SELF STERILIZATION OF BODIES

DURING OUTER PLANET ENTRY*

A. R. Hoffman, W. Jaworski and D. M. Taylor

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103, USA

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Abstract

As a body encounters the atmosphere of an outer planet, whether accidentally or by plan, it will be subjected to heat loads which could result in high temperature conditions that render terrestrial organisms on or within the body nonviable. To determine whether an irregularly shaped entering body, consisting of several different materials, would be sterilized during inadvertent entry at high velocity, the thermal response of a typical outer planet spacecraft instrument was studied. The results indicate that the Teflon-insulated cable and electronic circuit boards may not experience sterilizing temperatures during a Jupiter, Saturn, or Titan entry. Another conclusion of the study is that small plastic particles entering Saturn from outer space have wider survival corridors than do those at Jupiter.

1.0 Introduction

Many researchers [1, 2, 3] have recognized the difficulty in designing a Jupiter entry probe that would survive to the regions of interest of the Jovian atmosphere. Because of this, many were, and still are, of the opinion that it would be extremely unlikely for an unsterilized flyby or orbiter spacecraft to survive (and thereby contaminate) the Jovian atmosphere during inadvertent entry.

To justify this assertion analytically, the Pioneer project office at the NASA Ames Research Center (ARC) performed a study to determine whether spacecraft components inadvertently entering the Jovian atmosphere at high velocity could survive [4, 5]. To summarize the published ARC conclusions:

(1) All metal pieces will be consumed during entry.

(2) Plastic pieces capable of ablation may survive entry, but such pieces must have characteristic sizes of 0.2 to 0.5 m at the start of entry to survive.

(3) Biological contamination by an unsterilized spacecraft impacting Jupiter is "highly doubtful."

A previous COSPAR report on the subject [6] presented the work done on the thermal response of small particles, insulating blankets, antenna, and supporting struts when the spacecraft passes through the free molecular regime of the atmospheric entry. It was determined that the spacecraft will break up as a result of heating at the boundary of the continuum flow regime, whereupon the antenna, struts, and blanket will disintegrate and burn away. The only survivors will probably be the science platform and bus, which will enter the continuum flow regime.

In this paper, the thermal response of the science platform and part of the bus are discussed, and representative test results are presented. In addition, the extended analysis of small particles, which also covers entries into the atmosphere of Saturn, is included.

2.0 Technical Discussion

The major part of the effort to be reported on is concerned with determining the thermal response of the science platform. A typical ultraviolet spectrometer (UVS), a very complex instrument mounted on the platform, was selected for a detailed thermal response analysis largely because of the abundance of plastic materials concentrated in the lower part of the instrument. Figure 1 schematically illustrates the location of these materials.

The plastic materials found within the instrument were (1) G10 epoxy-fiberglass, (2) Castall, (3) Diallyl phthalate, (4) polycarbonate, and (5) Teflon. Decomposition data on these materials were generated by testing the samples in a precision-type thermogravinometer, where each sample was decomposed in a vacuum under constantly increasing heat and the loss of the sample weight was measured as a function of temperature.

In addition to the decomposition data, the thermophysical properties of the above materials as well as their chemical makeup were compiled or otherwise obtained by tests. The materials were also subjected to baking at 650°C in a specially designed vacuum-type oven. The latter was necessary to provide information on the materials' disintegration status at the melting temperature of aluminum, which constitutes a primary structure of the instrument.

The first item subjected to the analysis was the UVS cable, consisting of copper wires insulated with Teflon. A typical cable cross-section is depicted in Fig. 2. The cable is approximately 13 mm in diameter. The copper wires, Teflon jackets, and voids between the cables are clearly shown. It was assumed for the purposes of the analysis that the cable length was about 400 mm, and that its configuration was straight. This approach, although conservative with regard to the UVS instrument, was found to be justified when cable configurations in the spacecraft bus were studied. Conservatively, entry along the cable axis was assumed.

The two cases analyzed (considered extremes) were -15-deg entry into the warm atmosphere and -90-deg entry into the cool atmosphere, as defined by the engineering models for Jupiter [7]. It was assumed initially that the Teflon insulation could be considered separately, and that the influence of the copper wires could be superimposed on the results obtained.

Figures 3 and 4 present the analytical results of Teflon decomposition for the warm atmosphere entries. It is seen that only a part of the 400-mm-long insulation will be disintegrated, and that the remaining length will not develop a temperature level high enough to sterilize all of the undecomposed portions of the cable. The temperature responses for the simulated entry were calculated down to cloud level in order to establish the insulation status at that altitude.

To account for the effects of wire heating and melting on decomposition of the insulation, an ablation test was performed on a 240-mm-long sample of the cable. An oxy-acetylene torch was used to ablate the wire and the insulation. The flame was moved from right to left at a rate corresponding to a complete ablation of the cross-section of the cable (Teflon and wires combined). Dual thermocouples were installed at each indicated location on the center wire; one on the bare wire and the other on the outside of the insulation. It was found that approximately 3 mm from the flame front, the temperatures of the wire and the insulation were between 500 and 600°C (i. e., at the maximum temperature of Teflon decomposition). This is a relatively small temperature difference between the wires and insulation, in spite of the proximity to the melting wires, where the temperature was 1080°C.

It can be concluded that the presence of wires did not significantly affect the process of insulation decomposition, lending the analytical results described previously an adequate degree of validity. An inspection of the spacecraft bus reveals that typical cable harnesses are frequently thicker and longer than the sample analyzed.

