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IRCREW DOSE AND ENGINE DUST INGESTION
FROM NUCLEAR CLOUD PENETRATION

THESIS

IT/GNE/PH/85M-4
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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
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by

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Preface

This independent study began as an effort to perform a more detailed, more realistic, analysis of the factors contributing to aircrew radiation dose from a descending nuclear cloud. Military planners are interested in this problem both for strategic and command and control aircraft. Recent exposure of aircraft to volcanic dust clouds has also generated interest in predicting the dust mass characteristics of nuclear clouds. The dust as well as the radiation in a nuclear cloud will contribute to equipment degradation. Accordingly, this study was extended to include calculations of dust ingestion by the aircraft as well as dose to the aircrew.

This study is based on the AFIT Fallout Smear Code as modified by Hickman (Ref 10) and Kling (Ref 16) to allow airborne dose rather than ground dose to be determined.

The nuclear cloud model developed by this study allows various activity size distributions to be used. The distributions are affected by fractionation and target and weapon characteristics. The distributions are converted to 100 discrete equal activity groups, and each group's initial vertical and lateral locations in the nuclear cloud are determined by fits to an initial cloud computed by the DELFIC fallout code. Each group is then tracked as it falls using McDonald-Davies fall mechanics and as it expands laterally using a model suggested by the WSEG-10 fallout code.

I would like to acknowledge my gratitude to Dr. Charles J. Bridgman for help during this research. I am also indebted to my wife, Ceecy, for the patience and love given during this work.

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Abstract

This study evaluates the threat to aircraft and aircrew members from the dust and radioactivity in a cloud generated by nuclear surface bursts.

A model of the nuclear cloud is generated, using any number and type of weapons and any desired dust size distribution. The cloud is propagated through the atmosphere for a given time, then penetrated by an aircraft. The activity density in the cloud is converted to dose to the crew for a given path through the cloud. Radiation shielding and dust filters are included in the calculations. Alternatively, the cloud dust mass density can be converted to mass trapped in a filter or the cabin: or to the dust mass that has entered the engine.

Methods for determining particle size and altitude distributions are presented. The ionizing dose to the crewmember is computed for both sky-shine and the dust trapped in the cabin during cloud passage. A method of computing the shielding power of the crew compartment against sky-shine is presented. Given the air flow rate into a filter or engine, the mass of ingested dust is found.

The nuclear cloud and aircraft models developed by this study are incorporated in a computer code oriented toward operational use. A significant feature of the code includes the ability to easily change the scenario with menu driven options.

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I. Introduction

Background

Defense planners have expressed growing concern over the radiation exposure to strategic and Airborne Command Post aircraft in the event of a massive nuclear strike on the United States. Such aircraft may be required to penetrate nuclear clouds in the course of their wartime missions. A realistic estimate of the radiation dose to the aircrew penetrating the cloud is needed. In addition, recent experience with aircraft losing power while flying through volcanic ash clouds (Ref 13) has generated interest in determining the effects of dust ingestion on aircraft engines. Currently, experimenters are attempting to determine the tolerance of engines to dust ingestion (Ref 14). A realistic estimate of dust densities in a nuclear cloud is needed also to relate engine dust tolerance to the survivability of the aircraft.

Aircraft penetration of radioactive dust clouds is hazardous in at least four ways. First, the aircrew is exposed to ionizing radiation from the cloud through the aircraft's skin and by dust trapped in the cabin. Second, the aircrew may ingest or come in contact with the radioactive particles. Third, electronic equipment could malfunction if the ionizing dose rate is high enough. Fourth, if the dust density is high enough the aircraft's engines could fail or be degraded by ingestion of the dust particles. This study focuses on the first and last hazards. The second hazard can be nearly eliminated if the crew wears normal equipment to prevent exposure of bare skin and uses oxygen masks to preclude inhalation of particles. An estimate of the dose to electronic equipment can be made by converting tissue dose to rad(Si).

Problem

No useable data on previous flights through radioactive clouds could be found (Ref 28, 29).[1] The problem addressed in this study is to determine the doses to aircrews for different size distributions of nuclear cloud dust particles and for different aircraft. For comparison purposes, the baseline case will be a one megaton burst, fission fraction of 0.5, DELFIC (Defense Land Fallout Information Code) default particle size distribution, a cross track wind shear of 1 (km/hr)/km, an 8-hour mission duration after cloud penetration, and a KC-135 aircraft.

The computer program developed for this study finds 100 equal activity-size groups for a given particle size distribution. The distribution is a function of the mean radius (rm) and standard deviation of the mean radius (σ_{rm}). From the yield, the initial altitude distribution of the particles is determined: then the cloud is allowed to fall for a specified time. This allows the activity density at any altitude to be computed. Cabin dose, caused by the ingestion of particles at the aircraft's altitude, and sky-shine dose from the distributed cloud are computed from the activity density.

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[1] Manned B-29 in Operation Snapper (1952 surface burst) and F-80 drones in Operation Upshot-Knothole (1956 airbursts).

The dust mass density of the cloud is determined by the same method, if the equal activity-size groups are replaced by equal mass-size groups. The mass of dust trapped in a filter or passed through an engine can be found from the dust mass density.

Scope

This study highlights modeling of the nuclear cloud and aircraft likely to be exposed to the cloud. The initial nuclear cloud model is based on the AFIT Fallout Smear model (Ref 1). Changes to the model include finding new terms for the cloud horizontal distribution σ_0 and the vertical normal distribution σ_z at stabilization time. The new terms are polynomials least-square fit to DELFIC predictions for σ_0 and σ_z at cloud stabilization time. The horizontal expansion model of the cloud for later times is taken from the AFIT Smear Model as modified by Bridgman and Hickman (Ref 2).

The aircraft model uses a worst-case approximation for cabin dose, in that all of the dust that enters the cabin is assumed to stay there. However, allowance is made for particle removal from the air before entry into the pressurized cabin. This removal allows the effectiveness of known or proposed engine and filter designs to be considered. The same method is used to compute the mass of dust ingested by an engine or trapped in a filter.

A method of finding a realistic shielding factor for sky-shine radiation is developed to replace Kling's (Ref 10) approximation of a single 0.063 inch thick aluminum skin. This model is detailed enough so that the sky-shine dose can be considered a realistic estimate rather than a worst-case limit.

Speed, altitude, and payload for each aircraft used in this study were selected to reflect typical wartime missions. These parameters can be varied to allow for different missions or changed entirely to represent different aircraft.

Although other effects may be present, only tissue dose from external gamma radiation and dust ingestion in engines and filters are addressed in this report.

The crew dose and dust ingestion information provided by this study will allow planners to determine the threat to the aircraft if location, time of burst, yield and wind profiles are known. The aircraft's planned flight path or altitude can be changed to reduce the threat if required. The accompanying computer code also allows research into the effects of different particle size distributions, aircraft configurations, and types of filter.

Assumptions

Several explicit assumptions are made in this report. They are:

1. The initial conditions for the stabilized cloud are those for DELFIC as shown in Appendix A.
2. The activity density of the nuclear cloud does not vary significantly within five gamma mean free paths of the aircraft.
3. All of the gamma-rays have energies of 1 MeV.
4. All of the dust that enters the cabin is trapped and there is no internal shielding from the dust except by the air in the cabin.
5. The shielding factor for sky-shine (external) radiation can be

found by using an 'average' mass integral taken directly from the mass and surface area of the cabin and that all of the cabin mass has the gamma-ray cross section of aluminum.

These assumptions are discussed in more detail later in the text.

Approach

The development of the nuclear cloud model and a summary of the results for the baseline scenario in terms of activity density in Curies per vertical meter versus altitude at various times are presented in Chapter II. Also presented are results for larger and smaller particle size distributions. Nuclear clouds composed of more than one burst are examined.

The mathematical development for the external dose from both trapped cabin dust activity and sky-shine is presented in Chapter III. The results for a single, one megaton ground burst are then presented in tabular form. These tables include the doses received and the particle contributing the most activity at the specified altitude for several different aircraft.

Treatments of nuclear cloud dust density, cabin air filters, and engine dust ingestion are in Chapter IV. Results for the same aircraft and nuclear clouds used in Chapter III are given.

Conclusions and recommendations are in Chapter V.

II. Cloud Model

Background

This chapter relies heavily on data computed by DELFIC. A brief description of this code will be given to clarify later discussion.

DELFIC is recognized as a benchmark against which other fallout codes are measured: however, its size, complexity and expense to run prevent easy use. DELFIC is constructed as a set of sequential modules. Here we are concerned only with the predicted initial, stabilized nuclear cloud. The modules of interest are Fireball, Cloud Rise, Interface, and Diffusive Transport. The cloud parameters at the end of Cloud Rise are printed at the beginning of the Diffusive Transport module.

A near surface nuclear burst generates a fireball that vaporizes a significant quantity of material from the target area. This vaporized soil mixes with vaporized weapon material, such as the weapon case, unburned fuel, and fission products, which are highly radioactive. The Fireball module models this phase of the burst. A default particle size distribution representing Nevada soil is built into DELFIC.

As the cloud rises, the vapors cool and the radioactive material is mixed in with condensed soil material. Fractionation occurs as materials condense at different temperatures: some of the radioactive material will be distributed throughout the volume while radioactive elements that melt at lower temperatures will condense on the surface of the particles. The number, size, and fractionation of the particles will be determined by the type of weapon and the type of soil in the target area. The fractionation predicted by DELFIC along with the default particle number-size distribution produces the default activity-size distribution used in DELFIC. This phase is described by the Cloud Rise module.

Examination of DELFIC output for this study shows that cloud stabilization occurs in two steps. In the first step, vertical stabilization takes place. This happens when all particles have reached their maximum altitudes and the largest ones begin to fall back. This occurs from 3 to 6 minutes after the burst. The radius of the cloud that DELFIC predicts at this point is the value that Ruotanen (Ref 25) used to correct the standard deviation of the initial cloud radius, σ_0, for the WSEG model and is the value this study will use to determine σ_0.

In the second step, the cloud does not rise any further but continues to expand rapidly in the horizontal direction. This is due to the momentum of the toroidal circulation which began during step one. The end of this second step is what is usually referred to as the stabilized cloud. The second step ends at 5 to 15 minutes after the nuclear burst.

The DELFIC Interface module couples the stabilized cloud to the winds over the target and allows the cloud particles to be blown downwind in the Diffusive Transport module. Further sections of the code determine the location, activity, and dose of the fallout on the ground. In this study, we will use only the initial stabilized cloud. The parameters for this initial cloud are printed at the beginning of the Diffusive Transport section of a typical DELFIC printout.

DELFIC is a disc tosser code, so called because it subdivides the particles in a cloud into monosize groups, models each group as a disc, then tracks each disc as it falls and is blown downwind. DELFIC is normally set to track 100 discs. Each disc is in turn composed of 20 wafers, each containing 5% of the monosize particle group. The radii and the altitudes for the top and bottom of each wafer are printed in the output. The DELFIC data used in this study are reproduced in Appendix A.

The cloud model used in this study will be presented in the following manner.

First, particle size distributions will be discussed and the distributions used in this study will be presented. The distributions are converted into 100 equal activity-size and 100 equal mass-size groups.

Second, the model of the DELFIC initial cloud will be presented. This includes the stabilization time and radius of the cloud. The rigid DELFIC discs are converted to the 'smeared' discs of the AFIT Fallout Smear model. The determination of initial altitude and vertical distribution of each particle size group are then considered.

Third, a description of the activity distribution in the cloud will be developed.

Fourth, cloud growth, cloud fall, and smearing by wind will discussed.

Finally, clouds consisting of multiple bursts will be considered.

Particle Size Distributions

Dust particles found in nuclear burst clouds have particle size distributions that have been found to fit the cumulative lognormal function as described in Bridgman and Bigelow (Ref 2). This function is given as:

$$F(r) = \frac{1}{\sqrt{2\pi}\ \beta r} \exp\left\{ -\frac{1}{2} \left[\frac{\ln(rm) - \alpha_n}{\beta} \right]^2 \right\} \quad [1/m] \qquad (\ 1\ )$$

where

$\alpha_0 = \ln(rm)$

$\beta = \ln(\sigma_{rm})$

$\alpha_n = \alpha_0 + n\beta^2$

A useful feature of cumulative lognormal functions is that different moments of the expression (represented by n) are also cumulative lognormal with the same slope. The value of n in this equation determines the type of distribution. A value of n = 3 will create a volume distribution, and, if the particle density is uniform, a mass distribution. If n = 2 then Eq (1) will describe a surface area distribution. When n = 0, the original number-size distribution results.

The values in Table I are number-size distributions from Bridgman (Ref 3). Except for DELFIC they were computed from the experimentally determined cumulative lognormal activity-size distributions by using the 2.5 moment approximation suggested by Freiling, which is explained below.

Fractionation effects will cause refractory radionuclides to be distributed throughout the volume of the particles, while volatile nuclides will be deposited on the surface. The ratio of volume deposition to surface deposition is difficult to determine experimentally or theoretically, but it must lie at a point between n = 2 (all surface) and n = 3 (all volume). As an approximation, Freiling suggested n = 2.5.

The activity-size distribution of a nuclear cloud is generally found directly by experiment. If that activity-size distribution is lognormal, then a lognormal number-size distribution can be computed, using Freiling's n = 2.5. The number-size distributions in Table I were all computed in this manner except for the DELFIC default distribution.

DELFIC activity-size distributions are found by DELFIC computing the fractionation of each decay chain of the fission products. Bridgman and Bigelow (Ref 2) found that the DELFIC activity-size distribution which results from this chain by chain calculation can be represented by the sum of two cumulative lognormal distributions:

$$F(r) = Fv\ clnf(n=3) + (1 - Fv)\ clnf(n=2) \qquad (2)$$

where the volume fraction Fv equals 0.68 and clnf(n) is the cumulative log normal function in Eq (1). This study uses Eq (2) to compute the DELFIC activity-size distribution. DELFIC is the only distribution in Table I to use this method.

TABLE I

Particle Number-size Distributions

NAME	rm(μm)	σ_{rm}	SOURCE	REMARKS
TTAPS	.25	2	Turco	no tail
NRDL-N61	.00039	7.24	Freiling	Nevada soil
NRDL-C61	.0103	5.38	Freiling	Coral
NRDL-D	.01	5.42	Polan	Nevada Dynamic
DELFIC	.204	4	Polan	Fv = .68
USWB-HI	3.48	2.72	Polan	Hicap
USWB-LO	3.84	3	Polan	Locap
FORD-T	5.98	2.23	Polan	
RANDWSEG	10.6	2	Polan	
NRDL-SII	27.1	1.48	Polan	Saltwater II
NRDL-SI	36.8	1.51	Polan	Saltwater I
TOR-C	50.6	1.36	Polan	Coral

DELFIC was selected for the baseline case. NRDL-N61 and TOR-C were selected because they are extreme examples of 'small' and 'large' size distributions. Figures (1) and (2) plot the cumulative activity-size and mass-size fractions versus radius of the particle. Tables II through VII list the 100 equal activity and equal mass particle groups for these three distributions. They were generated by the program in Appendix C using Eq (1).

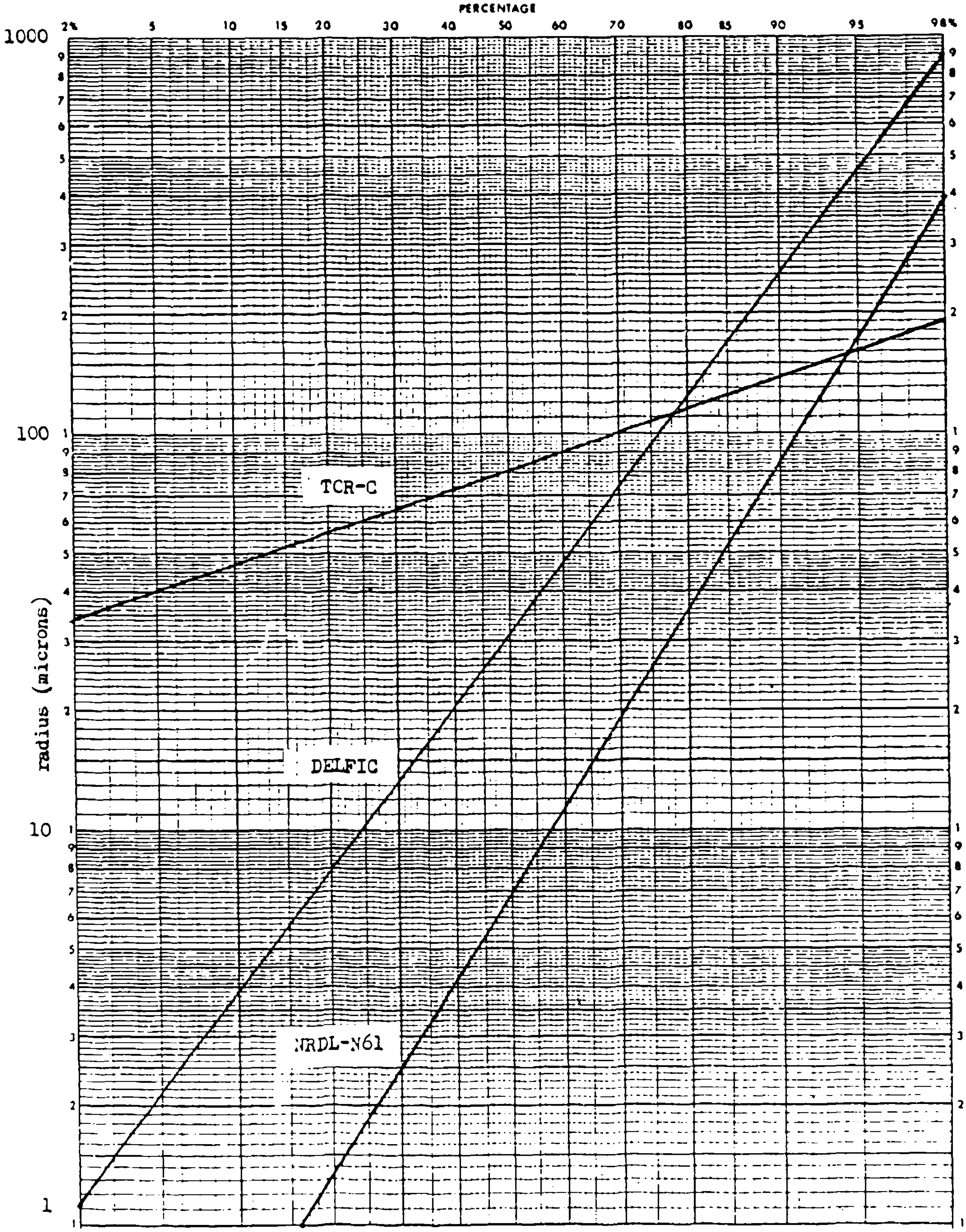

Figure 1. Cumulative Activity-size Fractions used in this study

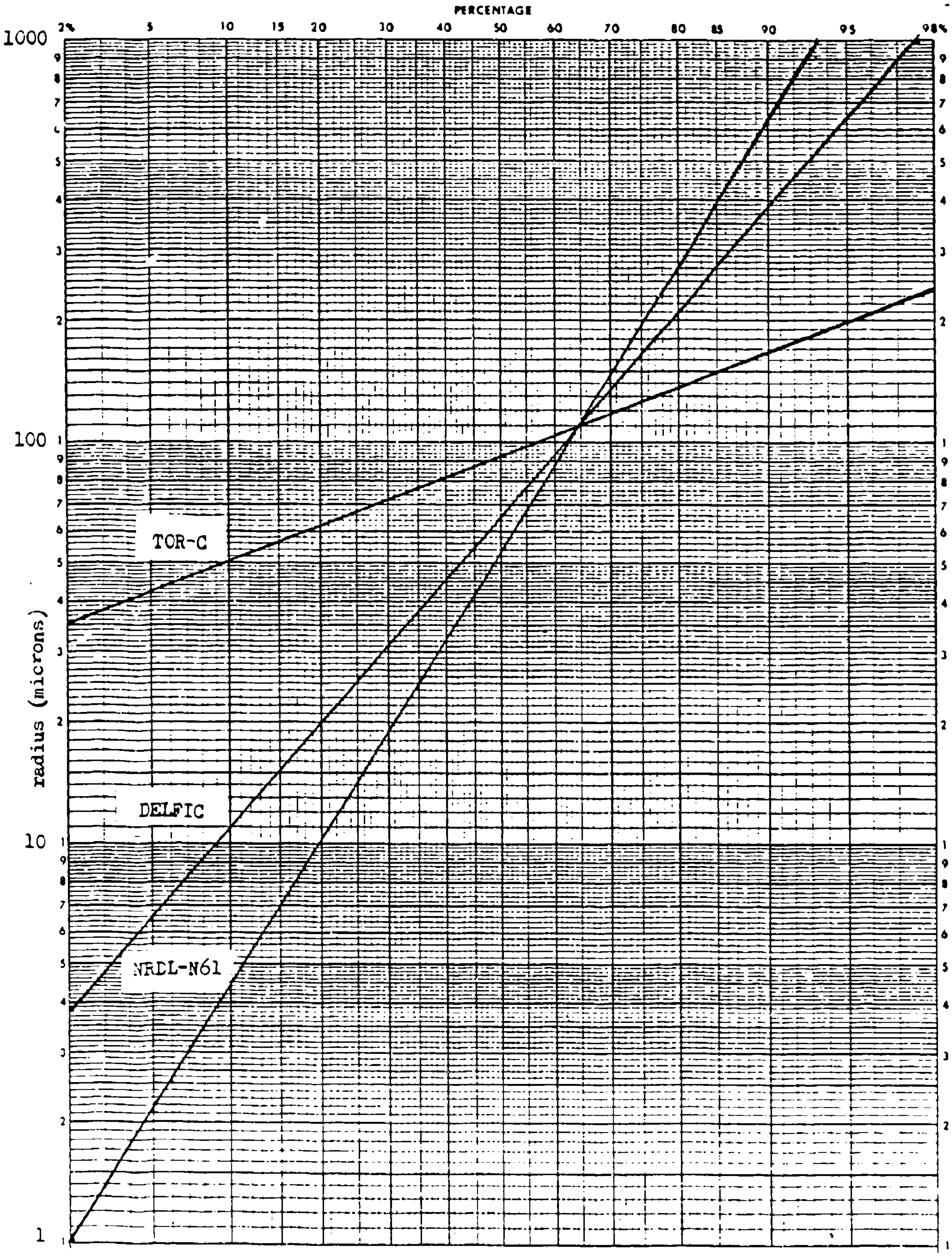

Figure 2. Cumulative Mass-size Fractions used in this study

TABLE II

DELFIC Mean radii in microns of the 100 equal-activity groups
computed from rm = .204: σ_{rm} = 4: Fv = .68

.473	.904	1.27	1.62	1.97
2.32	2.68	3.04	3.41	3.80
4.19	4.60	5.02	5.45	5.89
6.35	6.83	7.32	7.82	8.35
8.89	9.45	10.0	10.6	11.2
11.8	12.5	13.2	13.9	14.6
15.4	16.1	17.0	17.8	18.7
19.5	20.5	21.4	22.4	23.5
24.5	25.6	26.8	28.0	29.2
30.5	31.8	33.2	34.7	36.2
37.7	39.4	41.1	42.8	44.7
46.6	48.6	50.7	52.9	55.1
57.5	60.1	62.7	65.5	68.4
71.4	74.7	78.1	81.7	85.5
89.5	93.8	98.4	103.	108.
113.	119.	126.	133.	140.
148.	157.	167.	177.	189.
202.	216.	232.	251.	272.
297.	326.	361.	403.	457.
529.	629.	782.	1064.	1917.

TABLE III

DELFIC mean radii in microns of the 100 equal-mass groups
computed from rm = .204: σ_{rm} = 4: Fv = .68

1.83	3.21	4.30	5.28	6.20
7.10	7.97	8.84	9.71	10.5
11.4	12.3	13.2	14.1	15.0
15.9	16.8	17.8	18.7	19.7
20.7	21.7	22.8	23.9	24.9
26.1	27.2	28.4	29.6	30.8
32.0	33.3	34.7	36.0	37.4
38.8	40.3	41.8	43.4	44.9
46.6	48.3	50.0	51.8	53.7
55.6	57.6	59.6	61.7	63.9
66.2	68.5	71.0	73.5	76.1
78.8	81.6	84.6	87.6	90.8
94.1	97.6	101.	105.	108.
113.	117.	122.	126.	132.
137.	143.	149.	155.	162.
169.	177.	185.	194.	203.
214.	225.	237.	251.	265.
282.	300.	320.	343.	370.
400.	436.	478.	531.	596.
682.	802.	985.	1318.	2311.

TABLE IV

NRDL-N61 mean radii in microns of the 100 equal-activity groups
computed from rm = .00039: $\sigma_{rm} = 7.24$

.0432	.095	.145	.194	.245
.296	.350	.406	.464	.524
.587	.652	.720	.790	.864
.940	1.02	1.10	1.18	1.27
1.37	1.47	1.57	1.67	1.78
1.90	2.02	2.14	2.27	2.41
2.55	2.70	2.85	3.01	3.18
3.36	3.54	3.73	3.93	4.14
4.35	4.58	4.82	5.07	5.33
5.61	5.89	6.19	6.51	6.84
7.19	7.55	7.94	8.34	8.77
9.22	9.70	10.2	10.7	11.2
11.8	12.5	13.1	13.8	14.6
15.4	16.3	17.2	18.2	19.2
20.3	21.6	22.9	24.3	25.8
27.5	29.3	31.3	33.4	35.8
38.4	41.3	44.6	48.2	52.3
57.0	62.3	68.4	75.5	83.9
94.0	106.	121.	140.	166.
201.	253.	340.	517.	1161.

TABLE V

NRDL-N61 mean radii in microns of the 100 equal-mass groups
computed from rm = .00039: $\sigma_{rm} = 7.24$

.303	.678	1.02	1.37	1.73
2.10	2.48	2.87	3.29	3.71
4.16	4.62	5.10	5.60	6.12
6.66	7.23	7.82	8.43	9.07
9.74	10.4	11.1	11.9	12.6
13.5	14.3	15.2	16.1	17.1
18.1	19.1	20.2	21.4	22.5
23.8	25.1	26.4	27.8	29.3
30.9	32.5	34.2	35.9	37.8
39.7	41.8	43.9	46.1	48.5
51.0	53.6	56.3	59.2	62.2
65.4	68.8	72.3	76.1	80.1
84.3	88.7	93.5	98.5	103.
109.	115.	122.	129.	136.
144.	153.	162.	172.	183.
195.	208.	222.	237.	254.
272.	293.	316.	342.	371.
404.	441.	485.	535.	595.
666.	752.	860.	996.	1177.
1427.	1797.	2409.	3651.	8140.

TABLE VI

TOR-C mean radii in microns of the 100 equal-activity groups
computed from rm = 50.6: σ_{rm} = 1.36

29.0	32.8	35.0	36.7	38.0
39.2	40.2	41.1	42.0	42.8
43.5	44.3	44.9	45.6	46.2
46.9	47.5	48.0	48.6	49.2
49.7	50.2	50.8	51.3	51.8
52.3	52.8	53.3	53.8	54.3
54.7	55.2	55.7	56.2	56.6
57.1	57.6	58.1	58.5	59.0
59.5	59.9	60.4	60.9	61.4
61.9	62.3	62.8	63.3	63.8
64.3	64.8	65.3	65.8	66.3
66.8	67.3	67.9	68.4	69.0
69.5	70.1	70.6	71.2	71.8
72.4	73.0	73.6	74.3	74.9
75.6	76.3	77.0	77.7	78.4
79.2	80.0	80.8	81.6	82.5
83.4	84.4	85.4	86.4	87.5
88.7	89.9	91.2	92.7	94.2
95.8	97.7	99.7	102.	104.
107.	111.	117.	124.	141.

TABLE VII

TOR-C mean radii in microns of the 100 equal-mass groups
computed from rm = 50.6: σ_{rm} = 1.36

30.4	34.4	36.7	38.4	39.8
41.1	42.1	43.1	44.0	44.9
45.7	46.4	47.1	47.8	48.5
49.1	49.8	50.4	51.0	51.5
52.1	52.7	53.2	53.8	54.3
54.8	55.3	55.9	56.4	56.9
57.4	57.9	58.4	58.9	59.4
59.9	60.4	60.9	61.4	61.9
62.4	62.9	63.3	63.8	64.3
64.8	65.4	65.9	66.4	66.9
67.4	67.9	68.5	69.0	69.5
70.1	70.6	71.2	71.7	72.3
72.9	73.5	74.1	74.7	75.3
75.9	76.6	77.2	77.9	78.6
79.3	80.0	80.7	81.5	82.2
83.0	83.9	84.7	85.6	86.5
87.5	88.5	89.5	90.6	91.8
93.0	94.3	95.7	97.1	98.7
100.	102.	104.	107.	109.
113.	117.	122.	130.	148.

Initial Stabilized Cloud

The initial cloud is modeled as an upright circular cylinder that resembles a tomato soup can, as in Figure 3. The DELFIC data for stabilization time and horizontal cloud radius as a function of yield were least-squares fit to a polynomial in ln(Y) for this study. The data taken from DELFIC to generate these fits are reproduced in Appendix A. The expressions to fit the DELFIC data are:

$$T_{vs} = 385.295 - 99.1476\,(\ln Y) + 64.6314\,(\ln Y)^2 - 8.21379\,(\ln Y)^3 + .323598\,(\ln Y)^4 \quad [s] \qquad (3)$$

where T_{vs} is vertical stabilization time in seconds and Y is yield in kilotons: and

$$S_0 = 868.277 - 632.399\,\ln Y + 625.132\,(\ln Y)^2 - 112.586\,(\ln Y)^3 + 7.16648\,(\ln Y)^4 \quad [m] \qquad (4)$$

where S_0 is the cloud radius in meters at vertical stabilization time. This radius is assumed here to represent a 2σ distribution so that when finding σ_x and σ_y using the formulae for toroidal growth (discussed later in this section), the initial cloud horizontal distribution σ_0 will be

$$\sigma_0 = \frac{S_0}{2} \qquad (5)$$

The expressions for the time since burst and cloud radius at the end of horizontal stabilization step are given in Appendix A.

In this study, no DELFIC information for times later than vertical cloud stabilization is used.

Hopkins (Ref 11) developed a fit for the vertical distribution of the cloud. Hopkins ran DELFIC with yields from 1 kiloton to 15 megatons and fitted particle size versus altitude to a linear function for each yield. The altitude used for this was the average center altitude of all of the wafers for a given particle size group. The slopes and intercepts were then fit to polynomials in logarithmic yield so that

$$z_0^{\,i} = I_m + 2\ rm^i\ S_m \quad [m] \qquad (6)$$

where rm^i is the mean radius of the particle size group in microns, $z_0^{\,i}$ is the initial center altitude of each particle group distribution in meters, I_m is the (zero-radius) intercept in meters, and S_m is the slope in meters (of altitude) per micron (of radius). Hopkins found:

$$I_m = \mathrm{EXP}\{7.889 + 0.34\ (\ln Y) + .001226\ (\ln Y)^2 - .005227\ (\ln Y)^3 + .000417\ (\ln Y)^4\} \qquad (7)$$

$$S_m = -\mathrm{EXP}\{1.54 - .01197\ (\ln Y) + .03636\ (\ln Y)^2 - 0.0041\ (\ln Y)^3 + .0001965\ (\ln Y)^4\} \qquad (8)$$

where Y is the yield in kilotons.

Hopkins developed the above equations using the DELFIC default particle size distribution. Many DELFIC runs were made with a variety of particle size distributions for this study. It was determined that Hopkins' size versus altitude function does not change when different size distributions are used. This is discussed further in Appendix A.

Bridgman and Hickman (Ref 2) incorporated Hopkins' vertical cloud distribution into the AFIT Smear Code fallout model, and further assumed that the vertical distribution of each size group was gaussian with

$$\sigma_z^{\,i} = .18 \; z_0^{\,i} \qquad [\mathrm{m}] \qquad (\;9\;)$$

i.e. the higher the particle, the larger its σ_z. Study of DELFIC data has shown that this approximation is valid only for yields above 1 megaton. Particles lofted by megaton size yields have a nearly constant σ_z at all altitudes, while sub megaton yields show a decreasing σ_z with increasing altitude. The DELFIC data for vertical particle distribution were incorporated in a polynomial least-squares fit to yield in a manner similar to Hopkins' fit for particle initial altitude,

$$\Delta z^i = I_d + 2 \; rm^i \; S_d \qquad [\mathrm{m}] \qquad (\;10\;)$$

where Δz^i is the predicted vertical thickness of the i^{th} monosize particle group and I_d and S_d are the intercept and slope. It was found that

$$\begin{aligned} S_d &= 7 - \mathrm{EXP}[1.78999 - .048249\,(\ln Y) + .0230248\,(\ln Y)^2 \\ &\qquad - .00225965\,(\ln Y)^3 + .000161519\,(\ln Y)^4] \qquad (\;11\;) \end{aligned}$$

$$\begin{aligned} I_d &= \mathrm{EXP}[7.03518 + .158914\,(\ln Y) + .0837539\,(\ln Y)^2 \\ &\qquad - .0155464\,(\ln Y)^3 + .000862103\,(\ln Y)^4] \qquad (\;12\;) \end{aligned}$$

The σ_z is then arbitrarily taken as

$$\sigma_z^i = \frac{1}{4} \Delta z^i \qquad [m] \qquad (13)$$

That is, Δz is assumed to be a 2σ distribution about a point midway between the top and bottom of the Δz function. Functions that independently fit particle size versus altitude for the upper and lower limits of each monosize particle group can be found in Appendix A. Hopkins' formulae Eq (7,8) are fits to the average altitude of the 20 wafer centers in each group.

Cloud Activity Distribution

The cloud takes 3 to 6 minutes to stabilize vertically at a height and diameter depending on weapon yield. The initial, stabilized, nuclear cloud is modeled as a right circular cylinder. The cylinder represents the limits of a 2σ normal distribution in the lateral dimensions and the limit of the sum of the 2σ normal distributions of the airborne particle groups in the vertical dimension. See Figure 3.

The activity in the cloud varies as a function of position and time. The vertical distribution of the different size groups is assumed to be that of DELFIC, as modeled by Hopkins. Each individual particle size group is assumed to be normally distributed both vertically and horizontally: and these spatial distributions are assumed to be independent of each other. Thus the activity density A''' at a point in the cloud is

$$A'''(x,y,z,t) = \int_0^\infty A_r'''(x,y,z,r,t)dr \qquad [Ci/m^3] \qquad (14)$$

where $A'''(x,y,z,r,t)$ is the specific activity density in

Curies/m^3-micron. The three spatial dimensions are independent, thus separable. The horizontal distributions in (x,y) are assumed to be independent of particle size r so that

$$A_r'''(x,y,z,t) = f(x,t)\ f(y,t) \int_0^\infty A_r'(z,r,t)dr \quad [\mathrm{Ci/m^3}] \quad (15)$$

where $A_r'(z,r,t)$ is the specific activity in Curies per meter of altitude per micron of radius as a function of r and time t. The normalized horizontal distributions are of the form

$$f(x,t) = \frac{1}{\sqrt{2\pi}\ \sigma_x(t)} \exp\left\{-\frac{1}{2}\left[\frac{x - x_0}{\sigma_x(t)}\right]^2\right\} \quad [1/\mathrm{m}] \quad (16)$$

$$f(y,t) = \frac{1}{\sqrt{2\pi}\ \sigma_y(t)} \exp\left\{-\frac{1}{2}\left[\frac{y - y_0}{\sigma_y(t)}\right]^2\right\} \quad [1/\mathrm{m}] \quad (17)$$

where the point x_0, y_0 is defined as the center of the cloud.

The integral in Eq (15) can be replaced by a summation over 100 discrete monosize particle groups.

$$\int_0^\infty A_r'(z,r,t)dr = \sum_{i=1}^{100} A^i\ f^i(z,t) \quad [\mathrm{Ci/m}] \quad (18)$$

where each group A^i contains 1% of the total activity at unit time and the normalized vertical activity distribution for each group is

$$f^i(z,t) = \frac{1}{\sqrt{2\pi}\ \sigma_z} \exp\left\{-\frac{1}{2}\left[\frac{z^i - z}{\sigma_z^i}\right]^2\right\} \quad [1/\mathrm{m}] \quad (19)$$

σ_x, σ_y, and σ_z will be discussed later in this chapter.

