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ANALYSES AND SENSITIVITY STUDIES RELATED TO POST-LAUNCH RECONTAMINATION OF SPACECRAFT AND THE PROBABILITY OF CONTAMINATION OF A PLANET

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FINAL REPORT

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ABSTRACT

Analyses of the probability of post-launch recontamination of spacecraft and the subsequent probability of planetary contamination were performed for fly-by, orbiter and lander capsule unmanned planetary missions. Sources of microbial contamination, pertinent mission events and spacecraft design and operating characteristics were identified and analyzed. The recontamination of the spacecraft from the shroud during the launch phase was identified as a problem common to all types of missions. The additional factor of redistribution of organisms from the non-sterile portions of the spacecraft to the attached lander capsule prior to capsule de-orbit was also studied.

Studies were made of the sensitivity of the probability of planetary contamination to the various factors involved in recontamination for the three types of missions. Of the various factors, the probability of particle ejection from spacecraft surfaces was found to be of greatest significance for all missions.

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1.0 SUMMARY

The objective of the effort described herein was to perform analyses and sensitivity studies to delineate those spacecraft events which sufficiently impact the allocation for the overall probability of contamination of a planet to merit further evaluation by analytical and experimental means.

The scope of the analysis included studies of non-sterile fly-by and orbiter spacecraft, as well as a sterile lander capsule attached to a non-sterile orbiter spacecraft. Contamination of the planet by ejecta released after encounter by the fly-by and orbiter spacecraft was considered. The source of ejecta included the external spacecraft surfaces only, with contamination from internal systems, large non-sterile impactables and orbital decay of hardware not considered.

Analytical modeling of the hardware sources, mission events and recontamination factors was performed. This included the development of equations relating the sources, events and factors. Curves were plotted to show the sensitivity of the probability of planetary contamination to the pertinent recontamination factors.

Evaluations were performed of relationship of the microbial burden at a specific mission event for a given element of the system to the burden at a previous event, as influenced by recontamination from another portion of the system. For instance, the ratio of the burden on the spacecraft at encounter to that at shroud separation was evaluated as a function of the probability of ejection during cruise and the number of events which provide a force sufficient to dislodge an organism from the spacecraft surfaces. Dislodging events were identified as midcourse firings, attitude control system firings and deployment of appendages for all spacecraft, and also separation of the bioshield cap and lander capsule for lander missions.

For all missions, the probability of contamination of the planet was shown to be directly proportional to the burden on the spacecraft at encounter. This burden was shown to be exponentially related to the probability of ejection during cruise. The probability of contaminating the planet either by post-

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encounter ejecta or by recontamination of a sterile lander capsule was found to be sensitive to the probability of ejecting an organism from the spacecraft. For the lander capsule, mission and design constraints were identified which would minimize recontamination.

A recommendation is made for expanding the analytical model of recontamination of the lander capsule, which would involve developing more detailed equations for burden redistribution than presented in this report. These equations would be in a form suitable for computer programming with both probability distributions and discrete values as input and output. These equations would identify the physical factors associated with the relative probabilities. Analytical studies to determine the probabilities of ejection, transfer and adhesion of organisms should be continued, supported by experimental data if available.

Because of the sensitivity to the probability of ejection, knowledge of the burden at shroud separation is important. This requirement establishes the need to evaluate the transfer of burden to the spacecraft from the shroud during launch and for a precise estimation of the probability of organism ejection from spacecraft surfaces during cruise and after encounter.

2.0 INTRODUCTION

2.1 General Statement of Problem

Contamination of a planet with microbial organisms of terrestrial origin can occur as a consequence of exploration by unmanned spacecraft. These organisms are present on the spacecraft as a result of normal manufacturing, assembly and testing operations, and will remain until launch unless removed by surface decontamination of terminal heat sterilization. For spacecraft which are not intended to land on a planetary surface, reduction of microbial burden by such methods is not normally provided. A non-sterile spacecraft may receive microbial burden during the launch phase from the shroud in addition to the original burden on the spacecraft at launch. This increase in burden is termed "recontamination". For lander missions, sterile portions of the spacecraft are susceptible to transfer of organisms from non-sterile spacecraft hardware during the entire mission. This redistribution of burden is also termed "recontamination."

Whether recontamination of planetary spacecraft as a result of post-launch events does or does not significantly affect the overall probability of contamination of a planet depends upon the events which occur subsequent to recontamination. These events include the survival of microbial organisms in space, their transport to the planet and release and growth in its atmosphere or on its surface. If the values for those factors used on the Planetary Quarantine analysis are sufficiently small, then the recontamination problem is not of significance. However, recent experimental and analytical studies have indicated that the values for these factors are such that recontamination of the spacecraft may indeed be a factor of concern.[1] This is particularly true for a lander mission where the probability that a viable organism may be transported to the planet if it is on the lander may be high enough to result in violation of the quarantine constraint.

Much work has been done to identify events which may occur during the performance of a planetary mission and result in recontamination of the spacecraft.[2,3,4] Analytical studies have identified parametric relationships for many factors involved in these events, and subsequent experimentation has produced values for several of the parameters. Further analyses and experiments have been suggested for the determination of values for other parameters.

It was the purpose of this effort to identify those aspects of the recontamination problem to which the overall probability of planetary contamination is especially sensitive. For these specific aspects, further experimentation or analytical investigations may be warranted to obtain quantitative data on the probability of occurrence of events related to transport, survival or release of viable microbial organisms during planetary missions.

2.2 Objective

The objective of the effort described herein was to perform analyses and sensitivity studies to delineate those spacecraft events which sufficiently impact the allocation for the overall probability of contamination of a planet to merit further evaluation by analytical and experimental means.

2.3 Scope

The scope of the effort included fly-by, orbiter and lander missions. The mission profiles utilized are typified by the Mariner-Mars '69 for the fly-by, Mariner-Mars '71 for the orbiter and Viking '75 for the lander mission. The analysis did not consider the release of viable organisms from spacecraft internal systems, nor the contamination of the planet by impactable hardware, such as an upper stage or separation debris, which is not intended to land on the planet. Contamination of the planet from decay of the orbit of a bioshield or an orbiting spacecraft, or from trajectory errors relative to aim-point biasing, was likewise outside the scope of this effort.

The effort was conducted under JPL Contract 953009, "Analyses and Sensitivity Studies Related to Post-Launch Recontamination of Spacecraft and the Probability of Contamination of a Planet." The approximate expenditure of effort was two man-months, over a ten week period, excluding preparation of this final report.

3.0 TECHNICAL DISCUSSION

3.1 Literature Study

Sources of information on recontamination were identified and reviewed to provide a consolidation of previous analyses and experimental efforts. A bibliography of identified documents is presented as Appendix A.

From an examination of the data available in the literature, the following is apparent:

a. The information in the literature is rarely expressed as probability of occurrence of an event; rather, the literature primarily contains estimates of the magnitude of the severity of the interplanetary environment from the standpoint of micrometeoroid flux, solar wind and magnetic forces. Table I presents a summary of probability values obtained from the literature. Values of pertinent variables are included in the abstracts of selected references presented in Appendix A.

b. The reported experimental results and analytical conclusions are based on a wide range of assumptions and constraints, including specific assumptions regarding design characteristics, material properties and mission profiles. As a result, correlation of quantitative values is exceedingly difficult. No attempt was made to perform this correlation.

Because of the above factors, little use could be made of quantitative information obtained from the literature in performance of the sensitivity analyses.

3.2 Analysis

The primary emphasis of the effort was on determining the sensitivity of the probability of planetary contamination to factors affecting the recontamination of spacecraft.

Analyses were conducted for fly-by and orbiter missions initially, then expanded to cover the case of a landing capsule. The general approach and constraints are common to all three missions, permitting the analysis to

TABLE I SUMMARY OF RECONTAMINATION PROBABILITIES

PARAMETER	VALUE	SOURCE
Probability of recontamination from micrometeoroid puncture for typical Mars mission	$p_r = 1.1 \times 10^{-4}$	**Ref. 2**
Probability of surviving environment	$Pr = 10^{-3}$	**Ref. 2**
Probability of surviving entry, etc.	$Pr = 10^{-5}$	**Ref. 2**
Probability of surviving UV kill for single organism	$Pr = 7 \times 10^{-8}$	**Ref. 3**
Fraction of organisms ejected at bioshield opening	$.02 < Pr < .1$	**Ref. 3**
Probability of contaminating Mars as a result of recontaminating a lander	$Pr = 4 \times 10^{-5}$	**Ref. 3**

be developed first for the fly-by and then expanded to meet the needs of the orbiter and lander missions. The similarity of the recontamination factors for the three missions is illustrated by Figure 1.

3.2.1 Definitions and Notation

3.2.1.1 Definitions

The following definitions were used for the flight equipment items, mission events and recontamination factors discussed in this report. Figure 2 identifies the flight equipment items defined herein. Figure 3 presents a composite mission profile which identifies the mission events defined herein.

Adhesion

The attachment of an organism to a surface such that a force is required to break the physical bond for detachment and subsequent ejection.

Bioshield

The item of flight equipment which encloses the capsule for the purpose of maintaining sterility subsequent to terminal sterilization.

Capsule

The item of flight equipment borne to the target planet by the spacecraft, being separated from the spacecraft and entering the planetary atmosphere from planetary orbit. Due to planetary quarantine constraints and biological experimentation requirements, the capsule is assumed to be biologically sterile at time of launch, i.e. the probability of an organism remaining on or in the capsule at launch is several orders of magnitude less than unity.

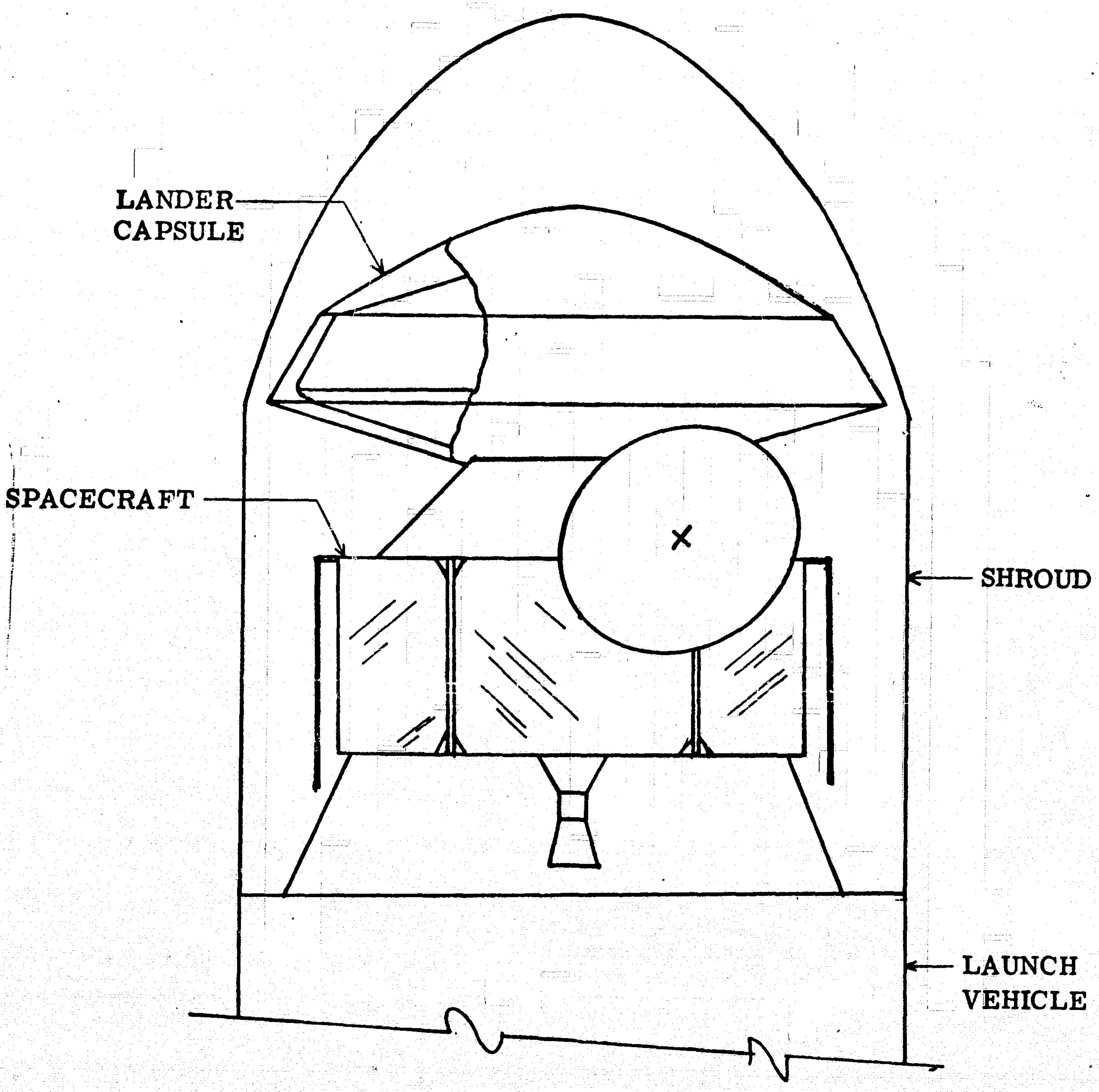

FIGURE 2. IDENTIFICATION OF FLIGHT HARDWARE

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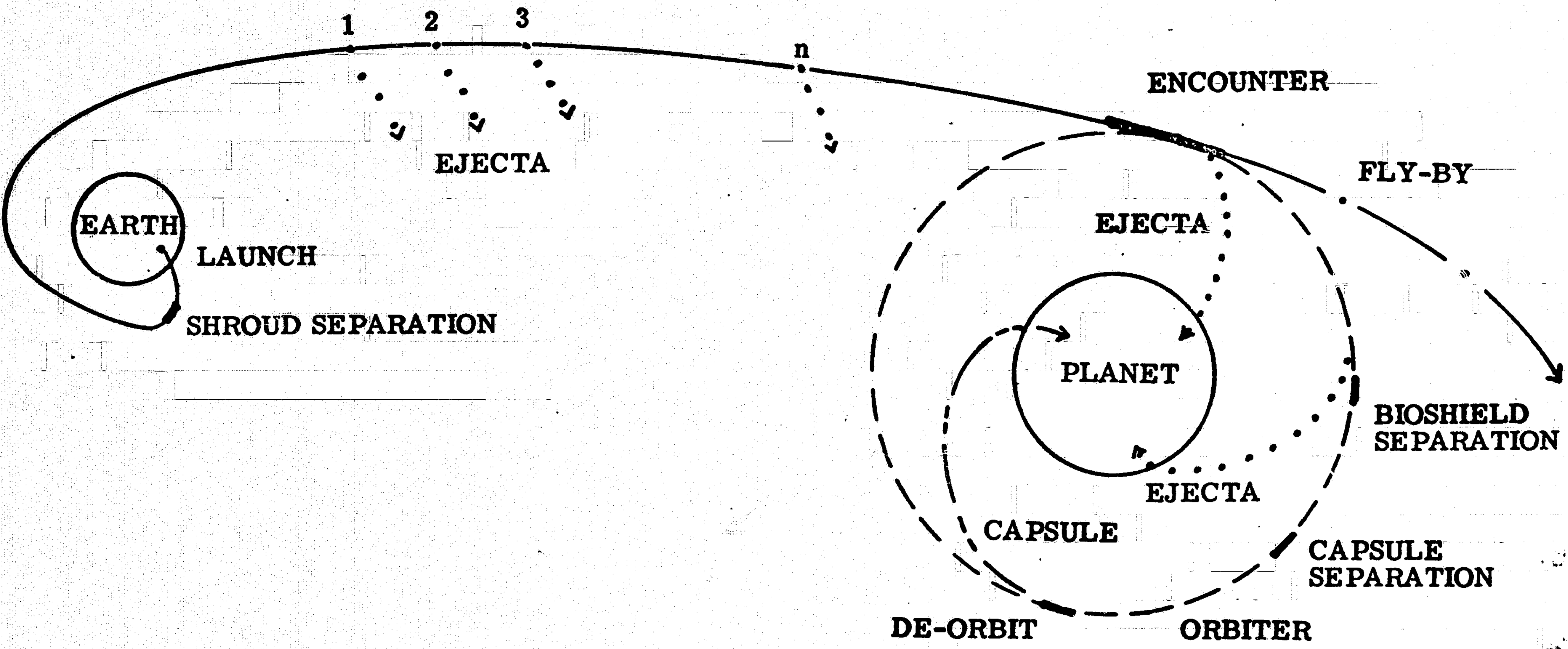

FIGURE 3. COMPOSITE MISSION PROFILE

De-orbit

The event in the lander flight sequence which commits the mission to intentional penetration of the planetary atmosphere and impact on the surface by the capsule.

