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The Voyager Planetary Quarantine Model 1973 Mission

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Contents

I. Introduction 1

II. Planetary Quarantine Policy and Requirements 1

A. Establishment of Planetary Quarantine 1

B. Planetary Quarantine Requirements 1

1. Infection (of an extraterrestrial planet) 1

2. Contamination (of an extraterrestrial planet) 2

3. Quarantine (of an extraterrestrial planet) 2

C. Planetary Quarantine Policy 2

III. Planetary Quarantine Model and Probability Allocations 2

A. Introduction 2

B. The Validity of the Mathematical Model 7

C. The Planetary Quarantine Model 7

IV. Concluding Remarks 8

Appendix 9

References 17

Figures

1. First level breakdown of planetary quarantine model 3

2. Launch vehicle portion of planetary quarantine model 3

3. Intact planetary vehicle portion of planetary quarantine model 4

4. Orbiting spacecraft portion of planetary quarantine model 5

5. Separated entry capsule portion of planetary quarantine model 6

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.

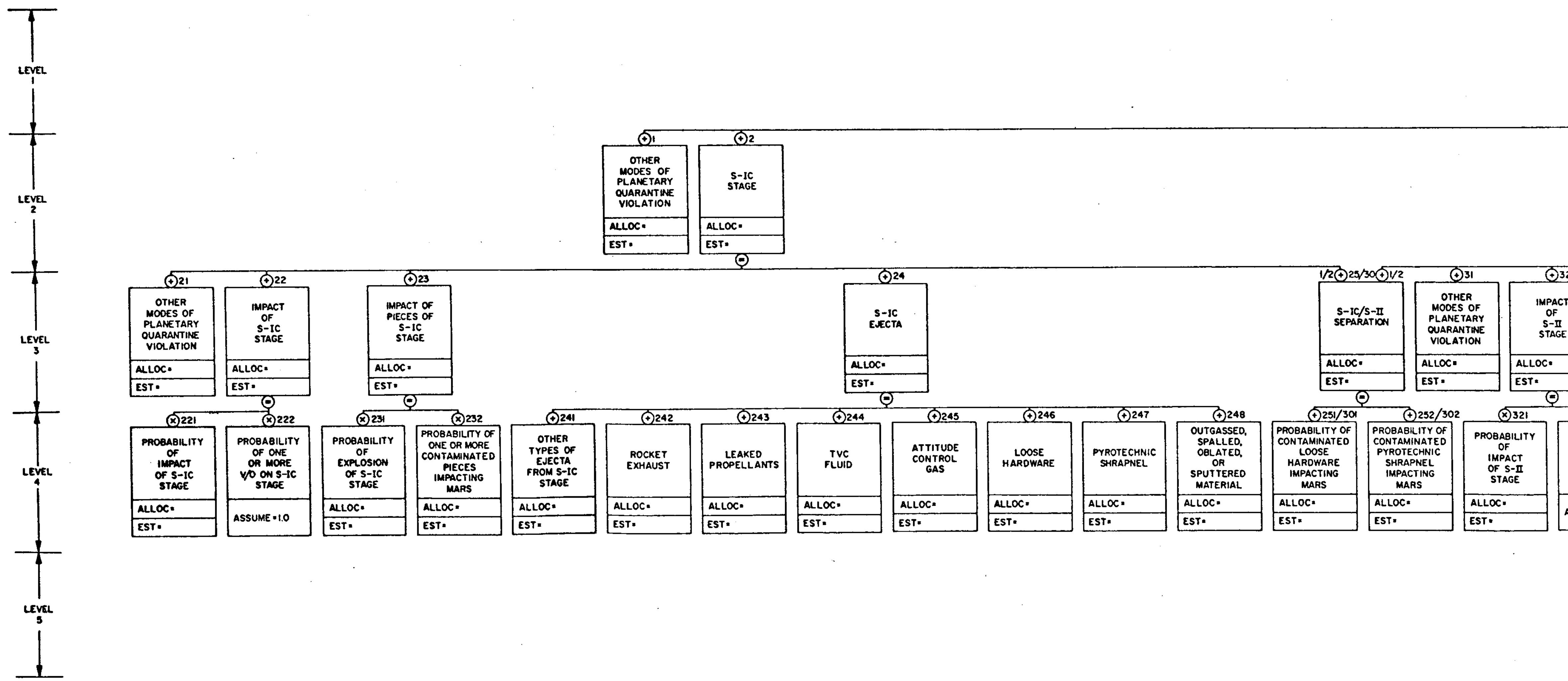
Figures 1–5 diagram the *Voyager* 1973 Mission planetary quarantine model, and show (or can show) the following:

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.



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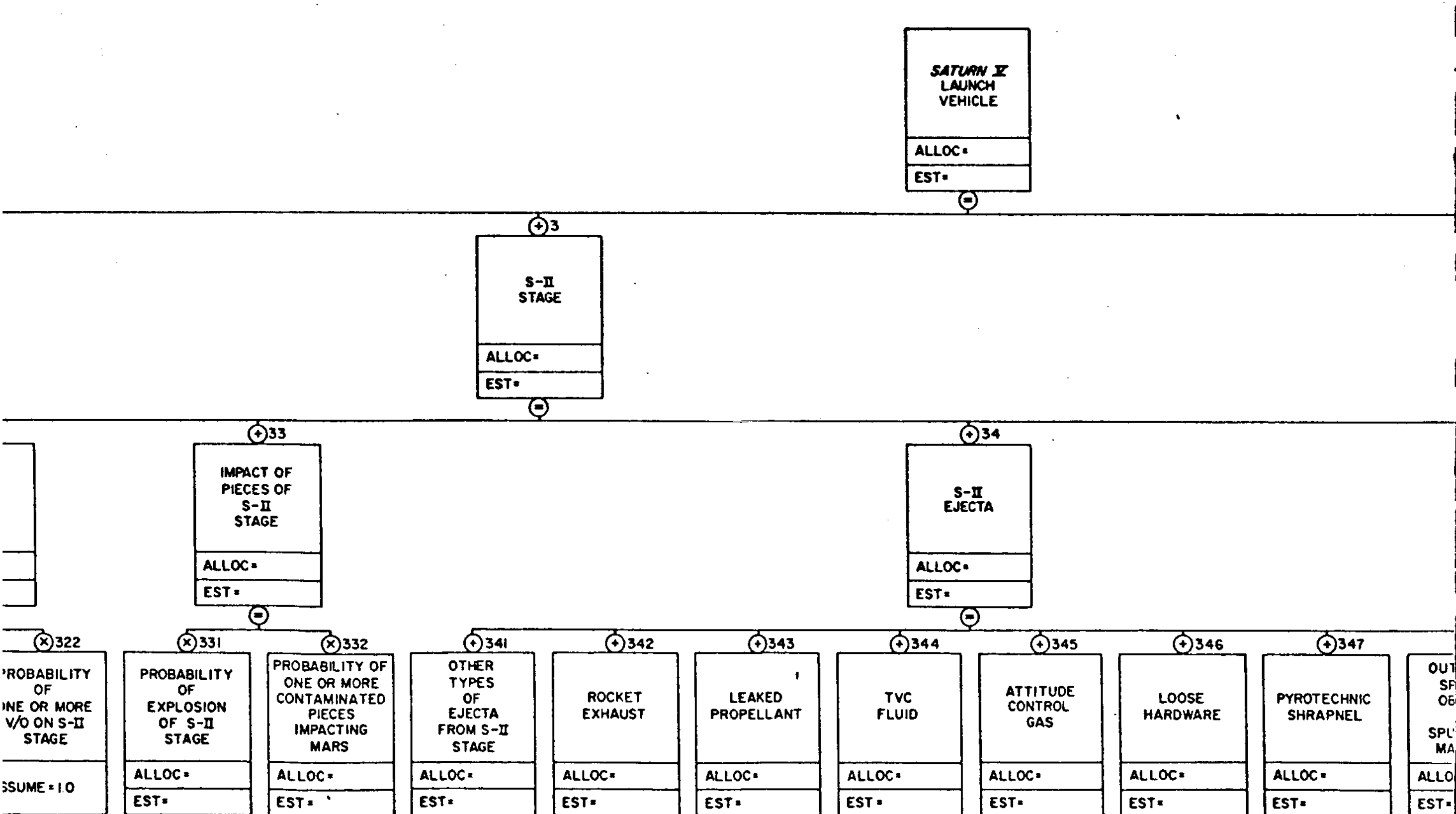

