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SPACE STATION SAFETY STUDY

FINAL ORAL REVIEW

D2-113070-3

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THE **BOEING** COMPANY
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INTRODUCTION

The Space Station Safety Study was, as the name implies, a study of the safety problems of future space stations, with the emphasis being on crew safety only, rather than the broader system safety concept. Other factors which will influence future station design and development, such as cost, weight, operational suitability, and the like, were not specifically considered. Further, only the on-orbit phase of the mission was examined and therefore, anything having to do with launch, boost, orbit injection, de-orbit, re-entry, and recovery has not been considered as such. Management decisions will be required in which the desirability or necessity of safety features must be weighed against the demands imposed by other factors.

With the intent of making the study as complete as possible, all hazards and undesired events which could be identified were examined, and measures to cope with them were devised. As a result, some of the safety measures described will seem trite or self-evident, or describe actions already being taken. Also, no attempt was made in general to determine the probability of occurrence of a hazard, or establish reliability numbers. In short, the degree of risk associated with the various hazards was not determined and therefore, some safety measures may be directed against hazards which have a very low probability of occurrence.

The analytical techniques employed during the study were discussed during the mid-term review and are described in detail in the various report documents and will be mentioned only briefly in the review. Medical problems of the station and base are, for the most part, not discussed explicitly but are, instead, included in the study results.

The major portion of this presentation will be devoted to study results, but before going to that, a short discussion of the study background is in order.

INTRODUCTION

STUDY MILESTONES

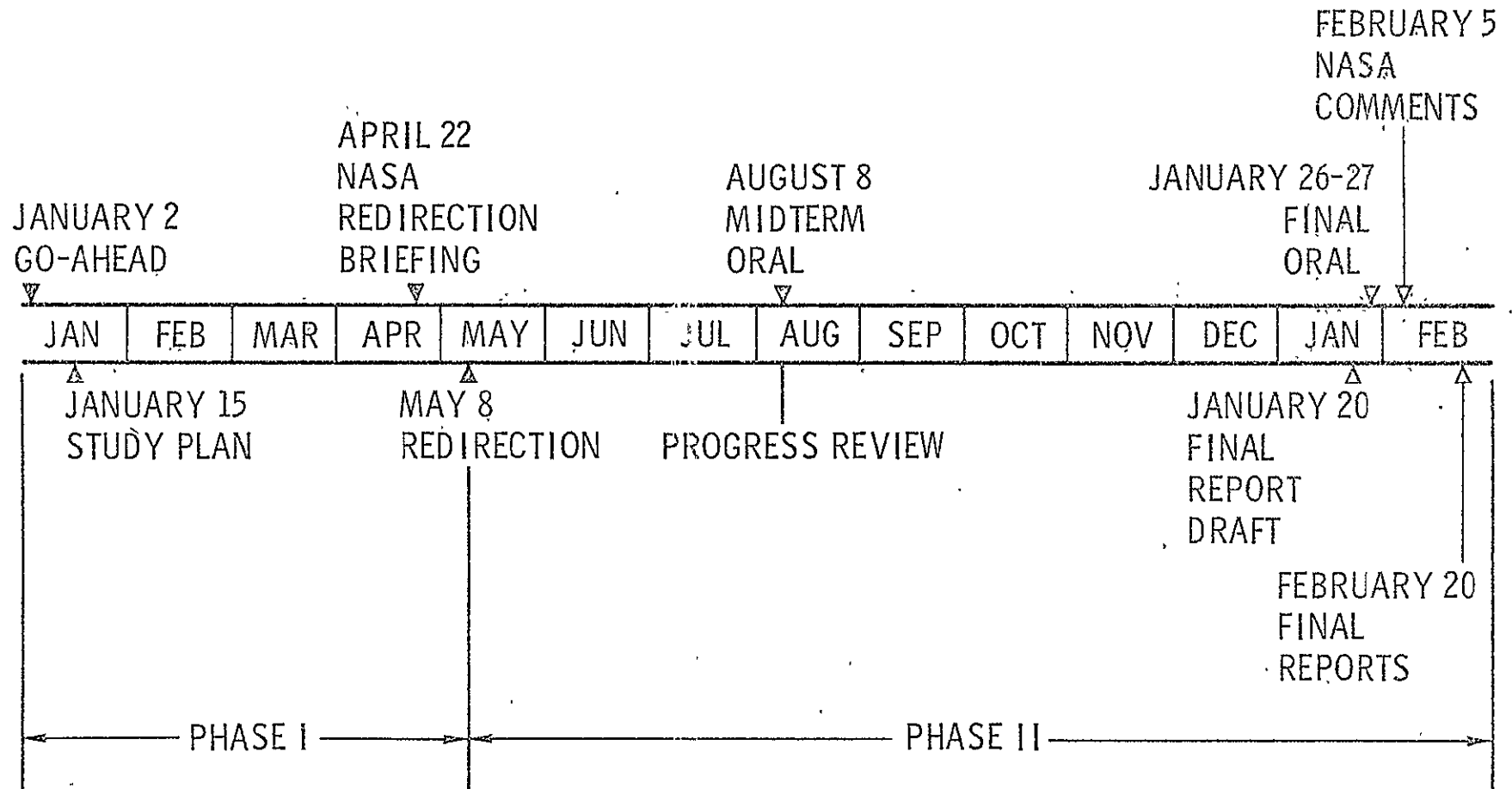
The major milestones of the study are shown on this chart and it is, for the most part, self-explanatory. However, a few words concerning the study phases are in order.

In the month or so just before study initiation and during the first months of the study, the thinking on future space stations underwent a considerable revision, culminating in the concepts now being studied by two other contractors. The Safety Study, as it was then contemplated, was not oriented to support the new concepts as well as was desired. During the latter part of April and early May, the study was redirected to better support the future space station concepts. By way of identification, the period prior to redirection was called Phase I and subsequent, Phase II.

Two major changes in the study resulted from the redirection. First, orientation was shifted from consideration of specific hardware as exemplified in the three baseline configurations used, to consideration of future concepts. This broadened the study but restricted its detail. Second, the study product was changed from Handbooks of Safety Design Guidelines and Astronaut Safety Operating Procedures to a tool by which management could evaluate "crew safety" in future space station concepts and designs.

Every effort was made during Phase II to utilize the work done in Phase I and no distinction is made, in general, between the two phases in this review.

STUDY MILESTONES

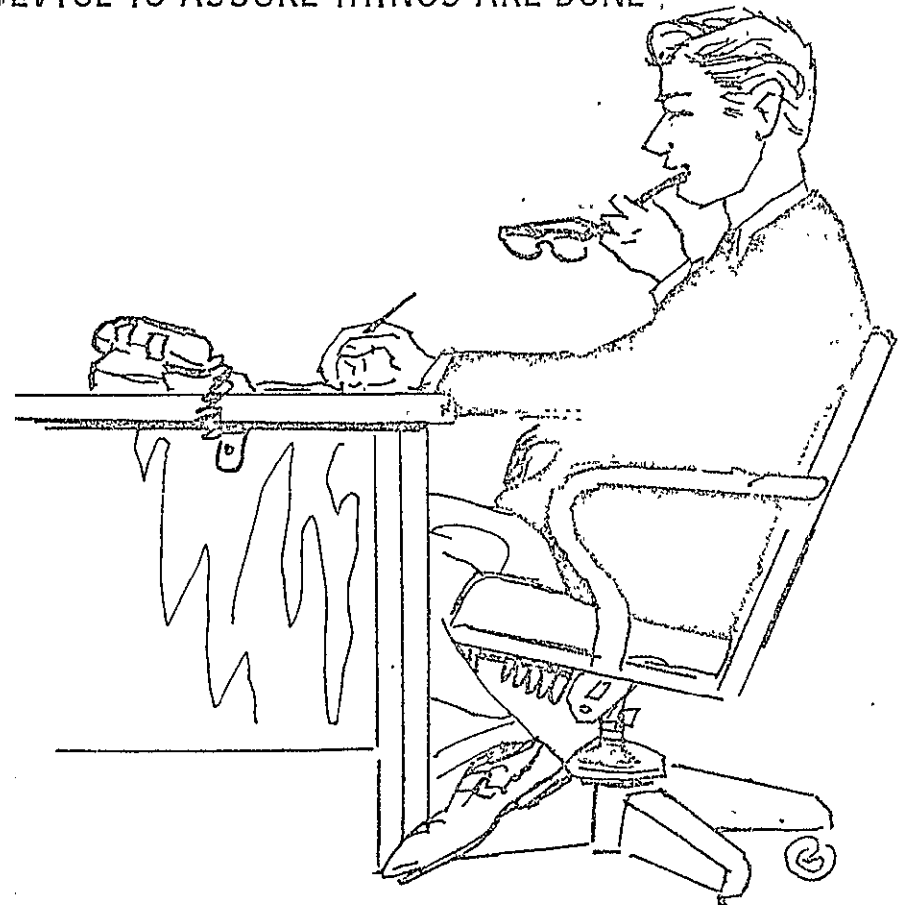


STUDY OBJECTIVES

More formal statements of the scope and objectives of the study are contained in charts in the back of this brochure. Reduced to its essentials, we were asked these two questions. First, we were required to identify, to the maximum extent possible, the actions necessary in order to maximize crew safety in the space station or base. Second, we were asked to provide a "tool" or device by which management could focus its attention on safety and assure that the appropriate safety actions were taken, or, if not taken, had been considered and rejected for known and adequate reasons.

STUDY OBJECTIVES

- WHAT THINGS TO DO TO MAKE THE STATION/BASE SAFE
- WHAT MANAGEMENT DEVICE TO ASSURE THINGS ARE DONE



STUDY CONSTRAINTS

The study was subject to certain constraints, as listed here. The orientation of the study to safety only, and more specifically to crew safety, has been mentioned before and is re-emphasized here. The broader system safety concept, in which equipment performance and mission accomplishment are of interest, was not considered. However, it should be noted that many actions needed for crew safety also enhance mission accomplishment.

Only the on-orbit phase of the mission was considered. Launch, boost, orbit injection, de-orbit, re-entry and recovery were not examined as such and the study results are not directed at these phases. It should be noted, though, that these phases have much in common with on-orbit operations and many safety measures needed for the orbital phase are also appropriate for other phases.

The study dealt with concepts, rather than hardware, and no laboratory or test work seemed to be appropriate.

No reliability or probability numbers were established for or derived during the study. While we were free to establish or use such numbers if it seemed appropriate, this constraint seemed desirable in the interest of assuring that we had identified and examined as complete a list of hazards as possible, including those which may prove, in the final analysis, to be rather insignificant.

STUDY CONSTRAINTS

- CREW SAFETY
- ON-ORBIT OPERATIONS
- NO LABORATORY OR TEST WORK
- NO RELIABILITY OR PROBABILITY NUMBERS

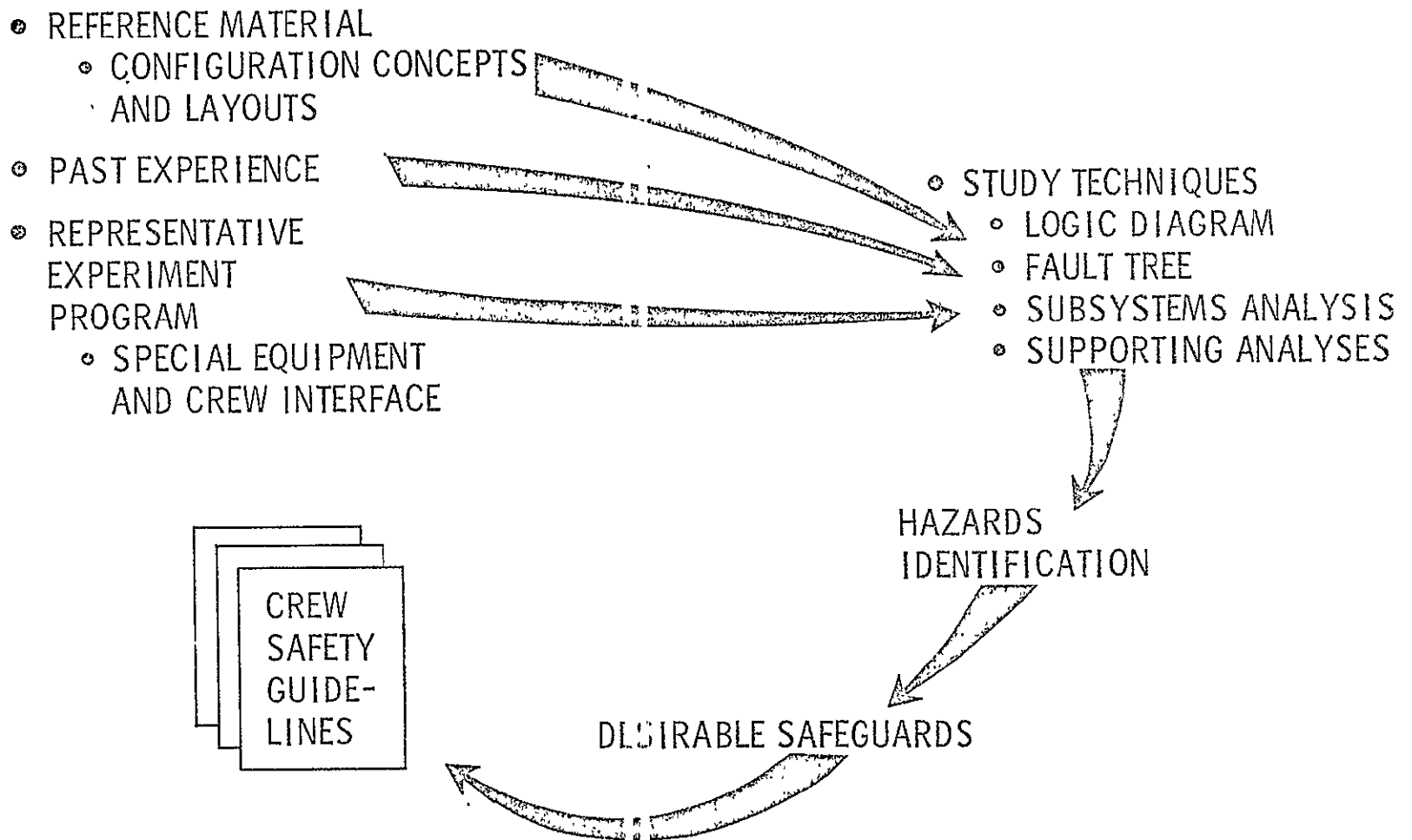
STUDY APPROACH

The basic approach taken in the study, and that which underlies all of the effort, was to confine our attention to crew safety only, to the exclusion of other factors, but within that framework to examine all identifiable hazards and develop some course of action to alleviate each hazard.