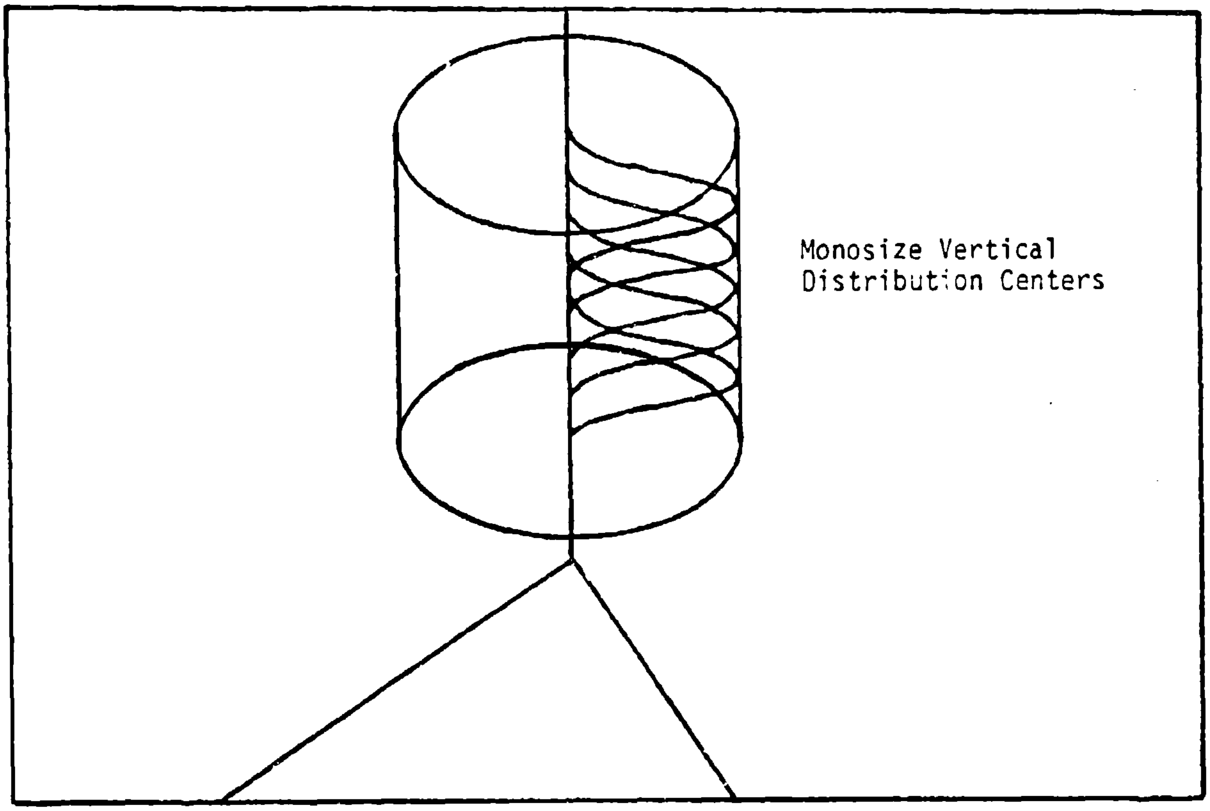

Figure 3. Initial Cloud

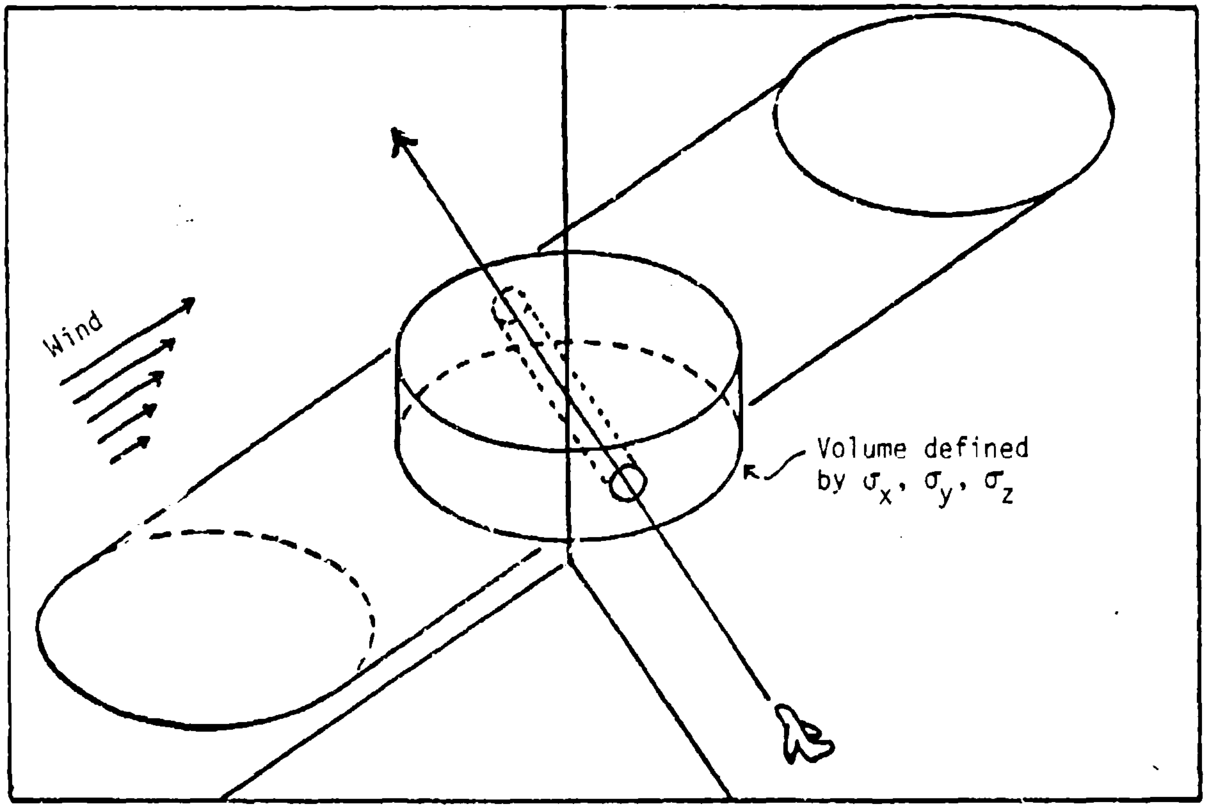

Figure 4. Late Time Cloud

Now, Eq (14) can be rewritten as

$$A'''(x,y,z,t) = f(x,t)\ f(y,t) \sum_{i=1}^{100} A^i\ f^i(z,t) \quad [\mathrm{Ci/m^3}] \qquad (20)$$

Note that this equation gives the activity density for any point in the cloud. If we set $\Delta x = x - x_0 = 0$ and $\Delta y = y - y_0 = 0$ in Eq (16,17), we have the activity at the horizontal cloud center as a function of altitude, which is the maximum activity density at any altitude.

Finally, activity is a function of time, as radioactive decay takes place. The Way-Wigner approximation is used:

$$A(t) = A_1\ t^{-1.2} \quad [\mathrm{Ci}] \qquad (21)$$

where A(t) is the total activity in Curies at a given time t in hours since burst and where A_1 is equal to 530 gamma megacuries per kiloton of fission yield at unit time (1 hour since burst) (Ref 8).

This completes our description of the initial stabilized cloud. In the next section we will consider horizontal cloud growth due to wind shear and toroidal cloud expansion, and vertical cloud growth as the particles fall to the ground.

Late Time Cloud

We define the term $\sum_{i=1}^{100} A^i\ f^i(z,t)$ in Eq (20) as f(z,t), the (total) activity per vertical meter. Values for f(z,t) used in this study are shown in Figures 6-9. These vertical activity densities can be converted to Curies/meter^3 (the activity density) by evaluating f(x,t) and f(y,t) in Eq (16,17) for Eq (20). This requires that the horizontal size of the cloud, in terms of σ_x and σ_y, be found.

DELFIC output for this study included information only on the initial cloud conditions. No attempt was made to model the cloud in time. Therefore, the toroidal growth and wind shear terms incorporated in the AFIT Fallout Smear Code for σ_x and σ_y are retained.

Wind shear is the term representing the change in wind velocity with altitude normally observed in the atmosphere. The total wind shear is composed of two components. Directional shear is due to a change of wind direction with altitude, and speed shear is due to a change of wind speed with altitude. These two factors are summed in quadrature to obtain the total shear S_t in km/hr-km.

The upright circular cylinder used to describe the initial cloud is stretched in the direction of the total wind shear (due to the difference in velocity of the top and bottom of the cloud) until the cloud resembles a sardine can from above as depicted in Figure 4.

Fallout models designed to produce ground dose, such as WSEG or the AFIT Smear model, usually employ a single constant wind (assumed to be in the x direction) for simplicity in determining the fallout hotline. For this 'average' single constant wind, the speed shear term is applied to the downwind direction and the directional shear term is applied to the transverse (crosswind) direction. The directional shear used in WSEG and AFIT models is called S_y and is given a value of 1 km/hr-km. The speed shear,

S_x, is ignored because any elongation of the cloud in the downwind direction will change the time of deposition, not the amount, of fallout. The cloud is transported downwind by the average wind velocity v_x and translated crosswind by the directional shear S_y.

Hickman (Ref 10), who developed an airborne dose model from the AFIT Smear model, and Kling (Ref 16), who refined Hickman's model, retained this interpretation of the single constant wind in their theses. In effect, the aircraft was held fixed at a point over the ground and the cloud passed it at velocity v_x equal to the aircraft cruise speed. Bridgman and Hickman (Ref 2) recognized that, for an airborne cloud penetration, the choice of a preferred coordinate system was arbitrary: relative to an aircraft penetrating the cloud, the wind could be from any direction. They arbitrarily assigned S_x equal to S_y and applied them to σ_x and σ_y respectively, as discussed later in this section.

That assumption of similar magnitudes for S_x and S_y can be improved upon. A typical wind has a speed shear of 8 to 10 km/hr-km, an order of magnitude larger than the directional shear of 1 km/hr-km proposed by WSEG.[2] This means that the cloud will be elongated much more in the downwind direction (due to speed shear)

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[2] This can be verified by watching a typical summer thunderstorm, which has dimensions similar to a nuclear cloud (for similar reasons: the energy released in a thunderstorm is the same or greater than a nuclear burst). The main shaft of the thunderstorm resembles Figure 4 when seen from the side, stretching from west to east. During the storm's mature stage, the direction and speed of the stratospheric winds can be easily visualized as they 'blow off' the top cloud layers. This upper level wind velocity can be compared to that perceived at the surface (beyond the distance that the storm's gust front reaches) to obtain a feeling for the quantities involved.

than in the crosswind direction (due to directional shear). Because this downwind elongation was ignored by Hickman and Kling, the activity densities (and dose rates) inside their cloud models can be considered too high. In the next chapter, however, we will see that elongation of the cloud in the direction of penetration (assumed by Hickman and Kling to be downwind) will not affect dose.

In this study, the motions of an aircraft are considered relative to the surrounding air, not the ground. The aircraft is allowed to penetrate the cloud at any altitude, direction, airspeed, or time after the burst. Thus speed as well as directional shear is required. Because we are concerned only with the cloud and the aircraft, we will ignore the ground and define the x axis as relative to the aircraft and in the direction of its velocity vector. Total shear will be broken down into its components relative to the aircraft direction, rather than relative to the wind direction. This is equivalent to choosing an aircraft cloud penetration angle relative to the wind direction (see Figure 5) by using the law of cosines.

These shears are defined as:

$$S_x = dV_x/dz \quad [1/\mathrm{hr}] \qquad (22)$$

$$S_y = dV_y/dz \quad [1/\mathrm{hr}] \qquad (23)$$

where S is wind shear and V is the wind velocity. The x and y coordinates are now referenced to the aircraft, where x is in the direction of the aircraft heading and y is at right angles to this.

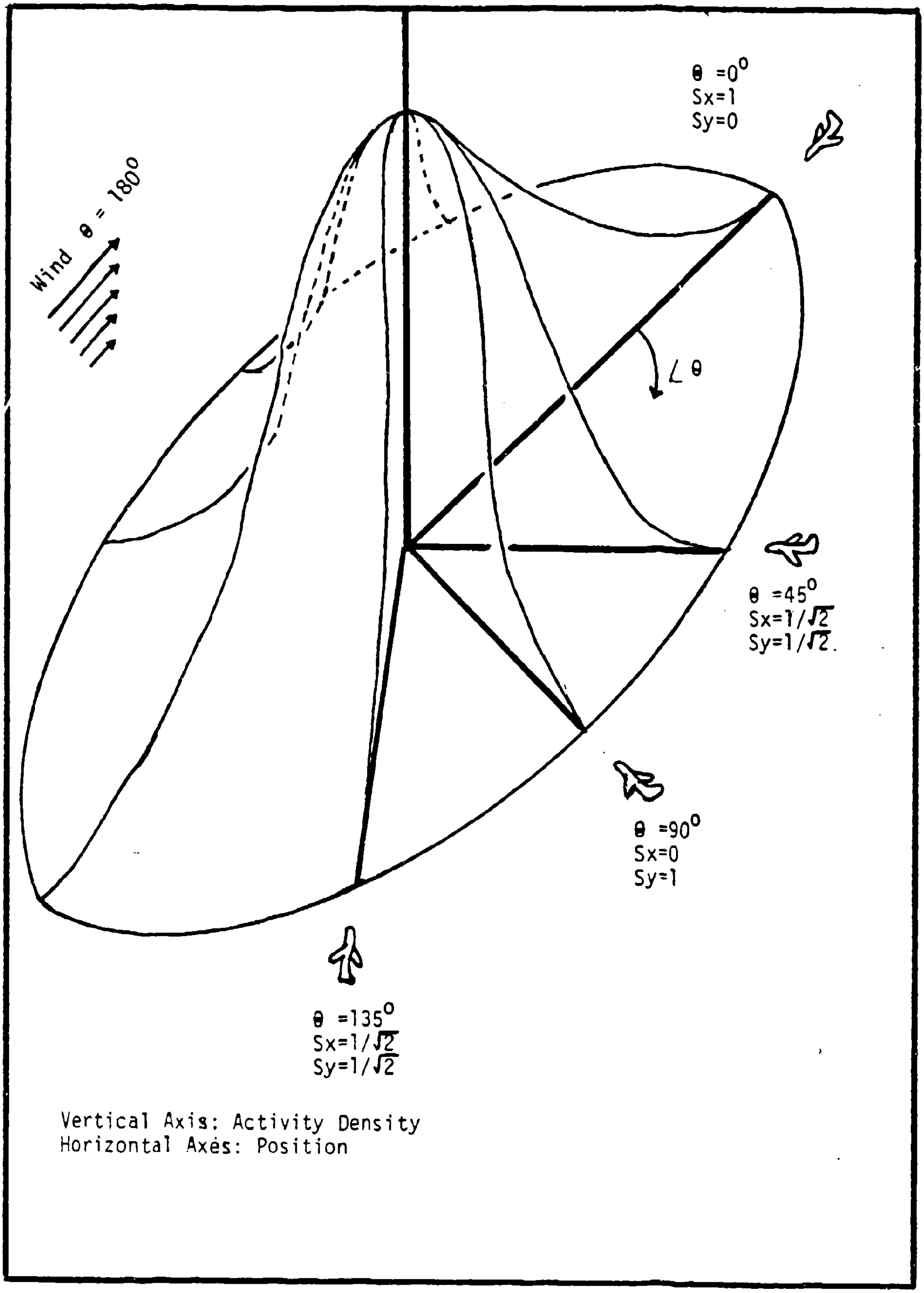

Figure 5. Penetration of Late Time Cloud

The total shear S_t is equal to the square root of the sum of $(S_x)^2$ and $(S_y)^2$. In this study, we will take $S_y = 1/\text{hr}$ and $S_x = 0/\text{hr}$ in the same sense that Hickman and Kling used, for comparison purposes. In the next chapter, we will see how penetration direction affects dose.

From WSEG, the empirical formulae relating shear to the standard deviation of the normal distributions are

$$(\sigma_x)^2 = (\sigma_0)^2 \{1+(8TA)/TC\} + (\sigma_z S_x t)^2 \quad [m] \qquad (24)$$

$$(\sigma_y)^2 = (\sigma_0)^2 \{1+(8TA)/TC\} + (\sigma_z S_y t)^2 \quad [m] \qquad (25)$$

where TA = t for times less than three hours and TA = 3 for times greater than three hours, and TC from WSEG is

$$TC = 12(H_c/304.8)/60-\{2.5((H_c/304.8)/60)^2\} \quad [1/hr] \qquad (26)$$

Polan (Ref 24) incorporates a correction factor so that

$$TCP = TC\ 1.05732\ (1 - .5\ EXP\{ -((H_c/304.8)/25)^2\})\ [1/hr] \qquad (27)$$

TCP is the time constant for the toroidal growth term in this study. Toroidal growth is assumed to stop at the end of three hours. H_c is the cloud activity center height. In this study, the empirical H_c from WSEG is not used, but rather H_c is taken from Hopkins formula Eq (6) where rm^i for the median size particle group (i = 50) is selected.

The fall mechanics of the particles in each size group behave according to the equations of McDonald (Ref 18) and Davies (Ref 6) after Bridgman and Bigelow (Ref 1). An atmosphere with no vertical wind is assumed.

The fall velocity of each group is found by this method and the distance fallen in an interval is

$$z^i_j = z^i_{j-1} - v^i \Delta t \quad [m] \qquad (28)$$

where z^i_j is the new altitude of the vertical distribution center of particle size group i and z^i_{j-1} is the altitude at the end of the previous interval.

The fall velocity v^i is determined by the atmospheric density and viscosity at altitude z^i_{j-1}. The initial altitude the particle falls from is given by Eq(6). The interval Δt must be small enough so that the atmospheric properties do not change significantly in the distance fallen during the interval.

It was determined by Hickman (Ref 10) and Kling (Ref 16) and confirmed in this study that at early times (less than about one hour) the cloud fall calculations are inaccurate with time intervals of less than 0.1 hour. Each interval uses a large amount of computer time. A variable Δt was found to reduce the amount of calculation needed. For times greater than one hour, Δt can be increased becaus the heaviest particles have already 'fallen out' and the remaining cloud settles more slowly with time. Also, particle groups more than 3σ away from the aircraft or more than 3σ below ground level can be ignored. With these modifications, the cloud model can be advanced 48 hours from burst time in less than 35 minutes on a typical 8 bit home computer (Kaypro II).

Solutions for specific activity in Curies per vertical meter from Eq(20) for a variety of times and altitudes and the DELFIC default particle size distribution are shown in Figure 6.

Figures 7 and 8 show solutions for sizes weighted towards smaller (NRDL-N61) and larger (TOR-C) distributions.

Note that both NRDL-N61 and TOR-C have larger specific activities than DELFIC at the vertical activity centers. This is balanced by lesser activities at other altitudes. It can be seen that for DELFIC and NRDL-N61, the settling rate of the dust through the atmosphere is unimportant compared to the rate at which the activity decays with time. In these cases, the vertical activity center remains near its initial stabilized altitude until the activity has decayed to low levels. An aircraft may reduce its exposure by flying as far below or above the peak activity as feasible: although the latter is unlikely for megaton size yields.

Figure 8 for TOR-C shows that the large particles in this distribution settle very quickly compared to the decay rate: in this case, an aircraft may be better advised to stay high after about an hour after burst. This plot is presented again in Figure 9 with a linear activity scale so that the cloud fall may be more easily visualized.

These plots are presented based on a fission fraction of 1 so that activities for any desired fission fraction can be found by applying a simple multiplicative factor. Dose calculations in the next chapter will be carried out with a fission fraction of .5, which is more nearly representative of a one megaton burst.

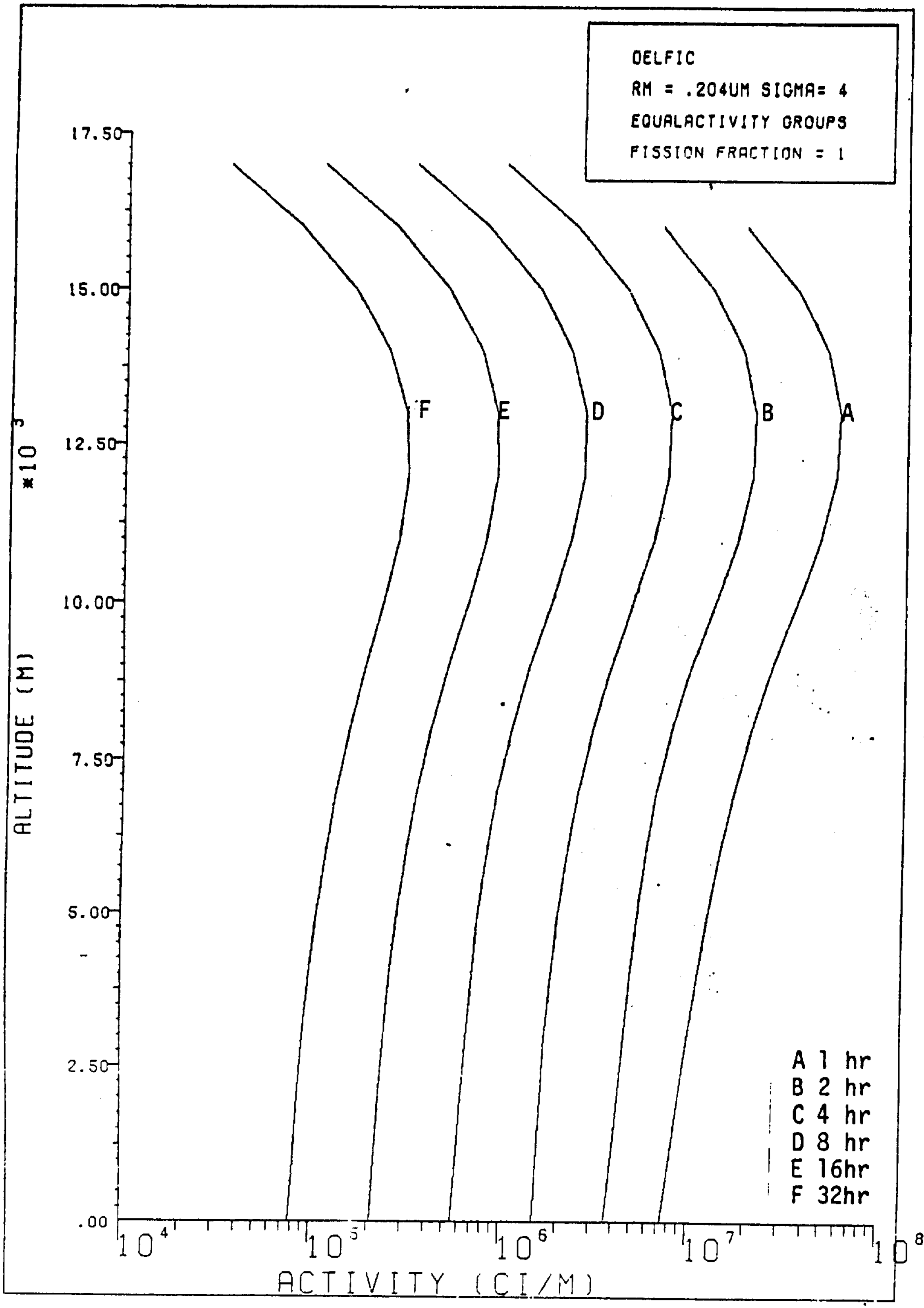

FIGURE 6-BASELINE DELFIC CLOUD ACTIVITY- 1 MEGATON

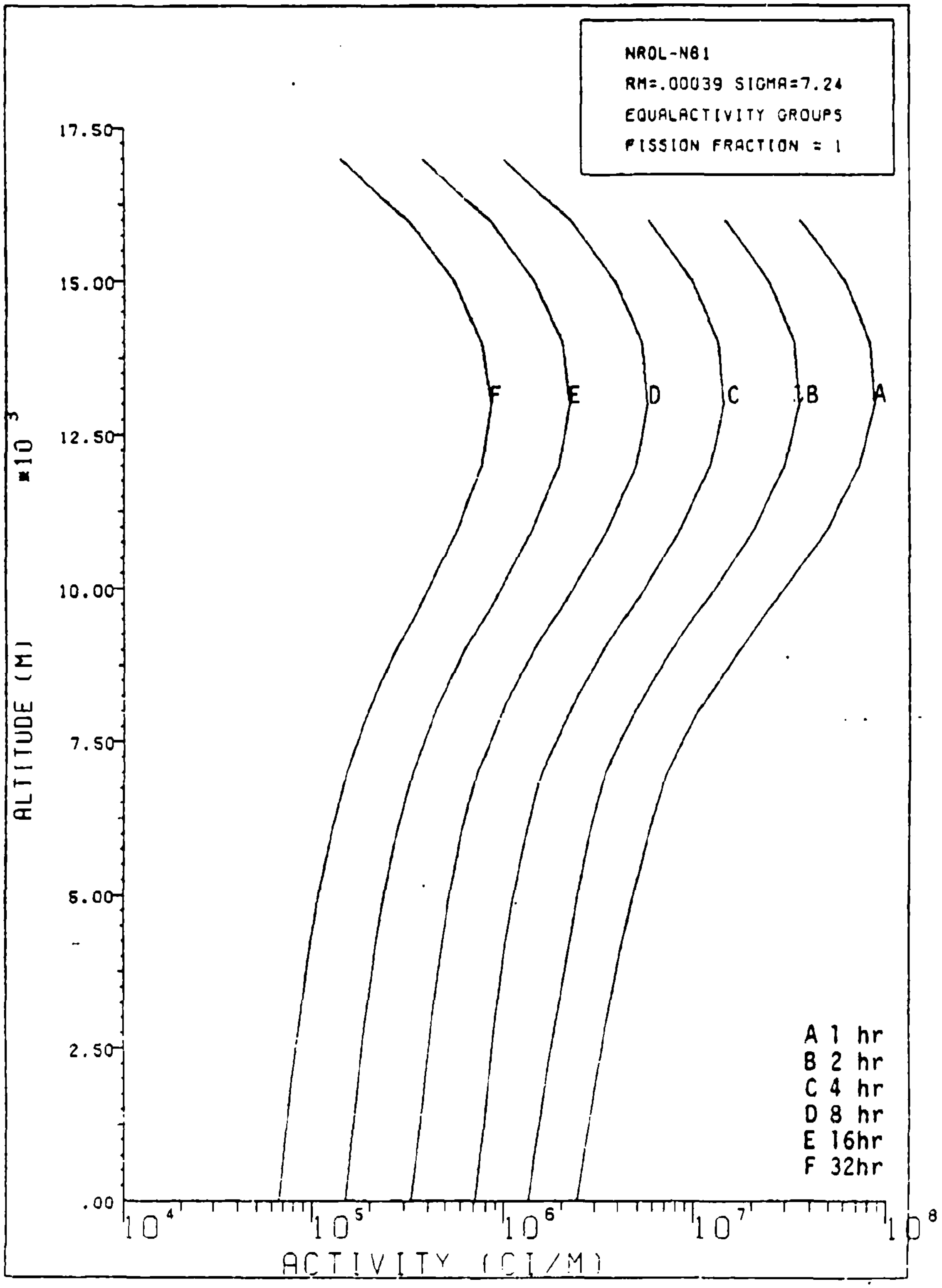

FIGURE 7 - NROL-N61 CLOUD ACTIVITY - ONE MEGATON

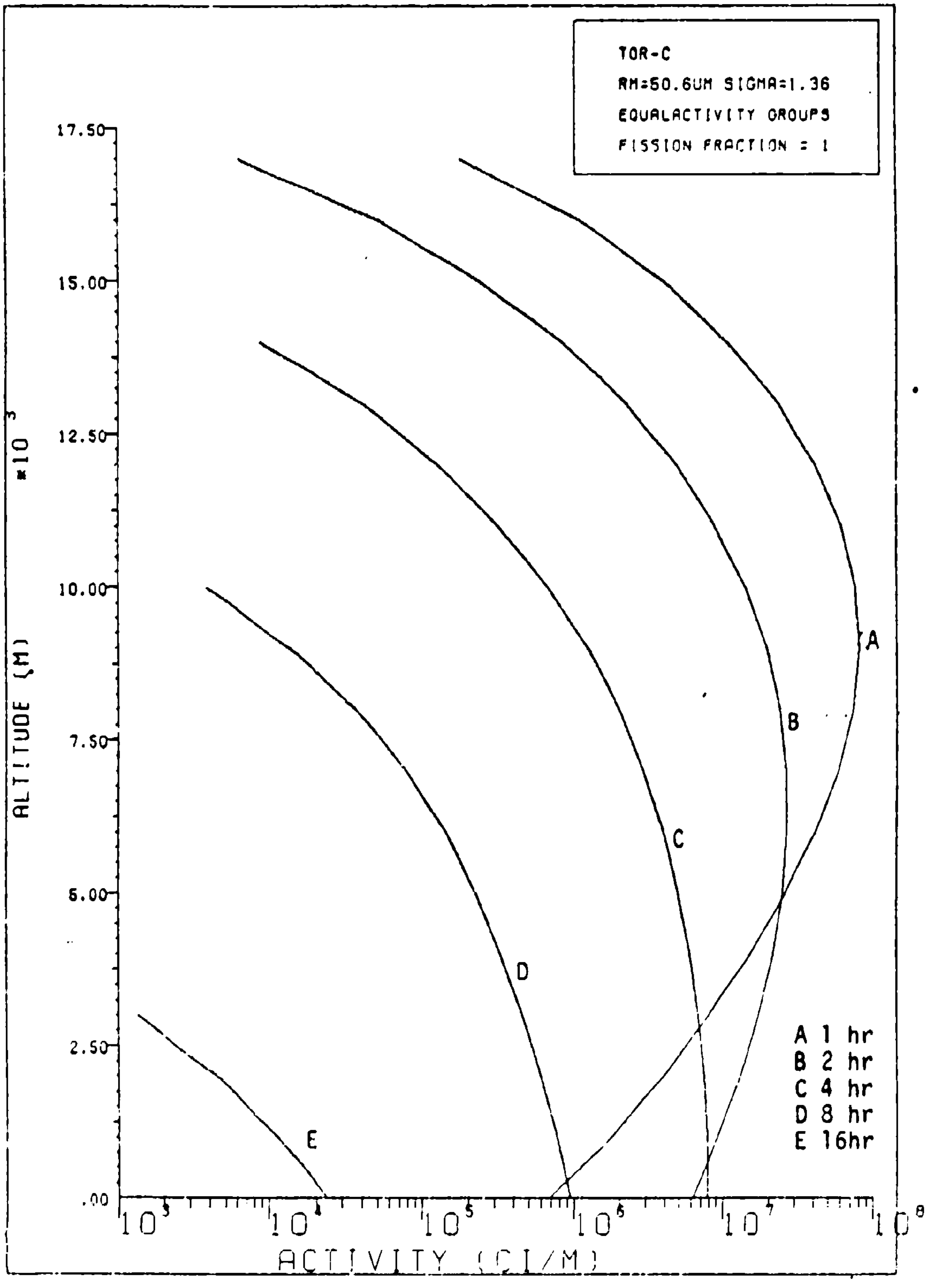

FIGURE 8 - TOR-C ACTIVITY - ONE MEGATON

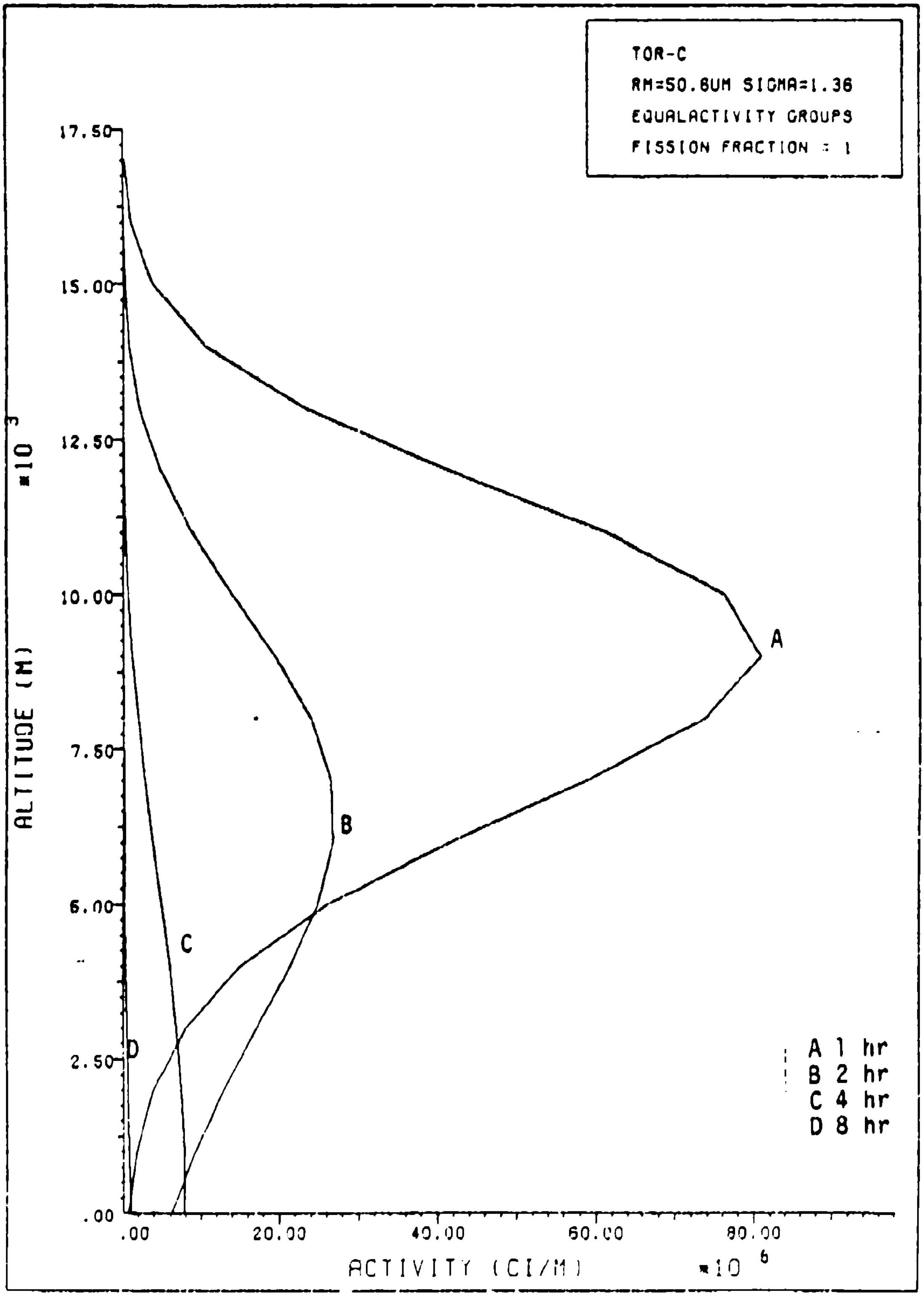

FIGURE 9 - TOR-C ACTIVITY - ONE MEGATON

Multiple Bursts

Crandley (Ref 5) has shown that a multiburst attack on a limited area, such as a missile field, can be modeled by a simple burst amplification factor applied to the activity density of a single burst case.

For target field of dimensions Lx by Wy, attacked by a total of $N = Nx \cdot Ny$ uniformly distributed equal yield bursts,

$$f(x,t_a) = \frac{\sqrt{N}}{Lx} \int_{-z}^{+z} \frac{1}{\sqrt{2\pi}\;\sigma_x(t_a)} \exp\left\{ -\frac{1}{2} \left[\frac{x - v_x\, t_a}{\sigma_x(t_a)^2} \right]^2 \right\} dx \qquad (29)$$

where $z = Lx/2$, v_x is the wind velocity, and a similar expression for $f(y,t_a)$. These reduce to

$$Fx = \frac{Nx}{Lx} \sqrt{2\pi}\;\sigma_x(t_a) \qquad (30)$$

and

$$Fy = \frac{Ny}{Wy} \sqrt{2\pi}\;\sigma_y(t_a) \qquad (31)$$

where the burst amplification factor F is multiplied by the single burst activity density in Eq (16) to produce the multiburst activity density. This factor can also be applied to the dust density in Chapter IV.

The next two chapters must be considered before results for multiburst dose and dust ingestion can be found. Appendices I and J present results for a multiburst attack of 300 one megaton weapons in a 150 km square field.

III. Dose Analysis

Background

There are four ways that an aircraft crew can be exposed to gamma radiation from a nuclear cloud. They are ground-shine, skin-shine, sky-shine, and exposure to the radioactive dust that enters with the air provided to pressurize and cool the cabin and equipment.

Ground-shine is disregarded in this study. Hickman and Kling have previously shown that ground-shine exposure to an aircraft is negligible for an aircraft flying a few gamma mean free paths above the ground. At sea level, the 1 MeV gamma mean free path is 120 meters. Hickman (Ref 10) has shown that for an aircraft flying 305 meters above the ground, the dose rate at the aircraft is equal to 10^{-11} times the ground activity.

Skin-shine results from nuclear cloud particles attached to the outer skin of the aircraft. No quantifiable information on this phenomenon could be found. However, dust particles small enough to stay airborne for significant periods may not be able to penetrate the aerodynamic boundary layer outside the skin of the aircraft and attach to the skin in numbers large enough to cause a significant dose to the crew inside. Skin-shine will be disregarded as being beyond the scope of this study.

The baseline aircraft used to compute sky-shine and cabin dose in this study is a KC-135 aircraft. For simplicity, doses are computed for the center of the cabin. Note that the model used in this study is very different from those employed by

Hickman and Kling. Different cabin sizes, shielding factors, and airflow rates are used. It should also be noted that the KC-135 and EC-135 aircraft are based on the Boeing 717 which is very different from a Boeing 707. The E-3 is based on the 707 not the KC-135. These differences will be discussed in more detail later.

Cabin Geometry

The internal dimensions of the cabin are assumed to be a cylinder. Although a cylinder is a reasonable model for most aircraft cabins, some adjustments need to be made. For instance, the values used by Hickman and Kling for cabin radius and length result in a volume more than twice as large as the pressurized volume stated for the cabin, resulting in too much dose. Part of this is due to a too large radius, but the rest is due to the fact that in a KC-135 or EC-135 aircraft (Boeing 717, NOT 707) the floor is a pressure bulkhead. The entire circular cross section of the fuselage is not pressurized.

To allow for variations of the simplified cylindrical model compared to the real aircraft, a pseudolength is used for this model. This length represents the value obtained by dividing the pressurized volume of the cabin by the cross sectional area {pressurized volume/(πr^2) = pseudolength}. This is the cabin length that will be used for the cabin dose rate integral described later in this chapter. Length is chosen to vary rather than radius because radius is the most accurately known and least variable dimension, and because the cabin geometry factor is more sensitive to radius than length.