Ejection

The release of an organism from a surface with sufficient velocity to escape from that surface, except as otherwise defined herein.

Encounter

The phase of the mission comprising the closest approach to the planet on the fly-by mission, or the period of the orbit insertion firing for orbiter and lander missions.

Final Stage

The item of flight equipment which imparts the heliocentric injection velocity to the spacecraft.

Launch

The mission phase which begins at lift-off and terminates with injection of the spacecraft into a heliocentric trajectory.

Recontamination

An increase in viable microbial burden over a baseline value at launch due to transport from a biologically contaminated source. For the fly-by and orbiter missions, recontamination can only occur during the launch phase from the shroud and launch vehicle. For the lander mission, recontamination also includes redistribution of organisms from the spacecraft or bioshield to the previously sterile landing capsule.

Redistribution

The transfer of organisms from one element of flight equipment to another, such as from the shroud to the spacecraft or the bioshield to the capsule.

Separation

The phase of the mission comprising the physical separation of flight equipment items, such as the capsule and spacecraft, the displacement of the items due to an imparted relative velocity, and any spacecraft for capsule operations, such as re-stabilization, which immediately follow.

Spacecraft

The item of flight equipment which is launched into a heliocentric trajectory to encounter the target planet. At encounter, the spacecraft either continues on a fly-by past the planet or is injected into an orbit about the planet. In the lander mission, the spacecraft carries a capsule which is dispatched to the planetary surface.

Transfer

The physical displacement of an organism from one element of flight equipment to another, due to a combination of ejection velocity from the source, geometrical factors affording impact and/or attractive forces to the recontaminated item.

3.2.1.2 Notation

Figure 4 illustrates the notation system used in this report in the form of a segment of a model representing the relationship between two or more events, sources and recontamination factors. Table II summarizes the subscripts used in the analysis.

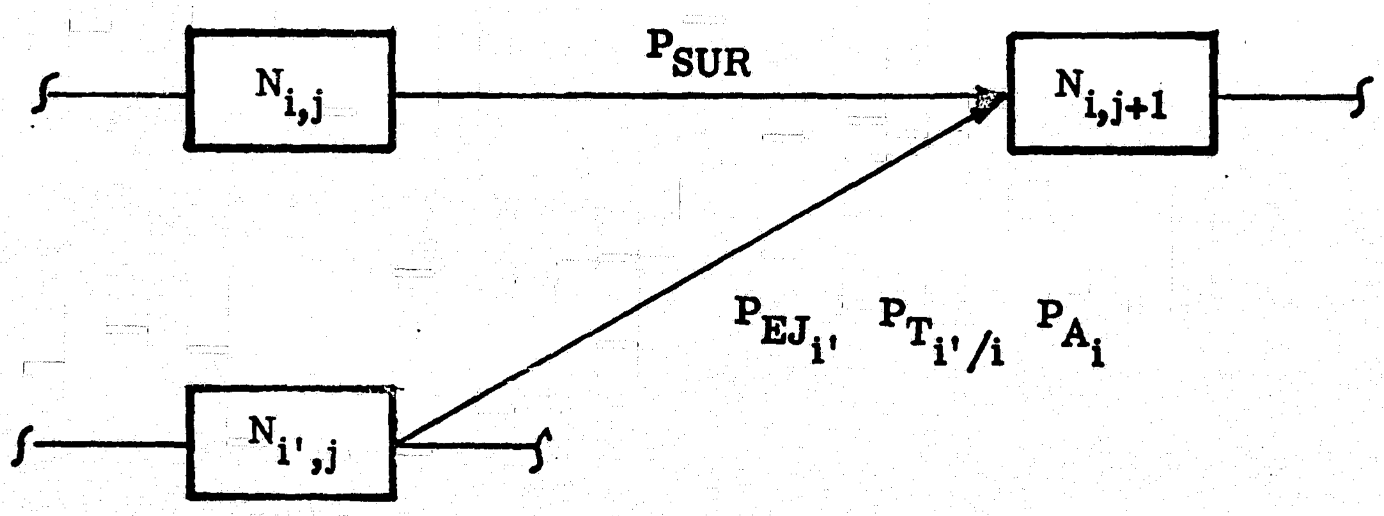

FIGURE 4. NOTATION EXAMPLE

TABLE II

NOTATION FOR RECONTAMINATION ANALYSIS

ith Item of flight Equipment		jth Mission Event		kth Factor	
Capsule	C	Launch	L	Ejected (From)	EJ
Bioshield	B	Shroud Separation	SS	Survives (During)	SUR
Spacecraft	SC	Encounter	EN	Transfer (From/To)	T
Shroud	SH	Bioshield Separation	BS	Adhere (From/To)	A
Launch Vehicle	LV				

Parameters describe either the number of organisms: N , or the probability of occurrence of an event: P. The utilization of subscripts is as follows, referring to Figure 4 for illustration:

$N_{i,j}$ - The number of organisms on the ith item of flight equipment at the jth mission event.

Example: - $N_{SC,BS}$ denotes the burden on the spacecraft at bioshield separation.

P_k - The probability of occurrence of the kth factor influencing recontamination. When this probability involves one or more items of flight equipment, it is written:

P_{k_i} or $P_{k_{i/i'}}$ where i and i' denote two items of flight equipment.

Examples: $P_{EJ_{SC}}$ is the probability of ejection from the spacecraft and $P_{T_{SC/BS}}$ the probability of transfer from the spacecraft to the bioshield.

3.2.2 Analysis of a Fly-By Mission

The generalized profile for the fly-by mission is shown in Figure 5. The pertinent mission events and factors which contribute to spacecraft recontamination and contamination of the planet are shown schematically in Figure 6. The source of contamination with which we are concerned is the viable ejecta from the spacecraft surfaces, consistent with our exclusion of large impactables and internal system ejecta. The probability of contamination from ejecta is expressed as

$$P_C = (N_{EJ_{SC}} \prod P_k) \; P_R \; P_G \qquad (1)$$

This expression relates the probability of contamination to the number of organisms ejected from the spacecraft, the probability of reaching the planet in a viable condition and then being released and growing on the surface. Since the last two terms are usually specified by NASA directives, they may effectively be treated as constants.

The values used for solution of this equation are such that for actual missions, their product is far less than unity. It has become accepted practice to express the product as a probability, rather than a quantity, even though this is not mathematically rigorous. This convention is followed here and in subsequent applications of the general equation.

The P_K's in the product term include the following:

P_{SEJ} = Probability of the organism surviving the ejection process. For dislodges surface ejecta, this term may be assumed to equal unity.

P_I = Probability of the organism being on an impact trajectory to the planet.

$P_{SUR_{EN}}$ = Probability of the organism surviving the space environment in the time period between ejection from

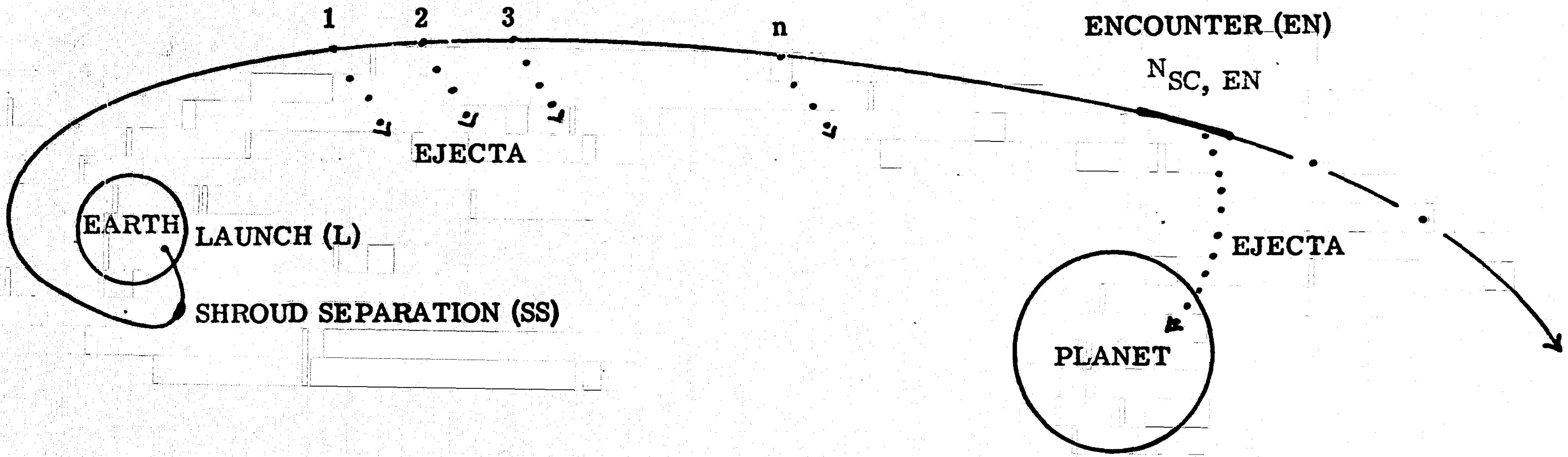

FIGURE 5. MISSION PROFILE FOR FLY-BY SPACECRAFT

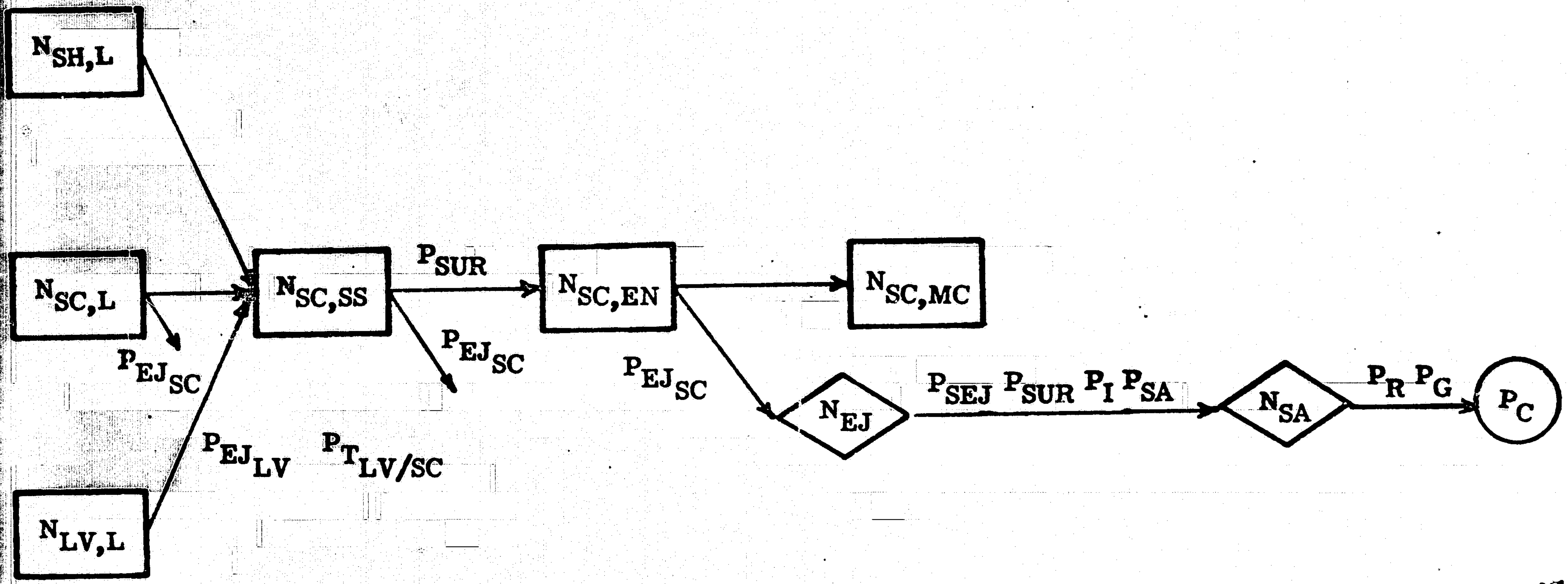

FIGURE 6. RECONTAMINATION AND PLANETARY CONTAMINATION EVENTS FOR FLY-BY AND ORBITER

the spacecraft and entry into the planetary atmosphere. For the fly-by mission, the short time of exposure induces this term to effectively equal unity.

P_{SA} = Probability of the organism surviving entry into the planetary atmosphere.

