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SPACE STATION

SAFETY STUDY

LOGIC DIAGRAM

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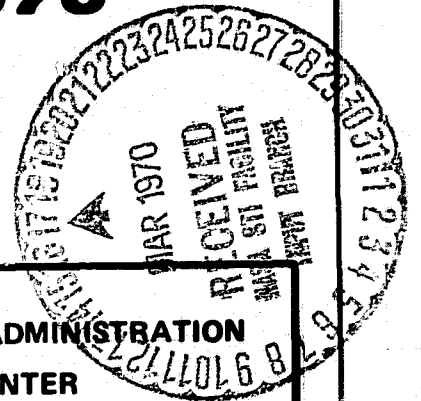
NATIONAL AERONAUTICS & SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

THE **BOEING** COMPANY

AEROSPACE SYSTEMS DIVISION, SEATTLE, WASHINGTON



NASA CR 108291

SPACE STATION SAFETY STUDY

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LOGIC DIAGRAM

D2-113070-9

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PREFACE

This document constitutes one volume of the final report prepared under Contract NAS9-9046, Space Station Safety Study, which was conducted by the Aerospace Systems Division, Aerospace Group, The Boeing Company, under the direction of the Advanced Projects Office, Advanced Missions Program Office, Manned Spacecraft Center, NASA. The objective of the study was to develop a management tool for evaluating conceptual designs of future manned space systems from a safety viewpoint. This objective was achieved through the application of methodical techniques, which are described where necessary in appropriate volumes of this final report, for analyzing space station safety problems. This work resulted in the development of Crew Safety Guidelines which can be used in evaluating future space station concepts.

In Phase I of the study, the work was directed toward a broad class of space stations, using several specific configurations as examples, and considering both crew safety and mission accomplishment as safety goals. In May 1969, the study was redirected by NASA into Phase II to provide more direct support to the NASA Phase B Future Space Station Study, considering only crew safety as the safety goal. To the extent possible, the work done in Phase I was revised and adapted to Phase II and all documents of this final report, except as otherwise noted, include the results from both phases. In both phases the study scope included only on-orbit operations and not launch, boost, de-orbit, and recovery operations, or any operations of the logistics support system, except for close-in rendezvous and docking operations.

The approach taken in the study was to examine the space station from the viewpoint of safety only, with the intent of identifying as complete a list as possible of those measures which should be taken to maximize crew safety. Also, and especially in Phase II, the study dealt primarily with station concepts, rather than specific designs or hardware items. It was not possible, and no attempt was made, to examine the impact of safety measures on other important aspects of space station development, such as cost, design difficulty, or operational suitability. As station development proceeds, trade studies between safety measures and other factors will be required and management decisions must be made as to the extent to which other desirable features will be permitted to override safety measures.

The documents constituting the final study report are:

- D2-113070-4, Condensed Summary Report
- D2-113070-5, Crew Safety Guidelines, Volumes I and II

D2-113070-9

- D2-113070-6, Supporting Analyses
 - Analysis of Operations
 - Experiment Program
 - Traffic Patterns Analysis
 - Human Requirements
 - Meteoroid Penetration
- D2-113070-9, Logic Diagram
- D2-113070-10, Fault Tree Analysis
- D2-113070-11, Subsystems Analysis

Other documents produced during the study but not part of the final report are:

- D2-113070-1, Detail Study Plan (Phase I only)
- D2-113070-2, Midterm Oral Report
- D2-113070-3, Final Oral Report
- D2-113070-7, Baseline Mission Description (Phase I only)
- D2-113070-8, Baseline System Description (Phase I only)

The references applicable to this document are shown in Section 6.0. However, all the references for those documents which comprise the final study report are compiled in D2-113070-5.

D2-113070-9

ABSTRACT

The logic diagram in this document explicates a heuristic analysis directed at discovering what is required for the crew of an Earth orbital manned space system to be safe. With the aid of the definitions of a few symbols, provided in Section 3.0, the complete diagram or any increment of it can be read as English prose. It was developed primarily to locate essential elements of hardware function and crew activity but may also be used to infer the probability of (or degree of belief in) crew safety, or be used as a basic management plan for task and responsibility assignment.

KEY WORDS

safety	human performance	systems engineering
space station	emergencies	heuristic method
crew escape	space programs	analysis
Earth orbits	design criteria	mathematical logic

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D2-113070-9

TABLE OF CONTENTS

<u>Section</u>	<u>Title</u>	<u>Page</u>
	Preface	iii
	Abstract and Key Words List	v
	Table of Contents	viii
	List of Tables	ix
1.0	Introduction	1
2.0	Logic Diagram Development	3
	2.1 Literary Format	3
	2.2 Functional Rules	3
	2.3 Rationale for Proposition Development	4
	2.4 Termination of Proposition Analysis	6
3.0	Logic Diagram Description	7
	3.1 Proposition Identification	7
	3.2 Symbols for Proposition Relationships	7
	3.3 Inter-chart Transfer Codes	8
	3.4 Typical Applications of Logic Symbology	10
4.0	End-Points	13
	4.1 End-point Valuation	13
	4.2 End-point Categories	13
	4.3 End-point Propositions	17
5.0	Summary of "Open" Propositions	29
	5.1 Definition and Rationale	29
	5.2 Interpretive Comments	29
	5.3 Index of Headings	30
6.0	Logic Diagram	79
7.0	References	161
Appendix I	Logical and Analytical Principles	165

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D2-113070-9

LIST OF TABLES

<u>Table</u>	<u>Subject</u>	<u>Page</u>
4-1	Assumptions	19
5-1	Safety Constraints on Experiments	33
5-2	Safety Constraints on Non-experimental Functions	38
5-3	Human Engineering	40
5-4	Crew Capabilities	45
5-5	Oxygen Supply Specifications	49
5-6	Quality of Atmospheric Environment	51
5-7	Nuclear Reactors and Ancillary Hardware	54
5-8	Stabilization, Propulsion, Control and Ancillary Systems	56
5-9	Spacecraft Structure	62
5-10	Medical Facilities	66
5-11	Life Support and Health	71
5-12	Injury and Damage Prevention or Restoration	73
5-13	Warning Systems	76

1.0 INTRODUCTION

1.1 The problem of assuring that safety is provided to space station crews is one which can be and has been approached by many analytical techniques. Also, a variety of formats may be used by which the analyses are recorded and presented. The success of the efforts to date is suggested by the safety record of the on-orbit and deep-space portions of the manned space program (N.B., through Apollo XII as of this writing). Nevertheless, present analytical methods leave considerable ambiguity in results and are often highly subjective. Managers and decision-makers have been forced to adopt courses of action without the desirable degree of assurance that all reasonable alternate courses have been considered and without clearly identifying the assumptions on which their decisions were based.

1.2 Initiation of the logic analysis described here was based largely on a desire to find an approach which would reduce ambiguity, expose assumptions, and identify alternatives. Furthermore, it was desired that the analysis be clearly set forth, easily understood, readily modified to accommodate new information or changed assumptions, and logically valid. Finally, it was intended to permit inferences to be made as to the probability of crew safety in order to assist in trade studies at a later date.

1.3 In achieving the goals expressed in the preceding paragraph, the analysis explicated in this document was performed with the particular objectives of:

- a. Locating heuristically, as a basis for safety criteria, those hardware and human functions which must be performed (or controlled) to maintain crew safety, and
- b. Developing a schema of implications as a basis for inferring the likelihood of crew safety, from concepts that are simpler and more easily agreed upon than the general subject of crew safety itself.

The analysis is published in the form of a logic diagram, rather than some other format, for two major reasons. First, it provides a clarified context for most of the courses of action suggested in document D2-113070-5, Crew Safety Guidelines, as an aid in applying them appropriately. Second, it facilitates the identification of the basic assumptions that were used so that they may be examined separately and in detail, and permits the analysis to be modified to correct for new information or changed situations, or to accommodate different assumptions, without starting all over.

1.4 At the outset, two basic modes of expression were considered. The first was the "positive," in which the statements are couched in terms that denote crew well-being, as expressed by the proposition, "All crew members will be safe during their orbital stay." The second was the "negative," which uses phraseology connoting that the crew is endangered,

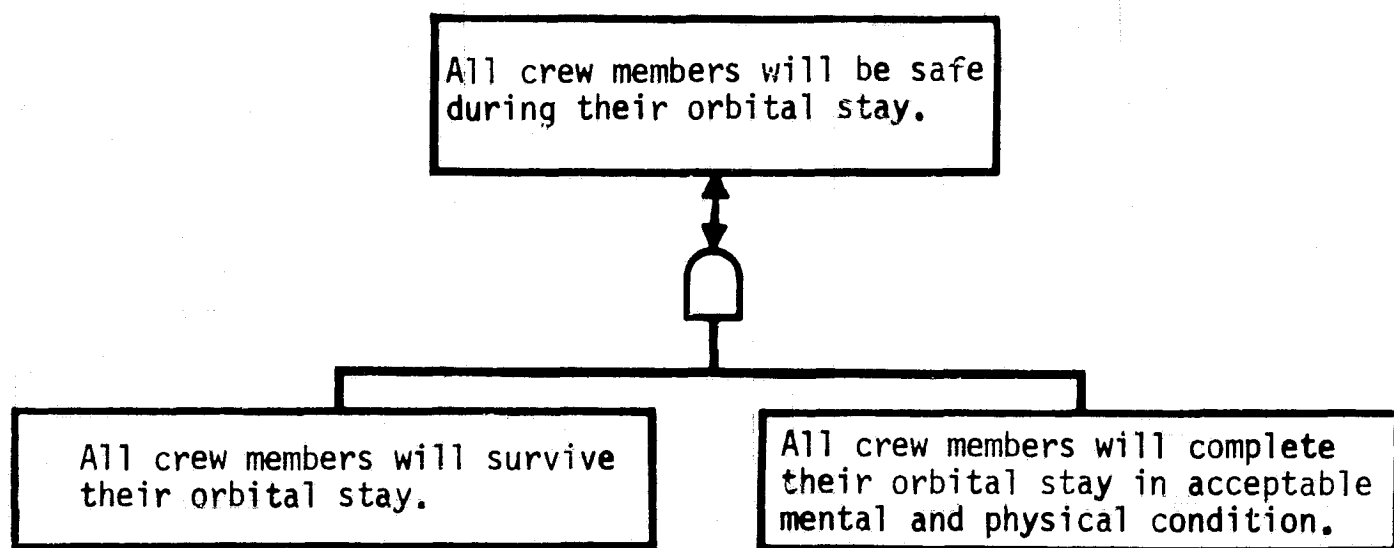
as exemplified by the statement, "All crew members will not be safe during their orbital stay." (The negation can also be stated, "Not all crew members will be safe during their orbital stay.") Either approach could have been used and, in theory at least, both would have identified the same measures to assure crew safety. The "positive" mode of expression was adopted on the basis of being more appropriate to the spirit of the study. (It should be noted that either mode can be converted to the other by a simple routine of symbol manipulation based on definitions of logical functions. Illustrations of this are given in Appendix I.)

1.5 The rules and techniques used in performing the analysis and the means of assembling and using the logic diagram are briefly discussed in Sections 2.0 and 3.0 of this document. Appendix I contains a more detailed description of the principles used in the analysis, and shows alternate ways of presenting the material.

2.0 LOGIC DIAGRAM DEVELOPMENT

2.1 LITERARY FORMAT

The basic language of the logic diagram is common English, with word meanings as defined in Webster's Third International Dictionary and Webster's Seventh New Collegiate Dictionary. No words are used out of sentence context and all simple propositions are expressed as complete English sentences. A simple proposition is one in which the thought does not consist of connecting two or more propositions (see 2.2-g below). Thus, the complete diagram, or any segment thereof, can be read as English prose. For example, the segment reproduced here of the logic diagram on Chart No. 1 can be read as



follows* (in which the underlined words are represented unambiguously in the diagram by the arch-shaped symbol, the double-headed arrow and the connecting lines):

"All crew members will be safe during their orbital stay, -if and only if-

All crew members will survive their orbital stay, -and-

All crew members will complete their orbital stay in acceptable mental and physical condition."

2.2 FUNCTIONAL RULES

The logic diagram itself is a set of related statements or "propositions" arranged in "tree**" form and circumscribed by the following rules

* Alternate, logically equivalent, ways of reading this segment are provided in Appendix I, Section I-4.0

**Tree is used here in the sense defined in Appendix I, Section I-5.0

- a. All elements are propositions about increments of time, space, substance and action (i.e., mission, equipment, people, procedures, or natural environment) which are:
 - 1) Specifically discussed in or suggested by the technological material listed in Section 6.0.
 - 2) Not specifically ruled out by direction in Reference No. 93.
- b. All subsidiary propositions are connected to the origin proposition, "All crew members will be safe during their orbital stay," by one or more implications.
- c. All connectives between propositions are either the implicative function, the function of conjunction or disjunction, equality (i.e., identical repetition), or sequence of expression (i.e., position relative to other connectives).*
- d. All connectives are expressed by defined symbols or connecting lines.
- e. Diagram end points consist of the proposition quoted in "b" above (as the upper limit of the logic analysis) and other propositions whose truth, falsity, relative frequency of truth or falsity, or degree of believability have been (at least tentatively or for the purpose of this study) agreed upon.
- f. All simple propositions in the diagram are either discussed explicitly, or are implied by reference material or by other propositions in the diagram.
- g. Compound propositions are formed by relating two or more simple propositions. The relationships so expressed are those considered to be strongly supported by source material, common experience, or other propositions in the diagram. Such relationships are deemed to be useful in pursuit of the objectives described in Section 1.0 and are proposed as being either self-evidently true, or at least tentatively acceptable.

2.3

RATIONALE FOR PROPOSITION DEVELOPMENT

The origin proposition, "All crew members will be safe during their orbital stay," was established only after consideration of many other ways of making the statement. Although it is arbitrary in the sense that no doubt there are numerous ways to put words together which would equally satisfy the requirement, it was felt that this statement would be at once succinct and sufficiently accurate to encompass the overall context of the Safety

*The functions of implication, conjunction, and disjunction are rigorously defined in Appendix I, Section I-2.0.

Study. The logic diagram then was developed regressively* from the origin proposition, by incrementally and repeatedly making and recording decisions of the following types for each simple proposition:

- a. Should the simple proposition being examined be considered an end point, i.e., premise, of the study, by assuming it true or false (or as having some assigned probability of truth or falsity), or should it be considered an origin proposition for a next, more detailed, level of study? An end-point proposition that has been identified as a basic premise (described in detail in Section 3.0) can have no successors in the analysis. The necessary steps (of thought process, expression and checking)** for additional analysis from propositions that are not end-points, which therefore can be used as origin propositions in their own right for further development, are identified in "b" through "h" below.
- b. What other, more easily grasped (or nearer basic data), proposition does the origin proposition imply?
- c. What other, more easily grasped, proposition or propositions imply the origin proposition?
- d. Can the problem be usefully subdivided by progressing, through implication, from one origin proposition to two or more conjoined or disjoined propositions?
- e. Will unidirectional implication be sufficient to determine the truth or falsity of the origin proposition, or will equivalence be necessary? (Section I-3.0 of the Appendix defines the process of inference and its relationship to the implication function.)
- f. Are we prepared to assert that the implications we have proposed are true? (Will they survive all logical tests suggested by the definitions in Section 3.0 and the logical principles expressed in Appendix I? For example: Since "A implies B" is equivalent to "the negation of B implies the negation of A," it would not be logical to believe that "A implies B" if it is evident that the negation of B does not imply the negation of A.)***

* Appendix I includes, in Section I-1.0, a description of heuristic principles which are the basis for this method.

** These steps appear to be implicit in any analysis although rarely do they seem to be identified in descriptions of particular analytical methods.

***Note that in this question we are concerned only with the validity of the implication function itself as a matter of logical development, not with the truth or falsity of the proposition statement in terms of its real-world application. This is a fundamental point of the analytical process, since the structure of the logical development must be unassailable before one can have faith in the practical aspects of whether or not the concepts contained within the total analysis can be rendered true (or false, as the case may be).

- g. Are our assertions clearly expressed? (Can another person understand our expression without auxiliary explanation sufficiently either to agree that the implication(s) pass all logical tests, or to recognize a particular and unambiguous point of disagreement?)
- h. Should the expression be modified to achieve agreement that the implication(s) are self-evidently true and will pass all logical tests?

2.4 TERMINATION OF PROPOSITION ANALYSIS

Obviously, it became necessary at some point in the development of the logic diagram to terminate further analytical effort. The lowest level statements at these terminal points are classed as (a) "end-point" propositions, whose categories are described in Section 4.0 and for which no further study currently is contemplated, and (b) "open" propositions for which decisions concerning further study have not been established. (The "open" propositions are designated by triangles, as described in Section 3.0, adjacent to the bases of the containing rectangles but without alpha-numeric code identification of continuation. A summary listing is given in Section 5.0.) The reasons or assumptions for end-pointing are discussed in detail in Section 4.0. End-point propositions, for which no further study is currently contemplated, are indicated by a circle tangent to the base of the containing rectangle (usually at the center). For convenience, code numbers are entered in each end-point circle to designate the appropriate assumption category, as described and illustrated in Section 4.0.

3.0 LOGIC DIAGRAM DESCRIPTION

3.1 PROPOSITION IDENTIFICATION

Each simple proposition* is expressed in the diagram as an English sentence set off by enclosing it in a rectangular box. To establish a unique code designation for each simple proposition in the diagram, a capital letter of the English alphabet is placed adjacent to the right end of the base of each rectangle. A different letter of the alphabet is associated with each different proposition on a given chart. (However, the same letter is used for any given proposition whenever it is repeated on the same chart.) A simple proposition is, therefore, uniquely identified by the number of the chart on which it appears, followed by the capital letter associated with it on that chart.

All crew members will be safe during their orbital stay.

A

3.2 SYMBOLS FOR PROPOSITION RELATIONSHIPS

Compound propositions* in the diagram are two or more simple propositions which are related through one or more of the functions of implication, equivalence, disjunction, or conjunction.* The following symbols are used to denote these functions:

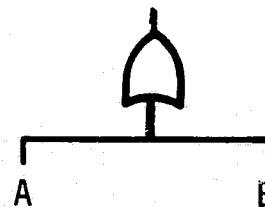
- a. Implication is shown by a single-headed arrow and may be read, "A implies B."



- b. Equivalence is shown by a double-headed arrow and may be read, "A is equivalent to B."

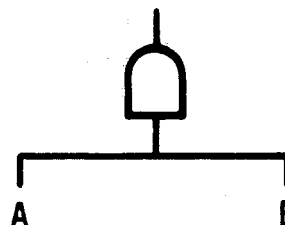


- c. Disjunction is shown by a pointed shield and may be read "A or B (or both)."



*The terms simple proposition, compound proposition, implication, equivalence, disjunction and conjunction are rigorously defined in Appendix I, Section I-2.0.

- d. Conjunction is shown by a round arch and may be read "A and B."



The shield and arch symbols have been borrowed from computer design technology in which they are often used to symbolize electronic modules whose "transfer" characteristics are analogous to the truth-falsity relationships of "disjunction" and "conjunction." (Military Standard MIL-STD-806B describes such usage.)

3.3 INTER-CHART TRANSFER CODES

Although all propositions in the total logic diagram are interconnected by logical connectives, i.e., logical functions, it is not feasible to put the complete diagram on a single sheet of paper or to show all connections, even on a given sheet, by continuous lines. Therefore, the following consistent code or symbology was used to show continuity between diagram segments.

- a. A triangular-shaped symbol always* denotes continuation to or from some other point(s) in the diagram, (either elsewhere on the same chart or on some other chart).



- b. A lower-case letter of the English alphabet is placed in the apex of each triangle. This letter is unique for each triangle on any given chart. Lower-case apex letters do not necessarily coincide with the capital letters used to identify proposition statements (see paragraph 3.1) on a given chart, in the interest of maintaining sequential continuity within each identifier system.



- c. A number in the triangle or immediately beneath it references the number of the chart on which its complement, i.e., a similar triangle denoting connection to the one in question, appears. More than one chart number may be necessary to show all connections.



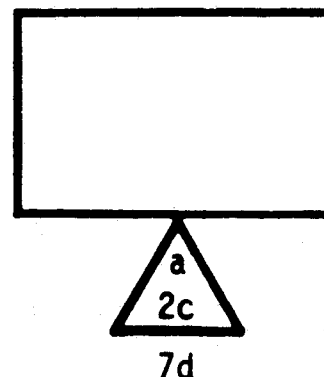
*Except for "open" propositions, which are discussed in paragraph 3.4.4.

- d. The letter appended to each chart number in or beneath a triangle is the "apex letter" of the complementary triangle and thus uniquely identifies the particular connective triangle on the designated chart. This alphanumeric system provides unambiguous identification of each triangle and its associated proposition statement throughout the entire logic diagram. (The example shown says that the proposition, or its equivalent, to which this triangle "a" is attached will also be found on Chart 2 attached to triangle "b".)

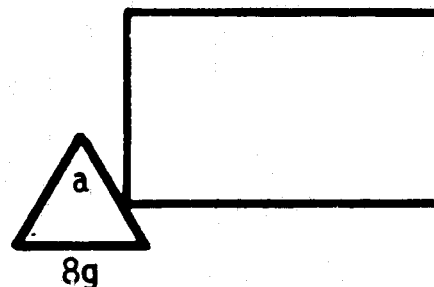


- e. A triangle whose apex is at or near the center of the base of a rectangle denotes that:

- 1) The proposition in the rectangle is repeated with one or more of its successors* on the sheet whose number is in the triangle, and
- 2) The proposition in the rectangle is repeated with one or more predecessors* on the sheet(s) whose number(s) is beneath the triangle.



- f. A triangle located at the corner of a rectangle denotes that the proposition in the rectangle is repeated with one or more of its predecessors on the sheet(s) whose number(s) appears in or beneath the triangle. (The companion or complementary proposition may not necessarily be identically verbatim, depending upon their context and usage, but intent and application are always the same and logical equivalence is maintained.)



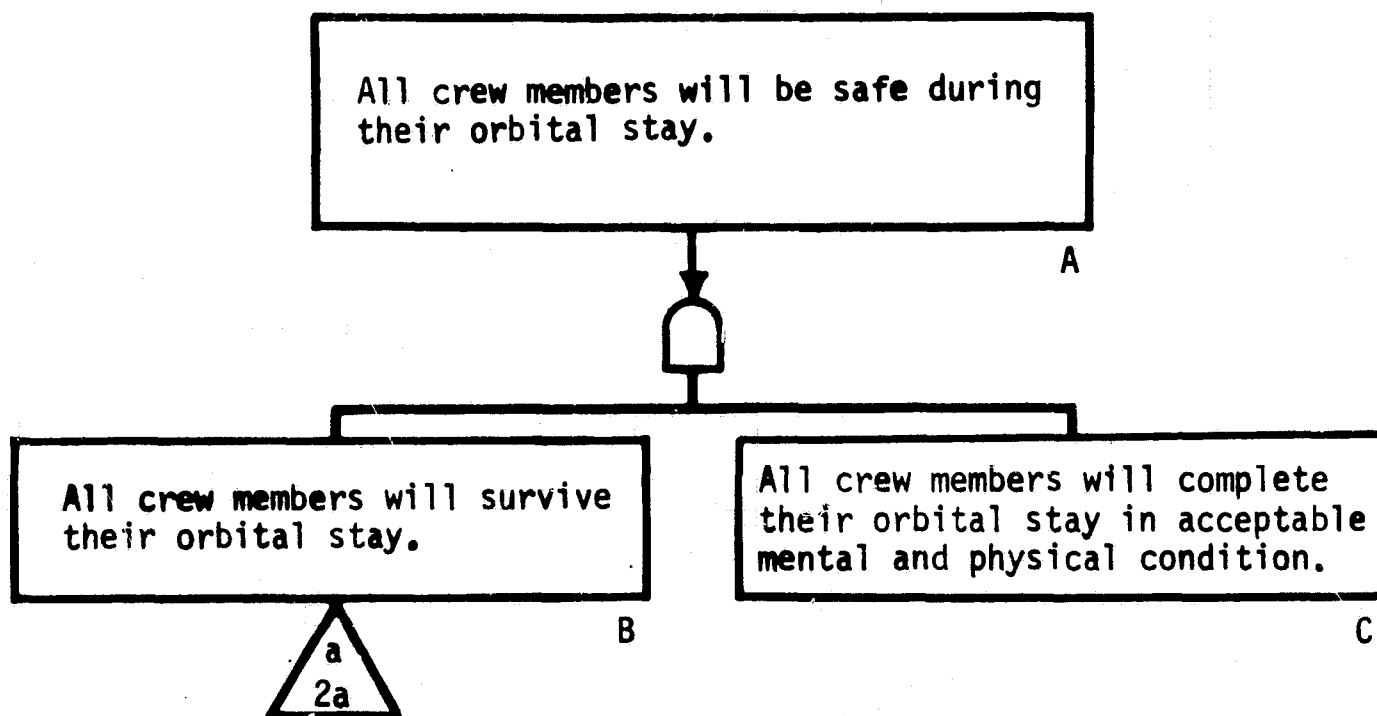
- g. A number in parentheses in a triangle refers to a footnote on the same page regarding further development of that proposition by the fault tree technique (D2-113070-10).

*"Successors" and "predecessors" are defined in Appendix I, Section I-5.0.

3.4

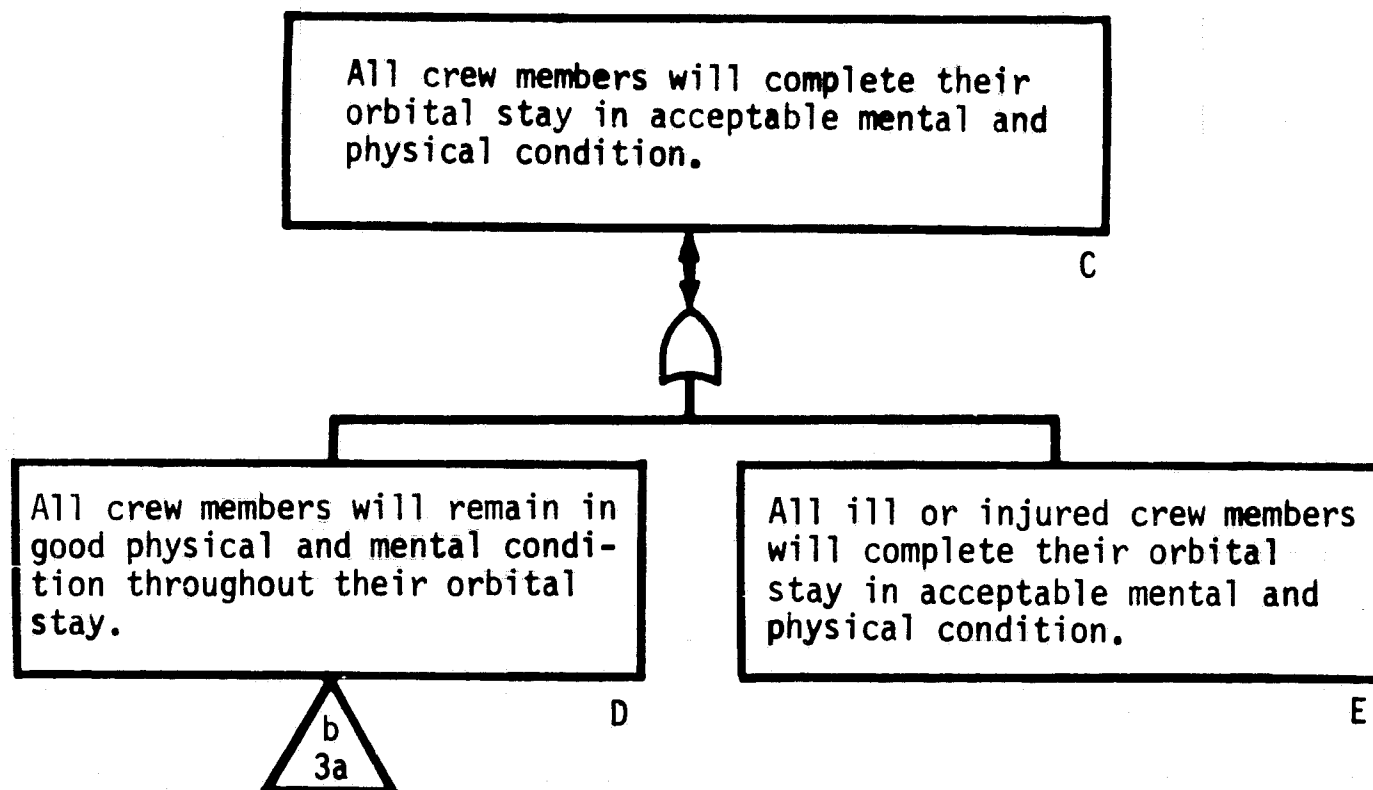
TYPICAL APPLICATIONS OF LOGIC SYMBOLOLOGY

3.4.1 To illustrate what has been said to this point, some extracts from the logic diagram will be used. The following is found at the top of Chart No. 1, with the exception that a double arrow indicating equivalence appears on the chart itself, whereas a single arrow is used here for illustrative purposes.



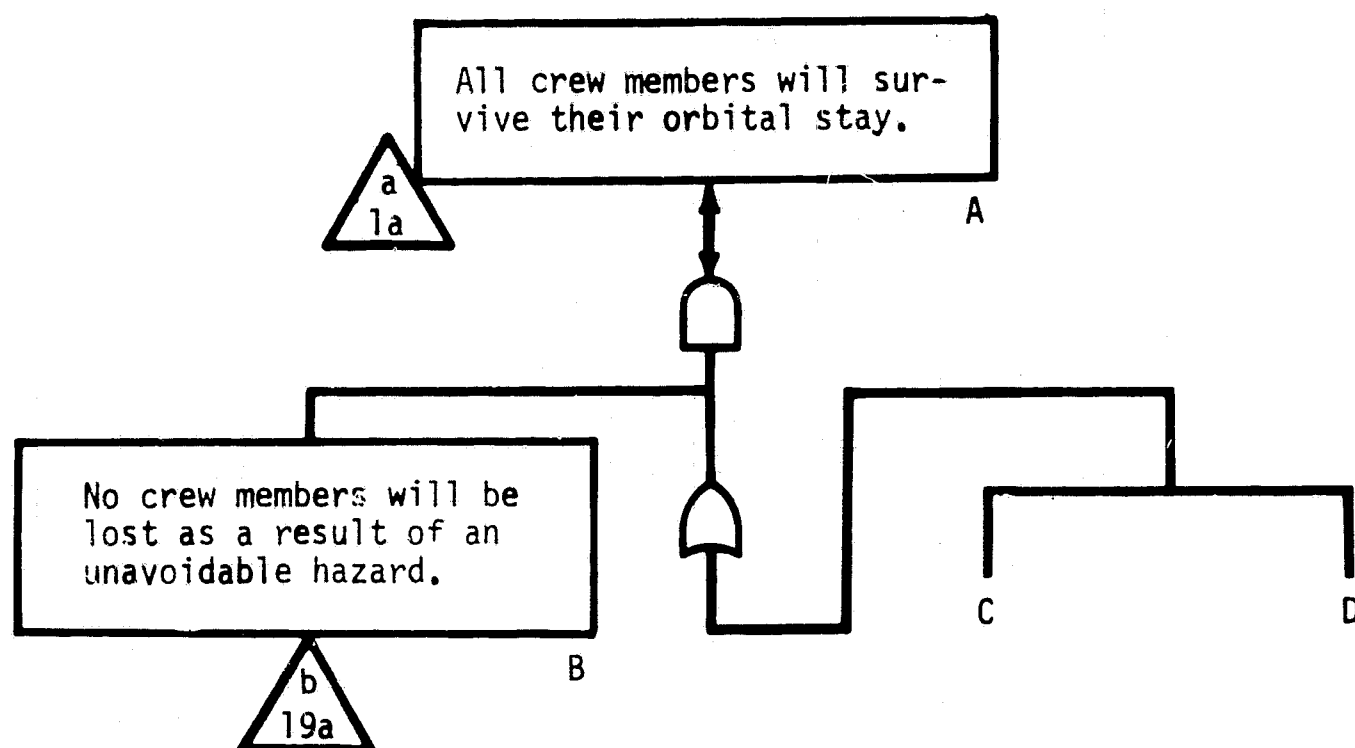
One of the ways in which this may be read is: "If it is true that all crew members will be safe during their orbital stay, then it must be true that all crew members will survive their orbital stay and that all crew members will complete their orbital stay in acceptable mental and physical condition." (It may also be validly read: "If it is true that not all crew members will survive their orbital stay or that not all crew members will complete their orbital stay in acceptable mental and physical condition, then it must be true that not all crew members will be safe during their orbital stay." Note here that the negation involves a reversal in the sequence in which the statements are read, and in the direction of the implication symbol. Also, the conjunction--arch--becomes a disjunction--shield.) The sentence, "Crew members will survive their orbital stay," is identified as proposition 1A and the other two propositions are 1B and 1C, respectively. The triangle connected to proposition 1B shows that the proposition is repeated on Chart No. 2 where it is identified by triangle a.

3.4.2 Proposition 1C is further developed on Chart No. 1 as:



This may be read as: "If it is true that all crew members will complete their orbital stay in acceptable mental and physical condition, then it must be true either that all crew members will remain in good physical and mental condition throughout their orbital stay, or that all ill or injured crew members will complete their orbital stay in acceptable mental and physical condition; and moreover, if it is true either that all crew members will remain in good physical and mental condition throughout their orbital stay, or that all ill or injured crew members will complete their orbital stay in acceptable mental and physical condition, then it must be true that all crew members will complete their orbital stay in acceptable mental and physical condition." The individual propositions are identified as 1C, 1D, and 1E. Proposition 1D is repeated on Chart No. 3 where it is identified by triangle a. The foregoing is representative of the positive relationship established by an equivalence (double-headed arrow), in which the logical validity of the subject propositions must remain irrefutable regardless of the sequence in which they are read. This is a primary consideration throughout the logic development.

3.4.3 As a final illustration, Chart No. 2 shows:



This may be read as: "If it is true that all crew members will survive their orbital stay, then it must be true that no crew members will be lost as a result of an unavoidable hazard, and either that (proposition 2C is true) or that (proposition 2D is true); and moreover, (the implication in the reverse direction as read in the previous illustration)." Propositions are identified as 2A, 2B, 2C and 2D. Proposition 2A will be found repeated, as shown by the connected triangle, on Chart 1, where it is identified by triangle a. Proposition 1B in turn is repeated on Chart No. 19, where it is identified by triangle a and is developed with additional successor propositions.

4.0 END-POINTS4.1 END-POINT VALUATION

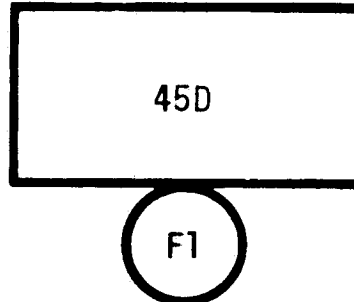
The truth or falsity (or the "probability" of either) of origin or intermediate propositions can be inferred* from the truth, falsity, or "probability" of their successor end-points. However, most end-points generally must be considered premises, and as with all premises, their truth or falsity usually cannot be established unequivocally. Therefore, the results of these inferences, like the results of most practical problems, must be considered provisional and will be valid if and only if the premises are accepted. It becomes apparent that some method of measuring a proposition's validity might be appropriate when its absolute truth or falsity cannot be established with certainty. Such values may well be arbitrary, and more a matter of judgment than mathematical precision, but they can be useful in determining the relative validity of dependent predecessor statements. Philosophically, a number between zero and one, associated with the truth or falsity of a proposition, may be viewed as an expression of a degree of belief in the validity of the statement, in which a value of unity would represent complete and unequivocal belief. This can be applied equally well to either complete belief in truth, or complete belief in falsity. An intermediate value also could be considered as (a) the relative frequency (per opportunity) with which a statement actually proved to be true (or false), (b) the probability that such would be the case, (c) a fair betting quotient, or (d) an expression of an opinion of the frequency with which the statement would be true or false (per opportunity) in the future. Any or all of these approaches may be used in relation to this logic diagram; during the analysis no attempt was made to differentiate explicitly between them. A value of one can be assumed where no figure otherwise is given.

4.2 END-POINT CATEGORIES

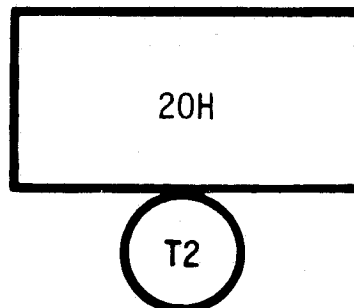
Development of the logic diagram included an evolution of the kinds of end-points that had to be considered. It was found that several different types of assumptions were required due to various reasons such as lack of hardware definition, or functions outside the scope of the study. By the time the logic analysis effort was terminated, the categories given below had been defined for the end-point assumptions that were made. An end-point proposition is identified in the logic diagram by a circle tangent to the base of its block. Within the circle the letter T or F appears, together with a numeral indicating the end-point category. When some factor of belief less than unity (see Paragraph 4.1) was involved, this is placed below the category number. Many of these factors are necessarily arbitrary and subject to personal opinion, but they do intimate that the statement should be given a more searching inspection and not just be accepted blindly.

*Appendix I includes, in Section I-3.0, a description of the principles of logical inference used in this analysis.

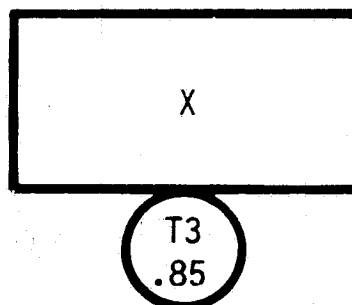
1. Propositions that appear so self-evidently true, or false, in the light of common experience that no explanation is warranted. For example, it is assumed that the proposition, "Crew members will not produce carbon dioxide," is so self-evidently false that no further rationale, development or rigorous proof is necessary, and would be coded F1 as shown.



2. Propositions whose study would be beyond the scope of the current task but for which some assumption of truth or falsity is considered necessary to continue the portion which is within the scope. For example, it would be pointless to study what might happen to crew members during their orbital stay if they arrived fatally ill. Thus, we must assume that the proposition, "All crew members will be in good physical and mental condition at the start of their orbital stay," is true as a necessary adjunct to the study. However, any results concerning the truth or falsity of the proposition, "All crew members will be safe during their orbital stay," are valid only to the extent that this assumption is correct. In such cases no explanation is provided other than noting that the proposition is Category 2, and would be coded T2 as shown.



3. Propositions whose truth, falsity, or "probability" thereof, can be substantiated by specific data from past missions, tests, or experiments, assuming that they are analogous to the mission and system being studied. As illustrated here, the code says that proposition X is an end-point of Category 3 with a .85 probability of being true.



N.B. This category was established early in the study to handle certain hardware considerations. In revising the logic diagram to conform with Phase II of this study, detailed hardware analysis was eliminated and end-points of this type consequently do not appear in the current diagram. The category has been retained for the sake of sequential consistency and for possible application during future logic analysis effort.

4. Propositions which are:

- a. not considered self-evidently true or false,
- b. not explicitly beyond assigned study scope, and
- c. not substantiated or refuted by data on hand; but
- d. are considered of such low relative interest, or are so imponderable that available resources should be applied to exploring other branches of the analysis, and
- e. for which some assumption is necessary (as in Category 2 above) to enable rational study of other branches.

In such cases the following information is denoted by appending ".1" or ".2" to the basic category number "4":

4.1 The proposition is conjoined with other propositions to imply an origin proposition (or is implied by such a conjoined proposition). Therefore, if it were assumed false, the origin proposition must be false and no effort would need to be expended on the other propositions of this branch. Thus, it must be assumed true, or to have a significant probability of truth, to enable further study. As illustrated, proposition 16F is a Category 4.1 end-point proposition which has been assigned a .95 probability of being true.

16F

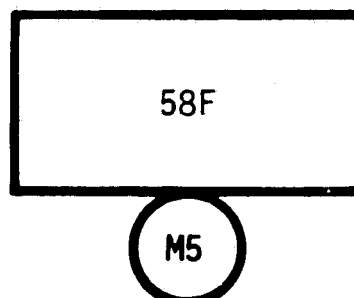
T4.1
.95

4.2 The disjunction of this proposition and others implies an origin proposition (or implies such a disjoined proposition). Therefore, if it were assumed true, the origin proposition must be true and no effort would need to be expended on the other propositions of this branch. Thus, it must be assumed false, or to have a significant probability of being false, to enable further study. Proposition 26H shown here is a Category 4.2 end-point proposition with a .90 probability of being false.

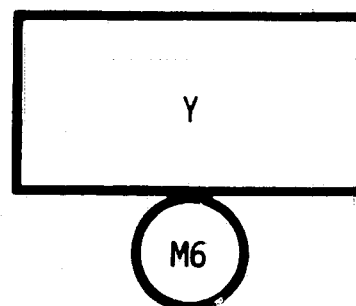
26H

F4.2
.90

5. A proposition whose further study, or whose truth or falsity, would be immaterial because it is used in the diagram as a member of a conjoined set of propositions, implied by a higher-level proposition, of which another member is self-evidently false (Cat. 1). In such a case, since the higher-level proposition must be false regardless of the truth or falsity of the one in question, no truth value has been assigned to the latter. As illustrated, proposition 58F is a Category 5 proposition whose further development is immaterial.

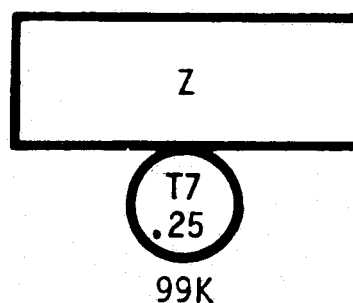


6. A proposition whose further development would be immaterial because it is used in the diagram to imply a higher-level proposition which is already implied disjunctively by a proposition considered self-evidently true (Cat. 1). In such a case, since the higher-level proposition must be true regardless of the truth or falsity of the one in question, no truth value has been assigned to the latter. Proposition Y is indicated here as a Category 6 proposition whose further development is immaterial.



N.B. This category was established as the converse to Category 5. No occasion for its use arose during the current logic analysis effort.

7. A proposition which is the negation of some intermediate (non-end-point) proposition. The truth value of this proposition is, therefore, the complement of the intermediate proposition's truth value, which can be inferred from those of its successors. After making this inference, the truth value of the proposition in question can be assigned. As illustrated, proposition Z is a Category 7 proposition that is the complement (negation) of proposition K on Chart No. 99. If it is inferred that proposition 99K has a probability of .75 of being true, its negation will have a truth value of .25.



N.B. This category was established during early development of the logic diagram. Subsequent refinement of the analysis resulted in deletion of the relationships which prompted this concept, but the category has been retained for possible future application. Propositions Z and 99K therefore are fictional and are used here for illustrative purposes only.

4.3 END-POINT PROPOSITIONS

4.3.1 Propositions which are classed as end-points in the current logic diagram, and are identified accordingly as described in Paragraph 4.2 above, together comprise the principal assumptions necessary for conducting this safety study. Further development of the logic analysis would have led to additional end-points (assumptions) at increasing levels of detail. An examination of these end-points, or assumptions, then, becomes one of the features of the effort by exposing areas which were not conducive to analysis at this point, and delimiting the scope of the study. It should be noted that many propositions have been end-pointed for the purposes of this study, without intending to imply that further development would necessarily be fruitless; in each case the end-point category, together with an explanation (where given), should provide the rationale used by the study group for making this decision.

4.3.2 Table 4-1 lists all of the simplifying assumptions used in the logic diagram, under arbitrary headings chosen to suggest the subject matter, which provide a convenient method of sorting out these assumptions. Each end-point is correlated with the diagram by showing which chart(s) it appears on, thus permitting a determination of the logical context for that assumption. For example, the first item in the table, "Crew selection will eliminate crew members with incipient system defects," appears on Charts 20, 27, 31, 68 and 71 of the diagram. In addition, the code provided on those charts denotes that this particular assumption was made, not because its truth was considered self-evident, but because its pursuit was considered beyond the assigned scope of this study. Thus, this assumption could be considered a result of the analysis, i.e., something determined by the analysis as needed for crew safety.

4.3.3 End-point propositions in Table 4-1 are grouped under the headings listed below. The "Proposition Code" column indicates chart number and statement identifier for each proposition quoted.

<u>Table</u>	<u>Subject</u>	<u>Page</u>
4-1.1	Statements about Crew Members assumed to be True	19
4-1.2	Statements about Crew Members assumed to be False	20
4-1.3	Statements about Potential Hazards assumed to be True	20

<u>Table</u>	<u>Subject</u>	<u>Page</u>
4-1.4	Statements about Emergencies assumed to be True	21
4-1.5	Statements about Emergencies assumed to be False	21
4-1.6	Statements about the Orbiting System assumed to be True	21
4-1.7	Statements about the Orbiting System assumed to be False	23
4-1.8	Statements about Ground Support assumed to be True	24
4-1.9	Statements about Decorbit Systems assumed to be True	25
4-1.10	Statements about Risk Limits assumed to be True	25
4-1.11	Statements about Risk Limits assumed to be False	26
4-1.12	Statements about Crew Functions assumed to be True	26
4-1.13	Statements about Crew Functions assumed to be False	27
4-1.14	Statements about Crew Member Replacement assumed to be False	27

TABLE 4-1
ASSUMPTIONS

		<u>Proposition Code</u>
4-1.1	<u>Statements about Crew Members assumed to be True</u>	
a.	Crew selection will eliminate crew members with incipient system defects.	20I, 27H, 31H, 68K, 71E
b.	All crew members will be in good physical and mental condition at the start of their orbital stay.	3B, 20H, 68C, 68J, 69D, 70D
c.	Crew members not incapacitated by deprivation of vital supplies, physical injuries, infectious illness, or systemic breakdown will be physically capable of performing tasks that are performable by normal people.	27G
d.	Crew members that are physically, technically, mentally, and emotionally capable, have the necessary resources, and have opportunities of time and place, will be able to perform all crew tasks necessary to sustain life.	18H
e.	No crew member will become mentally ill during his orbital stay.	31D, 68D
f.	Crew members will perform all medical tasks necessary to treat critical injuries.	69J, 71I
g.	Critically injured crew members will respond to treatment.	69K, 71H
h.	Crew members will perform all medical tasks necessary to treat critical infections.	70J
i.	Any crew member who is critically ill with an infection will respond to treatment.	70K
j.	Some vital crew tasks will be performed by assigned crew members using designated equipment.	50D

Proposition Code

- k. Any crew member with any potentially fatal injury will satisfactorily respond to treatment. 23H

4-1.2 Statements about Crew Members assumed to be False

- a. Each crew member will receive special training in performing the basic bodily functions of breathing, ingesting, digesting, sleeping, metabolism and thermal control, urinary elimination and fecal waste elimination. 29G
- b. Some crew members will be trained to breathe atmospheric gas not breathable by normal untrained people. 41H
- c. Crew members will not produce carbon dioxide. 45D

4-1.3 Statements about Potential Hazards assumed to be True

- a. Heat, radiation, chemicals, shock, acceleration, collision, decompression, overpressure, and noise are the only external agencies that can cause direct physical impairment of a person. 75M
- b. Crew members will not be in immediate danger of physical injury from external hazards other than chemicals, electricity, pressure, radiation, heat, vacuum, or some form of relative motion. 8J, 16J, 24K, 34K
- c. There will be no immediate danger of directly fatal collision other than collision between crew members and meteoroids, flying debris, equipment, or themselves. 13H, 52G, 65H
- d. Relative motion will not cause any injury other than concussion, puncture, fracture, lacerations, incisions, or injury to internal organs. 25I

Proposition Code

- e. No crew member will be injured by anything other than chemicals, heat, radiation, overpressure, decompression, electrical shock or some form of relative motion during his orbital stay. 32H
- f. Impairment of hearing or hypnotic effects are the only ways that noise can incapacitate a person. 77H
- g. Impairment of vision or hypnotic effects are the only ways that light can incapacitate a person. 78I
- h. No chemicals on-board the spacecraft other than narcotics, stimulants, sedatives, hypnotics, corrosives, toxins or noxious chemicals will be potentially incapacitating. 76M

4-1.4 Statements about Emergencies assumed to be True

- a. Any potentially fatal space flight emergency situation must involve immediate danger, crew inability to function, return system failure, or failure of ground support functions. 4H, 6H, 49H
- b. Some potentially fatal emergencies will be remedied by systems especially produced for that purpose. 5E

4-1.5 Statements about Emergencies assumed to be False

- a. All potentially fatal emergencies will be remedied by systems produced and used for some other basic purpose. 5B

4-1.6 Statements about the Orbiting System assumed to be True

- a. There will be no extra-terrestrial haven outside the spacecraft for endangered crew members. 80E

Proposition Code

- b. There will be no non-spacecraft equipment, other than logistic vehicles and co-orbiting modules. 26C, 54D, 67D .
- c. There will be no significant sources of radiation other than the sun and those in the spacecraft. 36E, 37E, 55E
- d. There will be no potentially dangerous sources of radiation on-board the spacecraft other than nuclear power plants for the generation of spacecraft power. 36H, 38C, 56C
- e. Normal systems will supply to each crew member sufficient oxygen for immediate needs at the start of his orbital stay. 15I, 42E
- f. There will be no immediate danger of directly fatal electrical shock of any crew member from any source outside the spacecraft. 62C
- g. There will be no potentially fatal spacecraft electrical sources other than power; communications; experimental, medical, housekeeping, life support, EVA or recreational equipment; navigation; rendezvous; or stability and control equipment. 62H
- h. Provision of vital supplies, provision of means of return to haven, prevention of directly fatal injury or illness, and effective treatment of illness and injury are the only space system functions necessary to sustain life. 47I
- i. There will be no in-flight hardware element, necessary to the safety of the orbital space system, other than the spacecraft subsystems, internal hardware interfaces, hardware interfaces between orbital space vehicles, man/machine interfaces, maintenance functions, on-board support resources, and in-flight support and resupply functions. 9J

Proposition Code

- | | | |
|----|--|-----|
| j. | All spacecraft subsystems will perform at the start of the orbital mission in accordance with operational parameters which ensure crew survival. | 10B |
| k. | All gaseous requirements, other than oxygen, necessary to a breathable atmosphere will be provided by any system which supplies crew members with immediately necessary breathable atmosphere. | 42B |

4-1.7 Statements about the Orbiting System
assumed to be False

- | | | |
|----|--|-----|
| a. | A special remedial system will be provided for emergency escape to Earth haven. | 80H |
| b. | There will be means of protecting any crew member in immediate danger of being subjected to directly fatal radiation from the sun (other than heat) by introducing a shield between him and the sun. | 37G |
| c. | There will be means for rapidly moving crew members far enough into space away from the sun that they effectively escape sun radiation that would be fatal if they were not moved or shielded. | 39C |
| d. | The means provided to escape dangerous radiation from electromagnetic solar storms will effectively return the crew to Earth. | 39E |
| e. | There will be no radiation reaching the spacecraft from electromagnetic solar storms that would be directly fatal to an exposed crew member. | 55G |
| f. | There will be an extra-terrestrial haven outside the spacecraft adequately shielded from solar radiation. | 39H |

	<u>Proposition Code</u>
g. There will be no primary nuclear power plants on the spacecraft.	38E, 56E
h. The initial supply of oxygen provided by normal systems to each crew member at the start of his orbital stay will be enough for all needs that will arise during his orbital stay.	42F
i. All vital crew tasks can be performed without special training or without special equipment.	50C
j. Any existing immediate danger of crew loss will not be potentially correctable.	14C
k. Special remedial systems will be provided to prevent directly fatal collision of logistics vehicles with crew members during extra-vehicular activities.	63D
l. Special remedial systems will be provided to prevent directly fatal collision of co-orbiting modules with crew members during extra-vehicular activities.	26H
m. All spacecraft subsystems will perform unattended and unaugmented throughout the orbital mission within operational tolerances which ensure crew survival.	10E

4-1.8 Statements about Ground Support assumed to be True

a. Normal ground systems will be capable of performing all ground support functions necessary to crew survival.	4D, 6E, 49E
---	-------------

Proposition Code

4-1.9 Statements about Deorbit Systems assumed to be True

- | | | |
|----|---|-----|
| a. | Systems produced and used for some other basic purpose will provide capability of return to Earth haven not provided by the basic return vehicle or special remedial systems. | 49F |
| b. | The return trip to haven will place no fatal physiological stress on any ill or injured crew member whose illness or injuries are potentially curable. | 79D |

4-1.10 Statements about Risk Limits assumed to be True

- | | | |
|----|--|--------------------|
| a. | Deprivation of food and water will not constitute immediate danger of death. | 7G, 15G, 33G, 51G |
| b. | There will be no immediate danger of directly fatal exposure of any crew member to overpressure. | 16F, 34G, 81C |
| c. | No crew member will be injured by overpressure. | 24I, 32I, 72G, 75K |
| d. | Relative motion, other than collisions or physiological stress due to tumbling, rotation, or linear motion, will not be directly fatal. | 11D, 17D, 35D |
| e. | Any immediate danger of any ill or injured crew member succumbing to their illness or injury will be potentially correctable. | 33D |
| f. | Shielding on spacecraft primary power reactors will be sufficient to protect all crew members from radiation during specified maximum normal operation. | 58C |
| g. | Shielding on spacecraft primary power reactors will be sufficient to protect all crew members from radiation from power excursions levels that activate all emergency backup controls. | 58E |

	<u>Proposition Code</u>
h. No crew member will be disabled by hypnotic effects of noise.	77G
i. No crew member will be disabled by hypnotic effects of light.	78J
j. Each crew member will be able to utilize oxygen supplied to him.	15J
k. Removal of an injured crew member from the condition or environment causing his injury will avert aggravation of the injury by that cause.	72L
4-1.11 <u>Statements about Risk Limits assumed to be False</u>	
a. No infectious illness contracted by any crew member during his orbital stay will be potentially fatal.	21E
b. Any crew member infected with any potentially fatal illness (or sustaining any potentially fatal injury) for which there is no cure (or remedy) in orbit will always be returned to Earth haven before the illness (his condition) becomes critical.	22B, 23B
c. Incurably ill or injured crew members will be able to withstand the return trip to Earth haven.	79G
d. Shielding on spacecraft primary power reactors will be sufficient to protect all crew members from radiation from a completely uncontrolled chain reaction resulting in dispersion of the critical mass by thermal stress.	58G
4-1.12 <u>Statements about Crew Functions assumed to be True</u>	
a. There will be no crew functions necessary to sustain life other than routine tasks and corrective actions.	12D

Proposition Code

- b. Crew duty cycles will preclude breakdown of crew members who do not have incipient system defects.

