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A BRIEF SURVEY OF FALLOUT PREDICTION MODELS AND INTRODUCTION OF--ETC(U)
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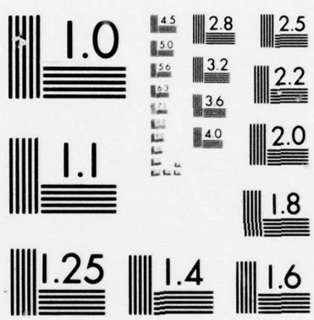

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A BRIEF SURVEY OF FALLOUT PREDICTION MODELS AND INTRODUCTION OF A FALLOUT PREDICTION MODEL UTILIZING ALTITUDE DEPENDENT WINDS

THESIS

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A BRIEF SURVEY OF FALLOUT PREDICTION MODELS AND INTRODUCTION OF A FALLOUT PREDICTION MODEL UTILIZING ALTITUDE DEPENDENT WINDS

Master's THESIS

Presented to the faculty of the School of Engineering
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Master of Science

by

Robert M. Savage, Jr.

~~Captain~~ [redacted]

Graduate Nuclear Effects

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Approved for public release; distribution unlimited.

Preface

I thank my thesis advisor, Dr. Charles J. Bridgman, for his guidance and insight throughout my research effort. I also wish to thank Mr. David Auton of the Defense Nuclear Agency for providing experimental data on fallout and Dr. David Bensen of the Civil Preparedness Agency, Department of Defense, for providing information and literature on OCD fallout models.

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Abstract

A brief study was made of three fallout prediction models: the ENW model presented by Samuel Glasstone, the Miller model by C. F. Miller, and the WSEG-10 model by George Pugh and Robert Galiano. Each of these models used an effective wind that had constant direction and speed. A FORTRAN computer code of the Miller model was prepared by the author and is available in the report.

To ascertain the effects of more realistic winds that varied direction and speed with altitude, the author developed a model that utilized an altitude dependent wind as well as a thin stabilized cloud, a log-normal particle size-activity distribution, a gaussian distribution of activity within the cloud, and fall time equations based on the equations of C. N. Davies. This model was prepared as a FORTRAN computer code by the author, and the code is included in the report.

The two most significant results of the variable wind model are the asymmetric pattern produced on the ground and the non-linear centerline of that pattern. The model allows the user to introduce his own discription of the physical processes of fallout deposition and is therefore not constrained as are the stylized models of Glasstone and Miller.

A BRIEF SURVEY OF FALLOUT PREDICTION MODELS AND INTRODUCTION OF A FALLOUT PREDICTION MODEL UTILIZED ALTITUDE DEPENDENT WINDS

I. Introduction

The most significant residual effect of a land surface nuclear detonation is the biological hazard from the radioactive debris or fallout of the explosion. When a surface nuclear detonation takes place, some of the soil nearest the explosion is vaporized by the intense heat. Mixed with the vaporized soil is the radioactive residue or debris of the weapon. This debris consists of the remaining fissile material of the weapon and the fission products of that portion of the fissile material that had fissioned. This mixture is carried upward within the cloud formed by the detonation and at once beings to cool and condense into particles that may be as small as a few microns (10^{-6} m). Each of these particles will carry some of the radioactive debris distributed within the mass of the particle or condensed on its surface, and each will eventually be deposited on the ground. The time required for this deposition will vary from a few minutes for the larger particles to several years for the smaller particles.

The deposition of this radioactive debris, or fallout, from nuclear explosions has been a concern of the public and of governmental agencies for many years because of the immediate health hazards and possible long range genetic damage due to the radiation. To help forecast the extent and the degree of contamination of the earth's surface by such fallout, several models of the deposition patterns that would predict the location of the fallout and the radiation intensity were prodcued in the late 1950's and early 1960's. These models were idealized approximations to experimental data gathered from American weapons tests that included the effects of the weapon's total and fission yield, and the mean wind speed. The Miller model introduced the effects of fractionation, whereas the other models postulated that the activity of a fallout particle was proportional to its volume. The factors for which these models could not account include variations in weather conditions such as humidity and precipitation, variations in terrain and in soil content, and variation of wind speed and wind direction with altitude.

The purpose of this thesis was to evaluate three of the early models and relax one of their constraints by including a variable wind. Local fallout will be considered as that fallout deposited within 1500 kilometers of the ground-zero of the burst. Such factors as fractionation, entrained debris, and neutron activation of the soil and debris will not be addressed.

The author will briefly examine the fallout model presented by Samuel Glasstone (1963) in "The Effects of Nuclear Weapons" (ENW), the Miller model by Carl F. Miller (1963), and the WSEG-10 model by George Pugh and Robert Galiano (1959) and then discuss the developement of a model produced here that allows for a horizontal wind that varies in direction and speed with altitude.

II. The ENW Model

This model was first presented in 1957 (Ref 1) and again in 1963 (Ref 2) after the incorporation of new and more extensive information. It was intended for use by the widest possible range of readers and thus offers the advantage that a high level of technical expertise is not needed for its use. This model is presumably an empirical fit to experimental data.

Figure 1 (Ref 2:449) displays a typical fallout pattern as presented in Reference 2. This pattern represents the unit-time reference dose-rate (Roentgens/hour at H+1 hour). Reference 2 explains how to scale this pattern for other yields and wind speeds. The simplicity of the scaling operations for windspeed and weapon yield make this model ideal for use by a field commander with limited technical assistance who must have some estimate of the extent and degree of fallout contamination so that he can limit the exposure of his men. Several charts and tables are presented in Reference 2 that further enhance the value of this model. These include protective factors for different structures, accumulated absorbed dose as a function of time exposed, and absorption or

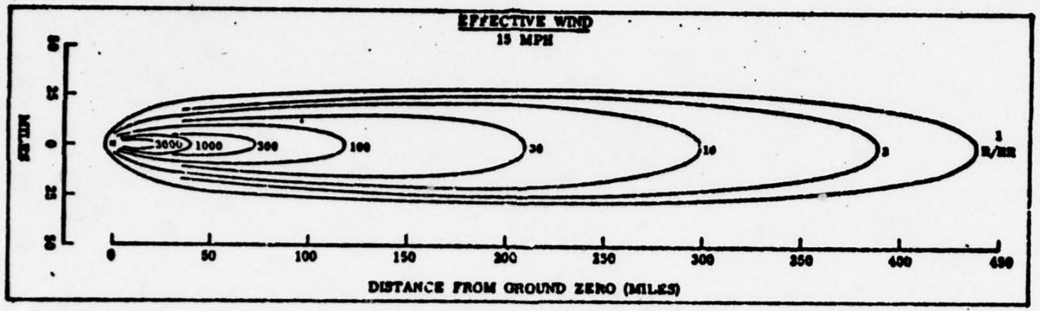

Figure 1. Idealized unit-time reference dose-rate pattern for early fallout from a 1-megaton fission yield surface burst with a 15 mph effective wind speed. (ENW Model)

or attenuation coefficients for gamma radiation in various materials.

This model ignores neutron induced activity, stem fallout, and throwout within a blast-damage circle about ground zero. It assumes that the wind will have a constant velocity and direction and will remain so for the lifetime of the deposition process. As previously stated, the patterns produced by this model are idealized, therefore the reader would not expect them to closely approximate the experimental data from any particular burst. This author has found no experimentally obtained fallout pattern which is accurately predicted by this model. Preparing a computer code based on this model would not be difficult if some accurate figures of the examples in Reference 2 could be obtained. If this data could be found or extracted, then the resultant computer code would be quite fast. If not, then this model would still be very useful in a "handbook" status.

III. The Miller Model

Carl F. Miller first published the results of his fallout modeling efforts in 1963 (Ref 3). The Miller model is an empirical fit to experimental data that, like Glasstone's model, utilizes a constant speed and constant direction wind. In his model Miller included the results of investigations into the thermodynamics of fallout particle formation, fireball behavior, fractionation of fission products, the effect of wind shear, and the biological effect of ionizing radiation.

The fallout pattern or footprint resembles the shadow of a mushroom shaped cloud characteristic of nuclear explosions. This cloud is described by the Miller model as a truncated, inverted exponential cone (stem) topped by an oblate spheroid (cloud). Of the models surveyed, the Miller model was unique in two respects. First, it attempted to model stem fallout, and secondly, it constructed the predicted fallout pattern around several characteristic points of location and dose rate. The radiation intensity or unit-time reference dose-rate varies as an inverse exponential with distance away from and along the pattern centerline. The scaling procedures for windspeed and weapon yield are not as simple here as in the ENW model, but then the scaling procedures for Miller's model are of a different type than are those of the ENW model. The complexity of the Miller model does not permit the linear scaling used by ENW, however the Miller model does more adequately describe the physical process of fallout particle formation and deposition.

Because this model presents an idealized pattern and isointensity contours one should not expect it to accurately predict the fallout deposition from a particular burst, but to present a generalized approximation to many actual patterns. The pattern predicted by this model has a shape similar to that predicted by ENW but is considerably shorter and thus encloses less land area within any isointensity contour.

The thoroughness and completeness of this model is exemplified by the variety of ways available to extract data from it. One can compute the unit-time reference dose-rate at a point, describe an isointensity contour as a function of two-directional displacement, and determine the area within a given contour. This author chose to prepare a FORTRAN IV computer code of this model based on the adaptation of it presented in Reference 7. Figure 2 presents the output from this code for a 1 MT, 100 percent

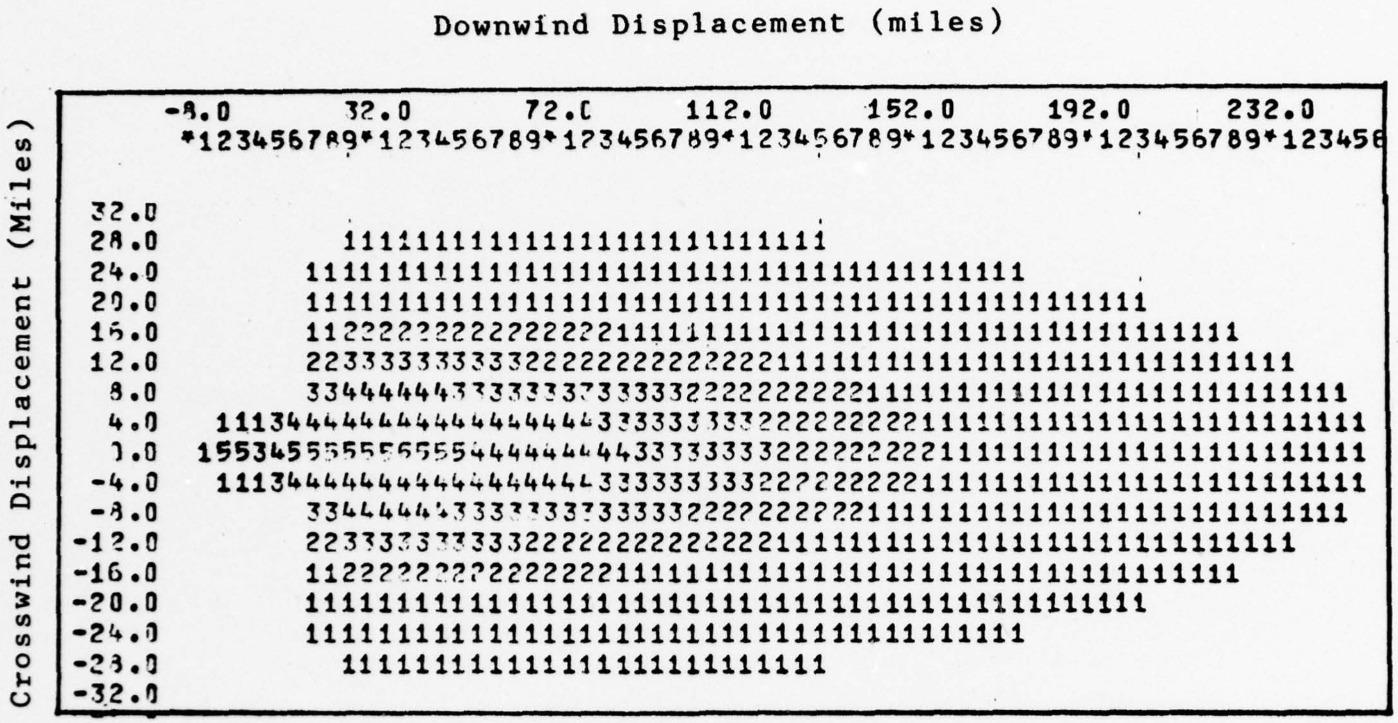

Figure 2. Deposition pattern for a 1 MT, 100 percent fission yield surface burst (Miller Model). Showing the unit-time reference dose rate. Map legend; 1 - 1 to 30 R/HR, 2 - 30 to 100 R/HR, 3 - 100 to 300 R/HR, 4 - 300 to 1000 R/HR, 5 - 1000 to 3000 R/HR.

fission yield burst with a 15 mph wind. The most striking dissimilarity between Figure 2 and Figure 1 is the "bud" on the upwind end of the footprint in Figure 2. This "bud" represents the contribution of stem fallout. One can readily see that this contribution, though a high dose rate, may be of slight concern to those persons within its perimeter because they would probably be dead from other effects. A complete listing, and glossary of terms of this computer code is available to the reader in Appendix A.

