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LONG DURATION EXPOSURE FACILITY (LDEF) CONTAMINATION MODELING

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SUMMARY

The Integrated Spacecraft Environments Model (ISEM) was used to model the LDEF induced neutral molecular environment at several different times and altitudes during the mission. The purpose of this effort was to provide the community with an estimate of the neutral molecular environment to assist in phenomenology studies.

INTRODUCTION

The objectives of this modeling effort were twofold. First, to model the overall vehicle induced neutral environment and to determine the flux of various molecular species on different surface locations. Secondly, to use the overall modeling results as input for the modeling of the molecular flux through a small aperture (vacant screw hole) into the vehicle interior. This second modeling effort was of interest because of very noticeable brown deposition patterns on interior surfaces in close proximity to the aperture. It was believed that understanding the molecular environment in the vicinity of the aperture would help in determining the mechanism which produced the deposition pattern.

INTEGRATED SPACECRAFT ENVIRONMENTS MODEL (ISEM)

ISEM is a collisional molecular transport code which computes the molecular density and flux in a three dimensional modeling volume for any number of user defined molecular species.

MODELING PARAMETERS

Three different periods in the LDEF mission were modeled to obtain representative results over the mission lifetime. These periods were representative of the beginning, middle and end of the mission timeline and corresponded to orbital altitudes of 463 km, 417 km, and 333 km respectively. Table 1 shows the ambient values for the six different ambient molecular species modeled at the three periods. The values were obtained using the atmosphere-predicting model MSIS86 and represent annual and orbital position averaged values for the periods modeled.

Table 2 shows the outgassing and erosion rates used for the modeling. External surfaces were modeled as having an average uniform outgassing rate which decreased with time. The initial outgassing rates were based on test data and the percentages of various materials present. Outgassing from internal surfaces was allowed to escape to the external environment via the numerous holes around the experiment trays. The external outgassing rate was assumed to decrease with an e folding time of 6000 hours. The internal outgassing rate was assumed to decrease with an e folding time of 7000 hours. The e folding times were based on Skylab measurements, taking into account differences in materials and materials control between the two programs. The average erosion rate was assumed to be 15% of Kapton for all the surfaces. The erosion rate given in Table 2 is for a surface normal to ram; a cosine dependence (relative to the velocity vector) was assumed for non-normal surfaces.

GEOMETRY MODEL

LDEF was modeled as the geometric structure shown in Figure 1. Based on data at the time of the modeling, the geometric structure was rotated 10 degrees relative to ram as shown in Figure 2.

GENERAL MODELING RESULTS

Density

ISEM was used to compute the density of every tracked species throughout the three dimensional modeling volume for the mission beginning, middle, and end cases described previously. Figures 3, 4 and 5 show the total iso-density contours for a plane of values from the three dimensional modeling volume. The total density value is the sum of ambient species, surface reemitted ambient species, internal and external outgassed species, and the scatter portions of all species. The contour values have been normalized to the total undisturbed ambient density at the respective altitude. Figure 3 shows the total iso-density contours for the early mission case at an altitude of 463 km. A slight ram buildup can be seen in front of the vehicle (velocity vector from left to right), but the density around the vehicle is dominated by the outgassing. Figure 4 shows the total iso-density contours for the middle mission case at an altitude of 417 km. In this figure one can see a significant ram buildup and a distinct wake region. The density in the wake region is dominated by the outgassing. Figure 5 shows the total iso-density contours for the late mission case at an altitude of 333 km. There is a strong density buildup in front of the vehicle due to ambient and erosion products. The wake is very well defined and although the densities are much less than on the ram side the density in the wake region is still dominated by the outgassed species. Figure 6 is an iso-density contour plot of only the erosion products. The plot shows a strong ram angle dependence.

Flux

From the standpoint of surface materials interaction with the molecular environment, molecular flux of the different species is much more important than density. Flux of each tracked species was computed to each of the LDEF facets. Figures 7 through 10 show the surface incident flux at the three modeled altitudes for O, O_2, N, and N_2 respectively. In the figures the surface incident flux is plotted as a function of incidence angle as measured from the ram direction. The term "direct" on the plots refers to flux of molecules which have not had a collision; they still retain the kinetic energy of the orbital velocity (in the spacecraft reference frame). Figure 11 shows the flux of outgassed and erosion products at the three modeled altitudes. Note that there is no direct flux in these plots because only transport via scattering can produce the return flux of these species to the external surfaces (this is not necessarily true on the scale of individual trays).

SMALL SCALE MODELING RESULTS

The second portion of the modeling effort was to model the molecular flux through a small aperture and the resulting incident flux on an internal surface (the side of an experiment tray). Figure 12 shows the geometrical relationship of the aperture and the internal surface. Figure 13 shows the energy distribution in the spacecraft reference frame of atomic oxygen and nitrogen in terms of electron volts. Figure 14 shows the angular distribution in the spacecraft reference frame of atomic oxygen due to the ambient thermal velocity distribution. Figure 15 shows the incident flux distribution of atomic oxygen on the internal surface due to flow through the small aperture. The flux distribution on the surface is due primarily to the thermal distribution of atomic oxygen. The dotted lines indicate the approximate cone angle of the observed deposition pattern.

CONCLUSIONS

We believe that the internal deposition modeled was due to atomic oxygen fixing of internally outgassed contaminants present on internal surfaces. The pattern observed is consistent with the thermally distributed flux of ambient atomic oxygen in the spacecraft reference frame.

The atomic oxygen erosion rates at the end of the mission were comparable to initial outgassing rates of LDEF surfaces. Return flux of erosion species near the end of the mission were an order of magnitude greater than the return flux of outgassed products early in the mission.

ACKNOWLEDGMENTS

We would like to acknowledge the financial support of Dr. Ann Whitaker at NASA Marshall Space Flight Center. We would also like to thank Ralph Carruth at MSFC for his technical and logistical assistance.

