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FINAL REPORT

SPACE STATION CONTAMINATION MODELING

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1.0 INTRODUCTION

Current plans for the operation of Space Station Freedom allow the orbit to decay to approximately an altitude of 200 km before reboosting to approximately 450 km. This operational scenario presents considerably different problems with regard to the induced external environment than those determined for the constant density orbit scenario previously planned. The Space Station will encounter dramatically increasing ambient and induced environmental effects as the orbit decays, with the most extreme environment being encountered at the lowest orbit attained prior to reboost. Unfortunately, Shuttle docking, which has been been of concern as a high contamination period, will likely occur during the time when the station is in the lowest orbit. The combination of ambient and induced environments along with the presence of the docked Shuttle could cause very severe contamination conditions at the lower orbital altitudes prior to Space Station reboost.

The purpose of this contract is to determine the effects on the induced external environment of Space Station Freedom with regard to the proposed changes in altitude. The change in the induced environment will be manifest in several parameters. The ambient density buildup in front of ram facing surfaces will change. The source of such contaminants can be outgassing/offgassing surfaces, leakage from the pressurized modules or experiments, purposeful venting, and thruster firings. The third induced environment parameter with altitude dependence is the glow.

In order to determine the altitude dependence of the induced environment parameters we have used the integrated Spacecraft Environment Model (ISEM) which was developed for Marshall Space Flight Center. The analysis required numerous ISEM runs. The assumptions and limitations for the ISEM runs are described in the individual sections that follow.

2.0 DENSITY BUILDUP

Space Station surfaces which have ram incidence angles of less than 90 degrees will experience a significant (relative to the ambient atmospheric density) buildup of ambient molecules above the ram facing side of the surface. The molecular buildup is caused by surface incident molecules which thermally accommodate on the surface and are reemitted. In general the largest flux of surface incident molecules is comprised of ambient molecular species. Consequently, the majority of the molecular buildup is due to reemitted ambient. The density increases primarily due to the differences in the velocities between the incoming ambient molecules and the reemitted ambient molecules, but collisions (backscattering) of the reemitted ambient with the incoming ambient molecules also contribute to the buildup.

To determine the potential impacts of altitude on the induced external environment of Space Station Freedom, the induced molecular densities above the solar panels were computed and compared for a range of orbital altitudes. The solar panels were chosen because they represent the largest surface areas of the Space Station. Also, the solar panels are likely to be sensitive to density buildups which could contribute to arcing problems. The solar panels were oriented facing directly into the velocity vector for the series of runs. Densities along a line of sight normal to the solar panel surface have been plotted for five different altitudes in Figure 1. The five altitudes plotted cover the range from 200 km to 500 km. The vertical axis is total density in units of molecules/cm^3. The horizontal axis is in meters and gives the normal distance from the solar panel surface. As can be seen in the plot, the densities falloff about an order of magnitude by the distance of 25 meters. Smaller surfaces have very similar densities at the surface but falloff much more rapidly with distance. More important to this study however, is the