27I, 31I, 68L

4-1.13 Statements about Crew Functions assumed to be False

- a. It is possible for one person to perform the basic bodily functions of another.

29F

4-1.14 Statements about Crew Member Replacement assumed to be False

- a. An able alternate crew member will always be available to replace any crew member who cannot perform a task necessary to sustain life because of incapacitation from exposure to chemicals.

76B

- b. An able alternate crew member will always be available to replace any crew member who cannot perform a task necessary to sustain life because of incapacitation from the effects of noise.

77B

- c. An able alternate crew member will always be available to replace any crew member who cannot perform a task necessary to sustain life because of incapacitation caused by any form of radiation other than heat.

78D

5.0 SUMMARY OF "OPEN" PROPOSITIONS

5.1 DEFINITION AND RATIONALE

An ideally complete logic diagram would have all of its branches terminating in end-points of one kind or another (Section 4.0), in which each end-point would represent the lowest possible (or desirable) level of detail in knowledge or available information on that particular item. Prior to such a case it is necessary that any branch that has not been carried to its ultimate conclusion will be terminated some place relatively higher in the "tree," and that such a termination perforce must be left blank in its references to possible future development. Such terminations are called "open" propositions since decisions concerning further study have not been made, and they do not appear suitable for relegating to end-point status at this time. For very gross, high-level, non-hardware-oriented studies such as this it is understandable that many open propositions will remain at the end of the logical analysis effort. At the same time, however, these open propositions can engender trains of thought that can lead to very meaningful interim conclusions, when considered by experienced and imaginative system specialists, and thus be transformed into interesting, useful or important concepts. The current Safety Study has depended upon this aspect of analytical effort to produce numerous guidelines with a crew safety connotation, which might not otherwise have been generated.

5.2 INTERPRETIVE COMMENTS

Tables 5-1 through 5-13 in this section are listings of all the open propositions established by the logic analysis up to the time engineering effort ceased. They are listed here primarily as a compendium to review for possible follow-on action, and are grouped under headings which may assist the reader or researcher to concentrate on particular areas of interest, without the necessity of searching through the entire set of charts to find appropriate items. Correlation of any open proposition listed to another concept in the diagram is provided by the "Proposition Code" reference, thereby permitting an examination of the context for each statement. The following considerations should be borne in mind while reviewing the listings in these tables:

- a. The same item may appear under more than one heading in the table. For example, if the proposition, "There will be sufficient time for available crew members to accomplish any human task necessary to sustain life," is to be true, then schedules of both experimental and non-experimental activities must provide time for such tasks, warning systems must work, and crew members must be capable of performing them in the time available. Therefore, this proposition appears in Tables 5-1, 5-2 (by inclusion of the general note), 5-4 and 5-13.

- b. The verbal treatment and amount of detail on human activities, direct exposure of the human body, oxygen systems, natural phenomena, and medical subjects as compared, for example, to details of hardware configuration, may seem unfamiliar and perhaps awkward from the standpoint of practical application. This emphasis is due to a concentration on determining what needs to be accomplished in view of the natural limits of man and nature, while attempting to avoid being overly restrictive and pre-empting design by examining how it might be accomplished. (In principle, the complete implemental planning could be done by continuation of this analysis through consideration of all the ways these propositions could be made true and the reasons for selecting one in preference to another.) Furthermore, by ground rule of the Safety Study, detailed analysis of specific hardware concepts was omitted.
- c. At times it might appear that two propositions are contradictory in the case that, if one were true, then the other would not be needed. However, examination of their context in the logic diagram will reveal that they are, in fact, shown as alternates (disjoined). (Also, unless the truth of one can be guaranteed, it is common to include both of a pair of alternates in a system.)
- d. Some of the language may seem stilted and legalistic. However, such language was found necessary to formulate statements, for the logic diagram, that would withstand logical tests. It was decided to quote them literally in these tabulations, rather than to risk misunderstanding or oversight leading to error by paraphrasing them in the more cryptic and less precise language common to engineering documents.

5.3 INDEX OF HEADINGS

Open propositions in Tables 5-1 through 5-13 are grouped under the headings listed below. The "Proposition Code" column indicates chart number and statement identifier for each proposition quoted.

<u>Table</u>	<u>Subject</u>	<u>Page</u>
5-1	<u>Safety Constraints on Experiments</u>	33
5-1.1	Scheduling	33
5-1.2	Equipment Arrangement	33
5-1.3	Tie-Down, Containment, and Explosives	34
5-1.4	Electrical Equipment	34
5-1.5	Potential Heat Sources	34
5-1.6	Light	34
5-1.7	Noise	35
5-1.8	Chemicals	35
5-2	<u>Safety Constraints on Non-Experimental Functions</u>	38

<u>Table</u>	<u>Subject</u>	<u>Page</u>
5-3	<u>Human Engineering</u>	40
5-3.1	Portability and Ease of Operation	40
5-3.2	Protective Equipment	40
5-3.3	Waste Disposal and Hygiene Provisions	41
5-3.4	Access	41
5-3.5	Escape, Damage Control, and Rescue Provisions	42
5-3.6	Equipment Indicators and Warning Systems	42
5-3.7	Medical Equipment	43
5-3.8	Operations, Maintenance and Support	43
5-4	<u>Crew Capabilities</u>	45
5-4.1	Training Goal	45
5-4.2	Cross Training	45
5-4.3	Skill Level	45
5-4.4	Emergency Rescue or Escape	46
5-4.5	First Aid	47
5-4.6	Use of Medical Facilities	47
5-5	<u>Oxygen Supply Specifications</u>	49
5-5.1	Sources of Supply	49
5-5.2	Reliability	49
5-5.3	Operability and Maintainability	50
5-5.4	Emergency Systems	50
5-6	<u>Quality of Atmospheric Environment</u>	51
5-6.1	Basic Requirements	51
5-6.2	Cleanliness Control	51
5-6.3	Chemical Contaminants Control	52
5-6.4	Temperature Control	53
5-7	<u>Nuclear Reactors and Ancillary Hardware</u>	54
5-7.1	Containment and Structural Integrity	54
5-7.2	Reactor Control	54
5-7.3	Maintainability	54
5-7.4	Control of Working Fluids and Coolants	55
5-7.5	Dosage Monitoring	55
5-8	<u>Stabilization, Propulsion, Control and Ancillary Systems</u>	56
5-8.1	Parent Spacecraft	56
5-8.2	Logistics Vehicles (Ferries, Escape Vehicles, and Space Tugs)	58
5-8.3	Co-orbiting Modules	60
5-8.4	Extra-Vehicular Activities	61

<u>Table</u>	<u>Subject</u>	<u>Page</u>
5-9	<u>Spacecraft Structure</u>	62
5-9.1	Shell, Wall and Closure Integrity	62
5-9.2	General Layout of Spacecraft	63
5-10	<u>Medical Facilities</u>	66
5-10.1	Types of Medical Facilities Required	66
5-10.2	Medical Equipment Reliability and Spares Availability	67
5-10.3	Control of Medical Supplies	68
5-10.4	Diagnostic Capability	69
5-11	<u>Life Support and Health</u>	71
5-12	<u>Injury and Damage Prevention or Restoration</u>	73
5-13	<u>Warning Systems</u>	76

TABLE 5-1
SAFETY CONSTRAINTS ON EXPERIMENTS

		<u>Proposition Code</u>
5-1.1	<u>Scheduling</u>	
a.	There will be sufficient time for available crew members to accomplish any human task necessary to sustain life.	18D
b.	The locations and activities of crew members will make technically capable crew members available for performing any human task necessary to sustain life.	28C
5-1.2	<u>Equipment Arrangement</u>	
a.	Arrangement of equipment in the spacecraft will permit access by a normal person to any equipment in the spacecraft whose manipulation is necessary to provide vital supplies to any crew member.	48C
b.	Any visual indicators on equipment in the spacecraft whose recognition is essential to properly perform operations necessary to provide vital supplies to any crew member will be clearly visible to persons with normal sight.	48H
c.	There will be no immediate danger of directly fatal collision between one crew member and another.	52F
d.	There will be no immediate danger of directly fatal collision of spacecraft equipment, not attached to the spacecraft, with crew members.	53C
e.	All hardware interfaces among internal equipment will perform their respective spaceflight operational functions in the manner necessary to ensure crew survival.	9C
f.	Any equipment in the spacecraft whose manipulation is a routine task necessary to protect crew members from directly fatal physical injury from external causes will be accessible and operable by normal people.	47D

Proposition Code5-1.3 Tie-down, Containment and Explosives

- a. No crew member will be injured by any form of relative motion during his orbital stay. 32C
- b. There will be no immediate danger of directly fatal collision of spacecraft equipment, not attached to the spacecraft, with crew members. 53C
- c. Any immediate danger of directly fatal collision of spacecraft equipment, not fixed to the spacecraft, will be potentially correctable. 66C
- d. Any immediate danger of directly fatal collision between one crew member and another will be potentially correctable. 65F
- e. Any immediate danger of directly fatal collision of flying debris with crew members will be potentially correctable. 65D

5-1.4 Electrical Equipment

- a. No crew member will be injured by electrical shock during his orbital stay. 32G
- b. There will be no immediate danger of directly fatal electrical shock from experimental equipment. 62E

5-1.5 Potential Heat Sources

- a. No crew member will be injured by heat during his orbital stay. 32D

5-1.6 Light

- a. Any visual indicators on equipment in the spacecraft whose recognition is essential to properly perform operations necessary to provide vital supplies to any crew member will be clearly visible to persons with normal sight. 48H

Proposition Code

- b. Any crew member incapacitation from any form of radiation, other than heat, will occur at a time that will not prevent his performing any task necessary to sustain life. 78B
- c. No crew member will suffer disabling impairment of vision due to exposure to light. 78G

5-1.7 Noise

- a. Any auditory signals from equipment in the spacecraft whose recognition is essential to properly perform operations necessary to provide vital supplies to any crew member will be clearly audible to persons with normal hearing. 48I
- b. Noise will not cause disabling hearing defects in any crew members. 77E
- c. Any crew member incapacitation from noise will occur at a time that will not prevent his performing any task necessary to sustain life. 77D

5-1.8 Chemicals

- a. No crew member will be injured by chemicals during his orbital stay. 32B
- b. There will be no immediate danger of any crew member swallowing any poisonous chemical that would be directly fatal. 59B
- c. There will be no immediate danger of any crew member having any deadly poison injected or implanted in his body. 59E
- d. No crew member will be in immediate danger of directly fatal exposure of large areas of his body to any poisonous or corrosive chemical. 59F

	<u>Proposition Code</u>
e. No supplies, materials for experiments, or spacecraft materials will constitute a contact poison that would be directly fatal through simple skin contact not involving large areas of the body.	60B
f. No contact poisons that would be directly fatal through simple skin contact that does not involve large areas of the body will be generated by accident or by any experimental, housekeeping, spacecraft operation, or logistics activity.	60C
g. No supplies, materials for experiments, or spacecraft materials will constitute a poison that would be directly fatal if breathed.	61B
h. No poison that would be directly fatal if breathed will be generated by accident or by any experimental, housekeeping, spacecraft operation, or logistics accident.	61C
i. Any supplies, materials for experiments, or spacecraft materials that constitute a deadly contact poison will be kept contained and controlled in a manner that does not present any immediate danger to the life of any crew member.	60D
j. Any deadly contact poison that is generated by accident or by any experimental, housekeeping, spacecraft operation, or logistics activity will be contained and controlled in a manner that does not present any immediate danger to the life of any crew member.	60E
k. Any supplies, materials for experiments, or spacecraft materials that constitute a poison that would be directly fatal if breathed will be contained or controlled in a manner that does not present any immediate danger to the life of any crew member.	61D

Proposition Code

- | | | |
|----|--|-----|
| 1. | Any poison generated by accident or by any experimental, housekeeping, space-craft operation, or logistics activity that would be directly fatal if breathed will be contained and controlled in a manner that does not present any immediate danger to the life of any crew member. | 61E |
| m. | Any injurious corrosive chemicals or contact poison on the skin of crew members will be washed off or neutralized. | 73D |
| n. | Any crew member incapacitation from chemicals will occur at a time that will not prevent his performing any task necessary to sustain life. | 76D |

TABLE 5-2
SAFETY CONSTRAINTS ON NON-EXPERIMENTAL FUNCTIONS

NOTE: All items in Table 5-1 apply here, except 5-1.4-b.

	<u>Proposition Code</u>
a. There will be no immediate danger of directly fatal electrical shock from the spacecraft primary power distribution system, test equipment or maintenance equipment.	62D
b. There will be no immediate danger of directly fatal electrical shock from communications or data management equipment.	62F
c. There will be no immediate danger of directly fatal electrical shock from housekeeping, medical, recreational, life support or EVA equipment.	62I
d. Any immediate danger of any crew member being subjected to directly fatal exposure to radiation from a nuclear power plant on the spacecraft will be potentially correctable.	38D
e. No crew member will be injured by radiation from nuclear power plants on the spacecraft.	36F
f. All hardware interfaces among external equipment, and other orbital space vehicles, will perform their respective spaceflight operational functions in the manner necessary to ensure crew survival.	9D
g. All spacecraft subsystems will be designed and produced to conform with operational parameters which will ensure crew survival.	10D
h. Any spacecraft subsystem which requires built-in redundancy to perform within acceptable tolerances continuously throughout the orbital mission will have the necessary redundancy incorporated.	10F

Proposition Code

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|---|-----|
| i. All spacecraft subsystems incorporating appropriate built-in redundancy or maintainability features will perform satisfactorily throughout the orbital mission. | 10H |
| j. There will be no immediate danger of directly fatal electrical shock from any navigation and guidance, rendezvous and docking, or stability and control equipment that may be in the spacecraft. | 62J |
| k. Any immediate danger of directly fatal collision of meteoroids with crew members will be potentially correctable. | 65B |
| l. Any immediate danger of directly fatal collision of co-orbiting modules with crew members during extra-vehicular activities will be potentially correctable. | 67E |

TABLE 5-3
HUMAN ENGINEERING

Proposition Code5-3.1 Portability and Ease of Operation

- | | | |
|----|--|-----|
| a. | No human task necessary to sustain life will be beyond the physical capability of normal people. | 27E |
| b. | Any equipment controls in the spacecraft whose operation is necessary to provide vital supplies to any crew member will be operable by normal people. | 48E |
| c. | Any equipment in the spacecraft whose manipulation is a routine task necessary to protect crew members from directly fatal injury from external causes will be accessible and operable by normal people. | 47D |
| d. | Any equipment item, materials, supplies, spare parts, or tools whose manual transportation is necessary to provide vital supplies to any crew member will be transportable by normal people. | 48D |
| e. | Any tools whose use in the spacecraft is necessary to provide vital supplies to any crew member will be usable by normal people. | 48G |

5-3.2 Protective Equipment

- | | | |
|----|---|-----|
| a. | Any equipment features whose manipulation is an extra-vehicular human task necessary to sustain life will be accessible and operable by a normal person. | 46B |
| b. | Any equipment in the spacecraft whose manipulation is a non-routine task necessary to protect crew members from directly fatal physical injury from external causes will be accessible and operable by normal people. | 47E |

Proposition Code

- c. There will be at least one crew member technically capable of performing any extra-vehicular task necessary to sustain life. 28G
- d. Any equipment features whose manipulation is an inter-vehicular task necessary to sustain life will be accessible and operable by a normal person. 46C

5-3.3 Waste Disposal and Hygiene Provisions

- a. Any equipment in the spacecraft whose manipulation is necessary to prevent any directly fatal illness, other than that caused by injury or deprivation, will be accessible and operable by normal people. 47F
- b. The environment of any crew member will not prevent sufficient elimination of body wastes to sustain life by any normal untrained person. 30E

5-3.4 Access

- a. The spacecraft structure will permit access by a normal person to any equipment in the spacecraft whose manipulation is necessary to provide vital supplies to any crew member. 48B
- b. Arrangement of equipment in the spacecraft will permit access by a normal person to any equipment in the spacecraft whose manipulation is necessary to provide vital supplies to any crew member. 48C
- c. Any opening, closing, removal, replacement, disassembly, or assembly operation in the spacecraft necessary to provide vital supplies to any crew member will be performable by normal people. 48F

Proposition Code

5-3.5 Escape, Damage Control, and Rescue Provisions

- a. Any equipment features whose manipulation is an extra-vehicular human task necessary to sustain life will be accessible and operable by a normal person. 46B
- b. Any equipment in the spacecraft whose manipulation is necessary to enable return of any crew member to a haven will be accessible and operable by normal people. 47C
- c. Any equipment in the spacecraft whose manipulation is a non-routine task necessary to protect crew members from directly fatal physical injury from external causes will be accessible and operable by normal people. 47E
- d. The spacecraft structure will permit access by a normal person to any equipment in the spacecraft whose manipulation is necessary to provide vital supplies to any crew member. 48B
- e. Any equipment in the spacecraft whose manipulation is necessary to prevent ill or injured crew members from succumbing will be accessible and operable by normal people. 47G

5-3.6 Equipment Indicators and Warning Systems

- a. Any visual indicators on equipment in the spacecraft whose recognition is essential to properly perform operations necessary to provide vital supplies to any crew member will be clearly visible to persons with normal sight. 48H
- b. Any auditory signals from equipment in the spacecraft whose recognition is essential to properly perform operations necessary to provide vital supplies to any crew member will be clearly audible to persons with normal hearing. 48I

Proposition Code

- c. A solar radiation warning system will not fail to provide signals, recognizable by each crew member as instruction to seek protection, in time for all crew members to go to a shielded haven in the spacecraft before solar radiation becomes of fatal type and intensity. 40B, 74D
- d. Any immediate danger of any crew member being subjected to directly fatal exposure to radiation from a nuclear power plant on the spacecraft will be potentially correctable. 38D
- e. Any immediate danger of any crew member being subjected to any directly fatal heat will be potentially correctable. 34D
- f. Any immediate danger of any crew member being subjected to any directly fatal decompression will be potentially correctable. 34C
- g. Any immediate danger of any crew member being subjected to directly fatal exposure to chemicals will be potentially correctable. 34I
- h. Any immediate danger of directly fatal physiological stress from tumbling, rotation, or linear motion will be potentially correctable. 35E

5-3.7 Medical Equipment

- a. Any equipment in the spacecraft whose manipulation is necessary to prevent ill or injured crew members from succumbing will be accessible and operable by normal people. 47G

5-3.8 Operations, Maintenance and Support

- a. All man/machine operational interfaces will perform their respective space-flight functions in the manner necessary to ensure crew survival. 9E

D2-113070-9

Proposition Code

- b. All scheduled and unscheduled maintenance functions pertaining to the orbital space system will be performed in the manner necessary to ensure crew survival. 9F
- c. All on-board support resources required during spaceflight operations will perform in the manner necessary to ensure crew survival. 9G
- d. All orbital space system in-flight logistic support and resupply functions will be performed in the manner necessary to ensure crew survival. 9H
- e. Any spacecraft subsystem which requires inflight maintenance to perform within acceptable tolerances continuously throughout the orbital mission will be maintainable in the operational environment. 10G

TABLE 5-4
CREW CAPABILITIES

		<u>Proposition Code</u>
5-4.1	<u>Training Goal</u>	
a.	At least one crew member will be trained to perform any spacecraft task, other than basic bodily functions, necessary to sustain life that is not performable by normal untrained people.	29B
b.	There will be at least one crew member technically capable of performing any extra-vehicular human task necessary to sustain life.	28G
c.	There will be at least one crew member technically capable of performing any inter-vehicular human task necessary to sustain life.	28F
5-4.2	<u>Cross Training</u>	
a.	Special remedial systems will perform all routine crew functions necessary to sustain life that are not performed by assigned crew members.	12B
b.	Special remedial systems will perform all corrective actions necessary to sustain life that are not performed by assigned crew members.	12E
c.	All vital crew tasks not performed by assigned crew members using designated equipment will be performed by other means.	50E
5-4.3	<u>Skill Level</u>	
a.	There will be sufficient time for available crew members to accomplish any human task necessary to sustain life.	18D
b.	Crew members will be mentally and emotionally capable of performing any human task necessary to sustain life.	18G

Proposition Code5-4.4 Emergency Rescue or Escape

- a. Any crew member with burn injuries will be evacuated from any location subjected to extreme heat. 72B
- b. Any crew member injured by electrical shock will be protected from conductors whose power is not turned off. 72E
- c. Any crew member injured by physiological stress caused by linear or angular acceleration will be removed from any injurious acceleration situation that cannot be corrected. 72H
- d. Any crew member injured by collision of any kind will be protected from further collision injury. 72J
- e. Any crew member injured by decompression will be removed from low pressure areas that cannot be pressurized. 72I
- f. Any crew member injured by breathing toxic chemicals will be removed from any toxic atmosphere that cannot be purged clean. 73B
- g. Any crew member with radiation injuries will be evacuated from any location subjected to further injurious radiation. 72C
- h. All crew members will react promptly to warnings of the approach of sun radiation bursts of directly fatal type and intensity. 74E
- i. There will be effective means of transporting all crew members who are unable to transport themselves to a haven in the spacecraft that is shielded from solar radiation. 40D
- j. All crew members will be removed, rapidly enough to prevent illness, from any location whose atmosphere is becoming contaminated with any material that prevents safe breathing by normal untrained people. 45E

Proposition Code

- k. Special remedial systems will provide means of travel, or escape, to a safe haven in the spacecraft in case routine means are inadequate.

80B

5-4.5 First Aid

- a. Systems produced and used for some other basic purpose will protect all ill or injured crew members, that are not protected by special remedial systems, from immediate danger of succumbing to their illness or injury.
- b. Special remedial systems will supply to all crew members all immediately necessary oxygen not supplied by normal systems.
- c. Any injurious corrosive chemicals or contact poison on the skin of crew members will be washed off or neutralized.
- d. Crew members will perform all medical tasks necessary to prevent any potentially fatal illness contracted by any crew member during his orbital stay from becoming critical.
- e. Crew members will perform all medical tasks necessary to prevent potentially fatal injuries from becoming critical.

51D

42D

73D

22F

23G

5-4.6 Use of Medical Facilities

- a. At least one crew member will be trained to perform any spacecraft task, other than basic vital bodily functions, necessary to sustain life that is not performable by normal untrained people.
- b. There will be adequate medical facilities in the spacecraft to treat any potentially fatal illness contracted by any crew member during his orbital stay.

29B

22D

Proposition Code

- c. There will be adequate medical facilities to treat any potentially fatal decompression injury sustained by any crew member during his orbital stay. 24C
- d. There will be adequate medical facilities to treat any potentially fatal injury from exposure to heat sustained by any crew member during his orbital stay. 24D
- e. There will be adequate medical facilities to treat any potentially fatal radiation injury sustained by any crew member during his orbital stay. 24E
- f. There will be adequate medical facilities to treat any potentially fatal injury from electrical shock sustained by any crew member during his orbital stay. 24F
- g. There will be adequate medical facilities to treat any potentially fatal injury from exposure to chemicals sustained by any crew member during his orbital stay. 24G
- h. There will be adequate medical facilities to treat any potentially fatal puncture wound sustained by any crew member during his orbital stay. 25C
- i. There will be adequate medical facilities to treat any potentially fatal lacerations or incisions sustained by any crew member during his orbital stay. 25E

TABLE 5-5
OXYGEN SUPPLY SPECIFICATIONS

Proposition Code

5-5.1 Sources of Supply

- a. Normal systems will replace from oxygen, salvaged from atmospheric gas removed from crew locations, any immediately necessary oxygen that is consumed, dissipated, or removed from the volume immediately available to each crew member and not replaced from stored sources. 43C
- b. Normal systems will contain sufficient stored sources to replace any immediately necessary oxygen that is consumed, dissipated, or removed from the volume immediately available to each crew member and not replaced from oxygen salvaged from atmospheric gas removed from crew locations. 43D
- c. Normal systems will include sufficient means to store and conduct to crew members replacement oxygen for any immediately necessary oxygen that is consumed, dissipated or removed from the volume immediately available to each crew member and not replaced from oxygen salvaged from atmospheric gas removed from crew locations. 43E
- d. Systems produced and used for some other basic purpose will supply to all crew members all immediately necessary oxygen not supplied by normal systems or special remedial systems. 51E

5-5.2 Reliability

- a. There will be no immediate danger of the rate of supply of breathable oxygen to any crew member decreasing below the rate necessary to sustain life. 15K

Proposition Code

- b. There will be no failure of normal systems for storing and conducting to crew members replacement oxygen for any immediately necessary oxygen that is consumed, dissipated, or removed from the volume immediately available to each crew member and not replaced from oxygen salvaged from atmospheric gas removed from crew locations.

43F

5-5.3 Operability and Maintainability

- a. Any equipment controls in the spacecraft whose operation is necessary to provide vital supplies to any crew member will be operable by normal people.
- b. Any opening, closing, removal, replacement, disassembly, or assembly operation in the spacecraft necessary to provide vital supplies to any crew member will be performable by normal people.

48D

48F

5-5.4 Emergency Systems

- a. Special remedial systems will be potentially capable of supplying any immediate oxygen needs of any crew member not supplied by normal systems.

33I

TABLE 5-6
QUALITY OF ATMOSPHERIC ENVIRONMENT

		<u>Proposition Code</u>
5-6.1	<u>Basic Requirements</u>	
a.	Atmospheric gas whose contaminant level permits breathing without physical illness by normal untrained people will be supplied to each crew member.	44B
b.	Atmospheric gas whose temperature permits breathing without physical illness by normal untrained people will be supplied to each crew member.	44D
c.	Atmospheric gas whose partial pressure of oxygen permits breathing without physical illness by normal untrained people will be supplied to each crew member.	44C
d.	Atmospheric gas whose total pressure permits breathing without physical illness by normal untrained people will be supplied to each crew member.	44E
5-6.2	<u>Cleanliness Control</u>	
a.	No crew member will contract any infectious illness during his orbital stay.	21D
b.	No crew member will become physically ill during his orbital stay due to infection.	31G, 70G
c.	The crew members available to perform tasks necessary to sustain life will not have been incapacitated by infectious illness.	27D
d.	Any atmospheric gas, in crew locations that are being contaminated with any material that prevents its safe breathing, will be removed or diluted at a rate that enables continued breathing by normal untrained people without illness.	45B

Proposition Code5-6.3 Chemical Contaminants Control

- a. No crew member will be injured by exposure to chemicals during his orbital stay. 32B
- b. Any supplies, materials for experiments or spacecraft materials that constitute a poison that would be directly fatal if breathed will be contained or controlled in a manner that does not present any immediate danger to the life of any crew member. 61D
- c. Any poison generated by accident or by experimental, housekeeping, spacecraft operation, or logistics activity that would be directly fatal if breathed will be contained or controlled in a manner that does not present any immediate danger to the life of any crew member. 61E
- d. Any atmospheric gas, in crew locations that are being contaminated with any material that prevents its safe breathing, will be removed or diluted at a rate that enables continued breathing by normal untrained people without illness. 45B
- e. No crew member will be incapacitated by exposure to any chemical narcotic. 76E
- f. No crew member will be incapacitated by exposure to any chemical stimulant. 76F
- g. No crew member will be incapacitated by exposure to any chemical sedative. 76G
- h. No crew member will be incapacitated by exposure to any chemical hypnotic. 76H
- i. No crew member will be incapacitated by exposure to any toxic chemical. 76J
- j. No crew member will be incapacitated by exposure to any noxious chemical. 76K

Proposition Code

- k. No crew member will be incapacitated by exposure to any corrosive chemical.

76I

5-6.4 Temperature Control

- a. The temperature environment of each crew member will permit vital basic metabolism and thermal control functions of a normal untrained human body.

30C

TABLE 5-7
NUCLEAR REACTORS AND ANCILLARY HARDWARE

		<u>Proposition Code</u>
5-7.1	<u>Containment and Structural Integrity</u>	
a.	The effectiveness of spacecraft nuclear power reactor shielding in preventing fatal crew member exposure will not be destroyed by structural damage.	57E
b.	There will be no immediate danger of directly fatal collision of flying debris with crew members.	52D
c.	No crew member will be injured by radiation from nuclear power plants on the spacecraft.	36F
5-7.2	<u>Reactor Control</u>	
a.	Any immediate danger of any crew member being subjected to directly fatal exposure to radiation from a nuclear power plant will be potentially correctable.	38D
b.	Nuclear excursions of spacecraft primary power reactors will never exceed specified maximum normal operation.	58B
c.	Nuclear excursions of spacecraft primary power reactors will never exceed the upper limit of power excursion levels specified to activate all emergency back-up controls.	58D
d.	No crew member will be injured by radiation from nuclear power plants on the spacecraft.	36F
5-7.3	<u>Maintainability</u>	
a.	No crew member will be in immediate danger of directly fatal radiation exposure during repair, refurbishment, or refueling of spacecraft nuclear power reactors.	57F

Proposition Code

5-7.4 Control of Working Fluids and Coolants

- | | | |
|----|--|-----|
| a. | Containment vessels will not permit fluid radioactive materials to leak from shielded spacecraft nuclear power reactor compartments into crew areas. | 57D |
| b. | No crew member will be injured by exposure to chemicals during his orbital stay. | 32B |
| c. | No crew member will be incapacitated by exposure to any corrosive chemical. | 76I |

5-7.5 Dosage Monitoring

- | | | |
|----|---|-----|
| a. | Any crew member with radiation injuries will be evacuated from any location subjected to further injurious radiation. | 72C |
|----|---|-----|

TABLE 5-8
STABILIZATION, PROPULSION, CONTROL AND ANCILLARY SYSTEMS

	<u>Proposition Code</u>
5-8.1 <u>Parent Spacecraft</u>	
5-8.1.1 Stability and Control	
a. No crew member will be injured by any form of relative motion during his orbital stay.	32C
b. There will be no immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft tumbling.	53D
c. There will be no immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft rotation.	53E
d. There will be no immediate danger of directly fatal collision of spacecraft equipment, not attached to the spacecraft, with crew members.	53C
e. There will be no immediate danger of directly fatal physiological stress from tumbling, rotation, or linear motion.	17E
f. The crew members available to perform tasks necessary to sustain life will not have been incapacitated by physiological effects of angular or linear acceleration.	75F
5-8.1.2 Alarm Systems and Alternate Controls	
a. Any immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft tumbling will be potentially correctable.	66D

Proposition Code

- | | |
|---|-----|
| b. Special remedial systems will protect all crew members from any immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft tumbling. | 64D |
| c. Any immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft rotation will be potentially correctable. | 66E |
| d. Special remedial systems will protect all crew members from any immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft rotation. | 64E |
| e. Any immediate danger of directly fatal physiological stress from tumbling, rotation, or linear motion will be potentially correctable. | 35E |
| f. Special remedial systems will protect all crew members from any immediate danger of directly fatal physiological stress due to tumbling, rotation, or linear motion. | 11E |
| g. Special remedial systems will protect all crew members from any immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft linear motion. | 64F |
| h. Any immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft linear motion will be potentially correctable. | 66F |

5-8.1.3 Prevention of Propellant Fire or Explosion

- | | |
|---|-----|
| a. There will be no immediate danger of directly fatal exposure of any crew member to heat. | 16D |
| b. No crew member will be injured by heat during his orbital stay. | 32D |

	<u>Proposition Code</u>
c. No crew member will be injured by any form of relative motion during his orbital stay.	32C
d. There will be no immediate danger of directly fatal collision of spacecraft equipment, not attached to the spacecraft, with crew members.	53C
e. Special remedial systems will protect all crew members from any immediate danger of directly fatal collision of flying debris with crew members.	13D
5-8.2 <u>Logistics Vehicles (Ferries, Escape Vehicles, and Space Tugs)</u>	
5-8.2.1 Basic Transportation Requirements for Safety Purposes	
a. Basic return systems will be capable of returning crew members to safe haven.	4E
b. The basic return vehicles will transport crew members to Earth haven.	80F
c. All necessary resources will be available to any crew member performing any human task necessary to sustain life.	18E
d. A normal system will be available to move any crew member, whose oxygen supply is not being maintained at his current location, to another location where he will be supplied with immediately necessary oxygen.	42G
e. Special remedial systems will protect all crew members from all directly fatal heat exposure not prevented by normal systems.	8D
f. Any crew member with burn injuries will be evacuated from any location subjected to extreme heat.	72B
g. All crew members will be removed, rapidly enough to prevent illness, from any location whose atmosphere is becoming contaminated with any material that prevents safe breathing by normal untrained people.	45E

Proposition Code

- h. The elapsed time of a return trip to Earth haven will not be long enough to prevent successful evacuation of any ill or injured crew member whose illness or injury is potentially curable. 79E
- i. No crew member will become physically ill during his orbital stay due to deprivation of food or water. 41C

5-8.2.2 Stability and Control

- a. There will be no immediate danger of directly fatal physiological stress from tumbling, rotation, or linear motion. 17E
- b. There will be no immediate danger of directly fatal collision of logistics vehicles with crew members during extra-vehicular activities. 54B, 63B
- c. The crew members available to perform tasks necessary to sustain life will not have been incapacitated by physiological effects of angular or linear acceleration. 75F
- d. The crew members available to perform tasks necessary to sustain life will not have been incapacitated by shock or injury from any form of collision. 75G

5-8.2.3 Maneuverability and docking capability

- a. No crew member will be injured by any form of relative motion during his orbital stay. 32C
- b. There will be no immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft linear motion. 53F

Proposition Code

- c. There will be no immediate danger of directly fatal collision of logistics vehicles with crew members during extra-vehicular activities.
- d. The crew members available to perform tasks necessary to sustain life will not have been incapacitated by shock or injury from any form of collision.

54B, 63B

75G

5-8.2.4 Alarm Systems and Alternate Controls

- a. Any immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft linear motion will be potentially correctable.
- b. Special remedial systems will protect all crew members from any immediate danger of directly fatal physiological stress due to tumbling, rotation, or linear motion.
- c. Special remedial systems will protect all crew members from any immediate danger of directly fatal collision of spacecraft equipment, not attached to the spacecraft, with crew members.
- d. Any immediate danger of directly fatal collisions of logistics vehicles with crew members during extra-vehicular activities will be potentially correctable.

66F

11E

64C

67B

5-8.3 Co-orbiting Modules

5-8.3.1 Stability and Control

- a. There will be no immediate danger of directly fatal collision of co-orbiting modules with crew members during extra-vehicular activities.

26F, 54E

Proposition Code

5-8.4 Extra-Vehicular Activities

5-8.4.1 Stability and Control

- a. No crew member will be injured by any form of relative motion during his orbital stay. 32C
- b. The crew members available to perform tasks necessary to sustain life will not have been incapacitated by shock or injury from any form of collision. 75G
- c. The crew members available to perform tasks necessary to sustain life will not have been incapacitated by physiological effects of angular or linear acceleration. 75F

5-8.4.2 Maneuverability and Operability

- a. Any immediate danger of directly fatal collision of the spacecraft proper with crew members due to spacecraft rotation will be potentially correctable. 66E
- b. Any equipment features whose manipulation is an extra-vehicular human task necessary to sustain life will be accessible and operable by a normal person. 46B

TABLE 5-9
SPACECRAFT STRUCTURE

	<u>Proposition Code</u>
5-9.1 <u>Shell, Wall, and Closure Integrity</u>	
a. No crew member will be injured by decompression during his orbital stay.	32F
b. The crew members available to perform tasks necessary to sustain life will not have been incapacitated by the effects of decompression.	75H
c. There will be no immediate danger of directly fatal exposure of any crew member to decompression.	16C
d. There will be no immediate danger of the rate of supply of breathable oxygen to any crew member decreasing below the rate necessary to sustain life.	15K
e. No crew member will be injured by solar radiation during his orbital stay.	36C
f. There will be no immediate danger of directly fatal collision of meteoroids with crew members.	52B
g. There will be no immediate danger of directly fatal collision of flying debris with crew members.	52D
h. Any supplies, materials for experiments, or spacecraft materials that constitute a poison that would be directly fatal if breathed will be contained or controlled in a manner that does not present any immediate danger to the life of any crew member.	61D
i. Any poison generated by accident or by any experimental, housekeeping, spacecraft operation, or logistics activity that would be directly fatal if breathed will be contained or controlled in a manner that does not present any immediate danger to the life of any crew member.	61E

Proposition Code

- j. The effectiveness of spacecraft nuclear power reactor shielding in preventing fatal crew member exposure will not be destroyed by structural damage. 57F

5-9.2 General Layout of Spacecraft

5-9.2.1 Relative Locations and Emergency Access Provisions

- a. The spacecraft structure will permit access by a normal person to any equipment in the spacecraft whose manipulation is necessary to provide vital supplies to any crew member. 48B
- b. Any opening, closing, removal, replacement, disassembly, or assembly operation in the spacecraft necessary to provide vital supplies to any crew member will be performable by normal people. 48F
- c. Any equipment item, materials, supplies, spare parts or tools whose manual transportation is necessary to provide vital supplies to any crew member will be transportable by normal people. 48E
- d. The locations and activities of crew members will make technically capable crew members available for performing any human task necessary to sustain life. 28C
- e. No crew member will be in immediate danger of directly fatal radiation exposure during repair, refurbishment, or refueling of spacecraft nuclear power reactors. 57F
- f. There will be a haven available to all crew members that is effectively shielded from any radiation from the sun that would be directly fatal to unshielded persons. 74B

Proposition Code

5-9.2.2 Compartmentalization and Emergency Havens

- | | |
|--|-----|
| a. Any immediate danger of any crew member being subjected to any directly fatal decompression will be potentially correctable. | 34C |
| b. Special remedial systems will protect all crew members from all directly fatal decompression not prevented by normal systems. | 8C |
| c. Any crew member injured by decompression will be removed from low pressure areas that cannot be pressurized. | 72I |
| d. Any immediate danger of any crew member being subjected to any directly fatal heat will be potentially correctable. | 34D |
| e. Special remedial systems will protect all crew members from all directly fatal heat exposure not prevented by normal systems. | 8D |
| f. Any crew member with burn injuries will be evacuated from any location subjected to extreme heat. | 72B |
| g. Any immediate danger of any crew member being subjected to directly fatal exposure to radiation from a nuclear power plant on the spacecraft will be potentially correctable. | 38D |
| h. There will be one or more havens in the spacecraft that are shielded from all potentially fatal solar radiation and capable of holding all crew members. | 40C |
| i. Any crew member with radiation injuries will be evacuated from any location subjected to further injurious radiation. | 72C |
| j. Any immediate danger of any crew member being subjected to directly fatal exposure to chemicals will be potentially correctable. | 34I |

Proposition Code

- | | | |
|----|---|-----|
| k. | Any crew member injured by breathing toxic chemicals will be removed from any toxic atmosphere that cannot be purged clean. | 73B |
| | | |
| l. | Systems produced and used for some other basic purpose will protect all crew members, not protected by normal or special remedial systems, from all immediate danger of directly fatal injury from external causes. | 51B |

5-9.2.3 Location of Havens and Escape Routes Relative to Hazards

- | | | |
|----|---|-----|
| a. | Any immediate danger of any crew member being subjected to any directly fatal decompression will be potentially correctable. | 34C |
| | | |
| b. | Any immediate danger of any crew member being subjected to any directly fatal heat will be potentially correctable. | 34D |
| | | |
| c. | Any immediate danger of any crew member being subjected to any directly fatal exposure to chemicals will be potentially correctable. | 34I |
| | | |
| d. | Any immediate danger of any crew member being subjected to directly fatal exposure to radiation from a nuclear power plant on the spacecraft will be potentially correctable. | 38D |

5-9.2.4 Meteoroid Protection

- | | | |
|----|---|-----|
| a. | Special remedial systems will protect all crew members from any immediate danger of directly fatal collision of meteoroids with crew members. | 13B |
|----|---|-----|

TABLE 5-10
MEDICAL FACILITIES

		<u>Proposition Code</u>
5-10.1	<u>Types of Medical Facilities Required</u>	
a.	There will be adequate medical facilities in the spacecraft to treat any potentially fatal illness contracted by any crew member during his orbital stay.	22D
b.	There will be adequate medical facilities in the spacecraft to treat any potentially fatal infection of any crew member.	70H
c.	Special remedial systems will alleviate any critical illness due to infection.	71B
d.	There will be adequate medical facilities to treat any potentially fatal decompression injury sustained by any crew member during his orbital stay.	24C
e.	There will be adequate medical facilities to treat any potentially fatal injury from exposure to heat sustained by any crew member during his orbital stay.	24D
f.	There will be adequate medical facilities to treat any potentially fatal radiation injury sustained by any crew member during his orbital stay.	24E
g.	There will be adequate medical facilities to treat any potentially fatal injury from electrical shock sustained by any crew member during his orbital stay.	24F
h.	There will be adequate medical facilities to treat any potentially fatal injury from exposure to chemicals sustained by any crew member during his orbital stay.	24G

Proposition Code

- | | |
|--|-----|
| i. There will be adequate medical facilities to treat any potentially fatal concussion sustained by any crew member during his orbital stay. | 25B |
| j. There will be adequate medical facilities to treat any potentially fatal puncture wound sustained by any crew member during his orbital stay. | 25C |
| k. There will be adequate medical facilities to treat any potentially fatal lacerations or incisions sustained by any crew member during his orbital stay. | 25E |
| l. There will be adequate medical facilities to treat any potentially fatal injury to internal organs by collision or acceleration. | 25G |
| m. Any injurious corrosive chemicals or contact poison on the skin of crew members will be washed off or neutralized. | 73D |
| n. Any crew member who is ill at the end of his orbital stay due to deprivation of vital supplies will be curable. | 68I |
| o. There will be adequate medical facilities to treat any potentially fatal abrasions sustained by any crew member during his orbital stay. | 25F |

5-10.2 Medical Equipment Reliability and Spares Availability

- | | |
|--|-----|
| a. There will be no malfunction of spacecraft medical equipment that will prevent its effective performance of any function necessary to prevent any potentially fatal illness from becoming critical. | 22E |
| b. There will be no malfunction of spacecraft medical equipment that will prevent its effective performance of functions necessary to treat critical infections. | 70I |

Proposition Code

- c. There will be no malfunction of spacecraft medical equipment that will prevent its effective performance of any function necessary to keep any potentially fatal injury from becoming critical. 23E
- d. There will be no malfunction of spacecraft medical equipment that will prevent its effective performance of functions necessary to treat critical injuries. 69I, 71G
- e. There will be no immediate danger of directly fatal electrical shock from housekeeping, medical or recreational equipment. 62I

5-10.3 Control of Medical Supplies

- a. There will be no immediate danger of any crew member having any deadly poison injected or implanted in his body. 59E
- b. There will be no immediate danger of any crew member swallowing any poisonous chemical that would be directly fatal. 59B
- c. Any supplies, materials for experiments, or spacecraft materials that constitute a deadly contact poison will be kept contained and controlled in a manner that does not present any immediate danger to the life of any crew member. 60D
- d. Any crew member incapacitation from chemicals will occur at a time that will not prevent his performing any task necessary to sustain life. 76D
- e. No crew member will be incapacitated by exposure to any chemical narcotic. 76E
- f. No crew member will be incapacitated by exposure to any chemical stimulant. 76F
- g. No crew member will be incapacitated by exposure to any chemical sedative. 76G

	<u>Proposition Code</u>
h. No crew member will be incapacitated by exposure to any chemical hypnotic.	76H
i. No crew member will be incapacitated by exposure to any corrosive chemical.	76I
j. No crew member will be incapacitated by exposure to any noxious chemical.	76J
5-10.4 <u>Diagnostic Capability</u>	
a. There will be adequate medical facilities in the spacecraft to treat any potentially fatal infectious illness contracted by any crew member during his orbital stay.	22D
b. There will be adequate medical facilities in the spacecraft to treat any potentially fatal radiation injury sustained by any crew member during his orbital stay.	24E
c. There will be adequate medical facilities to treat any potentially fatal concussion sustained by any crew member during his orbital stay.	25B
d. There will be adequate medical facilities to treat any potentially fatal fracture sustained by any crew member during his orbital stay.	25D
e. There will be adequate medical facilities to treat any potentially fatal injury to internal organs caused by collision or acceleration.	25G
f. Treatment of any crew member with any potentially fatal infection will prevent his condition from becoming critical.	70E
g. Any crew member injured by eating or drinking toxic or corrosive materials will be protected from ingesting additional poisonous materials.	73C

D2-113070-9

Proposition Code

- h. Any crew member injured by breathing toxic chemicals will be removed from any toxic atmosphere that cannot be purged clean.

73B

TABLE 5-11
LIFE SUPPORT AND HEALTH

	<u>Proposition Code</u>
a. The environment of any crew member will not prevent sufficient elimination of body wastes to sustain life by any normal untrained person.	30E
b. Any injurious corrosive chemicals or contact poison on the skin of crew members will be washed off or neutralized.	73D
c. No crew member will contract any infectious illness during his orbital stay.	21D
d. No crew member will become physically ill during his orbital stay due to an infection.	31G, 70G
e. Edible food and potable water will be accessible to all crew members under conditions that permit eating and drinking by normal untrained people sufficiently to sustain life.	30D
f. No crew member will become physically ill during his orbital stay due to deprivation of food or water.	41C
g. Any atmospheric gas, in crew locations that are being contaminated with any material that prevents its safe breathing, will be removed or diluted at a rate that enables continued breathing by normal untrained people without illness.	45B
h. No crew member will be incapacitated by exposure to any noxious chemical.	76K
i. All necessary resources will be available to any crew member performing any human task necessary to sustain life.	18E
j. Any equipment in the spacecraft whose manipulation is necessary to prevent any directly fatal illness, other than that caused by injury or deprivation, will be accessible and operable by normal people.	47F

	<u>Proposition Code</u>
k. The crew members available to perform tasks necessary to sustain life will not have been incapacitated by deprivation of vital supplies.	27B
l. No human task necessary to sustain life will be beyond the physical capability of normal people.	27E
m. The environment of any crew member will not prevent sufficient sleep to sustain life by any normal untrained person.	30F
n. The crew members available to perform tasks necessary to sustain life will not have been incapacitated by the effects of heat.	75B
o. The crew members available to perform tasks necessary to sustain life will not have been incapacitated by electrical shock.	75E
p. No crew member will be incapacitated by exposure to any form of radiation other than heat or light.	78F

TABLE 5-12
INJURY AND DAMAGE PREVENTION OR RESTORATION

	<u>Proposition Code</u>
a. Special remedial systems will protect all crew members from all directly fatal decompression not prevented by normal systems.	8C
b. Special remedial systems will protect all crew members from all directly fatal heat exposure not prevented by normal systems.	8D
c. Special remedial systems will protect all crew members from all directly fatal exposure to chemicals not prevented by normal systems.	8H
d. Any supplies, materials for experiments, or spacecraft materials that constitute a poison that would be directly fatal if breathed will be contained or controlled in a manner that does not present any immediate danger to the life of any crew member.	61D
e. Any poison generated by accident or by any experimental, housekeeping, spacecraft operation, or logistics activity that would be directly fatal if breathed will be contained or controlled in a manner that does not present any immediate danger to the life of any crew member.	61E
f. Special remedial systems will protect all crew members from all directly fatal electrical shock not prevented by normal systems.	8G
g. All necessary resources will be available to any crew member performing any human task necessary to sustain life.	18E
h. There will be at least one crew member technically capable of performing any intervehicular human task necessary to sustain life.	28F

	<u>Proposition Code</u>
i. There will be at least one crew member technically capable of performing any extra-vehicular human task necessary to sustain life.	28G
j. Any crew member injured by decompression will be removed from low-pressure areas that cannot be pressurized.	72I
k. Any crew member injured by breathing toxic chemicals will be removed from any toxic atmosphere that cannot be purged clear.	73B
l. Any crew member with burn injuries will be evacuated from any location subjected to extreme heat.	72B
m. Any crew member injured by collision of any kind will be protected from further collision injury.	72J
n. Any equipment in the spacecraft whose manipulation is a non-routine task necessary to protect crew members from directly fatal physical injury from external causes will be accessible and operable by normal people.	47E
o. Any equipment in the spacecraft whose manipulation is necessary to enable return of any crew member to a haven will be accessible and operable by normal people.	47C
p. The spacecraft structure will permit access by a normal person to any equipment in the spacecraft whose manipulation is necessary to provide vital supplies to any crew member.	48B
q. Any opening, closing, removal, replacement, disassembly, or assembly operation in the spacecraft necessary to provide vital supplies to any crew member will be performable by normal people.	48F

Proposition Code

- r. Any equipment item, materials, supplies, spare parts or tools whose manual transportation is necessary to provide vital supplies to any crew member will be transportable by normal people. 48E
- s. Special remedial systems will protect all crew members from all directly fatal electrical shock not prevented by normal systems. 8G
- t. Special remedial systems will protect all crew members from any immediate danger of directly fatal collision between one crew member and another. 13F

TABLE 5-13
WARNING SYSTEMS

	<u>Proposition Code</u>
a. Special remedial systems will protect all crew members from all directly fatal exposure to chemicals not prevented by normal systems.	8H
b. There will be no immediate danger of the rate of supply of breathable oxygen to any crew member decreasing below the rate necessary to sustain life.	15K
c. Special remedial systems will protect all crew members from all directly fatal radiation exposure not prevented by normal systems.	8E
d. Special remedial systems will protect all crew members from all directly fatal heat exposure not prevented by normal systems.	8D
e. Special remedial systems will protect all crew members from all directly fatal decompression not prevented by normal systems.	8C
f. Special remedial systems will protect all crew members from any immediate danger of directly fatal physiological stress from tumbling, rotation, or linear motion.	11E
g. There will be sufficient time for available crew members to accomplish any human task necessary to sustain life.	18D
h. Any immediate danger of any crew member being subjected to directly fatal exposure to radiation from a nuclear power plant on the spacecraft will be potentially correctable.	38D
i. Any immediate danger of any crew member being subjected to directly fatal electrical shock will be potentially correctable.	34H

Proposition Code

- j. A solar radiation warning system will not fail to provide signals, recognizable by each crew member as instruction to seek protection, in time for all crew members to go to a shielded haven in the spacecraft before solar radiation becomes of fatal type and intensity. 40B, 74D
- k. Any visual indicators on equipment in the spacecraft whose recognition is essential to properly perform operations necessary to provide vital supplies to any crew member will be clearly visible to persons with normal sight. 48H
- l. Any auditory signals from equipment in the spacecraft whose recognition is essential to properly perform operations necessary to provide vital supplies to any crew member will be clearly audible to persons with normal hearing. 48I
- m. The locations and activities of crew members will make technically capable crew members available for performing any human task necessary to sustain life. 28C
- n. All crew members will be removed, rapidly enough to prevent illness, from any location whose atmosphere is becoming contaminated with any material that prevents safe breathing by normal untrained people. 45E
- o. Special remedial systems will protect all crew members from all directly fatal overpressure not prevented by normal systems. 8F
- p. Special remedial systems will protect all crew members from all directly fatal electrical shock not prevented by normal systems. 8G

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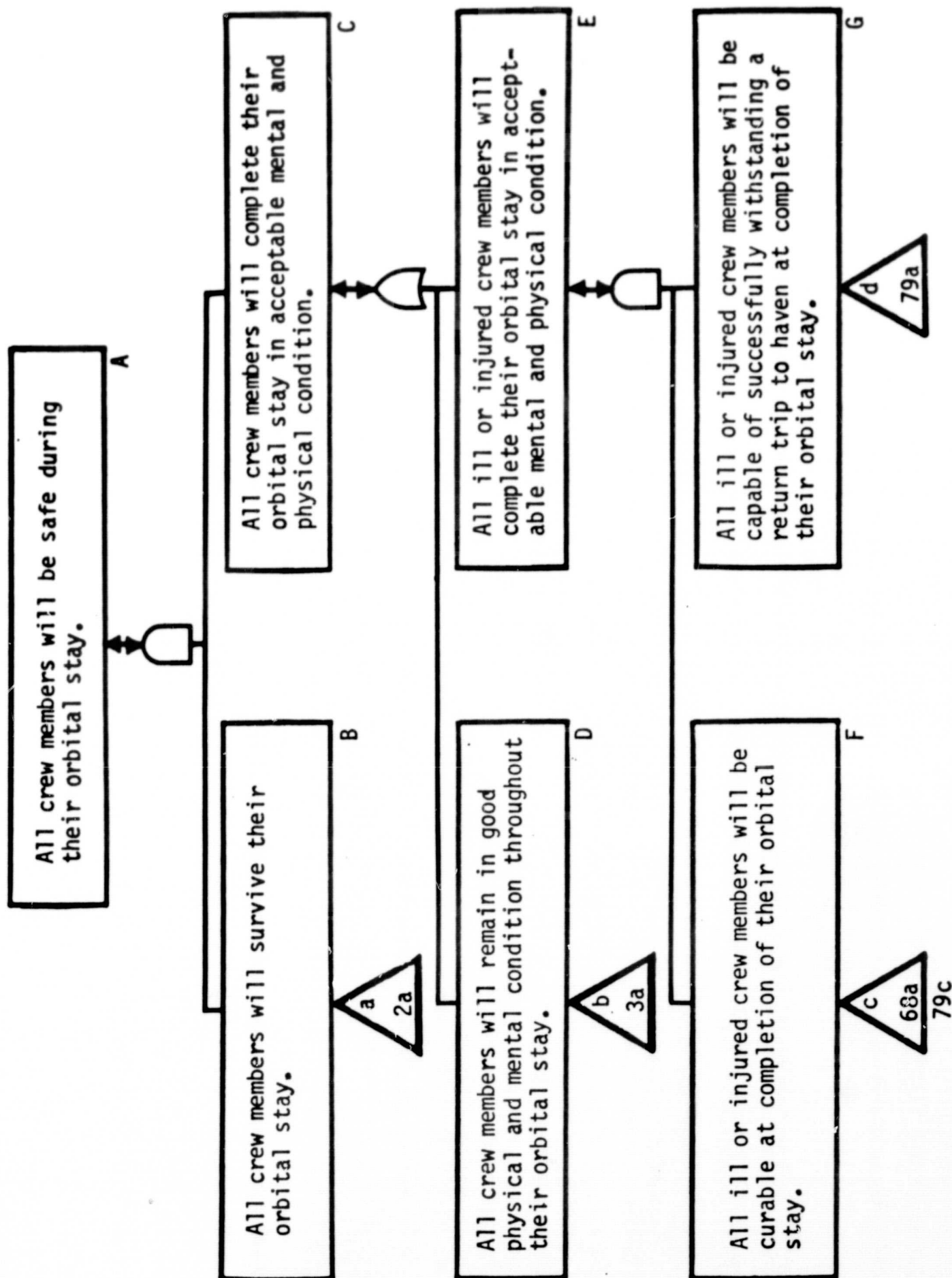
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6.0 LOGIC DIAGRAM

6.1 The following charts comprise the Space Station Safety Study Logic Diagram. They are arranged where possible in essentially descending "levels," starting with the top level, or "origin proposition," on Chart No. 1. For an abstract description of the logical "tree" concept, which starts from an origin and descends from "predecessor" to "successor," the reader is referred to Appendix I, Section I-5.0.

