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SPACE STATION

SAFETY STUDY

CONDENSED SUMMARY REPORT

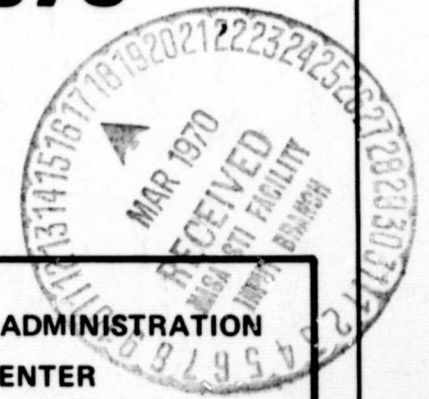
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 HOUSTON, TEXAS

THE **BOEING** COMPANY
 AEROSPACE SYSTEMS DIVISION, SEATTLE, WASHINGTON

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SPACE STATION SAFETY STUDY

MSC-00190

**CONDENSED
SUMMARY REPORT**

D2-113070-4

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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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

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- 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)

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1.0 INTRODUCTION

The Space Station Safety Study summarized in this document was performed during 1969 as one of a series of studies of space safety conducted by or for the NASA. Unlike previous studies, in which the emphasis had been directed toward actions to be taken after an emergency occurred, the emphasis of this study was directed primarily toward defining measures which would tend to prevent, or reduce the probability of, occurrence of an emergency or hazardous condition.

The safety measures defined are expressed as a set of Crew Safety Guidelines which are published in their entirety, together with appropriate cross-references, in a companion document, D2-113070-5. The guidelines may be used as a checklist with which to evaluate the safety measures included in, or omitted from, a spacecraft design. However, a more valuable application would appear to be the use of the guidelines to develop space station or base concepts in which crew safety is the primary consideration. These concepts then would provide a safety baseline against which other desirable station features or aspects of station development could be compared. An example of this sort of application is described in Section 5.0 of this document. Regardless of how applied, the sine qua non for guidelines application is that management establish a strong safety organization through which to plan and control the safety program.

The primary emphasis of the study, as stated above, was directed toward preventive, rather than remedial actions and the majority of the guidelines reflect this emphasis. In addition, some attention was devoted to problems of spacecraft damage containment and control and a set of guidelines which are pertinent to that subject have been identified. A brief discussion of damage containment and control measures is included in Section 5.0 of this document.

Nothing was found in the study which would indicate that an acceptable level of crew safety could not be attained within the current state of the art. There are some instances, however, in which uncertainties exist or assumptions were made which indicate the desirability of further work. The further work which seems desirable is listed and described briefly.

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2.0 STUDY OBJECTIVES

In essence, there were two primary objectives throughout the study, which were to find the answers to these closely related questions:

- a. What measures must be taken to provide maximum assurance of safety in future space stations, and
- b. How can management be assured that proper consideration is given to the safety measures identified by the answers to question "a"?

These objectives were achieved by a methodical analysis of the safety problems of a space station, during which hazards were identified, a means of safeguarding against each hazard was derived, and the safeguards were expressed as Crew Safety Guidelines. Each guideline is a statement that points the way toward a course of action which will enhance safety.

The study objectives are expressed more formally in the Statement of Work. For Phase I the objectives were:

Development of safety guidelines and concepts that ensure astronaut safety by examining and analyzing the crew activities carried out during normal and emergency space station operations.

Investigation from both the astronaut safety and the space station design standpoints of preventive and remedial safety problems associated with long-term operational space stations and the development of safety procedural and design guidelines.

Development of damage containment and control procedures applicable over broad classes of space stations.

In Phase II the objectives were restated as:

The overall objective of this study is to develop a tool for guiding and evaluating conceptual designs of future manned space systems from a safety viewpoint. This objective will be achieved through application of methodical techniques for analyzing the subject of manned space systems safety. The techniques will be documented such that they can be updated and/or modified in the future.