The Miller model as presented in Reference 7 has several singularities at which the model fails or gives unreliable results (Ref 7:16-18). These singularities are identified by certain combinations of weapon yield and windspeed. The program listing in Appendix A includes a test for these singularities in the subroutine CONST. The user must observe the limits on wind speed and yield of

0 < wind speed < 75 mph and 1KT < yield < 5000 KT.

IV. WSEG-10

Much of the effort put into the preparation of fallout modles was motivated by the operational needs of field commanders. WSEG-10, first published in 1959, was an attempt to provide such commanders with a tool with which they could quickly estimate the location and radiation intensity of radioactive fallout. The authors of WSEG-10, George Pugh and Robert Galiano, had the following to say about the situation:

> "Fallout estimates for use in operational planning have usually been obtained either by use of stylized patterns or by detailed machine calculations. Stylized patterns are too inflexible and too unrealistic to answer many questions encountered in operations research. Detailed calculations which have been used previously are laborious and costly, and unless meteorological conditions are known in extreme detail they do not produce accuracy of results commensurate with the effort. The purpose of this memorandum is to introduce a simplified computational model which is more directly tied to the physics of fallout than the stylized patterns, so that changes in physical knowledge or assumptions can be more readily incorporated." (Ref 8:1)

WSEG-10 was an attempt to describe the physical nature of fallout by modeling the spatial distribution of activity within the radioactive cloud, assuming a uniform particle activity that varied only with particle volume, and describing the fall of each particle as a sphere in a viscous medium. This model describes the activity distribution within the cloud as a normal distribution, and the particle size-activity distribution as a log-normal distribution, as does ENW, with the mode radius equal to 28 microns, the average radius equal to 44 microns, and a standard deviation of about 0.69. The use of a constant wind direction and windspeed was probably due to its intended use in operational situations with little time and limited technical assistance available.

The results of this model were not presented in "footprint" form as were the results of Miller and Glasstone, but were given in tables that offered dimensions and locations of unit-time reference dose-rate isointensity contours as functions of particular weapon yields, windspeeds, and wind shear. Such a presentation could be very valuable to a field commander in an operational environment. Table I is an example of the tabular presentation of WSEG-10 results.

The patterns produced by this model are considerably longer and wider than those of Glasstone, indicate peak unit-time reference does-rates well below those of Glasstone or Miller, and encompass much more surface area than either of the two previous models.

Table I

A Tabular Presentation of WSEG-10 Results

Calculated Fallout Contours

(Maximum Biological Dose)

1 YIELD (MEGATONS) 10 WIND (KNOTS)

ALL DISTANCES AND AREAS ARE SHOWN IN STATUTE MILES TO 2 DECIMAL PLACES. DECIMAL (NOT SHOWN) SHOULD BE READ BEFORE LAST 2 DIGITS.

EFFECTIVE FALLOUT SHEAR 0.1 KNOTS/1000 FT. ALTITUDE

1 DOSE (ROENTGENS)	2 MAXIMUM UPWIND POSITION	3 MAXIMUM DOWNWIND DISTANCE	4 CROSSWIND HALFWIDTH AT ORIGIN	5 MAXIMUM CROSSWIND HALFWIDTH	6 ACTUAL AREA	7 ESTIMATED AREA (ELLIPSE)	8 RANGE TO MAXIMUM WIDTH
1	726-	31398	923	4589	2141337	2319317	19200
3	676-	27783	866	3875	1598502	1709853	19200
10	613-	23706	790	3086	1093136	1178223	15400
30	553-	19893	732	2433	739869	781368	12000
100	479-	15433	652	1781	430356	450785	9000
300	403-	11706	568	1200	237341	239706	6400
1000	304-	7497	459	706	98839	96346	4200
3000	190-	3988	330	468	31020	33669	1000
10000	523	1060		75	626	1065	1000
30000							
MAXIMUM DOSE 10319							

EFFECTIVE FALLOUT SHEAR 0.2 KNOTS/1000 FT. ALTITUDE

1 DOSE (ROENTGENS)	2 MAXIMUM UPWIND POSITION	3 MAXIMUM DOWNWIND DISTANCE	4 CROSSWIND HALFWIDTH AT ORIGIN	5 MAXIMUM CROSSWIND HALFWIDTH	6 ACTUAL AREA	7 ESTIMATED AREA (ELLIPSE)	8 RANGE TO MAXIMUM WIDTH
1	724-	29327	957	7441	3195244	3608855	19200
3	672-	25677	898	6202	2307962	2706918	15400
10	611-	21594	828	4793	1520495	1671908	15400
30	551-	17798	759	3673	963480	1058691	12000
100	477-	13631	674	2545	521187	562758	9000
300	400-	9825	587	1670	255036	269632	6400
1000	301-	5970	473	919	91915	90476	2400
3000	185-	3068	337	514	24183	26844	1000
10000							
30000							
MAXIMUM DOSE 9295							

EFFECTIVE FALLOUT SHEAR 0.4 KNOTS/1000 FT. ALTITUDE

1 DOSE (ROENTGENS)	2 MAXIMUM UPWIND POSITION	3 MAXIMUM DOWNWIND DISTANCE	4 CROSSWIND HALFWIDTH AT ORIGIN	5 MAXIMUM CROSSWIND HALFWIDTH	6 ACTUAL AREA	7 ESTIMATED AREA (ELLIPSE)	8 RANGE TO MAXIMUM WIDTH
1	718-	27101	1083	13131	5019774	5737890	19200
3	666-	23422	1014	10601	3333220	4011010	15400
10	604-	19300	934	7941	2125324	2482837	12000
30	543-	15493	854	5787	1235048	1447761	9000
100	463-	11354	757	3758	630593	697963	6400
300	390-	7761	656	2519	274006	296942	4200
1000	289-	4300	523	1218	77324	87794	2400
3000	166-	2047	361	603	18984	20975	1000
10000							
30000							
MAXIMUM DOSE 8162							

The advantage of WSEG-10 is that it attempts to predict fallout deposition based on the physical properties of the atmosphere and the fallout particles and on a statistical analysis of the particle distribution. It is not an empirical fit to experimental data. This attempt to predict or model the physical process of fallout deposition led this author to develop a fallout model that would describe the physical processes of falling and dislocation, and that would allow the use of a wind that varies direction and speed with altitude.

V. A Variable Wind Model

The previous models each used a wind that was constant in speed and direction. Only Glasstone addressed, but did not incorporate, the fact that atmospheric winds may vary in both direction and speed with altitude. This author developed a fallout deposition model that would incorporate the effects of an altitude dependent wind.

There were several simplifying assumptions made to limit the scope of this problem and form the basis for its solution. These are listed below:

1. the source of all fallout particles is a thin pancake cloud,
2. all particles are solid spheres,
3. the activity-particle size distribution is a log-normal distribution,
4. the distribution of activity horizontally across the pancake cloud is a gaussian distribution,
5. there is no fractionation of fission products; i.e. the activity is volume or mass distributed within each particle.

The activity-particle size distribution presented by Miller and Sartor (Ref 10:69) was chosen to represent the actual distribution. It was a log-normal distribution with a mean radius of 105 microns, a mode radius of 30 microns, and a standard deviation of about 1.1. This distribution was separated into 97 distinct groups. Each group was selected so that the largest member of each group would fall 10 percent faster than the largest member of the group just below it in size. The smallest average particle radius used was 13.78 microns for group number 97. The group containing the largest particles was group number 1. The mean particle radius for each group and the activity fraction contributed by each group is given in Appendix B.

Each particle group was treated as a separate cloud; the fall time for which was computed using a drag-coefficient Reynolds-number method (Ref 9:4) that employed the density and viscosity of air as given in Reference 11, a particle of specific gravity 2.6, and Davies polynomials. This method and the Davies polynomials are given below where ρ is the particle density (g/cm³), ρ_a is the air density (g/cm³), d is the particle diameter (cm), η is the dynamic viscosity of air (g/cm-sec), g is the acceleration due to gravity (constant) (cm/sec²), C_d is the drag coefficient, R is the Reynolds number, V_t is the terminal velocity (cm/sec), ΔH is the distance fallen (cm), and T is the time elapsed to fall ΔH(sec).

$$C_dR^2 = 4g\rho_a d^3/3\eta^2 \qquad (1)$$

$$R = \frac{C_dR^2}{24} - 2.3363\text{X}10^{-4}\text{x}(C_dR^2)^2 + 2.0154\text{X}10^{-6}\text{x}(C_dR^2)^3$$

$$- 6.9105\text{X}10^{-9}\text{x}(C_dR^2)^4 \quad \text{for } C_dR^2 \leq 138 \qquad (2)$$

$$\log_{10}R = -1.29536 + 0.986 \log_{10}C_dR^2 - 0.046677(\log_{10}C_dR^2)^2$$

$$+ 0.0011235(\log_{10}C_dR^2)^3 \quad \text{for } 138 \leq C_dR^2 \leq 4.7\text{X}10^7 \qquad (3)$$

$$V_t = (R\eta/\rho_a d)(1+2.33\text{X}10^{-4}/d\rho_a) \qquad (4)$$

$$T = \Delta H/V_t \qquad (5)$$

The second term in parentheses in the V_t equation is a correction factor for small particles at high altitudes where d and ρ_a are in microns and grams per cubic centimeter respectively. The time-to-fall from various altitudes for several particle sizes, as computed by this method, are very much like those given by Glasstone (Ref 2:496), except for the smaller particles where the times given by Glasstone are much longer. Figures 3 and 4 allow some comparison of computed fall times by the reader.