P_I and P_{SA} are values with distributions corresponding to the time of ejection relative to encounter, mass and velocity of the ejected particle, mass properties of the planet and the atmospheric characteristics. They are the actual variables in the $\prod P_k$ term, which is expressed as a parameter in Figure 6, the plot of

$$P_c / P_R \; P_G = N_{EJ_{SC}} \prod P_k \tag{2}$$

Figure 6 identifies the parameter of concern in evaluating the probability of contamination as the number of organisms ejected from the spacecraft. To determine $N_{EJ_{SC}}$, we must know the number of organisms on the spacecraft at encounter, $N_{SC,EN}$, and then introduce the assumption that all of the ejecta will be released in a sufficiently brief time period that the post-encounter $P_{EJ_{SC}}$ will be a single discrete value. We may then write

$$N_{EJ_{SC}} = N_{SC,EN} \; P_{EJ_{SC}} \tag{3}$$

The spacecraft burden at encounter is a value which we can relate to the burden at other points in the mission, the principal one being shroud separation. This allows us to evaluate the effect of organisms ejected during cruise by ratioing the burden at encounter to that at shroud separation. This expression is

$$N_{SC,EN} / N_{SC,SS} = P_{SUR_C} \; (1 - P_{EJ_{SC}})^n \tag{4}$$

Where n denotes the number of dislodging events between shroud separation and encounter and P_{SUR_C} the probability of surviving the cruise phase. The assumption herein is that each event, including engine firings, attitude control system actuations, micrometeoroid hits and deployment of appendages, ejects organisms with equal probability and imparts to them sufficient velocity to escape the gravitational and electrostatic influence of the spacecraft. P_{SUR_C} is taken

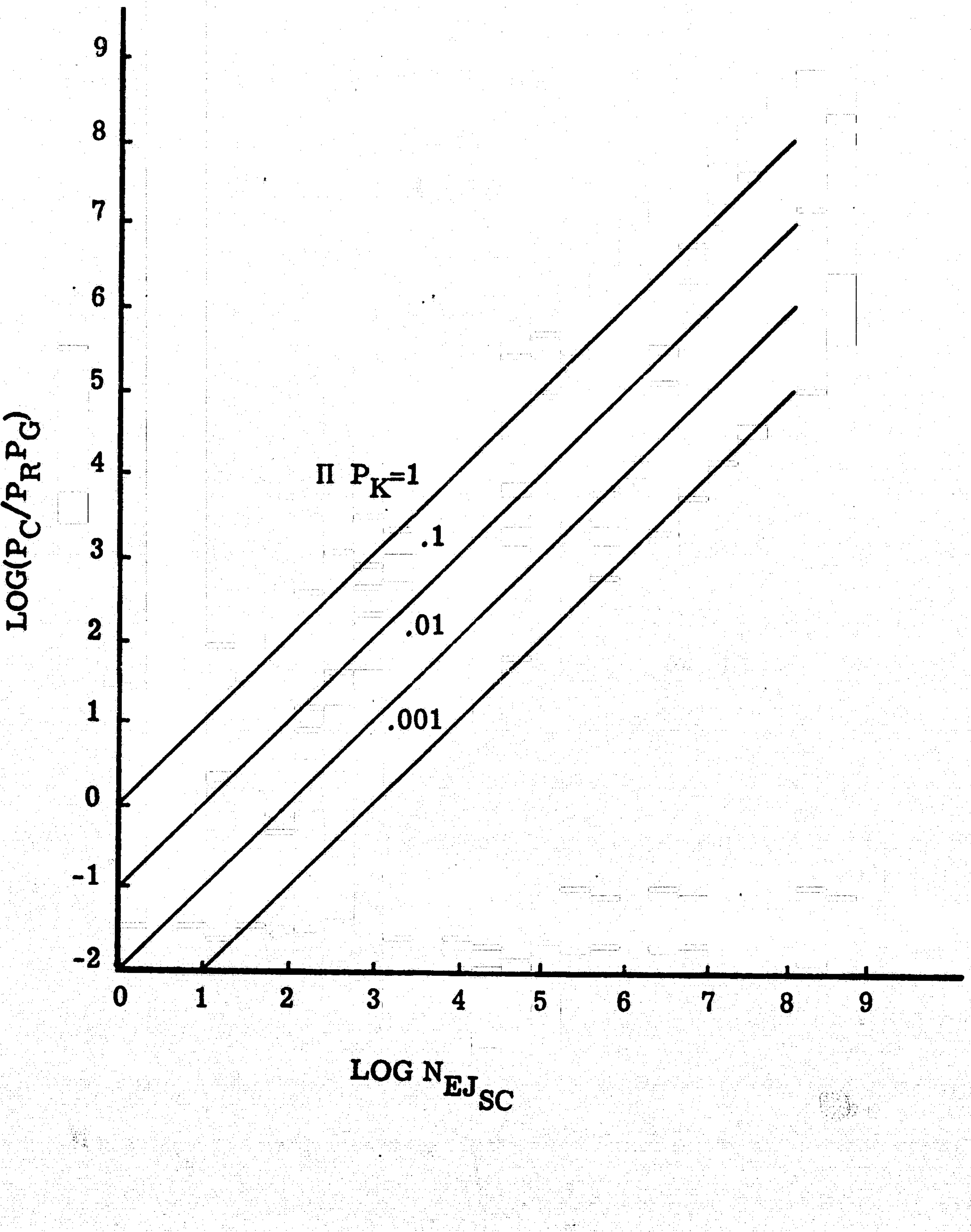

FIGURE 7. GENERAL EQUATION FOR PLANETARY CONTAMINATION

as a constant and the sensitivity of the burden ratio to it not evaluated.

Figure 8 shows the sensitivity of the burden ratio to the probability of ejection and the number of dislodging events. The curves illustrate that the burden ratio becomes very sensitive to the probability of ejection beyond approximately $P_{EJ_{SC}} = .1$, indicating the need for determining the actual values of $P_{EJ_{SC}}$ for the specific mission and spacecraft configuration. For an actual mission, the curves of interest will be for $n > 10$, since a minimum number of events must occur for the spacecraft to achieve encounter and perform its operational functions.

We have introduced the assumption that the post-encounter dislodgement of organisms occurs as a single event with the same probability of ejection as each pre-encounter dislodgement. The justification for this assumption is that the time during which the spacecraft is in the vicinity of the planet is very short relative to the cruise phase, and the likelihood of performing more than one reorientation or stabilization maneuver is small. Appendages will have been deployed and no further course corrections are required. The number of organisms ejected during this event can be related to the burden at shroud separation by

$$N_{EJ_{SC}} / N_{SC,SS} = P_{SUR_C} \; P_{EJ_{SC}} \; (1 - P_{EJ_{SC}})^n \tag{5}$$

This expression yields, in non-dimensional form, the ejected burden on the event following n previous dislodging events. That is, n events have occurred since shroud separation to release organisms and thereby reduce the burden on the spacecraft at encounter. The next event releases a number of organisms expressed by $N_{EJ_{SC}} / N_{SC,SS}$.

Figure 9 shows equation (5) plotted with n as a parameter. The fact that each curve has a maximum and decreases as $P_{EJ_{SC}}$ approaches either 0 or 1 is of particular interest. The physical interpretation of the curves is that, for very low $P_{EJ_{SC}}$, the spacecraft is still highly contaminated (relative to its burden at shroud separation), but there is a low probability

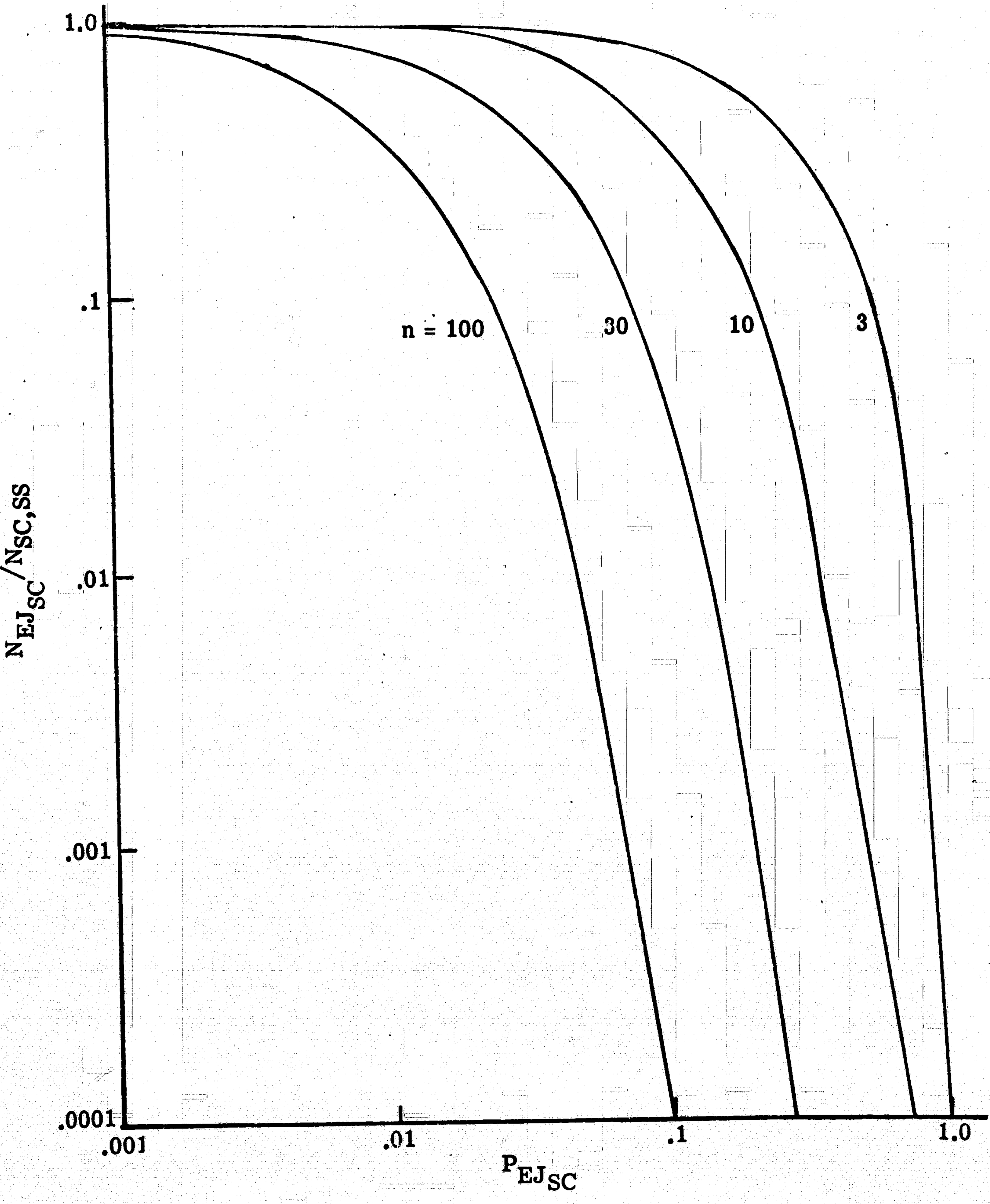

FIGURE 8. BURDEN ON SPACECRAFT AT ENCOUNTER

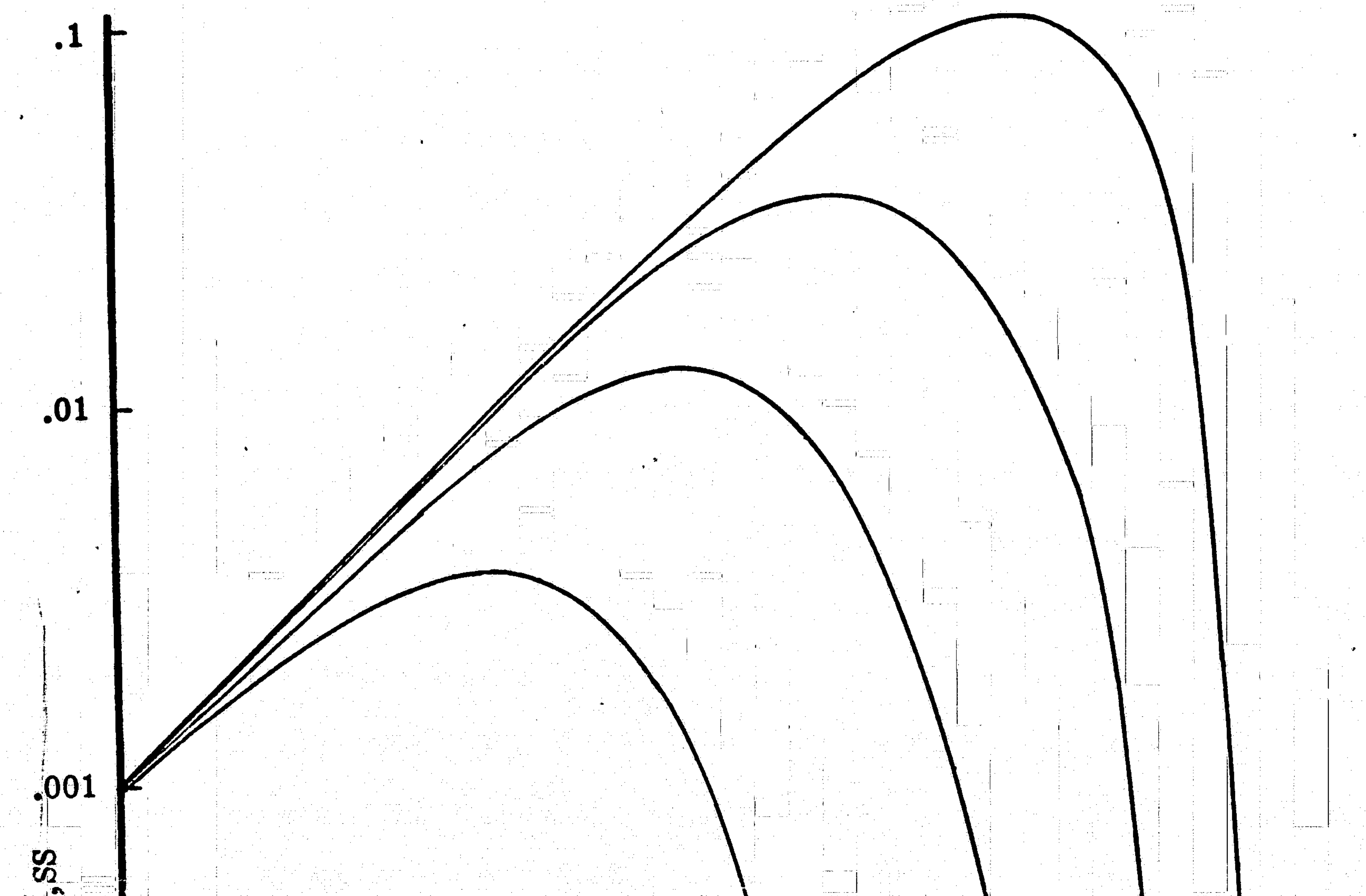

FIGURE 9. ORGANISMS EJECTED DURING ENCOUNTER

of organisms being released in a post-encounter event. For the other extreme, where $P_{EJ_{SC}}$ approaches unity, almost all of the organisms are shaken off early in the cruise phase, leaving a relatively clean spacecraft at encounter. Even though the burden at encounter has a high probability of being released in the latter case, the low burden at this time will result in a low quantity of ejecta being released at a post-encounter event. The curves of interest will again be for n > 10, as established previously. We see that the burden ratio is more sensitive to $P_{EJ_{SC}}$ between the maximum and unity, providing a reduction of an order of magnitude or more in the burden ratio for doubling the value of $P_{EJ_{SC}}$. It is therefore of importance to know the actual value of $P_{EJ_{SC}}$ for the mission and spacecraft configuration of interest to determine whether the value is on the steep side of the maximum where the burden ratio is extremely sensitive, or to the left where the ratio varies directly with $P_{EJ_{SC}}$. It is also important to establish, through mission and design analysis, the number of dislodging events prior to encounter, in order to determine which curve to use.

