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RESIDUAL DUST AND RADIATION MODEL

(REDRAM)

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MODEL DESCRIPTION

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FOREWORD

REDRAM development was motivated by the B-1B project office at Aeronautical Systems Division, Wright-Patterson AFB, OH. The majority of code development work was completed while the authors were assigned to the System Survivability Branch (ENSSS) in the Systems Analysis Division (ENSS) of the Directorate for Systems Engineering (ASD/ENS). We thank Mr. James Sunkes (ENSS) and Mr. Hugh Griffis (ENSSS) for their valuable guidance and support during the development and application of this model.

TABLE OF CONTENTS

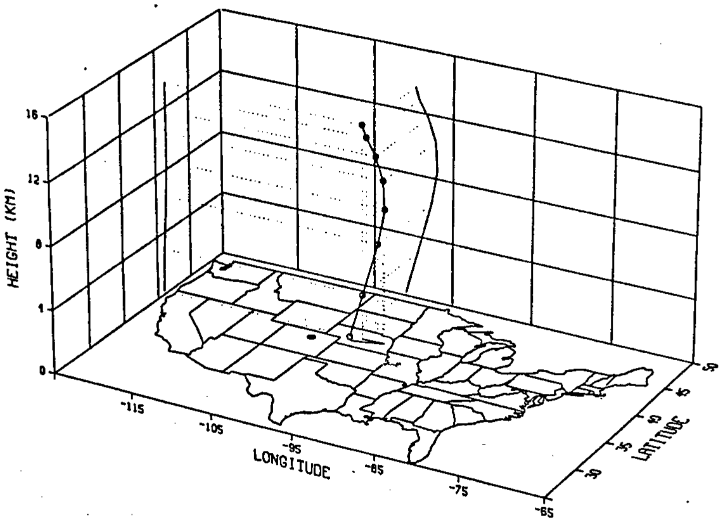
EXECUTIVE SUMMARY

RESIDUAL DUST AND RADIATION MODEL (REDRAM)

MODEL DESCRIPTION

REDRAM is a computer model that simulates airborne nuclear cloud environments. Development was motivated by requirements for survivability assessments of advanced strategic aircraft. Survivability assessments need estimates of airborne particle sizes, mass and radioactivity levels.

REDRAM starts with a stabilized cloud of falling trace particles and transports them with spatially varying winds in a layered atmosphere. At a specified time after burst, REDRAM determines the particle sizes that remain aloft: their positions define the cloud axis. The figure below shows an example of a cloud axis at 10 hours after a one megaton nuclear burst.



Cloud Axis From a 1 Megaton Weapon, 10 Hours After Burst

REDRAM superimposes three-dimensional normal distribution functions along the cloud axis, using particle positions as modes. The resulting distribution function assembly forms a three-dimensional cloud model that can be sampled along hypothetical aircraft flight paths.

REDRAM uses methods that are supported by empirical data wherever possible. The variable wind fields are modeled with polynomial fits to observed global winds. The particle size distribution is based on data from atmospheric nuclear tests, as are the cloud heights, total dust mass and radioactivity levels. Validation exercises included comparisons with Mount St. Helens ash cloud movement and ashfall data. In addition, the three-dimensional cloud mass distributions were compared to aircraft sample data from a high explosive dust cloud and to calculations from a hydrocode.

The model has been used to estimate particle mass and radioactivity levels downwind of single and multiple nuclear bursts. REDRAM is currently used to assist with the establishment of nuclear criteria for advanced systems.

REDRAM MODEL

RESIDUAL DUST AND RADIATION MODEL (REDRAM)

I. INTRODUCTION

REDRAM is a FORTRAN computer code that simulates the transport and dispersion of particles from an atmospheric nuclear burst. The code was developed to estimate the dust particle sizes, mass concentrations and radioactivity levels that are airborne long after the burst. Model development was motivated by a requirement to estimate the dust and radiation burden to advanced strategic aircraft instrumentation and crew. In the event of a nuclear war, aircraft may have to operate in environments containing the radioactive debris lofted by weapons from intercontinental and submarine-launched ballistic missiles. Escaping bombers and tankers, national command authority aircraft, and command, control and communication aircraft are examples of systems that may potentially be affected by the nuclear clouds.

A variety of computer codes have been developed to explore late time airborne dust and radiation environments (13; 19; 22). The models have been used to estimate environments with varying degrees of fidelity, depending upon their intended use. Fast running codes sacrifice resolution for speed of operation; they are intended for studies that cannot tolerate the long run times and tedious interpretation required by the larger, more detailed methods. However, all computer models of nuclear clouds suffer from the fact that there is no atmospheric nuclear test data that will support their complete and unambigious validation.

The R&D Associates (RDA) dust and radiation environment model (19) was developed for Headquarters, Defense Nuclear Agency (DNA). RDA based their model on as much reliable, empirical data as possible. RDA used the model for a general assessment of environment severity following a hypothetical large scale nuclear exchange. DNA and RDA cooperated with REDRAM's development by providing valuable references and constructive comments regarding the technical areas where improvements would be most beneficial.

REDRAM is philosophically similar to the RDA model in that computational methods were based on empirical correlations of observed test data wherever reliable data was available. REDRAM significantly differs from the RDA model in at least two respects: REDRAM uses a continuously varying spectrally decomposed wind field for improved lateral transport calculations, and REDRAM development has stressed validation of transport methods with as much relevant test data as available in order to develop confidence in simulation fidelity.

This report describes the REDRAM code, and its submodels of nuclear environments. Efforts to validate the wind-driven transport simulation are summarized. Results of a one megaton cloud transport calculation illustrate typical cloud translation, shear and airborne mass/radiation gradients.