These techniques will result in the development of:

- a) Safety guidelines which can be applied to the NASA Phase B Space Station Activity.
- b) Rationale and supporting engineering data for safety guidelines and documentation of this data for ready reference by conceptual designers.

NOTE: Damage containment is recognized as a basic consideration, but will be developed as a solution-oriented output rather than as a specific task.

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3.0 RELATIONSHIP TO OTHER NASA EFFORTS

Up to the present time, safety has been an intrinsic part of the manned space program through the use of highly reliable equipment, constant vigilance by designers and engineers, and, whenever possible, provisions for an option to terminate or abort the mission if something goes wrong. These measures undoubtedly will be continued in future manned space programs, but some current factors, such as greatly increased mission duration, larger crews, and reliance on a re-entry vehicle separate from the space station, may dictate different or additional safety measures. A series of safety-oriented studies, of which this Space Station Safety Study is one, have been conducted to examine the safety problems of future space programs.

The emphasis of previous studies has been on remedial actions to cope with in-flight emergencies. A study by The Rand Corporation emphasized "...the saving of lives after an emergency has occurred in space." Similarly, a study by the Aerospace Corporation was oriented to "Define potential emergency conditions (and) examine the...feasibility of remedial concepts..." Other studies, for example, one by Lockheed, have examined escape device concepts. By contrast, the emphasis of this Safety Study was on measures which should be taken to eliminate or minimize the probability of the occurrence of an emergency, or to mitigate the consequences if an emergency did occur.

This study, especially in Phase II, dealt with space station concepts and functions, rather than with the hardware. While this placed some limitations on the study, as will be discussed later, it also had the advantage of making the study results broadly applicable to manned space programs in general. The Crew Safety Guidelines, then, while developed specifically with a space station or base in mind, are, in general, sufficiently broad to be applicable, at least as a starting point, to safety problems of any other manned space programs, including logistics systems, shuttle vehicles, and lunar or planetary exploration.