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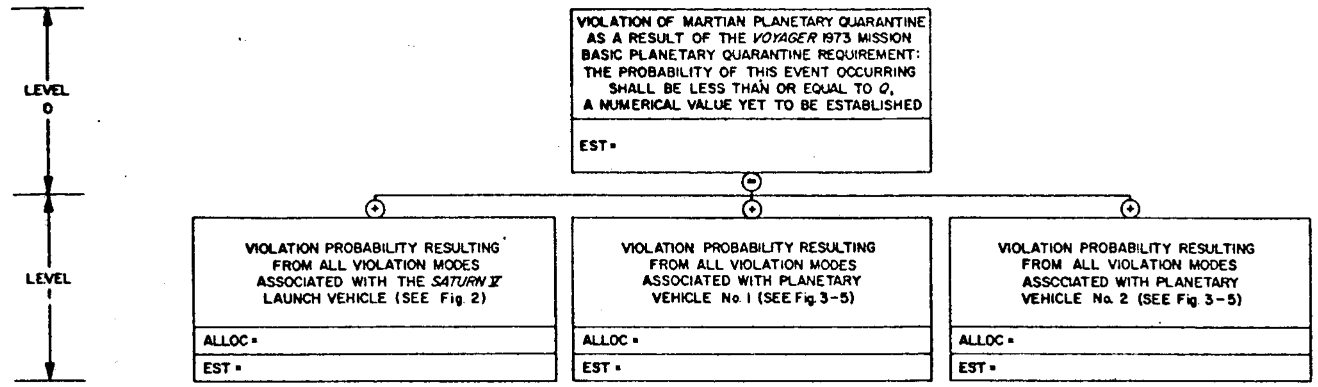

Fig. 1. First level breakdown of planetary quarantine model

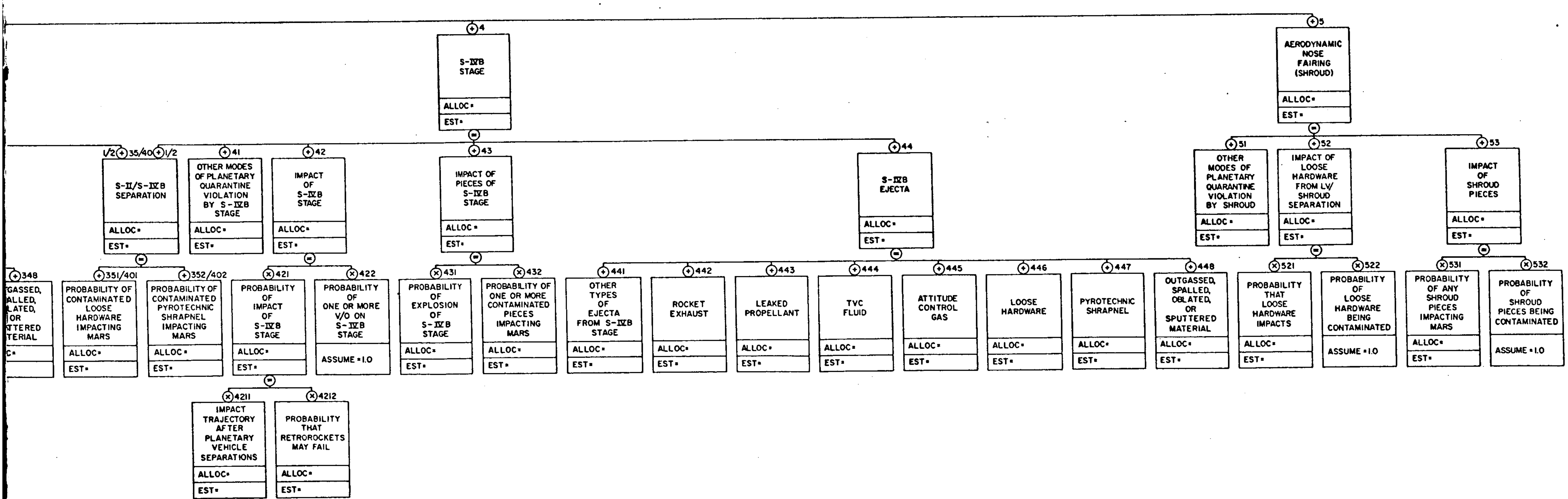

Fig. 2. Launch vehicle portion of planetary quarantine model

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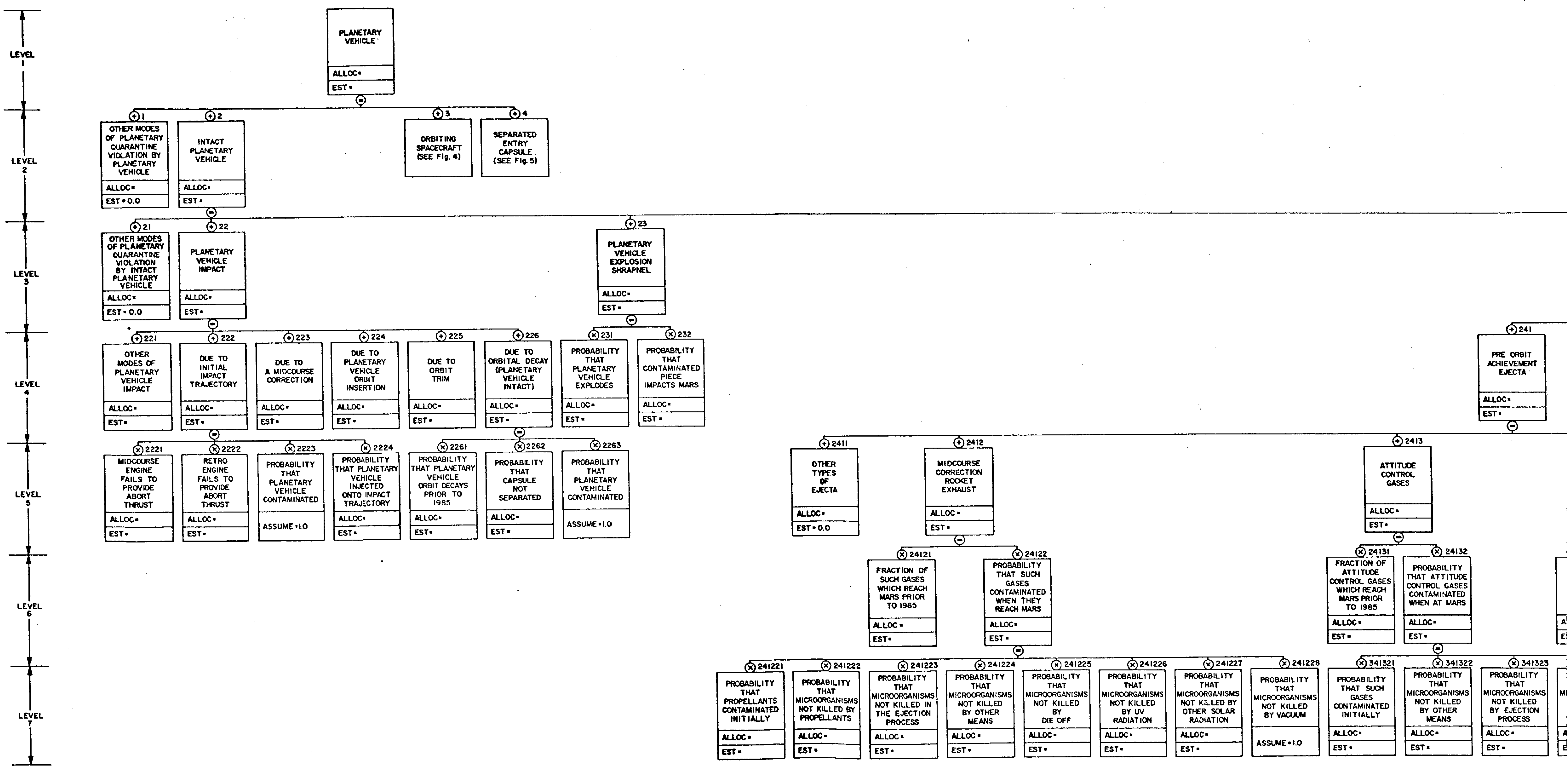