The next items collectively analyzed were circuit boards (cards) and the detector bodies, both made of G10 epoxy-fiberglass. Referring to Fig. 1, and assuming that entry into the atmosphere is to the right of the depicted instrument, we can see that a set of front circuit boards is followed by a bank of detectors and, finally, a set of the rear circuit boards. Each set will, in turn, be exposed to the heat pulse upon disintegration of its predecessor. It was assumed that the thin aluminum cover would instantly melt away, and that the rest of the aluminum structure, placed some distance away from the concentration of plastics, would also melt and be blown away ahead of the plastic disintegration. The melting of the aluminum very close to or adjacent to the plastic materials will be delayed by the heat "blockage" caused by the great amount of gas resulting from plastic decomposition. In short, the adjacent metal will be melting at approximately the speed of plastic decomposition, ensuring some structural integrity during the process.

Figure 5 presents the results of the analysis. In the case of -90-deg entry into the cool atmosphere, the third group (rear circuit boards) will be partially decomposed.

To evaluate in-depth temperature profiles for -90-deg cool atmosphere entry, two profiles made at the end of recession were compared. It can be concluded from this comparison that in the -90-deg cool atmosphere entry, the temperature rise will be less, leaving the unablated portion of rear circuit boards unsterilized.

Small particle heating calculations were done for two areas:

(1) The effect of the increased heat transfer rate at low speed in free-molecular entry.

(2) The contraction of the small size, small entry angle, nonsterilizing corridor for particles liberated at successively greater levels of ambient atmospheric density.

Figure 6 shows features of a typical small particle entry into the Jupiter warm atmosphere.

Figure 7 illustrates the contraction of the survival entry corridor for Jupiter, which moves progressively toward smaller entry angles and smaller particle sizes with an increase of the atmospheric density at which the particles leave the spacecraft. Similar calculations were performed for the other Jupiter atmospheres and for the three Saturn model atmospheres. Figures 8 and 9 show these results for a Saturn and a Titan calculation, respectively.

In addition, a preliminary analysis has been done to determine, the entry body and trajectory conditions likely to result in the least total heating for the major components of a spacecraft entering Saturn. Total convective plus radiative heating in the stagnation region, per unit mass, was calculated for bodies of different size and weight, in entry at -90, -15, and -3 deg into the three Saturn model atmospheres.

The main differences in the case of Saturn are:

(1) The heating is always considerably less than in the Jupiter case when analogous entry heating parameters are considered.

(2) The radiative heating, which comes into play at large nose radius for heavy bodies, is a smaller fraction of the total heating, i.e., radiative plus convective.

(3) The total heating at -15-deg entry is considerably less than at -90 and -3 deg. This is in contrast to the Jupiter case, where the result of a high heating rate for a short entry time at -90-deg entry is comparable to that of a low heating rate for a long entry time at -3 deg, as well as to the -15-deg entry case.

3.0 Conclusions

3.1. Jupiter — Large Impactables

In contrast to previous expectations, a possibility of survival of organisms which reside within the large impactables (spacecraft, launch vehicles, or large pieces thereof) has been uncovered in the present analysis. The surviving remnants of plastic materials may descend down to the cloud level, where environmental conditions of growth are regarded as favorable.

Among the most critical components are the cable harnesses, which have a finite chance of surviving Jupiter entries without being sterilized. This is also true of circuit boards where microbial survival depends on the grouping, size, and orientation of the boards; those placed in a series stand a better chance of surviving. It has been shown that the last group of boards in the ultraviolet spectrometer may not reach sterilizing temperatures during a -90-deg entry into the cool atmosphere. The results presented are also applicable to the elements of the spacecraft bus, which have a design configuration similar to that of the UVS.

3.2. Jupiter — Small Particles

Small particles, which include spheres, flakes, and needles with characteristic dimensions in the range of 1 to at least several hundred μm, have little liklihood of unsterilized entry into Jupiter. The exception is small particles entrained with a spacecraft at first entry, for which a narrow nonsterilizing entry corridor exists in a shallow entry. The entry corridor, ranging in size from 1 to approximately 30 μm, rapidly contracts if the particle liberation is delayed until ambient atmospheric density levels in the range of 1 to 20×10^{-12} g cm^{-3} are reached. The corridor vanishes when liberation occurs at ambient atmospheric density levels above about 30×10^{-12} g cm^{-3}. Particles generated later from spacecraft breakup (mainly around a density level of about 10^{-9} g cm^{-3}) have no chance of unsterilized entry.

3.3. Saturn — Large Impactables

Based on a cursory study of large impactable entry into the atmosphere of Saturn, it is concluded that the components with the best chance of survival in Saturn entry are the heavy components with large nose radius entering at an angle of about -15 deg.

3.4. Saturn — Small Particles

The same general conclusions are obtained concerning survival of small particles during Saturn entry as for Jupiter entry except for displacement of entry corridors. The corridor for a particle vanishes when liberation occurs at ambient atmospheric densities of 50×10^{-12} g cm^{-3}.

3.5. Titan — Large Impactables

Although no detailed studies have been performed, it is believed that unsterilized bodies entering the atmosphere of Titan are more likely to have more components surviving the entry heating than in the case of Jupiter or Saturn.

3.6. Titan — Small Particles

The survival corridor for small particles is wider than that for Saturn. The corridor vanishes when liberation occurs at ambient densities of $\sim 10^{-8}$ kg m^{-3}.

4.0 Acknowledgements

The small-particle entry results were calculated by A. McRonald, and the overall advanced missions task was coordinated by C. Gonzalez, both of the Jet Propulsion Laboratory. The cooperation and support of these individuals is deeply appreciated and gratefully acknowledged.