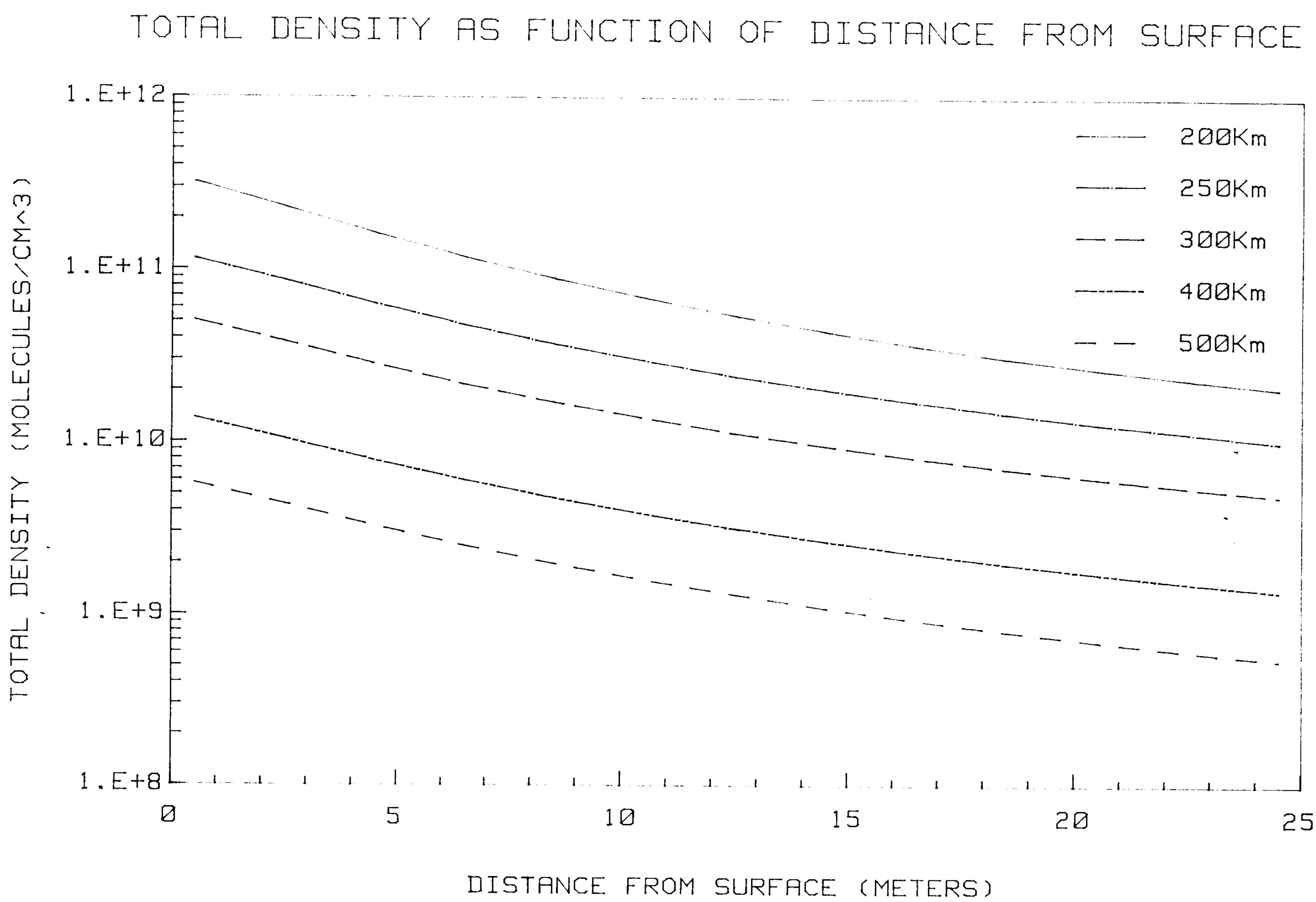

TOTAL DENSITY AS FUNCTION OF DISTANCE FROM SURFACE
200Km
250Km
300Km
400Km
500Km
1.E+12
1.E+11
1.E+10
1.E+9
1.E+8
0
5
10
15
20
25
DISTANCE FROM SURFACE (METERS)
TOTAL DENSITY (MOLECULES/CM^3)

Figure 1.

relative change in density as a function of altitude. The average total ambient density at 200 km was modeled (using MSIS 86) in ISEM as being 9.875 E+9 molecules/cm^3 and at 500 km as 1.0659 E+8 molecules/cm^3. The ratio between these two represents a factor of approximately 93 between the average ambient density at 200 km to the average ambient density at 500 km. It is interesting to note, however, that the corresponding ratio of induced densities plotted in Figure 1 is only a factor of 56. One would expect the induced densities to track the ambient densities in a roughly linear fashion. The difference is caused by the outgassing of contaminants which represent an increasingly larger percentage of the total induced density as the altitude increases and the ambient densities decrease.

3.0 BACKSCATTERED FLUX

One of the most important parameters from a contamination standpoint is the backscattered flux which is also often referred to as return flux. This molecular transport mechanism allows outgassed/offgassed, leaked, and vented molecular species to be scattered back to critical spacecraft surfaces. Critical spacecraft surfaces are generally designed such that they are protected from direct line of sight molecular fluxes from known natural and spacecraft produced sources. This is done by the use of baffles and other methods of controlling the field of view of a critical surface so that it can never "see" the contaminant sources. However, the backscatter mechanism provides a means whereby contaminants from sources out of the field of view of a critical surface can still have a significant incident flux on that surface. This problem is made worse by the fact that the backscattered contaminants (especially in the case of outgassed contaminants) are often the molecules which are most likely to deposit on a critical surface.