The approach taken in specific study tasks was generally as shown on the chart. The available body of experience was called upon in the form of documents, reports and the like, including various space station configurations, and a representative experiment program. A review and evaluation of this information established a baseline from which to proceed, presuming that future space stations would be analogous in some respects to past programs. The study techniques listed were used to provide a methodical means of applying past experience to future concepts to establish hazards likely to be encountered. This included hazards already known and new or changed hazards which could be expected in the future concepts.

A safeguard against each hazard was developed and expressed as a Crew Safety Guideline.

STUDY APPROACH



STUDY PRODUCTS

The primary product of the study was the Crew Safety Guidelines, which have just been mentioned, and secondary products included the report documentation and techniques which have been used in the study or identified by it as appropriate for further use.

STUDY PRODUCTS

PRIMARY PRODUCT

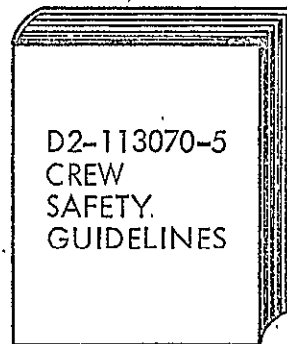
The primary study product is the set of 282 Crew Safety Guidelines which are contained in Document D2-113070-5. Over 500 guidelines were derived initially, being reduced to 282 during the study and particularly during the final review. Most of the guidelines deleted were, in fact, combined with other nearly identical or very similar guidelines. In a few cases guidelines were deleted because they were not feasible or did not alleviate the hazard.

Each guideline appears in the document only once, listed under an appropriate hazard group. They are, in addition, cross-referenced to other hazard groups, to the subsystems affected by the guideline, by key words, and by those applicable to damage containment and control.

The guidelines are a list of the actions which should be taken in the interest of crew safety and together they provide the tool by which management can evaluate future concepts from the safety viewpoint.

The guidelines will be discussed in more detail shortly.

PRIMARY PRODUCT



- 280+ GUIDELINES
- CROSS-REFERENCED BY:
 - HAZARD GROUP
 - AFFECTED SUBSYSTEMS
 - KEY WORDS
 - DAMAGE CONTROL

LIST OF THINGS TO BE DONE

PROVIDES BASIC MANAGEMENT DEVICE OR CHECKLIST
FOR EVALUATION OF SPACE STATION SAFETY

HAZARD GROUPS

The hazard groups used are shown in this chart together with the number of guidelines in each group. These groups were identified originally by the logic diagram as being representative of hazard groupings or classifications identified or used by previous investigators. Like all hazard groupings examined, there is a considerable amount of overlap between groups in this list and assignment of guidelines to a hazard group was frequently arbitrary. A brief description of each group follows:

- 1.0 Contamination--the undesired presence of a material, either toxic or non-toxic.
- 2.0 Debris and Meteoroid Impact--collision or impact with natural or man-made objects which are not part of or associated with the station.
- 3.0 Decompression/Overpressure--Deviation of station pressure from established limits.
- 4.0 Electrical--any hazard associated with electricity, including static electricity.
- 5.0 Equipment Impact--collision or impact with equipment, subsatellites, or other vehicles within or outside the station and which are associated with the station.
- 6.0 Explosion--sudden disruption of station or components.
- 7.0 Illness and Injury--a condition in which the health of a crew member departs from normal.
- 8.0 Loss of Vital Supplies--loss of food, air or water.
- 9.0 Radiation--all electromagnetic radiation, cosmic rays and by-products of nuclear reactions.
- 10.0 Temperature Extremes--either extreme heat or cold but also includes variations of temperature from normal.
- 11.0 Spacecraft Accelerations--any motion of the space station, whether planned or unplanned.
- 12.0 General--not particularly applicable to any group, or applies to many or all groups.

HAZARD GROUPS

NO.	TITLE	NO. OF GUIDELINES	NO.	TITLE	NO. OF GUIDELINES
1.0	CONTAMINATION	32	7.0	ILLNESS AND INJURY	23
2.0	DEBRIS AND METEROID IMPACT	4	8.0	LOSS OF VITAL SUPPLIES	33
3.0	DECOMPRESSION/OVERPRESSURE	25	9.0	RADIATION	21
4.0	ELECTRICAL	14	10.0	TEMPERATURE EXTREMES	30
5.0	EQUIPMENT IMPACT	12	11.0	SPACECRAFT ACCELERATIONS	12
6.0	EXPLOSION	13	12.0	GENERAL	63

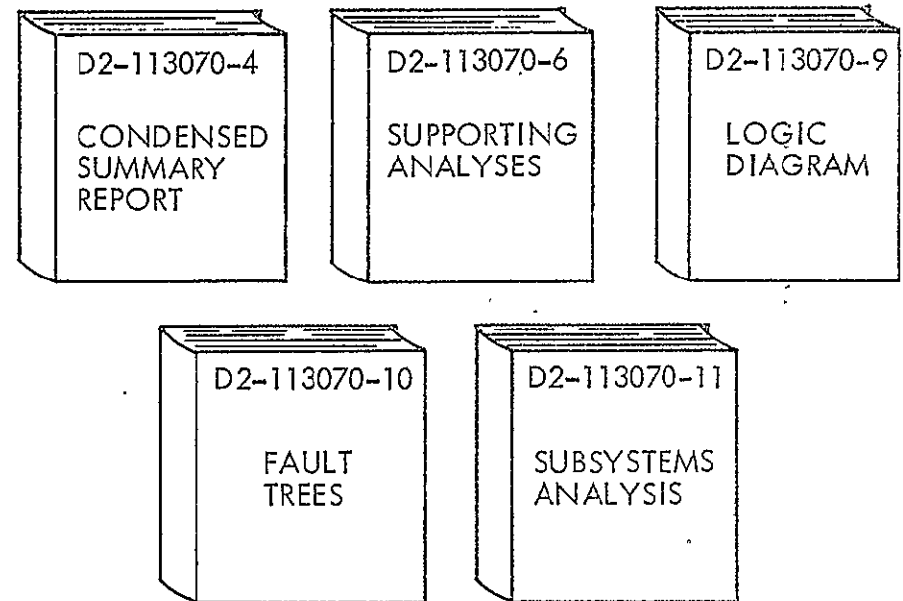
SECONDARY PRODUCTS

The secondary products include the other report documents, which describe the techniques used in the study and provide the reasoning and rationale on which study conclusions were based. Also included are analytical techniques that are not described in the report documentation but which were identified during the study as possible useful techniques for future work. CASP was used to a limited extent in the Traffic Pattern analysis of the study but is capable of much broader application. It consists of a computer program with which the total space mission can be examined including consideration of factors such as crew skills, power requirements, Sun angles, targets, and the like. MARCEP is also a computer program by means of which an optimum maintainability and reliability program for a space station may be developed. The Incipient Failure Detection analysis provides a means by which acoustical energy is used to detect failures of parts and components in their initial stages of the failure.

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SECONDARY PRODUCTS

● REPORT DOCUMENTATION



● ANALYTICAL TECHNIQUES

- CREW ACTIVITY SEQUENCING PROGRAM (CASP)
- MAINTAINABILITY AND RELIABILITY COST EFFECTIVENESS PROGRAM (MARCEP)
- INCIPIENT FAILURE DETECTION ANALYSIS

GUIDELINES APPLICATION

Since the guidelines are the primary product, the remainder of the briefing will be devoted to a discussion of what they are, what limitations or cautions are necessary for their application, and their implications. The guidelines are intended to be specific enough to be useful and at the same time broad enough to be generally applicable to any future space station. In one application they could be used simply as a check list with which to review and evaluate safety features of a final design. At the other extreme from this would be to apply them systematically to the development of station and base concepts that incorporate the desired safety features. In either case, however, it is necessary that management establish a strong safety organization having responsibility for planning and controlling the space station/base safety program. In that regard, the guidelines provide a basis for establishing a viable safety program.

During the final stages of the study we conducted a feasibility review to assure ourselves that the guidelines were feasible and could be applied. Further discussion will show that, at least for those guidelines discussed, they are feasible.

GUIDELINE APPLICATIONS

WHAT IS A GUIDELINE?

No suitable existing definition was found for the term "guideline." This definition was synthesized as the best expression to be found of the term in the sense in which the guidelines derived during the study are intended.

In the case of crew safety guidelines, of course, it is understood that the course of action, if taken, will to some degree enhance crew safety in the space station or base. Furthermore, all guidelines are equally applicable to either the station or the base unless the sense of the guideline clearly limits its application.

WHAT IS A GUIDELINE?

IT IS A STATEMENT THAT POINTS THE WAY
TOWARD A COURSE OF ACTION

GROUND RULE

Early in the study, we attempted to work first with the zero-gravity station and then translate the results to the artificial-gravity space base. Because of significant differences in the two concepts, this approach appeared less effective than the reverse, namely, to deal first with the base and translate the results to the station. In the latter part of the study, especially during Phase II, the ground rule as shown, then, applied.

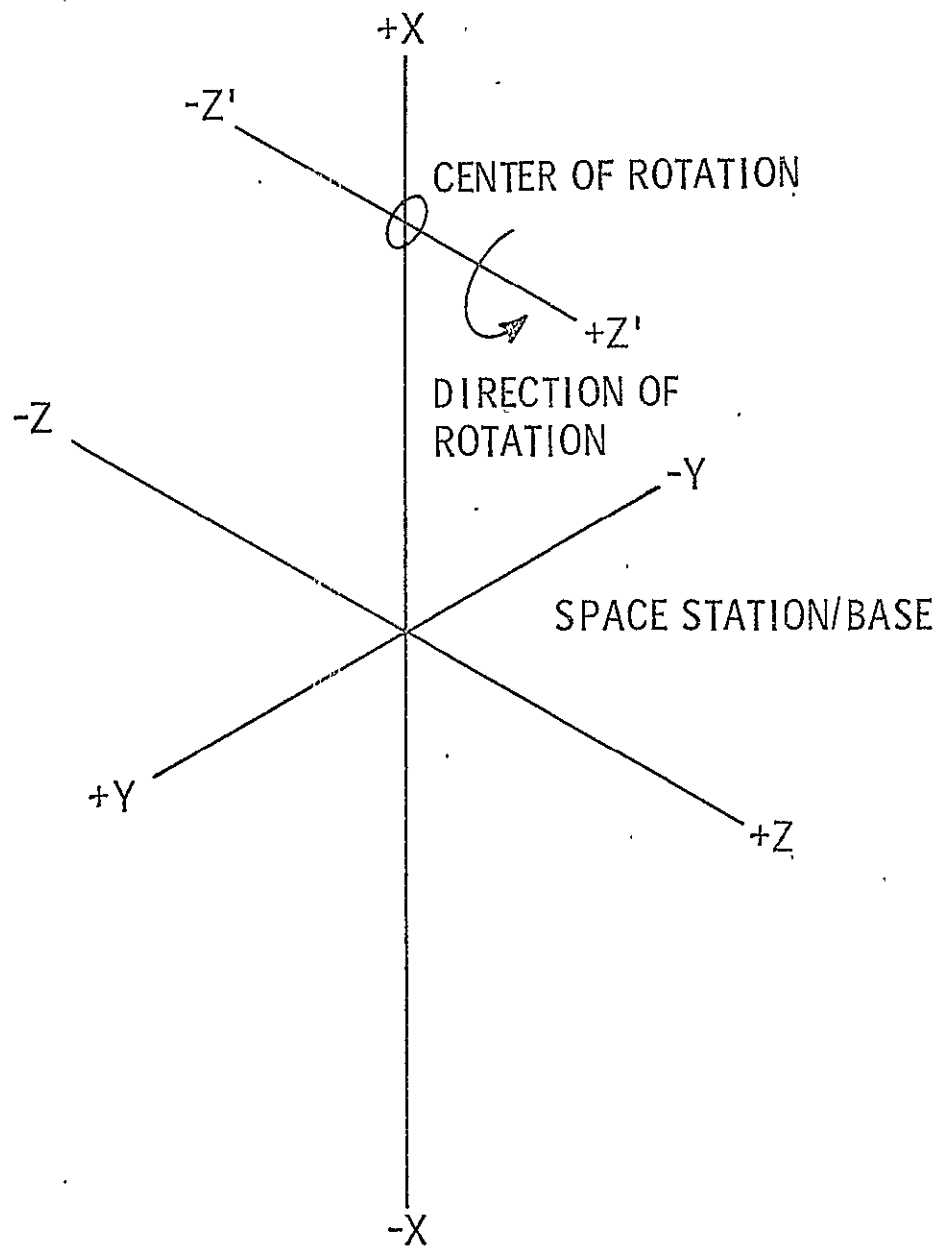
GROUND RULE

- ② STATEMENTS MADE ARE EQUALLY APPLICABLE
TO SPACE STATION AND SPACE BASE

COORDINATE SYSTEM

The coordinate system shown was arbitrarily established. In this system the Z' -axis is the axis of rotation, the X-axis is the radius of rotation and the Y-axis is tangent to the rotation. Rotation is in the $-Y$ direction. In the station and the rotating portion of the base, the usual X, Y, and Z axes are used.