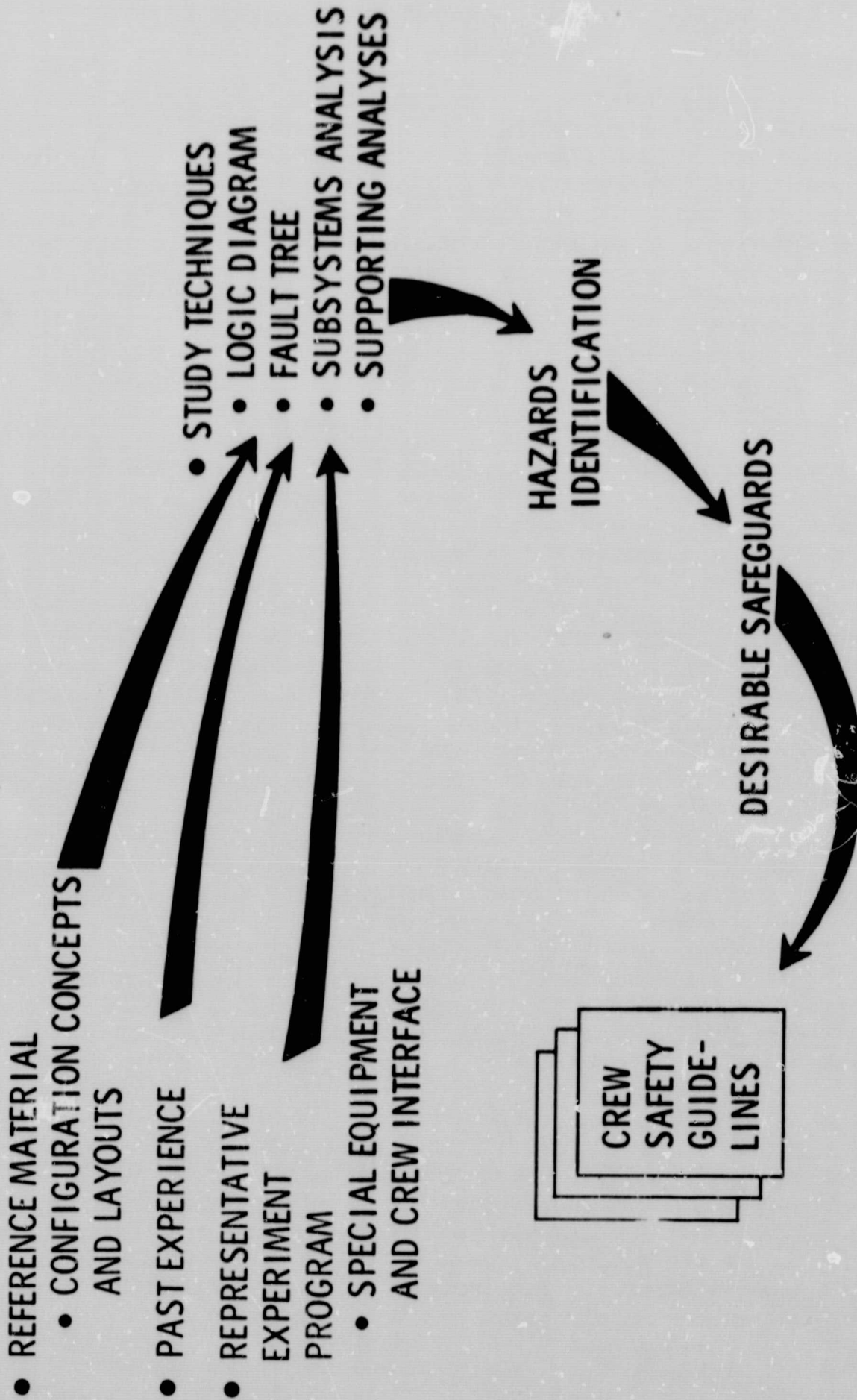


Figure 1: STUDY APPROACH

- 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 logic diagram is a set of related statements or "propositions" arranged in "tree" form and circumscribed by certain rules and logical procedures. It was developed regressively (see Appendix I in D2-113070-9) from the origin proposition, "All crew members will be safe during their orbital stay," which was considered to express succinctly, and sufficiently accurately, the overall context of the Safety Study. Starting with the origin proposition, logical development consisted of incrementally and repeatedly making and recording decisions for each proposition concerning assumptions as to its truth or falsity, the implications both upward and downward that were involved, subdivision through disjunctive or conjunctive relationships, and numerous other considerations such as clarity of expression. The resulting tree of proposition statements was organized to be reproducible on normal document pages, using specific geometric locations and logic symbology to express properly their logical relationships. "End-point" and "open" propositions were recorded for future evaluation. Document D2-113070-9 contains the entire diagram, together with detailed explanations of all aspects of its development and interpretation.

Fault Tree Analysis

The systems safety fault tree analysis provides a graphic representation of Boolean relationships between discrete normal and adverse situations which, taken singly or in combination, could result in the development of a specific undesired event. As a deductive technique it can be applied to the investigation of either gross or detailed systems. The depth to which it can be evolved is restricted only by the level of detail available. On this study, the analytical effort resulted in gross, top-level fault trees carried down only to major components or functions. Three specific hazardous conditions were analyzed as extensions of certain proposition statements derived in the logic diagram: decompression, temperature extremes, and radiation. In brief, the fault tree analysis consists of stating the basic undesired event; subdividing the problem into numerous subsidiary undesired events by several different, but appropriate, categories; stating all the necessary events which would cause each such subsidiary undesired event; and reiterating the process until the most basic identifiable causal events have been established. This procedure results in a progressively expanding "tree" of events, organized to be reproducible on normal document pages, whose relationships are shown by certain symbols and interconnecting lines, as explained in D2-113070-10.

