NASA Technical Memorandum 86673

Proceedings of the Seminar on Space Station Human Productivity

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Compiled by Marc M. Cohen and Erika Rosenberg

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Space Administration

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Proceedings of the Seminar on Space Station Human Productivity

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National Aeronautics and
Space Administration

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HUMAN FACTORS IN SPACE STATION ARCHITECTURE

Minutes of Seminar on Space Station Human Productivity

Space Station Human Productivity Working Group Meeting

at NASA-Ames Research Center

Hosted by the Space Human Factors Office

Aero-Space Human Factors Division

Ames Research Center

National Aeronautics and Space Administration

March 1, 1984

Opening Address Angelo Guastaferro, ARC

The seminar opened with a welcoming address by Angelo "Gus" Guastaferro, Deputy Director of Ames Research Center. Gus affirmed Ames Center management support for Human Factors Research for the space station and for the Human Productivity Program.

Overview: Human Factors in Space Station Architecture Marc Cohen, ARC

Marc, the seminar chair, presented an overview of key issues for the day's session. A description of current program status covered the early program assumptions, the Concept Development Group's (CDG) Initial Operational Capability (IOC) model and the CDG Autonomy Baseline. Specific Human Factors topics were covered as follows:

(1) Space Human Factors
(2) Architecture
(3) Volume
(4) Reference Orientation
(5) Circulation
(6) Privacy
(7) Group Gathering Places
(8) Visual Systems
(9) Vibroacoustics
(10) Structures: Shells
(11) Mechanisms
(12) Utilities
(13) Function

This presentation was essentially a synopsis of a work in progress entitled *Space Station Architecture: Human Factors Definition.*

Space Station Windows and Visual Systems Richard Haines, ARC

Dick presented a paper entitled "A Preliminary Human Factors Design Planning Outline Related to Space Station Windows and CCTV Monitoring." In this paper, he discussed issues of window size, shape and location. He compared the capabilities and limitations of direct human vision to indirect vision by closed circuit television (CCTV). Asking the question, "Where do we need outside surveillance?" he discussed several EVA, rendez-vous and docking situations. The key variables for observation windows are inter-module spacing, window orientation, module radius and the field of view half-angle. Dick concluded with the recommendation that the viewing distance from the eye to the window be kept as short as possible.

JSC Configurations Jim Lewis, JSC

Jim presented a discussion of "JSC Configurations." He showed some remarkable color computer graphic slides of the "Big T" and "Delta" configurations. Then he described his Crew Station Group's estimated volume and area requirements for crews of four, six and eight people. He presented plan and section-elevation views of proposed module arrangements based on these estimates and concluded with a "Conceptual 48-Hour Space Station Time Line," which attempts to breakdown crew resources and activities over a typical two day period or cycle of work and living.

Man/Machine Interaction in Resources Module and MBA Abe Feinberg, JPL

Abe presented a brief overview of the proposed JPL research program in "Space Station Automation Assessment," with a focus on Man-Machine Tradeoff Studies. In their preliminary investigations, Wayne Zimmerman and Abe have selected the Resources or Utility Module and the Multiple Berthing Adapter (MBA) for detailed analysis. They hope to arrive at an assessment of the impact of autonomy on reliability, among other goals.

Design for Skylab Habitability at Raymond Loewy Sharon Skolnick

Sharon began with an anecdotal history of the earliest space station habitability studies conducted at Raymond Loewy/Wm. Snaith Industrial Design, Inc. during 1969. Raymond Loewy was responsible for many design artifacts of the twentieth century including the Coca-Cola bottle, the standard desktop telephone, the Studebaker and streamlined locomotives. The Loewy involvement represented an attempt to achieve design excellence at the inception of NASA's first space station effort. Then Sharon presented a critique of the final Skylab design. She pointed out that in many respects, the interior spaces of both the Airlock and Multiple Docking Adapter (MDA) on Skylab were not designed. The engineers had taken a cylindrical form, packed the inside walls with equipment and any habitable volume was purely residual. She discussed the crew deck and made the novel observation that although the sleeping compartments were of differing sizes, the fact that they were different shapes, and that the wardroom and other walls were at varied angles probably created a more interesting and stimulating environment than if all areas had been uniform and regularized.

Human Productivity Experience and Undersea Habitat Design Tom Taylor, TAI and John Spencer, SHDA

This presentation was a joint effort by Tom Taylor and John Spencer, who have collaborated previously. Tom Taylor conceived of the Aft Cargo Carrier (ACC) on the STS External Tank (ET) and John was his subcontractor for habitability applications of both the ET and the ACC. Tom began the presentation with a description of his experience as a heavy construction engineer on the North Slope of Alaska, living for three years in remote, isolated, and confined habitats within a severe and hostile environment. He compared two different construction camps and observed that the most important factorts in human productivity were food, privacy and group gathering places seperate from sleeping quarters. John Spencer described the activities of SHDA in developing the ACC space station module concept. He described also a conceptual design for an undersea habitat in which a "Privacy Gradient" is created from the diver's entry hatch/wettest area to the sleeping quarters/driest area.

Considerations for Space Station Interior Architecture Brand Griffin, Boeing

Brand began with a detailed description of Zero Gravity "Neutral Body anatomical changes, angular relationships, skeletal and muscular effects, vision and orientation and the work station envelope. He then covered shuttle cargo bay characteristics and limitations, addressing the implications for module shell and interior design. This analysis led to the description of a great variety of interior architectural options for a spectrum of crew sizes and mission requirements. He presented detailed cut-away drawings with a special emphasis on berthing accommodations for side to side berthing of reduced-diameter modules in the "Vertical Raft" configuration.

The ECLSS Module Concept Chris Poythress, Hamilton Standard

Chris presented a new Hamilton Standard concept for a special, dedicated Environmental Control and Life Support System Module as an alternative to the old debate between centralized and decentralized/distributed life support systems. In this concept, the ECLSS module would carry the ECLS for one or more adjacent space station modules, the health and hygiene facility, including a shower and an airlock for EVA with EVA (EMU) suit support. All these functions would be packed into a one segment common module, half the size of the pressurized portion of the proposed logistics module, and would remove from the logistics module the burden of hauling the hygiene facility up and down every 90 days. However, because the life support and hygiene are in a module seperate module from the rest of the station, it would be possible to return them to earth for maintenance or repairs, perhaps once every two years. Redundancy would be achieved by always having two or more ECLSS modules operational on the station.