Table 1. Average Ambient Atmosphere Density Values (MSIS 86)

Species $\#/cm^3$	4/84	Date 4/87	1/90
O	2.59×10^{7}	3.48×10^{7}	9.03×10^{8}
O_2	7.52×10^{3}	1.43×10^{4}	6.06×10^{6}
N	6.65×10^{5}	7.44×10^{5}	3.28×10^{7}
N_2	4.23×10^{5}	7.26×10^{5}	2.03×10^{8}
He	3.47×10^{6}	3.85×10^{6}	5.07×10^{6}
H	1.63×10^{5}	2.30×10^{5}	2.66×10^{4}
Total Density	3.06×10^{7}	4.04×10^{7}	1.15×10^{9}
Temperature (K)	920	829	1303
O Flux/cm^2	2.0×10^{13}	$2. \times 10^{13}$	7.0×10^{14}

Table 2. Outgassing and Erosion Rates

Rate $g/cm^2/sec$	463 km 4/84	417 km 4/87	333 km 1/90
External	2.0×10^{-9}	2.6×10^{-11}	1.4×10^{-12}
Internal	2.0×10^{-10}	5.6×10^{-12}	4.8×10^{-13}
Erosion	6.3×10^{-11}	8.5×10^{-11}	2.2×10^{-9}

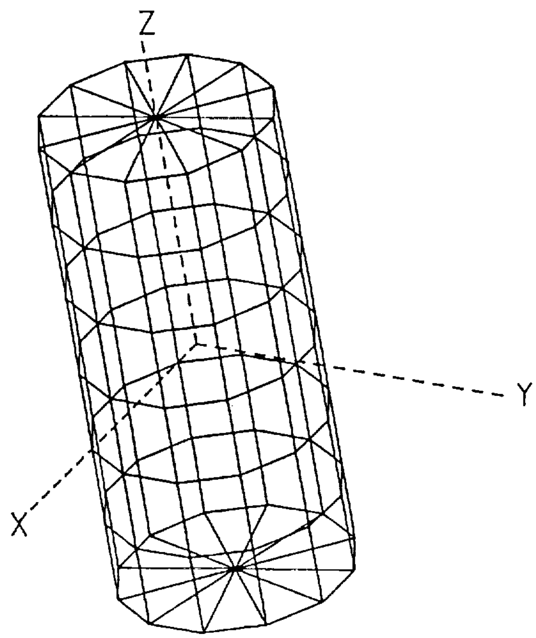

Figure 1. LDEF geometry model.

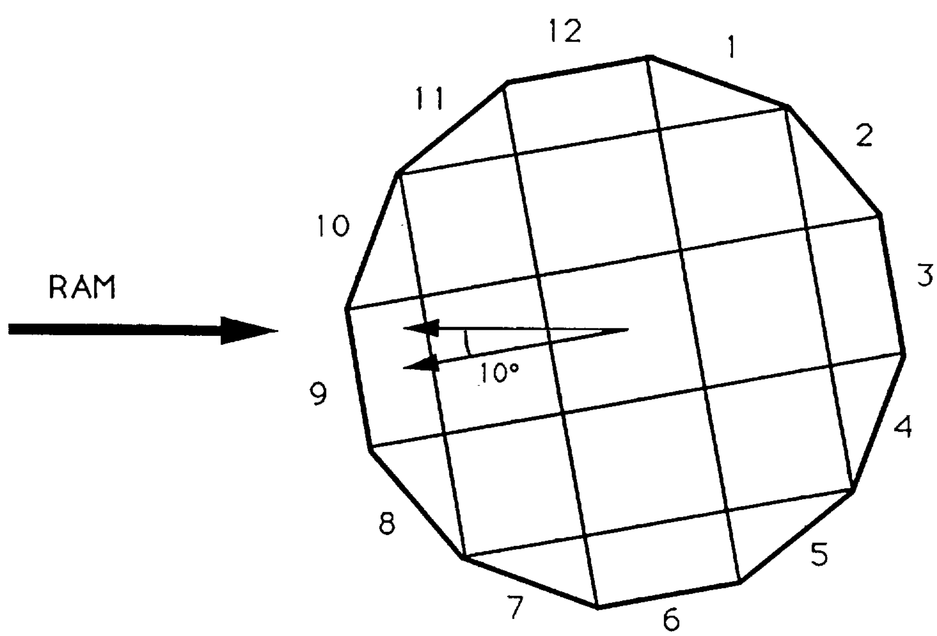

Figure 2. LDEF facet identification (from Earth end).

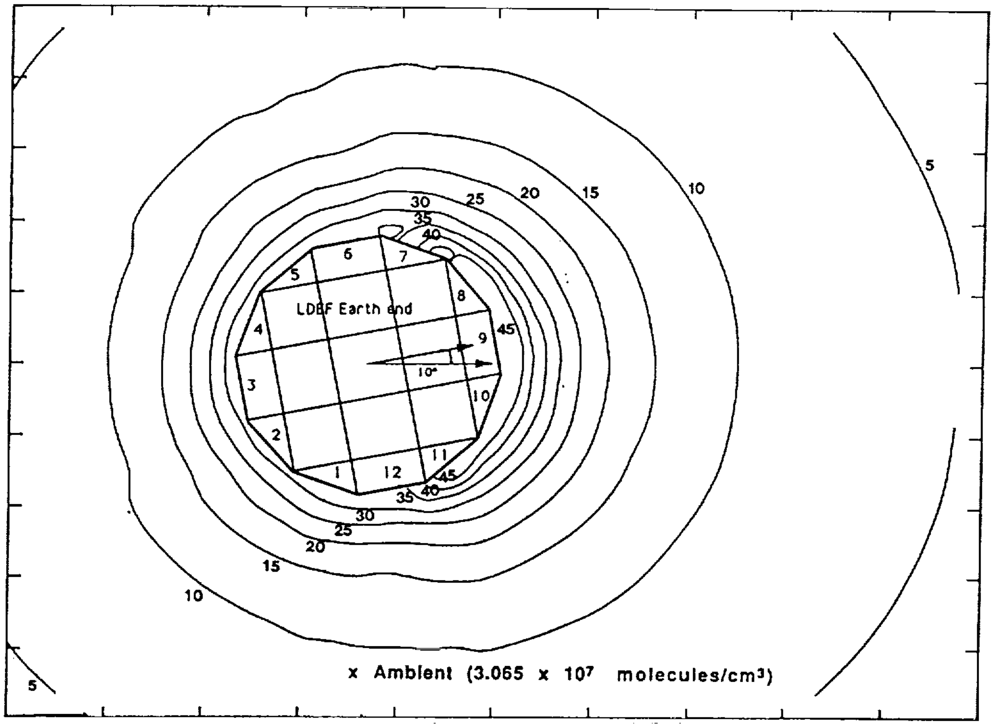

Figure 3. Total density at 463 km.

