

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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*The Voyager Planetary Quarantine Model
1973 Mission*

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Abstract

This Memorandum presents the framework of a model which treats all elements of the *Voyager* 1973 Mission in sufficient detail to allow reasonable assurance that the *Voyager* policy on planetary quarantine can and will be adhered to by the *Voyager* Project.

The *Voyager* 1973 Mission is examined from the point of view of planetary quarantine in order to isolate every conceivable source of contamination of the planet Mars. These sources are being studied in detail in order to ascertain the requirements that must be met by the hardware and mission designs in order to satisfy the constraints imposed by the planetary quarantine policy.

The Voyager Planetary Quarantine Model

1973 Mission

I. Introduction

This Memorandum consists of two parts. The first delineates the planetary quarantine policy and requirements which have been established for the *Voyager* Project. The second part describes the framework of a mathematical model for assessing whether this policy can and/or will be adhered to. The format of the model can also be used to present the quarantine violation probability allocations which must be placed by the *Voyager* Planetary Quarantine Office.

II. Planetary Quarantine Policy and Requirements

A. Establishment of Planetary Quarantine

A fundamental scientific and philosophic question that has remained unanswerable until the advent of space flight is whether life exists anywhere in the universe other than on Earth. As a result of observations and study of the solar system, there is speculation that the only opportunity to investigate the existence and nature of extraterrestrial life within the solar system may be the planet Mars. If there is life on Mars, it is fundamental to the understanding of the nature and origin of life whether that life is similar to the life on Earth or not.

The possibility of answering these vital questions would be seriously compromised if early interplanetary vehicles, such as *Voyager*, were to infect the planet Mars with any form of viable Earth life. In order to avoid such compromise, the planet Mars has been placed under quarantine.

Any attempt to investigate Mars by means of interplanetary vehicles must have associated with it some finite probability of infecting Mars, thus violating the quarantine. Quarantine requirements, to be meaningful, should be so placed that there is a very low probability that Mars is infected prior to completion of an adequate spectrum of biological experiments.

B. Planetary Quarantine Requirements

Infection, contamination and quarantine definitions are established in the following.

1. Infection (of an extraterrestrial planet). Infection is defined as growth and spreading of terrestrial microorganisms throughout major portions of the planet's surface, subsurface, and/or atmosphere. The only kind of infection of concern from the planetary quarantine point of view is, of course, that which results from terrestrial exploration of space.

2. *Contamination (of an extraterrestrial planet)*. Contamination is defined as release of one or more viable terrestrial microorganisms on the planetary surface, within the planetary subsurface, or in the planetary atmosphere.

3. *Quarantine (of an extraterrestrial planet)*. Quarantine is defined as a requirement to avoid infection prior to a specified calendar year or for a specified period of time.

The planetary quarantine requirements established by the *Voyager* Project Office for the *Voyager* 1973 Mission are typically as follows: the total probability of violation of the quarantine of the planet Mars as a result of the dual launch of the *Voyager* 1973 Mission shall be less than approximately 10^{-4} . In addition, the quarantine period has been set at 20 yr, so that the quarantine will not end prior to the calendar year 1985 A.D. These explicit requirements result from considerations which are outside the scope of this document; but see Ref. 1 and 2.

C. Planetary Quarantine Policy

In order to ensure adherence to the planetary quarantine requirements described in Subsection B, the *Voyager* Project has adopted the following policy for the 1973 Mission to the planet Mars:

1. All aspects of a proposed mission, including the complex interactions of the spacecraft with the interplanetary environment, shall be examined in order to isolate every conceivable source of planetary contamination.
2. Each separate source of contamination shall be investigated to yield an adequate understanding of the processes through which it occurs, and, wherever possible, mathematical models shall be formulated which adequately characterize the probability of violation of quarantine. These mathematical models shall be based upon standard probabilistic techniques, conservative assumptions shall be employed whenever uncertainties are present in the derivation of the probability formulae, and the limitations and assumptions inherent in their formulation shall be explicitly described in the explanations of their validity. Whenever an adequate mathematical model is impossible (for example, when the necessary assumptions are not meaningful), every effort shall still be exerted to describe suitable

ranges or bounds for the probability of violation of quarantine.

3. The total probability of violation of planetary quarantine shall be constrained to satisfy the planetary quarantine requirements by the allocation of probabilities to the above modes of violation.
4. Wherever possible, numerical estimates of the probabilities of violation of quarantine by the above modes shall be calculated; and the space vehicle shall be designed and constructed and the mission operations formulated such that these estimates conform to the allocated probability constraints. For those modes of violation of quarantine which cannot be adequately described by a mathematical model, the allocated probability constraints shall be employed as guidelines for the necessary engineering and scientific judgements.
5. All investigations of possible contamination sources and all numerical estimates of the probabilities of violation of quarantine shall be adequately documented.

III. Planetary Quarantine Model and Probability Allocations

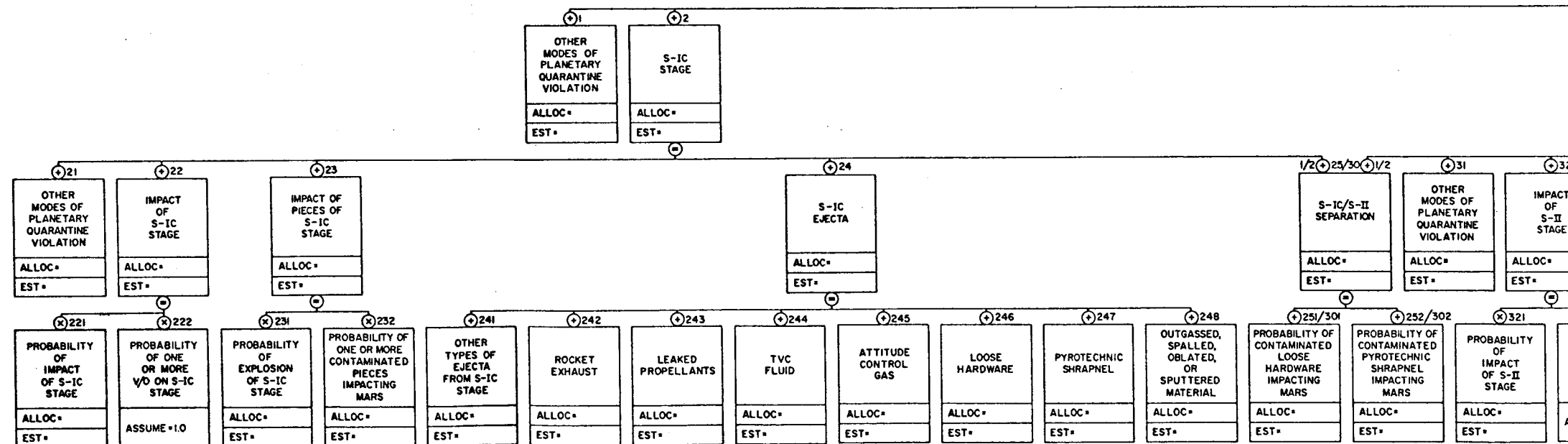
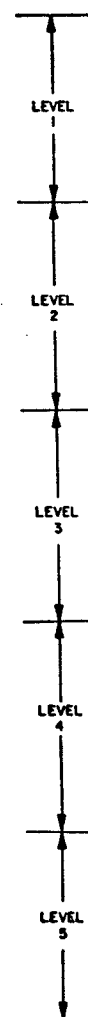
A. Introduction

The purpose of this section is twofold. First, the limitations and assumptions inherent in the application of probability theory to the planetary quarantine problem must be understood, and are discussed below. Second, all identified possible modes of violation of the planetary quarantine are presented.

Figures 1-5 diagram the *Voyager* 1973 Mission planetary quarantine model, and show (or can show) the following:

1. All identified possible modes of violation of quarantine.
2. The limiting probabilities of violation allocated to each mode by the *Voyager* Planetary Quarantine Office.
3. The contribution and relationship of each mode to the over-all probability of violation of planetary quarantine.

The model is also presented in an outline format in the Appendix.