In the analysis presented above, the burden on the spacecraft at shroud separation was considered as the initial condition and ratios for this burden or base were used. For an actual mission, this burden level cannot be measured directly but can only be estimated from the burden determined by assay at encapsulation. Assuming neither increase or decrease in burden level from encapsulation to launch, the only factors affecting the burden level on the spacecraft are those which occur during the launch phase, primarily the transfer of organisms from the shroud to the spacecraft. This relationship is expressed by

$$N_{SC,SS} = N_{SC,L} + N_{SH,L} \left(P_{EJ_{SH}} \; P_{T_{SH/SC}} \; P_{A_{SC}}\right) \qquad (6)$$

The above expression is plotted in Figure 10, which shows $N_{SC,SS}$ as a function of the original burden on the spacecraft at launch, $N_{SC,L}$, and the organisms transferred from the shroud. This increase in burden is the recontamination

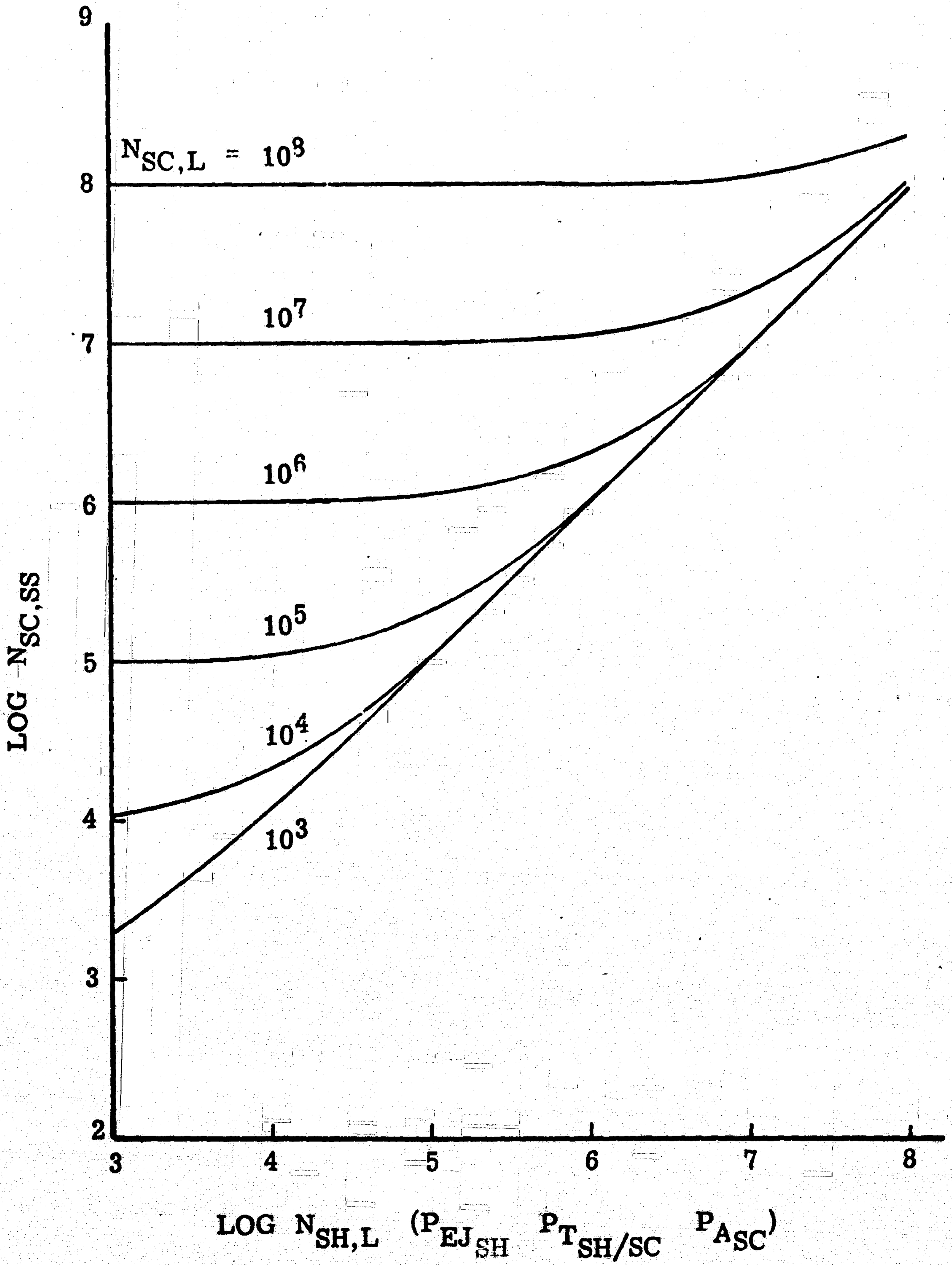

FIGURE 10. BURDEN ON SPACECRAFT AFTER SHROUD SEPARATION

mechanism for the fly-by spacecraft, assuming for this analysis that the original burden on the spacecraft is not dislodged by shock and vibration, but increased by the amount transferred from the shroud and adhering to the spacecraft.

From Figure 10, we can see that $N_{SC,SS}$ is controlled by either the original burden on the spacecraft or that transferred from the shroud, depending on the relative magnitude of these sources. Initially, let us assume that all of the burden on the shroud is ejected, transferred to and adheres to the spacecraft. Then, an equal number of organisms on the spacecraft and shroud at launch will result in a doubling of the burden on the spacecraft at shroud separation. This may be regarded as relatively insensitive, given the level of precision of microbiological assay data. If the shroud contribution is greater than the spacecraft original burden by an order of magnitude or more, however, the shroud contribution becomes the controlling factor and the spacecraft may effectively be ignored in its effect on $N_{SC,SS}$. In this case, no benefit will be accrued from reducing the spacecraft burden to a very low level by cleaning, as $N_{SC,SS}$ is effectively the shroud contribution. It therefore becomes important to determine what the probabilities are associated with transfer of organisms from the shroud. This will permit us to establish the value of knowing the spacecraft burden or the value of deliberately reducing its magnitude through decontamination operations or use of contamination control facilities.

A brief example is presented to illustrate the sensitivity relationships developed above, using the following values:

$P_C = 10^{-4}$ allocation for mission

$P_R = 1.0$ for surface burden which impact the planet as ejecta

$P_G = 10^{-4}$ for Mars surface

$P_{SUR_C} = .1$ for cruise phase

$P_{SUR_{EN}} = 1.0$ for encounter phase

$P_T = .1$ due to high encounter velocity and fly-by trajectory

$P_{SA} = .1$ due to entry heating if the organism does impact the planet

$P_{EJ_{SC}} = .1$ for each dislodging event

$n = 30$ dislodging events before encounter

The general equation for planetary contamination yields

$$P_C / P_R P_G = N_{EJ_{SC}} P_{SUR_{EN}} P_T P_{SA} \quad (7)$$

$$10^{-4} / (1) (10^{-4}) = N_{EJ_{SC}} (1) (.1) (.1) \quad (8)$$

Thus, $N_{EJ_{SC}} = 10^2$ organisms are allowed to be ejected from the spacecraft during encounter. The allowable burden on the spacecraft at encounter is therefore

$$N_{SC,EN} = 10^2 / .1 = 10^3 \quad (9)$$

Using Figure 9, we can determine the allowable burden on the spacecraft at shroud separation, given n = 30 dislodging events during cruise from

$$N_{EJ_{SC}} / N_{SC,SS} = .0004 \quad (10)$$

and

$$N_{SC,SS} = 10^2 / (4 \times 10^{-4}) = 2.5 \times 10^5 \quad (11)$$

The amount of microbial burden on the spacecraft at shroud separation could reasonably result from normal manufacturing of the spacecraft and shroud, followed by transfer from the shroud during launch. Figure 10 shows that reduction of the spacecraft original burden below 10^4 organisms is immaterial if the shroud burden level is greater than 10^5, and the effect of the spacecraft original burden decreases as the shroud contribution increases. Because $N_{SC,SS}$ is sensitive to shroud burden transfer, knowledge of $P_{EJ_{SH}}$, $P_{T_{SH/SC}}$ and $P_{A_{SC}}$ become important if accurate determination of $N_{SC,SS}$ is required. Therefore, we must evaluate how $N_{SC,SS}$ affects $N_{EJ_{SC}}$ in terms of sensitivity to $P_{EJ_{SC}}$.

Let us recompute our example with $P_{EJ_{SC}} = .2$, which doubles the value used originally. The number of organisms allowable on the spacecraft is now half as many, or 5×10^2, at encounter. The allowable ejecta remains the same, but the allowable burden at shroud separation increases as shown by Figure 9. We read, for n = 30,

$$N_{EJ_{SC}} / N_{SC,SS} = .00003 \tag{12}$$

which is more than an order of magnitude decrease from equation (11). This yields a value of

$$N_{SC,SS} = 10^2 / 3 \times 10^{-5} = 3.3 \times 10^6 \tag{13}$$

The sensitivity of the probability of contamination to $P_{EJ_{SC}}$ is thus shown by the fact that doubling the $P_{EJ_{SC}}$ results in more than a ten-fold increase in the allowable burden at shroud separation. This is due to the greater reduction in burden prior to encounter.

The following conclusions are offered for the fly-by spacecraft based on the above sensitivity analysis:

1. The probability of contaminating the planet is directly proportional to the number of organisms ejected from the spacecraft, which is exponentially related to the probability of ejecting organisms from the surface during cruise and encounter. For this reason, accurate knowledge of the actual value of $P_{EJ_{SC}}$ is required to determine the allowable burden at shroud separation.

2. Since the allowable burden at shroud separation may be critical, its sensitivity to the shroud contribution must be recognized and quantitative data on $P_{EJ_{SC}}$, $P_{T_{SH/SC}}$ and $P_{A_{SC}}$ obtained through analysis or experimentation.

3.2.3 Analysis of an Orbiter Mission

The mission profile for the orbiter spacecraft is shown in Figure 11. The events and factors which contribute to spacecraft recontamination and contamination of the planet may be represented by the same chart as presented in Figure 5 for the fly-by. The constraint placed on the fly-by mission regarding the exclusion of large impactables as a source of concern for this analysis is also applicable to the orbiter analysis, as is the decay of the spacecraft orbit. Both of these sources represent real potential for planetary contamination, but since they concern the impact of non-sterile hardware and not ejecta, we have excluded them from this analysis.

The effects of the recontamination of the spacecraft from the shroud during launch and the reduction of viable organisms during cruise are similar to those for the fly-by spacecraft, and the equations and curves presented earlier do hold. The mission profile, Figure 11, shows the departure from the fly-by mission in that there are m post-encounter dislodging events over a time period which exceeds the cruise phase by an order of magnitude or more.

Figure 12 shows the analytical model used for evaluating the effect of post-encounter dislodging events. The total ejecta from m events is related to the burden on the spacecraft at encounter by

$$\left(\sum_{i=1}^{m} N_{SC,i} \right) / N_{SC,EN} = 1 - (1 - P_{EJ})^{m} \qquad (14)$$