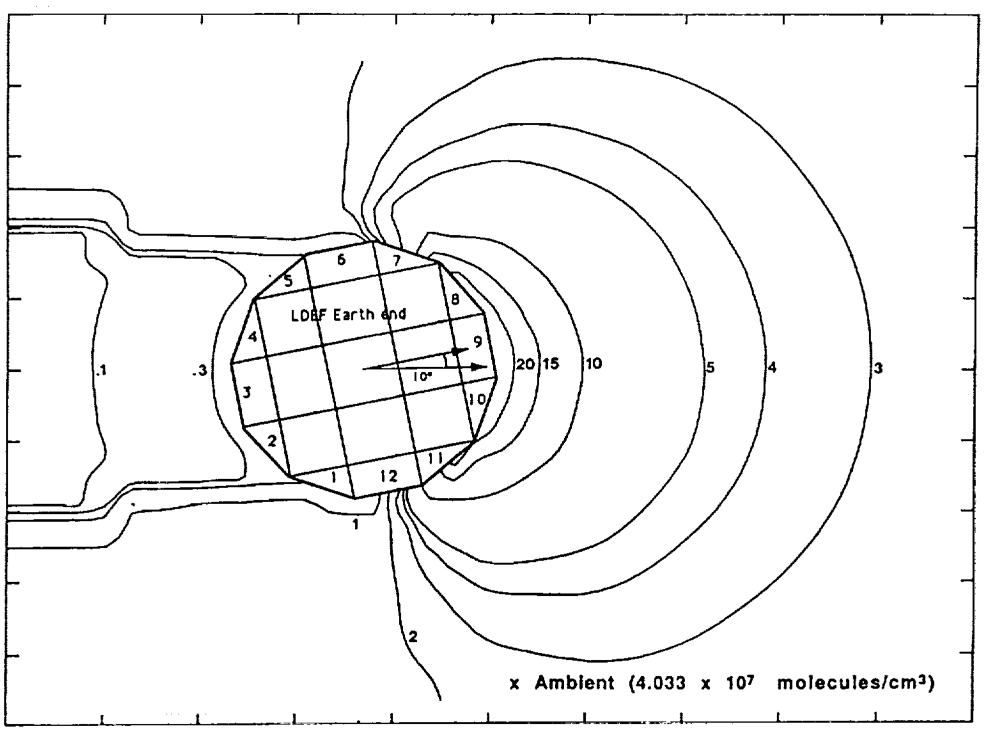

Figure 4. Total density at 417 km.

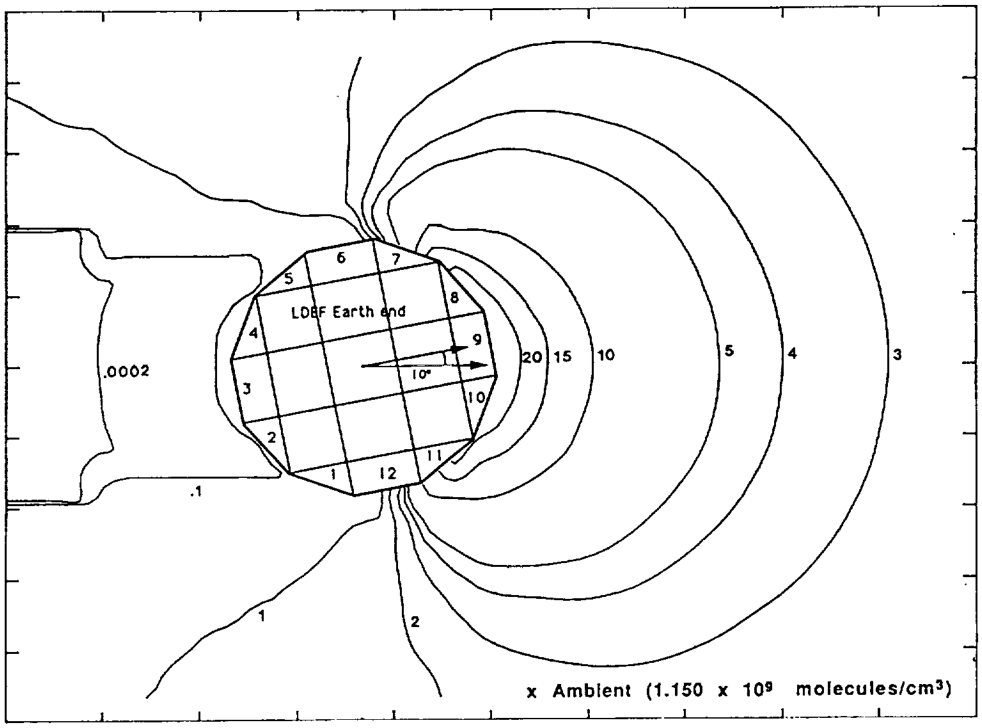

Figure 5. Total density at 333 km.

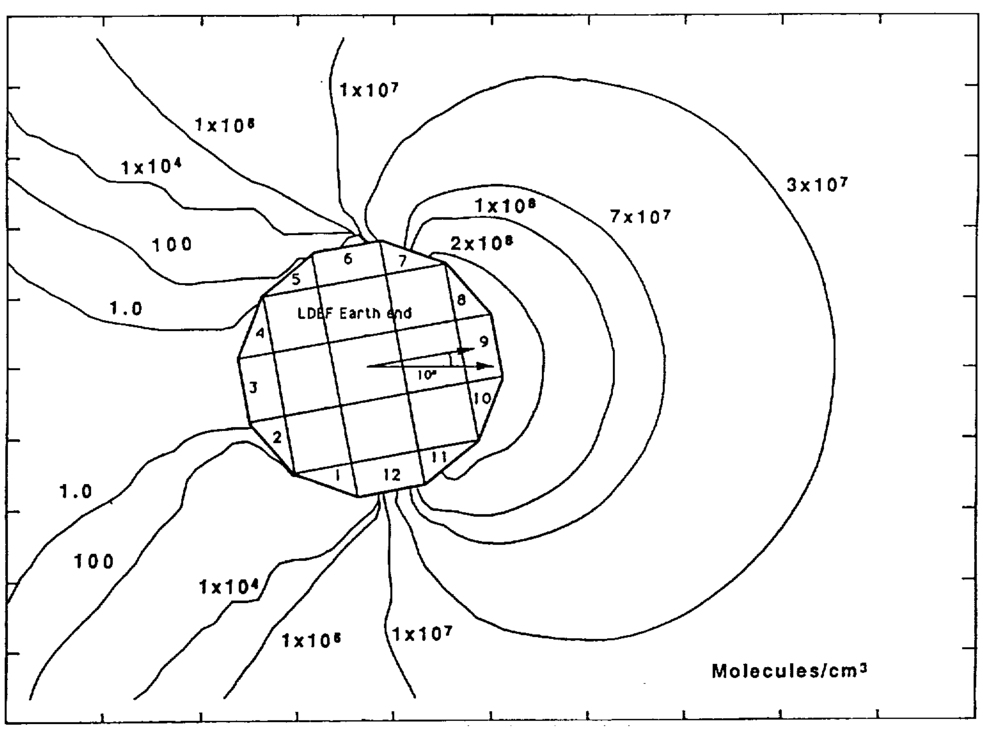

Figure 6. Density of erosion products at 333 km.

