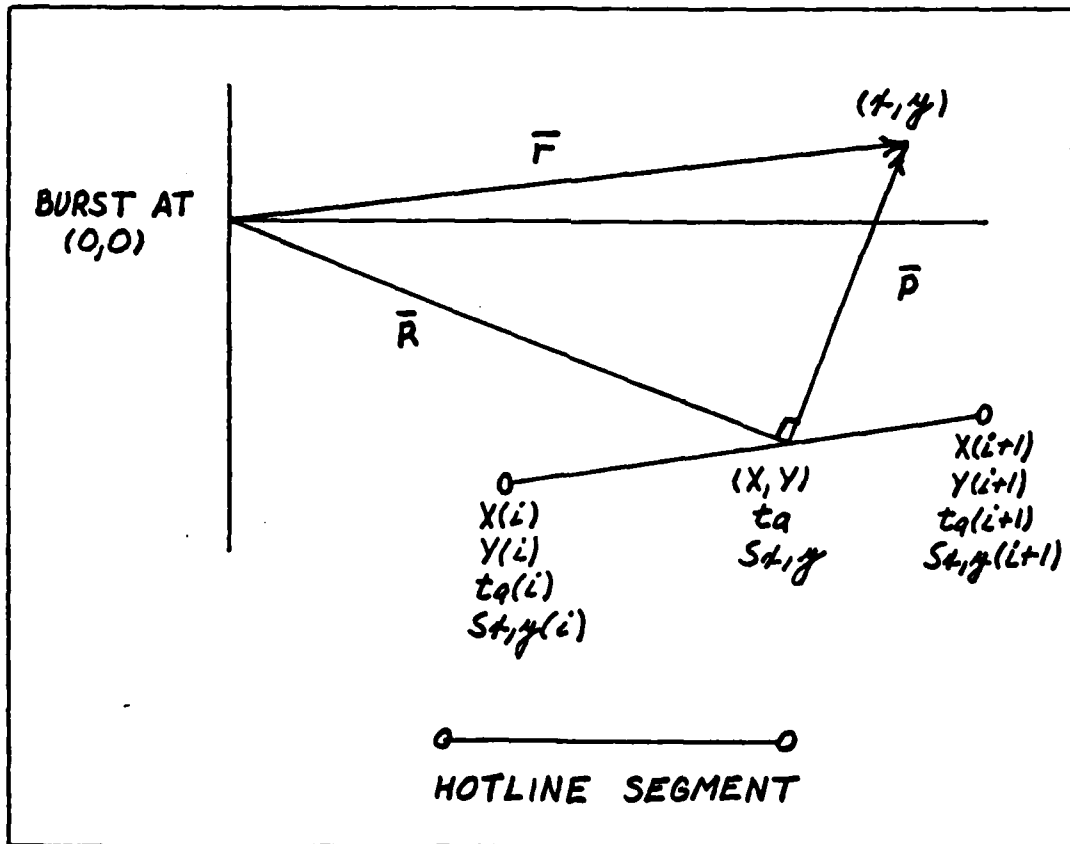


Figure 13

Hotline Coordinates for Dose at Arbitrary Coordinates

The equation of the line which contains the i th hotline segment is

$$Y = a(i)X + b(i) \quad (C-1)$$

where

$$a(i) = \frac{Y(i+1) - Y(i)}{X(i+1) - X(i)} \quad ; \quad X(i+1) \neq X(i) \quad (C-2)$$

and

$$b(i) = Y(i) - a(i)X(i) \quad (C-3)$$

Defining the vectors R , P , r as:

$$\bar{R} = X\hat{e} + Y\hat{f} \quad (C-4)$$

$$\bar{r} = x\hat{e} + y\hat{f} \quad (C-5)$$

$$\bar{p} = (x-X)\hat{e} + (y-Y)\hat{f} \quad (C-6)$$

Then, since (x,y) is in the crosswind direction,

$$\bar{R} \cdot \bar{p} = 0 \quad (C-7)$$

$$(x-X)X + (y-Y)Y = 0 \quad (C-8)$$

Substituting Eq(C-1) for Y into Eq(C-8) gives

$$AX^2 + BX + C = 0 \quad (C-9)$$

where

$$A = -a(i)^2 - 1 \quad (C-10a)$$

$$B = x + a(i)y - 2a(i)b(i) \quad (C-10b)$$

$$C = b(i)y - b(i)^2 \quad (C-10c)$$

Therefore,

$$X = \frac{-B \pm (B^2 - 4AC)^{1/2}}{2A} \quad (C-11)$$

Eq(C-11) gives two trial Xs on the straight line containing the ith hotline segment, such that (x,y) is in the crosswind direction. If neither trial X is on the ith segment, then the ith plus one segment must be checked. If only one trial x is on the ith segment, then that (X,Y) defines the hotline coordinate. If both trial Xs are on the hotline segment, then the one with the earliest time of arrival defines (X,Y).

To find the time of arrival and wind shear associated with the hotline coordinate (X,Y), let's assume that the time of arrival and wind shear vary linearly along the ith segment. Then with:

$$T = \frac{X - X(i)}{X(i+1) - X(i)} \quad (C-12)$$

Then

$$t_a = T t_a(i+1) + [1-T] t_a(i) \quad (C-13a)$$

$$S_x = T S_x(i+1) + [1-T] S_x(i) \quad (C-13b)$$

$$S_y = T S_y(i+1) + [1-T] S_y(i) \quad (C-13c)$$

with

t_a = the time of arrival

S_x, S_y = the wind shear in the x,y directions

Now these hotline variables can be used to calculate the unit time reference dose rate at (x,y).

Appendix D

Average Dose Across a Cell

In Figure 14, the dose rate at (x,y) is:

$$\dot{D}_1(x,y) = \frac{C}{\sqrt{2\pi} \sigma} e^{-\frac{1}{2} \left(\frac{xY - yX}{\sigma} \right)^2} \quad (D-1)$$

with

$$C = K Y_f g(t_a) t_a$$

$$\sigma = (\sigma_x^2 Y^2 + \sigma_y^2 X^2)^{1/2}$$

and with (X,Y) on the hotline. The average dose rate along the line ℓ is(14:739):

$$\dot{D}_{ave} = \frac{1}{b-a} \int_a^b \dot{D}_1(x,y) d\ell \quad (D-2)$$

At later times when $g(t_a)$ changes little in the time it takes for the fallout cloud to cross the cell, then the average dose rate calculated by Eq(D-2) is the average dose rate across the entire cell.

Defining α as:

$$\alpha = \tan^{-1}(Y/X) \quad (D-3)$$

then along the line of length ℓ ,

$$x = X - \ell \sin \alpha \quad (D-4a)$$

$$y = Y + \ell \cos \alpha \quad (D-4b)$$

when ℓ is zero on the hotline.

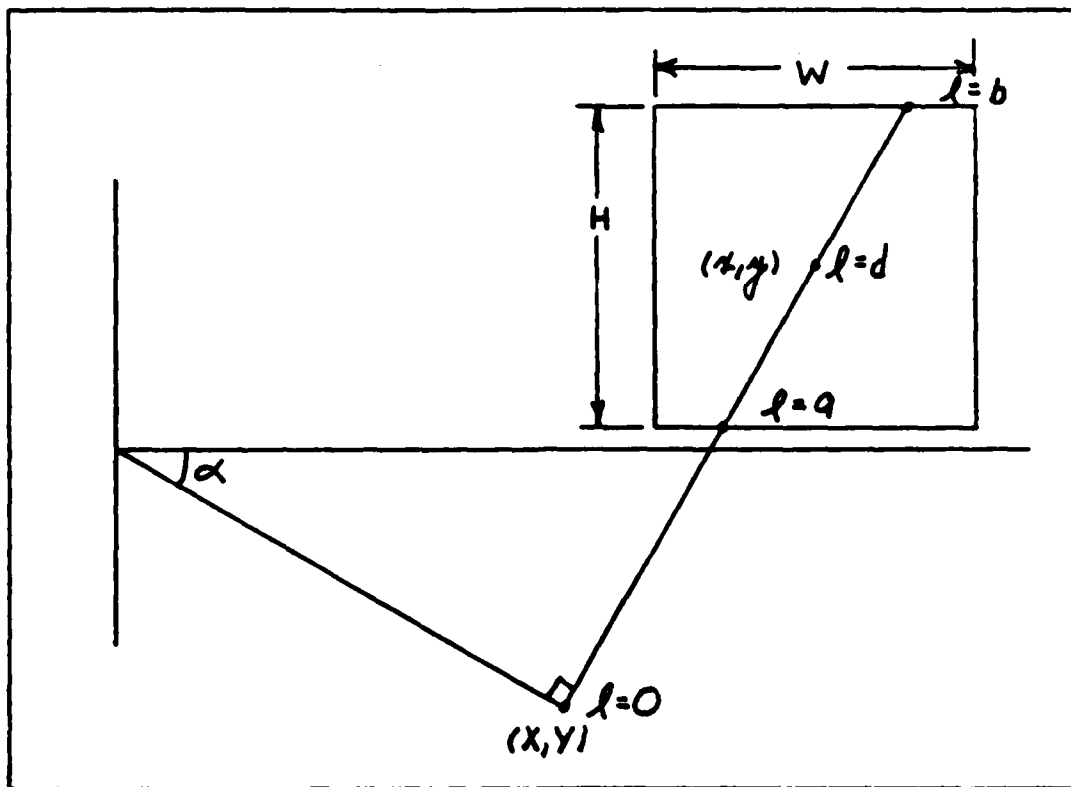


Figure 14

Average Dose Geometry

Substituting Eqs(D-4) into Eq(D-2) gives:

$$\dot{D}_{ave} = \frac{C}{b-a} \int_a^b \frac{1}{\sqrt{2\pi} r} \exp \left\{ -\frac{1}{2} \left[\frac{(x-l\sin\alpha)Y - (Y+l\cos\alpha)X}{r} \right]^2 \right\} dl \quad (D-5)$$

Let

$$z = \frac{(x-l\sin\alpha)Y - (Y+l\cos\alpha)X}{r} \quad (D-6)$$

then

$$dz = \frac{(-Y\sin\alpha - X\cos\alpha)}{r} dl \quad (D-7)$$

and substituting (D-6) and (D-7) into Eq(D-5) gives the average dose rate as:

$$\dot{D}_{ave} = \frac{C}{(b-a)(-Y\sin\alpha - X\cos\alpha)} \int_{a'}^{b'} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \quad (D-8)$$

where

$$a' = \frac{-aY\sin\alpha - aX\cos\alpha}{\sigma} \quad (D-9)$$

and

$$b' = \frac{-bY\sin\alpha - bX\cos\alpha}{\sigma} \quad (D-10)$$

The integral in Eq(D-8) is the cumulative normal function, which can be calculated by a polynomial approximation from Abramowitz and Stegun(1:932).

To find the line lengths a and b , defined α_{max} as:

$$\alpha_{max} = \tan^{-1}(W/H) \quad (D-11)$$

where

H = the north-south dimension of the cell

W = the east-west dimension of the cell.

Then with d defined as:

$$d = [(x-X)^2 + (y-Y)^2]^{1/2} \quad (D-12)$$

when $\alpha \geq \alpha_{max}$ then,

$$a = d - \frac{.5W}{|\sin\alpha|} \quad (D-13a)$$

$$b = d + \frac{.5W}{|\sin\alpha|} \quad (D-13b)$$

and when $\alpha \leq \alpha_{\max}$

$$a = d - \frac{.5H}{\cos \alpha} \quad (D-14a)$$

$$b = d + \frac{.5H}{\cos \alpha} \quad (D-14b)$$

Appendix E

Dose From Multiple Bursts Within a Rectangular Area

The following method finds the dose rate at a cell center from an area of bursts. Three primary assumptions are made. First, the fallout observer must be far downwind compared to the area dimensions, so that the fallout time of arrival does not vary significantly in the amount of time it takes the mega-cloud to pass his position. This means that $g(t_a)$ does not change significantly for each burst, and the observer cannot tell whether the fallout was deposited by an area or a line of bursts. The second assumption is that the summation of dose rates over the line of bursts can be replaced by a line integral. Crandley showed that this assumption is valid when the burst separation is less than one cloud standard deviation(8:5-11). Finally, it is assumed that each cloud in the area of bursts is translated by the wind affecting the center burst. The development below finds the burst density along a crosswind line through the center of the area of bursts then uses the burst density to calculate the dose.

Variable Burst Density Geometry

Consider the area of bursts in Figure 15, with height H, width W and with the bursts evenly distributed over the area. An observer far downwind cannot tell whether the fallout was deposited by the area of bursts or by a line of bursts in the crosswind direction.