The height of the radioactive center of the stabilized cloud is a function of weapon yield and

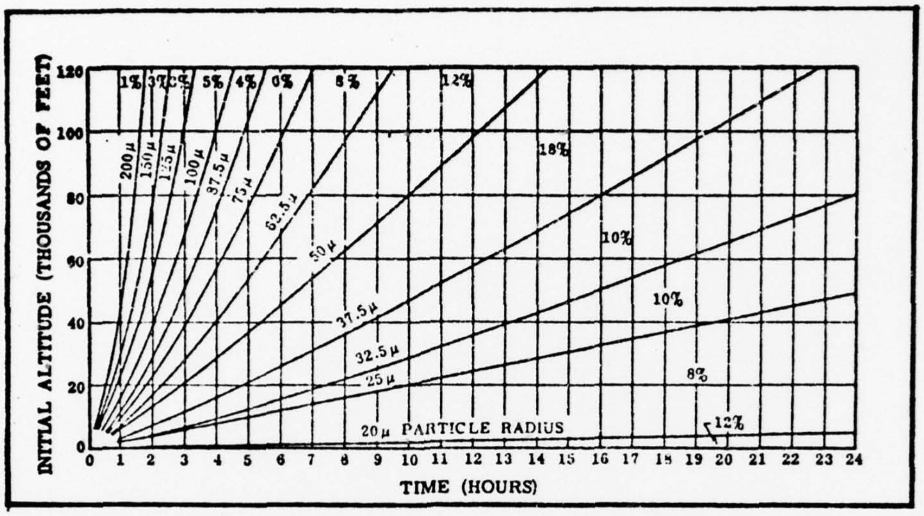

Figure 3. Times of fall of particles of different sizes from various altitudes and percentages of total activity carried (Glasstone).

was taken from WSEG-10 (Ref 8:24) in the form of the following equation:

$$H = 13.411 + 1.859 \ln Y - 0.0625(\ln Y + 2.42)\,|\ln Y + 2.42| \quad (6)$$

where H is in kilometers and Y is the weapon yield in megatons. This equation is graphed in Figure 5 (Ref 8:25) with H in thousands of feet. The equation for the cloud radius was extracted from the Miller model (Ref 3:14) and is the following:

$$R = 14.661 x Y^{0.431} \quad (7)$$

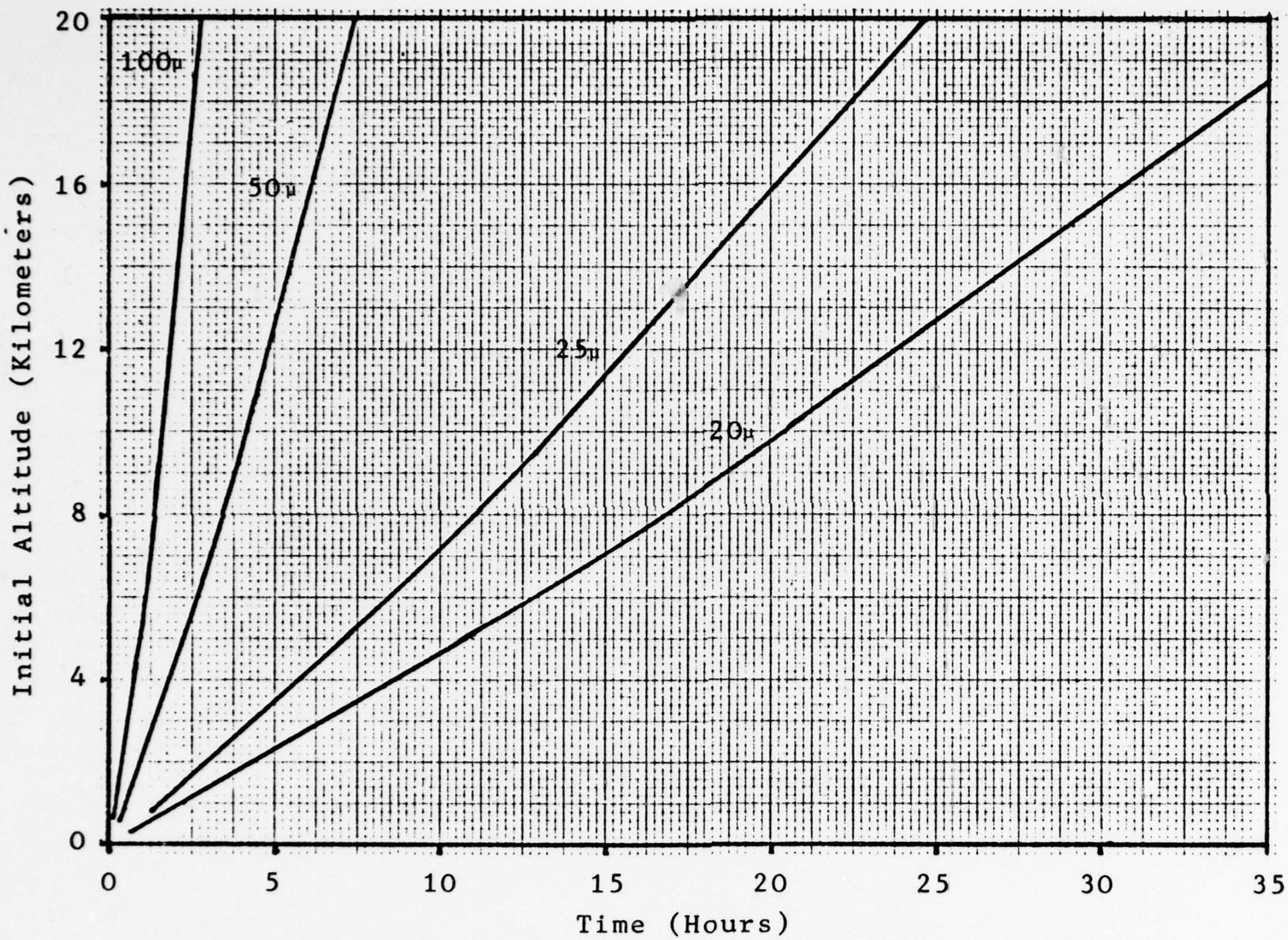

Figure 4. Times of fall for particles of different radii from various altitudes (Variable Wind Model).

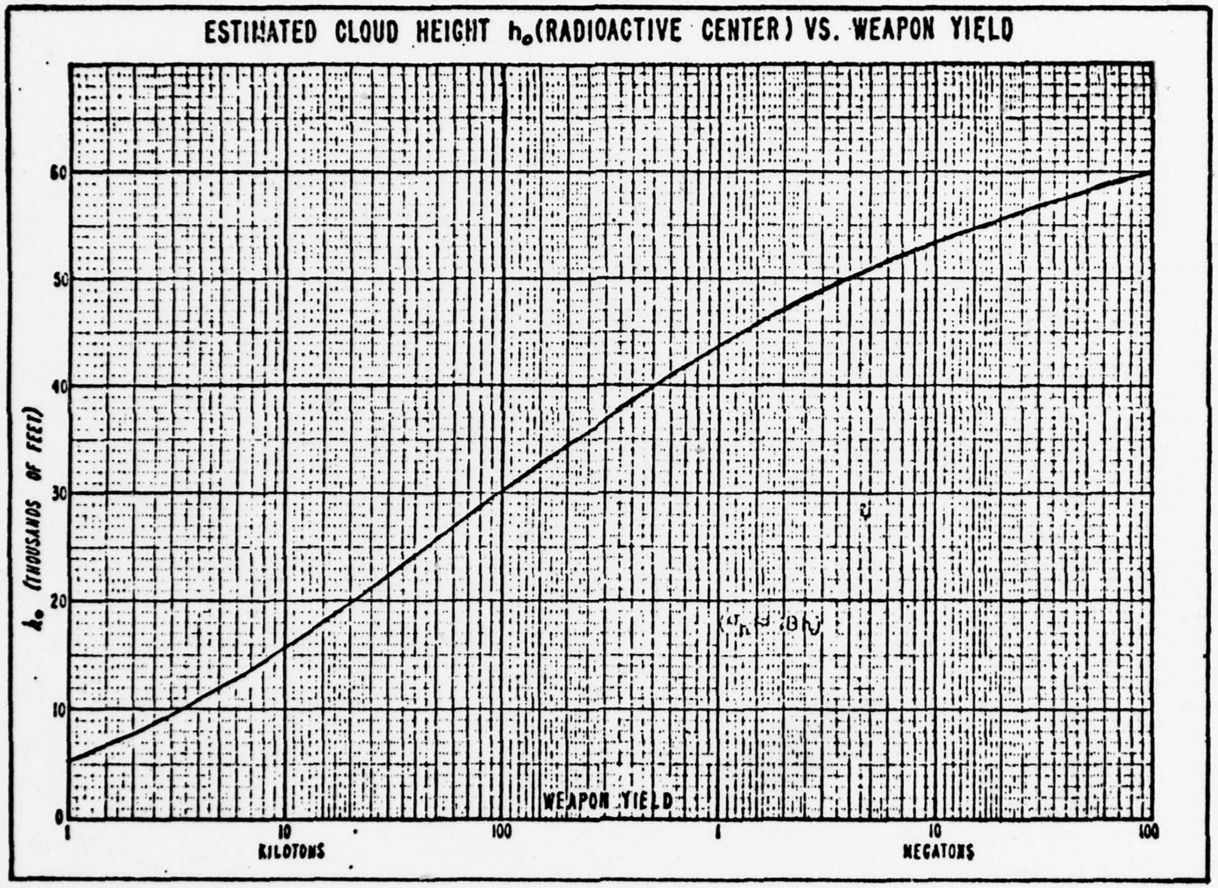

Figure 5. Cloud height as a function of weapon yield as per Equation (6).

where R is in kilometers and Y is in megatons. The cloud height is used to determine the altitude from which particles begin their descent. Multiples or fractions of the cloud radius as given by equation (6) are used as the standard deviation of the particles' horizontal distribution. This distribution is assumed to be a circular, symmetrical gaussian distribution, and, because it describes the distribution of each particle size group, it can be used to describe the distribution of the activity contributed by each particle size group. A comparison of this gaussian distribution of activity with the typical distribution is given in WSEG-10 (Ref 8:23) and shown in Figure 6. To partially account for this typical distribution, the standard deviation of each particle size group was increased by 0.020 of the standard deviation of group 1 over that of the particle group just larger. This had the effect of describing a cloud where the larger particle sizes were more concentrated near the center. This activity distribution is shown in Figure 7. Note that this distribution is flatter than the regular gaussian distribution and more nearly approximates the actual distribution shape given in Figure 6. The flattening of the activity distribution partially compensates for the effect of wind shear by dispersing each particle group by an arbitrary amount.