In this study, a Space Station solar panel was again used as a representative surface. The panel was oriented so that it faced into the velocity vector. The surface of the solar panel was given an outgassing rate of 3.12 E+13 molecules/cm^2/sec. The outgassing species was considered to be a large organic molecule of mass 100 amu with a collision cross section to ambient N_2 and O of 8.0 E-15 cm^2. Points to which the backscattered contaminant flux was computed were placed at 0.5, 5.5, and 10.5 meters above the outgassing surface. Figure 2 shows the normalized backscattered flux of contaminants to the three locations. The points were given a 2π steradian field of view looking into the velocity vector (directly away from the surface). The backscattered flux values were normalized to the flux values at 450 km for comparison purposes. As can be seen in Figure 2, the backscattered flux of the contaminant increases with decreasing altitude until about 250 km where the flux to the outer points at 5.5 and 10.5 meters begin to decrease with decreasing altitude. This reversal is caused by the relatively high ambient densities which scatter much of the contaminant back toward the surface before it reaches the vicinity of the outer points. This effect is not only a function of the ambient density, but also a function of the contaminant source rate and contaminant characteristics such as mass and cross section. The data plotted in Figure 3 is backscatter flux to the same points as in Figure 2, except that the field of view for the points was oriented normal to the velocity vector. Again the values have been normalized to the backscatter flux values at 450 km. Prior to normalization, the computed flux values for Figure 3 were approximately an order of magnitude smaller than the corresponding values for Figure 2. The backscatter flux values before and after normalization may be found in Table 1.