Fig. 3. Intact planetary vehicle portion of planetary quarantine model

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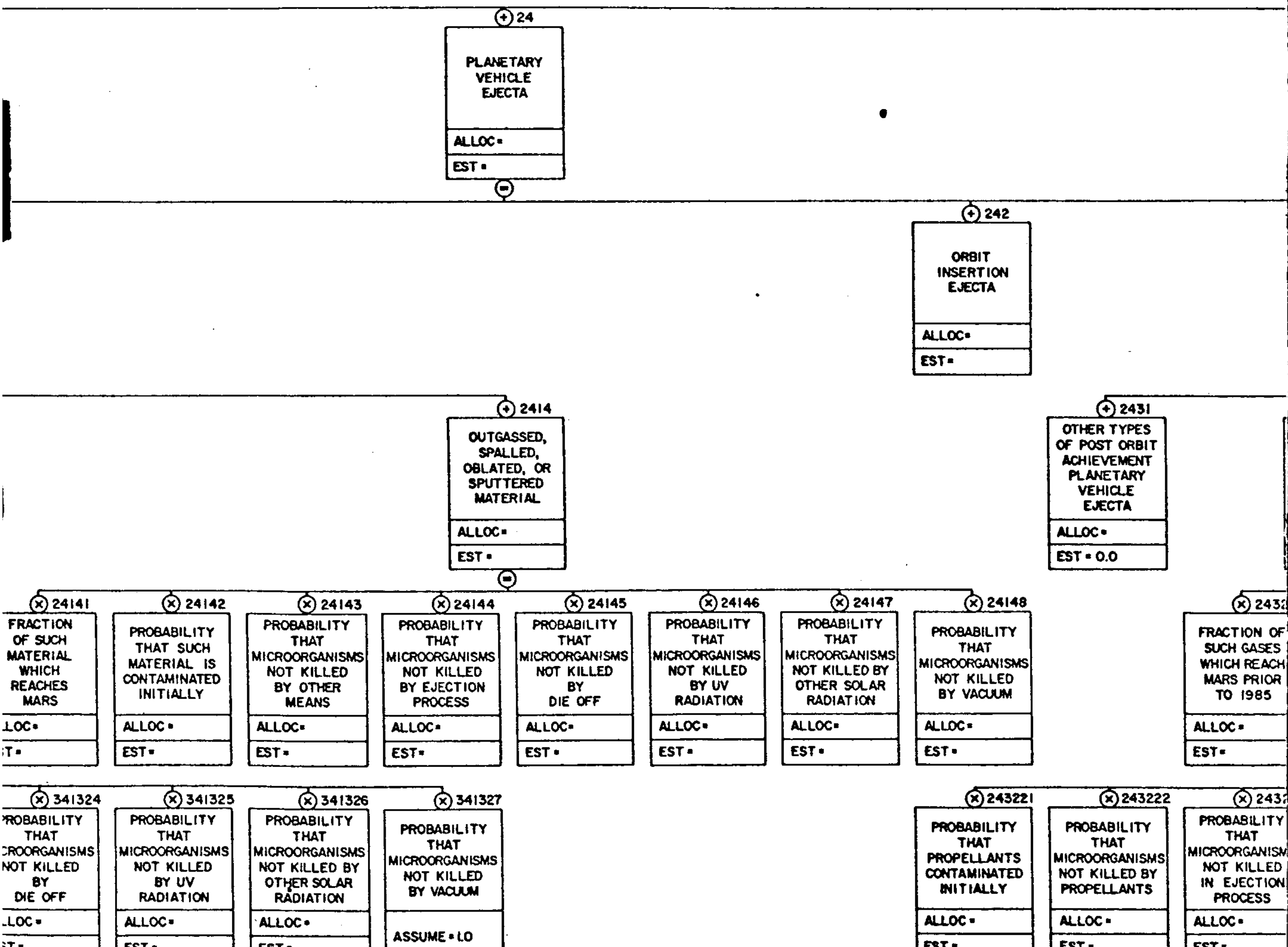

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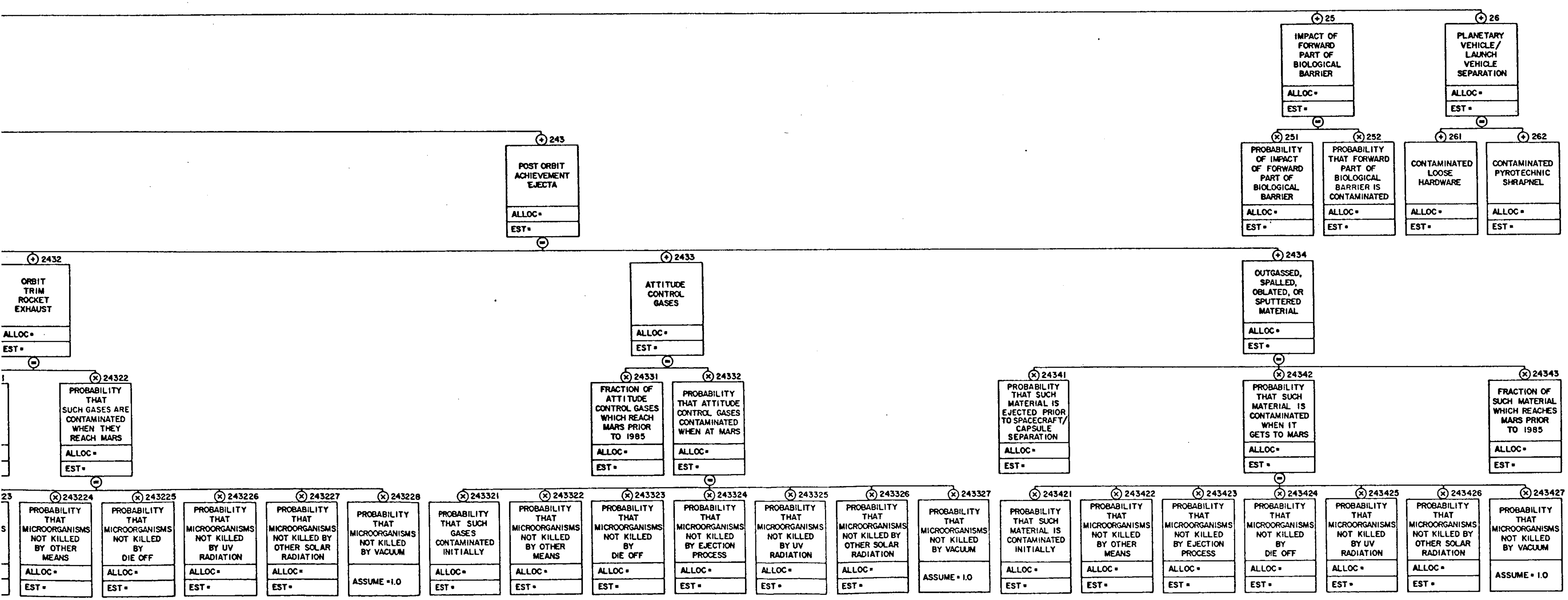
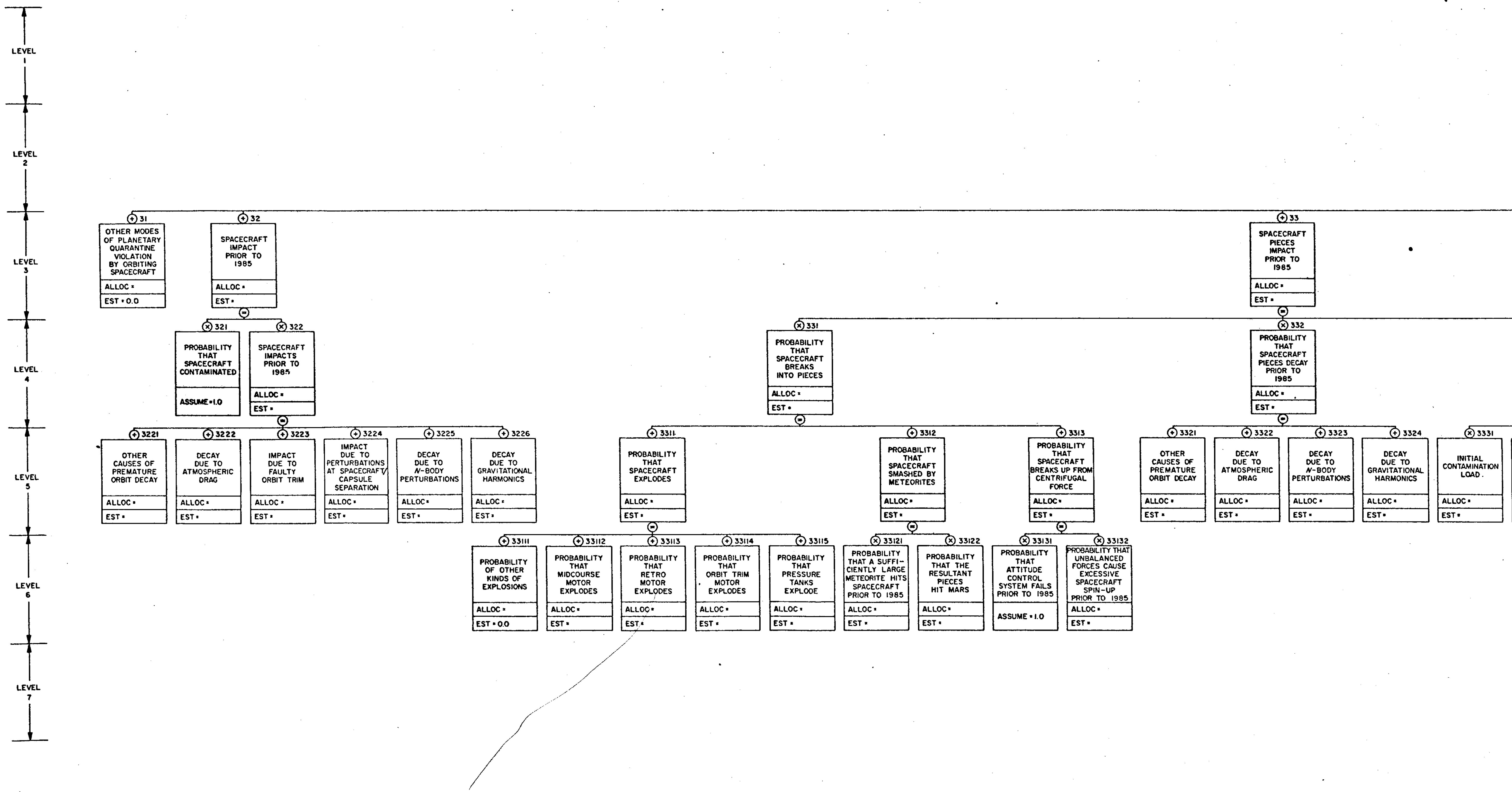