II. MODEL DESCRIPTION

General

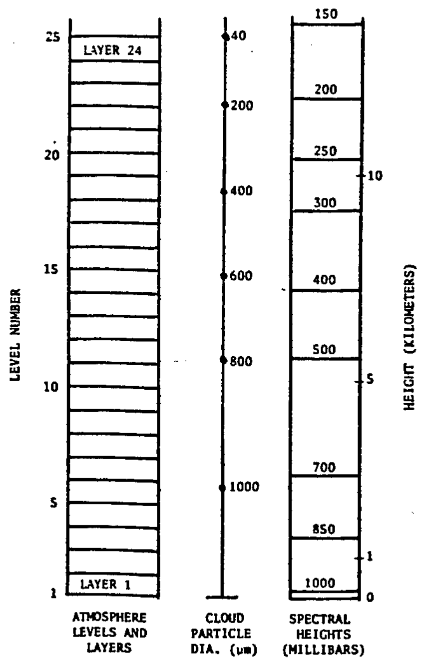
REDRAM starts with a stabilized cloud of trace particles, transports them downwind until they fall to the ground, then, backing up in time, reconstructs a three dimensional model of dust and radiation environments at a user-specified time. Of course, the specified time must precede the time at which the smallest trace particle lands.

The stabilized cloud is a gravity-sorted array of user-defined trace particle sizes. Different particle sizes start falling from different altitudes, depending on weapon yield. Starting heights are based on analyses of stabilized wafer heights in the Department of Defense Land Fallout Interpretive Code (DELFIC) (10; 16). One particle per size is used in REDRAM to represent the mode of a distribution of same-size particles in the vertical. Each falling trace particle is tracked from its starting height, through a variable wind field, to the ground. Intermediate particle positions are recorded, and used to interpolate back to find the position of each particle at a user-defined freeze frame time. The connection of all airborne particles at freeze frame time is the cloud's nearly vertical freeze frame axis, skewed by the spatially varying wind field through which the trace particles fell.

The particle positions are used as modal locations for expanding three-dimensional normal distributions. The distributions from all particles are superimposed at atmospheric layer heights up and down the freeze frame axis. The result is an axially skewed cloud of overlapping density functions in three dimensions. The normal density functions approximate the way cloud mass density and radiation vary with location about the cloud's axis. The space around the cloud is divided into horizontal meshes, vertically stacked with user-defined resolution.

Computational Mesh

REDRAM divides the atmosphere into a user-defined number of vertical layers. The upper and lower boundaries of layers are called levels, so a ten layer model has eleven levels. Atmospheric properties (density, kinematic viscosity) are computed at each level. Winds are defined on a different set of vertical levels; they are specified by the National Meteorological Center at twelve different isobaric heights above sea level. Winds are computed at the isobaric heights that are above and below particle starting heights, then the winds are interpolated to the particle heights. Particles start from size-dependent heights in the initial cloud, and fall through atmospheric layers until they reach ground. Thus, initially, there are three simultaneous schemes for representing altitude-varying parameters: 1) the computational mesh of evenly divided layers, 2) the isobaric wind levels and 3) initial heights of particles in the stabilized cloud. Figure 1 illustrates. REDRAM interpolates winds and particles onto the computational mesh in the process of computing the positions of falling trace particles.



PARTICLE HEIGHTS
ARE FOR A ONE
MEGATON CLOUD

Figure 1. Computational Mesh, Wind Levels and Initial Particle Heights

Input Data

The user supplies information about the burst, the particle size frequency functions and model parameter settings. Specifically, Table 1 identifies the data necessary for a REDRAM computer run. Inputs are contained in two separate units, one for the spectral coefficients and one for all other information.

TABLE 1

REDRAM INPUT DATA REQUIREMENTS

Weapon Yield
Burst Height
Trace Particle Sizes
Activity Fraction in each Particle Size
Mass Fraction in each Particle Size
Fission Fraction
Total Mass Lofted
Particle Mass Density
Latitude and Longitude of Burst Point
Numbers of Standard Deviations that Define
  Limits of Three Dimensional Mesh
Lateral Spatial Resolution
Wind Spectral Coefficients
Freeze Frame Time

Stabilized Cloud Height

Starting heights of particles in the initial, stabilized cloud are set by fits to the average heights of wafers in DELFIC code output. Reference 10 explains how the following yield-dependent fits were obtained. Constants are in Table 2.

$$Zp = -S\ Pd + I$$

$$\ln S = S0 + S1 \ln y + S2 (\ln y)^2 + S3 (\ln y)^3 + S4 (\ln y)^4$$

$$\ln I = I0 + I1 \ln y + I2 (\ln y)^2 + I3 (\ln y)^3 + I4 (\ln y)^4$$

where:
Zp = particle height (meters)
Pd = particle diameter (micrometers)
y = weapon yield (kilotons)
Sn and In = n-th constant
lny = natural logarithm of y

TABLE 2

POLYNOMIAL CONSTANTS FOR PARTICLE STARTING HEIGHTS

n	Sn	In
0	1.574	7.889
1	-0.1197	0.3400
2	0.03636	0.001226
3	0.00410	0.005236
4	0.0001965	0.000417

The correlations give particle heights that are gravity sorted; that is, larger particles start from lower altitudes than smaller particles. The particles are assumed to be spheres falling through a U.S. Standard Atmosphere.

Atmosphere

Atmospheric properties are needed to determine each particle's height-dependent fall speeds and residence times in the model's vertical layers. REDRAM uses the U.S. Standard Atmosphere generating equations (14) to compute atmospheric state variables needed for terminal velocity computation. The code determines U.S. standard air mass density and kinematic viscosity at the top and bottom of each layer. The U.S. Standard Atmosphere is used to approximate conditions at mid-latitudes in the northern hemisphere. Sensitivity studies with atmospheric variables from tropical latitudes show that particle fall speeds are not very sensitive to atmospheric properties (10).