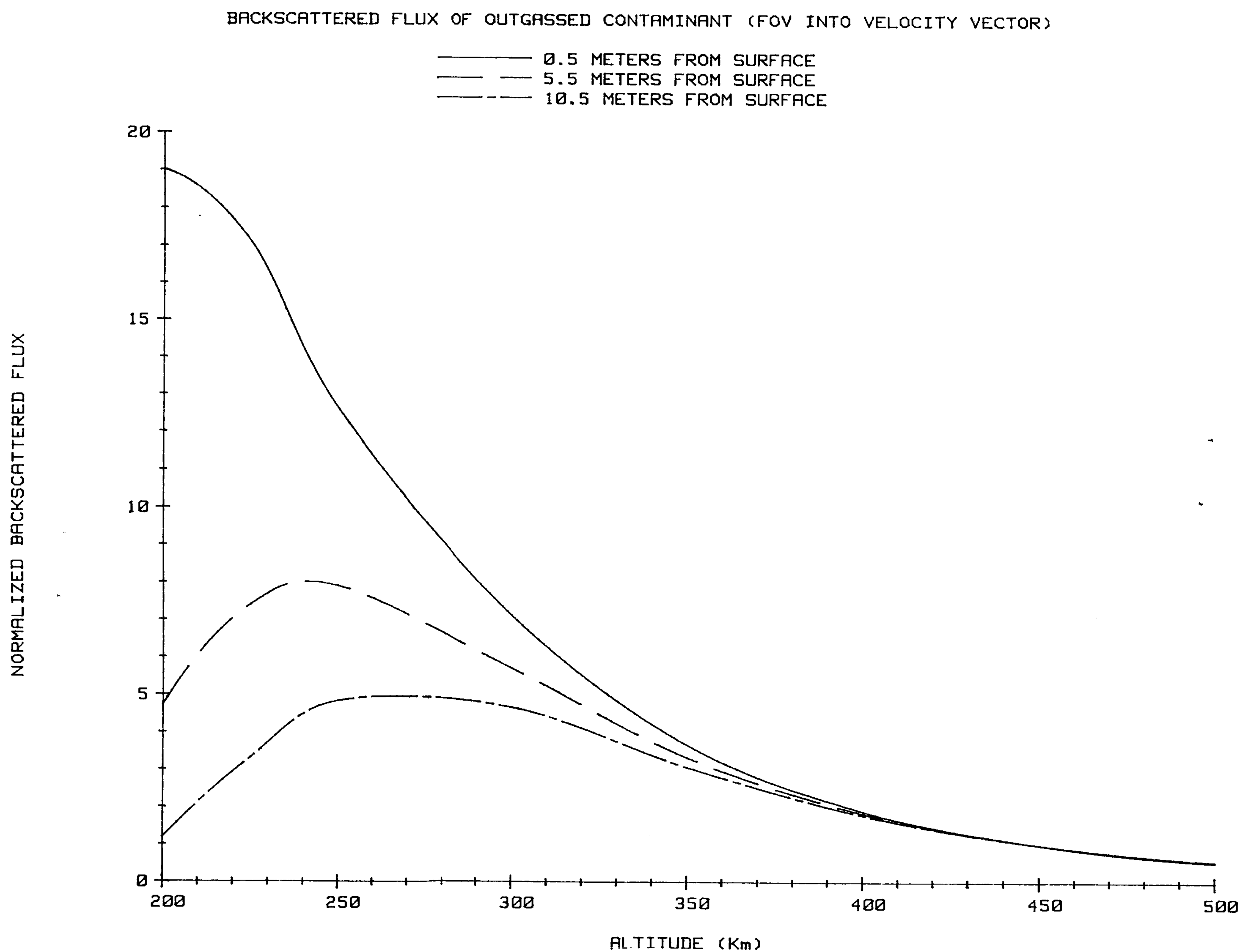

BACKSCATTERED FLUX OF OUTGASSED CONTAMINANT (FOV INTO VELOCITY VECTOR)
0.5 METERS FROM SURFACE
5.5 METERS FROM SURFACE
10.5 METERS FROM SURFACE
NORMALIZED BACKSCATTERED FLUX
20
15
10
5
0
200
250
300
350
400
450
500
ALTITUDE (Km)

Figure 2.