Subsystem Analysis

Subsystem analyses performed during this study consisted of two separate efforts, Phase I and Phase II. For Phase I it was conducted as a Failure, Safety, and Maintenance Analysis on each subsystem, based on the Saturn V Single Launch Space Station Study and was about 50 percent completed when redirection of this study resulted in its termination. For Phase II the analyses were oriented to the identification of hazards which could threaten crew safety, leading to recommended safeguards necessary to prevent or contain these hazards. Safety guidelines based on the recommended safeguards were then derived (see D2-113070-5). The Phase II analysis was not constrained to any particular space station configuration, so most of the work previously accomplished in Phase I was applicable and was used as a baseline for the Phase II effort. The Failure, Safety, and Maintenance Analysis conducted during Phase I was to have been performed at the component level for each of the SVSLSS subsystems. Each of the components was examined as to its function within the subsystem and its relationship to other elements of the subsystem, as well as to other subsystems. Numerous reference sources were reviewed to obtain appropriate hardware information for the analysis. Based on the information available, each component was evaluated for failure modes which could result in a potential hazard to the crew or mission. The potential hazards were analyzed to identify safety provisions which would prevent or alleviate the hazard. Also, each condition was examined for methods of detecting critical failures, and the maintenance requirements for correcting such failures. The analysis was documented on a form which combines the appropriate failure, safety, and maintenance data compiled in Appendix A of D2-113070-11. Since the study concept during Phase II was more universal in nature than that of Phase I, it was necessary to expand the hazard summary to include consideration of other subsystem configurations. Subsystem data available from reference material were analyzed for potentially hazardous situations considered inherent in the equipment or associated with its operation. As the potential hazards were identified, they were analyzed to determine what safeguards should be considered to prevent or alleviate them. Recommended safeguards are tabulated in D2-113070-11 and form a basis for many of the guidelines included in D2-113070-5.

Supporting Analyses

A series of relatively small tasks were undertaken in support or as an extension of the major analyses. These included: design support in developing configuration concepts of the space station and base, an analysis of operations, a traffic pattern analysis, human requirements support, and an analysis of meteoroid penetration hazards.

In addition to the assumptions previously stated, certain other assumptions were made. They were:

All crew members will be capable of performing their assigned duties in the space station or base.

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On their initial arrival at the space station or base, all crew members will be in good health.

The station and base or components thereof will arrive in orbit in proper working order and will remain in proper working order until required by the crew.

5.0 BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The primary output of the study is a set of 282 Crew Safety Guidelines which are contained in final report document D2-113070-5. A Crew Safety Guideline is defined as:

A statement which points the way to a course of action which, if taken, will tend to enhance crew safety in the space station or base.

In the report, each guideline appears only once, listed under an appropriate hazard group. There are in addition a series of cross-references leading to other hazard groups to which the guideline may apply, the subsystems affected by the guideline, guidelines pertinent to damage containment and control, and key words appropriate to various guidelines.

Individually, each guideline expresses or suggests some measure which will lessen the probability of occurrence of an undesired event or alleviate to some degree a hazard. In the aggregate, they are a list of the things which should be done to enhance crew safety and a checklist by which management can review and evaluate accomplishment of the identified safety measures.

Whether used as individuals to implement some safety measure or in the aggregate as a management checklist, however, the sine qua non for their use is that management establish a strong safety organization. The guidelines can form the basis on which this organization can plan and control a viable safety program. In doing so, though, certain restrictions or limitations on the use of the guidelines should be noted.

The first restriction is internal to each guideline as an individual and derives from the basic approach to the study. By this approach, factors other than safety were not considered, and neither was the degree of risk associated with the guideline determined. For each guideline, therefore, some degree of trade study, at least on an informal basis, is indicated in which the added safety increment obtained by application of the guideline can be balanced against other factors.

A second restriction applies to the relationship between two or more guidelines and derives from the fact that safety measures appropriate for one hazard may be incompatible with safety measures appropriate for another hazard. In these cases, a decision, again involving trade studies, is necessary to determine whether to apply only one guideline, to effect a compromise between them, or possibly to adopt some other course.

In considering how best to apply the guidelines, several means suggest themselves. Of these, the two extremes are to compare an existing and final station design against the guidelines, on the one hand, and to use the guidelines in establishing initial concepts on which the design is based, on the other hand. Of these extremes the latter is considered to be by far the most useful, because guidelines in many cases are configuration drivers, which must be incorporated early in the design stages if they are to be of any value.