6.2 There is no pretense on the part of the study team that the Logic Diagram as presented here is complete, even for the defined scope of the study; indeed, from the practical standpoint such a chart can never be complete because of the geometrically increasing amount of detail that would be involved at the lower levels of definition. This fact is implied by the summary of "open" propositions given previously in Section 5.0, many of which perhaps could be developed as extensively as the diagram reproduced on the following pages. However, it is felt that the diagram is fairly comprehensive as it stands, and that any aspect of space station safety could be rationally derived from the foundation that is provided here, should there be a desire to apply the necessary effort.

6.3 Ideally, a logic diagram should be drawn on a single sheet of paper. Since this is not possible, pains were taken during the development to segregate its branches in such a way that reproduction on normal document pages could be done without the need for foldouts.



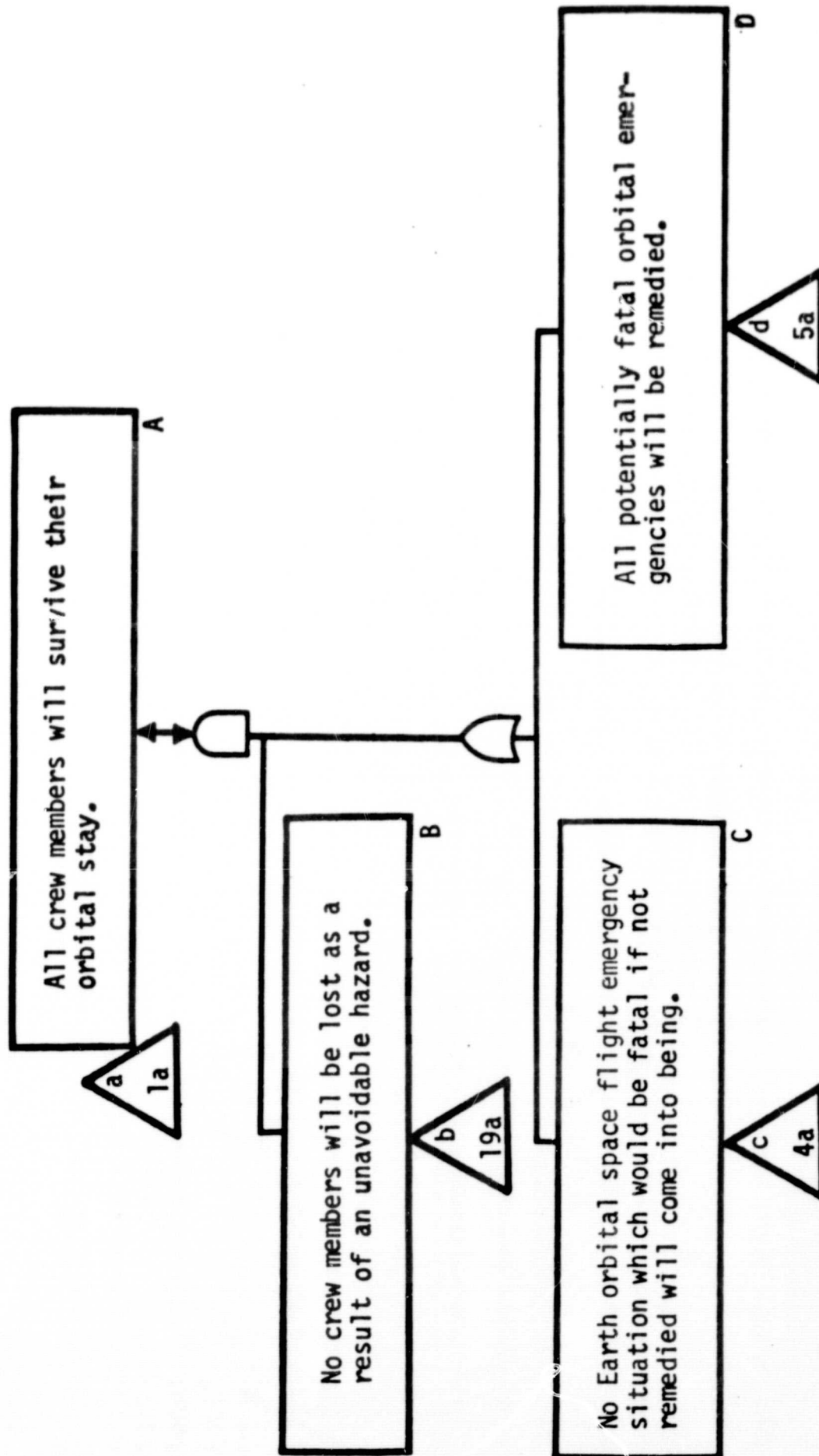
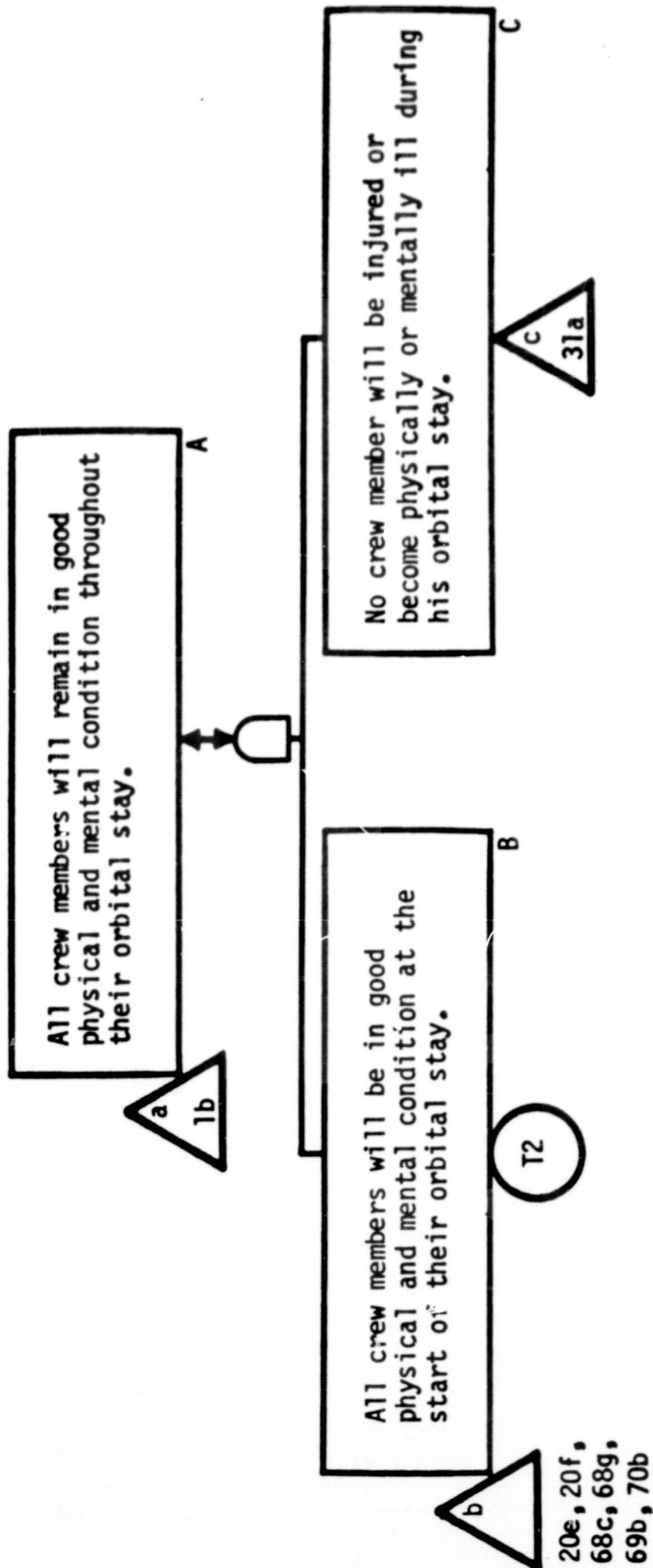


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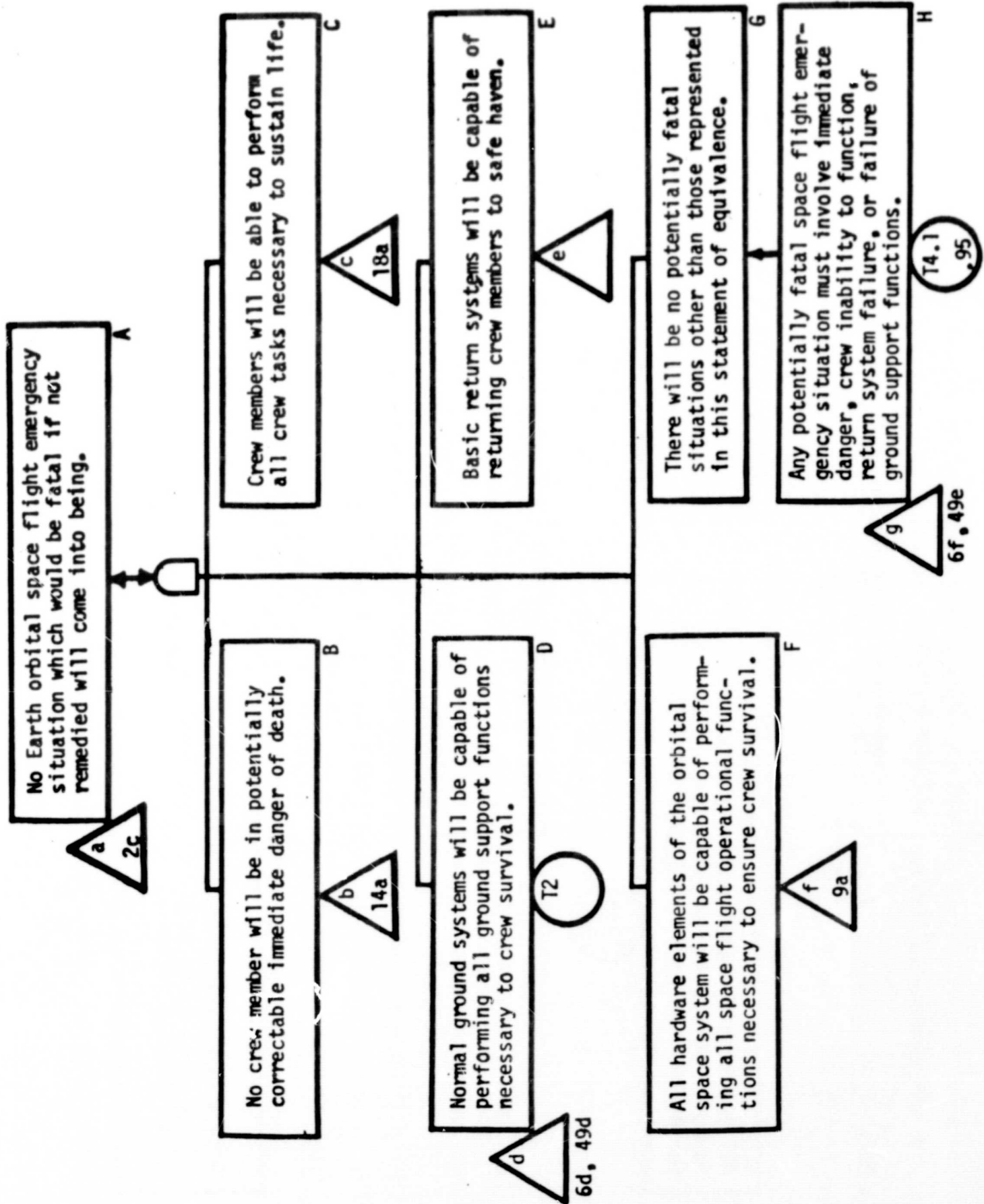
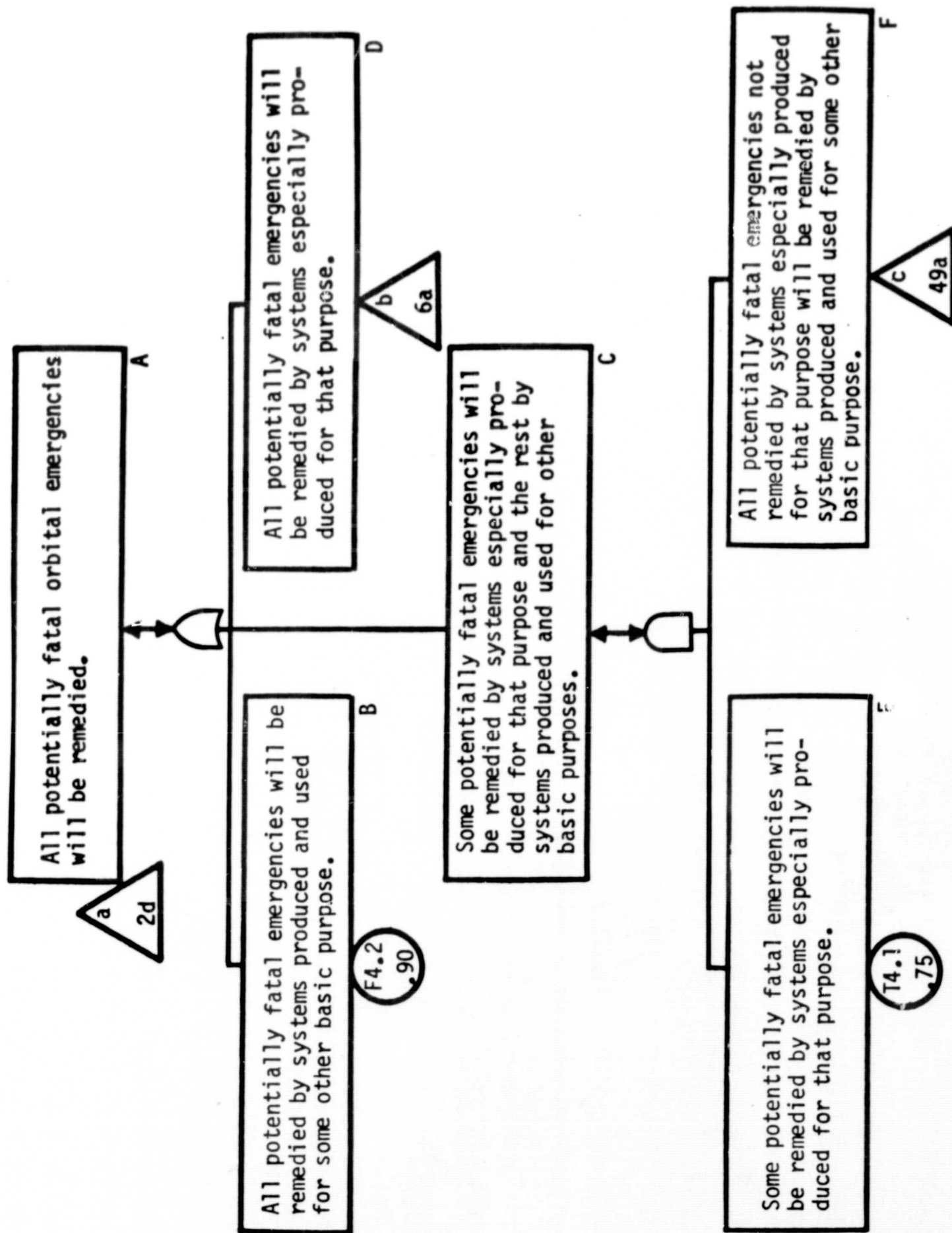


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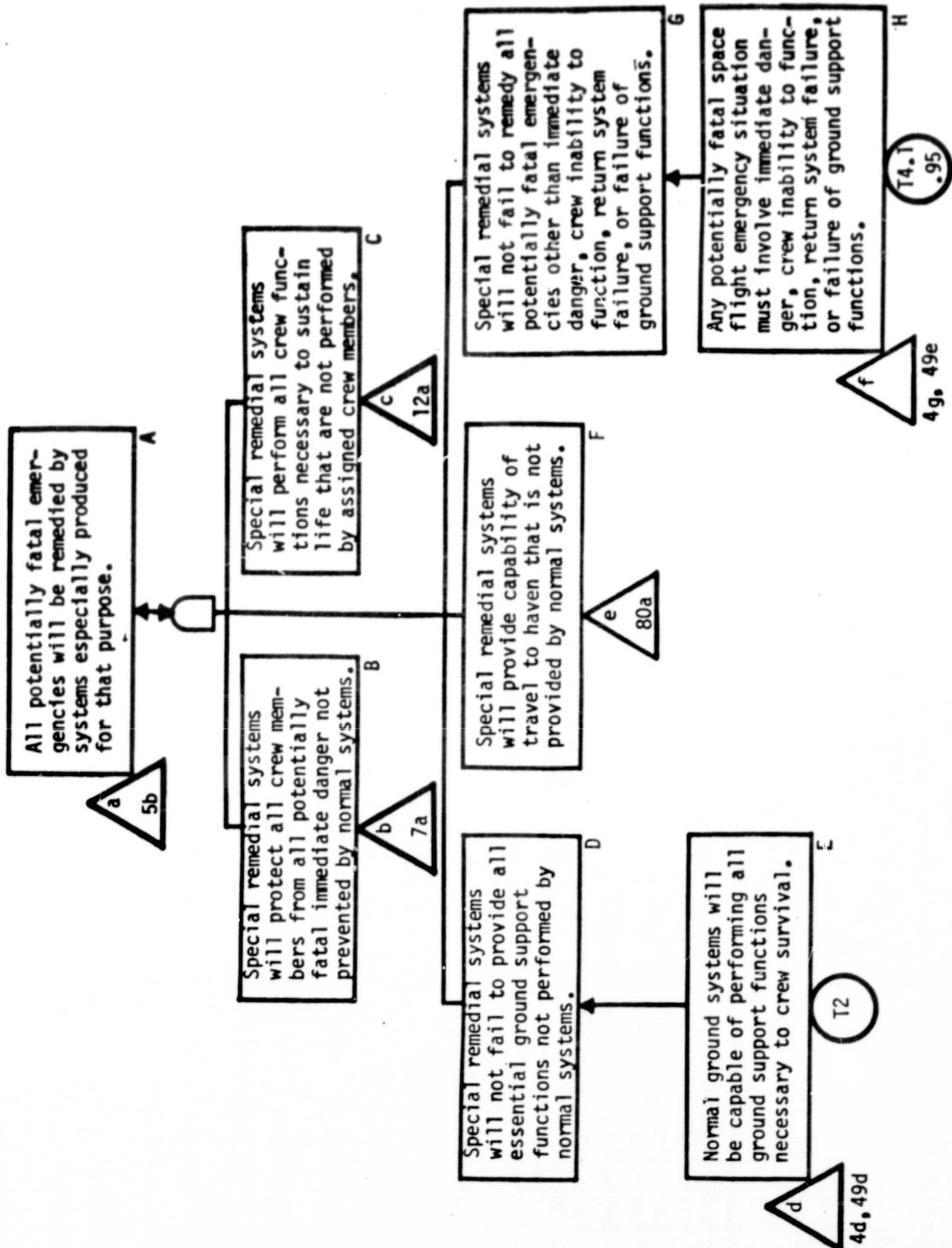
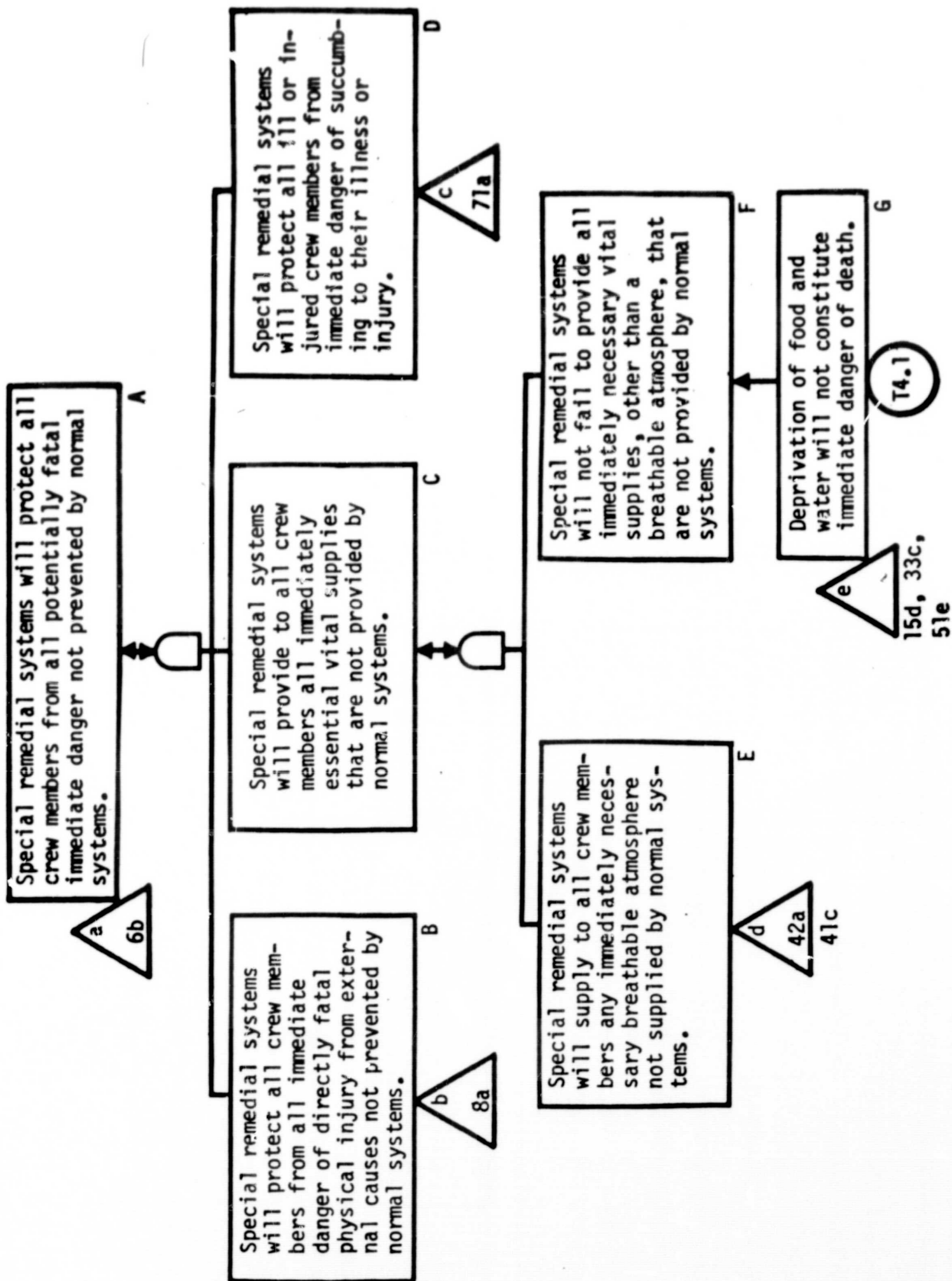


Chart No. 6

Chart No. 7



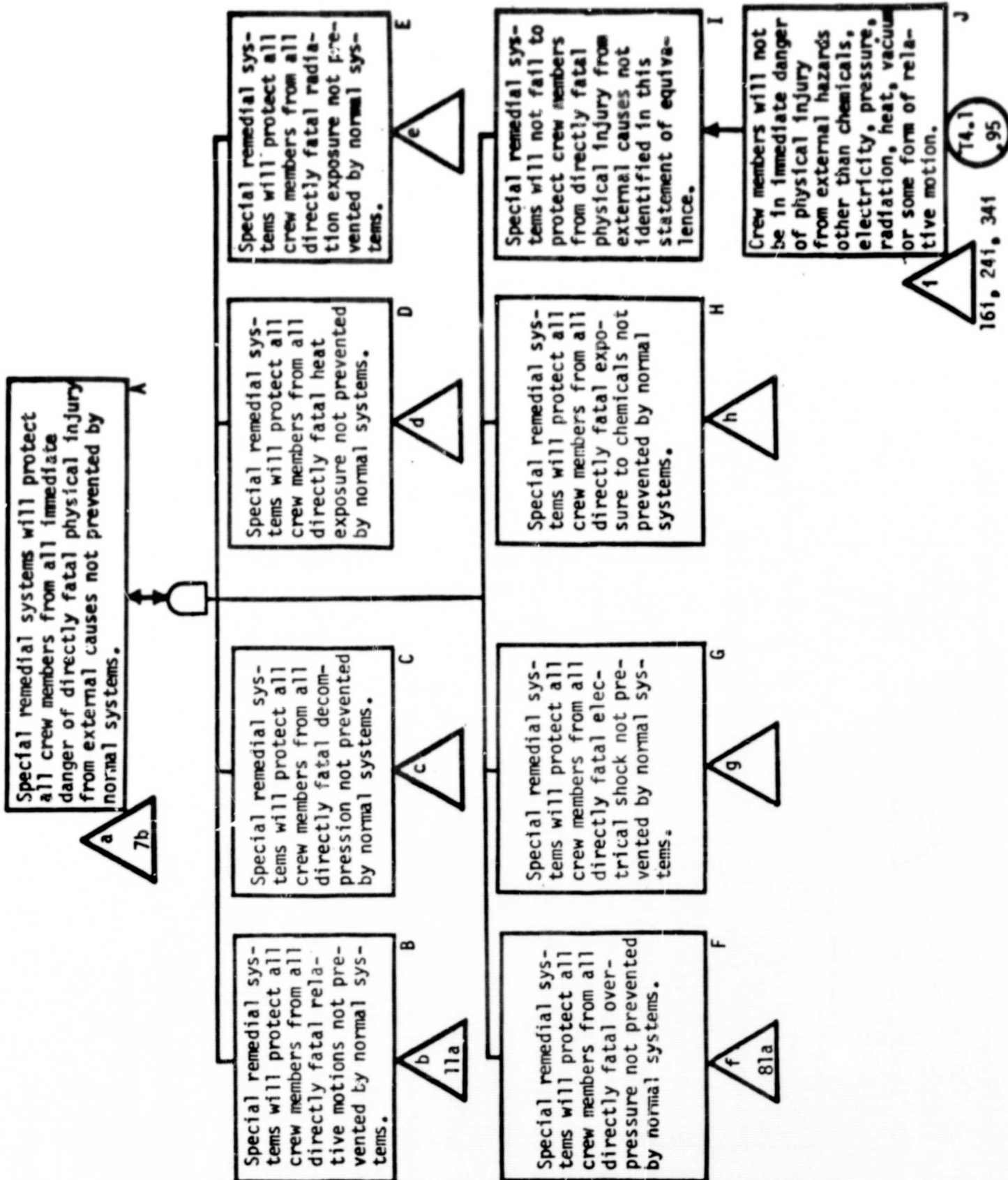
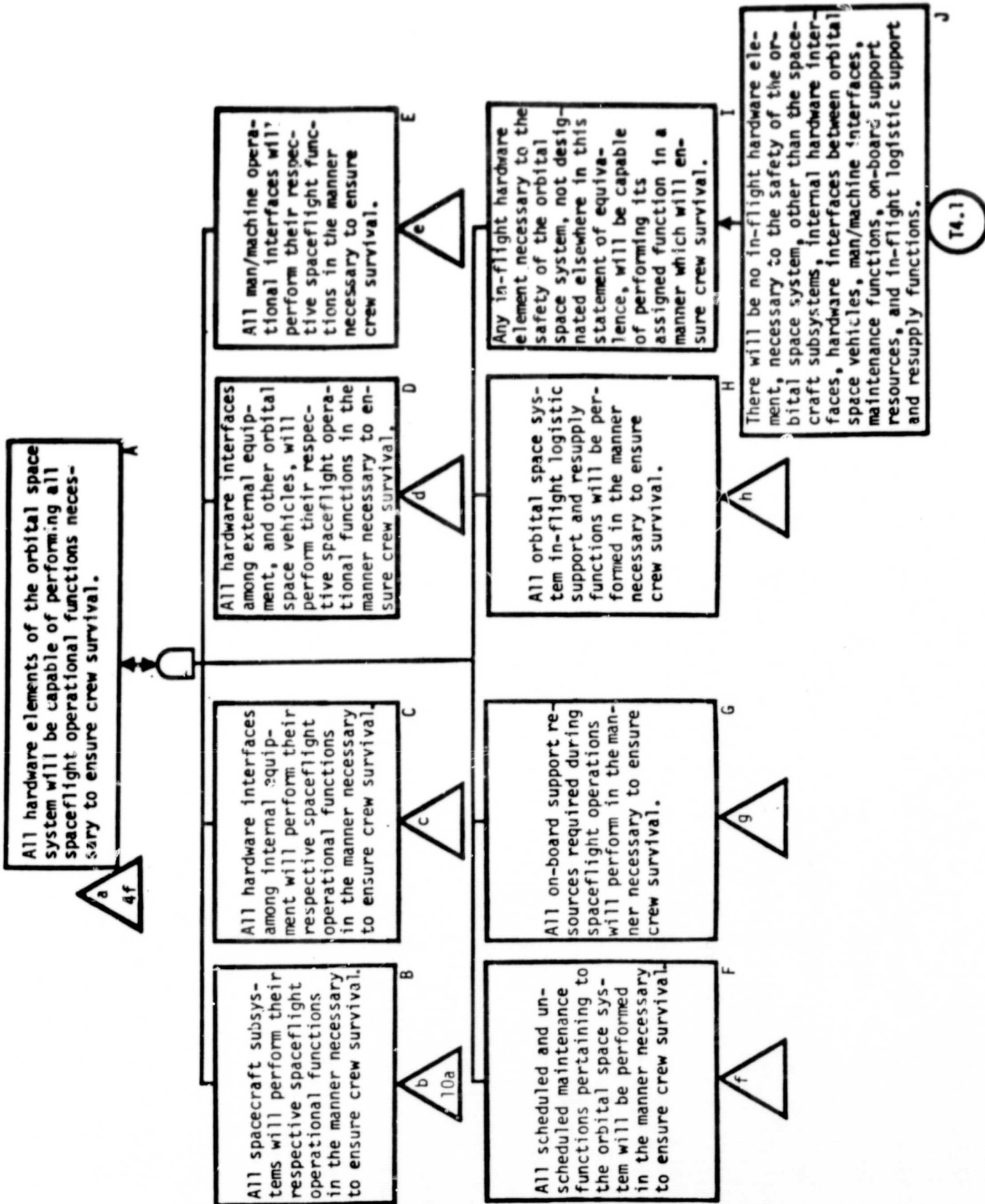


Chart No. 8

Chart No. 9



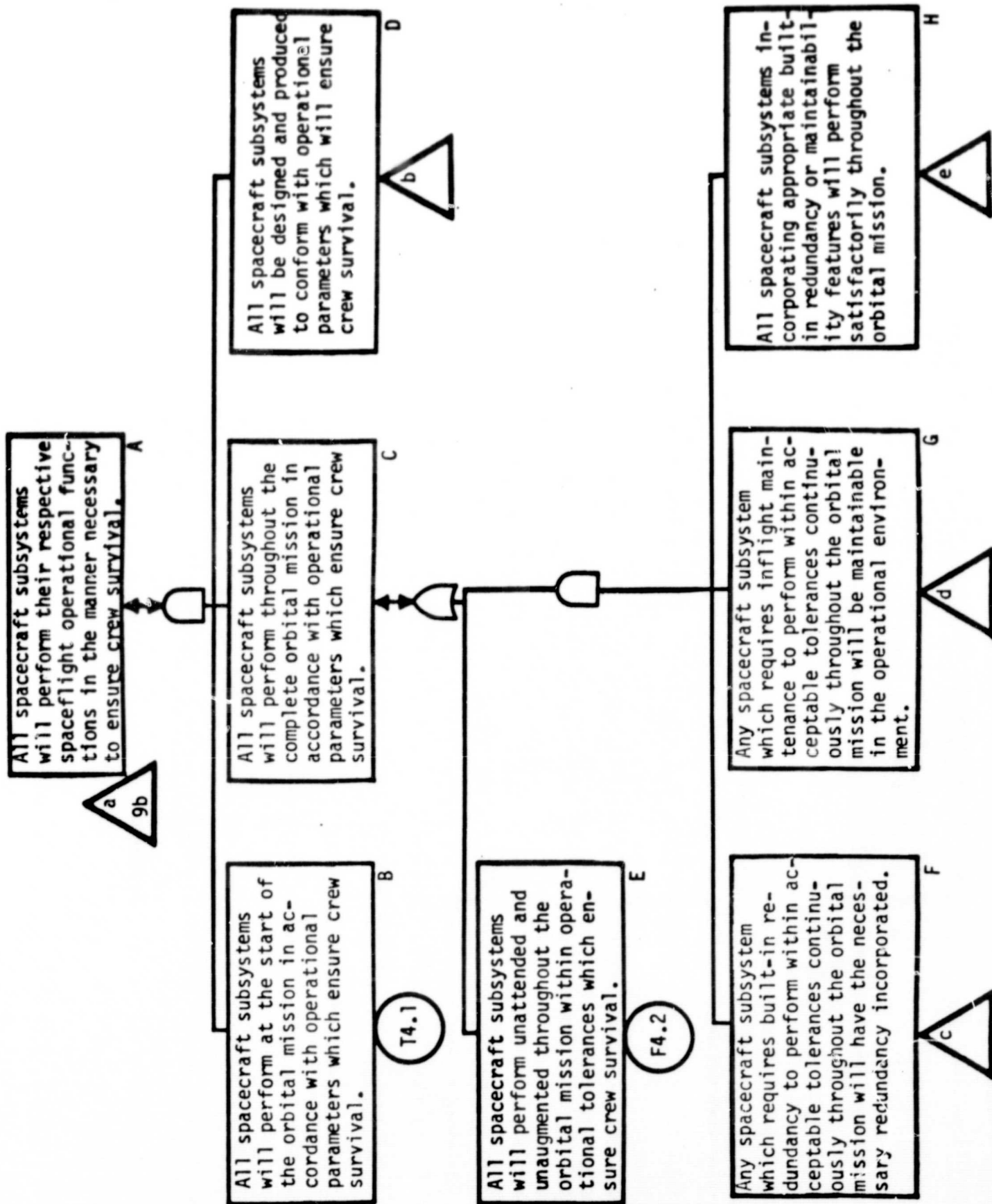
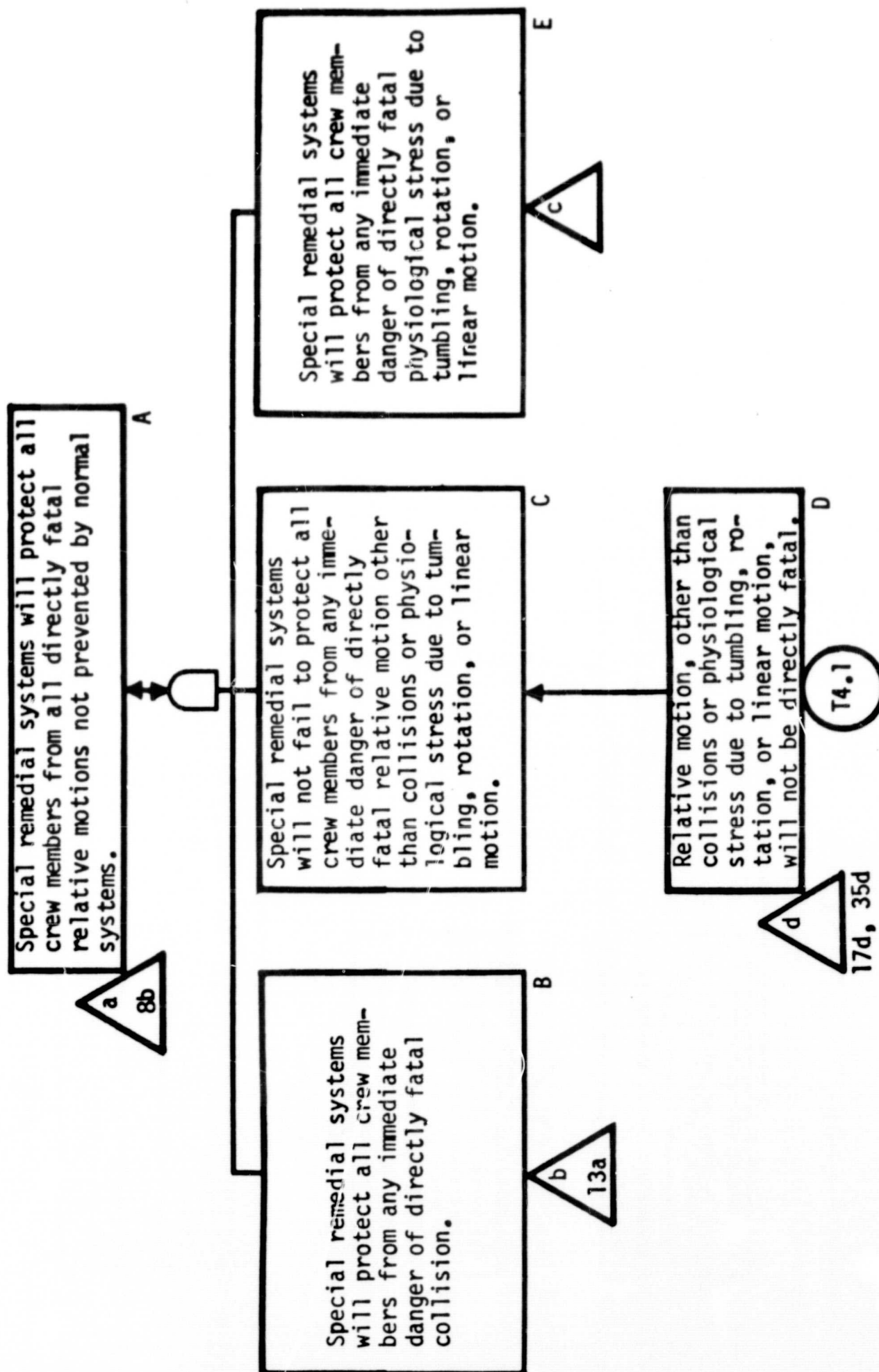
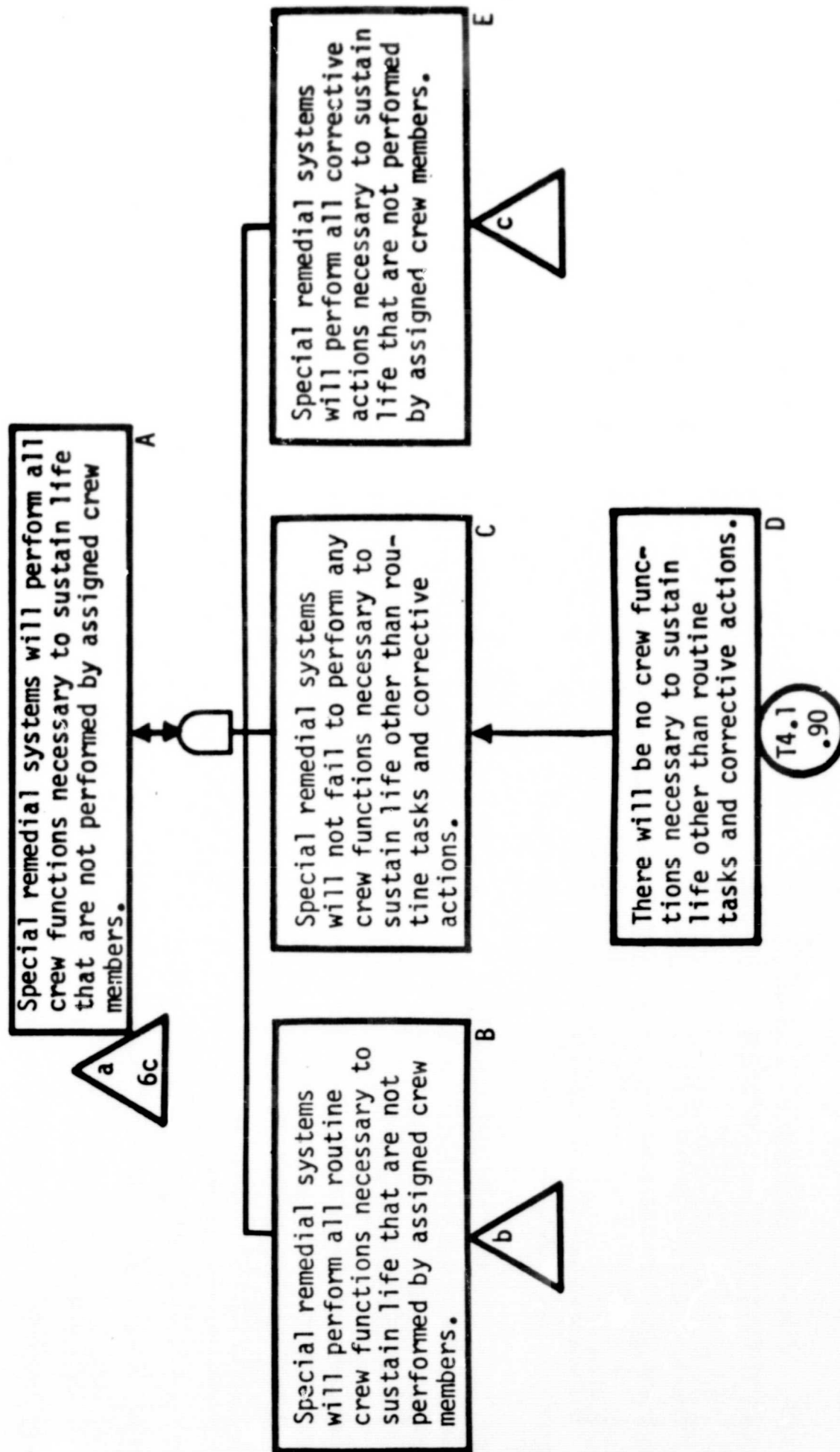


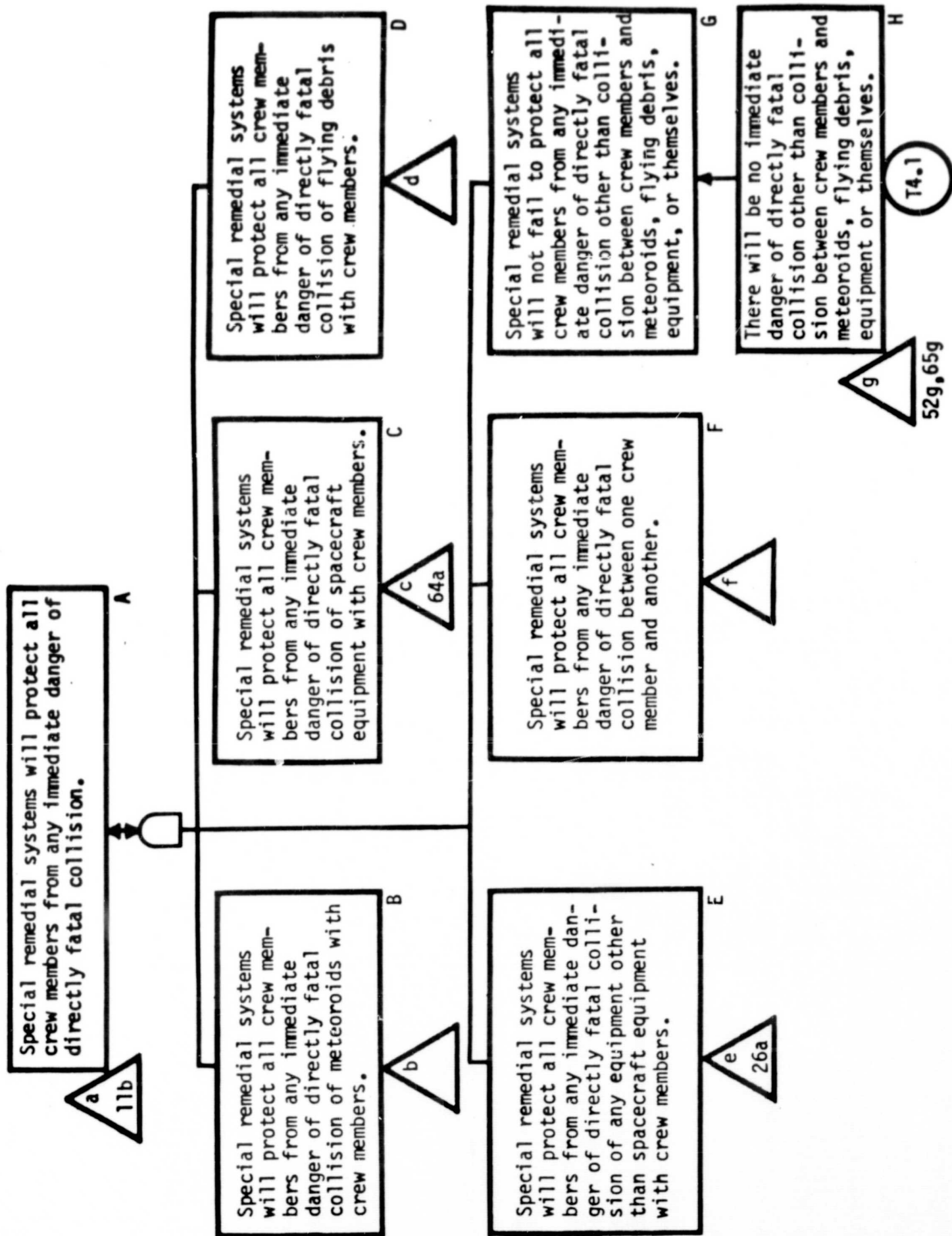
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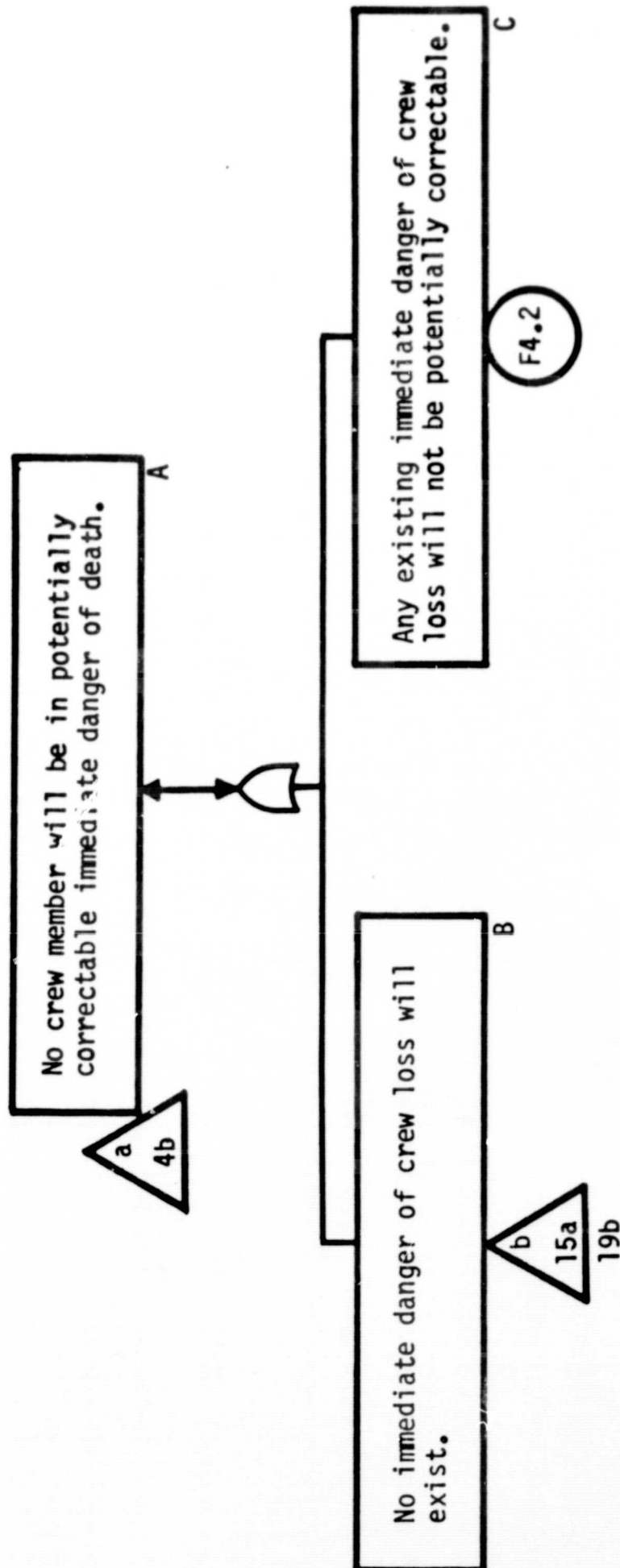
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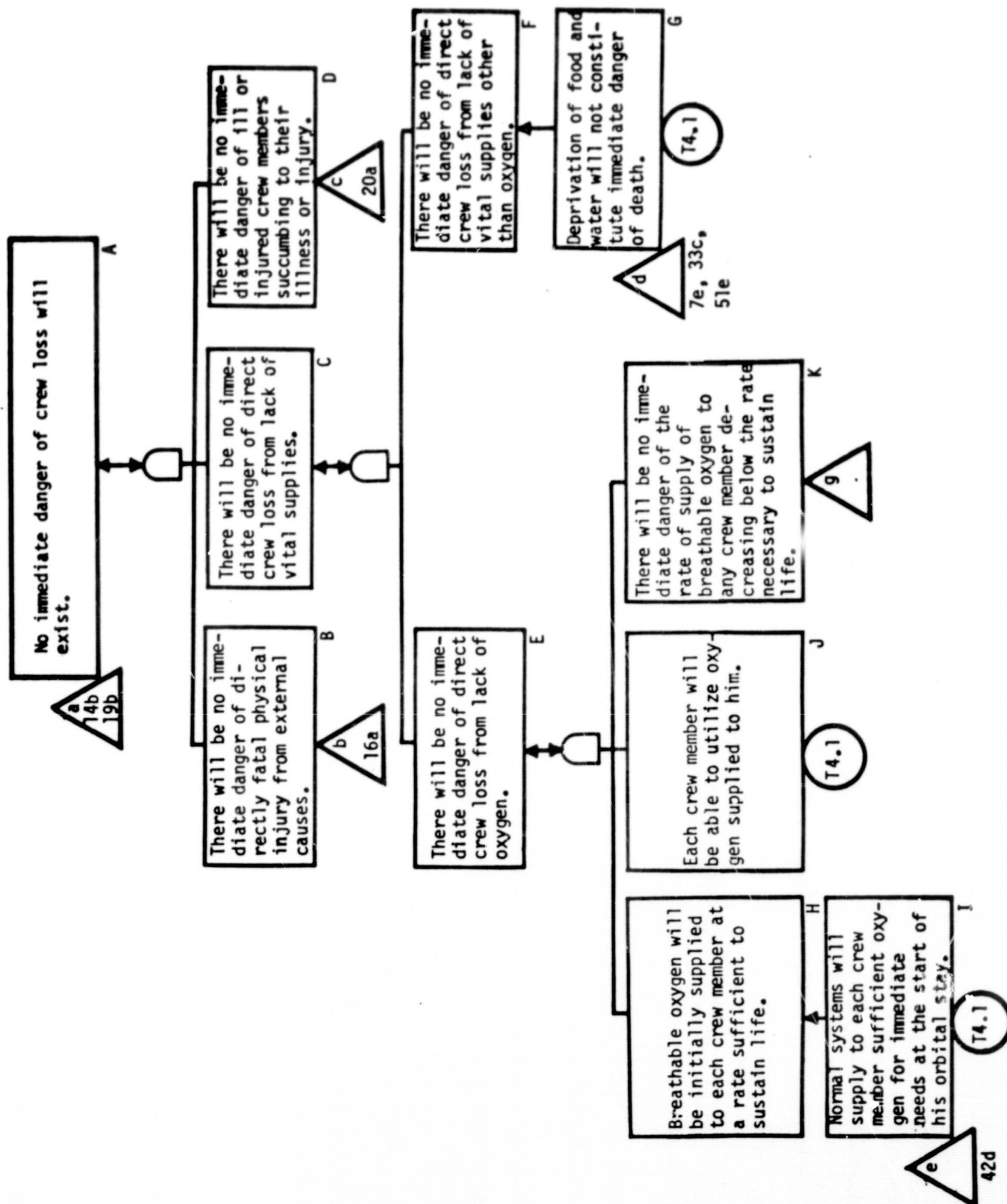
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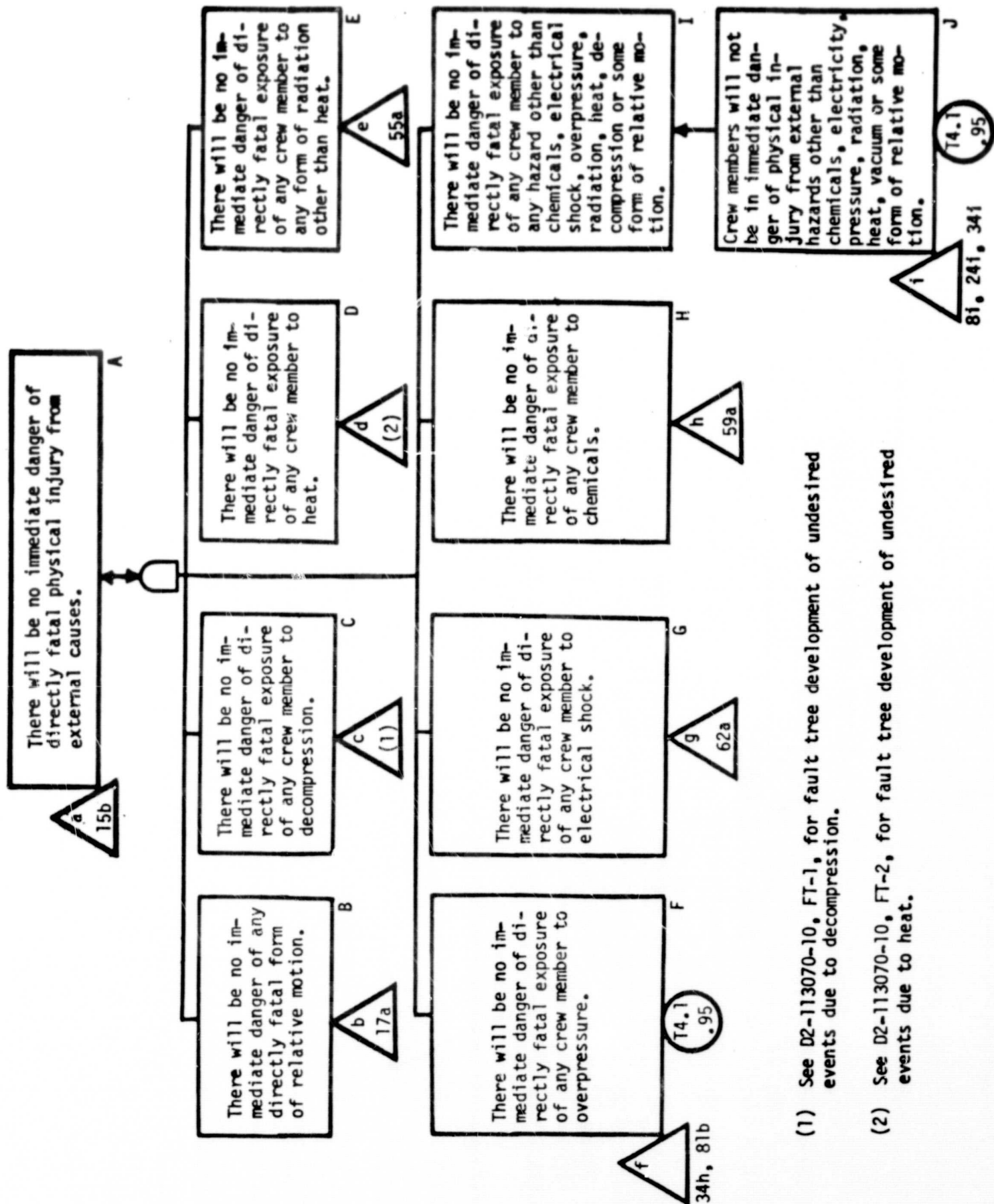