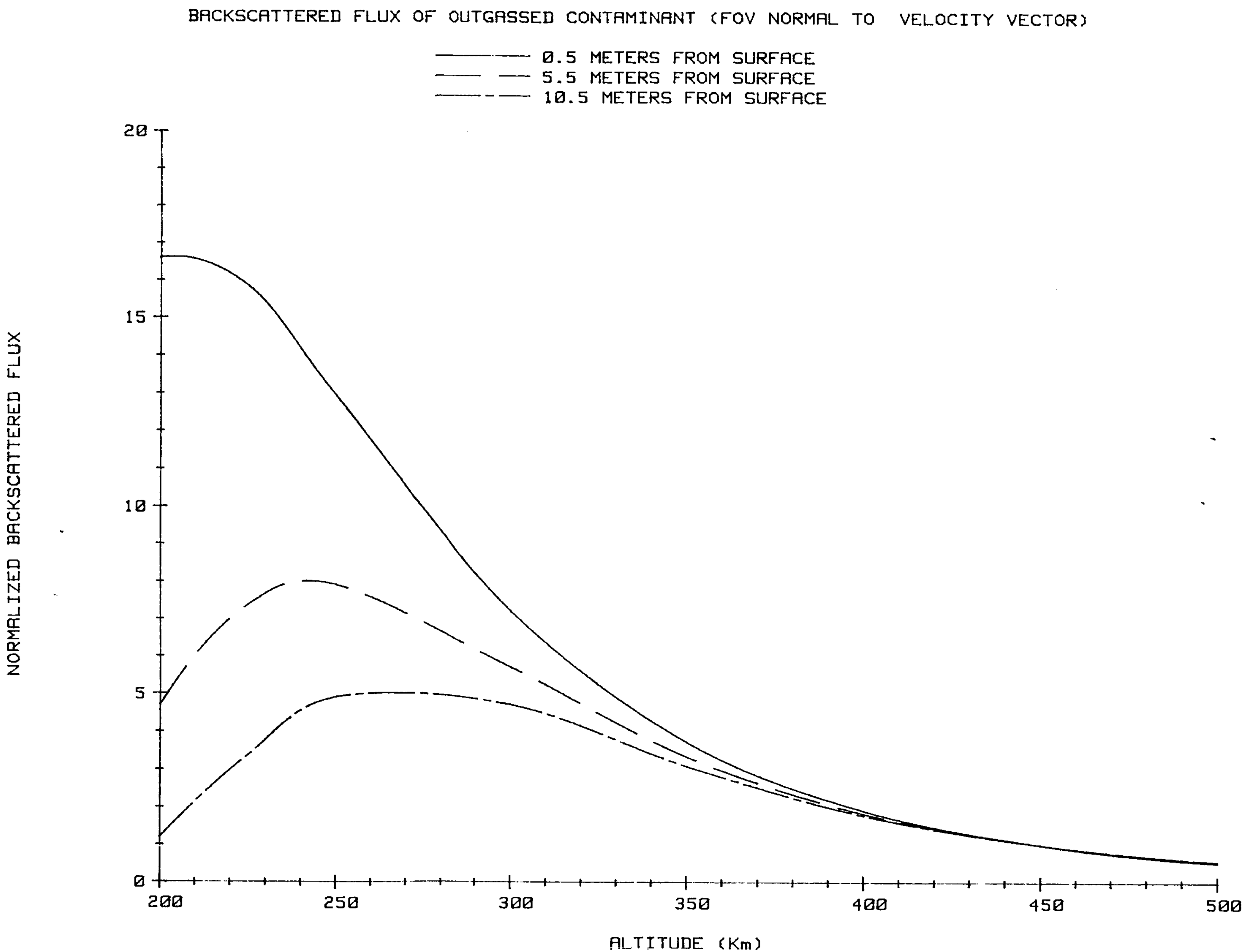

BACKSCATTERED FLUX OF OUTGASSED CONTAMINANT (FOV NORMAL TO VELOCITY VECTOR)
0.5 METERS FROM SURFACE
5.5 METERS FROM SURFACE
10.5 METERS FROM SURFACE
NORMALIZED BACKSCATTERED FLUX
0
5
10
15
20
200
250
300
350
400
450
500
ALTITUDE (Km)

Figure 3.

Table 1. Scattered Flux of Outgassed Contaminant

Altitude (km)	Distance (m) from surface	molecules/cm2/sec Viewing Dir. +X	Viewing Dir. +Z	Normalized to 450km Values +X	+Z
200	0.5	1.87 E 13	2.39 E 12	19.00	16.60
	5.5	2.53 E 12	5.40 E 11	4.73	4.70
	10.5	3.34 E 11	7.70 E 10	1.19	1.21
225	0.5	1.68 E 13	2.28 E 12	17.07	15.83
	5.5	3.96 E 12	8.49 E 11	7.41	7.38
	10.5	9.35 E 11	2.14 E 11	3.33	3.38
250	0.5	1.24 E 13	1.86 E 12	12.60	12.92
	5.5	4.22 E 12	9.08 E 11	7.89	7.90
	10.5	1.36 E 12	3.11 E 11	4.84	4.91
300	0.5	7.01 E 12	1.04 E 12	7.12	7.22
	5.5	3.05 E 12	6.56 E 11	5.70	5.70
	10.5	1.31 E 12	2.98 E 11	4.66	4.70
350	0.5	3.61 E 12	5.35 E 11	3.67	3.72
	5.5	1.78 E 12	3.83 E 11	3.33	3.33
	10.5	8.63 E 11	1.95 E 11	3.07	3.08
400	0.5	1.87 E 12	2.75 E 11	1.90	1.91
	5.5	9.82 E 11	2.11 E 11	1.84	1.83
	10.5	5.03 E 11	1.13 E 11	1.79	1.78
450	0.5	9.84 E 11	1.44 E 11	1.00	1.00
	5.5	5.35 E 11	1.15 E 11	1.00	1.00
	10.5	2.81 E 11	6.34 E 10	1.00	1.00
500	0.5	5.32 E 11	7.70 E 10	0.54	0.53
	5.5	2.94 E 11	6.72 E 10	0.55	0.55
	10.5	1.56 E 11	3.52 E 10	0.56	0.56

4.0 GLOW

The study of spacecraft glow has received increasing attention over recent years. To date, a limited amount of data has been collected on which numerous theories have been based with regard to exactly what the glow mechanisms are. At the present it appears that glow mechanisms can be divided into two basic classes, namely near field or surface glow and far field glow. The near field or surface glow theories generally treat the mechanisms for producing flow on ram facing surfaces and a short distance above the surface (approximately 20cm). The most popular theory for the surface glow involves the production of NO and NO_2 on the surface and the emissions from these molecules. Due to limited funds, we have not attempted to model any surface glow mechanisms although we believe ISEM is certainly flexible enough to allow such modeling. Instead, we have concentrated on the modeling of the far field glow which can extend many meters form the spacecraft surfaces. The far field glow model we have chosen assumes that the glow is produced by surface reemitted N_2 in an excited state to which one of three events will occur. If allowed sufficient time before suffering a collision, the excited N_2 will spontaneously decay into a lower energy state and in the process emit photons (Vegard-Kaplan). If, however, the excited N_2 collides with a high velocity (high kinetic energy) ambient molecule before it spontaneously decays, there is a probability that it will emit photons in a different set of wavelengths (Lyman-Birge-Hopfield). If the excited N_2 collides with a low velocity molecule prior to either spontaneous emission or a high velocity ambient collision, then the excited N_2 is reduced to a lower energy state (quenched) with no photon emission.