Define α_{max} as the angle between the x axis and the rectangle's diagonal, or

$$\alpha_{max} = \tan^{-1}(H/W) \quad (E-1)$$

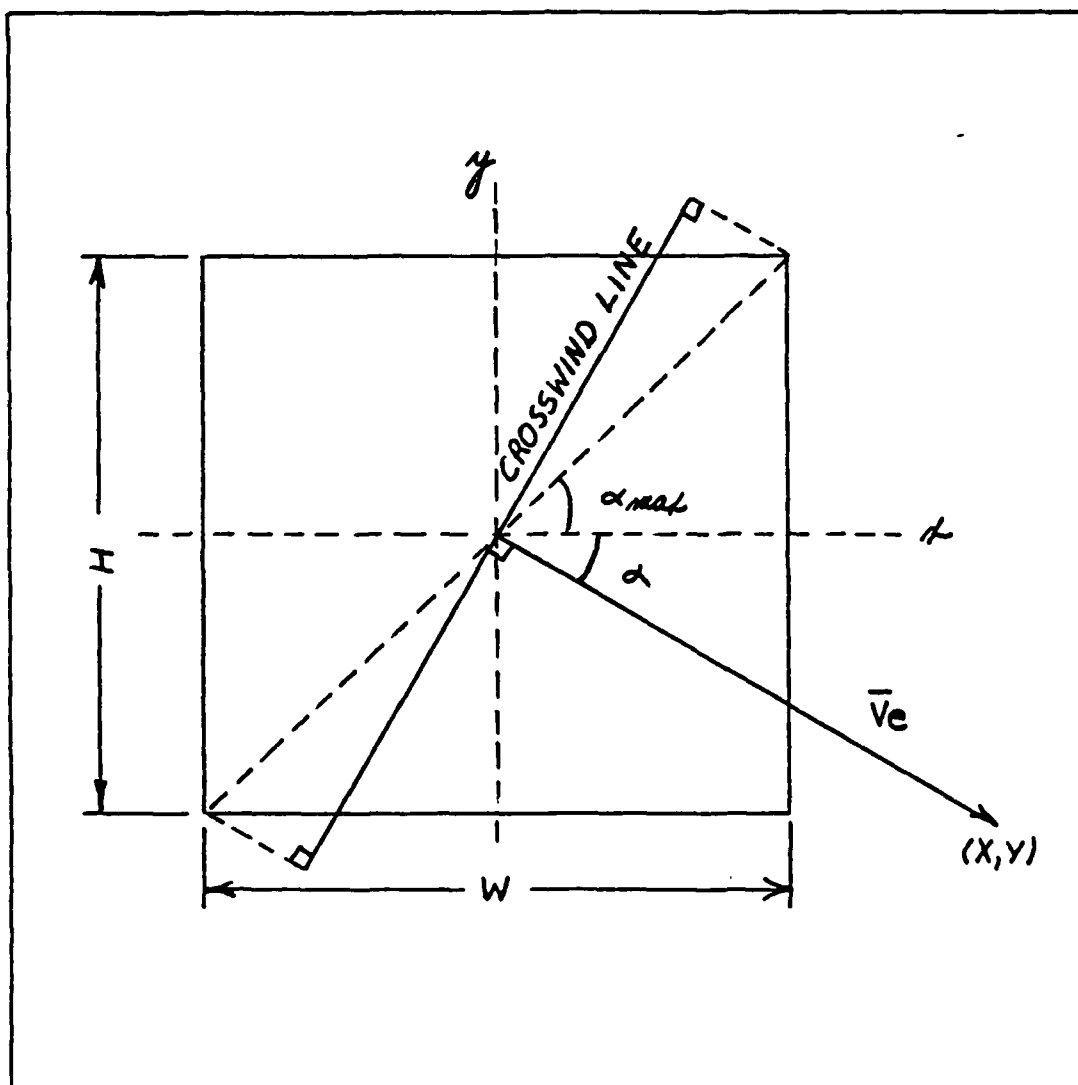


Figure 15
Effective Wind Vector and Crosswind Line
in a Rectangular Target Area

and define α as the angle between the effective wind vector and the x axis, or

$$\alpha = |\tan^{-1}(Y/X)| \quad (E-2)$$

Figure 16 shows that when $\alpha = 0$, or the effective wind is in the x direction, that the burst density is a constant in the crosswind direction. In the more general case when $0 < \alpha < \alpha_{max}$, Figure 17 shows that the burst density is a trapezoid. The area of the trapezoid is:

$$Area = \frac{1}{2}(b+l)h \quad (E-3)$$

which is also the total number of bursts within the target area. The diagonal of the target area is:

$$DIA = (H^2 + W^2)^{1/2} \quad (E-4)$$

and from figure 17, the base of the trapezoid, which is the crosswind line of length l is:

$$l = DIA \cos \beta \quad (E-5)$$

where β is the angle from the crosswind line to the diagonal in right triangle ABC.

Notice that

$$\beta = \frac{\pi}{2} - (\alpha + \alpha_{max}) \quad (E-6)$$

so that

$$l = DIA \sin(\alpha + \alpha_{max}) \quad (E-7)$$

Now, define ΔP as the line length DE, then the distance EF is equal to AG, or

$$AG = \frac{H}{2} - \Delta P \quad (E-8)$$

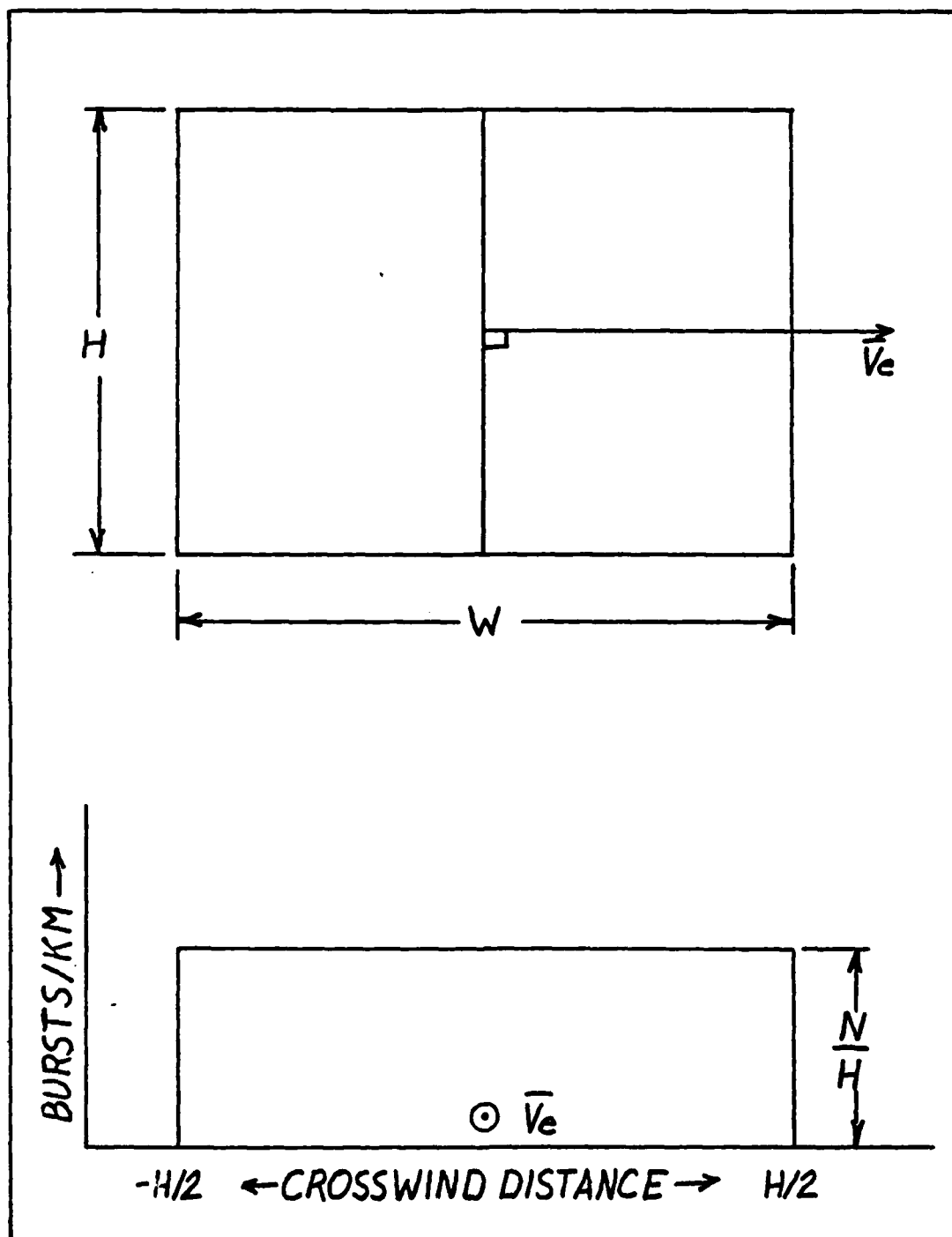


Figure 16

Constant Burst Density

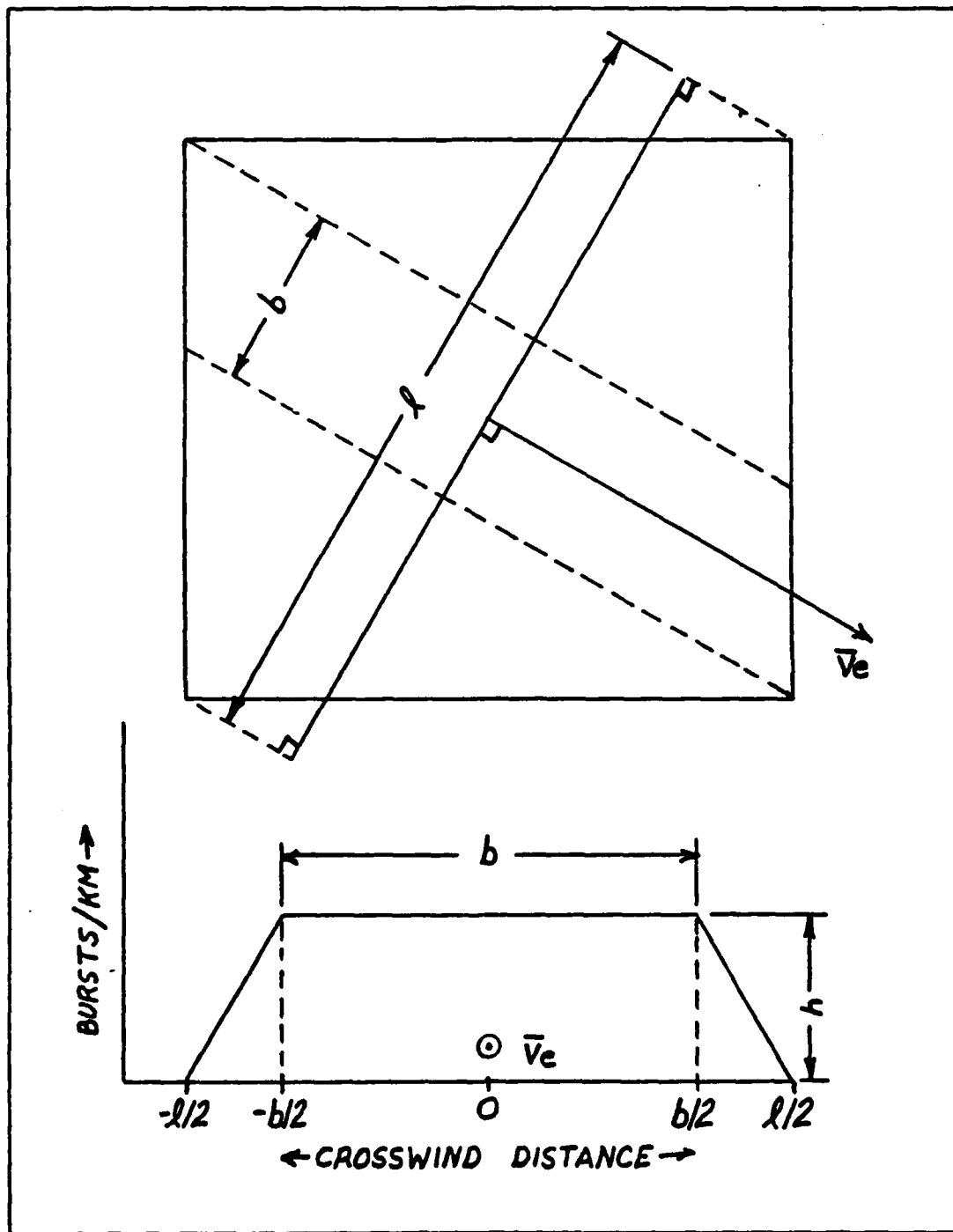


Figure 17

Trapezoidal Burst Density

From right triangle ADE,

$$\Delta P = \frac{W}{2} \tan \alpha \quad (E-9)$$

and from right triangle AGH and Eq(E-8),

$$\cos \alpha = \frac{b/2}{H/2 - \Delta P} \quad (E-10)$$

where b is the length of the top of the trapezoid in Figure 17.

Substituting Eq(E-9) into Eq(E-10) and solving for b yields:

$$b = (H - W \tan \alpha) \cos \alpha \quad (E-11)$$

Since the area of the trapezoid is equal to the total number of bursts N, then from Eq(E-3),

$$h = \frac{2N}{(b+l)} \quad (E-12)$$

where b is known from Eq(E-11) and l is known from Eq(E-7).

In a similar manner to the above, when $\alpha_{\max} \leq \alpha \leq \frac{\pi}{2}$ then:

$$l = DIA \sin (\alpha + \alpha_{\max}) \quad (E-13)$$

$$b = (W - H \cot \alpha) \sin \alpha \quad (E-14)$$

$$h = \frac{2N}{(b+l)} \quad (E-15)$$

Dose From a Line of Bursts

Crandley has shown that when $\theta = 0$, as in Figure 16, that (8:8),

$$\dot{D}_1(x, y) = \frac{C}{X} \frac{N}{H} \int_{-H/2}^{H/2} \frac{1}{\sqrt{2\pi} \sigma_y} e^{-\frac{1}{2} \left(\frac{y-S}{\sigma_y} \right)^2} dS \quad (E-16)$$

with

$$C = K Y_f g(t_a) t_a$$

X = the x value of the hotline coordinate

σ_y = the cloud standard deviation in the crosswind or y direction

N = the number of bursts

H = the length of the line of bursts

or

N/H = the constant burst density along the line of bursts

Figure 19 shows a line of bursts of length l in the crosswind direction depositing activity at (x^*, y^*) . Extending Crandley's results to a variable burst density and to the variable wind smearing equation, Eq(E-16) becomes

$$\dot{D}_1(x, y) = C \int_{-l/2}^{l/2} \frac{BD(S)}{\sqrt{2\pi} \sigma} e^{-\frac{1}{2} \left(\frac{x^*y - y^*x}{\sigma} \right)^2} dS \quad (E-17)$$

where

$$C = K Y_f g(t_a) t_a$$

$BD(S)$ = the burst density as a function of the distance S along the line of bursts

$$\sigma = (\sigma_x^2 y^2 + \sigma_y^2 x^2)^{1/2}$$

and x^*, y^* are functions of S .