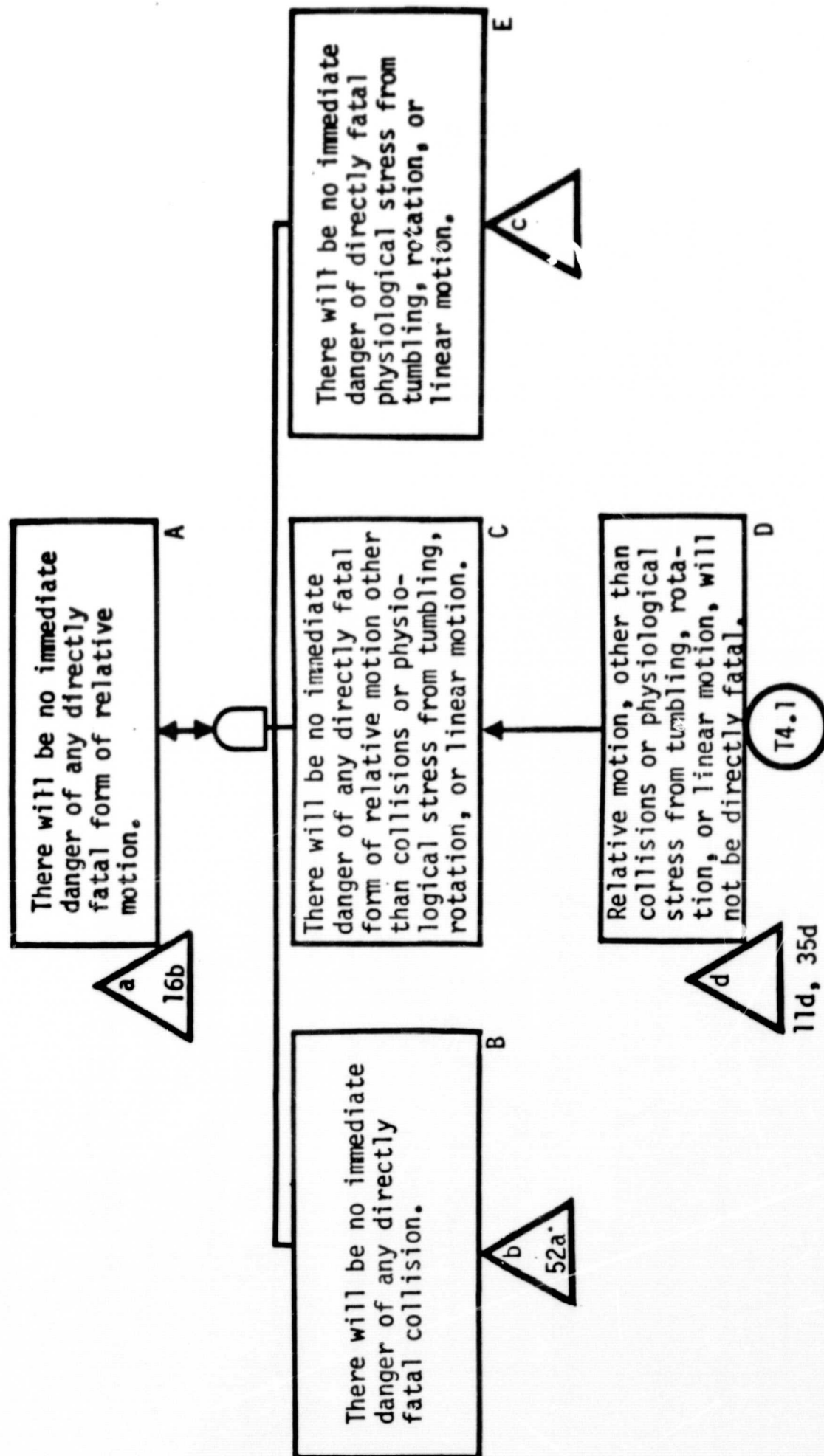






(1) See D2-113070-10, FT-1, for fault tree development of undesired events due to decompression.

(2) See D2-113070-10, FT-2, for fault tree development of undesired events due to heat.



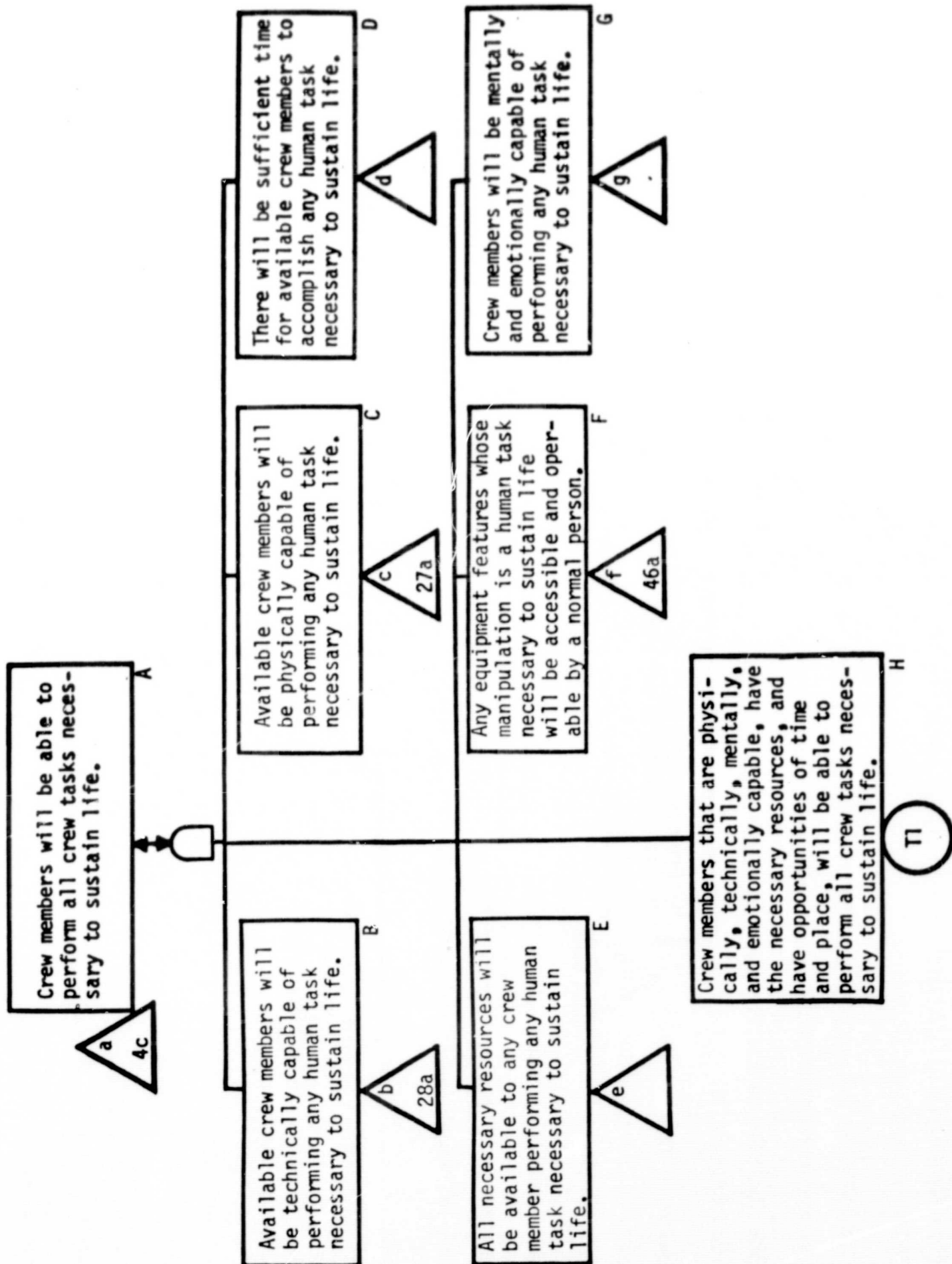
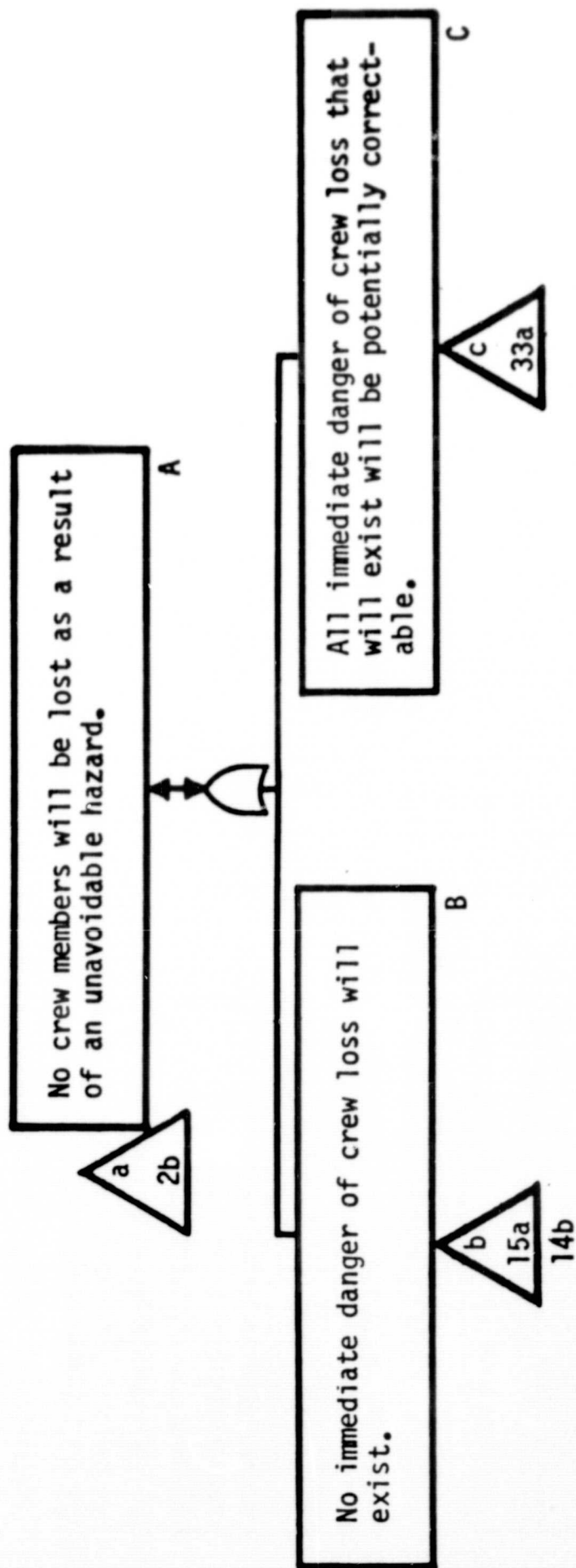


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Chart No. 19



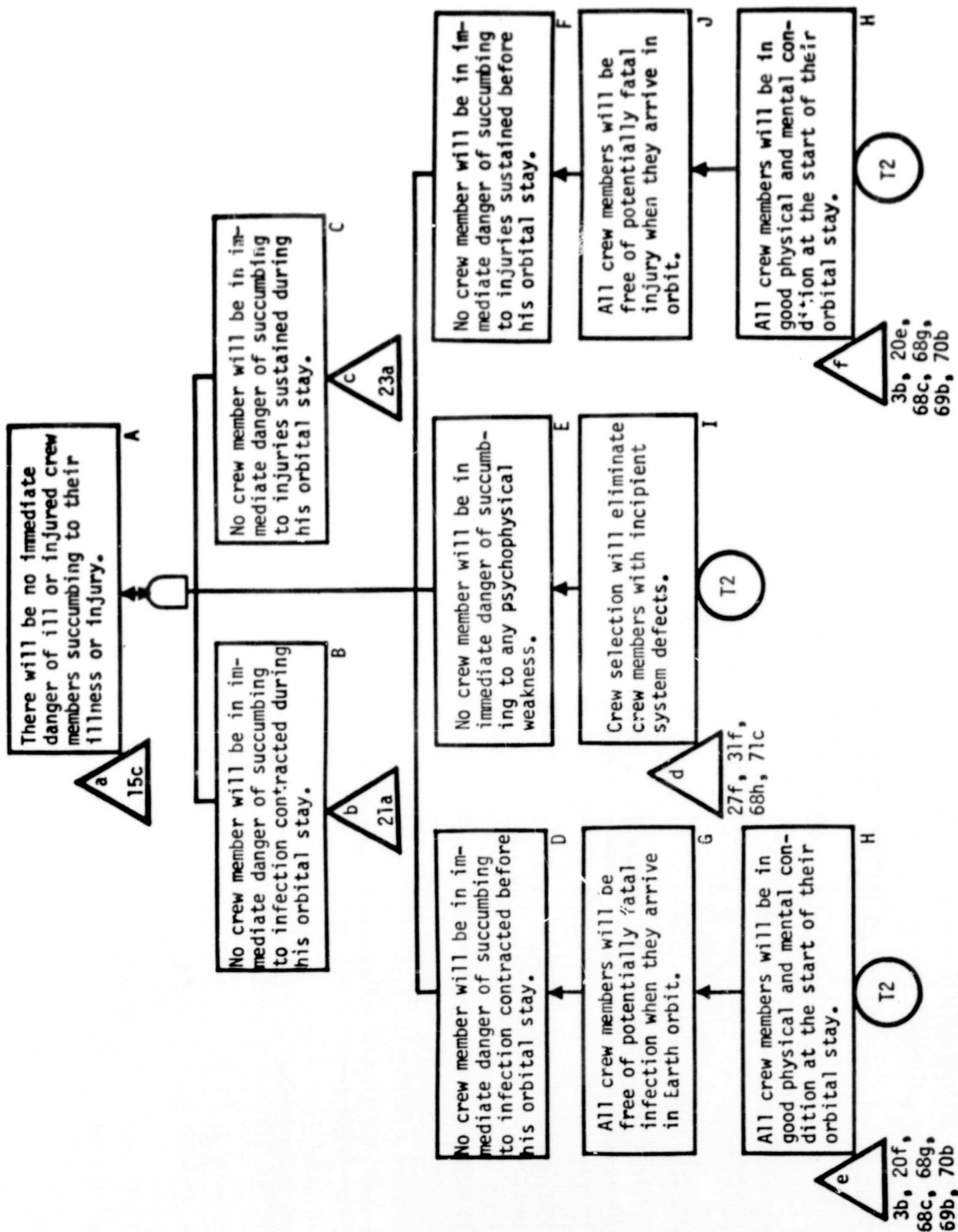
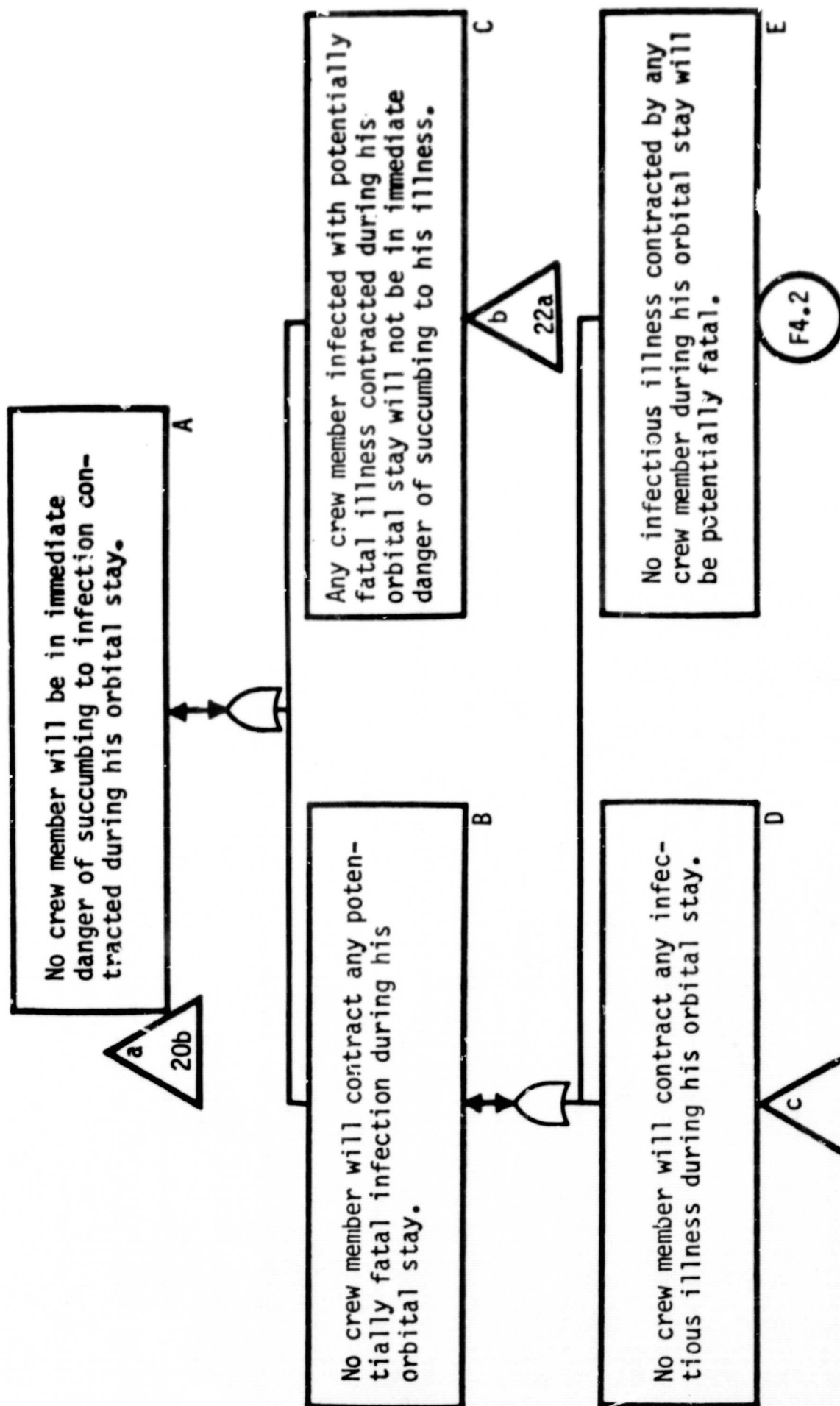


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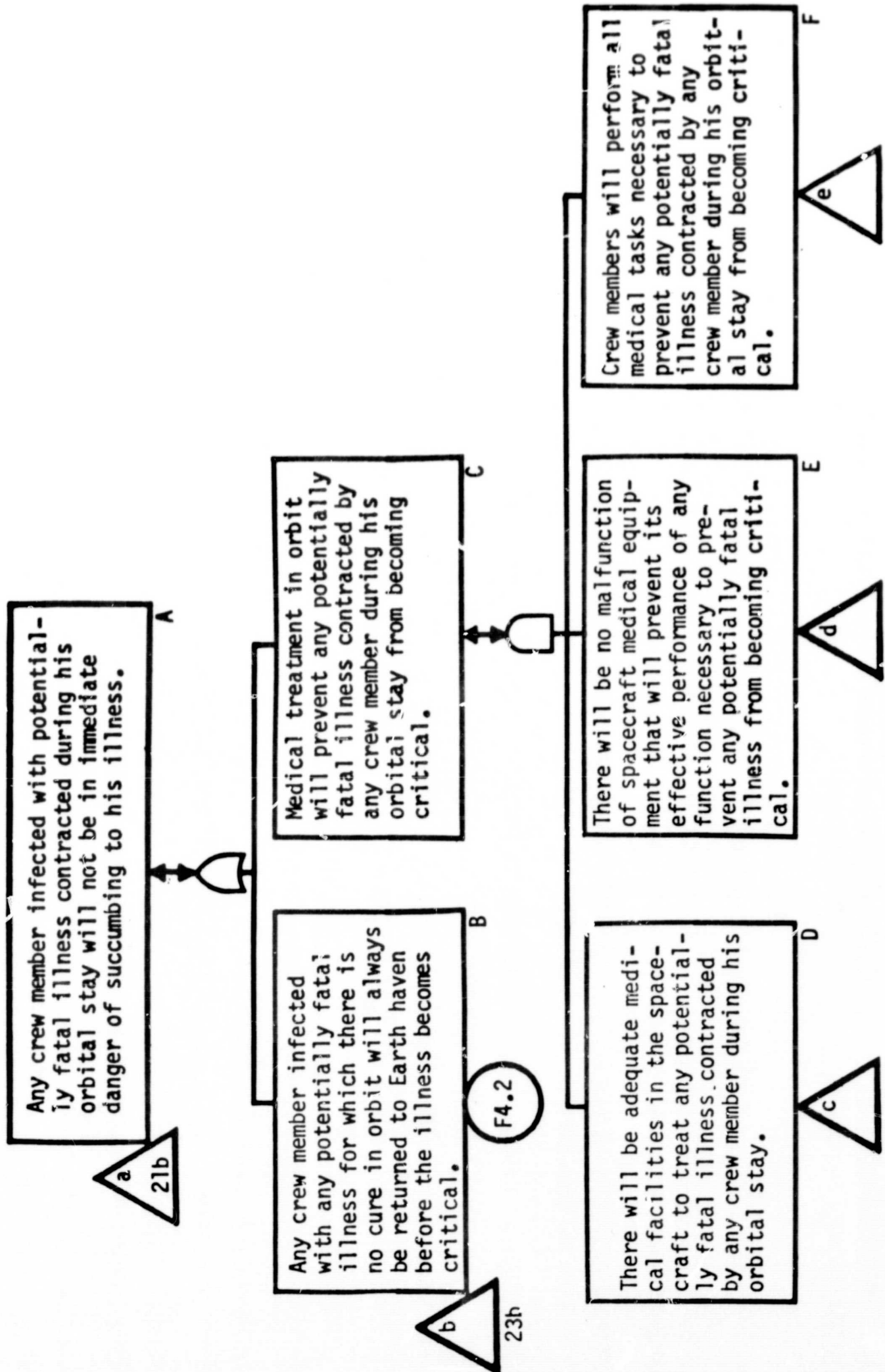
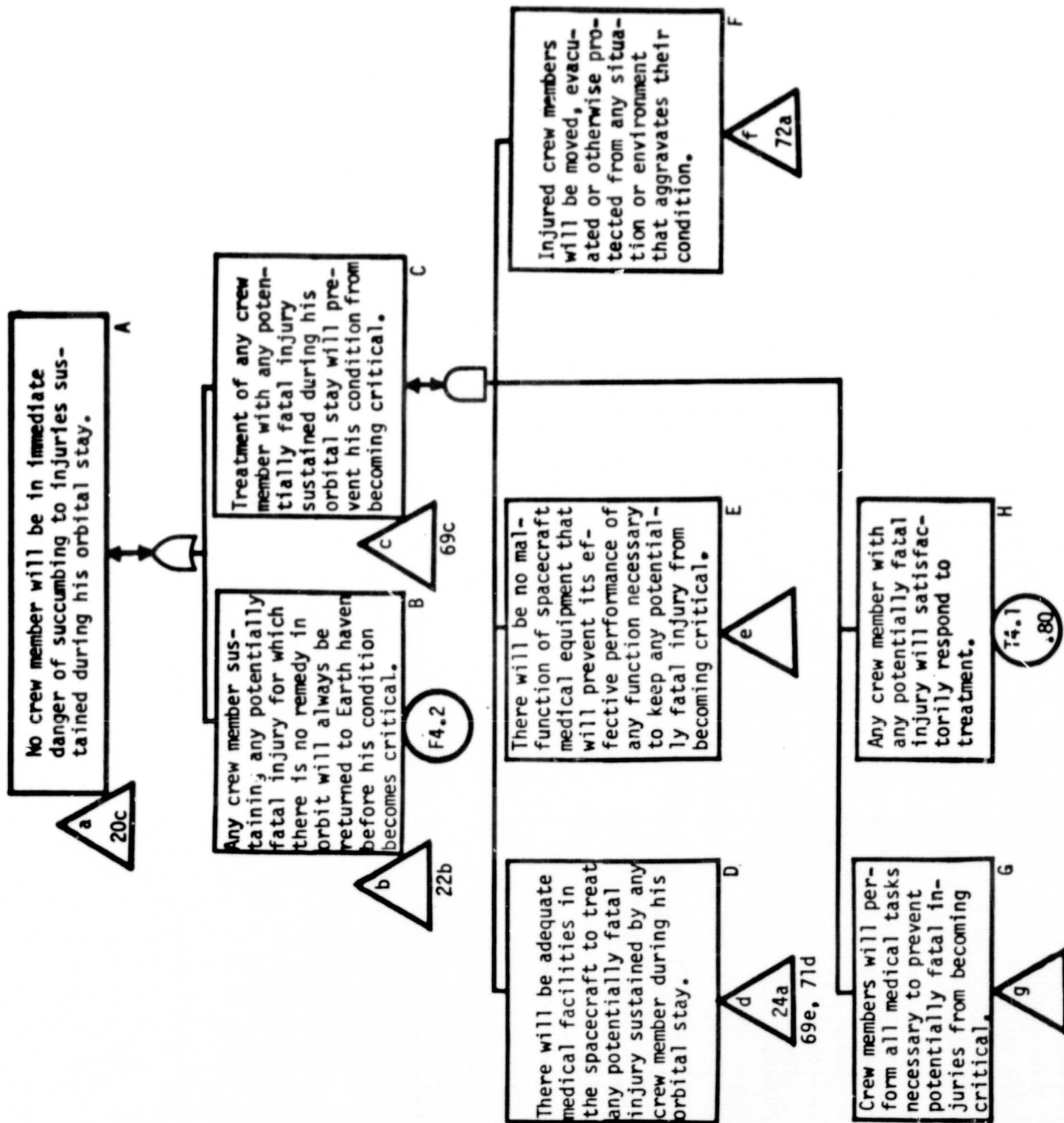


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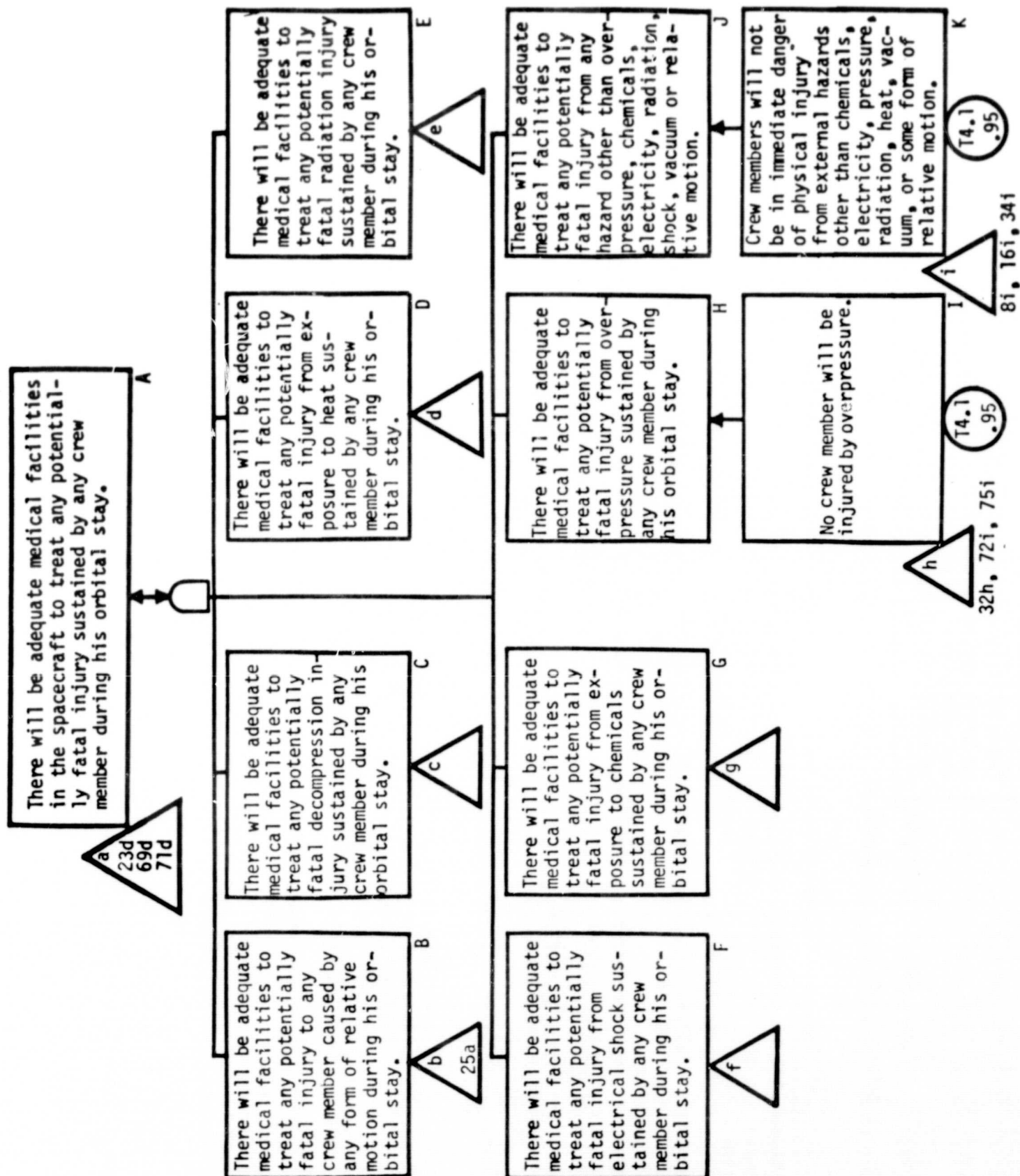
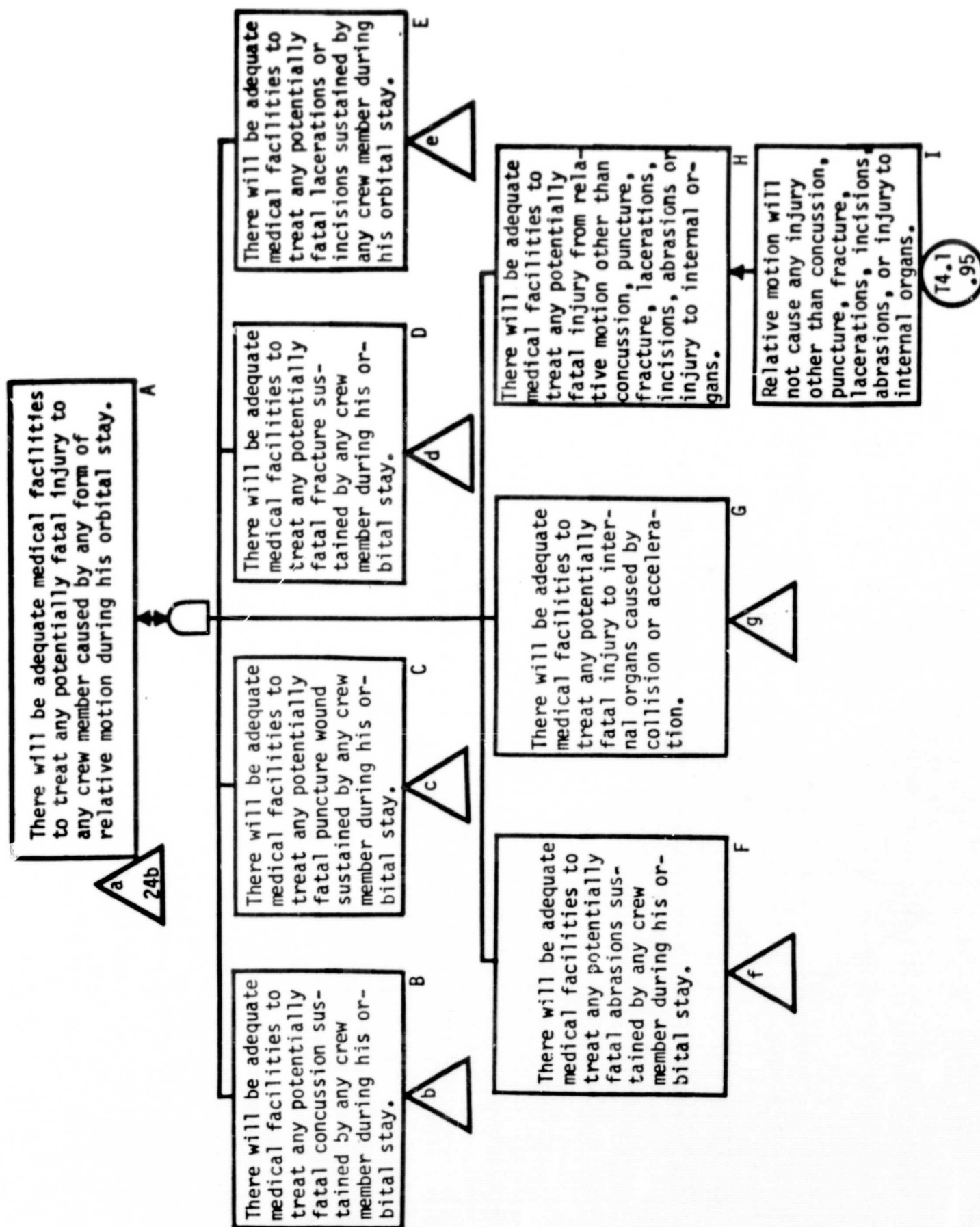


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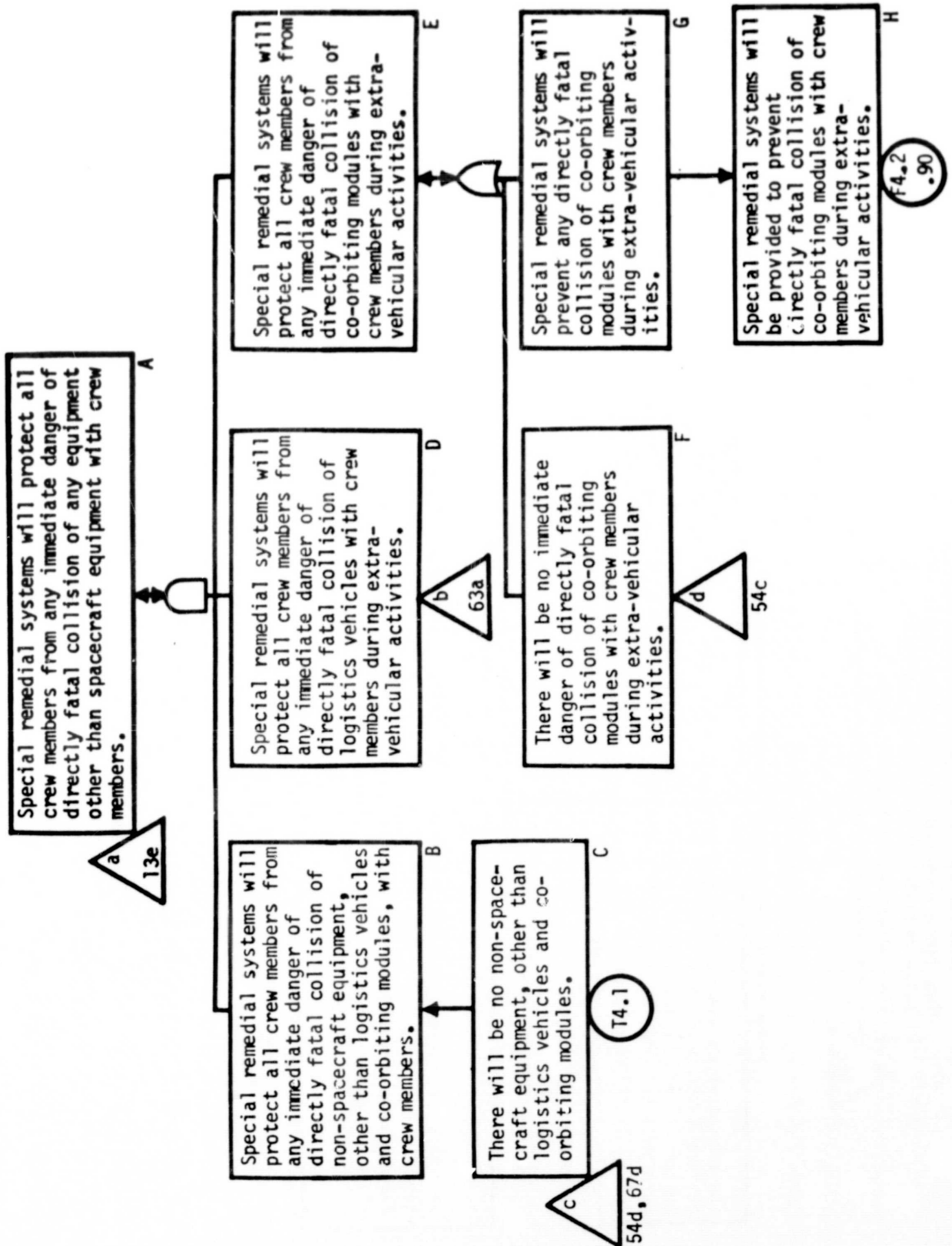
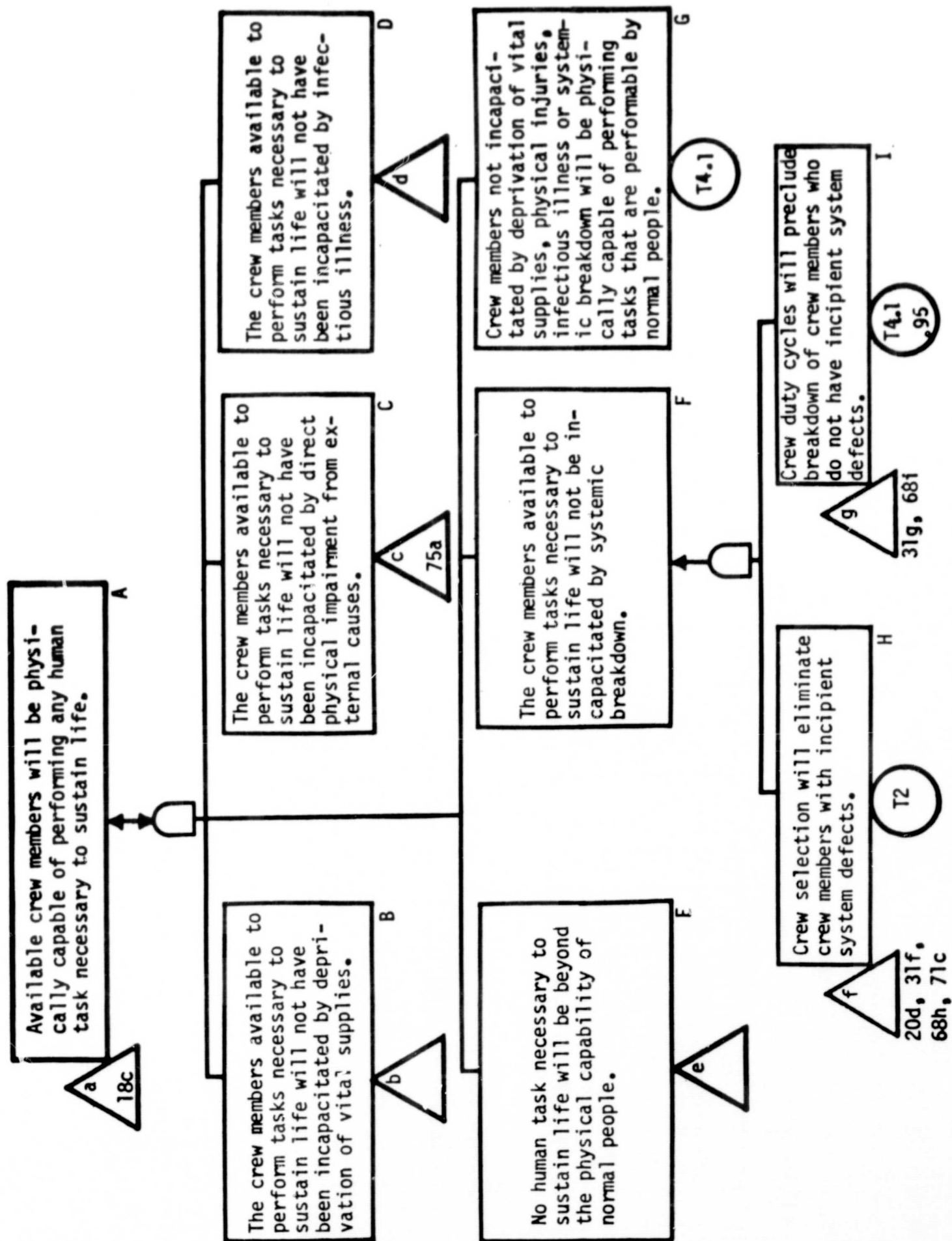


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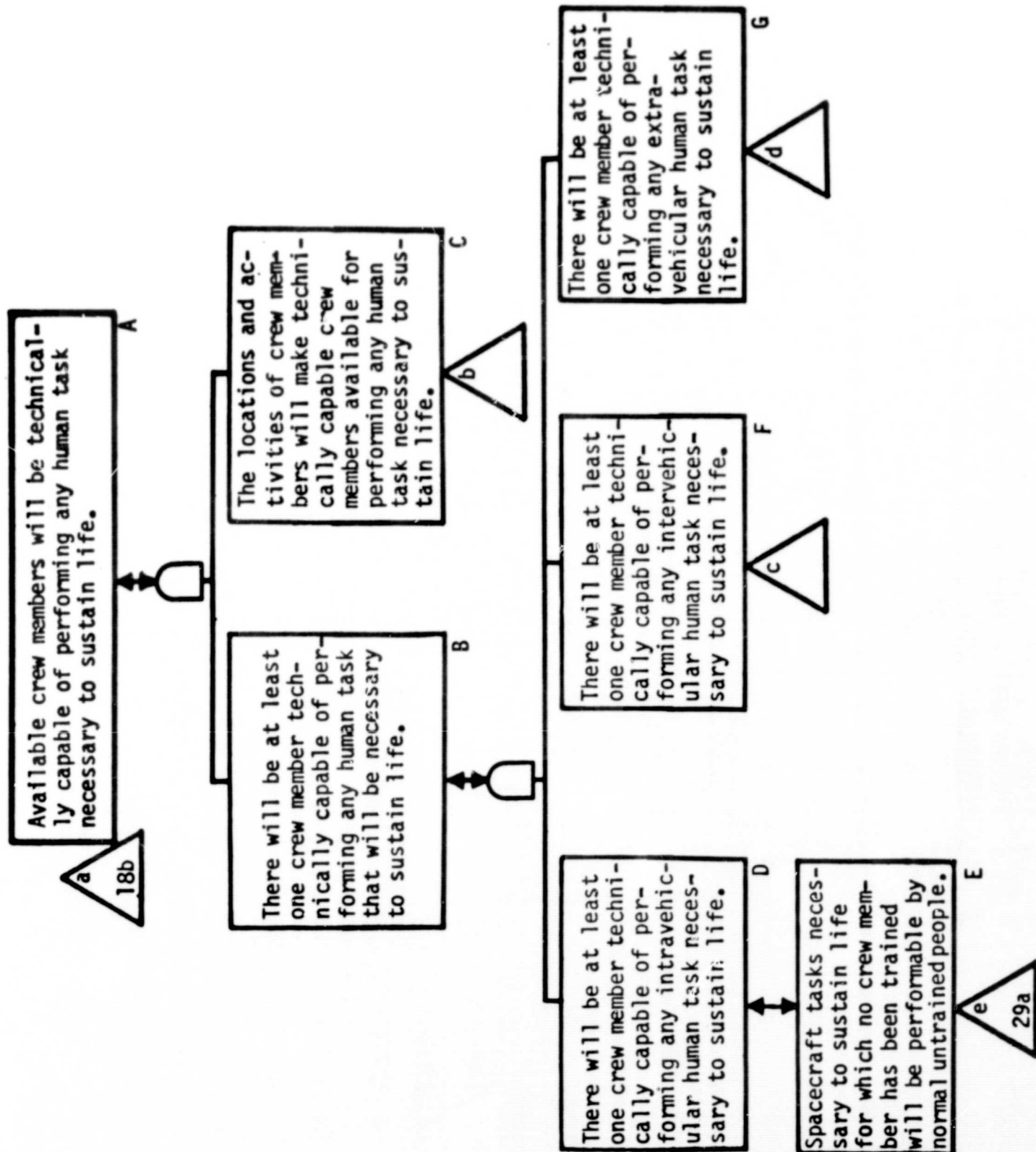
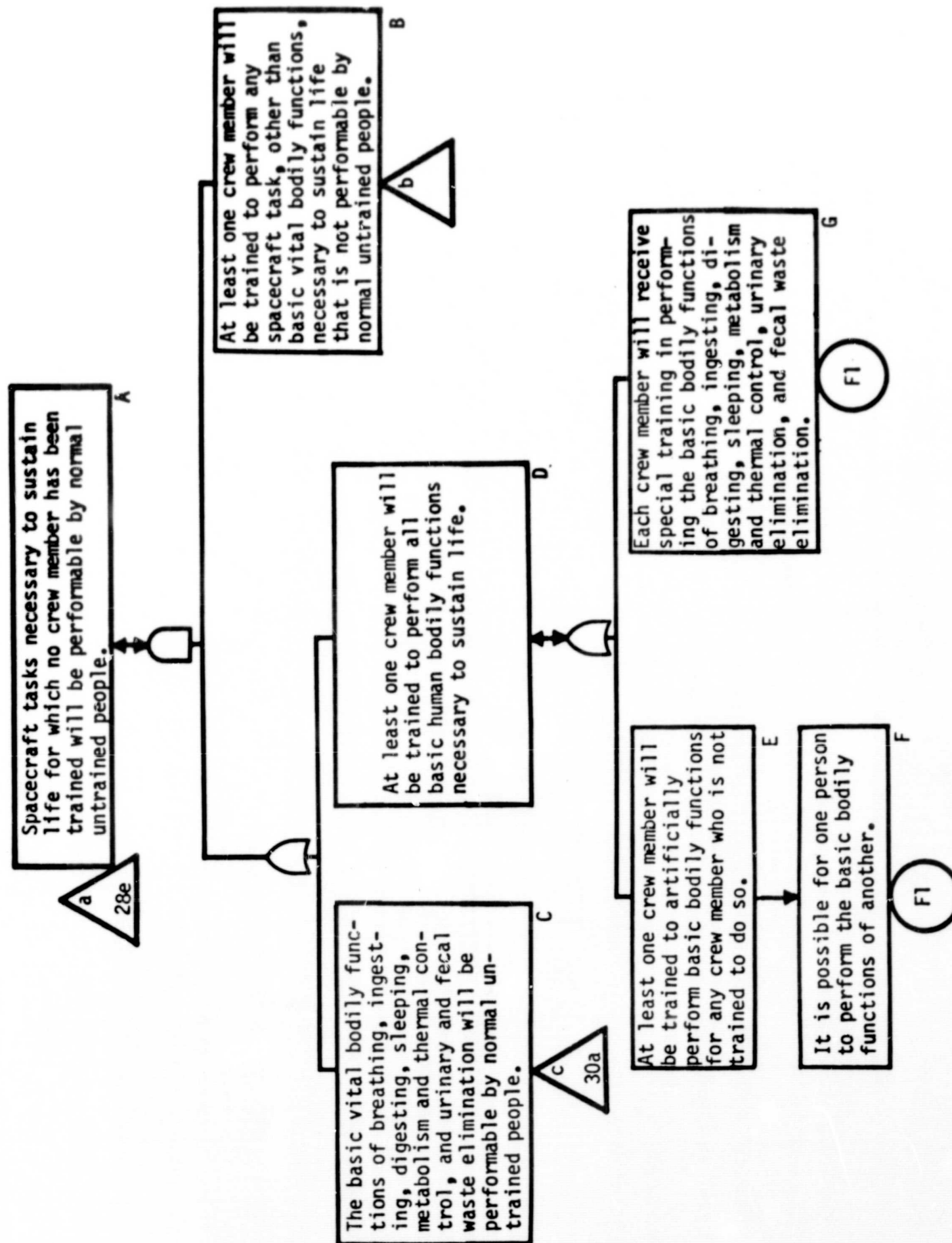