25
IMPACT OF FORWARD PART OF BIOLOGICAL BARRIER
ALLOC =
EST =
26
PLANETARY VEHICLE/ LAUNCH VEHICLE SEPARATION
ALLOC =
EST =
251
PROBABILITY OF IMPACT OF FORWARD PART OF BIOLOGICAL BARRIER
252
PROBABILITY THAT FORWARD PART OF BIOLOGICAL BARRIER IS CONTAMINATED
261
CONTAMINATED LOOSE HARDWARE
262
CONTAMINATED PYROTECHNIC SHRAPNEL
243
POST ORBIT ACHIEVEMENT EJECTA
2432
ORBIT TRIM ROCKET EXHAUST
2433
ATTITUDE CONTROL GASES
2434
OUTGASSED, SPALLED, OBLATED, OR SPUTTERED MATERIAL
24322
PROBABILITY THAT SUCH GASES ARE CONTAMINATED WHEN THEY REACH MARS
24331
FRACTION OF ATTITUDE CONTROL GASES WHICH REACH MARS PRIOR TO 1985
24332
PROBABILITY THAT ATTITUDE CONTROL GASES CONTAMINATED WHEN AT MARS
24341
PROBABILITY THAT SUCH MATERIAL IS EJECTED PRIOR TO SPACECRAFT/ CAPSULE SEPARATION
24342
PROBABILITY THAT SUCH MATERIAL IS CONTAMINATED WHEN IT GETS TO MARS
24343
FRACTION OF SUCH MATERIAL WHICH REACHES MARS PRIOR TO 1985
243224
PROBABILITY THAT MICROORGANISMS NOT KILLED BY OTHER MEANS
243225
PROBABILITY THAT MICROORGANISMS NOT KILLED BY DIE OFF
243226
PROBABILITY THAT MICROORGANISMS NOT KILLED BY UV RADIATION
243227
PROBABILITY THAT MICROORGANISMS NOT KILLED BY OTHER SOLAR RADIATION
243228
PROBABILITY THAT MICROORGANISMS NOT KILLED BY VACUUM
ASSUME = 1.0
243321
PROBABILITY THAT SUCH GASES CONTAMINATED INITIALLY
243322
PROBABILITY THAT MICROORGANISMS NOT KILLED BY OTHER MEANS
243323
PROBABILITY THAT MICROORGANISMS NOT KILLED BY DIE OFF
243324
PROBABILITY THAT MICROORGANISMS NOT KILLED BY EJECTION PROCESS
243325
PROBABILITY THAT MICROORGANISMS NOT KILLED BY UV RADIATION
243326
PROBABILITY THAT MICROORGANISMS NOT KILLED BY OTHER SOLAR RADIATION
243327
PROBABILITY THAT MICROORGANISMS NOT KILLED BY VACUUM
ASSUME = 1.0
243421
PROBABILITY THAT SUCH MATERIAL IS CONTAMINATED INITIALLY
243422
PROBABILITY THAT MICROORGANISMS NOT KILLED BY OTHER MEANS
243423
PROBABILITY THAT MICROORGANISMS NOT KILLED BY EJECTION PROCESS
243424
PROBABILITY THAT MICROORGANISMS NOT KILLED BY DIE OFF
243425
PROBABILITY THAT MICROORGANISMS NOT KILLED BY UV RADIATION
243426
PROBABILITY THAT MICROORGANISMS NOT KILLED BY OTHER SOLAR RADIATION
243427
PROBABILITY THAT MICROORGANISMS NOT KILLED BY VACUUM
ASSUME = 1.0



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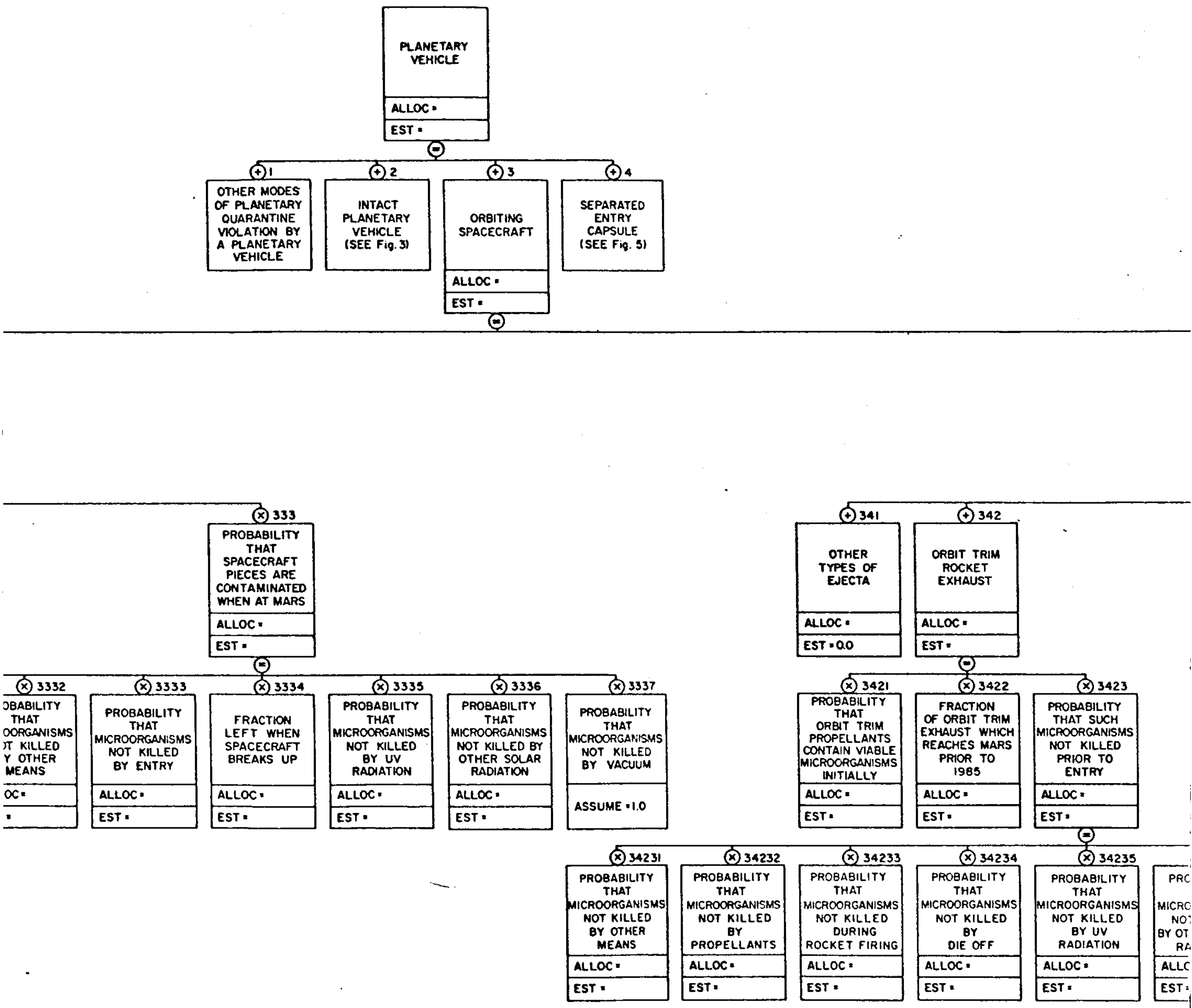