By definition, each burst point is the coordinate origin for the fallout from that burst (11:73-82). Since the same wind is assumed to

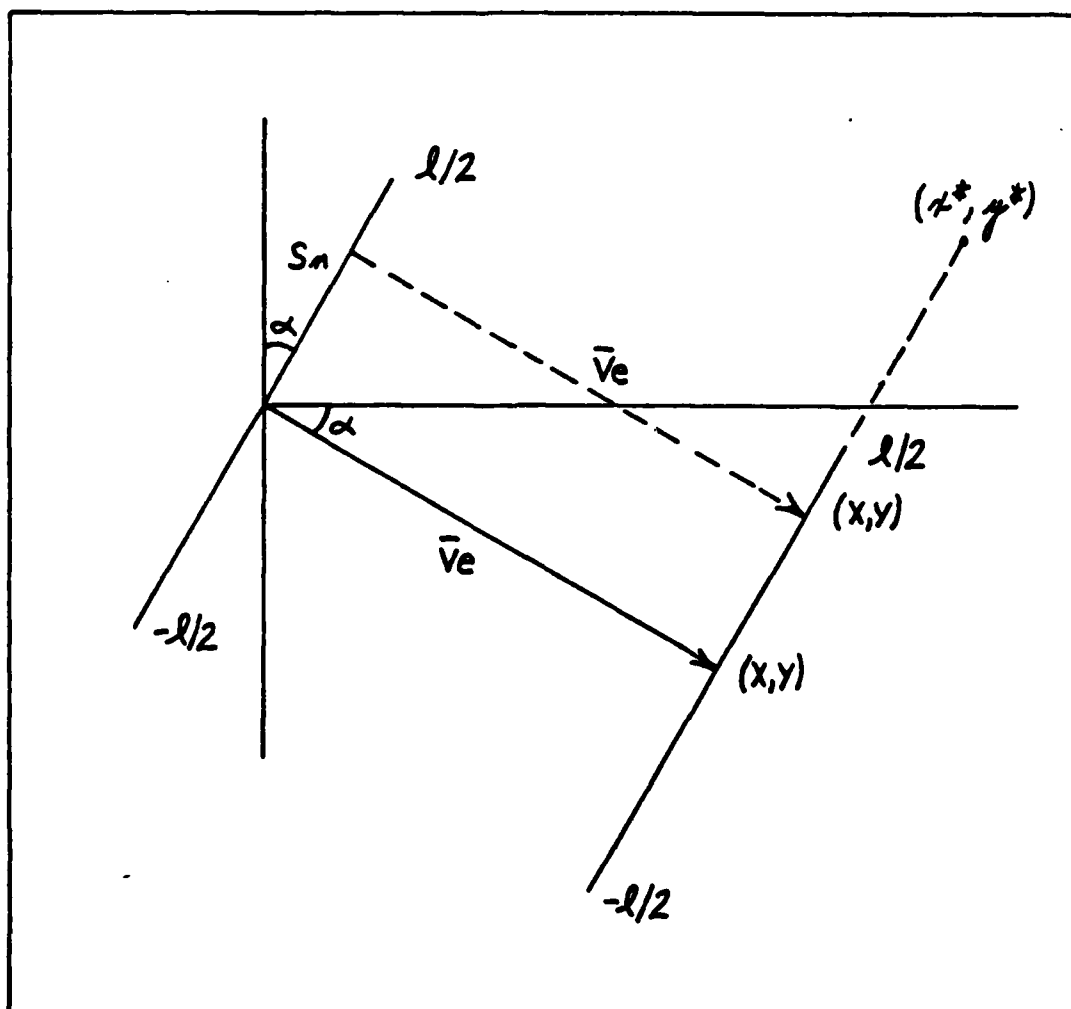


Figure 19

Dose From a Line of Bursts

translate all clouds, notice in Figure 19 that every burst on the line has the same effective wind vector to its hotline, and that X and Y are the same for each burst. However, the crosswind coordinates (x^*, y^*) are different for every burst. Redefining α as:

$$\alpha = \tan^{-1}(Y/X) \quad (E-18)$$

then from Figure 19, for burst number n at a distance S_n from the origin,

$$x^* = x + S_n \sin \alpha \quad (E-19a)$$

$$y^* = y - S_n \cos \alpha \quad (E-19b)$$

where x and y are defined from the center burst point where $S_n = 0$.

Substituting Eqs(E-19) into Eq(E-17) gives

$$\frac{D(x,y)}{C} = \int_{-\frac{1}{2}}^{\frac{1}{2}} \frac{BD(S)}{\sqrt{2\pi}r} \exp \left\{ -\frac{1}{2} \left[\frac{(x+S\sin\alpha)y - (y-S\cos\alpha)x}{r} \right]^2 \right\} dS \quad (E-20)$$

Let

$$z = \frac{(x+S\sin\alpha)y - (y-S\cos\alpha)x}{r} \quad (E-21a)$$

then

$$dz = \frac{(y\sin\alpha + x\cos\alpha)}{r} dS \quad (E-21b)$$

and

$$S = \frac{rz - (xy - yx)}{(y\sin\alpha + x\cos\alpha)} \quad (E-21c)$$

For $BD(S)$ in Eq(E-20), consider the trapezoidal burst density in Figure 16.

When $-\frac{a}{2} \leq S \leq -\frac{b}{2}$

$$BD(S) = \frac{2hS + lh}{(l-b)} \quad (E-22a)$$

when $-\frac{b}{2} \leq S \leq \frac{b}{2}$

$$BD(S) = h \quad (E-22b)$$

and when $\frac{b}{2} \leq S \leq \frac{l}{2}$

$$BD(S) = \frac{-2hS + lh}{(l-b)} \quad (E-22c)$$

Substituting Eqs(E-21) and Eqs(E-22) into Eq(E-20), we see that the integral in Eq(E-20) can be broken up into three integrals. The first integral is:

$$\int_{LL}^{UL} \left\{ \frac{2h}{(l-b)} \left[\frac{\sigma z - (y - yX)}{F^2} \right] + \frac{lh}{(l-b)F} \right\} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \quad (E-23a)$$

with

$$UL = \frac{(x - \frac{b}{2} \sin \alpha)Y - (y + \frac{b}{2} \cos \alpha)X}{r} \quad (E-24a)$$

$$LL = \frac{(x - \frac{b}{2} \sin \alpha)Y - (y + \frac{b}{2} \cos \alpha)X}{r} \quad (E-24b)$$

$$F = Y \sin \alpha + X \cos \alpha \quad (E-24c)$$

The second integral is:

$$\int_{LL'}^{UL'} \frac{h}{\sqrt{2\pi} F} e^{-\frac{1}{2}z^2} dz \quad (E-23b)$$

with

$$UL' = \frac{(x + \frac{b}{2} \sin \alpha)Y - (y - \frac{b}{2} \cos \alpha)X}{r} \quad (E-25a)$$

$$LL' = \frac{(x - \frac{b}{2} \sin \alpha)Y - (y + \frac{b}{2} \cos \alpha)X}{r} \quad (E-25b)$$

The third integral is:

$$\int_{LL''}^{UL''} \left\{ \frac{-2h}{(1-b)} \left[\frac{rz - (xY - yX)}{F^2} \right] + \frac{lh}{(1-b)F} \right\} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \quad (E-23c)$$

with

$$UL'' = \frac{(x + \frac{1}{2}\sin\alpha)Y - (y - \frac{1}{2}\cos\alpha)X}{r} \quad (E-26a)$$

$$LL'' = \frac{(x + \frac{1}{2}\sin\alpha)Y - (y - \frac{1}{2}\cos\alpha)X}{r} \quad (E-26b)$$

and with F defined by Eq(E-24c).

Eq(E-23a) reduces to three integrals:

$$\begin{aligned} &= \int_{LL}^{UL} \frac{2hFz}{(1-b)F^2} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \\ &+ \int_{LL}^{UL} \frac{(yX - xY)2h}{(1-b)F^2} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \\ &+ \int_{LL}^{UL} \frac{lh}{(1-b)F} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \quad (E-27) \end{aligned}$$

$$\begin{aligned} &= \frac{-2hF}{(1-b)F^2\sqrt{2\pi}} \left[e^{-\frac{1}{2}(UL)^2} - e^{-\frac{1}{2}(LL)^2} \right] \\ &+ \frac{(yX - xY)2h}{(1-b)F^2} \left[CNF(UL) - CNF(LL) \right] \\ &+ \frac{lh}{(1-b)F} \left[CNF(UL) - CNF(LL) \right] \quad (E-28a) \end{aligned}$$

where CNF is the cumulative normal function, which can be calculated by a polynomial approximation from Abramowitz and Stegun(1:932).

Eq(E-23b) reduces to

$$= \frac{h}{F} [CNF(UL') - CNF(LL')] \quad (E-28b)$$

Comparing Eq(E-23a) with Eq(E-23c), and comparing Eqs(E-24) with Eqs(E-26), we can write down the results of Eq(E-23c) directly as:

$$\begin{aligned} &= \frac{2h\sigma}{(1-b)F^2\sqrt{2\pi}} \left[e^{-\frac{1}{2}(UL'')^2} - e^{-\frac{1}{2}(LL'')^2} \right] \\ &\quad - \frac{(yX - xY)2h}{(1-b)F^2} [CNF(UL'') - CNF(LL'')] \\ &\quad + \frac{ph}{(1-b)F} [CNF(UL'') - CNF(LL'')] \quad (E-28c) \end{aligned}$$

Now, the dose rate from an area of bursts can be found from:

$$\dot{D}_1(x,y) = C [Eq(E-28a) + Eq(E-28b) + Eq(E-28c)] \quad (E-29)$$

Appendix F

Hotline Locator Program Listing

This program is the modified version of Hopkins' hotline locator described in Section II.

Table III is an example Tape20, a burst data file. The first line is for a single burst, and the second line is for multiple bursts in an area target. The entries in order are: center burst latitude, center burst longitude, weapon yield in megatons, number of bursts, height of target and width of target in kilometers, the yield fission fraction, the activity size distribution volume fractionation, natural log of the activity size distribution's mean radius, activity size distribution logarithmic slope, and particle density in grams per cubic centimeter. The activity size distribution is assumed to be log normal as described by Bridgman and Bigelow(4:210-211). The values in Table III are for the DELFIC default distribution. The hotline locator will work with any particle density, however, the dose program will only work with a particle density of 2.6 grams per cubic centimeter.

Table IV is an example Tape21, the program's output file. The first line is the burst data for the hotline. Following that is one line of data for each trace particle, showing in order: trace particle radius in meters, time of fall in seconds, x position in meters, x wind shear in per second, y position in meters, and y wind shear in per second.

TABLE III

Example Tape20 Burst Data File

47.95	97.40	.100E+01	1	000	000	.50	.68	-1.58964	1.38629	2.6
47.50	110.00	.100E+01	220	180	208	.50	.68	-1.58964	1.38629	2.6

TABLE IV

Example Tape21 Hotline Data File

47.95	97.40	.100E+01	1.	0.	0.	.50	.68	-1.58964	1.38629	2.6
	.200E-04	.942E+05	.176E+07	.316E-02	.440E+06	.393E-02				
	.213E-04	.840E+05	.169E+07	.310E-02	.502E+06	.389E-02				
	.225E-04	.754E+05	.163E+07	.304E-02	.539E+06	.385E-02				
	.250E-04	.621E+05	.151E+07	.291E-02	.552E+06	.374E-02				
	.275E-04	.522E+05	.136E+07	.282E-02	.511E+06	.363E-02				
	.300E-04	.448E+05	.121E+07	.285E-02	.441E+06	.358E-02				
	.338E-04	.365E+05	.102E+07	.312E-02	.326E+06	.349E-02				
	.400E-04	.275E+05	.779E+06	.366E-02	.181E+06	.337E-02				
	.500E-04	.178E+05	.505E+06	.432E-02	.527E+05	.331E-02				
	.875E-04	.821E+04	.238E+06	.444E-02	-.704E+04	.267E-02				
47.50	110.00	.100E+01	220.	180.	208.	.50	.68	-1.58964	1.38629	2.6
	.200E-04	.942E+05	.265E+07	.287E-02	-.788E+06	.581E-02				
	.213E-04	.840E+05	.232E+07	.273E-02	-.797E+06	.547E-02				
	.225E-04	.754E+05	.206E+07	.272E-02	-.905E+06	.520E-02				
	.250E-04	.621E+05	.163E+07	.309E-02	-.108E+07	.485E-02				
	.275E-04	.522E+05	.137E+07	.351E-02	-.111E+07	.473E-02				
	.300E-04	.448E+05	.120E+07	.380E-02	-.105E+07	.473E-02				
	.338E-04	.365E+05	.104E+07	.408E-02	-.922E+06	.483E-02				
	.400E-04	.275E+05	.844E+06	.433E-02	-.747E+06	.492E-02				
	.500E-04	.178E+05	.565E+06	.422E-02	-.522E+06	.488E-02				
	.875E-04	.821E+04	.251E+06	.386E-02	-.259E+06	.475E-02				

```

      PROGRAM HATCH
C   THIS IS A TRIAL RUN OF HATCHN CALLED HOLINE7 23 NOV 84
C   MODIFIED FOR TAPE20 INPUT
C   THIS PROGRAM COMPUTES THE TRANSLATION OF PARTICLES
C   FALLING FROM THE INITIAL CLOUD THROUGH SPECTRAL WINDS.
C   THE ATMOSPHERE IS DISCRETIZED INTO NL LAYERS, FROM EARTH
C   SURFACE UP TO THE HIGHEST PARTICLE.
C   WIND VECTORS ARE LINEARLY INTERPOLATED INTO A LAYER BY
C   INTERPOLATING WINDS FROM SPECTRAL LEVELS ABOVE AND BELOW.
      PARAMETER (NL=12,NP=10,JCAP=30,PI=3.14159265)
C
C   NL = NUMBER OF LAYERS IN ATMOSPHERE
C   NP = NUMBER OF TRACE PARTICLES USED TO DEFINE HOTLINE
C   CHOOSE DELZ GT 100 METERS (BL THICKNESS)
C
      DIMENSION PDIA(NP),ZPDIA(NP),WT(NP)
      DIMENSION ZMSL(NL+1),HGEO(NL+1),TZ(NL+1),PR(NL+1),
C      DENS(NL+1),VISK(NL+1)
      DIMENSION TR(NL)
      DOUBLE PRECISION CC,COLRAD
      DOUBLE PRECISION RR,RADLON,EPS(JCAP+2,JCAP+1)
      COMPLEX CU(1:12,1:JCAP+2,1:JCAP+1),CV(1:12,1:JCAP+2,1:JCAP+1)
      REAL BLAT,BLON,YM,NBURS,HLINE,WLINE,FF,FV,PALPH,PBETA,PDEN
C
      CALL EPSLN(EPS,JCAP)

      REWIND 10
      REWIND 20
      REWIND 21
      DO 99 LVL=1,12
        READ(10,98)((CU(LVL,N,L),N=1,32),L=1,31)
        READ(10,98)((CV(LVL,N,L),N=1,32),L=1,31)
99    CONTINUE
98    FORMAT(6E13.7,2X)
C
C
29    READ(20,30,END=31)BLAT,BLON,YM,NBURS,HLINE,WLINE,FF,FV,
C    PALPH,PBETA,PDEN
      WRITE(21,30)BLAT,BLON,YM,NBURS,HLINE,WLINE,FF,FV,
C    PALPH,PBETA,PDEN
30    FORMAT(F5.2,F8.2,E11.3,3F5.0,F5.2,F6.2,2F10.5,F5.1)

      COLRAD=PI/2.-BLAT*PI/180.
      RADLON=2.*PI-BLON*PI/180.
      CC=COLRAD
      RR=RADLON

C
      YKT=YM*1000.
      DATA PDIA/.004,.00425,.0045,.005,.0055,.006,.00675,.008,.01,.0175/
C
C   COMPUTE TRACE PARTICLE HEIGHTS IN THE STABILIZED CLOUD