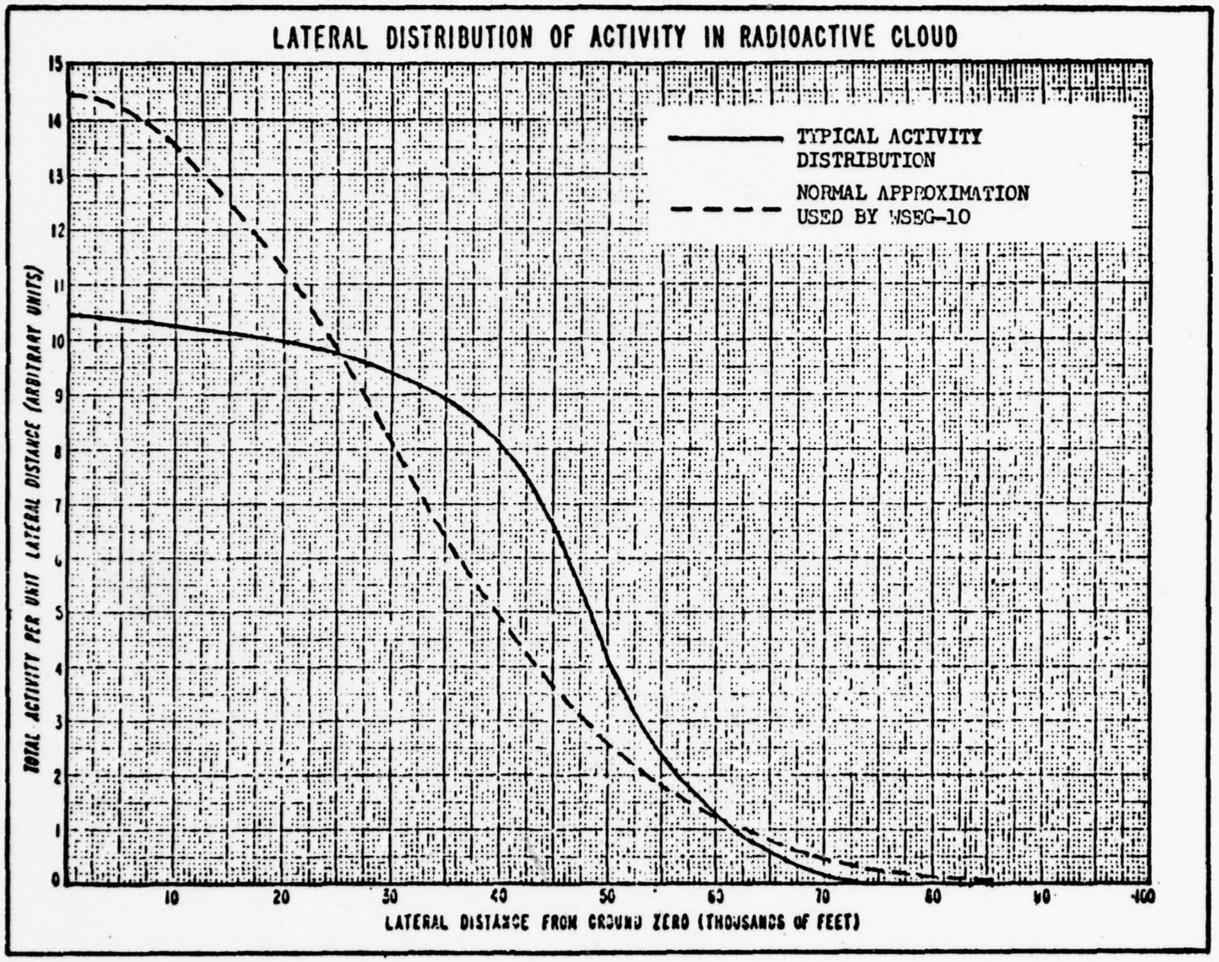

Figure 6. Lateral distribution of activity in a typical radioactive cloud (WSEG-10).

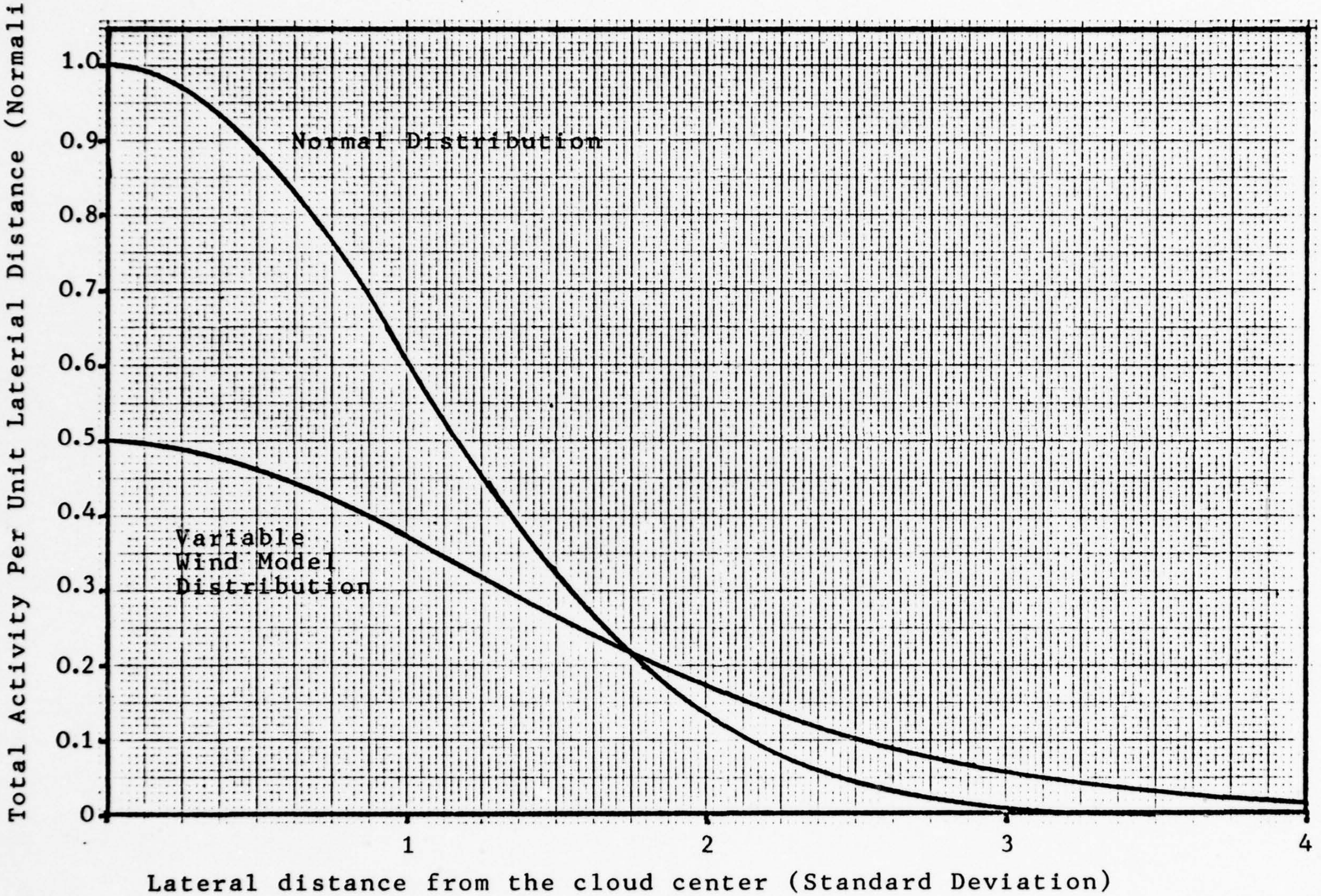

Figure 7. Lateral distribution of activity in the radioactive cloud (Variable Wind Model)

The residual activity available for use in fallout formation was estimated by ENW (Ref 2:492) to be approximately 550 gamma-megacuries per kiloton of yield at H+1 hour. The average energy of these gamma rays was computed to be 0.902 MeV (Ref 12:630), whereas ENW used an average energy of 0.95 MeV. The dose rate was calculated for a point in the air three feet above a smooth infinite plane. For a particular point on the ground, the unit-time reference dose-rate was determined by summing the contributions of each particle group. To compute these contributions it was necessary to know the location of the center of each particle group cloud on the ground. These locations were determined by calculating the effect of wind direction and speed on the group. Displacements in two dimensions were calculated by multiplying fall time through a wind layer one kilometer thick by the average wind speed and direction in that layer. For convenience, wind data was divided into 20 layers, each one kilometer thick. The reader will notice that according to equation (6) the weapon yield required to produce a stabilized cloud at an altitude of 20 kilometers is well in excess of 100 MT and is much larger than that of any weapon available today.

The attenuation of the gamma radiation in the air was not an unusual problem as the following derivation will show. The flux of gamma rays at point X in

Figure 8 can be found by integrating

$$\frac{d}{dr}\,(\text{FLUX}) = \frac{A\ 2\pi r}{4\ (r^2 + h^2)}\ e^{-\mu_{air} s} \tag{8}$$

to yield

$$\text{FLUX} = 2.18284\ A\ \frac{\gamma\text{-rays}}{\text{sec} - \text{m}^2} \tag{9}$$

where A is the gamma activity (γ-rays/sec-m^2) at area a, μ(m^{-1}) is the macroscopic cross section of 0.9 MeV gamma rays in air at STP conditions, r(m) is the ground distance from the area a to the point for which the dose rate is calculated, and s(m) is the slant range from that same point to area a. The dose rate is represented by

$$D = \text{FLUX} \times \bar{E} \times \sigma\ \frac{\text{MeV}}{\text{sec} - \text{g}} \tag{10}$$

where σ(m^2/g) is the linear absorption coefficient of air for gamma rays of average energy $\bar{E}$ (MeV). The final form of the equation for dose rate is

$$D = 1.147125\text{X}10^{-16}\ A \quad \text{R/Hr @ 1 Hr} \tag{11}$$

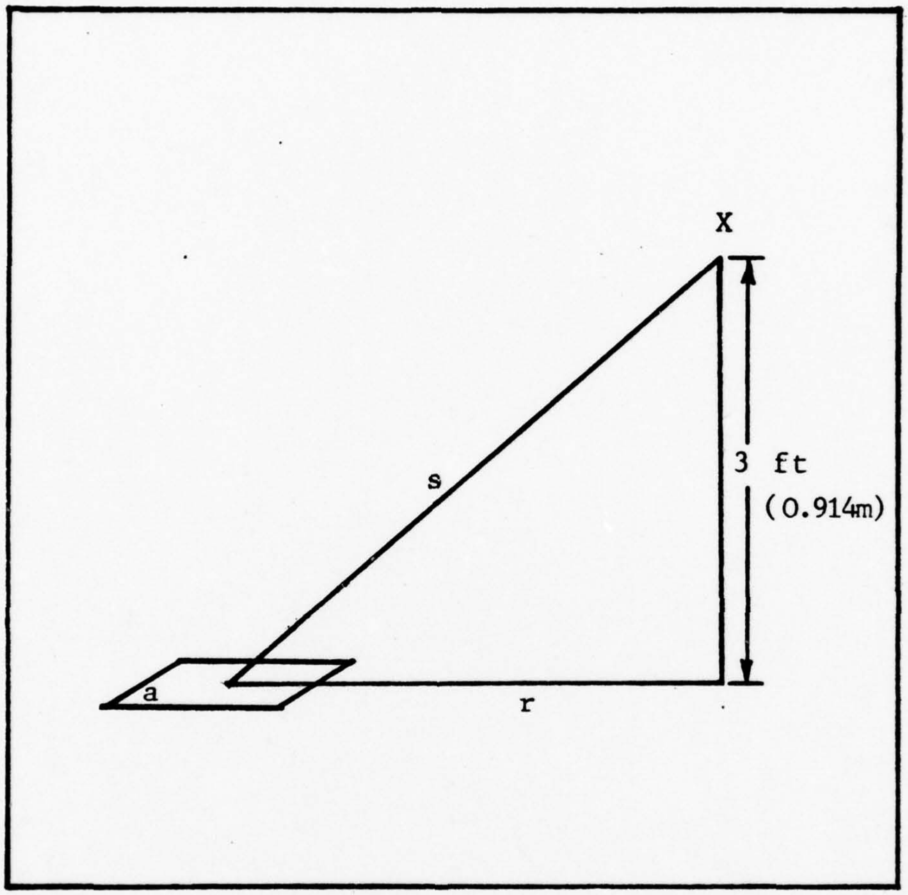

Figure 8. Schematic for dose rate calacultions

VI. Results

The footprint or deposition pattern of the variable wind model for a 1 MT, 100 percent fission yield burst with a constant 15 mph wind is shown in Figure 9. The similarity between Figure 9 and Figures 1 and 2 is readily apparent. The only significant differences between these three patterns is the variation in maximum dose rates, the variation in contaminated land areas, and the node in the extreme downwind portion of the pattern in Figure 9.