Design of Confined Environments Michael Kalil, Michael Kalil Designs

Michael presented a slide show of two environmental mock-ups. The first mock-up was an apartment interior in New York City and the second was a 22 foot diameter room for the Armstrong Corporation in Lancaster, PA (the same diameter as Skylab). Michael presented an innovative approach to "building-in" all types of furniture and fixtures to be "deployed" from the floor and walls. Using this technique, he is able to achieve a high degree of flexibilty in configuring the room interior both functionally and aesthetically. In a comment on the CDG Common Module Study Group approach of "Take this module and stuff it," Michael said: "Space is not made by 'stuffing' a form. Space is made by unfolding form to necessity" The modular, panelized walls and floors are "a continuous ribbon of matter that expands and contracts."

Vertical Versus Horizontal Sleep Compartments Tom Fisher, Lockheed

Tom presented a very detailed discussion of "Habitability Sleep Accommodations." He showed slides of the Lockheed "revolver" concept for sleeping quarters as part of a living quarters module. This concept is characterized by great flexibility in accommodating from four to eight crew without requiring construction changes but by the adjustment of folding and sliding partitions. Tom concluded with a philosophical but rousing appeal for unity among the Crew Systems/Human Factors community. "We need values to respect and also to be open to new values." He pointed out that the smaller the environment, the more territorial people become, and the more problems we are likely to have. "The hardware people have beaten us every time before, but if we all

Space Station Architecture Fritz Runge, McDonnell-Douglas

Fritz focused on "Customer and Mission Influences on Space Station Architecture," particularly the process of defining mission and operational requirements that become design drivers. These requirements led him to an emphasis on the "multiservice center" aspect of the station, an he explored various aspects of on-orbit servicing. Among the missions that received special attention were the laboratory modules and the Large Deployable Reflecting Telescope (LDR) that will be assembled by EVA on the "manned space platform" and then deployed on a free-flyer. Fritz illuminated the principle that different mission models will result in significantly different space station architectures.

Critique of the Presentations Maynard Dalton, JSC

Maynard began by stating emphatically that he would not critique anyone's presentation, but would instead offer some general comments on the body of presentations as a whole:

(1) Human Productivity studies will produce design drivers on a philosophical level only.

(2) Only through the dimensions of habitation and habitability will the arrangement of modules be impacted by human productivity.

(3) No matter how good the idea, if we cannot get it into space, it does not matter.

(4) We must be prepared to make compromises. Let the development designers We must be prepared to make compromises. Let the development designers integrate pieces provided by conceptual ideas. It is not possible to make everybody happy, and ironically, if nobody is completely happy, the designer knows he has the best design.

(5) We need a habitability/human productivity data base to draw upon. When opposing the hardware people, we strong quantitative and qualitative requirements. We need a data book that shows how people interact with the environment. Analog studies are educational, but not directly useful. We need space-specific standards. We need to show how people are affected by the environment, and through which modalities. Ultimately we must be able to prove and demonstrate a band of tolerance thresholds below which it is not acceptable to go.

BRAINSTORMING

The day concluded with a brainstorming session. The results are listed below. Dr. B.J. Bluth commented that the session was useful inbringing forth many issues of new relevance to human productivity. to human productivity, but that there were no surprises overall, which provided a confirmation of the scope of earlier efforts at the Space Station Task Force, NASA H.Q.

Lighting

long term effects

task versus ambient interior environment

external lighting - overall level, pointing, shading

Food

grow on orbit

capability for bulk stores

Cost Savings

station self-replication

closed systems

Flight Experiments

simulation through "cheap mock-ups"

build a "National Mockup" for human productivity

peer review is essential for any form of "simulation" or "test bed"

EVA Coordination

payload servicing

communications during operations

radiation effects of Ku band radio

Radiation - Consensus Needed
model of radiation environment
standard for human tolerance
optimization of shielding
integration trade study for the three items above

Volume - Standard for Cubic Feet per Person
sleep compartments/private cabins
work areas
How is volume defined?
What is usable Volume?
Allocation of Functions within volumes?

Human Performance Mesurement
Great need for non-intrusive, reliable work-load metrics.

Command Structure
Crew selection
Crew training
Crew mix

Crew Workspace
small group dynamics
psycho-social aspects
windows, effects on crew performance
disease transmission - biological contamination

Exercise versus Workload
schedule - rigor and flexibility
location of exercise
solitary or group activity
stability of station - perturbations from crew motion
quality of exercise

Distributed Control - Social Impact
alternatives to centralized, hierarchical control?
democratic organization
operational impacts?
emergency situations?

Station Autonomy

data handling
crew interaction with ground
controlling groups for various functions
Earth vs. on-orbit?

Medical Facility

health support systems
scope of services
location and proximities on station
health information network

Sensitive Issues

sex
death - handling a cadaver
tolerance for deviant behavior

MONDAY

INTRODUCTION

Judith E. Queller

The fourth meeting of the Human Productivity Working Group was held at the Ames Research Center from February 27 to March 2, 1984. It was attended by a total of 111 individuals over the course of a four day meeting. Attendees came from all of NASA, from private industry and from the academic community. The focus of the meeting was the exploration of the issues which surround some of the elements of the Human Productivity Program. Each of the elements was explored through presentations and these were followed by a general discussion and summary.

Five general topics were discussed: 1) crew safety, 2) internal contamination, 3) the definition of the Human Productivity Program, 4) aspects of architecture that affect productivity, 5) and the role of mock-ups in the Human Productivity Program.

The meeting was held at Ames in recognition of the creation of their new Aerospace Human Factors Research Division, and of the assertion by Ames' new Director, Dr. William Ballhaus, that Space Human Factors will be a principal thrust at Ames. This assertion was reaffirmed by Dr. Alan B. Chambers who opened the meeting on Monday, February 27, and welcomed the group.

