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AIRCREW IONIZING DOSES FROM RADIOACTIVE DUST CLOUD GENERATED BY NUCLEAR BURST

THESIS

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Major USAF

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THESIS

Presented to the Faculty of the School of Engineering
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by

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Preface

This independent study began as an effort to perform a worst-case analysis on the amount of radioactive fallout exposure to aircrew members when flying through a descending fallout cloud generated by a nuclear surface burst. This problem has recently generated a great amount of interest by military planners during this time of debate about the basing of the MX missiles. During a war, an attack against these sites by many megaton-size nuclear weapons could present a problem to aircrews aboard airborne command posts and similar strategic aircraft. Since these aircraft require extended periods of airborne time, penetration of radioactive fallout clouds generated by these bursts becomes almost inevitable.

Presented within are the results of my efforts to solve this problem by developing a computer code for calculating the ionizing dose rate of a radioactive dust cloud as a function of time, and also the external dose that an aircrew receives during and after the cloud transit. A simple and efficient procedure for handling multiple bursts is also presented.

I am especially grateful to Dr. Charles J. Bridgman for his direction and inexhaustible patience during this research. I am particularly indebted to my lovely wife, Kathi, and to my children for the great amount of patience and love they showed me throughout the period of this work. Finally, thanks are extended to Ms. Sharon Gabriel for typing this report.

Burl E. Hickman

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Abstract

This report will evaluate the threat of radioactive fallout to which aircrew members will be exposed when flying through a descending fallout cloud.

A computer program is developed for calculating the ionizing dose rate of a radioactive dust cloud as a function of time, and also the dose that an aircrew receives when flying through the respective cloud. A cloud model that is patterned after the AFIT fallout smearing code was developed. A comparison is made between the activities at various altitudes from 305 meters to 9150 meters to provide information for possible re-direction of flight.

The external ionizing dose to the aircrew is computed by the new code considering the cloud size, the aircraft's transit time through the cloud, and the ingestion rate of radioactive particles into the aircraft's cabin. Information is also provided to indicate the method by which doses can be computed from a cloud of multiple bursts. The results demonstrate that total dose to each aircrew member is approximately 8 rems after flying through a fallout cloud one hour after cloud stabilization of a 1 Mt burst, with the mission continuing for eight hours subsequent to the cloud transit.

AIRCREW IONIZING DOSES
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I. Introduction

Background

The basing site of the MX missile system would be a prime target for an enemy first-strike attack. Aided by the prevailing westerly winds, the numerous radioactive dust clouds generated by such an attack would cause vast areas of the United States to be exposed to a considerable amount of radioactive fallout. Airborne aircraft will be subjected to accidental or deliberate penetration of these clouds when performing their wartime missions. Consequently, the Strategic Air Command (SAC) has expressed a concern about the amount of fallout that the Airborne Command Post personnel would be exposed to when flying through the descending fallout particles generated by these bursts (Ref 16). Real-time information on the location, time, yield, height of burst, and fallout patterns with dose rates would provide the Airborne Command Post battle management with information on patterns of attack and on areas which would be hazardous to human life and electronic equipment. It would provide information necessary for the rational direction of aircraft during flight and recovery, as well as provide insight into ground facilities which may be unavailable as a result of excessive fallout. For example, a simple altitude change during flight might take the aircrew from an extremely hazardous environment to one with lesser hazards. Effective aircraft operating conditions must also be considered in such a decision, however.

Aircraft penetration of radioactive clouds poses potential hazards in three ways. First, the crew of the aircraft is exposed to ionizing radiation through the aircraft's ventilation system and directly through the skin of the aircraft. Second, the electronic equipment could suffer functional damage or operational upset when exposed to ionizing radiation (Ref 1). Third, the dust into the engine and aircraft ventilation system could cause erosion of engine parts (Ref 2). This study will focus only on the first hazard.

Problem

Flights through clouds may have taken place previously, but results from these flights could not be found. The problem addressed in this study is the determination of dose rates to which the Airborne Command Post personnel would be exposed when flying through the descending fallout particles generated by nuclear bursts. Initially, the particle distributions within a nuclear cloud as a function of yield, altitude, and settling time must be determined. Once the particle distribution is known, the total particle activities can be used to compute an average dose rate and the total dose to an aircrew member inside the aircraft's cabin.

Scope

This study has focused on modeling the potentially hazardous cloud and considered the activity that may enter and settle inside of the aircraft. The fraction of entering particles which settle out is a difficult question, but it directly affects the computation of personnel and equipment exposure. Therefore, for simplification purposes, only the worst-case concept, i.e., all of the radioactive particles that enter the aircraft as it passes through the cloud remain inside the cabin, was selected to illustrate the upper bound of the problem. This concept would also indicate whether or not a real problem does exist. Dust accumulation in the interior of the aircraft is primarily due to cabin pressurization and air conditioning, and to heavy-duty electronic cooling. Consequently, the aircrews are exposed to contamination from direct skin contact and from inhalation. This study will focus only on the whole body exposure due to external gamma-ray radiation.

Assumptions

Several other explicit assumptions are made in this work. They are:

1. The initial conditions for the stabilized cloud position as treated by Bridgman and Bigelow (Ref 3) are applicable.
2. The activity-size distribution of fallout particles as presented by DELFIC (Ref 4) is applicable.
3. No self-shielding from gamma radiation exists within the aircraft.
4. There is no significant adherence of radioactive dust particles to the external skin of the aircraft.
5. Megaton-size yields will be used against the hardened basing sites.

The assumptions will be discussed in greater detail later in the text.

Approach

The mathematical development and results of this analysis of the radioactive dust cloud model are presented in Chapter II. The results are presented in terms of activity density in curies per cubic meter versus altitude at a specified time. The mathematical development of the external dose to the aircrew is presented in Chapter III. The results are then presented in tabular form and include the most prominent particle-size group that affects the aircrew at each altitude. Chapter IV presents the analysis of multiple bursts, and Chapter V presents the conclusions and recommendations of this report.

II. Cloud Model

Background

Several different models have previously been developed to predict the radioactive fallout cloud, some of which were analyzed by Polan in 1962 (Ref 5). All of these models, however, concerned themselves primarily with the predicted footprint that the radioactive fallout makes over the ground as the cloud descends. Of these, the WSEG-10 and the DELFIC models appear to have been the most popular (Ref 6); WSEG-10 for its simplicity and ease of computation, and DELFIC for its predictive capability. Although WSEG-10 is easy to use, it fails to account for fractionation, to allow for variations in the activity particle-size distribution of the fallout, and to use realistic settling rates. DELFIC includes all of these provisions, but the program is very expensive to run and the model is quite difficult to learn.

Patrick (Ref 7) and Patrick et al (Ref 2) investigated aircraft penetration of radioactive clouds by using a simplified cloud model, but the model had some major shortcomings. Specifically, they assumed the cloud to have no variation in its parameters with altitude or range from the point of detonation, with the exception that it was a descending volume. Radioactive dust was depleted from this fixed cloud by an effect called the "nibbling mouse" assumption, i.e., particles with the largest radius fall out before any of the particles with the next smaller radius. The settling rates of these particles were computed by Stokes law with a constant air viscosity. Fractionation was also treated in a somewhat arbitrary manner.

Since that time, Bridgman and Bigelow have developed a new fallout prediction model, the AFIT model, that resembles WSEG-10 in some respects, but which produces results that compare better with those of DELFIC (Ref 3). Unlike WSEG-10, this new model does account for variation in activity size, fractionation, and uses realistic settling rates. Like WSEG-10, however, it is a cloud smearing model that concerns itself with the predicted fallout footprints over the ground.

This report is concerned only with the cloud when it is airborne, not when it is smeared over the ground. Therefore, the familiar $g(t)$ function, which is the normalized rate of arrival of activity on the ground everywhere and which is used in both the WSEG-10 and AFIT models, was inapplicable. Consequently, a new model which is patterned after the AFIT model because of its advantages over WSEG-10 was developed.

Theory

The DELFIC model is considered to be the standard-setting model. Since the cloud model suggested by Bridgman and Bigelow compares closely to the DELFIC model and computes in seconds or less, its initial conditions were used. Specifically, it is assumed that the radioactive dust cloud is generated from a surface burst. For this thesis, the burst is further assumed to be of a megaton-size yield. The cloud is formed from the vaporization of surface material and the weapon itself. The cloud then rises and stabilizes at a maximum height, H_c , approximately 10 minutes after detonation. The cloud center height as presented by WSEG-10 is

$$H_c = 44.0+6.1\ln(YLD) - 0.205(\ln(YLD)+2.42)|\ln(YLD)+2.42| \quad (1)$$

where H_c is in kilofeet and YLD is in megatons.

The stabilized cloud is modeled as a right circular cylinder, as shown in Figure 1. The radioactivity in the stabilized cloud is assumed to be normally distributed about H_c in the vertical and normally distributed about ground zero in the horizontal directions. The radioactivity is also a function of the particle sizes that make up the cloud and a function of time t , namely:

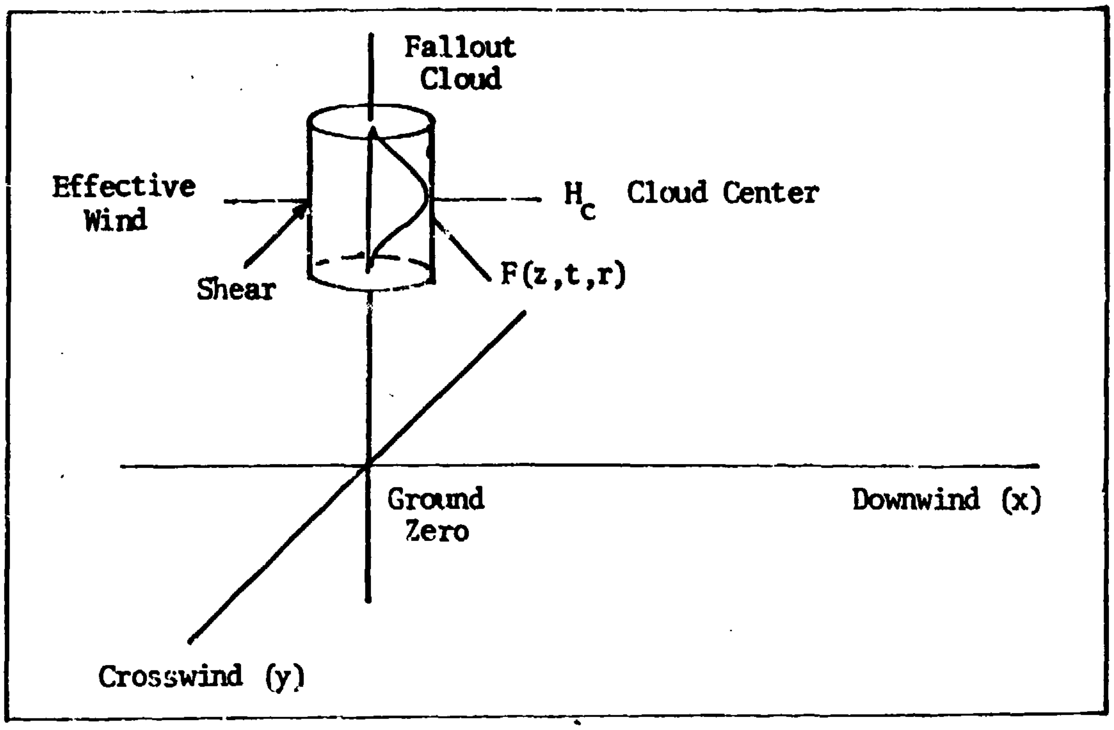

Figure 1. Fallout Cloud Model

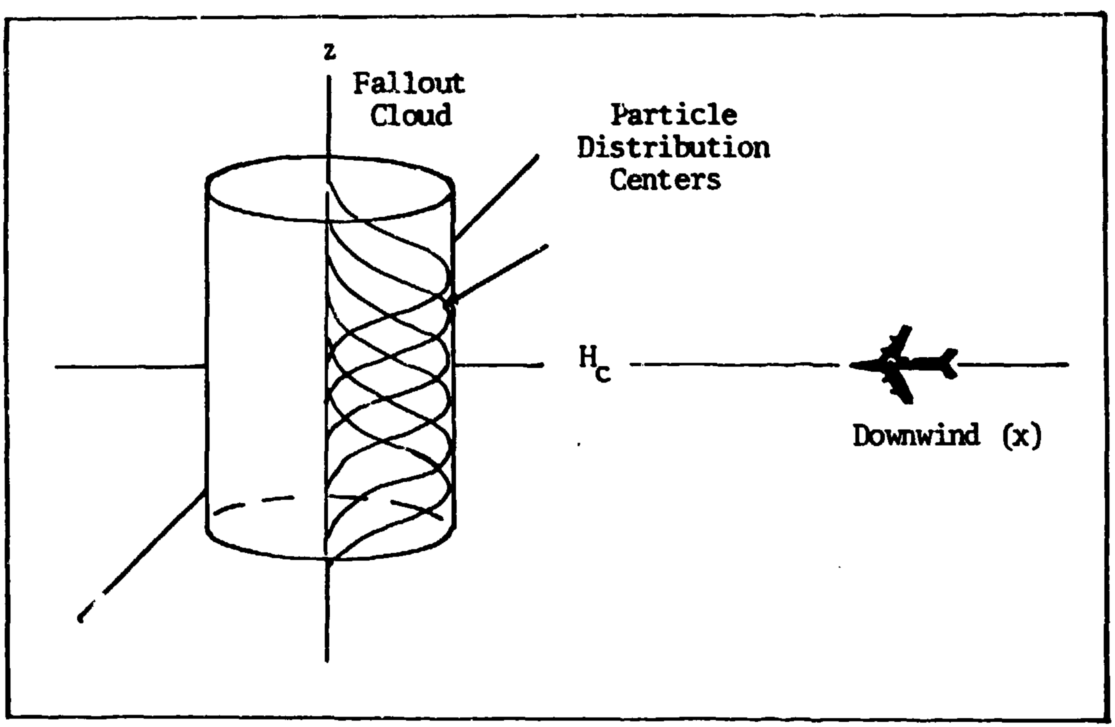

Figure 2. Fallout Cloud at Time t

$$A(r,x,y,z,t) = A_{Total}\, f(x,t) f(y,t) f(z,t) \tag{2}$$

where

$$f(x,t) = \frac{1}{\sqrt{2\pi}\,\sigma_x}\, e^{-\frac{1}{2}\left(\frac{x - V_x t}{\sigma_x}\right)^2} \tag{3}$$

$$f(y,t) = \frac{1}{\sqrt{2\pi}\,\sigma_y}\, e^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2} \tag{4}$$

and

$$f(z,t) = \frac{1}{\sqrt{2\pi}\,\sigma_z}\, e^{-\frac{1}{2}\left(\frac{z - H(t)}{\sigma_z}\right)^2} \tag{5}$$

where x is the downwind distance, y is the crosswind distance, t is time, z is the vertical height, and σ (which will be discussed later in the text) is a time-varying standard deviation or diffusion coefficient. V_x, in WSEG-10, is assumed to be the constant wind which rotates uniformly with altitude; however, since the aircraft and the cloud are suspended within the same medium, V_x is taken to be the true airspeed of the aircraft. The standard deviations in the horizontal directions are also assumed to be slowly varying functions of time.

The radioactivity as a function of particle sizes is represented by 100 discrete particle-size groups which were taken from the DELFIC model (Ref 4). This size distribution is converted to an activity distribution using the fractionation treatment of Bridgman and Bigelow. The fall mechanics of the size groups behave according to the equations of McDonald (Ref 9) and Davies (Ref 10). Therefore, at some later time t, the cloud has expanded not only in the horizontal directions, but has also fallen in the vertical direction as well. This results in each particle-size group distribution being located at different altitudes, as shown in Figure 2.

In this report, two (2) times the standard deviation, σ, in the horizontal and vertical directions is considered to be the lateral limit from the center of the cloud. This limit, when taken in either direction, contains from 95 to 98 percent of the total activity of the cloud in any direction. Values for σ_y and σ_z have been derived for the WSEG-10 and AFIT models (Refs 3, 11 and 12); however, because the $g(t)$ function was used, a σ_x function was never calculated. Therefore, it is assumed that the x direction will behave in a similar fashion as the torroidal growth of the y direction; but, a shear term will not be required when assuming a single effective wind in the x direction. The equation for σ_x then is

$$\sigma_x^2 = \sigma_0^2 [1 + 8T/T_c] \tag{6}$$

where T is the time of arrival, not to exceed three hours, and T_c is the time constant.

Now that the basic equation for the cloud model is known, values for specific altitudes and specific times will be required to solve the original problem. Therefore, the lateral limits of the cloud and the particle sizes that make up the cloud at a specified altitude are required at the time (TA) the aircraft arrives at the cloud. The $f(z,t)$ function, then, is also a function of particle size. Equation (5) then becomes

$$f(z,t,r) = \frac{1}{\sqrt{2\pi}\,\sigma_z} e^{-\frac{1}{2}\left[\frac{z_{a/c} - (z_o - \int_0^t V_z(r)dt')}{\sigma_z}\right]^2} \tag{7}$$

where $z_{a/c}$ is the aircraft altitude, z_o is the original cloud center height, and $V_z(r)$ is the fall velocity as a function of particle size. This expression, written for each of the 100 activity-size groups, will provide the amount of activity from each group at a given altitude. Since the cloud is of finite extent, the total cloud height is considered to be four times the standard deviation in the vertical direction. Consequently, the extent of the contribution of each particle-size group depends upon whether $2\sigma_z$ of a given particle-size group distribution lies within the aircraft's altitude. The cloud activity at its horizontal center at a given TA is

$$A_T = \sum_{i=1}^{100} A_i t^{-\frac{1}{4}} \tag{8}$$

where t is in hours after detonation, and

$$A_i = \frac{A^*}{100} f(x,t) f(y,t) f(z,t,r) \quad . \tag{9}$$

A^* , which is the activity in disintegrations per second at one hour, is given by

$$A^* = 530(3.7 \times 10^{16}) YLD_{KT} \times FF \tag{10}$$

FF is the fission fraction and YLD is the yield in kilotons. Caution must be exercised at this point because all activities are unit time reference activities. They must be transferred to real time using the Way-Wigner decay formula.

Note that Eq (10) is the activity per volume at the horizontal center of the cloud. Figure 3 shows the activities of a 1 Mt burst at altitudes ranging from 9150 meters, approximately 30,000 feet MSL, to 305 meters, approximately 1,000 feet MSL, and at aircraft arrival times at the horizontal center of the cloud that range from 0.5 hours to eight hours

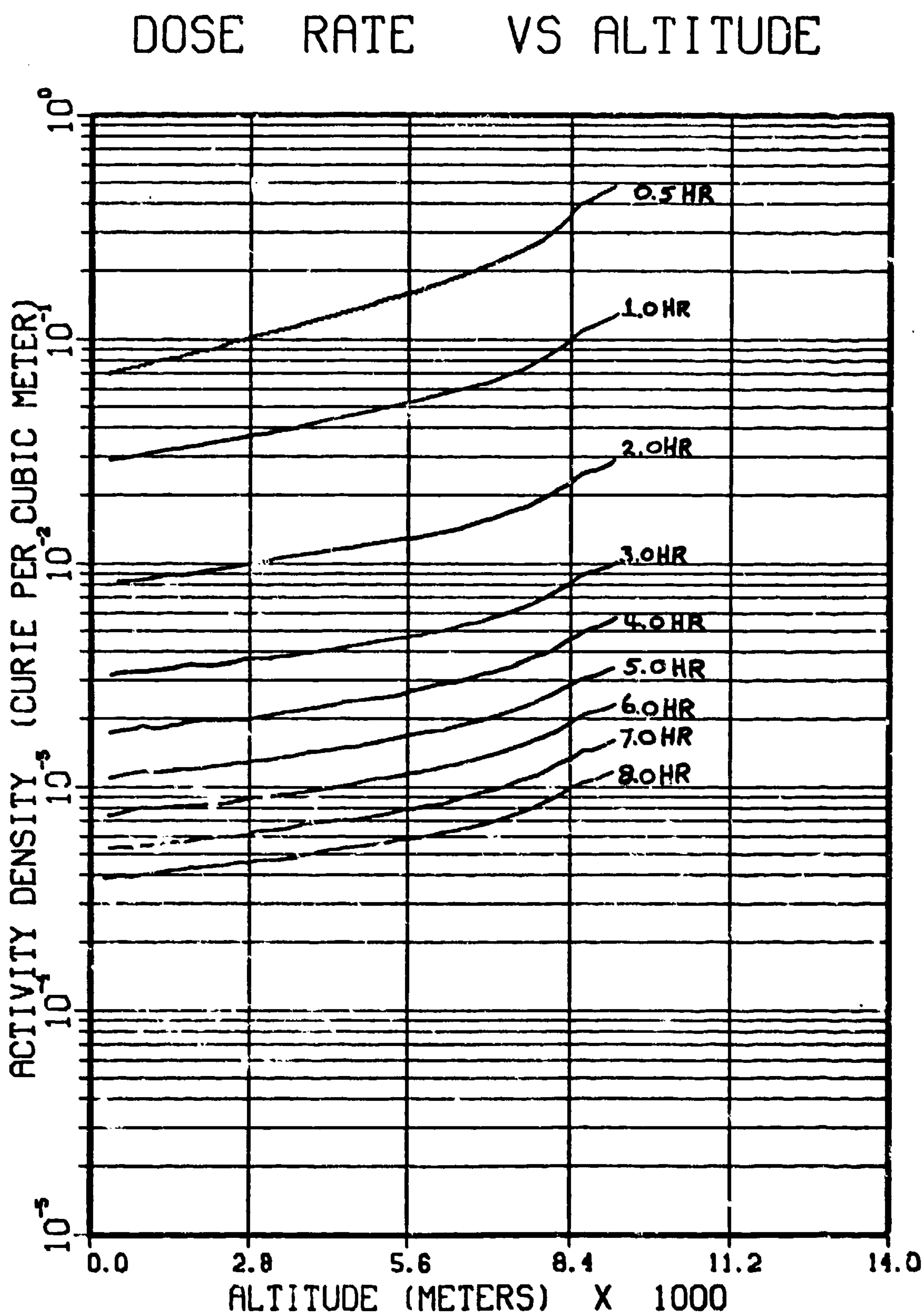

Figure 3. Dose Rate vs Altitude for 1 Mt Burst at Various Times of Arrival

after cloud stabilization. Notice that the activity per cubic meter decreases at lower altitudes. This suggests that a lesser dose rate would be received by the aircrew if lower altitudes were selected. These figures, however, do not include any stem fallout. The values do show the activity that will be ingested inside the aircraft at the given times from a 1 Mt burst. Considerations for multiple bursts are developed in Section IV. Cabin dose rates will be discussed in Section III.