COORDINATE SYSTEM



CONFIGURATION DRIVERS

Guidelines may serve to direct design details, establish procedures, or may tend to drive the configuration. Because most guidelines have elements of all three, they are not cross-referenced or grouped that way.

Since configuration drivers are most important, at least in the early stages of design and development, most of this discussion will deal with guidelines that are strongly configuration drivers.

CONFIGURATION DRIVERS

TRAFFIC/WORK FLOW GUIDELINES

Presumably, almost any guideline, or set of guidelines, which tend to establish the configuration could be chosen as a starting point. Those dealing with traffic and work flow were chosen because they appear to represent problems in future space stations, which will be considerably greater than similar problems of the past, particularly with respect to the artificial gravity space base.

Three typical guidelines in this area, the gist of which is shown on the chart, are:

- 7.7 Design of rotating spacecraft should be such that the direction of major traffic flow is parallel to the vehicle spin axis.
- 7.19 Design of rotating spacecraft should be such that radial traffic is kept to a minimum.
- 7.23 Crew living and working stations should be oriented such that during normal activity, the lateral axis through the crew members' ears is parallel to the axis of spin. In conjunction with this guideline, the work console instruments and controls should be designed so that left-right head rotations and up-down arm motions are minimized.

Considering these guidelines, and only these guidelines, a concept for the station/base can be developed.

TRAFFIC/WORK FLOW GUIDELINES

- 7.7 MAJOR TRAFFIC FLOW PARALLEL TO AXIS OF ROTATION
- 7.19 RADIAL TRAFFIC KEPT AT MINIMUM
- 7.23 AXIS THROUGH EARS PARALLEL TO AXIS OF ROTATION

TRAFFIC/WORK CONFIGURATION

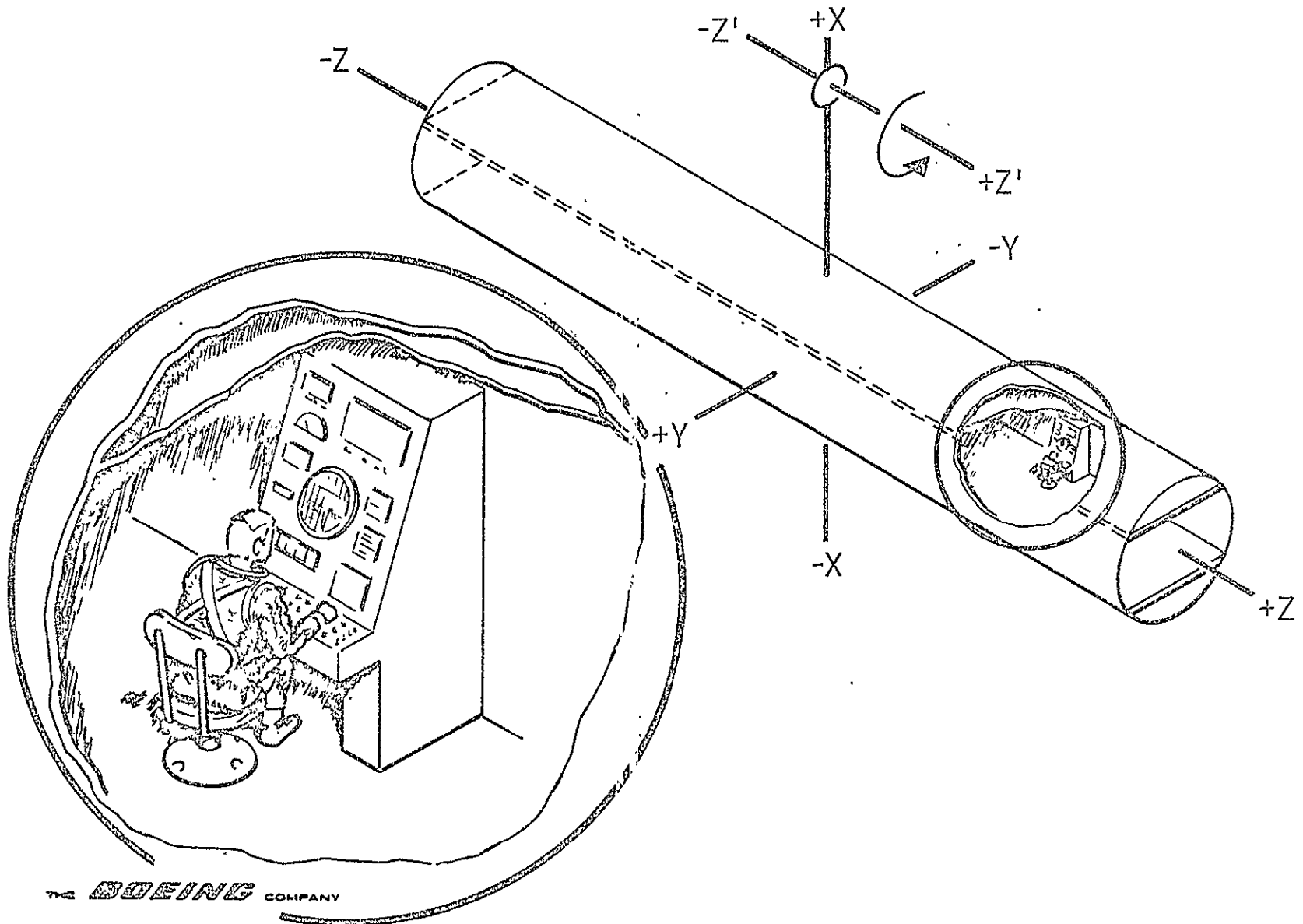
Such a concept is shown here, in which only the artificial gravity portion of the space base is shown. Other components would include a non-rotating hub along the Z' axis and counterbalances (e.g., nuclear electric power supplies) in the +X direction.

The base is long and slender, forcing the major flow of traffic in the axial direction, as specified. It has only one deck, thereby eliminating radial traffic except for traffic to the non-rotating, zero-gravity central hub, and such traffic apparently is unavoidable in any rotating configuration. The location and arrangement of the crew work station, as shown in the cut-away and the enlarged detail, complies with the guideline.

This concept is presented, not as a candidate configuration, but to illustrate two points with respect to the guidelines. First, if other factors such as launch and boost problems and rotation dynamics were considered, this particular concept might encounter some difficulties. Therefore a consideration of other factors, involving trade studies comparing safety features versus other important matters, is necessary with respect to most guidelines. Second, from the safety point of view alone, this concept does not include certain features which are also desirable. This points to a second set of trade studies to evaluate the relative merits of desired safety features and effect the best compromise possible.

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TRAFFIC/WORK CONFIGURATION



COMPARTMENTATION GUIDELINES

To illustrate the compromise necessary with respect to safety features, consider the requirements for compartmentation and associated features. Two typical guidelines in this area are:

- 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 escape routes, which should not terminate in a common compartment.

COMPARTMENTATION GUIDELINES

12.13 TWO OR MORE COMPARTMENTS

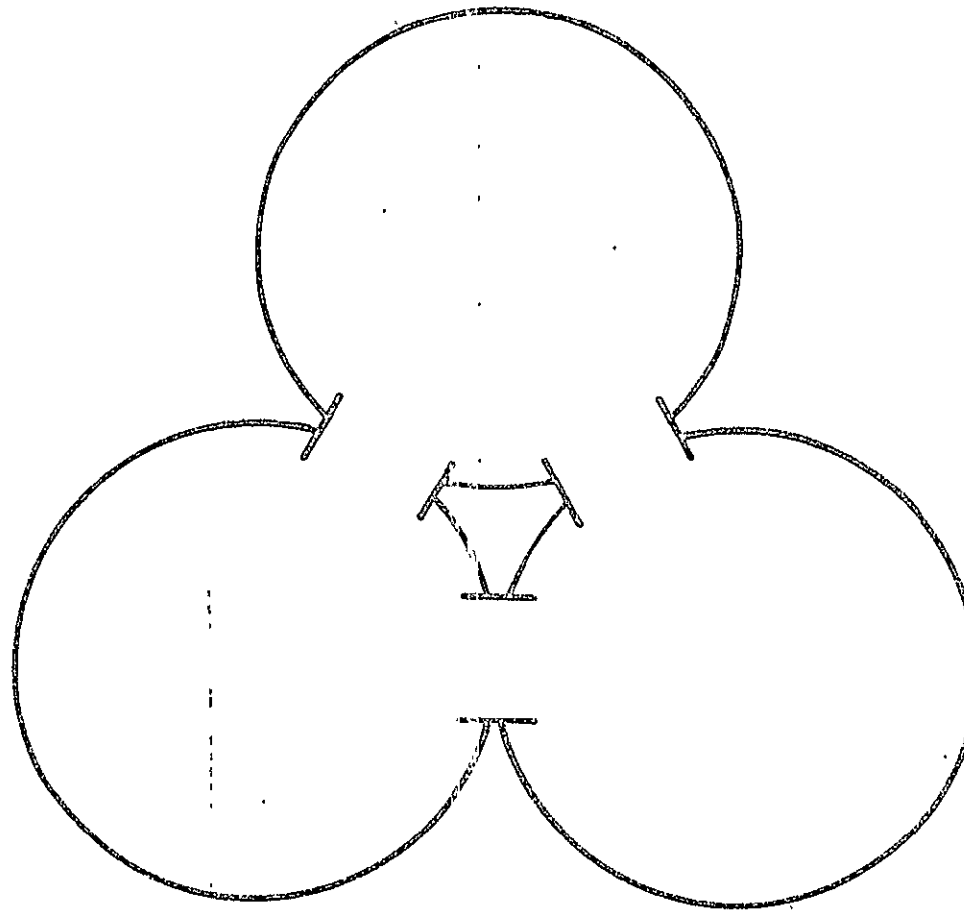
12.30 TWO OR MORE EXITS NOT TERMINATING AT COMMON POINT

COMPARTMENT--MINIMUM

This bubble diagram illustrates the ideas expressed in the guidelines just quoted. It indicates that the minimum number of compartments will be three, each of which has two ways of exit.

No conclusions should be drawn here as to the relative size of the compartments, nor as to their placement with respect to each other and the routes between them.

COMPARTMENTS—MINIMUM



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COMPARTMENTATION

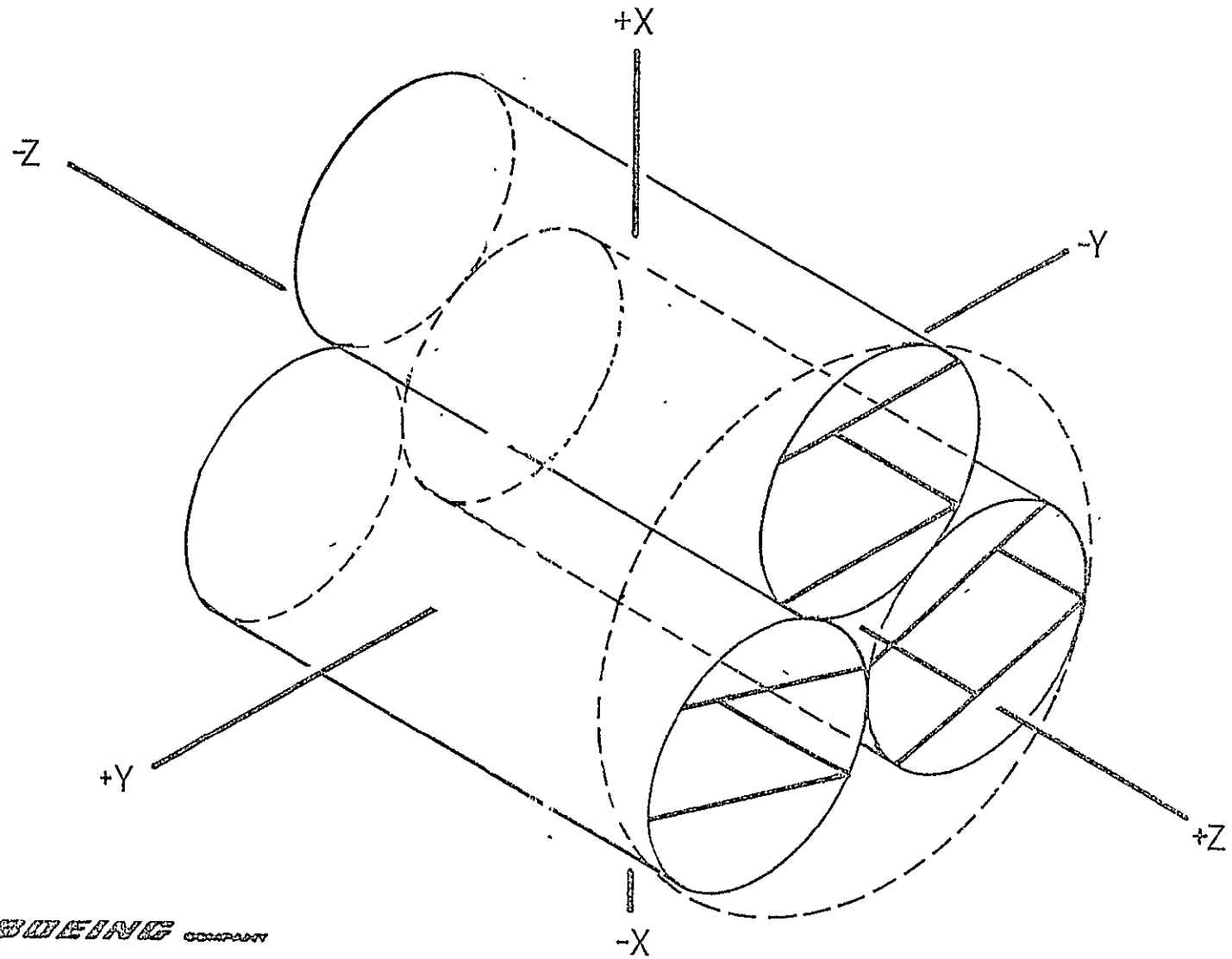
A compromise between the traffic pattern concept and the compartmentation concept can be reached as shown here, in which three, single-deck compartments are stacked as shown. In the artificial-gravity base, this arrangement would rotate in the Y direction about a central non-rotating hub displaced along the X-axis. This concept meets the compartmentation requirement, but does so at the expense of requiring some radial traffic in order to travel between decks.