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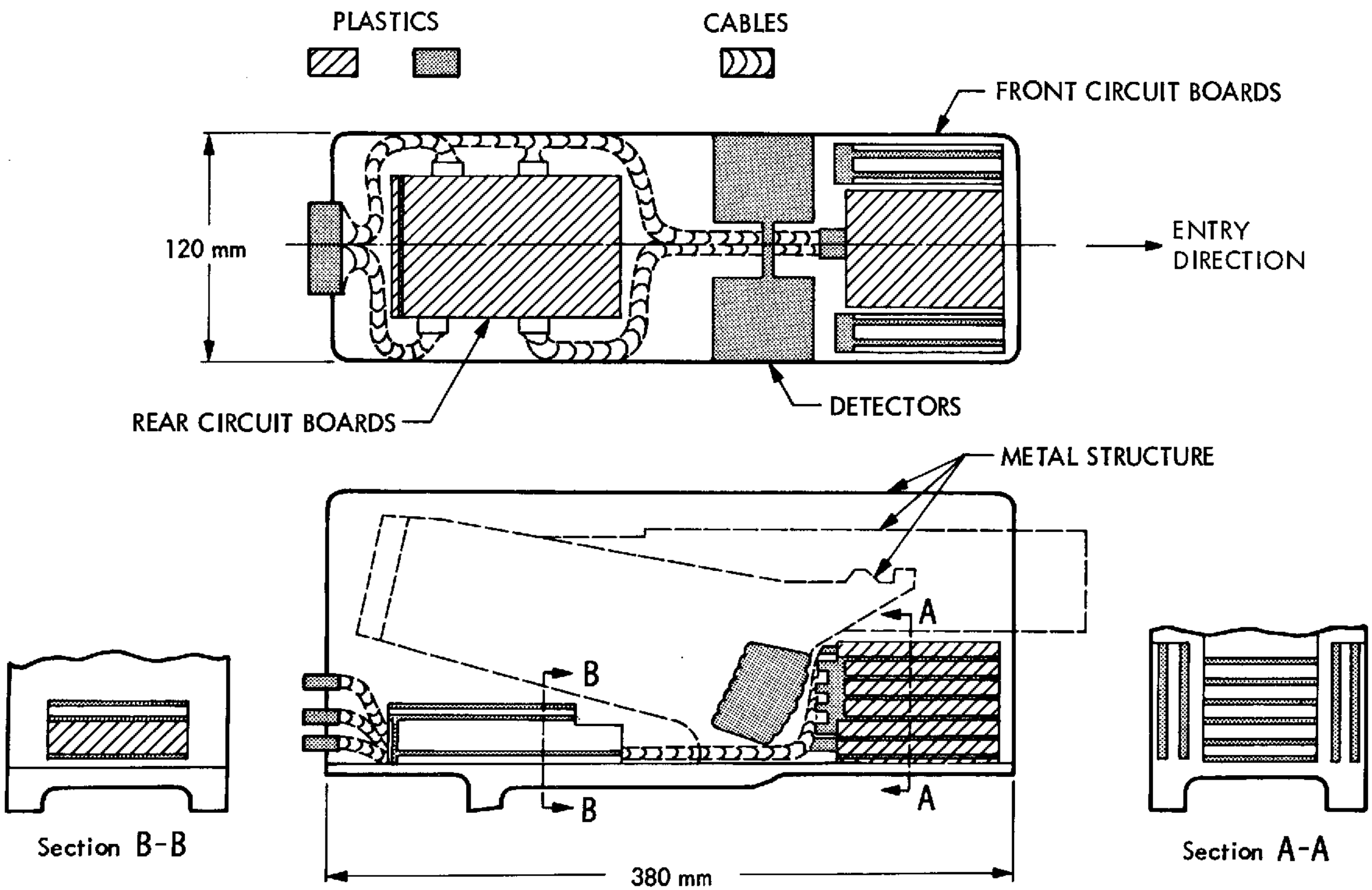