III. Cabin Analysis

Since SAC is interested in the exposure to Airborne Command Post personnel, an airborne-command type aircraft, such as the KC-135, is used in this study. This aircraft cruises at 231.5 m/s. It has an internal volume of 246.357 m^3 (Ref 14) and a mass flow rate of outside air into its air conditioning/pressurization system of approximately 150 lbs/min (Ref 15). Therefore, as the aircraft sweeps through the cloud in the x direction, it will be ingesting at a rate of 150 lbs/min those particle sizes that are co-located at the aircraft's altitude. The crew will be exposed to this ingested radioactivity and to whatever sky shine that is present.

Sky-Shine

As the aircraft passes through the radioactive cloud, the aircrew will be exposed to direct gamma radiation that is passing directly through the aircraft's skin and through any equipment or material inside the aircraft, because of the zero self-shielding assumption. Initially, the radiation would start at a low level as the aircraft enters the cloud, increase to a maximum level as the aircraft reaches the horizontal center of the cloud, and then decrease again as it exits the other side of the cloud. A worst-case analysis can be made if the analysis was performed at the cloud's horizontal center for the time duration that is required to traverse the cloud. Although it is not precisely true, it is assumed that the activity of the dust particles is uniform within a few mean free paths of the gamma radiation at a given altitude. Therefore, ignoring the shielding by the structure and internal equipment, the dose rate can be calculated by the use of spherical integration, namely

$$\dot{D}_{\substack{rad\\tissue}} = \sum_{i=1}^{100} A_i \int_0^{2\pi} \int_0^{\pi} \int_0^{s} \frac{\mu_a}{\rho} \frac{e^{-\mu_t s} s^2 \sin\phi \, d\theta \, d\phi \, ds}{4\pi s^2} \quad (11)$$

where $\frac{\mu_a}{\rho}$ is the absorption coefficient of tissue, and μ_t is the attenuation coefficient of air and s is the radius of the cloud. This equation readily equates to

$$\dot{D} = 1.6 \times 10^{-11} \sum_{i=1}^{100} A_i \frac{\mu_a}{\rho\mu_t} (1 - e^{-\mu_t s}) \quad (12)$$

By letting s approach ∞, which again is a worst-case assumption, Eq (12) reduces to

$$\dot{D} = 1.6 \times 10^{-11} \sum_{i=1}^{100} A_i \frac{\mu_a}{\rho\mu_t} \quad (13)$$

The total dose then can be computed by integrating Eq (13) with respect to time with the limits of TA to TA + Δt, where Δt is the transit time through the cloud:

$$D = \int_{t_a}^{t_a+\Delta t} \dot{D}t^{-1.2}\, dt \qquad (14)$$

Tables I through IX provide the results of sky-shine from a 1 Mt burst at different arrival times. It can be seen that the total dose is significant at early times, even though the length of time required to traverse the cloud is brief.

Ground-Shine

It has been shown that sky-shine is a significant factor with reference to this problem. On the other hand, it can be shown that the ground-shine (radioactivity from the cloud particles that have fallen to the ground) is an insignificant factor, provided the aircraft is flying at least a few gamma ray mean free paths above the ground. Patrick researched the problem in 1976 (Ref 8); however, he admitted that for short flyovers, as is the case in this study, his results were questionable. Since his report, no additional studies of this problem have been found.

Consider now that the aircraft is at height L above the surface radiation as in Figure 4. An assumption that considers the surface activity to be uniformly distributed is made in order to simplify the problem. In reality, the surface activity involves a more complex function because the activity varies with location and with time. However,

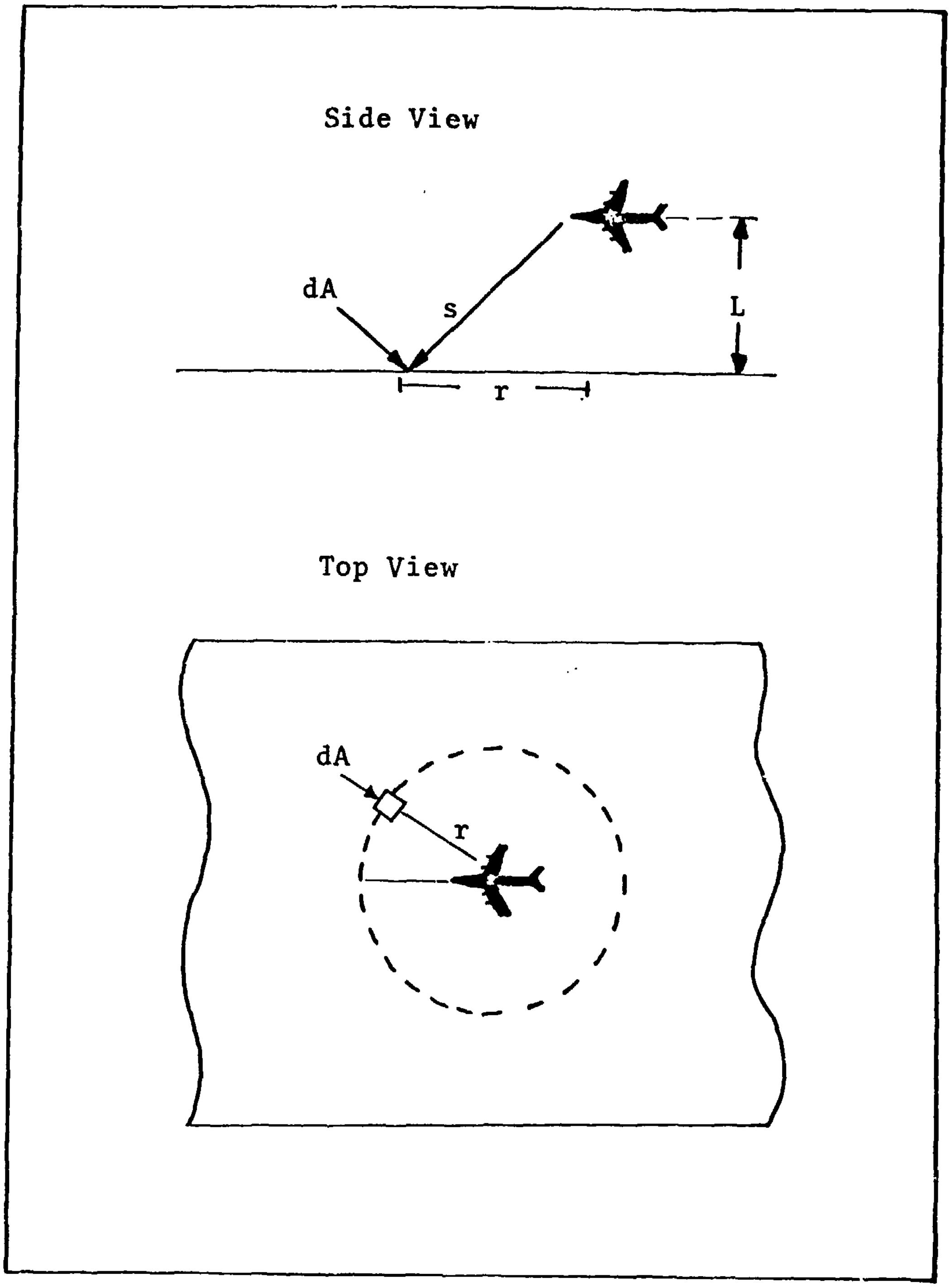

Figure 4. Flyover of Radioactive Surface Area

making this assumption reduces the problem to

$$d[\dot{D}] = \left(\frac{A(x,y)d(\text{Area})e^{-\mu_t s}}{4\pi s^2}\right) 2\pi r dr \qquad (15)$$

where $s^2 = r^2 + L^2$ and L is a constant value. $A(x,y)$ is the activity at the one-hour point of those particles that have reached the surface. Accounting for units, Eq (15) reduces further to

$$\dot{D} = A(x,y)\ 9.195 \times 10^{-11} \int_z^{\infty} \frac{e^{-z}}{z}\, dz \qquad (16)$$

where $z = \mu_t L$. When the altitude ranges of 9150 meters to 305 meters for this study are considered, values on the order of $A(x,y) \times 10^{-29}$ and $A(x,y) \times 10^{-11}$ are obtained. Consequently, ground-shine is omitted in the final analysis of this study.