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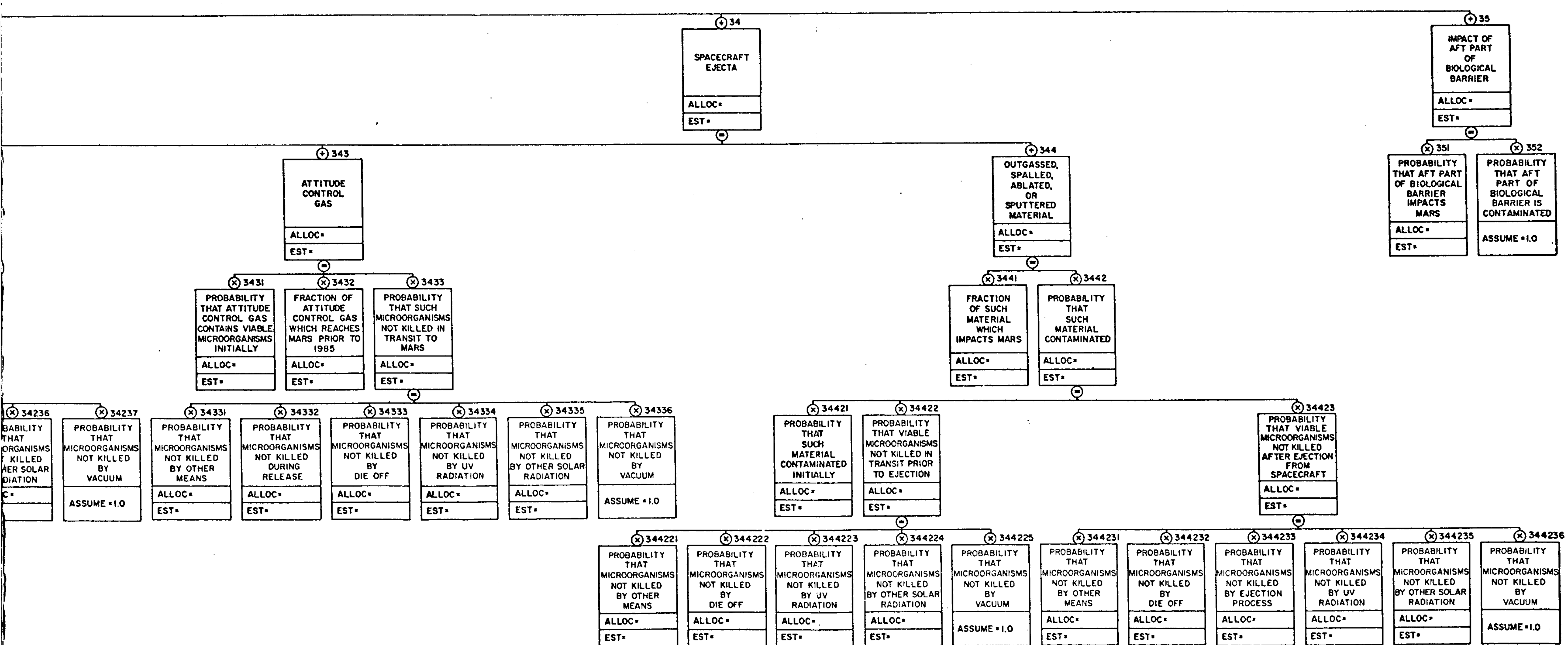

Fig. 4. Orbiting spacecraft portion of planetary quarantine model

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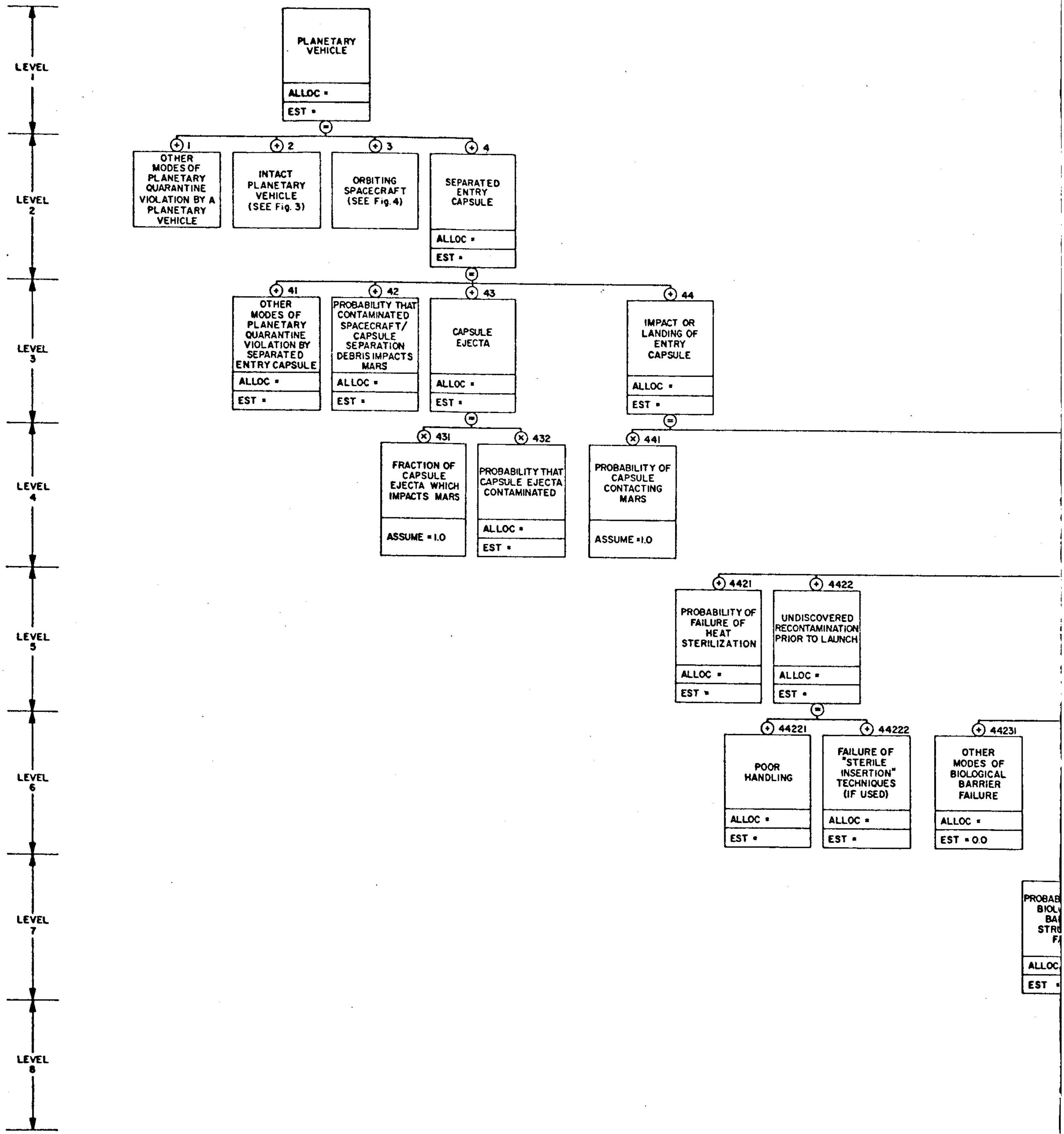