SATURN <i>II</i> LAUNCH VEHICLE
ALLOC*
EST*

3

S-II STAGE
ALLOC*
EST*

33

IMPACT OF PIECES OF S-II STAGE
ALLOC*
EST*

34

S-II EJECTA
ALLOC*
EST*

322	331	332	341	342	343	344	345	346	347	
PROBABILITY OF ONE OR MORE V/O ON S-II STAGE	PROBABILITY OF EXPLOSION OF S-II STAGE	PROBABILITY OF ONE OR MORE CONTAMINATED PIECES IMPACTING MARS	OTHER TYPES OF EJECTA FROM S-II STAGE	ROCKET EXHAUST	LEAKED PROPELLANT	TVC FLUID	ATTITUDE CONTROL GAS	LOOSE HARDWARE	PYROTECHNIC SHRAPNEL	OUT SP OB SPL MA ALLO
ASSUME = 1.0	ALLOC*	ALLOC*	ALLOC*	ALLOC*	ALLOC*	ALLOC*	ALLOC*	ALLOC*	ALLOC*	ALLO
	EST*	EST*	EST*	EST*	EST*	EST*	EST*	EST*	EST*	EST*

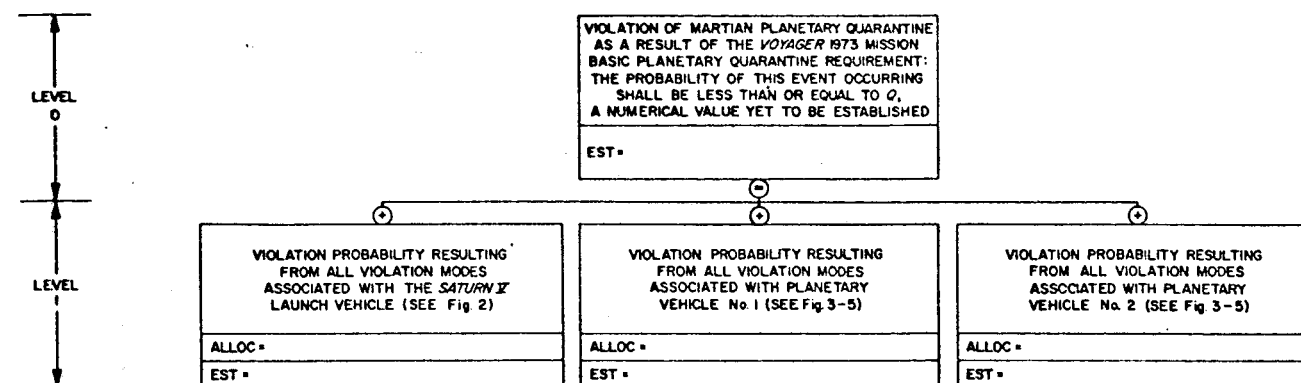


Fig. 1. First level breakdown of planetary quarantine model

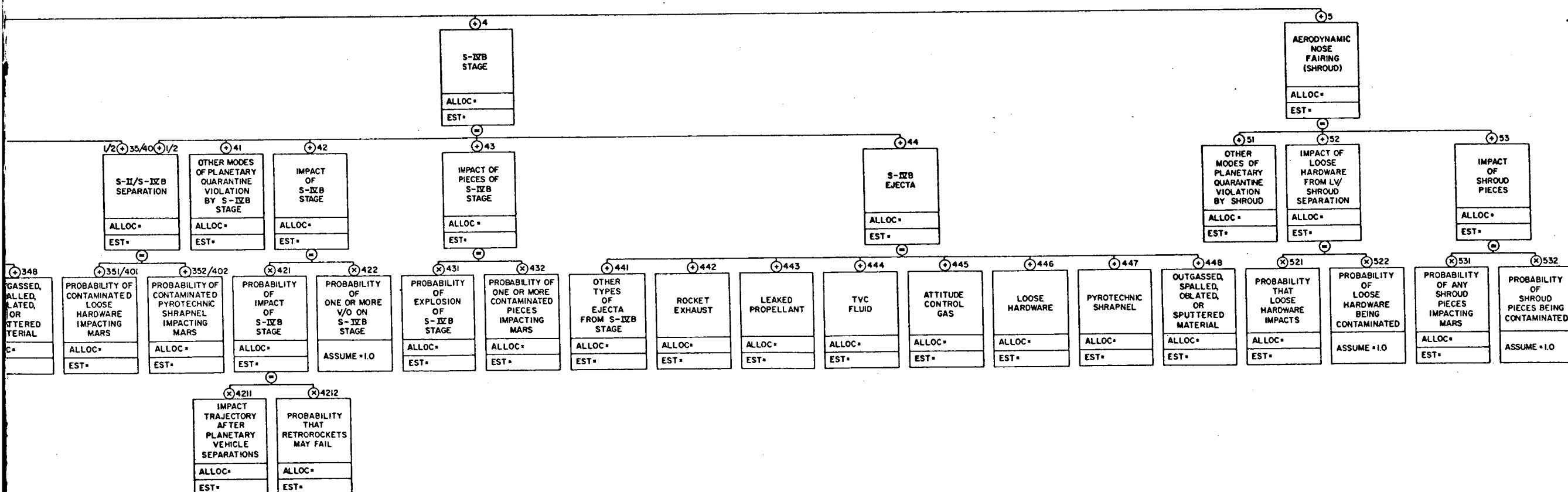


Fig. 2. Launch vehicle portion of planetary quarantine model

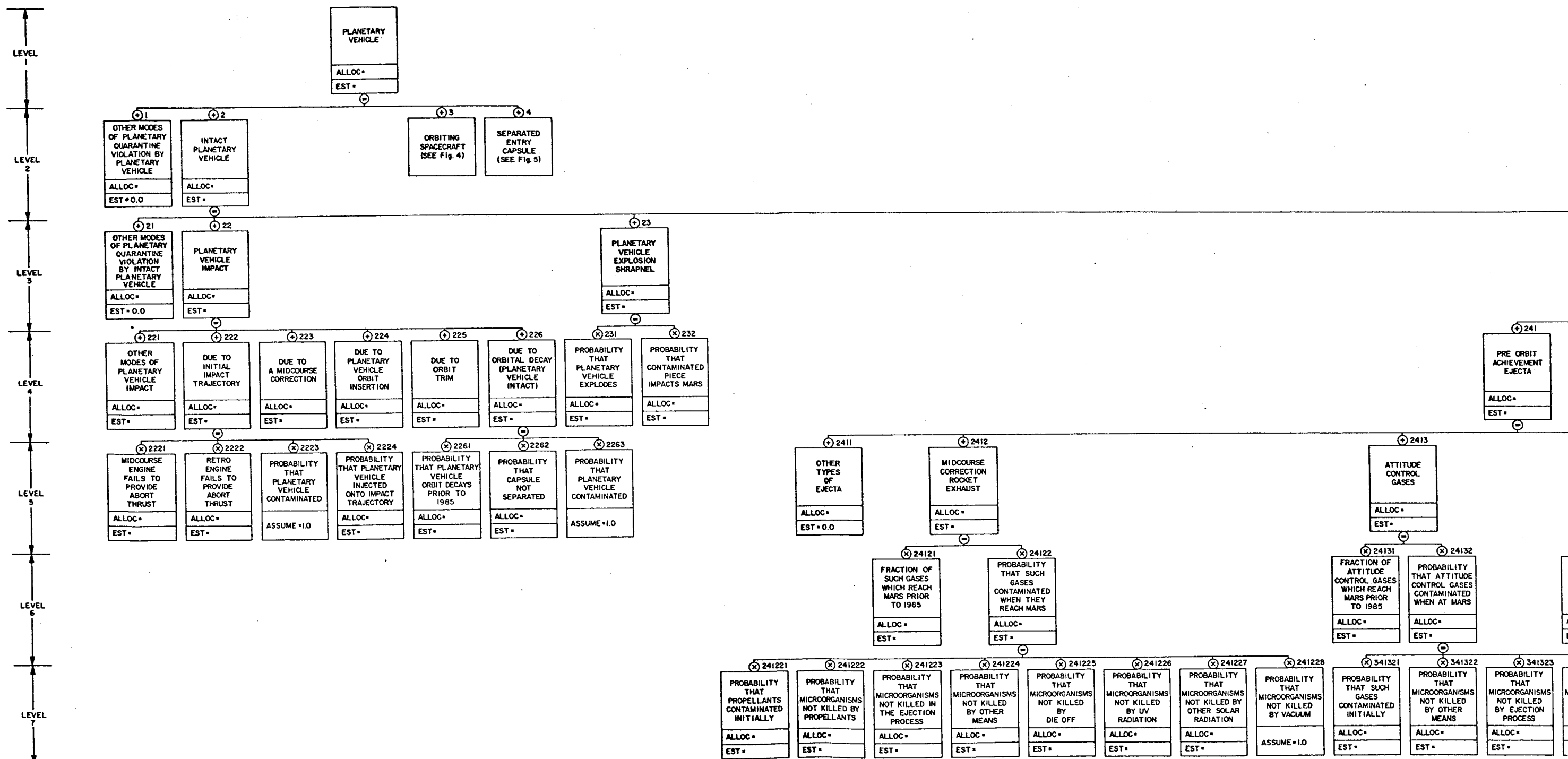


Fig. 3. Intact planetary vehicle portion of planetary quarantine model

FOLDOUT FRAME 1

FOLDOUT FRAME 2

(+) 24

PLANETARY VEHICLE EJECTA
ALLOC =
EST =

(+) 242

ORBIT INSERTION EJECTA
ALLOC =
EST =

(+) 2414

OUTGASSED, SPALLED, OBLATED, OR SPUTTERED MATERIAL
ALLOC =
EST =

(+) 2431

OTHER TYPES OF POST ORBIT ACHIEVEMENT PLANETARY VEHICLE EJECTA
ALLOC =
EST = 0.0

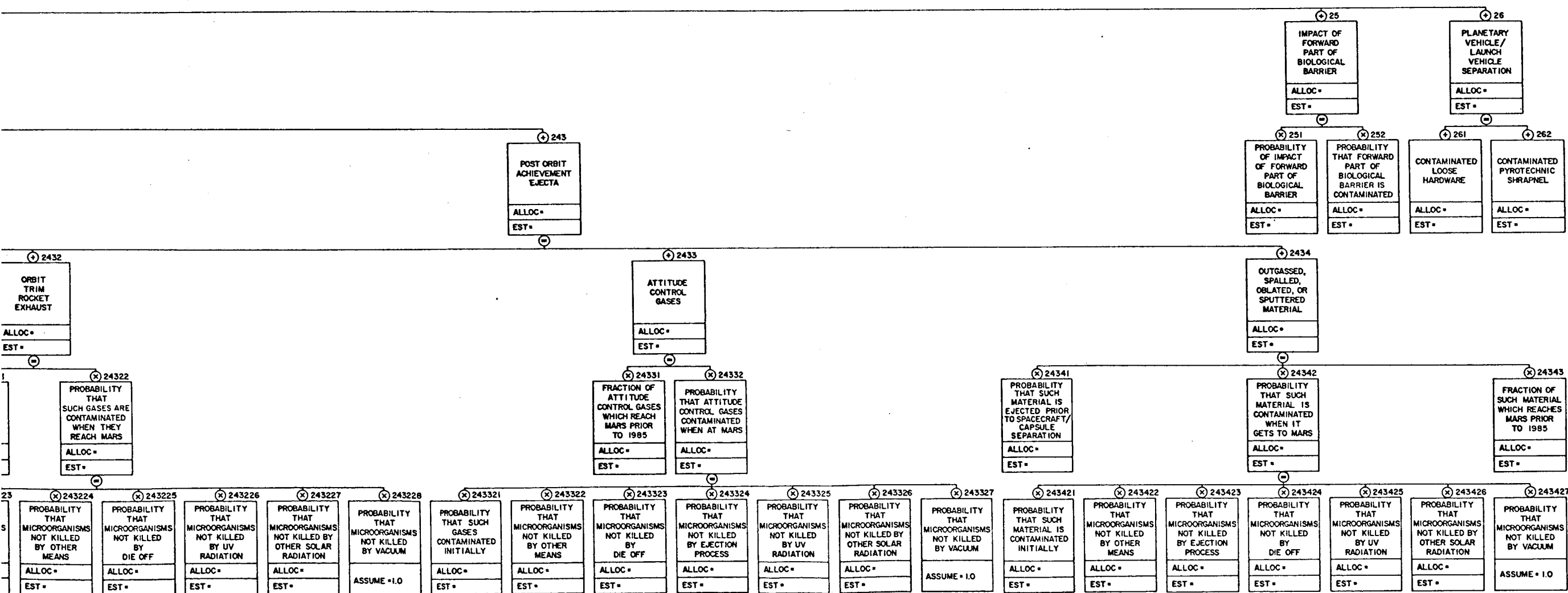