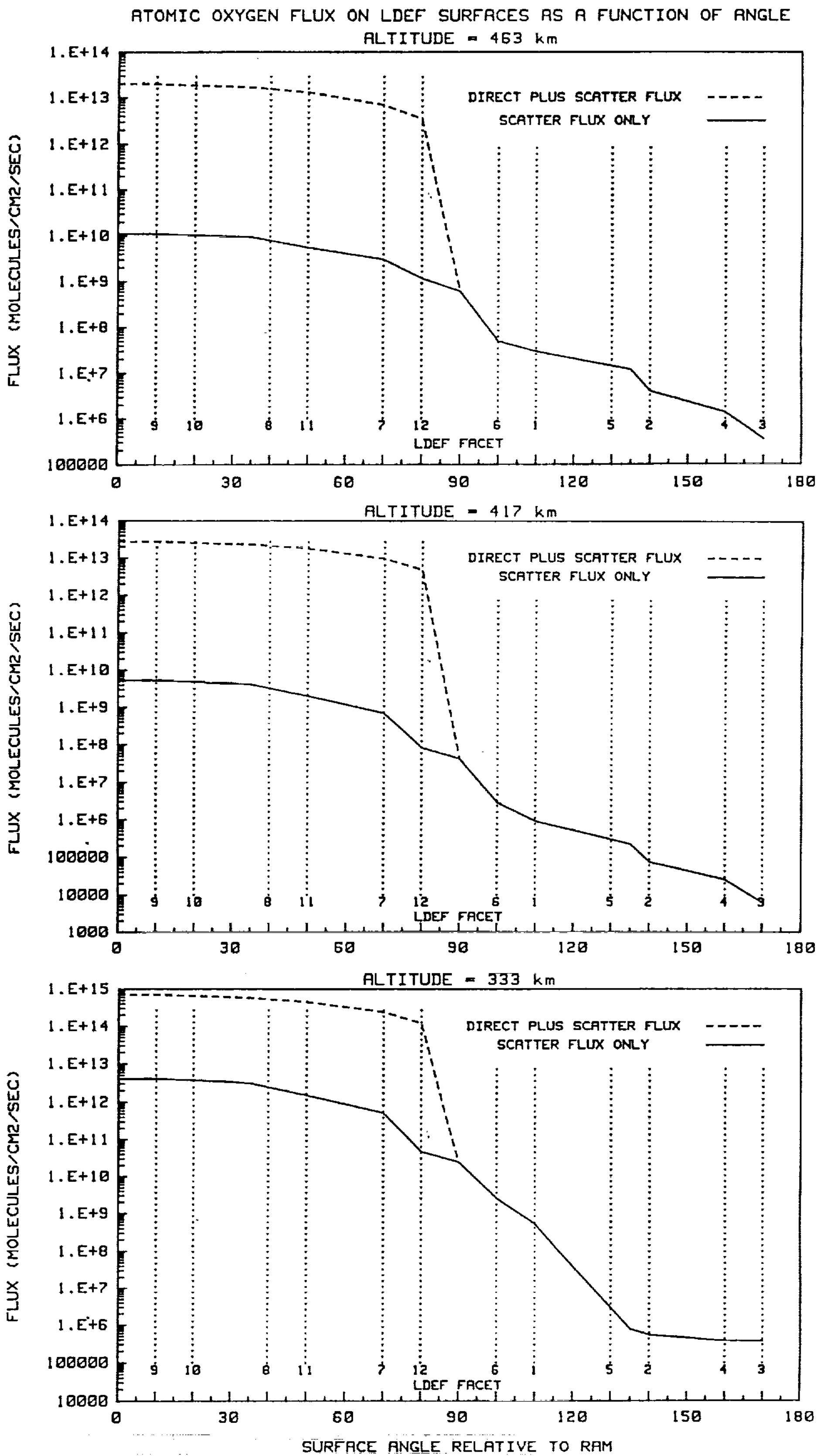

Figure 7. Atomic oxygen flux on LDEF surfaces.