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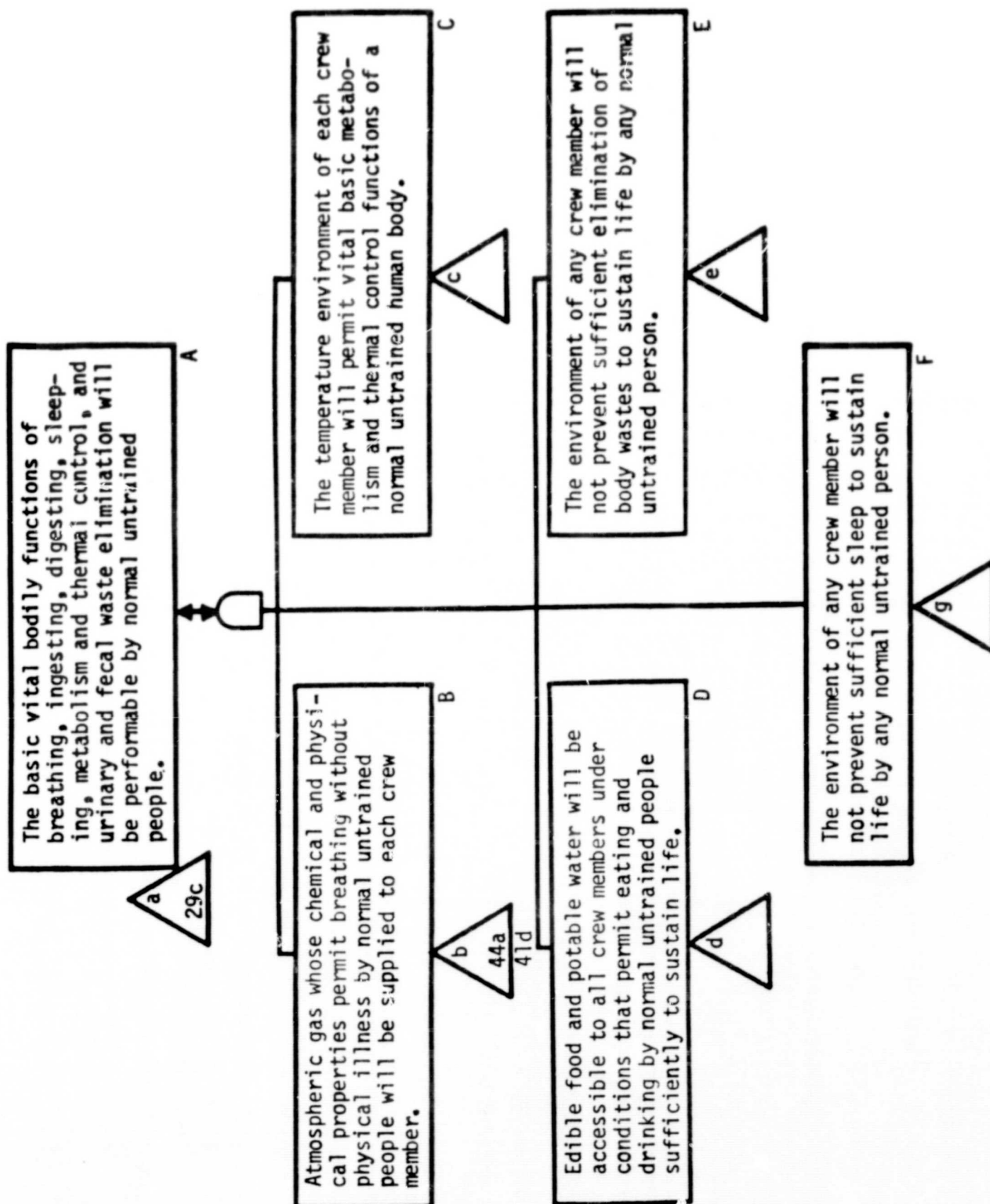
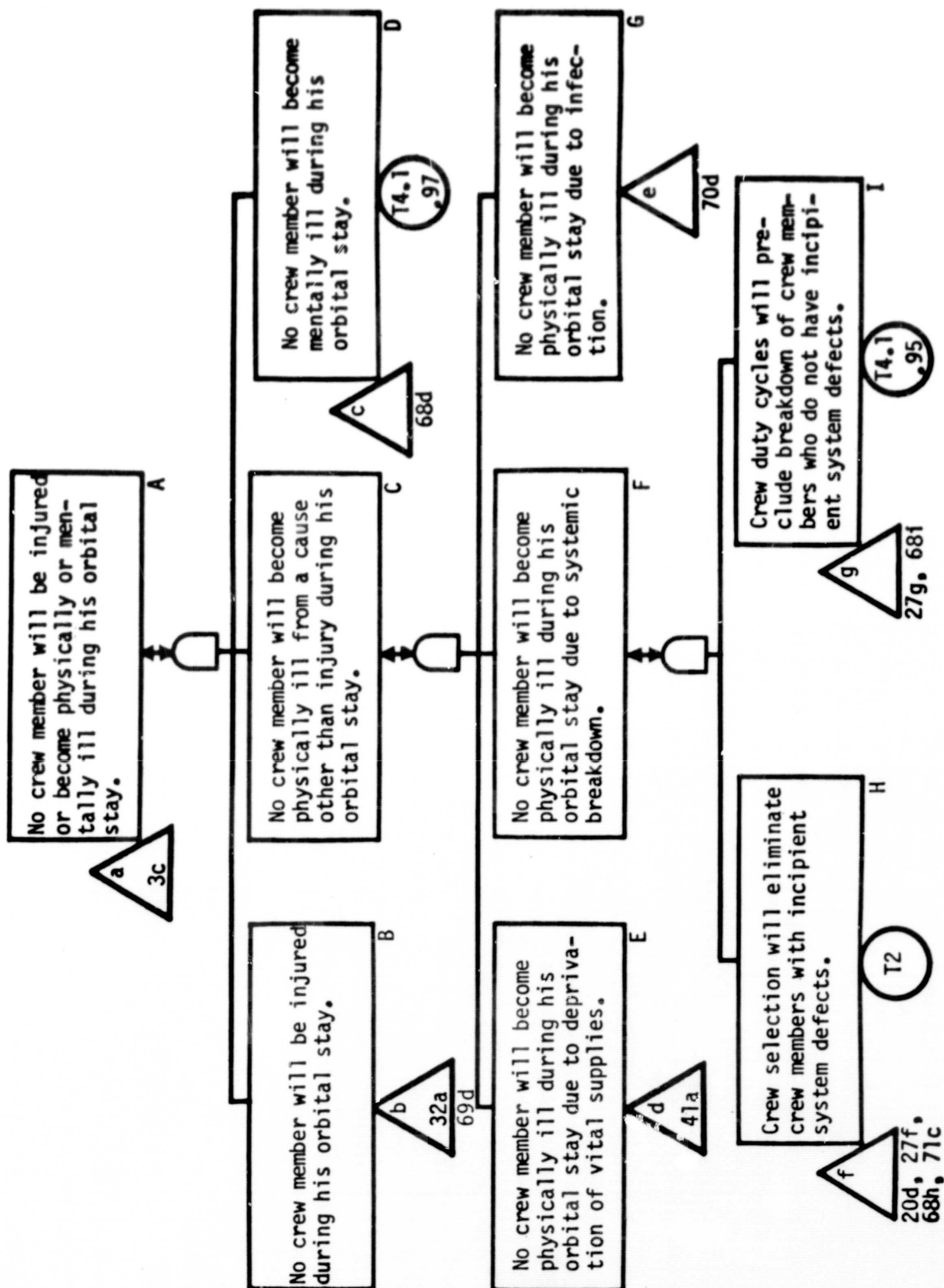
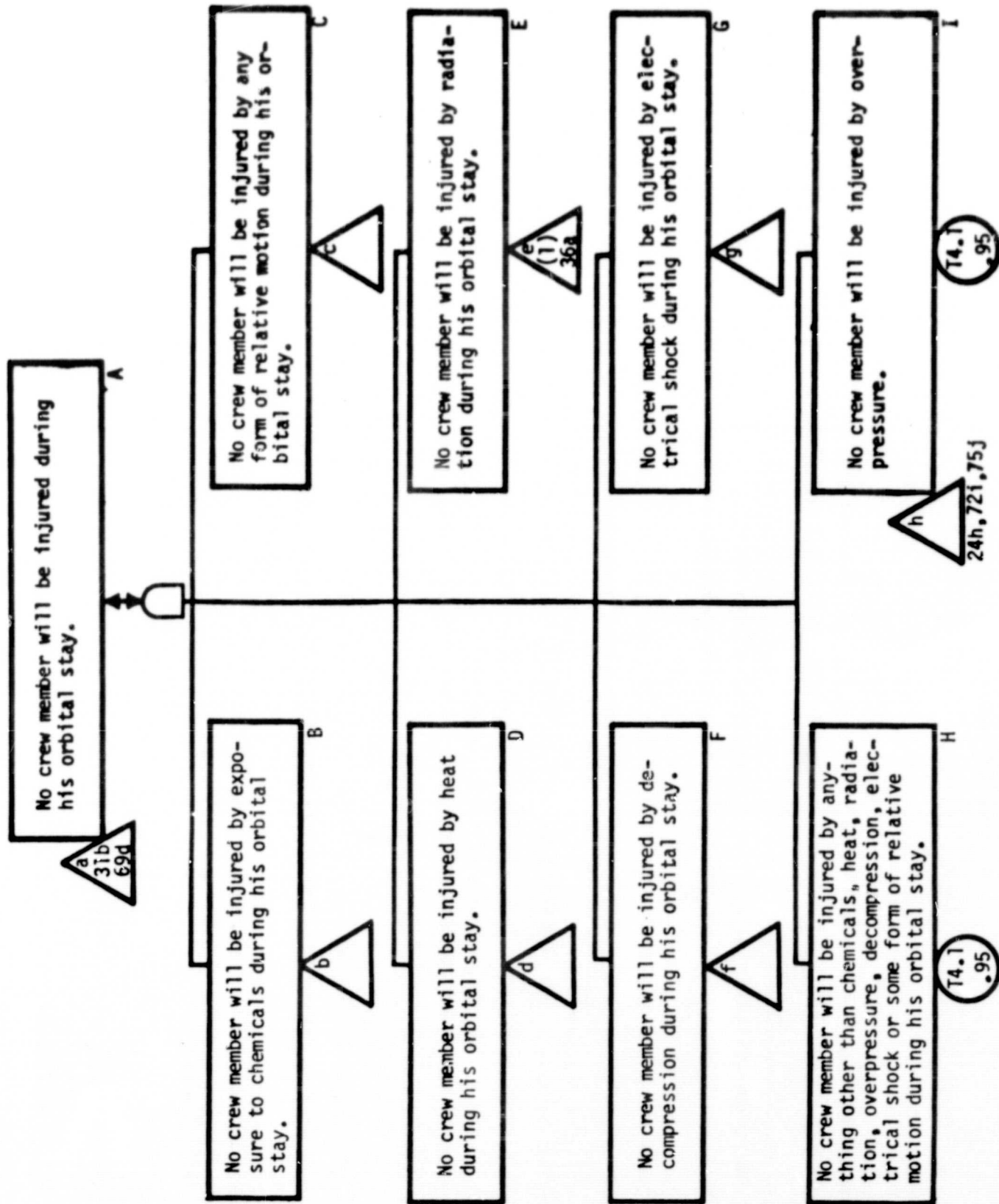


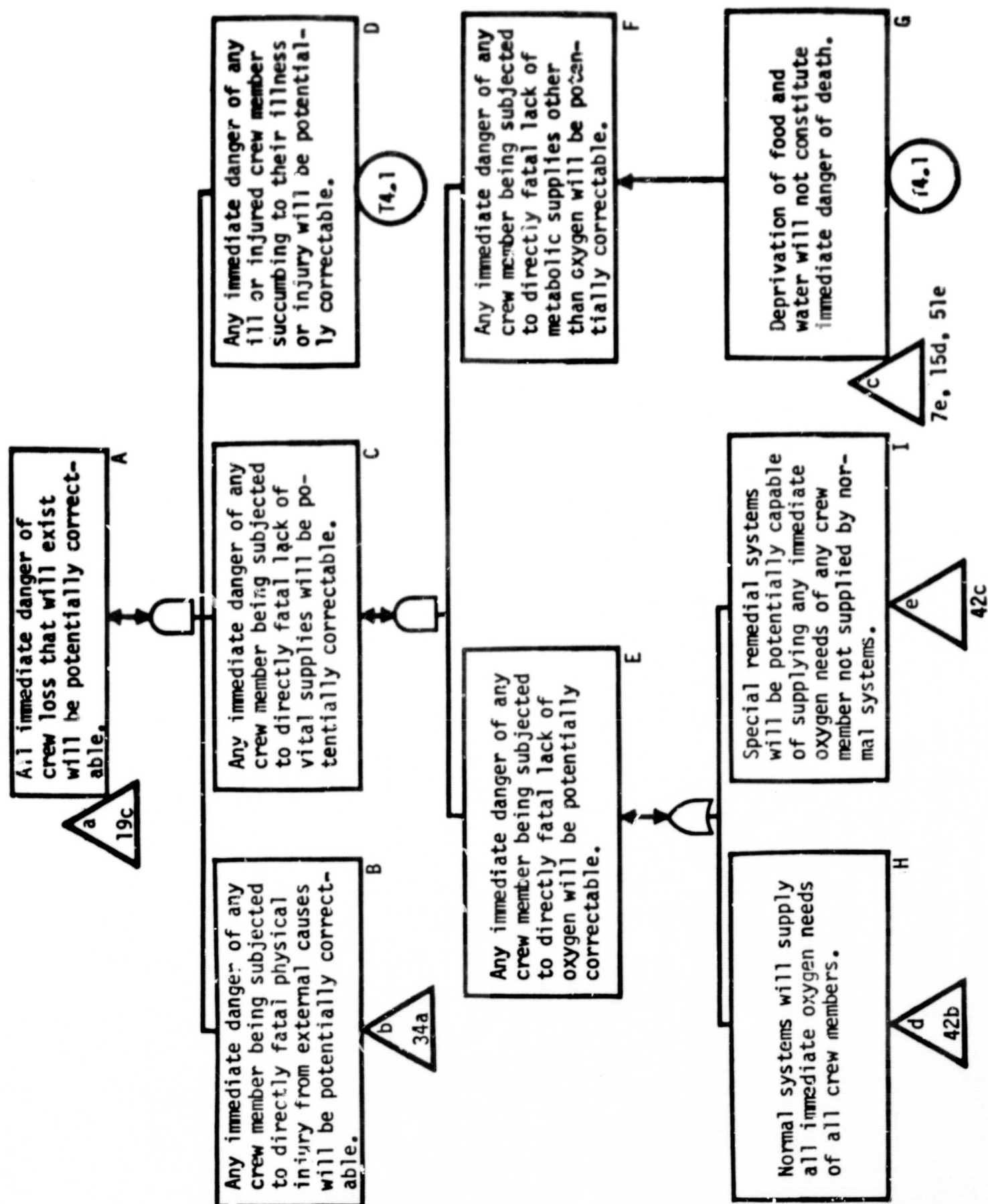
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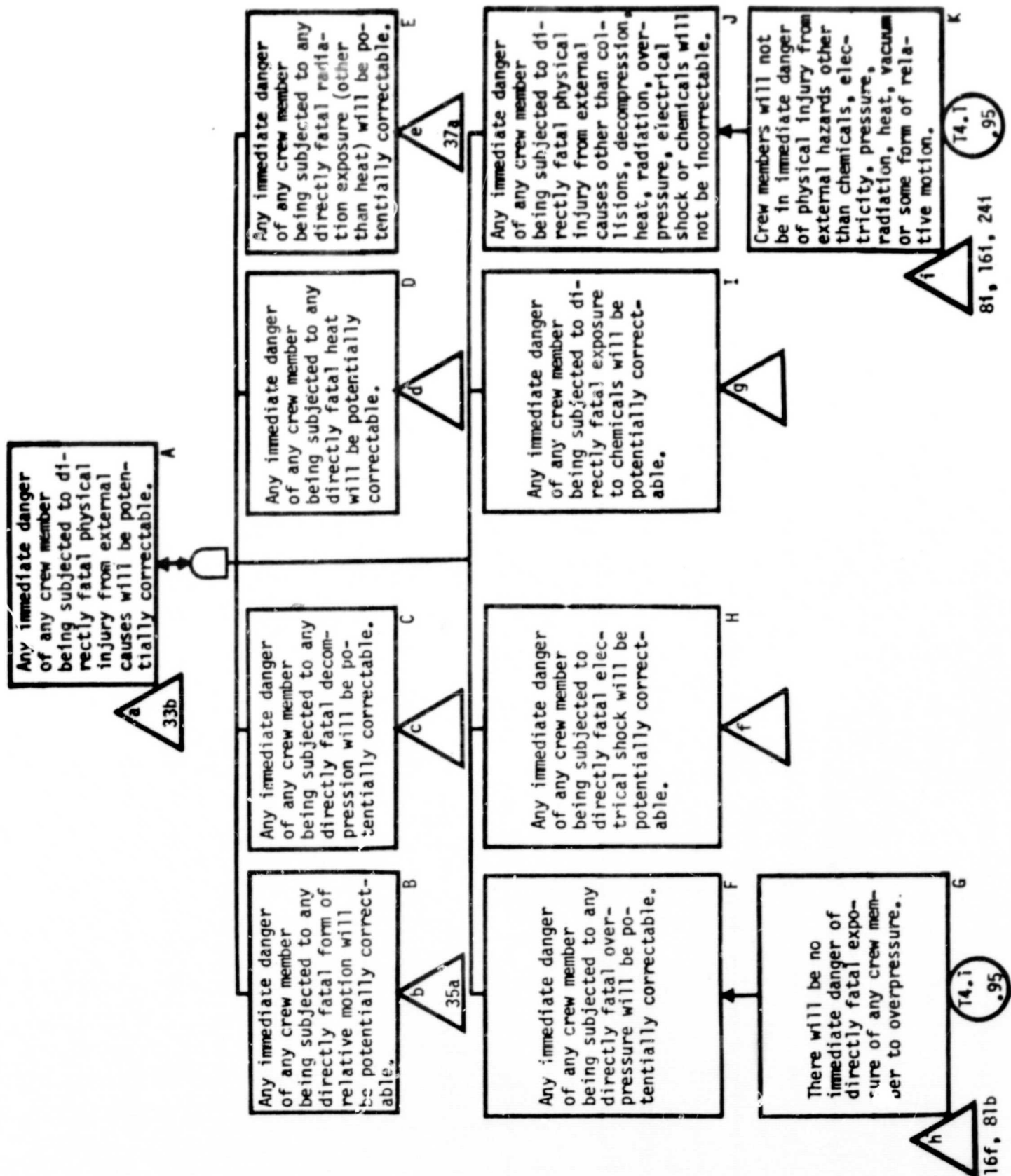
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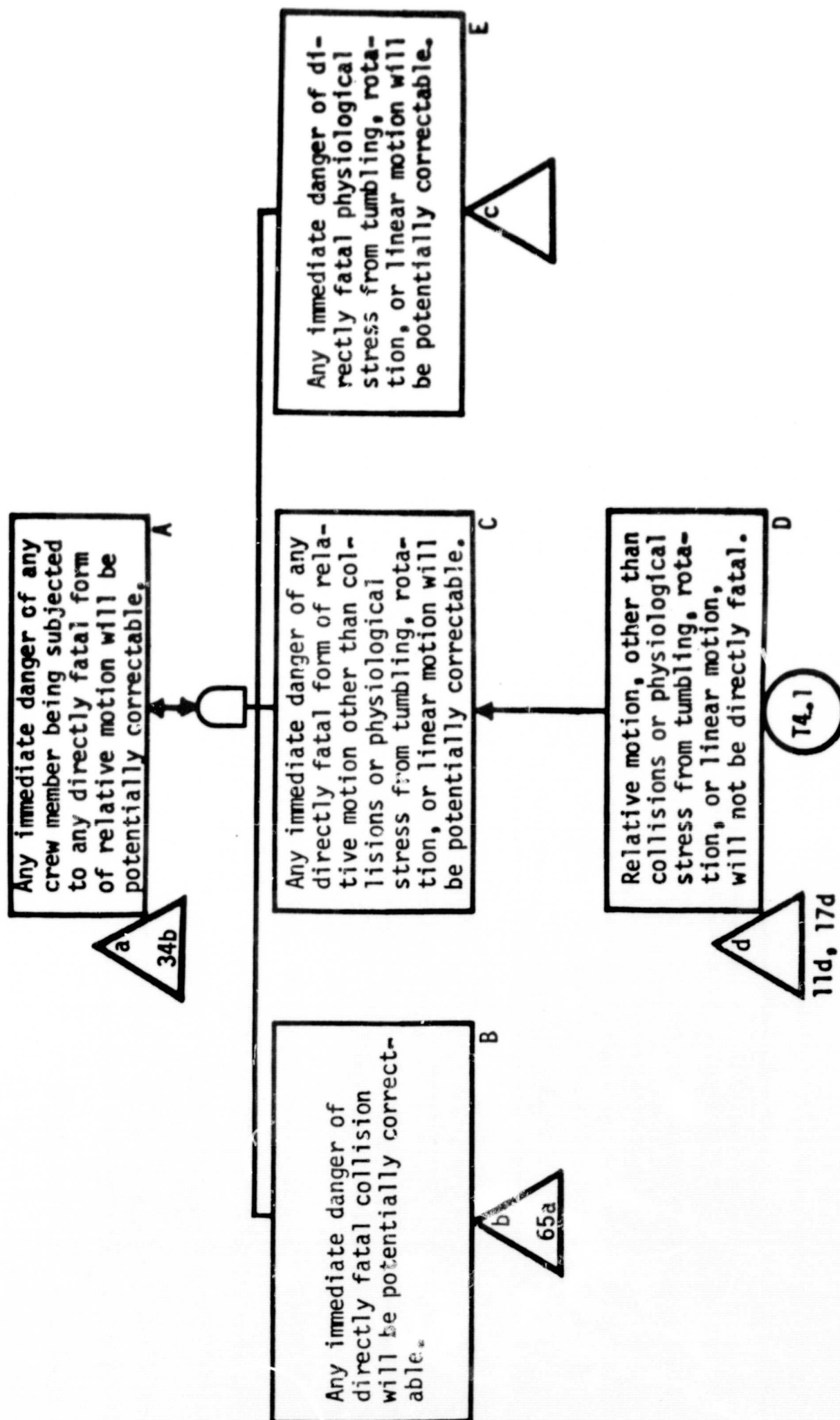


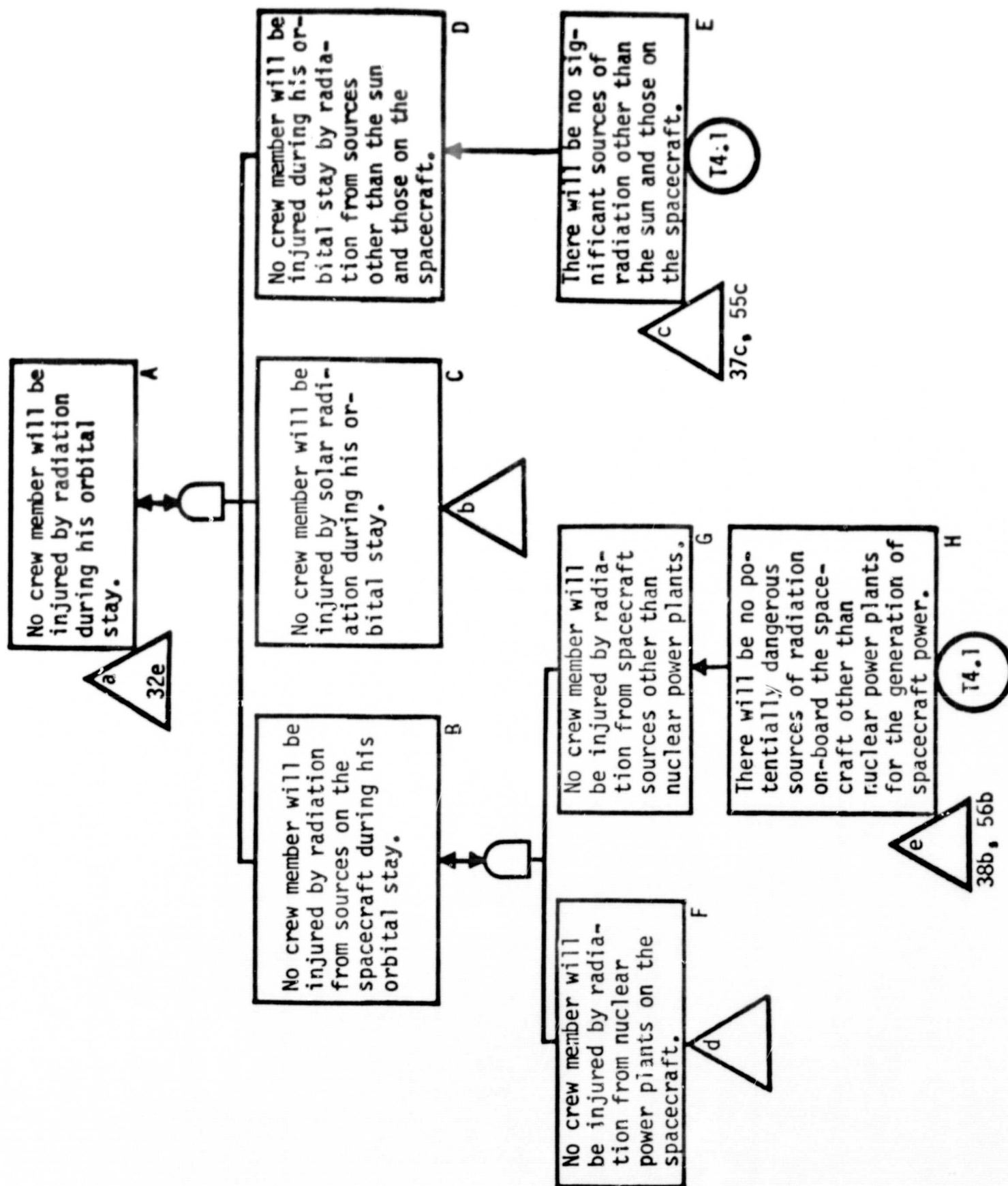


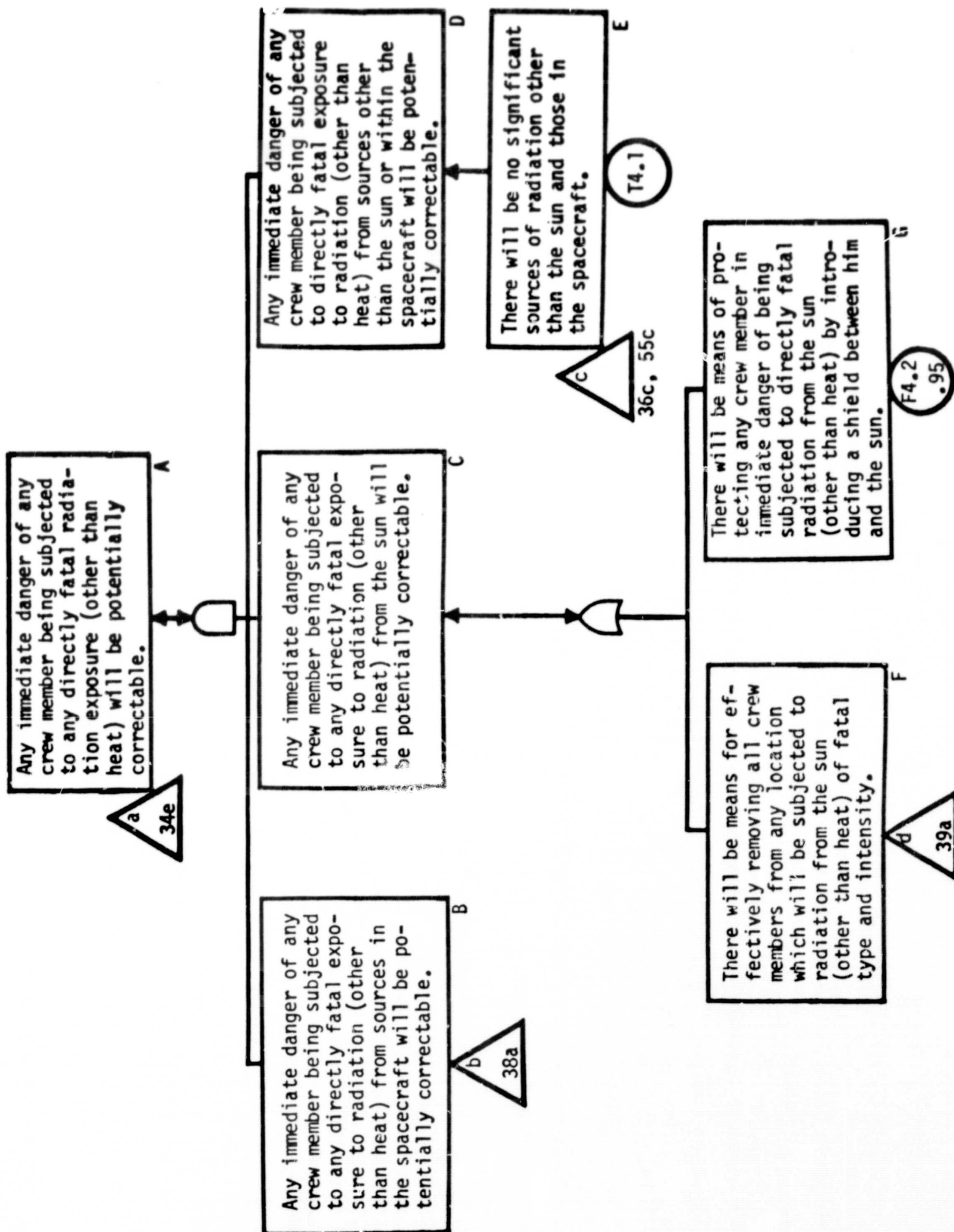
(1) See also D2-113070-10, FT-3, for fault tree development of undesired events due to radiation.











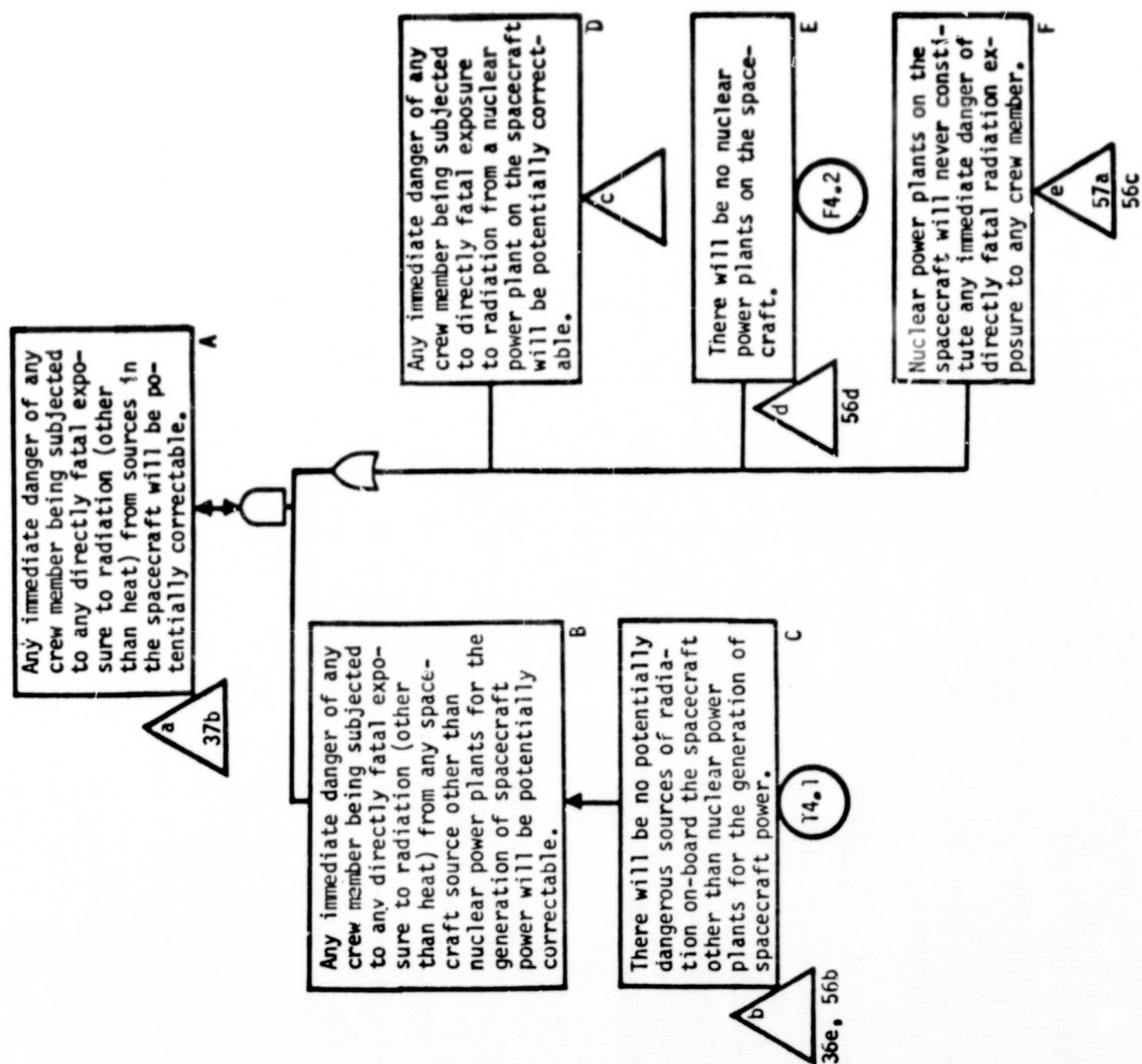
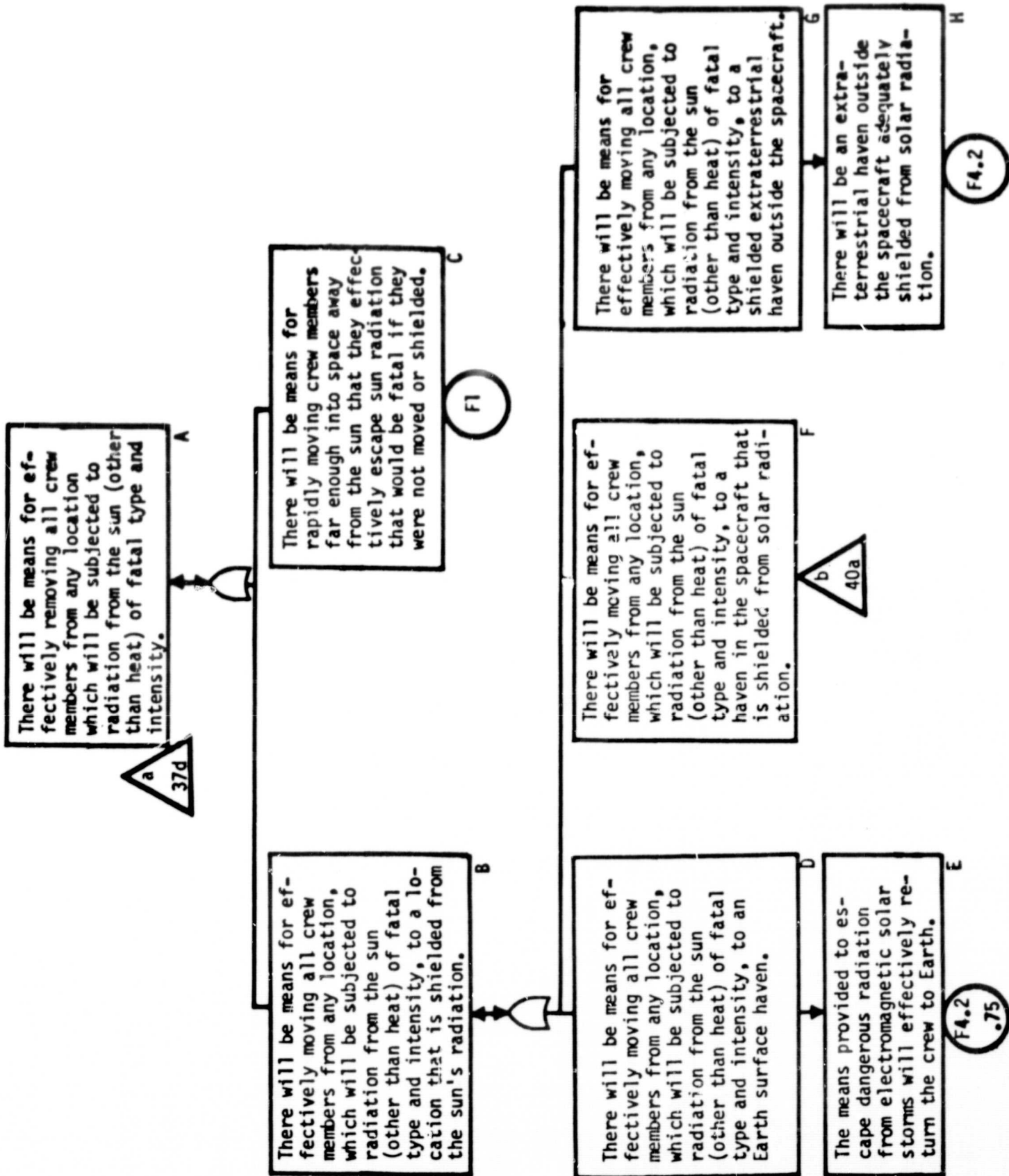


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Chart No. 39



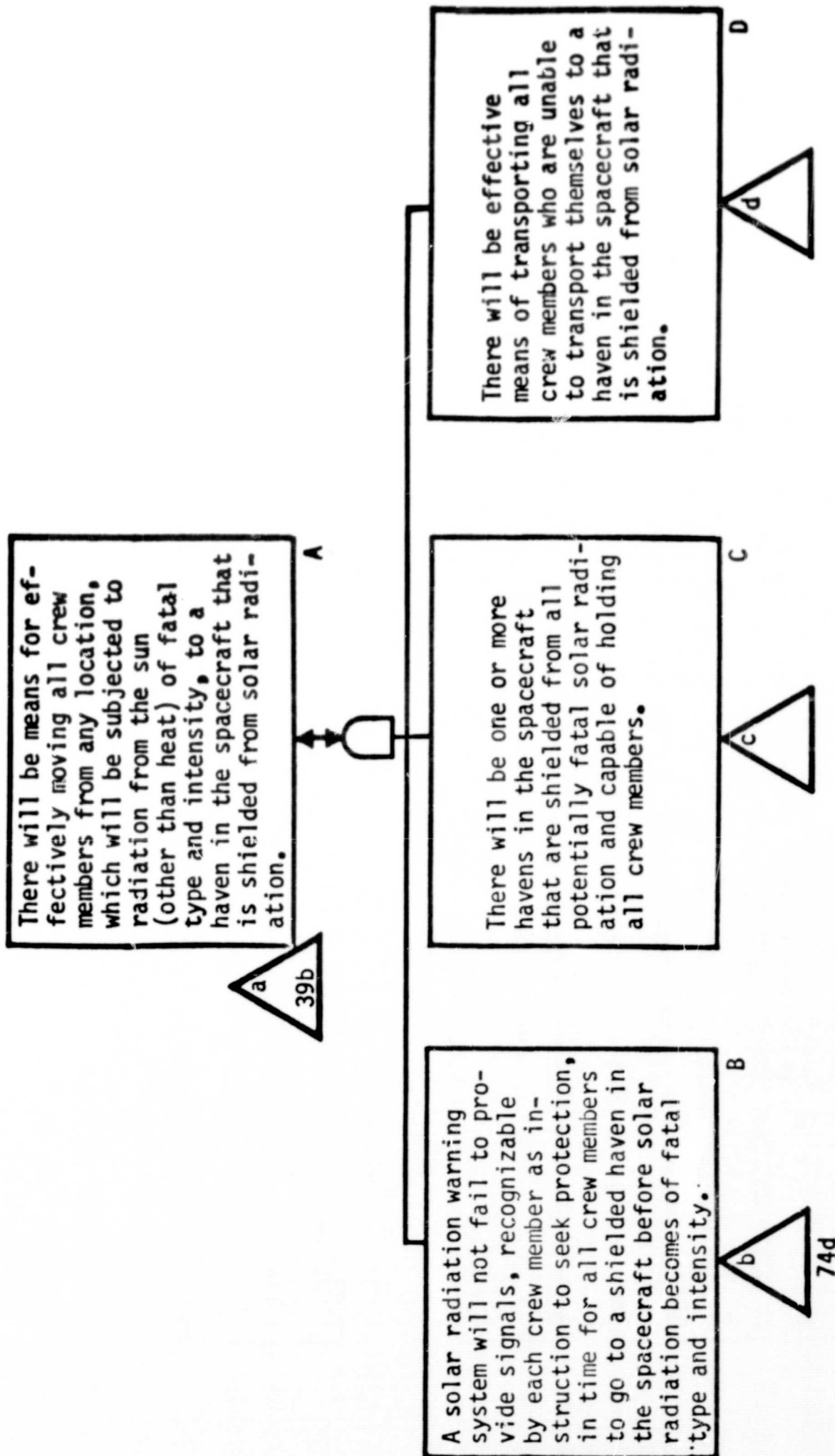
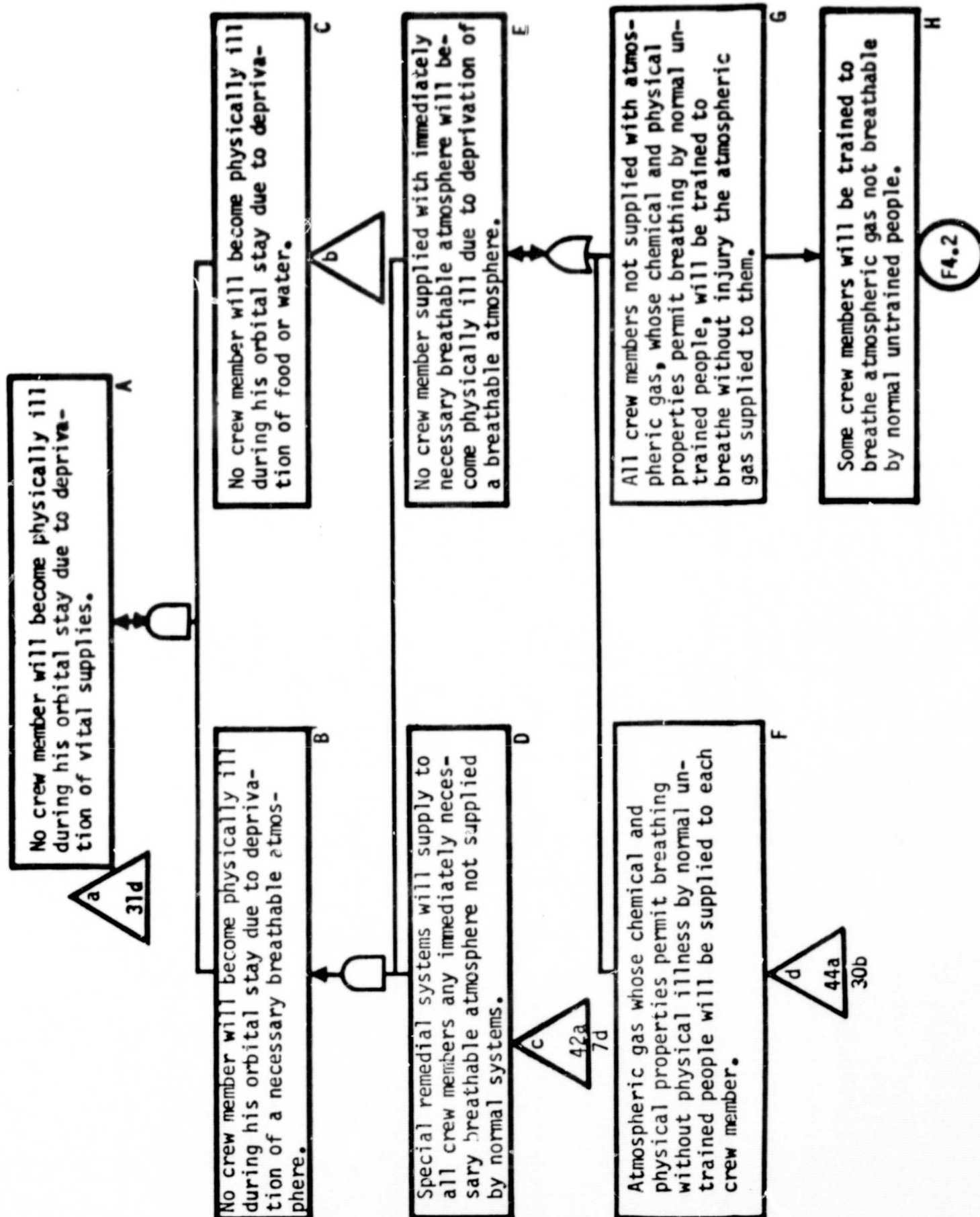


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Chart No. 41



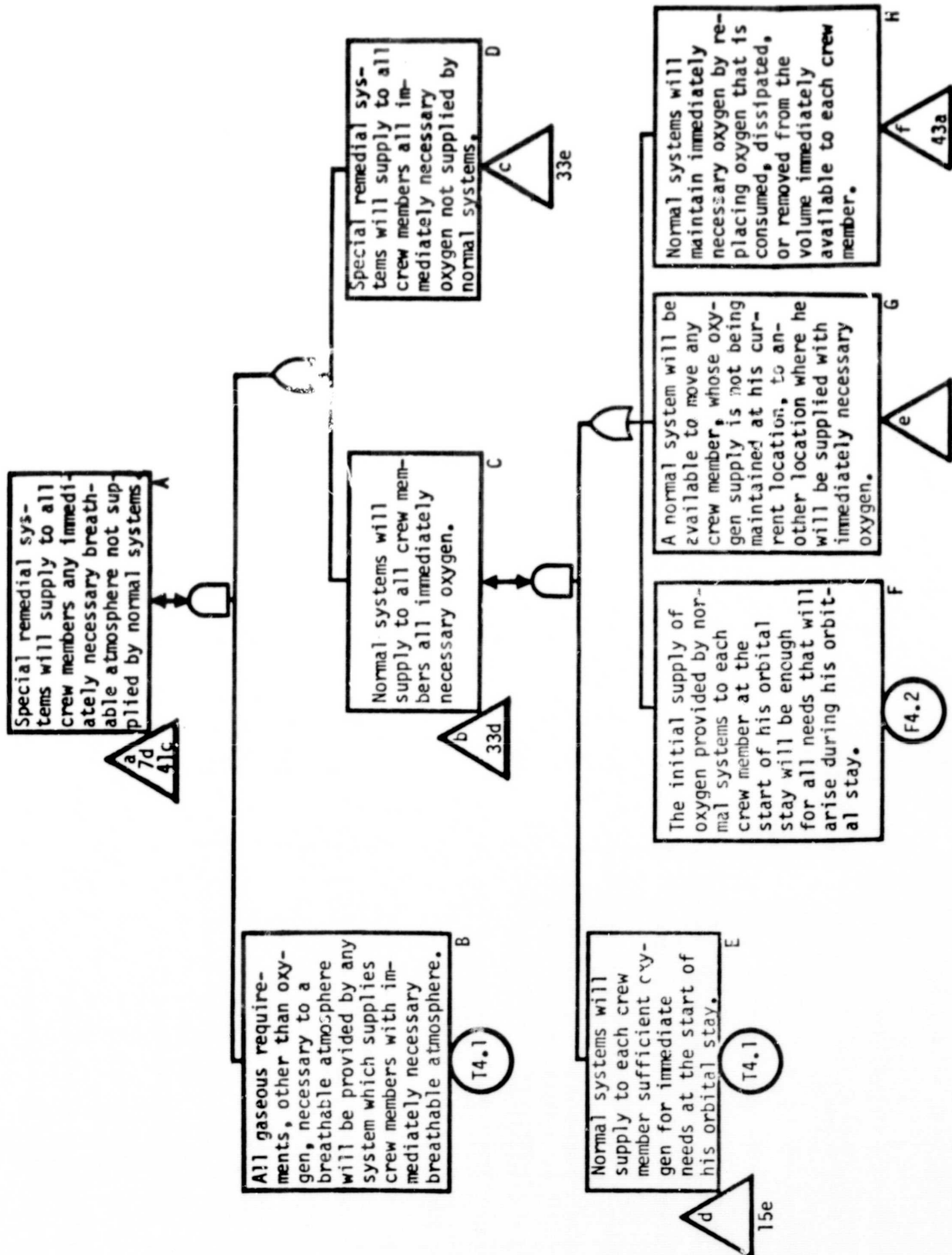
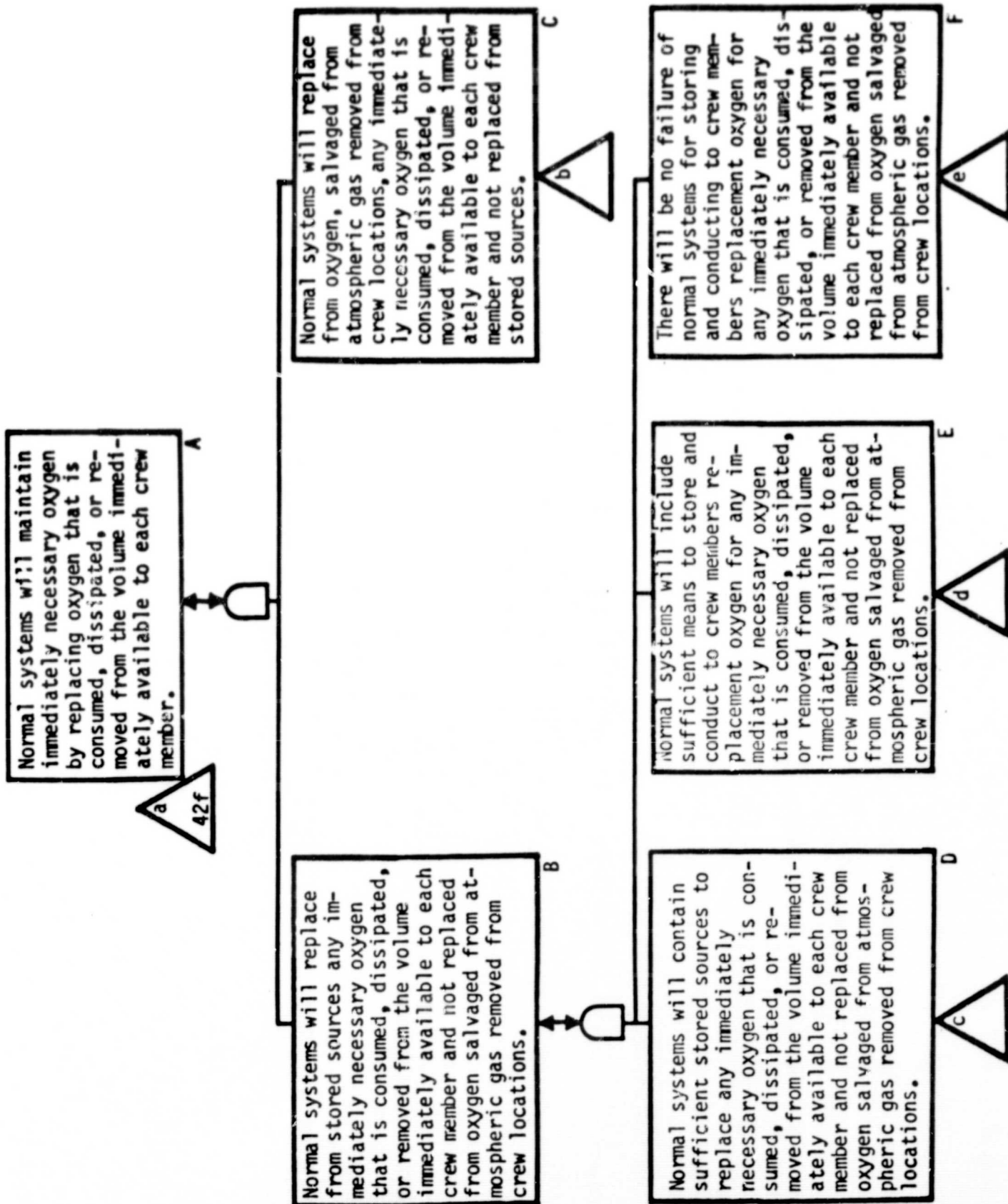