```

```

C USING DELFIC CORRELATIONS IN H082
C
  YL=LOG(YKT)
  SL=1.574-.01197*YL+.03636*YL*YL-.0041*YL**3+.0001965*YL**4
  SLOPE=EXP(SL)
  XI=7.889+.34*YL+.001226*YL*YL-.005227*YL**3+.000417*YL**4
  XINT=EXP(XI)
C
  DO 1 I=1,NP
    ZPDIA(I)=-SLOPE*PDIA(I)*10000. + XINT
  1 CONTINUE
C
C ZMAX IS THE HEIGHT OF THE SMALLEST TRACE PARTICLE:
C THE MAX HEIGHT OF WAFER CENTERS IN THE CLOUD
  ZMAX=ZPDIA(1)
C
C DIVIDE THE ATMOSPHERE INTO NL LAYERS FROM 0 TO ZMAX
  DELZ=ZMAX/NL
C
C COMPUTE ATMOSPHERE STATE PROPERTIES
C
C CONSTANTS IN ATMOSPHERE STATE EQUATIONS
  RERTH=6356766.
  GAMMA=1.
  GOP=9.80665
  XMO=28.9644
  RSTAR=8314.32
  BETA=1.458E-6
  S=110.4
C
  DO 4 I=1,NL+1
    ZMSL(I)=(I-1)*DELZ
    HGEO(I)=GAMMA*((RERTH*ZMSL(I))/(RERTH+ZMSL(I)))
    IF (HGEO(I).LE.11000.) THEN
      XLMB=-6.5
      TB=288.15
      HB=0.
      PB=101325.
    ELSEIF (HGEO(I).GT.11000.) THEN
      XLMB=0.
      TB=216.65
      HB=11000.
      PB=22632.
    ENDIF
    TZ(I)=TB+XLMB*(HGEO(I)-HB)/1000.
    IF (XLMB.NE.0.) THEN
      PR(I)=PB*(TB/TZ(I))**(GOP*XMO*1000./(RSTAR*XLMB))
    ELSE
      PR(I)=PB*EXP((-GOP*XMO*(HGEO(I)-HB))/(RSTAR*TB))
    ENDIF
    DENS(I)=(PR(I)*XMO)/(RSTAR*TZ(I))
    VISK(I)=BETA*(TZ(I)**1.5)/(TZ(I)+S)/DENS(I)
  4 CONTINUE

```

```

C
C
DO 9 M=1,NL+1
DENS(M)=DENS(M)*.001
VISK(M)=VISK(M)*10000.
9 CONTINUE
C
C DAVIES-MCDONALD METHOD TO COMPUTE TERMINAL VELOCITIES
C WT >>> CD*R2 >>> RE >>> VZ
C

DO 13 I=1,NP
SHRX=0.
SHRY=0.
COLRAD=CC
RADLON=RR
WT(I)=(4./3.)*3.14159*((PDIA(I)/2.))**3.)*PDEN*980.
DATA TR/NL*0./
XM=0.
YM=0.
XR=RADLON
YR=COLRAD

C
C IH DESIGNATES A TRACE PARTICLE'S STARTING LEVEL NO. IN ATMOSPHERE
C LEVEL 1 = SEA LEVEL
C (IH-1) X DELZ : STARTING HEIGHT
IH=(NL+1)*(ZPDIA(I)/ZMAX)
A=ZPDIA(I)-(IH-1)*DELZ
IF(A.GE.DELZ/2.) IH=IH+1

C
TFALL=0.
DO 12 J=IH,1,-1

C
C COMPUTE RESIDENCE TIME IN EACH LAYER
C (BETWEEN TWO LEVELS)
C
Q=8.*WT(I)/(3.1416*DENS(J)*(VISK(J)**2.))
IF(Q.LT.140.)THEN
R=Q/24.-(2.3363E-4)*Q**2.+(2.0154E-6)*Q**3.
C-(6.9105E-9)*Q**4.
ELSEIF(Q.GE.140.)THEN
RL=-1.29536+.986*(LOG10(Q))-0.046677*((LOG10(Q)**2.))+
C.0011235*((LOG10(Q)**3.))
R=(10.)*RL
ENDIF

C
V1=R*VISK(J)/PDIA(I)
IF(J.EQ.IH)THEN
V2=V1
GO TO 12
ENDIF
VZA=(V2+V1)/2.
DENA=(DENS(J)+DENS(J+1))/2.

```

```

      SLIPF=1.+(2.33E-7)/(PDIA(I)*.01*DENA*1000.)
      VZA=VZA*SLIPF
      V2=V1
C   TR(J) IS RESIDENCE TIME IN A LAYER (SECONDS)
      TR(J)=(DELZ*100.)/VZA
      TFALL=TFALL+TR(J)
C
C
C   THERE ARE IH-1 LAYERS OF ATMOSPHERE BELOW A PARTICLE
12  CONTINUE
      DO 14 JJ=IH-1,1,-1
        US=0.
        VS=0.
C
C   COMPUTE DISTANCE IN BOTH RADIANS AND METERS
C   ZZ IS STARTING HEIGHT OF PARTICLE
C
      ZZ=JJ*DELZ
C   USE ZZ TO FIND LEVELS OF WIND COEFFICIENTS ABOVE AND BELOW ZZ
      CALL LAYERS (ZZ,LAYER,HL,HU)
      IF (LAYER.EQ.1) THEN
        LVL=1
        CALL UVCOMP (COLRAD,RADLON,LVL,US,VS,EPS,CU,CV)
        UU=US
        VU=VS
        UL=0.
        VL=0.
        GO TO 19
      ELSEIF (LAYER.EQ.13) THEN
        LVL=12
        CALL UVCOMP (COLRAD,RADLON,LVL,US,VS,EPS,CU,CV)
        UU=US
        VU=VS
        UL=US
        VL=VS
        GO TO 19
      ENDIF
C
      LVL=LAYER
      CALL UVCOMP (COLRAD,RADLON,LVL,US,VS,EPS,CU,CV)
      UU=US
      VU=VS
      LVL=LVL-1
      CALL UVCOMP (COLRAD,RADLON,LVL,US,VS,EPS,CU,CV)
      UL=US
      VL=VS
C
C   INTERPOLATE BETWEEN THE TWO SPECTRAL WIND VECTORS.
19  AA=(ZZ-HL)/(HU-HL)
      BB=(HU-ZZ)/(HU-HL)
      US=AA*UU+BB*UL
      VS=AA*VU+BB*VL

```

```

      IF (JJ.EQ.IH-1) THEN
      USOLD=US
      VSOLD=VS
      GO TO 20
      ELSE
      SHRX=SHRX+ ( ((USOLD-US)/DELZ)**2 ) *TR(JJ+1)
      SHRY=SHRY+ ( ((VSOLD-VS)/DELZ)**2 ) *TR(JJ+1)
      USOLD=US
      VSOLD=VS
      ENDIF
C
C
20  DYM=VS*TR(JJ)
    DYR=DYM/RERTH
    YM=YM+DYM
    YR=YR+DYR
C  VY IS POSITIVE NORTHWARD
C  COLRAD IS POSITIVE SOUTHWARD
    COLRAD=COLRAD-DYR
C
    DXM=US*TR(JJ)
    DXR=DXM/(RERTH*DSIN(COLRAD))
    XM=XM+DXM
    XR=XR+DXR
    RADLON=RADLON+DXR
C
    IF (JJ.EQ.1) THEN
C
    SHRX=SQRT (SHRX/TFALL)
    SHRY=SQRT (SHRY/TFALL)
C
C
    PRAD=PDIA(I)/2.*.01
    WRITE (21,15) PRAD,TFALL,XM,SHRX,YM,SHRY
15  FORMAT (6E12.3)
    ENDIF
C
14  CONTINUE
C
13  CONTINUE
    GOTO 29
31  CONTINUE
C
    STOP
    END
C
C *****
C
    SUBROUTINE LAYERS (ZZ,LAYER,HL,HU)
C  THIS ROUTINE SETS THE WIND LAYER FOR SELECTING
C  SPECTRAL COEFFICIENTS; HEIGHTS ARE IN METERS.
    IF (ZZ.GE.0.AND.ZZ.LT.100) THEN
      LAYER=1

```

```
HL=0.
HU=100.
ELSEIF (ZZ.GE.100.AND.ZZ.LT.1450) THEN
LAYER=2
HL=100.
HU=1450.
ELSEIF (ZZ.GE.1450.AND.ZZ.LT.3000) THEN
LAYER=3
HL=1450.
HU=3000.
ELSEIF (ZZ.GE.3000.AND.ZZ.LT.5600) THEN
LAYER=4
HL=3000.
HU=5600.
ELSEIF (ZZ.GE.5600.AND.ZZ.LT.7200) THEN
LAYER=5
HL=5600.
HU=7200.
ELSEIF (ZZ.GE.7200.AND.ZZ.LT.9200) THEN
LAYER=6
HL=7200.
HU=9200.
ELSEIF (ZZ.GE.9200.AND.ZZ.LT.10400) THEN
LAYER=7
HL=9200.
HU=10400.
ELSEIF (ZZ.GE.10400.AND.ZZ.LT.11800) THEN
LAYER=8
HL=10400.
HU=11800.
ELSEIF (ZZ.GE.11800.AND.ZZ.LT.13600) THEN
LAYER=9
HL=11800.
HU=13600.
ELSEIF (ZZ.GE.13600.AND.ZZ.LT.16200) THEN
LAYER=10
HL=13600.
HU=16200.
ELSEIF (ZZ.GE.16200.AND.ZZ.LT.18500) THEN
LAYER=11
HL=16200.
HU=18500.
ELSEIF (ZZ.GE.18500.AND.ZZ.LT.20600) THEN
LAYER=12
HL=18500.
HU=20600.
ELSEIF (ZZ.GE.20600.) THEN
LAYER=12
HL=20600.
HU=100000.
ENDIF
RETURN
END
```

```

C
C *****
C
C   SUBROUTINE UVCOMP (COLRAD,RADLON,LVL,US,VS,EPS,CU,CV)
C
C   THIS ROUTINE COMPUTES WIND VECTOR COMPONENTS
C   FROM NWS SPECTRAL COEFFICIENTS.
C
C   THERE ARE JCAP+1 ZONAL WAVE NUMBERS AND JCAP+2 ORDINAL
C   WAVE NUMBERS IN THE SPHERICAL HARMONICS SUMMATION.
C
C   CU AND CV ARE COMPLEX SPECTRAL COEFFICIENTS
C   FOR W-E AND S-N WIND COMPONENTS.
C
C   THERE ARE 12 SETS OF COEFFICIENTS:
C   ONE SET FOR EACH LEVEL OF ATMOSPHERE.
C
C   EACH SET CONTAINS 992 COEFFICIENTS (COMPLEX PAIRS)
C   FOR JCAP=30.
C
C   PARAMETER (JCAP=30)
C   COMPLEX CU(1:12,1:JCAP+2,1:JCAP+1),CV(1:12,1:JCAP+2,1:JCAP+1)
C   COMPLEX EIL,USUM,VSUM
C   DOUBLE PRECISION EPS(JCAP+2,JCAP+1)
C   DOUBLE PRECISION RADLON
C   DOUBLE PRECISION COLRAD
C   REAL PLN(JCAP+2,JCAP+1)
C   PI=3.14159265
C
C   COLRAD AND RADLON ARE COLATITUDE AND LONGITUDE IN RADIANS
C
C
C
C   JCAP1=JCAP+1
C   JCAP2=JCAP+2
C
C
C   CALL PLN3(PLN,COLRAD,JCAP,EPS)
C
C   USUM=0.
C   VSUM=0.
C   DO 10 LL=1,JCAP1
C   L=LL-1
C   EIL=CMPLX(DCOS(L*RADLON),DSIN(L*RADLON))
C   DO 10 NN=1,JCAP2
C   AA=2.
C   IF(L.EQ.0) AA=1.
C   USUM=USUM+AA*PLN(NN,LL)*CU(LVL,NN,LL)*EIL
C   VSUM=VSUM+AA*PLN(NN,LL)*CV(LVL,NN,LL)*EIL
10  CONTINUE
C
C   IF(COLRAD.LT.1.D-10) THEN

```

```

      PRINT*, ' **** NORTH POLE ****'
      GO TO 9999
    ENDIF

C
C  WIND VECTOR COMPONENTS
      US=REAL(USUM)/DSIN(COLRAD)
      VS=REAL(VSUM)/DSIN(COLRAD)
C
C  9999 RETURN
      END

C
C  *****
C
C  SUBROUTINE EPSLN(EPS,JCAP)
C
C  ***** EPSILON COEFFICIENTS FOR COMPUTING
C  ASSOCIATED LEGENDRE POLYNOMIALS WITH
C  RECURSION RELATION IN NWS30 P.24
C
C  DOUBLE PRECISION EPS(1)
C  DOUBLE PRECISION A
C
C  JCAP=30
C  JCAP1=JCAP+1
C  JCAP2=JCAP+2
C
C  DO 100 LL=1,JCAP1
C  L=LL-1
C  JLE=L*JCAP2
C
C  EPS(JLE+INDE)=DSQRT(A)
100 CONTINUE
C
C  DO 200 LL=1,JCAP1
C  JLE=(LL-1)*JCAP2
C  EPS(JLE+1)=0.D+0
200 CONTINUE
      RETURN
      END
C  *****
C
C  SUBROUTINE PLN3(PLN,COLRAD,JCAP,EPS)
C
C  ***** ASSOCIATED LEGENDRE POLYNOMIALS COMPUTED
C  WITH RECURSION RELATIONS IN BELOUSOV
C  AND NWS30 P.24
C
C  DOUBLE PRECISION COLRAD
C  DOUBLE PRECISION EPS(1)
C  DOUBLE PRECISION SINLAT
C  DOUBLE PRECISION COS2
C  DOUBLE PRECISION PROD
C  DOUBLE PRECISION A