Figure 1. Location of plastic materials in ultraviolet spectrometer

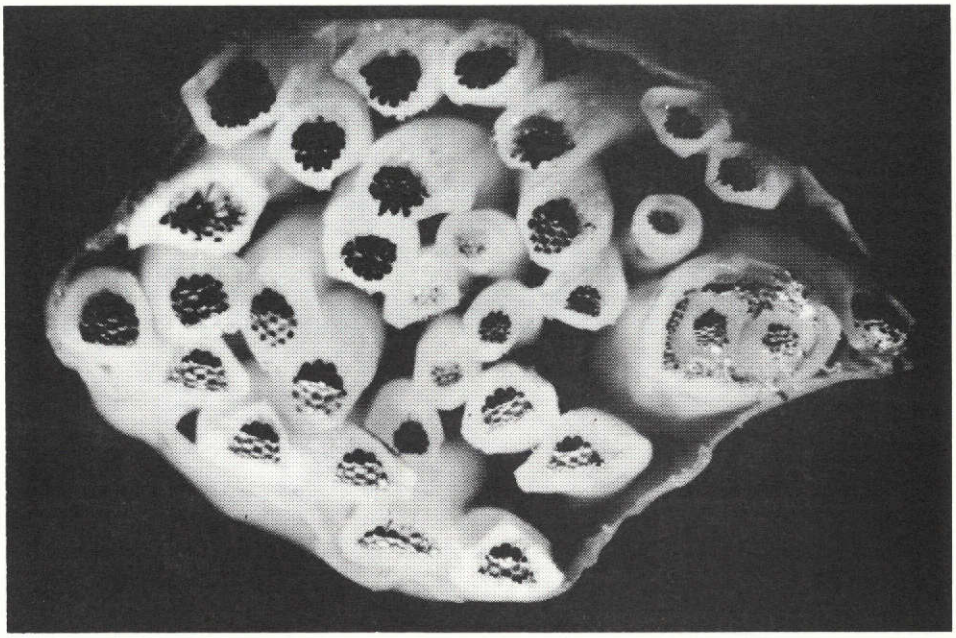

Figure 2. Typical cable cross-section

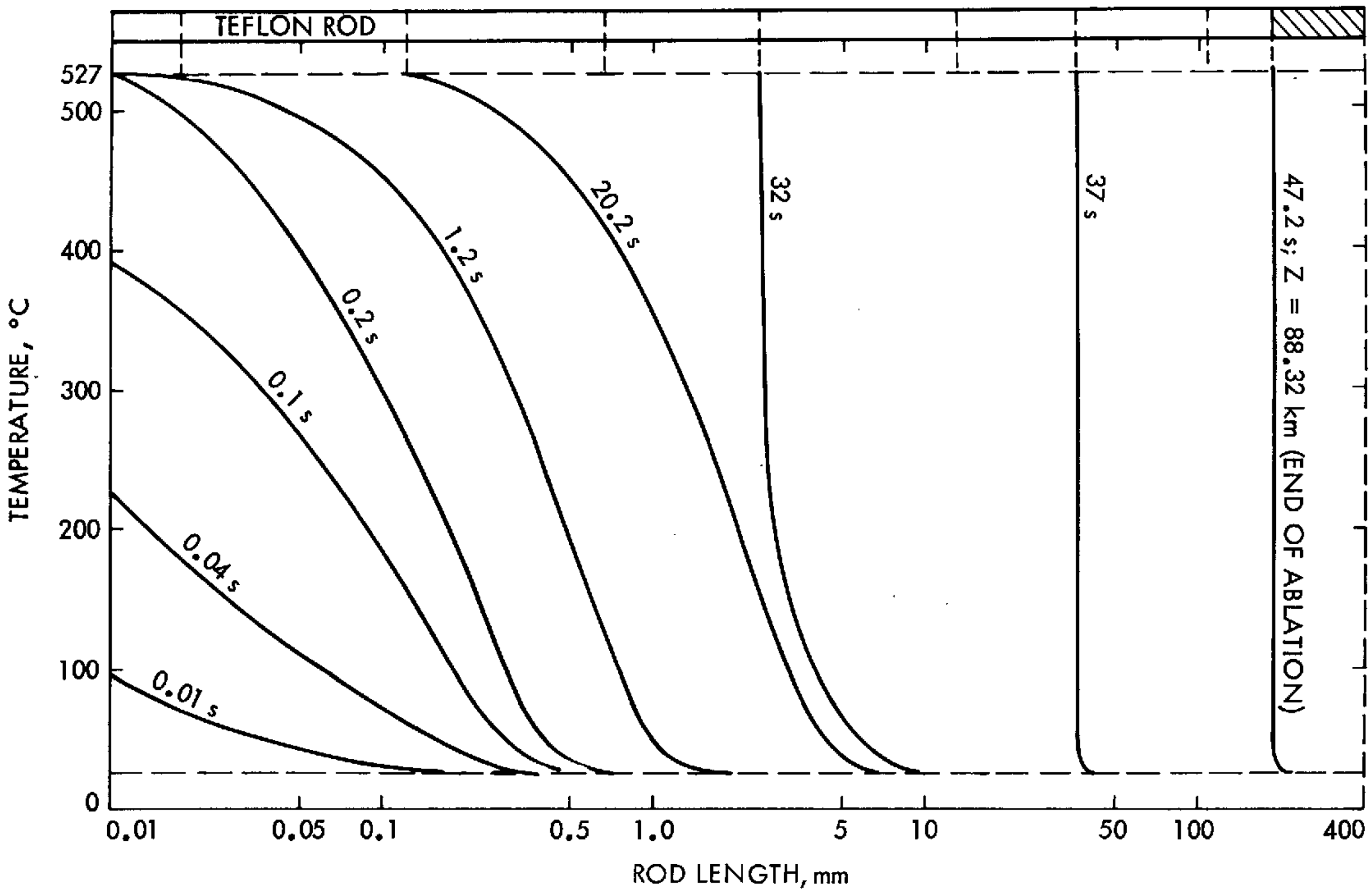

Figure 3. Temperature profiles of a Teflon rod for Jupiter entry at -15-deg entry angle: warm atmosphere, initial altitude = 750 km