The agenda for the Human Productivity Working Group meeting follows along with the proceedings of the meeting.

CREW SAFETY ALTERNATIVES

Space Station Crew Safety: Human Factors Model, Marc M. Cohen and Maria K. Junge, NASA-Ames Research Center.

Crew Safety Alternatives Study - Rockwell-Downey,
3/4 Interim Briefing Review - Bob Peercy

- Overview
- Threats and Strategies
- Alternate Strategy

Human Factors Overview - Lisa Rockoff, Rockwell International Corp.

- Human Factors Issues
- Historical Background
- Question of Windows
- Personal Privacy and Space
- Safety Criteria Update
- Conclusions

INTRODUCTION

Maria K. Junge

Videotape: EVA on STS-10   Lisa Rockoff, Rockwell-Downey

- Use of tools.
- Use of contingency procedures.
- Examples of poor quality communication between EVA astronauts, IVA astronauts and mission control.

Speakers:

Bob Peercy-	Manager, Systems Safety Group at Rockwell-Downey and a Program Manager on the Space Station Crew Safety Study.
Lisa Rockoff-	Principal Engineer on the Space Station Crew Safety Study at Rockwell-Downey.
Dr. Steve Ellis-	Staff Researcher in the Aerospace Human Factors Research Division at Ames Research Center and on the faculty at UC Berkeley.

SPACE STATION CREW SAFETY HUMAN FACTORS INTERACTION MODEL

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FEB. 27, 1984

NASA—Ames Research Center
Space Human Factors Office

N85-29540

SPACE STATION CREW SAFETY

HUMAN FACTORS INTERACTION MODEL

Abstract by Marc M. Cohen and Maria K. Junge

Space Human Factors Office

NASA-Ames Research Center

Presented at NASA HQ, May 8, 1984

As NASA prepares plans to devlop a space station, one of the major Human Factors study tasks is to develop an approach to Crew Safety. NASA has always been a paradigm of safety consciousness and recognizes that safety will be a key to reliability and human productivity on the space station.

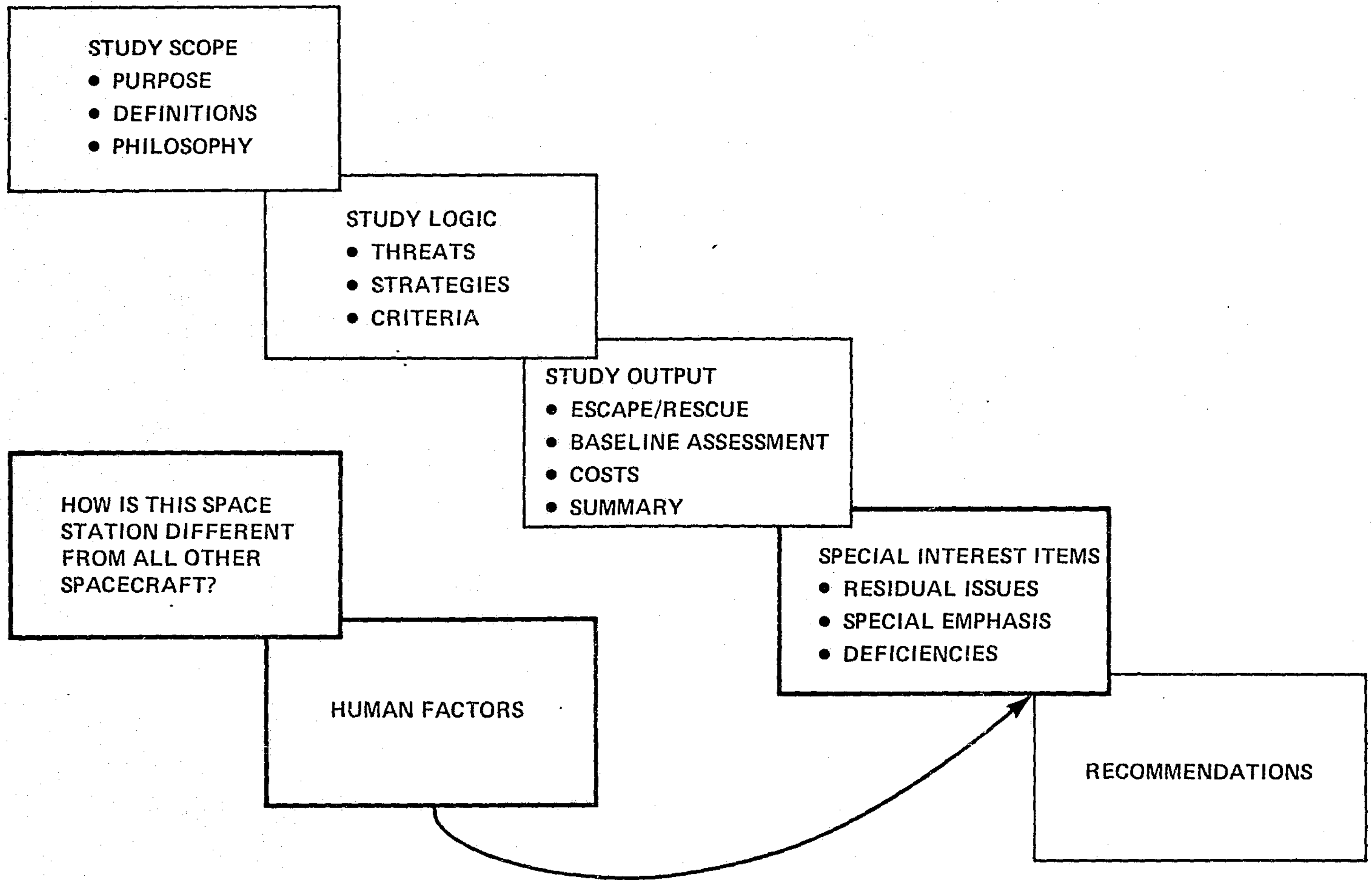
In evaluating safety strategies, it is also necessary to recognize both qualitatively and quantitatively how this space station will be different from all other spacecraft. During the initial phase of this study, it was recognized that the major difference between space station and previous spacecraft is the role of human factors and extra-vehicular activity (EVA). In this project, a model of the various human factors issues and interactions that might affect crew safety is developed.