In the case of certain aircraft, such as the B-52 or B-1 with square or triangular cabin cross sections, both length and radius must be adjusted to find a cylinder similar to the cabin configuration and having the same volume. Appendix D provides the data needed to evaluate a variety of aircraft. Numbers shown are for a typical operational wartime mission for each aircraft.

Sky-shine Shielding

Attenuation of gamma rays by any material follows the formula

$$A = A_0 \, e^{-(\mu_t/\rho)\,MI} \quad [\mathrm{Ci}] \qquad (32)$$

where A_0 is the incident gamma activity, μ_t/ρ is the gamma ray attenuation coefficient in m^2/kg, MI is the mass integral in kg/m^2, and A is the activity after passing through the shield. The dimensionless exponential term $e^{-(\mu_t/\rho)\,MI}$ will be referred to as the gamma transmission factor T_γ.

The shielding model developed for this study finds the mass integral by dividing the mass of the cabin by the surface area of the cabin, resulting in the desired kg/m^2 for the mass integral. This model necessitates the assumptions:

1. The mass and area of the wings, tail, fuel, and in bombers the fuselage aft of the crew compartment are ignored.
2. The radiation from the distributed cloud is isotropic.
3. The cabin wall is homogeneous. It is composed of a single material (aluminum), which is evenly distributed with a single thickness.

Although these assumptions may seem quite limiting, in practice they are not. In fact, they are generally conservative.

The wings and tail in the first assumption may provide a good shield, but they subtend a small angle as observed from the cabin, thus contributing little to overall shielding. The amount of fuel carried in the fuselage (if any) varies with time, and is ignored for simplicity. The fuselage aft of the crew compartment on bomber type aircraft can be considered an infinite shield. The angle subtended by the shield is highly variable at different points within the cabin, however. The aft fuselage is also ignored for simplicity. These are conservative choices.

Isotropic radiation from the distributed cloud was assumed in the previous section and does not pose a problem.

In the last case, about 80% of typical aircraft structure and equipment is aluminum and most of the remainder is low atomic number material with similar cross sections for gamma rays in the 1 MeV range.

All mass, including equipment inside the cabin, is included in the shield. Numerical analysis of several worst case mass distributions in the cabin leads to the conclusion that any reduction in shielding due to anisotropic mass distribution would be similar in magnitude to the increase in shielding realized by using a cylindrical rather than the implied spherical geometry, thus justifying the assumptions. These factors are on the order of -15% and +15% for a KC-135 type aircraft. The third assumption implies a spherical geometry for the shield because we assume the attenuation to be uniform for walls of a single, constant, thickness. This implied geometry is conservative: For a fixed wall thickness, any enclosed volume will receive the least shielding from a sphere.

Sky-shine Dose Rate

As the aircraft approaches the cloud, it will not be exposed to a significant amount of radiation until it is within a few gamma mean free paths of the cloud. Activity will rise until it reaches a peak at the center of the cloud, and will then fall off as the aircraft exits the cloud. There are three assumptions to be made at this point:

1. The activity density of the cloud does not vary vertically within a few gamma mean free paths.
2. The lateral cloud dimensions are at least 5 gamma mean free paths.
3. The aircraft does not penetrate the cloud prior to stabilization.

These assumptions are needed so that the integration for dose rate can be carried out analytically. The first two assumptions establish that the cloud is homogeneous in the vicinity of the aircraft. These assumptions are unlikely to be violated except at times less than 1 hour and altitudes above 40,000 feet. Any aircraft violating the last assumption is likely to be destroyed either by prompt effects or by turbulence and debris in the rising fireball.

The activity density A'''(x,y,z,t) in Ci/m^3 for the nuclear cloud is given by Eq (20). An aircraft immersed in the cloud will experience a dose rate from sky-shine calculated from the spherical integral

$$\dot{D} = C\ A'''(x,y,z,t) \int_0^{2\pi}\int_0^{\pi}\int_0^{S} \frac{\mu_a}{\rho}\ \frac{e^{-\mu_t s}\ s^2}{4\pi s^2}\ \sin\theta\ d\phi\ d\theta\ ds \qquad (\ 33\ )$$

where $A'''(x,y,z,t)$ is the activity density in the cloud and s is the radial direction from the aircraft. C is a factor to convert activity to dose rate and has a value of 2131 [rem-kg/Ci-hr] for 1 MeV gamma rays. The term μ_a/ρ is the tissue absorption coefficient, and μ_t is the total attenuation coefficient of air.

The attenuation due to the self-shielding of dust suspended in the air is negligible and is ignored. Information on dust densities developed in the next chapter is found in Appendices H and J. Comparing dust density to air density indicates that self-shielding from dust amounts to less than 0.3% of the self-shielding due to air for a single 1 megaton burst.

Integrating Eq (33) allowing S to approach infinity, and allowing for cabin shielding with the gamma transmission factor T_γ from Eq (32), the dose rate inside the cabin is

$$\dot{D} = C\, T_\gamma\, A'''(x,y,z,t)\, \frac{1}{\mu_t}\, \frac{\mu_a}{\rho} \qquad \text{[rem/hr]} \qquad (\ 34\ )$$

where activity is still at unit time reference and must be converted to penetration time by the Way-Wigner decay formula.

If the aircraft flies completely through the cloud in the x direction with velocity v_x then the sky-shine dose inside the cabin will be

$$D = \int_{-\infty}^{+\infty} \dot{D}(x,y,z,t')\, dt' = \int_{-\infty}^{+\infty} \dot{D}(x,y,z,t_a)\, dx/v_x \qquad \text{[rem]} \qquad (\ 35\ )$$

where $dx = v_x dt'$ and $t' = 0$ when $t = t_a$, the cloud penetration time. The cloud penetration time is defined as the time when the aircraft passes the cloud centerline, $y = y_0$.

Computing dose in this fashion assumes that the activity density profile in the cloud is constant with respect to both cloud expansion and activity decay with time. The cloud is therefore 'frozen' at time $t = t_a$ during the aircraft transit.

A rigorous treatment would have the activity density higher on the entry side of the cloud than on the exit side, since the cloud is expanding and activity is decaying during the time it takes the aircraft to transit the cloud. However, a numerical analysis for this study has shown that a rigorous treatment tends to average the doses received on each side of the cloud so that the cloud 'frozen' at $t = t_a$ in this study results in doses within 1% of the more detailed treatment for typical cloud sizes and aircraft velocities.

Collecting and expanding terms from Eq (35), dose is

$$D = \frac{T_\gamma}{3600\ v_x}\ \frac{C}{\mu_t}\ \frac{\mu_a}{\rho}\ f(y,t)\ A'(z,t) \int_{-\infty}^{+\infty} f(x,t)\ dx\ [\text{rem}] \qquad (36)$$

where the factor 3600 changes velocity from m/s to m/hr to match the conversion constant C. For an aircraft flying through the center of the cloud, $x-x_0 = 0$ and $y-y_0 = 0$. From Eq (17), $f(y,t)$ then reduces to $(\sqrt{2\pi}\sigma_y)^{-1}$. From Eq (16), the above integral of $f(x,t)$ is then just equal to unity, the value of the cumulative lognormal function integrated over all x.

Thus the dose is

$$D = \frac{T_\gamma}{3600\ v_x}\ \frac{C}{\mu_t}\ \frac{\mu_a}{\rho}\ \frac{(1)}{\sqrt{2\pi}\ \sigma_y}\ A'(z,t) \quad [\text{rem}] \qquad (37)$$

where $A'(z,t)$ is the activity per vertical meter found in Eq (18). Figures 6 through 9 show the numerical results found for $A'(z,t)$ in the cases used for this study.

Cabin Dust Dose Rate

The aircraft flies through the cloud in the x direction sweeping out all of the activity at a given altitude. The activity in a unit cross section of the cloud projected along the x axis is $A''(y,z,t)$, which might be described as an 'activity-integral' analogous to the 'mass-integral' MI.

$$A''(y,z,t) = f(y,t)\,A'(z,t) \int_{-\infty}^{+\infty} f(x,t)\,dx \quad [\mathrm{Ci/m^3}] \qquad (\ 38\ )$$

where $f(y,t)$ is found from Eq (17) and $A'(z,t)$ is found from Eq (18). The integral $\int_{-\infty}^{+\infty} f(x,t)\,dx$ is again equal to 1.

The amount of activity that enters the cabin can be determined by finding an equivalent inlet area IA_{cd} for the cabin. This is

$$IA_{cd} = \frac{\Omega}{v_x\,\rho_{air}} \quad [\mathrm{m^2}] \qquad (\ 39\ )$$

where Ω is the mass flow rate of air into the cabin from the engine compressor in kg/sec, ρ_{air} is the air density at the aircraft altitude in kg/m^3, and v_x is the aircraft velocity in m/sec.

The total amount of activity A_{cd} in Curies trapped in the cabin is the product of Eq (38) and Eq (39). It is the activity 'scooped out' from a tunnel that extends through the cloud (Figure 4).

Note that because the mass flow rate of air, Ω, into the cabin is constant, a higher aircraft velocity will result in a smaller effective inlet area, reducing the amount of dust ingested. This is because the cloud is traversed in less time, therefore a smaller volume is ingested at the constant mass flow rate.

Further note that increasing the dimensions of the cloud (either by expansion with time or smearing by wind) in the x direction while aircraft velocity is constant will not change the amount of dust ingested because the integral $\int_{-\infty}^{+\infty} f(x,t)\,dx$ is constant: all of the dust in a cross section through the cloud will be swept out, regardless of the particle location in the x direction. However, cloud expansion in the y direction (transverse to the aircraft's flight path) will reduce the amount of dust ingested because the value of $f(y,t)$ in Eq (38) will decrease as σ_y increases.

We will assume that all of the dust that enters the cabin is trapped and stays suspended for the remainder of the flight. This assumption is not true, but is used due to the complexities of flow and settling in the cabin. This is a worst case approximation.

The dose rate at the center of a cylindrical cabin is

$$\dot{D} = C \frac{A_{cd}}{PV} \frac{\mu_a}{\rho} \int_{-H}^{+H} \int_{0}^{R} \int_{0}^{2\pi} \frac{e^{-\mu_t (r^2+z^2)^{1/2}}}{4\pi (r^2+z^2)} \, r \, d\theta \, dr \, dz \quad (40)$$

where C is a factor to convert activity to dose rate and has a value of 2131 [rem-kg/Ci-hr] for 1 MeV gamma rays. A_{cd} is the unit time activity in Curies of the dust trapped inside the cabin and PV is the pressurized volume of the cabin. The term A_{cd}/PV is the activity density in the cabin. The term μ_a/ρ is the tissue absorption coefficient in m^2/kg, R is the radius of the cabin, H is one half the pseudolength of the cabin and the exponential term allows for self attenuation by the air inside the cabin: μ_t is the total attenuation coefficient of air in m^{-1}. The cabin air is maintained at a pressure equivalent to an 8000 foot altitude when the aircraft is higher than 8000 feet by the aircraft pressurization system. For this reason, μ_t for air at 8000 feet is used.

The integral of Eq (40) when evaluated results in a constant factor K which is dependent on the cabin geometry. This cabin geometry factor K has units of [m] and is a measure of how 'close' the distributed activity of the dust in the cabin is to a given point in the cabin. In this study, we compute dose to the center of the cabin. The above integral is solved numerically. A program to carry this out is found in Appendix K. Values of K for a variety of aircraft are found in Table VIII.

The unit time dose rate at the center of the cabin is

$$\dot{D} = C\,K\,\frac{A_{cd}}{PV}\,\frac{\mu_a}{\rho} \qquad [\text{rem/hr}] \qquad (\ 41\ )$$

The dose is then

$$D = \dot{D}\int_{t_a}^{t_a+\Delta t} t^{-1.2}\,dt \qquad [\text{rem}] \qquad (\ 42\ )$$

where $\dot{D}$ is the unit time dose rate, t_a is the penetration time since burst, and delta t is the time remaining from cloud penetration to mission completion. Doses for multiple cloud encounters can be obtained by summing the doses from each individual encounter. If this is done for multiple clouds in a single mission, care must be taken so that the mission time remaining from penetration time, Δt, is adjusted in each case so that the doses are computed for realistic exposure times, i.e. Δt equals mission duration minus the time between takeoff and cloud penetration for each cloud encountered during the mission.

The following table was computed using the above equations and the data for each aircraft found in Appendix D. It provides information on dose factors, airspeeds, and cabin sizes and airflow rates for a variety of typical aircraft on operational type missions.

TABLE VIII

AIRCRAFT DOSE DATA

Aircraft Type	Gamma Transmission Factor T_γ	Cabin Geometry Factor K M	Velocity v_x M/S	Cabin Air Mass Flow Ω KG/MIN	Cabin Pressurized Volume M^3	Cabin Radius M
B-1B	.5265	1.395	279.2	17	28.3	1.07
B-52G	.4360	2.035	231.5	22	51.9	1.75
B-52H	.4493	2.035	231.5	22	51.9	1.75
E-3	.5808	2.505	164.7	61.5	356.1	1.79
E-4B	.5246	4.586	164.7	276	1686	3.28
EC-135	.4537	2.468	154.2	50	244.2	1.79
KC-135	.7043	2.459	231.5	50	232.2	1.79

Filters

Exposure to dust in the cabin can be prevented or reduced in several ways. Depressurizing the cabin during cloud transit would prevent dust entry. Mission requirements may prevent this. Another method is to use a filter to prevent larger particles from entering.

Smaller particles could be allowed to pass through, as the mean residence time for air in the cabin is on the order of 5 minutes and the small particles would be quickly flushed out. In this case, the dust in the cabin would contribute to dose only while the aircraft was inside the cloud. For this study, however, the small particles that pass through the filter will remain trapped in the cabin as a worst case for comparison purposes.

It is possible that centrifugal effects in the compressor section of the aircraft engine could reduce or increase the dust density in the cabin airflow prior to filtration. Engines currently undergoing testing for dust erosion effects may provide data on this (Ref 14).

This study will model filtration by subdividing the nuclear cloud into to two congruent clouds. One cloud consists only of those particles which are small enough to pass through the filter. The other cloud consists of the remaining larger particles. The activity scooped out of the 'small particle cloud' is assumed to be trapped in the cabin and will be used for cabin dose computations. The activity scooped out of the 'large particle cloud' is trapped in the filter. Sky-shine dose calculations use the summed activity of both clouds.

A filter studied by Rockwell for the B-1 bomber (Ref 15) will trap all particles with a radius greater than 10 microns. Thus a filter transmission factor for all groups greater than this size in Eq (18) would be 0, i.e., none of them enter the cabin.

Particles between 5 and 10 microns in radius are trapped with a 90% efficiency for a filter transmission factor of 0.1. All particles smaller than 5 microns pass through the filter, for a filter transmission factor of 1.0.

It should be recognized that if a filter traps enough radioactive dust, it may present a hazard greater than unfiltered air would pose. Care must be taken that the filter is shielded or distant from the aircrew, ground crew, and electronics equipment.

If the filtering efficiency of engines and other parts of the cabin air supply system can be quantified, then a filter transmission factor for the entire system can be used.

Any filter has a limit to its capacity. The filter mentioned above will trap about 225 grams of dust before becoming clogged. After the filter is clogged, it must be bypassed and unfiltered air allowed into the cabin. The mass trapped in the filter for each cloud encounter can be determined as discussed in the next chapter.

Dose Results

The output for the baseline case is presented in Table X. The next two tables will be the same, except that the DELFIC particle size distribution is replaced with the NRDL-N61 distribution of rm = .00039 micrometers and σ_{rm} = 7.24 (Table XI). The TOR-C distribution of rm = 50.6 and σ_{rm} = 1.36 is used for Table XII.

For comparison purposes, the baseline case in this study will be a one megaton burst, fission fraction of 0.5, DELFIC (Defense Land Fallout Information Code) default particle size distribution, a cross track wind shear of 1 (km/hr)/km, an 8 hour mission duration after cloud penetration, and a KC-135 aircraft.

Table IX contains the input parameters for the baseline case.

Table IX

Baseline Case Input Parameters

```
31 Dec 1438
This is a dose report.
CUSTOM SCENARIO: Baseline case - DELFIC and KC-135

WEAPON/TARGET DATA:
Number of weapons ----------------- 1
Weapon yield ---------------------- 1000 KT
Fission fraction ------------------ 0.5
Dust fraction --------------------- 1/3
The size distribution input file is- DELFIC.RMA
                  Rm =  .204 : sigma Rm =  4
The soil density is --------------- 2600 KG/M³
The aircraft specification file is - KC-135.SPC
Aircraft velocity is -------------- 231.5 M/S
Time from cloud penetration
to end of mission ----------------- 8 HR
Wind shear X (along track) -------- 0 (KM/HR)/KM
Wind shear Y (cross track) -------- 1 (KM/HR)/KM
The output file will be named ------ A:BASELINE.DOP
```

Tables X and XI show that compared to DELFIC, an NRDL-N61 cloud will cause an increased dose at high altitudes, from 30% to 80% more, depending on the time since burst. Concurrently, the NRDL-N61 cloud has from 66% to 30% less dose at low altitudes. These effects are due to the large numbers of small particles in the NRDL-N61 distribution. The smaller particles are carried to higher altitudes and stay up longer, thereby adding to the activity density at high altitudes and subtracting from it at low altitudes. This can be seen by comparing Figure 7 to Figure 6. The dose is further increased at high altitude because the lower air density provides less attenuation.

Table XII shows the results for the TOR-C cloud (composed of relatively large particles) which causes similar doses compared to

DELFIC at early times, but at lower altitudes. Doses fall off very rapidly after the second hour at all altitudes. The dose at two hours is 30 percent less than DELFIC and at an altitude 4000 meters lower. These effects are caused by the rapid fall of the large particles and because the large particles start falling from a lower altitude. The aircrew dose is low because the cloud has fallen out of the air onto the ground. This can be easily visualized in Figure 9.

Tables XIII and XIV are for the B-1B in a DELFIC cloud, without and with a filter. The dose due to dust in the cabin is completely removed at low altitudes, and at high altitudes where there are particles too small for the filter to trap, the dose is reduced by 80%. As expected, the sky-shine dose does not change.

This study assumes a constant gamma ray energy of 1 MeV. It would be possible to make the gamma energy a function of time using data derived by Drinkwater (Ref 7), which gives gamma energies from 1.44 MeV at 0.27 hour to 0.5 MeV at 27 hours. A sample calculation, shown in table XV, carried out for a gamma energy of 0.7 MeV results in a shielding cross section increase of 10%. Combined with the lower gamma energy, dose is reduced about 35%.

In the baseline case, we took wind shear $S_x = 0$ and $S_y = 1$. If the nuclear cloud is stretched by wind shear in the x direction (the direction of penetration), the activity-integral and σ_y will not change and the dose will remain the same (see Eq (37)). This is shown in Table XVI, where $S_x = 10$ and $S_y = 1$: this represents a long, narrow cloud.

Table XVII shows the results if the aircraft in the last case penetrates the cloud in the transverse direction. This is accomplished by setting $S_x = 1$ and $S_y = 10$, so that the aircraft flies through a short, wide cloud. Both sky-shine and cabin dust dose are reduced by a factor of 5 at one hour and by a factor of 10 at eight hours. Dose is also inversely proportional to velocity, as shown for sky-shine in Eq (37) and for cabin dust in Eq (39).

Tables XVIII to XX show the doses that can be expected for a B-52G, E-4B, and EC-135 respectively. They penetrate the same DELFIC cloud that the baseline KC-135 in Table X used. The sky-shine dose varies with the gamma transmission factor, aircraft velocity, and the transverse size of the cloud. The cabin dust dose varies with velocity, mass flow rate of air into the cabin, the cabin geometry factor K, and the transverse size of the cloud.

Table X

Baseline Case - DELFIC Cloud and KC-135

```
*************************************************************************
31 Dec 1438    CUSTOM SCENARIO: Baseline - DELFIC and KC-135
time (hr) = 1  deltat (hr) = .0967423  %airborne = 90  sigmax = 3958.03 M
sigmay = 4355.52 M                  3 sigmay cloud diameter = 26133.1 M
Altitude      Cabin Dust    Sky Shine    Total Dose    Prominent Particle
   M             REM           REM          REM         microns radius
 12000          3.62          6.72         10.3          31.8
 10000          1.71          3.19         4.90          55.1
  8000          .790          1.46         2.25          78.1
  6000          .440          .817         1.25          103.
  4000          .275          .511         .786          126.
  2000          .180          .335         .515          157.
*************************************************************************
31 Dec 1438    CUSTOM SCENARIO: Baseline - DELFIC and KC-135
time (hr) = 2  deltat (hr) = .0967423  %airborne = 81  sigmax = 4865.07 M
sigmay = 6148.72 M                  3 sigmay cloud diameter = 36892.3 M
Altitude      Cabin Dust    Sky Shine    Total Dose    Prominent Particle
   M             REM           REM          REM         microns radius
 12000          1.44          1.73         3.18          22.4
 10000          .702          .842         1.54          36.2
  8000          .332          .399         .731          48.6
  6000          .196          .236         .432          60.1
  4000          .133          .160         .294          74.7
  2000          .0934         .112         .205          89.5
*************************************************************************
31 Dec 1438    CUSTOM SCENARIO: Baseline - DELFIC and KC-135
time (hr) = 4  deltat (hr) = .166667  %airborne = 69  sigmax = 5627.78 M
sigmay = 9500.64 M                  3 sigmay cloud diameter = 57003.8 M
Altitude      Cabin Dust    Sky Shine    Total Dose    Prominent Particle
   M             REM           REM          REM         microns radius
 12000          .482          .404         .886          15.4
 10000          .240          .200         .441          24.5
  8000          .116          .097         .214          31.8
  6000          .069          .058         .127          39.4
  4000          .046          .038         .085          46.6
  2000          .033          .028         .061          52.9
*************************************************************************
31 Dec 1438    CUSTOM SCENARIO: Baseline - DELFIC and KC-135
time (hr) = 8  deltat (hr) = .363636  %airborne = 57  sigmax = 5627.78 M
sigmay = 16435.6 M                  3 sigmay cloud diameter = 98613.5 M
Altitude      Cabin Dust    Sky Shine    Total Dose    Prominent Particle
   M             REM           REM          REM         microns radius
 12000          .130          .083         .213          11.2
 10000          .067          .042         .109          17.0
  8000          .033          .021         .054          22.4
  6000          .019          .012         .032          26.8
  4000          .013          8.58 E-03    .022          30.5
  2000          9.68 E-03     6.17 E-03    .015          34.7
```

Table XI

NRDL-N61 Cloud and KC-135

```
******************************************************************************
30 Dec 1300    CUSTOM SCENARIO: NRDL-N61 and KC-135
time (hr) = 1  deltat (hr) = .386969  %airborne = 97  sigmax = 3922.13 M
sigmay = 4329.41 M                  3 sigmay cloud diameter = 25976.5 M
Altitude      Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M             REM            REM          REM          microns radius
 12000          4.69           8.70         13.3           31.3
 10000          1.46           2.71         4.17           52.3
  8000          .407           .757         1.16           75.5
  6000          .176           .327         .503           94.0
  4000          .100           .185         .285           121.
  2000          .061           .114         .176           140.
******************************************************************************
30 Dec 1300    CUSTOM SCENARIO: NRDL-N61 and KC-135
time (hr) = 2  deltat (hr) = .386969  %airborne = 94  sigmax = 4806.59 M
sigmay = 6097.57 M                  3 sigmay cloud diameter = 36585.4 M
Altitude      Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M             REM            REM          REM          microns radius
 12000          2.13           2.55         4.68           22.9
 10000          .688           .825         1.51           38.4
  8000          .204           .244         .448           52.3
  6000          .094           .113         .208           62.3
  4000          .057           .069         .127           75.5
  2000          .037           .044         .082           94.0
******************************************************************************
30 Dec 1300    CUSTOM SCENARIO: NRDL-N61 and KC-135
time (hr) = 4  deltat (hr) = .386969  %airborne = 90  sigmax = 5551.88 M
sigmay = 9443.7 M                  3 sigmay cloud diameter = 56662.2 M
Altitude      Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M             REM            REM          REM          microns radius
 12000          .800           .669         1.46           16.3
 10000          .270           .226         .496           25.8
  8000          .086           .072         .158           33.4
  6000          .041           .034         .075           41.3
  4000          .025           .021         .046           48.2
  2000          .016           .014         .031           57.0
******************************************************************************
30 Dec 1300    CUSTOM SCENARIO: NRDL-N61 and KC-135
time (hr) = 8  deltat (hr) = .386969  %airborne = 84  sigmax = 5551.88 M
sigmay = 16402 M                  3 sigmay cloud diameter = 98411.9 M
Altitude      Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M             REM            REM          REM          microns radius
 12000          .244           .155         .399           11.2
 10000          .086           .055         .141           18.2
  8000          .029           .018         .047           22.9
  6000          .014           9.12 E-03    .023           27.5
  4000          8.94 E-03      5.70 E-03    .014           31.3
  2000          5.99 E-03      .003         9.81 E-03      35.8
```

Table XII

TOR-C Cloud and KC-135

```
**********************************************************************
30 Dec 1420    CUSTOM SCENARIO: TOR-C and KC-135
time (hr) = 1  deltat (hr) = .386969  %airborne = 100  sigmax = 3994.61 M
sigmay = 4394.87 M                    3 sigmay cloud diameter = 26369.2 M
Altitude        Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M               REM            REM          REM          microns radius
 12000           2.64           4.90         7.54          32.8
 10000           3.67           6.81         10.4          54.3
  8000           2.79           5.18         7.97          75.6
  6000           1.25           2.32         3.57          99.7
  4000           .366           .680         1.04          124.
  2000           .078           .145         .223          141.
**********************************************************************
30 Dec 1420    CUSTOM SCENARIO: TOR-C and KC-135
time (hr) = 2  deltat (hr) = .386969  %airborne = 100  sigmax = 4[illegible]24.5 M
sigmay = 6190.69 M                    3 sigmay cloud diameter = 37144.2 M
Altitude        Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M               REM            REM          REM          microns radius
 12000           .337           .405          .742          29.0
 10000           .745           .893          1.63          38.0
  8000           .996           1.19          2.19          51.8
  6000           .890           1.06          1.95          64.8
  4000           .573           .687          1.26          79.2
  2000           .281           .337          .619          94.2
**********************************************************************
30 Dec 1420    CUSTOM SCENARIO: TOR-C and KC-135
time (hr) = 4  deltat (hr) = .386969  %airborne = 84  sigmax = 5704.79 M
sigmay = 9539.53 M                    3 sigmay cloud diameter = 57237.2 M
Altitude        Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M               REM            REM          REM          microns radius
 12000           8.21 E-03      6.86 E-03     .015          29.0
 10000           .032           .027          .060          29.0
  8000           .076           .063          .140          32.8
  6000           .121           .101          .223          41.1
  4000           .148           .123          .271          48.0
  2000           .151           .126          .277          55.2
**********************************************************************
30 Dec 1420    CUSTOM SCENARIO: TOR-C and KC-135
time (hr) = 8  deltat (hr) = .386969  %airborne = 25  sigmax = 5704.79 M
sigmay = 16459.7 M                    3 sigmay cloud diameter = 98758.1 M
Altitude        Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M               REM            REM          REM          microns radius
 12000           0              0             0             29.0
 10000           1.44 E-04      9.18 E-05     2.35 E-04     29.0
  8000           1.07 E-03      6.84 E-04     .002          29.0
  6000           3.35 E-03      2.13 E-03     5.48 E-03     29.0
  4000           6.27 E-03      3.99 E-03     .010          32.8
  2000           9.35 E-03      5.96 E-03     .015          35.0
```

Table XIII

DELFIC Cloud and B-1B

WITHOUT CABIN AIR FILTER

```
*******************************************************************************
12 Jan 1406    CUSTOM SCENARIO: Baseline + B-1B without filter
time (hr) = 1  deltat (hr) = .0967423  %airborne = 90  sigmax = 3958.03 M
sigmay = 4355.52 M                   3 sigmay cloud diameter = 26133.1 M
Altitude       Cabin Dust     Sky Shine     Total Dose     Prominent Particle
   M              REM            REM           REM          microns radius
 12000           4.77           4.16          8.94            31.8
 10000           2.26           1.97          4.24            55.1
  8000           1.04           .909          1.95            78.1
  6000           .580           .506          1.08            103.
  4000           .362           .316          .679            126.
  2000           .237           .207          .445            157.
*******************************************************************************
12 Jan 1406    CUSTOM SCENARIO: Baseline + B-1B without filter
time (hr) = 2  deltat (hr) = .0967423  %airborne = 81  sigmax = 4865.07 M
sigmay = 6148.72 M                   3 sigmay cloud diameter = 36892.3 M
Altitude       Cabin Dust     Sky Shine     Total Dose     Prominent Particle
   M              REM            REM           REM          microns radius
 12000           1.90           1.07          2.98            22.4
 10000           .925           .521          1.44            36.2
  8000           .438           .247          .685            48.6
  6000           .259           .146          .405            60.1
  4000           .176           .099          .275            74.7
  2000           .123           .069          .192            89.5
*******************************************************************************
12 Jan 1406    CUSTOM SCENARIO: Baseline + B-1B without filter
time (hr) = 4  deltat (hr) = .156667  %airborne = 69  sigmax = 5627.78 M
sigmay = 9500.64 M                   3 sigmay cloud diameter = 57003.8 M
Altitude       Cabin Dust     Sky Shine     Total Dose     Prominent Particle
   M              REM            REM           REM          microns radius
 12000           .636          .250          .886            15.4
 10000           .316          .124          .441            24.5
  8000           .154          .060          .214            31.8
  6000           .091          .035          .127            39.4
  4000           .061          .024          .085            46.6
  2000           .044          .017          .061            52.9
*******************************************************************************
12 Jan 1406    CUSTOM SCENARIO: Baseline + B-1B without filter
time (hr) = 8  deltat (hr) = .363636  %airborne = 57  sigmax = 5627.78 M
sigmay = 16435.6 M                   3 sigmay cloud diameter = 98613.5 M
Altitude       Cabin Dust     Sky Shine     Total Dose     Prominent Particle
   M              REM            REM           REM          microns radius
 12000           .172          .051          .223            11.2
 10000           .088          .026          .114            17.0
  8000           .043          .013          .056            22.4
  6000           .026          7.81 E-03     .033            26.8
  4000           .017          5.32 E-03     .023            30.5
  2000           .012          3.82 E-03     .016            34.7
```

Table XIV

DELFIC Cloud and B-1B

WITH CABIN AIR FILTER

```
*****************************************************************************
14 Feb 1452    CUSTOM SCENARIO: Baseline B-1B with filter
time (hr) = 1  deltat (hr) = .0967423  %airborne = 90  sigmax = 3958.03 M
sigmay = 4355.52 M                     3 sigmay cloud diameter = 26133.1 M
Altitude       Cabin Dust     Sky Shine     Total Dose     Prominent Particle
    M             REM            REM           REM          microns radius
 12000           .850           4.16          5.01            31.8
 10000           .166           1.97          2.14            55.1
  8000           .011           .909          .921            78.1
  6000           0              .506          .506            103.
  4000           0              .316          .316            126.
  2000           0              .207          .207            157.
*****************************************************************************
14 Feb 1452    CUSTOM SCENARIO: Baseline B-1B with filter
time (hr) = 2  deltat (hr) = .0967423  %airborne = 81  sigmax = 4865.07 M
sigmay = 6148.72 M                     3 sigmay cloud diameter = 36892.3 M
Altitude       Cabin Dust     Sky Shine     Total Dose     Prominent Particle
    M             REM            REM           REM          microns radius
 12000           .408           1.07          1.48          22.4
 10000           .080           .521          .602          36.2
  8000           5.88 E-03      .247          .253          48.6
  6000           0              .146          .146          60.1
  4000           0              .099          .099          74.7
  2000           0              .069          .069          89.5
*****************************************************************************
14 Feb 1452    CUSTOM SCENARIO: Baseline B-1B with filter
time (hr) = 4  deltat (hr) = .166667  %airborne = 69  sigmax = 5627.78 M
sigmay = 9500.64 M                     3 sigmay cloud diameter = 57003.8 M
Altitude       Cabin Dust     Sky Shine     Total Dose     Prominent Particle
    M             REM            REM           REM          microns radius
 12000           .167           .250          .417          15.4
 10000           .033           .124          .158          24.5
  8000           2.52 E-03      .060          .063          31.8
  6000           0              .035          .035          39.4
  4000           0              .024          .024          46.6
  2000           0              .017          .017          52.9
*****************************************************************************
14 Feb 1452    CUSTOM SCENARIO: Baseline B-1B with filter
time (hr) = 8  deltat (hr) = .363636  %airborne = 57  sigmax = 5627.78 M
sigmay = 16435.6 M                     3 sigmay cloud diameter = 98613.5 M
Altitude       Cabin Dust     Sky Shine     Total Dose     Prominent Particle
    M             REM            REM           REM          microns radius
 12000           .056           .051          .108          11.2
 10000           .012           .026          .038          17.0
  8000           9.5 E-04       .013          .014          22.4
  6000           0              7.81 E-03     7.81 E-03     26.8
  4000           0              5.32 E-03     5.32 E-03     30.5
  2000           0              3.82 E-03     3.82 E-03     34.7
```

Table XV

DELFIC Cloud and KC-135, using 0.7 MeV gamma rays

```
*******************************************************************************
26 Feb 0041    CUSTOM SCENARIO: DELFIC cloud: KC-135: 0.7 MeV energy β xsec
time (hr) = 1  deltat (hr) = .0967423  %airborne = 90  sigmax = 3958.03 M
sigmay = 4343.43 M                   3 sigmay cloud diameter = 26060.6 M
Altitude      Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M             REM            REM          REM           microns radius
 12000          2.66           4.11          6.78           31.8
 10000          1.26           1.95          3.21           55.1
  8000          .582           .898          1.48           78.1
  6000          .324           .500          .825           103.
  4000          .202           .312          .515           126.
  2000          .132           .205          .338           157.
*******************************************************************************
26 Feb 0041    CUSTOM SCENARIO: DELFIC cloud: KC-135: 0.7 MeV energy β xsec
time (hr) = 2  deltat (hr) = .0967423  %airborne = 81  sigmax = 4865.07 M
sigmay = 6133.43 M                   3 sigmay cloud diameter = 36800.6 M
Altitude      Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M             REM            REM          REM           microns radius
 12000          1.06           1.06          2.12           22.4
 10000          .517           .515          1.03           36.2
  8000          .245           .244          .489           48.6
  6000          .145           .144          .289           60.1
  4000          .098           .098          .196           74.7
  2000          .068           .068          .137           89.5
*******************************************************************************
26 Feb 0041    CUSTOM SCENARIO: DELFIC cloud: KC-135: 0.7 MeV energy β xsec
time (hr) = 4  deltat (hr) = .166667  %airborne = 69  sigmax = 5627.78 M
sigmay = 9479.4 M                   3 sigmay cloud diameter = 56876.4 M
Altitude      Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M             REM            REM          REM           microns radius
 12000          .355           .247          .603           15.4
 10000          .176           .122          .299           24.5
  8000          .086           .059          .145           31.8
  6000          .051           .035          .086           39.4
  4000          .034           .023          .058           46.6
  2000          .024           .017          .041           52.9
*******************************************************************************
26 Feb 0041    CUSTOM SCENARIO: DELFIC cloud: KC-135: 0.7 MeV energy β xsec
time (hr) = 8  deltat (hr) = .363636  %airborne = 57  sigmax = 5627.78 M
sigmay = 16403.4 M                   3 sigmay cloud diameter = 98420.1 M
Altitude      Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M             REM            REM          REM           microns radius
 12000          .096           .050          .147           11.2
 10000          .049           .026          .075           17.0
  8000          .024           .012          .037           22.4
  6000          .014           7.71 E-03     .022           26.8
  4000          9.92 E-03      .005          .015           30.5
  2000          7.13 E-03      3.77 E-03     .010           34.7
```

Table XVI

DELFIC Cloud and KC-135: S_x=10, S_Y = 1

```
****************************************************************************
1 March 0503    CUSTOM SCENARIO: Baseline + Xshear = 10: Y shear = 1
time (hr) = 1  deltat (hr) = .0967423  %airborne = 90  sigmax = 18319.7 M
sigmay = 4343.43 M                    3 sigmay cloud diameter = 26060.6 M
Altitude      Cabin Dust    Sky Shine    Total dose     Prominent Particle
   M             REM           REM          REM          microns radius
 12000          3.62          6.72         10.3          31.8
 10000          1.71          3.19         4.90          55.1
  8000          .790          1.46         2.25          78.1
  6000          .440          .817         1.25          103.
  4000          .275          .511         .786          126.
  2000          .180          .335         .515          157.
****************************************************************************
1 March 0503    CUSTOM SCENARIO: Baseline + Xshear = 10: Y shear = 1
time (hr) = 2  deltat (hr) = .0967423  %airborne = 81  sigmax = 37665.1 M
sigmay = 6133.43 M                    3 sigmay cloud diameter = 36800.6 M
Altitude      Cabin Dust    Sky Shine    Total dose     Prominent Particle
   M             REM           REM          REM          microns radius
 12000          1.44          1.73         3.18          22.4
 10000          .702          .842         1.54          36.2
  8000          .332          .399         .731          48.6
  6000          .196          .236         .432          60.1
  4000          .133          .160         .294          74.7
  2000          .093          .112         .205          89.5
****************************************************************************
1 March 0503    CUSTOM SCENARIO: Baseline + Xshear = 10: Y shear = 1
time (hr) = 4  deltat (hr) = .166667  %airborne = 69  sigmax = 76487.8 M
sigmay = 9479.4 M                    3 sigmay cloud diameter = 56876.4 M
Altitude      Cabin Dust    Sky Shine    Total dose     Prominent Particle
   M             REM           REM          REM          microns radius
 12000          .4829         .4040        .886          15.4
 10000          .2402         .2009        .441          24.5
  8000          .1169         .0977        .214          31.8
  6000          .0693         .0580        .127          39.4
  4000          .0464         .0388        .085          46.6
  2000          .0335         .0280        .061          52.9
****************************************************************************
1 March 0503    CUSTOM SCENARIO: Baseline + Xshear = 10: Y shear = 1
time (hr) = 8  deltat (hr) = .363636  %airborne = 57  sigmax = 154180 M
sigmay = 16403.4 M                    3 sigmay cloud diameter = 98420.1 M
Altitude      Cabin Dust    Sky Shine    Total dose     Prominent Particle
   M             REM           REM          REM          microns radius
 12000          .1305         .083         .2137         11.2
 10000          .0670         .042         .1097         17.0
  8000          .0331         .021         .0543         22.4
  6000          .0197         .012         .0323         26.8
  4000          .0134         8.58 E-03    .0220         30.5
  2000          9.687 E-03    6.17 E-03    .0158         34.7
```