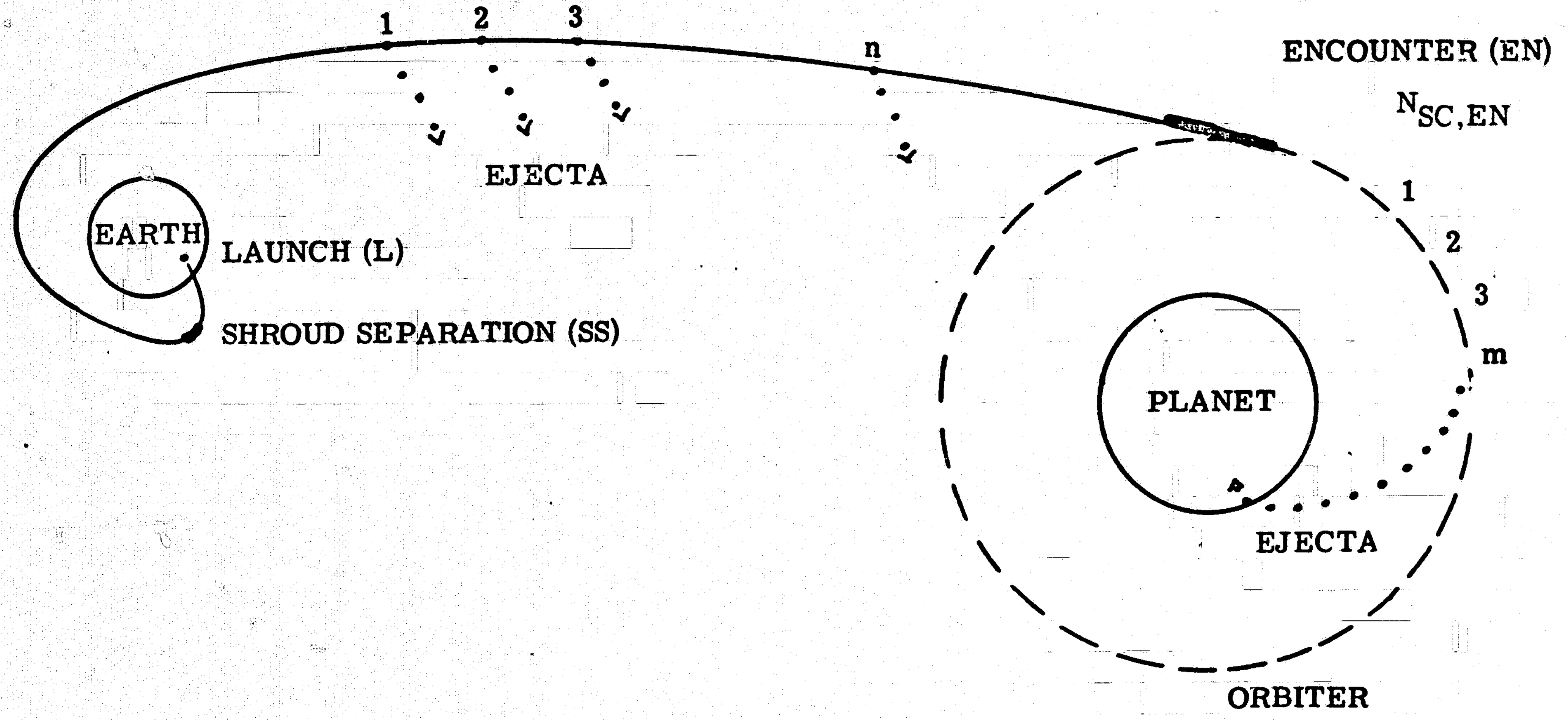

FIGURE 11. MISSION PROFILE FOR ORBITER SPACECRAFT

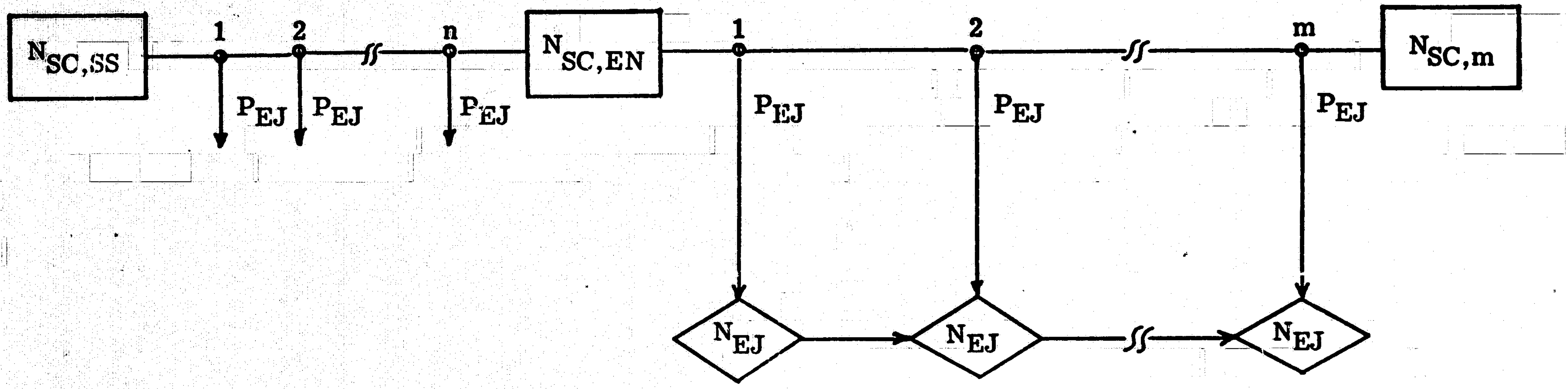

FIGURE 12. ANALYTICAL MODEL FOR ORBITER SPACECRAFT

The assumption used previously for the fly-by mission that each post-encounter event occurs with the same probability as those during cruise has been applied to the orbiter case. The expression for the burden at encounter

$$N_{SC,EN} \,/\, N_{SC,SS} = (1 - P_{EJ})^{n} \tag{15}$$

is valid for the orbiter analysis as it was for the fly-by analysis. Combining the above with equation (14), we have

$$\left(\sum_{i=1}^{m} N_{SC,i}\right) / \, N_{SC,SS} = (1 - P_{EJ})^{n} - (1 - P_{EJ})^{n+m} \tag{16}$$

Figure 13 shows the relationships expressed by the above equation for the assumptions that pre- and post-encounter probabilities of ejection are equal and that m = 10n, recognizing the order of magnitude difference between n and m. The sensitivity of the burden ratio to the probability of ejection is again demonstrated. Also of interest is the fact that the maximum burden transferred to the planet is approximately constant at about 70% of the burden at shroud separation. From the above analysis we can draw the same conclusions for the orbiter mission that were stated for the fly-by, relative to the importance of determining $P_{EJ_{SC}}$ and evaluating the effects of the shroud contribution. Also, mission and spacecraft design must be evaluated for the specific application to determine the values of n and m to be used. Estimation of the value of $P_{EJ_{SC}}$ applicable to the specific application is required to utilize Figure 13 to determine the data points on the steep side of the maximum for the given value of n where sensitivity is greatest.

3.2.4 Analysis of a Lander Capsule Mission

The mission profile for the lander capsule is shown in Figure 14 and a typical spacecraft and lander capsule configuration is shown in Figure 15. We have retained the constraints regarding contamination by large impactables, including decay of the orbiter and bioshield cap. The recontamination problem

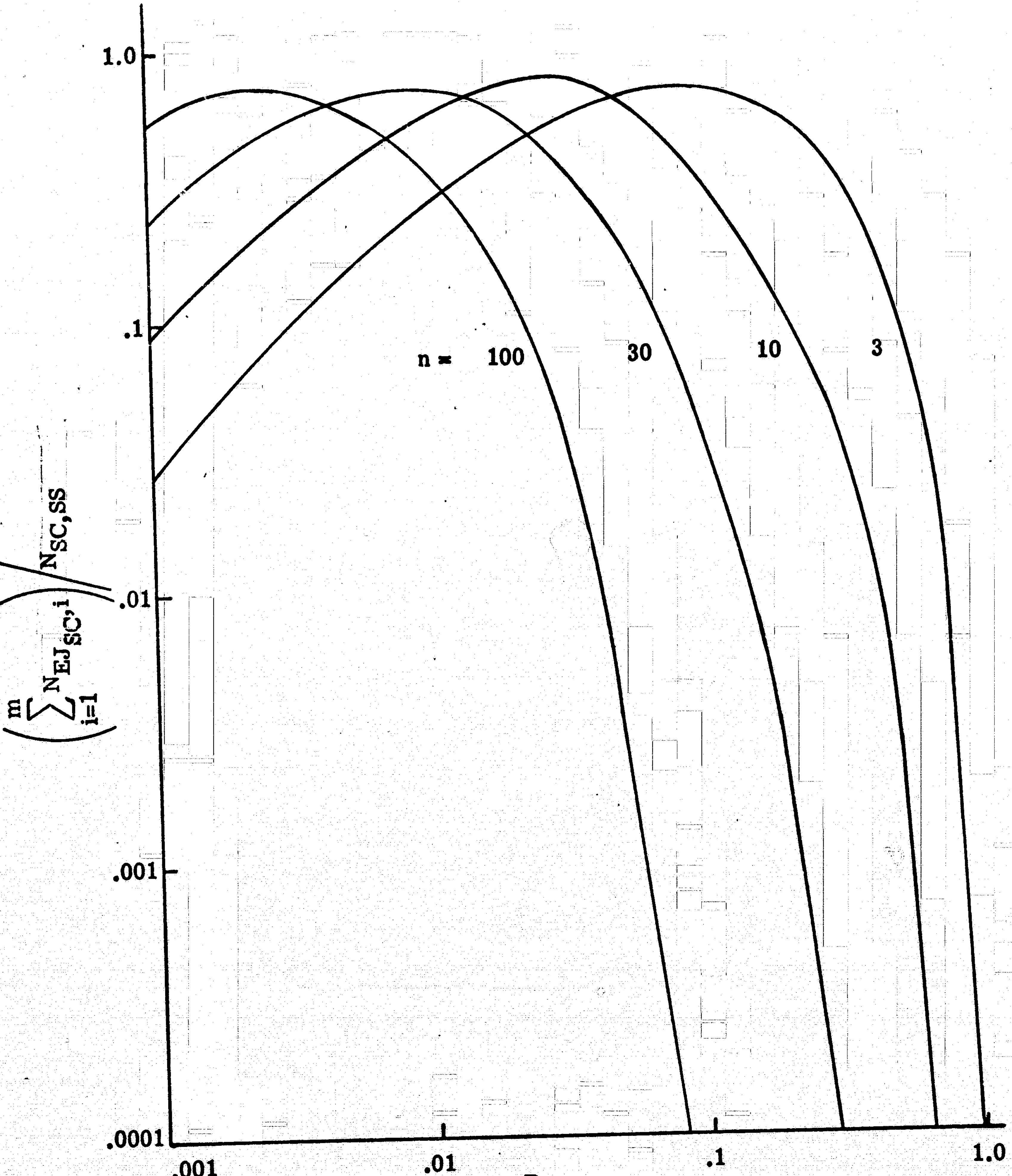

FIGURE 13. ORGANISMS EJECTED DURING ORBITAL PHASE

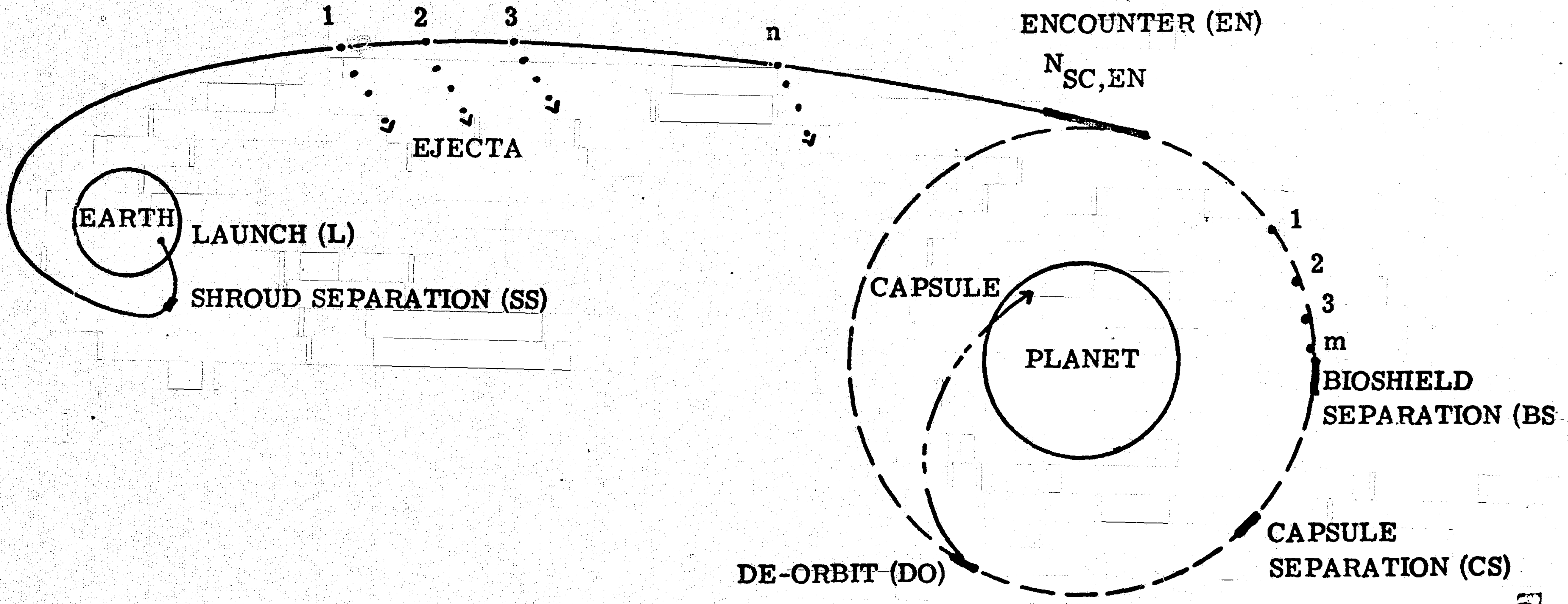

FIGURE 14. MISSION PROFILE FOR LANDER CAPSULE

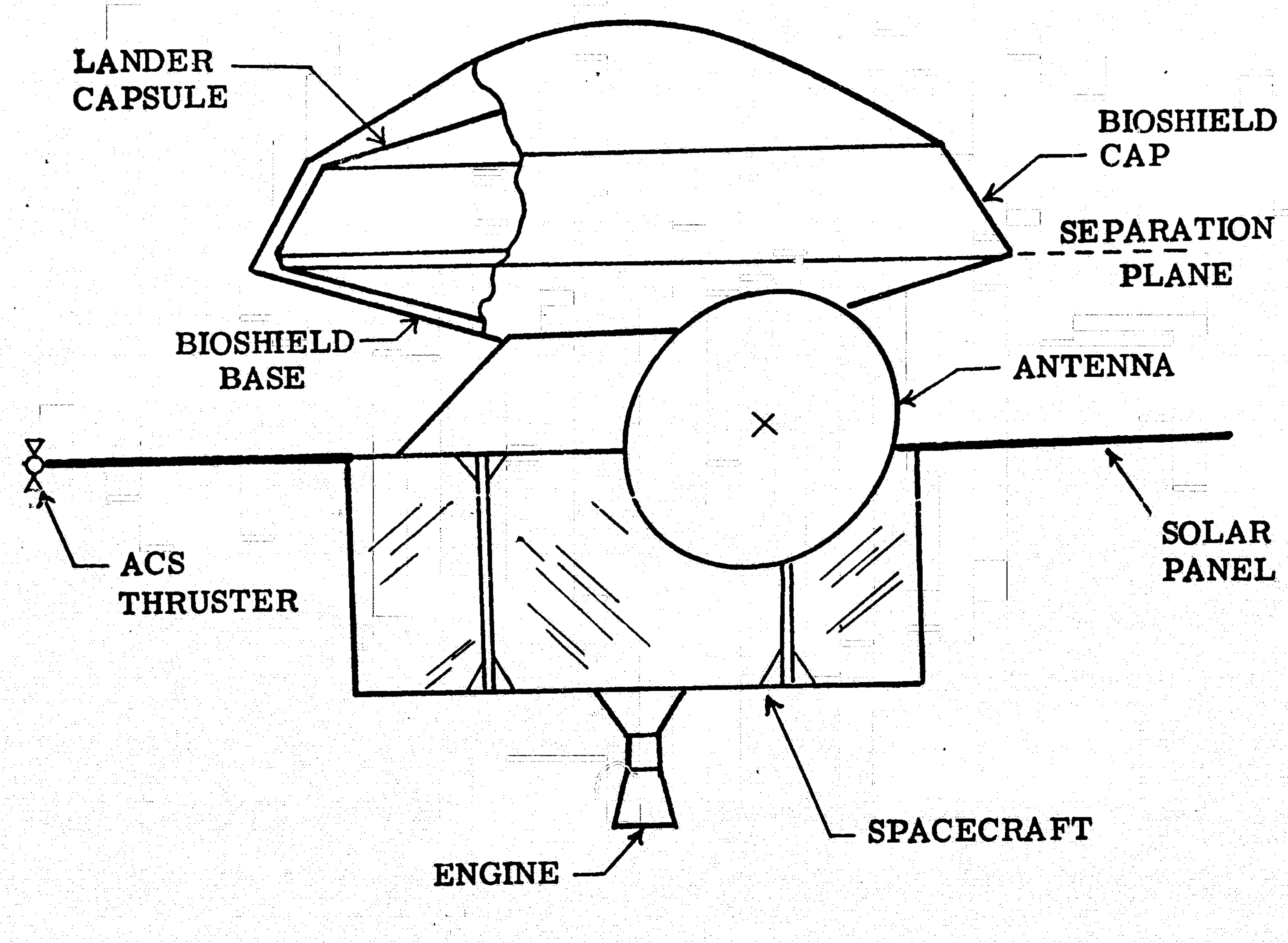

FIGURE 15. SPACECRAFT/LANDER CAPSULE CONFIGURATION

is more complex than for the fly-by and spacecraft, in that we are concerned not only with increasing the burden on the spacecraft and bioshield cap during the launch phase, but also with redistribution of burden between the spacecraft, bioshield cap and lander capsule. The eventual objective of the analysis is, in fact, the determination of the burden on the lander capsule at the time of de-orbit. The burden at de-orbit may be related to the probability of contamination by

$$P_c = N_{C,DO} \left(\prod P_k \right) P_R P_G \tag{17}$$

and the product terms of interest are P_I , $P_{SUR_{EN}}$ and P_{SA} as discussed in 3.2.2. Due to the existence of an intentional impact as a consequence of performing the deorbit maneuver, P_I will equal unity; $P_{SUR_{EN}}$ and P_{SA} must be evaluated for the actual mission. Once this is done, P_c / P_R P_G may be evaluated by using Figure 7 as discussed for the fly-by spacecraft.