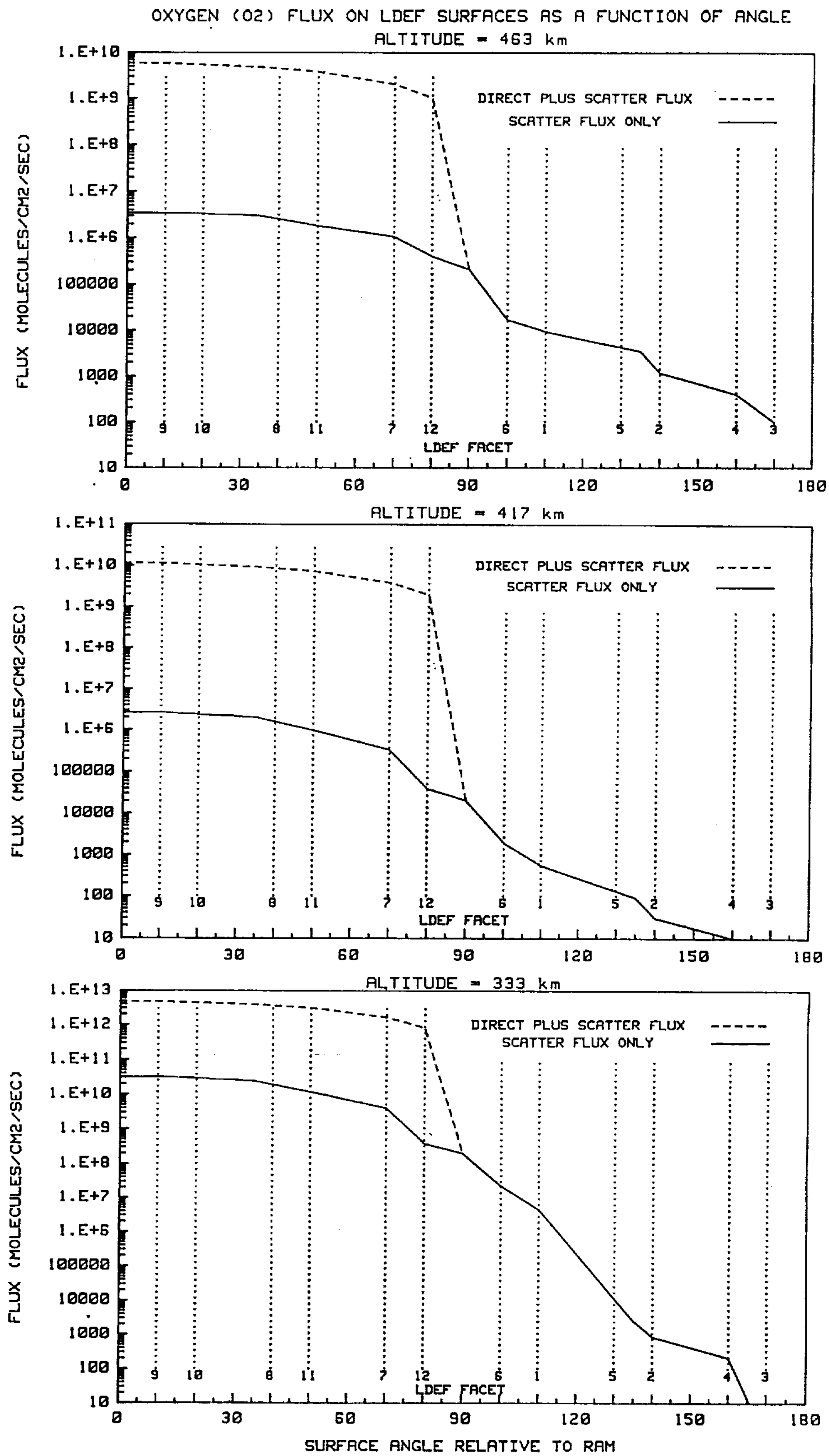

Figure 8. Oxygen flux on LDEF surfaces.

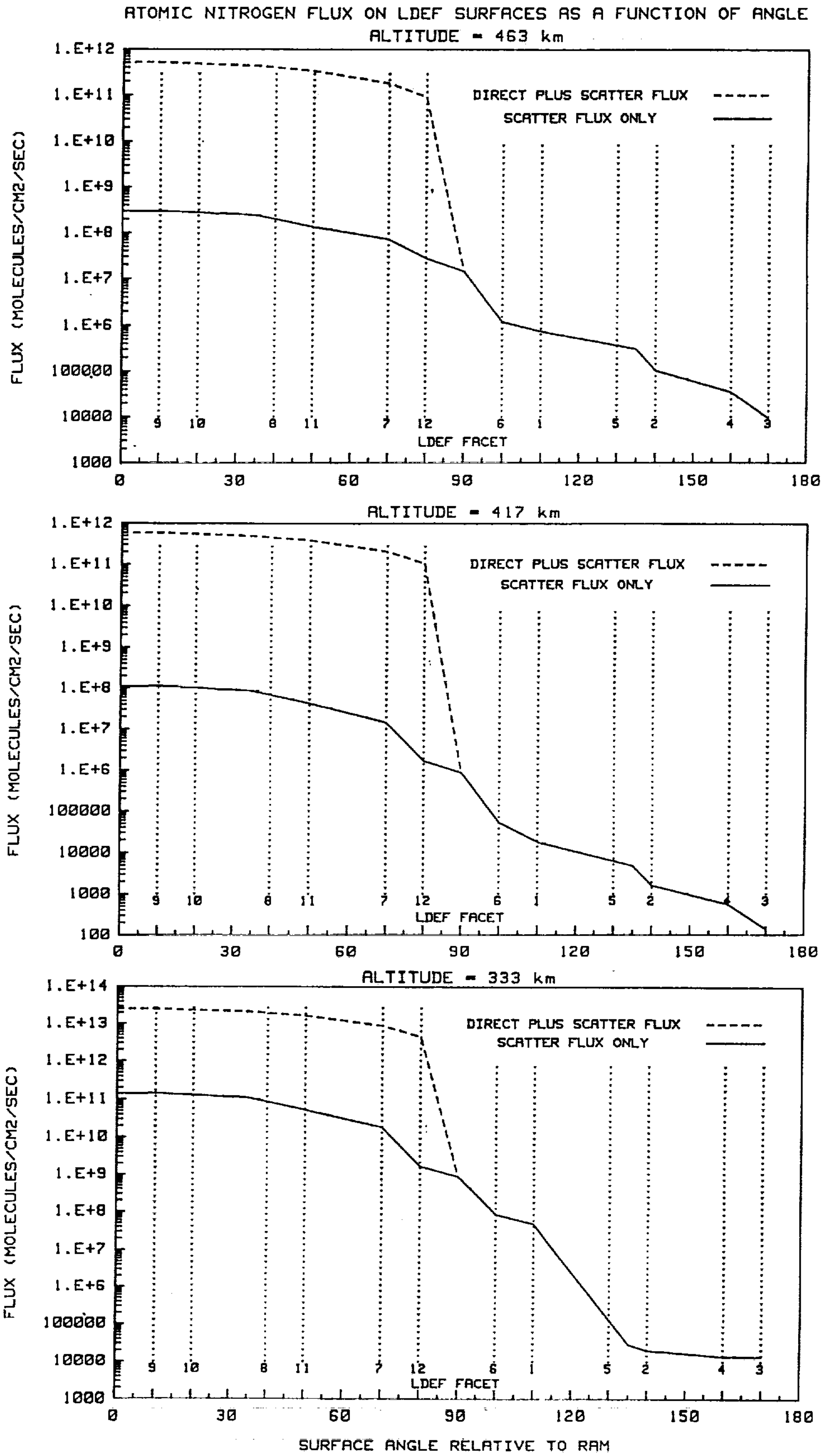

Figure 9. Atomic nitrogen flux on LDEF surfaces.