To illustrate what has been said, consider the following guidelines and their implications on station design:

7.7 Design of rotating spacecraft should be such that the direction of major traffic flow is parallel to the vehicle spin axis.

12.13 The space station/base areas inhabited by the crew should consist of two or more independently pressurizable compartments with more than one exit from each compartment.

12.30 Each compartment should have a minimum of two or more escape routes which should not terminate in a common compartment.

12.18 The number of crew members in any compartment at one time should be held to the minimum necessary to perform the required functions.

12.20 The areas in which crew members spend the majority of their time, e.g., staterooms, dining facilities, personal hygiene, exercise and recreation areas, should be located and designed to be the safest parts of the station.

In addition, there are numerous guidelines, not quoted here, which, if applied, would require redundancy or duplication of many safety-critical items.

Guideline 7.7 would dictate a long, slender, single-deck station so that tangential and radial traffic would be minimized and major traffic flow is axial. Such a configuration would likely be impractical for many reasons, not the least of which are those concerning safety. In particular, while a long, slender station could conceivably be divided into compartments as required by Guideline 12.13, providing more than one exit from each compartment would be difficult and likely impossible in light of Guideline 12.30 which requires that the exits should not terminate in a common compartment.

In the interest of minimizing the number of crew members who might be exposed to a particular hazard or emergency, Guideline 12.18 restricts the number of crew members in any compartment. This is not consistent with a finding of the study that crew members spend about two-thirds of their time, and, hence, congregate, in those areas devoted to crew health and well-being. Guideline 12.20, directed at this problem, specifies that crew areas should be the safest parts of the station, implying a central location. Here again, a long, slender station does not appear readily amenable to these requirements.

The net effect of the many guidelines dealing with redundancy is to specify, very nearly, two stations, rather than one, but joined so as to support each other. Stated differently, the station would consist of two halves which can be largely, if not entirely, independent of each other, but which can also provide each other with anything which is essential to crew survival.

The ideas expressed in the foregoing are incorporated in the station concept shown in Figure 2, which is the artificial-gravity portion of the space base, but which could operate by itself as the zero-gravity space station. It is essentially a Siamese twin, with the central bulkhead a pressure bulkhead dividing the station into two halves. Each half has access to the central, non-rotating hub (not shown) through its own elevator shaft. Two nuclear power plants, also not shown, opposite the station would supply power, with either one capable of powering the entire base. In addition, each of the systems which is essential to crew safety would be duplicated in each half and would have the capacity to serve both halves. The outer shell is a pressure hull, the two end bulkheads are pressure bulkheads, and the inner shell surrounding the centrally located, two-deck crew quarters is also a pressure shell. The major traffic flow direction is axial, with tangential and radial traffic minimized, and with an elevator providing the prime means of radial movement.

This concept was readily derived by successive application of the guidelines and represents one approach to a safety-optimized station. It provides a baseline against which other factors, or other guidelines for that matter, can be applied to establish the further compromises which may be necessary.

The major emphasis of the study was on preventive measures, e.g., those things which would tend to prevent the occurrence of an emergency or reduce the probability of its occurrence. However, preventive measures may, in some cases, have elements of remedial action as well. Also, certain features which are desirable to crew safety are also desirable from the viewpoint of remedial action in an emergency. Necessarily, then, some attention was devoted to problems of spacecraft damage containment and control, and certain of the guidelines are appropriate to that matter.

The containment and control of damage requires three distinct phases, although they may overlap or, in extreme emergencies, be conducted almost simultaneously. These phases are identification, isolation, and counter-action.

In the identification phase a determination is made that "damage" has occurred. This requires detectors or sensors which measure a parameter of interest and includes observation, inspection, and monitoring by crew members, as well as instrumentation. It also requires that a warning or alarm system be available to inform the crew that something is amiss and alert them to the need for further action. Depending on the seriousness of the emergency, automatic action may be initiated at the same time that warnings are given.