The complex inter-relationships in the redistribution of viable organisms between items of flight equipment is illustrated by Figure 16. Each transfer of organisms involves three factors:

$P_{EJ_{i'}}$:	The probability of ejection from the i'th item of flight equipment
$P_{T_{i'/i}}$:	The probability of transferring the organism from item i' to item i.
P_{A_i} :	The probability of the organism adhering to item i.

In combination, the burden on an item at a given event may be related to its burden at a previous event and the redistributed burden from another item may be stated as

$$N_{i,j+1} = N_{i,j} P_{SUR_C} + N_{i',j} P_{EJ_{i'}} P_{T_{i'/i}} P_{A_i} \tag{18}$$

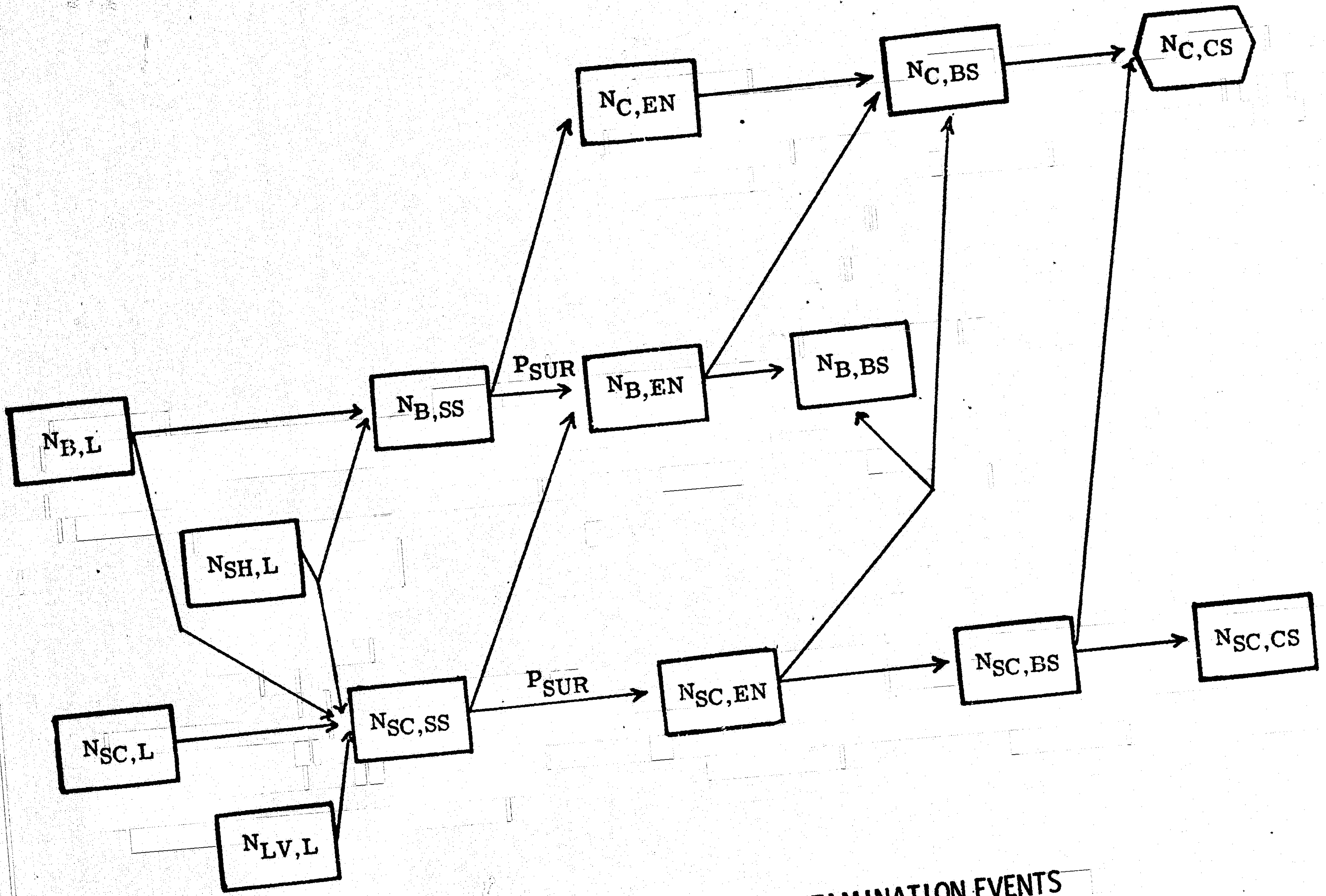

FIGURE 16. LANDER CAPSULE RECONTAMINATION EVENTS

The sensitivity of the burden at shroud separation may be evaluated by using Figure 10, introduced for the fly-by analysis, since the forms of equations (18) and (6) are the same. The potential for recontaminating the lander capsule for the cruise phase and subsequent events is evaluated below.

3.2.4.1 Cruise Phase

Figure 17 illustrates the recontamination factors associated with the cruise phase. The sources of contamination are the bioshield external surface and the spacecraft surfaces. The lander capsule and bioshield internal surface are assumed to be sterile as a result of the terminal sterilization process.

Penetration of the bioshield base appears to be of relatively less significance than penetration of the cap. The base must be constructed of heavier gage material to withstand the structural loads imposed by providing support for the cap. If the capsule installation is such that the aeroshell points toward the spacecraft, as shown in Figure 15, organisms penetrating the base will impact the aeroshell and be subjected to high heat fluxes during atmospheric entry, reducing P_{SA} in the general contamination equation. With the aeroshell installed in this manner, however, the base cover is exposed to organisms which penetrate the thinner material of the bioshield cap, as well as directly to ejecta after bioshield separation. These organisms will not receive the high heat fluxes of those on the aeroshell and will have a higher P_{SA}. Because of these factors, the "worst case" assumption that the aeroshell points toward the spacecraft, as shown in Figure 15, is used for all phases of this lander recontamination analysis.

The dislodging forces during cruise result from:

1. Firing of the spacecraft engine for midcourse corrections, orbit insertion and orbit trim maneuvers.

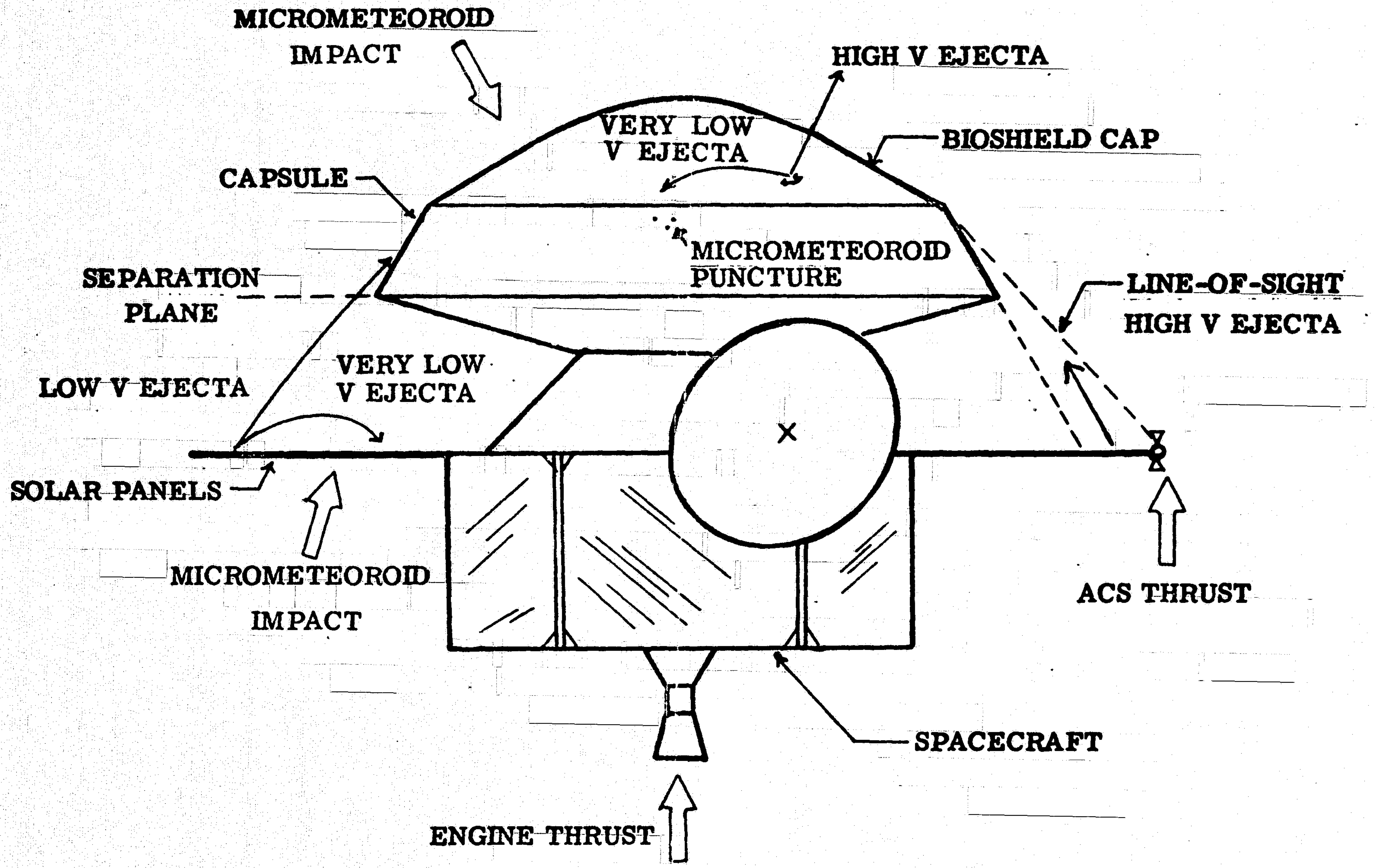

FIGURE 17. CAPSULE RECONTAMINATION DURING CRUISE

2. Micrometeoroid impact on the spacecraft and bioshield cap.

4. Firing of the ACS for vehicle stabilization and reorientation.

4. Deployment of appendages, including antennas, solar panels and instrument booms.

Application of sufficient force to spacecraft and bioshield surfaces will result in breaking of the adhesive bond between the organism and surface. Once separated, the organism will be ejected in one of three velocity regimes:

1. Very low velocity ejecta which re-impact near the point of dislodging.

2. Low velocity ejecta which enter unstable partial orbits about the vehicle, re-impacting at random on the bioshield or spacecraft. During cruise, the effects of radiation pressure may influence the trajectories of these ejecta toward or away from the bioshield surface.

3. High velocity ejecta which either escape from the gravitational and electrostatic attractive forces of the vehicle or impact on surfaces in the line-of-sight from the release point.

During cruise, penetration of the bioshield must be afforded by separation debris, structural failure or impact of micrometeoroids. The first two factors can be controlled by design constraints. Micrometeoroid impact is a factor for which the amount of penetrated area can be estimated. During a given mission, this will depend on the micrometeoroid flux and bioshield design characteristics, especially surface area and material strength. A representative estimate of the total penetrated area for a typical Mars mission was obtained from reference as 3.4×10^{-8} ft.^{2}/ft.^{2} of a bioshield surface.[2] Because of the large reduction in the probability of penetration afforded by this small area, recontamination of the capsule during cruise as a result of micrometeoroid impact was not considered a significant problem and no further analysis was conducted for the cruise phase.

3.2.4.2 Bioshield Separation Phase

Figure 18 illustrates the potential recontamination mechanisms during the bioshield separation phase. The sources of contamination are the same as for the cruise phase, but the events providing the dislodging forces are different. These include:

1. ACS firing for vehicle orientation and stabilization before and after separation of the bioshield cap.
2. Detachment of the bioshield cap from the base by mechanical or pyrotechnic devices which impart a separation velocity to the cap relative to the spacecraft.

The shock impulses and vibrations produced by the above events will release organisms in all the velocity regimes defined previously. The transfer probability is increased over the cruise phase due to the exposure of the lander capsule base cover directly to the environment and the possibility of direct impact by ejecta. The recontamination aspects of this mission phase are discussed below.

3.2.4.2.1 Spacecraft Ejecta

Very low velocity ejecta which reimpact on spacecraft surfaces may, by definition, be neglected as sources of recontaminating the lander capsule. For these organisms, $P_{EJ_{SC}} = 0$.