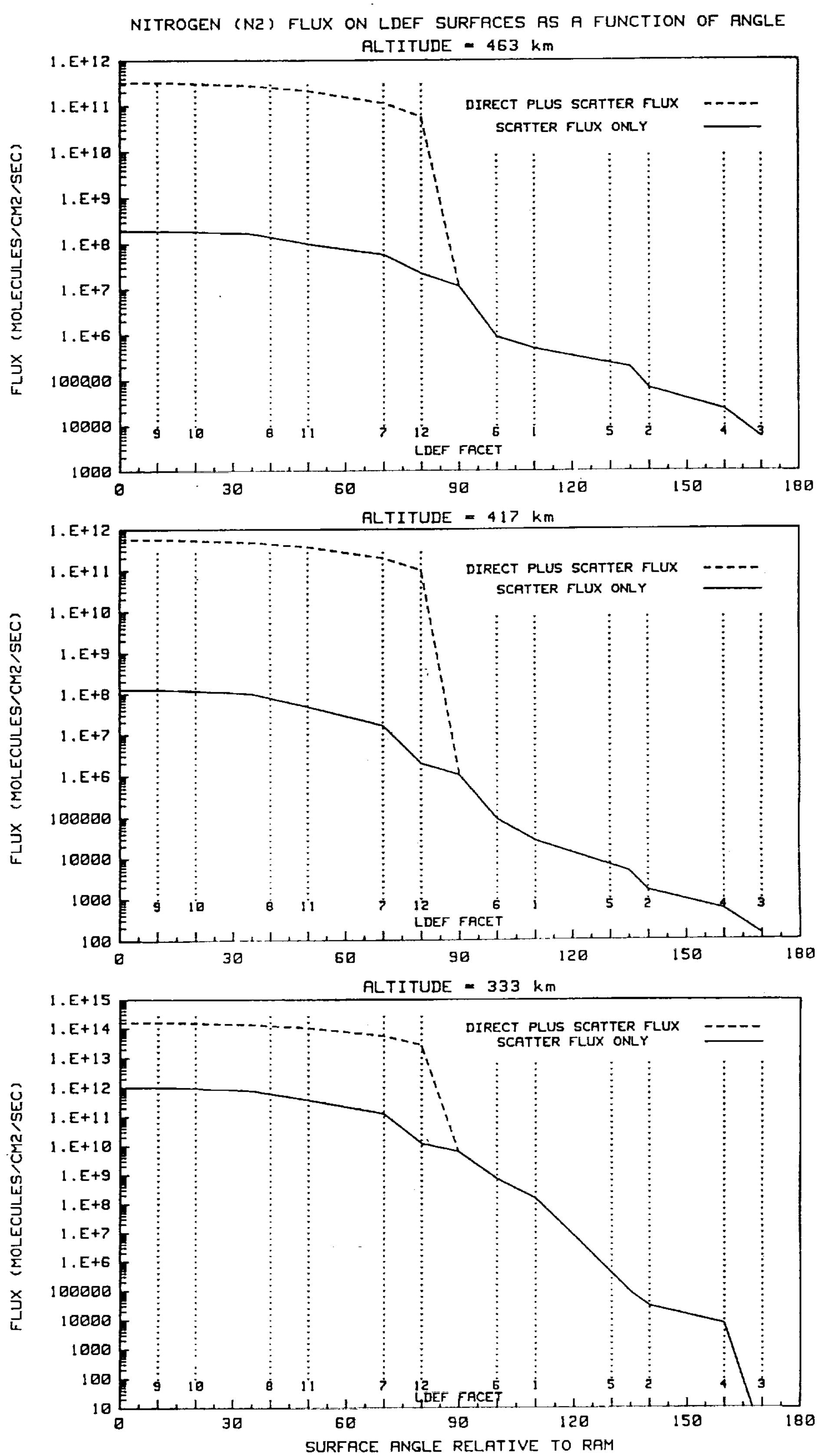

Figure 10. Nitrogen flux on LDEF surfaces.

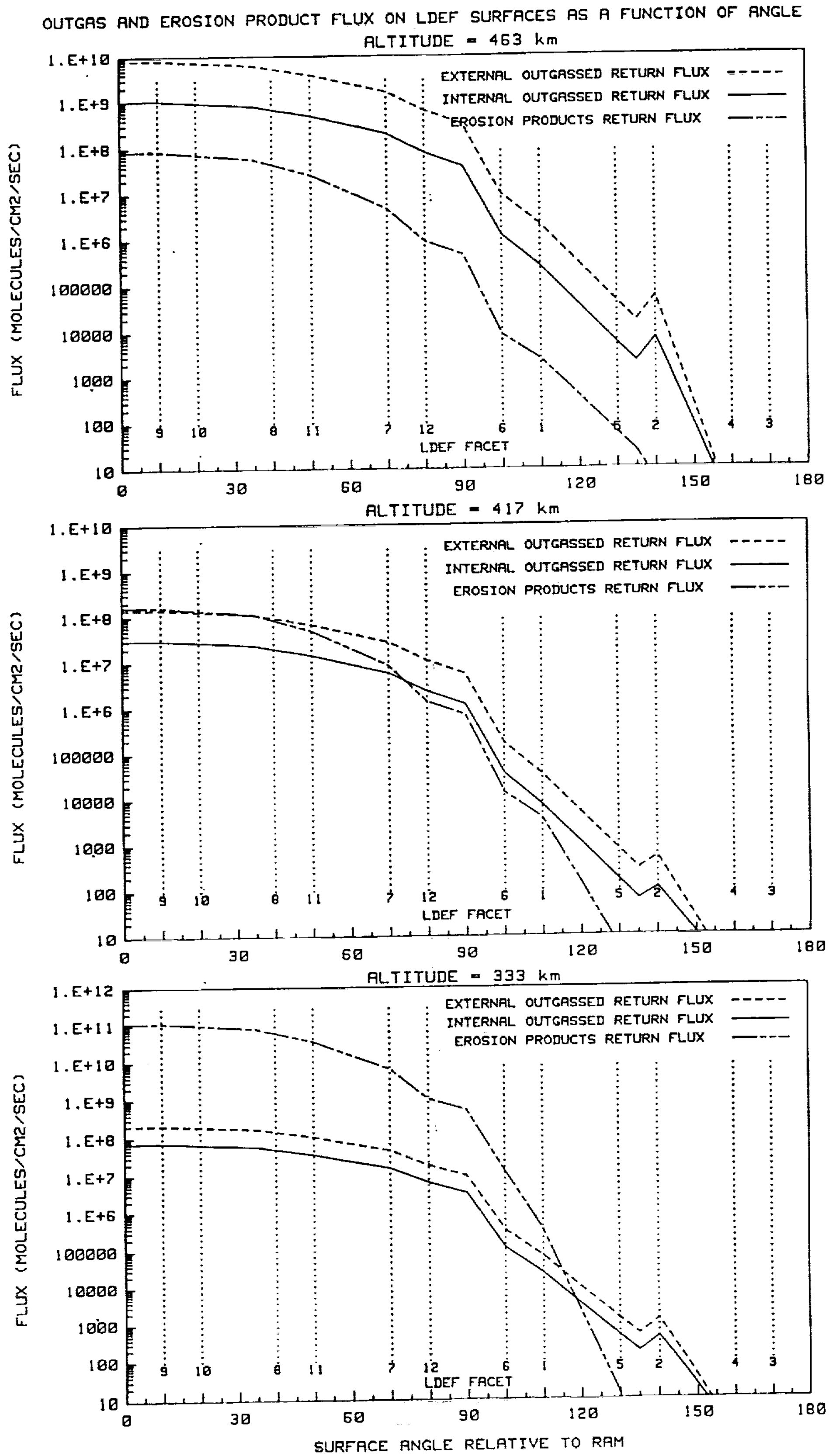

Figure 11. Outgassed and erosion products flux on LDEF surfaces.