Fig. 5. Separated entry capsule portion of planetary quarantine model

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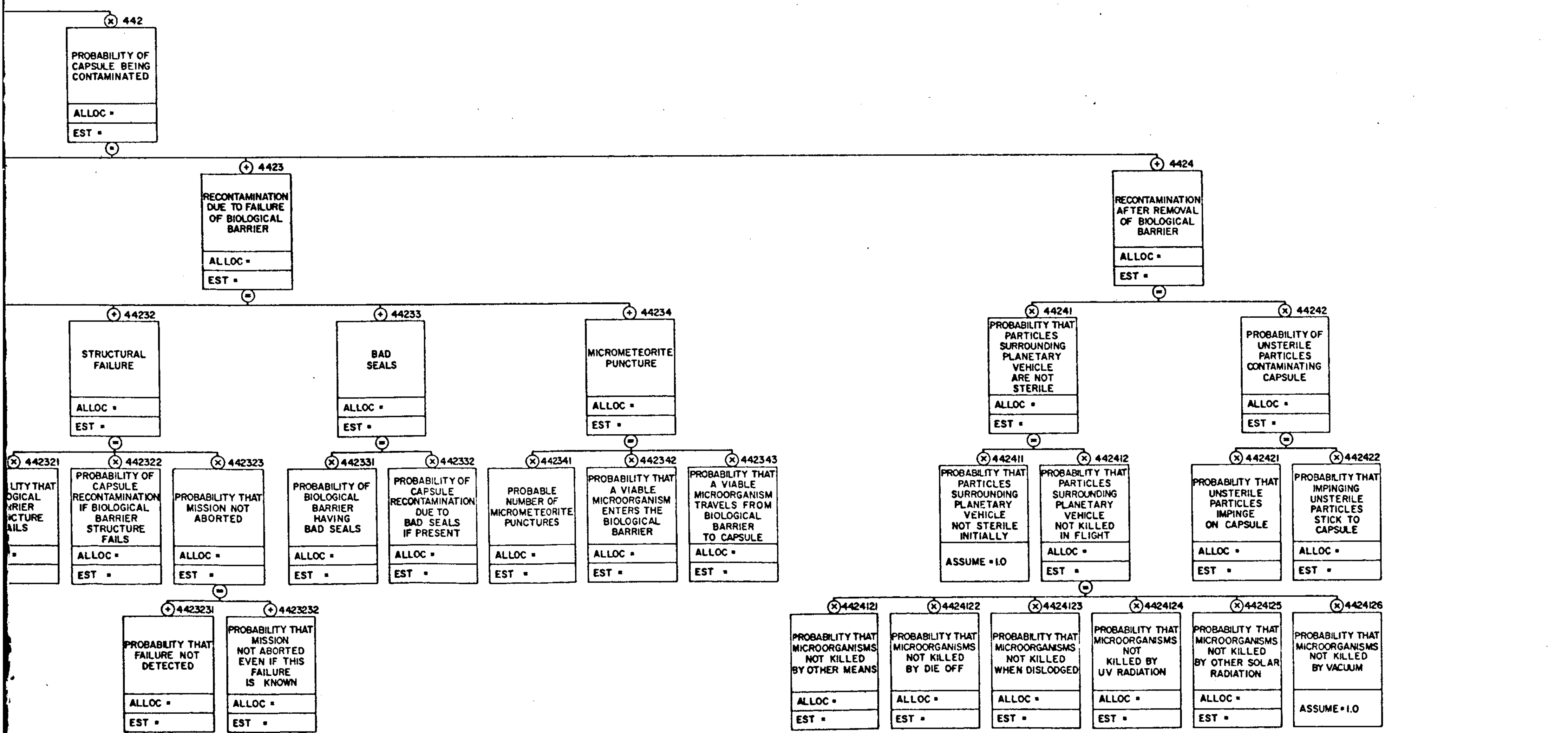

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B. The Validity of the Mathematical Model

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 $j = 1, \cdots, n$.) 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,

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

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:

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

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:

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

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,

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

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]

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

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

[3]A 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 (ALLOC[5]=______; EST[6]=______)

+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=______

×222 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=______

×232 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=______

---

[4]A numerical value yet to be established.

[5]Allocated value

[6]Estimated value

$+\frac{25\ (½)}{30\ (½)}$ Violation modes associated with the *Saturn IC/Saturn II* (S-IC/S-II) stage separation
ALLOC=________, half charged to S-IC stage, half to S-II stage; EST=________

$\leq\frac{251}{301}$ Probability that contaminated loose hardware resulting from an assumed S-IC/S-II separation will impact Mars
ALLOC=________; EST=________

$+\frac{252}{302}$ Probability that contaminated pyrotechnic shrapnel resulting from an assumed S-IC/S-II separation will impact Mars
ALLOC=________; EST=________

+3 Violation modes associated with the S-II stage
ALLOC=________; EST=________

=31 Violation modes associated with the S-II stage not identified below
Contingency ALLOC=________; EST=0.0

+32 Probability of violation due to impact of S-II stage
ALLOC=________; EST=________

=321 Probability of Martian impact of S-II stage
ALLOC=________; EST=________

×322 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
ASSUME=1.0

+33 Probability of violation due to Martian impact of a piece (or pieces) of the S-II stage
ALLOC=________; EST=________

≤331 Probability that the S-II stage explodes for any reason
ALLOC=________; EST=________

×332 Probability that any of the debris from an explosion of the S-II stage contains at least one viable terrestrial organism and impacts Mars
ALLOC=________; EST=________

+34 Violation modes associated with the ejecta from the S-II stage
ALLOC=________; EST=________

=341 Violation modes associated with other types of ejecta from the S-II stage than identified below
Contingency ALLOC=________; EST=0.0

+342 Probability of violation due to S-II rocket exhaust
ALLOC=________; EST=________

+343 Probability of violation due to propellant leaked from the S-II tanks
ALLOC=________; EST=________

+344 Probability of violation due to S-II stage TVC fluid
ALLOC=________; EST=________

+345 Probability of violation due to S-II stage attitude control gas
ALLOC=________; EST=________

+346 Probability of violation due to loose hardware associated with the S-II stage
ALLOC=________; EST=________

+347 Probability of violation due to shrapnel from S-II stage pyrotechnics
ALLOC=________; EST=________

+348 Probability of violation due to material outgassed, spalled, ablated, or sputtered from the S-II stage
ALLOC=________; EST=________

$+\frac{35\ (½)}{40\ (½)}$ Violation modes associated with the *Saturn II/Saturn IVB* (S-II/S-IVB) stage separation
ALLOC=________, half charged to S-II stage, half to S-IVB stage; EST=________

$\leq\frac{351}{401}$ Probability that contaminated loose hardware resulting from an assumed S-II/S-IVB separation will impact Mars
ALLOC=________; EST=________

$+\frac{352}{402}$ Probability that contaminated pyrotechnic shrapnel resulting from an assumed S-II/S-IVB separation will impact Mars
ALLOC=________; EST=________

+4 Violation modes associated with the S-IVB stage
ALLOC=________; EST=________

=41 Violation modes associated with the S-IVB stage not identified below
Contingency ALLOC=________; EST=0.0

+42 Probability of violation due to impact of S-IVB stage
ALLOC=________; EST=________

=421 Probability of Martian impact of S-IVB stage
ALLOC=________; EST=________

=4211 Probability S-IVB stage is on a Martian impact trajectory after both planetary vehicle separations
ALLOC=________; EST=________

×4212 Probability S-IVB retrorockets (if any) do not remove the S-IVB from an impact trajectory
ALLOC=________; EST=________

×422 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
ASSUME=1.0

+43 Probability of violation due to Martian impact of a piece (or pieces) of the S-IVB stage
ALLOC=________; EST=________

≤431 Probability of explosion of S-IVB stage for any reason
ALLOC=________; EST=________