```

```

DOUBLE PRECISION B
DOUBLE PRECISION FL
DOUBLE PRECISION P1
DOUBLE PRECISION P2
DOUBLE PRECISION P3
DOUBLE PRECISION UNFLOW
C
REAL PLN(1)
C
DATA UNFLOW/.75D-73/
C
SINLAT=DCOS(COLRAD)
COS2=1.D+0-SINLAT*SINLAT
PROD=1.D+0
A=1.D+0
B=0.D+0
JCAP1=JCAP+1
JCAP2=JCAP+2
C
DO 300 LL=1,JCAP1
L=LL-1
FL=L
JLE=L*JCAP2
IF(L.EQ.0) GO TO 400
A=A+2.D+0
B=B+2.D+0
C
C
FIX UNDERFLOW
IF(PROD.LE.UNFLOW) PROD=0.D+0
C
PROD=PROD*COS2*A/B
400 CONTINUE
C
P1=DSQRT(0.5D+0*PROD)
PLN(JLE+1)=SNGL(P1)
P2=DSQRT(2.D+0*FL+3.D+0)*SINLAT*P1
PLN(JLE+2)=SNGL(P2)
C
DO 500 N=3,JCAP2
LINDEX=JLE+N
P3=(SINLAT*P2-EPS(LINDEX-1)*P1)/EPS(LINDEX)
PLN(LINDEX)=SNGL(P3)
P1=P2
P2=P3
500 CONTINUE
C
300 CONTINUE
RETURN
END

```

Appendix G

Dose Program Listing

The dose program listing follows. All variables and routines are defined in the program header blocks.

```
PROGRAM DOSE5
*****
*   THIS PROGRAM CALCULATES THE DOSE DUE TO THE HOTLINE INFORMATION
*   PROVIDED BY HOLINE
*-----
*   VARIABLES
*   YO = YIELD OLD(MT) THE YIELD FROM THE PREVIOUS HOTLINE
*   YM = YIELD IN MEGATONS OF THE CURRENT HOTLINE
*   X = THE TRACE PARTICLE X COORDINATE
*   Y = THE TRACE PARTICLE Y COORDINATE
*   TFALL = THE TRACE PARTICLE TIME OF FALL
*   SHRX = THE WIND SHEAR IN THE X DIRECTION
*   SHRY = THE WIND SHEAR IN THE Y DIRECTION
*   R = TRACE PARTICLE RADIUS
*   NP = THE NUMBER OF TRACE PARTICLES FOR EACH HOTLINE
*   BLAT = THE BURST POINT LATITUDE
*   BLON = THE BURST POINT LONGTITUDE
*   MINLAT = THE MINIMUM LATITUDE FOR EACH HOTLINE THAT ACTIVITY IS
*           DEPOSITED AT
*   MAXLAT = THE MAXIMUM LATITUDE
*   MINLON = THE MINIMUM LONGTITUDE
*   MAXLON = THE MAXIMUM LONGTITUDE
*   HC = THE STABILIZED CLOUD HEIGHT ACCORDING TO WSEG
*   C = THE LAURENT SERIES COEFFICIENTS FOR R AS A FUNCTION OF TIME
*   SZ = THE STABILIZED CLOUD STANDARD DEVIATION IN THE VERTICAL
*       ACCORDING TO WSEG
*   SO = THE STABILIZED CLOUD STANDARD DEVIATION IN THE HORIZONTAL
*       ACCORDING TO WSEG
*   CELL = THE DOSE INFORMATION FOR EACH 1 DEG LAT BY 1 DEG LONG
*          CELL IN THE US
*          DIMENSIONED (I,J,K)
*          I - LATITUDE
*          J - LONGTITUDE
*          K=1 - DOSE TO INFINITY (RADS-TISSUE)
*          K=2 - UNIT TIME REFERENCE DOSE RATE
*          K=3 - DOSE RATE AT 1 DAY
*          K=4 - DOSE RATE AT 7 DAYS
```

```

*           K=5 - DOSE RATE AT 14 DAYS
*           K=6 - DOSE RATE AT 30 DAYS
*       CITY = THE DOSE TO INFINITY FOR EACH CITY
*       NKILL = THE NUMBER OF US POPULATION DEATHS DUE TO FALLOUT
*       A = THE SLOPE OF EACH HOTLINE SEGMENT
*       B = THE INTERCEPT OF EACH HOTLINE SEGMENT
*       NBURS = THE NUMBER OF BURSTS
*       HLINE,WLINE = THE HEIGHT(NS) AND WIDTH(EW) OF AN AREA OF BURSTS
*       FV = VOLUME FRACTION OF ACTIVITY
*       IF FV>1 THEN THE 2.5 MOMENT IS USED FOR ACTIVITY SIZE DIST.
*       FF = THE FISSION FRACTION OF THE YIELD
*       ALPHA = THE LOG MEAN OF THE ACTIVITY SIZE DISTRIBUTION
*       BETA = THE LOG SLOPE OF THE ACTIVITY SIZE DISTRIBUTION
*-----
* SUBROUTINES CALLED
*   UNITS - CONVERTS TFALL FROM SECONDS TO HOURS, SHEAR VALUES FROM
*           PER SECOND TO PER HOUR, AND (X,Y) FROM METERS TO
*           KILOMETERS
*   VALUES - FINDS THE STABILIZED CLOUD YIELD DEPENDENT VARIABLES
*   LIMITS - FINDS THE BOX CONTAINING THE HOTLINE AND THE CELLS
*           AFFECTED BY THE HOTLINE
*   FALOUT - FINDS THE DOSE INFORMATION FOR EACH CELL AND CITY
*   DEATH - FINDS THE POPULATION DEATHS DUE TO THE FALLOUT
*   RITE - OUTPUT THE NUMBER OF DEATHS AND THE CELL DOSE INFORMATION
*-----
* FILES USED
*   INPUT
*   TAPE21 - THIS FILE IS CREATED BY THE HOTLINE LOCATOR, AND FOR EACH
*           HOTLINE HAS: THE BURST LOCATION, YIELD, NUMBER OF BURSTS
*           SIZE OF THE BURST AREA, VOLUME AND FISSION FRACTIONS, AND
*           ACTIVITY SIZE DISTRIBUTION ALPHA AND BETA. AND FOR EACH
*           TRACE PARTICLE HAS THE PARTICLE TIME OF FALL, SIZE, THE
*           WIND SHEAR AND THE (X,Y) LOCATION
*   OUTPUT
*   TAPE22 - THIS IS THE PROGRAMS OUTPUT FILE CONTAINING THE NUMBER OF
*           POPULATION DEATHS AND THE DOSE INFORMATION FOR EACH CELL
*****
PARAMETER(NP=10)
REAL YD,YM,X(0:NP),Y(0:NP),TFALL(0:NP),SHRX(0:NP),
C   SHRY(0:NP),R(0:NP),BLAT,BLON,MINLAT,MAXLAT,MINLON,MAXLON,
C   HC,C(7),SZ,SO,CELL(25:49,67:124,6),CITY(316),NKILL,A(0:NP-1),
C   B(0:NP-1),NBURS,HLINE,WLINE,FV,FF,ALPHA,BETA
INTEGER I

DATA CELL/8700*0./
DATA CITY/316*0./
DATA YD/0./

REWIND 21
5  CONTINUE

READ(21,11,END=999)BLAT,BLON,YM,NBURS,HLINE,WLINE,FF,FV,

```

```

C   ALPHA,BETA
DO 10 I=NP,1,-1
    READ(21,12)R(I),TFALL(I),X(I),SHRX(I),Y(I),SHRY(I)
10  CONTINUE

11  FORMAT(F5.2,F8.2,E11.3,3F5.0,F5.2,F6.2,2F10.5,F5.1)
12  FORMAT(6E12.3)

    CALL UNITS(TFALL,X,SHRX,Y,SHRY,NP)

    CALL LIMITS(X,Y,BLAT,BLON,MINLAT,MAXLAT,MINLON,
C   MAXLON,NP,HLINE,WLINE)

    IF(YM.NE.YO)THEN
        CALL VALUES(YM,HC,C,SZ,SO)
        YO=YM
    ENDIF

    CALL FALOUT(CELL,CITY,X,Y,R,TFALL,YM,BLAT,BLON,MAXLAT,
C   MINLAT,MAXLON,MINLON,SO,SZ,C,NP,SHRX,SHRY,A,B,
C   NBURS,HLINE,WLINE,FF,FV,ALPHA,BETA)

    GOTO 5
999 CONTINUE

    CALL DEATH(CELL,CITY,NKILL)

    CALL RITE(CELL,NKILL)

    END

    SUBROUTINE UNITS(TFALL,X,SHRX,Y,SHRY,NP)
*****
*   THIS ROUTINE CHANGES THE UNITS OF THE VARIABLES IN THE ARGUMENT
*   LIST
*-----
*   VARIABLES
*   TFALL = TIME OF FALL, SECONDS TO HOURS
*   X = TRACE PARTICLE X COORDINATE, METERS TO KILOMETERS
*   SHRX = WIND SHEAR IN X DIRECTION, /SEC TO /HOUR
*   Y = TRACE PARTICLE Y COORDINATE, METERS TO KILOMETERS
*   SHRY = WIND SHEAR IN Y DIRECTION, /SEC TO /HOUR
*   NP = NUMBER OF TRACE PARTICLES
*   ...NOTE...THE IF STATEMENT INSURES A FINITE SLOPE FOR EACH
*   HOTLINE SEGMENT
*-----
*   NO SUBROUTINES CALLED
*-----
*   NO FILES USED
*****

    REAL TFALL(0:NP),X(0:NP),Y(0:NP),SHRX(0:NP),SHRY(0:NP)
    INTEGER I

```

```

DO 10 I=1,NP
  TFALL(I)=TFALL(I)/3600.
  X(I)=X(I)/1000.
  Y(I)=Y(I)/1000.
  SHRX(I)=SHRX(I)*3600.
  SHRY(I)=SHRY(I)*3600.
10  CONTINUE

  X(0)=0.
  Y(0)=0.
  TFALL(0)=0.
  SHRX(0)=0.
  SHRY(0)=0.

DO 20 I=0,NP-1
  IF(ABS(X(I+1)-X(I)) .LE. 1.E-03) X(I+1)=X(I)+.001
20  CONTINUE

```

END

```

SUBROUTINE VALUES(YM,HC,C,SZ,S0)
*****
* THIS ROUTINE COMPUTES YIELD DEPENDENT VALUES ACCORDING TO WSEG
* FORMULAS
*-----
* VARIABLES
*   YM = YIELD IN MEGATONS
*   HC = STABILIZED CLOUD HEIGHT IN KILOMETERS
*   C = LAURENT COEFFICIENTS FOR R(T)
*   CC = LAURENT COEFFICIENTS FOR NEXT HIGHER ALTITUDE
*   SZ = STABILIZED CLOUD STANDARD DEVIATION IN THE VERTICAL IN
*   KILOMETERS
*   S0 = STABILIZED CLOUD STANDARD DEVIATION IN THE HORIZONTAL IN
*   KILOMETERS
*   Z1,Z2 = HEIGHTS FROM THE LAURENT COEFFICIENT TABLE FOR
*   INTERPOLATION
*   YL = LOG OF YIELD IN MEGATONS
*   FRAC = LINEAR INTERPOLATION FACTOR BETWEEN ALTITUDES
*-----
* NO SUBROUTINES ARE CALLED
*-----
* FILES
* INPUT
* TAPE30 - A TABLE OF COLARCO'S LAURENT COEFFICIENTS AS A FUNCTION
* OF STABILIZED CLOUD HEIGHT, TABULATED EVERY 200 METERS
*****

```

```

REAL YM,HC,C(7),CC(7),SZ,S0,Z1,Z2,YL
INTEGER I

```

```

YL=LOG(YM)
HC=(44.+6.1*YL-.205*(YL+2.42)*ABS(YL+2.42))*1.609/5.280
SZ=.18*HC

```

```

S0=1.609*EXP(.70+1./3.*YL-3.25/(4.0+(YL+5.4**2)))

REWIND 30
READ(30,100)Z1,(C(I),I=1,4)
READ(30,100)Z1,(C(I),I=5,7)
10  CONTINUE
    READ(30,100)Z2,(CC(I),I=1,4)
    READ(30,100)Z2,(CC(I),I=5,7)
100  FORMAT(F5.1,4E11.5)

    IF(Z2.LT.HC)THEN
        Z1=Z2
        DO 20 I=1,7
            C(I)=CC(I)
20    CONTINUE
        GOTD 10
    ENDIF

    FRAC=(HC-Z1)/(Z2-Z1)
    DO 30 I=1,7
        C(I)=FRAC*(CC(I)-C(I))+C(I)
30    CONTINUE

    END

    SUBROUTINE LIMITS(X,Y,BLAT,BLON,MINLAT,MAXLAT,
C    MINLON,MAXLON,NP,HLINE,WLINE)
*****
*   THIS ROUTINE DEFINES THE LIMITS OF THE LATITUDE LONGITUDE BOX
*   WHICH CONTAINS THE HOTLINE AND ALL OF THE CELLS AFFECTED BY THE
*   HOTLINE
*-----
*   VARIABLES
*   X = TRACE PARTICLE X COORDINATE IN KILOMETERS
*   Y = TRACE PARTICLE Y COORDINATE IN KILOMETERS
*   BLAT = BURST LATITUDE
*   BLON = BURST LONGITUDE
*   MAXLAT = MAXIMUM LATITUDE OF THE BOX
*   MINLAT = MINIMUM LATITUDE OF THE BOX
*   MINLON = MINIMUM LONGITUDE OF THE BOX
*   MAXLON = MAXIMUM LONGITUDE OF THE BOX
*   NP = THE NUMBER OF TRACE PARTICLES
*   MAXX = MAXIMUM X OF BOX
*   MINX = MINIMUM X OF BOX
*   MAXY = MAXIMUM Y OF BOX
*   MINY = MINIMUM Y OF BOX
*   HLINE = HEIGHT OF AREA OF BURSTS
*   WLINE = WIDTH OF AREA OF BURSTS
*-----
*   NO SUBROUTINES ARE CALLED
*-----
*   NO FILES ARE USED
*****