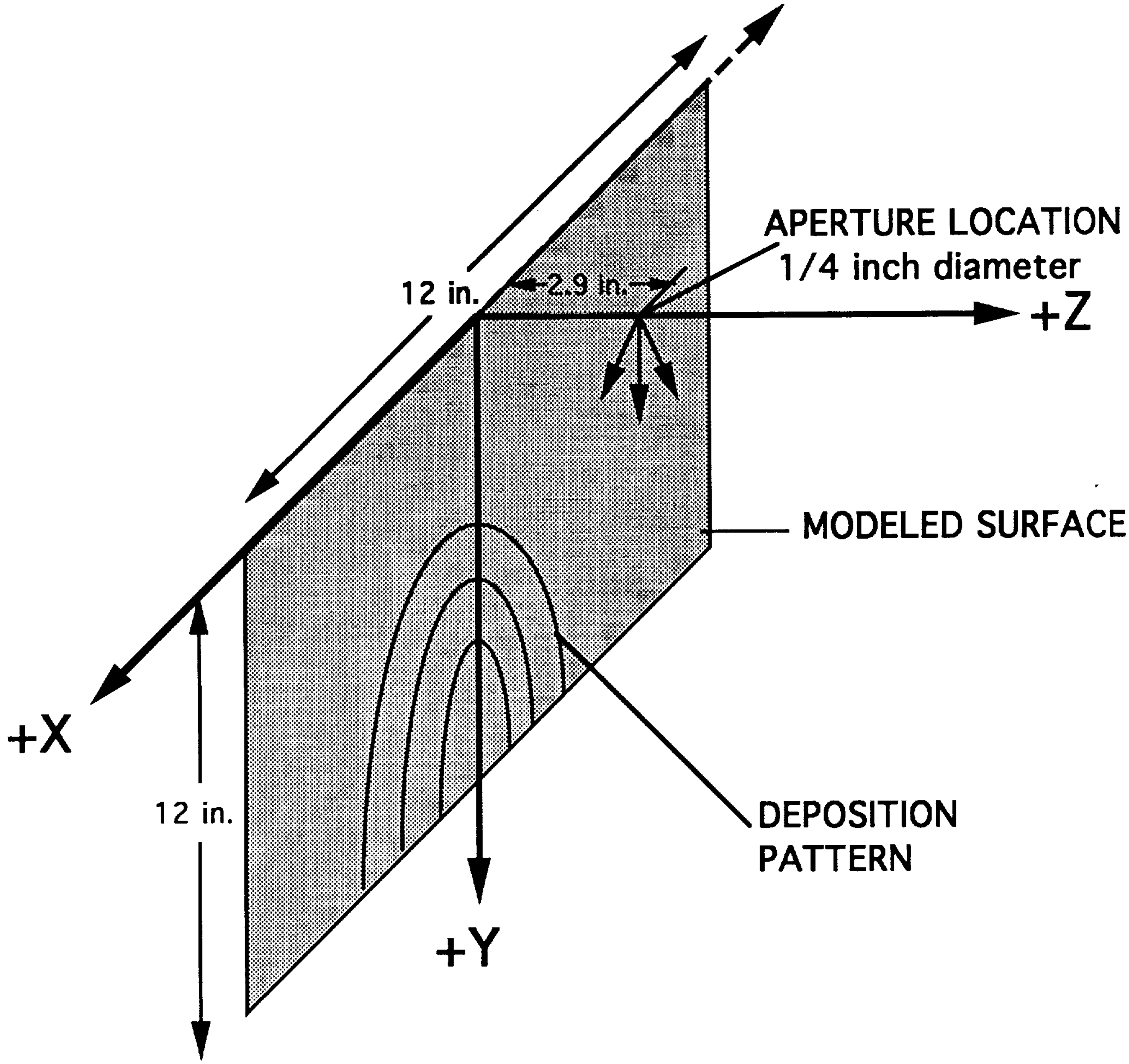

Figure 12. Internal surface deposition model geometry.

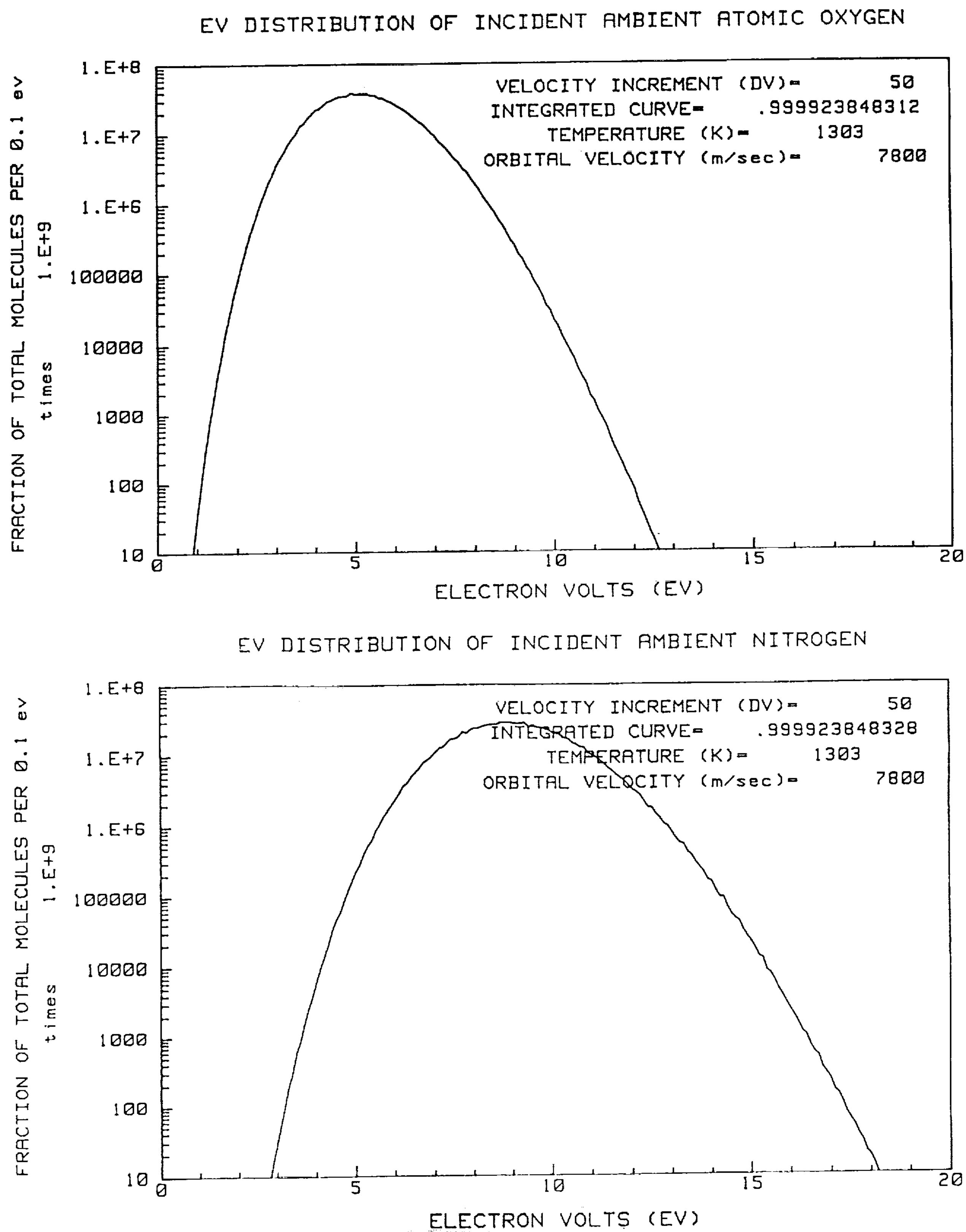

Figure 13. Energy distribution of atomic oxygen and nitrogen.