This, again, is not a candidate configuration. Neither should any conclusions be drawn from this as to the relative importance of compartmentation versus traffic flow.

While no attempt has been made to establish proportions or dimensions in these concepts, it was noted that three, 14-foot diameter compartments could be accommodated within a 33-foot diameter envelope.

As before, consideration of other factors might reveal shortcomings in this concept, but more important from our point of view, certain safety features are still lacking.

COMPARTMENTATION



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CREW DISTRIBUTION GUIDELINE

In the interest of exposing the fewest possible crew members to a hazard or emergency which occurs at a particular point in the station, the following guideline states:

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.

Compliance with this guideline may be difficult when some other findings of the study are considered.

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CREW DISTRIBUTION GUIDELINE

12.18 MINIMUM NUMBER IN ANY COMPARTMENT

CREW DISTRIBUTION

A finding of the study was that crew members spend about two-thirds of their time in those areas devoted to crew health and well-being. This chart shows man-hours per day spent in eating, sleeping, personal hygiene, recreation and exercise. In the 12-man space station illustrated, the crew tends to congregate in these areas on Decks 4 and 5. The other three decks of the station do not have any areas having more than 10 man-hours per day occupancy.

A similar finding was made with the other configurations examined and we find no reason to think that any other configuration will be greatly different. Possibly crew activity scheduling might alleviate the situation to some degree but probably not entirely.

CREW DISTRIBUTION

12-MAN SPACE STATION

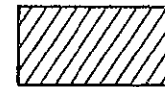
TOTAL MANHOURS PER DAY



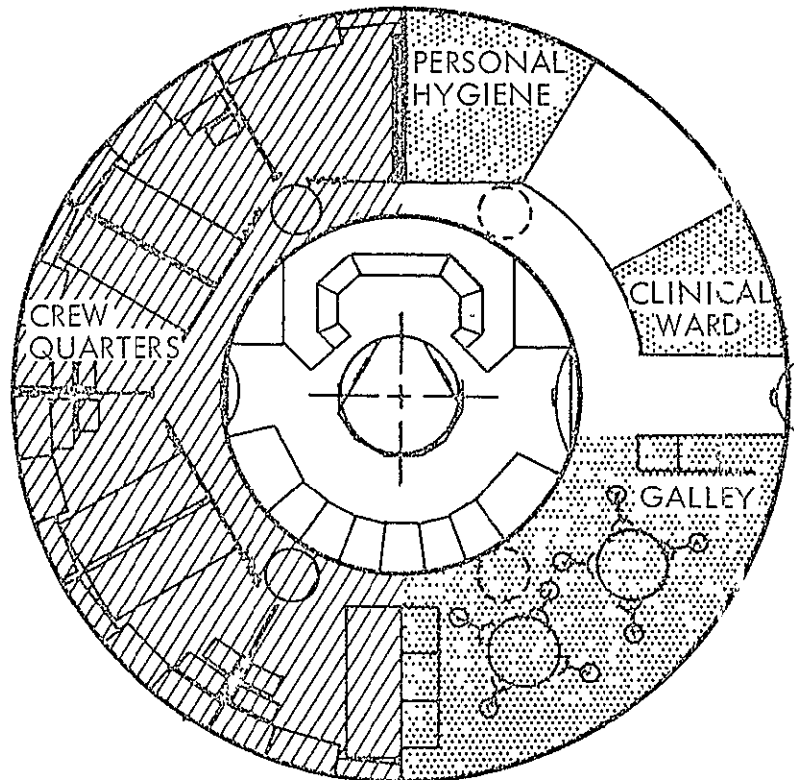
0 - 10



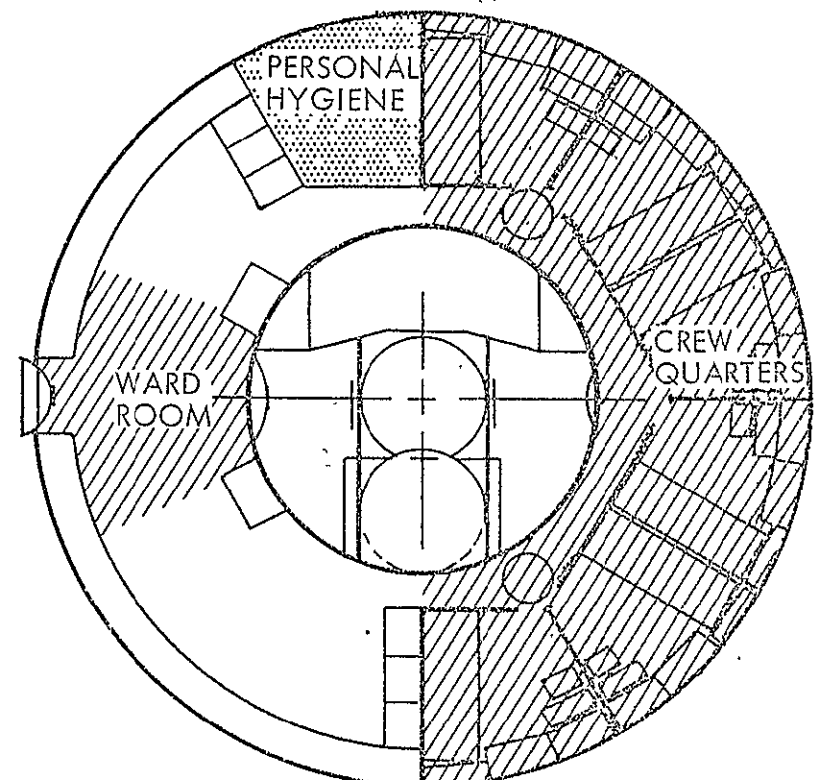
10 - 30



30 - 70



CREW QUARTERS, GALLEY, COMMAND AND CONTROL
DECK 4



CREW QUARTERS AND WARD ROOM
DECK 5

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CREW AREA LOCATION GUIDELINE

Recognizing, then, that the "minimum" number of crew members in a compartment may prove to be a relatively large number, the following guideline was derived:

- 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.

CREW AREA LOCATION GUIDELINE

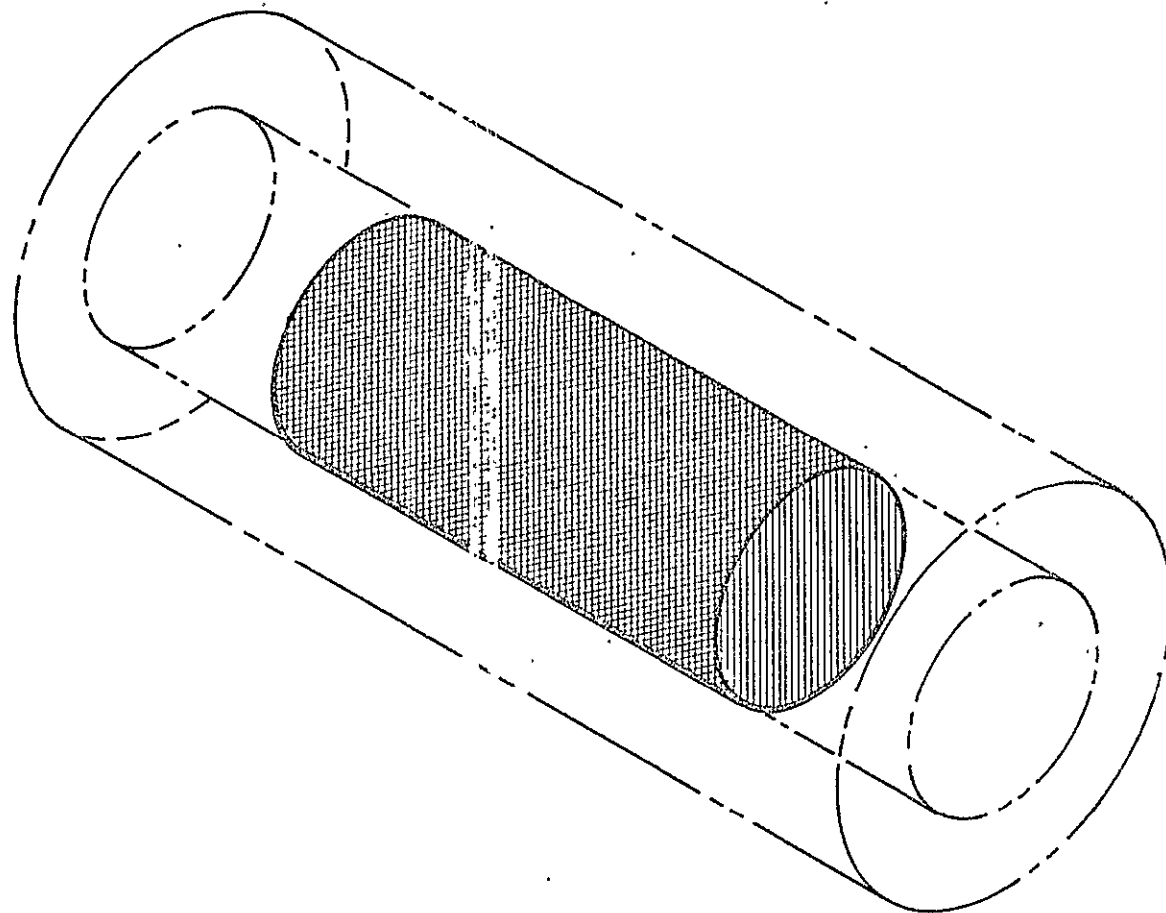
12.20 CREW-ORIENTED AREAS TO BE MAXIMUM SAFETY

CREW AREA LOCATION

A reasonable solution is shown in this concept in which the crew-oriented area is located centrally within the station. Walls and bulkheads surrounding the crew area are pressure structures, as are the exterior walls and bulkheads of the station. The area surrounding the crew area would be equipment and storage bays. Other features, such as conducting particularly hazardous operations at a location as remote as possible from the crew area, would also be required.

This concept appears to afford maximum protection to the crew from all hazards, except possibly high radiation levels.

CREW AREA LOCATION



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REDUNDANCY GUIDELINES

There is a considerable number of guidelines which express the idea of redundancy in one way or another. Only one will be quoted in entirety, which is:

- 8.9 A space station should include at least two independent EC/LSS's located in separate compartments. These systems should be capable of supplying the atmospheric requirements even with one system inoperative.

The other guidelines express the same ideas, namely, duplicate systems, either of which operating alone can supply the total station requirements, at least those requirements essential to crew safety.

In sum total, these guidelines require a configuration which begins to approach two interconnected and mutually supporting stations.