Particle Fall Speeds

The terminal velocity of each trace particle size is computed at the top and bottom of each atmospheric layer, and the average is used to determine that particle's residence time in the layer.

$$tr = dz/Vz$$

where:
tr = residence time
Vz = terminal velocity
dz = layer thickness

REDRAM uses the methods of Davies and MacDonald (6; 12) to compute the terminal velocities of uniform density spheres. The Davies-MacDonald methods are common to several nuclear fallout codes (e.g., references 3 and 16). Calculations are valid for spherical particles. If the majority of particles are not spheres, then results must be interpreted as equivalent sphere transport and transfer functions would be required to derive particle size-specific masses and radiation doses.

Wind Vector Components

The lateral translation of falling particles in each layer is performed by multiplying each particle's residence time by the wind speed at the center of the layer at the particle's latitude and longitude. It is assumed that wind speed and direction are constant in a model layer only for the span of time that a particle resides there.

Wind vector components are computed with a set of polynomials for each component at each of twelve isobaric heights. The polynomials are fits to global gridded wind data. The fits are spherical harmonics that describe the variation of each wind component as a function of latitude and longitude (9). Each polynomial is a finite sum of spectral terms that describe the vector component. Spectral decomposition accurately replicates the wave-like variations of wind speed around the earth. A general form of the spectral wind expansion follows:

$$U,V = \sum_{\ell=0}^{J} A \sum_{m=\ell}^{\ell+J+1} (U_m^\ell, V_m^\ell) P_m^\ell(\sin\phi) e^{i\lambda\ell}$$

where:
U,V = wind vector components
U_m^ℓ, V_m^ℓ = complex spectral coefficients for U,V
A = 1 when $\ell = 0$, otherwise $A = 2$
J = truncation limit
ℓ = latitudinal index
n = longitudinal index
P = associated Legendre polynomial
ϕ = latitude
λ = longitude
i = square root of -1

The spectral coefficients are computed external to REDRAM with software provided by the Air Force Geophysics Laboratory (AFGL). Monthly most probable wind data is gridded (2 1/2` x 2 1/2`) and fit with spherical harmonics. The fits yield the spectral coefficients. The above equations, with spectral coefficients, permit the calculation of wind vector component magnitude at any latitude and longitude.

This method is based on the National Meteorological Center's twelve layer 30 wave spectral model of the atmosphere. There are 961 (31 x 31) spectral coefficients required for each of the two wind vector components at each of the 12 isobaric levels.

Monthly most probable winds were provided by the USAF Environmental Technical Applications Center (USAFETAC). Winds were chosen by analyzing seven years of global wind data, and selecting specific days with the surface features and upper air flow patterns most typical of each month. USAFETAC provided gridded data for monthly most typical days and for one day before and after each typical day. USAFETAC's data was further resolved by interpolation to obtain a 2 1/2` x 2 1/2` wind field. Those gridded winds were then used as input to the AFGL software to obtain spectral coefficients. Winds were then computed from the coefficients at grid points and compared to USAFETAC data to verify the coefficient set.

Wind Shear

The lateral growth of a nuclear cloud is estimated with equations that require values of wind shear. Shear is defined in REDRAM as follows:

$$sx, sy = \sqrt{\sum_{j=1}^{N} \left(\frac{\Delta u, \Delta v}{\Delta z}\right)_j \frac{tr}{t_{fall}}} \Big/ N$$

where: sx,sy = shear components (x or y)

$\Delta u, \Delta v$ = change in wind speed (u or v component) over a vertical distance, Δz

Δz = layer thickness

tr = particle residence time in layer j

t_{fall} = total fall time of particle

N = total number of layers through which a particle falls

Shear is a residence time weighted average of shears that the falling cloud experiences in each of the model layers. Shear will be positive, expanding the cloud as time progresses.

Cloud Lateral Growth

As the cloud falls, different particle sizes fall with different speeds, so they are translated by winds for different lengths of time. It is possible, and typical, for the top and bottom of a cloud to be in different locations at a given time. The cloud spreads laterally, first with initial toroidal motion, then, with winds that shear the cloud. Small scale atmospheric motions dilute the cloud and diffuse the particles away from the cloud's axis. The cloud's lateral growth is a very complicated process to simulate precisely, and attempts to do so have met with varied degrees of success (1). REDRAM uses the lateral growth model that was developed for the WSEG-10 fallout code (20) and corrected by Bridgman in the AFIT fallout code (2; 3). The lateral growth model includes explicit dependence on weapon yield and wind shear.

The AFIT code is a constant wind fallout model that employs a semi-empirical expression for crosswind cloud dispersion. The method was adapted for REDRAM's variable wind treatment because the method includes the most influential causes of cloud growth, and because the method was developed to fit atmospheric test cloud data. The AFIT equations estimate the value of a standard deviation of an assumed normal probability density function oriented in the crosswind direction. In REDRAM, the same equations are used to give directional standard deviations with directional shear values computed from spectral winds.

Cloud Vertical Growth

In addition to the cloud spreading caused by variable fall rates of different sized particles, cloud thickness is affected by toroidal flow and entrainment/diffusion processes. However, because vertical velocity wind shears are generally so small compared to horizontal velocity shears, toroidal growth and particle fall dominate the process of vertical growth. Particle fall is explicitly treated with trace particle tracking. Trace particle positions are assumed to be the modes of normal distributions aligned with the cloud's freeze frame axis. Standard deviations of those modes are measures of cloud vertical growth, again based on fits to DELFIC cloud calculations (5). REDRAM models a cloud's vertical standard deviation as 25% of the visible cloud thickness. Vertical standard deviations vary with weapon yield and particle size in the initial cloud. The vertical Gaussian distribution associated with each particle size falls at a rate that is determined by the trace particle size, overlapping in time and space with distributions from other particle sizes.

Cloud Mass Loading

An atmospheric nuclear burst can raise a large mass of debris if the burst occurs close to the ground. Reference 15 contains a depiction of anhydrous cloud mass loading vs burst height normalized by weapon yield. The plot is reproduced in Figure 2.