Table XVII

DELFIC Cloud and KC-135: S_x=1, S_y = 10

```
********************************************************************************
1 March 0618    CUSTOM SCENARIO: Baseline + X shear = 1: Y shear = 10
time (hr) = 1  deltat (hr) = .0967423  %airborne = 90  sigmax = 4355.52 M
sigmay = 18604.2 M                   3 sigmay cloud diameter = 111625 M
Altitude       Cabin Dust      Sky Shine    Total dose     Prominent Particle
   M              REM             REM          REM           microns radius
 12000           .8086           1.50         2.30           31.8
 10000           .3870           .718         1.10           55.1
  8000           .1795           .333         .512           78.1
  6000           .1010           .187         .288           103.
  4000           .0636           .118         .181           126.
  2000           .0422           .078         .120           157.
********************************************************************************
1 March 0618    CUSTOM SCENARIO: Baseline + X shear = 1: Y shear = 10
time (hr) = 2  deltat (hr) = .0967423  %airborne = 81  sigmax = 6148.72 M
sigmay = 37913.8 M                   3 sigmay cloud diameter = 227483 M
Altitude       Cabin Dust      Sky Shine    Total dose     Prominent Particle
   M              REM             REM          REM           microns radius
 12000           .2302           .2761        .5064          22.4
 10000           .1121           .1344        .2465          36.2
  8000           .0533           .0639        .1172          48.6
  6000           .0316           .0379        .0696          60.1
  4000           .0215           .0258        .0474          74.7
  2000           .0151           .0181        .0333          89.5
********************************************************************************
1 March 0618    CUSTOM SCENARIO: Baseline + X shear = 1: Y shear = 10
time (hr) = 4  deltat (hr) = .166667  %airborne = 69  sigmax = 9500.64 M
sigmay = 76750.9 M                   3 sigmay cloud diameter = 460505 M
Altitude       Cabin Dust      Sky Shine    Total dose     Prominent Particle
   M              REM             REM          REM           microns radius
 12000           .059            .049         .1091          15.4
 10000           .029            .024         .0543          24.5
  8000           .014            .012         .0264          31.8
  6000           .0088           7.16 E-03    .0157          39.4
  4000           5.7  E-03       4.80 E-03    .0105          46.6
  2000           4.15 E-03       3.47 E-03    .0076          52.9
********************************************************************************
1 March 0618    CUSTOM SCENARIO: Baseline + X shear = 1: Y shear = 10
time (hr) = 8  deltat (hr) = .363636  %airborne = 57  sigmax = 16435.6 M
sigmay = 154523 M                    3 sigmay cloud diameter = 927139 M
Altitude       Cabin Dust      Sky Shine    Total dose     Prominent Particle
   M              REM             REM          REM           microns radius
 12000           .013            8.83 E-03    .022           11.2
 10000           7.12 E-03       4.54 E-03    .011           17.0
  8000           .003            2.24 E-03    5.77 E-03      22.4
  6000           2.10 E-03       1.34 E-03    3.44 E-03      26.8
  4000           1.43 E-03       9.13 E-04    2.34 E-03      30.5
  2000           1.03 E-03       6.56 E-04    1.68 E-03      34.7
```

Table XVIII

DELFIC Cloud and B-52G

```
*******************************************************************************
12 Jan 1549    CUSTOM SCENARIO: baseline + B-52G
time (hr) = 1  deltat (hr) = .0967423  %airborne = 90  sigmax = 3958.03 M
sigmay = 4355.52 M                    3 sigmay cloud diameter = 26133.1 M
Altitude       Cabin Dust    Sky Shine    Total Dose     Prominent Particle
   M              REM          REM           REM          microns radius
 12000           5.91          4.16          10.0           31.8
 10000           2.80          1.97          4.78           55.1
  8000           1.29          .908          2.19           78.1
  6000           .719          .506          1.22           103.
  4000           .449          .316          .766           126.
  2000           .294          .207          .502           157.
*******************************************************************************
12 Jan 1549    CUSTOM SCENARIO: baseline + B-52G
time (hr) = 2  deltat (hr) = .0967423  %airborne = 81  sigmax = 4865.07 M
sigmay = 6148.72 M                    3 sigmay cloud diameter = 36892.3 M
Altitude       Cabin Dust    Sky Shine    Total Dose     Prominent Particle
   M              REM          REM           REM          microns radius
 12000           2.36          1.07          3.43           22.4
 10000           1.14          .521          1.66           36.2
  8000           .543          .247          .790           48.6
  6000           .321          .146          .467           60.1
  4000           .218          .099          .317           74.7
  2000           .152          .069          .221           89.5
*******************************************************************************
12 Jan 1549    CUSTOM SCENARIO: baseline + B-52G
time (hr) = 4  deltat (hr) = .166667  %airborne = 69  sigmax = 5627.78 M
sigmay = 9500.64 M                    3 sigmay cloud diameter = 57003.8 M
Altitude       Cabin Dust    Sky Shine    Total Dose     Prominent Particle
   M              REM          REM           REM          microns radius
 12000           .788          .250          1.03           15.4
 10000           .392          .124          .516           24.5
  8000           .190          .060          .251           31.8
  6000           .113          .035          .149           39.4
  4000           .075          .024          .100           46.6
  2000           .054          .017          .072           52.9
*******************************************************************************
12 Jan 1549    CUSTOM SCENARIO: baseline + B-52G
time (hr) = 8  deltat (hr) = .363636  %airborne = 57  sigmax = 5627.78 M
sigmay = 16435.6 M                    3 sigmay cloud diameter = 98613.5 M
Altitude       Cabin Dust    Sky Shine    Total Dose     Prominent Particle
   M              REM          REM           REM          microns radius
 12000           .213          .051          .264           11.2
 10000           .109          .026          .135           17.0
  8000           .054          .013          .067           22.4
  6000           .032          7.80 E-03     .040           26.8
  4000           .022          5.31 E-03     .027           30.5
  2000           .015          3.82 E-03     .019           34.7
```

Table XIX

DELFIC Cloud and E-4B

```
****************************************************************************
12 JAN 1756    CUSTOM SCENARIO: Baseline + E-4B
time (hr) = 1  deltat (hr) = .0967423  %airborne = 90  sigmax = 3958.03 M
sigmay = 4355.52 M                   3 sigmay cloud diameter = 26133.1 M
Altitude        Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M               REM            REM          REM          microns radius
 12000            7.41           7.03         14.4          31.8
 10000            3.51           3.34         6.85          55.1
  8000            1.61           1.53         3.15          78.1
  6000            .901           .856         1.75          103.
  4000            .563           .535         1.09          126.
  2000            .369           .350         .720          157.
****************************************************************************
12 JAN 1756    CUSTOM SCENARIO: Baseline + E-4B
time (hr) = 2  deltat (hr) = .0967423  %airborne = 81  sigmax = 4865.07 M
sigmay = 6148.72 M                   3 sigmay cloud diameter = 36892.3 M
Altitude        Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M               REM            REM          REM          microns radius
 12000            2.96           1.81         4.78          22.4
 10000            1.43           .881         2.31          36.2
  8000            .681           .417         1.09          48.6
  6000            .403           .247         .650          60.1
  4000            .273           .167         .441          74.7
  2000            .191           .117         .308          89.5
****************************************************************************
12 JAN 1756    CUSTOM SCENARIO: Baseline + E-4B
time (hr) = 4  deltat (hr) = .166667  %airborne = 62  sigmax = 5627.78 M
sigmay = 9500.64 M                   3 sigmay cloud diameter = 57003.8 M
Altitude        Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M               REM            REM          REM          microns radius
 12000            .988           .423         1.41          15.4
 10000            .491           .210         .702          24.5
  8000            .239           .102         .341          31.8
  6000            .141           .060         .202          39.4
  4000            .095           .040         .135          46.6
  2000            .068           .029         .098          52.9
****************************************************************************
12 JAN 1756    CUSTOM SCENARIO: Baseline + E-4B
time (hr) = 8  deltat (hr) = .363636  %airborne = 57  sigmax = 5627.78 M
sigmay = 16435.6 M                   3 sigmay cloud diameter = 98613.5 M
Altitude        Cabin Dust     Sky Shine    Total Dose     Prominent Particle
   M               REM            REM          REM          microns radius
 12000            .267           .087         .354          11.2
 10000            .137           .044         .182          17.0
  8000            .067           .022         .090          22.4
  6000            .040           .013         .054          26.8
  4000            .027           8.99 E-03    .037          30.5
  2000            .019           6.46 E-03    .026          34.7
```

Table XX

DELFIC Cloud and EC-135

```
*****************************************************************************
13 Jan 0926     CUSTOM SCENARIO: Baseline + EC-135
time (hr) = 1   deltat (hr) = .0967423  %airborne = 90  sigmax = 3958.03 M
sigmay = 4355.52 M                      3 sigmay cloud diameter = 26133.1 M
Altitude        Cabin Dust    Sky Shine    Total Dose    Prominent Particle
   M               REM           REM          REM          microns radius
 12000            5.18          6.50         11.6          31.8
 10000            2.46          3.08         5.54          55.1
  8000            1.13          1.41         2.55          78.1
  6000            .631          .790         1.42          103.
  4000            .394          .494         .888          126.
  2000            .258          .323         .582          157.
*****************************************************************************
13 Jan 0926     CUSTOM SCENARIO: Baseline + EC-135
time (hr) = 2   deltat (hr) = .0967423  %airborne = 81  sigmax = 4865.07 M
sigmay = 6148.72 M                      3 sigmay cloud diameter = 36892.3 M
Altitude        Cabin Dust    Sky Shine    Total Dose    Prominent Particle
   M               REM           REM          REM          microns radius
 12000            2.07          1.67         3.75          22.4
 10000            1.00          .814         1.82          36.2
  8000            .476          .385         .862          48.6
  6000            .282          .228         .510          60.1
  4000            .191          .155         .346          74.7
  2000            .133          .108         .242          89.5
*****************************************************************************
13 Jan 0926     CUSTOM SCENARIO: Baseline + EC-135
time (hr) = 4   deltat (hr) = .166667  %airborne = 69  sigmax = 5627.78 M
sigmay = 9500.64 M                      3 sigmay cloud diameter = 57003.8 M
Altitude        Cabin Dust    Sky Shine    Total Dose    Prominent Particle
   M               REM           REM          REM          microns radius
 12000            .691          .390         1.08          15.4
 10000            .344          .194         .538          24.5
  8000            .167          .094         .262          31.8
  6000            .099          .056         .155          39.4
  4000            .066          .037         .104          46.6
  2000            .048          .027         .075          52.9
*****************************************************************************
13 Jan 0926     CUSTOM SCENARIO: Baseline + EC-135
time (hr) = 8   deltat (hr) = .363636  %airborne = 57  sigmax = 5627.78 M
sigmay = 16435.6 M                      3 sigmay cloud diameter = 98613.5 M
Altitude        Cabin Dust    Sky Shine    Total Dose    Prominent Particle
   M               REM           REM          REM          microns radius
 12000            .186          .080         .267          11.2
 10000            .096          .041         .137          17.0
  8000            .047          .020         .068          22.4
  6000            .028          .012         .040          26.8
  4000            .019          8.30 E-03    .027          30.5
  2000            .013          5.97 E-03    .019          34.7
```

IV. Mass Analysis

Background

There are two reasons why it is important to determine the mass of dust ingested by an aircraft. The first is that any filter designed to prevent radioactive dust from entering the cabin will eventually clog when exposed to enough dust. When this point is reached, the filter will be bypassed and unfiltered air will enter the cabin.

The second reason is that aircraft engines may be degraded or disabled by excessive amounts of dust. Recent experience with volcanic ash clouds (Ref 13) shows that erosion of turbine blades and glass-like deposits of melted dust may drastically increase fuel consumption or cause engine failure.

Theory

Determining the mass of dust ingested by the cabin, an air filter, or the engines in an aircraft, is identical in principle to the method described in Chapters II and III. The only changes needed are to substitute mass and mass densities for unit time activities and activity densities so that Eq (14) and Eq (18) are replaced by

$$M'''(x,y,z,t) = \int_0^{+\infty} M_r'''(x,y,z,r,t)\, dr \quad [KG/m^3] \qquad (43)$$

and

$$\int_0^{+\infty} M_r'(z,r,t)\, dr = \sum_{i=1}^{100} M^i \, f^i(z,t) \quad [KG/m] \qquad (44)$$

where the equal activity-size particle groups are replaced by equal mass-size particle groups. The mass density of the cloud is defined as mass of rock per unit volume of air with units of kg/m^3. Figures 10, 11 and 12 show mass density versus altitude in the cloud in the same manner that Figures 6, 7, and 8 depicted activity density versus altitude. Note that the mass density decreases at a much slower rate than the activity density. This is because the radioactivity is decaying with time as well as settling out.[3]

The total amount of mass initially lofted in the nuclear cloud depends on the target material, the height of burst, and the yield. A common rule of thumb is 1/3 ton of dust per ton of yield. This study found a least-squares fit polynomial to DELFIC default Nevada soil predictions for mass of dust lofted: this relationship is

$$DF = .204731 - .0240532 \ln Y + .00139148 (\ln Y)^2 - 4.88467 \times 10^{-5} (\ln Y)^3 + 8.62805 \times 10^{-7} (\ln Y)^4 \qquad (45)$$

where Y is yield in kilotons and DF is dust fraction, the ratio tons dust/tons yield so that total dust mass in kilotons equals the dust fraction times the yield in kilotons. DELFIC predicts a dust fraction from .1 to .2 depending on yield, for the default Nevada soil surface burst. This study will use a dust fraction of 1/3 because dust fractions for other soils were not found and because it is defense conservative.

---

[3] It is also possible to determine the mass fraction in each activity-size group or the activity fraction in each mass size group so that the calculations need be done only once. DELFIC operates in this manner. This is not done here.

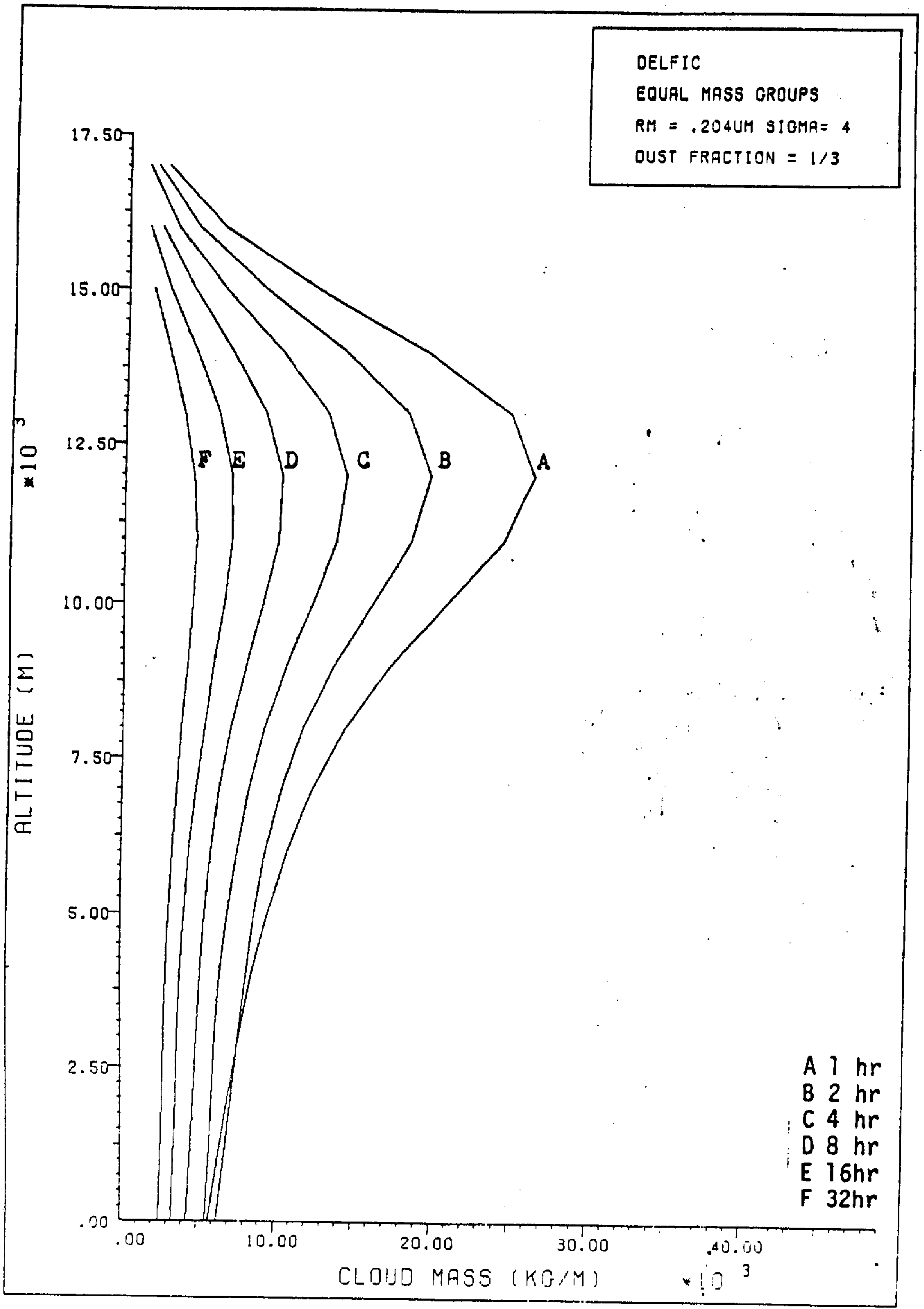

Figure 10.- BASELINE - DELFIC MASS - ONE MEGATON

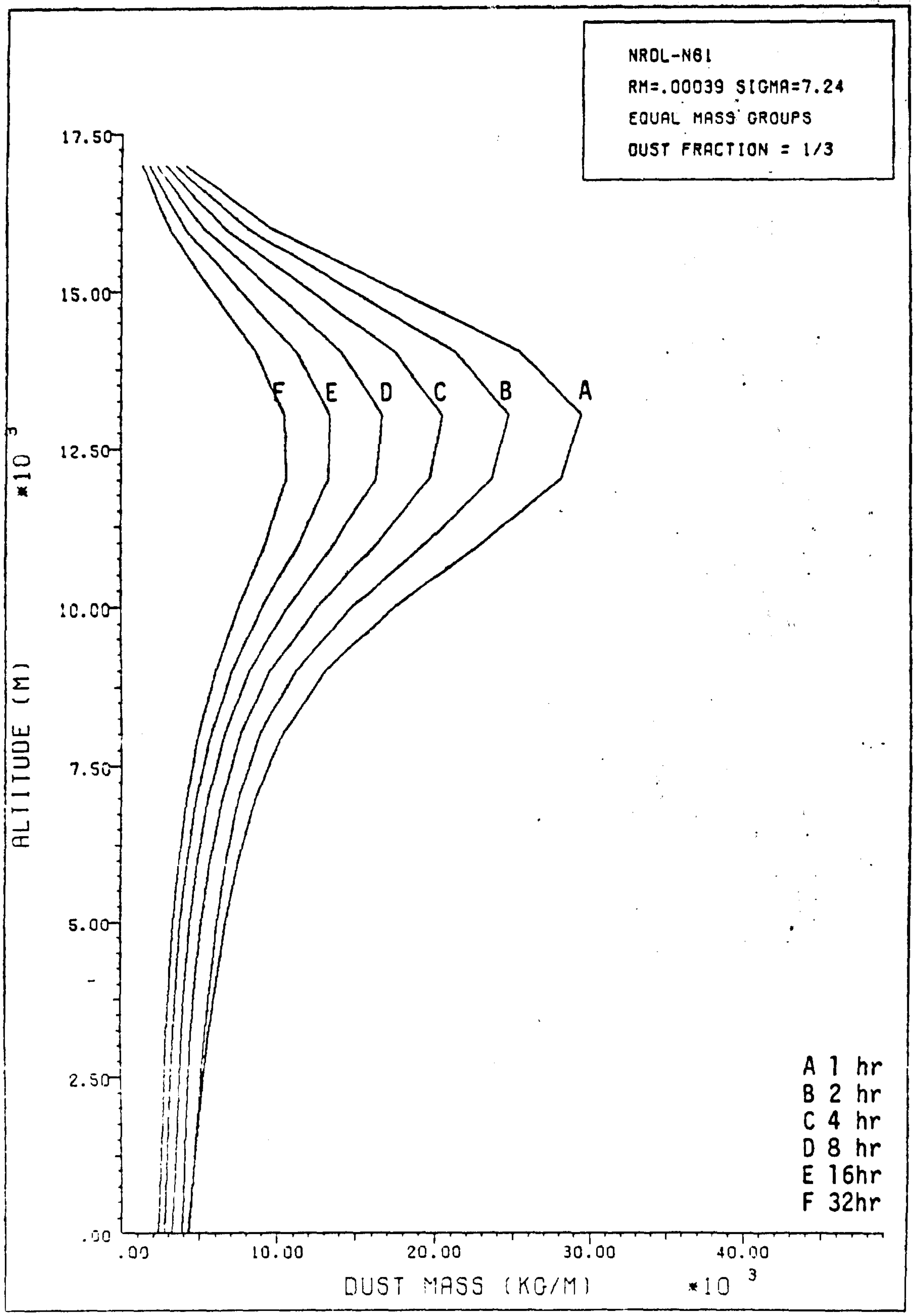

FIGURE 11 - NRDL-N61 CLOUD MASS - ONE MEGATON

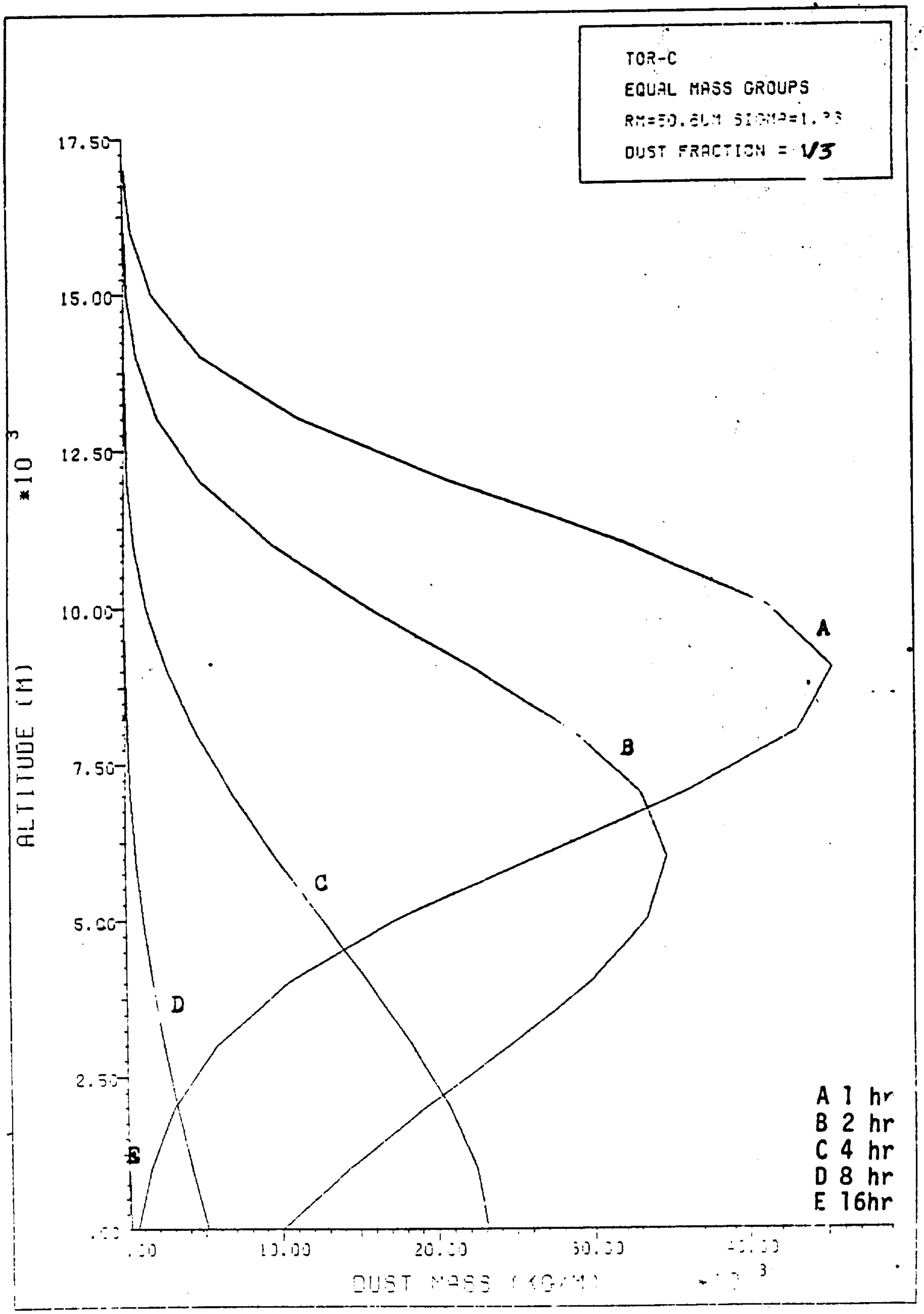

Figure 12. - TOR-C MASS - ONE MEGATON

Filter And Engine Ingestion

The mass of dust ingested into the cabin or trapped in a filter depends on the mass flow rate of air into the cabin. As before, the effective inlet area is

$$IA_{cd} = \frac{\Omega}{v_x \, \rho_{air}} \qquad [m^2] \qquad (39)$$

where Ω is the mass flow rate. The mass of dust is the product of the above equation and the mass integral of the airborne dust. The dust mass integral is found by the same method as the 'activity-integral' in Eq (38), where the activity densities are replaced by mass densities so that

$$M''(y,z,t) = f(y,t) \, M'(z,t) \int_{-\infty}^{+\infty} f(x,t) \, dx \quad [kg/m^2] \qquad (46)$$

where $M'(z,t)$ is given by Eq (44).

Engines may be affected both by dust density and by the total mass of dust ingested. The peak dust density is found in the center of the cloud in the same manner that activity densities were found in Chapters II and III. The amount of dust passing through an engine is found by substituting the mass flow of air into the engine for the mass flow of air to the cabin. Note that the physical inlet area of the engine is not used. If the dust entering the core section of a turbofan engine is desired, the total mass flow of the engine must be divided by the bypass ratio. Data for the engines used for the aircraft in this study are found in the following table.

TABLE XXI

ENGINE DATA

Aircraft Type	Engine Type	Mass Flow KG/S	Bypass Ratio
B-1B	F-101-GE-102	161	2.3
B-52G	J57-P-43WB	83	0
B-52H	TF-33-P-3	204	1.4
E-3	TF-33-P	204	1.4
E-4B	CF-6-50E2	729	4.3
EC-135	J57-P- WB	83	0
KC-135	J57-P- WB	83	0

The above flow rates are for each engine at unaugmented military rated thrust and standard (sea level) conditions.

Mass flow scales directly as thrust to a good approximation. If the percent thrust used for cruise speed at the penetration altitude is known, this percentage can be multiplied by the mass flow of the engine at sea level. This will result in a more realistic (and lower) mass flow through the engine. This refinement was not included in this study to simplify the treatment of the many different altitudes and aircraft examined: the percentage will vary for both these parameters.

Mass Results

Tables XXII, XXIII, and XXIV give the results for dust ingestion using the equal mass groups for the same DELFIC, NRDL-N61, and TOR-C clouds and initial conditions used in

Chapter III.

The amount of dust trapped in the cabin in Table XXII is much less than the capacity of the filter mentioned in Chapter III. It would appear that there is little danger of clogging the filter unless a large multiple burst cloud is encountered or a single cloud is entered many times.

Although no reliable quantitative data could be found on engine dust tolerance, the amount of dust ingested in these cases appears to be minimal. Earlier times and multiburst cloud results are given in Appendices G and I.

TABLE XXII

DELFIC Dust Cloud and KC-135

```
*************************************************************************************
13 Jan 0959    CUSTOM SCENARIO: Baseline DELFIC dust, KC-135,Dust Fraction=1/3
time (hr) = 1  deltat (hr) = .0967423  %airborne = 85  sigmax = 3994.78 M
sigmay = 4389.7 M             3 sigmay cloud diameter = 26338.2 M   Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust   Engine Dust  Particle
   M            mg/M^3          Kg            Kg            Kg       microns r
 12000          235.          0           .027          2.71        32.0
 10000          185.          0           .016          1.61        53.7
  8000          129.          0           8.84 E-03     .883        76.1
  6000          97.0          0           5.28 E-03     .527        101.
  4000          77.3          0           3.39 E-03     .339        126.
  2000          63.4          0           2.26 E-03     .226        155.
*************************************************************************************
13 Jan 0959    CUSTOM SCENARIO: Baseline DELFIC dust, KC-135,Dust Fraction=1/3
time (hr) = 2  deltat (hr) = .0967423  %airborne = 73  sigmax = 4924.79 M
sigmay = 6198.22 M            3 sigmay cloud diameter = 37189.3 M   Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust   Engine Dust  Particle
   M            mg/M^3          Kg            Kg            Kg       microns r
 12000          101.          0           .014          1.44        21.7
 10000          83.4          0           8.96 E-03     .894        36.0
  8000          60.6          0           5.11 E-03     .510        48.3
  6000          48.9          0           3.28 E-03     .328        61.7
  4000          42.6          0           2.30 E-03     .230        73.5
  2000          37.4          0           1.65 E-03     .164        87.6
*************************************************************************************
13 Jan 0959    CUSTOM SCENARIO: Baseline DELFIC dust, KC-135,Dust Fraction=1/3
time (hr) = 4  deltat (hr) = .166667  %airborne = 57  sigmax = 5705.15 M
sigmay = 9544.24 M            3 sigmay cloud diameter = 57265.5 M  Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust   Engine Dust  Particle
   M            mg/M^3          Kg            Kg            Kg       microns r
 12000          41.6          0           .006          .684        15.9
 10000          35.4          0           4.41 E-03     .440        24.9
  8000          26.7          0           .002          .261        32.0
  6000          21.8          0           .001          .169        38.8
  4000          18.9          0           1.19 E-03     .118        46.6
  2000          17.3          0           8.85 E-04     .088        53.7
*************************************************************************************
13 Jan 0959    CUSTOM SCENARIO: Baseline DELFIC dust, KC-135,Dust Fraction=1/3
time (hr) = 8  deltat (hr) = .363636  %airborne = 43  sigmax = 5705.15 M
sigmay = 16462.4 M            3 sigmay cloud diameter = 98774.5 M  Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust   Engine Dust  Particle
   M            mg/M^3          Kg            Kg            Kg       microns r
 12000          17.1          0           2.82 E-03     .281        11.4
 10000          15.2          0           1.89 E-03     .189        16.8
  8000          11.8          0           .001          .115        21.7
  6000          9.81          0           7.64 E-04     .076        26.1
  4000          8.75          0           5.49 E-04     .054        30.8
  2000          8.02          0           4.09 E-04     .040        34.7
```

TABLE XXIII

NRDL-N61 Dust Cloud and KC-135

```
************************************************************************
11 Jan 2207    CUSTOM SCENARIO: NRDL-N61 Dust Cloud,KC-135,Dust Fraction=1/3
time (hr) = 1  deltat (hr) = .0967423  %airborne = 81  sigmax = 3973.99 M
sigmay = 4360.21 M          3 sigmay cloud diameter = 26161.3 M  Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust   Engine Dust  Particle
   M            mg/M^3          Kg             Kg           Kg       microns r
 12000          254.          0            .029          2.91        30.9
 10000          158.          0            .013          1.36        53.6
  8000          93.8          0            6.39 E-03     .638        76.1
  6000          68.0          0            3.69 E-03     .368        103.
  4000          55.0          0            2.40 E-03     .239        129.
  2000          46.2          0            1.64 E-03     .164        153.
************************************************************************
11 Jan 2207    CUSTOM SCENARIO: NRDL-N61 Dust Cloud,KC-135,Dust Fraction=1/3
time (hr) = 2  deltat (hr) = .0967423  %airborne = 71  sigmax = 4891.03 M
sigmay = 6153.33 M          3 sigmay cloud diameter = 36920 M    Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust   Engine Dust  Particle
   M            mg/M^3          Kg             Kg           Kg       microns r
 12000          122.          0            .017          1.73        22.5
 10000          77.3          0            8.25 E-03     .823        35.9
  8000          46.3          0            3.88 E-03     .387        48.5
  6000          34.8          0            .002          .232        62.2
  4000          29.9          0            1.60 E-03     .160        76.1
  2000          26.1          0            1.14 E-03     .114        88.7
************************************************************************
11 Jan 2207    CUSTOM SCENARIO: NRDL-N61 Dust Cloud,KC-135,Dust Fraction=1/3
time (hr) = 4  deltat (hr) = .181818  %airborne = 60  sigmax = 5661.43 M
sigmay = 9493.12 M          3 sigmay cloud diameter = 56958.7 M  Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust   Engine Dust  Particle
   M            mg/M^3          Kg             Kg           Kg       microns r
 12000          57.3          0            9.39 E-03     .9371      16.1
 10000          36.7          0            4.53 E-03     .4526      25.1
  8000          22.3          0            2.17 E-03     .2167      32.5
  6000          16.6          0            1.28 E-03     .1285      39.7
  4000          13.9          0            8.67 E-04     .0865      46.1
  2000          12.4          0            6.29 E-04     .0628      53.6
************************************************************************
11 Jan 2207    CUSTOM SCENARIO: NRDL-N61 Dust Cloud,KC-135,Dust Fraction=1/3
time (hr) = 8  deltat (hr) = .363636  %airborne = 50  sigmax = 5661.43 M
sigmay = 16412.3 M          3 sigmay cloud diameter = 98474 M    Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust   Engine Dust  Particle
   M            mg/M^3          Kg             Kg           Kg       microns r
 12000          27.5          0            4.49 E-03     .448        11.1
 10000          18.0          0            2.23 E-03     .222        17.1
  8000          11.1          0            1.08 E-03     .107        22.5
  6000          8.29          0            6.41 E-04     .0639       26.4
  4000          7.02          0            4.37 E-04     .0436       30.9
  2000          6.22          0            3.15 E-04     .0314       34.2
```

TABLE XXIV

TOR-C Dust Cloud and KC-135

```
************************************************************************
12 JAN 0107    CUSTOM SCENARIO: TOR-C Dust Cloud,KC-135,Dust Fraction = 1/3
time (hr) = 1  deltat (hr) = .386969  %airborne = 100  sigmax = 3998.88 M
sigmay = 4396.15 M          3 sigmay cloud diameter = 26376.9 M  Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust    Engine Dust  Particle
  M              mg/M^3          Kg            Kg             Kg      microns r
 12000         18[illegible]          0            .021           2.15      30.4
 10000         369.           0            .032           3.21      54.3
  8000         386.           0            .026           2.64      75.9
  6000         236.           0            .012           1.28      98.7
  4000         94.1           0            4.14 E-03      .413      122.
  2000         27.2           0            9.76 E-04      .0974     148.
************************************************************************
12 JAN 0107    CUSTOM SCENARIO: TOR-C Dust Cloud,KC-135,Dust Fraction = 1/3
time (hr) = 2  deltat (hr) = .386969  %airborne = 100  sigmax = 4931.45 M
sigmay = 6178.95 M          3 sigmay cloud diameter = 37073.7 M  Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust    Engine Dust  Particle
  M              mg/M^3          Kg            Kg             Kg      microns r
 12000         25.8           0            3.68 E-03      .367      30.4
 10000         80.9           0            8.71 E-03      .869      38.4
  8000         148.           0            .012           1.25      51.5
  6000         179.           0            .012           1.20      64.3
  4000         154.           0            8.38 E-03      .836      79.3
  2000         100.           0            4.42 E-03      .442      94.3
************************************************************************
12 JAN 0107    CUSTOM SCENARIO: TOR-C Dust Cloud,KC-135,Dust Fraction = 1/3
time (hr) = 4  deltat (hr) = .386969  %airborne = 80  sigmax = 5713.77 M
sigmay = 9521.07 M          3 sigmay cloud diameter = 57126.4 M  Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust    Engine Dust  Particle
  M              mg/M^3          Kg            Kg             Kg      microns r
 12000         .717           0            1.18 E-04      .012       30.4
 10000         4.20           0            5.24 E-04      .052       30.4
  8000         13.3           0            1.30 E-03      .130       34.4
  6000         28.2           0            2.19 E-03      .219       41.1
  4000         45.4           0            2.85 E-03      .284       47.8
  2000         60.4           0            3.08 E-03      .308       55.3
************************************************************************
12 JAN 0107    CUSTOM SCENARIO: TOR-C Dust Cloud,KC-135,Dust Fraction = 1/3
time (hr) = 8  deltat (hr) = .386969  %airborne = 20  sigmax = 5713.77 M
sigmay = 16429.7 M          3 sigmay cloud diameter = 98578.3 M  Prominent
Altitude       Cloud Dens   Filtered Dust  Cabin Dust    Engine Dust  Particle
  M              mg/M^3          Kg            Kg             Kg      microns r
 12000         0              0            0              0               30.4
 10000         .018           0            2.24 E-06      2.24 E-04       30.4
  8000         .223           0            2.18 E-05      2.18 E-03       30.4
  6000         1.10           0            8.57 E-05      .008            30.4
  4000         2.83           0            1.78 E-04      .017            30.4
  2000         5.41           0            2.76 E-04      .027            36.7
```

V. Conclusions and Recommendations

Conclusions

This study has extended the calculation of aircrew dose to a wide variety of strategic aircraft. An improved model of the aircraft cabin was developed to allow better estimates of shielding from external gamma rays and dose rates for internal gamma rays. A 22% increase in the shielding factor and a 16% decrease in the cabin geometry factor reduce the aircrew dose due to sky-shine and cabin dust by proportionate amounts, compared to Kling's KC-135 model.