In the isolation phase, the damage and its effects are confined as much as possible to the original site. This requires, first, that the station be divided into several "compartments," but "compartments" in this sense include any isolatable area, which may not necessarily be a separately pressurizable area. Second, it requires that suitable hatches, valves, shut-offs, and closures be provided so that the compartments can be

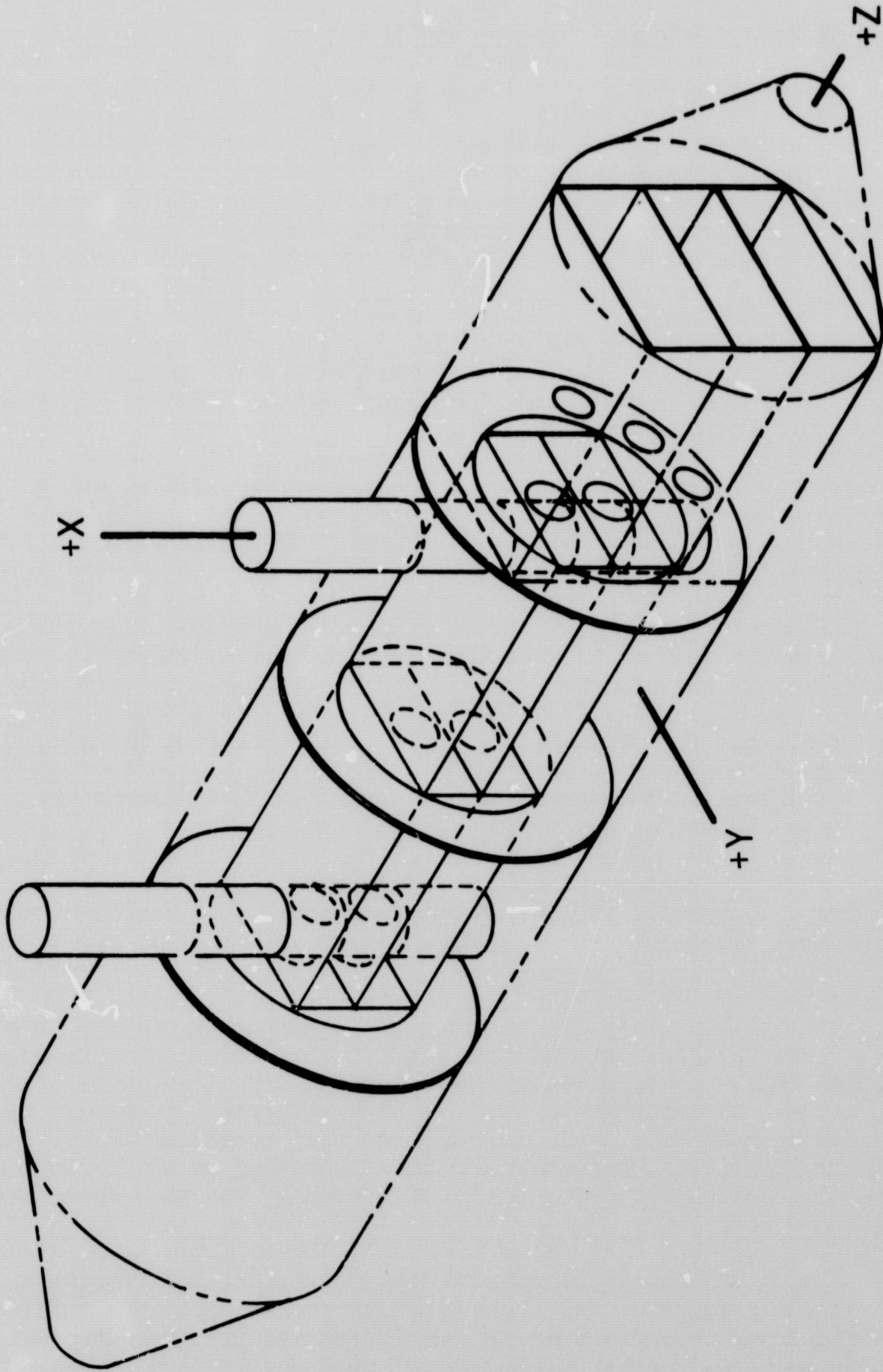


Figure 2: STATION/BASE CONCEPT

isolated. Also included are concepts of isolated "safe" areas for the conduct of hazardous operations or storage of hazardous materials, and damage suppression devices such as crack stoppers in structure. Finally, a means of protection for crew members in the area of the damage is required.