The first step addressed systematically the central question: How is this space station different from all other spacecraft? A wide range of possible issues was identified and researched. Five major topics of human factors issues that interacted with crew safety resulted: *Protocols*, *Critical Habitability*, *Work Related Issues*, *Crew Incapacitation and Personal Choice.*

Second, an interaction model was developed that would show some degree of cause and effect between objective environmental or operational conditions and the creation of potential safety hazards. The intermediary steps between these two extremes of causality were the effects on human performance and the results of degraded performance. The model contains three milestones: stressor, human performance (degraded) and safety hazard threshold. Between these milestones are two countermeasure intervention points. The first opportunity for intervention is the countermeasure against stress. If this countermeasure fails, performance degrades. The second opportunity for intervention is the countermeasure against error. If this second countermeasure fails, the threshold of a potential safety hazard may be crossed.

An example of how this interaction model works can be demonstrated. Under *Critical Habitability*, the primary environmental stressors include confinement, isolation and seperation from earth. There are two subgroups of within the first countermeasure against these stressors, social and architectural interventions. The social factors are communication with family and friends, visitors to the station and recreation. The architectural factors are design, station geometry and "local vertical" reference orientations and windows. When these social and architectural design level countermeasures against stress are not effective, crew performance may degrade in the form of morale deterioration, impaired judgement or faulty perceptions. The second set of countermeasures, against errors are operational or group social activities plus personal existential actions. These social subset countermeasures include group activities, hobbies and time for personal interests. The design/physical countermeasure subgroup includes color coding on interior functions, lighting and video systems. To the extent that this second defense of countermeasures is not successful, the threshold of potential safety hazards may be crossed. In this instance, potential safety hazards include a breakdown in group process and teamwork, and mistakes occuring in judgement, perception or action.

The third step, which is now in progress, is to apply a system of weighting to the various stressors and countermeasures in order to be able to evaluate their relative importance. This weighting will also require an element of time duration to identify which stressors or countermeasures are relevant at the beginning, middle or end of missions, and which are short-lived or chronic in nature.



STUDY SCOPE

- PURPOSE
- DEFINITIONS
- PHILOSOPHY

STUDY LOGIC

- THREATS
- STRATEGIES
- CRITERIA

STUDY OUTPUT

- ESCAPE/RESCUE
- BASELINE ASSESSMENT
- COSTS
- SUMMARY

SPECIAL INTEREST ITEMS

- RESIDUAL ISSUES
- SPECIAL EMPHASIS
- DEFICIENCIES

RECOMMENDATIONS

HOW IS THIS SPACE STATION DIFFERENT FROM ALL OTHER SPACECRAFT?

HUMAN FACTORS

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SPACE STATION CREW SAFETY
HUMAN FACTORS CONCERNS

1. PROTOCOLS
   - AUTONOMY FROM GROUND
2. WORK RELATED ISSUES
   - TASK ASSIGNMENT
   - ROLE DEFINITION
3. CRITICAL HABITABILITY
4. CREW INCAPACITATION
5. PERSONAL CHOICE
   - INDIVIDUAL SCHEDULE CHANGES
   - OPERATIONAL CHANGES
   - WORK PROCEDURE CHANGES

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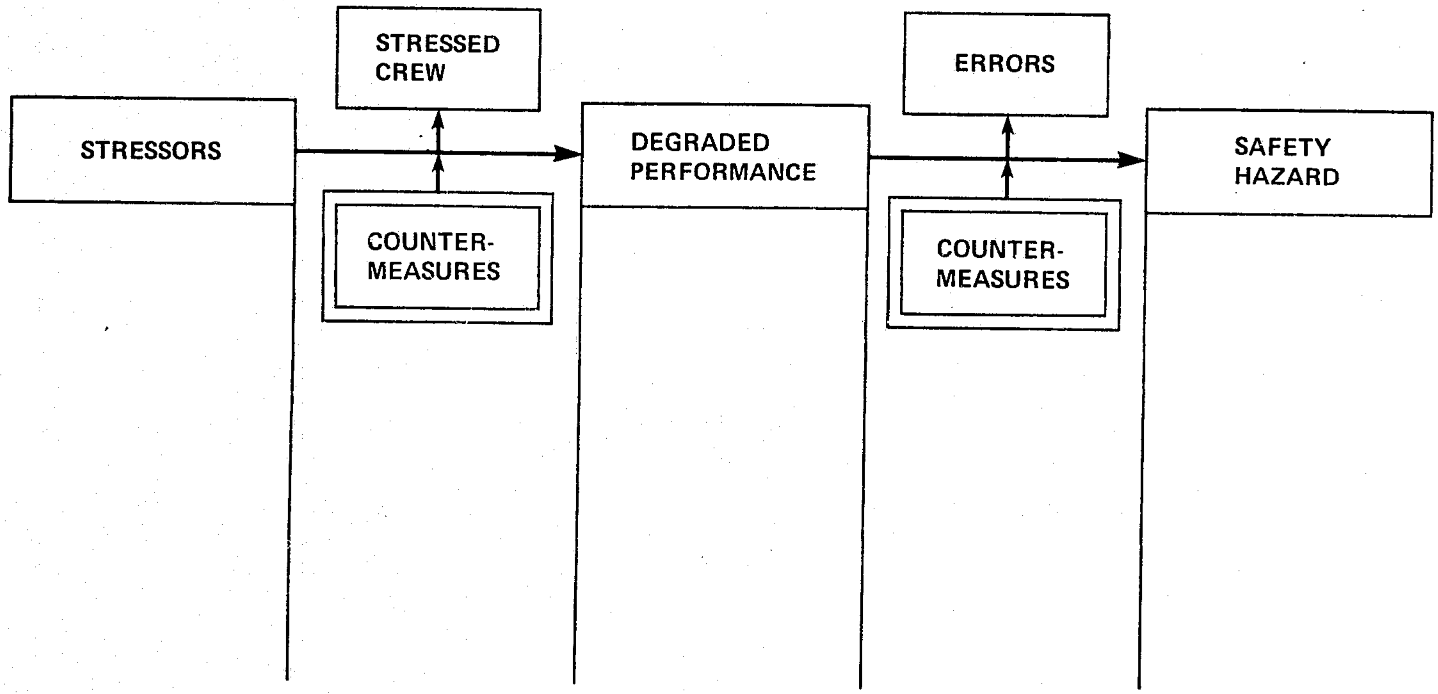
SPACE STATION CREW SAFETY