Additions to the nuclear cloud model as suggested by Bridgman and Bigelow (Ref 1) have allowed the effects of different particle size distributions to be considered. The differences are significant. Comparing doses at the maximum dose altitudes due to clouds composed primarily of small (NRDL-N61) and large (TOR-C) particles, the NRDL-N61 cloud caused 30% more dose to the aircrew at one hour for both sky-shine and cabin dust. After 4 hours, the differences in dose reached an order of magnitude: the total dose is small, however, due to decay of activity with time.

A simple extension to the cloud model allows dust densities and the mass of dust ingested by an engine or a filter to be found. Differences in the dust densities between the NRDL-N61 and TOR-C clouds were reversed compared to the doses at early times. At one hour, the TOR-C cloud had a 50% greater dust density. The rapid fallout of the larger particles in the TOR-C cloud reduces the cloud density much more rapidly, however, so that after 4 hours the densities are similar and after 8 hours only 20% of the original cloud was still airborne. Fifty percent of the NRDL-N61 cloud was still aloft at 8 hours.

Addition of a filter to the cabin air supply made a major difference to the dose due to the dust trapped in the cabin and demonstrated that filters need not stop sub-micron particles to be effective. For an 8 hour mission, a filter stopping particles larger than 20 microns trapped 80% of the cabin dust dose at 37,000 feet for 1 hour after the burst, and trapped all of it below 20,000 feet at any time. Since the smaller particles that pass through the filter are less likely to settle out in the cabin, the filter should be even more effective than these calculations showed.

Comparison of air density with dust densities likely to be found in a megaton size nuclear cloud indicates that self-shielding of the dust is negligible. The dust density is only 0.3% of the air density, and gamma cross sections are similar. Thus the attenuation due to air is much larger than any attenuation due to dust.

Splitting the single wind shear into two components allowed the aircraft to penetrate the late time cloud in any direction. After 1 hour of a typical wind ($S_t = 10.05$), penetrating the cloud along the major axis will result in 5 times as much dose as penetrating along the minor axis. After 8 hours, there will be a factor of 10 difference in dose. The increase in dose is due equally to sky-shine and cabin dust dose. Aircraft required to orbit an area downwind of a target area could follow a long, narrow racetrack at right angles to the prevailing wind, thereby minimizing dose.

Recommendations

There are six recommendations to be made. First, the constant gamma ray energy assumption of 1 MeV could be replaced by a time dependent energy. This would involve making all of the absorption and attenuation coefficients variables as well. Doses would be increased at early times and decreased at later times.

Second, the airflow through the cabin could be modeled to determine what size particles could be expected to stay suspended long enough to be removed from the cabin by the outgoing air. Patrick (Ref 20) suggests a method for doing this.

Third, equipment and structure inside the cabin could be modeled to account for shielding from the dust trapped in the cabin.

Fourth, aircraft engines could be tested to determine whether the dust densities predicted to exist in a nuclear cloud would degrade engine operation and thus be a concern for determining survivability of the aircraft.

Fifth, a more realistic wind model could be developed.

Last, an algorithm to adjust engine thrust (thus mass flow and engine dust ingestion) with altitude and airspeed could be added so that a more realistic engine mass ingestion could be found.

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APPENDIX A

DELFIC Data

This Appendix contains data and polynomials least-squares fit to data predicted by DELFIC for an initial nuclear cloud. Only data that appeared to be potentially useful for this study were extracted and reduced. Do not consider this study or this Appendix to be a complete summary of DELFIC. The raw data in this Appendix represents less than 1% of all data in a typical DELFIC printout. The term "DELFIC default" refers not only to the particle size distribution used (see Chapter II), but to the winds, fission fraction of the weapon, type of soil, and other variables. See Chapter II for more information on DELFIC. See Gogdin (Ref 9) for further details and information to run DELFIC.

The modules of interest for this study are Fireball, Cloud Rise, Interface, and Diffusive Transport. The data from them are presented below in no particular order. All times are in seconds, all altitudes are in meters, all masses are in kilograms, all particle diameters are in microns. Note that DELFIC assigns the smallest group number to the largest size group. The programs in this study use the opposite convention. Also note that this study refers to particle size in terms of radius. DELFIC refers to particle sizes by diameter.

The data presented here are for the:

1. Altitudes of the top and bottom, and the thickness of each disc for every ten particle size groups at vertical stabilization time.
2. Time since burst and radius of the cloud at vertical stabilization.
3. Time since burst and radius of the cloud at horizontal stabilization.
4. Time of solidification of the surface material evaporated in the fireball, and mass of dust airborne at solidification time.

A1. Particle Size versus Altitude at vertical stabilization time

DELFIC divides a particle size distribution into 100 equal mass-size groups. Each group is modeled as a disc, and each disc is subdivided into 20 wafers. Among other things, DELFIC prints the altitude of the top and bottom of each wafer for the initial cloud at vertical stabilization time. Each wafer and each disc may overlap adjoining wafers or discs. This data is printed at the beginning of the Diffusive Transport module.

DELFIC predicts the same altitude for a given size particle for all of the particle size distributions tested; DELFIC default, NRDL-N61, TTAPS, and TOR-C (Ref 3) (see Table I).

To limit the amount of data to be handled, altitude information was extracted for every tenth particle size group rather than for all 100 groups. The data extracted from DELFIC follows. BB refers to the altitude of the bottom of the lowest wafer in a particle size group. TT refers to the altitude of the top of the highest wafer in a particle size group. DeltaZ is the difference of these altitudes computed by this study.

****

PRIMARY DATA - from DELFIC default fitches and printout
initial cloud height data

****

1, kt 20 Oct 84 Delfic default Rm=.407 sigma = 4 silica soil

Delfic group	diameter	BB	TT	DeltaZ
10	799.84	0	0	0
20	427.59	0	1181	0
30	273.97	508.3	1886	1377.7
40	187.75	1057	2369	1312
50	132.13	1426	2682	1256
60	93.105	1663	2895	1232
70	64.063	1846	3043	1197
80	41.447	1957	3135	1178
90	22.824	2021	3189	1168
100	3.6513	2050	3212	1162

****

10, kt 20 Oct 84 Delfic default Rm=.407 sigma = 4 silica soil

Delfic group	diameter	BB	TT	DeltaZ
10	799.84	0	2583	0
20	427.59	1663	4269	2606
30	273.97	2721	5199	2478
40	187.75	3357	5747	2390
50	132.13	3785	6095	2310
60	93.105	4062	6334	2272
70	64.063	4272	6494	2222
80	41.447	4400	6595	2195
90	22.824	4474	6652	2178
100	3.6513	4505	6677	2172

****

100, kt 20 Oct 84 Delfic default Rm=.407 sigma = 4 silica soil

Delfic group	diameter	BB	TT	DeltaZ
10	799.84	1015	5676	4661
20	427.59	3755	8384	4629
30	273.97	5139	9786	4647
40	187.75	5980	10600	4620
50	132.13	6543	11110	4567
60	93.105	6921	11470	4549
70	64.063	7195	11700	4505
80	41.447	7365	11840	4475
90	22.824	7470	11930	4460
100	3.6513	7505	11960	4455

****

1000, kt 20 Oct 84 Delfic default Rm=.407 sigma = 4 silica soil

Delfic group	diameter	BB	TT	DeltaZ
10	799.84	2269	8646	6377
20	427.59	5653	12460	6807
30	273.97	7412	14980	7568
40	187.75	8497	16190	7693
50	132.13	9221	16960	7739
60	93.105	9725	17480	7755
70	64.063	10070	17800	7730
80	41.447	10300	18000	7700
90	22.824	10470	18150	7680
100	3.6513	10470	18150	7680

```
************************************************************************
 15000, kt  20 Oct 84 Delfic default Rm=.407 sigma = 4 silica soil
Delfic group    diameter        BB              TT              DeltaZ
 10             799.84          8187            19020           10833
 20             427.59          12530           28610           16080
 30             273.97          14900           32620           17720
 40             187.75          16360           34830           18470
 50             132.13          17350           36070           18720
 60             93.105          17980           36790           18810
 70             64.063          18430           37210           18780
 80             41.447          18670           37450           18780
 90             22.824          18810           37610           18800
 100            3.6513          18810           37610           18800
************************************************************************
 50000, kt  5 Dec 84 Delfic default Rm=.407 sigma = 4 silica soil
Delgrp         diameter         BB              TT              DeltaZ
 10             799.84          7847            24020           16173
 20             427.59          12390           37930           25540
 30             273.97          14890           43790           28900
 40             187.75          16440           46660           30220
 50             132.13          17490           48230           30740
 60             93.105          18220           49110           30890
 70             64.063          18650           49610           30960
 80             41.447          19040           49950           30910
 90             22.824          19040           50110           31070
 100            3.6513          19040           50150           31110
```

Values for the 50 MT burst were not incorporated into the polynomial fits; Hopkins' data covers 1 to 15000 kt only and yields larger than this will be uncommon in any event.

Following a method developed by Hopkins (Ref 11), for each yield a linear least-squares fit was obtained for particle diameter in microns versus altitude in meters. Deviations from linearity were quite small, with deviations in altitude typically less than 1%. DeltaZ was fitted in the same manner as altitude. The least-squares linear fits to the above data follow.

```
**********************************************************************
INTERMEDIATE DATA - slope and intercept for BB, TT, and DeltaZ
**********************************************************************


             TOP OF TOP WAFER

YIELD (kt)       slope(m/micron) intercept(m)

1                -5.01902         3316.48

10               -5.87268         6820.28

100              -8.7145         12182.5

1,000            -12.582         18456.3

15,000           -23.9386        38680

50,000           -33.4709        51809.4
----------------------------------------------

          BOTTOM OF BOTTOM WAFER

YIELD (kt)       slope(m/micron) intercept(m)

1                -5.91157         2171.19

10               -6.95509         4656.53

100              -9.19309         7703.61

1,000            -10.7505        10608.7

15,000           -14.0467        19077.2

50,000           -14.8734        19348.4
----------------------------------------------

                 DELTA Z

YIELD (kt)       slope(m/micron) intercept(m)

1                +1.01059         1135.89

10               +1.08241         2163.75

100              +0.260011        4503.59

1,000            -1.8315          7847.69

15,000           -9.89187        19603.5

50,000           -18.5842        32454.3
```

The natural log of each of the above slopes and each of the above intercepts were least-squares fit to a polynomial in ln(Y), the natural log of the yield in kilotons. The values for slope were combined with additive factors to make them non-negative so that the logs could be taken. This method of fit was used because it gave the smallest errors of all the methods tried.

Values for the 50 MT bursts were not incorporated into the polynomial fits; Hopkins' data covers 1 to 15000 kt only and yields larger than this will be uncommon in any event.

Slopes and Intercepts for the various fits are identified by subscripts. The subscript T identifies the fit to the Top of the top wafer, b identifies the fit to the bottom wafer, and d refers to the fit of the DeltaZ for each group. These polynomials are given below.

Also included below is the polynomial fit used by Hopkins. Hopkins found the center altitude for each of the twenty wafers in each group, then averaged them to obtain an (average) center altitude for the group. These polynomials are identified by the subscript m.

TOP OF TOP WAFER

The altitude of the top of the disc is the altitude of the topmost wafer in the disc.

$$S_T = -\mathrm{EXP}\ \{1.61324 - .0682128\ (\ln Y) + .0843986\ (\ln Y)^2 - .0123826\ (\ln Y)^3 + .000634405\ (\ln Y)^4\}$$

$$I_T = \mathrm{EXP}\ \{8.10667 + .302301\ (\ln Y) + .0191831\ (\ln Y)^2 - .00748407\ (\ln Y)^3 + .000518155\ (\ln Y)^4\}$$

BOTTOM OF BOTTOM WAFER

The altitude of the bottom of the disc is the altitude of the lowest disc in the wafer.

$$S_b = -\mathrm{EXP}\ \{1.77691 - .0325444\ (\ln Y) + .0679667\ (\ln Y)^2 -.0114241\ (\ln Y)^3 + .000590821\ (\ln Y)^4\}$$

$$I_b = \mathrm{EXP}\ \{7.68304 +.372472\ (\ln Y) - .0107429\ (\ln Y)^2 -.0039146\ (\ln Y)^3 + .000358551\ (\ln Y)^4\}$$

DELTA Z

The thickness of the disc , DeltaZ, is the difference in altitudes of the top and bottom of the disc.

$X = \ln(Y)$

$$S_d = 7 - \mathrm{EXP}\ \{1.78999 - .048249\ x + .0230248\ x^2 - .00225965\ x^3 + .000161519\ x^4\}$$

$$I_d = \mathrm{EXP}\ \{7.03518 + .158914\ (\ln Y) + .0837539\ (\ln Y)^2 - .0155464\ (\ln Y)^3 + .000862103\ (\ln Y)^4\}$$

DISC CENTER ALTITUDE

Altitude of the average center of a mono-size particle disc. The average center is determined by averaging the center heights of the wafers of which the disc is composed. (Ref 11)

$$S_m = -\ \mathrm{EXP}\ \{1.574 - .01197\ (\ln Y) + .03636\ (\ln Y)^2 - .0041\ (\ln Y)^3 + .0001965\ (\ln Y)^4\}$$

$$I_m = \mathrm{EXP}\ \{7.889 + .34\ (\ln Y) + .001226\ (\ln Y)^2 - .005227\ (\ln Y)^3 + .000417\ (\ln Y)^4\}$$

The altitude for a given particle size for any of the above fits is found by using the equation below. It will typically return values within 5% of the original data listed above.

PARTICLE SIZE VS INITIAL ALTITUDE 1 KT TO 15,000 KT

Particle Altitude Z = INTERCEPT + 2 (Particle Radius) (SLOPE)

where the particle radius is in micrometers and the altitude is in meters, and the yield for the intercepts and slopes is given in kilotons.

A2. Time since burst and radius of the cloud at vertical stabilization.

DELFIC raw data for vertical cloud stabilization

yield (KT)	RADIUS (M)	TIME (SEC)
1	856.6	347.1
10	1612	347.0
100	3324	313.2
1,000	5651	845.2
15,000	13680	162.9
50,000	22850	166.2

****

POLYNOMIAL FITS FOR VERTICAL CLOUD STABILIZATION 1 KT TO 50,000 KT

****

Vertical Stabilization Time (seconds)

$$T_s = 385.295 - 99.1476\,(\ln Y) + 64.6314\,(\ln Y)^2 - 8.21379\,(\ln Y)^3 + .323598\,(\ln Y)^4$$

Vertical Stabilization Radius (meters)

(see Eq (5) to convert radius to sigma radius)

$$S_0 = 868.277 - 632.399\,(\ln Y) + 625.132\,(\ln Y)^2 - 112.586\,(\ln Y)^3 + 7.16648\,(\ln Y)^4$$

A3. Time since burst and radius of the cloud at horizontal stabilization.

DELFIC raw data for vertical cloud stabilization

YIELD (KT)	RADIUS (M)	TIME (SEC)
1	902.8	382.1
10	1788	424.5
100	5213	610.7
1000	16620	845.2
15000	52330	850.4
50000	110000	918.7

****

POLYNOMIAL FITS FOR HORIZONTAL CLOUD STABILIZATION 1 KT TO 50,000 KT

****

(Cloud Rise module termination)

Horizontal Stabilization Time (seconds)

$$T_h = 385.295 - 99.1476 (\ln Y) + 64.6314 (\ln Y)^2 - 8.2\text{[illegible]}9 (\ln Y)^3 + .323598 (\ln Y)^4$$

Horizontal Stabilization Radius (meters)

(see Eq (5) to convert radius to sigma radius)

$$S_h = \mathrm{EXP} \{6.08948 + .0546004 (\ln Y) + .136646 (\ln Y)^2 - .0173576 (\ln Y)^3 + 7.42803\mathrm{E}{-4} (\ln Y)^4\}$$

A4. Time of solidification and mass of dust airborne at solidification time.

Delfic Raw Data For Dust Mass

Yield KT	Condensation Time SEC	Mass KG	Dust Fraction ton dust/ton yield
1	2.3278	9.0287e+5	.204732
10	3.6658	6.8862e+6	.156150
100	5.8238	5.2521e+7	.119095
1000	9.4618	4.0058e+8	.090835
15000	17.4996	4.3693e+9	.066052
50000	21.9029	1.2641e+10	.05733

****

POLYNOMIAL FITS FOR DUST MASS AND SOLIDIFICATION TIME 1 KT TO 50,000 KT

****

(Fireball module)

Solidification Time (seconds)

$$T_{solid} = 2.31466 + .786315\ (\ln Y) - .149574\ (\ln Y)^2 + .035455\ (\ln Y)^3 - .001189\ (\ln Y)^4$$

Dust Fraction

$$DF = .204731 - .0240532\ (\ln Y) + 1.39148E{-}3\ (\ln Y)^2 - 4.88467E{-}05\ (\ln Y)^3 + 8.62805E{-}7\ (\ln Y)^4$$

Appendix B

Glossary of Program Terms

ACCELLG	9.80665 m/s^2
ACTIVITY.REPORT$	menu control variable
ACTSIZE.REPORT$	menu control variable
AIRCRAFT.FILE$	name of aircraft specification program
AIRCRAFT$	name of aircraft to report on
ALPHA	cumulative log normal distribution term
ANS$	menu control variable
ANSWER$	menu control variable
AR(G)	activity of a particle group at an altitude
.DOP	dose report file name extant
.MOP	dust report file name extant
A1.PERCENT	unit time activity of a particle group
RM	mean radius of a dust particle
.RMA	equal activity group file extant
.RMM	equal mass group file extant
.SPC	aircraft specification file extant
BETA	cumulative log normal distribution term
BOMB.DENSITY	density of multiple bombs in target area
BURST.AMP.FACTOR	factor for multiple bursts
CABIN.ACTIVITY	total cabin activity
CABIN.AR	activity due to a given group
CABIN.DOSE	dose due to trapped dust in cabin

CABIN.DOSE.RATE	at the center of the cabin
CABIN.GEOMETRY	dimensionless factor for dust dose
CABIN.SUM.ACTIVITY.PER.METER	activity density of "unfiltered" cloud
DATE.TIME$	date stamp for files
DCF	dose conversion factor
DELAY	menu control variable
DELFIC	default particle size distribution
DELFIC.DOP	default output file name for dose report
DELTAT	time interval for cloud fall
DELTAX	aircraft miss distance to cloud center
DELTAY	aircraft miss distance to cloud center
DINTERCEPT	formula for thickness of particle group
DOSE	to aircrew in rem
DSLOPE	formula for thickness of particle group
DUST.DOSE$	menu control variable - dust or dose report?
ENGINE.MASS.FLOW	air mass flow through engine
ETAZ	viscosity of air at altitude z
FALL.VELOCITY	of a particle
FF	fission fraction of weapon
FIELD.WIDTH	width of target area for multiple bursts
FILTER.ACTIVITY	total filter activity
FILTER.AR	filter activity due to a single group
FILTER.CAPACITY	dust mass that will clog filter
FILTER.SUM.ACTIVITY.PER.METER	activity density of "filtered" cloud
FILTER.TX.FACTOR	fraction of a dust size that goes through
FV	fraction of activity inside a dust particle
FX	gaussian term for horizontal distribution
FY	gaussian term for horizontal distribution

FZ	gaussian term for altitude distribution
GAMMA.TX.FACTOR	gammas that make it through cabin walls
GAMMA.MFP	mean free path of a gamma ray in air
GAUSSIANZM	contribution of a partice group at an altitude
G.AT.Z	gravity at altitude z
HC	initial activity center altitude
HOW.MANY.TIMES	the number of report times
HR	time in hours
INPUT.FILE$	name of an input file
INTERVAL	time between report times
LAST.AREA	used in trapezoidal integration
LAST.TIME.STOP	the last time a report was made
LASTG	largest particle group still airborne
LK	atmospheric temperature lapse rate
MASS	of the cabin
MASS.FLOW	of air into the cabin
MASS.INTEGRAL	of the aircraft cabin
MASS.REPORT$	menu control variable
MASS.SIZE.REPORT$	menu control variable
MAXG	group that adds the most activity at altitude
MEV	gamma ray energy in MeV
MINTERCEPT	Hopkins formula for initial altitude of particle
MSLOPE	Hopkins formula for initial altitude of particle
MSN.TIME.REM	time from cloud penetration to landing
MUARHO	tissue absorption crossection
MUT.Z13	gamma ray transmission coefficient for aluminum
MUTRHO	gamma ray cross section for air at altitude z
NUMBER.BOMBS	number of weapons in multiple burst problem

OUTPUT.FILE$	name of output file to be created
PART.TIME	interval counter for cloud fall loop
PER(G)	% activity at an altitude due to group G
PI	3.14159
PRESSURE.VOLUME	volume of aircraft pressurized cabin
PV.AREA	area of aircraft pressurized cabin
PV.MASS	mass of aircraft pressurized cabin
PZ	atmospheric pressure at altitude z
RADIUS	radius of dust particle
REYNOLDS.NUMBER	dimensionless
RHOAIRZ	airdensity at altitude z
RHOFALLOUT	target material density
SHARP$	tag denoting multiple burst is too early
SHEAR	variation of wind speed with altitude
SIGMA.RM	particle cumulative log normal distribution
SIGMAX	horizontal normal distribution of cloud
SIGMAY	horizontal normal distribution of cloud
SIGMAZ	vertical normal distribution of cloud
SIZE.LABEL$	report label for size groups
SKYSHINE.DOSE	dose to crew due to immersion in cloud
STAB.TIME	time of cloud vertical stabilization
STAR$	tag denoting gamma mfp > .2 sigmax
SUM.ACTIVITY.PER.METER	activity density for all groups at an altitude
TA	time for toroidal growth
TC	time constant for toroidal growth
TIME	counter for cloud fall loop
TIME.STOP	one of the output report times
TK	atmospheric temperature in degrees K

TRANSIT.TIME	time to cross a multiple burst cloud
TRAP.CENTER	center of trapezoid of integration
TZ	atmospheric temperature lapse rate
VAC	True Air Speed of aircraft in m/s
WHICH%	menu selection command
WHICH$	menu selection command
WIND.SHEAR.X	longitudinal component of wind
WIND.SHEAR.Y	crosswind component of the wind
YIELDKT	yield of weapon in kilotons
ZAC	height of aircraft
WORST.ALT	estimated worst penetration altitude
ZAC.HI	highest penetration altitude
ZAC.LO	lowest penetration altitude
ZAC.STEP	distance between penetration altitudes
Z.STEPS	the number of altitudes to be reported
ZM(G)	altitude of particle in group G

Appendix C

Particle Size Program

This program will compute 100 equal activity groups and 100 equal mass groups from the rm and σ_{rm} of a number size distribution. Examples of some number size distributions that have been proposed for nuclear clouds are given in Table I. See Chapter II for details.

The program is menu driven and easy to use. Simply input the requested data at the prompts; both the activity size and mass size groups will be computed and stored in a disk file. The program can be used by itself or called by the menu program in Appendix E.

```
8000 '2, 2.5, 3 moment
8010 'compute size (um) of 100 equal activity and equal mass groups
8020 'given Rm, sigma Rm, and volume fraction, find equal activity
8030 'and equal mass size groups from the number size distribution
8040 '28 Dec 84 Capt Conners
8050 DIM RM(100)
8060 INPUT "What is the date and time";DATE.TIME$
8070 GOSUB 8991 :'print header
8080 PRINT "Select a number size distribution from the following list:"
8090 PRINT
8100 PRINT "                                    Rm              Sigma Rm"
8110 PRINT "                                micrometers"
8120 PRINT "   1      NRDL-N61                .00039              7.24"
8130 PRINT "   2      NRDL-C61                .0103               5.38"
8140 PRINT "   3      NRDL-D                  .01                 5.42"
```

```
8150 PRINT "   4    TOR-N             .079            4.48"
8160 PRINT "   5    DELFIC            .204            4"
8170 PRINT "   6    USWB-HI          3.48             2.72"
8180 PRINT "   7    USWB-LO          3.84             3"
8190 PRINT "   8    FORD-T           5.98             2.23"
8200 PRINT "   9    RANDWSEG        10.6              2"
8210 PRINT "  10    NRDL-SII        27.1              1.48"
8220 PRINT "  11    NRDL-SI         36.8              1.51"
8230 PRINT "  12    TOR-C           50.6              1.36"
8240 PRINT "  13    other"
8250 INPUT WHICH%
8260 IF WHICH% = 0 THEN WHICH% = 5                  :'default distribution
8270 IF WHICH% < 1 OR WHICH% > 13 THEN 8070
8280 IF WHICH% = 1 THEN DFILE$ = "NRDL-N61"   :RM=.00039 :SIGMA.RM=7.24
8290 IF WHICH% = 2 THEN DFILE$ = "NRDL-C61"   :RM=.0103  :SIGMA.RM=5.38
8300 IF WHICH% = 3 THEN DFILE$ = "NRDL-D"     :RM=.01    :SIGMA.RM=5.42
8310 IF WHICH% = 4 THEN DFILE$ = "TOR-N"      :RM=.079   :SIGMA.RM=4.48
8320 IF WHICH% = 5 THEN DFILE$ = "DELFIC"     :RM=.204   :SIGMA.RM=4
8330 IF WHICH% = 6 THEN DFILE$ = "USWB-HI"    :RM=3.48   :SIGMA.RM=2.72
8340 IF WHICH% = 7 THEN DFILE$ = "USWB-LO"    :RM=3.84   :SIGMA.RM=3
8350 IF WHICH% = 8 THEN DFILE$ = "FORD-T"     :RM=5.98   :SIGMA.RM=2.23
8360 IF WHICH% = 9 THEN DFILE$ = "RANDWSEG"   :RM=10.6   :SIGMA.RM=2
8370 IF WHICH% = 10 THEN DFILE$ = "NRDL-SII" :RM=27.1   :SIGMA.RM=1.48
8380 IF WHICH% = 11 THEN DFILE$ = "NRDL-SI"  :RM=36.8   :SIGMA.RM=1.51
8390 IF WHICH% = 12 THEN DFILE$ = "TOR-C"    :RM=50.6   :SIGMA.RM=1.36
8400 IF WHICH% = 13 THEN 8430
8410 PRINT "Distribution selected is: "DFILE$"   Rm ="RM"  Sigma Rm ="SIGMA.RM
8420 FOR DELAY = 1 TO 300 :NEXT DELAY :GOTO 8480
```

```
8430 ' input section ***********************************************************
8440 '*********************************************************************
8450 INPUT "MUST BE UPPER CASE: output file name (SOURCE)";DFILE$
8460 INPUT "mean radius of particle (Rm) (microns)";RM
8470 INPUT "sigma of mean radius";SIGMA.RM
8480 OUTPUT.DFILE$ = DFILE$+".RMA"
8490 ' set constants ***********************************************************
8500 '*********************************************************************
8510 PI = 3.14159
8520 ALPHA0 = LOG(RM)
8530 BETA = LOG(SIGMA.RM)
8540 SQR2PI.BETA = SQR(2*PI)*BETA  :'increase compute speed
8545 ALPHA(0) = ALPHA0  :'used to produce equal number size distributions
8550 ALPHA(2) = ALPHA0 + 2*BETA^2       :'=area size
8560 ALPHA(1) = ALPHA0 + 2.5*BETA^2     :'=activity size by Frieling approx
8570 ALPHA(3) = ALPHA0 + 3*BETA^2       :'=mass size
8580 FV = .68             :'for DELFIC activity
8590 N = 1
8600 'continue
8610 R = 0                :'dummy for A(R)
8620 RADIUS = 0           :'radius of particle in um
8630 AREA = 0             :'initial area under curve at 0 radius
8640 LAST.A(R) = 0        :'initial activity at 0 radius
8650 G = 1                :'group # counter
8660 DELTAR = .01         :'initial dr
8670 TRAP.CENTER = .005 :'half a hundredth; center of 1% activity increment
8680 ' compute radius of each 100 equal activity groups *********************
8690 '*********************************************************************
```

```
8700 RADIUS = RADIUS + DELTAR

8710 A(R) =  EXP(-.5*((LOG(RADIUS)-ALPHA(N))/BETA)^2)/(SQR2PI.BETA*RADIUS)

8720 IF RIGHT$(DFILE$,6) = "DELFIC" AND N = 1
THEN A(R) = (FV/(SQR2PI.BETA*RADIUS))*EXP(-.5*((LOG(RADIUS)-ALPHA(3))/BETA)^2)
     + ((1-FV)/(SQR2PI.BETA*RADIUS))*EXP(-.5*((LOG(RADIUS)-ALPHA(2))/BETA)^2)

8730 LAST.AREA = AREA

8740 AREA = AREA + (A(R) + LAST.A(R))*DELTAR*.5      :'trapezoidal integration

8750 LAST.A(R) = A(R)

8760 IF AREA < TRAP.CENTER GOTO 8700  :'is curve area = to 1%? if not, go back

8770 RM(G)=(TRAP.CENTER-LAST.AREA)*DELTAR/(AREA-LAST.AREA) + (RADIUS - DELTAR)

8780 IF G > 1 THEN DELTAR = (RM(G)-RM(G-1))*.1

8790 G = G + 1

8800 TRAP.CENTER = .01*G - .005

8810 IF G <= 100 GOTO 8700

8820 ' store 100 rm's in a disk file *******************************************

8830 '*************************************************************************

8840 OPEN "O",#1,OUTPUT.DFILE$

8850 FOR G = 1 TO 100 STEP 5

8860 PRINT#1,RM(G);RM(G+1);RM(G+2);RM(G+3);RM(G+4)

8870 NEXT G

8880 PRINT#1,"Rm = ";RM;"; sigma Rm = ";SIGMA.RM

8890 PRINT#1," " :PRINT#1," "

8900 IF N=1 THEN T$="activity" ELSE T$="mass"

8910 PRINT#1,"Mean radii in microns of the 100 equal "T$" groups"

8920 PRINT#1,OUTPUT.DFILE$"; computed from rm = ";RM;"; sigma rm = ";SIGMA.RM

8930 PRINT#1,"using inverse transform  alpha = "N")"

8940 PRINT#1,"from the program SIZE.BAS 28 Dec 84 by Capt. Conners"

8950 PRINT#1,DATE.TIME$

8960 CLOSE
```

```
8970 IF N = 1 THEN N = 3 ELSE PRINT STRING$(10,7) :CHAIN"MENU",1000,ALL

8980 OUTPUT.DFILE$ = DFILE$ + ".RMM"

8990 GOTO 8600

8991 'menu header ****************************************************************

8992 PRINT CHR$(26)             :'clear screen

8993 PRINT WHICH$ :PRINT

8994 RETURN
```

Appendix D

Aircraft Data

And Sample Specification Program

An Aircraft Specification Program must be coustructed to input the necessary information about the aircraft into the main program. The minimum data needed for a variety of aircraft are listed in the BASIC AIRCRAFT DATA table below. From this, the data listed in the DERIVED AIRCRAFT DATA table must be computed by the user or the user's program. A sample program is included for the B-1B bomber. A similar program must be constructed for each aircraft desired. The program must start at line 7000 and the program name must have an .SPC file name exteusion.

The cabin geometry factor K can be computed using the program in Appendix K.

BASIC AIRCRAFT DATA

Aircraft	Cabin Mass KG	Cabin Area M^2	Pressure Volume M^3	Mass Flow KG/MIN	@30,000 feet MACH	Radius M
B-1B	11,511	107.9	28.3	17	.85	1.07
B-52G	11,262	81.6	51.9	22	.72	1.75
B-52H	10,854	81.6	51.9	22	.72	1.75
E-3	36,949	408.8	356.1	61.5	.53	1.79
E-4B	137,551	1,282	1686.0	276	.53	3.28
EC-135	40,750	310	244.2	50	.50	1.79
KC-135	18,073	310	232.2	50	.72	1.79

****

DERIVED AIRCAFT DATA

Aircraft	Mass Integral KG/M^2	Transmission Factor T_{gamma}	Pseudo Length M	Geometry Factor K	Velocity M/S
B-1B	106.68	.5265	7.9	1.395	279.2
B-52G	138.06	.4360	5.4	2.035	231.5
B-52H	133.06	.4493	5.4	2.035	231.5
E-3	90.38	.5808	35.4	2.505	164.7
E-4B	107.29	.5246	50	4.586	164.7
EC-135	131.45	.4537	24.3	2.468	154.2
KC-135	58.30	.7043	23.1	2.459	231.5

****

```
7000 'Program B-1B.SPC specification program **********************************

7010 '4 dec Capt. Conners for Dr. Bridgman

7020 'activity density ******************************************************

7030 VAC = 279.2                         :'M/S TAS M.85 @30,000'

7040 PRESSURE.VOLUME = 28.34             :'M^3 crew and forward avionics

7050 MASS.FLOW = 17.01                   :'KG/min
range 11.34 to 22.68 depending on altitude, temperature, and leak rates.
Source uses 21.64 kg/min.

7055 engine.mass.flow = 161              :'KG/S bypass ratio = 2.3

7060 'shielding factor ******************************************************

7070 PV.MASS = 11511.1                   :'KG  to station 542"

7080 PV.AREA = 107.9                     :'M^2 wetted area to station 542"

7090 MASS.INTEGRAL = PV.MASS/PV.AREA     :'KG/M^2

7100 MUT.Z13 = 6.01271E-03               :'M^2/KG for aluminum at 1 MeV

7110 'assume average gamma = 1 MeV and fuselage materials have similar
gamma ray crossections (low z).  Total error in MUT estimated to be -0/+10%
based on the .7 and 1 MeV xsec of Al, C, O.  See RB Drinkwater gne/ph/74-3

7120 gamma.tx.factor = EXP(-MUT.Z13*MASS.INTEGRAL)

7125 cabin.geometry = 1.39961            :'space integral of cabin

7130 'since all fuel is carried aft of the crew compartment, it is part of

7140 'an infinite shield and does not contribute to gamma.tx.factor
```

```
7150 'source: phone calls to George Clark, RI 16 Nov 84; letter 3 Dec 84;

7155 'visit to B-1 SPO at WPAFB 16 Nov 84

7160 '*************************************************************************

7170 'filter routine

7190 FOR G = 1 TO 100

7210 IF RM(G) < 5 THEN filter.tx.factor(G) = 1!

7220 IF RM(G) >= 5 AND RM(G) <= 10 THEN filter.tx.factor(G) = .1

7230 IF RM(G) > 10 THEN filter.tx.factor(G) = 0

7235 filter.tx.factor(G) = 1

7240 NEXT G

7250 FILTER.CAPACITY = .225             :'KG

7260 'trap 225 g dust defined by m(R)=6.5-ln(R) AND 10microns<= R <= 80microns

7270 'filter.tx.factor=1 for none trapped;=0 if all trapped; =.1 if 90%trapped

7280 'source: TFD-82-890 "Radiation Threat From Nuclear Dust In The ECS
Particle Filter", W.Clark Powell III, Rockwell International 16 Dec 82, p13

7300 chain"DOSE",4000,ALL
```

Appendix E

Menu Program

This program prompts the user for all the data necessary for the main program to compute dose to the aircrew or the dust ingested by the aircraft. To save memory and increase the speed of the main program, many housekeeping functions are accomplished by this part of the code. The program is written in Microsoft Basic version 5.02. No exotic software or machine dependent functions are used so that the code is highly portable.

The code is heavily documented; out of 40K of code, about 12K is documentation. The program is laid out in modules and is structured to prevent impediments in following the program flow. Long logical lines are broken up into a series of shorter physical lines. A semicolon : separates logical lines on a single physical line, and an apostrophe ′ is a short form of rem, the BASIC remark statement.