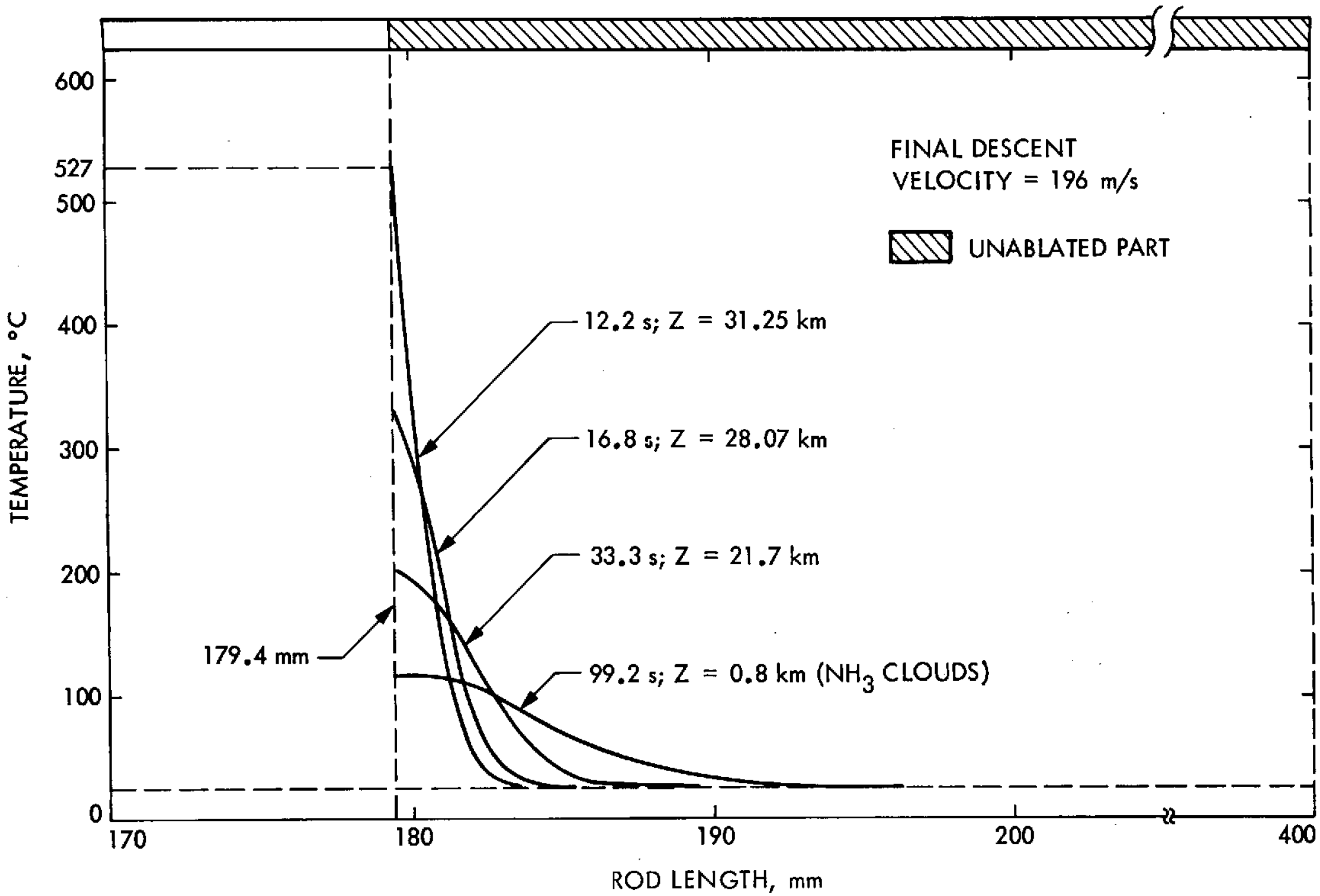

Figure 4. Temperature profiles in unablated Teflon: entry at -15-deg, warm atmosphere