HUMAN FACTORS INTERACTION MODEL



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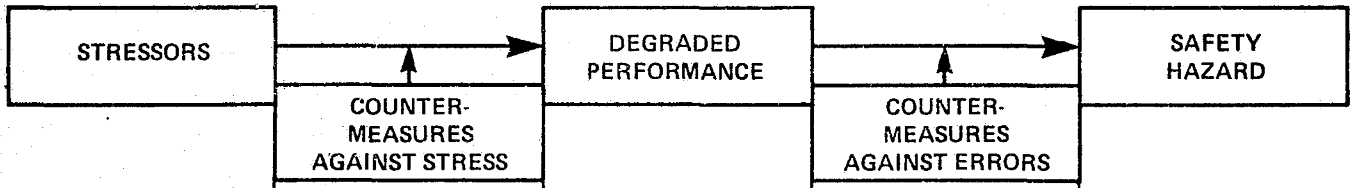
SPACE STATION CREW SAFETY
HUMAN FACTORS INTERACTION MODEL

1. PROTOCOLS



STRESSORS	COUNTER-MEASURES AGAINST STRESS	DEGRADED PERFORMANCE	COUNTER-MEASURES AGAINST ERRORS	SAFETY HAZARD
	AUTONOMY FROM GROUND			
SCHEDULING OVERLOAD	SCHEDULING CHANGES CREW ROTATION	SCHEDULING CONFLICTS	DAILY SCHEDULING POST-FLIGHT DEBRIEFING	LACK OF COORDINATION MISUNDERSTANDING
FAMILY PROBLEMS	FAMILY INTERACTION/SECURE COMMUNICATIONS	SOCIALLY DEVIANT BEHAVIOR? DEPRESSION	DISCIPLINE	DELIBERATE CONFLICT
DISAGREEMENTS WITH GROUND CONTROL	AUTONOMY FROM GROUND	CONFLICTING OBJECTIVES	CHANGES IN MISSION OBJECTIVES	VIOLATION OF SAFETY CRITERION
TERRITORIALITY	ACCESS/ NON-ACCESS	TURF CONFLICTS	NEGOTIATIONS	IMPROPER ENTRY OR INADEQUATE ACCESS
INCOMPATIBILITIES	CREW SELECTION CREW TRAINING	INCOMPATIBILITIES	TRAINING GROUP PROCESS CRISIS MANAGEMENT (FOR ALL OF THE ABOVE)	LACK OF COOPERATION

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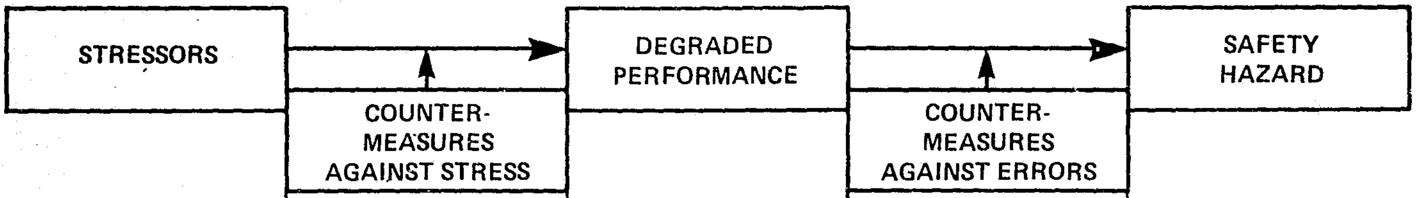
SPACE STATION CREW SAFETY
HUMAN FACTORS INTERACTION MODEL

2. CRITICAL HABITABILITY I



STRESSORS

DEGRADED PERFORMANCE

SAFETY HAZARD

COUNTER-MEASURES AGAINST STRESS

COUNTER-MEASURES AGAINST ERRORS

VOLUME LIMITATIONS	ARCHITECTURE: DESIGN PRIVACY, WINDOWS	FEELINGS OF CLAUSTROPHOBIA LACK OF PRIVACY	PRIVACY OR EVACUATION	IRRITABILITY PARANOIA
NOISE	VIBRATION, ISOLATION AND CONTROL	SLEEP DISTURBANCES POOR COMMUNICATION	EARMUFFS, HEADSETS, DRUGS COMMUNICATION DEVICES	FAILURE TO RESPOND FAILURE TO COMMUNICATE OR COORDINATE
HOUSEKEEPING	ROUTINES AND TRAINING	ENVIRONMENT QUALITY DETERIORATION	ASSIGNMENT OF RESPONSIBILITIES	BREAKDOWN IN LIFE SUPPORT
HYGIENE CLEANLINESS	PERSONAL PRACTICES	DISCOMFORT TO OTHERS ILLNESS DISEASE	GROUP PRACTICES	PERSONAL ILLNESS OR IMPAIRMENT INABILITY TO PERFORM TASKS