The counteraction phase includes those actions necessary to remedy the damage and return the station to normal operations, or at least to a "safe" condition. A means to assure survival, escape, or rescue of crew members from the damaged area is required. Access to and communications with the damaged area are necessary. A means of remedying the damage is required, e.g., fire extinguishing systems, a method of repairing breeched pressure hulls or bulkheads, and a means of clean-up and decontamination.

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6.0 STUDY LIMITATIONS

The study, particularly in Phase II, was limited to consider only those items which affect the safety of the crew. The broader system safety concept, in which vehicle performance and mission accomplishment are considered, was not included except to the extent, which may be considerable, that crew safety items also affect system safety. For example, measures taken to preclude or extinguish fires in the interest of crew safety would also be expected to enhance mission performance.

Only the on-orbit phase of the space station or base was examined. Launch, boost, orbit injection, de-orbit, re-entry and recovery were not specifically considered. Here again, however, a hazard associated with and examined as part of on-orbit operation may also occur during other phases. For example, loss of vehicle atmosphere or hazards associated with unrestrained or shifting cargo may be expected in other phases of the total mission. Measures appropriate against such hazards on-orbit may also be appropriate in other phases.

The study was limited to considering concepts only and not specific hardware items. This had the effect of restricting the depth of the investigation, but has an offsetting advantage in that study results are broad and more generally applicable than they would otherwise have been. Closely related to this limitation is the fact that no laboratory or test work was accomplished during the study.

Finally, no reliability or probability numbers were established for or derived during the study. This resulted in the consideration of and development of guidelines to alleviate some hazards which may have a very low probability of occurrence. Again, however, it broadened the study in that all identified hazards were carefully considered. There were two exceptions to this limitation. The first was the probability of a meteoroid penetration, which the Statement of Work for the Phase B Future Space Station Study stipulated as the probability of no penetrations in a ten-year period (P_0) = 0.9. The second exception was in the Logic Diagrams in which it was felt necessary to end-point certain propositions as true or false, and assign a numerical value to the confidence of their truth or falsity. This value is expressed as a percentage, and was determined subjectively.

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7.0 IMPLICATIONS FOR RESEARCH

The area discussed in this section includes only matters which were outside the scope of the study. Therefore, nothing would have been done with respect to them, even if time and resources had been available.

The study revealed no reason to believe that it was impossible to achieve an acceptable level of crew safety in space stations or bases within the current state of the art. Therefore, no urgent research is implied unless future developments introduce hazards not currently known. There are, however, some areas in which sufficient uncertainty exists or in which it was necessary for us to make assumptions, to indicate the desirability of further exploration.

In the area of toxicology allowable concentrations of toxic materials are usually expressed as Threshold Limit Values or maximum allowable concentrations, but these are predicated on the basis of exposures of relatively short duration. Allowable concentrations of toxic materials should be determined for spacecraft, taking into account the long duration of the exposure, the closed ecology of the spacecraft, the peculiar spacecraft environment of zero or reduced gravity, oxygen tension if different from Earth normal, increased particulate load, reduced pressures, noise, vibration, and the like.

Meteoroid penetration does not appear to constitute a great hazard, because the probability of a meteoroid penetration is believed to be quite low. If a penetration does occur, however, there is evidence to indicate that the effects will be quite drastic. Furthermore, there appears to be considerable variation among the estimates of meteoroid flux. Further research is considered desirable, both in the areas of meteoroid penetration effects on stations or bases of the sizes and configurations planned and on the normal level and fluctuations of the meteoroid flux itself.

