

## 1. Introduction and Summary

The Environmental Management of the Space & Missile Systems Command has set out to evaluate the depletion of stratospheric ozone caused by Air Force activities in space. Potential destruction of ozone by launch vehicle exhaust is one item of concern (Ref. 1.1). The use of advanced propellants to minimize launch-induced ozone destruction is discussed in a companion report. The present report describes a quantitative assessment of another potential destroyer of stratospheric ozone: deorbiting space debris.

The results of the present study lead to the conclusion that deorbiting space debris has very little impact on stratospheric ozone. The task-by-task analysis leading to this conclusion is summarized as follows:

### Characterize the debris flux into the stratosphere.

Debris object density was characterized by size and altitude. Orbital decay was calculated and the results led to an estimate of the flux into the stratosphere as a function of object size. The results showed a preferential population of the stratosphere by smaller debris objects. The calculated stratospheric object density for one micrometer size particles is in reasonable agreement with measured values.

### Calculate reentry trajectory and heating.

Several object sizes and materials were considered. In general, sub-millimeter size objects settle slowly through the stratosphere. Intermediate size objects (millimeter to decimeter) may melt/vaporize in or above the stratosphere. Larger objects (decimeters) may survive to the earth's surface. It is essential to account for the balance between convective heating and radiation heat loss to characterize the thermal response of the deorbiting debris. The trajectory/heating results provided initial conditions for assessment of ozone depletion by several mechanisms.

### Evaluate ozone depletion by heterogeneous mechanisms.

Deorbiting debris provides several sources for deposition of small particles into the stratosphere. Two mechanisms, for example, are: direct orbital decay of small particles and stripping small particles from surfaces of larger space objects by aerodynamic drag forces generated during the deorbit/reentry process. The small particles provide active sites for heterogeneous reactions similar to those of the polar stratospheric cloud (PSC) particles. MIT performed experiments to measure the rate parameter for heterogeneous reactions in terms of the reaction probability. The measured data was used for the assessment of local and global effects on stratospheric ozone due to surface reactions. The impact on local ozone is evaluated based on a simple one-dimensional diffusion model for a single particle. Attention is focused on micrometer size particles because they provide the greatest total surface area. The resultant ozone depletion by heterogeneous mechanisms is estimated to be small:  $10^4$ - $10^5$  years to destroy one percent of the stratospheric ozone.

Evaluate ozone depletion by homogeneous mechanisms.

Deorbiting debris reentering the stratosphere at hypersonic speeds creates a high temperature region between the bow shock and the body. The temperature immediately behind the shock reaches temperatures as high as 20,000 degrees Kelvin. At such extreme temperature large amounts of nitric oxide will be produced according to the Zeldovich mechanism and ambient ozone is subsequently consumed through the nitric oxide catalytic cycle. An additional source of nitric oxide is generated as pyrolysis products from spacecraft paint or ablation materials (material bound nitrogen). The impact of these mechanisms on stratospheric ozone is estimated to be small: destruction of one stratospheric ozone molecule per one billion per day by the material-bound nitrogen mechanism and one part per ten billion per year by the thermal mechanism.