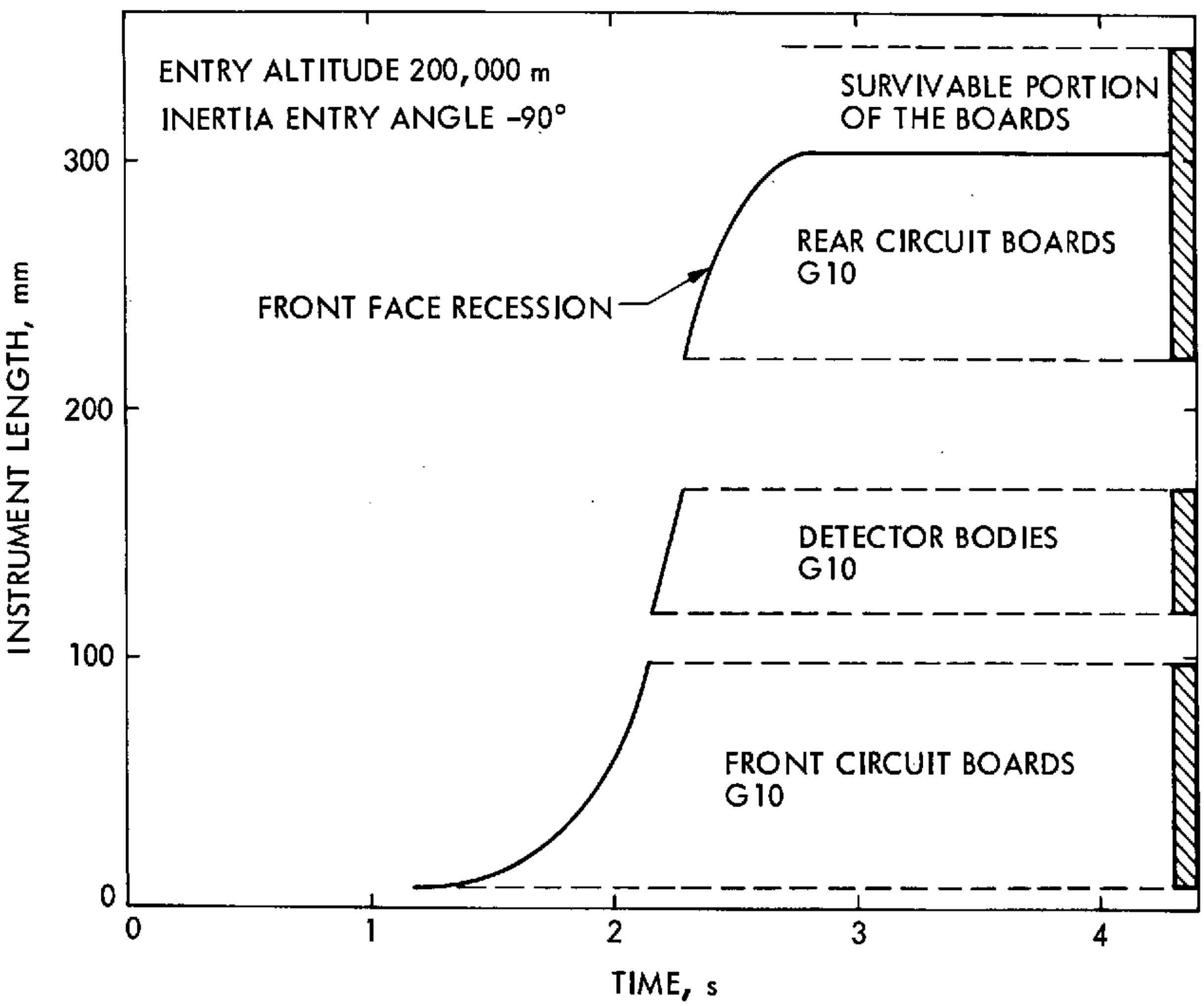

Figure 5. Ultraviolet spectrometer disintegration of plastics due to heat of Jupiter entry: entry at -90-deg, cool atmosphere