The variable wind model does not calculate stem fallout and thus ignores what could be a very high dose rate area near ground zero. The variation in contaminated land areas may be attributed to differences in fall time calculations and activity distribution. The node mentioned above is due to the lateral separation of particle groups and is caused by the markedly increased fall times for the smaller particles. The separation of particle groups can be more easily seen in Figure 10 which is the footprint for an 18 KT, 96 percent fission yield burst with altitude dependent winds as given in Appendix B, Table II. The detached "hot spots" of radioactivity are due to the lateral separation of the smaller

East-West Displacement (Kilometers)

North-South Displacement (Kilometers)

```
      -49.0     146.7     342.4     538.2     733.9     929.6    1125.4    1321.1
        *123456789*123456789*123456789*123456789*123456789*123456789*123456789*12

 99.1       11111111111
 79.6     11222211111111111111111111111
 60.0    1222222222222222111111111111111111111111111111111
 40.4   1223333222222222222222221111111111111111111111111111111111111111   11
 20.8   2233333332222222222222222111111111111111111111111111111111111111111111
  1.3   2333333332222222222222222221111111111111111111111111111111111111111111
-18.3   2233333333222222222222222111111111111111111111111111111111111111111111
-37.9   12333333222222222222222111111111111111111111111111111111111111111  111
-57.5   1122222222222222111111111111111111111111111111111111
-77.0    111222221111111111111111111111111
-96.6      11111111111111
```

Figure 9. Deposition pattern for a 1 MT, 100 percent fission yield burst with a constant 15 mph (24.1 kph) wind showing the unit-time reference dose rate. (Variable Wind Model) Map legend: 1 - 1 to 10 R/HR; 2 - 10 to 100 R/HR; 3 - 100 to 1000 R/HR.

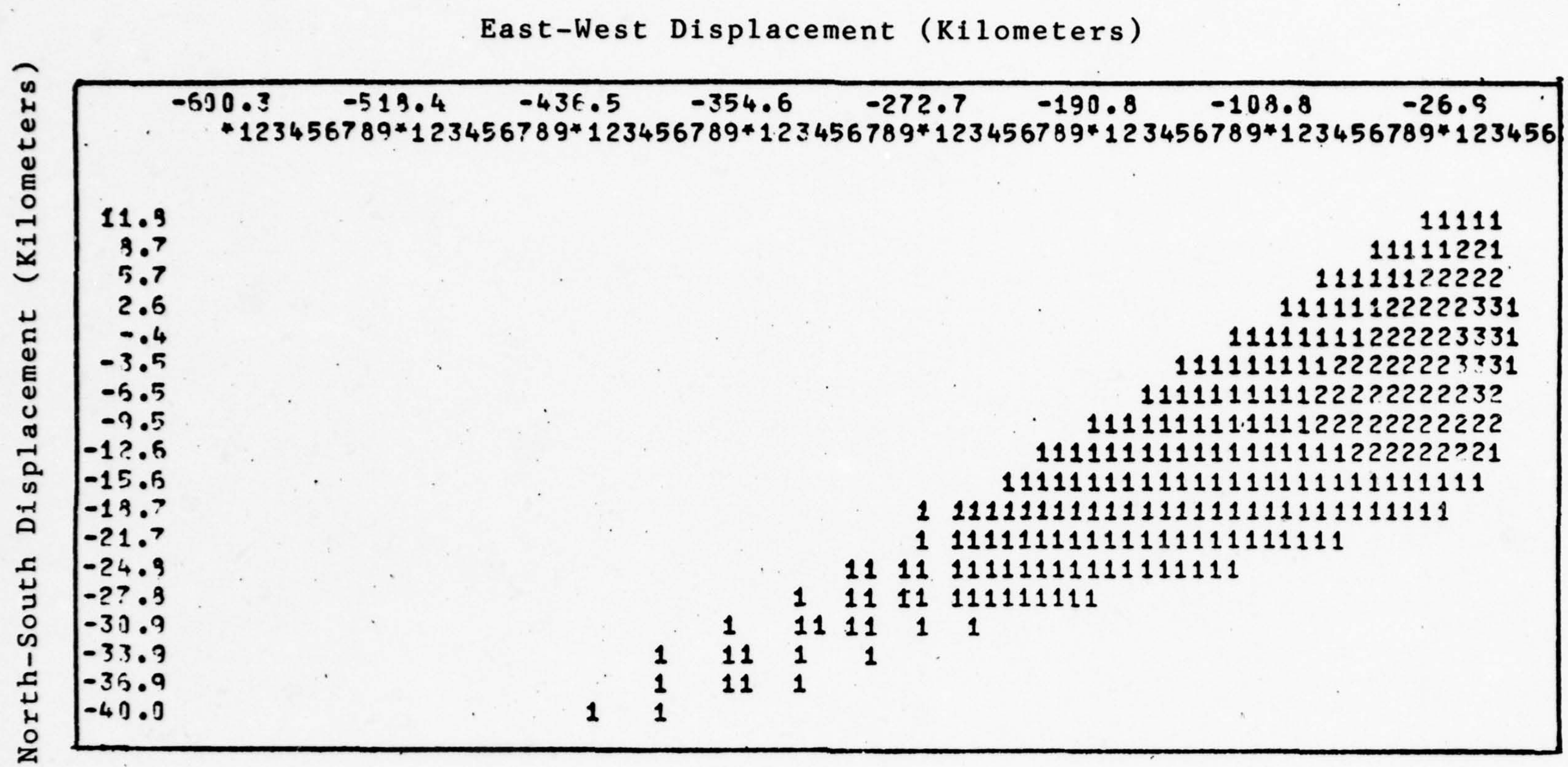

Figure 10. Unit-time reference dose rate pattern from a 18 KT, 96 percent fission yield burst with varying winds (Variable Wind Model).

particle groups. The effect is enhanced by the scale used on each axis. A finer or smaller scale would show areas or "splotches" of activity instead of activity at only a few points.

The asymmetry of the pattern in Figure 9 clearly demonstrates an effect of altitude dependent winds. Previous models would have predicted a symmetrical pattern in the same general direction. An example of the source of this asymmetry is given in Figure 11. The figure represents the actual pattern centerline for a 10.4 MT, 70.2 percent fission yield burst with altitude dependent winds as given in Appendix B, Table III. The solid curved line represents the locus of the particle size groups as each impacted the ground. The dashed line is a straight line connecting the location of the first and last particle size groups. This figure indicates that the effects of varying altitude dependent winds are more pronounced for the larger particles.

The width of these footprints can be manipulated until it approximates that of experimentally obtained patterns or that of other models by varying the standard deviation of the particle size groups or adjusting the particle size-activity distribution. The downwind extent of these contours is still considerably greater than that of other models. A FORTRAN

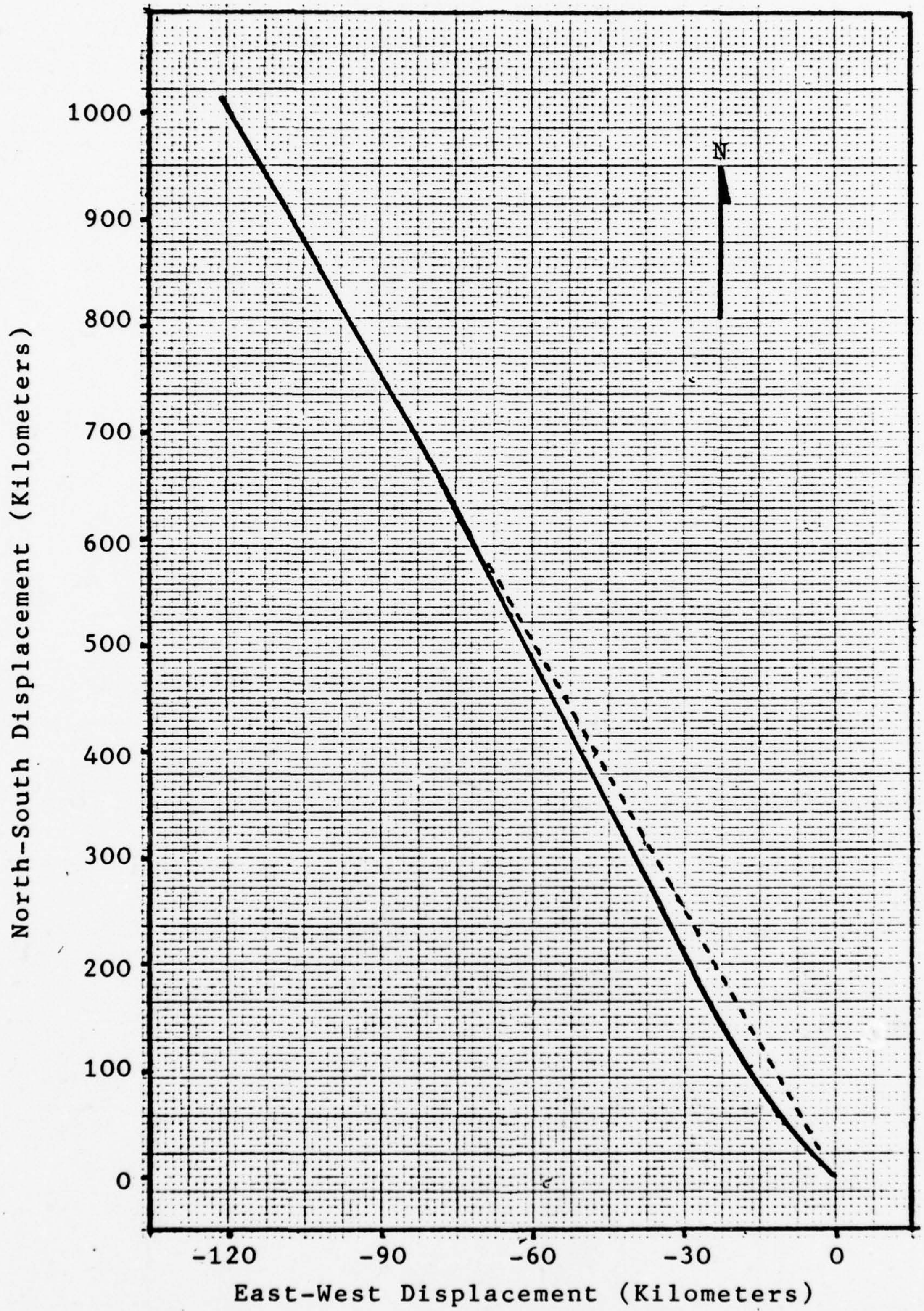

Figure 11. The locus of particle groups on the ground for a 10.4 MT, 70.2 percent fission yield burst with varying winds (Variable Wind Model).

computer code of the variable wind model and a glossary of terms is available in Appendix B.

VII. Conclusions and Recommendations

The usefulness of the variable wind model is obvious. But its complexity may make it too awkward for use in a handbook or "yardstick" fashion and thus unsuitable for field commanders in an operational environment. If technical assistance and computer facilities are available to field commanders and time varying winds are employed, this model may provide a much more accurate prediction of fallout deposition than any previous model.

The value of this model lies in its potential for describing the fallout deposition process. To improve the existing model more effort and attention should be given to determining accurate fall times and terminal velocities, describing a more realistic activity-particle size distribution, more accurately describing the activity distribution within the stabilized cloud, and to estimating the residual gamma ray activity from a nuclear burst. To expand the model, research into the use of a cloud with a finite thickness, winds that vary with time as well as altitude, and fallout particle formation below the stabilized cloud should be conducted and incorporated.

The ripples and splotches observed in the pattern of Figures 9 and 10 could be eliminated by increasing the number of particle size groups or by distributing the activity of two adjacent groups on the ground so that the separation between each group is filled with some activity. This could also reduce the downwind extent of each isointensity contour.