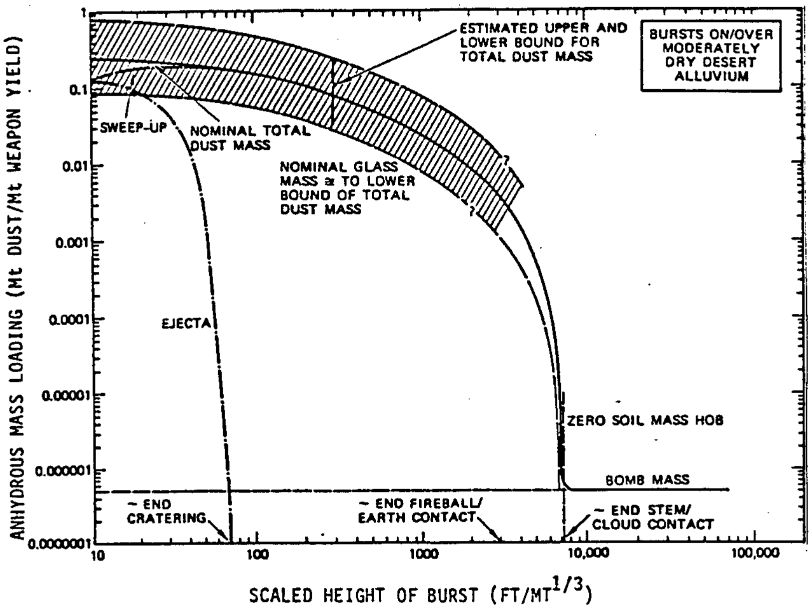


Figure 2. Cloud Mass Loading

The cloud mass loading curve was digitized and fit with five quadratics.

$$\ln (M/Y) = a_0 + a_1(x) + a_2(x)^2$$

where:
M/Y = megatons (MT) of debris/megaton of weapon yield
$x = \ln$ (SHOB)
SHOB = scaled height of burst (feet/$MT^{1/3}$)
ln = natural logarithm

Table 3 shows the values of quadratic constants.

TABLE 3

Quadratic Constants for Mass Loading Equations

x	a_0	a_1	a_2
$x < 2.2215$	- 1.31	-.048	0
$2.2215 \leq x < 7.9537$	- 2.984	1.042	-0.1707
$7.9537 \leq x < 8.3337$	-82.637	22.258	-1.580
$8.3337 \leq x < 8.8289$	-325.684	84.066	-5.498
$8.8289 \leq x$	-18141.701	4148.995	-237.351

Mass loading is an imprecisely known quantity. Data is sparse, controversial and of questionable relevance to bursts over soil types that are different from desert alluvium. However, several of the mass loading estimates were derived by independent techniques, agreeing on the approximate 1/3 megaton of dust per megaton of yield for surface bursts. Uncertainty increases with burst height.

Particle Size Distributions

A recent survey of particle size distribution (PSD) functions illustrated the wide variation in PSDs that can be produced by nuclear bursts (22). PSDs vary with the same features that mass loadings do: soil type, water content, rock strength and burst height to name a few. The REDRAM user can specify any PSD by supplying trace particle sizes and the mass and activity density function values associated with them. However, to be consistent with REDRAM's development philosophy of using empirically based information, the DELFIC-default number size spectrum is currently used for code development and verification.

DELFIC-default is a particle distribution derived from measurements of particle sizes that fell from the cloud produced by a low yield atmospheric nuclear test in Nevada. The DELFIC-default activity-size distribution is accurately replicated as the weighted sum of two log-normal density functions.

$$a(r) = \frac{f_v}{\sqrt{2\pi}\,\beta r}\, e^{-\frac{1}{2}\left(\frac{\ln(r)-\alpha_3}{\beta}\right)^2} + \frac{(1-f_v)}{\sqrt{2\pi}\,\beta r}\, e^{-\frac{1}{2}\left(\frac{\ln(r)-\alpha_2}{\beta}\right)^2}$$

where: a(r) = fraction of particles with radius r

r = particle radius

fv = fraction of the population with radioactivity distributed within the particle's volume

1-fv = fraction of the population with radioactivity distributed on the particle's surface

β = log slope of distribution

α_3, α_2 = medians of the volume and surface distributions

Values of the activity fraction and mass fraction are inputs to REDRAM, not hard-wired, so that other PSDs can be studied.

Output Reports

REDRAM output echoes the input data except the spectral coefficients, which are too numerous to list each time that REDRAM operates. Particle trajectories are summarized by printing particle position coordinates at each level in the atmosphere. Locations of points on the freeze frame cloud axis are printed along with shears and conversions to earth radians in a spherical coordinate system. The output listing includes a level by level expansion of the three dimensional normal distribution function values for each particle size. The expansions are reported after REDRAM repositions the freeze frame cloud axis onto user-defined grid node locations. The expansions are printed first for the northeast quadrant of a cloud, then values are reported again for the fully expanded cloud. Full expansion uses symmetry properties of the distribution functions to reflect values into the other three cloud quadrants. Figure 3 illustrates the process of translating the particles, freezing their positions at a user-defined time, computing density function values in the northeast quadrant, then reflecting the northeast quadrant's numbers into the other quadrants.