The glow modeling attempted here should be considered an initial effort as there are numerous assumptions and approximations which will undoubtedly be refined with time. Of particular concern is the algorithm used for the surface production rate of excited N_2. The production rate is a function of the surface incident N_2 and 0. However, there may be other factors involved, and the mathematical equation describing the dependence may well change with altitude. For this modeling, a very simple equation was used to determine the production of excited N_2 based on surface incident flux of ambient N_2 and 0.

$$N2A = C \times (N2)^2 \times 0 \qquad (1)$$

where, N2A = Reemission rate of excited N_2 (molecules/cm^2/sec)

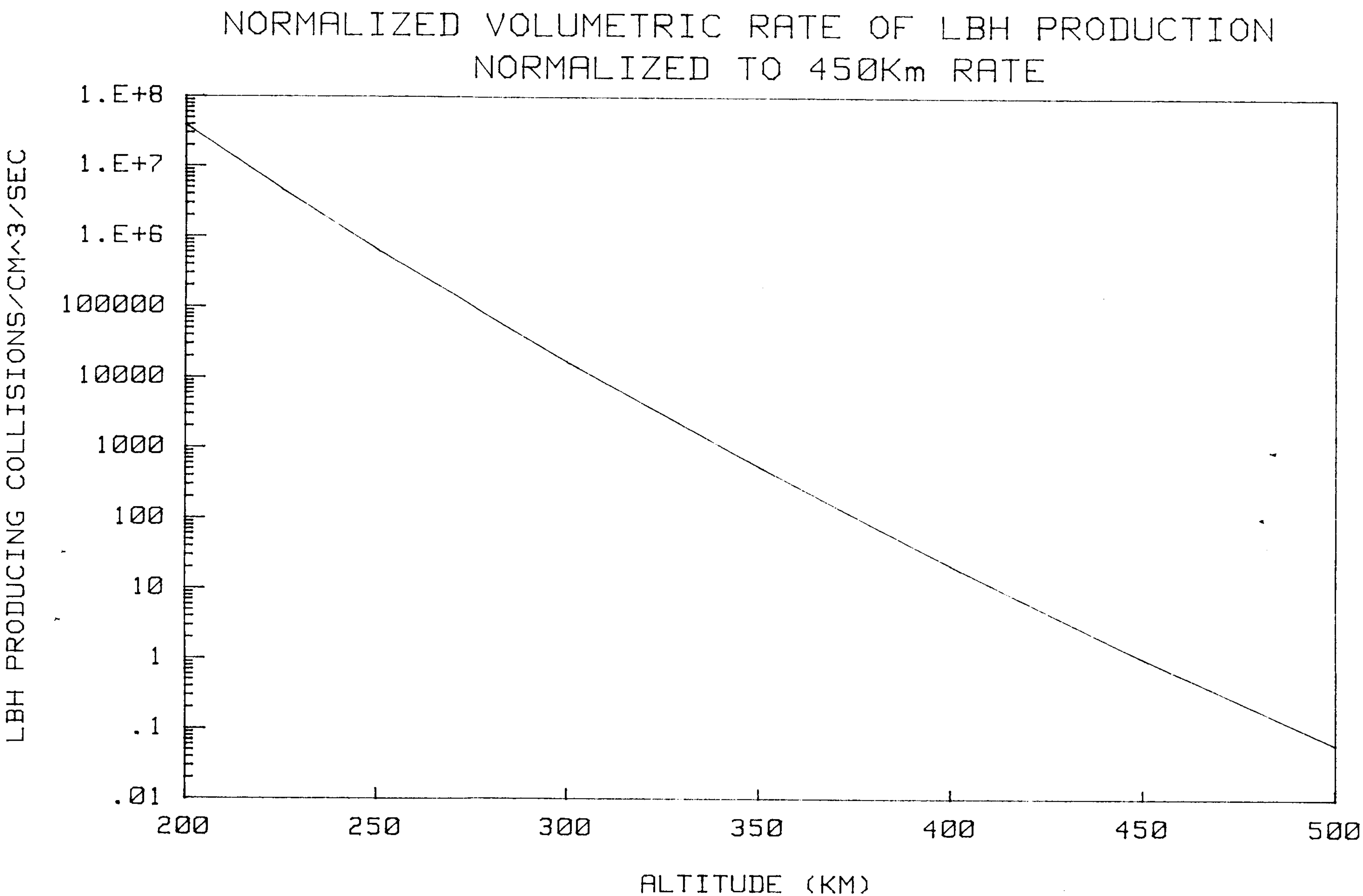
N2 = Surface incident flux of ambient N_2