(X) 24141	(X) 24142	(X) 24143	(X) 24144	(X) 24145	(X) 24146	(X) 24147	(X) 24148
FRACTION OF SUCH MATERIAL WHICH REACHES MARS	PROBABILITY THAT SUCH MATERIAL IS CONTAMINATED INITIALLY	PROBABILITY THAT MICROORGANISMS NOT KILLED BY OTHER MEANS	PROBABILITY THAT MICROORGANISMS NOT KILLED BY EJECTION PROCESS	PROBABILITY THAT MICROORGANISMS NOT KILLED BY DIE OFF	PROBABILITY THAT MICROORGANISMS NOT KILLED BY UV RADIATION	PROBABILITY THAT MICROORGANISMS NOT KILLED BY OTHER SOLAR RADIATION	PROBABILITY THAT MICROORGANISMS NOT KILLED BY VACUUM
LOC =	ALLOC =	ALLOC =	ALLOC =	ALLOC =	ALLOC =	ALLOC =	ALLOC =
EST =	EST =	EST =	EST =	EST =	EST =	EST =	EST =

(X) 2432

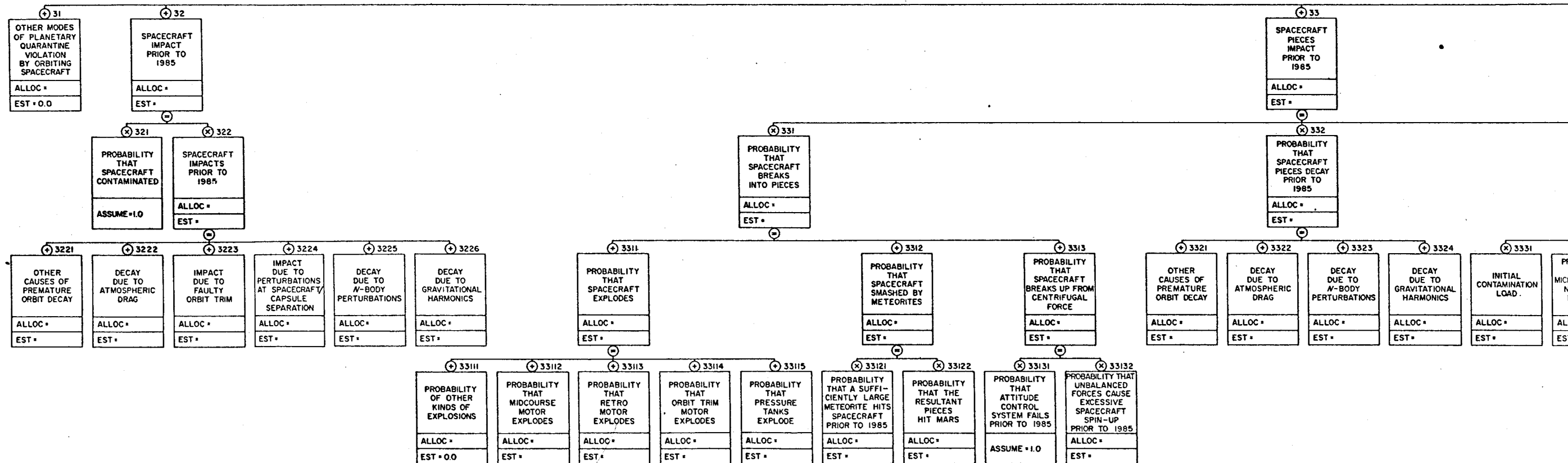
FRACTION OF SUCH CASES WHICH REACH MARS PRIOR TO 1985
ALLOC =
EST =

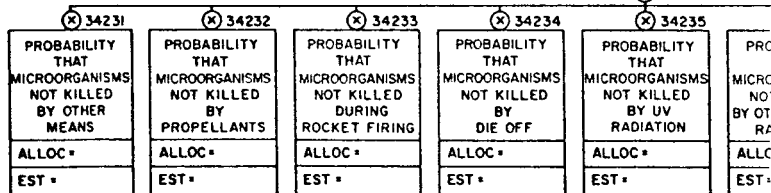
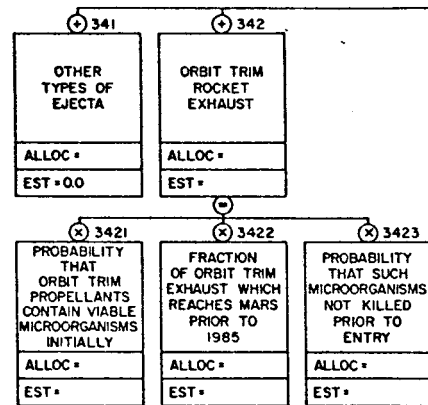
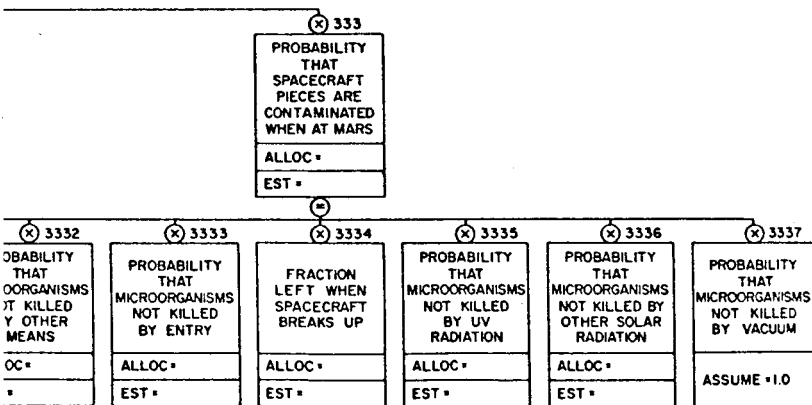
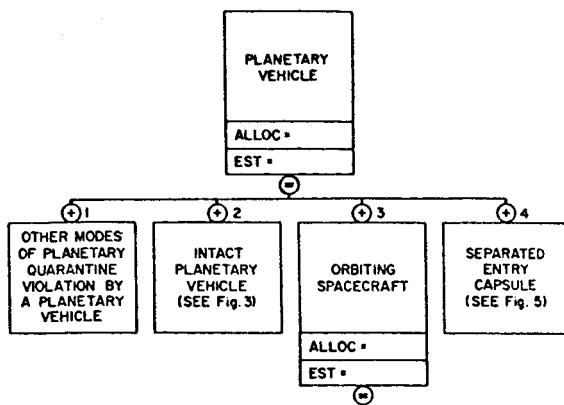
(X) 341324	(X) 341325	(X) 341326	(X) 341327
PROBABILITY THAT MICROORGANISMS NOT KILLED BY DIE OFF	PROBABILITY THAT MICROORGANISMS NOT KILLED BY UV RADIATION	PROBABILITY THAT MICROORGANISMS NOT KILLED BY OTHER SOLAR RADIATION	PROBABILITY THAT MICROORGANISMS NOT KILLED BY VACUUM
LOC =	ALLOC =	ALLOC =	ASSUME = LO
EST =	EST =	EST =	