REDUNDANCY GUIDELINES

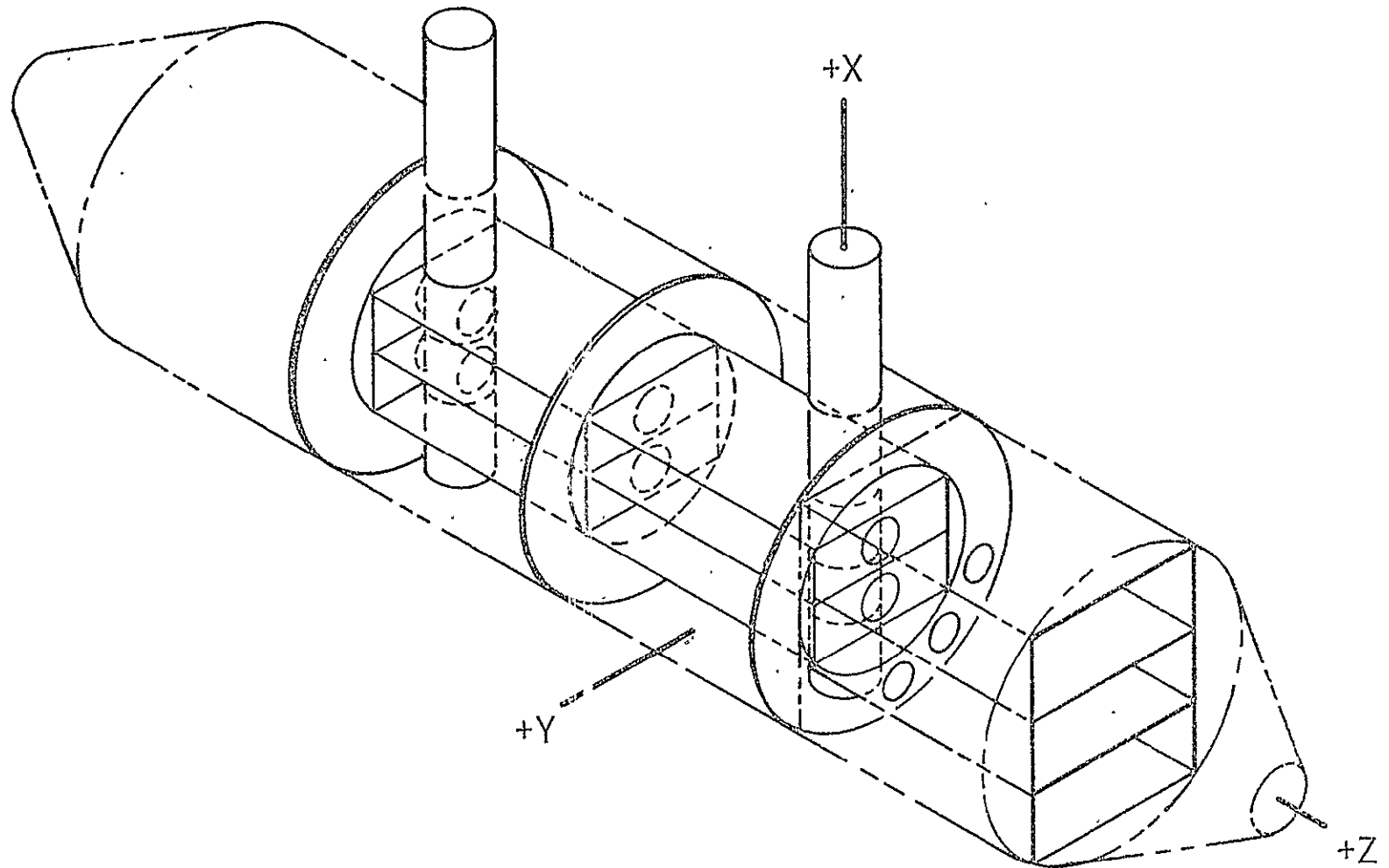
- 1.4 CONTAMINANT DETECTION EQUIPMENT SHOULD BE REDUNDANT
- 1.12 FOOD STORED IN MORE THAN ONE CONTAINER
- 1.14 FOOD REFRIGERATION SHOULD BE REDUNDANT
- 5.5 MORE THAN ONE DOCKING PORT
- 8.14 MORE THAN ONE OXYGEN STORAGE TANK
- 8.33 MORE THAN ONE WATER STORAGE TANK
- 10.26 THERMAL CONTROL EQUIPMENT SHOULD BE REDUNDANT
- 12.23 REDUNDANT DOCKING MECHANISMS
- 4.9 ELECTRICAL DISTRIBUTION SYSTEM REDUNDANT
- 4.11 MORE THAN ONE ELECTRICAL POWER SUPPLY
- 8.9 AT LEAST TWO INDEPENDENT EC/LSS'S

STATION/BASE CONCEPT

The concept shown here incorporates all the safety features, or necessary compromises, that have been discussed previously. It is essentially a Siamese twin, divided into two halves by a central pressure bulkhead through which hatches allow access between the halves. The crew area is double-decked, located centrally with pressure bulkheads at the ends and with the shell surrounding the area a pressure wall. Exterior walls and bulkheads are pressure structures. Note that this arrangement of pressure walls and bulkheads provides six separately pressurizable compartments. Work and laboratory areas at the ends are shown triple-decked but could, of course, have other arrangements.

In the rotating space base configuration, an elevator shaft for each half allows access to the central non-rotating hub and, further, to two nuclear electric power sources which also are counterweights. Major traffic flow is axial with radial and tangential traffic minimized. Also, the elevator would provide the normal means of radial movement.

STATION/BASE CONCEPT



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AIRLOCKS AND PASSAGEWAYS GUIDELINES

With the general concept in mind, we can now proceed to see how other guidelines will affect or be affected by it. There are a number of guidelines which have to do with airlocks and passageways. The gist of several are shown in the chart, of which only two are quoted in entirety:

- 3.9 Provision should be made for an airlock in the hatch or hatchway between separately pressurizable compartments.
- 12.1 Accessways between and within compartments should be sized in such a manner that an IVA-suited crew member will be allowed access to normally used areas.

These, together with others of a like nature, can strongly affect the configuration.

AIRLOCKS AND PASSAGEWAYS GUIDELINES

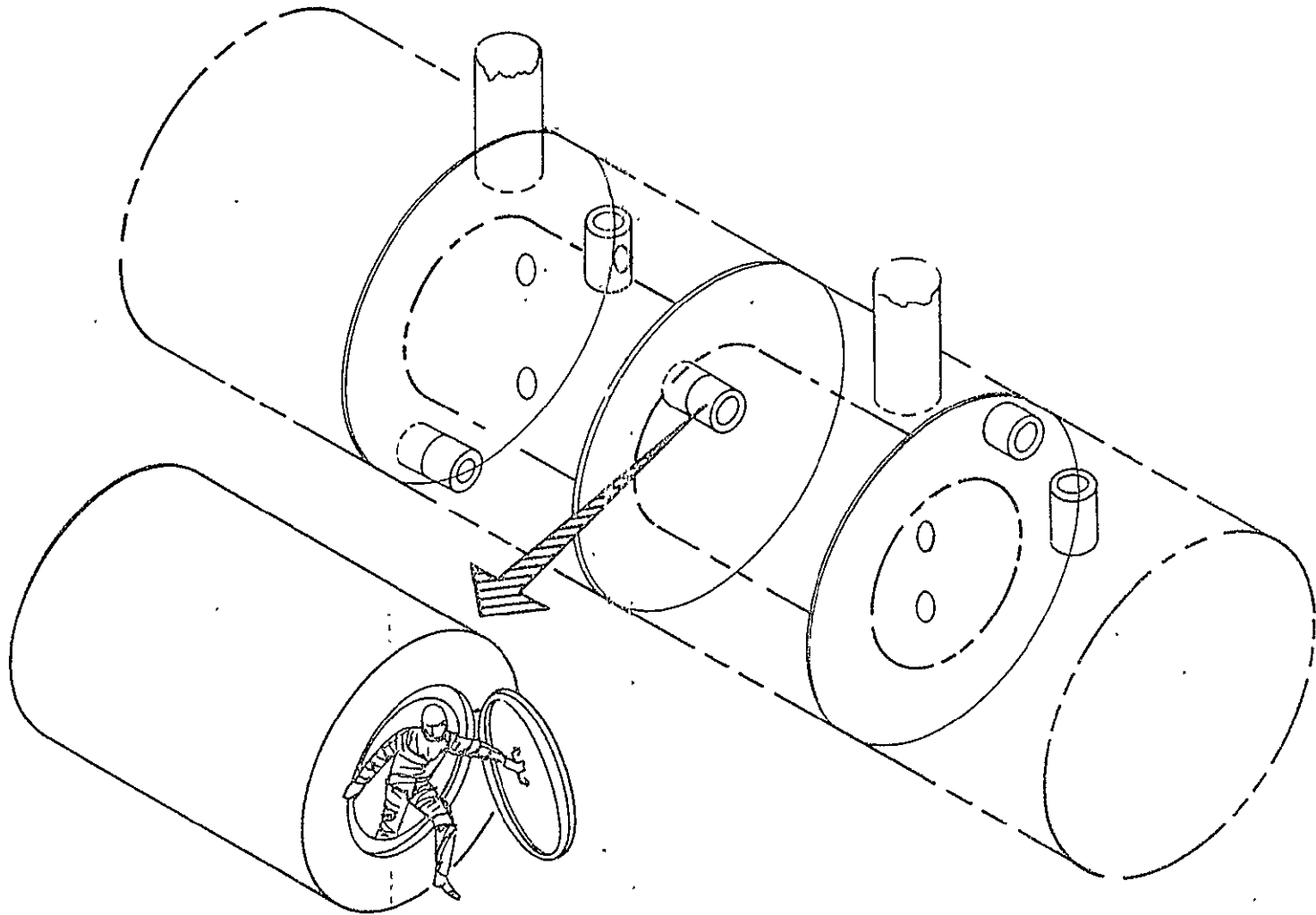
- 3.9 AIRLOCK IN HATCH BETWEEN COMPARTMENTS
- 12.1 ACCESSWAYS LARGE ENOUGH FOR SUITED CREWMAN
- 12.4 MORE THAN ONE EXTERNAL AIRLOCK
- 12.30 AT LEAST TWO EXITS FROM COMPARTMENTS
- 12.62 TRAFFIC ROUTES SO AS TO MINIMIZE CONGESTION

AIRLOCKS AND PASSAGEWAYS

As shown here, strict application of these guidelines will call for fairly good sized hatches, which may be unavoidable, and numerous airlocks. This illustrates again the point made earlier, that a valid guideline may require, in the practical application, some compromises.

The idea of airlocks between compartments, of course, is to allow access to a depressurized compartment without having to depressurize the entire station. If the number of compartments is small, the requirement for airlocks between them becomes much more urgent. On the other hand, if there are many compartments, it would be possible, and might be more desirable, to gain access by depressurizing an adjacent compartment. An alternate which might also be considered would be use of a portable airlock.

AIRLOCKS AND PASSAGEWAYS



DESIGN DETAILS

The guidelines discussed so far have been primarily configuration drivers. Many guidelines are concerned with design details, insofar as we were able to cover them in the study, and some of these will be discussed.

DESIGN DETAILS

COMMAND, CONTROL, AND WARNING GUIDELINES

A set of guidelines has to do with command and control and the provision of detection devices and warning systems. The gist of some of them is given in this chart.

COMMAND, CONTROL, AND WARNING GUIDELINES

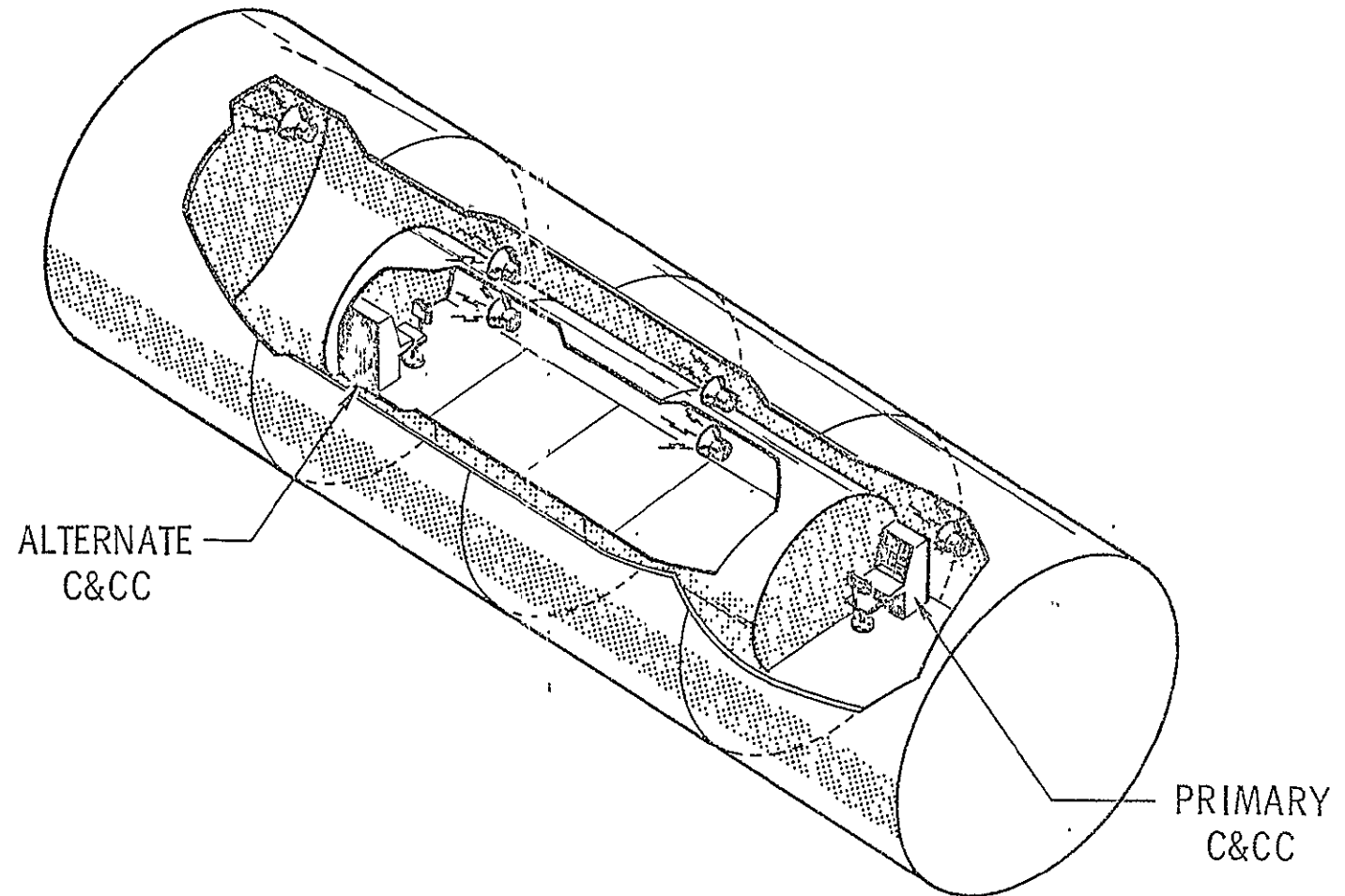
- 1.24 VISUAL/AUDIBLE CONTAMINATION WARNING
- 3.24 CABIN PRESSURE WARNING SYSTEM
- 3.25 WARNING SYSTEMS FAIL SAFE AND INDICATE FAILURE
- 8.30 VISUAL/AUDIBLE WARNING OF OFF-LIMITS OXYGEN PRESSURE
- 12.5 PROVIDE AN ALTERNATE COMMAND AND CONTROL CENTER
- 12.8 C&C CENTER TO AUTHORIZE HAZARDOUS OPERATIONS
- 12.10 MONITOR HAZARDOUS OPERATION BY REMOTE TV
- 12.22 CRITICAL WARNING ALARMS IN ALL COMPARTMENTS

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COMMAND, CONTROL, AND WARNING SYSTEM

Here we show two command and control centers. They are located in separate compartments and are physically well separated from each other. A warning or alarm system is shown in each compartment.