0 = Surface incident flux of ambient 0

C = Production efficiency constant

The production efficiency constant was unknown at the time of this study and therefore chosen arbitrarily. The constant effects the absolute value of the surface produced excited N_2 and subsequent collision based computations of glow. However, by normalizing the results to the values obtained at 450 km the constant drops out of the computations. Consequently, the normalized results provide comparative information of how glow may increase with decreasing altitude without needing to know the actual value for the constant. Another somewhat arbitrary constant used in the computations was the Lyman-Birge-Hopfield (LBH) production coefficient. When the excited N_2 collides with a high velocity ambient molecule, only a certain percentage of the collisions produce LBH emission. The remaining collisions simply result in quenching the excited N_2 without emissions. The LBH production coefficient chosen for this study was 20% or 0.2. This value was suggested by Dr. Douglas Torr in personal conversations on the subject.

Figure 4 shows the normalized volumetric rate of LBH production as a function of altitude. As stated previously, the values have been normalized



NORMALIZED VOLUMETRIC RATE OF LBH PRODUCTION
NORMALIZED TO 450Km RATE
LBH PRODUCING COLLISIONS/CM^3/SEC
1.E+8
1.E+7
1.E+6
100000
10000
1000
100
10
1
.1
.01
200
250
300
350
400
450
500
ALTITUDE (KM)

Figure 4.

to the value at 450 km. Figure 5 shows the normalized number column densities of uncollided excited N_2. The number column densities of uncollided excited N_2 are proportional to the quantity of Vagard-Kaplan (VC) emissions produced. It is interesting to note that the normalized LBH production (Figure 4) increases more rapidly than the normalized $N_2(A)$ number column density (Figure 5) as the altitude decreases. This is likely due to increasing dominance of the $N_2(A)$-ambient collisions at lower altitudes as well as the increased quenching which would tend to affect the VC production more than the LBH production.

The final step of computing actual values for glow intensity along a line of sight due to LBH or VC emissions has not been made for two reasons. To obtain absolute intensity values requires knowledge of the actual value for the excited N_2 surface production constant as discussed previously. Since this constant was chosen in a totally arbitrary fashion, it would be irresponsbile to state an absolute intensity value based on the constant. The second reason for not computing the glow intensities is that the thrust of this study was to determine the effects of altitude on the induced external Space Station environment. The normalized plots in Figures 4 and 5 adequately illustrate the effects of altitude on the glow production.

5.0 SUMMARY

Decreasing the orbital altitude of the Space Station Freedom will dramatically effect its induced external environment. The molecular density induced above ram facing surfaces seems to scale in a nearly linear fashion with the increased ambient densities at lower altitudes. The total densities plotted in Figure 1 disguise this fact somewhat due to the increasing percentage of the surface outgassed contaminants to the total density at the higher altitudes.