×432 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=________

+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=________

×522 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=________

×532 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=________

×2222 Probability retro (orbit insertion) engine fails to produce abort
ALLOC=________; EST=________

×2223 Probability PV is contaminated when at Mars
ASSUME=1.0

×2224 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=________

×2262 Probability capsule not separated
ALLOC=________; EST=________

×2263 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=________

=231 Probability PV explodes
ALLOC=________; EST=________

×232 Probability that a contaminated piece of an exploded PV will impact Mars
ALLOC=________; EST=________

+24 Violation modes associated with ejecta from PV 1
ALLOC=________; EST=________

=241 Violation modes associated with ejecta released from PV 1 prior to orbit achievement
ALLOC=________; EST=________

=2411 Violation modes associated with other types of ejecta from PV 1 than identified below
Contingency ALLOC=________; EST=0.0

+2412 Probability of violation due to midcourse maneuver exhaust gases
ALLOC=________; EST=________

=24121 Fraction of such gases which will reach Mars prior to 1985
ALLOC=________; EST=________

×24122 Probability such gases are contaminated when they reach Mars
ALLOC=________; EST=________

=241221 Initial microbial load of such propellants
ALLOC=________; EST=________

×241222 Probability initially viable microorganisms in the propellants are not killed by the propellants
ALLOC=________; EST=________

×241223 Probability remaining microorganisms are not killed in the ejection process
ALLOC=________; EST=________

×241224 Probability remaining microorganisms are not killed by other means
ALLOC=________; EST=________

×241225 Probability remaining microorganisms do not "die off" (due to time, lack of food, etc.)
ALLOC=________; EST=________

×241226 Probability remaining microorganisms are not killed by UV radiation
ALLOC=________; EST=________

×241227 Probability remaining microorganisms are not killed by other solar radiation
ALLOC=________; EST=________

×241228 Probability remaining microorganisms are not killed by vacuum
ASSUME=1.0

+2413 Probability of violation due to attitude control gases
ALLOC=________; EST=________

=24131 Fraction of transit attitude control gases which will reach Mars prior to 1985
ALLOC=________; EST=________

×24132 Probability such gases are contaminated when they reach Mars
ALLOC=________; EST=________

=241321 Initial microbial load of such gases
ALLOC=________; EST=________

×241322 Probability microorganisms not killed by other means
ALLOC=________; EST=________

×241323 Probability remaining microorganisms not killed by ejection process
ALLOC=________; EST=________

×241324 Probability remaining microorganisms not killed by "die off"
ALLOC=________; EST=________

×241325 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

×241326 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

×241327 Probability remaining microorganisms not killed by vacuum
ASSUME=1.0

+2414 Probability of violation due to outgassed, spalled, ablated, sputtered, or other material
ALLOC=________; EST=________

=24141 Fraction of such material which will reach Mars prior to 2023
ALLOC=________; EST=________

×24142 Initial microbial load of such material
ALLOC=________; EST=________

×24143 Probability microorganisms not killed by other means
ALLOC=________; EST=________

×24144 Probability remaining microorganisms not killed by ejection process
ALLOC=________; EST=________

×24145 Probability remaining microorganisms not killed by "die off"
ALLOC=________; EST=________

×24146 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

×24147 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

×24148 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=________

+243 Violation modes associated with ejecta released from PV 1 after orbit insertion
ALLOC=________; EST=________

=2431 Violation modes associated with other types of ejecta from PV 1 than identified below
Contingency ALLOC=________; EST=0.0

+2432 Probability of violation due to orbit trim rocket exhaust gases
ALLOC=________; EST=________

=24321 Fraction of such gases which will reach Mars prior to 1985
ALLOC=________; EST=________

×24322 Probability such gases are contaminated when they reach Mars
ALLOC=________; EST=________

=243221 Initial microbial load of retro propellants
ALLOC=________; EST=________

×243222 Probability microorganisms are not killed by propellants
ALLOC=________; EST=________

×243223 Probability remaining microorganisms not killed by ejection process
ALLOC=________; EST=________

×243224 Probability remaining microorganisms not killed by other means
ALLOC=________; EST=________

×243225 Probability remaining microorganisms not killed by "die off"
ALLOC=________; EST=________

×243226 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

×243227 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

×243228 Probability remaining microorganisms not killed by vacuum
ASSUME=1.0

+2433 Probability of violation due to attitude control gas from PV 1
ALLOC=________; EST=________

=24331 Fraction of such gases will reach Mars prior to 1985
ALLOC=________; EST=________

×24332 Probability attitude control gases contaminated when at Mars
ALLOC=________; EST=________

=243321 Probability such gases contaminated initially
ALLOC=________; EST=________

×243322 Probability microorganisms not killed by other means
ALLOC=________; EST=________

×243323 Probability remaining microorganisms not killed by "die off"
ALLOC=________; EST=________

×243324 Probability remaining microorganisms not killed by ejection process
ALLOC=________; EST=________

×243325 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

×243326 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

×243327 Probability remaining microorganisms not killed by vacuum
ASSUME=1.0

+2434 Probability of violation due to outgassed, spalled, ablated, sputtered, etc., material
ALLOC=________; EST=________

=24341 Expected microbial load of such material ejected prior to spacecraft/capsule separation
ALLOC=________; EST=________

×24342 Probability such material is contaminated when it reaches Mars
ALLOC=________; EST=________

=243421 Probability such material is contaminated initially
ALLOC=________; EST=________

×243422 Probability microorganisms not killed by other means
ALLOC=________; EST=________

×243423 Probability remaining microorganisms not killed by ejection process
ALLOC=________; EST=________

×243424 Probability remaining microorganisms not killed by "die off"
ALLOC=________; EST=________

×243425 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

×243426 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

×243427 Probability remaining microorganisms not killed by vacuum
ASSUME=1.0

×24343 Fraction of such material which reaches Mars prior to 1985
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=________

×252 Probability forward part of biological barrier contaminated
ALLOC=________; EST=________

+26 Violation modes associated with Launch Vehicle/Planetary Vehicle 1 separation
ALLOC=________; EST=________

=261 Violation due to impact of contaminated loose hardware
ALLOC=________; EST=________

+262 Violation due to impact of contaminated pyrotechnic shrapnel
ALLOC=________; EST=________

+3 Violation modes associated with the orbiting spacecraft
ALLOC=________; EST=________

=31 Violation modes associated with an orbiting spacecraft not identified below
Contingency ALLOC=________; EST=0.0

+32 Violation due to premature impact of the orbiting spacecraft
ALLOC=________; EST=________

=321 Probability orbiting spacecraft contaminated at impact
ASSUME=1.0

×322 Probability orbiting spacecraft impacts prior to 1985
ALLOC=________; EST=________

=3221 Probability of premature orbit decay as a result of other causes than shown below
Contingency ALLOC=________; EST=________

+3222 Probability of premature decay due to atmospheric drag
ALLOC=________; EST=________

+3223 Probability of impact due to faulty orbit trim maneuvers
ALLOC=________; EST=________

+3224 Probability of impact due to perturbations at spacecraft/capsule separation
ALLOC=________; EST=________

+3225 Probability of decay due to N-body gravitational perturbations
ALLOC=________; EST=________

+3226 Probability of decay due to gravitational harmonics
ALLOC=________; EST=________

+33 Violation due to impact of spacecraft pieces prior to 1985
ALLOC=________; EST=________

=331 Probability spacecraft breaks into pieces
ALLOC=________; EST=________

=3311 Probability spacecraft explodes
ALLOC=________; EST=________

=33111 Probability of any other explosion on the orbiting spacecraft
Contingency ALLOC=________; EST=0.0

+33112 Probability midcourse motor explodes
ALLOC=________; EST=________

+33113 Probability orbit insertion motor explodes
ALLOC=________; EST=________

+33114 Probability orbit trim motor explodes
ALLOC=________; EST=________

+33115 Probability pressure tanks explode
ALLOC=________; EST=________

+33116 Probability batteries explode
ALLOC=________; EST=________

+3312 Probability spacecraft smashed by meteorites
ALLOC=________; EST=________

=33121 Probability a sufficiently large meteorite hits the spacecraft prior to 1985
ALLOC=________; EST=________

×33122 Probability that any of the resultant pieces impact Mars prior to 1985
ALLOC=________; EST=________