COMMAND, CONTROL, AND WARNING SYSTEM



TETHERS AND RESTRAINTS GUIDELINES

A positive means of controlling the motion of cargo at all times will be required and this is especially true in the artificial gravity base. These guidelines express this idea:

- 5.1 All bulk cargo should be properly tethered or otherwise controlled during zero-gravity or reduced-gravity operations.
- 5.10 Adequate restraints, tethers or aids to assist the crew in personal movements and handling large-mass equipment should be available throughout the interior and exterior of the space station.

TETHERS AND RESTRAINTS GUIDELINES

- 5.1 CARGO SHOULD BE TETHERED OR CONTROLLED
- 5.10 RESTRAINTS TO ASSIST IN MOVING LARGE-MASS EQUIPMENT SHOULD BE PROVIDED

RESTRAINTS CONCEPTS

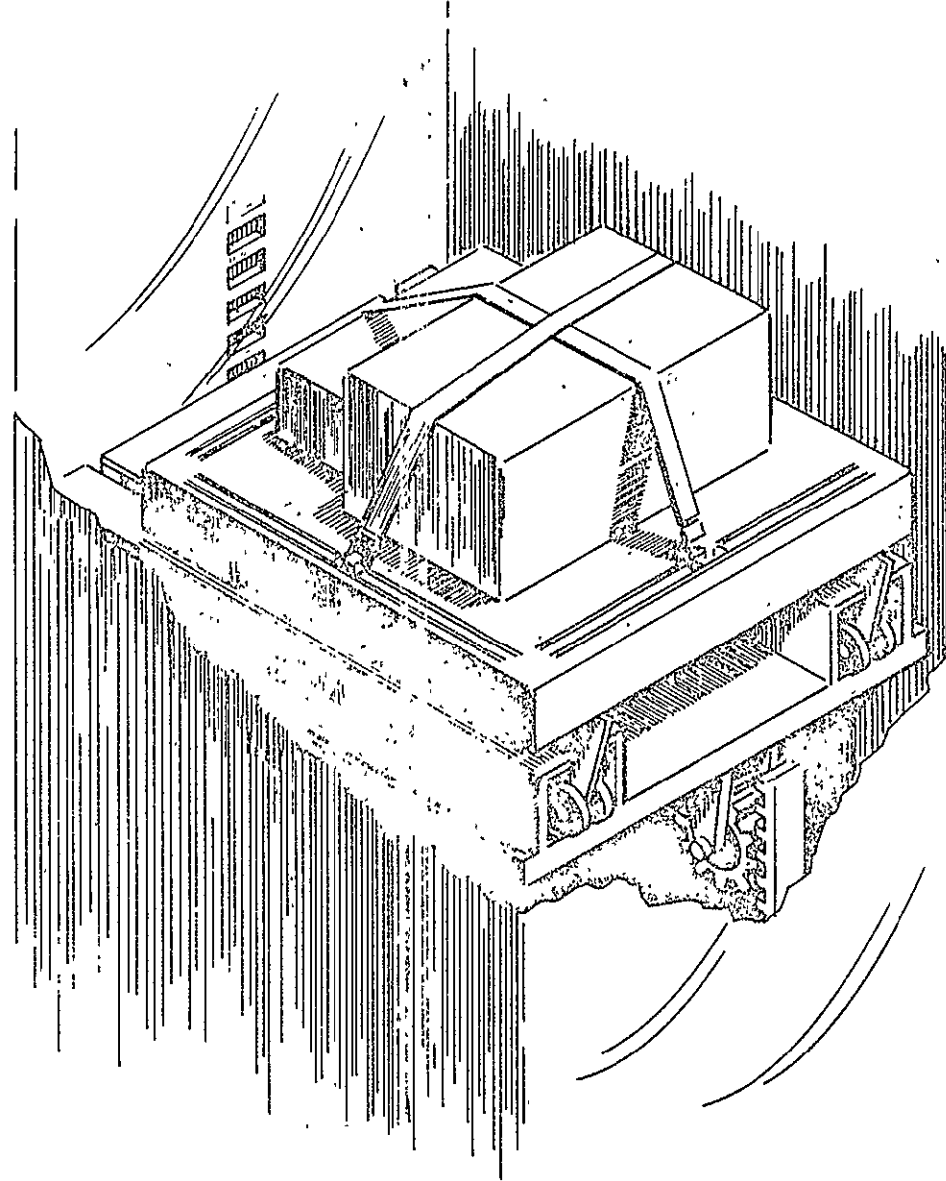
This chart shows cargo being moved by elevator between the non-rotating hub and the artificial gravity portion of the space base.

The cargo is tied down to a pallet or dolly which is equipped with several sets of dual wheels or castors. The wheels operate in slotted tracks in the elevator platform with similar slotted tracks in all decks of the base. The wheels are provided with a braking system, for example, expanding the wheels against the sides of the slots. This concept restrains the cargo from all motion, including translation and rotation, except as desired along the tracks. It will operate under all gravity conditions including the transition from zero gravity to artificial gravity.

The elevator itself is driven by a reversible motor operating a cog wheel or wheels which engage tracks in the elevator shaft walls. In addition to moving cargo, the elevator would also be the primary means of crew movement. For simplicity, this sketch does not show the grills, guards or other protector devices which would be required.

This concept, as stated, can be used under all gravity conditions but the question arises as to how to transfer across the interface between the rotating and non-rotating portions of the station.

RESTRAINTS CONCEPTS



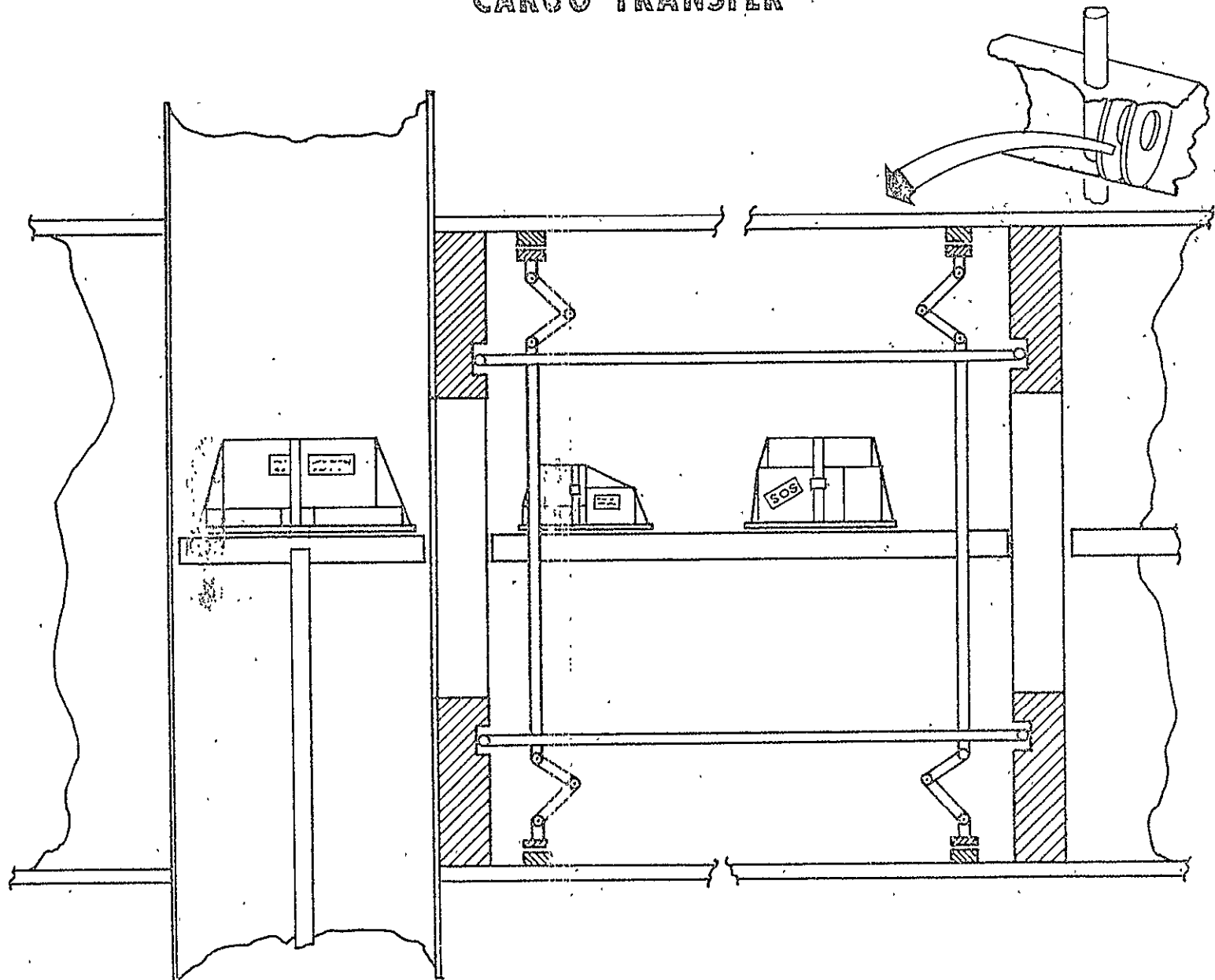
CARGO TRANSFER

This chart shows a concept for accomplishing transfer of cargo, and also personnel across the rotating/non-rotating interface. A transfer cage is located across the interface, the cage being free to rotate but restrained from other motion by travellers following slots in the bulkheads. A transfer platform, having slotted tracks, is mounted in the cage. A set of clutches permits the cage to be coupled with, and match the motion of, either the rotating or non-rotating sections.

Assume that cargo is to be transferred from the non-rotating hub to the artificial gravity section. The cargo, on the dolly previously illustrated is initially on the non-rotating deck. The appropriate clutch is engaged to match cage motion to that of the non-rotating section and with the transfer platform aligned with the station deck. The cargo dolly is then wheeled from the deck to the transfer platform. By disengaging the one clutch and engaging the other, cage motion is matched to that of the rotating portion with the transfer platforms aligned with the elevator platform. The cargo dolly is wheeled onto the elevator platform and transported by elevator to its destination deck.

For simplicity, safety guards and grills and other features are not shown.

CARGO TRANSFER



SHUT-OFFS AND CONNECTORS GUIDELINES

Fluid lines may be damaged and require replacement or, in any case, may require disconnect and connect from time to time. Certain guidelines are directed toward prevention of contamination from the fluids in the lines. They include:

- 1.21 Connectors used to connect plumbing or components in fluid systems should be designed for minimum loss of fluid when disconnected.
- 1.22 The number of connectors used in plumbing and connections of fluid systems should be kept to a minimum.