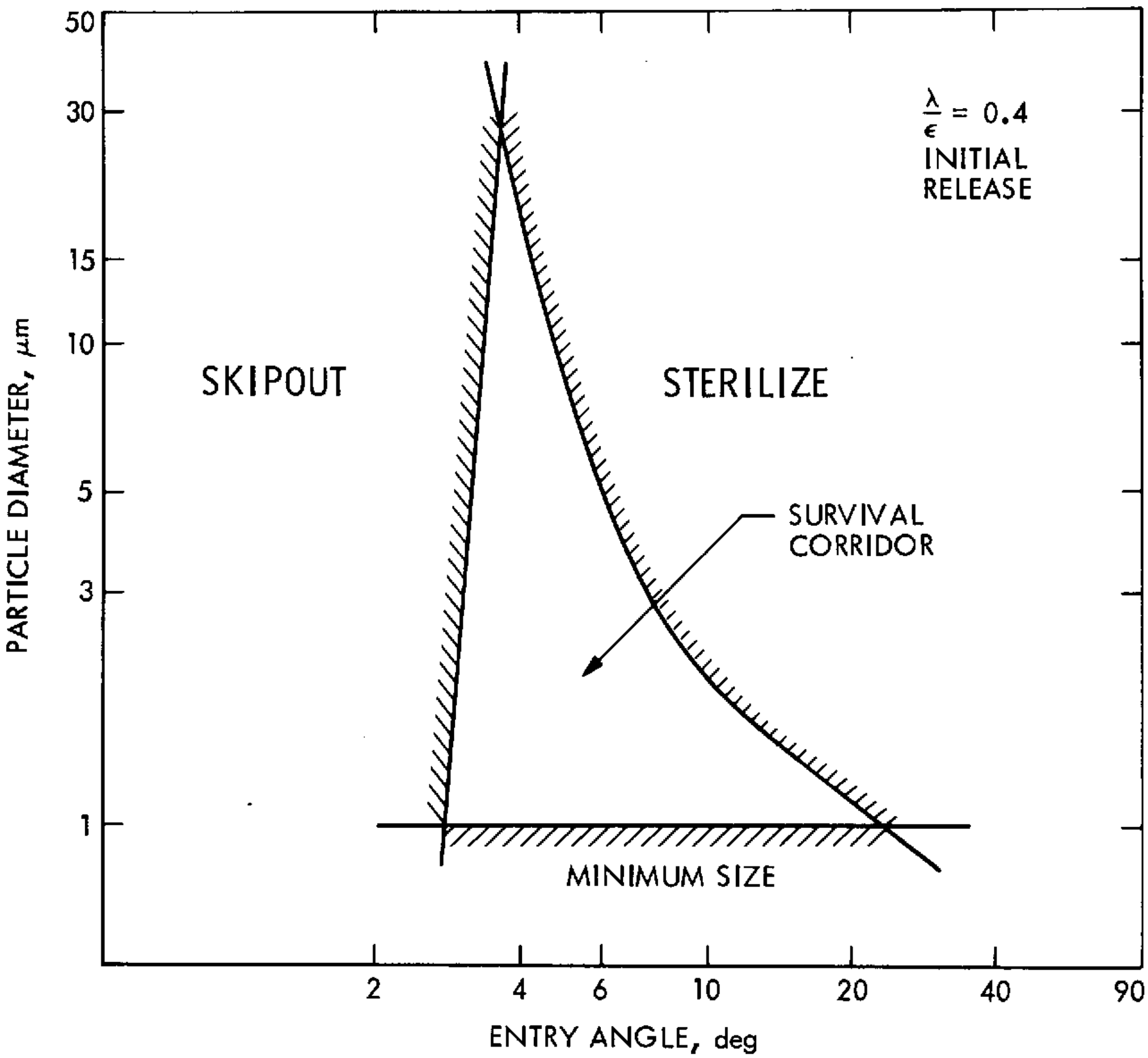

Figure 6. Survival corridor for small particle entry: Jupiter nominal atmosphere

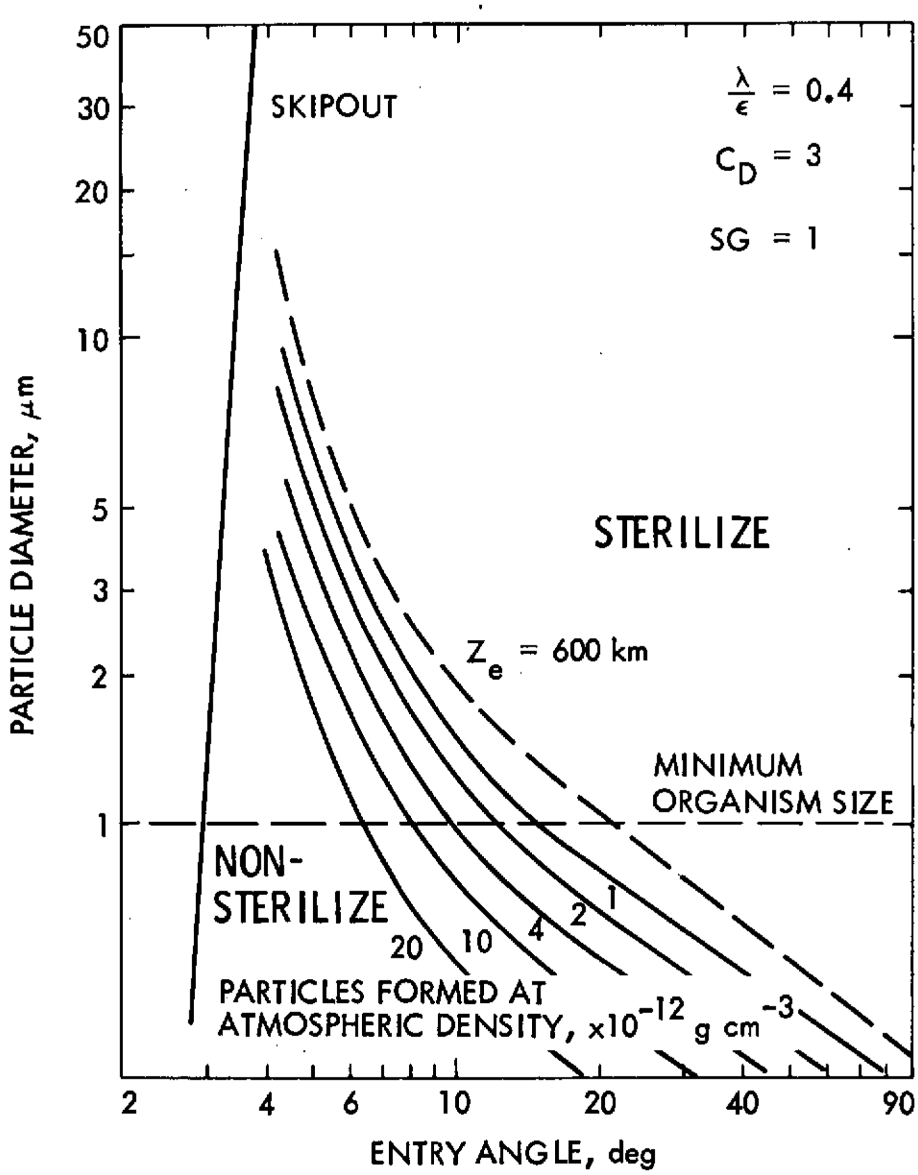

Figure 7. Effect of delayed release on small particle survival corridors: Jupiter nominal atmosphere