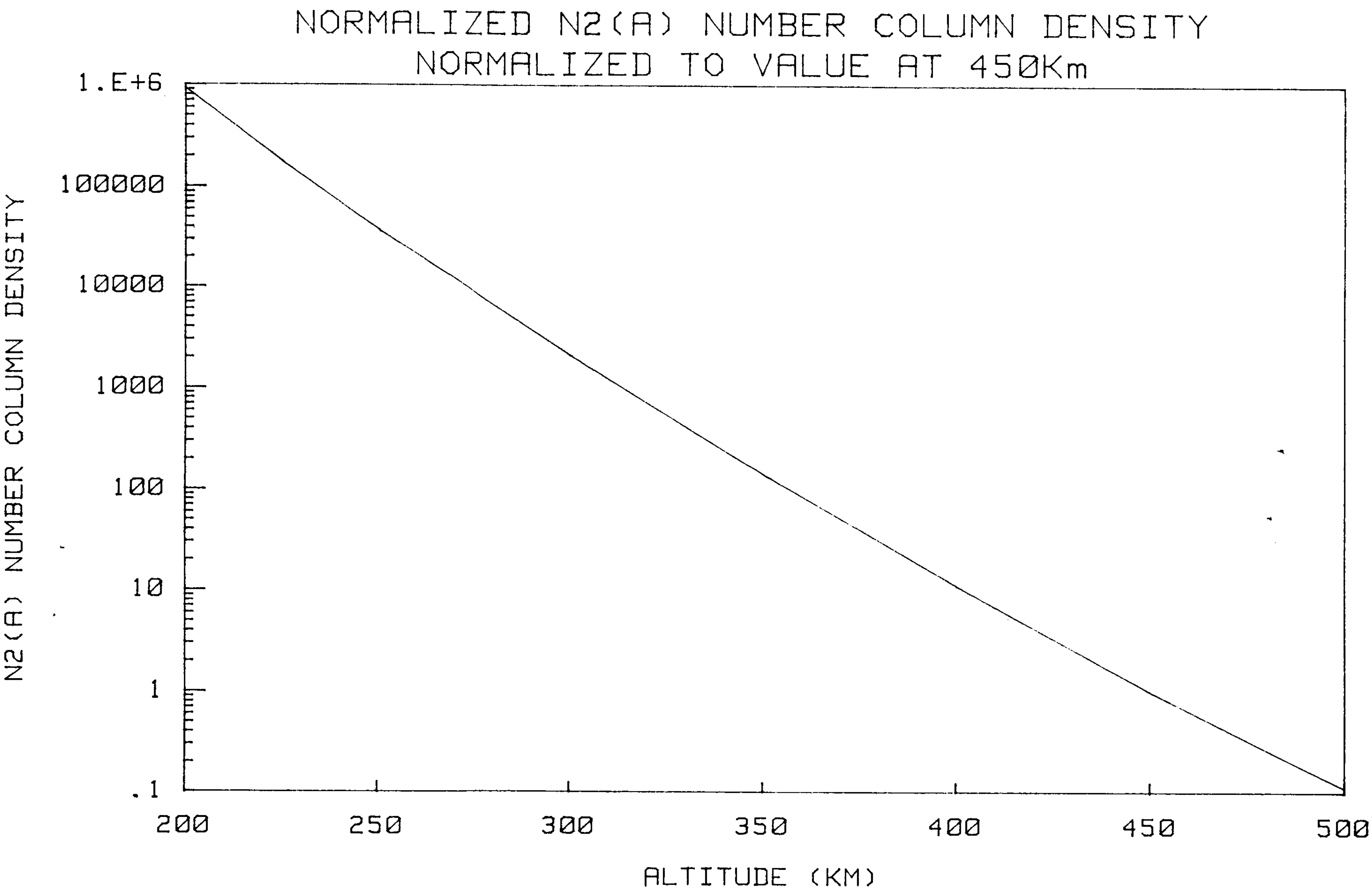

NORMALIZED N2(A) NUMBER COLUMN DENSITY
NORMALIZED TO VALUE AT 450Km
N2(A) NUMBER COLUMN DENSITY
1.E+6
100000
10000
1000
100
10
1
.1
200
250
300
350
400
450
500
ALTITUDE (KM)

Figure 5.

The backscatterd flux as shown in Figure 2 and Figure 3 generally increased with decreasing altitude. Altitude is only one of many parameters which determine backscattered flux of a contaminant. As such backscattered flux cannot easily be scaled to changes in altitude. Source parameters such as rate, distribution, mass, and collision cross section are factors in the backscattered flux computation. Also, the characteristics at the point where the flux is being computed such as field of view, viewing direction, and location relative to contaminant sources and primary scatterers (i.e. ram) are important to the calculation. Figure 2 and Figure 3 depict the computational results for backscattered flux for two different viewing directions, namely into ram and normal to ram. Although the normalized curves are very similar, the absolute values prior to normalization differs by roughly an order of magnitude (see Table 1). Both figures show significant differences of backscattered flux with regard to the location of the three points relative to the outgassing surface. At the lower altitudes, much of the outgassing contaminant was attenuated via scattering with the ambient atmosphere before it could reach the vicinity of the outer (more distant from surface) points.

In this study we performed the computations for a reasonably benign scenario of backscattered flux of a contaminant from an outgassing surface to nearby points. Although the trends of increasing flux with decreasing altitude are undoubtedly general in nature, it is very difficult to extrapolate these results to a scenario with another set of source and location parameters.

The production of LBH and VC emissions as shown in Figures 4 and 5 respectively showed a very significant dependence on altitude. Although we have only attempted to model a portion of the total glow problem, and are subject to the limitations and uncertainties described in Section 4.0, it appears that the glow may be the most significant problem for Space Station at lower altitudes from the point of view of optical instruments.

In this preliminary study we have only looked at a limited number of issues associated with the proposed altitude changes. For example we did not look at the result of altitude changes on the effects of atomic oxygen flux or ion densities. More work needs to be done on the modeling of the glow mechanisms both surface and far field. The glow mechanisms installed in ISEM need refinement, particularly with regard to the production algorithms for surface production of excited N_2. Missing coefficients need to be determined so that the final step can be made, the calculation of intensites at different wavelengths for various viewing directions.