This model offers a tool for the study of fallout deposition that should be used and explored.

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Appendix A

The Miller Model

The required and unformated input for this program is:

1. total weapon yield (MT)
2. fractional fission yield
3. mean wind speed (mph)
4. the number of specific points, if any, for which the user desires to know the unit-time reference dose-rate
5. the number of expansions of the pattern desired
6. the coordinates of those points for which the user desires to know the dose rate, if any (miles)

The expansion mentioned in 5., above, is simply a reduction in scale of the first printout by a factor of one-third.

Glossary of Terms

AB, A1, A2, A3, A4, A5, A6, A7 - dummy variables used to identify specific dose rates in the fallout pattern.

AJ - line value of the vertical axis on the deposition pattern (miles).

DX - increment used to determine the downwind distance at which a dose rate is to be calculated (miles).

DXX - line values of the horizontal axis on the deposition pattern (miles).

DY - same as for DX but for crosswind distance (miles).

FF - fractional fission yield of the weapon.

I - the total dose rate at a specific point (R/Hr. @ 1 Hr.).

IBAK - the number of DX increments upwind to enclose the upwind portion of the pattern.

IC - the dose rate due to cloud fallout only (R/Hr. @ 1 Hr.).

IEXP - the number of pattern enlargements desired.

IFLD - the fallout pattern as a rectangular grid.

IS - the dose rate due to stem fallout only (R/Hr. @ 1 Hr.).

ITEST - a dummy variable used to check for discontinuities within the model.

IX, IY - initial values of DX and DY respectively (miles).

I23, I6, I7, I9 - dose rates at the characteristic points X2, X6, X7, X9 respectively (R/Hr. @ 1 Hr.).

N - the number of specific points for which the user desires dose rate values.

PX, PY - the downwind and crosswind points at which a dose rate is calculated (miles).

V - the average wind velocity during fallout deposition (miles per hour), $0 < V < 75$.

W, WY - the fission yield and total yield of the weapon (megatons).

X - the upwind or downwind distance to a specific point for which the user desires a dose rate (miles).

X1 - the maximum upwind extent of the 1R/Hr. contour (miles) on the pattern centerline.

X2 - the center of the stem fallout pattern (miles) on the pattern centerline.

X6, X7 - the distance to the most upwind and most downwind extent of the high radiation intensity ridge due to cloud fallout (miles).

X9, X9P - the maximum downwind extent of the 1R/Hr. contour for a 15 mph wind and any other windspeed respectively (miles).

Y - the crosswind distance to the specific point for which the user desires a dose rate (miles).

YS - the stem pattern half-width of the 1R/Hr. contour at X2 (miles).

Y6 - the cloud pattern half-width of the 1R/Hr. contour at X6 (miles).

Y8, Y8P - the cloud pattern maximum half-width of the 1R/Hr. controu for a 15 mph wind and any other windspeed respectively (miles).

```
      PROGRAM MILLER(INPUT,OUTPUT)
      DIMENSION IFLD(120,23),DXX(13)
      COMMON/BLOK1/V,H,ITEST,WY,FF/BLOK2/PX,PY,IS,IC/BLOK3/X2,X4,X5,X6,
     1       X7,X9P,YS,Y8P,Y6,I23,I6,I7,I9
      REAL I,IS,IC,I23,I6,I7,I9
      INTEGER A8,A1,A2,A3,A4,A5,A6,A7
      DATA A8,A1,A2,A3,A4,A5,A6,A7/1H ,1H1,1H2,1H3,1H4,1H5,1H6,1H7/
1     READ*,WY,FF,V,N,IEXP
      IF(WY.LT.0.0) STOP
      PRINT82,WY,FF,V,N,IEXP
      IF((V.LE.0.0).OR.(V.GT.75.)) GO TO 199
      W=WY*FF
      CALL CONST
      IF(ITEST.EQ.0) GO TO 150
      IF(IEXP.GT.0) GO TO 200
      DO 100 J=1,N
      READ*,X,Y
      PX=X
      PY=ABS(Y)
      CALL FIELD
      I=IS+IC
100   PRINT80,X,Y,I,IS,IC
      GO TO 1
150   PRINT86,ITEST
      GO TO 1
199   PRINT81
      GO TO 1
200   PRINT87
      IY=Y8P/22.+1
      IX=(X9P-X2+YS)/120.+1
      IF(IX.GT.IY) IY=IX
      IF(IX.LT.IY) IX=IY
      DY=IY
      DX=IX
      IBAK=(X2-YS)/DX-1.
205   DO 340 K=1,23
      IK=24-K
      PY=(K-1)*DY
      DO 340 L=1,120
      PX=(L-1+IBAK)*DX
      CALL FIELD
      I=IS+IC
      IF(I-1.) 309,310,301
301   IF(I-30.) 310,311,302
302   IF(I-100.) 311,312,303
303   IF(I-300.) 312,313,304
304   IF(I-1000.) 313,314,305
305   IF(I-3000.) 314,315,306
306   IF(I-10000.) 315,316,316
309   IFLD(L,IK)=A8
      GO TO 340
310   IFLD(L,IK)=A1
      GO TO 340
311   IFLD(L,IK)=A2
      GO TO 340
312   IFLD(L,IK)=A3
      GO TO 340
```

```
313 IFLD(L,IK)=A4
    GO TO 340
314 IFLD(L,IK)=A5
    GO TO 340
315 IFLD(L,IK)=A6
    GO TO 340
316 IFLD(L,IK)=A7
340 CONTINUE
    DO 360 J=1,13
360 DXX(J)=DX*(IBAK+(J-1)*10.)
    PRINT83,DX,DY,DXX
    DO 375 J=1,23
    AJ=(23-J)*DY
375 PRINT84,AJ,(IFLD(M,J),M=1,120)
    DO 376 J=1,22
    IM=23-J
    AJ=-J*DY
376 PRINT84,AJ,(IFLD(M,IM),M=1,120)
    IEXP=IEXP-1
    IF(IEXP) 1,1,380
380 DY=2./3.*DY
    DX=2./3.*DX
    GO TO 205
80  FORMAT(" "/5X"AT THE POINT X= "F5.1" MILES, AND Y= "F5.1
   1       " MILES, THE RADIATION INTENSITY DUE TO FALLOUT"/5X
   2       " IS "F9.1" R/HR, WITH "F9.1" R/HR DUE TO STEM FALLOUT AND"
   3        F9.1" R/HR DUE TO CLOUD FALLOUT"/)
81  FORMAT(" "//10("X")2X"WIND SPEED OUT OF LIMITS, PROCEED TO "
   1       "NEXT PROBLEM"/////)
82  FORMAT("1"4X"INPUT DATA: "3F10.3,2I4)
83  FORMAT("1"5X"HORIZONTAL (DOWNWIND) SCALE IS "F6.2" TO 1. MILES"
   1       5X  "VERTICAL (CROSSWIND) SCALE  IS "F6.2" TO 1, MILES"///
   2       5X,F6.1,12(4X,F6.1)/8X"*"12("123456789*")//)
84  FORMAT(" "F6.1,1X,120A1)
86  FORMAT(" "5X"ITEST= "I2, 5X"DISCONTINUITY IN CONSTANTS DUE TO "
   1       "INPUT DATA OR MODEL LIMITS. PROCEED TO NEXT PROBLEM."///)
87  FORMAT(" "4X"MAP LEGEND "//5X"1- 1 TO 30 R/HR"/5X"2- 30 TO 100"
   1       " R/HR"/5X"3- 100 TO 300 R/HR"/5X"4- 300 TO 1000 R/HR"/5X
   2       "5- 1000 TO 3000 R/HR"/5X"6- 3000 TO 10,000 R/HR"/5X
   3       "7- 10,000 OR MORE R/HR"//)
    END
```

```
      SUBROUTINE CONST
      COMMON/BLOK1/V,W,ITEST,WY,FF/BLK3/X2,X4,X5,X6,X7,X9P,YS,Y8P,Y6,
     1       I23,I6,I7,I9
      REAL I23,I6,I7,I9
      W05=W/5.
      V20=V/20.
      I23=4000.*(1./W05)**0.42*(1./V20)**0.75
      I6=3720.*SQRT(W05)*(1.-(V-25.)**2/2500.)
      I7=5000.*SQRT(W05)*(1./V20)**0.40
      I9=15./V
      X2=1.75+0.23*(V-20.)*W05**0.23
      X4=35.*V20*W05**0.23
      YS=7.1*W05**0.35*(1./V20)**0.75
      X1=X2-YS
      X6=25.*V20*W05**0.20
      X5=X6-11.*W05**0.30*(1.+(V-20.*W05**0.30)/80.+(V-20.*W05**0.30)
     1   **2/600.)
      X7=63.1*W05**0.30*V20
      Y6=26.*(1./V20)**0.90*W05**0.30
      Y8=45.*(1./V20)**0.56*W05**0.32
      X9=552.*W05**0.30*V20
      Y8P=Y8*ALOG10(I7)/(ALOG10(I7)-ALOG10(I9))
      X9P=(X9*ALOG10(I7)-X7*ALOG10(I9))/(ALOG10(I7)-ALOG10(I9))
      PRINT85,WY,V,W,FF,X1,X2,X4,X5,X6,X7,X9P,YS,Y6,Y8P,I23,I6,I7,I9
      ITEST=0
      IF((I23.GT.1.).AND.(I6.GT.1.).AND.(I7.GT.1.).AND.(I7.GT.I9).AND.
     1 (X4.GT.X2).AND.(X6.GT.X5).AND.(X7.GT.X6).AND.(X9P.GT.X7)
     2 .AND.(X2.GE.0.0).AND.(YS.LE.(X4-X2)).AND.(Y8P.LE.(X9P-X7)))
     3 ITEST=1
   85 FORMAT(" "//5X"PROBLEM DATA"//5X"WEAPON YIELD - "F7.3" MT"/5X
     1       "WIND SPEED - "F4.1" MPH"/5X"FISSION YIELD - "F7.3" MT"
     2       /5X"FRACTIONAL FISSION YIELD - "F5.3///5X,60("* ")//5X
     3       "** NOTE **  ALL DISTANCES (X'S AND Y'S) ARE IN MILES"
     4       ", AND ALL INTENSITIES (I'S) ARE IN R/HR AT 1HR."//5X
     5       60("* ")//5X"PROMINENT POINTS OF THE PATTERN"//5X"X1= "F6.1
     6       ,3X"X2= "F6.1,3X"X4= "F6.1,3X"X5= "F6.1,3X"X6= "F5.1,3X
     7       "X7= "F6.1,3X"X9P= "F6.1/18X"YS= "F5.1,29X"Y6= "F5.1,3X
     8       "Y8P= "F5.1,/18X"I23= "F9.1,25X"I6= "F7.1,2X"I7= "F7.1,2X
     9       "I9= "F7.1///)
      RETURN
      END
```

```
      SUBROUTINE FIELD
      COMMON/BLOK2/PX,PY,IS,IC/BLOK3/X2,X4,X5,X5,X7,X9P,YS,Y8P,Y6,I23,
     1      I6,I7,I9
      REAL IS,IC,I23,I6,I7,I9
      IS=0.0
      IC=0.0
      IF(PX-X4) 502,502,555
  502 IF(PY-YS) 503,503,599
  503 IF(PX-X2+YS) 599,515,505
  505 IF(PX-X2) 515,510,510
  510 IS=I23**(1.-SQRT(((PX-X2)/(X4-X2))**2+(PY/YS)**2))
      GO TO 555
  515 IS=I23**(1.-SQRT((PX-X2)**2+PY**2)/YS)
  555 IF(PX-X5) 599,557,556
  556 IF(PX-X9P) 557,557,599
  557 IF(PY-Y8P) 560,560,599
  560 IF(PX-X6) 570,590,580
  570 IC=I6**(1.-SQRT(((X5-PX)/(X6-X5))**2+(PY/Y6)**2))
      RETURN
  580 IF(PY-X7) 590,590,595
  590 A=(X7-PX)/(X7-X6)
      B=1.-A
      IC=(I6**A*I7**B)**(1.-PY/(A*Y6+B*Y8P))
      RETURN
  595 IC=I7**(1.-SQRT(((PX-X7)/(X9P-X7))**2+(PY/Y8P)**2))
  599 RETURN
      END
```

Appendix B

The Variable Wind Model

Table II

97 Group Particle Size-Activity Distribution from a Log-Normal Distribution with a Mean Radius of 105 Microns and a Standard Deviation of 0.69.