(X) 243221	(X) 243222	(X) 243223
PROBABILITY THAT PROPELLANTS CONTAMINATED INITIALLY	PROBABILITY THAT MICROORGANISMS NOT KILLED BY PROPELLANTS	PROBABILITY THAT MICROORGANISMS NOT KILLED IN EJECTION PROCESS
ALLOC =	ALLOC =	ALLOC =
EST =	EST =	EST =



LEVEL 1
LEVEL 2
LEVEL 3
LEVEL 4
LEVEL 5
LEVEL 6
LEVEL 7





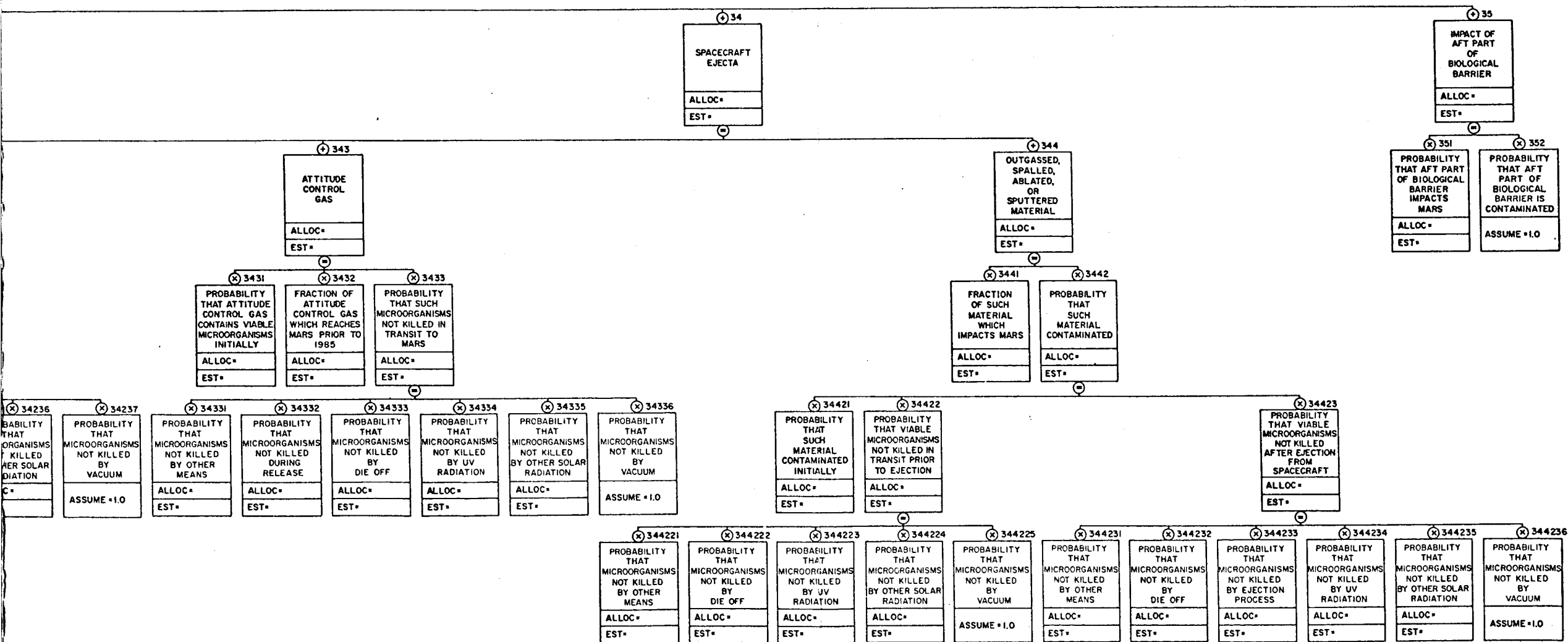


Fig. 4. Orbiting spacecraft portion of planetary quarantine model

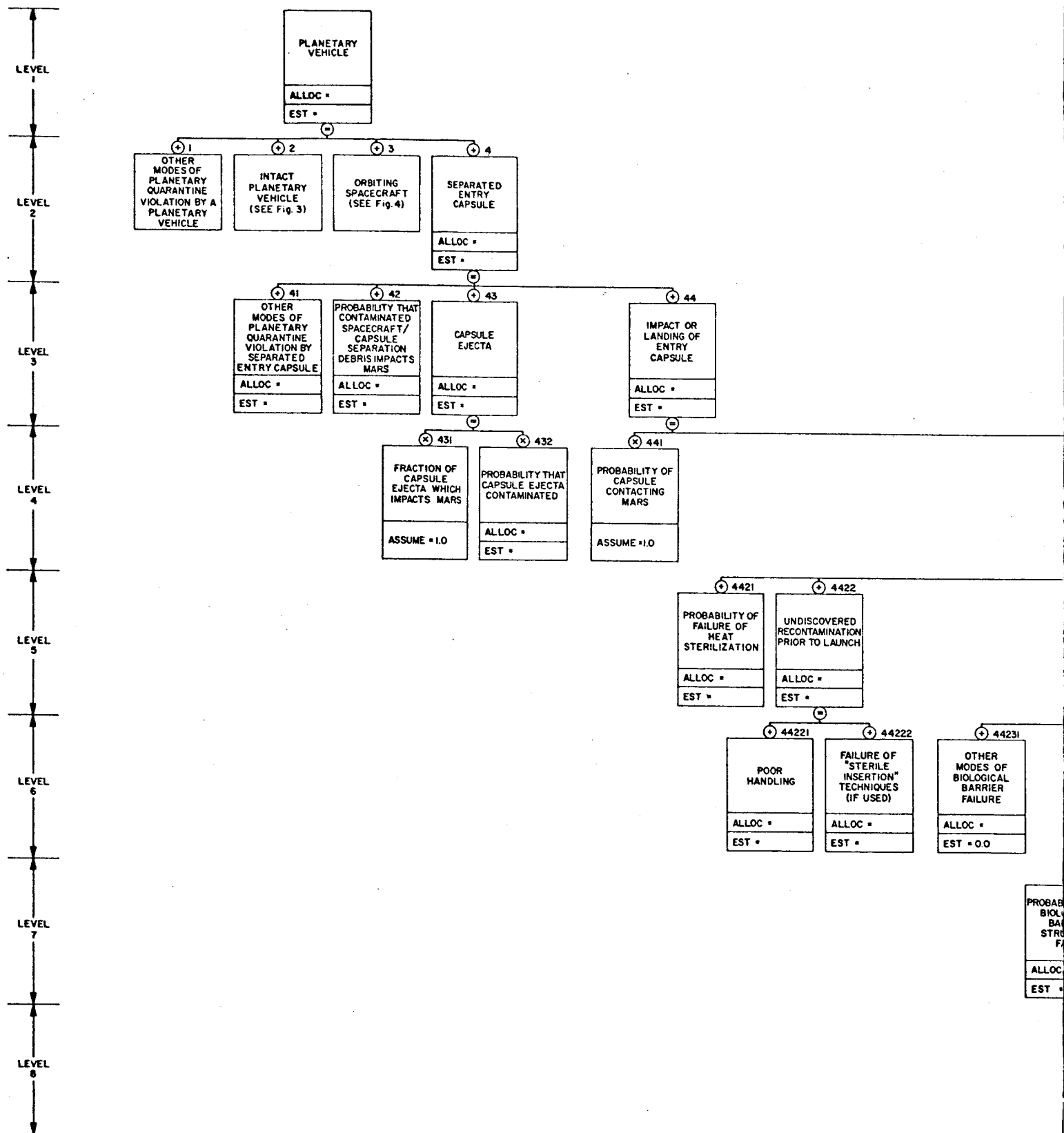
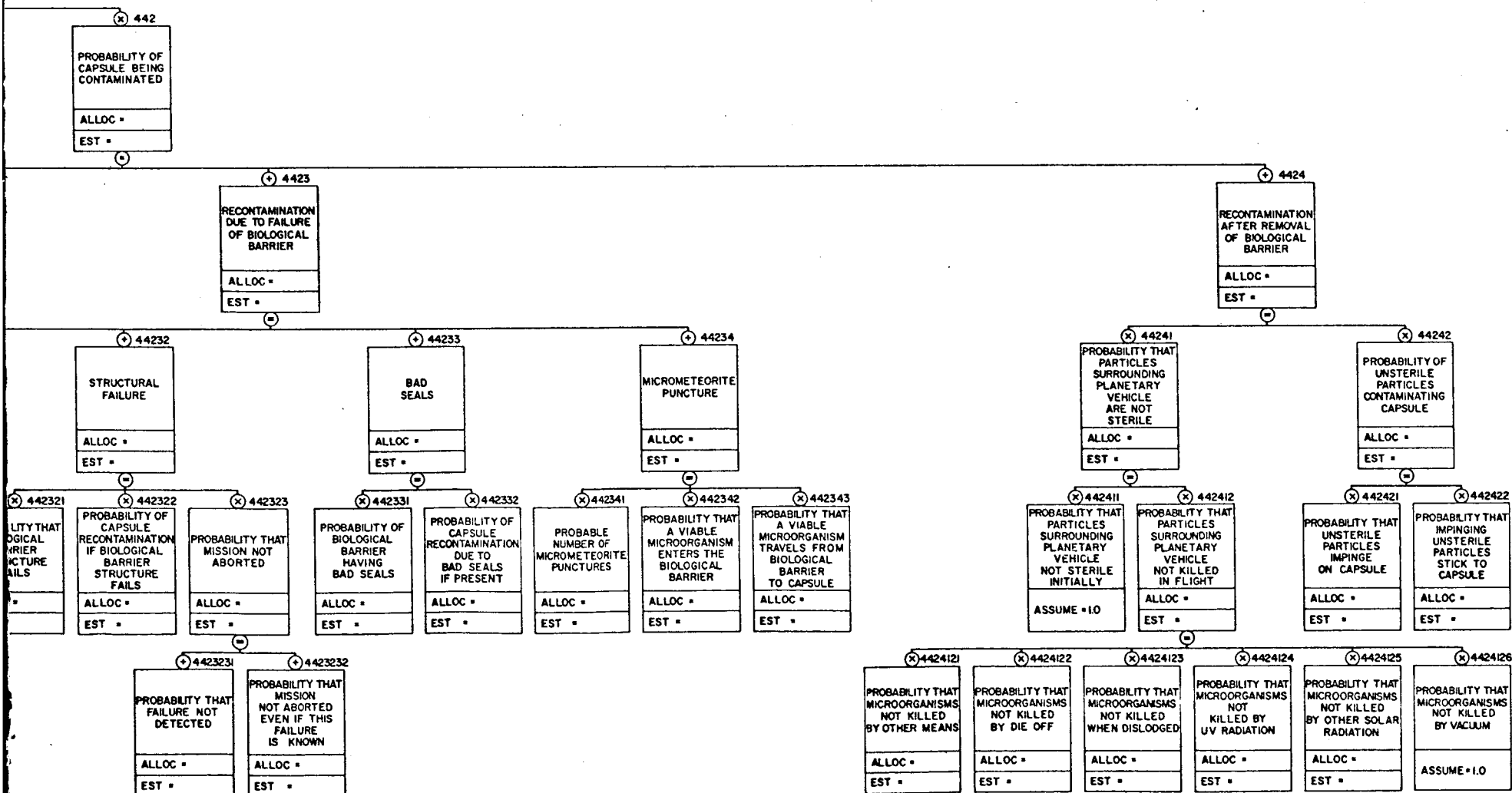