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Chart No. 43



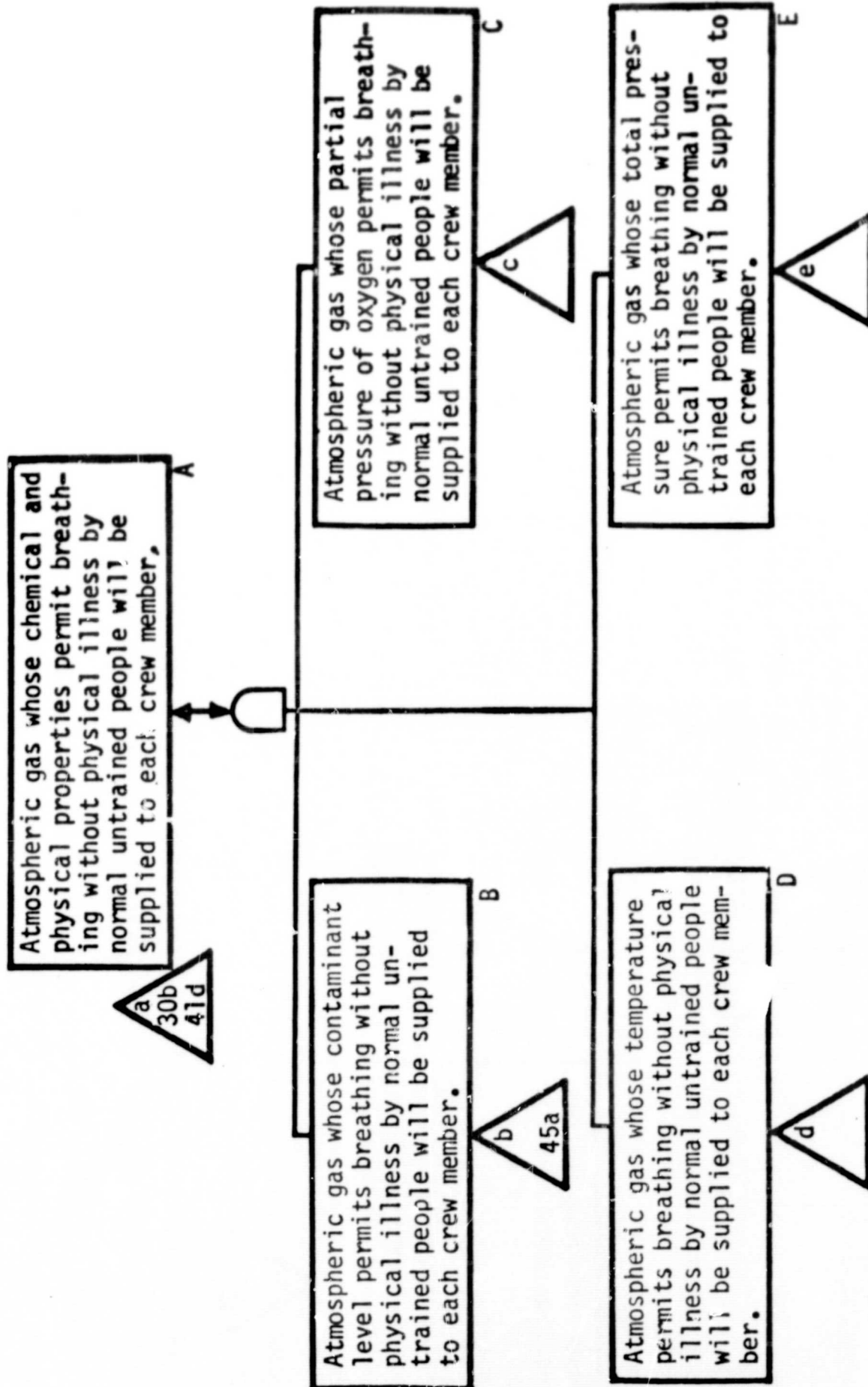
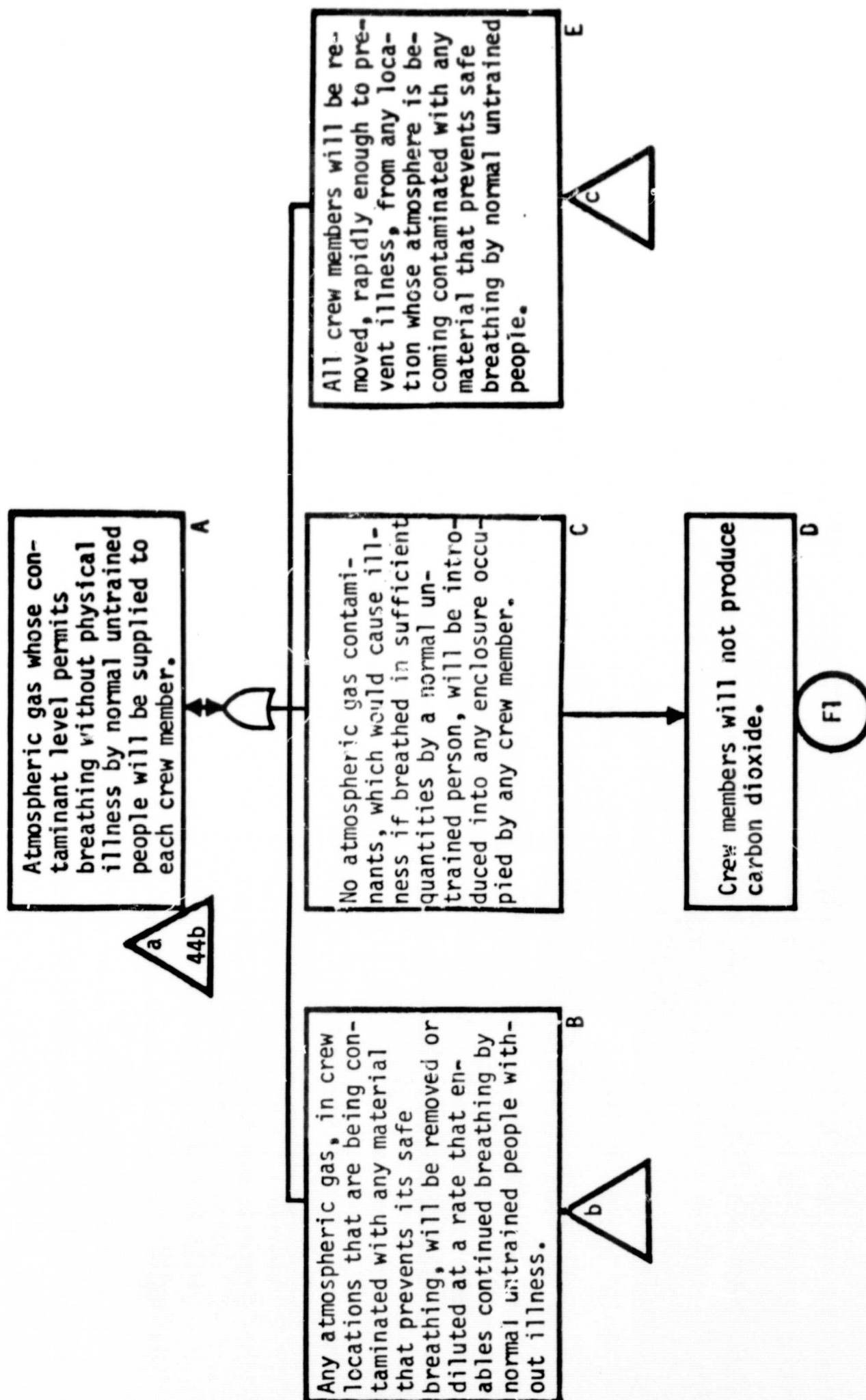
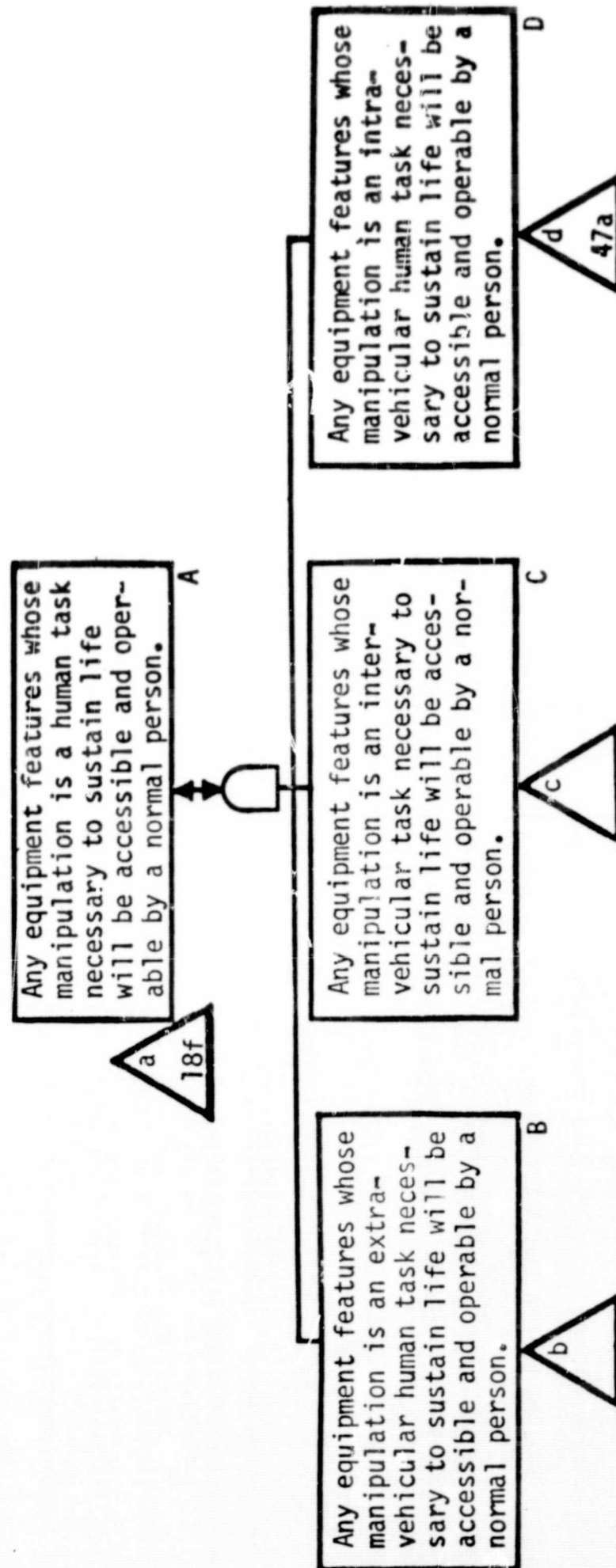
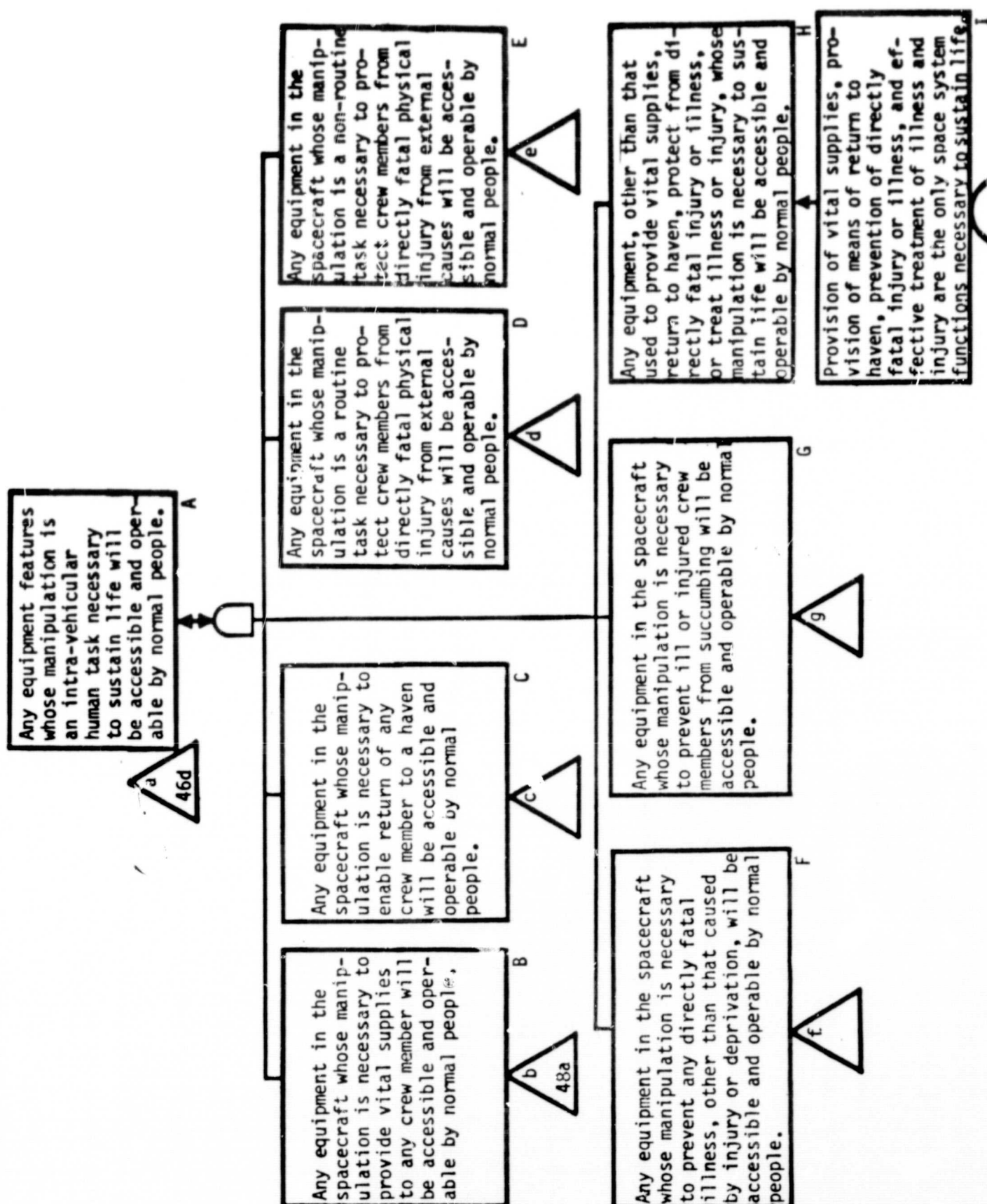


Chart No. 44







T4.1

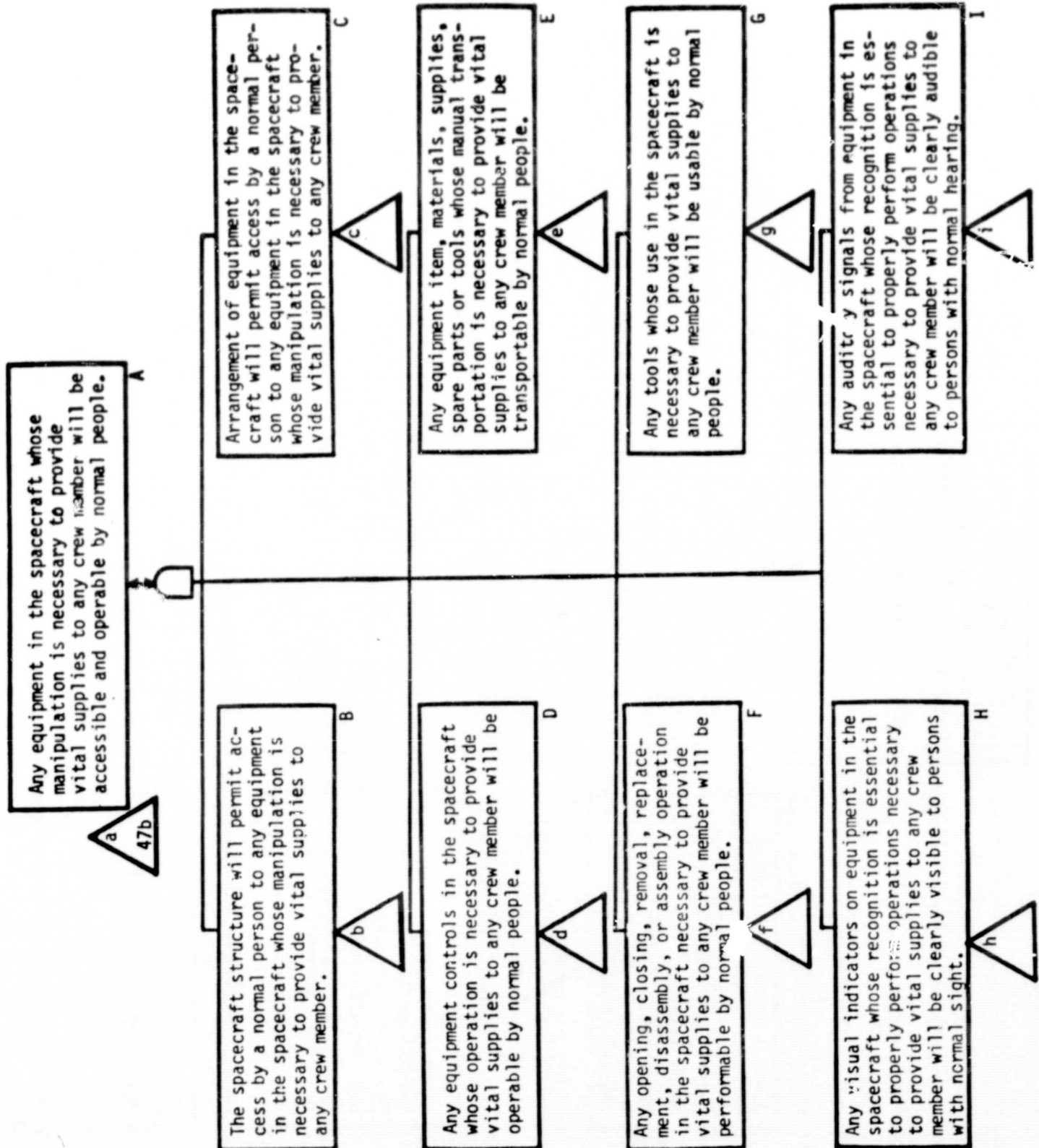
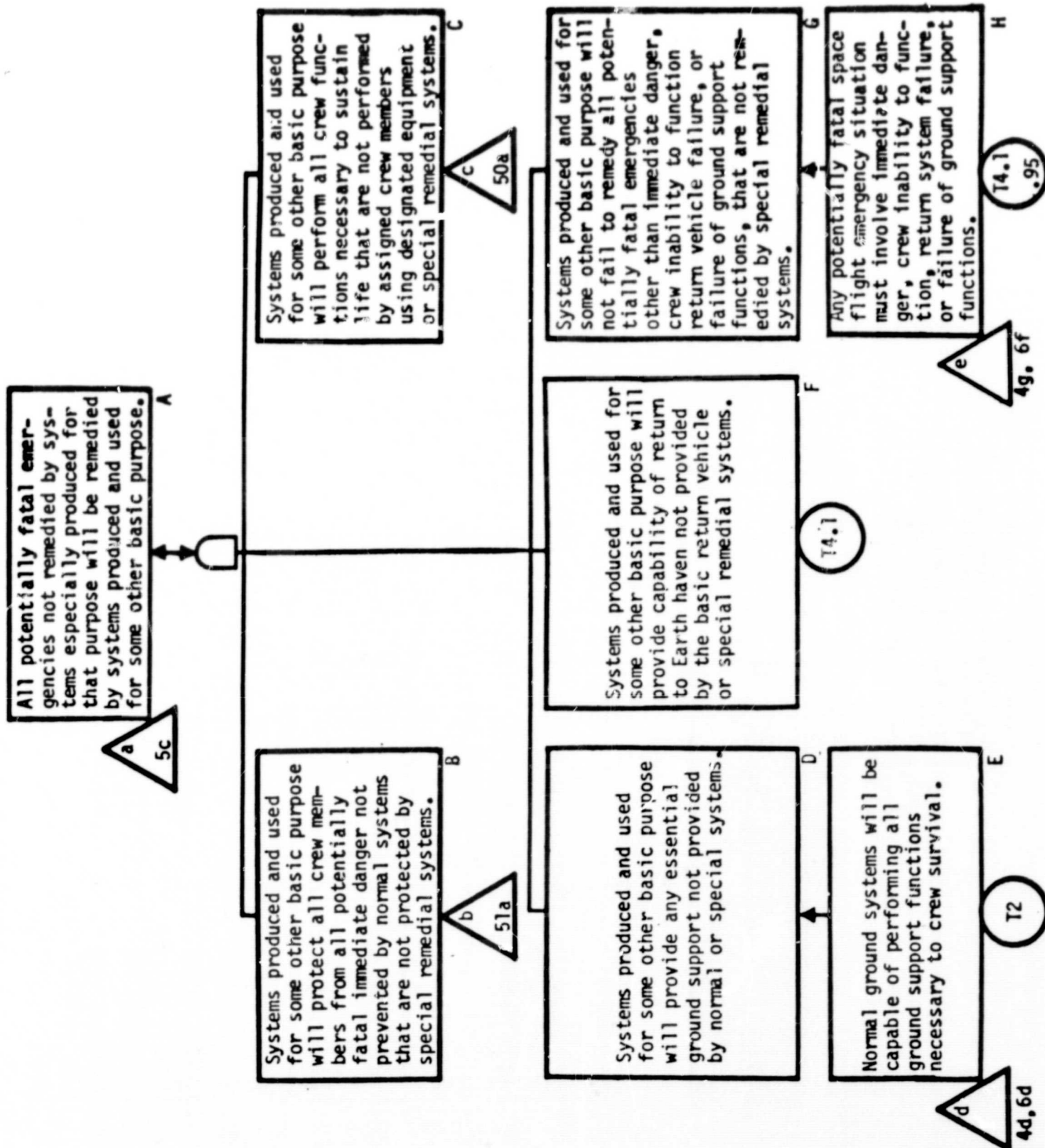


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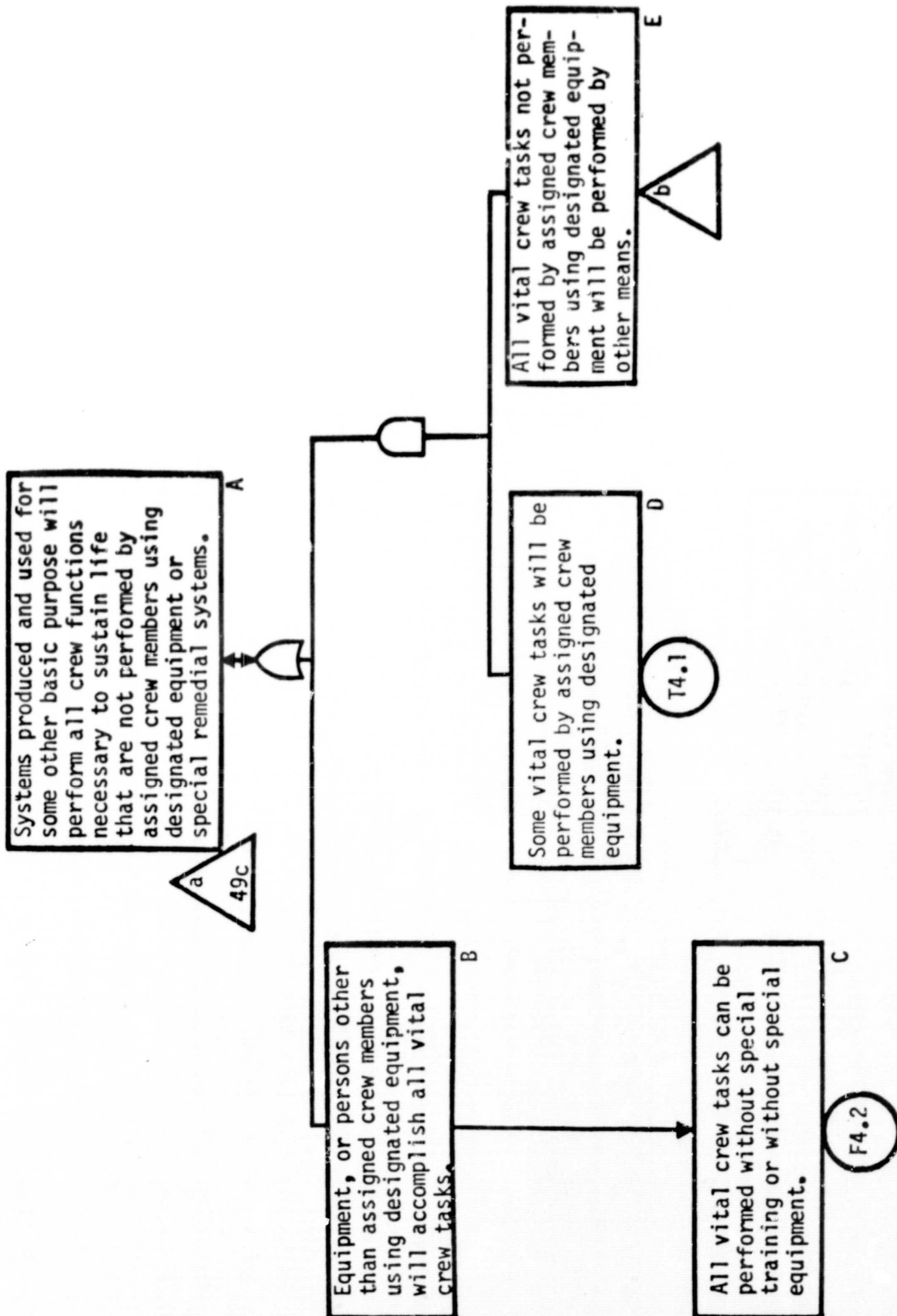
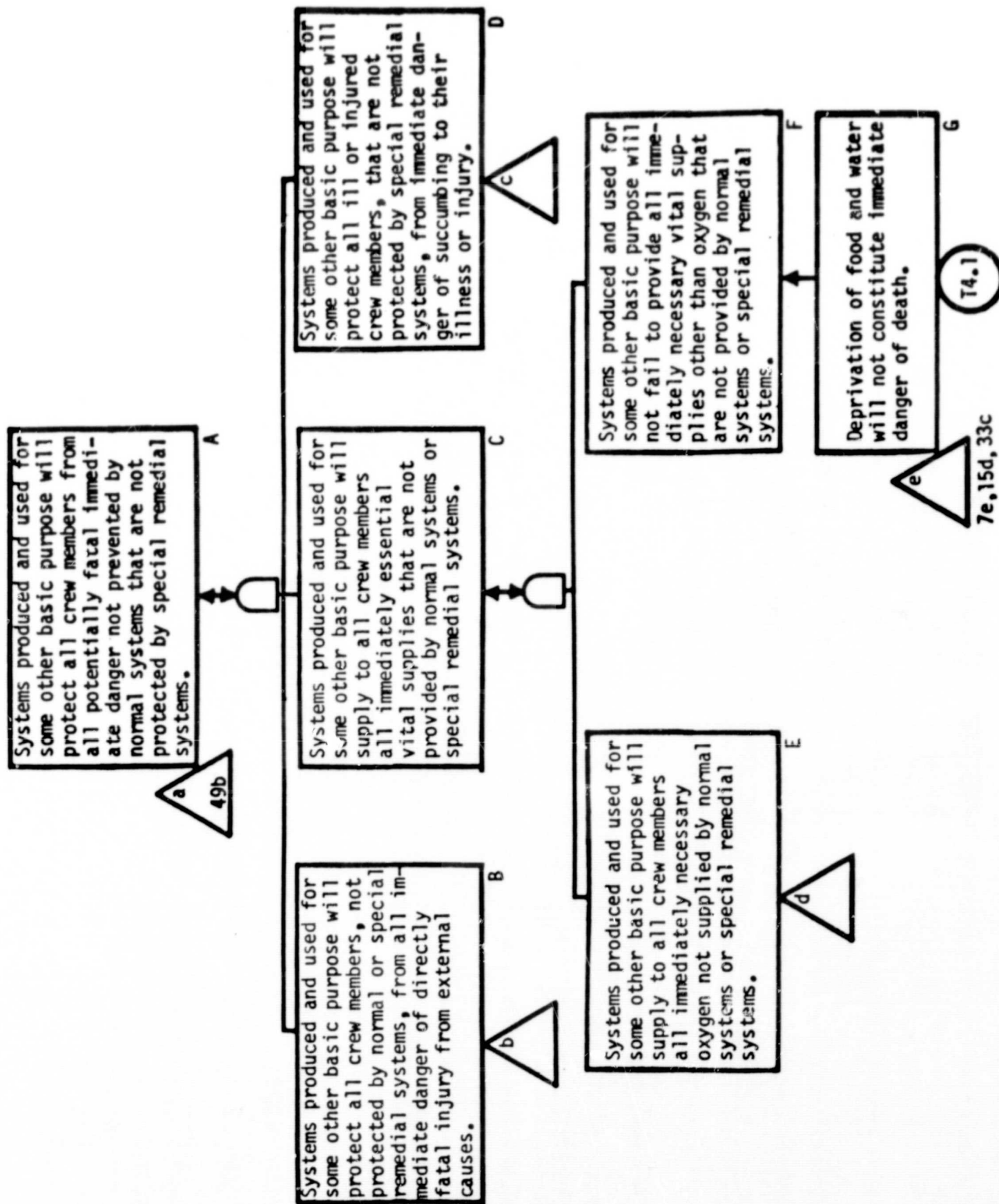
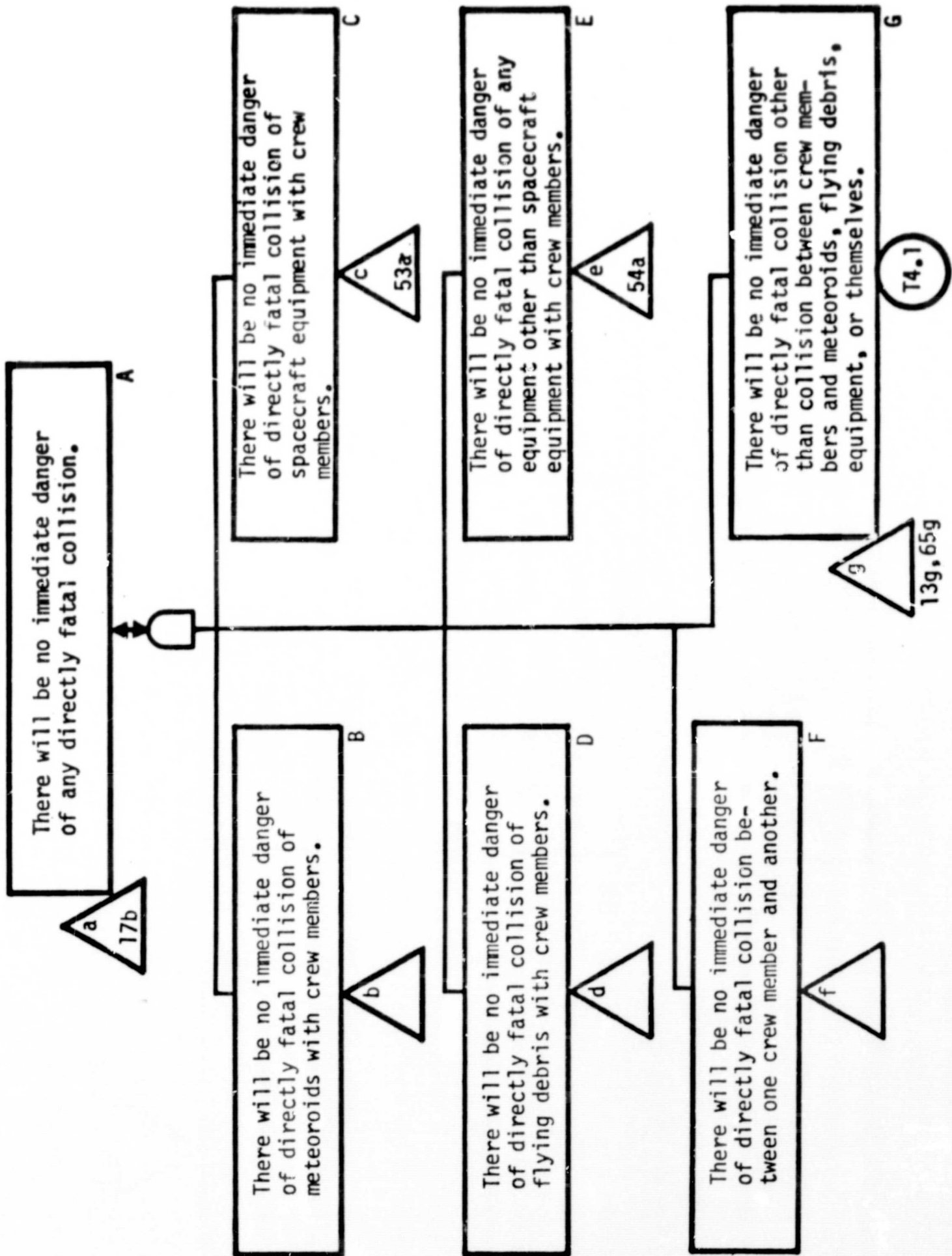
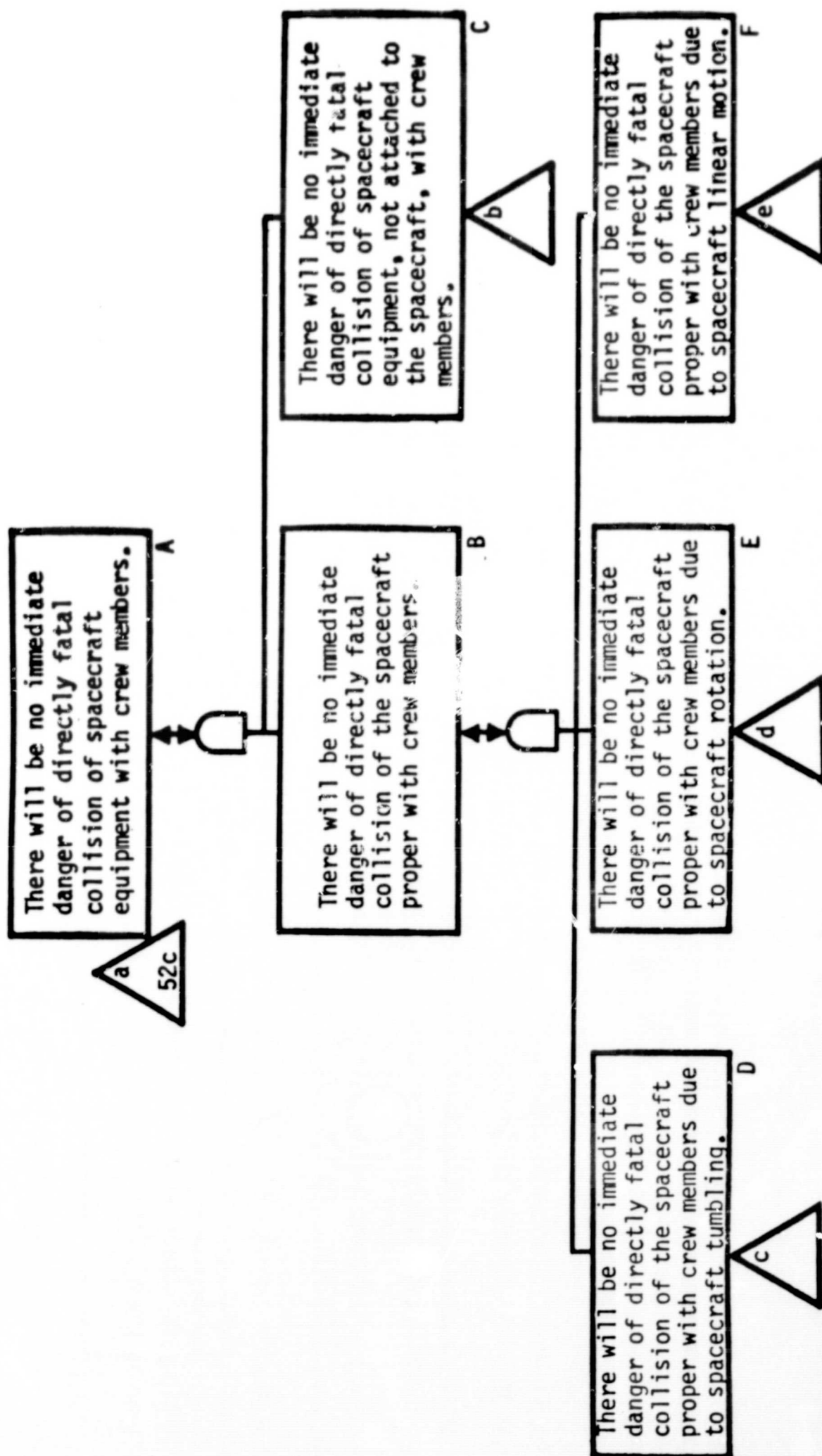
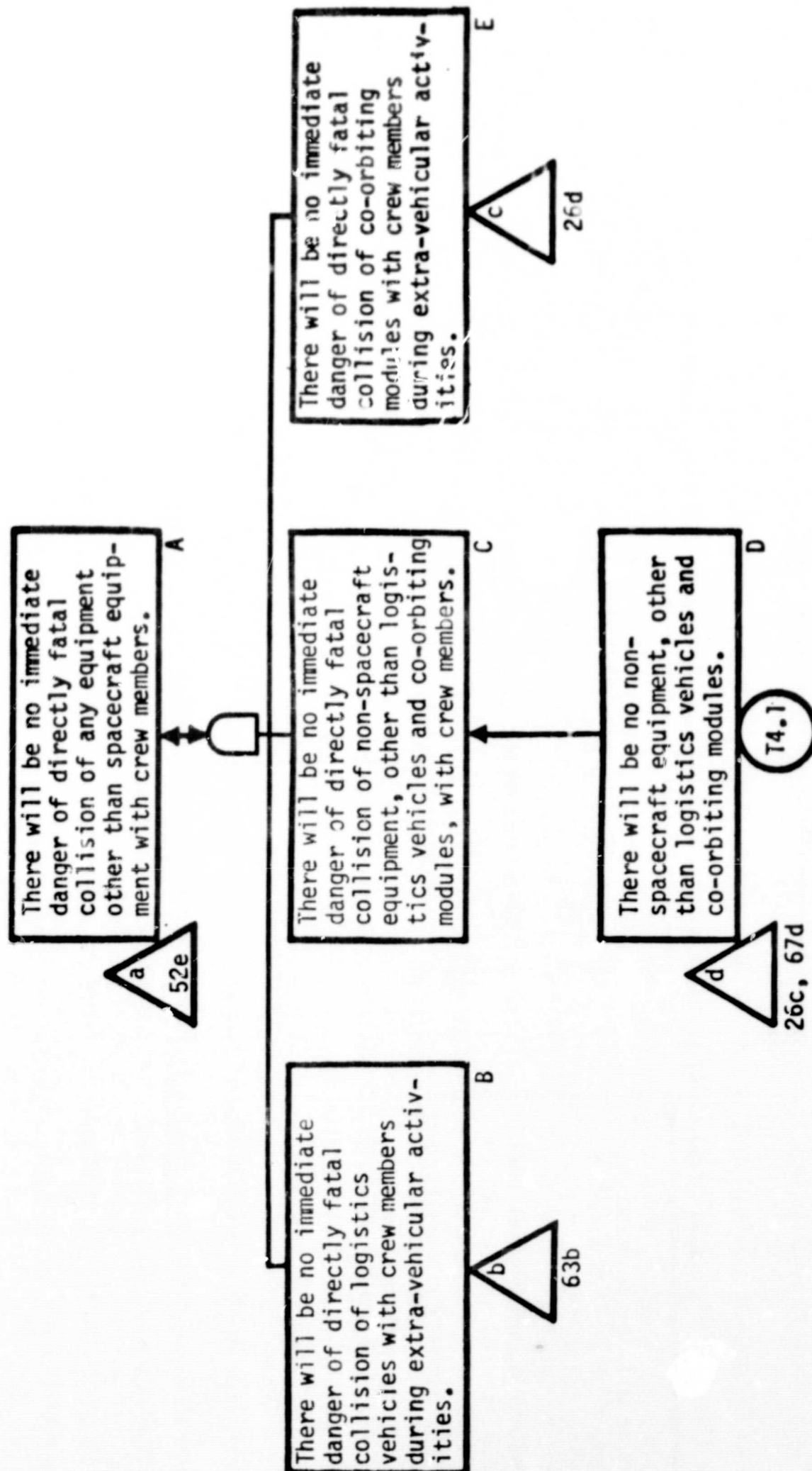


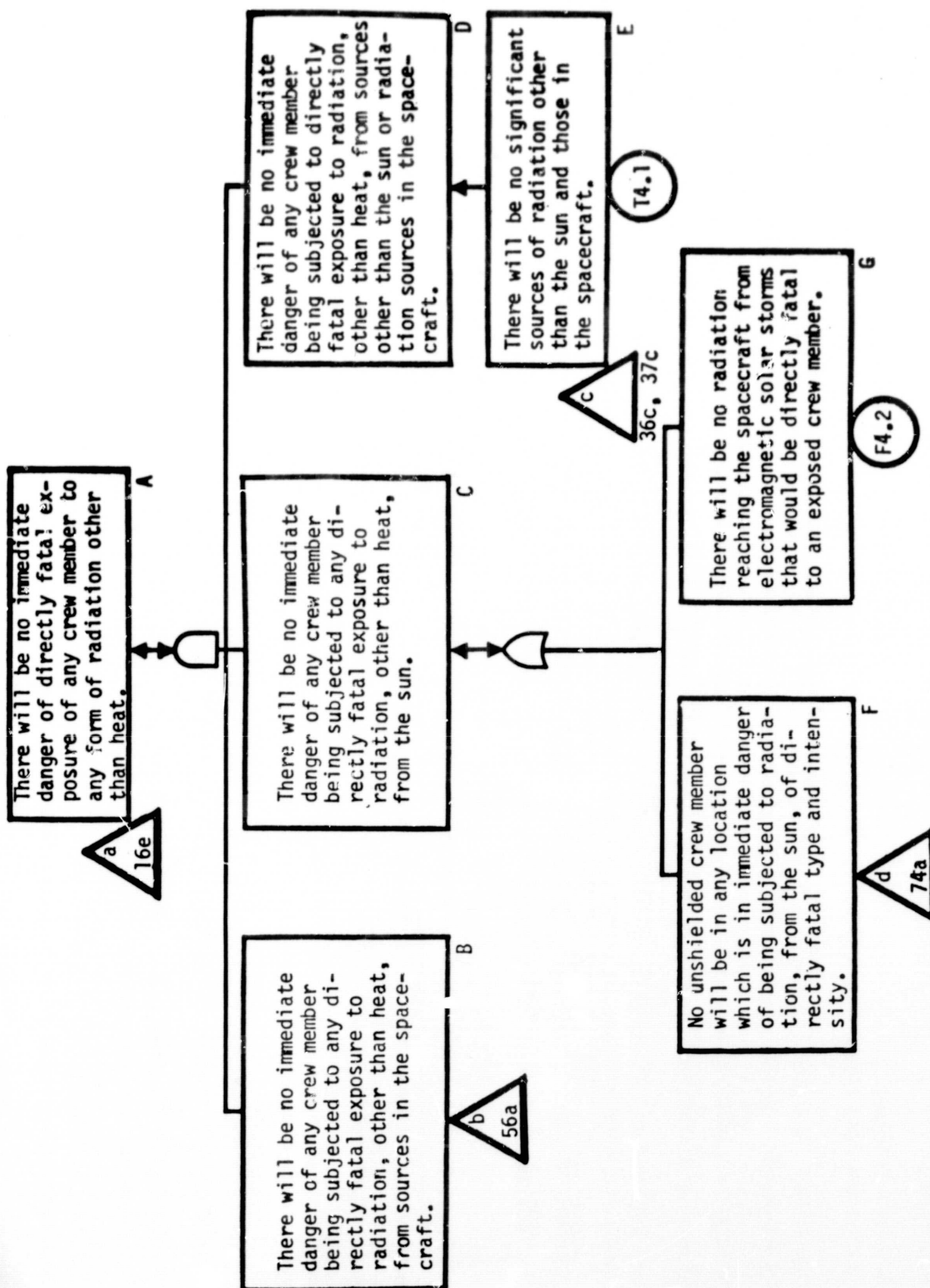
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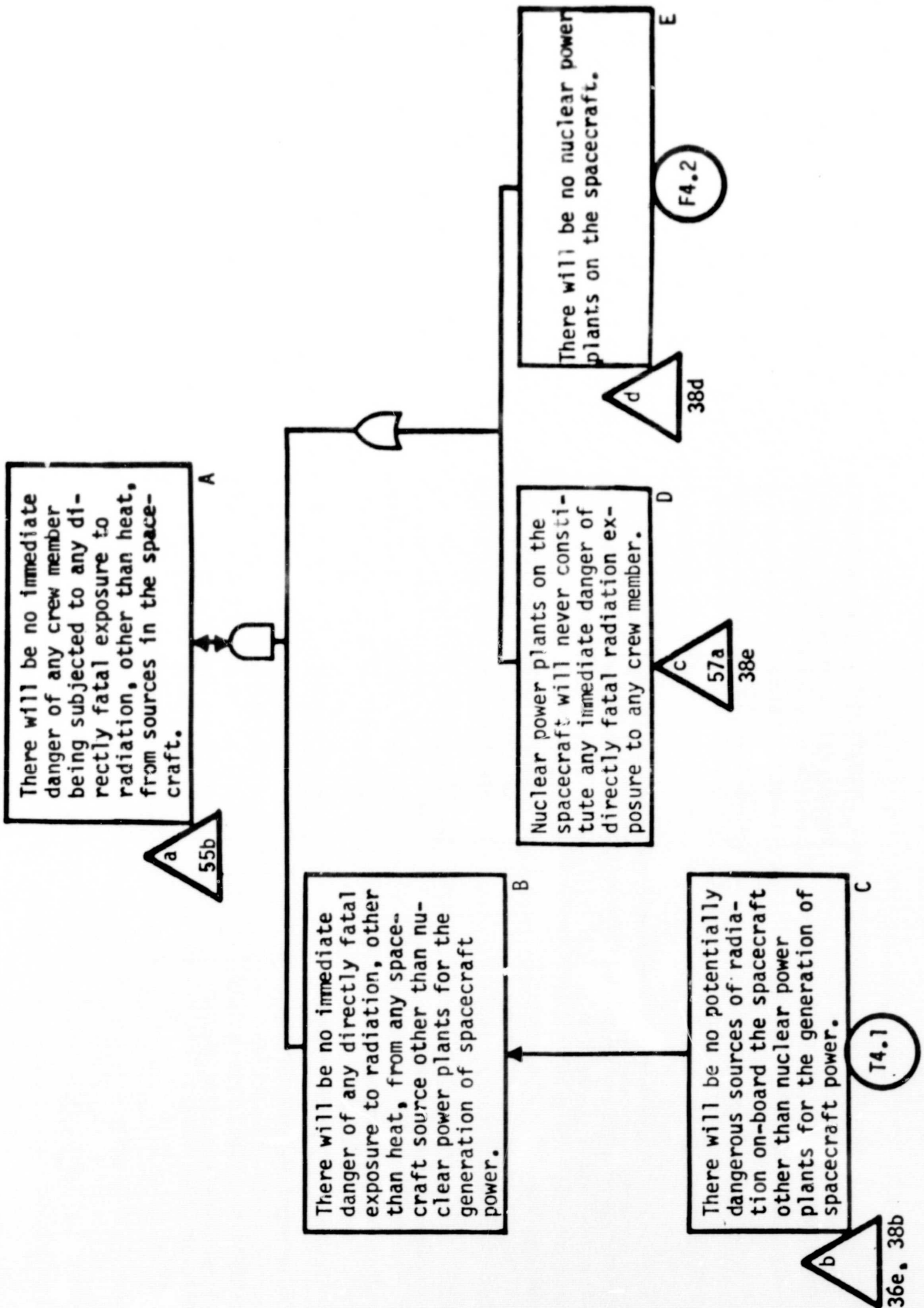
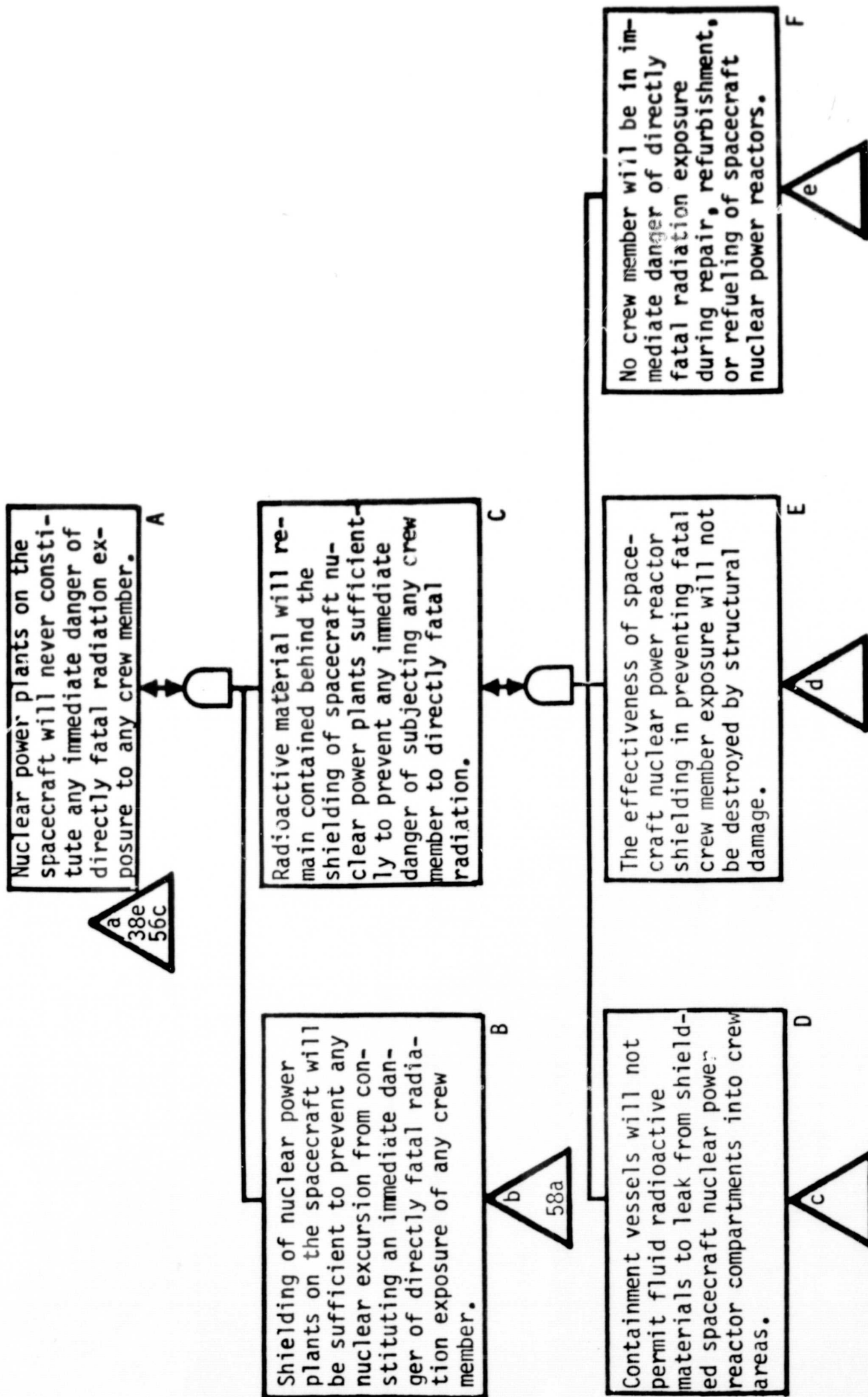