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SPACE STATION CREW SAFETY
HUMAN FACTORS INTERACTION MODEL

CRITICAL HABITABILITY II

STRESSORS	COUNTER-MEASURES AGAINST STRESS	DEGRADED PERFORMANCE	COUNTER-MEASURES AGAINST ERRORS	SAFETY HAZARD
THERMAL/HUMIDITY CLOSED ATMOSPHERE	ENVIRONMENTAL CONTROLS	DISCOMFORT IRRITABILITY	AIR MOVEMENT GAS COMPOSITION CONTROL TEMPERATURE AND HUMIDITY CONTROL	INCREASED ANXIETY IMPAIRED RESPONSE
CONFINEMENT ISOLATION SEPARATION	COMMUNICATION WITH FAMILY AND FRIENDS VISITORS SOCIAL EVENTS RECREATION COUNSELING ARCHITECTURE GEOMETRY STOWAGE AND RETRIEVAL "LOCAL VERTICAL"	LONELINESS MORALE DETERIORATION IMPAIRED JUDGMENT PERCEPTION UNDER STRESS CLAUSTROPHOBIA	GROUP ACTIVITIES HOBBIES PERSONAL INTERESTS PERCEPTION AND JUDGMENT CHECKS COLOR CODING LIGHTING MULTIPLE ACCESS CHOICES MOBILITY AIDS PERSONAL RESTRAINTS	BREAKDOWN IN GROUP PROCESS, TEAMWORK MISTAKES IN JUDGMENT, PERCEPTION OR ACTION PARANOIA
ARTIFICIAL LIGHTING	LIGHTING DESIGN, "NATURAL LIGHT"	FATIGUE IRRITABILITY BLURRED VISION	SPECIAL TASK LIGHTING	MISTAKEN PERCEPTION

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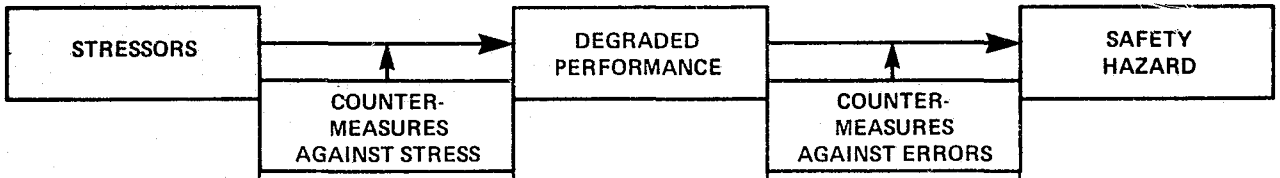
SPACE STATION CREW SAFETY
HUMAN FACTORS INTERACTION MODEL

3. TASK RELATED ISSUES


STRESSORS

COUNTERMEASURES AGAINST STRESS

DEGRADED PERFORMANCE

COUNTERMEASURES AGAINST ERRORS

SAFETY HAZARD

TASK ASSIGNMENT/ROLE DEFINITION

WORK ENVIRONMENT PROBLEMS	STATION ORGANIZATION/ DESIGN	FATIGUE FACTORS	WORK STATION DESIGN	MISTAKE/ INADVERTENT ACTION
WORK ORGANIZATION/ LEADERSHIP	LEADERSHIP TRAINING CONSENSUS	CONFLICTS WITH LEADERSHIP	CRISIS RESOLUTION/ CHAIN OF COMMAND	CONFLICTING ACTIONS
TASK ASSIGNMENT	TASK SELECTION	MONOTONY, BOREDOM	TASK ROTATION	"FAMILIARITY BREEDS CONTEMPT LACK OF CAUTION"
PHYSICAL LIMITATIONS	CREW SELECTION PHYSICAL ENDURANCE	STRAIN ON ENDURANCE	MANDATORY PHYSICAL EXERCISE REGIMEN	"CUTTING CORNERS" PHYSICAL INABILITY TO PERFORM TASKS
SCHEDULING AND COORDINATION CONFLICTS	GROUP MEALS AND MEETINGS	BLAME ASSIGNMENT	CREW/BUDDY CHECKS AND DRILLS	LACK OF EFFECTIVE CREW INTERACTION

EVA ROUTINES AND PROCEDURES

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SPACE STATION CREW SAFETY
HUMAN FACTORS INTERACTION MODEL

4. CREW INCAPACITATION

STRESSORS	COUNTER-MEASURES AGAINST STRESS	DEGRADED PERFORMANCE	COUNTER-MEASURES AGAINST ERRORS	SAFETY HAZARD
SPACE SICKNESS GAS BUBBLES IN WATER	SELECTION/ ADJUSTMENT MAINTAIN/CHECK FUEL CELLS	RELIABILITY GAS PAINS	TREATMENT SLING WATER TO SEPARATE GAS	CREW FAILURE TO RESPOND
ILLNESS	EXAMINATIONS AND HEALTH MAINTENANCE PROGRAM	SHORT TERM INCAPACITATION	TREATMENT	CONTAGION?
INJURY	SPACE INDUSTRIAL SAFETY	LONG TERM INCAPACITATION	RETURN TO EARTH? STABILIZE ON ORBIT?	DISTRACTION OF OTHER CREW MEMBERS
EMOTIONAL/ MENTAL PROBLEM	CREW SELECTION GROUP TRAINING	STRAIN ON OTHERS/ LACK OF TRUST	RELIEF FROM DUTY	SOCIALLY DEVIANT BEHAVIOR?
FAILURE IN LIFE SUPPORT SYSTEM	ABANDON, EVACUATE ONE MODULE	CONFINEMENT, TRAUMA	REPAIRS, REPLACEMENT	LOSS OF ACCESS TO CRITICAL FUNCTIONS
DEATH	COUNSELING	TRAUMA TO CREW DISRUPTION OF TEAMWORK	COUNSELING	PRESERVATION OR DISPOSAL OF BODY LACK OF EXPERTISE ON BOARD

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SPACE STATION CREW SAFETY
HUMAN FACTORS INTERACTION MODEL

5. PERSONAL CHOICE

STRESSORS	COUNTER-MEASURES AGAINST STRESS	DEGRADED PERFORMANCE	COUNTER-MEASURES AGAINST ERRORS	SAFETY HAZARD
COOKING/EATING HABITS	SHARED MEALS ACCOMMODATION FOR INDIVIDUAL CREW PREFERENCE	IRRITATION DEPRESSION	ADEQUATE TRAINING	FIRE SMELLS OUTGASSING
INDIVIDUAL PROPERTY	EDUCATION MONITORING AND CONTROL CREW TRAINING	PERSONAL AUTONOMY DIMINISHED	MONITORING AND CONTROL	OUTGASSING CONTAMINATION FLAMMABILITY
BOREDOM, MONOTONY	ENTERTAINMENT CREW SELECTED ACTIVITIES	LACK OF VIGILANCE	ADEQUATE CREW ACTIVITIES PLANNING AND SCHEDULING	PRACTICAL JOKES DISTRACTION ACCIDENTS
CLOTHING	VARIETY, LAUNDRY CREW PREFERENCE	IRRITATION, DISCOMFORT LESS PERSONAL FREEDOM	CLEAN FILTERS	LINT PROBLEM