MEAN GROUP RADIUS (MICRONS)	ACTIVITY FRACTION CONTRIBUTED	MEAN GROUP RADIUS (MICRONS)	ACTIVITY FRACTION CONTRIBUTED	MEAN GROUP RADIUS (MICRONS)	ACTIVITY FRACTION CONTRIBUTED
1337.22	.001191850	291.02	.011251860	63.33	.015548350
1274.99	.001316200	277.48	.011701620	60.39	.015227430
1215.66	.001450800	264.56	.012146550	57.58	.014885160
1159.08	.001596170	252.25	.012584750	54.90	.014523320
1105.14	.001752810	240.51	.013014310	52.34	.014143700
1053.71	.001921210	229.32	.013433300	49.91	.013748180
1004.68	.002101850	218.65	.013839790	47.58	.013338660
957.92	.002295160	208.47	.014231850	45.37	.012917090
913.34	.002501550	198.77	.014607570	43.26	.012485380
870.94	.002721390	189.52	.014965110	41.25	.012045480
830.31	.002955000	180.70	.015302650	39.33	.011599290
791.67	.003202640	172.29	.015618460	37.50	.011143680
754.83	.003464530	164.27	.015910910	35.75	.010695490
719.70	.003740810	156.63	.016178450	34.09	.010241490
686.21	.004031550	149.34	.016419650	32.50	.009788370
654.27	.004336750	142.39	.016633190	30.99	.009337760
623.82	.004656290	135.76	.016817930	29.55	.008891190
594.79	.004990010	129.44	.016972830	28.17	.008450110
567.11	.005337630	123.42	.017097050	26.86	.008015850
540.72	.005698750	117.68	.017189890	25.61	.007589560
515.56	.006072900	112.20	.017250830	24.42	.007172550
491.55	.006459480	106.98	.017279530	23.28	.006765340
468.69	.006857790	102.00	.017275830	22.20	.006370150
446.88	.007267000	97.25	.017239750	21.17	.005986350
426.08	.007686200	92.73	.017171490	20.18	.005615120
406.25	.008114340	88.41	.017071430	19.24	.005257050
387.35	.008550270	84.30	.016940140	18.35	.004912580
369.32	.008992730	80.37	.016778340	17.49	.004582070
352.13	.009440350	76.63	.016586930	16.68	.004265790
335.75	.009891570	73.07	.016366960	15.90	.003963390
320.12	.010345140	69.67	.016119530	15.16	.003676460
305.22	.010793110	66.43	.015846280	14.46	.003403470
				13.78	.003144850

Table III

Wind Data For Figure 9

Altitude (km)	Wind Direction (degrees)	Wind Speed (km/hr)
0 - 1	90	8.0
1 - 2	90	25.7
2 - 3	90	25.7
3 - 4	95	27.4
4 - 5	115	27.4
5 - 6	152	22.5
6 - 7	152	22.5
7 - 8	170	24.1
8 - 9	170	24.1
9 - 10	220	32.2
10 - 11	220	32.2
11 - 12	230	27.4
12 - 13	230	27.4
13 - 14	230	27.4
15 - 16	220	22.5
16 - 17	220	22.5
17 - 18	220	22.5
18 - 19	220	22.5
19 - 20	220	22.5

Table IV

Wind Data for Figure 10

Altitude (km)	Wind Direction (degrees)	Wind Speed (kph)
0 - 1	66	38.6
1 - 2	60	37.0
2 - 3	79	11.3
3 - 4	149	4.8
4 - 5	134	24.1
5 - 6	100	29.0
6 - 7	100	29.0
7 - 8	62	16.1
8 - 9	184	22.5
9 - 10	270	27.4
10 - 11	270	27.4
11 - 12	220	59.5
12 - 13	220	59.5
13 - 14	290	56.3
14 - 15	290	56.3
15 - 16	310	62.8
16 - 17	230	11.3
17 - 18	230	11.3
18 - 19	260	27.4
19 - 20	260	27.4

Glossary of Terms

A, A2 - the change of altitude and the average altitude respectively through which a particle falls (kilometers)

ACT - the total residual gamma-ray activity from the burst (gamma's/sec)

AC, AE, AF, AM, AN - variables used to reduce computer time requirements by postulating a linear pattern centerline

BA, B1, B2, B3, B4, B5 - dummy variables used to identify specific dose rates in the fallout pattern

CDR - the dimensionless variable $C_d R^2$ used to compute a Reynolds number and hence a terminal velocity for each particle size

CR - the stabilized cloud radius as given by Miller (kilometers)

CZ - the stabilized cloud height as given by WSEG-10 (kilometers)

DB - a dummy variable used in fall time calculations

DH - the change of altitude that a particle experiences as it falls. The same as A. (kilometers)

DR - the dose rate at a particle point PX, PY (R/HR @ 1 HR)

DT - the time required for a particle to fall a distance A or DH (hours)

DX, DY - the horizontal displacements either east-west or north-south experienced by a particle group as it falls through any wind layer, also the DX and DY increments used in the fallout pattern determination (kilometers or miles)

DXL, DYL - the number of DX and DY increments, respectively, below or behind ground zero that would allow the minimum upwind and crosswind extent of the fallout pattern to be included in the fallout

DXX - line values of the horizontal axis on the deposition pattern (kilometers or miles)

EX - the exponent used in determining each particle group's contribution to the total dose rate

FF - the fractional fission yield of the weapon

GDL - the ground level altitude of the burst (kilometers)

H - the same as AZ (kilometers)

I - a dummy variable used to determine AZ

IEXP - the number of pattern enlargements desired by the user

IXY - a single line of the pattern for a specific value of PY

NP - the number of points for which the user desires a dose rate

NN - a dummy variable used in the fall time determinations

PIR - a conversion factor used to convert degrees to radians (radians/degree)

PR - an array used to store all pertinent information about a particle group: average particle size (microns) of the group, fraction of total activity contributed by this group, the standard deviation of the spatial distribution of a group (kilometers), the time to fall from the stabilized cloud to the ground (hours), the east-west displacement of the group cloud center (kilometers or miles), and the north-south displacement of the group cloud center (kilometers or miles)

PX, PY - the coordinate of a point within the pattern for which a dose rate is to be calculated (kilometers or miles)

R - the particle radius for which a fall-time is computed (microns)

RE - the Reynolds number calculated from CDR and used to compute the terminal velocity

SIGMA - the value of the standard deviation of the spatial distribution for the largest group (kilometers)

SUM - a dummy variable used to sum the dose rate contributions by each particle group

u - the dynamic viscosity of air at any altitude (kg/m-sec)

VT - the average terminal velocity of a particle as it falls through DH

WIND - an array that stores all the wind and altitude data: the average true direction of the wind (360° is true north) that is later converted to machine direction (degrees) for each kilometer of altitude, the average windspeed (kph or mph) for each kilometer of altitude, and the mid-point density of the air for each kilometer of altitude (kg/m^3)

YH - a dummy variable used to limit the computer time required by the program

YLD - the total weapon yield (megatons)

YLDO - a dummy variable used to limit the computer time required by the program

YND - the same as for AC, AE, AF, AM, and AN

A FORTRAN Computer Code for the Variable Wind Model

The required and unformatted input for this program is:

1. the mid-range particle radius of each particle group in microns and the fraction of the total residual activity carried by each group
2. the true wind direction and wind speed of each 1 km thick layer of atmosphere up to an altitude of 20 km
3. total weapon yield (MT)
4. fractional fission yield
5. ground level of the area contaminated by the fallout (KM), burst is at sea level
6. the number of specific points at which the user desires to know the unit-time reference dose rate (if any)
7. the number of pattern expansions desired
8. the coordinates of those points from 4.