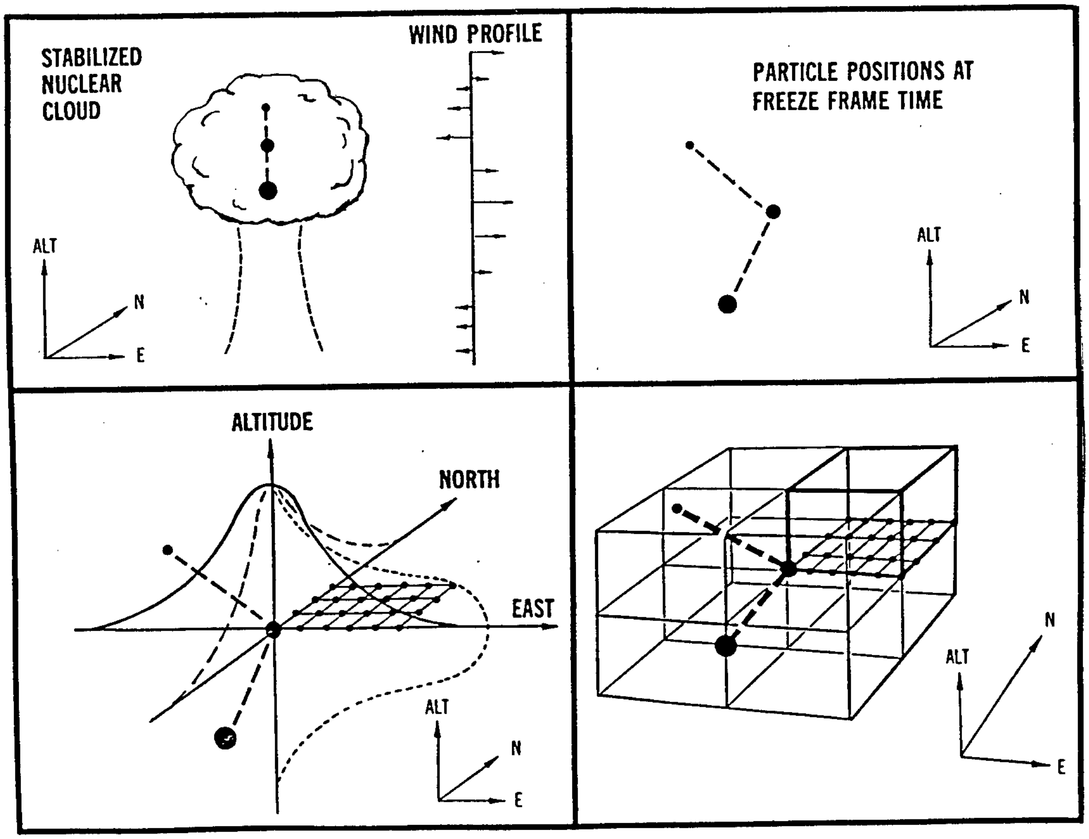


Figure 3. REDRAM Computation Sequence

III. CELL ENVIRONMENT CALCULATIONS

Using the previously described methods of computing relevant cloud behavior, REDRAM determines unit time reference dose rate and particulate mass concentrations in each cell. Following is a general description of the model's approach to calculating cell environments.

Dose Rate

REDRAM reports values of unit time reference dose rate and particle mass concentrations at discrete points in the atmosphere. Those points represent the centers of three dimensional cells that are one layer thickness high (meters) and one increment of lateral mesh (radians) in each horizontal direction. Dose rate is skyshine from particles within the cell volume, so cell dimensions should be larger than the mean free paths of gamma photons emitted by radioactive elements in the particles. Figure 4 illustrates the geometry.

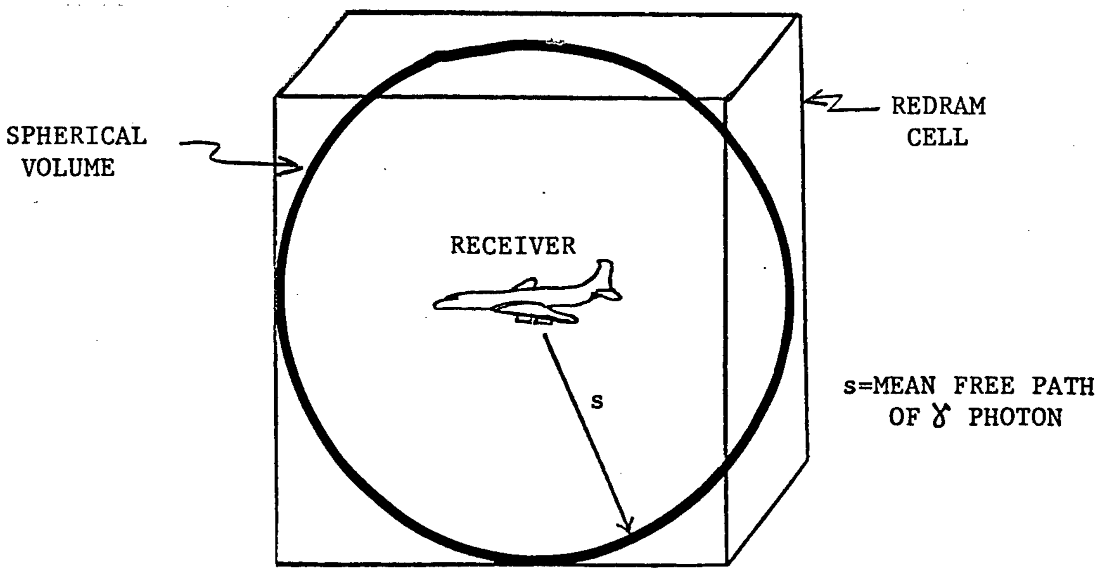


Figure 4. Cell - Receiver Geometry

The dose rate to a receiver located at cell center is the sum of each particle size's activity, converted to dose rate, attenuated by intervening air and multiplied by REDRAM's determination of how much of the three dimensional density function is in the cell.

$$\dot{D}_1 = \left[\sum_{NPR} \int_{\Delta r} a(r)\,dr\right] (Y_{kt})(ff)(SNC)(F)\left(\frac{\mu_a}{\rho}\right)\langle h\nu\rangle \iiint_{\substack{\text{Cell}\\ \text{Volume}}} \frac{e^{-\left(\frac{\mu_t}{\rho}\right)_{air}(M.I.)}}{4\pi s^2}\, d\,\text{Volume}$$

where: $\dot{D}_1$ = unit time reference dose rate

NPR = number of different particle sizes in cell

Δr = finite particle radius interval

Y_{kt} = weapon yield

ff = fission fraction

F = REDRAM calculation of three dimensional density function

SNC = source normalization constant

(μ_a/ρ) = mass attenuation coefficient for receiver

$\langle h\nu\rangle$ = average energy of photons emitted by radioactive particles

(μ_t/ρ) = total mass attenuation coefficient for air

M.I. = mass integral of air between source of radiation and receiver

s = path length traveled by γ photon

REDRAM assumes 530 megacuries of gamma radioactivity per kiloton of fission (8). The volume integral is solved analytically by assuming that the overwhelming majority of radiation is coming from within the cell, so the integration can be performed within an infinite sphere. Typical values of attenuation coefficients were used for air and receiver materials (7).