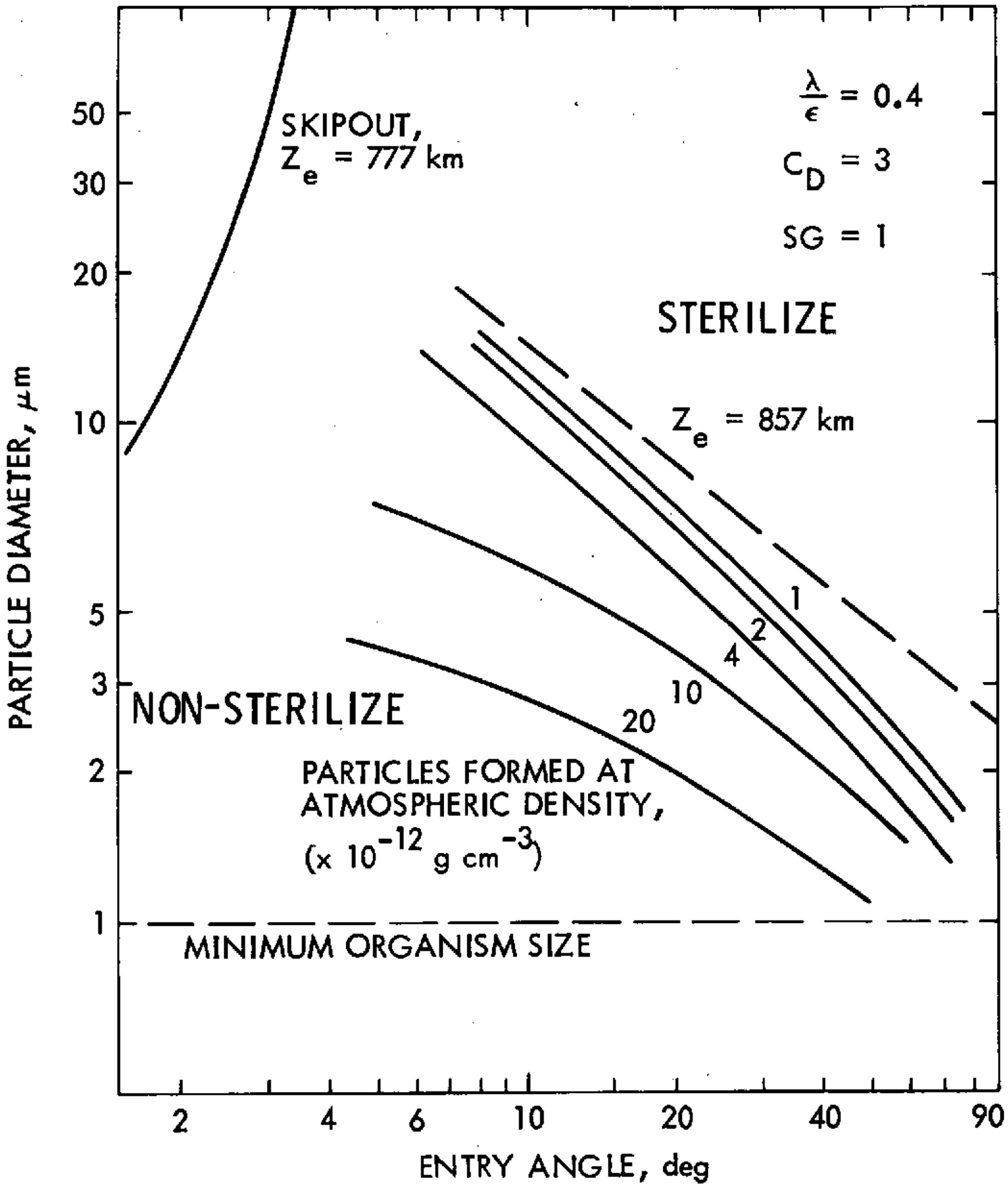

Figure 8. Effect of delayed release on small particle survival corridors: Saturn nominal atmosphere

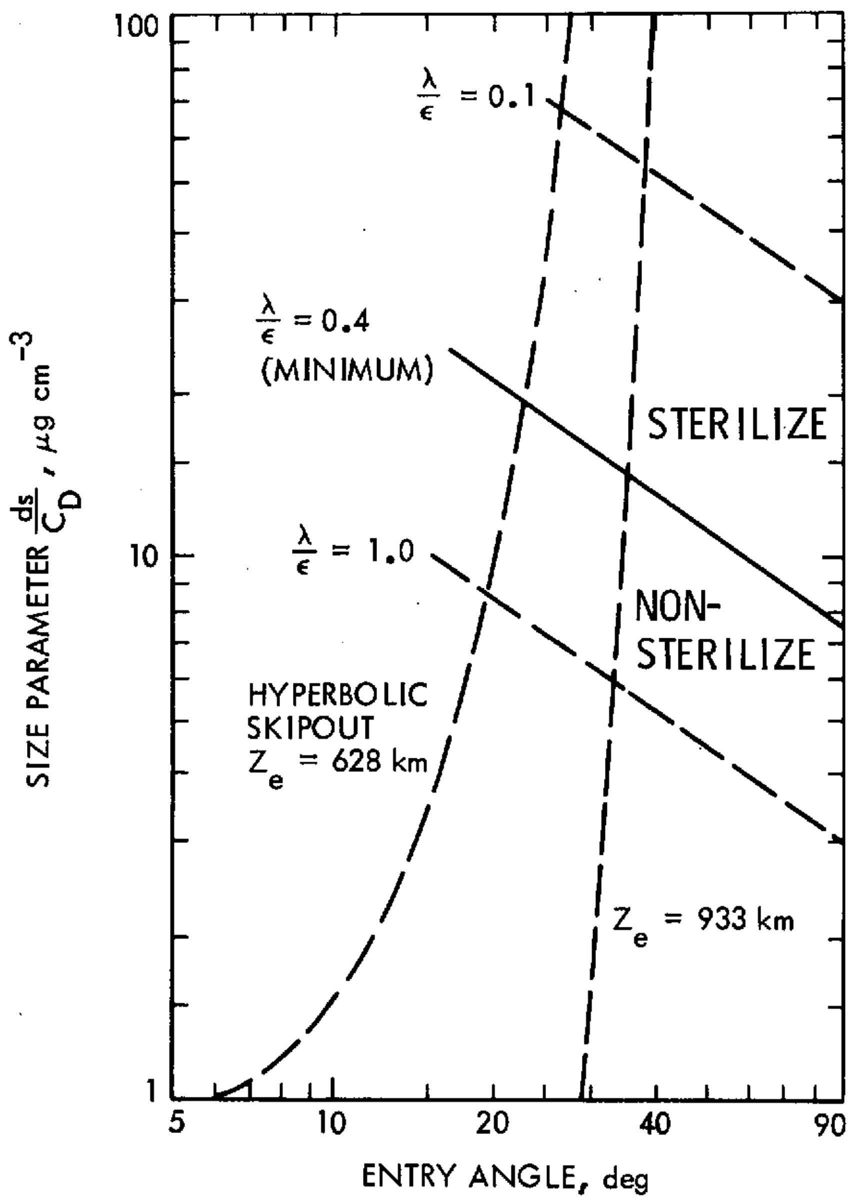

Figure 9. Effect of delayed release on small particle survival corridors: Titan nominal atmosphere