Cabin Ingestion

The cloud's activity at a given altitude was calculated in terms of the activity per cubic meter. When the aircraft traverses the cloud, it travels completely through the cloud in the x direction, and this happens regardless of the time after detonation. Therefore, the $F(x,t)$ function in Eq (2) is always equal to unity when integrated over the transit time TA - $2\sigma_x/V_x$ to TA + $2\sigma_x/V_x$. Then Eq (2) reduces to the activity (DPS) per square meter, namely

$$A/m^2 \text{ (outside air)} = 530 \times 3.7 \times 10^{16} \times 500F(y,t)F(z,t,r)\ \frac{DPS}{m^2} \qquad (17)$$

The cabin air is taken through the fifth stage of the engine compressor in such a manner that a constant mass flow of 150 pounds of air per minute enters the cabin (Ref 15). This mass rate is the same at any aircraft velocity or altitude. Thus, the equivalent area of the effective cabin air inlet port is

$$\text{Inlet Area} = \frac{150\#}{\text{min}} \times \frac{1}{\rho_{air}\#/\text{ft}^3} \times \frac{1}{V_x\ \text{Ft/min}}$$

and the total activity ingested per pass is the area times Eq (17); namely

$$\text{Activity inside cabin (DPS)} = A/m^2\text{(outside air)} \times \frac{150}{\rho_{air}\ V_x} \qquad (18)$$

where ρ is the air density at the aircraft altitude (m) and V_x is the aircraft velocity in meters per hour. This

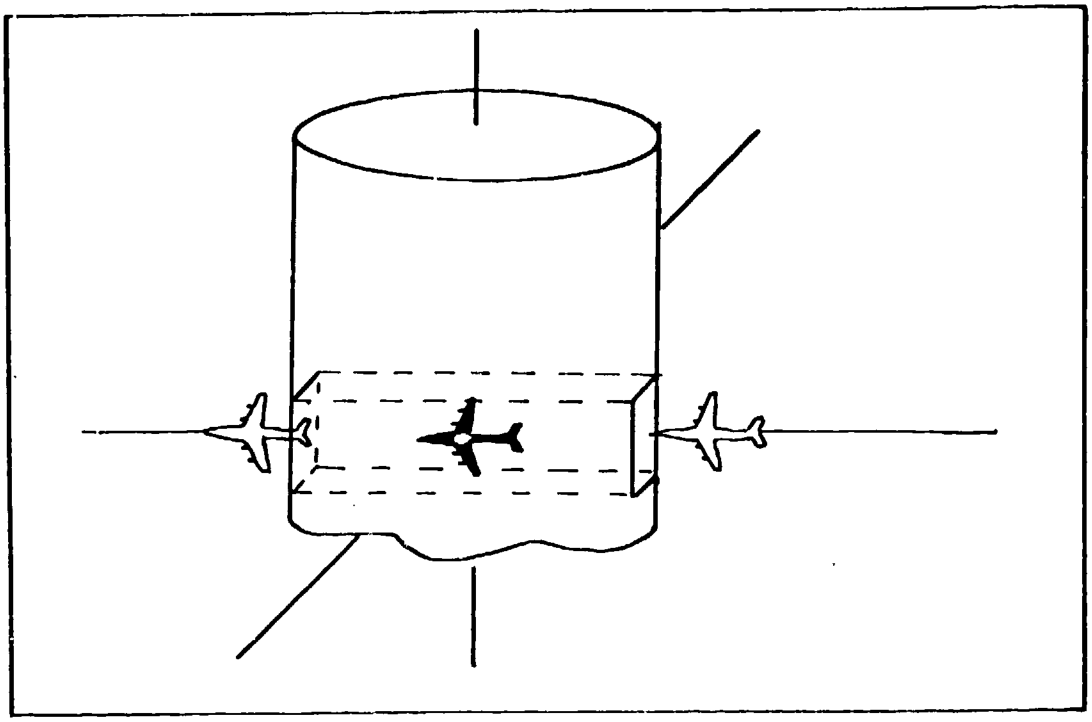

Figure 5. Aircraft Transit Through Fallout Cloud

equation is based upon a gamma ray energy of 1 Mev (Ref 17). Note that, as the velocity V_x increases, the activity that enters the cabin decreases.

Modeling the behavior of the dust particles after they have entered the aircraft presents another complication because of the placement of air-conditioning duct outlets and electronic/mechanical equipment. By considering the ingestion flow rate and the total internal volume of the cabin, it was determined that the absolute minimum time for 99% of the internal air to be displaced is approximately 21 minutes. Therefore, it is assumed that the activity that enters the cabin is equally distributed. The cabin activity per cubic meter is then the total activity divided by the total volume of 246.357 cubic meters.

To obtain meaningful dose rates, the internal cabin is modeled as a right circular cylinder having the dimensions of the internal cabin. Again, self-shielding is considered to be zero, and the assumption that all the activity that enters the cockpit remains inside the cabin is still valid. The dose rate at the center of the cylinder due to the suspended dust is

$$\dot{D} = 2 \int_0^{16.0274} \int_0^{2.7432} \int_0^{2\pi} A \frac{\mu_a}{\rho_a} \frac{e^{-\mu_t (r^2+z^2)^{1/2}}}{4\pi (r^2+z^2)} r d\theta dr dz \tag{19}$$

where r is the radius of the cylinder, z is one-half the height of the cylinder, and A is the one-hour activity of those particles that enter the aircraft. Due to the complex nature of the integral in Eq (19), a numerical integration is required. After integrating over $d\theta$, the equation becomes

$$\dot{D} = A \frac{\mu_a}{\rho} \int_0^{16.0274} \int_0^{2.7432} \frac{e^{-\mu_t (r^2+z^2)^{1/2}}}{(r^2+z^2)} r dr dz \tag{20}$$

and

$$\dot{D} = 3.47 \, A \, \frac{\mu_a}{\rho}_{tissue} \tag{21}$$

when the numerical integration is performed. The total dose is obtained from Eq (14). The dose results from a 1 Mt burst at aircraft arrival times ranging from 0.5 hours to 8 hours are shown in Tables I through IX.

TABLE I

Summary of Doses and Prominent Particle Sizes
at 1 Mt Burst, TA = 0.5 Hrs, 8-Hour Mission Flown After Cloud Transit

Altitude (meters)	Internal Cabin Dose (rems)	Sky-Shine Dose (rems)	Most Prominent Particle Size Diameter (μm)
9150	4.544	18.336	196.38
8840	3.993	16.116	216.52
8535	3.499	14.120	228.62
8230	2.760	11.135	241.79
7925	2.305	9.300	253.68
7620	2.017	8.141	268.29
7315	1.770	7.142	283.74
7010	1.586	6.399	302.50
6710	1.426	5.757	317.37
6400	1.290	5.207	338.35
6100	1.182	4.768	338.35
5800	1.064	4.295	360.71
5490	0.975	3.934	390.75
5180	0.894	3.609	390.75
4880	0.815	3.289	416.60
4570	0.749	3.022	416.60
4270	0.690	2.784	449.83
3960	0.636	2.565	478.79
3660	0.587	2.367	478.79
3355	0.540	2.179	525.35
3050	0.505	2.040	525.35
2745	0.467	1.883	525.35
2440	0.431	1.738	573.68
2135	0.397	1.600	573.68
1830	0.372	1.501	631.48
1525	0.343	1.386	631.48
1220	0.323	1.305	631.48
915	0.298	1.204	700.69
610	0.280	1.130	700.69
305	0.257	1.040	37349.0

TABLE II

Summary of Doses and Prominent Particle Sizes
at 1 Mt Burst, TA = 1.0 Hrs, 8-Hour Mission Flown After Cloud Transit

Altitude (meters)	Internal Cabin Dose (rems)	Sky-Shine Dose (rems)	Most Prominent Particle Size Diameter (μm)
9150	2.360	5.791	121.0
8840	2.101	5.156	125.5
8535	1.865	4.578	137.0
8230	1.535	3.767	142.6
7925	1.309	3.212	149.62
7620	1.160	2.846	157.00
7315	1.043	2.559	163.4
7010	0.946	2.322	170.05
6710	0.867	2.128	178.41
6400	0.788	1.934	187.18
6100	0.730	1.792	196.38
5800	0.672	1.648	196.38
5490	0.622	1.527	206.04
5180	0.577	1.416	216.52
4880	0.537	1.317	228.62
4570	0.498	1.223	228.62
4270	0.464	1.138	241.79
3960	0.431	1.057	253.68
3660	0.401	0.985	253.68
3355	0.378	0.928	268.29
3050	0.353	0.865	268.29
2745	0.328	0.806	283.74
2440	0.310	0.761	283.74
2135	0.290	0.711	302.50
1830	0.270	0.663	317.37
1525	0.256	0.629	317.37
1220	0.239	0.588	338.35
915	0.227	0.557	338.35
610	0.212	0.520	360.71
305	0.197	0.483	360.71

TABLE III

Summary of Doses and Prominent Particle Sizes
at 1 Mt Burst, TA = 2.0 Hrs, 8-Hour Mission Flown After Cloud Transit

Altitude (meters)	Internal Cabin Dose (rems)	Sky-Shine Dose (rems)	Most Prominent Particle Size Diameter (μm)
9150	0.962	1.525	80.163
8840	0.855	1.361	83.435
8535	0.771	1.222	86.840
8230	0.648	1.028	90.383
7925	0.558	0.885	94.07
7620	0.497	0.788	98.00
7315	0.451	0.715	101.91
7010	0.410	0.651	106.10
6710	0.378	0.599	110.40
6400	0.348	0.551	110.40
6100	0.324	0.514	116.00
5800	0.300	0.476	121.00
5490	0.283	0.449	125.50
5180	0.262	0.416	125.50
4880	0.249	0.394	131.43
4570	0.231	0.366	137.00
4270	0.219	0.348	142.60
3960	0.206	0.326	142.60
3660	0.196	0.311	149.62
3355	0.184	0.292	149.62
3050	0.175	0.278	157.00
2745	0.165	0.261	163.40
2440	0.155	0.246	163.40
2135	0.147	0.234	170.05
1830	0.138	0.219	178.41
1525	0.133	0.212	178.41
1220	0.125	0.199	187.18
915	0.118	0.186	187.18
610	0.112	0.178	196.38
305	0.107	0.169	196.38

TABLE IV

Summary of Doses and Prominent Particle Sizes
at 1 Mt Burst, TA = 3.0 Hrs, 8-Hour Mission Flown After Cloud Transit

Altitude (meters)	Internal Cabin Dose (rems)	Sky-Shine Dose (rems)	Most Prominent Particle Size Diameter (μm)
9150	0.511	0.650	63.06
8840	0.461	0.586	65.632
8535	0.413	0.525	68.311
8230	0.353	0.449	71.100
7925	0.303	0.385	74.00
7620	0.271	0.345	77.02
7315	0.246	0.312	80.163
7010	0.223	0.284	83.435
6710	0.207	0.263	83.435
6400	0.190	0.241	86.84
6100	0.177	0.224	90.384
5800	0.165	0.209	94.07
5490	0.153	0.195	94.07
5180	0.144	0.184	98.00
4880	0.134	0.170	101.91
4570	0.125	0.159	101.91
4270	0.119	0.151	106.10
3960	0.112	0.142	110.40
3660	0.106	0.135	110.40
3355	0.100	0.127	116.00
3050	0.096	0.122	116.00
2745	0.090	0.115	121.00
2440	0.086	0.110	121.00
2135	0.082	0.104	125.50
1830	0.079	0.101	131.43
1525	0.075	0.095	131.43
1220	0.071	0.090	137.00
915	0.068	0.087	137.00
610	0.065	0.083	142.60
305	0.062	0.078	142.60

TABLE V

Summary of Doses and Prominent Particle Sizes
at 1 Mt Burst, TA = 4.0 Hrs, 8-Hour Mission Flown After Cloud Transit