```

```

PARAMETER(PI=3.14159265)
REAL X(0:NP),Y(0:NP),BLAT,BLON,MINLAT,MAXLAT,
C MINLON,MAXLON,MAXX,MINX,MAXY,MINY,HLINE,WLINE
INTEGER I

MAXX=0.
MINX=0.
MAXY=0.
MINY=0.

DO 10 I=0,NP
  MAXX=MAX(X(I),MAXX)
  MINX=MIN(X(I),MINX)
  MAXY=MAX(Y(I),MAXY)
  MINY=MIN(Y(I),MINY)
10 CONTINUE
  MAXY=MAXY+HLINE/2.
  MINY=MINY-HLINE/2.
  MAXX=MAXX+WLINE/2.
  MINX=MINX-WLINE/2.

MAXLAT=MAXY/110.94 + BLAT +6.
MINLAT=MINY/110.94 + BLAT -6.
MAXLON=-MINX/(COS(BLAT*PI/180.)*110.94)+ BLON +8.
MINLON=-MAXX/(COS(BLAT*PI/180.)*110.94)+ BLON -8.
MAXLAT=MIN(MAXLAT,50.)
MINLAT=MAX(MINLAT,25.)
MAXLON=MIN(MAXLON,125.)
MINLON=MAX(MINLON,67.)

END

SUBROUTINE FALOUT(CELL,CITY,X,Y,R,TFALL,YM,BLAT,BLON,MAXLAT,
C MINLAT,MAXLON,MINLON,SO,SZ,C,NP,SHRX,SHRY,A,B,
C NBURS,HLINE,WLINE,FF,FV,ALPHA,BETA)
*****
* THIS ROUTINE CALCULATES THE DOSE FOR EACH CELL AND CITY AFFECTED
* BY THE HOTLINE.
*-----
* VARIABLES
* CELL = THE DOSE INFORMATION FOR EACH CELL
* DIMENSIONED (I,J,K)
* I - CELL LATITUDE
* J - CELL LONGITUDE
* K=1 DOSE TO INFINITY
* K=2 UNIT TIME REFERENCE DOSE RATE
* K=3 DOSE RATE AT 1 DAY
* K=4 DOSE RATE AT 7 DAYS
* K=5 DOSE RATE AT 14 DAYS
* K=6 DOSE RATE AT 30 DAYS
* CITY = DOSE TO INFINITY FOR EACH CITY
* X = TRACE PARTICLE X COORDINATE IN KILOMETERS

```

```

*   Y = TRACE PARTICLE Y COORDINATE IN KILOMETERS
*   R = TRACE PARTICLE RADIUS IN METERS
*   TFAIL = TRACE PARTICLE TIME OF FALL IN HOURS
*   YM = YIELD IN MEGATONS
*   BLAT = BURST LATITUDE
*   BLON = BURST LONGTITUDE
*   MAXLAT = BOX MAXIMUM LATITUDE
*   MINLAT = BOX MINIMUM LATITUDE
*   MAXLON = BOX MAXIMUM LONGTITUDE
*   MINLON = BOX MINIMUM LONGTITUDE
*   SO = STABILIZED CLOUD HORIZONTAL STANDARD DEVIATION
*   SZ = STABILIZED CLOUD VERTICAL STANDARD DEVIATION
*   C = LAURENT COEFFICIENTS FOR R AS A FUNCTION OF TIME
*   SHRX = WIND SHEAR IN X DIRECTION FOR EACH TRACE PARTICLE
*   SHRY = WIND SHEAR IN Y DIRECTION FOR EACH TRACE PARTICLE
*   NP = NUMBER OF TRACE PARTICLES
*   HOTX,HOTY = POSITION ON THE HOTLINE DEPOSITING ACTIVITY AT
*              (XX,YY)
*   HOTTA = THE TIME OF ARRIVAL AT (HOTX,HOTY)
*   HOTSX,HOTSY = THE WIND SHEAR AT (HOTX,HOTY)
*   DINF = TIME INTEGRATED DOSE TO INFINITY
*   UTRDR = UNIT TIME REFERENCE DOSE RATE
*   DR1 = DOSE RATE AT 1 DAY
*   DR7 = DOSE RATE AT 7 DAYS
*   DR14 = DOSE RATE AT 14 DAYS
*   DR30 = DOSE RATE AT 30 DAYS
*   CLAT = CITY LATITUDE
*   CLON = CITY LONGTITUDE
*   LON = CELL CENTER LONGTITUDE
*   LAT = CELL CENTER LATITUDE
*   CLOMIN = MINIMUM CELL CENTER LONGTITUDE OF FALLOUT BOX
*   CLOMAX = MAXIMUM CELL CENTER LONGTITUDE
*   CLAMIN = THE MINIMUM CELL CENTER LATITUDE
*   CLAMAX = MAXIMUM CELL CENTER LATITUDE
*   A,B = SLOPE AND INTERCEPT OF THE STRAIGHT LINE EQUATION FOR EACH
*         HOTLINE SEGMENT
*   SWI = LOGICAL SWITCH; IF SWI=.TRUE. THEN THERE IS NO POINT ON
*         THE HOTLINE WITH A CROSSWIND VECTOR TO THE CELL CENTER OR
*         CITY LOCATION. NO ACTIVITY DEPOSITED AT THAT POINT.
*   CSWI = LOGICAL SWITCH; IF CSWI=.TRUE. THEN FINDING ACTIVITY AT
*         A CITY
*   XX,YY = POINT AT WHICH FINDING ACTIVITY DEPOSITED
*   NBURS = NUMBER OF BURSTS
*   HLINE,WLINE = HEIGHT AND WIDTH OF AN AREA OF BURSTS
*   FV = VOLUME FRACTION OF ACTIVITY
*   FF = FISSION FRACTION OF YIELD
*   ALPHA,BETA = PARAMETERS OF ACTIVITY SIZE DISTRIBUTION
* -----
*   SUBROUTINES CALLED
*   SLOINT - FINDS THE SLOPE AND INTERCEPT FOR THE LINE EQUATION OF
*           EACH HOTLINE SEGMENT
*   POSIT - FINDS THE POSITION (XX,YY) FROM THE BURST POINT FOR THE
*           LAT LON COORDINATES

```

```

* HLLOC - FINDS THE HOTLINE COORDINATE (HOTX,HOTY) WHICH DEFINES THE
*          ACTIVITY DEPOSITED AT (XX,YY)
* SMEAR - FINDS THE DOSE INFORMATION AT (XX,YY) DUE TO (HOTX,HOTY)

```

```

* FILES USED

```

```

* INPUT

```

```

* TAPE53 - THIS FILE IS A LIST OF EACH CITY'S LATITUDE, LONGITUDE
*          AND POPULATION

```

```

*****

```

```

REAL CELL(25:49,67:124,6),CITY(316),X(0:NP),Y(0:NP),R(0:NP),
C   TFALL(0:NP),YM,BLAT,BLON,MAXLAT,MINLAT,MAXLON,MINLON,SO,SZ,
C   XX,YY,LAT,LON,SHRX(0:NP),SHRY(0:NP),HOTX,HOTY,HOTTA,DINF,
C   DR1,DR7,DR14,UTRDR,CLAT,C(7),DR30,A(0:NP-1),B(0:NP-1),
C   NBURS,HLINE,WLINE,ALPHA,BETA

```

```

INTEGER I

```

```

LOGICAL SWI,CSWI

```

```

SWI=.FALSE.

```

```

CSWI=.FALSE.

```

```

CALL SLOINT(X,Y,A,B,NP)

```

```

CLOMAX=INT(MAXLON)+.5

```

```

IF(CLOMAX.GT.125.)CLOMAX=124.5

```

```

CLOMIN=INT(MINLON)+.5

```

```

CLAMAX=INT(MAXLAT)+.5

```

```

IF(CLAMAX.GT.50.)CLAMAX=49.5

```

```

CLAMIN=INT(MINLAT)+.5

```

```

DO 10 LON=CLOMIN,CLOMAX

```

```

DO 10 LAT=CLAMIN,CLAMAX

```

```

CALL POSIT(XX,YY,BLAT,BLON,LAT,LON)

```

```

CALL HLLOC(XX,YY,X,Y,TFALL,HOTX,HOTY,HOTTA,SWI,SHRX,SHRY,

```

```

C   HOTSX,HOTSY,NP,A,B)

```

```

IF(SWI)THEN

```

```

    SWI=.FALSE.

```

```

    GOTO 10

```

```

ENDIF

```

```

CALL SMEAR(HOTX,HOTY,XX,YY,HOTTA,DINF,UTRDR,DR1,DR7,DR14,YM,

```

```

C   SO,SZ,C,HOTSX,HOTSY,DR30,NBURS,HLINE,WLINE,ALPHA,BETA,

```

```

C   FV,FF,CSWI,BLAT)

```

```

CELL(INT(LAT),INT(LON),1)=CELL(INT(LAT),INT(LON),1)+DINF

```

```

CELL(INT(LAT),INT(LON),2)=CELL(INT(LAT),INT(LON),2)+UTRDR

```

```

CELL(INT(LAT),INT(LON),3)=CELL(INT(LAT),INT(LON),3)+DR1

```

```

CELL(INT(LAT),INT(LON),4)=CELL(INT(LAT),INT(LON),4)+DR7

```

```

CELL(INT(LAT),INT(LON),5)=CELL(INT(LAT),INT(LON),5)+DR14

```

```

CELL(INT(LAT),INT(LON),6)=CELL(INT(LAT),INT(LON),6)+DR30

```

```

10 CONTINUE

```

```

REWIND 53

```

```

SWI=.FALSE.

```

```

CSWI=.TRUE.

```

```

DO 20 I=1,316
  READ(53,11)CLAT,CLON,POP
  IF(CLAT.GT.MAXLAT+1 .OR. CLAT.LT.MINLAT-1. .OR. CLON.GT.MAXLON+1.
C  .OR. CLON.LT.MINLON-1.)GOTO 20
  CALL POSIT(XX,YY,BLAT,BLON,CLAT,CLON)
  CALL HLLOC(XX,YY,X,Y,TFALL,HOTX,HOTY,HOTTA,SWI,SHRX,SHRY,
C  HOTSX,HOTSY,NP,A,B)
  IF(SWI)THEN
    SWI=.FALSE.
    GOTO 20
  ENDIF
  CALL SMEAR(HOTX,HOTY,XX,YY,HOTTA,DINF,UTRDR,DR1,DR7,DR14,YM,
C  SO,SZ,C,HOTSX,HOTSY,DR30,NBURS,HLINE,WLINE,ALPHA,
C  BETA,FV,FF,CSWI,BLAT)
  CITY(I)=CITY(I)+DINF
20  CONTINUE
11  FORMAT(2F9.2,F10.0)

```

END

SUBROUTINE DEATH(CELL,CITY,NKILL)

```

*****
* THIS ROUTINE CALCULATES THE NUMBER OF DEATHS DUE TO FALLOUT
* -----
* VARIABLES
* CELL = THE DOSE INFORMATION FOR EACH 1 DEG LAT BY 1 DEG LONG
*       CELL IN THE US
*       DIMENSIONED(I,J,K)
*       I - LATITUDE
*       J - LONGITUDE
*       K=1 - DOSE TO INFINITY
* CITY = THE DOSE TO INFINITY FOR EACH CITY
* NKILL = THE TOTAL NUMBER OF DEATHS
* DOSS = DOSE SURE SAFE, NO DEATHS FOR DOSES LESS THAN THIS VALUE
* DOSK = DOSE SURE KILL, 100% DEATHS FOR DOSE GREATER THAN THIS
* A,B = DUMMY VARIABLES FOR THE CITY LAT LON WHICH IS NOT USED
* POP = POPULATION FOR EACH CELL AND THOUSANDS FOR EACH CITY
* CNF = THE PROBABILITY OF DEATH
* PF = PROTECTION FACTOR FROM DOSE GIVEN BY FALLOUT SHELTER
* ALPHA = LOG(MEAN) OF PROBABILITY OF DEATH DISTRIBUTION
* BETA = LOG(SLOPE) OF PROBABILITY OF DEATH DISTRIBUTION
* Z = ARGUMENT FOR A CUMULATIVE LOG-NORMAL DISTRIBUTION
* -----
* SUBROUTINES CALLED
* FUNCTION CNF - CALCULATES THE PROBABILITY OF DEATH, ASSUMING
*               THE PROBABILITY IS A CUMULATIVE LOG NORMAL FUNCTION, OF
*               DOSE, AND THAT DOSS HAS A PROBABILITY OF .01 AND DOSK HAS A
*               PROBABILITY OF .99
* -----
* FILES USED
* TAPE55 - THE RURAL POPULATION DATA FOR EACH CELL
* TAPE53 - THE URBAN POPULATION FOR EACH CITY
*****

```

```

REAL CELL(25:49,67:124,6),CITY(316),NKILL,DOSS,DOSK,PF,A,B,
C POP,ALPHA,BETA,Z
INTEGER I,J

DATA DOSS/169./
DATA DOSK/1198./
DATA PF/.333333/

ALPHA=.5*LOG(DOSK*DOSS)
BETA=LOG(DOSK/DOSS)/4.656

REWIND 55
NKILL=0.
DO 20 I=25,49
DO 20 J=67,124
  READ(55,21)A,B,POP
  IF(CELL(I,J,1)*PF.LT.DOSS)GOTO 20
  IF(CELL(I,J,1)*PF.GT.DOSK)THEN
    NKILL=NKILL+POP
  ELSE
    Z=(LOG(CELL(I,J,1)*PF)-ALPHA)/BETA
    NKILL=NKILL+POP*CNF(Z)
  ENDIF
20 CONTINUE
21 FORMAT(2F8.1,E10.3)

REWIND 53
DO 30 I=1,316
  READ(53,40)A,B,POP
  IF(CITY(I)*PF.LT.DOSS)GOTO 30
  IF(CITY(I)*PF.GT.DOSK)THEN
    NKILL=NKILL+POP*1000.
  ELSE
    Z=(LOG(CITY(I)*PF)-ALPHA)/BETA
    NKILL=NKILL+POP*1000.*CNF(Z)
  ENDIF
30 CONTINUE
40 FORMAT(2F9.2,F10.0)

END

SUBROUTINE RITE(CELL,NKILL)
*****
* THIS ROUTINE WRITES THE NUMBER OF DEATHS AND THE DOSE INFORMATION
* FOR EACH CELL TO TAPE22
*-----
* VARIABLES
* CELL = THE DOSE INFORMATION FOR EACH CELL
* DIMENSIONED (I,J,K)
* I=1 - CELL LATITUDE
* J - CELL LONGITUDE
* K=1 DOSE TO INFINITY