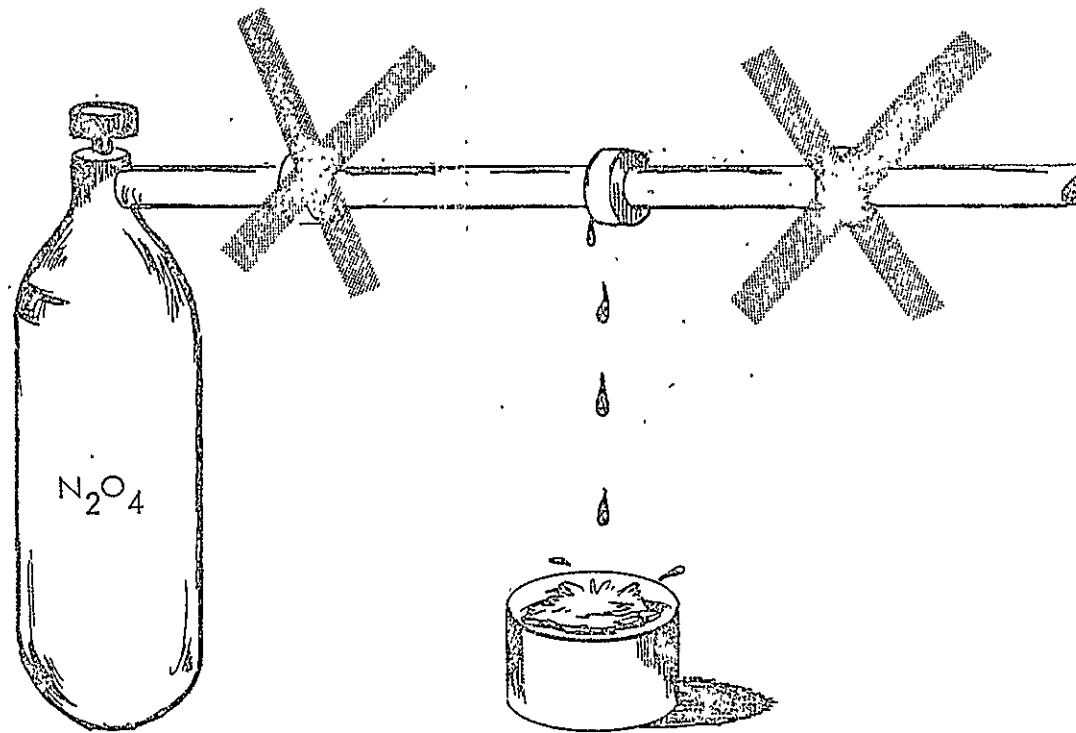
SHUTOFFS AND CONNECTORS GUIDELINES

- 1.10 BE ABLE TO SHUT OFF FLUID FLOW TO DAMAGED SECTIONS
- 1.21 MINIMUM FLUID LOSS WHEN DISCONNECTING
- 1.22 KEEP NUMBER OF CONNECTORS TO MINIMUM

VALUES AND CONNECTORS

This sketch illustrates the ideas expressed in the guidelines, namely, a means of shut-off of the fluid flow, minimizing the number of connectors as shown by the two which are crossed out, and providing a means of collecting escaping fluid when a disconnect is required. Under zero gravity, of course, a more sophisticated device than that shown will be required.

VALVES AND CONNECTORS



PROCEDURAL

We have discussed guidelines which are primarily configuration drivers and some which dictate design details. A few guidelines which are directed more toward procedures will now be discussed.

PROCEDURAL

HAZARDOUS MATERIALS GUIDELINES

The operational and experimental requirements of the space station and base will dictate that certain hazardous materials will be on board. In addition, it is possible for some materials which are not in themselves particularly hazardous to interact with other materials and/or the spacecraft subsystems so as to form new, and hazardous materials.

The guidelines summarized in the chart are typical of those intended to reduce the probability of contamination.

HAZARDOUS MATERIAL GUIDELINES

- 1.15 QUANTITY OF HAZARDOUS MATERIAL SHOULD BE LIMITED
- 1.18 THERE SHOULD BE CONFIGURATION CONTROL OVER ALL MATERIALS
- 7.13 ACCESS TO HAZARDOUS MATERIALS RESTRICTED

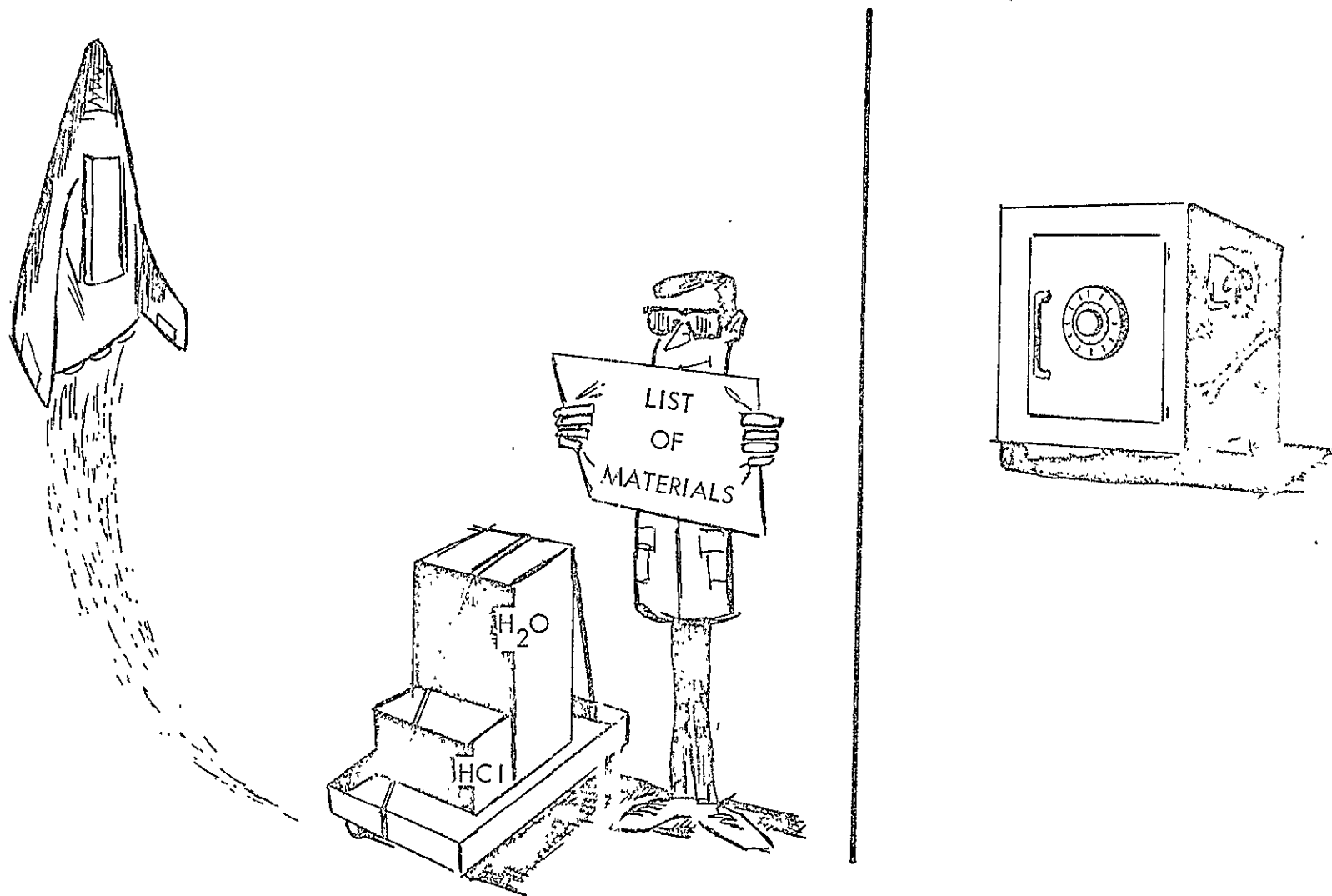
HAZARDOUS MATERIALS

This cartoon illustrates the points made in the guidelines.

Materials configuration control, as contemplated here, is quite comprehensive. It covers not only those materials brought on board the spacecraft for operational or experimental purposes but also materials, including solvents and cleaners, used during manufacture and personal possessions of the crew. The intent is first, to bar any material which is not required and, second, to maintain a record of materials as a starting point in the event that unexpected contamination occurs.

While access to hazardous materials may often be restricted by procedures, there will undoubtedly be some materials, such as poisons, drugs, highly toxic substances, and the like, for which locked storage will be necessary.

HAZARDOUS MATERIALS



VENTING AND WASTE GUIDELINES

During final review and evaluation of the guidelines it was noticed that a number of them dealt with the general subject of the generation and disposal of waste material. This included venting or dumping of materials overboard.

None of these guidelines will be quoted here in entirety but the gist of some of them is shown in the chart. The possible impact on the space base is shown in the next chart.

VENTING AND WASTE GUIDELINES

- 1.28 CONTROL (VENTING) OF EFFLUENTS FROM WASTE
- 3.21 CABIN PRESSURE VENTS SEPARATE FROM OTHER FLUIDS
- 8.31 PROCEDURES NEEDED FOR DISPOSAL OF CONTAMINATED WATER
- 9.2 MEANS FOR DISPOSING OF RADIOACTIVE WASTE
- 10.2 COMBUSTIBLE WASTE STORED WITHOUT FIRE HAZARD
- 11.11 NO TORQUES FROM VENT OUTLETS

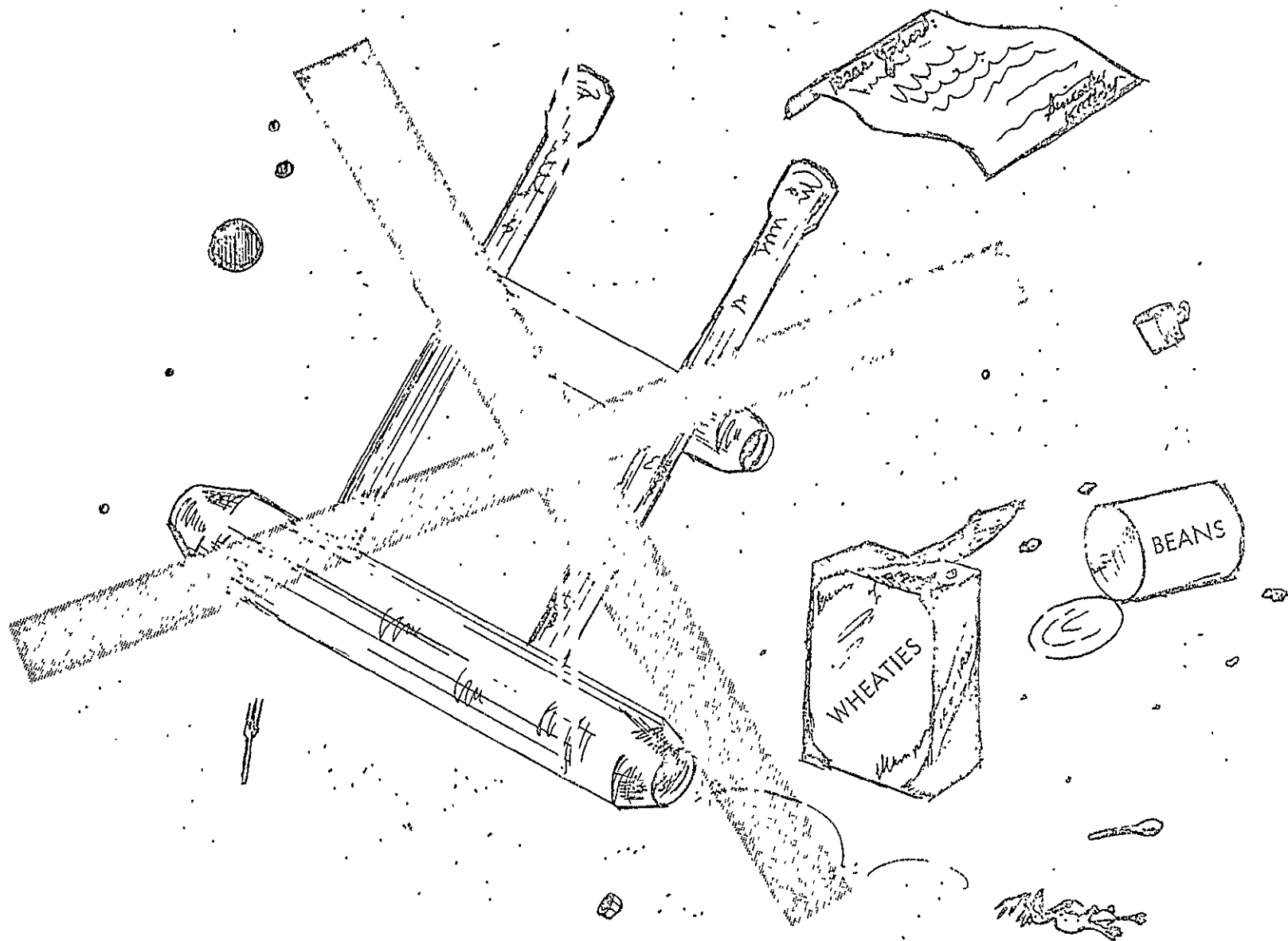
WASTE DISPOSAL

This cartoon, of course, is somewhat exaggerated, but it does illustrate the problem, namely, that the vicinity of the spacecraft could become contaminated with waste materials. The impact on crew safety does not appear to be great, although this came along too late in the study for detailed analysis, and there is no guideline which specifically restricts dumping or venting overboard.

During Phase I some preliminary work was done with respect to performance of the mission. During this work there were indications that some portions of the experimental program could be seriously impaired by effluents or debris in the vicinity of the station. While this work did not progress to the point where definite conclusions could be drawn, it does appear that venting or disposal of material overboard should be held to the minimum possible.

This raises the question of how to dispose of waste.

WASTE DIS.