For study purposes, it was assumed that crew members would be able to perform their assigned tasks with no degradation in performance during their stay in the station or base. This does not take into account the possible detrimental effects on humans of long-term exposure to isolation, limited space, hazardous environment, dependence on complicated means for life support, gravity conditions radically different from those of Earth, and the like. Research in this area is desirable, although it is recognized that it may be necessary for such research to be done concurrently with the station or base operation.

Fire in the space station or base was considered to be a major hazard and, for study purposes, it was assumed that a fire, once initiated, would continue to propagate unless remedial actions were taken. There appears to be some uncertainty as to the characteristics of fire in space stations, particularly with respect to the effect of reduced or zero-gravity conditions. Research in this area is indicated, both as to characteristics of space station fires and the appropriate means of combatting them.

Certain emergency conditions, such as massive contamination, decompression, or fire, may occur that leave crew members exposed to the emergency with short, but significant, times in which to react. While devices such as protective coveralls worn as the customary garb, oxygen masks, and the like would afford some protection in such situations, a device such as a full pressure suit would be more desirable. Present pressure suits, however, must be individually fitted and require long times to don. Development of a readily available, universal, quick-donning survival device is considered highly desirable.

There is a possibility that pressure walls and bulkheads may be damaged or holed, with a resulting unacceptably high loss of station pressure. A method of repairing damage to these pressure structures should be developed. Most probably, the method must be one which can be accomplished by a crew member during EVA or at least while wearing a full pressure suit.

8.0 SUGGESTED ADDITIONAL EFFORT

The effort discussed in this section generally includes matters which are considered to be within the scope of the study but which could not be covered within the time, resources, and information available.

As discussed in Section 5.0, the evolved guidelines will require application on the basis of a considerable series of trade studies. These include the trades implicit in each guideline in which the safety increment added by application of the guideline must be weighed against other significant factors, such as cost, weight, operational suitability, and the like. Also included are the trades involving two or more guidelines which are to some degree contradictory and the application of which requires the compromise of one or more of the guidelines. This effort, it is expected, would continue throughout the design and development of the space station and base.

The crew safety problems associated with nuclear-fueled electrical power supplies were treated only in a general way in the study. The initial investigation into the nuclear safety problem indicated that the scope and magnitude of the effort required was substantially greater than could be made available during the study. It is suggested that a separate study, at about the same level of effort as this safety study, should be conducted exclusively on the problem of nuclear power supply safety.

At this early stage of space station development, the experiment program for the station has not, of course, been defined in detail. Review of the information available on the experiment program did not reveal any safety problems which had not already been examined in some other connection. In the future, as the experiment program is better defined, a further safety review is suggested to ensure that unanticipated safety problems do not, in fact, exist.

The Boeing Crew Activity Sequencing Program (CASP) is a computer program which was used in a limited application to traffic pattern problems during the study. It is capable of much broader application to include the total space station or base mission and the consideration of many factors, such as power requirements, viewing targets, crew skills, and others. It is suggested that CASP be updated to include safety factors, the future experiment program, and new requirements imposed by the space station and base, and used as a means of reviewing and evaluating future programs.

The Logic Diagram was developed during the study as a rigorous technique to reduce ambiguity, expose assumptions, identify alternatives, and permit inferences as to the probability of various events. It is capable of development to a greater level of detail. Also, it is amenable to the preparation of a computer program which could be used to explore the effects on safety of various assumptions, alternatives, or probabilities, and, thus, reveal those critical safety areas which are most sensitive and to which

effort should be directed. It is suggested that development of the Logic Diagram be continued and a computer program based on it be prepared.

While examination of other space systems or programs was outside the scope of the study, the safety problems of other programs are to a large degree common to those considered during this study. The results of the study, then, are also generally applicable to other programs. It is suggested that safety studies be initiated on other programs, for example, the space shuttle and lunar or planetary exploration programs, using the results of this study as a starting point.