```

```

*           K=2 UNIT TIME REFERENCE DOSE RATE
*           K=3 DOSE RATE AT 1 DA
*           K=4 DOSE RATE AT 7 DAYS
*           K=5 DOSE RATE AT 14 DAYS
*           K=6 DOSE RATE AT 30 DAYS
*           NKILL = THE TOTAL NUMBER OF DEATHS
*           ND = CHARACTER STRING 'THE NUMBER OF DEATHS = '
*           HEADER = CHARACTER STRING HEADER FOR CELL DOSE INFORMATION
*-----
*           NO SUBROUTINES ARE CALLED
*-----
*           FILES
*           OUTPUT
*           TAPE22 - CONTAINS THE NUMBER OF DEATHS DUE TO FALLOUT, AND THE
*                   DOSE INFORMATION FOR EACH CELL CENTER
*****

      REAL CELL(25:49,67:124,6),NKILL
      INTEGER I,J
      CHARACTER ND*22,HEADER*75

      REWIND 22
      ND='THE NUMBER OF DEATHS ='
      HEADER=' LAT LONG DINF UTRDR DR1 DR7'
      C // ' DR14 DR30'

      WRITE(22,10)ND,NKILL
      WRITE(22,11)HEADER
      DO 20 I=25,49
      DO 20 J=67,124
      WRITE(22,12)REAL(I)+.5,REAL(J)+.5,(CELL(I,J,K),K=1,6)
20    CONTINUE

10    FORMAT(A22,E8.3)
11    FORMAT(A75)
12    FORMAT(2(F5.1,2X),6(E8.3,3X))

      END

      SUBROUTINE POSIT(XX,YY,BLAT,BLON,LAT,LON)
*****
*           GIVEN THE BURST LATITUDE AND THE BURST LONGITUDE, THIS ROUTINE
*           FINDS THE POSTION (XX,YY) CORRESPONDING TO (LAT,LON)
*-----
*           VARIABLES
*           XX - THE DISTANCE ALONG THE X AXIS FOR POINT(LAT,LON)
*           YY - THE DISTANCE ALONG THE Y AXIS FOR POINT(LAT,LON)
*           BLAT = BURST LATITUDE IN DEGREES, 0 ON THE X AXIS
*           BLON = BURST LONGITUDE IN DEGREES, 0 ON THE Y AXIS
*           LAT = LATITUDE OF A POINT
*           LON = LONGITUDE OF A POINT
*           NOTE: THERE ARE ABOUT 110.94 KM/DEGREE OF LATITUDE
*-----

```

* NO SUBROUTINES CALLED

* NO FILES ARE USED

PARAMETER(PI=3.14159265)
REAL XX,YY,BLAT,BLON,LAT,LON

XX=(BLON-LON)*COS(BLAT*PI/180.)*110.94
YY=(LAT-BLAT)*110.94

END

SUBROUTINE HLLOC(XX,YY,X,Y,TFALL,HOTX,HOTY,HOTTA,SWI,SHRX,SHRY,
C HOTSX,HOTSY,NP,A,B)

* THIS ROUTINE LOCATES THE POSITION ON THE HOTLINE WHICH DETERMINES
* THE UNIT TIME REFERENCE DOSE RATE AT THE POSITION(XX,YY) OFF THE
* HOTLINE, ACCORDING TO HOPKINS' SMEAR EQUATION. THE TIME OF ARRIVAL
* AND WIND SHEAR AT THE HOTLINE POINT ARE ALSO FOUND.

* VARIABLES

* XX = X COORDINATE OF A POINT OFF THE HOTLINE
* YY = Y COORDINATE OF A POINT OFF THE HOTLINE
* X,Y = TRACE PARTICLE COORDINATES
* TFALL = TRACE PARTICLE TIMES OF FALL
* HOTX,HOTY = THE HOTLINE COORDINATE TO CALCULATE ACTIVITY AT
* (XX,YY)
* HOTTA = TIME OF ARRIVAL AT (HOTX,HOTY)
* SWI = LOGICAL VARIABLE, WHEN TRUE, THERE IS NO POINT ON THE
* HOTLINE CONTRIBUTING ACTIVITY AT (XX,YY)
* SHRX,SHRY = WIND SHEAR FOR TRACE PARTICLES IN X AND Y DIRECTION
* HOTSX,HOTSY = WIND SHEAR AT (HOTX,HOTY) IN X AND Y DIRECTION
* NP = NUMBER OF TRACE PARTICLES
* A = THE SLOPE OF A HOTLINE SEGMENT
* B = THE INTERCEPT OF A HOTLINE SEGMENT
* AA,BB,CC = QUADRATIC COEFFICIENTS TO FIND (HOTX,HOTY)
* XX1,XX2 = TRIAL HOTLINE X COORDINATES
* T = THE PARAMETER IN THE PARAMETRIC REPRESENTATION OF THE
* HOTLINE SEGMENT

* SUBROUTINES CALLED

* LINSEG - DETERMINES IF A TRIAL X IS ON A HOTLINE SEGMENT, AND IF
* BOTH TRIAL X ARE ON A HOTLINE SEGMENT, PICKS THE
* EARLIEST ONE

* NO FILES ARE USED

REAL XX,YY,X(0:NP),Y(0:NP),TFALL(0:NP),HOTX,HOTY,HOTTA,
C SHRX(0:NP),SHRY(0:NP),HOTSX,HOTSY,AA,BB,CC,XX1,XX2,
C T,A(0:NP-1),B(0:NP-1)
LOGICAL SWI

```

INTEGER I

DO 10 I=0,NP-1
  AA=-A(I)**2-1.
  BB=XX+A(I)*YY-2.*A(I)*B(I)
  CC=B(I)*YY-B(I)**2
  IF(BB**2.LT.4.*AA*CC)GOTO 10
  XX1=(-BB+SQRT(BB**2-4.*AA*CC))/(2*AA)
  XX2=(-BB-SQRT(BB**2-4.*AA*CC))/(2*AA)
  HOTX=0.
  IF(X(I+1).GE.X(I))THEN
    CALL LINSEG(X(I),TFALL(I),XX1,XX2,X(I+1),TFALL(I+1),HOTX)
  ELSE
    CALL LINSEG(X(I+1),TFALL(I+1),XX1,XX2,X(I),TFALL(I),HOTX)
  ENDIF

  IF(HOTX.NE.0.)THEN
    HOTY=A(I)*HOTX+B(I)
    GOTO 20
  ENDIF
10 CONTINUE

SWI=.TRUE.
RETURN

20 CONTINUE

T=(HOTX-X(I))/(X(I+1)-X(I))
HOTA=T*TFALL(I+1)+TFALL(I)*(1.-T)
HOTSX=T*SHRX(I+1)+SHRX(I)*(1.-T)
HOTSY=T*SHRY(I+1)+SHRY(I)*(1.-T)

END

SUBROUTINE SMEAR(X,Y,XX,YY,TA,DINF,UTRDR,DR1,DR7,DR14,YM,S0,SZ,
C          C,SHRX,SHRY,DR30,NBURS,HLINE,WLINE,ALPHA,
C          BETA,FV,FF,CSWI,BLAT)
*****
* THIS ROUTINE CALCULATES THE DOSE AT (XX,YY) FROM THE HOTLINE (X,Y)
*-----
* VARIABLES
*   X,Y = HOTLINE COORDINATES
*   XX,YY = OFF HOTLINE COORDINATES
*   TA = TIME OF ARRIVAL IN HOURS AT (X,Y)
*   DINF = THE TIME INTEGRATED DOSE TO INFINITY AT (XX,YY)
*   UTRDR = UNIT TIME REFERENCE DOSE RATE AT (XX,YY)
*   DR1 = THE DOSE RATE AT 1 DAY AT (XX,YY)
*   DR7 = THE DOSE RATE AT 7 DAYS AT (XX,YY)
*   DR14 = THE DOSE RATE AT 14 DAYS AT (XX,YY)
*   DR30 = THE DOSE RATE AT 30 DAYS AT (XX,YY)
*   YM = YIELD IN MEGATONS
*   S0 = INITIAL STABILIZED CLOUD STANDARD DEVIATION IN THE
*        HORIZONTAL

```

```

* SZ = STABILIZED CLOUD STANDARD DEVIATION IN THE VERTICAL
* C = COLARCO'S COEFFICIENTS FOR R(T)
* SHRX = WIND SHEAR IN THE X DIRECTION AT (X,Y)
* SHRY = WIND SHEAR IN THE Y DIRECTION AT (X,Y)
* HC = STABILIZED CLOUD HEIGHT
* NBURS = NUMBER OF BURSTS
* HLINE = HEIGHT OF AREA OF BURSTS
* WLINE = WIDTH OF AREA OF BURSTS
* TASTAR,TC = TIME VARIABLES TO FIND SIGX,SIGY ACCORDING TO WSEG
* SIGY = THE STABILIZED CLOUD Y STANDARD DEVIATION AT (X,Y)
* SIGX = THE STABILIZED CLOUD X STANDARD DEVIATION AT (X,Y)
* R = PARTICLE RADIUS IN MICRONS OR METERS
* T = DUMMY TIME VARIABLE TO AVOID GTA SINGULARITY AT T=0
* RT = DR/DT OF FALLOUT AT (X,Y)
* ALPHA,BETA,ALPH2,ALPH3 = PARAMETERS FOR ACTIVITY SIZE
* DISTRIBUTION
* FV = ACTIVITY VOLUME FRACTION
* FF = FISSION FRACTION OF YIELD
* DENOM,CONST1,CONST2 = DUMMY VARIABLES TO SIMPLIFY EXPRESSIONS
* FOR ACTIVITY SIZE DISTRIBUTION
* Z3,Z2 = EXPONENTIAL POWERS FOR ACTIVITY SIZE VOLUME AND AREA
* FRACTIONS
* AR = ACTIVITY FOR PARTICLES OF SIZE R
* CIF = TERM IN HOPKINS' SMEARING EQUATION
* Z1 = EXPONENTIAL TERM IN HOPKINS' SMEARING EQUATION
* FXY = THE 2 DIMENSIONAL GAUSSIAN TERM OF HOPKINS' SMEARING
* EQUATION
* K = SOURCE NORMALIZATION CONSTANT
* GTA = THE FRACTION OF ACTIVITY ARRIVING EVERYWHERE AT TA
* BLAT = BURST LATITUDE
* CSWI = LOGICAL SWITCH, IF .TRUE. THEN FINDING DOSE AT A CITY
* -----
* SUBROUTINES CALLED
*   SINGLE - FINDS THE AVERAGE DOSE ACROSS A CELL OR CITY FOR A
*             SINGLE BURST
*   MULTI - FINDS THE DOSE AT A CELL CENTER OR CITY FOR AN AREA OF
*            BURSTS
* -----
* NO FILES ARE USED
*****

PARAMETER(PI=3.14159265)
REAL X,Y,XX,YY,TA,DINF,UTDR,DR1,DR7,DR14,YM,S0,SZ,C(7),SHRX,
C   SHRY,HC,SIGX,SIGY,R,T,RT,ALPHA,BETA,ALPH3,ALPH2,FV,DENOM,
C   CONST2,CONST3,Z2,Z3,AR,GTA,CIF,Z1,FXY,DR30,K,FF,NBURS,
C   HLINE,WLINE,D,B,A,Z6,Z7,ANG,ANGM
LOGICAL CSWI
INTEGER I

DATA K/7452./
HC=SZ/.18*5.280/1.609
TASTAR=MIN(TA,3.)
TC=12.*HC/60.-2.5*(HC/60.)*2

```

```

SIGY=S0**2*(1+8.*TASTAR/TC)+(SZ*SHRY*TA/10.)**2
SIGY=SQRT(SIGY)
SIGX=S0**2*(1+8.*TASTAR/TC)+(SZ*SHRX*TA/10.)**2
SIGX=SQRT(SIGX)

T=MAX(TA,.1)
R=0.
DO 10 I=1,6
    R=R+C(I)*T**(I-6)
10 CONTINUE
    R=R+C(7)/SQRT(T)
R=R*1.E06

RT=0.
DO 20 I=1,5
    RT=RT+(I-6)*C(I)*T**(I-7)
20 CONTINUE
    RT=RT-.5*C(7)*T**(-1.5)
RT=RT*1.E06

ALPH3=ALPHA+3.*BETA**2
ALPH2=ALPHA+2.*BETA**2
DENOM=SQRT(2*PI)*BETA*R
CONST3=FV/DENOM
CONST2=(1.-FV)/DENOM

IF(FV.GT.1.)THEN
    ALPH3=ALPHA+2.5*BETA**2
    FV=1.
ENDIF

Z3=((LOG(R)-ALPH3)/BETA)**2
Z2=((LOG(R)-ALPH2)/BETA)**2
AR=CONST3*EXP(-.5*Z3)+CONST2*EXP(-.5*Z2)
GTA=-AR*RT
IF(TA.LT..1)GTA=GTA*TA/.1

IF(NBURS.LT.2.)THEN
    CALL SINGLE(FXY,X,Y,XX,YY,SIGX,SIGY,BLAT,CSWI)
ELSE
    CALL MULTI(FXY,X,Y,XX,YY,SIGX,SIGY,HLINE,WLINE,NBURS)
ENDIF

UTRDR=K*YM*FF*1000.*GTA*FXY*TA
IF(UTRDR.LT..1E-05)UTRDR=0.
DINF=5.*UTRDR*TA**(-.2)
DR1=UTRDR*24.**(-1.2)
DR7=UTRDR*168.**(-1.2)
DR14=UTRDR*336.**(-1.2)
DR30=UTRDR*720.**(-1.2)

END

```

```

SUBROUTINE SINGLE(FXY,X,Y,XX,YY,SIGX,SIGY,BLAT,CSWI)
*****
* FINDS THE AVERAGE DOSE ACROSS A CELL OR CITY FROM A SINGLE BURST
*
*-----
* VARIABLES
*   FXY = THE 2D GAUSSIAN TERM IN HOPKINS' SMEARING EQUATION
*   X,Y = HOTLINE COORDINATE
*   XX,YY = COORDINATE OF A CITY OR CELL CENTER
*   SIGX,SIGY = STANDARD DEVIATION OF 2D GAUSSIAN IN X,Y DIRECTION
*   BLAT = BURST LATITUDE
*   CSWI = LOGICAL SWITCH, IF .TRUE. THEN FINDING DOSE AT A CITY
*   Z1 = DISTANCE IN STANDARD DEVIATIONS SQUARED FROM (X,Y) TO
*       (XX,YY)
*   D = DISTANCE FROM (X,Y) TO (XX,YY)
*   HLINE,WLINE = HEIGHT AND WIDTH OF THE ONE DEGREE BY ONE DEGREE
*                 LATITUDE BY LONGITUDE CELL
*   ANGM = ANGLE FROM THE Y AXIS TO THE CELL DIAGONAL
*   ANG = ANGLE FROM THE X AXIS TO THE EFFECTIVE WIND VECTOR
*   A,B = LIMITS OF INTEGRATION TO FIND AVERAGE DOSE ACROSS A CELL
*        OR CITY, IN KM
*   UL,LL = LIMITS OF INTEGRATION TO FIND AVERAGE DOSE, IN STANDARD
*          DEVIATIONS
*-----
* SUBROUTINES CALLED
*   CNF - CUMULATIVE NORMAL FUNCTION TO FIND AVERAGE DOSE
*-----
* NO FILES ARE USED
*****

```

```

PARAMETER(PI=3.14159265)
REAL FXY,X,Y,XX,YY,SIGX,SIGY,BLAT,Z1,D,HLINE,WLINE,ANGM,ANG,B,
C   A,SIG,UL,LL
LOGICAL CSWI

```

```

Z1=(XX*Y-YY*X)**2/((SIGY*X)**2+(SIGX*Y)**2)
IF(Z1 .GT. 500.) THEN
  FXY=0.
  RETURN
ENDIF

```

```

D=SQRT((XX-X)**2+(YY-Y)**2)
HLINE=110.94
WLINE=COS(BLAT*PI/180.)*110.94
ANGM=ATAN(WLINE/HLINE)
ANG=ATAN(Y/X)
IF (ABS(ANG) .GT. ANGM) THEN
  B=D+.5*WLINE/ABS(SIN(ANG))
  A=D-.5*WLINE/ABS(SIN(ANG))
ELSE
  B=D+.5*HLINE/COS(ANG)
  A=D-.5*HLINE/COS(ANG)
ENDIF

```

IF (CSWI) THEN

B=D+38.