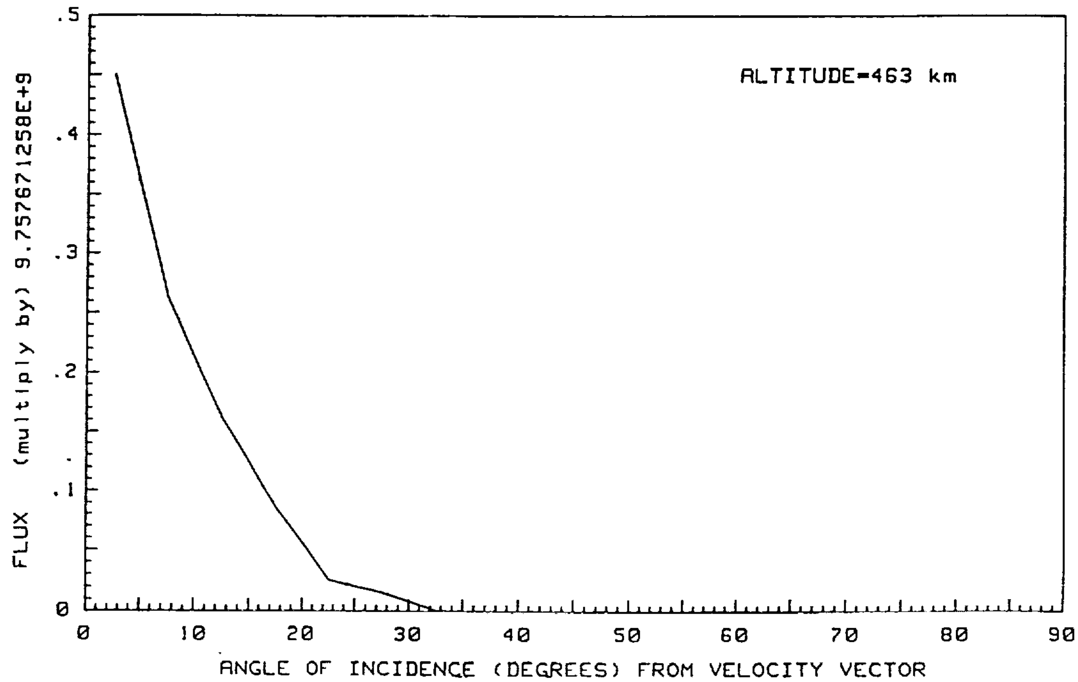

Figure 14. Atomic oxygen angular distribution from ram direction.

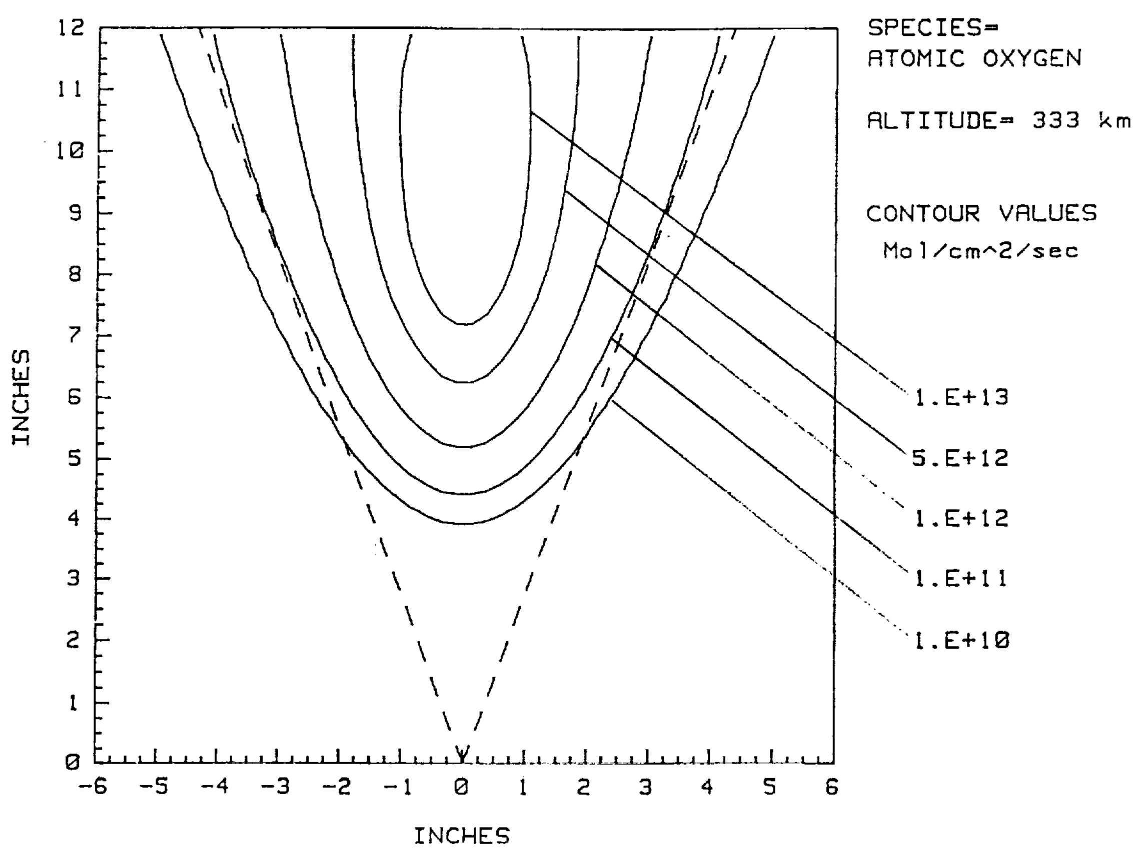

Figure 15. Iso-flux contours of atomic oxygen on internal surface.