Since the dose rate values are for one hour after burst (unit time reference), that value must be integrated from receiver arrival time to receiver departure time to obtain dose to receiver.

$$D = \int_{t_a}^{t_d} \dot{D}_1 \, t^{-1.26} \, dt$$

where: $\dot{D}_1$ = dose (rads) to receiver

ta = arrival time

td = departure time

Assuming that the ensemble of fission products decay with a net $t^{-1.26}$ dependence, the above integral can be solved analytically for total dose to the receiver. This step is not performed in REDRAM, since arrival and departure times are scenario dependent.

Particulate Mass

The total particulate mass in a cell is the sum of the masses contributed by each particle size. REDRAM's three dimensional spatial distribution function gives the fraction of each particle size that is contained in each cell. Multiplying that fraction by the fraction of mass contained in each particle size, then by the total cloud mass yields total mass contributed to a cell by each particle size.

$$M(r) = (TM)\ (F)\ m(r)$$

where: M(r) = total mass contributed to a cell by particle size r

TM = total cloud mass lofted

F = REDRAM calculation of three dimensional density function

m(r) = fraction of TM contained in trace particle size r

The values of m(r) for each trace particle size are inputs to REDRAM. The total cloud mass, TM, comes from the quadratic fits to the mass loading curve, Figure 2.

IV. SAMPLE CALCULATIONS

REDRAM was used to compute the cloud particle mass and radioactivity levels associated with a one megaton nuclear burst. Following is a list of initial conditions for these sample calculations.

Weapon Yield: 1 megaton
Burst Height: 0 (surface burst)
Mass Fraction Per Particle Size = 0.03
Fission Fraction: 0.5
Total Mass Lofted: 0.33 megatons
Particle Mass Density : 2.6 grams per cubic centimeter
Latitude and Longitude of Burst Point: 40N, 100W
Lateral Spatial Resolution = 0.05 degrees
Wind Spectral Coefficients: 16 July 1981, 1200Z

Figures 5 and 6 show cloud mass density contours at 8 and 10 hours after burst. These sequential slices of cloud clearly illustrate the effects of variable winds translating and shearing the cloud. Figures 7 and 8 illustrate the cloud's axis at the same two times. Variable wind effects are again evident, as is the cloud's general motion downwind. Trace particles have also fallen to lower altitudes.

REDRAM was also used to compute the airborne dust mass densities produced by 50 simultaneous one megaton bursts. The calculations simulated a hypothetical attack on a missile field in the north central United States. Single burst calculations were linearly superimposed to estimate the multiple burst environments. Reference 4 describes this REDRAM application for reentry vehicle fratricide studies.