Low velocity ejecta will be released with velocities and in quantities depending on their proximity to the source of the dislodging force

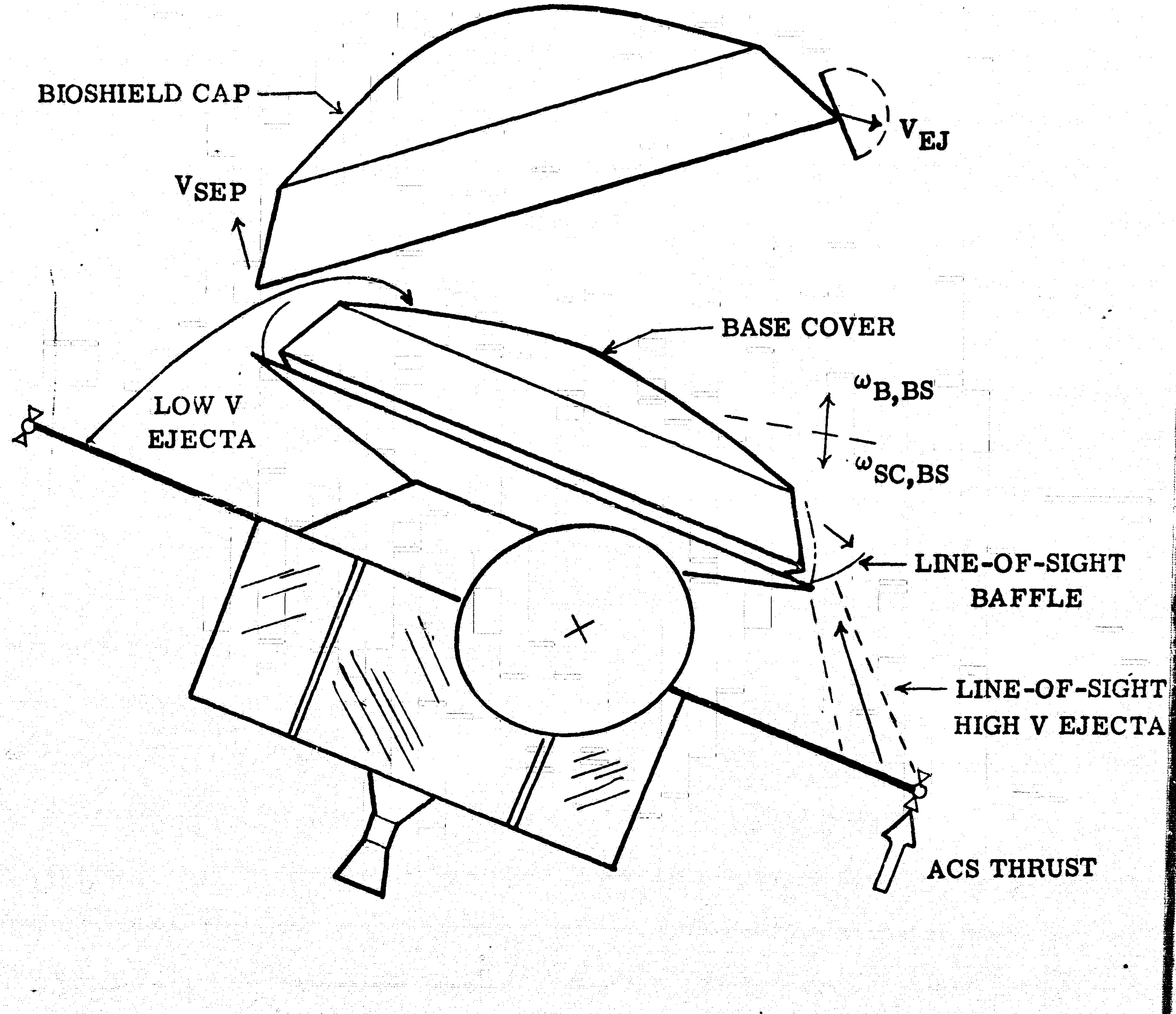

FIGURE 18. CAPSULE RECONTAMINATION DURING BIOSHIELD SEPARATION

such that a measurable influence on their trajectory is exerted by the spacecraft's gravity and electrostatic charge. These ejecta will enter into unstable orbits with re-impact points spread randomly over the bioshield and spacecraft surfaces.

It has been shown that the characteristics of these partial orbits change radically with small changes in the ejection velocity, so random distribution of the re-impact of these ejecta can be reasonably assumed.[2] The source for these ejecta is the entire spacecraft surface, and is not constrained by line-of-sight geometry.

The assumption is that, due to the short duration of the bioshield separation phase, solar pressure effects will not significantly influence the orbits of these ejecta and they will all re-impact on either the spacecraft or exposed base cover. The probability of transferring an organism to the base cover will be proportional to the ratio between the base cover area to the total vehicle surface area, assuming uniform mass and electrostatic surface charge distribution for the vehicle.

Additionally, consideration must be given to angular rates imparted to the spacecraft due to asymmetric separation of the bioshield cap, such that the base cover could rotate into the path of low velocity ejecta before vehicle re-stabilization is accomplished.

High velocity ejecta present a recontamination problem if a line-of-sight geometrical relationship exists between the base cover surfaces and contaminated spacecraft surfaces, as shown in Figure 18. This source can be eliminated, at the expense of weight, design complexity and reliability, through the use of line-of-sight baffles on the bioshield base, as shown in the Figure. A general equation for the capsule burden after bioshield separation may be written as

$$N_{C,BS} / N_{SC,EN} = \alpha \ (A_{BC}/A_V) \ P_{EJ_{SC}} \ (1 - P_{EJ_{SC}})^m \ P_{A_C} \quad (19)$$

where

A_{BC}/ A_V is the ratio of base cover area to the total vehicle surface area m is the number of dislodging events

α is proportional to the line-of-sight geometrical relationships between the spacecraft and base cover surfaces.

3.2.4.2.2 Bioshield Ejecta

The low velocity ejecta are a potential problem for the same reason as for low velocity spacecraft ejecta. Like the very low velocity ejecta, however, release of these organisms is essentially an instantaneous event associated with the separation itself, since no dislodging forces can be imparted to the bioshield cap after separation. Asymmetric separation of the cap must be evaluated, particularly since the likelihood of restabilizing the bioshield after separation is minimal without complex design ramifications. In the extreme, impact of the cap and base cover is possible.

High velocity ejecta do not present a recontamination problem, since none of the contaminated surfaces see the exposed base cover. All ejecta will have radially outward velocity components at the time of separation, assumed to be sufficient to overcome gravitational and electrostatic attractive forces.

The general equation for the bioshield as a source of recontamination during this phase is

$$N_{C,BS} / N_{B,EN} = P_{EJ_B} \; P_{T_{B/C}} \; P_{A_C} \qquad (20)$$

Where $P_{T_{B/C}}$ depends on the area relationships between base cover and spacecraft surfaces as discussed earlier, again assuming random re-impact of low velocity ejecta and uniform mass and charge distribution.

3.2.4.3 Capsule Separation Phase

Figure 19 illustrates the recontamination problem during the capsule separation phase. The only source of contamination is now the spacecraft, as the bioshield cap has long since moved away due to its separation

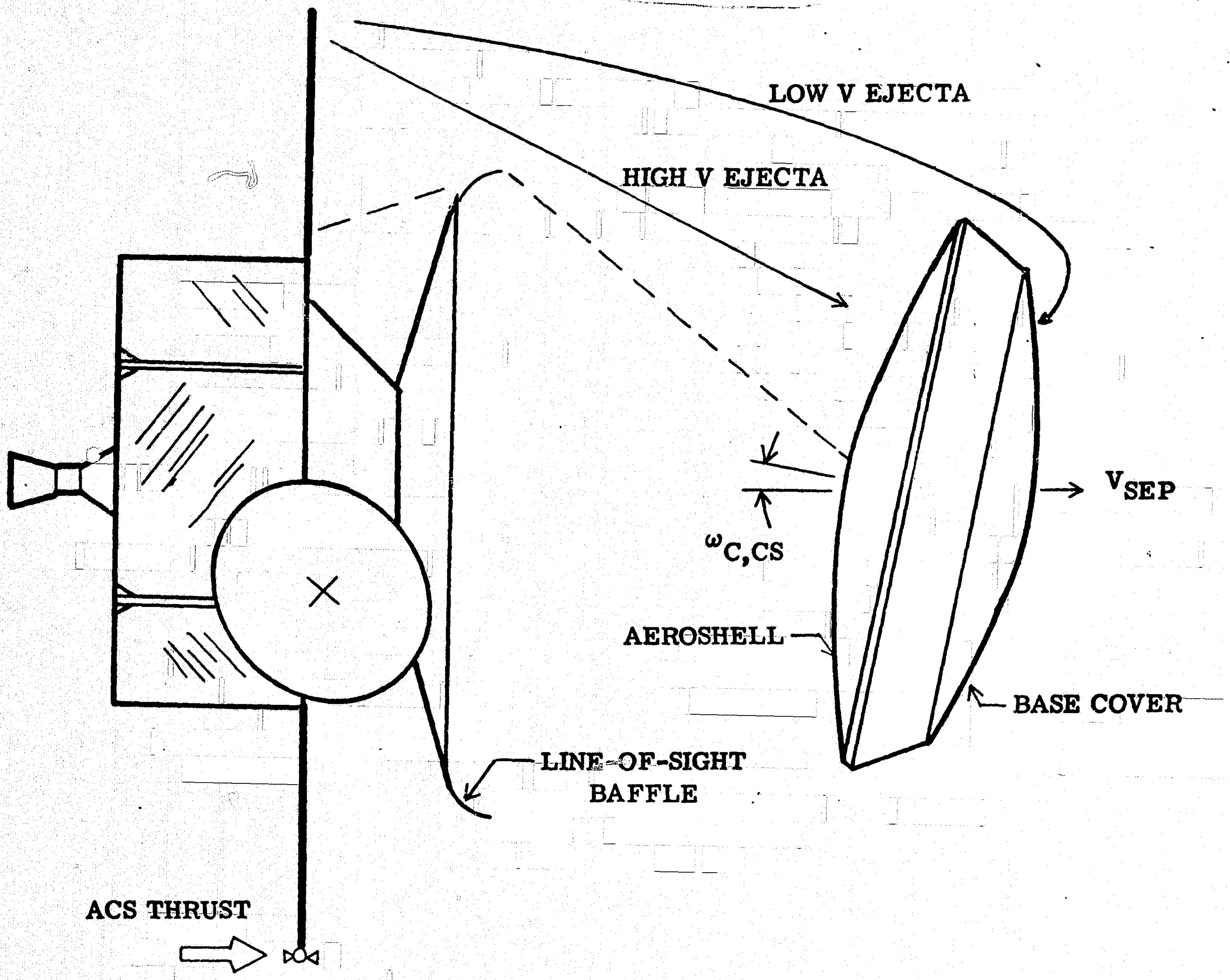

FIGURE 19. CAPSULE RECONTAMINATION DURING CAPSULE SEPARATION

velocity. Dislodging forces are provided by:

1. ACS firing for vehicle orientation and stabilization before and after separation of the capsule.

2. Detachment of the capsule from the adapter by mechanical or pyrotechnic devices, which impart a separation velocity to the capsule relative to the spacecraft.

The shock impulses and vibrations associated with these events will release ejecta in all the velocity regimes. As during the bioshield separation phase, the base cover is directly exposed to the environment and impact of ejecta. After capsule separation, the aeroshell is also vulnerable to impact by ejecta.

Very low velocity ejecta do not present a recontamination problem, as they re-impact on the spacecraft itself.

Low velocity ejecta may be of significance until the capsule achieves a separation distance exceeding the orbital distance of the ejecta relative to the spacecraft. As it moves out, it may impact low velocity ejecta dislodged by ACS firings just prior to separation, if these ejecta are trapped in partial orbits which intersect the separation trajectory of the capsule.

High velocity ejecta can be precluded from impacting the base cover through the use of line-of-sight baffles and mission constraints on maneuvering the capsule until sufficient displacement has been achieved. After the capsule has moved beyond the "cone of protection" offered by the bioshield base and line-of-sight baffles, the aeroshell is vulnerable to impact by ejecta which are dislodged with a velocity exceeding the capsule separation velocity. If the angular rates of the capsule due to asymmetrical separation are great enough, the base cover may also be exposed to impact by high velocity ejecta. As noted earlier, recontamination of the base cover is of greater consequence to planetary contamination than recontamination of the aeroshell, due to the higher heat flux on the aeroshell during atmospheric entry.

A general equation for recontamination of the capsule during separation is:

$$N_{C,CS} / N_{SC,BS} = \beta \, P_{EJ_{SC}} \, (1 - P_{EJ_{SC}})^m \, P_{T_{SC/C}} \, P_{A_C} \qquad (21)$$

β is a factor depending on the geometrical relationships between the spacecraft line-of-sight surfaces and the capsule surfaces during the capsule separation sequence.

$P_{T_{SC/C}}$ considers the partial orbits of low velocity particles and the probability of intercepting the capsule separation trajectory. The reduction of viable burden on the spacecraft surfaces due to ejection in the time period between bioshield separation and capsule separation is accounted for by the exponent m, the number of dislodging events. $N_{C,CS}$ would have to be apportioned between aeroshell and base cover surfaces to be of use in solving the general equation for planetary contamination.

The burden on the capsule at de-orbit, which may be expressed as a probability of a single organism being on the surface if it is less than unity, may be related back to the burden at previous mission events through combination of the equations presented herein. Development of the analytical models and rigorous mathematical expressions to express the redistribution of organisms between items of flight hardware was not attempted within the scope of this effort. Due to the complexity of the expressions, the need for computerization of the model for meaningful numerical solution and evaluation of sensitivities is apparent.

Conclusions regarding capsule recontamination are presented in the following section.

4.0 CONCLUSIONS

The following conclusions were drawn on the basis of this effort.

4.1 Literature Survey

Most of the data in the literature is expressed as estimates of the magnitude of the physical phenomena involved, rather than probability of occurrence of recontamination events. Experimental results and analytical conclusions are of limited value, due to the specific nature of the assumptions involved.

4.2 Sensitivity Analyses

4.2.1 Fly-by Mission

The probability of contaminating the planet varies directly with the number of organisms ejected during the encounter phase, which is exponentially related to the probability of ejection during cruise. The burden at encounter also varies directly with the burden at shroud separation, so that determination of the latter burden is also of significance. Due to the exponential relationship to the probability of ejection, however, it is this parameter which must be determined for a specific design and mission in order to establish the probability of contaminating the planet.

If analysis shows that a potential exists for planetary contamination, the burden at shroud separation also becomes a parameter of importance. This burden is sensitive to either the original burden on the spacecraft or the number of organisms transferred from the shroud, depending on the relative magnitude of these burden values. If more than an order of magnitude of difference exists, then the smaller of the two becomes unimportant in the determination of the burden at shroud separation. For this reason, no benefit accrues from determining the precise value of the lower burden or of making elaborate efforts to reduce this burden.

4.2.2 Orbiter Mission

The conclusions for the orbiter spacecraft are similar to those for fly-by spacecraft regarding the sensitivity of the burden at encounter to the probability of ejection during cruise and the number of organisms on the spacecraft at shroud separation. The probability of contamination of the planet is a direct function of the number of organisms ejected after encounter, but in this case the period of potential contamination includes the orbital operations phase and/or the duration of planetary quarantine constraints. The number of organisms ejected from the orbiter surfaces is exponentially related to the probability of ejection, with the number of dislodging events as the exponent. The importance of the burden at the beginning of the orbital period has been shown, and by extension the conclusions for the fly-by mission regarding the importance of the shroud separation burden and the effects of the launch phase also are applicable.

4.2.3 Lander Capsule

The conclusions regarding the sensitivity of the burden on the spacecraft and bioshield cap at encounter are analogous to those for the missions discussed above. The problem of redistribution of burden among the items of flight equipment is added for this type of mission. The contamination problem during cruise, bioshield separation and capsule separation is similar to the fly-by and orbiter missions, in that the probability of ejection is still the dominant parameter. Important differences exist, however, among the mission phases of the lander capsule regarding the potential for recontamination.