+3313 Probability spacecraft breaks up from centrifugal force prior to 1985
ALLOC=________; EST=________

=33131 Probability attitude control system fails prior to 1985
ASSUME=1.0

×33132 Probability unbalanced forces cause excessive spacecraft spin-up prior to 1985
ALLOC=________; EST=________

×332 Probability any spacecraft pieces decay prior to 1985
ALLOC=________; EST=________

×333 Probability any spacecraft pieces which decay prior to 1985 are contaminated when at Mars
ALLOC=________; EST=________

=3331 Initial spacecraft microbial load
ALLOC=________; EST=________

×3332 Probability microorganisms not killed by other means
ALLOC=________; EST=________

×3333 Probability microorganisms not killed by entry
ALLOC=________; EST=________

×3334 Fraction of initial load left when spacecraft breaks up
ALLOC=________; EST=________

×3335 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

×3336 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

×3337 Probability remaining microorganisms not killed by vacuum
ASSUME=1.0

+34 Violation modes associated with ejecta from an orbiting spacecraft
ALLOC=________; EST=________

=341 Violation modes associated with other types of ejecta from orbiting spacecraft than identified below
Contingency ALLOC=________; EST=0.0

+342 Probability of violation due to orbit trim rocket exhaust gases
ALLOC=________; EST=________

=3421 Probability orbit trim rocket propellants contaminated initially
ALLOC=________; EST=________

×3422 Fraction of such gases which reach Mars prior to 1985
ALLOC=________; EST=________

×3423 Probability microorganisms not killed prior to Mars entry
ALLOC=________; EST=________

=34231 Probability microorganisms not killed by other means
ALLOC=________; EST=________

×34232 Probability remaining microorganisms not killed by propellants
ALLOC=________; EST=________

×34233 Probability remaining microorganisms not killed during rocket firing
ALLOC=________; EST=________

×34234 Probability remaining microorganisms not killed by "die off"
ALLOC=________; EST=________

×34235 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

×34236 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

×34237 Probability remaining microorganisms not killed by vacuum
ASSUME=1.0

+343 Probability of violation due to attitude control gases
ALLOC=________; EST=________

=3431 Probability attitude control gas contains viable terrestrial microorganisms initially (or initial microbial load)
ALLOC=________; EST=________

×3432 Fraction of attitude control gas which reaches Mars prior to 2023
ALLOC=________; EST=________

×3433 Probability microorganisms not killed in transit to Mars
ALLOC=________; EST=________

=34331 Probability remaining microorganisms not killed by means other than identified below
ALLOC=________; EST=________

×34332 Probability remaining microorganisms not killed during release
ALLOC=________; EST=________

×34333 Probability remaining microorganisms not killed by "die off"
ALLOC=________; EST=________

×34334 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

×34335 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

×34336 Probability remaining microorganisms not killed by vacuum
ASSUME=1.0

+344 Probability of violation due to material outgassed, spalled, etc.
ALLOC=________; EST=________

=3441 Fraction of such material which impacts Mars prior to 1985
ALLOC=________; EST=________

×3442 Probability such material contaminated when at Mars
ALLOC=________; EST=________

=34421 Initial microbial load of such material
ALLOC=________; EST=________

×34422 Probability viable microorganisms not killed in transit prior to ejection
ALLOC=________; EST=________

=344221 Probability microorganisms not killed by means other than as follows
ALLOC=________; EST=________

×344222 Probability remaining microorganisms not killed by "die off" in transit
ALLOC=________; EST=________

×344223 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

×344224 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

×344225 Probability remaining microorganisms not killed by vacuum
ASSUME=1.0

×34423 Probability viable microorganisms not killed during or after ejection from spacecraft
ALLOC=________; EST=________

=344231 Probability remaining organisms not killed by means other than as follows
ALLOC=________; EST=________

×344232 Probability remaining microorganisms not killed by "die off"
ALLOC=________; EST=________

×344233 Probability remaining microorganisms not killed by ejection process
ALLOC=________; EST=________

×344234 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

×344235 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

×344236 Probability remaining microorganisms not killed by vacuum
ASSUME=1.0

+35 Violation due to impact of the aft part of the biological barrier
ALLOC=________; EST=________

=351 Probability aft part of biological barrier impacts Mars
ALLOC=________; EST=________

×352 Probability aft part of biological barrier is contaminated when it impacts Mars
ASSUME=1.0

+4 Violation modes associated with a separated entry capsule
ALLOC=________; EST=________

=41 Violation modes associated with a separated entry capsule not identified below
Contingency ALLOC=________; EST=0.0

+42 Probability contaminated spacecraft/capsule separation debris impacts Mars prior to 1985
ALLOC=________; EST=________

+43 Violation modes associated with capsule ejecta
ALLOC=________; EST=________

=431 Fraction of capsule ejecta which impacts Mars
ASSUME=1.0

×432 Probability capsule ejecta is contaminated when it reaches Mars
ALLOC=________; EST=________

+44 Violation modes associated with impact or landing of an entry capsule
ALLOC=________; EST=________

=441 Probability of capsule contacting Mars
ASSUME=1.0

×442 Probability of capsule being contaminated when contacting Mars
ALLOC=________; EST=________

=4421 Probability of failure of heat sterilization
ALLOC=________; EST=________

+4422 Probability of recontamination occurring and remaining undiscovered prior to launch
ALLOC=________; EST=________

=44221 Probability of undiscovered recontamination due to poor handling
ALLOC=________; EST=________

+44222 Probability of failure of "sterile insertion" techniques (if used)
ALLOC=________; EST=________

+4423 Probability of recontamination due to failure of biological barrier
ALLOC=________; EST=________

=44231 Recontamination due to modes of biological barrier failure other than shown below
Contingency ALLOC=________; EST=0.0

+44232 Recontamination due to structural failure of biological barrier
ALLOC=________; EST=________

=442321 Probability biological barrier structure fails
ALLOC=________; EST=________

×442322 Probability capsule recontaminated if the biological barrier structure fails
ALLOC=________; EST=________

×442323 Probability mission not aborted if there is structural failure of the biological barrier
ALLOC=________; EST=________

=4423231 Probability structural failure of biological barrier is not detected
ALLOC=________; EST=________

+4423232 Probability failure is detected and mission is still not aborted
ALLOC=________; EST=________

+44233 Probability of recontamination due to bad biological seals on the biological barrier
ALLOC=________; EST=________

=442331 Probability of biological barrier having bad seals
ALLOC=________; EST=________

×442332 Probability capsule recontaminated if bad seals are present
ALLOC=________; EST=________

+44234 Probability of recontamination due to micrometeoric puncture of biological barrier
ALLOC=________; EST=________

=442341 Probable number of micrometeoric punctures
ALLOC=________; EST=________

×442342 Probability that a viable terrestrial microorganism enters a puncture hole in the biological barrier
ALLOC=________; EST=________

×442343 Probability that such organisms would travel from the biological barrier to the capsule
ALLOC=________; EST=________

+4424 Probability of recontamination of the entry capsule after the removal of the biological barrier
ALLOC=________; EST=________

=44241 Probability that particles surrounding the planetary vehicle are not sterile
ALLOC=________; EST=________

=442411 Number of particles surrounding planetary vehicle which are not sterile initially
ALLOC=________; EST=________

X442412 Probability microorganisms on such particles are not killed in flight
ALLOC=________; EST=________

=4424121 Probability microorganisms not killed by other means than shown below
ALLOC=________; EST=________

X4424122 Probability remaining microorganisms not killed by "die off"
ALLOC=________; EST=________

X4424123 Probability microorganisms not killed when dislodged
ALLOC=________; EST=________

X4424124 Probability remaining microorganisms not killed by UV radiation
ALLOC=________; EST=________

X4424125 Probability remaining microorganisms not killed by other solar radiation
ALLOC=________; EST=________

X4424126 Probability remaining microorganisms not killed by vacuum
ASSUME=1.0

X44242 Probability of unsterile particles contaminating capsule
ALLOC=________; EST=________

=442421 Probability unsterile particles impinge on capsule
ALLOC=________; EST=________

X442422 Probability impinging unsterile particles stick to the capsule
ALLOC=________; EST=________

III. Violation probability resulting from all violation modes associated with planetary vehicle No. 2
ALLOC=________; EST=________

This submodel probability is similar to that for planetary vehicle No. 1, detailed in preceding Subsection II.

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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).