INDIVIDUAL SCHEDULE CHANGES
WORK PROCEDURE CHANGES
OPERATIONAL CHANGES

PERSONAL HABITS: SMOKING ALCOHOL DRUGS	CREW SELECTION CREW TRAINING	REASONS FOR CONCEALMENT WITHDRAWAL SYMPTOMS POOR HEALTH INTERFERENCE WITH DUTIES	COUNSELING? EVACUATION EARLY CREW CHANGEOUT	FIRE IMPAIRED JUDGMENT DESTRUCTION OF "TEAM"

NASA—Ames Research Center
Space Human Factors Office

Space Station
Crew Safety Alternatives Study

SSD84-0106

Third Quarter Status Briefing

CONTRACT NAS1-17242

27 FEBRUARY 1984

Space Station
Crew Safety Alternatives Study

SSD84-0106

Third Quarter Status Briefing

CONTRACT NAS1-17242

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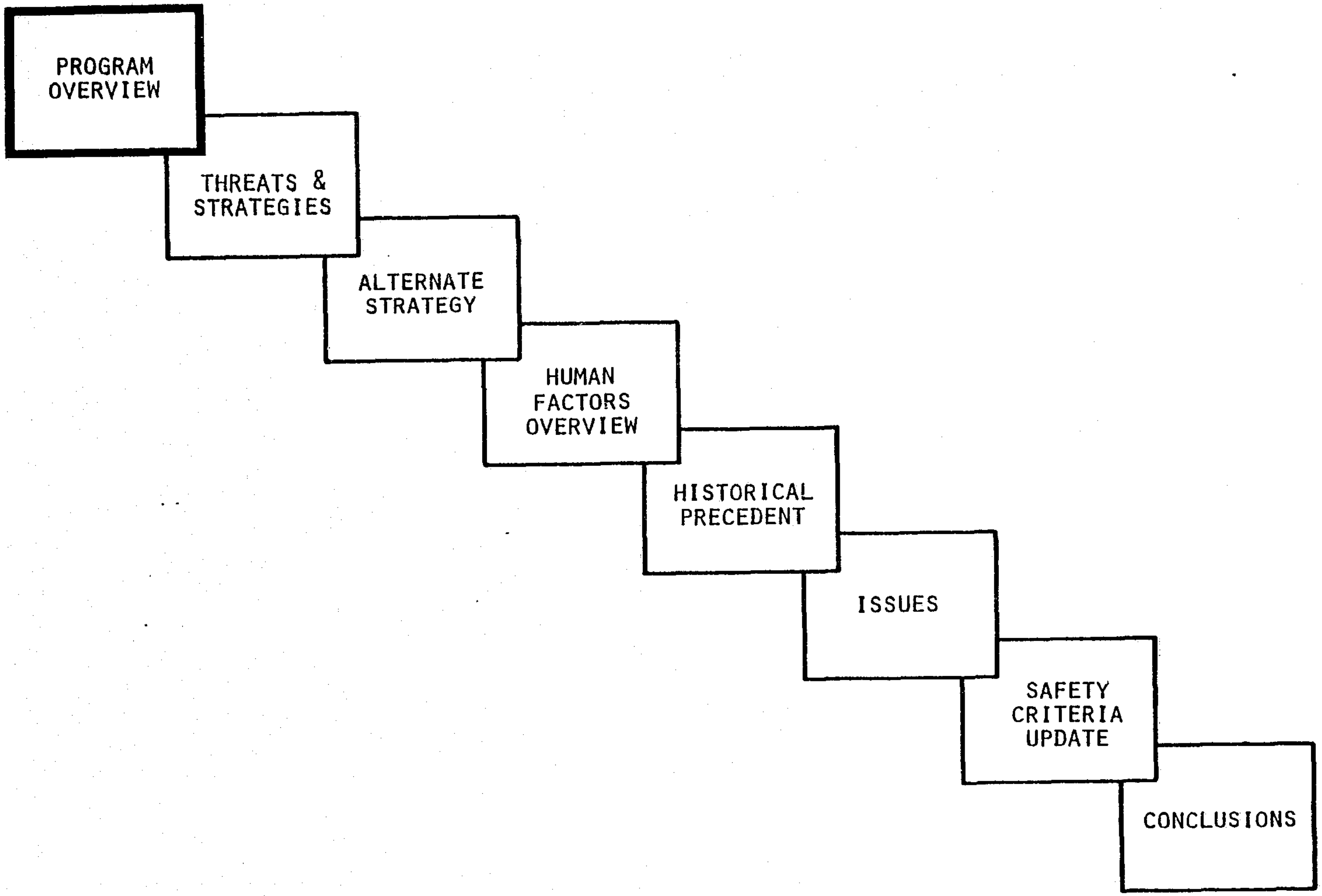