Altitude (meters)	Internal Cabin Dose (rems)	Sky-Shine Dose (rems)	Most Prominent Particle Size Diameter (µm)
9150	0.324	0.358	53.74
8840	0.291	0.322	55.928
8535	0.263	0.291	58.211
8230	0.225	0.249	60.59
7925	0.197	0.217	63.06
7620	0.176	0.195	65.632
7315	0.160	0.177	68.311
7010	0.146	0.162	68.311
6710	0.133	0.148	71.10
6400	0.124	0.137	74.00
6100	0.115	0.127	77.02
5800	0.107	0.119	77.02
5490	0.100	0.110	80.163
5180	0.092	0.102	83.435
4880	0.087	0.096	83.435
4570	0.081	0.090	86.84
4270	0.077	0.085	90.384
3960	0.073	0.081	90.384
3660	0.069	0.076	94.07
3355	0.064	0.071	94.07
3050	0.061	0.068	98.00
2745	0.058	0.064	98.00
2440	0.056	0.062	101.91
2135	0.053	0.058	101.91
1830	0.050	0.056	106.10
1525	0.048	0.053	106.10
1220	0.045	0.050	110.40
915	0.044	0.049	110.40
610	0.042	0.046	116.00
305	0.039	0.043	116.00

TABLE VI

Summary of Doses and Prominent Particle Sizes
at 1 Mt Burst, TA = 5.0 Hrs, 8-Hour Mission Flown After Cloud Transit

Altitude (meters)	Internal Cabin Dose (rems) x 10^{-2}	Sky-Shine Dose (rems) x 10^{-2}	Most Prominent Particle Size Diameter (μm)
9150	21.81	21.88	47.279
8840	19.75	19.81	49.604
8535	17.89	17.95	51.63
8230	15.47	15.52	53.74
7925	13.50	13.55	55.928
7620	12.01	12.05	58.211
7315	10.97	11.00	58.211
7010	9.97	10.00	60.59
6710	9.24	9.28	63.06
6400	8.50	8.53	65.632
6100	7.92	7.94	65.632
5800	7.39	7.42	68.311
5490	6.89	6.91	71.10
5180	6.43	6.45	71.10
4880	6.02	6.04	74.00
4570	5.69	5.71	77.02
4270	5.34	5.35	77.02
3960	5.06	5.07	80.163
3660	4.75	4.76	80.163
3355	4.51	4.53	83.435
3050	4.24	4.25	83.435
2745	3.97	3.99	86.84
2440	3.84	3.85	86.84
2135	3.61	3.62	90.384
1830	3.45	3.46	90.384
1525	3.24	3.26	94.07
1220	3.15	3.16	94.07
915	2.98	2.99	98.00
610	2.81	2.82	98.00
305	2.69	2.70	101.91

TABLE VII

Summary of Doses and Prominent Particle Sizes
at 1 Mt Burst, TA = 6.0 Hrs, 8-Hour Mission Flown After Cloud Transit

Altitude (meters)	Internal Cabin Dose (rems) x 10^{-2}	Sky-Shine Dose (rems) x 10^{-2}	Most Prominent Particle Size Diameter (μm)
9150	15.563	14.522	43.644
8840	14.030	13.096	45.430
8535	12.736	11.884	47.279
8230	10.995	10.260	47.279
7925	9.646	9.001	49.604
7620	8.628	8.051	51.630
7315	7.879	7.352	53.740
7010	7.152	6.674	55.928
6710	6.636	6.193	55.928
6400	6.097	5.689	58.211
6100	5.739	5.356	60.590
5800	5.302	4.947	60.590
5490	5.002	4.667	63.060
5180	4.620	4.311	65.632
4880	4.378	4.085	65.632
4570	4.099	3.825	68.311
4270	3.889	3.629	68.311
3960	3.647	3.403	71.100
3660	3.423	3.194	74.000
3355	3.298	3.077	74.000
3050	3.097	2.890	77.020
2745	2.948	2.751	77.020
2440	2.772	2.587	80.163
2135	2.602	2.428	80.163
1830	2.523	2.355	83.435
1525	2.375	2.217	83.435
1220	2.270	2.118	86.840
915	2.175	2.029	86.840
610	2.050	1.913	90.384
305	1.927	1.800	90.384

TABLE VIII

Summary of Doses and Prominent Particle Sizes
at 1 Mt Burst, TA = 7.0 Hrs, 8-Hour Mission Flown After Cloud Transit

Altitude (meters)	Internal Cabin Dose (rems) x 10^{-2}	Sky-Shine Dose (rems) x 10^{-2}	Most Prominent Particle Size Diameter (µm)
9150	11.471	10.115	39.970
8840	10.417	9.186	41.670
8535	9.464	8.346	43.644
8230	8.225	7.253	45.430
7925	7.205	6.354	45.430
7620	6.443	5.681	47.279
7315	5.876	5.181	49.604
7010	5.330	4.700	51.630
6710	4.988	4.400	51.630
6400	4.584	4.042	53.740
6100	4.268	3.764	55.928
5800	3.985	3.514	55.928
5490	3.673	3.239	58.211
5180	3.475	3.064	58.211
4880	3.255	2.870	60.590
4570	3.085	2.720	63.060
4270	2.896	2.553	63.060
3960	2.750	2.425	65.632
3660	2.585	2.280	65.632
3355	2.426	2.139	68.311
3050	2.345	2.068	68.311
2745	2.206	1.945	71.100
2440	2.101	1.853	71.100
2135	2.006	1.769	74.000
1830	1.887	1.664	74.100
1525	1.802	1.589	77.020
1220	1.722	1.519	77.020
915	1.621	1.429	80.163
610	1.552	1.369	80.163
305	1.487	1.311	83.435

TABLE IX

Summary of Doses and Prominent Particle Sizes
at 1 Mt Burst, TA = 8.0 Hrs, 8-Hour Mission Flown After Cloud Transit

Altitude (meters)	Internal Cabin Dose (rems) x 10^{-2}	Sky-Shine Dose (rems) x 10^{-2}	Most Prominent Particle Size Diameter (μm)
9150	8.812	7.426	36.600
8840	7.970	6.715	38.400
8535	7.249	6.109	39.970
8230	6.341	5.343	41.670
7925	5.550	4.677	43.644
7620	4.957	4.178	43.644
7315	4.518	3.807	45.430
7010	4.133	3.483	47.279
6710	3.829	3.227	49.604
6400	3.516	2.963	49.604
6100	3.305	2.785	51.630
5800	3.052	2.572	51.630
5490	2.843	2.396	53.740
5180	2.688	2.265	55.928
4880	2.518	2.121	55.928
4570	2.388	2.012	58.211
4270	2.243	1.890	58.211
3960	2.130	1.795	60.590
3660	2.005	1.689	60.590
3355	1.883	1.587	63.060
3050	1.795	1.513	63.060
2745	1.714	1.444	65.632
2440	1.611	1.358	65.632
2135	1.541	1.299	68.311
1830	1.472	1.241	68.311
1525	1.407	1.186	71.100
1220	1.325	1.117	71.100
915	1.268	1.068	74.000
610	1.191	1.004	74.000
305	1.135	0.956	77.020

IV. Multiple Bursts

The previous sections of this study have been concerned with a single burst only. However, airborne aircraft may be subjected to a radioactive dust cloud generated by multiple nuclear bursts. The single burst model must then be modified to account for this possibility.

Consider a proposed MX base hit by 300 one-megaton surface bursts. The burst field is then approximated by a 100 Km square geometry with 17.32 weapons in the North-South (NS) direction, and 17.32 weapons in the East-West (EW) direction. The cloud activity density will then be represented as

$$A_{vol}(x,y,z,t) = 530 \times 3.7 \times 10^{16} \cdot YLD \cdot FF \cdot f(x,t)f(y,t)f(z,t) \text{ DPS/m}^3 \tag{22}$$

where, as Crandley states (Ref 13),

$$f(y,t) = \frac{\sqrt{300}}{100} \int_{-50}^{+50} \frac{1}{\sqrt{2\pi}\,\sigma_y(t)} e^{-\frac{1}{2}\left(\frac{y - y'}{\sigma_y(t)}\right)} dy' \tag{23}$$

which is the sum of the overlapped gaussian distributions. The f(x,t) function in the EW direction is

$$f(x,t) = \frac{\sqrt{300}}{100} \int_{-50}^{+50} \frac{1}{\sqrt{2\pi}\ \sigma_x(t)} e^{-\frac{1}{2}\left(\frac{x - x'}{\sigma_x(t)}\right)} dx' \qquad (24)$$

Therefore, the description of the bursts in the x,y directions is a superposition of 300 gaussian distributions laid out in a square matrix. Since the aircraft is again traveling in the x direction, Eq (24) must be integrated over the distance, namely

$$\int_{-\infty}^{+\infty} f(x,t)dx = \int_{-\infty}^{+\infty} \frac{\sqrt{300}}{100} \int_{-50}^{+50} \frac{1}{\sqrt{2\pi}\ \sigma_x(t)} e^{-\frac{1}{2}\left(\frac{x - x'}{\sigma_x(t)}\right)^2} dx' dx \qquad (25)$$

Unlike the single burst case which integrated to unity, this equation integrates to the square root of the number of bursts, $\sqrt{300}$. Because the height of the cloud depends only upon yield of each burst, the f(z,t) function remains the same as a single burst

$$f(z,t) = \sum_{i=1}^{100} f_i(z,t) \qquad (26)$$

The activity per square meter resulting from an EW pass at the horizontal center is

$$A(DPS/m^2) = 530 \times 3.7 \times 10^{16} \cdot YLD \cdot FF \cdot (300)(1)(1/100) f(z,t) \qquad (27)$$

where $F(y,t) = \frac{\sqrt{300}}{100}$ at $y = 0$. This equation is the same equation for a single burst (Eq (17)) of Section III, except for the number of bursts divided by field length multiplied by the quantity $\sqrt{2\pi}\,\sigma_y(t)$. It can be concluded, then, that multiple bursts can be treated by multiplying the results for a single burst by the number of bursts times the standard deviation in the y direction and $\sqrt{2\pi}$ divided by the field length. In this example, the value of this constant is

$$\frac{300 \text{ bursts}}{100 \text{ Km}} \times \sqrt{2\pi}\,\sigma_y(t) \tag{28}$$

where $\sigma_y(t)$ is in kilometers.

V. Conclusions and Recommendations

Conclusions

The results obtained from this analysis, which was done from a worst-case approach, demonstrate that aircrew exposure to radioactive fallout generated by nuclear surface bursts can be significant. This significance is dependent upon the aircraft arrival time, speed, and altitude. The problem is most prominent at early arrival and penetration times where the higher sky-shine and the ingestion of the more concentrated dust particles occurs. The hazards can be further exaggerated if multiple bursts and/or longer missions are flown after cloud penetration. Multiple burst activities are determined by multiplying the results of a single burst by a constant function.

The results also showed that the radioactive dust cloud's activity density decreased with a decrease in altitude at a given time after the burst. When cloud penetration at early times is required, the heavier particles at the lower altitudes are more widely distributed than the lighter particles at the higher altitudes. This results in a lower cloud activity density at the lower altitudes and, therefore, a lesser number of particle sizes would enter the aircraft. Secondly, filtration of the larger particle-size groups at the lower altitudes is easier to accomplish than filtration of the smaller particle-size groups. However, filtration would create a point source of radiation until the filters are discarded.