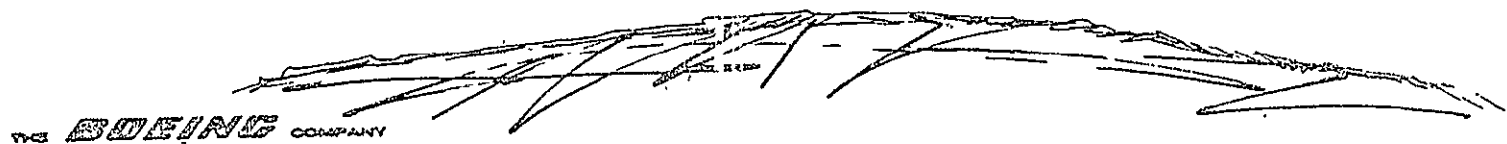
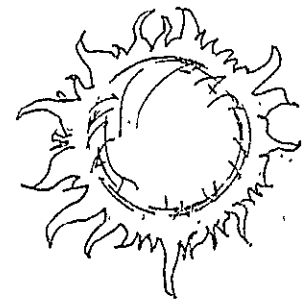
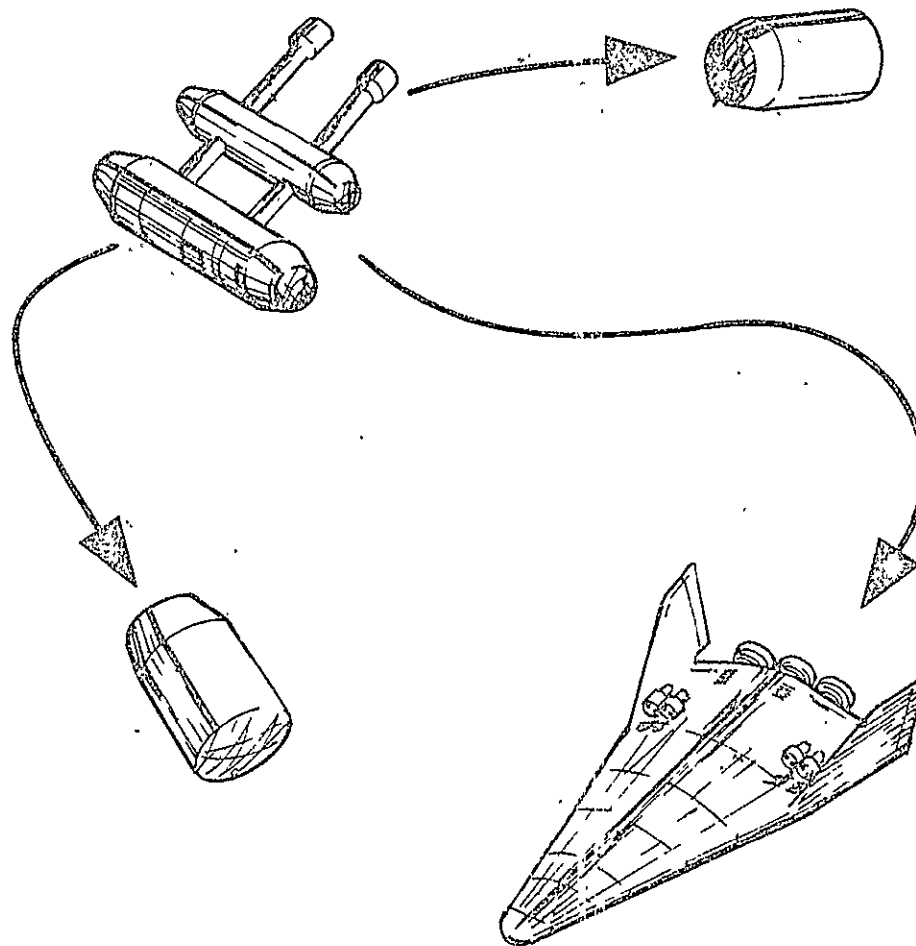
WASTE DISPOSAL ALTERNATIVES

Shown here are three possible alternatives for the disposal of waste.

In the first alternative, the waste, in a suitable container, is placed in a solar orbit or solar impact trajectory. The energy requirements for this method, of course, are quite high and it probably would not be acceptable except possibly for highly hazardous items such as radioactive waste. It follows, then, that whatever goes up must come back down and two means of coming back down are shown.

In one way the waste, in a suitable container, is allowed to reenter the earth's atmosphere and either burn up during reentry or impact in a suitable disposal area, such as an ocean. In the other way, the space shuttle is used to return the waste for disposal, in such manner as may be acceptable, after landing. The implications on the space shuttle are self-evident.

WASTE DISPOSAL ALTERNATIVES



DAMAGE CONTAINMENT AND CONTROL

Damage containment and control was not specifically set forth as a task in Phase II but was to be covered to the extent possible as a corollary to other efforts. The subject was considered briefly in the analysis of operations, and in addition, those guidelines which are particularly applicable to damage containment and control were identified and cross-referenced. The gist of these guidelines is summarized on this chart.

The first step is identification of the damage which implies the existence of some sort of a system of sensors or detectors to determine that damage has occurred and to provide a warning or alarm to the crew. The ideas of inspecting the station and monitoring hazardous operations are also included.

Having identified the damage, the next step is to isolate it to prevent its spread into other portions of the station beyond the original site. The ideas included here are such things as compartmentation of the station and providing hatches, valves, and other types of closures; isolated stores of hazardous material; safe areas in which hazardous operations can be conducted; and suppression devices such as crack stoppers in structures.

Finally, are the actions taken to remedy the damage and return the station to normal conditions or at least to a safe condition. The ideas included here are that access to damaged areas be required; that communications systems be available, that a means for survival or rescue of crew members in damaged areas be provided and, of course, that means of remedying or repairing the damage be available.

DOING

DAMAGE CONTAINMENT AND CONTROL

● IDENTIFICATION — 10 GUIDELINES

- DETECTION, WARNING, ALARM
- INSPECTION
- MONITORING

● ISOLATION — 19 GUIDELINES

- COMPARTMENTATION
- HATCHES, VALVES, CLOSURE DEVICES
- ISOLATED STORAGE
- "SAFE" AREAS
- SUPPRESSION DEVICES

● COUNTERACTION — 14 GUIDELINES

- ACCESS
- COMMUNICATIONS
- RESCUE/SURVIVAL
- REMEDIES

SUMMARY

The safety problems of the future space station and base have been thoroughly reviewed. We found no reason to think that an acceptable safety level cannot be achieved within the current state of the art.

A set of Crew Safety Guidelines has been derived which constitutes a list of actions which should be taken to enhance the safety of the station or base. They are a checklist, as well, by which management can review and evaluate future space stations from the safety standpoint.

Application of the guidelines appears to be feasible but must be made subject to a number of compromises. Within individual guidelines, the desirability of the safety features obtained must be weighed against other factors such as cost. In addition, safety features required by two or more different guidelines are sometimes incompatible and one or all must be compromised to some degree. The guidelines provide a basis, nevertheless, for a viable safety program.

Damage containment and control procedures and actions to be taken are spelled out in some of the guidelines which have been identified by cross-references.

SUMMARY

- ① SPACE STATION/BASE SAFETY PROBLEMS REVIEWED
 - NO COMPELLING REASON THAT SAFETY LEVEL WILL BE UNACCEPTABLE
- ② CREW SAFETY GUIDELINES DERIVED
 - SUGGESTED ACTIONS TO ENHANCE SAFETY
 - CHECKLIST OF SAFETY ITEMS
 - BASIS FOR VIABLE SAFETY PROGRAM
- ③ GUIDELINE APPLICATION WILL REQUIRE COMPROMISES
 - WITHIN INDIVIDUAL GUIDELINES
 - AMONG TWO OR MORE GUIDELINES
- ④ DAMAGE CONTAINMENT AND CONTROL
 - INCLUDED IN GUIDELINES AND CROSS-REFERENCED

DESIRABLE FUTURE EFFORT

"Off-normal" gravity means a gravity environment different from that of earth, either zero gravity or artificial gravity produced by rotation. For study purposes, two assumptions were made, the first being that the crew could perform assigned tasks in the station/base environment and the second being that fires in the station/base would continue to burn once they started. Further investigation in these areas is needed, although it is recognized that such investigation likely must be concurrent with station/base operation.

Only preliminary work was done in the study with respect to nuclear-fueled electrical power supply systems safety. It was apparent that adequate coverage of this area would require far greater resources than were available in the study, probably an effort approaching the magnitude of the safety study itself.

The Crew Activity Sequencing Program (CASP) is available as a computer program. It could be readily modified to incorporate desired safety factors (which it does not currently do), a modified experiment program and the advanced station/base concepts. It would then provide a means of reviewing future space programs, not only from the safety viewpoint but from mission accomplishment as well. Similarly, the Logic Diagram is amenable to development of a computer program based on it. The effect of changing assumption could be readily explored and the most critical and sensitive safety areas identified.

The safety study was confined to on-orbit operation of the space station or base. However, many safety problems of other space programs such as the space shuttle, lunar surface exploration and interplanetary missions are identical, or very similar to, those of the space station and base. This study provides a starting point for safety studies of these other programs. In any case, such safety studies should be conducted.

DESIRABLE FUTURE EFFORT

- ④ HUMAN EFFECTS OF "OFF-NORMAL" GRAVITY
- ④ FIRE CHARACTERISTICS IN "OFF-NORMAL" GRAVITY
- ④ NUCLEAR-FUELED ELECTRICAL POWER SUPPLY SAFETY
- ④ APPLICATION OF AVAILABLE TECHNIQUES TO FUTURE STATION/BASE SAFETY
 - CASP
 - LOGIC DIAGRAM
- ④ SAFETY STUDIES OF OTHER SPACE PROGRAMS

PHASE I

No distinction has been made in this review between Phase I and Phase II. The scope, objective, product and station configurations used in Phase I are summarized briefly here. A more detailed discussion can be found in Document D2-113070-2 "Mid-term Oral Review."

PHASE I

● SCOPE

- BROAD CLASSES OF SPACE STATIONS
- CREW SAFETY—MISSION PERFORMANCE

● OBJECTIVES

- SAFETY GUIDELINES AND CONCEPTS
- SAFETY PROCEDURAL AND DESIGN GUIDELINES
- DAMAGE CONTAINMENT AND CONTROL PROCEDURES

● PRODUCT—MATERIAL FOR HANDBOOKS

- SAFETY DESIGN GUIDELINES
- ASTRONAUT SAFETY OPERATING PROCEDURES

● CONFIGURATIONS—SLSS, EOSS, JAG-1

PHASE II

Similarly, greater detail on Phase II scope, objective and product can be found in D2-113070-2, "Midterm Oral Review" and in the final study report documents.

PHASE II

- SCOPE

- CREW SAFETY IN PHASE B FUTURE SPACE STATION/BASE

- OBJECTIVE

- MANAGEMENT TOOL TO GUIDE AND EVALUATE CONCEPTUAL DESIGNS OF SPACE STATIONS/SPACE BASES FROM A SAFETY VIEWPOINT

- PRODUCT

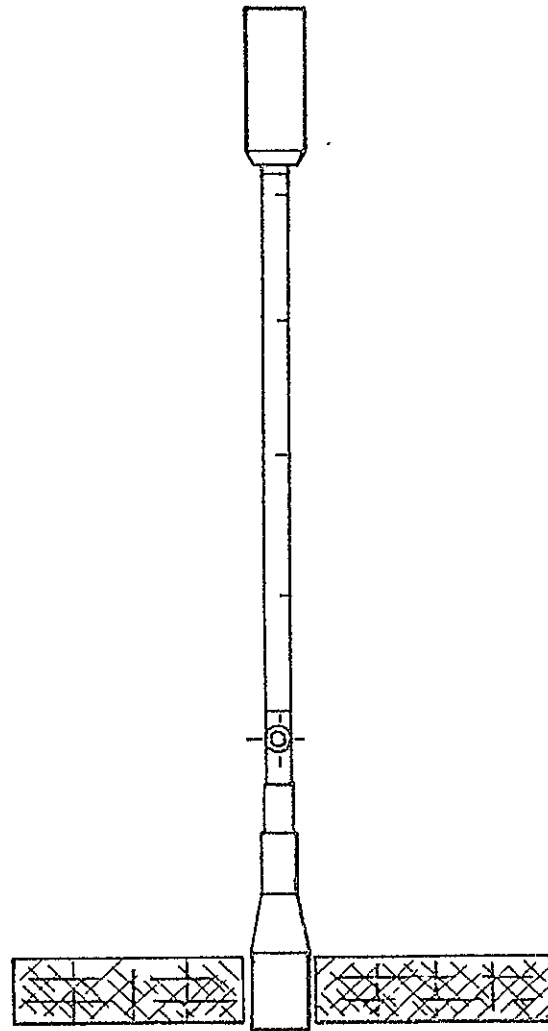
- CREW SAFETY GUIDELINES
 - APPROACH TO DAMAGE CONTAINMENT AND CONTROL PROCEDURES

PHASE II CONFIGURATIONS

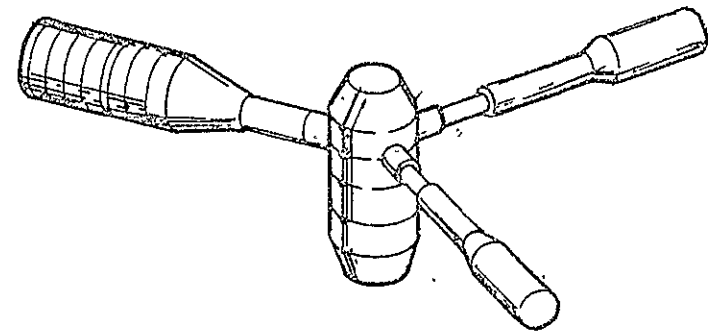
The station and base configurations used during Phase II of the study are shown here. They were developed early in Phase II and did not incorporate any safety features derived during the study.

They are to the same scale, the space station being in the artificial-gravity experiment configuration. As can be seen, from this review incorporation of safety features would change these concepts very radically.

PHASE II CONFIGURATIONS



SPACE STATION



SPACE BASE