Fig. 5. Separated entry capsule portion of planetary quarantine model



B. The Validity of the Mathematical Model

Several valid objections are applicable to any attempt to precisely formulate a mathematical model to ensure that the planetary quarantine requirements are met. The principal difficulty arises from the extremely small value of the limiting probability of violation of quarantine. Many of the contributing quantities are statistical in nature, and the applicability of the usually assumed probability distributions may be questionable at large variances. Strictly valid formulations would become involved with confidence levels on the variances of the actual distributions and would become extremely complex. Furthermore, even if confidence levels could be meaningfully incorporated into a usable model, empirical testing necessary to establish reasonable confidence levels at the extremely small probabilities involved would be hopelessly long and costly. Finally, a case could be made for the argument that the probability of overlooking a significant mode of violating the planetary quarantine exceeds the extremely small allocations for contingency. All of these objections are quite valid to the extent that a mathematical model is incapable of *proving* that the requirements have been satisfied. The objections, however, should not preclude a rational attempt to meet the planetary quarantine requirements insofar as is possible and feasible.

The fact that the limiting probability of violation of quarantine is so small does bear one benefit, in that the probability equations are simplified: Assume n independent sources of violation of quarantine. Define p_j to be the probability of violation by the j^{th} mode. (Then $0 \leq p_j \leq 1$, and $j = 1, \dots, n$.) Then, the probability that quarantine will not be violated by the j^{th} mode is $(1 - p_j)$.

Now, the probability that the quarantine will be maintained is the product of the individual probabilities. Further, the planetary quarantine requirement is that this probability be greater than or equal to $(1 - Q)$, where Q is the limiting probability of violation of quarantine. Thus,

$$\prod_{j=1}^n (1 - p_j) \geq 1 - Q \quad (1)$$

Now, since Q is very small, the individual p_j must be very small, so that on expansion of the product, the terms involving products of the p_j will be negligible.

Therefore, equation (1) may be rewritten as follows:

$$\sum_{j=1}^n p_j \leq Q \quad (2)$$

Thus, we see from Eq. (2) that the sum of the individual probabilities of violating the quarantine over all the various modes of violation must be less than or equal to the limiting probability of violation.

C. The Planetary Quarantine Model

The acceptable overall probability of violating the quarantine of the planet Mars on a single mission has been established as an extremely small number (on the order of 10^{-4}), for the reasons discussed in Subsection A. As a result, a very large number of unlikely modes of quarantine violation must be considered in any attempt to ensure that the actual probability will be below the established limit.

An equation to express the estimated violation probability would not only be unwieldy, but confusing and unclear, unless a departure from the usual format for equations is used. Furthermore, the various modes of quarantine violation can be considered at several levels of detail. To illustrate both of these points, consider the following:

$$Q = p_{LV} + p_{PV1} + p_{PV2} \quad (3)$$

where

Q = overall probability of violating the planetary quarantine of the planet Mars as a result of the *Voyager* 1973 Mission.

p_{LV} = probability of violating the planetary quarantine of the planet Mars as a result of all violation modes associated with the launch vehicle.

p_{PV1} = violation probability resulting from all modes associated with planetary vehicle 1.

p_{PV2} = violation probability resulting from all modes associated with planetary vehicle 2.

But, each term on the right in Eq. (3) requires further expansion. For example,

$$p_{PV1} = p_1 + p_2 + p_3 \quad (4)$$

where

p_1 = violation probability resulting from an intact (spacecraft/capsule not separated) planetary vehicle 1.

p_2 = violation probability resulting from an orbiting spacecraft from planetary vehicle 1.

p_3 = violation probability resulting from a separated entry capsule from planetary vehicle 1.

Again, each term in Eq. (4) requires further expansion, but such expansion will not be illustrated at this point in the discussion.

Two alternative formats for the presentation of the equation for the assessment of the overall violation probability are presented in Fig. 1-5, and in the outline in the Appendix. It should be noted that both formats can be used for assessment (by starting at the bottom and working up) and for allocation (by starting at the top and working down). Both formats present the same probability equation and may be used in conjunction with each other. Submodels for many of the key factors have yet to be established before an adequate assessment can be made; further breakdown of any of the lowest level entries is, of course, possible.

The probabilities allocated to various possible modes of violation of quarantine are shown by the abbreviation ALLOC=. Estimated values of various relevant parameters are shown by the abbreviation EST=. Certain probabilities have been conservatively assumed to be unity and are indicated by the abbreviation ASSUME=1.0. In the figures and in the outline, the computational relationships of the various parameters are represented by signs for equality, addition, and multiplication.

The process of treating the quarantine model in successively more explicit detail is handled in the outline format (the Appendix) by indentation, and in Fig. 1-5 by branching to successive levels.

IV. Concluding Remarks

This document presents a discussion of the need for the establishment of a quarantine of the planet Mars, a description of the current JPL planetary quarantine policy and requirements, and a description of a model of

the *Voyager* 1973 Mission (as modeled from a quarantine point of view).

The model which makes up the bulk of this document is not the only one which can be constructed. It is intended to provide an illustration of the complexity of the planetary quarantine problem, and to delineate most of the elements which must be considered. A number of the items in the model represent a great deal of analytical effort.¹

At the lowest levels shown, kill processes are generally treated as independent, while in fact the processes may combine to give higher kill probabilities than implied. This simplification is a conservative one, and therefore permitted. It may be desirable in some cases to be more precise by using joint kill probabilities or joint probability distributions instead. In some cases, the relationships shown are oversimplified in another way. That is, some of the parameters of particular elements undergo wide variation during the course of the mission.² In such cases, the required probabilities can be conservatively estimated, or the addition relationships can be considered as generalized sums (integrals or summations), and the product relationships considered as factors in the integrand.

Kill probabilities, for example, may not be independent of the number of microorganisms to be operated upon. This complication can be treated by use of probability distributions rather than point estimates of probabilities as is done here. This elaboration of the analysis can be applied to individual branches of the tree, if desired.

Finally, it should be noted that there may be cases — particularly when simpler missions, such as fly-by missions, are considered — in which it is unnecessary to evaluate all of the elements of the model in order to estimate or to allocate violation probabilities. It may be quite reasonable to simply note that some branches have a negligible contribution to the overall probability of violation of quarantine.³

¹For example, the fraction of orbiting spacecraft orbit trim rocket exhaust gases which reach Mars prior to 1985.

²For example, the probability that planetary vehicle attitude control gases ejected during transit will reach Mars prior to 1985.

³A branch has a "negligible contribution" if its estimated probability is less than an allocation so small as to not materially affect the allocations to other branches at the same level.