A=D-38.

ENDIF

SIG=SQRT((SIGY*X)**2+(SIGX*Y)**2)

UL=(-B*Y*SIN(ANG)-B*X*COS(ANG))/SIG

LL=(-A*Y*SIN(ANG)-A*X*COS(ANG))/SIG

FXY=(CNF(UL)-CNF(LL))/((B-A)*(-Y*SIN(ANG)-X*COS(ANG)))

END

SUBROUTINE MULTI(FXY,X,Y,XX,YY,SIGX,SIGY,HLINE,WLINE,NBURS)

* THIS ROUTINE FINDS THE DOSE AT A CELL CENTER OR CITY FOR AN AREA
* OF BURSTS

* VARIABLES

* FXY = 2D GAUSSIAN TERM IN HOPKINS' SMEARING EQUATION

* X,Y = HOTLINE COORDINATE

* XX,YY = CELL CENTER OR CITY COORDINATE

* SIGX,SIGY = STANDARD DEVIATION OF 2D GAUSSIAN CLOUD IN X,Y
* DIRECTION

* HLINE,WLINE = HEIGHT AND WIDTH OF AN AREA OF BURSTS

* NBURS = NUMBER OF BURSTS

* Z1 = DISTANCE IN STANDARD DEVIATIONS FROM (X,Y) TO (XX,YY)

* ANGM = ANGLE FROM X AXIS TO DIAGONAL OF AREA OF BURSTS

* ANG = ANGLE BETWEEN X AXIS AND EFFECTIVE WIND VECTOR

* DIA = DIAGONAL OF THE AREA OF BURSTS

* L = BASE OF BURST DENSITY TRAPEZOID

* B = TOP OF BURST DENSITY TRAPEZOID

* H = HEIGHT OF BURST DENSITY TRAPEZOID

* SIGP = KM PER STANDARD DEVIATION IN THE CROSSWIND DIRECTION

* SIGL = NUMBER OF STANDARD DEVIATIONS IN CROSSWIND DIRECTION
* FROM CENTER OF TRAPEZOID BASE TO END OF BASE

* FACT = CONSTANT FACTOR FROM LINE INTEGRATION OF TRAPEZOID

* SIG = CONSTANT FACTOR FROM LINE INTEGRATION OF TRAPEZOID

* UL,LL = LIMITS OF INTEGRATION IN NUMBER OF STANDARD DEVIATIONS

* UL1,LL1 = DUMMY VARIABLES TO PREVENT TAKING EXPONENT OF TOO
* SMALL OF A NUMBER

* MULT1,MULT2,MULT3 = CONSTANTS IN FRONT OF INTEGRALS FOR ENDS OF
* TRAPEZOID INTEGRATION

* PART1,PART2,PART3 = THREE PARTS OF EACH INTEGRAL ON THE ENDS OF
* THE TRAPEZOID

* INT1,INT2,INT3 = INTEGRALS FOR THE THREE REGIONS OF THE
* TRAPEZOID

* SUBROUTINES CALLED

* CNF - CUMULATIVE NORMAL FUNCTION

* NO FILES ARE USED

```

PARAMETER(PI=3.14159265)
REAL FXY,X,Y,XX,YY,SIGX,SIGY,HLINE,WLINE,NBURS,Z1,ANGM,ANG,DIA,
C      L,B,H,SIGP,SIGL,FACT,SIG,UL,LL,MULT1,MULT2,MULT3,PART1,
C      PART2,PART3,INT1,INT2,INT3,COT
COT(X)=1./TAN(X)

Z1=SQRT((XX*Y-YY*X)**2/((SIGY*X)**2+(SIGX*Y)**2))
ANGM=ATAN(HLINE/WLINE)
ANG=ABS(ATAN(Y/X))
DIA=SQRT(HLINE**2+WLINE**2)

IF(ANG .LE. ANGM)THEN
  L=DIA*SIN(ANG+ANGM)
  B=COS(ANG)*(HLINE-WLINE*TAN(ANG))
  H=2.*NBURS/(B+L)
ELSE
  L=DIA*SIN(ANG+ANGM)
  B=SIN(ANG)*(WLINE-HLINE*COT(ANG))
  H=2.*NBURS/(B+L)
ENDIF

ANG=ATAN(Y/X)
SIGP=SQRT((SIGX*SIN(ANG))**2+(SIGY*COS(ANG))**2)
SIGL=L/(2.*SIGP)

IF(Z1 .GT. (SIGL+3.))THEN
  FXY=0.
  RETURN
ENDIF

FACT=Y*SIN(ANG)+X*COS(ANG)
SIG=SQRT((SIGX*Y)**2+(SIGY*X)**2)

IF((L-B) .LT. L/100.)THEN
  L=(L+B)/2.
  UL=((XX+L/2.*SIN(ANG))*Y-(YY-L/2.*COS(ANG))*X)/SIG
  LL=((XX-L/2.*SIN(ANG))*Y-(YY+L/2.*COS(ANG))*X)/SIG
  FXY=NBURS/(L*FACT)*(CNF(UL)-CNF(LL))
  RETURN
ENDIF

UL=((XX-B/2.*SIN(ANG))*Y-(YY+B/2.*COS(ANG))*X)/SIG
LL=((XX-L/2.*SIN(ANG))*Y-(YY+L/2.*COS(ANG))*X)/SIG
MULT1=-2.*H*SIG/((L-B)*FACT**2*SQRT(2.*PI))
UL1=MIN(ABS(UL),30.)
LL1=MIN(ABS(LL),30.)
PART1=MULT1*(EXP(-.5*UL1**2)-EXP(-.5*LL1**2))
MULT2=2.*H*(YY*X-XX*Y)/((L-B)*FACT**2)
PART2=MULT2*(CNF(UL)-CNF(LL))
MULT3=L*H/((L-B)*FACT)
PART3=MULT3*(CNF(UL)-CNF(LL))
INT1=PART1+PART2+PART3

```

```

UL=((XX+B/2.*SIN(ANG))*Y-(YY-B/2.*COS(ANG))*X)/SIG
LL=((XX-B/2.*SIN(ANG))*Y-(YY+B/2.*COS(ANG))*X)/SIG
INT2=H/FACT*(CNF(UL)-CNF(LL))

```

```

UL=((XX+L/2.*SIN(ANG))*Y-(YY-L/2.*COS(ANG))*X)/SIG
LL=((XX+B/2.*SIN(ANG))*Y-(YY-B/2.*COS(ANG))*X)/SIG
UL1=MIN(ABS(UL),30.)
LL1=MIN(ABS(LL),30.)
PART1=-MULT1*(EXP(-.5*UL1**2)-EXP(-.5*LL1**2))
PART2=-MULT2*(CNF(UL)-CNF(LL))
PART3=MULT3*(CNF(UL)-CNF(LL))
INT3=PART1+PART2+PART3

```

```

FGY=INT1+INT2+INT3

```

```

END

```

```

SUBROUTINE SLOINT(X,Y,A,B,NP)

```

```

*****
* THIS ROUTINE FINDS THE SLOPE AND INTERCEPT OF EACH LINE SEGMENT
* DEFINED BY THE HOTLINE
*-----

```

```

* VARIABLES
* X = THE HOTLINE X COORDINATES IN KM
* Y = THE HOTLINE Y COORDINATES IN KM
* A(I) = THE SLOPE OF THE HOTLINE SEGMENT FROM I TO I+1
* B(I) = THE INTERCEPT OF THE HOTLINE SEGMENT
*-----

```

```

* NO SUBROUTINES ARE CALLED
*-----

```

```

* NO FILES ARE USED
*****

```

```

REAL X(0:NP),Y(0:NP),A(0:NP-1),B(0:NP-1)
INTEGER I

```

```

DO 10 I=0,NP-1
  A(I)=(Y(I+1)-Y(I))/(X(I+1)-X(I))
  B(I)=Y(I)-A(I)*X(I)
10 CONTINUE

```

```

END

```

```

SUBROUTINE LINSEG(XL,TAL,XX1,XX2,XG,TAG,HOTX)

```

```

*****
* THIS ROUTINE FINDS WHETHER XX1 AND/OR XX2 IS ON THE HOTLINE
* SEGMENT DEFINED BY XL AND XG. HOTX IS THE CLOSEST POINT TO THE
* ORIGIN ON THE SEGMENT. IF NEITHER POINT IS ON THE SEGMENT, HOTX=0.
*-----

```

```

* VARIABLES
* XL = X LESSER OF THE TWO ENDPOINTS DEFINING THE SEGMENT
* XX1 = ONE OF THE QUADRATIC ROOTS ON THE LINE

```

```

*      XX2 = ONE OF THE QUADRATIC ROOTS ON THE LINE
*      XG = X GREATER OF THE TWO ENDPOINTS DEFINING THE LINE SEGMENT
*      HOTX = THE POINT XX1 OR XX2 WHICH IS ON THE LINE SEGMENT
*      TAL = TIME OF ARRIVAL FOR XL, THE SMALLEST X ON HOTLINE SEGMENT
*      TAG = TIME OF ARRIVAL FOR XG, THE GREATEST X ON HOTLINE SEGMENT
*-----
*      NO SUBROUTINES ARE CALLED
*-----
*      NO FILES ARE USED
*****

      REAL XL,XX1,XX2,XG,HOTX,TAL,TAG
      IF(XX1 .EQ. 0.)XX1=1.E25
      IF(XX2 .EQ. 0.)XX2=1.E25

      IF(XX1 .GE. XL .AND. XX1 .LE. XG)HOTX=XX1
      IF(XX2 .GE. XL .AND. XX2 .LE. XG)HOTX=XX2

      IF(XX1 .GE. XL .AND. XX2 .GE. XL .AND. XX1 .LE. XG .AND.
C      XX2 .LE. XG)THEN
          IF(TAL .LT. TAG)THEN
              IF(ABS(XX1-XL) .LT. ABS(XX2-XL))THEN
                  HOTX=XX1
              ELSE
                  HOTX=XX2
              ENDIF
          ELSE
              IF(ABS(XX1-XG) .LT. ABS(XX2-XG))THEN
                  HOTX=XX1
              ELSE
                  HOTX=XX2
              ENDIF
          ENDIF
      ENDIF

      END

      REAL FUNCTION CNF(Z)
*****
*      CALCULATES THE CUMULATIVE NORMAL FUNCTION, BY POLYNOMIAL APPROX.
*      FROM ABRAMOWITZ AND STEGUN.
*-----
*      VARIABLES
*      C1,C2,C3,C4 = POLYNOMIAL COEFFICIENTS
*      Z = ARGUMENT OF FUNCTION
*      X = VARIABLE IN POLYNOMIAL EXPANSION
*-----
*      NO SUBROUTINES ARE CALLED
*-----
*      NO FILES ARE USED
*****

```

AD-A154 465

INCORPORATION OF HOPKINS' VARIABLE WIND MODEL INTO A
POPULATION-DOSE FALL. (U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.

2/2

UNCLASSIFIED

J W ST. LEDGER MAR 85 AFIT/GNE/ENP/85M-18

F/G 18/8

NL

END

FILED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
PARAMETER(C1=.196854,C2=.115194,C3=.000344,C4=.019259)  
REAL X,Z
```

```
X=ABS(Z)  
CNF=1.+C1*X+C2*X**2+C3*X**3+C4*X**4  
CNF=.5/CNF**4  
IF(Z.E.0.)CNF=1.-CNF
```

```
END
```

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21. Wendel, Arthur H. Casualties Due to Fallout From Counterforce Attacks Upon the United States. MS Thesis, GNE83M-13. School of Engineering, Air Force Institute of Technology(AU), Wright-Patterson AFB, Ohio, March 1982.

Vita

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→ Hopkins' variable wind fallout model is used to predict the dose and population insult across the United States from a nuclear attack. The dose calculation is performed by two programs written in Fortran V for a CYBER 845 computer. Hopkins' hotline locator program was modified to reduce its run time, and it is used to locate the fallout hotline as trace particles are translated to the ground in a spatially varying wind field. The second program analytically smears fallout activity along the hotline. To reduce run time and to match the population model, the dose program uses a computational grid of one degree latitude by one degree longitude. A difference of cumulative normal functions gives the average dose across a grid cell. An analytical method was developed to treat multiple bursts against an area target as one cloud.

For the winds of 0000 Universal Time on 16 January 1982, a hypothetical attack against twenty five air bases and six Minuteman missile fields results in 26.9 million fallout deaths. This calculation used 407 seconds of computer time. *Keywords:*

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