Chart No. 56

Chart No. 57



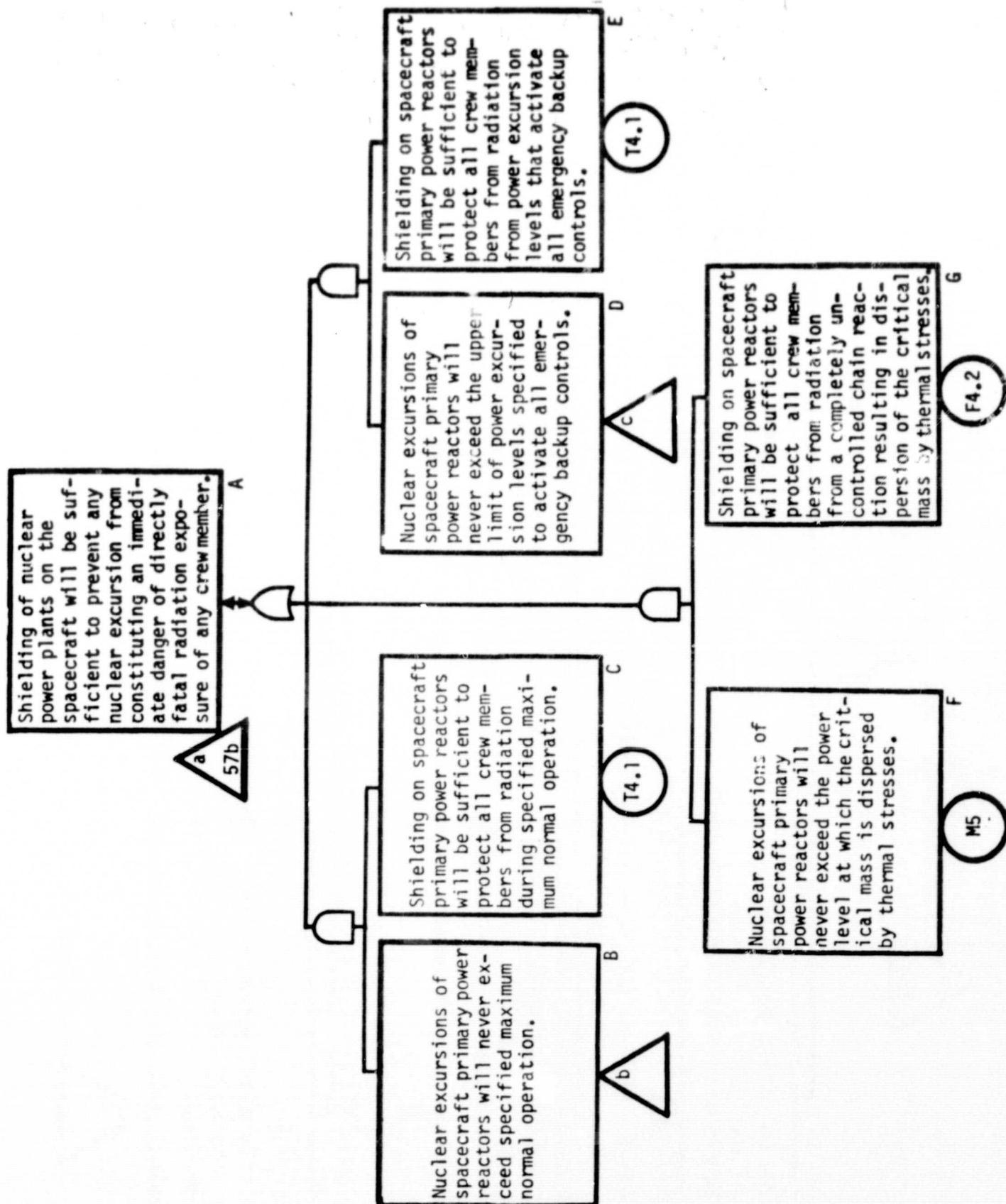
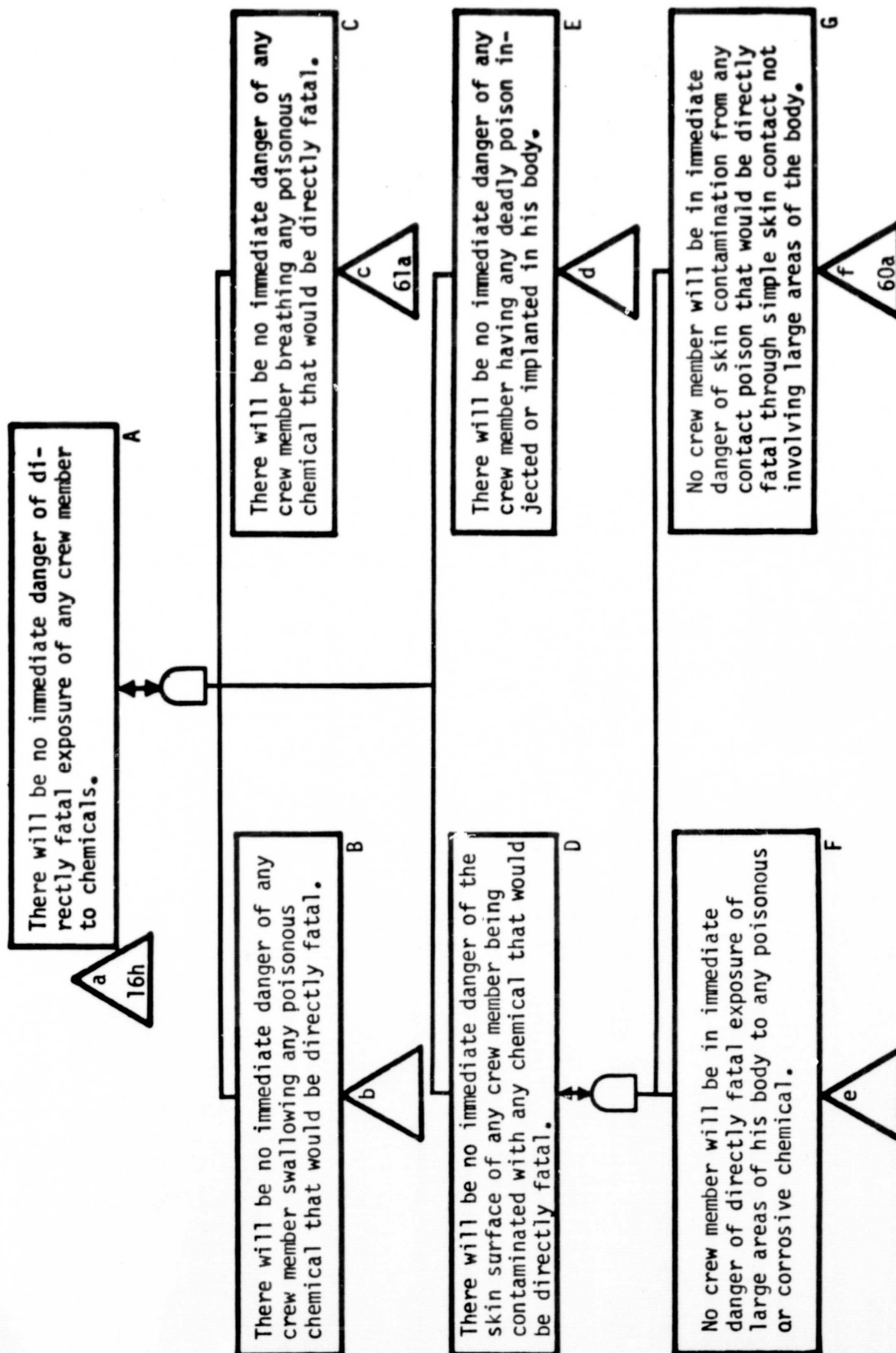
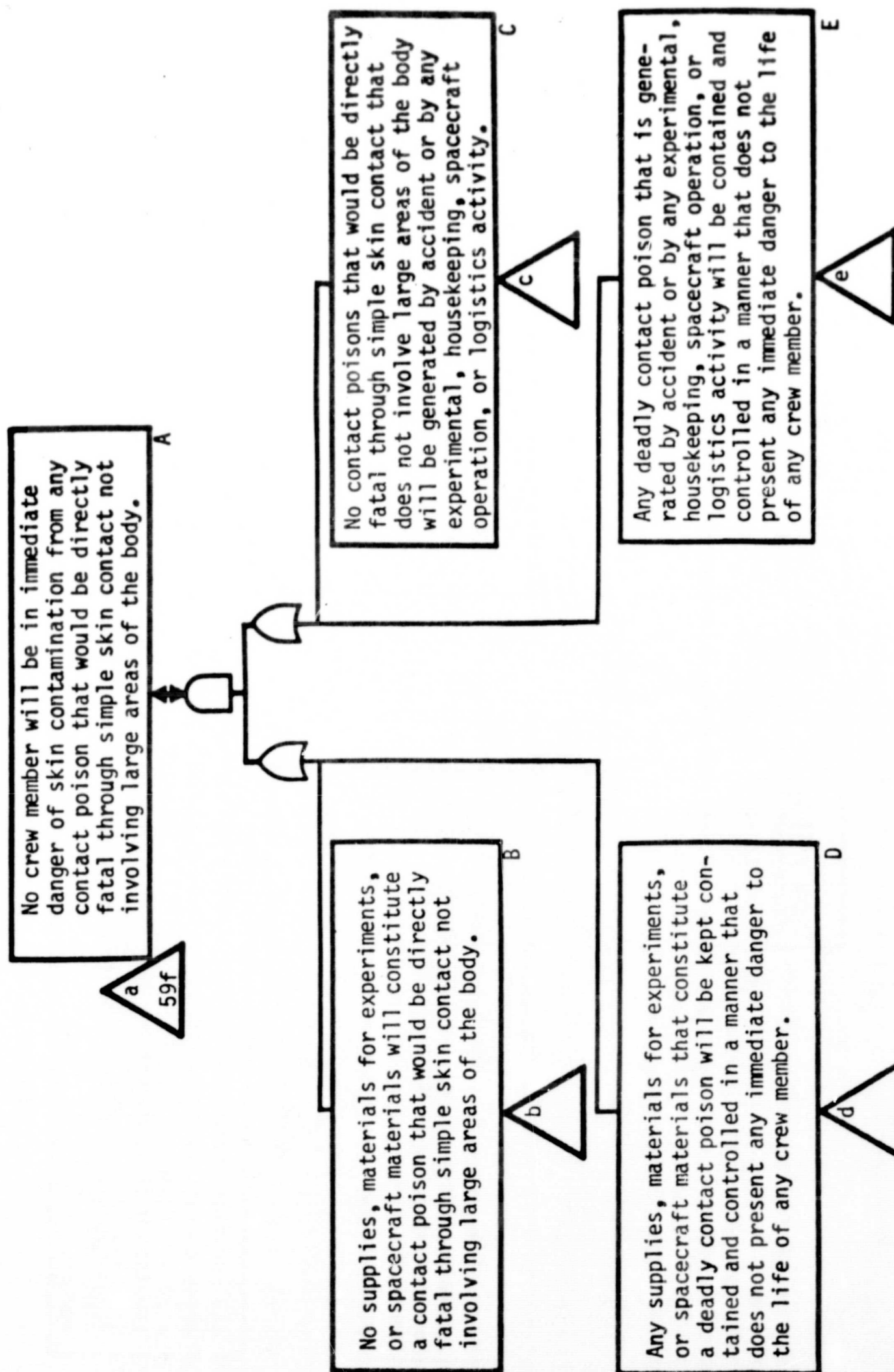
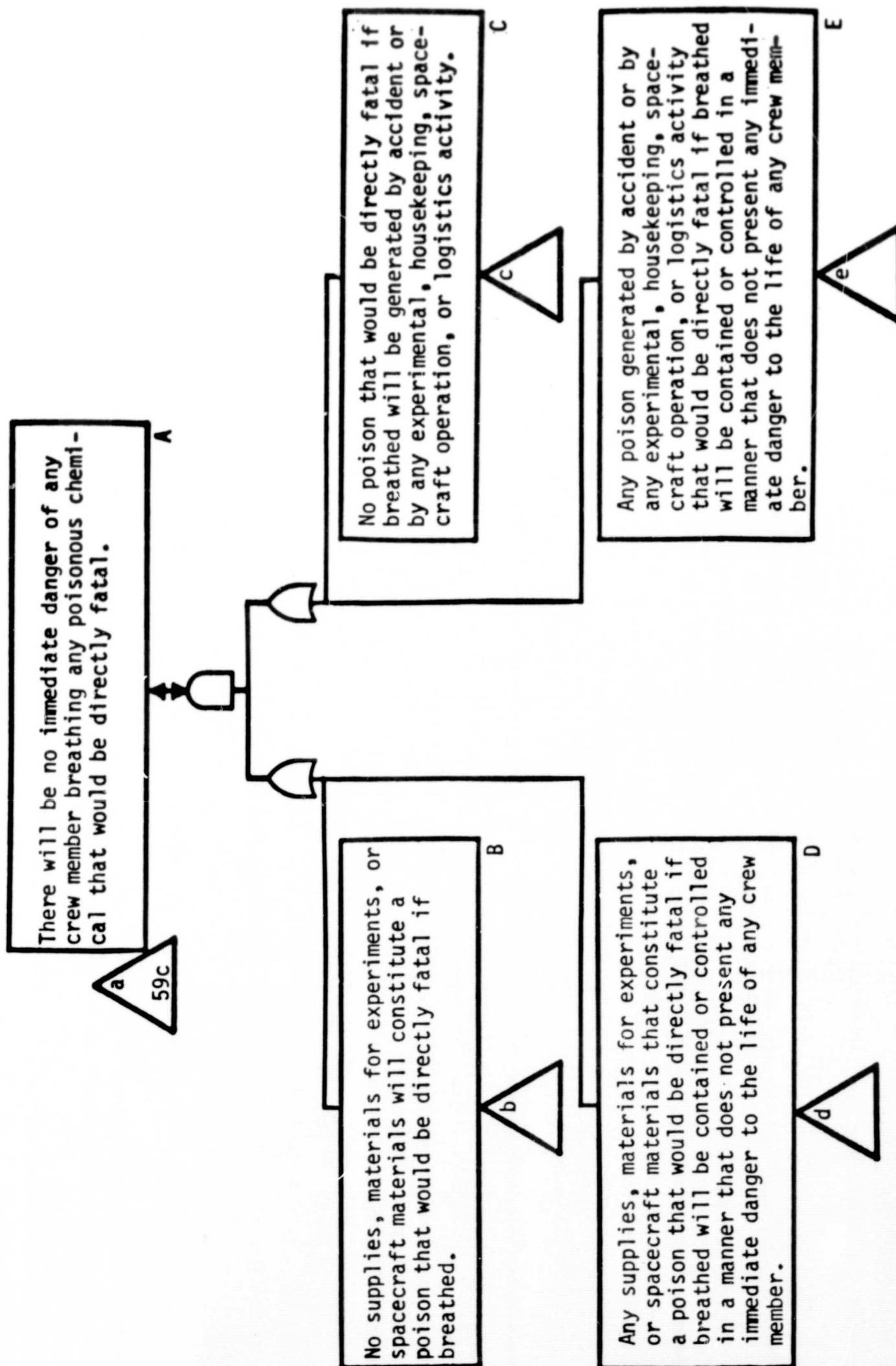


Chart No. 59







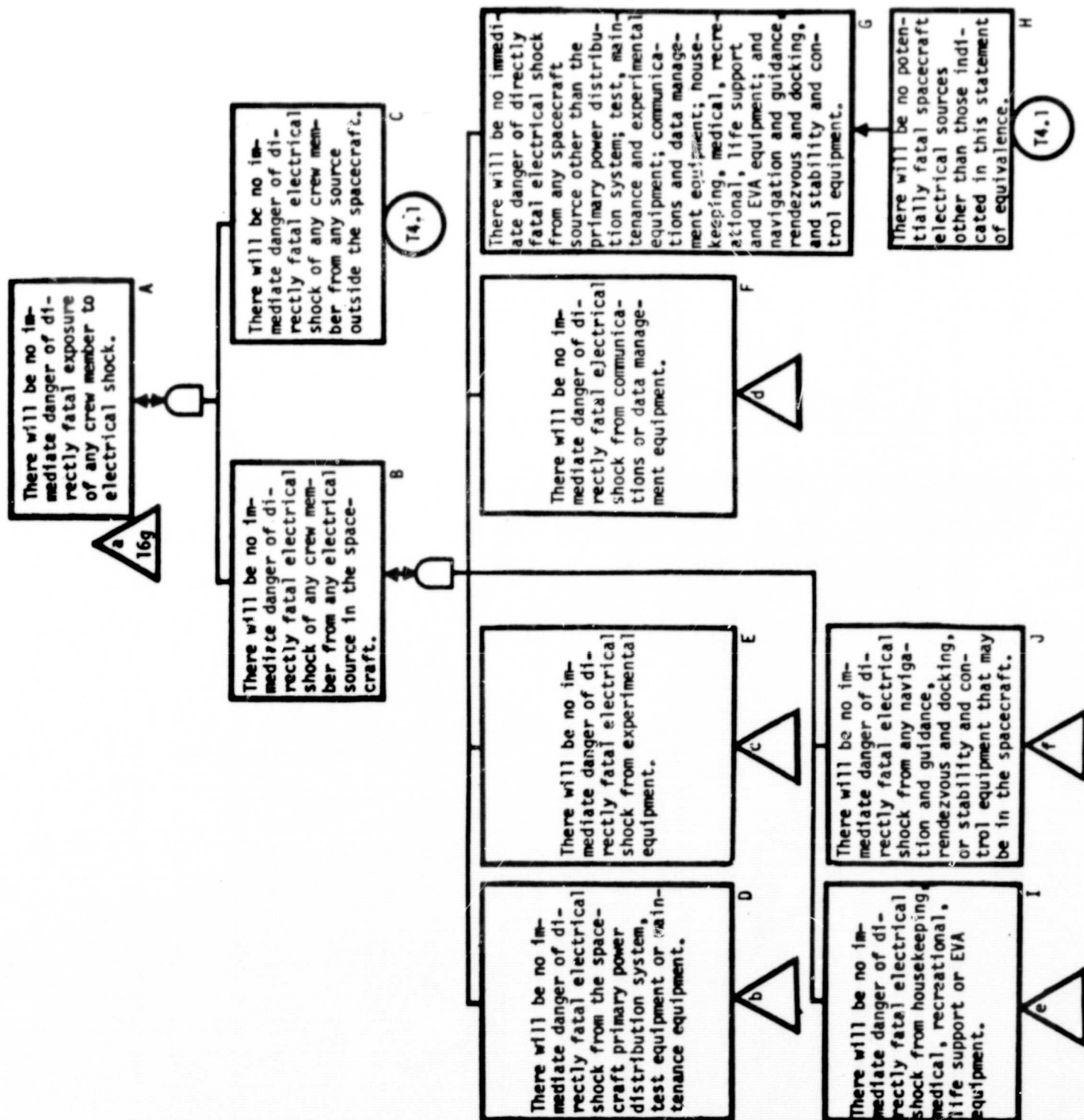
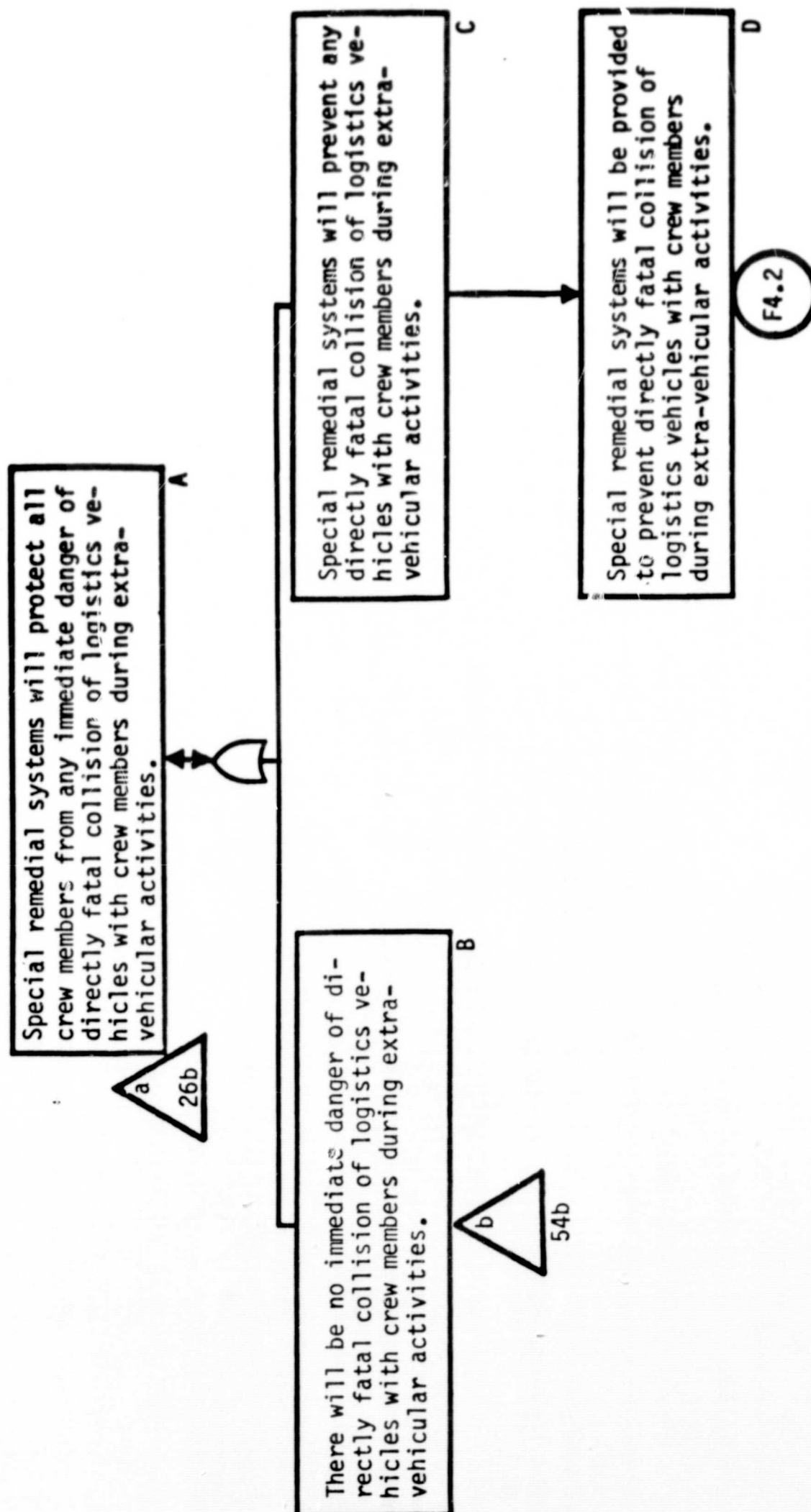
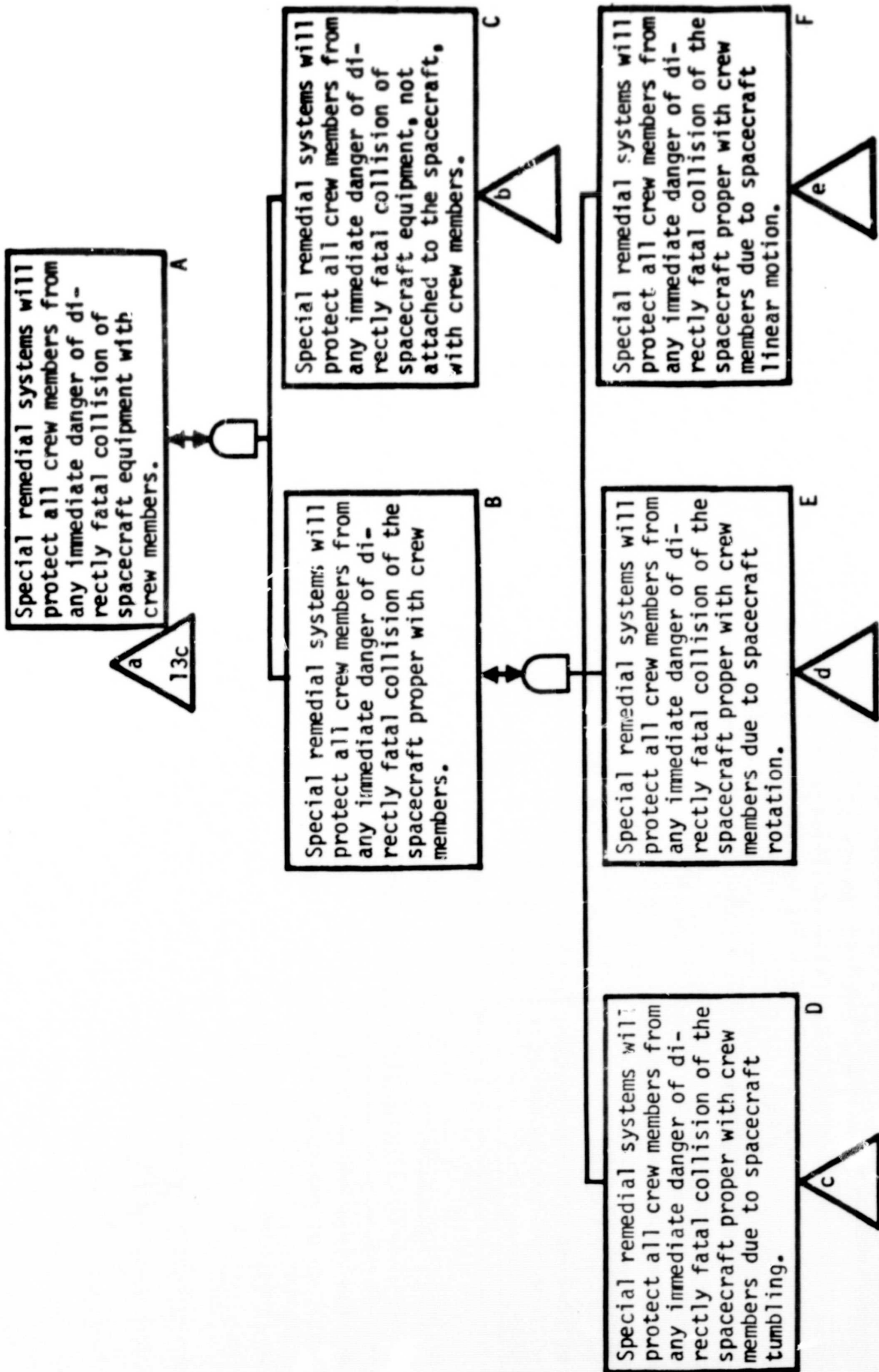
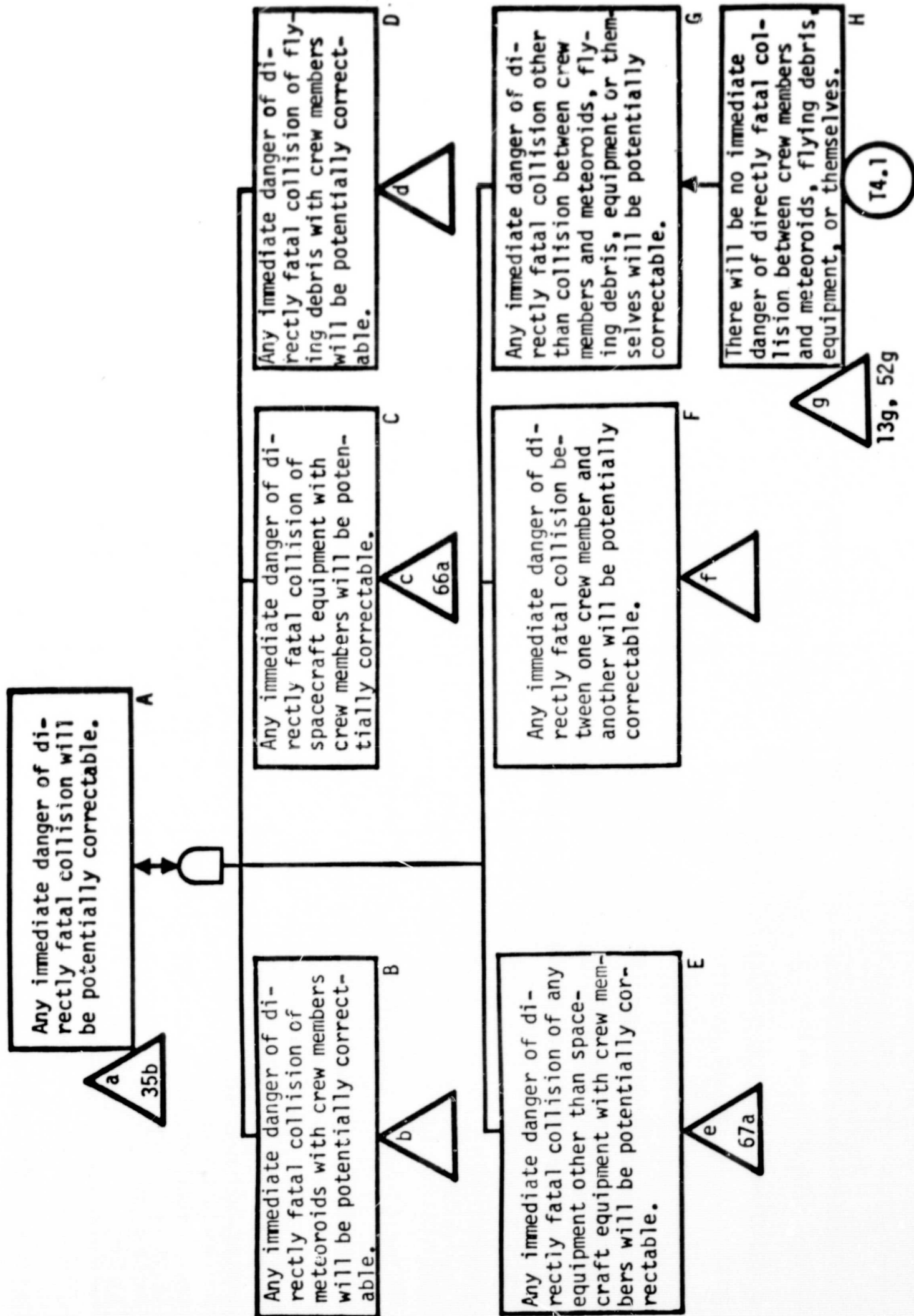


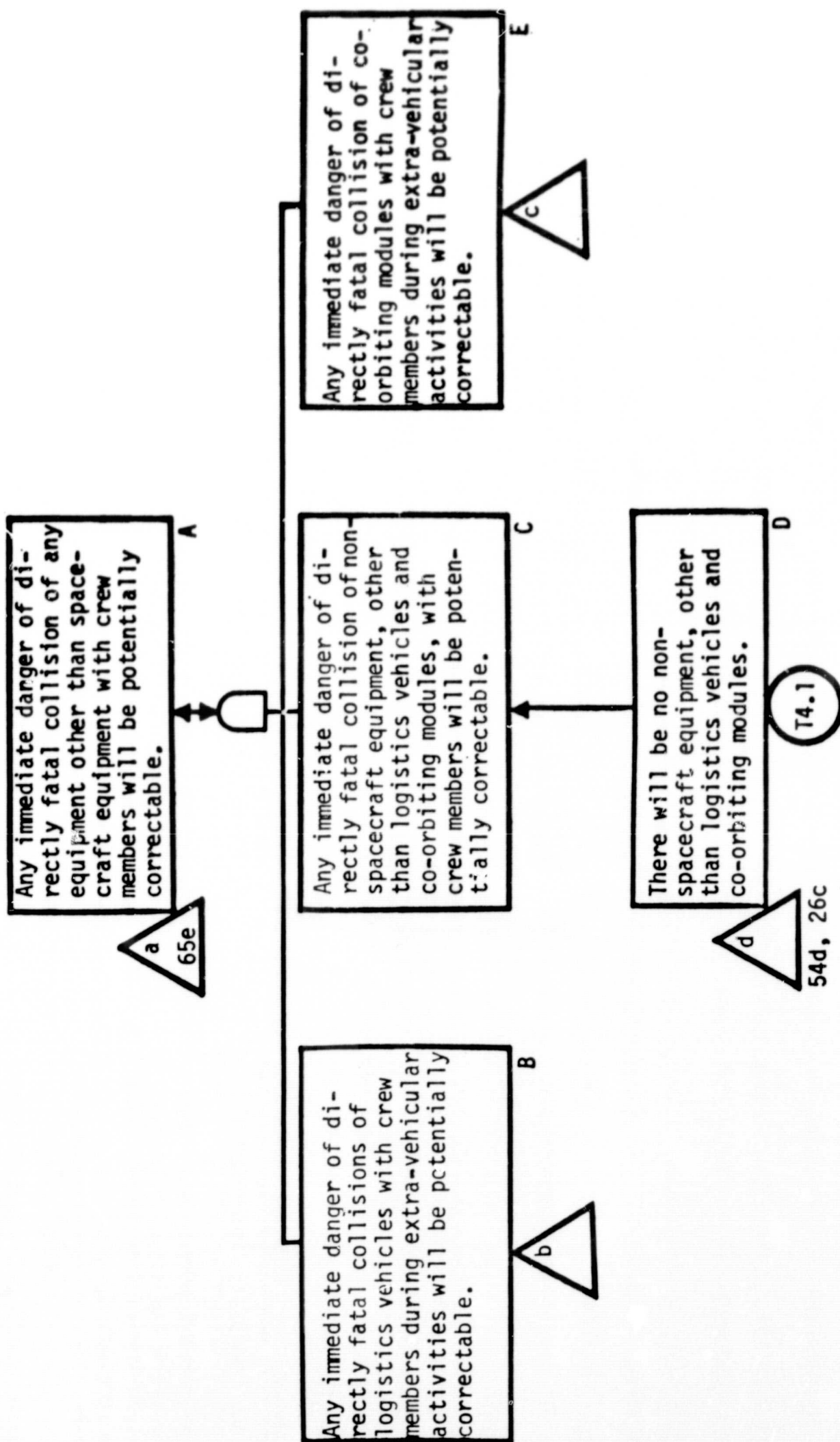
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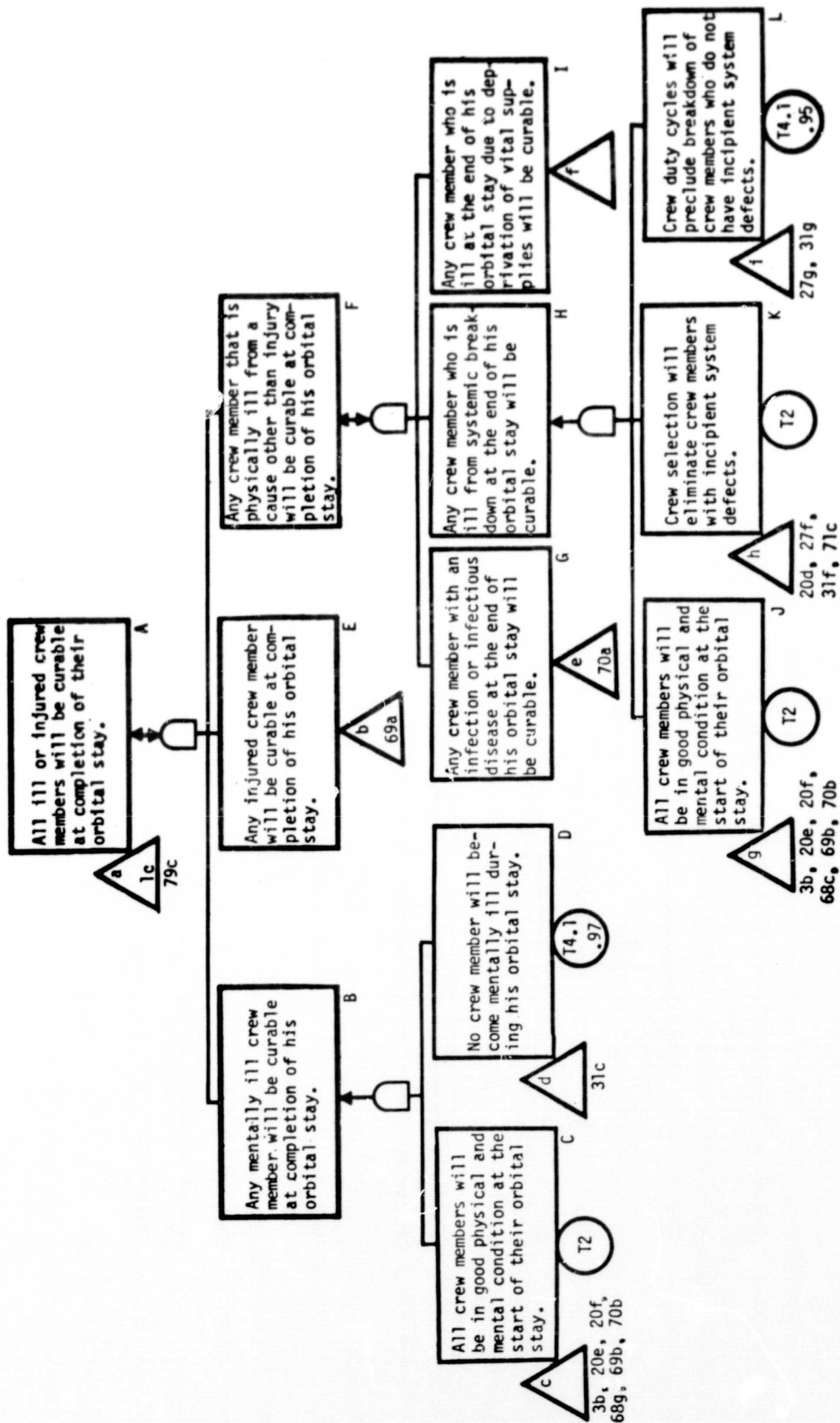
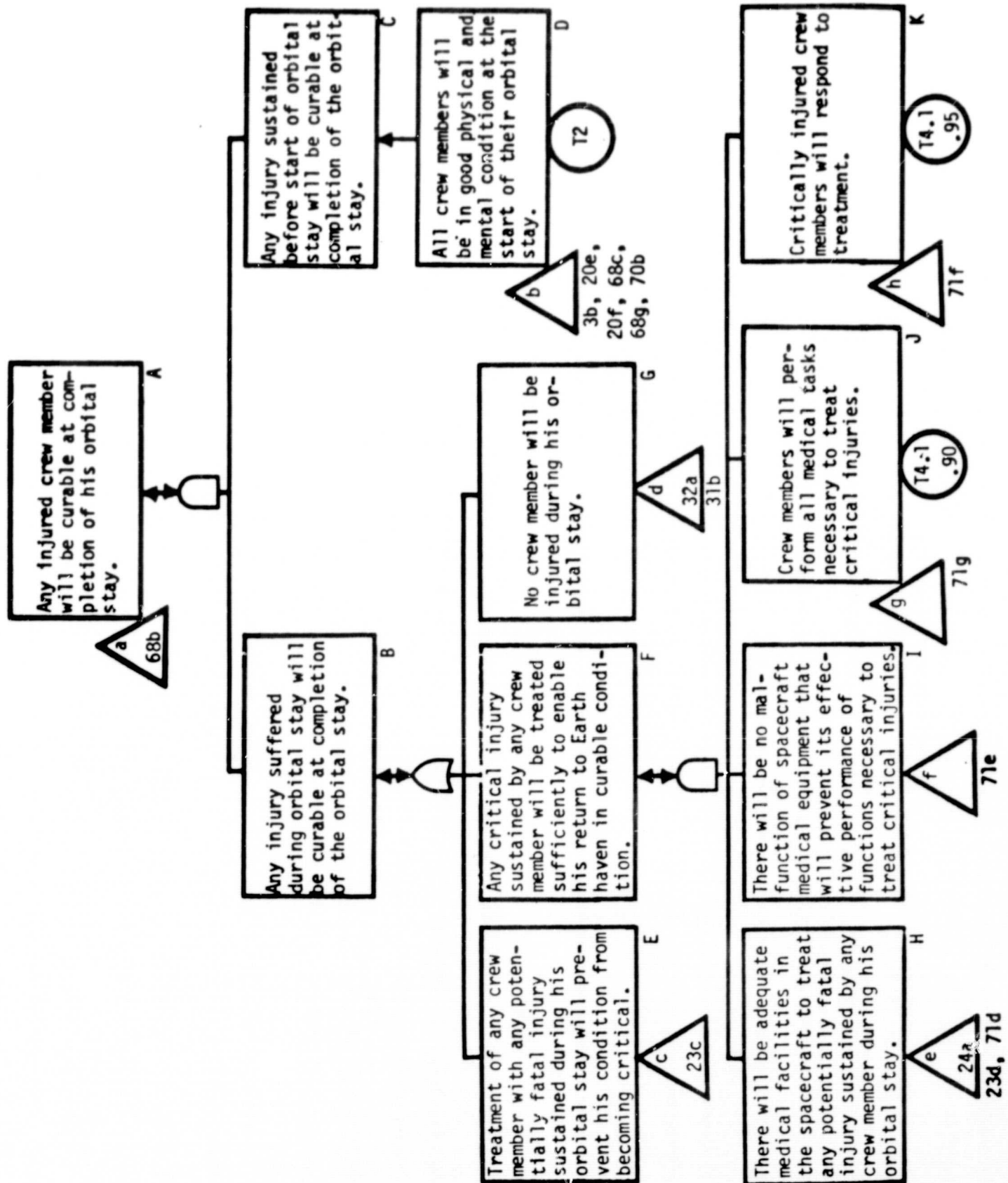


Chart No. 68

Chart No. 69



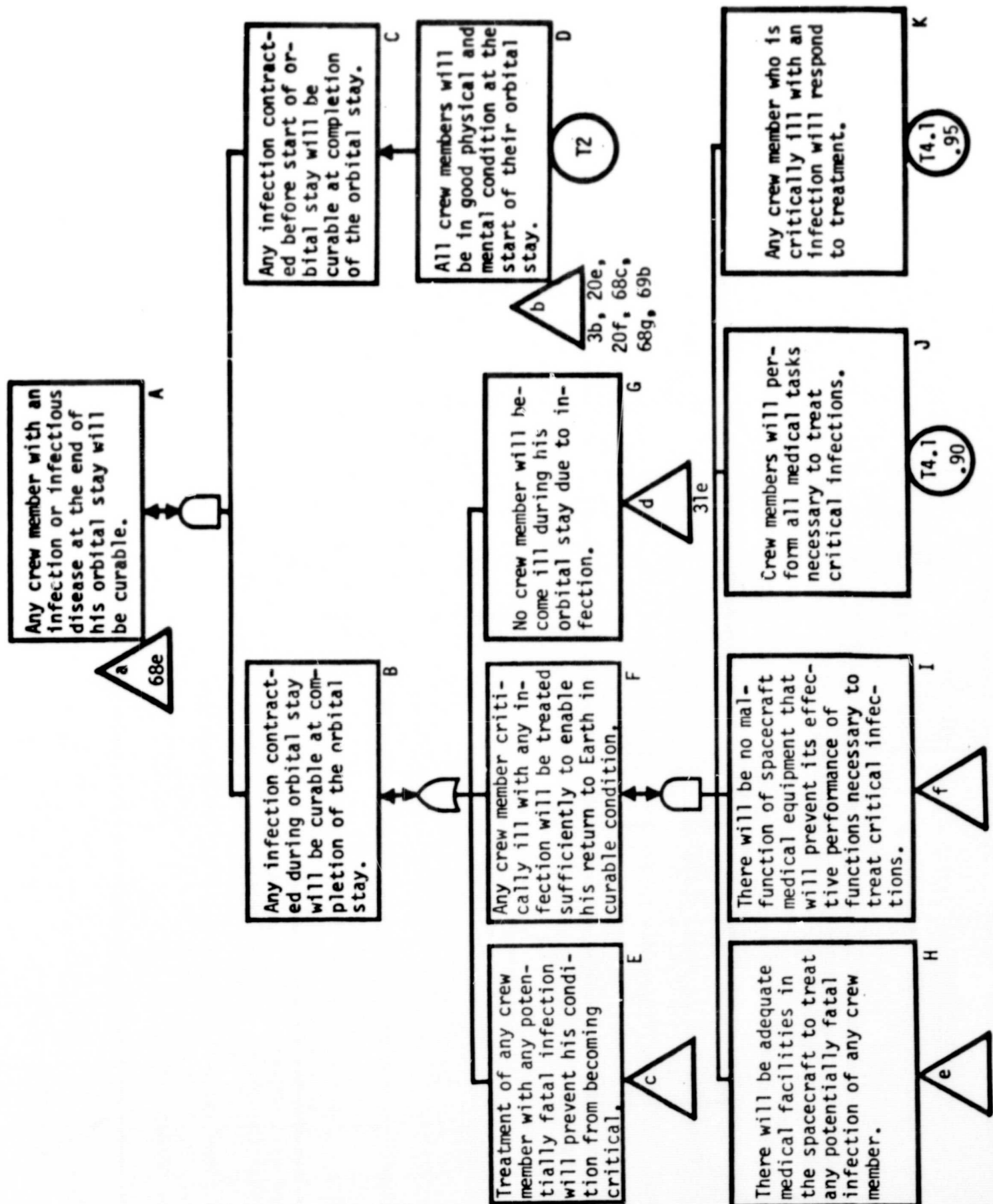
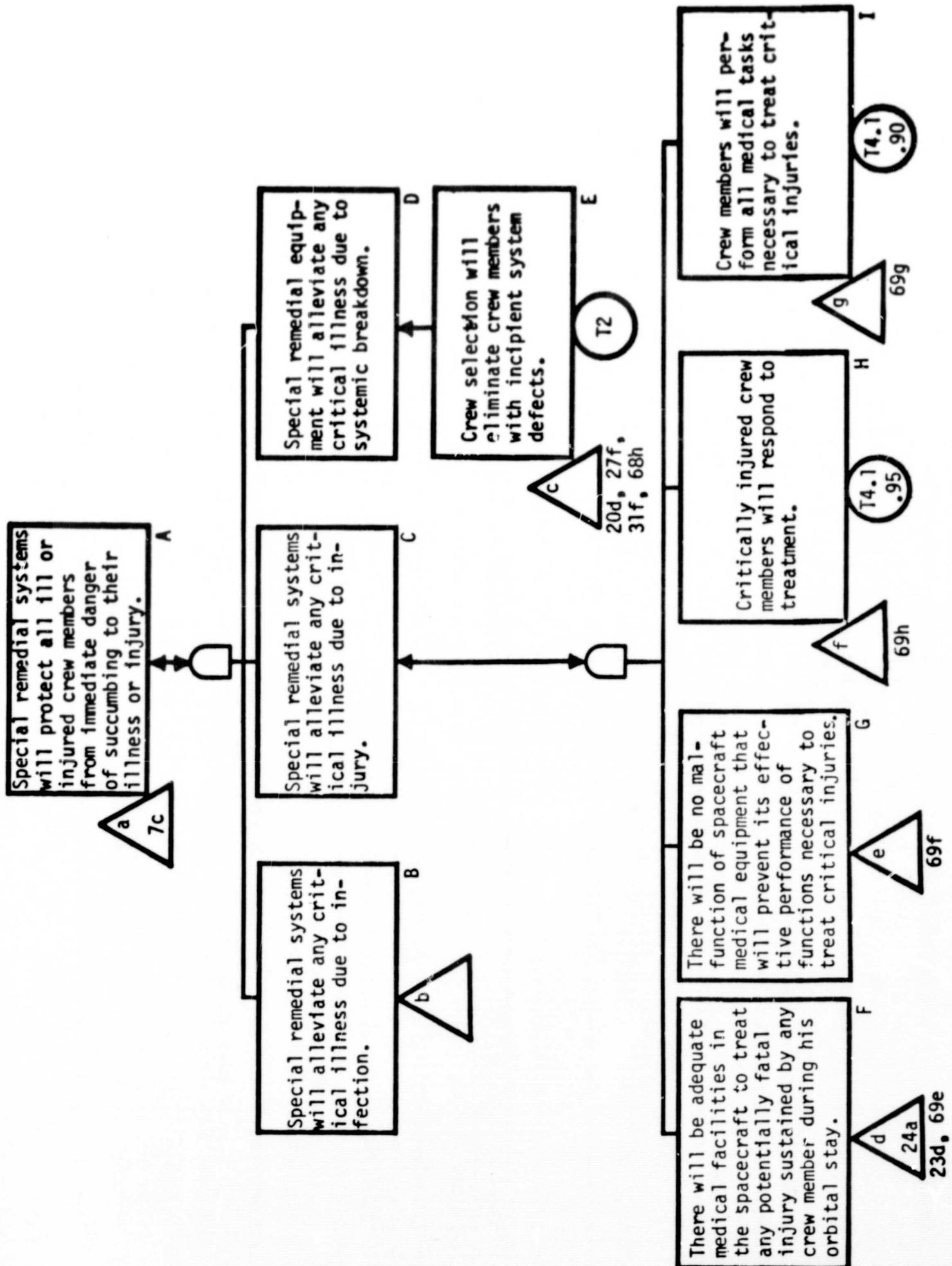