During cruise, access to the sterile lander must be afforded through a compromise of bioshield integrity such as micrometeoroid punctures. Because of the small penetrated area and the low number of punctures for a typical mission, and the geometrical constraints on impact of high velocity ejecta, recontamination during cruise was determined not to be a significant problem.

During bioshield separation, direct exposure of the sterile lander surfaces to impact by high or low velocity ejecta presents a greater recontamination problem than exists during cruise. High velocity ejecta require a line-of-sight geometrical relationship between the base cover and contaminated spacecraft surfaces, a condition which can be precluded through the use of physical baffles. Low velocity ejecta are more of a problem as no design or mission constraints are readily apparent to preclude their re-impacting on the base cover. Therefore, the number of organisms ejected in the low velocity regime must be determined. To do this, the velocity range which causes re-impact, the probability of ejecting organisms in this velocity range, the number of dislodging events during the bioshield separation phase and the burden distribution on the spacecraft and bioshield are all factors requiring evaluation for the specific design and mission being studied. The exponential relationships between surface burden, probability of ejection and number of organisms ejected that were developed for the orbiter analysis are equally valid for this phase of the lander capsule analysis.

Similar conclusions are advanced for the capsule separation phase, with the additional problem of impact by high velocity ejecta requiring determination of the number of organisms ejected in this regime, the probability of ejection and the burden at time of capsule separation. The exponential relationship between ejection probability and ejected burden is also valid here.

The problem of asymmetrical separation of the bioshield cap and lander capsule was also identified as potentially affecting the recontamination probability, as geometrical relationships regarding line-of-sight between sterile and contaminated surfaces could be altered. Design and mission constraints on spacecraft and capsule re-stabilization and manuevering require evaluation in the light of the potential recontamination hazard.

5.0 RECOMMENDATIONS

To maximize the benefits obtained from this program, it is recommended that further analyses be performed. These analyses should include the following:

1. Establishing the sensitivity of the probabilities of ejection, transfer and adhesion to the environments and forces acting on the spacecraft during cruise and operations.

2. Development of detailed and comprehensive analytical models for recontamination of the lander capsule during cruise, bioshield separation and capsule separation phases. This effort should include development of equations in forms suitable for probability distribution inputs and solutions, input of physical factors and computerization of the models for flexibility and speed of implementation.

3. Analytical investigations, supplemented by the experimental data if required, to determine the values of the probability of ejecting organisms for the missions, spacecraft designs and materials of interest to specific applications. Evaluation of the mission and spacecraft design will be required to establish the number of cruise and post-encounter dislodging events.

4. Analysis of the effect of asymmetrical separation of the bioshield and capsule on the probability of low or high velocity ejecta impacting the capsule.

6.0 NEW TECHNOLOGY

No reportable items of new technology have been identified as a course of this effort.

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APPENDIX A

ABSTRACTS OF SELECTED REFERENCES

TITLE: "NON-EXISTENCE OF A 'BIOTA-CLOUD' RE-CONTAMINATION HAZARD FOR A PLANETARY LANDER,"

J. Friedrich Vandrey, RIAS, MARTIN-MARIETTA CORPORATION, DECEMBER, 1967

PAGE	SUBJECT	INFORMATION OR DATA
4	Biobarrier thickness and bioburden	Tobey's analysis showing 8% of bioburden required to contaminate to $Pr=10^{-4}$ for 200 day mission.
7	Spacecraft mass Properties	$D = 6m$, $M = 10^4$ kg
	Particle mass Properties	Spores: $D = 10^{-6}m$, $M = 10^{-15}$ kg "Dust" particles: $D = 10^{-4}m$, $m = 10^{-9}$ kg
8	Gravitational Forces	S/C gravity = 10^{-7} m/sec^2 escape velocity = 10^{-3} m/sec
9	Solar Pressure Acceleration	2.5×10^{-2}-10^4 times spacecraft gravity for dust spores respectively
10	Solar Pressure Velocity	.1 - 1 m/sec for 10^{-4} -10^{-6} m particles over diameter of S/C
11	Reflected Solar Radiation	Assumes metallic surface with mirror finish on orbiter
11-12	Surface Temperatures & Emissivity	$T = 270^\circ$ k, $\varepsilon = 1$
13	Canister Surface Radiation	4 watts/m^2 sufficient to overpower S/C gravity for particles up to 5×10^{-5} m
14-15	Electrical fields	Due to: 1. Interaction with UV component of solar radiation 2. Interaction with plasma of solar wind
16	Direction of Solar Wind	Oblique angle striking S/C at 45° to direction of travel
	Effect of Solar Wind	No reason to expect release of biota with velocity adequate to recontaminate.

PAGE	SUBJECT	INFORMATION OR DATA
16	Electron Bombardment	Electrical acceleration ranges from 6.8 x 10^{-8} to 1.6 x 10^{-6} m/sec for spores and dust particles.
23	Interplanetary Magnetic Field	Radius of gyration of particles is 300 m: inconsequential.
25	Summary of interaction effects	Dissipative interactions of environment greater than S/C gravity, which alone can retain particles.
29	Gas leaks & ACS firing	Helium jet assumed: $T = 273^{o}$ K $V = 1300$ m/sec, $m = 10^{-3}$ kg/sec $F = 1.3$ kg m/sec^2 Turns s/c by one radian/2-3 min.
30	Plume impingement	Geometrically and physically impossible due to hemispherical pattern of exhaust.
	Plume boundary layer	Cannot recontaminate due to gas particle density.
34	Mid-course maneuver hazard	Safe up to 8 days according to Tobey.

TITLE: "VOLUME 3 - PLANETARY QUARANTINE STUDY," GE DOCUMENT NUMBER VOY-CO-FR,
GENERAL ELECTRIC CO., PHILADELPHIA, PENNSYLVANIA 28 JULY 1970

PAGE	SUBJECT	INFORMATION OR DATA
3-93	Lander Recontamination	Comprehensive survey of recontamination events and state of knowledge concerning the various sources.
3-97	Lander Separation	Evaluates alternate separation concepts.
3-98	Recontamination Matrix	Presents analytical approach for evaluation of numerical probability of contamination of planet due to recontamination of sterile lander. Tabulates representative values of probabilities associated with sub-events.
3-99	Fraction Ejected at Bioshield Opening	$.02 < Pr < .1$ for surface area $100\ ft^2 < A_s < 1300\ ft^2$.
4-6	UV Radiation on Clumps	Discusses protection offered to spores by clumping and shielding from surrounding material against the lethal effects of UV radiation.
4-15	Solar Pressure and UV Radiation	Probability of surviving entry and transport phases. UV kill almost total: Pr of survival = 7×10^{-8} for single organism.
Appendix D	Micrometeoroid Effects	Analytical and theoretical studies of micrometeoroid impact effects on release of organism from spacecraft surfaces. Includes: survey of previous and related work; analytical studies related to amount and size of particles released; effects on viability of organism experimental results from impact tests.
Appendix E	Loose Particles	Evaluates problems related to small particles on spacecraft surfaces, including: size ranges and distribution; types of materials; sources of particles. Compares distribution of particles deposited during manufacture to those generated during flight.
Appendix F	Electrostatic Charge	Analysis of electrostatic forces acting on particles ejected near spacecraft. Reflection of ACS gas from spacecraft and bio-shield surfaces after separation is considered. Random motion of particles along spacecraft surface analyzed.

TITLE: "CONTINUATION OF THE DEVELOPMENT OF A TYPICAL MARS LANDING CAPSULE STERILIZATION CONTAINER,"
AVCO Corp. Applied Technology Division, Report AVATD-0081-69-RR Contract NAS 8-20682, Final Report

PAGE	SUBJECT	INFORMATION OR DATA
63	Meteoroid Punctures	Analysis assuming bio-barrier composed of 0.02 in. aluminum overlaid with eight 0.005 in. aluminized mylar sheets 0.125 in. apart. Average punctured area $S_p = 3.4 \times 10^{-8} ft^2/ft^2$ of canister area. Estimated Pr (recontamination) from particle entering meteoroid hole = 1.1×10^{-4}. From $L = 2P_c/S_p\ A\ P_c$ Where $P_c = 10^{-4}$, and $A = 650\ ft^2$, $L = 82000$ micro organisms/ft^2 redistributed on spacecraft surface. Estimates $10^5 - 10^6$ orgs/ft^2 on spacecraft exterior at time of launch, or 8% must be redeposited for $Pr > 10^{-4}$.
64	Deployment	Considers information on deployment shock to be insufficient at this time.
65	Solar UV Lethality	"decade reduction in a few seconds"
66	Solar Protons Lethality	4×10^{-5} rads required for decade reduction, therefore 10 hrs exposure required.
66-67	Forces Binding Organism to Surface	Vanderwaals attraction: graph of force vs separation distance. Experimental data show that g = 34 releases significant numbers of organisms, but tightly bound microbes not released by g = 7000.
73		Vanderwaals force effective up to 10^{-4} cm.
74	Interplanetary Magnetic Field	$\sim 8 \times 10^{-23}$ Newtons; may be neglected.
76	Parameters for Idealized Model	Spacecraft: Spherical, metal 1-10m dia. $10^2 - 10^4$ kg mass, 0-10v + potential Solar wind: $\rho = 1$ proton/cm^3, 1 electron/cm^3 $V = 500$ km/sec, $\lambda = 8$m, magnetic field = 5×10^{-5} gauss Microbes: Mass = $10^{-15} - 10^{-8}$ kg Dia = $10^{-6} - 10^{-4}$m $\rho = 1 g/cm^3$ Max excess charge = 3×10^9 (dia)m

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79-82	Particle Escape Velocity	$V = 1.35 \times 10^{-6}/a$, where a = particle diameter in m & V=max escape (m/sec) assuming s/c charge = +7v and particle charge = -10v.
84	Spacecraft Overtakes Escaped Particle	Assuming $V_{sc} = 0.3$ m/sec, $T_{crit} = 145$ sec during which particle travels 19.5 m. If particle does not escape, T = 43-180 sec.
	Predominant Forces	Large particles (>100μ) = neglect all but solar radiation. Small particles - primarily influenced by electrostatic forces.
86	Particle Capture	Particles with velocities near escape threshold have longest excursion times.
88	Primary Recontamination Hazards	1. Particles located in line-of-sight of the unreleased lander at moment of canister lid separation. 2. Large particles ejected directly toward the lander deployment corridor by any deployment maneuver. 3. Small particles pulled into a collision course by attraction to the spacecraft.
94-95	Release of Organisms Due to Vibration	Table of test data for frequencies, accelerations given vs number of organisms detected.
127ff	Recontamination Model	Defines "opportunity probability factors" related to mission events and "transport probability factors" related to survival and capture of organisms.
132		Effect of bio shield pressure on sterility = ½ in. of H_2O. Δp above ambient sufficient at ambient.
132		Canister venting system: pore type filters weight prohibitive. If one assumes venting and survival of environment, $P_t P_v$ must be small.
133		Conservative valves of event probabilities: P_r (organism survives environment) = 10^{-3} P_r (organism survives entry, etc.) = 10^{-5}
134	Ground Test Certification	Recommend tests for evaluation of venting made, but not cruise mode events. Lid separation can be simulated for times up to one second.

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137	Deployment Locale and Orientation Parameters	Direction of sun, solar radiation flux, solar wind flux. Direction and range of planet, density and temperature of atmosphere, velocity of spacecraft, orientation of spacecraft. Assume interplanetary conditions prevail at large range from planet. Treat spacecraft as immobile object in solar wind. Closer, consider as having orbital velocity in rarified ionized gas.
140-141	Possible Flight Tests	1. Survival of microbes on unprotected surfaces subject to vibration 2. Acceleration and shock levels to release organisms 3. Mobility of tagged particles, including particle size, transport distance and decay time of particle fallout 4. Cumulative effects of environment 5. Potential difference of sun and shadow surfaces 6. Electrical properties of plasma medium
A-30-33	Sequence of Events	Description of events and their contamination potential. Tables of information.

	LAUNCH AND ASCENT	SHROUD SEPARATION	FINAL STAGE SEPARATION	C
FLY-BY SPACECRAFT	SHOCK AND VIBRATION DISLODGE ORGANISMS FROM • SPACECRAFT • SHROUD • ADAPTER AIRFLOW AND ACCELERATION TRANSFER ORGANISMS FROM SHROUD TO SPACECRAFT		SHOCK AND VIBRATION DISLODGE ORGANISMS FROM • SPACECRAFT • ADAPTER • LAUNCH VEHICLE SEPARATION DEBRIS IMPACTS CONTAMINATED SURFACE RETRO PLUME IMPINGES CONTAMINATED SURFACE	S A R B S F O S F O M I A O
ORBITER SPACECRAFT				
SPACECRAFT/ LANDER	SHOCK AND VIBRATION DISLODGE ORGANISMS FROM BIOSHIELD			
	AIRFLOW AND ACCELERATION TRANSFER ORGANISMS FROM • SHROUD TO BIOSHIELD • BIOSHIELD TO SPACECRAFT		SEPARATION DEBRIS PENETRATES BIOSHIELD	

FOLDOUT FRAME

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<table>
<tr><th>CRUISE</th><th>ENCOUNTER</th><th>ORBITAL OPERATIONS</th><th>BIOSHIELD SEPARATION</th><th>CAPSULE SEPARATION</th></tr>
<tr><td colspan="2" rowspan="3">SPACECRAFT APPENDAGE DEPLOYMENT RELEASES ORGANISMS BY
• ABRASION OF CONTAMINATED SURFACES
• EJECTION OF CONTAMINATED DEBRIS
• SHOCK AND VIBRATION
SPACECRAFT ACS FIRING RELEASES ORGANISMS BY
• PLUME IMPINGING CONTAMINATED SURFACE
• PLUME CONTAMINATION
• SHOCK AND VIBRATION
SPACECRAFT ENGINE FIRING RELEASES ORGANISMS BY
• PLUME IMPINGING CONTAMINATED SURFACE
• PLUME CONTAMINATED
• SHOCK AND VIBRATION
MICROMETEOROID IMPACTS SPACECRAFT AND RELEASES ORGANISMS</td><td colspan="3">NOT APPLICABLE</td></tr>
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• PLUME IMPINGING CONTAMINATED SURFACE
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<tr><td colspan="3">MICROMETEOROID IMPACTS BIOSHIELD AND RELEASES ORGANISMS</td><td rowspan="2">SEPARATION SHOCK DISLODGES ORGANISMS FROM BIOSHIELD AND SPACECRAFT</td><td>SEPARATION SHOCK DISLODGES ORGANISMS FROM SPACECRAFT</td></tr>
<tr><td colspan="3">MICROMETEOROIDS PENETRATE BIOSHIELD</td><td>CAPSULE INTERCEPTS PREVIOUSLY EJECTED ORGANISMS</td></tr>
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FIGURE 1. RECONTAMINATION FACTORS FOR FLY-BY, ORBITER AND LANDER CAPSULE MISSIONS.