Recommendations

There are three recommendations to be made. First, it is recommended that a stem fallout analysis be made because this analysis was performed without consideration to stem fallout. Although this fallout is assumed to be caused primarily by larger particle-size groups, the activity densities at lower altitudes could be appreciably affected by it at earlier times. Secondly, this analysis considered a single effective westerly wind at all altitudes. As more information is received on the treatment of horizontal winds, a study could be performed to consider the effects on the cloud by these winds at the changing altitudes. Third, a more detailed analysis of dust particle behavior could be made to determine what percentage of the radioactive dust particles actually settled out inside of the aircraft. Although a worst-case analysis was made in this study, surely some percentage of the radioactive dust exits the aircraft with the outgoing air.

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APPENDIX A

Glossary of FORTRAN Terms

Inputs:

FFR	=	Fission fraction
YLD	=	Yield in kilotons
RT	=	Range of aircraft from fallout cloud in meters
VAC	=	True airspeed of aircraft in meters per second
TR	=	Time remaining in mission after cloud arrival

Terms:

ACALT	=	Aircraft altitude	(meters)
HC	=	Cloud center height	(kilofeet)
HC1	=	HC x 3.048 x 10^2	(meters)
TA	=	Time of aircraft arrival to fallout cloud	(seconds)
HR	=	TA/3600	(hours)
SZ	=	σ_z = .18 HC1	(meters)
RHOPAR	=	Particle density	(kg/m^3)
DIA	=	Particle diameters	(meters)
R	=	Radius of particle	(meters)
TC	=	Time constant	(hours)
SO	=	σ_o	(meters)
ZDIST	=	Particle-size distribution center height	(meters)

FZ	=	F(z,t,r)	($meters^{-1}$)
SY	=	σ_y	(meters)
AR	=	Particle-size group activity	(DPS/m^3)
AMAX	=	Total activity of cloud	(DPS)
ATOT	=	Activity inside aircraft	(DPS)
APERM3	=	ATOT per cubic meter	(DPS/m^3)
ATOTTA	=	Cloud activity at time t after detonation	(DPS/m^3)
RHOALT	=	Air density at altitude	(kg/m^3)
ACPALT	=	Aircraft pressure altitude	($Newtons/m^2$)
MUARHO	=	Mass absorption coefficient for tissue	(m^2/kg)
MUTRHO	=	Mass attentuation coefficient for air	(m^2/kg)
MUT	=	Attenuation coefficient for air	(m^{-1})
DRATE	=	Dose rate at one hour	(rads/sec)
TDOSE	=	Total tissue dose to aircrew	(rem)
RHO1	=	Density inside aircraft	(kg/m^3)
DV	=	Dynamic viscosity	($Newton\text{-}sec/m^2$)
KINV	=	Kinematic viscosity	(m^2/s)
SOUND	=	speed of sound	(m/s)
DRAGCF	=	Slip correction factor	(dimensionless)
T	=	Temperature at altitude	(°K)
RE	=	Reynolds number	(dimensionless)
TERMV	=	Terminal velocity of particle	(m/s)
RC	=	R^2C_d	(dimensionless)

APPENDIX B

Dose Program

This appendix contains the dose program explanation and listing. The dose program is designed to be run either interactively or by a card deck. It requires five different input parameters in order to run. These parameters are:

(a) Fission fraction

(b) Yield in kilotons

(c) Range of aircraft to the burst in meters

(d) True airspeed velocity of the aircraft in meters per second

(e) Flight time remaining after cloud arrival in hours.

The program will ask the user for these parameters when they are needed. The program then calculates and displays the aircraft's cabin altitude, the total dose accumulated in rems for the stated mission, the sky-shine dose in rems, and the activity density of the outside air in disintegrations per second per cubic meter. The information is displayed for 30 different altitudes ranging from 9150 meters (approximately 30,000 feet) to 305 meters (approximately 1,000 feet).