Chart No. 70

Chart No. 71



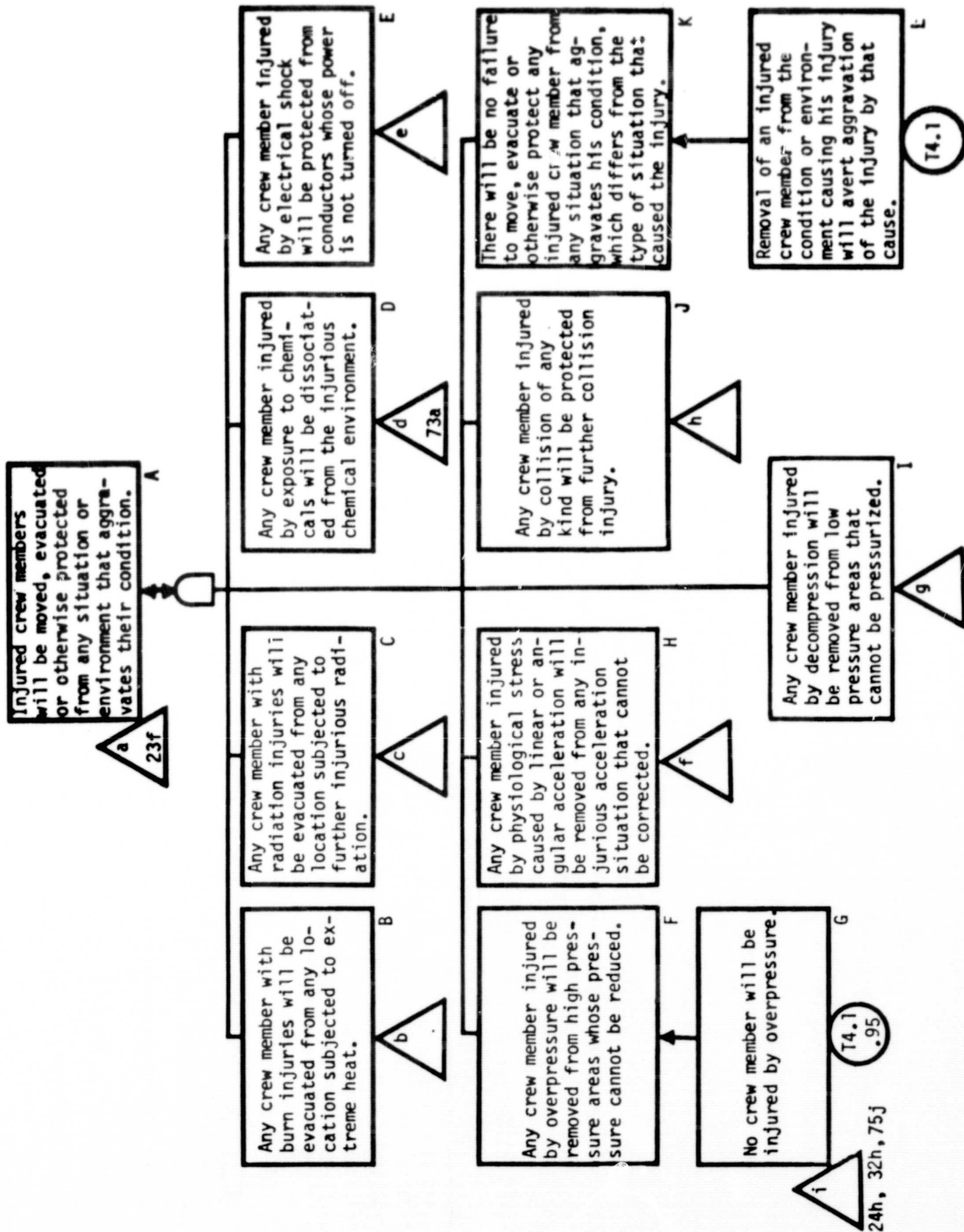
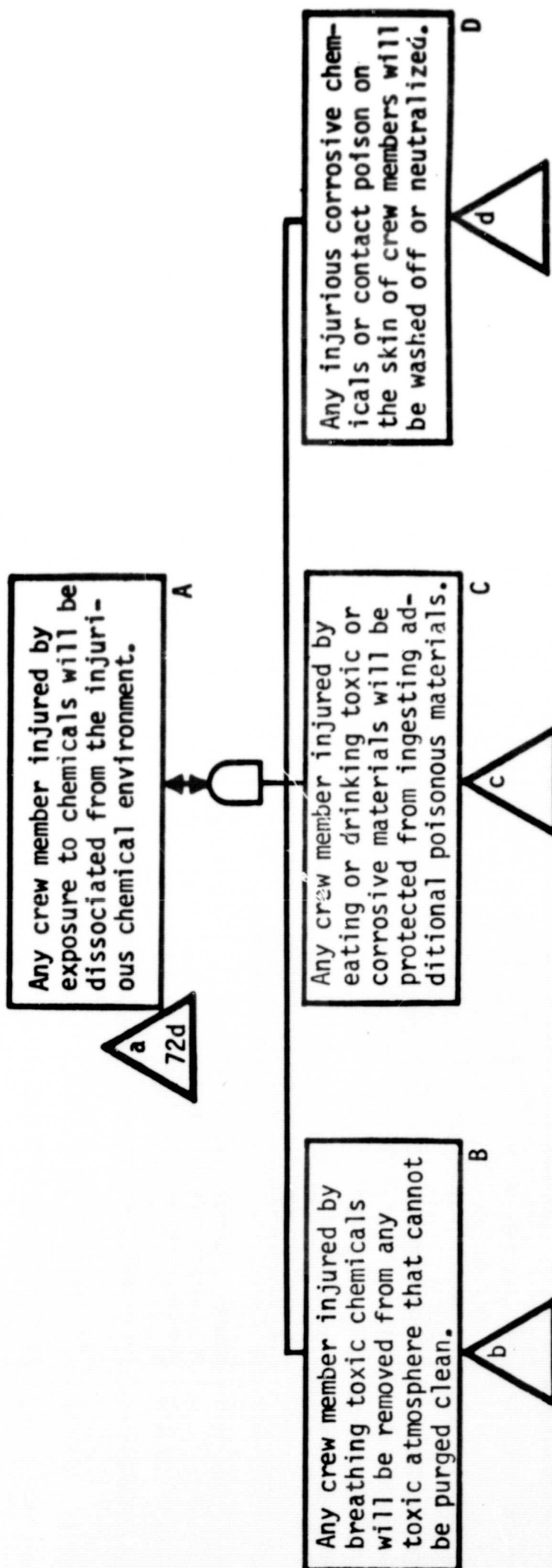


Chart No. 72



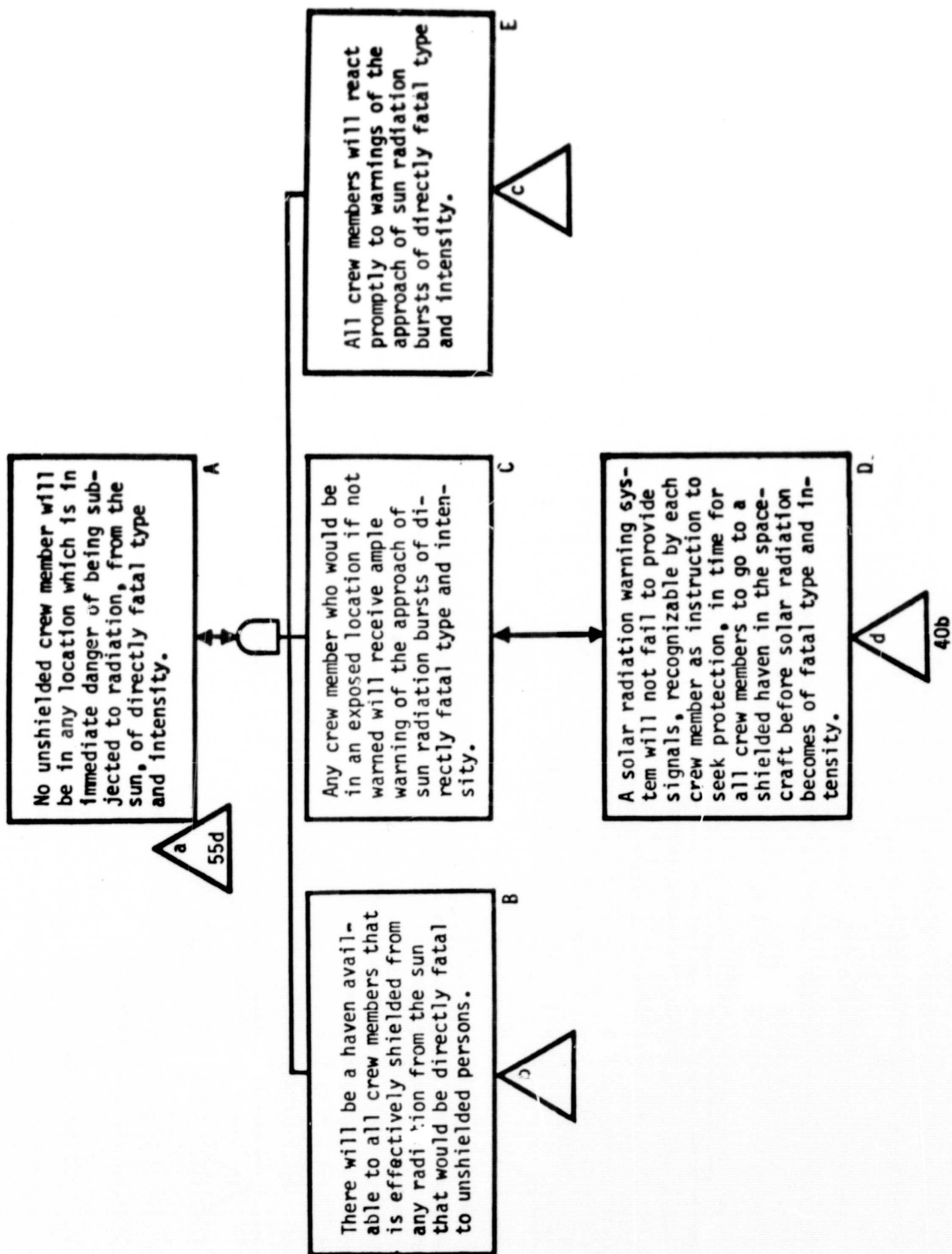
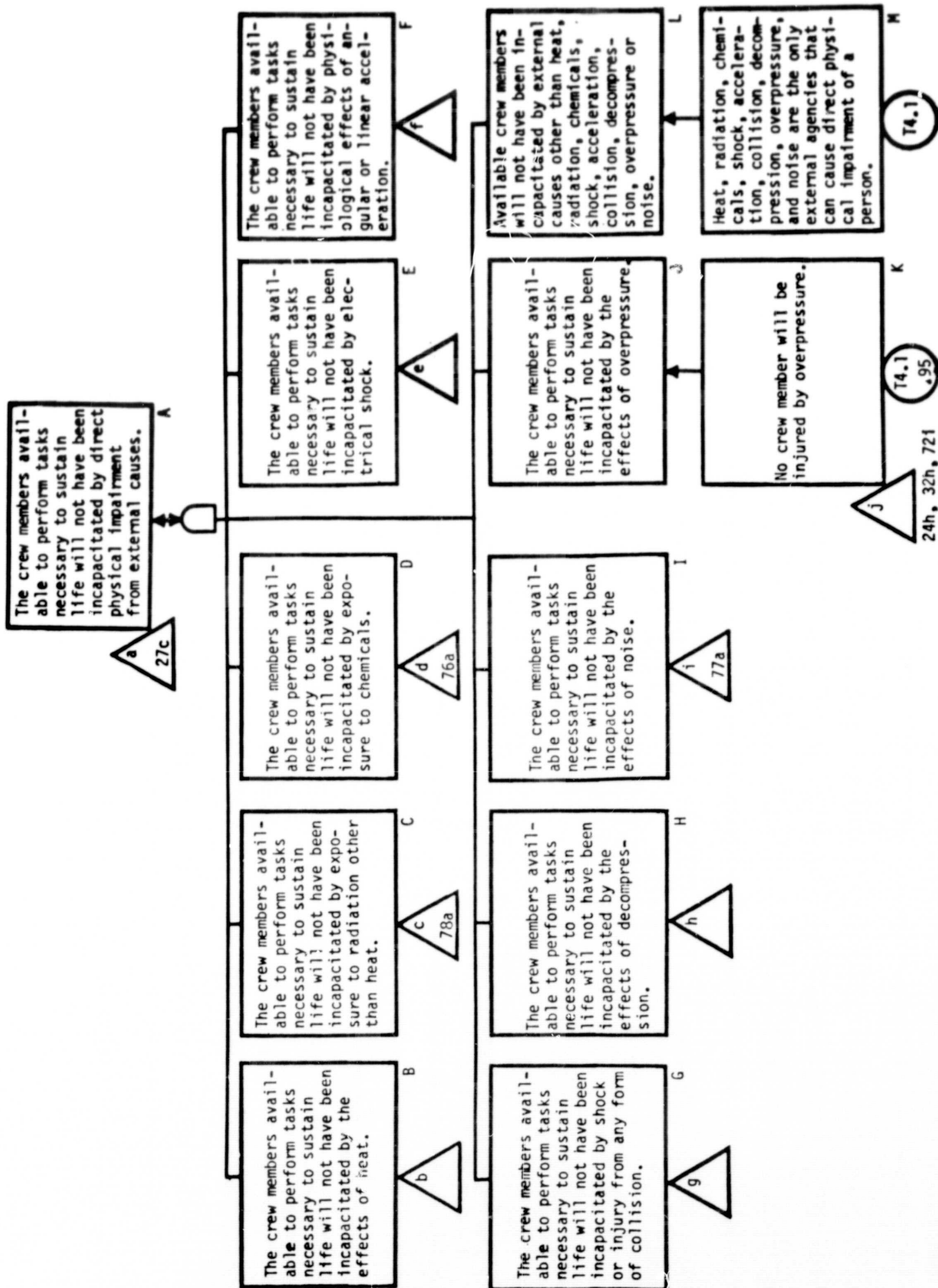


Chart No. 74



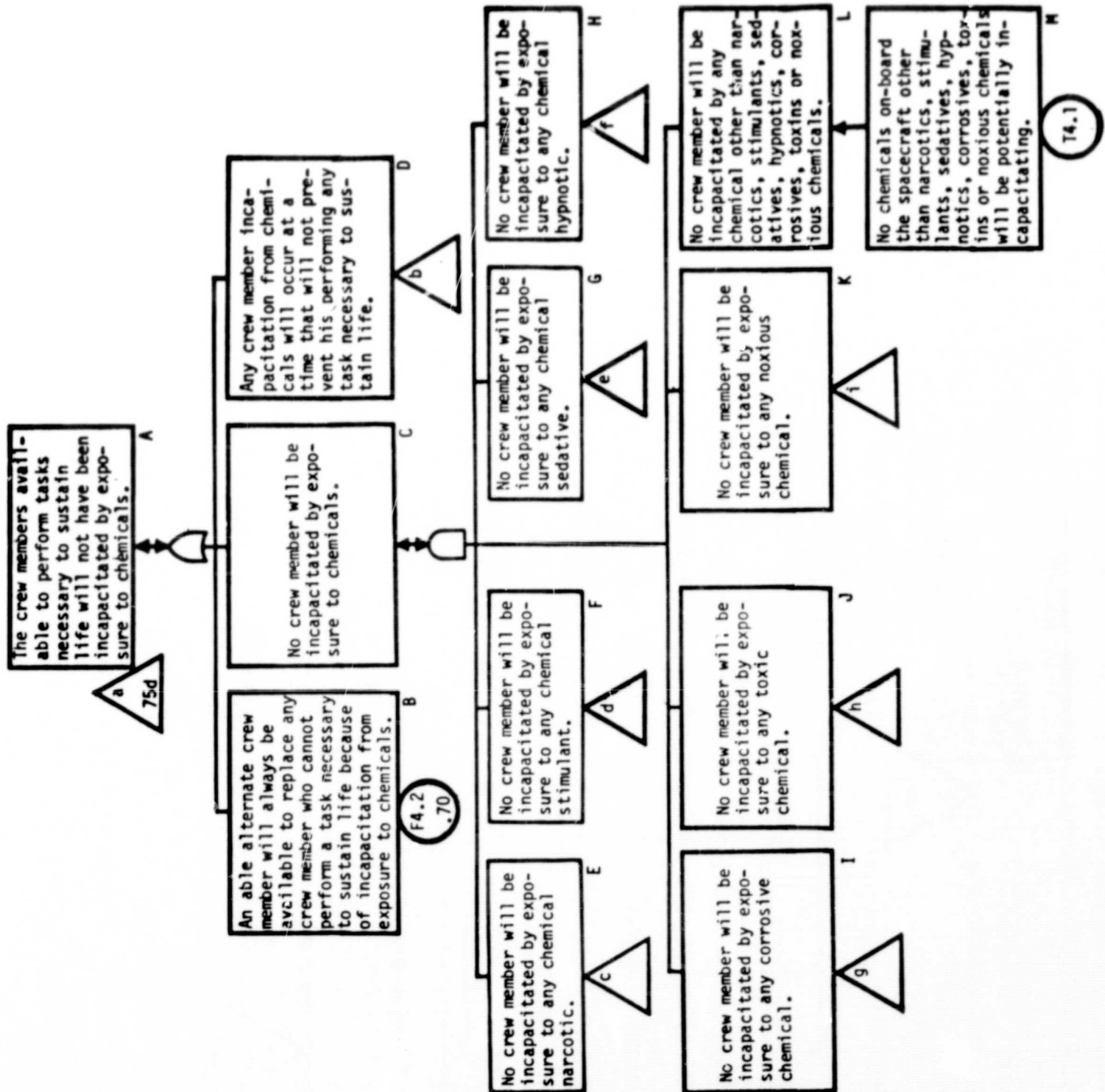
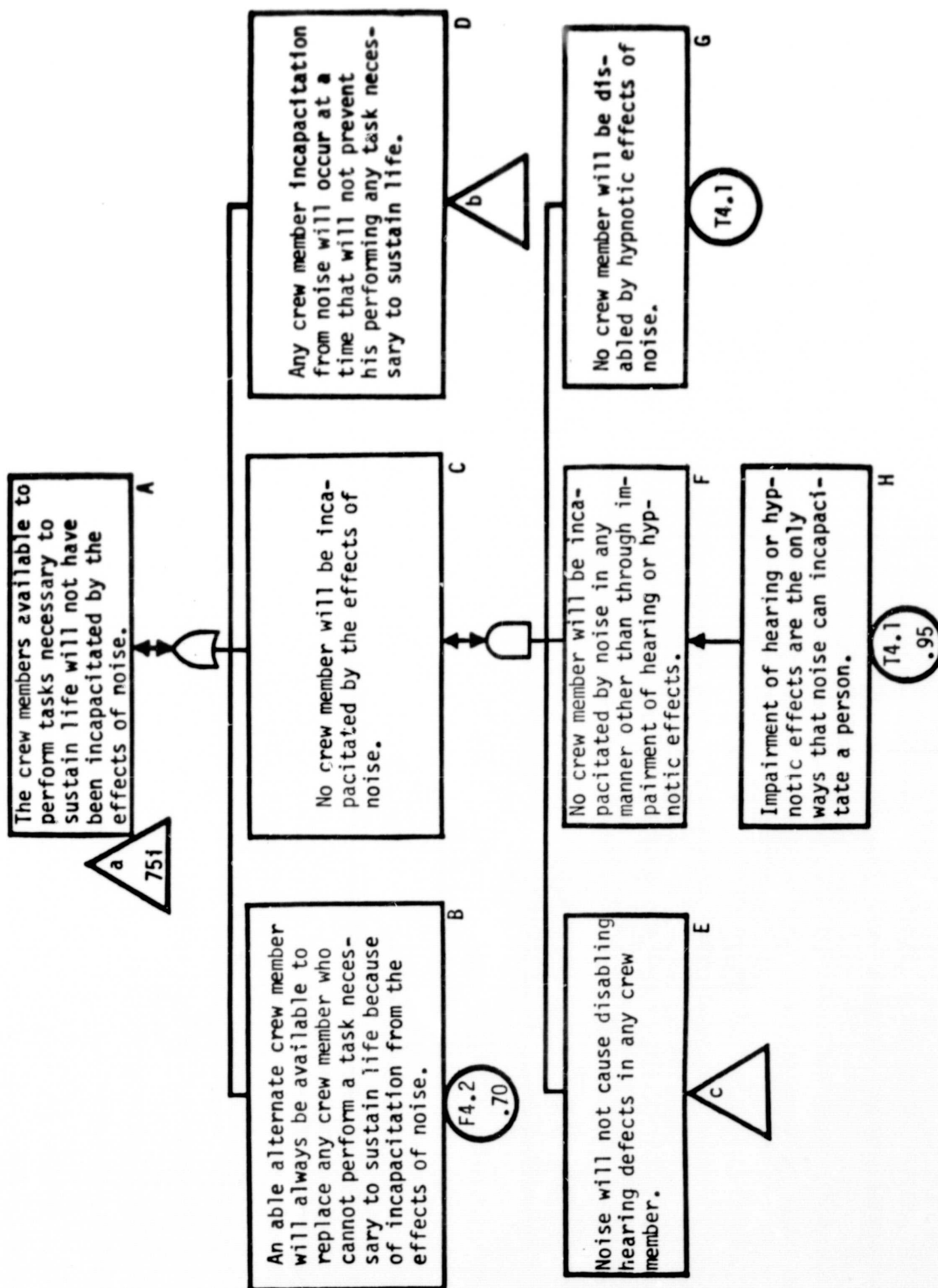


Chart No. 76



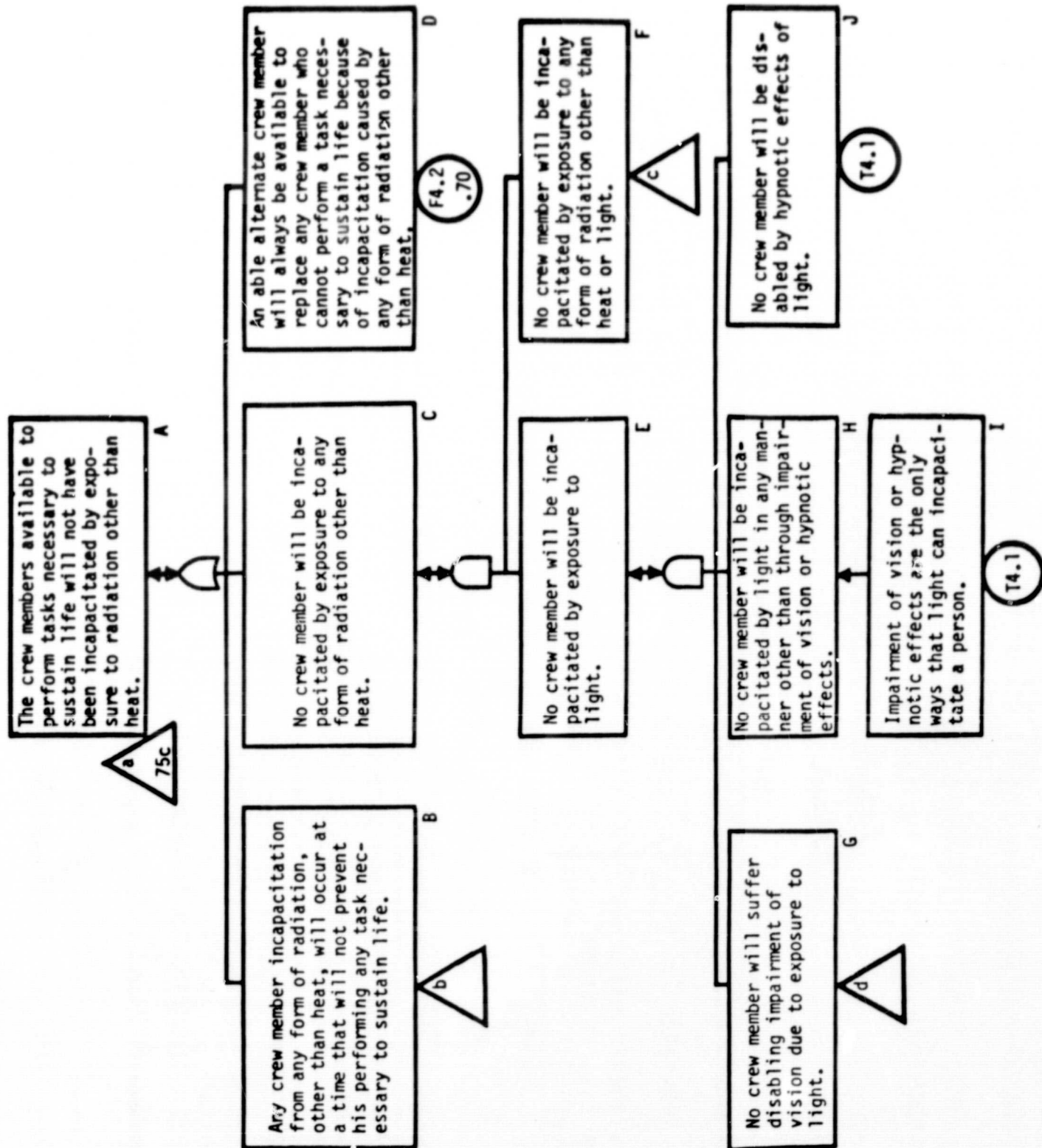
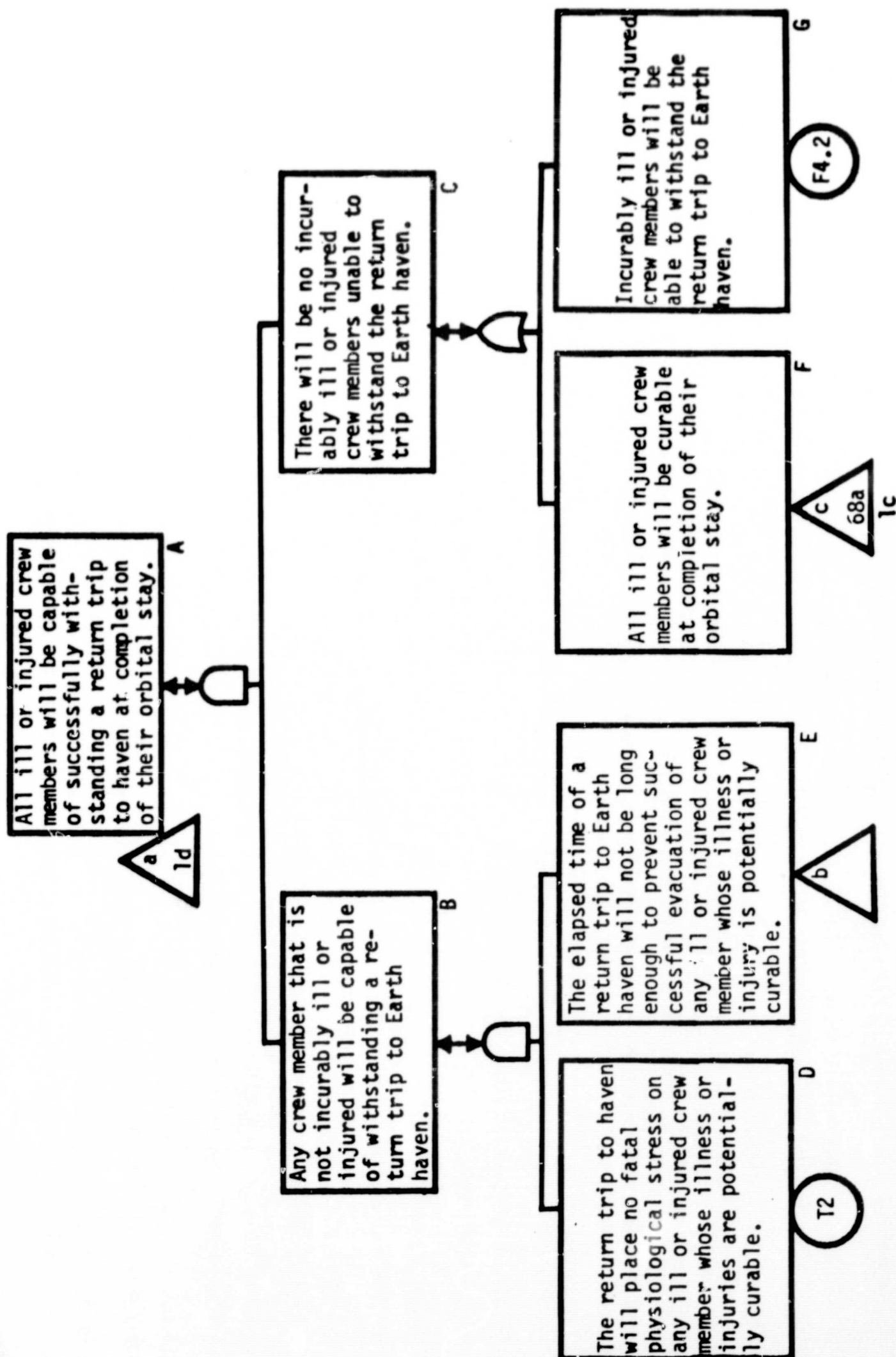


Chart No. 78



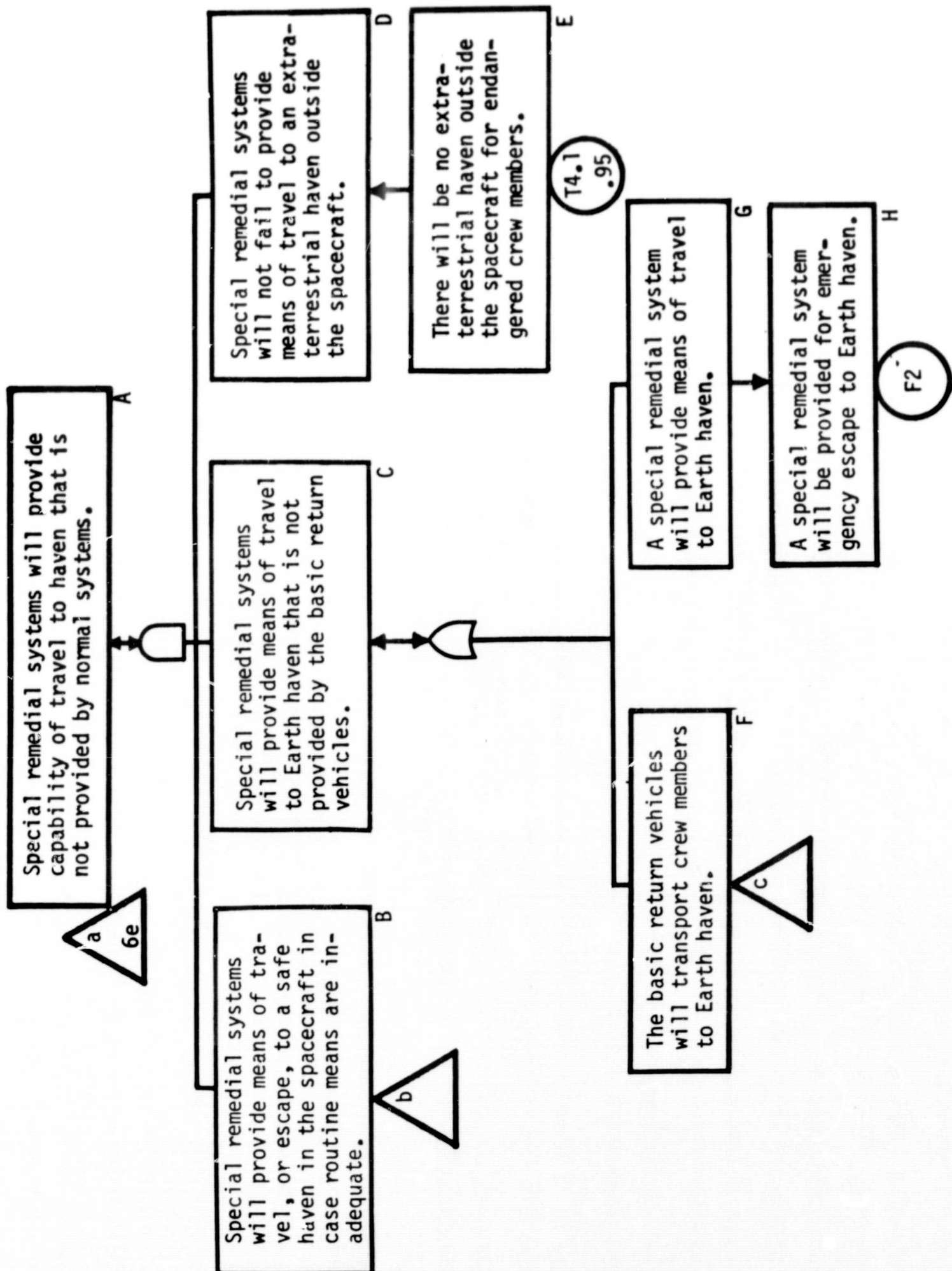
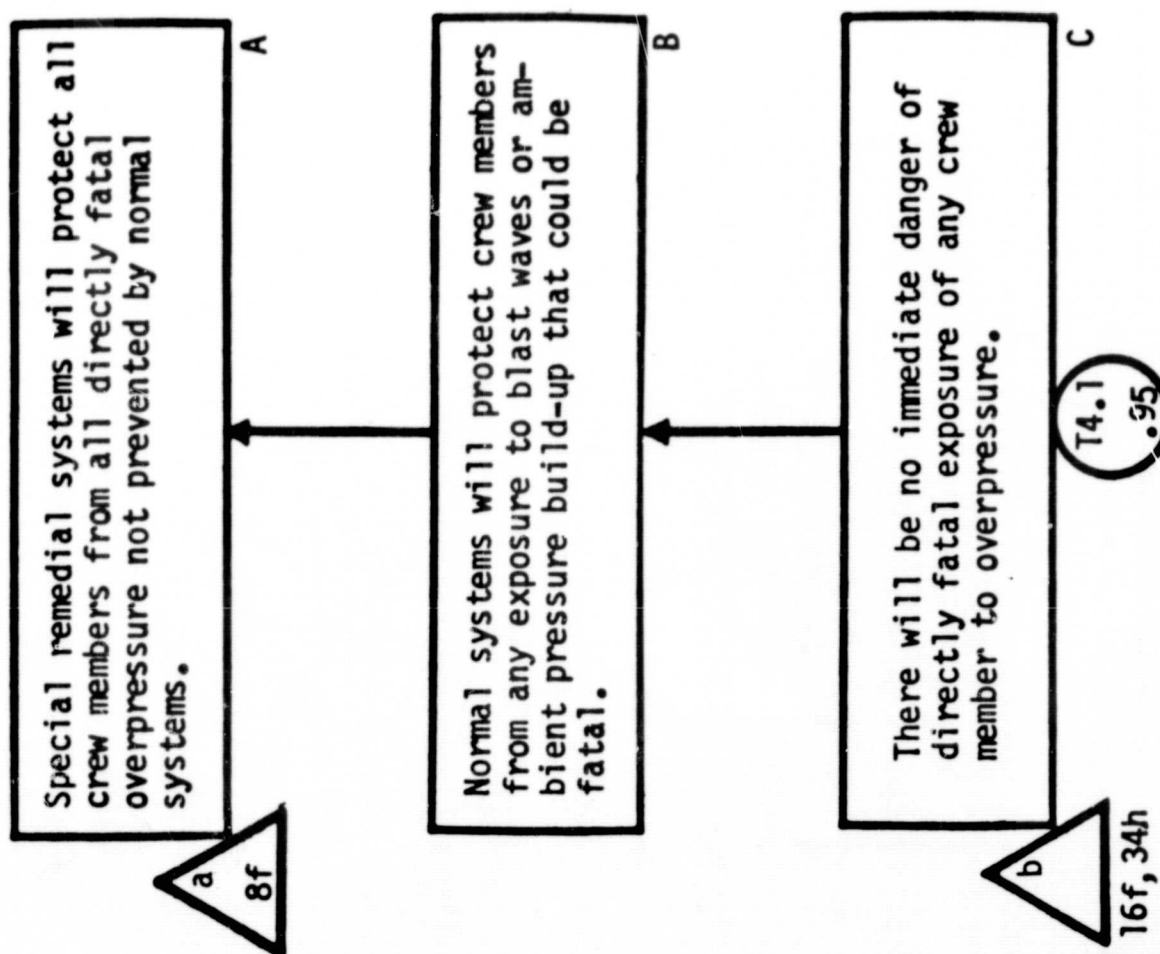


Chart No. 80

D2-113070-9



D2-113070-9

7.0 REFERENCES

The references listed on the following pages were used during the time the logic analysis was being developed. Reference numbers match those of the master reference list given in Document D2-113070-5, Crew Safety Guidelines.

No.	Title	Report No.	Source	Date	Contract No.	Cl.
16	Concept for Space Flight Safety, A	---	R.B. Richards-- Paper presented at the 4th Space Con- gress, Canaveral Council of Techni- cal Societies, Cocoa Beach	4/67	---	U
18	Contingency Planning for Space-Flight Emer- gencies	Memorandum RM-5200-NASA	S.H. Dole, et al-- Rand Corp., Santa Monica	1/67	NASr-21(13)	U
29	First-Order Logic	---	Raymond M. Smullyan --Springer-Verlag New York, Inc.	1968	---	U
39	Introduction to Symbolic Logic	---	A.H. Basson, D.J. O'Connor--The Free Press of Glencoe, Illinois	1960	---	U
52	Manned Space Flight Program Risk Analysis	ASD-MR-08-67- 7, Preliminary Draft	Apollo Support De- partment, General Electric Company, Daytona Beach	8/67	---	U
56	Mathematical Discovery. (On understanding, learning, and teaching problem solving), Volumes I and II	---	George Polya, John Wiley & Sons, Inc.	1965	---	U
70	Principia Mathematica	Volume I, 2nd Edition (1927)	Whitehead and Russell, Cambridge University Press	1963	---	U

No.	Title	Report No.	Source	Date	Contract No.	Cl.
89	Space Flight Emergencies and Space Flight Safety---A Survey	73-1780	Staff Study for the Subcommittee on NASA Oversight, of the Committee on Science & Astronautics, U.S. House of Representatives, 90th Congress, U.S. Government Printing Office, Washington	1967	---	U
92	Space Station Program Definition Study (Phase B)--Statement of Work	9-4-7895	NASA/Headquarters	4/14/69	---	U
93	Space Station Safety Study--Statement of Work	---	NASA/MSC	1968	NAS9-9046	U
100	Symbolic Logic (Third Edition)	---	Irving M. Copi-- The McMillan Co.	1967	---	U
104	System Safety Requirements for Manned Space Flight	NASA Safety Program Directive No. 1	NASA/Headquarters	1/69	---	U
112	Webster's Seventh New Collegiate Dictionary	---	G&C Merriam Company	1967	---	U
113	Webster's Third International Dictionary	---	G&C Merriam Company	1966	---	U
114	World of Mathematics, The (Volumes I, II and III)	---	James R. Newman-- Simon and Shuster	1956	---	U

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D2-113070-9

APPENDIX I

LOGICAL AND ANALYTICAL PRINCIPLES

	<u>Page</u>
I-1.0 Heuristic Method and Logical Reasoning	167
I-2.0 Metalanguage -- Symbolic Logic	168
I-3.0 Inference	171
I-4.0 Alternate Methods of Rendering Propositions	173
I-5.0 The Unordered Finitely Generated Tree	174

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D2-113070-9

APPENDIX I

LOGICAL AND ANALYTICAL PRINCIPLES

I-1.0 Heuristic Method and Logical Reasoning

I-1.1 The following extracts from Reference No. 56 summarize the philosophy of the heuristic method used in development of this diagram:

- "We conquer an empire province by province, using at each stage the provinces already won as a base of operations to win the next province. ...If the unknown has many components we may advance along several lines simultaneously. ...The essential thing is to use the information already gathered as a base of operations to gather further information."
- "'From desire ariseth the thought of some means we have seen produce the like of that which we aim at; and from the thought of that, the thought of means to that mean and so continually, till we come to some beginning within our power.' -- Thomas Hobbes. Hobbes' words ... describe (the) basically important (problem solving) pattern (of) regressive planning or working backwards (that) the Greek geometers called ... analysis which means 'backward solution.' The complementary work of execution which proceeds from the things in our possession to the aim ... is called, in contradiction, progressive planning or working forward, or synthesis which means 'putting together.'"
- "...When working backward we may expect to spend most of our time in doing clear-cut problems. When working forward we may expect to spend much of our time in hesitating between problems we might do or in doing problems which are no help...."
- "In some cases there is little choice. In many practical problems the thing we want to find (to construct, to acquire ...) is quite definite, but the things we could possibly use for attaining our aim we scarcely know and they are impossible to survey, there are so many of them. We can hardly have a good reason to begin with an item in that unmanageable heap of data, and so we are almost obliged to plan regressively."

I-1.2 The following extract from an article by Alfred Tarski in Reference No. 114 summarizes the philosophy of logical reasoning used in the development of this diagram:

- "It should be observed what an extremely elementary form -- from the psychological point of view -- (such) reasonings assume, due to knowledge and application of the laws of logic and the rules of inference; complicated mental processes are ... reducible to

such simple activities as the attentive observation of statements ..., the perception of structural, purely external connections among these statements and the execution of mechanical transformations as prescribed by the rules of inference. It is obvious that, in view of such a procedure, the possibility of committing mistakes ... is reduced to a minimum."

I-2.0 Metalanguage -- Symbolic Logic

The extract (denoted by " ") in I-2.1 below is from Reference No. 29, that in I-2.4 from Reference No. 112, and that in I-2.5 from Reference No. 100, while those in I-2.2, I-2.3 and I-2.6 are from Reference No. 70. They provide much of the logical foundation for the logic diagram and are the basis for the definitions, in Paragraph 3.2, of the special logical symbols used in it. (Parenthetical statements following each numbered extract explain its use in this document.)

I-2.1

- "We shall use for our (undefined) logical connectives the following four symbols:

- (a) $\sim$ [read "not"]
- (b) $\wedge$ [read "and"]
- (c) $\vee$ [read "or"]
- (d) $\supset$ [read "implies"]

These symbols are respectively called the negation, conjunction, disjunction, and implication symbols."

I-2.2

- "We introduce the primitive idea $p \mid q$ which may be read 'p is incompatible with q', and it is true whenever either or both are false. Thus, it may be read 'p is false or q is false' or again, 'p implies not - q' We now put

$$\begin{aligned}\sim p &= .p \mid p \\ p \supset q &= .p \mid \sim q \\ p \vee q &= . \sim p \mid \sim q \\ p . q &= . \sim (p \mid q)\end{aligned}$$

(This extract provides rigorous definitions for $\sim$, $\supset$, $\vee$, and $\wedge$ -- where $p \cdot q = p \wedge q$.)

I-2.3

- "The contradictory function with argument p , where p is any proposition, is the proposition which is the contradictory of p , that is, the proposition asserting p is not true. This is denoted by $\sim p$ (and) means the negation of the proposition p ."
- "The logical sum is a propositional function with two arguments p and q , and is the proposition asserting p or q disjunctively, that is, asserting that at least one of the two p and q is true (not excluding the case in which both are true). This is denoted by $p \vee q$."
- "The logical product is a propositional function with two arguments p and q and is the proposition asserting p and q conjunctively, that is, asserting that both p and q are true. Accordingly, $p \cdot q$, (i.e., $p \wedge q$), means that both p and q are true (and) it must be false that either $\sim p$ or $\sim q$ is true. Hence -- $[p \wedge q = \sim(\sim p \vee \sim q)]$ "
- "The implicative function is a propositional function with two arguments p and q , and is the proposition that either not- p or q is true; that is, it is the proposition $\sim p \vee q$. Thus if p is true, $\sim p$ is false, and accordingly the only alternative left by the proposition $\sim p \vee q$ is that q is true.... In this sense $\sim p \vee q$ will be quoted as stating that p implies q , The symbol employed for ' p implies q ,' i.e., for ' $\sim p \vee q$ ' is ' $p \supset q$.' This symbol may also be read 'if p then q '."
- "Two propositions p and q are said to be 'equivalent' when p implies q and q implies p . This relation between p and q is denoted by ' $p \equiv q$.' (Thus $p \equiv q$ stands for $(p \supset q) \wedge (q \supset p)$.)"

(The above extracts provide definitions for $\sim$, $\vee$, $\wedge$ and $\supset$, which are equivalent to (and possibly easier to understand than) those provided in Paragraph I-2.2, and introduce a definition for equivalence.)

I-2.4

- "Proposition ... an expression in language or signs of something that can be believed, doubted, or denied, or is either true or false."

(Although this is the common "dictionary" definition of "proposition," it is repeated here to ensure understanding of Paragraphs I-2.5 and I-2.6 below.)

I-2.5

- "All statements can be divided into two kinds, simple and compound. A simple statement is one which does not contain any other statement as a component part, whereas every compound statement does contain another statement as a component part. (Compound statements of interest are those in which) there is a necessary connection between the truth value of the compound statement and the truth values of its component statements."

(This differentiation between simple and compound statements, i.e., propositions, is the one used in Section 3.0 and subsequently in the logic diagram.)

I-2.6

- "Our system begins with 'atomic propositions.' We accept these as a datum, because the problems which arise concerning them belong to the philosophical part of logic, and are not amenable (at any rate at present) to mathematical treatment. Atomic propositions may be defined negatively as propositions containing no parts that are propositions, and not containing the notions 'all' or 'some' ..."
- "An analysis of the paradoxes to be avoided shows that they all result from a certain kind of vicious circle. The vicious circles in question arise from supposing that a collection of objects may contain members which can only be defined by means of the collection as a whole.... The principle which enables us to avoid illegitimate totalities may be stated as follows: 'Whatever involves all of a collection must not be one of the collection.'"

(The simple propositions used in this logic diagram are "atomic propositions" as defined in this extract, except that words such as "all" or "some" have been permitted. No consistent strategem has been used to avoid "vicious circle" fallacies; however, there has been a subjective attempt to do so by examination. The example of a paradox in Figure I-1 may aid in understanding the potential significance of such a fallacy.)

p = I am fifty years old. q = I have a brown dog. r = Propositions p, q and r are false.

FIGURE I-1
EXAMPLE OF LOGICAL PARADOX (Vicious Circle Fallacy)

I-3.0 Inference

The extracts below, from Reference Nos. 70, 100, and 70 respectively, and the following corollaries, define the process of inference sufficiently for the purposes of this document:

I-3.1

- "Inference. The process of inference is as follows: a proposition 'p' is asserted, and a proposition "p implies q" is asserted, and then as a sequel the proposition 'q' is asserted. The trust in inference is the belief that if the two former assertions are not in error, the final assertion is not in error. ...An inference is the dropping of a true premise; it is the dissolution of an implication."

I-3.2

- "The three simplest and intuitively valid forms (of inference) are:

<u>Modus Ponens</u>	<u>Modus Tollens</u>	<u>Hypothetical Syllogism</u>
If p then q	If p then q	If p then q
$\therefore p$	$\therefore \sim q$	If q then r
$\therefore q$	$\therefore \sim p$	$\therefore$ If p then r"

I-3.3

- "Primitive Propositions. Some propositions must be assumed without proof, since all inference proceeds from propositions previously asserted.... It will be found that, owing to the weakness of the imagination in dealing with simple abstract ideas, no very great stress can be laid upon their obviousness. ...The following are the primitive propositions employed in the calculus of propositions. The letters 'P_p' stand for 'primitive proposition.' (The sign '⊢' stands for 'it is asserted that.')

1) Anything implied by a true premise is true P_p.
This is the rule which justifies inference.

2) $\vdash : p \vee p. \supset p.$ P_p,
i.e., if (p or p) is true then (p) is true.

3) $\vdash : q. \supset .p \vee q$ P_p,
i.e., if (q) is true then (p or q) is true.

$$4) \quad \vdash : p \vee q. \supset .q \vee p \quad P_p,$$

i.e., if (p or q) is true then (q or p) is true.

$$5) \quad \vdash : p \vee (q \vee r). \supset .q \vee (p \vee r) \quad P_p,$$

i.e., if [(p) is true or (q or r) is true] then
[either (q) is true or (p or r) is true].

$$6) \quad \vdash : .q \supset r. \supset : p \vee q. \supset .p \vee r \quad P_p,$$

i.e., if [(q) implies (r)] then [(p or q) implies (p or r)]."

I-3.4

Corollaries

(The following stem from the definitions of logical functions in Paragraph I-1.2 and the primitive propositions and definitions of inference above. Many other corollaries can be expressed and these are only a representative set, any of which may be immediately useful or could suggest other useful ones.)

$$(A \supset B) \equiv (\sim B \supset \sim A); \quad (A \equiv B) \equiv (\sim A \equiv \sim B)$$

$$[A \supset (B \vee C)] \equiv [(\sim B \wedge \sim C) \supset \sim A]$$

$$[A \supset (B \wedge C)] \equiv [(\sim B \vee \sim C) \supset \sim A]$$

$$[A \equiv (B \vee C)] \equiv [\sim A \equiv (\sim B \wedge \sim C)]$$

$$[A \equiv (B \wedge C)] \equiv [\sim A \equiv (\sim B \vee \sim C)]$$

And (for $\vdash$ = "ASSERT," and $\therefore$ = "Therefore")

$$\vdash A \supset B$$

$$\vdash A$$

$$\therefore \vdash B$$

$$\vdash A \supset B$$

$$\vdash \sim B$$

$$\therefore \vdash \sim A$$

$$\vdash A \equiv B$$

$$\vdash B$$

$$\therefore \vdash A$$

$$\vdash A \equiv B$$

$$\vdash \sim B$$

$$\therefore \vdash \sim A$$

$$\vdash A \supset (B \wedge C)$$

$$\vdash A$$

$$\therefore \vdash (B \wedge C)$$

$$\therefore \vdash B \wedge C$$

$$\vdash A \supset (B \wedge C)$$

$$\vdash \sim B \wedge \vdash \sim C$$

$$\therefore \vdash \sim A$$

$$\vdash A \equiv (B \vee C)$$

$$\vdash B \vee \vdash C$$

$$\therefore \vdash A$$

$$\begin{array}{lll}
\vdash A \supset (B \vee C) & \vdash A \supset (B \vee C) & \vdash A \equiv (B \vee C) \\
\vdash A & \vdash (\sim B \wedge \sim C) & \vdash A \\
\therefore \vdash (B \vee C) & \therefore \vdash \sim A & \therefore \vdash (B \vee C) \\
\\
\vdash \sim(\sim B \supset \sim A) & & \\
\therefore \vdash [\sim(A \supset B)] \wedge \vdash \{ \sim[A \supset (B \wedge C)] \} \\
\\
\vdash \sim[(\sim B \wedge \sim C) \supset \sim A] & & \\
\therefore \vdash \sim[A \supset (B \vee C)] & &
\end{array}$$

I-4.0

Alternate Methods of Rendering Propositions

One of several valid ways to "read" the logic diagram segment at the top of Chart No. 1 is given in Paragraph 3.4. (It should be noted that one need not commit himself to any belief in the truth or falsity of any of the simple propositions in this compound proposition to agree that they are related in the manner stated. Thus, a problem may be subdivided without assuming things not readily evident.) I-4.1 and I-4.2 below provide two more alternate, equivalent*, and equally valid ways of "reading" the same diagram segment. There is no logical necessity that any such compound statements be considered true or false; however, if any one of a set of equivalent propositions (A B C) is considered false, it does logically follow that all must be considered false. Thus, "reading" a compound proposition in such alternate ways provides a powerful tool for ensuring that communication and agreement, or disagreement, are real instead of illusory.

I-4.1

- "If it is true that - Crew members will be safe during their orbital stay, - then it must be true that -
 - Crew members will complete their orbital stay in acceptable mental and physical condition, - and -
 - Crew members will survive their orbital stay, - and -
 - if it is true that -
 - Crew members will survive their orbital stay - and -

*As defined in I-2.3.

- Crew members will complete their orbital stay in acceptable mental and physical condition,
- then it must be true that - Crew members will be safe during their orbital stay."

I-4.2

- "If it is true that - Crew members will not be safe during their orbital stay, -
then it must be true that -
- Crew members will not survive their orbital stay, - or -
- Crew members will not complete their orbital stay in acceptable mental or physical condition,
- and -
- if it is true that -
- Crew members will not survive their orbital stay,
- or -
- if it is true that -
- Crew members will not complete their orbital stay in acceptable mental or physical condition,
- then it must be true that -
- Crew members will not be safe during their orbital stay."

I-5.0

The Unordered Finitely Generated Tree

The following extract from Reference No. 29 provides an abstract definition of the form in which the analysis in this document is expressed. It is, in this sense, an *unordered, finitely generated tree* except that in this document a point is permitted to have more than one predecessor.

- "By an *unordered tree*, T , we shall mean a collection of the following items:
- 1) A set Σ of elements called *points*.
- 2) A function, λ , which assigns to each point x a positive integer $\lambda(x)$ called the *level* of x .
- 3) A relation $x R y$ defined in Σ , which we read ' x is a *predecessor* of y ' or ' y is a *successor* of x .' This relation must obey the following conditions:

C_1 : There is a unique point a_1 of level 1. This point we call the *origin* of the tree.

C_2 : Every point other than the origin has a unique predecessor.*

C_3 : For any points x, y , if y is a successor of x , then
 $\lambda(y) = \lambda(x) + 1$.

- "We shall call a point x an *end point* if it has no successors; a *simple point* if it has exactly one successor, and a *junction point* if it has more than one successor. By a *path* we mean any finite or denumerable sequence of points, beginning with the origin, which is such that each term of the sequence (except the last if there is one) is the predecessor of the next. By a *maximal path* or *branch* we shall mean a path whose last term is an end point of the tree, or a path which is infinite.
- "It follows at once from C_1, C_2, C_3 that for any point x , there exists a unique path P_x whose last term is x . If y lies on P_x , then we shall say that y *dominates* x , or that x is *dominated by* y . If x dominates y , and $x \neq y$, then we shall say that x is (or lies) *above* y , or that y lies *below* x . We shall say that x is *comparable* with y if x dominates y or y dominates x . We shall say that y is *between* x and z if y is above one of the pair $\{x, z\}$ and below the other.
- "By an *ordered tree*, T , we shall mean an unordered tree together with a function θ which assigns to each junction point z a sequence $\theta(z)$ which contains no repetitions, and whose set of terms consists of all the successors of z . Thus, if z is a junction point of an ordered tree, we can speak of the 1st, 2nd, ..., nth, ... successors of z (for any n up to the number of successors of z) meaning, of course, the 1st, 2nd, ..., nth, ... terms of $\theta(z)$.
- "For a simple point x , we shall also speak of the successor of x as the *sole* successor of x .
- "We shall usually display ordered trees by placing the origin at the top and the successor(s) of each point x below x , and in the order, from left to right, in which they are ordered in the tree. And we draw a line segment from x to y to signify that y is a successor of x .
- "We shall have occasion to speak of adding 'new' points as successors of an end point x of a given tree T . By this we mean more precisely the following: For any element y outside T , by the adjunction of y as the sole successor of x , we mean the tree obtained by adding y to the set Σ , and adding the

*See exception in introductory paragraph.

ordered pair $[x, y]$ to the relation R (looked at as a set of ordered pairs), and extending the function λ by defining $\lambda(y) = \lambda(x) + 1$. For any distinct elements $y_1, \dots, y_n$, each outside Σ , by the adjunction of $y_1, \dots, y_n$ as respective 1st, 2nd, ..., n th successors of x , we mean the tree obtained by adding the y_i to Σ , adding the pairs $[x, y_i]$ to R and extending λ by setting $\lambda(y_1) = \dots = \lambda(y_n) = \lambda(x) + 1$, and extending the function θ by defining $\theta(x)$ to be the sequence $(y_1, \dots, y_n)$. [It is obvious that the extended structure obtained is really a tree.]

- "A tree is called *finitely generated* if each point has only finitely many successors. A tree, T , is called *finite* if T has only finitely many points; otherwise the tree is called *infinite*. Obviously, a finitely generated tree may be infinite."