The program is run by entering BASIC and LOADing the menu program. The menu program takes over at this point and prompts the user for all necessary input. All other programs are called automatically by the CHAIN statement. All programs and data files must be on the same disk or the filename calling the CHAINed program or data file must be preceeded by the drive designator.

```
1000 ON ERROR GOTO 3810

1010 ′master menu for dose and dust program

1020 ′set up default scenario or accept user inputs

1030 ′

1040 ′2,7,8,20 dec 84 Capt. Conners for Dr. Bridgman
```

```
1050 PRINT CHR$(26)                     :'clear screen

1060 PRINT "AIRCREW RADIATION DOSE AND DUST DENSITY PROGRAM" :PRINT

1070 PRINT "Version 8.0------------------------------28 Dec 1984"

1080 PRINT "Created by Capt. Stephen P. Conners for Dr. Bridgman"

1090 PRINT STRING$(10,13)

1100 PRINT "All keyboard entries must be terminated by <CR>" :PRINT

1110 INPUT "Enter the current date and time";DATE.TIME$ :PRINT

1120 PRINT "Do you wish to:"

1130 PRINT "1   Use the standard scenario"

1140 PRINT "2   Create your  own scenario" :PRINT

1150 INPUT WHICH% :IF WHICH% = 2 THEN 2320

1160 IF WHICH% < 0 OR WHICH% > 1 THEN 1120

1170 'default scenario *******************************************************

1180 'bomb design/target data ************************************************

1190 WHICH$ = "DEFAULT OPTION FOR STANDARD SCENARIO"

1200 YIELDKT = 1000                     :'1 megaton

1210 NUMBER.BOMBS = 1

1220 FF = .5                            :'fission FRACTION

1230 DF = .333333                       :'dust FRACTION
1/3 ton of dust per ton of yield

1240 SIZE$ = "DELFIC"           :'size distribution rm=.2035, sigma=4.

1250 DUST.DOSE$ = "dose"        :'select crew dose, not dust density output

1260 ACTIVITY.REPORT$ = "n"

1270 ACTSIZE.REPORT$ = "n"

1280 INPUT.FILE$ = SIZE$ + ".RMA"

1290 RHOFALLOUT = 2600                  :'KG/M^3 density of silicate rock

1300 'aircraft type **********************************************************

1310 AIRCRAFT$ = "KC-135"

1320 AIRCRAFT.FILE$ = AIRCRAFT$ + ".SPC"
```

```
1330 'mission parameters *****************************************************

1340 'reporting times ********************************************************

1350 MSN.TIME.REM = 8                    :'HR crew is exposed to cabin dust
for 8 hours after encounter

1360 HOW.MANY.TIMES = 4

1370 TIME.STOP(1) = 1                    :'HR

1380 TIME.STOP(2) = 2

1390 TIME.STOP(3) = 4

1400 TIME.STOP(4) = 8

1410 'reporting altitudes and winds ******************************************

1420 Z.STEPS  = 6

1430 ZAC.HI   = 12000

1440 ZAC.LO   = 2000                     :'M

1450 ZAC.STEP = 2000

1460 WIND.SHEAR.X = 0                    :'(KM/HR)/KM for computing sigma x

1470 WIND.SHEAR.Y = 1                    :'(KM/HR)/KM for computing sigma y

1480 'output *****************************************************************

1490 OUTPUT.FILE$ = "DELFIC.DOP"

1500 PRINT CHR$(26) :PRINT WHICH$ :PRINT

1510 PRINT "WEAPON/TARGET DATA:"

1520 PRINT "Number of weapons ------------------"NUMBER.BOMBS

1530 IF NUMBER.BOMBS > 1
THEN PRINT "Width of target field --------------"FIELD.WIDTH/1000"KM

1540 PRINT "Weapon yield -----------------------"YIELDKT"kt"

1550 PRINT "Fission fraction -------------------"FF

1560 PRINT "Dust fraction ----------------------"DF

1570 PRINT "The size distribution input file is- "INPUT.FILE$

1580 PRINT "The soil density is ----------------"RHOFALLOUT"KG/M^3" :PRINT

1590 PRINT "AIRCRAFT DATA:"
```

```
1600 PRINT "The aircraft specification file is - "AIRCRAFT.FILE$ :PRINT

1610 FOR DELAY = 1 TO 1500 :NEXT DELAY

1620 PRINT CHR$(26) :PRINT WHICH$ :PRINT

1630 PRINT "TIME DATA:"

1640 PRINT "Time from cloud penetration"

1650 PRINT "to end of mission ------------------"MSN.TIME.REM"HR" :PRINT

1660 PRINT "Reporting times:"

1670 FOR T = 1 TO HOW.MANY.TIMES

1680 PRINT TIME.STOP(T)"HR"

1690 NEXT T

1700 FOR DELAY = 1 TO 1500 :NEXT DELAY

1710 PRINT CHR$(26) :PRINT WHICH$ :PRINT

1720 PRINT "WIND AND ALTITUDE DATA:"

1730 PRINT "Wind shear X (along track) ---------"WIND.SHEAR.X"(KM/HR)/KM"

1740 PRINT "Wind shear Y (cross track) ---------"WIND.SHEAR.Y"(KM/HR)/KM"

1750 PRINT :PRINT "Reporting altitudes:"

1760 ZAC = ZAC.HI + ZAC.STEP

1770 FOR Z = 1 TO Z.STEPS

1780 ZAC = ZAC - ZAC.STEP

1790 PRINT ZAC"M"

1800 NEXT Z

1810 FOR DELAY = 1 TO 1500 :NEXT DELAY

1820 PRINT CHR$(26) :PRINT WHICH$ :PRINT

1830 PRINT "The output file will be named ------ "OUTPUT.FILE$ :PRINT

1840 PRINT DATE.TIME$

1850 DIM RM(100),ZM(111),GAUSSIANZM(101),AR(101),PERCENT.25(101),PER(101),
SIGMAZ(101),CABIN.AR(101),FILTER.AR(101),FILTER.TX.FACTOR(101)

1860 DIM SUM.ACTIVITY.PER.METER(Z.STEPS),A3(Z.STEPS),CABIN.ACTIVITY(Z.STEPS),
CABIN.DOSE(Z.STEPS),SKYSHINE.DOSE(Z.STEPS),GAMMA.MFP(Z.STEPS),
```

```
STAR$(Z.STEPS),CABIN.SUM.ACTIVITY.PER.METER(Z.STEPS)

1870 DIM FILTER.SUM.ACTIVITY.PER.METER(Z.STEPS),FILTER.ACTIVITY(Z.STEPS),
MAXG(Z.STEPS),ENGINE.MASS(Z.STEPS)

1880 'DELFIC initial cloud parameters ***************************************

1890 X = LOG(YIELDKT)

1900 MSLOPE=-EXP(1.54     -.01197*X  +.03636*X^2      -.0041*X^3+.0001965*X^4)

1910 MINTERCEPT=EXP(7.889    +.34*X +.001226*X^2    -.005227*X^3 +.000417*X^4)

1920 DSLOPE=7-EXP(1.79-.048249*X+.0230248*X^2-2.25965E-03*X^3+1.61519E-04*X^4)

1930 DINTERCEPT=EXP(7.0352+.15892*X+.083754*X^2 -.0155464*X^3+8.62103E-04*X^4)

1940 ' compute initial alt for each =activity or group *********************

1950 '**********************************************************************

1960 PRINT "Now loading "INPUT.FILE$

1970 OPEN "I",#2,INPUT.FILE$

1980 FOR G = 1 TO 100

1990 INPUT#2,RM(G)                        :'radii in UM of 100 =activity groups

2000 ZM(G) = MINTERCEPT+MSLOPE*2*RM(G)  :'METERS altitude of      ""    ""

2010 SIGMAZ(G) = (DINTERCEPT+DSLOPE*2*RM(G))/4  :'M DeltaZ/2 = 2 sigma

2020 NEXT G

2030 INPUT#2,SIZE.LABEL$

2040 CLOSE#2

2050 'WSEG functions ********************************************************

2060 'Y = LOG(YIELDKT/1000)               :'ln yield megatons

2070 'HC=(44+6.1*Y-.205*(Y+2.42)*ABS(Y+2.42))*304.8     :'M

2080 'SIGMA0=EXP((.7+Y/3)-3.25/(4+(Y+5.4)^2))*1609.34  :'M

2090 'DELFIC functions ******************************************************

2100 HC= ZM(50)                   :'M to =activity altitude

2110 SIGMA0 = (868.277-632.399*X+625.132*X^2-112.586*X^3+7.16648*X^4)/2
:'delfic radius = 2 sigma .:. 1 sigma = delfic radius/2

2120 TC = 12*(HC/304.8)/60-(2.5*((HC/304.8)/60)^2)     :'1/HR
```

```
2130 TC=TC*1.05732*(1!-.5*EXP(-((HC/304.8)^2))/(25^2)):'correction from Polan

2140 ' program constants ****************************************************

2150 '*********************************************************************

2160 A1.PERCENT=5.3E+08*YIELDKT*FF/100  :'unittime activity in CURIES/group

2170 ACCELLG  = 9.80665                 :'M/S^2 acceleration due to gravity

2180 LASTG = 100                        :'initially 100 -size groups are used

2190 LOG10 = LOG(10)                    :'used to convert ln to log

2200 MASS1.PERCENT = DF*YIELDKT*(1000*2000*.4535923700000003#)/100 :'KG/group

2210 MEV = 1                            :'Ev*1e6

2220 MUARHO = .00306                :'M^2/KG tissue absorption xsection @1 MeV

2230 MUT = 6.73015E-03                  :'M^2/KG air xsection (Std Atm) @1 MeV

2240 DCF=3.7E+10*1.6E-11*3600*MUARHO*MEV        :'dose conversion factor

2250 SQR2PI = SQR(2*3.14159)

2260 STAB.TIME = (385.295-99.1476*X+64.6314*X^2-8.21379*X^3+.323598*X^4)/3600
:'HRS time for cloud stabilisation

2270 TIME = STAB.TIME                   :'minimum time is cloud stab time

2280 TIME.STOP = STAB.TIME              :'minimum time is cloud stab time

2290 '*********************************************************************

2300 PRINT "Now loading "AIRCRAFT$" specifications file."

2310 CHAIN AIRCRAFT.FILE$,7000,ALL

2320 'create your own scenario *********************************************

2330 INPUT "What is the titie for your scenario";WHICH$

2340 WHICH$ = "CUSTOM SCENARIO: " + WHICH$

2350 'report screen ********************************************************

2360 GOSUB 3610 :'print header

2370 PRINT :PRINT "Do you want a:"

2380 PRINT "1    Crew dose report"

2390 PRINT "2    Dust density report" :PRINT

2400 INPUT "(Default = 1 (dose))",WHICH%
```

```
2410 IF WHICH% = 1 OR WHICH% = 0 THEN DUST.DOSE$ = "dose" :GOTO 2440

2420 IF WHICH% = 2 THEN DUST.DOSE$ = "dust" :GOTO 2500

2430 GOTO 2780

2440 PRINT "You have selected a crew dose report" :PRINT

2450 INPUT "Do you wish an activity report (y/n)";ANS$

2460 IF ANS$ = "N" OR ANS$ = "n" THEN ACTIVITY.REPORT$ = "n"

2465 PRINT

2470 INPUT "Do you wish a prominent particle report (y/n)";ANS$

2480 IF ANS$ = "N" OR ANS$ = "n" THEN ACTSIZE.REPORT$ = "n"

2490 GOTO 2530

2500 PRINT "You have selected a dust density report" :PRINT

2502 INPUT "Do you wish a cloud mass report (y/n)";ANS$

2504 IF ANS$ = "N" OR ANS$ = "n" THEN MASS.REPORT$ = "n"

2506 PRINT

2510 INPUT "Do you wish a prominent particle report (y/n)";ANS$

2520 IF ANS$ = "N" OR ANS$ = "n" THEN MASS.SIZE.REPORT$ = "n"

2530 'bomb screen *****************************************************************

2540 GOSUB 3610 :'print header

2550 PRINT :PRINT "What is the weapon yield in KILOTONS?"

2560 INPUT "(Default = 1000 kt)",YIELDKT

2570 IF YIELDKT = 0 THEN YIELDKT = 1000

2580 PRINT :PRINT "How MANY weapons created the cloud?"

2590 INPUT "(Default = 1)",NUMBER.BOMBS

2600 IF NUMBER.BOMBS = 0 THEN NUMBER.BOMBS = 1

2610 IF NUMBER.BOMBS > 1 THEN GOSUB 3720

2620 IF NUMBER.BOMBS < 1 THEN 2580

2630 PRINT :PRINT "What is the fission FRACTION of the weapon?"

2640 INPUT "(Default = .5)",FF
```

```
2650 IF FF < 0 OR FF > 1 THEN 2630
2660 IF FF = 0 THEN FF = .5
2670 PRINT :PRINT "What is the dust FRACTION of the weapon?"
2680 INPUT "(Default = DELFIC prediction)",DF
2690 IF DF < 0 OR DF > 1 THEN 2670
2700 X = LOG(YIELDKT)
2710 IF DF = 0
THEN DF = .204731-.0240532*X+1.39148E-03*X^2-4.88467E-05*X^3+8.62805E-07*X^4
2720 'soil screen ************************************************************
2730 GOSUB 3610 :'print header
2740 PRINT "What is the size distribution input FILE NAME?"
2750 INPUT "(Default = DELFIC)",SIZE$
2760 IF SIZE$ = "" THEN SIZE$ = "DELFIC"
2770 IF DUST.DOSE$ = "dose" THEN INPUT.FILE$ = SIZE$ + ".RMA"
2780 IF DUST.DOSE$ = "dust" THEN INPUT.FILE$ = SIZE$ + ".RMM"
2790 PRINT :PRINT "What is the soil density in KG/M^3?"
2800 INPUT "(Default = 2600 KG/M^3)",RHOFALLOUT
2810 IF RHOFALLOUT = 0 THEN RHOFALLOUT = 2600
2820 'aircraft screen ********************************************************
2830 GOSUB 3610 :'print header
2840 PRINT "Select an aircraft from the following list:" :PRINT
2850 PRINT "   1     B-1B"
2860 PRINT "   2     B-52G"
2870 PRINT "   3     B-52H"
2880 PRINT "   4     E-3"
2890 PRINT "   5     E-4B"
2900 PRINT "   6     EC-135"
2910 PRINT "   7     KC-135"
```

```
2920 PRINT "   8    other"

2930 INPUT WHICH%

2940 IF WHICH% = 0 THEN WHICH% = 7               :'default aircraft

2950 IF WHICH% < 1 OR WHICH% > 8 THEN 2830

2960 IF WHICH% = 1 THEN AIRCRAFT$ = "B-1B"

2970 IF WHICH% = 2 THEN AIRCRAFT$ = "B-52G"

2980 IF WHICH% = 3 THEN AIRCRAFT$ = "B-52H"

2990 IF WHICH% = 4 THEN AIRCRAFT$ = "E-3"

3000 IF WHICH% = 5 THEN AIRCRAFT$ = "E-4B"

3010 IF WHICH% = 6 THEN AIRCRAFT$ = "EC-135"

3020 IF WHICH% = 7 THEN AIRCRAFT$ = "KC-135"

3030 IF WHICH% = 8 THEN 3860

3040 PRINT "Aircraft selected is: "AIRCRAFT$

3050 FOR DELAY = 1 TO 300 :NEXT DELAY

3060 AIRCRAFT.FILE$ = AIRCRAFT$ + ".SPC"

3070 'time screen ************************************************************

3080 DIM TIME.STOP(10)

3090 GOSUB 3610 :'print header

3100 ERASE TIME.STOP

3110 PRINT "How many cloud encounters do you wish to examine?"

3120 INPUT "(Default = 4)",HOW.MANY.TIMES

3130 IF HOW.MANY.TIMES=0 THEN HOW.MANY.TIMES = 4
:DIM TIME.STOP(HOW.MANY.TIMES)
:TIME.STOP(1) = 1
:TIME.STOP(2) = 2
:TIME.STOP(3) = 4
:TIME.STOP(4) = 8
:GOTO 3220

3140 DIM TIME.STOP(HOW.MANY.TIMES)

3150 PRINT "Please enter time in HOURS since burst in increasing order."

3160 PRINT
```

```
3170 FOR E = 1 TO HOW.MANY.TIMES

3180 PRINT "What is time"E"?" :INPUT TIME.STOP(E)

3190 IF TIME.STOP(E) < .15
THEN PRINT "Time must be exceed .15 HR to allow cloud stabilization"
:PRINT "and the Way-Wigner decay approximation." :GOTO 3150

3200 IF TIME.STOP(E) < TIME.STOP(E-1) THEN 3150

3210 NEXT E

3220 PRINT "The following times will be used:"

3230 FOR E = 1 TO HOW.MANY.TIMES
:PRINT TIME.STOP(E)"HR"
:NEXT E

3240 INPUT "Is this acceptable (y/n)";ANSWER$

3250 IF ANSWER$ = "N" OR ANSWER$ = "n" THEN 3090

3260 PRINT

3270 PRINT "How many HOURS from encounter time to end of mission ?"

3280 INPUT "(Default = 8 Hr)",MSN.TIME.REM

3290 IF MSN.TIME.REM = 0 THEN MSN.TIME.REM = 8

3300 'altitude screen *********************************************************

3310 GOSUB 3610 :'print header

3320 PRINT "All altitudes are in METERS" :PRINT

3330 INPUT "What is the HIGHEST penetration altitude you wish to use";ZAC.HI

3340 INPUT "What is the LOWEST  penetration altitude you wish to use";ZAC.LO

3350 INPUT "What altitude INCREMENT do you wish to use";ZAC.STEP

3360 IF ZAC.HI   = 0 THEN ZAC.HI = 12000 :ZAC.LO = 2000 :ZAC.STEP = 2000

3370 IF ZAC.STEP = 0 THEN 3310

3380 Z.STEPS = INT(((ZAC.HI-ZAC.LO)/ZAC.STEP)+1.49999)

3390 '*************************************************************************

3400 GOSUB 3610 :'print header

3410 PRINT "The following altitudes will be used:" :PRINT

3420 ZAC = ZAC.HI + ZAC.STEP
```

```
3430 FOR Z = 1 TO Z.STEPS
:ZAC = ZAC - ZAC.STEP
:PRINT ZAC"M"
:NEXT Z

3440 INPUT "Is this acceptable (y/n)";ANSWER$

3450 IF ANSWER$ = "N" OR ANSWER$ = "n" THEN 3310

3460 '*************************************************************************

3470 GOSUB 3610 :'print header

3480 PRINT "Wind shear is given in (KM/HR)/KM"

3490 PRINT "What is the wind shear in X (along track)"

3500 INPUT "(Default = 0)";WIND.SHEAR.X

3510 PRINT "What is the wind shear in Y (cross track)"

3520 INPUT "(Default = 1)";WIND.SHEAR.Y

3530 IF WIND.SHEAR.Y = 0 THEN WIND.SHEAR.Y = 1

3540 IF WIND.SHEAR.Y = 1 THEN INPUT "Do you want Y shear to be 0?(y/n)",ANSWER$

3550 IF ANSWER$ = "Y" OR ANSWER$ = "y" THEN WIND.SHEAR.Y = 0

3560 PRINT : PRINT "What is the output FILE NAME"

3565 IF DUST.DOSE$ = "dose" THEN D$ = ".D" ELSE D$ = ".M"

3570 PRINT "(Default is "SIZE$;D$"OP)"

3580 INPUT OUTPUT.FILE$

3590 IF OUTPUT.FILE$="" AND DUST.DOSE$="dose" THEN OUTPUT.FILE$=SIZE$ + ".DOP"

3595 IF OUTPUT.FILE$="" AND DUST.DOSE$="dust" THEN OUTPUT.FILE$=SIZE$ + ".MOP"

3600 GOTO 1500

3610 'menu header *************************************************************

3620 PRINT CHR$(26)             :'clear screen

3630 PRINT WHICH$ :PRINT

3640 PRINT "All file names MUST be in UPPERCASE!"

3650 PRINT "Hit <CR> to insert the default value for any input."

3660 PRINT

3670 RETURN
```

```
3680 'create non-delfic size files ******************************************

3690 PRINT "This option currently unimplemented."
:FOR DELAY = 1 TO 700 :NEXT DELAY :GOTO 2740

3700 'create other aircraft files ********************************************

3710 PRINT "This option currently unimplemented."
:FOR DELAY = 1 TO 700 :NEXT DELAY :GOTO 2830

3720 'number.bombs subroutine ************************************************

3730 PRINT

3740 PRINT "The target field is assumed to be square."

3750 INPUT "What is its width in KILOMETERS?",FIELD.WIDTH

3760 IF FIELD.WIDTH < .1 THEN 3740

3770 FIELD.WIDTH = FIELD.WIDTH*1000      :'convert KM to METERS

3780 BOMB.DENSITY = NUMBER.BOMBS/FIELD.WIDTH

3790 RETURN

3800 IF ERR = 53 AND ERL = 1970
THEN CHAIN"SIZE",8000,ALL

3810 IF ERR = 53 AND ERL = 2310
THEN PRINT "This file does not exist on the specified disk drive."

3820 IF ERR = 53 AND ERL = 2310
THEN PRINT "You must create and/or place the specified file on the correct drive."

3830 PRINT STRING$(10,7)                          :'Hey, you!

3840 ON ERROR GOTO 0

3850 END

3860 PRINT "This option currently unimplemented"

3870 FOR DELAY = 1 TO 1500 : NEXT DELAY

3880 GOTO 2820
```

Appendix F

Main Program

```
4000 'DOSE  .BAS

4010 'MegaCi/m at a given alt at a given time after burst

4020 'find MCi/m^2 & MCi/m^3, compute skyshine and dust dose for crew

4030 'using sigmaz(G) = dslope and dintercept

4040 '15,16 Dec 84 Capt Stephen P. Conners for Dr. Bridgman

4050 PRINT "US Standard Atmosphere (Mid Latitude, Spring/Fall).
No vertical winds."

4060 GOSUB 5120                    :'print output header

4070 IF DUST.DOSE$ = "dust" THEN A1.PERCENT = MASS1.PERCENT :'for dust report

4080 GOTO 6200                     :'main program; subroutines first for speed

4090 ' US std atmosphere ********************************************************

4100 '*******************************************************************************

4110 IF ZM(G) < 0 THEN RHOAIRZ = 1.22473        :ETAZ = 1.78938E-05 :GOTO 4250

4120 IF ZM(G) < 11000 THEN  TK=288.15:PK=101300!:LK=-.006545  :ZK=0 :GOTO 4200

4130 IF ZM(G) < 20000 THEN  TK=216.65:PK=22690 :LK=0      :ZK=11000 :GOTO 4200

4140 IF ZM(G) < 32000 THEN  TK=216.65:PK=5528  :LK=.001   :ZK=20000 :GOTO 4200

4150 IF ZM(G) < 47000! THEN TK=228.65:PK=888.8 :LK=.0028  :ZK=32000 :GOTO 4200

4160 IF ZM(G) < 52000! THEN TK=270.65:PK=115.8 :LK=0      :ZK=47000!:GOTO 4200

4170 IF ZM(G) < 71000! THEN TK=270.65:PK=115.8 :LK=-.00283:ZK=52000!:GOTO 4200

4180 IF ZM(G) < 84852! THEN TK=214.65:PK=3.956 :LK=-.002  :ZK=71000!:GOTO 4200

4190 IF ZM(G) >= 84852! THEN PRINT "Cloud MUCH too high! zm = "ZM(G):END

4200 IF LK = 0 THEN TZ=TK :PZ=PK*EXP((-.034164*(ZM(G)-ZK))/TK)      :GOTO 4230

4210 TZ=TK + LK*(ZM(G) - ZK) :PZ=PK*(TK/TZ)^(.034164/LK)          :'if LK <> 0

4220 'tz = temperature in degrees K     :'pz = pressure in TORR
```

```
4230 RHOAIRZ=(28.964/8314)*(PZ/TZ)       :'density KG/M^3

4240 ETAZ=(TZ)^1.5*1.458E-06/(TZ+110.4) :'dynamic viscosity KG/M-S

4250 RETURN

4260 ' cloud fall computations *******************************************

4270 'mcdonald - davies formulae *****************************************

4280 '********************************************************************

4290 IF ZM(G)<0 THEN G.AT.Z = ACCELLG:GOTO 4310:'realistic settling rate@zm=0

4300 G.AT.Z=ACCELLG*6370.95^2/(6370.95+ZM(G)/1000)^2  :'correct g for altitude

4310 Q = 32*RHOAIRZ*RHOFALLOUT*G.AT.Z*(RM(G))^3/(3*ETAZ^2) :'q=Re^2*Cd

4320 LOG10.Q = LOG(Q)/LOG10

4330 IF Q < 140 THEN REYNOLDS.NUMBER = Q/24
- 2.3363E-04*Q^2 + 2.0154E-06*Q^3 - 6.9105E-09*Q^4

4340 IF Q >= 140 THEN REYNOLDS.NUMBER = 10^(-1.29536 + .986*(LOG10.Q)
-  .046677*(LOG10.Q)^2 + .0011235*(LOG10.Q)^3)

4350 IF Q > 4.5E+07 THEN PRINT "q too large = "Q

4360 FALL.VELOCITY = REYNOLDS.NUMBER*ETAZ/(2*RHOAIRZ*RM(G))     :'m/s

4370 FALL.VELOCITY = FALL.VELOCITY*(1 + 1.165E-07/(RHOAIRZ*RM(G)))

4380 'correction for drag "slip" at high altitude

4390 ZM(G) = ZM(G) - FALL.VELOCITY*DELTAT*3600  :'new altitude after deltat

4400 RETURN

4410 'compute sigma x, y and dose to crew ***********************************

4420 '********************************************************************

4430 IF TIME > 3! THEN TA = 3! ELSE TA = TIME

4440 SIGMAX = SQR((SIGMA0^2)*(1!+(8!*TA)/TC)
+ (SIGMAZ(MAXG(Z.STEP))*WIND.SHEAR.X*TIME)^2)

4450 SIGMAY = SQR((SIGMA0^2)*(1!+(8!*TA)/TC)
+ (SIGMAZ(MAXG(Z.STEP))*WIND.SHEAR.Y*TIME)^2)

4460 DELTAY = 0                           :'M fly through center of cloud
deltay = y1 - y0 in meters

4470 'FX = 1                              :'by definition

4480 FY = EXP(-.5*((DELTAY/SIGMAY)^2))/(SQR2PI*SIGMAY)
```

```
4490 IF NUMBER.BOMBS = 1
THEN BURST.AMP.FACTOR = 1
ELSE BURST.AMP.FACTOR = BOMB.DENSITY*(SQR2PI*SIGMAY)

4500 CABIN.SUM.ACTIVITY.PER.METER(Z.STEP) =
 CABIN.SUM.ACTIVITY.PER.METER(Z.STEP)*BURST.AMP.FACTOR

4510 FILTER.SUM.ACTIVITY.PER.METER(Z.STEP) =
FILTER.SUM.ACTIVITY.PER.METER(Z.STEP)*BURST.AMP.FACTOR

4520 CA2 =  CABIN.SUM.ACTIVITY.PER.METER(Z.STEP)/(SQR2PI*SIGMAY)

4530 FA2 = FILTER.SUM.ACTIVITY.PER.METER(Z.STEP)/(SQR2PI*SIGMAY)

4540 A3(Z.STEP) = (CA2 + FA2)/(SQR2PI*SIGMAX)

4550 G=111 :ZM(G) = ZAC :GOSUB 4090      :'us std atm; fetch rhoairz

4560  CABIN.ACTIVITY(Z.STEP) = CA2*(MASS.FLOW/60)/(RHOAIRZ*VAC)

4570 FILTER.ACTIVITY(Z.STEP) = FA2*(MASS.FLOW/60)/(RHOAIRZ*VAC)

4580 ENGINE.MASS(Z.STEP) = (CA2 + FA2)*(ENGINE.MASS.FLOW)/(RHOAIRZ*VAC)

4590 CABIN.DOSE.RATE=DCF*CABIN.ACTIVITY(Z.STEP)*CABIN.GEOMETRY/PRESSURE.VOLUME

4600 CABIN.DOSE(Z.STEP) = 5*CABIN.DOSE.RATE*(TIME^-.2-(TIME+MSN.TIME.REM)^-.2)

4610 MUTRHO = MUT*RHOAIRZ                :'M^2/KG air cross section at Z

4620 GAMMA.MFP(Z.STEP) = 1/MUTRHO

4630 IF GAMMA.MFP(Z.STEP) < .2*SIGMAX
THEN STAR$(Z.STEP) = ""
ELSE STAR$(Z.STEP) = "*"

4640 FZ = (CABIN.SUM.ACTIVITY.PER.METER(Z.STEP)
+ FILTER.SUM.ACTIVITY.PER.METER(Z.STEP))

4650 D1 = DCF*(FZ/MUTRHO)*(FY/(VAC*3600))

4660 SKYSHINE.DOSE(Z.STEP) = D1*(TIME^-1.2)*GAMMA.TX.FACTOR

4670 IF NUMBER.BOMBS = 1 THEN RETURN    :'else

4680 'BURST.AMP.FACTOR = BOMB.DENSITY*(SQR2PI*SIGMAY)

4690 IF SIGMAY < (FIELD.WIDTH/1000)/SQR(NUMBER.BOMBS) THEN SHARP$ = "#"

4730 DELTAX = 0                          :'Fly through center of cloud

4740 FX = EXP(-.5*((DELTAX/SIGMAX)^2))/(SQR2PI*SIGMAX)

4750 TRANSIT.TIME = (2*2*SIGMAX)/(VAC*3600)    :'HRS to cross 2 sigma cloud
```

```
4760 SKYSHINE.DOSE(Z.STEP) = D1*GAMMA.TX.FACTOR*(FX*VAC*3600)*5*
((TIME-TRANSIT.TIME/2)^-.2-(TIME+TRANSIT.TIME/2)^-.2)
:'The overlapped gaussians create a cloud with little horizontal variation

4770 RETURN

4780 ' compute & sum the gaussian at A/C alt for each group *****************

4790 '**********************************************************************

4800 'activities are at unit time

4810 ZAC = ZAC.HI + ZAC.STEP                          :'start at zac.hi

4820 FOR Z.STEP = 1 TO Z.STEPS

4830 ZAC = ZAC - ZAC.STEP

4840  CABIN.SUM.ACTIVITY.PER.METER = 0

4850 FILTER.SUM.ACTIVITY.PER.METER = 0

4860 FOR G = 1 TO LASTG

4870 IF ABS(ZAC - ZM(G)) > 3*SIGMAZ(G) THEN GOTO 4960

4880 IF ABS(ZAC-ZM(G)) < ABS(ZAC-ZM(G-1)) THEN MAXG(Z.STEP) = G :'top down!

4890 GAUSSIANZM(G) = EXP(-.5*((ZAC-ZM(G))/SIGMAZ(G))^2)/(SQR2PI*SIGMAZ(G))

4900 'gaussian part of zm(G) contributing to activity at ZAC

4910 AR(G) = A1.PERCENT*GAUSSIANZM(G)

4920 CABIN.AR(G)  = AR(G)*   FILTER.TX.FACTOR(G)

4930 FILTER.AR(G) = AR(G)*(1-FILTER.TX.FACTOR(G))

4940  CABIN.SUM.ACTIVITY.PER.METER= CABIN.SUM.ACTIVITY.PER.METER + CABIN.AR(G)

4950 FILTER.SUM.ACTIVITY.PER.METER=FILTER.SUM.ACTIVITY.PER.METER +FILTER.AR(G)

4960 NEXT G

4970  CABIN.SUM.ACTIVITY.PER.METER(Z.STEP) =  CABIN.SUM.ACTIVITY.PER.METER

4980 FILTER.SUM.ACTIVITY.PER.METER(Z.STEP) = FILTER.SUM.ACTIVITY.PER.METER

4990 IF ZAC = WORST.ALT THEN GOSUB 5030 :'compute %activity

5000 GOSUB 4410                          :'compute dose

5010 NEXT Z.STEP

5020 RETURN
```

```
5030 'compute percent activity **********************************************

5040 '*********************************************************************

5050 FOR G = 1 TO LASTG

5060 PER(G) = (AR(G)/(CABIN.SUM.ACTIVITY.PER.METER
+ FILTER.SUM.ACTIVITY.PER.METER))*100

5070 IF PER(G) > PER(G-1) AND ZM(G) < 0 THEN PER(G) = PER(G-1)

5080 PERCENT.25(G) = INT(PER(G)*4*100)/100

5090 IF PERCENT.25(G) > 255 THEN PERCENT.25(G) = 255 :'max basic line length

5100 NEXT G

5110 RETURN

5120 ' print header ******************************************************

5130 '*********************************************************************

5140 OPEN "O",#1,OUTPUT.FILE$

5150 PRINT#1,DATE.TIME$ :PRINT#1,"This is a "DUST.DOSE$" report."

5160 PRINT#1,WHICH$ :PRINT#1," "

5170 PRINT#1,"WEAPON/TARGET DATA:"

5180 PRINT#1,"Number of weapons ------------------"NUMBER.BOMBS
:IF NUMBER.BOMBS > 1
THEN PRINT#1,"Width of target field --------------"FIELD.WIDTH/1000"KM

5190 PRINT#1,"Weapon yield -----------------------"YIELDKT"KT"

5200 PRINT#1,"Fission fraction -------------------"FF

5210 PRINT#1,"Dust fraction ----------------------"DF

5220 PRINT#1,"The size distribution input file is- "INPUT.FILE$

5230 PRINT#1,"                    "SIZE.LABEL$ :PRINT#1," "

5240 PRINT#1,"The soil density is ----------------"RHOFALLOUT"KG/M^3"

5250 PRINT#1," "

5260 PRINT#1,"The aircraft specification file is - "AIRCRAFT.FILE$

5270 PRINT#1,"Aircraft velocity is ---------------"VAC"M/S"

5280 PRINT#1," "

5290 PRINT#1,"Time from cloud penetration"
```

```
5300 PRINT#1,"to end of mission ------------------"MSN.TIME.REM"HR"

5310 PRINT#1," "

5320 PRINT#1,"Wind shear X (along track) ---------"WIND.SHEAR.X"(KM/HR)/KM"

5330 PRINT#1,"Wind shear Y (cross track) ---------"WIND.SHEAR.Y"(KM/HR)/KM"

5340 PRINT#1," "

5350 PRINT#1,"The output file will be named ------ "OUTPUT.FILE$ :PRINT#1," "

5360 RETURN

5370 'report subroutine ******************************************************

5380 IF DUST.DOSE$ = "dust" THEN GOTO 5800      :'print mass report

5390 ' print dose report to disk *********************************************

5400 PRINT#1,STRING$(78,42)

5410 'activities are in unit time and must be converted before printing

5420 PRINT#1,DATE.TIME$"    "WHICH$

5430 PRINT#1,"time (hr) ="TIME;SHARP$" deltat (hr) ="DELTAT" %airborne =
"LASTG" sigmax ="SIGMAX"M"

5440 PRINT#1,"sigmay ="SIGMAY"M                    3 sigmay cloud diameter =
"2*3*SIGMAY"M"

5450 PRINT#1,"Altitude","Cabin Dust","Sky Shine","TotalDose","Prominent Particle"

5460 PRINT#1,"    M","   REM","   REM","   REM "," microns radius"

5470 ZAC = ZAC.HI + ZAC.STEP

5480 FOR Z.STEP = 1 TO Z.STEPS

5490 ZAC = ZAC - ZAC.STEP

5500 PRINT#1,ZAC,CABIN.DOSE(Z.STEP),SKYSHINE.DOSE(Z.STEP),CABIN.DOSE(Z.STEP)
+SKYSHINE.DOSE(Z.STEP);STAR$(Z.STEP),RM(MAXG(Z.STEP))*1E+06

5510 NEXT Z.STEP

5520 IF STAR$(1) = "*" THEN PRINT#1,
"* Skyshine may be inaccurate due to large gamma mean free path (mfp >.2sigmax)"
:'only highest alt need be tested because if it occurs at some altitude,
it will occur for any higher altitude

5530 IF SHARP$ = "#" THEN
 PRINT#1,"# Dose inaccurate because burst field has not yet coalesced." ELSE
 PRINT#1,""
```

```
5540 IF ACTIVITY.REPORT$ = "n" THEN 5690

5550 'print activity report ***************************************************

5560 PRINT#1,STRING$(78,45) :PRINT#1,DATE.TIME$"    "WHICH$

5570 PRINT#1,"time (hr) ="TIME;SHARP$" deltat (hr) ="DELTAT" %airborne =
"LASTG" sigmax ="SIGMAX"M"

5580 PRINT#1,"Altitude,","Cloud Act","Filter Act","Cabin Act",
"Prominent Particle"

5590 PRINT#1,"   M","  MCi/M","    Ci","    Ci","microns r"

5600 ZAC = ZAC.HI + ZAC.STEP

5610 FOR Z.STEP = 1 TO Z.STEPS

5620 ZAC = ZAC - ZAC.STEP

5630 PRINT#1,ZAC,(CABIN.SUM.ACTIVITY.PER.METER(Z.STEP)
+FILTER.SUM.ACTIVITY.PER.METER(Z.STEP))*(TIME^-1.2)/1E+06,
FILTER.ACTIVITY(Z.STEP),CABIN.ACTIVITY(Z.STEP),RM(MAXG(Z.STEP))*1E+06

5640 NEXT Z.STEP

5650 PRINT#1,"For Group #","size (microns)","Altitude (M)"

5660 FOR G = 10 TO LASTG STEP 10

5670 PRINT#1,G,RM(G)*1E+06,ZM(G)

5680 NEXT G

5690 IF ACTSIZE.REPORT$ = "n" THEN 5790

5700 'print actsize vs alt report ********************************************

5710 PRINT#1,STRING$(78,45) :PRINT#1,DATE.TIME$"    "WHICH$

5720 PRINT#1,"The graph shows percent of total cloud activity for eachgroup at

the maximum activity penetration altitude of "WORST.ALT"meters (1/4% per star)"
5730 PRINT#1,"Group#";"   Size"," Altitude","PERCENT of Total Activity"

5740 PRINT#1,"      ";"   "CHR$(197)"M ","    M",
"0  |   |   |   |   5  |   |   |   |   10 |   |   |"

5750 FOR G = 1 TO LASTG

5760 PRINT#1,G;RM(G)*1E+06,ZM(G),STRING$(PERCENT.25(G),42)

5770 NEXT G

5780 PRINT#1,"      ";"      ","     ",
```

```
"0  |    |    |    |   5  |    |    |    |   10 |    |    |"

5790 RETURN

5800 'print density report ****************************************************

5810 PRINT#1,STRING$(78,42) :PRINT#1,DATE.TIME$"    "WHICH$

5820 PRINT#1,"time (hr) ="TIME;SHARP$" deltat (hr) ="DELTAT" %airborne =
"LASTG" sigmax ="SIGMAX"M"

5830 PRINT#1,"sigmay ="SIGMAY"M                      3 sigmay cloud diameter =
"2*3*SIGMAY"M"

5840 PRINT#1,"Altitude","Cloud Dens","Filter Mass","Cabin Mass","Engine Mass";
"Prom Part"

5850 PRINT#1,"    M","    mg/M^3","     Kg","     Kg","     Kg      ";"microns r"

5860 ZAC = ZAC.HI + ZAC.STEP

5870 FOR Z.STEP = 1 TO Z.STEPS

5880 ZAC = ZAC - ZAC.STEP

5890 PRINT#1,ZAC,A3(Z.STEP)*(1000*1000),FILTER.ACTIVITY(Z.STEP),
CABIN.ACTIVITY(Z.STEP),ENGINE.MASS(Z.STEP);" ";RM(MAXG(Z.STEP))*1E+06

5900 NEXT Z.STEP

5910 IF MASS.REPORT$ = "n" THEN 6080

5920 'print mass report *******************************************************

5930 PRINT#1,STRING$(78,45) :PRINT#1,DATE.TIME$"    "WHICH$

5940 PRINT#1,"time (hr) ="TIME;SHARP$" deltat (hr) ="DELTAT" %airborne =
"LASTG" sigmax ="SIGMAX"M"

5950 PRINT#1,"sigmay ="SIGMAY"M                      3 sigmay cloud diameter =
"2*3*SIGMAY"M"

5960 PRINT#1,"initial dust lofted = "MASS1.PERCENT*100"Kg",
"   dust now airborne ="MASS1.PERCENT*LASTG"Kg"

5970 PRINT#1,"Altitude","Cloud Mass"

5980 PRINT#1,"    M","    Kg/M"

5990 ZAC = ZAC.HI + ZAC.STEP

6000 FOR Z.STEP = 1 TO Z.STEPS

6010 ZAC = ZAC - ZAC.STEP

6020 PRINT#1,ZAC,(CABIN.SUM.ACTIVITY.PER.METER(Z.STEP)
```

```
+ FILTER.SUM.ACTIVITY.PER.METER(Z.STEP))

6030 NEXT Z.STEP

6040 PRINT#1,"For Group #","size (microns)","Altitude (M)"

6050 FOR G = 10 TO LASTG STEP 10

6060 PRINT#1,G,RM(G)*1E+06,ZM(G)

6070 NEXT G

6080 IF MASS.SIZE.REPORT$ = "n" THEN 6180

6090 'print mass size vs alt report *************************************

6100 PRINT#1,STRING$(78,45) :PRINT#1,DATE.TIME$"    "WHICH$

6110 PRINT#1,"The graph shows percent of total cloud mass for each group at
the maximum density penetration altitude of "WORST.ALT"meters (1/4% per star)"

6120 PRINT#1,"Group#";"   Size"," Altitude","PERCENT of Total Mass"

6130 PRINT#1,"      ";"   "CHR$(197)"M ","    M",
"0  |   |   |   |   5  |   |   |   |   10 |   |   |"

6140 FOR G = 1 TO LASTG

6150 PRINT#1,G;RM(G)*1E+06,ZM(G),STRING$(PERCENT.25(G),42)

6160 NEXT G

6170 PRINT#1,"      ";"       ","     ",
"0  |   |   |   |   5  |   |   |   |   10 |   |   |"

6180 RETURN

6190 '****************************************************************

6200 'main program ****************************************************

6210 '****************************************************************

6220 FOR G = 1 TO 100

6230 RM(G) = RM(G)*.000001              :'convert micrometers to METERS

6240 NEXT G

6250 'find initial delta t *********************************************

6260 G=90 :z90 = zm(90) :ZM(90)=0

6270 GOSUB 4090 :GOSUB 4260 :'find fall.velocity of 1 hr group at lowest alt
```

```
6275 zm(90) = z90

6280 INTERVAL = TIME.STOP(1) - TIME.STOP

6290 DELTAT = INTERVAL/INT(INTERVAL/(1400/(FALL.VELOCITY*3600)))
:'find the largest deltat that will not cause the largest particle to fall more
than 1400 meters; also, deltat must be an integral divisor of interval.

6300 '1400 meters is chosen because empirical testing has shown that this
is the largest distance a particle can fall without significantly affecting
the  result.

6310 IF DELTAT < .1 OR DELTAT > 100 THEN DELTAT = INTERVAL/8

6320 'find worst case altitude to to plot %activity vs rm ********************

6330 IF YIELDKT < 10000 THEN ZSHIFT = 1000 ELSE ZSHIFT = 2000

6340 IF TIME <= 2 THEN WORST.ALT = HC ELSE WORST.STEP = HC - ZSHIFT

6350 'yield and time correction factors empirical from vertact for delfic

6360 '(worst case means maximum Ci/m; might not be maximum dose)

6370 IF DUST.DOSE$ = "dust" THEN WORST.ALT = ZM(50)

6380 ZAC = ZAC.HI + ZAC.STEP

6390 FOR Z.STEP = 1 TO Z.STEPS

6400 ZAC = ZAC - ZAC.STEP

6410 IF ABS(ZAC-WORST.ALT) <= .5*ZAC.STEP
THEN WORST.STEP = Z.STEP
:WORST.ALT = ZAC
:GOTO 6440

6420 NEXT Z.STEP

6430 WORST.STEP = 1

6440 'compute activity vs altitude for various fall times ********************

6450 '************************************************************************

6460 FOR T = 1 TO HOW.MANY.TIMES

6470 LAST.TIME.STOP = TIME.STOP

6480 TIME.STOP = TIME.STOP(T)

6490 PRINT "Now computing for time ="TIME.STOP"hr"

6500 INTERVAL = TIME.STOP - LAST.TIME.STOP

6510 IF FALL.VELOCITY*DELTAT*3600 < 1400
```

```
THEN DELTAT = INTERVAL/INT(INTERVAL/(1400/(FALL.VELOCITY*3600)))
:IF DELTAT<.1 OR DELTAT>100 THEN DELTAT = INTERVAL/8
:'if the largest size group falls<1400 meters in deltat, compute larger deltat

6520 G = 1

6530 WHILE G <= LASTG

6540 FOR PART.TIME = 1 TO INTERVAL/DELTAT

6550 GOSUB 4090                        :'us std atm

6560 GOSUB 4260                        :'cloud fall

6570 IF ZM(G) < -3*SIGMAZ(G)
THEN LASTG = G-1
:FOR CC = G TO LASTG
:ZM(CC) = -100000!
:NEXT CC
:'skip drift down if > 3 sigma underground

6580 NEXT PART.TIME

6590 G = G + 1

6600 WEND                              :'g <= lastg

6610 TIME = TIME + INTERVAL

6620 GOSUB 4780                        :'sum gaussians for each altitude

6630 GOSUB 5370                        :'print output

6640 NEXT T

6650 PRINT#1,CHR$(12)                  :'form feed

6660 CLOSE

6670 PRINT STRING$(10,7)                       :'awaken operator

6680 PRINT "Computations complete. File is stored in "OUTPUT.FILE$

6690 END
```