Subroutine ACT computes the total outside activity at a given altitude by determining which particle-size groups are contributing to this activity. This information is then passed on to subroutines SHINE and BDOSE so that sky-shine and aircrew body dose can be calculated. Particle fall velocities and times are calculated by subroutine CLOUD. United States Standard Atmospheric information is also calculated by this subroutine. Subroutine TCHEK merely cross references the time of arrival of the aircraft to the cloud with the distances that each particle-size group distribution center has traveled in that given time. The subroutine DENS obtains the correct air density for the corresponding cabin altitude.

```
      PROGRAM DOSE
C     THIS PROGRAM CALCULATES THE ACTIVITY, IN DISINTEGRATIONS PER
C     SECOND , THAT ENTERS THE AIRCRAFT WHEN FLYING THROUGH A
C     RADIOACTIVE DUST CLOUD.
      PARAMETER (MAXL=30)
C     FFR = FISSION FRACTION
C     YLD = YIELD IN KILOTONS
C     RT = RANGE OF AIRCRAFT FROM FALLOUT CLOUD
C     TACT = TOTAL ACTIVITY (DPS)
C     RHO = AIR DENSITY AT RESPECTIVE ALTITUDE
C     ACALT = ALTITUDE OF AIRCRAFT IN METERS
      REAL FFR,YLD,RT,VAC,ACALT(30),TACT(30),ZDIST(0:400),AR(0:100),
     :RHOALT(400)
      REAL RHO,TR,ATOTC,MDOSE,SKYDOS,TDOSE
      INTEGER K
      DATA (ACALT(I),I=1,30)/9150.0,8840.0,8535.0,8230.0,7925.0,7620.0,
     :7315.0,7010.0,6710.0,6400.0,6100.0,5800.0,5490.0,5180.0,4880.0,
     :4570.0,4270.0,3960.0,3660.0,3355.0,3050.0,2745.0,2440.0,2135.0,
     :1830.0,1525.0,1220.0,915.0,610.0,305.0/
      PRINT*,'INPUT FISSION FRACTION'
      READ*,FFR
      PRINT*,'INPUT YIELD (KT)'
      READ*,YLD
      PRINT*,'INPUT RANGE OF A/C (M)'
      READ*,RT
C     VAC IS VELOCITY OF A/C
      PRINT*,'INPUT A/C TRUE AIRSPEED (M/S)'
      READ*,VAC
      PRINT*,'INPUT FLIGHT TIME REMAINING AFTER TA IN HOURS'
      READ*,TR
C     RV IS RESULTANT VELOCITY
      DO 10 K=1,30
      ZDIST(0)=0.0
      PRINT*,'                                   '
      PRINT*,' ************************************************'
```

```
      ATOT=0.0
      ATOTC=0.0
      CALL ACT(FFR,YLD,RT,VAC,ACALT(K),K,ZDIST,HC1,HC,RHOALT,DD,HR,RVEL,
     :DZ,SZ,ATOT,RHO,TR,ATOTTA,ATOTC,SKYDOS,TDOSE)
      TACT(K)=ATOTTA
      PRINT*,'TOTAL ACTIVITY AT ALTITUDE ',ACALT(K) ,' IS  ',TACT(K)
      MDOSE=SKYDOS+TDOSE
      PRINT*,'TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR ',TR,' HOUR MISS
     :ION AFTER FLYING INTO CLOUD IS  ',MDOSE
      PRINT*,' ***************************************************'
10    CONTINUE
      STOP
      END
```

```
      SUBROUTINE ACT(FFR,YLD,RT,VAC,ACALT,K,ZDIST,HC1,HC,RHOALT,DD,HR,
     :RVEL,DZ,SZ,ATCT,RHO,TR,ATOTTA,ATOTC,SKYDOS,TDOSE)
C     RHOALT = ALTITUDE DENSITY
C     DIA = DELFIC PARTICLE DIAMETERS
C     HC1= CLOUD CENTER HEIGHT IN METERS
C     SZ = CLOUD SPREAD IN THE Z-DIRECTION
C     DZ = THE 98% POINT OF CLOUD SPREAD
      PARAMETER (MAXM=100)
      PARAMETER (D=50)
      REAL ACALT,ZDIST(*),RHOALT(*)
      REAL DIA(1:MAXM),PGALT(1:MAXM),FFR,RT,YLD,HC,HC1,RHOPAR,
     :TC,TC1,TC2,SO,SX,SY,SZ,DZ
      REAL FZ,DIR,VAC,VC,FXC,ATOTC,ARC(1:MAXM)
      REAL AR(0:MAXM),FX,FY,AMAX,ATOT,DD,ATOTTA
      REAL RHO,DIST(1:0400)
      REAL RVEL,HR,APERM3,YDIS,DM
      INTEGER MAXN,J,K,I,L,M
      DATA (DIA(I),I=1,31)/3.7349E-02,3.0781E-03,1.96661E-03,1.4983E-03,
     :1.2169E-03,1.0287E-03,8.9075E-04,7.8373E-04,7.0069E-04,6.3148E-04,
     :5.7368E-04,5.2535E-04,4.7879E-04,4.4983E-04,4.166E-04,3.9075E-04,
     :3.6071E-04,3.3835E-04,3.1737E-04,3.025E-04,2.8374E-04,2.6829E-04,
     :2.5368E-04,2.4179E-04,2.2862E-04,2.1652E-04,2.0604E-04,1.9638E-04,
     :1.8718E-04,1.7841E-04,1.7005E-04/
      DATA (DIA(I),I=32,60)/1.634E-04,1.57E-04,1.4962E-04,1.426E-04,
     :1.37E-04,1.3143E-04,1.255E-04,1.21E-04,1.16E-04,1.104E-04,
     :1.061E-04,1.0191E-04,9.8E-05,9.407E-05,9.0384E-05,8.684E-05,
     :8.3435E-05,8.0163E-05,7.702E-05,7.4E-05,7.11E-05,6.8311E-05,
     :6.5632E-05,6.306E-05,6.059E-05,5.8211E-05,5.5928E-05,5.374E-05,
     :5.163E-05/
      DATA (DIA(I),I=61,100)/4.9604E-05,4.7279E-05,4.543E-05,4.3644E-05,
     :4.167E-05,3.997E-05,3.84E-05,3.66E-05,3.49E-05,3.352E-05,
     :3.22032E-05,3.0694E-05,2.926E-05,2.789E-05,2.658E-05,2.529E-05,
     :2.3952E-05,2.265E-05,2.159E-05,2.0411E-05,1.93E-05,1.8103E-05,
     :1.7254E-05,1.6185E-05,1.518E-05,1.4014E-05,1.315E-05,1.2174E-05,
     :1.144E-05,1.0424E-05,9.5455E-06,8.6717E-06,7.8152E-06,6.9871E-06,
```

```
     :6.148E-06,5.3232E-06,4.5E-06,3.655E-06,2.7845E-06,1.779E-06/
      RVEL=VAC
C     THE AIRCRAFT IS ASSUMED TO BE TRAVELING IN THE X-DIRECTION ONLY.
      TA=RT/RVEL
      HR=TA/3600.0
      IF (I .GT. 1 .OR.  K .GT. 1 ) GO TO 40
      PRINT*,'TIME OF ARRIVAL (S) =  ',TA
      PRINT*,'TIME OF ARRIVAL (HR) =  ',HR
      DO 70 J=1,MAXM
      AR(J)=0.0
70    CONTINUE
40    DO 30 I=1,MAXM
10     HC=44.0+6.1*LOG(YLD/1000.0)-0.205*(LOG(YLD/1000.0)+2.42)
     :*ABS(LOG(YLD/1000.0)+2.42)
C      HC MUST BE CHANGED FROM KILOFEET TO METERS
      HC1=HC*3.048E02
      IF (I .GT. 1 .OR.  K .GT. 1 ) GO TO 20
      PRINT*,'CLOUD CENTER HEIGHT IN KILOFEET =  ',HC
      PRINT*,'CLOUD CENTER HEIGHT IN METERS =  ',HC1
20    MAXN=NINT(HC1/D)
       DD=HC1/MAXN
      MAXN=MAXN+1
      L=NINT(HC1-ACALT)/DD
      SZ=.18*HC1
C     4*SZ IS THE CLOUD VERTICLE HEIGHT
      DZ=2.0*SZ
      MAXN=MAXN+NINT(DZ/DD)
      RHOPAR=2.6E03
      IF (K .GT. 1 ) GO TO 90
      CALL CLOUD(HC1,DIA(I),RHOPAR,ACALT,ZDIST(I),TA,RT,DIR,VAC,VC,MAXN,
     :DD,DZ,RHO,DIST,RHOALT)
C ***********************************************************
C     THIS CALL IS FOR CALCULATOIN OF PARTICLE DYNAMICS AND TRACKS
C     THE CENTER OF PARTICLE DISTRIBUTIONS AS A FUNCTION OF TIME .
C ***********************************************************
```

```
90    IF (I .EQ. 1 ) GO TO 95
C     ACTIVITY IS REINITIALIZED TO INSURE THAT THOSE PARTICLES THAT WERE
C     NOT CONSIDERED IN THE CALCULATIONS DO NOT CONTRIBUTE TO THE TOTAL
C     ACTIVITY WHEN THE AIRCRAFT IS AT LOW ALTITUDES.
      IF (ZDIST(I) .LT. 0.0 .AND. ZDIST(I-1) .EQ. 0.0 ) THEN
      ATOT=0.0
C     RESETS ATOT TO ZERO
      ATOTC=0.0
      GO TO 30
      ENDIF
95    IF (ABS(ACALT   -ZDIST(I)) .LE. DZ) THEN
      FZ=(1.0/(((2.0*3.14159)**0.5)*SZ)*EXP(-0.5*((ACALT   -ZDIST(I))/
     :SZ)**2.0))
      ELSE
100   AR(I)=0.0
      GO TO 30
      ENDIF
      TC1=(12.0*(HC)  /60.0)-(2.5*(HC   /60.0)**2.0)
      TC2=(1.0-0.5*EXP(-(HC**2.0)/(25.0**2.0)))
      TC=TC1*TC2*1.0573203
      SO=EXP((0.7+LOG(YLD/1000)/3.0)-3.25/(4.0+(LOG(YLD/1000)+5.4)**2.0)
     :)*1609.344
C     SO CHANGED FROM MILES TO METERS
      IF (HR .GT.3.0 ) THEN
      TT=3.0
      ELSE
      TT=HR
      ENDIF
      SY= ((SO**2.0)*(1.0+(8.0*TT) /TC)+(SZ*1.0*HR)**2.0)**0.5
      YDIS=0.0
      FY=(1.0/(((2.0*3.14159)**0.5)*SY))*EXP(-0.5*(YDIS/SY)**2.0)
      SX= ((SO**2.0)*(1.0+(8.0*TT) /TC))**0.5
C     DUE TO TRAVEL THROUGH CLOUD IN X-DIRECTION, FX MUST EQUAL 1 AND
C     DIMENSIONLESS.
      FX=1.0
```

```
      FXC=(1.0/((((2.0*3.14159)**0.5)*SX))*EXP((-0.5*(0.0)/SX)**2.0)
C     FXC IS FX COMPUTATION FOR CLOUD CENTER
      AMAX=530.0*3.7E16*YLD*FFR
      AR(0)=0.0
      AR(I)=(AMAX/100.0)*FX*FY*FZ
      ARC(I)=AR(I)*FXC
      ATOT=ATOT+AR(I)
      ATOTC=ATOTC+ARC(I)
30    CONTINUE
      CALL DENS(RHO,RHOALT,ACALT,DIST,MAXN,DD)
      ATOTTA=ATOTC*HR**(-1.2)
      ATOT=ATOT*(((150.0*60.0)*453.59237E-03)/RHO)*(1/(RVEL*3600.0))
      APERM3=ATOT/246.357
      CALL BDOSE(APERM3,ACALT,TR,RHOALT,ACPALT,DIST,MAXN,DD,RHO1,HR,MUT,
     :MUARHO,MUTRHO,TDOSE)
      CALL SHINE(SX,DDOT,DDOT1,SKYDOS,MUARHO,MUT,HR,RVEL,ATOTC,TA,
     :MUTRHO,RHO)
      J=1
      DM=AR(1)
      DO 80 M=2,MAXM
      IF (DM .LT. AR(M)) THEN
      DM=AR(M)
      J=M
      ENDIF
80    CONTINUE
      PRINT*,'MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS ',
     :DIA(J),' DIAMETER'
      RETURN
      END
```

```
      SUBROUTINE CLOUD (Z,RD,RHOPAR,ACALT,CDIST,TA,RT,DIR,VAC,VC,MAXN,
     :DD,DZ,RHO,DIST,RHOALT)
      INTEGER MAXN
      REAL PZRO,PONG,GL,TSL,Z,BETA,SU,SOUND,RD,RHOPAR
      REAL T(0400),P(0400),RHOALT(0400),DV(0400),KINV(0400),TERMV(0:
     :0400),RE(0400)
      REAL Y(0:0400),TIMEZ(0:0400),AVGVEL(0400)
      REAL DRAGCF,DD
      REAL DIST(1:0400),TA,RVEL,VC,VAC,DIR,RT
      REAL CDIST,ACALT,R
      REAL RHO
C     RHOPAR= DENSITY OF PARTICLE
C     RD = DIAMETER OF PARTICLE
C     PZRO = PRESSURE AT SEA LEVEL
C     GL = GRAVITY (M/S**2.0)
C     TSL = TEMP AT SEA LEVEL
C     Z = ALTITUDE IN METERS
C     BETA = CONSTANT, HILSENRATH,ET AL,1955
C     SU = SUTHERLAND CONSTANT
      PZRO=1.01325E05
      R=RD/2.0
      GL=9.80665
      DO 10 I=1,MAXN
      IF (Z .LE. 11000) THEN
      TSL=288.15
      T(I)=TSL-0.0065*Z
      P(I)=PZRO*(T(I)/TSL)**5.2509
      GO TO 20
      ELSE IF (Z .GT. 11000 .AND. Z .LE.20000) THEN
      T(I)=216.65
      P(I)=0.224*PZRO*EXP(-0.0001582*(Z-11000))
      GO TO 20
      ENDIF
      PRINT*,'BURST ABOVE 20 KM,V(Z) NOT CALCULATED'
20    RHOALT(I)=0.003484*(P(I)/T(I))
```

```
      SOUND=SQRT(1.4*P(I)/RHOALT(I))
      BETA=1.458E-06
      SU=110.4
      DV(I)=(BETA*T(I)**(3.0/2.0))/(T(I)+SU)
      KINV(I)=DV(I)/RHOALT(I)
      RC=32.0*RHOPAR*GL*(R**3.0)/(3.0*RHOALT(I)*(KINV(I)**2.0))
      IF (RC .GE. 140.0) THEN
      GO TO 40
      ENDIF
30    RE(I)=RC/24.0-2.3363E-04*((RC)**2.0)+2.0154E-06*((RC)**3.0)
     :-6.9105E-09*((RC)**4.0)
      GO TO 50
40    RE(I)=-1.29536+0.986*LOG10(RC)-0.046677*((LOG10(RC))**2.0)+0.001
     :1235*(LOG10(RC)**3.0)
      RE(I)=10**RE(I)
50    TERMV(I)=(RE(I)*KINV(I))/(2.0*R)
      DRAGCF=1.0+1.165E-07/(R*RHOALT(I))
      TERMV(I)=TERMV(I)*DRAGCF
      TIMEZ(0)=0.0
      TERMV(0)=TERMV(1)
      AVGVEL(1)=TERMV(1)
      AVGVEL(I)=(TERMV(I-1)+TERMV(I))/2.0
      TIMEZ(I)=(50.0/AVGVEL(I))+TIMEZ(I-1)
      DIST(I)=Z
      TIMEZ(1)=0.0
      Z=Z-DD
10    CONTINUE
      CALL TCHEK (TIMEZ,DIST,CDIST,TA,AVGVEL,MAXN,RHOALT,RHO)
      RETURN
      END
```

```
      SUBROUTINE TCHEK (TIMEZ,DIST,CDIST,TA,AVGVEL,MAXN,RHOALT,RHO)
      REAL TIMEZ(0:*),AVGVEL(1:*),DIST(1:*),RHOALT(1:*),RHO
      INTEGER I,N
      N=261
      DO 50 I=2,MAXN
      IF (TA .LE. TIMEZ(I) .AND. TA .GT. TIMEZ(I-1)) THEN
      CDIST=DIST(I-1)-(TA - TIMEZ(I-1))*AVGVEL(I)
      GO TO 60
      ELSE
      CDIST=0.0
      ENDIF
50    CONTINUE
60    RETURN
      END
```

```
      SUBROUTINE DENS(RHO,RHOALT,ACALT,DIST,MAXN,DD)
      REAL DD,RHO,ACALT,RHOALT(1:*),DIST(1:*)
      INTEGER I,MAXN
      DO 70 I=2,MAXN
      IF (ACALT .GE. DIST(I) .AND. ACALT .LT. DIST(I-1)) THEN
      RHO=RHOALT(I-1)+(DIST(I-1)-ACALT)*(RHOALT(I)-RHOALT(I-1))/DD
      GO TO 80
      ELSE
      RHO=0.0
      ENDIF
70    CONTINUE
80    RETURN
      END
```

```
      SUBROUTINE BDOSE(APERM3,ACALT,TR,RHOALT,ACPALT,DIST,MAXN,DD,RHO1,
     :HR,MUT,MUARHO,MUTRHO,TDOSE)
C     DOSE THAT AN INDIVIDUAL WOULD BE EXPOSED TO WHEN POSITIONED
C     WITHIN THE CENTER OF THE CABIN.
C     DRATE IS THE DOSE RATE.
C     TDOSE IS THE TOTAL DOSE.
      REAL RHOALT(*),DIST(1:*),APERM3,ACALT,TR,ACPALT,MAXN,DD,RHO1,HR
      REAL MUT,MUTRHO,MUARHO
      IF ( ACALT .LE. 6858.0 ) THEN
      ACPALT=0.0
      ELSE IF ( ACALT .GT. 6858.0 .AND. ACALT .LE. 12192.0) THEN
      ACPALT =((3.8879E-01)*ACALT)-2653.75401
      ELSE
      ACPALT=24110.8939-268952111.0/ACALT
      ENDIF
      PRINT*,'ACPALT =  ',ACPALT
      CALL DENS(RHO1,RHOALT,ACPALT,DIST,MAXN,DD)
      MUARHO=0.0030
      MUTRHO=0.00636
C     MUARHO IS ATTENUATION COEFFICIENT FOR ABSORPTION IN TISSUE (UA/RHO
C     ),SQUARE METERS/KG
C     MUTRHO IS ATTENUATION COEFFICIENT IN AIR (UT/RHO) , SQUARE METERS
C     PER KG
      MUT=MUTRHO*RHO1
      DRATE=APERM3*MUARHO*3.47*1.6E-11
C     DRATE IS THE DOSE RATE AT ONE HOUR (RADS/SEC)
      TDOSE=5.0*(DRATE*3600.0)*(HR**(-0.2)-(HR+TR)**(-0.2))
      PRINT*,'TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON ',TR,' HR
     :MISSION IS ',TDOSE
      RETURN
      END
```

```
      SUBROUTINE SHINE(SX,DDOT,DDOT1,SKYDOS,MUARHO,MUT,HR,RVEL,ATOTC,
     :TA,MUTRHO,RHO)
      REAL A,B,DSX,TDX,DDOT,DDOT1,SKYDOS,MUARHO,MUT,HR,ATOTC,RVEL,TA
      REAL MUTT,MUTRHO,RHO
      A=2.0*SX
      B=2.0*(-SX)
      DSX=(A-B)
      TDX=DSX/(RVEL*3600.0)
      MUTT=MUTRHO*RHO
      DDOT1=ATOTC*(MUARHO/MUTT)*(1.0-EXP(-MUTT*A))*3600.0*1.6E-11
      DDOT=DDOT1*(HR**(-1.2))
      SKYDOS=DDOT1*5.0*(((HR-TDX/2.0)**(-0.2))-(HR+TDX/2.0)**(-0.2))
      PRINT*,'SKY-SHINE DOSE =  ',SKYDOS
      RETURN
      END
```