Appendix

Outline Format for the Model of the Probability of Violation of the Quarantine of the Planet Mars as a Result of the Voyager 1973 Mission

Basic planetary quarantine requirement: The probability of violation of the quarantine of the planet Mars as a result of the *Voyager* 1973 Mission shall be less than or equal to Q^4 . This probability equals (=)

I. Violation probability resulting from all violation modes associated with the *Saturn V* launch vehicle (ALLOC⁵=____; EST⁶=____)

+II. Violation probability resulting from all violation modes associated with planetary vehicle No. 1 (PV 1) (ALLOC=____; EST=____)

+III. Violation probability resulting from all violation modes associated with planetary vehicle No. 2 (PV 2) (ALLOC=____; EST=____)

I. Violation probability resulting from all violation modes associated with the *Saturn V* launch vehicle
ALLOC=____; EST=____

=1 Violation probability resulting from all violation modes associated with the launch vehicle not identified below
Contingency ALLOC=____; EST=0.0

+2 Violation modes associated with the *Saturn IC* (S-IC) stage
ALLOC=____; EST=____

=21 Violation modes associated with the S-IC stage not identified below
Contingency ALLOC=____; EST=0.0

+22 Probability of violation due to impact of S-IC stage
ALLOC=____; EST=____

=221 Probability of Martian impact of S-IC stage
ALLOC=____; EST=____

X222 Probability that at least one viable terrestrial organism is on or within the S-IC stage at Martian impact, given that malfunctions occur in such a way that the S-IC stage impacts Mars
ASSUME=1.0

+23 Probability of violation due to Martian impact of a piece (or pieces) of the S-IC stage
ALLOC=____; EST=____

≤231 Probability that the S-IC stage explodes for any reason
ALLOC=____; EST=____

X232 Probability that any of the debris from an explosion of the S-IC stage contains at least one viable terrestrial organism and impacts Mars
ALLOC=____; EST=____

+24 Violation modes associated with the ejecta from the S-IC stage
ALLOC=____; EST=____

=241 Violation modes associated with other types of ejecta from the S-IC stage than identified below
Contingency ALLOC=____; EST=0.0

+242 Probability of violation due to S-IC rocket exhaust
ALLOC=____; EST=____

+243 Probability of violation due to propellant leaked from the S-IC tanks
ALLOC=____; EST=____

+244 Probability of violation due to S-IC stage thrust vector control (TVC) fluid
ALLOC=____; EST=____

+245 Probability of violation due to S-IC stage attitude control gas
ALLOC=____; EST=____

+246 Probability of violation due to loose hardware associated with the S-IC stage
ALLOC=____; EST=____

+247 Probability of violation due to shrapnel from S-IC stage pyrotechnics
ALLOC=____; EST=____

+248 Probability of violation due to material outgassed, spalled, ablated, or sputtered from the S-IC stage
ALLOC=____; EST=____

*A numerical value yet to be established.

*Allocated value

*Estimated value

+ 25 (1/2)	Violation modes associated with the Saturn IC/Saturn II (S-IC/S-II) stage separation	+346	Probability of violation due to loose hardware associated with the S-II stage
+ 30 (1/2)	ALLOC=_____, half charged to S-IC stage, half to S-II stage; EST=_____		ALLOC=_____; EST=_____
≤ 251	Probability that contaminated loose hardware resulting from an assumed S-IC/S-II separation will impact Mars	+347	Probability of violation due to shrapnel from S-II stage pyrotechnics
301	ALLOC=_____; EST=_____		ALLOC=_____; EST=_____
+ 252	Probability that contaminated pyrotechnic shrapnel resulting from an assumed S-IC/S-II separation will impact Mars	+348	Probability of violation due to material outgassed, spalled, ablated, or sputtered from the S-II stage
+ 302	ALLOC=_____; EST=_____		ALLOC=_____; EST=_____
+3	Violation modes associated with the S-II stage	+ 35 (1/2)	Violation modes associated with the Saturn II/Saturn IVB (S-II/S-IVB) stage separation
	ALLOC=_____; EST=_____	+ 40 (1/2)	ALLOC=_____, half charged to S-II stage, half to S-IVB stage; EST=_____
=31	Violation modes associated with the S-II stage not identified below	≤ 351	Probability that contaminated loose hardware resulting from an assumed S-II/S-IVB separation will impact Mars
	Contingency ALLOC=_____; EST=0.0	401	ALLOC=_____; EST=_____
+32	Probability of violation due to impact of S-II stage	+ 352	Probability that contaminated pyrotechnic shrapnel resulting from an assumed S-II/S-IVB separation will impact Mars
	ALLOC=_____; EST=_____	+ 402	ALLOC=_____; EST=_____
=321	Probability of Martian impact of S-II stage		
	ALLOC=_____; EST=_____		
X322	Probability that at least one viable terrestrial organism is on or within the S-II stage at Martian impact, given that malfunctions occur in such a way that the S-II stage impacts Mars	+4	Violation modes associated with the S-IVB stage
	ASSUME=1.0		ALLOC=_____; EST=_____
+33	Probability of violation due to Martian impact of a piece (or pieces) of the S-II stage	=41	Violation modes associated with the S-IVB stage not identified below
	ALLOC=_____; EST=_____		Contingency ALLOC=_____; EST=0.0
≤331	Probability that the S-II stage explodes for any reason	+42	Probability of violation due to impact of S-IVB stage
	ALLOC=_____; EST=_____		ALLOC=_____; EST=_____
X332	Probability that any of the debris from an explosion of the S-II stage contains at least one viable terrestrial organism and impacts Mars	=421	Probability of Martian impact of S-IVB stage
	ALLOC=_____; EST=_____		ALLOC=_____; EST=_____
+34	Violation modes associated with the ejecta from the S-II stage	=4211	Probability S-IVB stage is on a Martian impact trajectory after both planetary vehicle separations
	ALLOC=_____; EST=_____		ALLOC=_____; EST=_____
=341	Violation modes associated with other types of ejecta from the S-II stage than identified below	X4212	Probability S-IVB retrorockets (if any) do not remove the S-IVB from an impact trajectory
	Contingency ALLOC=_____; EST=0.0		ALLOC=_____; EST=_____
+342	Probability of violation due to S-II rocket exhaust	X422	Probability that at least one viable terrestrial organism is on or within the S-IVB stage at Martian impact, given that the S-IVB stage impacts Mars
	ALLOC=_____; EST=_____		ASSUME=1.0
+343	Probability of violation due to propellant leaked from the S-II tanks	+43	Probability of violation due to Martian impact of a piece (or pieces) of the S-IVB stage
	ALLOC=_____; EST=_____		ALLOC=_____; EST=_____
+344	Probability of violation due to S-II stage TVC fluid	≤431	Probability of explosion of S-IVB stage for any reason
	ALLOC=_____; EST=_____		ALLOC=_____; EST=_____
+345	Probability of violation due to S-II stage attitude control gas	X432	Probability that any of the debris from an explosion of the S-IVB stage contains at least one viable terrestrial organism and impacts Mars
	ALLOC=_____; EST=_____		ALLOC=_____; EST=_____
		+44	Violation modes associated with the ejecta from the S-IVB stage
			ALLOC=_____; EST=_____

=441 Violation modes associated with other types of ejecta from the S-IVB stage than identified below
Contingency ALLOC=____; EST=0.0

+442 Probability of violation due to S-IVB rocket exhaust
ALLOC=____; EST=____

+443 Probability of violation due to propellant leaked from the S-IVB tanks
ALLOC=____; EST=____

+444 Probability of violation due to S-IVB stage TVC fluid
ALLOC=____; EST=____

+445 Probability of violation due to S-IVB attitude control gas
ALLOC=____; EST=____

+446 Probability of violation due to loose hardware associated with the S-IVB stage
ALLOC=____; EST=____

+447 Probability of violation due to shrapnel from S-IVB pyrotechnics
ALLOC=____; EST=____

+448 Probability of violation due to material outgassed, spalled, ablated, sputtered, etc., from the S-IVB stage
ALLOC=____; EST=____

+5 Violation modes associated with the aerodynamic nose fairing (shroud)
ALLOC=____; EST=____

=51 Violation modes associated with the shroud not identified below
Contingency ALLOC =____; EST=0.0

+52 Probability of violation due to loose hardware associated with the shroud
ALLOC=____; EST=____

=521 Probability that loose hardware associated with the shroud will impact Mars
ALLOC=____; EST=____

X522 Probability that at least one viable terrestrial organism is on or within loose hardware associated with the shroud, given that such hardware impacts Mars
ASSUME=1.0

+53 Probability of violation due to Martian impact of a piece (or pieces) of the shroud
ALLOC=____; EST=____

≤531 Probability that any shroud pieces impact Mars
ALLOC=____; EST=____

X532 Probability that at least one viable terrestrial organism is on or within the shroud piece (or pieces) which impact Mars, given that such impact occurs
ASSUME=1.0

II. Violation probability resulting from all violation modes associated with planetary vehicle No. 1
ALLOC=____; EST=____

=1 Violation probability resulting from all modes associated with PV 1 not identified below
Contingency ALLOC=____; EST=0.0

+2 Violation modes associated with an intact planetary vehicle
ALLOC=____; EST=____