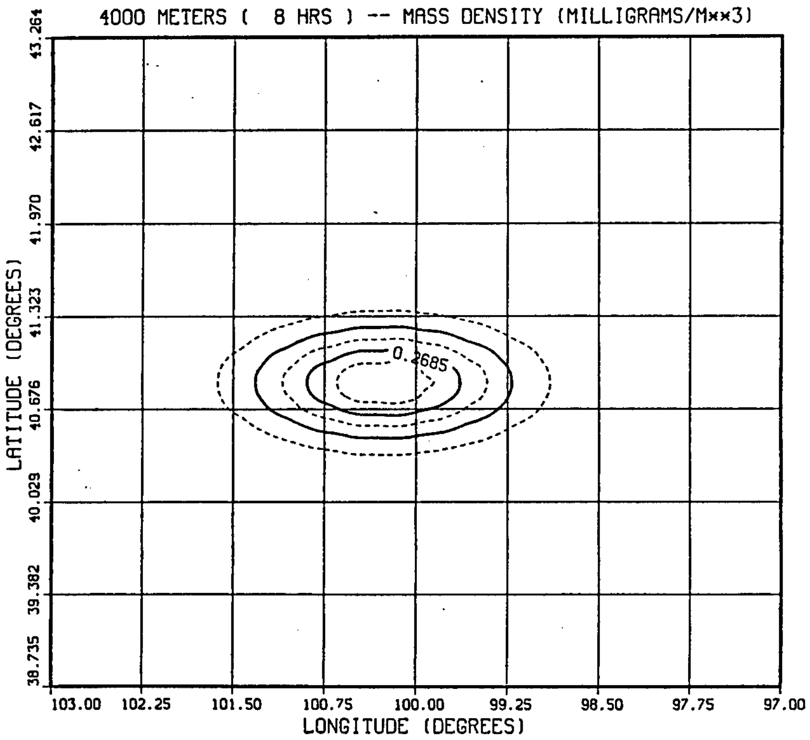


Figure 5. Cloud Density Contours, 8 hours

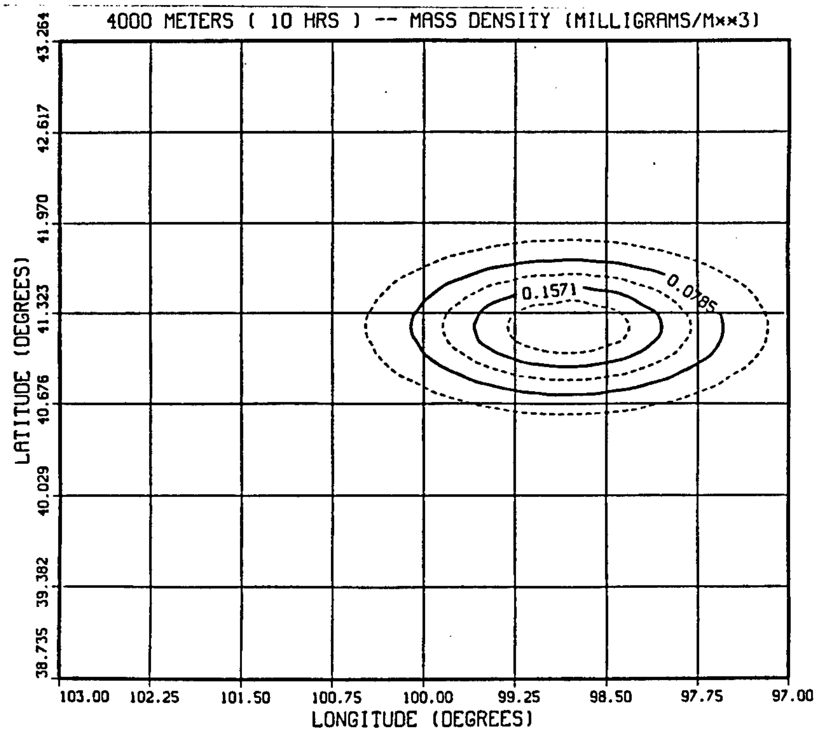


Figure 6. Cloud Density Contours, 10 Hours

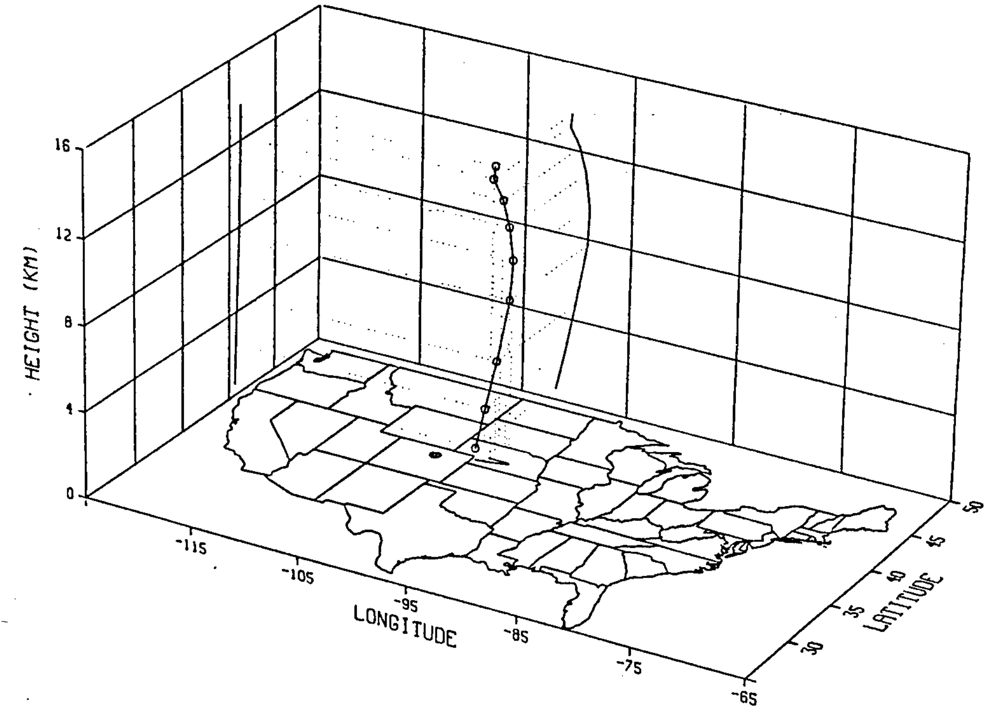


Figure 7. Cloud Axis at 8 Hours

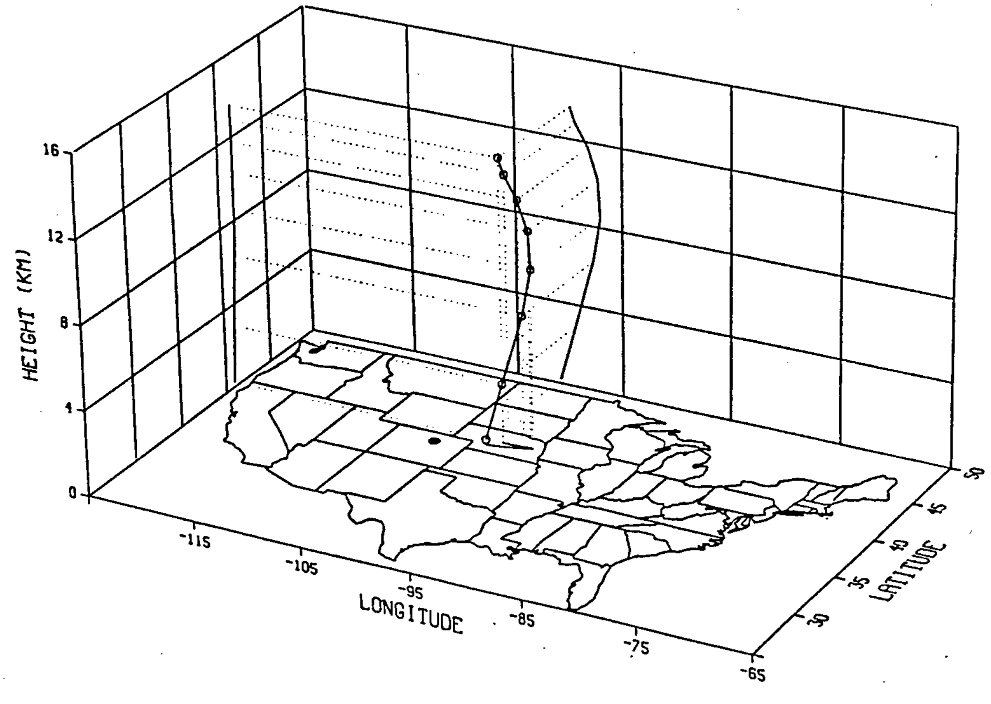


Figure 8. Cloud Axis at 10 Hours

V. VALIDATION SUMMARY

Since nuclear cloud simulation requires so much estimation and modeling with so little unambiguous data, a significant portion of REDRAM development work was spent on validation exercises. From the beginning, code development philosophy was to use the best available empirical models. This section briefly summarizes the results of three different validation exercises. REDRAM was intended for late time environment calculations to support survivability assessments of advanced strategic aircraft. Accordingly, much emphasis was placed on development of the capability to transport the clouds realistically, with variable winds, for long times. Validation studies of the new spectral wind transport methods were performed with two recent, highly reliable data sources and a hydrocode calculation.