Appendix G

Sample Single Burst Dose Output - Full Report

```
14 Feb 1556
This is a dose report.
CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb

WEAPON/TARGET DATA:
Number of weapons ------------------ 1
Weapon yield ----------------------- 1000 KT
Fission fraction ------------------- 1
Dust fraction ---------------------- .333333
The size distribution input file is- DELFIC.RMA
                        Rm =  .204 ; sigma Rm =  4
The soil density is ---------------- 2600 KG/M^3
The aircraft specification file is - B-1B.SPC
Aircraft velocity is --------------- 279.2 M/S
Time from cloud penetration
to end of mission ------------------ 8 HR
Wind shear X (along track) --------- 0 (KM/HR)/KM
Wind shear Y (cross track) --------- 1 (KM/HR)/KM
The output file will be named ------ B:GAPP.DOP

*******************************************************************************
14 Feb 1556   CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
time (hr) = .15  deltat (hr) =-9.50774E-03  %airborne = 98  sigmax = 2977.15 M
sigmay = 2983.01 M                 3 sigmay cloud diameter = 17898 M
Altitude      Cabin Dust     Sky Shine     TotalDose      Prominent Particle
   M             REM            REM           REM          microns radius
 17000         3.89241        58.7864       62.6788 *      .473992
 16000         7.05376        118.791       125.845 *      .473992
 15000         9.85256        187.335       197.188 *      .473992
 14000         10.6072        231.806       242.413 *      .473992
 13000         8.80336        226.604       235.407        42.8646
 12000         5.6323         176.928       182.56         126.317
 11000         2.77723        112.437       115.214        202.228
 10000         1.09192        62.2996       63.3916        272.629
 9000          .331339        30.981        31.3123        326.279
 8000          .0777644       15.1821       15.2599        403.868
 7000          0              7.64285       7.64285        457.979
 6000          0              4.65089       4.65089        529.291
 5000          0              3.12039       3.12039        529.291
 4000          0              2.17059       2.17059        629.064
 3000          0              1.49812       1.49812        629.064
 2000          0              1.24043       1.24043        782.496
 1000          0              1.1288        1.1288         782.496
 0             0              .72757        .72757         782.496
* Skyshine may be inaccurate due to large gamma mean free path (mfp >.2sigmax)
```

```
------------------------------------------------------------------------------
14 Feb 1556    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
time (hr) = .15  deltat (hr) =-9.50774E-03  %airborne = 98  sigmax = 2977.15 M
Altitude,      Cloud Act      Filter Act     Cabin Act      Prominent Particle
   M            MCi/M            Ci             Ci          microns r
 17000          123.019        9.06398        3.00584        .473992
 16000          291.046        18.9426        5.44714        .473992
 15000          537.382        30.8546        7.60847        .473992
 14000          778.527        39.4025        8.1912         .473992
 13000          890.88         39.7273        6.79824        42.8646
 12000          814.094        31.9767        4.34945        126.317
 11000          605.527        20.9404        2.14466        202.228
 10000          379.584        11.9479        .843216        272.629
 9000           213.261        6.10505        .255871        326.279
 8000           117.655        3.05709        .0600522       403.868
 7000           66.4701        1.5692         0              457.979
 6000           45.2521        .954904        0              529.291
 5000           33.8754        .640669        0              529.291
 4000           26.2107        .445659        0              629.064
 3000           20.0758        .30759         0              629.064
 2000           18.392         .254681        0              782.496
 1000           18.4828        .231761        0              782.496
 0              13.1261        .149382        0              782.496
For Group #    size (microns)                Altitude (M)
 10             3.80268        13593.3
 20             8.35085        13509.8
 30             14.6576        13401.4
 40             23.5162        13262.6
 50             36.2252        13084.8
 60             55.1961        12844.3
 70             85.5478        12480.7
 80             140.637        11797.8
 90             272.629        9955.32
------------------------------------------------------------------------------
14 Feb 1556    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
The graph shows percent of total cloud activity for each group at
the maximum activity penetration altitude of  13000 meters (1/4% per star)
Group#   Size    Altitude      PERCENT of Total Activity
          uM        M          0  |   |   |   |   5  |   |   |   |   10 |   |   |
 1  .473992     13657.2        ****
 2  .904308     13648.8        ****
 3  1.27327     13641.6        ****
 4  1.62603     13634.8        ****
 5  1.97515     13628.1        ****
 6  2.32639     13621.3        ****
 7  2.68294     13614.5        ****
 8  3.04692     13607.6        ****
 9  3.41978     13600.5        *****
 10  3.80268    13593.3        *****
```

```
11  4.19655   13585.9      *****
12  4.60222   13578.3      *****
13  5.02038   13570.5      *****
14  5.45171   13562.5      *****
15  5.89686   13554.3      *****
16  6.35641   13545.9      *****
17  6.83098   13537.2      *****
18  7.32119   13528.3      *****
19  7.8276    13519.2      *****
20  8.35085   13509.8      *****
21  8.89157   13500.2      *****
22  9.45039   13490.3      *****
23  10.028    13480.2      *****
24  10.625    13469.8      *****
25  11.2422   13459.1      *****
26  11.8803   13448.1      *****
27  12.5401   13436.9      *****
28  13.2223   13425.4      *****
29  13.9278   13413.5      *****
30  14.6576   13401.4      *****
31  15.4124   13389        *****
32  16.1934   13376.3      *****
33  17.0015   13363.2      *****
34  17.8378   13349.9      *****
35  18.7035   13336.2      *****
36  19.5996   13322.2      *****
37  20.5276   13307.8      *****
38  21.4887   13293.1      *****
39  22.4844   13278        *****
40  23.5162   13262.6      *****
41  24.5856   13246.8      *****
42  25.6944   13230.6      *****
43  26.8444   13214        *****
44  28.0374   13197        *****
45  29.2756   13179.5      *****
46  30.5611   13161.6      *****
47  31.8962   13143.2      *****
48  33.2835   13124.3      *****
49  34.7255   13104.8      *****
50  36.2252   13084.8      *****
51  37.7855   13064.1      *****
52  39.4098   13042.8      *****
53  41.1016   13020.7      *****
54  42.8646   12998        *****
55  44.7032   12974.4      *****
56  46.6215   12950        *****
57  48.6246   12924.7      *****
58  50.7175   12898.7      *****
59  52.906    12871.8      *****
60  55.1961   12844.3      *****
```

```
61  57.5948   12816.1      *****
62  60.109    12787.3      *****
63  62.7472   12757.7      *****
64  65.5178   12726.7      *****
65  68.4309   12692.1      *****
66  71.4967   12651.7      *****
67  74.7277   12612.4      *****
68  78.1363   12570.9      *****
69  81.7377   12527        *****
70  85.5478   12480.7      *****
71  89.5848   12431.5      *****
72  93.8697   12379.3      *****
73  98.4248   12323.7      *****
74  103.277   12264.3      *****
75  108.456   12200.7      *****
76  113.995   12132.3      ****
77  119.933   12058.6      ****
78  126.317   11978.9      ****
79  133.198   11892.2      ****
80  140.637   11797.8      ****
81  148.708   11694.4      ****
82  157.495   11580.3      ****
83  167.101   11454        ****
84  177.652   11313.2      ***
85  189.298   11155.7      ***
86  202.228   10977.5      ***
87  216.678   10774.8      **
88  232.947   10542.1      **
89  251.428   10272.1      **
90  272.629   9955.32      *
91  297.255   9578.12      *
92  326.279   9121.48
93  361.108   8557.42
94  403.868   7842.96
95  457.979   6908.04
96  529.291   5631.13
97  629.064   3776.22
98  782.496   896.84
                           0   |   |   |   |   5   |   |   |   |   10  |   |   |
```

```
******************************************************************************
14 Feb 1556    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
time (hr) = 1  deltat (hr) = .10625  %airborne = 90  sigmax = 3958.03 M
sigmay = 4343.43 M                  3 sigmay cloud diameter = 26060.6 M
Altitude       Cabin Dust     Sky Shine     TotalDose      Prominent Particle
   M              REM            REM           REM         microns radius
 17000          1.15023        2.59592       3.74614 *      .473992
 16000          2.09225        5.1946        7.28685 *      .473992
 15000          2.93373        8.14236       11.0761        .473992
 14000          3.17099        10.1127       13.2837        .473992
 13000          2.64601        10.1119       12.7579        17.0015
 12000          1.70168        8.33252       10.0342        31.8962
 11000          .843251        5.89719       6.74044        42.8646
 10000          .333273        3.95198       4.28525        55.1961
 9000           .101657        2.61766       2.71931        65.5178
 8000           .0239879       1.81552       1.83951        78.1363
 7000           0              1.31614       1.31614        89.5848
 6000           0              1.01115       1.01115        103.277
 5000           0              .793417       .793417        113.995
 4000           0              .631872       .631872        126.317
 3000           0              .508593       .508593        140.637
 2000           0              .414059       .414059        157.495
 1000           0              .338848       .338848        167.101
 0              0              .278331       .278331        189.298
* Skyshine may be inaccurate due to large gamma mean free path (mfp >.2sigmax)
```

```
-------------------------------------------------------------------------------
14 Feb 1556    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
time (hr) = 1  deltat (hr) = .10625  %airborne = 90  sigmax = 3958.03 M
Altitude,      Cloud Act      Filter Act     Cabin Act      Prominent Particle
  M            MCi/M            Ci             Ci           microns r
 17000          8.02132         3.18426        2.00859        .473992
 16000         18.7928          6.73761        3.65361        .473992
 15000         34.4885         11.1649         5.12305        .473992
 14000         50.1508         14.6921         5.53736        .473992
 13000         58.6231         15.6072         4.62061        17.0015
 12000         56.4814         13.6967         2.97156        31.8962
 11000         46.7546         10.3242         1.47253        42.8646
 10000         35.4182          7.32352         .58198        55.1961
 9000          26.4852          5.05882         .177519       65.5178
 8000          20.6628          3.58987         .0418891      78.1363
 7000          16.7965          2.63278        0              89.5848
 6000          14.4225          2.02269        0              103.277
 5000          12.6149          1.58714        0              113.995
 4000          11.1662          1.26399        0              126.317
 3000           9.96142         1.01738        0              140.637
 2000           8.96404          .828279       0              157.495
 1000           8.09427          .677828       0              167.101
 0              7.31141          .556771       0              189.298
For Group #    size (microns)                 Altitude (M)
 10             3.80268        13573.5
 20             8.35085        13420.4
 30            14.6576         13133.9
 40            23.5162         12595.6
 50            36.2252         11615.5
 60            55.1961          9937.44
 70            85.5478          7302.32
 80           140.637           3084.51
 90           272.629          -4810.92
-------------------------------------------------------------------------------
14 Feb 1556    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
The graph shows percent of total cloud activity for each group at
the maximum activity penetration altitude of  13000 meters (1/4% per star)
Group#  Size   Altitude     PERCENT of Total Activity
         uM      M          0 |  |  |  |  5 |  |  |  |  10 |  |  |
 1  .473992    13656.6      *******
 2  .904308    13647.2      *******
 3  1.27327    13638.9      *******
 4  1.62603    13630.6      *******
 5  1.97515    13622.2      *******
 6  2.32639    13613.4      *******
 7  2.68294    13604.2      *******
 8  3.04692    13594.5      *******
 9  3.41978    13584.3      *******
 10  3.80268   13573.5      *******
```

```
11  4.19655   13562       *******
12  4.60222   13549.9     *******
13  5.02038   13537       *******
14  5.45171   13523.3     *******
15  5.89686   13508.7     *******
16  6.35641   13493.2     *******
17  6.83098   13476.6     *******
18  7.32119   13459.1     *******
19  7.8276    13440.4     *******
20  8.35085   13420.4     *******
21  8.89157   13399.2     *******
22  9.45039   13376.6     *******
23  10.028    13352.6     *******
24  10.625    13327       *******
25  11.2422   13299.7     *******
26  11.8803   13270.6     *******
27  12.5401   13239.6     *******
28  13.2223   13206.6     *******
29  13.9278   13171.4     *******
30  14.6576   13133.9     *******
31  15.4124   13094       *******
32  16.1934   13051.5     *******
33  17.0015   13006.2     *******
34  17.8378   12958       *******
35  18.7035   12906.6     *******
36  19.5996   12851.9     *******
37  20.5276   12793.6     *******
38  21.4887   12731.7     *******
39  22.4844   12665.7     *******
40  23.5162   12595.6     *******
41  24.5856   12521.1     *******
42  25.6944   12442       *******
43  26.8444   12357.9     *******
44  28.0374   12268.8     *******
45  29.2756   12174.4     *******
46  30.5611   12074.5     *******
47  31.8962   11968.8     ******
48  33.2835   11857.2     ******
49  34.7255   11739.5     ******
50  36.2252   11615.5     ******
51  37.7855   11484.9     *****
52  39.4098   11347.7     *****
53  41.1016   11203.5     *****
54  42.8646   11051.9     ****
55  44.7032   10892.3     ****
56  46.6215   10723.4     ****
57  48.6246   10545.6     ***
58  50.7175   10355.9     ***
59  52.906    10154.1     **
60  55.1961   9937.44     **
```

```
61  57.5948   9705.86      **
62  60.109    9463.34      *
63  62.7472   9221.43      *
64  65.5178   8987.47      *
65  68.4309   8742.13      *
66  71.4967   8483.64
67  74.7277   8208.73
68  78.1363   7921.02
69  81.7377   7619.13
70  85.5478   7302.32
71  89.5848   6968.98
72  93.8697   6620.18
73  98.4248   6253.74
74  103.277   5868.45
75  108.456   5463.14
76  113.995   5036.52
77  119.933   4585.97
78  126.317   4112.48
79  133.198   3612.63
80  140.637   3084.51
81  148.708   2525.55
82  157.495   1933
83  167.101   1303.91
84  177.652   634.534
85  189.298  -78.9946
86  202.228  -843.808
87  216.678  -1682.04
88  232.947  -2605.78
89  251.428  -3650.72
90  272.629  -4810.92
                           0  |   |   |   |   5  |   |   |   |  10 |   |   |
```

Appendix H

Sample Single Burst Dust Output - Full Report

```
14 Feb 1540
This is a dust report.
CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb

WEAPON/TARGET DATA:
Number of weapons ------------------ 1
Weapon yield ----------------------- 1000 KT
Fission fraction ------------------- .5
Dust fraction ---------------------- .333333
The size distribution input file is- DELFIC.RMM
                        Rm =  .204 ; sigma Rm =  4
The soil density is ---------------- 2600 KG/M^3
The aircraft specification file is - B-1B.SPC
Aircraft velocity is --------------- 279.2 M/S
Time from cloud penetration
to end of mission ------------------ 8 HR
Wind shear X (along track) --------- 0 (KM/HR)/KM
Wind shear Y (cross track) --------- 1 (KM/HR)/KM
The output file will be named ------ B:HAPP.DOP

*******************************************************************************
14 Feb 1540    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
time (hr) = .15  deltat (hr) =-9.50774E-03  %airborne = 97   sigmax = 2984.51 M
sigmay = 2990.18 M                  3 sigmay cloud diameter = 17941.1 M
Altitude      Cloud Dens     Filter Mass   Cabin Mass    Engine MassProm Part
  M             mg/M^3          Kg            Kg             Kg      microns r
 17000         96.0304       4.68404E-03   4.6579E-04    2.9246    1.83114
 16000         239.548       .0101235      8.4865E-04    6.2311    1.83114
 15000         466.649       .0170645      1.19152E-03   10.3676    1.83114
 14000         715.181       .022608       1.28914E-03   13.5712    1.83114
 13000         868.852       .0237215      1.07498E-03   14.082    43.4013
 12000         846.547       .0199445      6.9087E-04    11.7188    126.928
 11000         674.985       .0137109      3.42125E-04   7.98073    203.969
 10000         455.84        .0082512      1.35056E-04   4.76257    265.922
 9000          276.339       4.45783E-03   4.11434E-05   2.55497    343.731
 8000          163.329       2.35157E-03   9.69034E-06   1.34096    400.475
 7000          98.2576       1.26553E-03   0              .718694   436.194
 600C          67.5878       7.77917E-04   0              .44178   531.013
 5000          50.5038       5.20975E-04   0              .295862    531.013
 4000          39.6719       3.67796E-04   0              .208872    596.673
 3000          31.9375       2.66809E-04   0              .151521    682.738
 2000          26.9662       2.0351E-04    0              .115573    682.738
 1000          24.0379       1.64272E-04   0              .0932903    802.408
 0             17.8357       1.10625E-04   0              .0628238    802.408
```

```
---------------------------------------------------------------------------
14 Feb 1540    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
time (hr) = .15  deltat (hr) =-9.50774E-03  %airborne = 97  sigmax = 2984.51 M
sigmay = 2990.18 M                  3 sigmay cloud diameter = 17941.1 M
initial dust lofted =  3.02395E+08 Kg        dust now airborne = 2.93323E+08 Kg
Altitude       Cloud Mass
   M             Kg/M
 17000           5400.47
 16000           13471.5
 15000           26243
 14000           40219.7
 13000           48852.6
 12000           47581.4
 11000           37926.3
 10000           25606.5
 9000            15518.5
 8000            9170.19
 7000            5516.02
 6000            3793.01
 5000            2834.26
 4000            2225.89
 3000            1791.44
 2000            1512.6
 1000            1347.86
 0               1000.09
For Group #    size (microns)              Altitude (M)
 10             10.58          13470.6
 20             19.7693        13319.5
 30             30.8404        13157.7
 40             44.9982        12970.6
 50             63.9711        12744.1
 60             90.8408        12416.3
 70             132.016        11907.1
 80             203.969        10953.3
 90             370.042        8410.07
---------------------------------------------------------------------------
14 Feb 1540    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
The graph shows percent of total cloud mass for each group at
the maximum density penetration altitude of  12000 meters (1/4% per star)
Group#   Size   Altitude     PERCENT of Total Mass
          uM       M         0 |   |   |   |   5 |   |   |   |   10 |   |   |
 1  1.83114   13630.8        ****
 2  3.21367   13604.4        ****
 3  4.30037   13583.9        ****
 4  5.28023   13565.7        ****
 5  6.20587   13548.6        ****
 6  7.10111   13532.3        ****
 7  7.9791    13516.5        ****
 8  8.84808   13501          ****
 9  9.71369   13485.7        ****
 10  10.58    13470.6        ****
```

```
11  11.4502   13455.5      ****
12  12.3266   13440.5      ****
13  13.2115   13425.5      ****
14  14.1066   13410.6      ****
15  15.0134   13395.6      ****
16  15.9334   13380.5      ****
17  16.8678   13365.4      ****
18  17.8178   13350.2      ****
19  18.7846   13334.9      ****
20  19.7693   13319.5      ****
21  20.7729   13304        ****
22  21.7967   13288.4      ****
23  22.8416   13272.7      ****
24  23.9087   13256.8      ****
25  24.9991   13240.7      ****
26  26.1139   13224.5      ****
27  27.2543   13208.1      ****
28  28.4213   13191.6      ****
29  29.6162   13174.8      ****
30  30.8404   13157.7      ****
31  32.0949   13140.5      ****
32  33.3813   13123        ****
33  34.7007   13105.2      ****
34  36.0549   13087.1      ****
35  37.4452   13068.6      *****
36  38.8732   13049.8      *****
37  40.3407   13030.6      *****
38  41.8495   13011.1      *****
39  43.4013   12991        *****
40  44.9982   12970.6      *****
41  46.6422   12949.7      *****
42  48.3356   12928.3      *****
43  50.0805   12906.5      *****
44  51.8797   12884.3      *****
45  53.7356   12861.8      *****
46  55.6511   12838.9      *****
47  57.6291   12815.7      *****
48  59.6728   12792.2      *****
49  61.7856   12768.5      *****
50  63.9711   12744.1      *****
51  66.2332   12718.5      *****
52  68.5758   12690.3      *****
53  71.004    12657.9      *****
54  73.522    12627.1      *****
55  76.1352   12595.2      *****
56  78.8492   12562.2      *****
57  81.6698   12527.9      *****
58  84.6039   12492.2      *****
59  87.6583   12455        *****
60  90.8408   12416.3      *****
```

```
61  94.1597   12375.8      *****
62  97.6242   12333.5      *****
63  101.244   12289.2      *****
64  105.031   12242.8      *****
65  108.996   12194.1      *****
66  113.153   12142.8      *****
67  117.516   12088.7      *****
68  122.102   12031.6      *****
69  126.928   11971.2      *****
70  132.016   11907.1      ******
71  137.386   11839.2      ******
72  143.065   11766.9      *****
73  149.079   11689.6      *****
74  155.463   11606.9      *****
75  162.252   11518.1      *****
76  169.487   11422.3      *****
77  177.217   11319.1      *****
78  185.497   11207.3      *****
79  194.389   11085.9      *****
80  203.969   10953.3      *****
81  214.324   10808        *****
82  225.559   10648.3      ****
83  237.799   10471.8      ****
84  251.192   10275.6      ****
85  265.922   10056.4      ***
86  282.217   9809.62      ***
87  300.358   9529.92      **
88  320.709   9210.09      **
89  343.731   8840.96      *
90  370.042   8410.07      *
91  400.475   7900.48
92  436.194   7288.29
93  478.866   6538.93
94  531.013   5599.73
95  596.673   4385.95
96  682.738   2752.28
97  802.408   541.882
                           0 |   |   |   |   5 |   |   |   |  10 |   |   |
```

```
*****************************************************************************
14 Feb 1540    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
time (hr) = 1  deltat (hr) = .10625  %airborne = 85  sigmax = 3994.78 M
sigmay = 4378.37 M                  3 sigmay cloud diameter = 26270.2 M
Altitude       Cloud Dens      Filter Mass     Cabin Mass     Engine MassProm Part
  M              mg/M^3           Kg              Kg              Kg      microns r
 17000          22.7993         1.32932E-03    3.0722E-04     .929394    1.83114
 16000          56.6174         2.90802E-03    5.63101E-04    1.97125    1.83114
 15000          110.898         5.01159E-03    7.95494E-04    3.29785    1.83114
 14000          173.446         6.89122E-03    8.66153E-04    4.40542    1.83114
 13000          221.131         7.71939E-03    7.27852E-04    4.7972    16.8678
 12000          235.488         7.21194E-03    .0004714       4.36338    32.0949
 11000          218.207         5.84564E-03    2.35215E-04    3.45333    43.4013
 10000          185.638         4.47778E-03    9.35721E-05    2.59607    53.7356
 9000           153.775         .0033223       2.87353E-05    1.90306    66.2332
 8000           128.932         2.48813E-03    6.82243E-06    1.41689    76.1352
 7000           110.215         1.90005E-03    0              1.07904    87.6583
 6000           96.7586         1.49065E-03    0              .846539    101.244
 5000           85.9754         .0011871       0              .674155    113.153
 4000           77.1518         9.57393E-04    0              .543704    126.928
 3000           69.6583         7.7892E-04     0              .442349    143.065
 2000           63.237          6.38787E-04    0              .362768    155.463
 1000           57.5372         5.26304E-04    0              .298888    169.487
 0              52.3251         4.34401E-04    0              .246697    185.497
```

```
-----------------------------------------------------------------------------
14 Feb 1540    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
time (hr) = 1  deltat (hr) = .10625  %airborne = 85  sigmax = 3994.78 M
sigmay = 4378.37 M                  3 sigmay cloud diameter = 26270.2 M
initial dust lofted =  3.02395E+08 Kg        dust now airborne = 2.57035E+08 Kg
Altitude      Cloud Mass
  M             Kg/M
 17000          2546.49
 16000          6323.67
 15000          12386.3
 14000          19372.4
 13000          24664.8
 12000          26230.3
 11000          24280.7
 10000          20637.6
 9000           17076.3
 8000           14304.9
 7000           12215.8
 6000           10711.5
 5000           9507.85
 4000           8521.78
 3000           7683.29
 2000           6967.52
 1000           6331.85
 0              5750.36
For Group #   size (microns)                Altitude (M)
 10             10.58        13328.9
 20             19.7693      12841.3
 30             30.8404      12052.5
 40             44.9982      10866.5
 50             63.9711      9118.46
 60             90.8408      6866.34
 70             132.016      3697.73
 80             203.969      -944.286
-----------------------------------------------------------------------------
14 Feb 1540    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; one 1MT bomb
The graph shows percent of total cloud mass for each group at
the maximum density penetration altitude of  12000 meters (1/4% per star)
Group#   Size   Altitude      PERCENT of Total Mass
          uM       M          0 |  |  |  |  5 |  |  |  |  10 |  |  |
 1  1.83114    13625.7        *******
 2  3.21367    13590          *******
 3  4.30037    13559          *******
 4  5.28023    13528.8        *******
 5  6.20587    13498.3        *******
 6  7.10111    13467          *******
 7  7.9791     13434.7        *******
 8  8.84808    13401          *******
 9  9.71369    13365.8        *******
 10  10.58     13328.9        *******
```

```
11  11.4502   13290.3       ********
12  12.3266   13249.7       ********
13  13.2115   13207.1       ********
14  14.1066   13162.3       ********
15  15.0134   13115.3       ********
16  15.9334   13065.8       ********
17  16.8678   13013.8       ********
18  17.8178   12959.1       ********
19  18.7846   12901.7       ********
20  19.7693   12841.3       *********
21  20.7729   12778         *********
22  21.7967   12711.4       *********
23  22.8416   12641.7       *********
24  23.9087   12568.5       *********
25  24.9991   12491.8       *********
26  26.1139   12411.5       *********
27  27.2543   12327.5       *********
28  28.4213   12239.8       *********
29  29.6162   12148.1       *********
30  30.8404   12052.5       **********
31  32.0949   11952.9       **********
32  33.3813   11849.3       *********
33  34.7007   11741.5       *********
34  36.0549   11629.6       *********
35  37.4452   11513.5       *********
36  38.8732   11393.2       *********
37  40.3407   11268.5       *********
38  41.8495   11139.4       *********
39  43.4013   11005.5       ********
40  44.9982   10866.5       ********
41  46.6422   10721.6       ********
42  48.3356   10571.5       *******
43  50.0805   10414.4       *******
44  51.8797   10249.3       ******
45  53.7356   10076.2       ******
46  55.6511   9893.3        *****
47  57.6291   9702.54       *****
48  59.6728   9505.04       ****
49  61.7856   9306.29       ****
50  63.9711   9118.46       ***
51  66.2332   8927.23       ***
52  68.5758   8729.88       **
53  71.004    8524.63       **
54  73.522    8310.94       *
55  76.1352   8089.71       *
56  78.8492   7861.08       *
57  81.6698   7624.8        *
58  84.6039   7380.54
59  87.6583   7128.02
60  90.8408   6866.34
```

```
61  94.1597   6596.72
62  97.6242   6317.82
63  101.244   6029.23
64  105.031   5730.49
65  108.996   5421.24
66  113.153   5100.92
67  117.516   4769.05
68  122.102   4424.04
69  126.928   4067.66
70  132.016   3697.73
71  137.386   3313.83
72  143.065   2914.9
73  149.079   2500.2
74  155.463   2068.61
75  162.252   1619.14
76  169.487   1150.56       *
77  177.217   661.687
78  185.497   151
79  194.389  -383.061
80  203.969  -944.286
81  214.324  -1545.16
82  225.559  -2191.07
83  237.799  -2880.13
84  251.192  -3637.58
85  265.922  -4445.72
                            0  |   |   |   |   5  |   |   |   |   10 |   |   |
```