=21 Violation modes associated with an intact planetary vehicle not identified below
Contingency ALLOC=____; EST=0.0

+22 Probability of violation due to impact of the intact planetary vehicle
ALLOC=____; EST=____

=221 Probability of violation due to impact resulting from causes other than those identified below
Contingency ALLOC=____; EST=0.0

+222 Probability of violation due to PV being placed on an impact trajectory at injection
ALLOC=____; EST=____

=2221 Probability midcourse engine fails to deliver sufficient control and/or thrust to produce abort (i.e., to remove PV from impact trajectory)
ALLOC=____; EST=____

X2222 Probability retro (orbit insertion) engine fails to produce abort
ALLOC=____; EST=____

X2223 Probability PV is contaminated when at Mars
ASSUME=1.0

X2224 Probability PV is placed on impact trajectory at injection
ALLOC=____; EST=____

+223 Probability of violation due to PV being placed on an impact trajectory by a midcourse maneuver
ALLOC=____; EST=____

+224 Probability of violation due to PV impact resulting from orbit insertion attempt
ALLOC=____; EST=____

+225 Probability of violation due to PV impact resulting from orbit trim attempts
ALLOC=____; EST=____

+226 Probability of violation due to orbital decay of intact planetary vehicle
ALLOC=____; EST=____

=2261 Probability PV orbit decays prior to 1985
ALLOC=____; EST=____

X2262 Probability capsule not separated
ALLOC=____; EST=____

X2263 Probability PV contaminated at the time of orbit decay
ASSUME=1.0

+23	Probability of violation due to impact of PV explosion shrapnel ALLOC=____; EST=____	=24131	Fraction of transit attitude control gases which will reach Mars prior to 1985 ALLOC=____; EST=____
=231	Probability PV explodes ALLOC=____; EST=____	X24132	Probability such gases are contaminated when they reach Mars ALLOC=____; EST=____
X232	Probability that a contaminated piece of an exploded PV will impact Mars ALLOC=____; EST=____	=241321	Initial microbial load of such gases ALLOC=____; EST=____
+24	Violation modes associated with ejecta from PV 1 ALLOC=____; EST=____	X241322	Probability microorganisms not killed by other means ALLOC=____; EST=____
=241	Violation modes associated with ejecta released from PV 1 prior to orbit achievement ALLOC=____; EST=____	X241323	Probability remaining microorganisms not killed by ejection process ALLOC=____; EST=____
=2411	Violation modes associated with other types of ejecta from PV 1 than identified below Contingency ALLOC=____; EST=0.0	X241324	Probability remaining microorganisms not killed by "die off" ALLOC=____; EST=____
+2412	Probability of violation due to midcourse maneuver exhaust gases ALLOC=____; EST=____	X241325	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____
=24121	Fraction of such gases which will reach Mars prior to 1985 ALLOC=____; EST=____	X241326	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____
X24122	Probability such gases are contaminated when they reach Mars ALLOC=____; EST=____	X241327	Probability remaining microorganisms not killed by vacuum ASSUME=1.0
=241221	Initial microbial load of such propellants ALLOC=____; EST=____	+2414	Probability of violation due to outgassed, spalled, ablated, sputtered, or other material ALLOC=____; EST=____
X241222	Probability initially viable microorganisms in the propellants are not killed by the propellants ALLOC=____; EST=____	=24141	Fraction of such material which will reach Mars prior to 2023 ALLOC=____; EST=____
X241223	Probability remaining microorganisms are not killed in the ejection process ALLOC=____; EST=____	X24142	Initial microbial load of such material ALLOC=____; EST=____
X241224	Probability remaining microorganisms are not killed by other means ALLOC=____; EST=____	X24143	Probability microorganisms not killed by other means ALLOC=____; EST=____
X241225	Probability remaining microorganisms do not "die off" (due to time, lack of food, etc.) ALLOC=____; EST=____	X24144	Probability remaining microorganisms not killed by ejection process ALLOC=____; EST=____
X241226	Probability remaining microorganisms are not killed by UV radiation ALLOC=____; EST=____	X24145	Probability remaining microorganisms not killed by "die off" ALLOC=____; EST=____
X241227	Probability remaining microorganisms are not killed by other solar radiation ALLOC=____; EST=____	X24146	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____
X241228	Probability remaining microorganisms are not killed by vacuum ASSUME=1.0	X24147	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____
+2413	Probability of violation due to attitude control gases ALLOC=____; EST=____	X24148	Probability remaining microorganisms not killed by vacuum ASSUME=1.0

+242	Violation modes associated with ejecta released from PV 1 during orbit insertion ALLOC=____; EST=____	X243322	Probability microorganisms not killed by other means ALLOC=____; EST=____
+243	Violation modes associated with ejecta released from PV 1 after orbit insertion ALLOC=____; EST=____	X243323	Probability remaining microorganisms not killed by "die off" ALLOC=____; EST=____
=2431	Violation modes associated with other types of ejecta from PV 1 than identified below Contingency ALLOC=____; EST=0.0	X243324	Probability remaining microorganisms not killed by ejection process ALLOC=____; EST=____
+2432	Probability of violation due to orbit trim rocket exhaust gases ALLOC=____; EST=____	X243325	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____
=24321	Fraction of such gases which will reach Mars prior to 1985 ALLOC=____; EST=____	X243326	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____
X24322	Probability such gases are contaminated when they reach Mars ALLOC=____; EST=____	X243327	Probability remaining microorganisms not killed by vacuum ASSUME=1.0
=243221	Initial microbial load of retro propellants ALLOC=____; EST=____	+2434	Probability of violation due to outgassed, spalled, ablated, sputtered, etc., material ALLOC=____; EST=____
X243222	Probability microorganisms are not killed by propellants ALLOC=____; EST=____	=24341	Expected microbial load of such material ejected prior to spacecraft/capsule separation ALLOC=____; EST=____
X243223	Probability remaining microorganisms not killed by ejection process ALLOC=____; EST=____	X24342	Probability such material is contaminated when it reaches Mars ALLOC=____; EST=____
X243224	Probability remaining microorganisms not killed by other means ALLOC=____; EST=____	=243421	Probability such material is contaminated initially ALLOC=____; EST=____
X243225	Probability remaining microorganisms not killed by "die off" ALLOC=____; EST=____	X243422	Probability microorganisms not killed by other means ALLOC=____; EST=____
X243226	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____	X243423	Probability remaining microorganisms not killed by ejection process ALLOC=____; EST=____
X243227	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____	X243424	Probability remaining microorganisms not killed by "die off" ALLOC=____; EST=____
X243228	Probability remaining microorganisms not killed by vacuum ASSUME=1.0	X243425	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____
+2433	Probability of violation due to attitude control gas from PV 1 ALLOC=____; EST=____	X243426	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____
=24331	Fraction of such gases will reach Mars prior to 1985 ALLOC=____; EST=____	X243427	Probability remaining microorganisms not killed by vacuum ASSUME=1.0
X24332	Probability attitude control gases contaminated when at Mars ALLOC=____; EST=____	X24343	Fraction of such material which reaches Mars prior to 1985 ALLOC=____; EST=____
=243321	Probability such gases contaminated initially ALLOC=____; EST=____	+25	Probability of violation due to impact to the forward part of the biological barrier ALLOC=____; EST=____

=251	Probability of impact of the forward part of the biological barrier ALLOC=____; EST=____	+33113	Probability orbit insertion motor explodes ALLOC=____; EST=____
X252	Probability forward part of biological barrier contaminated ALLOC=____; EST=____	+33114	Probability orbit trim motor explodes ALLOC=____; EST=____
+26	Violation modes associated with Launch Vehicle/Planetary Vehicle 1 separation ALLOC=____; EST=____	+33115	Probability pressure tanks explode ALLOC=____; EST=____
=261	Violation due to impact of contaminated loose hardware ALLOC=____; EST=____	+33116	Probability batteries explode ALLOC=____; EST=____
+262	Violation due to impact of contaminated pyrotechnic shrapnel ALLOC=____; EST=____	+3312	Probability spacecraft smashed by meteorites ALLOC=____; EST=____
+3	Violation modes associated with the orbiting spacecraft ALLOC=____; EST=____	=33121	Probability a sufficiently large meteorite hits the spacecraft prior to 1985 ALLOC=____; EST=____
=31	Violation modes associated with an orbiting spacecraft not identified below Contingency ALLOC=____; EST=0.0	X33122	Probability that any of the resultant pieces impact Mars prior to 1985 ALLOC=____; EST=____
+32	Violation due to premature impact of the orbiting spacecraft ALLOC=____; EST=____	+3313	Probability spacecraft breaks up from centrifugal force prior to 1985 ALLOC=____; EST=____
=321	Probability orbiting spacecraft contaminated at impact ASSUME=1.0	=33131	Probability attitude control system fails prior to 1985 ASSUME=1.0
X322	Probability orbiting spacecraft impacts prior to 1985 ALLOC=____; EST=____	X33132	Probability unbalanced forces cause excessive spacecraft spin-up prior to 1985 ALLOC=____; EST=____
=3221	Probability of premature orbit decay as a result of other causes than shown below Contingency ALLOC=____; EST=____	X332	Probability any spacecraft pieces decay prior to 1985 ALLOC=____; EST=____
+3222	Probability of premature decay due to atmospheric drag ALLOC=____; EST=____	X333	Probability any spacecraft pieces which decay prior to 1985 are contaminated when at Mars ALLOC=____; EST=____
+3223	Probability of impact due to faulty orbit trim maneuvers ALLOC=____; EST=____	=3331	Initial spacecraft microbial load ALLOC=____; EST=____
+3224	Probability of impact due to perturbations at spacecraft/capsule separation ALLOC=____; EST=____	X3332	Probability microorganisms not killed by other means ALLOC=____; EST=____
+3225	Probability of decay due to N-body gravitational perturbations ALLOC=____; EST=____	X3333	Probability microorganisms not killed by entry ALLOC=____; EST=____
+3226	Probability of decay due to gravitational harmonics ALLOC=____; EST=____	X3334	Fraction of initial load left when spacecraft breaks up ALLOC=____; EST=____
+33	Violation due to impact of spacecraft pieces prior to 1985 ALLOC=____; EST=____	X3335	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____
=331	Probability spacecraft breaks into pieces ALLOC=____; EST=____	X3336	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____
=3311	Probability spacecraft explodes ALLOC=____; EST=____	X3337	Probability remaining microorganisms not killed by vacuum ASSUME=1.0
=33111	Probability of any other explosion on the orbiting spacecraft Contingency ALLOC=____; EST=0.0	+34	Violation modes associated with ejecta from an orbiting spacecraft ALLOC=____; EST=____
+33112	Probability midcourse motor explodes ALLOC=____; EST=____		