APPENDIX C

Sample Output

DATA

```
INPUT FISSION FRACTION
INPUT YIELD (KT)
INPUT RANGE OF A/C (M)
INPUT A/C TRUE AIRSPEED (M/S)
INPUT FLIGHT TIME REMAINING AFTER TA IN HOURS

 ****************************************************
TIME OF ARRIVAL (S) =  3600.
TIME OF ARRIVAL (HR) =  1.
CLOUD CENTER HEIGHT IN KILOFEET =  42.799438
CLOUD CENTER HEIGHT IN METERS =  13045.2687024
ACPALT =  903.67449
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
2.359422090052
SKY-SHINE DOSE =  5.790639340872
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.000121 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 9150. IS  4.820310422825E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  8.150061420924
 ****************************************************

 ****************************************************
ACPALT =  783.14959
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
2.100825493734
SKY-SHINE DOSE =  5.1559756929
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.0001255 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 8840. IS  4.455084500193E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  7.256801126635
 ****************************************************

 ****************************************************
ACPALT =  664.56864
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
1.865349614413
SKY-SHINE DOSE =  4.578056191476
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.000137 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 8535. IS  4.10226901092E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  6.443405805889
 ****************************************************
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*****************************************************
ACPALT =  545.98769
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
1.534641000955
SKY-SHINE DOSE =  3.766410694189
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.0001426 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 8230. IS  3.498923539154E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.

 HOUR MISSION AFTER FLYING INTO CLOUD IS  5.301051695143
 *****************************************************

 *****************************************************
ACPALT =  427.40674
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
1.308926458781
SKY-SHINE DOSE =  3.212448129039
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00014962 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 7925. IS  3.092963227286E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  4.52137458782
 *****************************************************

 *****************************************************
ACPALT =  308.82579
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
1.159524984609
SKY-SHINE DOSE =  2.84577780699
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.000157 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 7620. IS  2.838845618447E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  4.005302791599
 *****************************************************
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****************************************************
ACPALT =  190.24484
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
1.042698759571
SKY-SHINE DOSE =  2.559055672582
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.0001634 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 7315. IS  2.644205022266E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  3.601754432154
****************************************************

****************************************************
ACPALT =  71.66389
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.9441630986135
SKY-SHINE DOSE =  2.322131893291
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00017005 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 7010. IS  2.484571082904E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  3.268294991904
****************************************************

****************************************************
ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.8670248018576
SKY-SHINE DOSE =  2.127905799347
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00017841 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 6710. IS  2.35557891873E+9

TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  2.994930601204
****************************************************
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****************************************************
ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.7878471344113
SKY-SHINE DOSE =  1.933583079424
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00018718 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 6400. IS  2.216447541793E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  2.721430213835
****************************************************

****************************************************
ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.7301364179016
SKY-SHINE DOSE =  1.791945875871
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00019638 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 6100. IS  2.124043784637E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  2.522082293773
****************************************************

****************************************************
ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.6715175027912
SKY-SHINE DOSE =  1.648079715241
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00019638 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 5800. IS  2.019514916699E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  2.319597218032
****************************************************

****************************************************
ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.622167930959
SKY-SHINE DOSE =  1.526962949178
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00020604 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 5490. IS  1.935938497283E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  2.149130880137
****************************************************
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 *****************************************************
ACPALT =   0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.5770797373751
SKY-SHINE DOSE =   1.416304720713
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00021652 DIAMETER


TOTAL ACTIVITY AT ALTITUDE 5180. IS  1.857361143592E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.993384458088
 *****************************************************

 *****************************************************
ACPALT =   0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.536663228086
SKY-SHINE DOSE =   1.317112028276
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00022862 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 4880. IS  1.784246433983E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.853775256362
 *****************************************************

 *****************************************************
ACPALT =   0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.4984423600211
SKY-SHINE DOSE =   1.223308014092
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00022862 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 4570. IS  1.713239520227E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.721750374113
 *****************************************************
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****************************************************
ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.4635222741813
SKY-SHINE DOSE =  1.137604983437
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00024179 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 4270. IS  1.644942873289E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.601127257618
****************************************************

****************************************************
ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.4305220802764
SKY-SHINE DOSE =  1.056613870104
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00025368 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 3960. IS  1.578724020659E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.48713595038
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ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.4012181864789
SKY-SHINE DOSE =  .9846944447063
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS

.00025368 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 3660. IS  1.518306887751E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.385912631185
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 ****************************************************
ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.3779560595926
SKY-SHINE DOSE =  .9276030966844
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00026829 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 3355. IS  1.476430381812E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.305559156277
 ****************************************************

 ****************************************************
ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.3525437323577
SKY-SHINE DOSE =  .8652345942124
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00026829 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 3050. IS  1.421264792797E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.21777832657
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ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.3284837776951
SKY-SHINE DOSE =  .8061851680035
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00028374 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 2745. IS  1.366363018789E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.134668945699
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ACPALT =  0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.3101831319877
SKY-SHINE DOSE =  .7612705934156
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00028374 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 2440. IS  1.330948669312E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.071453725403
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 ****************************************************
ACPALT =   0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.2897135933697
SKY-SHINE DOSE =   .7110329879378


MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.0003025 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 2135. IS  1.282050092228E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  1.000746581308
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 ****************************************************
ACPALT =   0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.2702162089122
SKY-SHINE DOSE =   .6631813032219
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00031737 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 1830. IS  1.23294572408E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  .9333975121341
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 ****************************************************
ACPALT =   0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.2562640813347
SKY-SHINE DOSE =   .6289391303088
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00031737 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 1525. IS  1.205373317856E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  .8852032116435
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 ******************************************************
ACPALT =   0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.2394179318636
SKY-SHINE DOSE =   .5875942701853
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00033835 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 1220. IS  1.160641163277E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  .8270122020489
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 ******************************************************
ACPALT =   0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.2269109068974
SKY-SHINE DOSE =   .5568987573223
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00033835 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 915. IS  1.133474192062E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  .7838096642197
 ******************************************************

 ******************************************************
ACPALT =   0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.2116215255932

SKY-SHINE DOSE =   .5193746137498
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00036071 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 610. IS  1.089030102543E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  .730996139343
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 ******************************************************
ACPALT =   0.
TOTAL TISSUE DOSE FROM PARTICLES INSIDE A/C ON 8. HR  MISSION IS
.1968728070704
SKY-SHINE DOSE =   .4831773981566
MOST PROMINENT PARTICLE  SIZE GROUP AT THIS ALTITUDE IS
.00036071 DIAMETER
TOTAL ACTIVITY AT ALTITUDE 305. IS  1.043517255612E+9
TOTAL TISSUE DOSE ACCUMULATED IN REMS FOR 8.
 HOUR MISSION AFTER FLYING INTO CLOUD IS  .680050205227
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Vita

Burl E. Hickman was born 28 August 1945 in Bryan, Texas. Soon after, his family relocated in Houston, Texas, where he completed high school in 1963. He entered Howard University School of Engineering and Architecture in the mechanical engineering curriculum. In his junior year, he enrolled in the advanced ROTC program and received his B.S.M.E. and USAF commission in June 1968. His first assignment was a Group Mechanical Engineer in a research and development space operations program at Vandenberg AFB, California. During this assignment, he earned a Master's Degree in Systems Management from the University of Southern California. In January 1973, he attended undergraduate pilot training, and upon graduation was assigned to Peterson Field, Colorado, where he was an Instructor Pilot in the T-33 aircraft from June 1974 until May 1976. He was then transferred to K.I. Sawyer AFB, Michigan. He flew the F-106 from May 1976 to July 1980, first as a Squadron Flight Commander and later as the Assistant Operations Officer. Major Hickman was assigned to the Air Force Institute of Technology's master's degree program in Nuclear Effects in August 1980.

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Lynn E. Wolaver

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Nuclear Radiation
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Crew Survivability/Vulnerability
Radioactive Dust Clouds
Cloud Penetration

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report will evaluate the threat of radioactive fallout to which aircrew members will be exposed when flying through a descending fallout cloud. A computer program is developed for calculating the ionizing dose rate of a radioactive dust cloud as a function of time, and also the dose that an aircrew receives when flying through the respective cloud. A cloud model that is patterned after the AFIT fallout smearing code was developed. A comparison is made between the activities at various altitudes from 305 meters t0 9150 meters

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BLOCK 20: ABSTRACT (Continued)

to provide information for possible re-direction of flight. The external ionizing dose to the aircrew is computed by the new code considering the cloud size, the aircraft's transit time through the cloud, and the ingestion rate of radioactive particles into the aircraft's cabin. Information is also provided to indicate the method by which doses can be computed from a cloud of multiple bursts. The results demonstrate that total dose to each aircrew member is approximately 8 rems after flying through a fallout cloud one hour after cloud stabilization of a 1 Mt burst, with the mission continuing for eight hours subsequent to the cloud transit.