The expansion mentioned in 5. above uses a scale down factor of one-half.

```
      PROGRAM NORMAL(INPUT,OUTPUT)
      COMMON/BLOK1/WIND(20,3),DT,DX,DY/BLOK2/PR(97,6),DR,ACT
C     THE PATTERN IS A MAXIMUM OF 100 SPACES WIDE
      DIMENSION IXY(100),DXX(11)
      INTEGER BA,B1,B2,B3,B4,B5
      DATA BA,B1,B2,B3,B4,B5      /1H ,1H1,1H2,1H3,1H4,1H5    /
C    DATA STATEMENT LOADS MID-POINT AIR DENSITY FOR EACH KM
C     OF ALTITUDE
      DATA WIND(1,3),WIND(2,3),WIND(3,3),WIND(4,3),WIND(5,3),WIND(5,3),
     1    WIND(7,3),WIND(8,3),WIND(9,3),WIND(10,3),WIND(11,3),
     2    WIND(12,3),WIND(13,3),WIND(14,3),WIND(15,3),WIND(16,3),
     3    WIND(17,3),WIND(18,3),WIND(19,3),WIND(20,3)
     4    /1.16730,1.05810,0.95695,0.86340,0.77704,0.69747,0.62431,
     5    0.55719,0.49576,0.43966,0.38857,0.33743,0.28538,0.24646,
     6    0.21066,0.18006,0.15391,0.13157,0.11248,0.09526/
      READ*,((PR(N,M),M=1,2),N=1,97)
  101 READ*,((WIND(N,M),M=1,2),N=1,20)
      PRINT80,(((PR(N,M),M=1,3),(WIND(N,L),L=1,3)),N=1,20),
     1        ((PR(N,M),M=1,3),N=21,97)
C     CONVERT TRUE WIND DIRECTION TO MACHINE DIRECTION
      DO 102 J=1,20
      WIND(J,1)=450.-WIND(J,1)
      IF(WIND(J,1).GT.360.) WIND(J,1)=WIND(J,1)-360.
  102 CONTINUE
    1 READ*,YLD,FF,GDL,NP,IEXP
      DO 2 J=1,97
      DO 2 K=4,6
    2 PR(J,K)=0.0
C     TEST FOR USER DIRECTIONS: += CONTINUE, 0= READ NEW YLD,
C     -= STOP
      IF(YLD) 99,101,3
    3 PRINT81,YLD,FF,GDL,NP,IEXP
C     CZ COMPUTES THE MEAN CLOUD HEIGHT OF A SEA LEVEL BURST
      CZ=0.3048*(44.+6.1*ALOG(YLD)-0.205*(ALOG(YLD)+2.42)*
     1    ABS(ALOG(YLD)+2.42))
      IF(CZ.GT.20.) GO TO 5
      CR=14.661*YLD**0.431
      SIGMA=1.*CR
    4 ACT=YLD*FF*2.035E+22
      GO TO 8
    5 PRINT82,CZ
      IF(NP.EQ.0) GO TO 1
      DO 7 J=1,NP
    7 READ*,PX,PY
      GO TO 1
    8 DO 10 J=1,97
   10 PR(J,3)=SIGMA*(1.+(J- 1)*0.020)
      PRINT83,YLD,FF,YLD*FF,GDL,CZ,CR,SIGMA,ACT
C     COMPUTE FALL TIMES AND DISPLACEMENTS FOR EACH GROUP
      I=CZ
      A=CZ-I
      A2=A/2.+I
      DB=0.0
   15 DO 20 J=1,97
      CALL FALL(A2,PR(J,1),A)
      PR(J,4)=PR(J,4)+DT
      PR(J,5)=PR(J,5)+DX
```

```
20    PR(J,6)=PR(J,6)+DY
      IF(DB.GT.0.0) GO TO 32
      A2=I+0.5
      DO 30 K=1,I
      A2=A2-1.0
      IF(A2.LT.(GDL+1.)) GO TO 31
      DO 30 J=1,97
      CALL FALL(A2,PR(J,1),1.)
      PR(J,4)=PR(J,4)+DT
      PR(J,5)=PR(J,5)+DX
30    PR(J,6)=PR(J,6)+DY
      GO TO 32
31    DB=A2+0.5
      A=DB-GDL
      A2=(DB-GDL)/2.+GDL
      GO TO 15
32    PRINT86,((PR(N,M),M=1,6),N=1,97)
      IF(NP.GT.0) GO TO 95
C     TEST FOR 1500 KM LIMIT
33    DO 48 J=1,97
      IF(SQRT((PR(J,5)-PR(1,5))**2+(PR(J,6)-PR(1,6))**2).GT.1500.)
     1 GO TO 49
48    CONTINUE
      J=J-1
C     DEFINE DISTANCE LIMITS OF THE PATTERN
49    AM=(PR(J,6)-PR(1,6))/(PR(J,5)-PR(1,5))
      AN=5.*PR(J,3)
      DX=(ABS(PR(J,5)-PR(1,5))+5.*(PR(J,3)+PR(1,3)))/100.+2.0
      DY=(ABS(PR(J,6)-PR(1,6))+5.*(PR(J,3)+PR(1,3)))/100.+2.0
      DXL=(PR(J,5)-5.*PR(J,3))/DX
      DYL=(PR(J,6)-5.*PR(J,3))/DY
      IF(PR(J,5).GT.PR(1,5)) DXL=(PR(1,5)-PR(1,3)*5)/DX
      IF(PR(J,6).GT.PR(1,6)) DYL=(PR(1,5)-5.*PR(1,3))/DY
60    DO 61 J=1,11
61    DXX(J)=DX*(DXL+1+(J-1)*10.)
      PRINT84,DX,DY,DXX
      ICKA=0
C     BEGIN DOSE RATE CALCULATIONS FOR EACH POINT (PX,PY) OF A
C     RECTANGULAR GRID
      DO 79 K=1,101
      PY=(DYL+101.-K)*DY
      ICKB=0
      DO 78 J=1,100
      PX=(DXL+J)*DX
C     THESE 6 CARDS REDUCE THE CPA TIME REQUIRED BY
C      ELEMINATING UNNECESSARY DOSE RATE CALCULATIONS
      YNO=AM*(PX-PR(1,5))+PR(1,6)
      AC=SQRT((PX-PR(1,5))**2+(YNO-PR(1,6))**2)
      IF(AC.LT.0.1) GO TO 65
      AF=PY-YNO
      AE=ABS((PX-PR(1,5))*AF/AC)
      IF(AE.GT.AN) GO TO 70
65    CALL FIELD(PX,PY)
C     DETERMINE THE DOSE RATE RANGE AT THE POINT (PX,PY)
      IF(DR-1.) 70,71,66
66    IF(DR-10.) 71,72,67
67    IF(DR-100.) 72,73,68
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68   IF(DR-1000.) 73,74,69
69   IF(DR-3000.) 74,75,75
70   IXY(J)=BA
     ICKB=ICKB+1
     GO TO 78
71   IXY(J)=B1
     ICKA=1
     GO TO 78
72   IXY(J)=B2
     GO TO 78
73   IXY(J)=B3
     GO TO 78
74   IXY(J)=B4
     GO TO 78
75   IXY(J)=B5
78   CONTINUE
     IF((ICKA.EQ.0).AND.(ICKB.GT.99)) GO TO 79
     IF((ICKA.GT.0).AND.(ICKB.GT.99)) GO TO 90
     PRINT85,PY,IXY
79   CONTINUE
C    THESE STATEMENTS ALLOW FOR AN EXPANDED SCALE WHICH
C    SHOWS MORE DETAIL OF THE MAIN PORTION OF THE PATTERN
90   IEXP=IEXP-1
     IF(IEXP) 1,1,93
93   DX=DX/2.
     DY=DY/2.
     GO TO 60
95   CALL SINGLE(NP)
     IF(IEXP.GT.0) GO TO 33
     GO TO 1
80   FORMAT("1"5X"BASE DATA INPUT"///5X"PARTICLE DATA"25X"WIND DATA"
    1      //20(6X,F6.1,3X,F10.8,3X,F6.2,10X,F5.1,3X,F5.1,3X,F7.5/),
    2      77(6X,F6.1,3X,F10.8,3X,F6.2/))
81   FORMAT("1"5X"INPUT DATA: "3F10.3,2I6//)
82   FORMAT(//" "5("X")2X"C7= "F5.1" KM, AND EXCEEDS 20 KM. PROCEED "
    1      "TO NEXT PROBLEM"//)
83   FORMAT(" "5X"WEAPON'S TOTAL YIELD - "F7.3" MT"//6X"FISSION "
    1      "FRACTION - "F5.3/6X"WEAPON'S FISSION YIELD - "F7.3" MT"/
    2      6X"GRND LVL OF THE PATTERN - "F7.2" KM"/6X"MEAN CLOUD "
    3      "HEIGHT - "F5.1" KM"/6X"MEAN CLOUD RADIUS - "F5.1" KM"/6X
    4      "SIGMA = "F5.2" KM"/6X"TOTAL GAMMA ACTIVITY AT 1 HOUR = "
    5      1PE12.5" GAMMAS PER SECOND"//10X,40("* ")/10X"NOTE:  ALL "
    6      "DISTANCES ARE IN KILOMETERS, AND ALL INTENSITIES ARE IN "
    7      "R/HR AT 1 HOUR"/10X,40("* ")//10X"MAP LEGEND"//10X
    8      "1 - 1 TO 10 R/HR"/10X"2 - 10 TO 100 R/HR"/10X"3 - 100 TO "
    9      "1000 R/HR"/10X"4 - 1000 TO 3000 R/HR"/10X"5 - 3000 OR "
    A      "MORE R/HR"//)
84   FORMAT("1"9X"THE HORIZONTAL SCALE IS "F6.2" TO 1 KM, AND THE "
    1      "VERTICAL SCALE IS "F6.2" TO 1 KM."//10X"THE HORIZONTAL "
    2      "AXIS REPRESENTS THE EAST-WEST DISPLACEMENT"//7X,
    3      10(F6.1,4X),F6.1/10X,10("*123456789")"*"//)
85   FORMAT(" "F6.1,3X,100A1)
86   FORMAT("1"5X"PARTICLE GROUP DATA"//5X"MID-RANGE"5X"ACTIVITY"5X
    1      "STANDARD"5X"TIME TO"5X"EAST-WEST"5X"NORTH-SOUTH"/6X
    2      "RADIUS   "5X"FRACTION"5X"DEVIATION"4X"FALL"8X"DISPLACEMENT"
    3      2X,"DISPLACEMENT"/6X"(MICRONS)"18X"(KM)"9X"(HRS.)"6X
    4      "(KM)"10X"(KM)"/97(/6X,F7.2,6X,F10.8,4X,F6.2,7X,F7.1,5X,
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    5      F8.1,7X,F8.1)//)
 99 STOP
    END

      SUBROUTINE FALL(H,P,DH)
      COMMON/BLOK1/WIND(20,3),DT,DX,DY
      DATA PIR/1.7453292513939/
C     THIS SUBROUTINE COMPUTES FALL TIMES AND DISPLACEMENTS
C     FOR EACH GROUP
      U=1.4216E-05
      IF(H.LT.11.) U=1.7894E-05-3.3361E-07*H
      NN=H+1
      COR=2.717866E-13*WIND(NN,3)*R**3/U**2
      RE=COR/24.-2.3363E-04*COR**2+2.0154E-06*COR**3-6.9105E-09*COR**4
      IF(COR.GE.138.) RE=10.**(-1.29536+0.986*ALOG10(COR)-0.046677*
     1                   (ALOG10(COR))**2+0.0011235*(ALOG10(COR))**3)
      VT=1.8E+06*RE*U/(WIND(NN,3)*R)*(1.+0.1165/(R*WIND(NN,3)))
      DT=DH/VT
      DX=-DT*WIND(NN,2)*COS(WIND(NN,1)*PIR/100.)
      DY=-DT*WIND(NN,2)*SIN(WIND(NN,1)*PIR/100.)
      RETURN
      END

      SUBROUTINE FIELD(PX,PY)
      COMMON/BLOK2/PR(97,6),DR,ACT
C     THIS SUBROUTINE COMPUTES AND SUMS THE DOSE RATE
C     CONTRIBUTED BY EACH PARTICLE GROUP
      SUM=0.0
      DO 400 L=1,97
      EX=((PX-PR(L,5))**2+(PY-PR(L,6))**2)/2./PR(L,3)**2
      IF(EX.GT.50.) GO TO 400
      SUM=SUM+PR(L,2)*0.3989*EXP(-EX)/PR(L,3)**2
  400 CONTINUE
      DR=1.147125E-16*SUM*ACT
      RETURN
      END

      SUBROUTINE SINGLF(N)
      COMMON /BLOK2/ PR(97,6),DR,ACT
C     THIS SUBROUTINE COMPUTES THE DOSE RATE AT A SINGLE POINT
      PRINT88
      DO 600 NJ=1,N
      READ*,PX,PY
      CALL FIELD(PX,PY)
  600 PRINT87,PX,PY,DR
   87 FORMAT("0"5X"AT THE POINT X= "F6.1" KM, AND Y= "F6.1" KM, THE "
     1       "RADIATION INTENSITY DUE TO FALLOUT IS "F7.1" R/HR AT 1 HR")
   88 FORMAT("1"5X"INTENSITIES FOR SPECIFIC POINTS ARE AS FOLLOWS:"/)
      RETURN
      END
```

Vita

Robert M. Savage, Jr. was born to Bob and Nona on April 15, 1951 in Montgomery, Alabama. He received the degree of Bachelor of Science in Chemical Engineering from the University of Alabama in May 1973 and was commissioned a second lieutenant in the United States Air Force on 13 May 1973. He was assigned to the 90th SMW at F. E. Warren AFB, Wyoming until the summer of 1976 and is presently enrolled in the Graduate Nuclear Effects program in the Air Force Institute of Technology.

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A brief study was made of three fallout prediction models: the ENW model, presented by Samuel Glasstone, the Miller model, by C. F. Miller, and the WSEG-10 model, by George Pugh and Robert Galiano. Each of these models used an effective wind that had constant direction and speed. A FORTRAN computer code of the Miller model was prepared by the author and is available in the report. → next page

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To ascertain the effects of more realistic winds that varied direction and speed with altitude, the author ~~developed a~~ model ~~that~~ utilized an altitude dependent wind as well as a thin stabilized cloud, and fall time equations based on the equations of C. N. Davies. This model was prepared as a FORTRAN computer code ~~by the author~~, and the code is included in the report.

The two most significant results of the variable wind model are the asymmetric pattern produced on the ground and the non-linear centerline of that pattern. The model allows the user to introduce his own discription of the physical processes of fallout deposition and is therefore not constrained as are the stylized models of Glasstone and Miller.