=341	Violation modes associated with other types of ejecta from orbiting spacecraft than identified below Contingency ALLOC=____; EST=0.0	X34333	Probability remaining microorganisms not killed by "die off" ALLOC=____; EST=____
+342	Probability of violation due to orbit trim rocket exhaust gases ALLOC=____; EST=____	X34334	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____
=3421	Probability orbit trim rocket propellants contaminated initially ALLOC=____; EST=____	X34335	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____
X3422	Fraction of such gases which reach Mars prior to <u>1985</u> ALLOC=____; EST=____	X34336	Probability remaining microorganisms not killed by vacuum ASSUME=1.0
X3423	Probability microorganisms not killed prior to Mars entry ALLOC=____; EST=____	+344	Probability of violation due to material outgassed, spalled, etc. ALLOC=____; EST=____
=34231	Probability microorganisms not killed by other means ALLOC=____; EST=____	=3441	Fraction of such material which impacts Mars prior to <u>1985</u> ALLOC=____; EST=____
X34232	Probability remaining microorganisms not killed by propellants ALLOC=____; EST=____	X3442	Probability such material contaminated when at Mars ALLOC=____; EST=____
X34233	Probability remaining microorganisms not killed during rocket firing ALLOC=____; EST=____	=34421	Initial microbial load of such material ALLOC=____; EST=____
X34234	Probability remaining microorganisms not killed by "die off" ALLOC=____; EST=____	X34422	Probability viable microorganisms not killed in transit prior to ejection ALLOC=____; EST=____
X34235	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____	=344221	Probability microorganisms not killed by means other than as follows ALLOC=____; EST=____
X34236	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____	X344222	Probability remaining microorganisms not killed by "die off" in transit ALLOC=____; EST=____
X34237	Probability remaining microorganisms not killed by vacuum ASSUME=1.0	X344223	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____
+343	Probability of violation due to attitude control gases ALLOC=____; EST=____	X344224	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____
=3431	Probability attitude control gas contains viable terrestrial microorganisms initially (or initial microbial load) ALLOC=____; EST=____	X344225	Probability remaining microorganisms not killed by vacuum ASSUME=1.0
X3432	Fraction of attitude control gas which reaches Mars prior to 2023 ALLOC=____; EST=____	X34423	Probability viable microorganisms not killed during or after ejection from spacecraft ALLOC=____; EST=____
X3433	Probability microorganisms not killed in transit to Mars ALLOC=____; EST=____	=344231	Probability remaining organisms not killed by means other than as follows ALLOC=____; EST=____
=34331	Probability remaining microorganisms not killed by means other than identified below ALLOC=____; EST=____	X344232	Probability remaining microorganisms not killed by "die off" ALLOC=____; EST=____
X34332	Probability remaining microorganisms not killed during release ALLOC=____; EST=____	X344233	Probability remaining microorganisms not killed by ejection process ALLOC=____; EST=____

X344234	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____	+4423	Probability of recontamination due to failure of biological barrier ALLOC=____; EST=____
X344235	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____	=44231	Recontamination due to modes of biological barrier failure other than shown below Contingency ALLOC=____; EST=0.0
X344236	Probability remaining microorganisms not killed by vacuum ASSUME=1.0	+44232	Recontamination due to structural failure of biological barrier ALLOC=____; EST=____
+35	Violation due to impact of the aft part of the biological barrier ALLOC=____; EST=____	=442321	Probability biological barrier structure fails ALLOC=____; EST=____
=351	Probability aft part of biological barrier impacts Mars ALLOC=____; EST=____	X442322	Probability capsule recontaminated if the biological barrier structure fails ALLOC=____; EST=____
X352	Probability aft part of biological barrier is contaminated when it impacts Mars ASSUME=1.0	X442323	Probability mission not aborted if there is structural failure of the biological barrier ALLOC=____; EST=____
+4	Violation modes associated with a separated entry capsule ALLOC=____; EST=____	=4423231	Probability structural failure of biological barrier is not detected ALLOC=____; EST=____
=41	Violation modes associated with a separated entry capsule not identified below Contingency ALLOC=____; EST=0.0	+4423232	Probability failure is detected and mission is still not aborted ALLOC=____; EST=____
+42	Probability contaminated spacecraft/capsule separation debris impacts Mars prior to 1985 ALLOC=____; EST=____	+44233	Probability of recontamination due to bad biological seals on the biological barrier ALLOC=____; EST=____
+43	Violation modes associated with capsule ejecta ALLOC=____; EST=____	=442331	Probability of biological barrier having bad seals ALLOC=____; EST=____
=431	Fraction of capsule ejecta which impacts Mars ASSUME=1.0	X442332	Probability capsule recontaminated if bad seals are present ALLOC=____; EST=____
X432	Probability capsule ejecta is contaminated when it reaches Mars ALLOC=____; EST=____	+44234	Probability of recontamination due to micrometeoritic puncture of biological barrier ALLOC=____; EST=____
+44	Violation modes associated with impact or landing of an entry capsule ALLOC=____; EST=____	=442341	Probable number of micrometeoritic punctures ALLOC=____; EST=____
=441	Probability of capsule contacting Mars ASSUME=1.0	X442342	Probability that a viable terrestrial microorganism enters a puncture hole in the biological barrier ALLOC=____; EST=____
X442	Probability of capsule being contaminated when contacting Mars ALLOC=____; EST=____	X442343	Probability that such organisms would travel from the biological barrier to the capsule ALLOC=____; EST=____
=4421	Probability of failure of heat sterilization ALLOC=____; EST=____	+4424	Probability of recontamination of the entry capsule after the removal of the biological barrier ALLOC=____; EST=____
+4422	Probability of recontamination occurring and remaining undiscovered prior to launch ALLOC=____; EST=____	=44241	Probability that particles surrounding the planetary vehicle are not sterile ALLOC=____; EST=____
=44221	Probability of undiscovered recontamination due to poor handling ALLOC=____; EST=____	=442411	Number of particles surrounding planetary vehicle which are not sterile initially ALLOC=____; EST=____
+44222	Probability of failure of "sterile insertion" techniques (if used) ALLOC=____; EST=____		

X442412	Probability microorganisms on such particles are not killed in flight ALLOC=____; EST=____	X4424126	Probability remaining microorganisms not killed by vacuum ASSUME=1.0
=4424121	Probability microorganisms not killed by other means than shown below ALLOC=____; EST=____	X44242	Probability of unsterile particles contaminating capsule ALLOC=____; EST=____
X4424122	Probability remaining microorganisms not killed by "die off" ALLOC=____; EST=____	=442421	Probability unsterile particles impinge on capsule ALLOC=____; EST=____
X4424123	Probability microorganisms not killed when dislodged ALLOC=____; EST=____	X442422	Probability impinging unsterile particles stick to the capsule ALLOC=____; EST=____
X4424124	Probability remaining microorganisms not killed by UV radiation ALLOC=____; EST=____	III. Violation probability resulting from all violation modes associated with planetary vehicle No. 2 ALLOC=____; EST=____	
X4424125	Probability remaining microorganisms not killed by other solar radiation ALLOC=____; EST=____	This submodel probability is similar to that for planetary vehicle No. 1, detailed in preceding Subsection II.	

References

1. Sagan, Carl, and Coleman, Sidney, "Spacecraft Sterilization Standards and Contamination of Mars," *Astronautics and Aeronautics*, May 1965.
2. A Note on COSPAR Resolution 26.5, NASA Position Paper COSPAR, NASA Headquarters, May 1966.
3. Craven, C. W., *Planetary Quarantine Plan, Voyager Project*, Jet Propulsion Laboratory, March 15, 1966 (1st Rev., October 15, 1966).