First, the spectral wind transport method was used to compute the time-varying position of the ash cloud lofted by the 18 May 1980 eruption of the Mount St. Helens volcano. That comparison confirmed that the basic approach of moving a gravity-sorted particle stack in a Lagrangian reference frame can replicate the motion of a real cloud in the atmosphere with surprisingly good fidelity (9; 11).

Second, REDRAM was adapted to compute the time-varying position and content of the dust cloud created by the DIRECT COURSE high explosive (HE) test. DIRECT COURSE was a 600 ton elevated spherical charge that was detonated at White Sands Missile Range, New Mexico on 26 October 1983. The cloud was tracked and dust measurements were taken by an instrumented aircraft at a variety of altitudes. The REDRAM code, with the HE cloud height and lateral cloud spread substituted for the nuclear cloud correlation was exercised to compute cloud position and airborne mass densities (9; 17) at times that corresponded to sampling aircraft passes. A particle size distribution was developed from ground core sample data and used in REDRAM to compute specific mass density values. Trace particle sizes were selected to correspond to size bins in the aircraft sampling instrumentation, and results were path integrated for a direct comparison with aircraft instrumentation output. The DIRECT COURSE cloud position was accurately computed by REDRAM with spectral coefficients for 26 October 1983 supplied by the National Meteorological Center. The cloud mass densities also compared favorably with the aircraft sample data. REDRAM histograms of mass fraction per size range as a function of particle size agreed with aircraft data best when samples were taken at high enough altitudes to preclude orographic effects on the wind field. Reference 17 contains a complete summary of the REDRAM validation exercise with DIRECT COURSE data. Generally, that effort confirmed the quality of REDRAM's spectral wind transport method and produced quantitative evidence that airborne dust mass levels can be estimated accurately.

Third, REDRAM results were compared to calculations made with the Defense Nuclear Agency's DICE (Dirt Implicit Code Eulerian) hydrocode (21). DICE is the agency's baseline code for simulating details of cloud formation and growth. REDRAM results were in good agreement with the more sophisticated and detailed DICE data. For example, Figure 9 illustrates the similar contours of 10E-8 grams per cubic centimeter particle mass density computed by REDRAM and DICE. A more detailed description of the REDRAM-DICE comparison is contained in Reference 18.

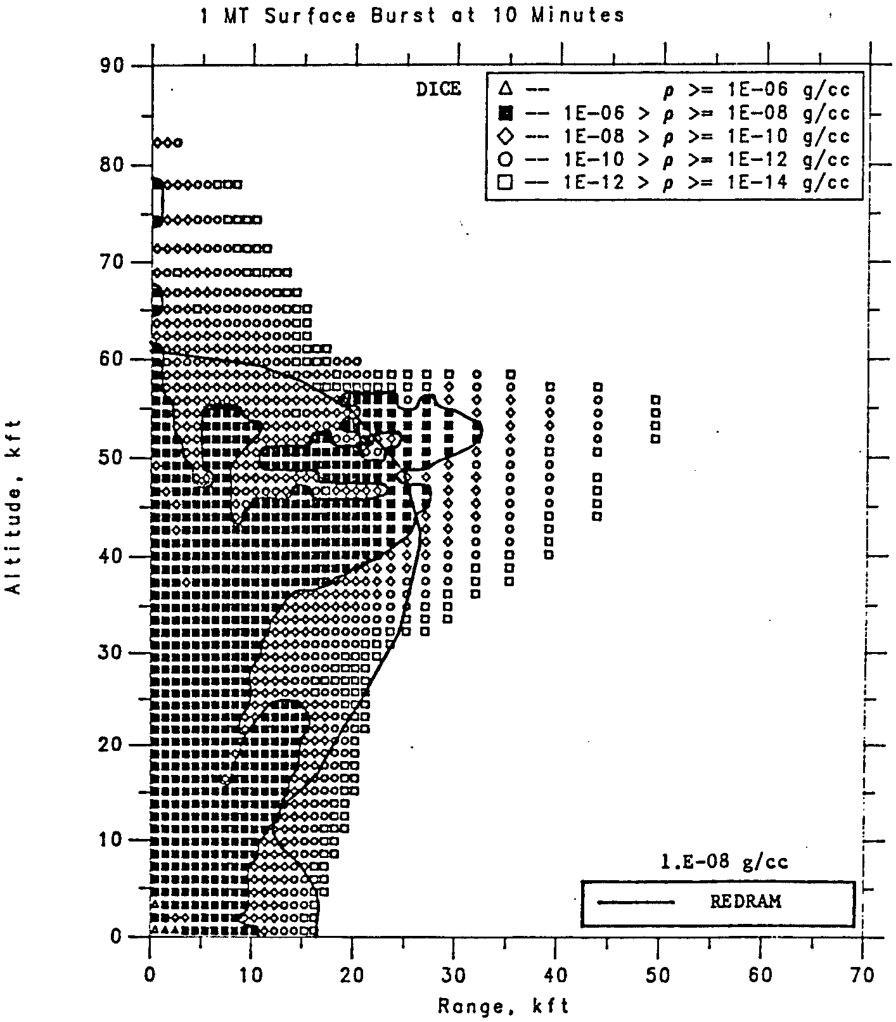


Figure 9. REDRAM - DICE Cloud Comparison

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