Appendix I

Sample Multi Burst Dose Output - Full Report

```
14 Feb 1621
This is a dose report.
CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs

WEAPON/TARGET DATA:
Number of weapons ------------------ 300
Width of target field -------------- 150 KM
Weapon yield ----------------------- 1000 KT
Fission fraction ------------------- 1
Dust fraction ---------------------- .333333
The size distribution input file is- DELFIC.RMA
                        Rm =  .204 ; sigma Rm =  4
The soil density is ---------------- 2600 KG/M^3
The aircraft specification file is - B-1B.SPC
Aircraft velocity is --------------- 279.2 M/S
Time from cloud penetration
to end of mission ------------------ 8 HR
Wind shear X (along track) --------- 0 (KM/HR)/KM
Wind shear Y (cross track) --------- 1 (KM/HR)/KM
The output file will be named ------ B:IAPP.DOP

********************************************************************************
14 Feb 1621    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
time (hr) = .15  deltat (hr) =-9.50774E-03  %airborne = 98  sigmax = 2977.15 M
sigmay = 2983.01 M                 3 sigmay cloud diameter = 17898 M
Altitude      Cabin Dust     Sky Shine     TotalDose     Prominent Particle
   M             REM            REM           REM         microns radius
 17000         58.3781        1407.91       1466.29 *     .473992
 16000         105.792        2845.01       2950.8 *      .473992
 15000         147.768        4486.62       4634.39 *     .473992
 14000         159.086        5551.69       5710.77 *     .473992
 13000         132.007        5426.07       5558.08       42.8646
 12000         84.4263        4235.02       4319.45       126.317
 11000         41.6165        2690.48       2732.1        202.228
 10000         16.3577        1490.34       1506.7        272.629
 9000          4.96265        740.976       745.939       326.279
 8000          1.16438        363.006       364.17        403.868
 7000          0              182.706       182.706       457.979
 6000          0              111.154       111.154       529.291
 5000          0              74.5758       74.5758       529.291
 4000          0              51.8589       51.8589       629.064
 3000          0              35.7926       35.7926       629.064
 2000          0              29.622        29.622        782.496
 1000          0              26.9561       26.9561       782.496
 0             0              17.3747       17.3747       782.496
* Skyshine may be inaccurate due to large gamma mean free path (mfp >.2sigmax)
```

```
--------------------------------------------------------------------------
14 Feb 1621    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
time (hr) = .15  deltat (hr) =-9.50774E-03  %airborne = 98  sigmax = 2977.15 M
Altitude,     Cloud Act      Filter Act     Cabin Act     Prominent Particle
  M            MCi/M           Ci             Ci          microns r
 17000         1845.03        135.941        45.0815       .473992
 16000         4365.1         284.1          81.6959       .473992
 15000         8059.62        462.755        114.111       .473992
 14000         11676.3        590.956        122.851       .473992
 13000         13358.8        595.716        101.94        42.8646
 12000         12203          479.321        65.1968       126.317
 11000         9073.77        313.791        32.1376       202.228
 10000         5686.42        178.988        12.6319       272.629
 9000          3194.12        91.4386        3.83232       326.279
 8000          1761.67        45.7743        .899172       403.868
 7000          995.074        23.4914        0             457.979
 6000          677.265        14.2916        0             529.291
 5000          506.996        9.58857        0             529.291
 4000          392.153        6.66776        0             629.064
 3000          300.365        4.60202        0             629.064
 2000          275.044        3.80864        0             782.496
 1000          276.403        3.46588        0             782.496
 0             196.295        2.23395        0             782.496
For Group #    size (microns)               Altitude (M)
 10            3.80268        13593.3
 20            8.35085        13509.8
 30            14.6576        13401.4
 40            23.5162        13262.6
 50            36.2252        13084.8
 60            55.1961        12844.3
 70            85.5478        12480.7
 80            140.637        11797.8
 90            272.629        9955.32
--------------------------------------------------------------------------
14 Feb 1621    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
The graph shows percent of total cloud activity for each group at
the maximum activity penetration altitude of  13000 meters (1/4% per star)
Group#  Size   Altitude     PERCENT of Total Activity
         uM       M         0 |   |   |   |  5 |   |   |   |  10 |   |   |
 1  .473992    13657.2      ****
 2  .904308    13648.8      ****
 3  1.27327    13641.6      ****
 4  1.62603    13634.8      ****
 5  1.97515    13628.1      ****
 6  2.32639    13621.3      ****
 7  2.68294    13614.5      ****
 8  3.04692    13607.6      ****
 9  3.41978    13600.5      *****
 10  3.80268   13593.3      *****
```

```
11  4.19655   13585.9     *****
12  4.60222   13578.3     *****
13  5.02038   13570.5     *****
14  5.45171   13562.5     *****
15  5.89686   13554.3     *****
16  6.35641   13545.9     *****
17  6.83098   13537.2     *****
18  7.32119   13528.3     *****
19  7.8276    13519.2     *****
20  8.35085   13509.8     *****
21  8.89157   13500.2     *****
22  9.45039   13490.3     *****
23  10.028    13480.2     *****
24  10.625    13469.8     *****
25  11.2422   13459.1     *****
26  11.8803   13448.1     *****
27  12.5401   13436.9     *****
28  13.2223   13425.4     *****
29  13.9278   13413.5     *****
30  14.6576   13401.4     *****
31  15.4124   13389       *****
32  16.1934   13376.3     *****
33  17.0015   13363.2     *****
34  17.8378   13349.9     *****
35  18.7035   13336.2     *****
36  19.5996   13322.2     *****
37  20.5276   13307.8     *****
38  21.4887   13293.1     *****
39  22.4844   13278       *****
40  23.5162   13262.6     *****
41  24.5856   13246.8     *****
42  25.6944   13230.6     *****
43  26.8444   13214       *****
44  28.0374   13197       *****
45  29.2756   13179.5     *****
46  30.5611   13161.6     *****
47  31.8962   13143.2     *****
48  33.2835   13124.3     *****
49  34.7255   13104.8     *****
50  36.2252   13084.8     *****
51  37.7855   13064.1     *****
52  39.4098   13042.8     *****
53  41.1016   13020.7     *****
54  42.8646   12998       *****
55  44.7032   12974.4     *****
56  46.6215   12950       *****
57  48.6246   12924.7     *****
58  50.7175   12898.7     *****
59  52.906    12871.8     *****
```

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60  55.1961   12844.3      *****
61  57.5948   12816.1      *****
62  60.109    12787.3      *****
63  62.7472   12757.7      *****
64  65.5178   12726.7      *****
65  68.4309   12692.1      *****
66  71.4967   12651.7      *****
67  74.7277   12612.4      *****
68  78.1363   12570.9      *****
69  81.7377   12527        *****
70  85.5478   12480.7      *****
71  89.5848   12431.5      *****
72  93.8697   12379.3      *****
73  98.4248   12323.7      *****
74  103.277   12264.3      *****
75  108.456   12200.7      *****
76  113.995   12132.3      ****
77  119.933   12058.6      ****
78  126.317   11978.9      ****
79  133.198   11892.2      ****
80  140.637   11797.8      ****
81  148.708   11694.4      ****
82  157.495   11580.3      ****
83  167.101   11454        ****
84  177.652   11313.2      ***
85  189.298   11155.7      ***
86  202.228   10977.5      ***
87  216.678   10774.8      **
88  232.947   10542.1      **
89  251.428   10272.1      **
90  272.629   9955.32      *
91  297.255   9578.12      *
92  326.279   9121.48
93  361.108   8557.42
94  403.868   7842.96
95  457.979   6908.04
96  529.291   5631.13
97  629.064   3776.22
98  782.496   896.84
                           0   |   |   |   |   5  |   |   |   |   10 |   |   |
```

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*************************************************************************************
14 Feb 1621    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
time (hr) = 1  deltat (hr) = .10625  %airborne = 90  sigmax = 3958.03 M
sigmay = 4343.43 M                   3 sigmay cloud diameter = 26060.6 M
Altitude       Cabin Dust     Sky Shine      TotalDose      Prominent Particle
   M              REM            REM            REM           microns radius
 17000          25.4727        91.7404        117.213 *       .473992
 16000          46.3348        183.578        229.913 *       .473992
 15000          64.97          287.753        352.723         .473992
 14000          70.2242        357.387        427.611         .473992
 13000          58.5092        356.816        415.325         17.0015
 12000          37.5767        293.627        331.203         31.8962
 11000          18.6022        207.601        226.204         42.8646
 10000          7.34381        138.968        146.311         55.1961
 9000           2.23797        91.9615        94.1994         65.5178
 8000           .52749         63.7091        64.2366         78.1363
 7000           0              46.1374        46.1374         89.5848
 6000           0              35.4026        35.4026         103.277
 5000           0              27.7528        27.7528         113.995
 4000           0              22.078         22.078          126.317
 3000           0              17.7481        17.7481         140.637
 2000           0              14.4278        14.4278         157.495
 1000           0              11.7971        11.7971         167.101
 0              0              9.67145        9.67145         189.298
* Skyshine may be inaccurate due to large gamma mean free path (mfp >.2sigmax)
```

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-----------------------------------------------------------------------------
14 Feb 1621    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
time (hr) = 1  deltat (hr) = .10625  %airborne = 90  sigmax = 3958.03 M
Altitude,      Cloud Act     Filter Act    Cabin Act     Prominent Particle
   M            MCi/M          Ci            Ci          microns r
 17000         177.639       70.5181       44.482        .473992
 16000         416.183       149.21        80.9124       .473992
 15000         763.778       247.255       113.454       .473992
 14000         1110.63       325.368       122.63        .473992
 13000         1296.29       345.11        102.172       17.0015
 12000         1247.23       302.454       65.6186       31.8962
 11000         1031.41       227.752       32.4843       42.8646
 10000         780.456       161.377       12.8242       55.1961
 9000          583.069       111.369       3.90807       65.5178
 8000          454.372       78.9406       .921134       78.1363
 7000          368.973       57.835        0             89.5848
 6000          316.435       44.3786       0             103.277
 5000          276.511       34.7892       0             113.995
 4000          244.489       27.6756       0             126.317
 3000          217.833       22.2479       0             140.637
 2000          195.733       18.0857       0             157.495
 1000          176.592       14.7881       0             167.101
 0             159.204       12.1235       0             189.298
For Group #    size (microns)              Altitude (M)
 10            3.80268       13573.5
 20            8.35085       13420.4
 30            14.6576       13133.9
 40            23.5162       12595.6
 50            36.2252       11615.5
 60            55.1961       9937.44
 70            85.5478       7302.32
 80            140.637       3084.51
 90            272.629       -4810.92
-----------------------------------------------------------------------------
14 Feb 1621    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
The graph shows percent of total cloud activity for each group at
the maximum activity penetration altitude of  13000 meters (1/4% per star)
Group#   Size      Altitude      PERCENT of Total Activity
          uM          M          0 |  |  |  |  5 |  |  |  |  10 |  |  |
 1  .473992        13656.6       *******
 2  .904308        13647.2       *******
 3  1.27327        13638.9       *******
 4  1.62603        13630.6       *******
 5  1.97515        13622.2       *******
 6  2.32639        13613.4       *******
 7  2.68294        13604.2       *******
 8  3.04692        13594.5       *******
 9  3.41978        13584.3       *******
 10  3.80268       13573.5       *******
```

```
11   4.19655   13562       *******
12   4.60222   13549.9     *******
13   5.02038   13537       *******
14   5.45171   13523.3     *******
15   5.89686   13508.7     *******
16   6.35641   13493.2     *******
17   6.83098   13476.6     *******
18   7.32119   13459.1     *******
19   7.8276    13440.4     *******
20   8.35085   13420.4     *******
21   8.89157   13399.2     *******
22   9.45039   13376.6     *******
23   10.028    13352.6     *******
24   10.625    13327       *******
25   11.2422   13299.7     *******
26   11.8803   13270.6     *******
27   12.5401   13239.6     *******
28   13.2223   13206.6     *******
29   13.9278   13171.4     *******
30   14.657[illegible]  13133.9     *******
31   15.4124   13094       *******
32   16.1934   13051.5     *******
33   17.0015   13006.2     *******
34   17.8378   12958       *******
35   18.7035   12906.6     *******
36   19.5996   12851.9     *******
37   20.5276   12793.6     *******
38   21.4887   12731.7     *******
39   22.4844   12665.7     *******
40   23.5162   12595.6     *******
41   24.5856   12521.1     *******
42   25.6944   12442       *******
43   26.8444   12357.9     *******
44   28.0374   12268.8     *******
45   29.2756   12174.4     *******
46   30.5611   12074.5     *******
47   31.8962   11968.8     ******
48   33.2835   11857.2     ******
49   34.7255   11739.5     ******
50   36.2252   11615.5     ******
51   37.7855   11484.9     *****
52   39.4098   11347.7     *****
53   41.1016   11203.5     *****
54   42.8646   11051.9     ****
55   44.7032   10892.3     ****
56   46.6215   10723.4     ****
57   48.6246   10545.6     ***
58   50.7175   10355.9     ***
59   52.906    10154.1     **
60   55.1961   9937.44     **
```

```
 61  57.5948   9705.86       **
 62  60.109    9463.34       *
 63  62.7472   9221.43       *
 64  65.5178   8987.47       *
 65  68.4309   8742.13       *
 66  71.4967   8483.64
 67  74.7277   8208.73
 68  78.1363   7921.02
 69  81.7377   7619.13
 70  85.5478   7302.32
 71  89.5848   6968.98
 72  93.8697   6620.18
 73  98.4248   6253.74
 74  103.277   5868.45
 75  108.456   5463.14
 76  113.995   5036.52
 77  119.933   4585.97
 78  126.317   4112.48
 79  133.198   3612.63
 80  140.637   3084.51
 81  148.708   2525.55
 82  157.495   1933
 83  167.101   1303.91
 84  177.652   634.534
 85  189.298  -78.9946
 86  202.228  -843.808
 87  216.678  -1682.04
 88  232.947  -2605.78
 89  251.428  -3650.72
 90  272.629  -4810.92
                            0 |  |  |  |  5 |  |  |  |  10 |  |  |
```

Appendix J

Sample Multi Burst Dust Output - Full Report

```
14 Feb 1642
This is a dust report.
CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs

WEAPON/TARGET DATA:
Number of weapons ------------------ 300
Width of target field -------------- 150 KM
Weapon yield ----------------------- 1000 KT
Fission fraction ------------------- 1
Dust fraction ---------------------- .333333
The size distribution input file is- DELFIC.RMM
                         Rm =  .204 ; sigma Rm =  4
The soil density is ---------------- 2600 RG/M^3
The aircraft specification file is - B-1B.SPC
Aircraft velocity is --------------- 279.2 M/S
Time from cloud penetration
to end of mission ------------------ 8 HR
Wind shear X (along track) --------- 0 (KM/HR)/KM
Wind shear Y (cross track) --------- 1 (KM/HR)/KM
The output file will be named ------ B:JAPP.MOP

********************************************************************************
14 Feb 1642   CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
time (hr) = .15  deltat (hr) =-9.50774E-03  %airborne = 97  sigmax = 2984.51 M
sigmay = 2990.18 M                  3 sigmay cloud diameter = 17941.1 M
Altitude      Cloud Dens     Filter Mass    Cabin Mass    Engine MassProm Part
  M             mg/M^3          Kg             Kg             Kg      microns r
 17000         1443.77       .0704225       7.00295E-03   43.97   1.83114
 16000         3601.49       .152202        .0127591      93.6817   1.83114
 15000         7015.86       .256557        .0179139      155.872   1.83114
 14000         10752.4       .339901        .0193816      204.037   1.83114
 13000         13060.4       .356577        .0161589      211.677   43.4013
 12000         12720.5       .299693        .0103813      176.091   126.928
 11000         10139.3       .205959        5.13924E-03   119.883   203.969
 10000         6845.7        .123915        2.02824E-03   71.5232   265.922
 9000          4148.75       .0669267       6.17697E-04   38.3585   343.731
 8000          2451.58       .0352973       1.45453E-04   20.128   400.475
 7000          1474.67       .0189932       0             10.7863   436.194
 6000          1014.03       .0116712       0             6.62811   531.013
 5000          757.719       7.81628E-03    0             4.43888   531.013
 4000          595.075       5.51691E-03    0             3.13306   596.673
 3000          478.929       4.00102E-03    0             2.27218   682.738
 2000          404.381       3.05179E-03    0             1.73312   682.738
 1000          360.34        2.46252E-03    0             1.39847   802.408
 0             267.367       1.65832E-03    0             .941762   802.408
```

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-----------------------------------------------------------------------------
14 Feb 1642    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
time (hr) = .15  deltat (hr) =-9.50774E-03  %airborne = 97  sigmax = 2984.51 M
sigmay = 2990.18 M                   3 sigmay cloud diameter = 17941.1 M
initial dust lofted =  3.02395E+08 Kg       dust now airborne = 2.93323E+08 Kg
Altitude      Cloud Mass
   M             Kg/M
 17000          81193.6
 16000          202537
 15000          394551
 14000          604685
 13000          734341
 12000          714974
 11000          569712
 10000          384553
 9000           232984
 8000           137645
 7000           82785.3
 6000           56907.3
 5000           42523
 4000           33388.2
 3000           26864.2
 2000           22682.6
 1000           20205.1
 0              14991.9
For Group #    size (microns)             Altitude (M)
 10             10.58         13470.6
 20             19.7693       13319.5
 30             30.8404       13157.7
 40             44.9982       12970.6
 50             63.9711       12744.1
 60             90.8408       12416.3
 70             132.016       11907.1
 80             203.969       10953.3
 90             370.042       8410.07
-----------------------------------------------------------------------------
14 Feb 1642    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
The graph shows percent of total cloud mass for each group at
the maximum density penetration altitude of  12000 meters (1/4% per star)
Group#   Size   Altitude     PERCENT of Total Mass
          uM       M         0 |   |   |   |  5 |   |   |   |  10 |   |   |
 1  1.83114   13630.8        ****
 2  3.21367   13604.4        ****
 3  4.30037   13583.9        ****
 4  5.28023   13565.7        ****
 5  6.20587   13548.6        ****
 6  7.10111   13532.3        ****
 7  7.9791    13516.5        ****
 8  8.84808   13501          ****
 9  9.71369   13485.7        ****
 10  10.58    13470.6        ****
```

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11  11.4502   13455.5      ****
12  12.3266   13440.5      ****
13  13.2115   13425.5      ****
14  14.1066   13410.6      ****
15  15.0134   13395.6      ****
16  15.9334   13380.5      ****
17  16.8678   13365.4      ****
18  17.8178   13350.2      ****
19  18.7846   13334.9      ****
20  19.7693   13319.5      ****
21  20.7729   13304        ****
22  21.7967   13288.4      ****
23  22.8416   13272.7      ****
24  23.9087   13256.8      ****
25  24.9991   13240.7      ****
26  26.1139   13224.5      ****
27  27.2543   13208.1      ****
28  28.4213   13191.6      ****
29  29.6162   13174.8      ****
30  30.8404   13157.7      ****
31  32.0949   13140.5      ****
32  33.3813   13123        ****
33  34.7007   13105.2      ****
34  36.0549   13087.1      ****
35  37.4452   13068.6      *****
36  38.8732   13049.8      *****
37  40.3407   13030.6      *****
38  41.8495   13011.1      *****
39  43.4013   12991        *****
40  44.9982   12970.6      *****
41  46.6422   12949.7      *****
42  48.3356   12928.3      *****
43  50.0805   12906.5      *****
44  51.8797   12884.3      *****
45  53.7356   12861.8      *****
46  55.6511   12838.9      *****
47  57.6291   12815.7      *****
48  59.6728   12792.2      *****
49  61.7856   12768.5      *****
50  63.9711   12744.1      *****
51  66.2332   12718.5      *****
52  68.5758   12690.3      *****
53  71.004    12657.9      *****
54  73.522    12627.1      *****
55  76.1352   12595.2      *****
56  78.8492   12562.2      *****
57  81.6698   12527.9      *****
58  84.6039   12492.2      *****
59  87.6583   12455        *****
60  90.8408   12416.3      *****
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61  94.1597   12375.8      *****
62  97.6242   12333.5      *****
63  101.244   12289.2      *****
64  105.031   12242.8      *****
65  108.996   12194.1      *****
66  113.153   12142.8      *****
67  117.516   12088.7      *****
68  122.102   12031.6      *****
69  126.928   11971.2      *****
70  132.016   11907.1      ******
71  137.386   11839.2      ******
72  143.065   11766.9      *****
73  149.079   11689.6      *****
74  155.463   11606.9      *****
75  162.252   11518.1      *****
76  169.487   11422.3      *****
77  177.217   11319.1      *****
78  185.497   11207.3      *****
79  194.389   11085.9      *****
80  203.969   10953.3      *****
81  214.324   10808        *****
82  225.559   10648.3      ****
83  237.799   10471.8      ****
84  251.192   10275.6      ****
85  265.922   10056.4      ***
86  282.217   9809.62      ***
87  300.358   9529.92      **
88  320.709   9210.09      **
89  343.731   8840.96      *
90  370.042   8410.07      *
91  400.475   7900.48
92  436.194   7288.29
93  478.866   6538.93
94  531.013   5599.73
95  596.673   4385.95
96  682.738   2752.28
97  802.408   541.882
                           0 |  |  |  |  5 |  |  |  |  10 |  |  |
```

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********************************************************************************
14 Feb 1642    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
time (hr) = 1  deltat (hr) = .10625  %airborne = 85  sigmax = 3994.78 M
sigmay = 4378.37 M                   3 sigmay cloud diameter = 26270.2 M
Altitude      Cloud Dens    Filter Mass   Cabin Mass     Engine MassProm Part
  M             mg/M^3         Kg             Kg              Kg      microns r
 17000         508.615       .0296549      6.85355E-03    20.7332   1.83114
 16000         1263.04       .064873       .0125618       43.9754   1.83114
 15000         2473.95       .1118         .0177461       73.5695   1.83114
 14000         3869.29       .153732       .0193224       98.2776   1.83114
 13000         4926.36       .171973       .0162151       106.872   16.8678
 12000         5239.02       .160447       .0104874       97.0741   32.0949
 11000         4849.64       .129919       5.22764E-03    76.7499   43.4013
 10000         4121.99       .0994262      2.07771E-03    57.6442   53.7356
 9000          3410.69       .0736875      6.37338E-04    42.2092   66.2332
 8000          2857.15       .0551374      1.51186E-04    31.3985   76.1352
 7000          2439.88       .0420624      0              23.8873   87.6583
 6000          2139.43       .0329598      0              18.7179   101.244
 5000          1899.02       .0262206      0              14.8907   113.153
 4000          1702.07       .0211214      0              11.9948   126.928
 3000          1534.6        .0171599      0              9.74512   143.065
 2000          1391.64       .0140576      0              7.98332   155.463
 1000          1264.67       .0115682      0              6.5696   169.487
 0             1148.53       9.53506E-03   0              5.41497   185.497
```

```
--------------------------------------------------------------------------
14 Feb 1642    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
time (hr) = 1  deltat (hr) = .10625  %airborne = 85  sigmax = 3994.78 M
sigmay = 4378.37 M                   3 sigmay cloud diameter = 26270.2 M
initial dust lofted =  3.02395E+08 Kg         dust now airborne = 2.57035E+08 Kg
Altitude        Cloud Mass
  M               Kg/M
 17000          56807.9
 16000          141070
 15000          276318
 14000          432166
 13000          549483
 12000          583557
 11000          539637
 10000          458245
 9000           378747
 8000           317000
 7000           270428
 6000           236843
 5000           210009
 4000           188002
 3000           169266
 2000           153332
 1000           139175
 0              126220
For Group #     size (microns)                 Altitude (M)
 10             10.58          13328.9
 20             19.7693        12841.3
 30             30.8404        12052.5
 40             44.9982        10866.5
 50             63.9711        9118.46
 60             90.8408        6866.34
 70             132.016        3697.73
 80             203.969        -944.286
--------------------------------------------------------------------------
14 Feb 1642    CUSTOM SCENARIO: B-1B; WITH filter; DELFIC cloud; 300 1MT bombs
The graph shows percent of total cloud mass for each group at
the maximum density penetration altitude of  12000 meters (1/4% per star)
Group#   Size   Altitude      PERCENT of Total Mass
         uM       M           0  |  |  |  |  5  |  |  |  |  10  |  |  |
 1  1.83114    13625.7        *******
 2  3.21367    13590          *******
 3  4.30037    13559          *******
 4  5.28023    13528.8        *******
 5  6.20587    13498.3        *******
 6  7.10111    13467          *******
 7  7.9791     13434.7        *******
 8  8.84808    13401          *******
 9  9.71369    13365.8        *******
 10  10.58     13328.9        *******
```

```
11  11.4502   13290.3      ********
12  12.3266   13249.7      ********
13  13.2115   13207.1      ********
14  14.1066   13162.3      ********
15  15.0134   13115.3      ********
16  15.9334   13065.8      ********
17  16.8678   13013.8      ********
18  17.8178   12959.1      ********
19  18.7846   12901.7      ********
20  19.7693   12841.3      *********
21  20.7729   12778        *********
22  21.7967   12711.4      *********
23  22.8416   12641.7      *********
24  23.9087   12568.5      *********
25  24.9991   12491.8      *********
26  26.1139   12411.5      *********
27  27.2543   12327.5      *********
28  28.4213   12239.8      *********
29  29.6162   12148.1      *********
30  30.8404   12052.5      **********
31  32.0949   11952.9      **********
32  33.3813   11849.3      *********
33  34.7007   11741.5      *********
34  36.0549   11629.6      *********
35  37.4452   11513.5      *********
36  38.8732   11393.2      *********
37  40.3407   11268.5      *********
38  41.8495   11139.4      *********
39. 43.4013   11005.5      ********
40  44.9982   10866.5      ********
41  46.6422   10721.6      ********
42  48.3356   10571.5      *******
43  50.0805   10414.4      *******
44  51.8797   10249.3      ******
45  53.7356   10076.2      ******
46  55.6511   9893.3       *****
47  57.6291   9702.54      *****
48  59.6728   9505.04      ****
49  61.7856   9306.29      ****
50  63.9711   9118.46      ***
51  66.2332   8927.23      ***
52  68.5758   8729.88      **
53  71.004    8524.63      **
54  73.522    8310.94      *
55  76.1352   8089.71      *
56  78.8492   7861.08      *
57  81.6698   7624.8       *
58  84.6039   7380.54
59  87.6583   7128.02
60  90.8408   6866.34
```

```
61  94.1597    6596.72
62  97.6242    6317.82
63  101.244    6029.23
64  105.031    5730.49
65  108.996    5421.24
66  113.153    5100.92
67  117.516    4769.05
68  122.102    4424.04
69  126.928    4067.66
70  132.016    3697.73
71  137.386    3313.83
72  143.065    2914.9
73  149.079    2500.2
74  155.463    2068.61
75  162.252    1619.14
76  169.487    1150.56       *
77  177.217    661.687
78  185.497    151
79  194.389  -383.061
80  203.969  -944.286
81  214.324  -1545.16
82  225.559  -2191.07
83  237.799  -2880.13
84  251.192  -3637.58
85  265.922  -4445.72
                            0  |   |   |   |    5  |   |   |   |   10  |   |   |
```

Appendix K

Cylindrical Integration Program for Cabin Geometry Factor K

This program takes the pseudolength and radius of a cylinder (in meters)that represents the cabin of an aircraft and computes the spatial integral fcr the center of the cabin. It includes the self attenuation of the air in the cabin. The integration intervals are automatically computed by a method found to give results within 5% of using .1 meter intervals.

```
10 'multiple integral algorithm 4.4
20 'Burden, Faires, Reynolds, NUMERICAL ANALYSIS, 2ed ed.
30 'To approximate I=double integral ((f(x,y) dy dx)) with limits
40 '   of integration from a to b for x and from c to d for y.
50 '
60 'Input: endpoints a,b,c,d: positive integers M,n.
70 'Output: approximation J.
80 '
90 'Limits of integration
100 DEF FNXY = EXP(-MUT*SQR(Y^2+X^2)) *Y/(Y^2+X^2)
110 MUT = 6.48072E-03 :'for cabin air at 8000 feet
120 INPUT "pseudolength,radius";B,D
125 b = b/2
130 A = 0 :C = 0
140 M = INT(2*D)
145 IF M < 5 THEN M = 5
150 N = INT(8*B)
155 IF N < 10 THEN N = 10
```

```
160 H = (B-A)/(2*N)

170 FOR I = 1 TO 2*N+1

180 X = A+I*H

190 HX = (D-C)/(2*M)

200 Y = C :LL = FNXY

210 Y = D :UL = FNXY

220 K1 = LL + UL :K2 = 0 :K3 = 0

230 FOR J = 1 TO 2*M-1

240 Y = C + J*HX :Z = FNXY

250 IF J = 2*(J\2)
THEN K2 = K2 + Z
ELSE K3 = K3 + Z

260 NEXT J

270 L = (K1 + 2*K2 + 4*K3)*HX/3

280 IF I=0 OR I=2*M
THEN J1=J1+L
ELSE IF I=2*(I\2)
THEN J2=J2+L
ELSE J3=J3+L

290 NEXT I

300 J = (J1 + 2*J2 + 4*J3)*H/3

310 PRINT "The Cabin Geometry Factor K is:";J

320 END
```

Vita

Stephen P. Conners was born 9 November 1954 to an Air Force family at Wright-Patterson AFB, Ohio. He grew up at a variety of Air Force Bases and completed high school at Rogersville, Pennsylvania. He entered Duquesne University in August 1972 with an AFROTC scholarship. He graduated with a B.S. in Physics in May of 1976. He was called to active duty in December 1976, assigned to Undergraduate Navigator Training School at Mather AFB, California. He continued his training at the Electronic Warfare School there. After completing B-52 Combat Crew Training School at Castle AFB, California, he was assigned to the 325th Bomb Squadron at Fairchild AFB, Washington as an Electronic Warfare Officer. He upgraded to instructor status in February of 1982. In July of 1984 he completed work leading to an additional AFSC for Aircraft Maintaince Officer. Captain Conners was assigned to the Air Force Institute of Technology's master's degree program in Nuclear Effects in July of 1984.

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FROM NUCLEAR CLOUD PENETRATION

Thesis Chairman: Dr. Charles J. Bridgman
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Block 19 continued.

Abstract

This study evaluates the threat to aircraft and aircrew members from the dust and radioactivity in a cloud generated by nuclear surface bursts.

A model of the nuclear cloud is generated, using any number and type of weapons and any desired dust size distribution. The cloud is propagated through the atmosphere for a given time, then penetrated by an aircraft. The activity density in the cloud is converted to dose to the crew for a given path through the cloud. Radiation shielding and dust filters are included in the calculations. Alternatively, the cloud dust mass density can be converted to mass trapped in a filter or the cabin: or to the dust mass that has entered the engine.

Methods for determining particle size and altitude distributions are presented. The ionizing dose to the crewmember is computed for both sky-shine and the dust trapped in the cabin during cloud passage. A method of computing the shielding power of the crew compartment against sky-shine is presented. Given the air flow rate into a filter or engine, the mass of ingested dust is found.

The nuclear cloud and aircraft models developed by this study are incorporated in a computer code oriented toward operational use. A significant feature of the code includes the ability to easily change the scenario with menu driven options.

AD-A159246

CHANGE 1
to

AIRCREW DOSE AND ENGINE DUST INGESTION FROM NUCLEAR CLOUD PENETRATION

by Capt. Stephen P. Conners

Thesis date: March 85 DTIC number: ADA 159 246
Change 1 date: 1 May 86 ******************************** 1.1, 29 May 86

NOTE: Many of the colons in the text should be semicolons; the problem was that the greek printwheel used to print the thesis did not have a semicolon available. Other slight irregularities are due to this problem.

Add "ch 1" next to all changes

Title page: below name block, add: CHANGE 1 - 1MAY 86

page i: below "March 1985", add: CHANGE 1 - 1MAY 86

page iv:

change "Sample Activity Output" to "Sample Single Burst Activity Output"

change "Sample Multi Burst Output" to "Sample Multi Burst Activity Output"

page 9:

paragraph 1, line 3: change "in" to "by"

in Eq 1, in the first term after "where", add after ln(rm): "[rm is the mean radius of a distribution]"

in Eq 1, in the second term after "where", add after ln(σ_{rm}): "[σ_{rm} is the standard deviation of the mean radius of a distribution]"

page 10: Add the following note at the bottom of the page.

"NOTE: Nomenclature used here for lognormal functions follows that used by DELFIC. A statistician would be more comfortable with the following equivalent terms:

particle size distribution:	radius distribution
volume distribution:	volume distribution with respect to radius
surface area distribution:	surface area distribution with respect to radius"

page 12: in Figure 1, the line for DELFIC was not plotted properly; DELFIC is the sum of two cumulative log normals, and is therefore not a straight line on this graph. The maximum deviation of the proper line is no more than 1/8" left of the existing line at midpoint. The proper line can be found by plotting data from Table II on Figure 1.

[illegible]e 17: Equation 3 is incorrect; the equation given is actually the horizontal stabilization time, T_{hs}, which is also found on page 85. The correct expressions for Equation 3 follow:

"For 1 to 10 KT:

$$T_{vs} = 347.0 \text{ [s]} \qquad (3.1)$$

For 10 to 15,000 KT:

$$T_{vs} = 368.384 - 37.0093 (\ln Y) + 21.7003 (\ln Y)^2 - 4.8593 (\ln Y)^3 + 0.288199 (\ln Y)^4 \text{ [s]} \qquad (3.2)$$

For 15,000 to 50,000 KT:

$$T_{vs} = 164.0 \text{ [s]} \qquad (3.3)"$$

page 28: paragraph 3, line 4: change "less" to "more"

page 39:

paragraph 1, line 5: change "three" to "two"

paragraph 1, line 7: change assumption 1. to read:
"1. The activity density of the cloud does not vary vertically or laterally within five gamma mean free path lengths."

paragraph 1, line 9: delete assumption 2.

paragraph 1, line 11: change assumption "3." to "2."

paragraph 2, line 2: change "two assumptions" to "assumption"

paragraph 2, line 3: change "establish" to "establishes"

page 44: paragraph 2, line 7: add the following sentance:
"(An analytical solution is also available in Appendix K.)"

page 45:

Table VIII: after "Cabin Radius M" add a column as follows:

"	Analytical Cabin Geometry Factor K
B-1B	1.53
B-52G	2.20
B-52H	2.20
E-3	2.69
E-4B	4.86
EC-135	2.65
KC-135	2.65"

page 51: see below
page 67: see below
page 70: add:

NOTE

Tables X through XX and Tables XXII through XXIV were created using the horizontal cloud stabilization time rather than the vertical cloud stabilization time. The text of the thesis correctly uses the results of the vertical cloud stabilization time for comparisons. No major differences in output between the two cases (vertical or horizontal stabilization time) will be noted for the Time = 1 hr cases used in the text of the thesis. At very early times computed by the user, there would be differences. This problem is fixed by changing Equation 3 (above, page 17) and changing Appendix A2. and Appendix E (below, pages 84, 104).

page 73: paragraph 14, line 2: change "Offut" to "Offutt"

page 84: in the first table, change the line that reads
"1,000 5651 845.2" to
"1,000 5651 202.7"

change the equation for <u>Vertical stabilization Time (seconds)</u> to:
"For 1 to 10 KT:

$$T_{vs} = 347.0 \text{ [s]}$$

For 10 to 15,000 KT:

$$T_{vs} = 368.384 - 37.0093 (\ln Y) + 21.7003 (\ln Y)^2 - 4.8593 (\ln Y)^3 + .288199 (\ln Y)^4 \text{ [s]}$$

For 15,000 to 50,000 KT:

$$T_{vs} = 164.0 \text{ [s]}$$ "

page 85: line 2: change "vertical" to "horizontal"

page 88: line 13: change "largest particle" to "largest size particle"

page 90:
line 7: change definition to read "component of wind along track"

line 8: change definition to read "component of wind across track"

line 14: change "distance" to "vertical distance"

page 91: paragraph 2, line 3: change "a disk file" to "disk files"

page 98: line 7235 must be deleted or commented out if the filter described in lines 7210, 7220, and 7230 is to be used. Line 7235 overwrites the variable filter.tx.factor(G) with the factor 1 (none are trapped) when it is desired to run the case without a filter.

page 100:
add line 1045: "1045 'change 1, 1 May 86 by Capt. Conners"

replace line 1070 with the following line:
"1070 PRINT "Version 8.1-------------------------------1 May 86"

add line 1165: "1165 'ELSE CONTINUE :'(WHICH% = 1) "

add at the end of line 1220: " :'number of bombs"

add at the end of line 1230: " - see text for justification" page 101:

line 1370: change ":'HR" to ":'HR since burst"

line 1430: add ":'M" to the end of the line

line 1450: add ":'M" to the end of the line

page 104:

add line 2245:

```
"2245  'Units - 3.7E+10 Curies/sec - 1.6E-11 J/MEV - 3600 sec/hr"
```

replace line 2260 with the following lines:

```
"2260 IF KT >= 1 OR KT <= 10 THEN STAB.TIME = 347.0/3600

 2261 IF KT > 10 OR KT < 15000 THEN
 STAB.TIME = (368.384-37.0093*X+21.7003*X^2-4.8593*X^3+.288199*X^4)/3600

 2262 IF KT >= 15000 OR KT <= 50000 THEN STAB.TIME = 164.0/3600
 :'HRS time for vertical cloud stabilization - CHANGE 1 - 1 MAY 86"
```

page 106: add to end of line 2710: ":'DELFIC prediction, Nevada soil"

page 113: add to end of line 4650: ":'unit time dose, no shielding"

page 115: add line 5145:

```
"5145 PRINT#1, "DUST/DOSE ver 8.1, 1 May 86 by Capt. Stephen P. Conners"
```

page 117: line 5650: change the third comma (,) to a semicolon (;)

page 119: line 6040: change the third comma (,) to a semicolon (;)

page 120:

line 6340: change "ELSE WORST.STEP" to "ELSE WORST.ALT"

line 6470: add to end of line: ":'penetration time"

page 121:

change line 6510 from

```
":IF DELTAT<.1 OR DELTAT>100 THEN DELTAT = INTERVAL/8"
```

to

```
":IF DELTAT < .1 THEN DELTAT = INTERVAL    :'to reduce compute time
 :IF DELTAT > 100 THEN DELTAT = INTERVAL/8"
```

add to end of line 6530

":'for each group (disc)..."

add to end of line 6540

":'for each deltat"

add to end of line 6550

":'let cloud fall"

add to end of line 6570

":'get rid of grounded groups"

add to end of line 6610

":'advance time to next penetration/stop time"

add to end of line 6620
":'find activity and dose, or mass, etc."

page 154: add to beginning of line 1: "K1."

page 155: add below the last line:

"Note that a Cabin Geometry Factor K can be computed for a point other than the middle of the cylinder. Determine the distance from the desired point to each end of the cylinder; call these two distances D1 and D2. The program is then run twice using using D1 and D2 for the pseudolength, producing results K1 and K2. The aggregate K factor is then (K1 + K2)/2. Further note that the less central the point is, the less reliable the assumption of uniform distribution of mass around the cabin.

K2. Analytical Solution for Cabin Geometry Factor K

2 Lt. Peter Vanden Bosch of the USAF School of Aerospace Medicine has developed an analytic solution for the cylindrical cabin integral contained in Eq 40. The solution to this equation is the term K in Eq 41.

$$K = \frac{1}{2} \quad H \ln(H^2+R^2) + R \tan^{-1}(H/R) - H \ln(H)$$

$$+ \frac{1}{2} \left[uH \, (H^2+R^2)^{.5} + uR^2 \ln[H+(H^2+R^2)^{.5}] - uH^2 - uR^2 \ln(R) \right]$$

$$+ \frac{1}{4} u^2R^2H$$

for a cylinder of radius R and length H.

Non-central cylinder locations can be determined by the same method noted above.

page 156:
paragraph 1, line 13: change "1984" to "1983"

paragraph 1, line 13: change "1984" to "1983"

add: "Current address is: Capt. Stephen P. Conners
Chief Physicist
544 SIW/DIA
Offutt AFB, NE 68113-5000

Current telephone is: 402-294-4666, AUTOVON 271-4666"

NOTE: A clarification of the lognormal distribution arguments in DELFIC and a derivation of the analytical solution of the cylinderical cabin integral are available at the above address.

Post this change at the back of the thesis.