PROGRAM OVERVIEW

THREATS & STRATEGIES

ALTERNATE STRATEGY

HUMAN FACTORS OVERVIEW

HISTORICAL PRECEDENT

ISSUES

SAFETY CRITERIA UPDATE

CONCLUSIONS

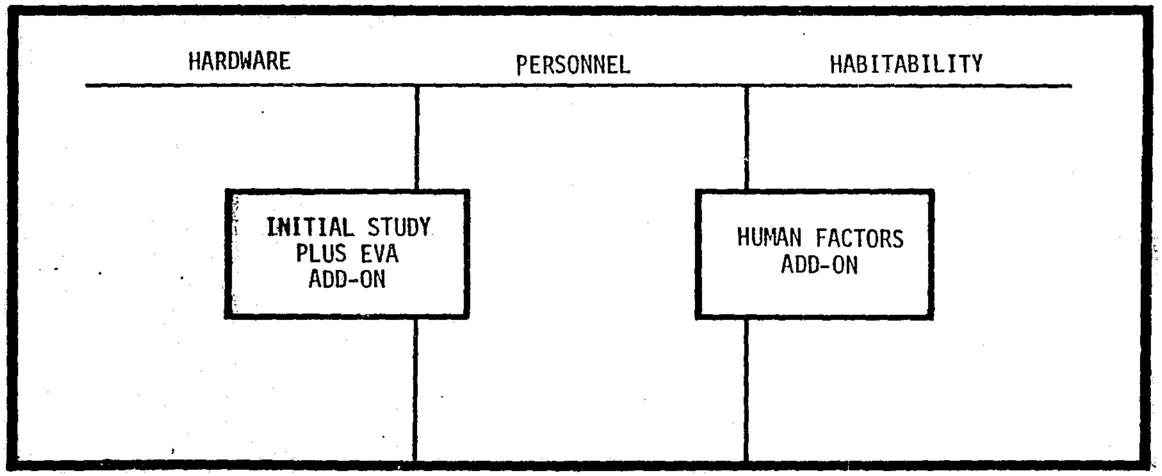
PURPOSE OF STUDY

- IDENTIFY THREATS THAT COULD CAUSE AN ESCAPE OR RESCUE DECISION
  - LOOK AT STRATEGIES WITHIN THE BASELINE TO ACCOMMODATE THESE THREATS - GENERATE CRITERIA
- IDENTIFY OPTIONS & PERFORM ROM COSTING FOR ESCAPE/RESCUE
- MAKE RECOMMENDATIONS FOR ADDITIONAL STUDY
  - SOFT AREAS
  - VOIDS

CREW SAFETY STUDY

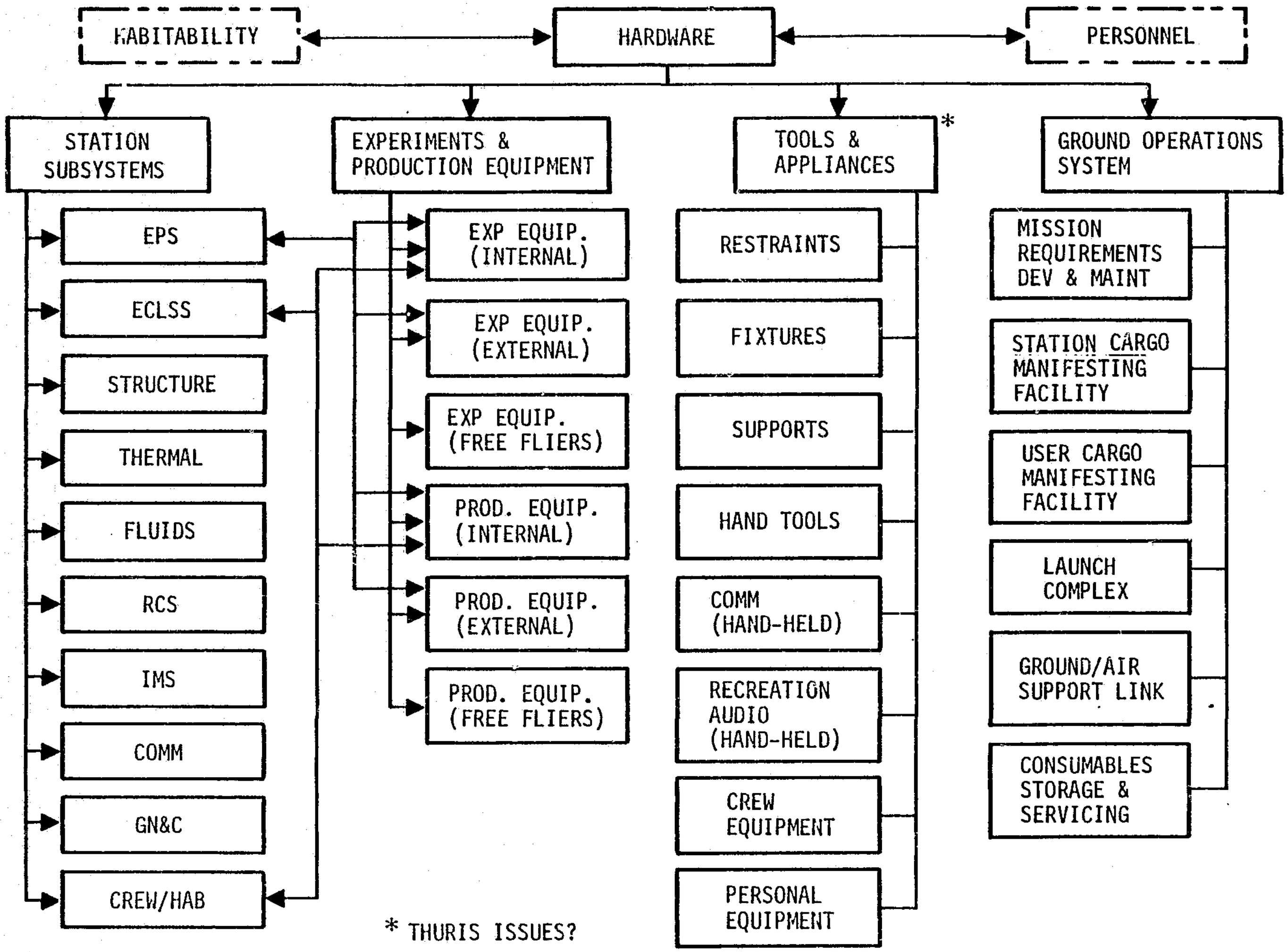
NAS1-17242

- AREAS ADDRESSED OR BEING ADDRESSED



- OBJECTIVE:
  - IDENTIFY SAFETY ISSUES
  - PROPOSE CONTROLLING CRITERIA

STUDY SEGMENTS - HARDWARE



HABITABILITY

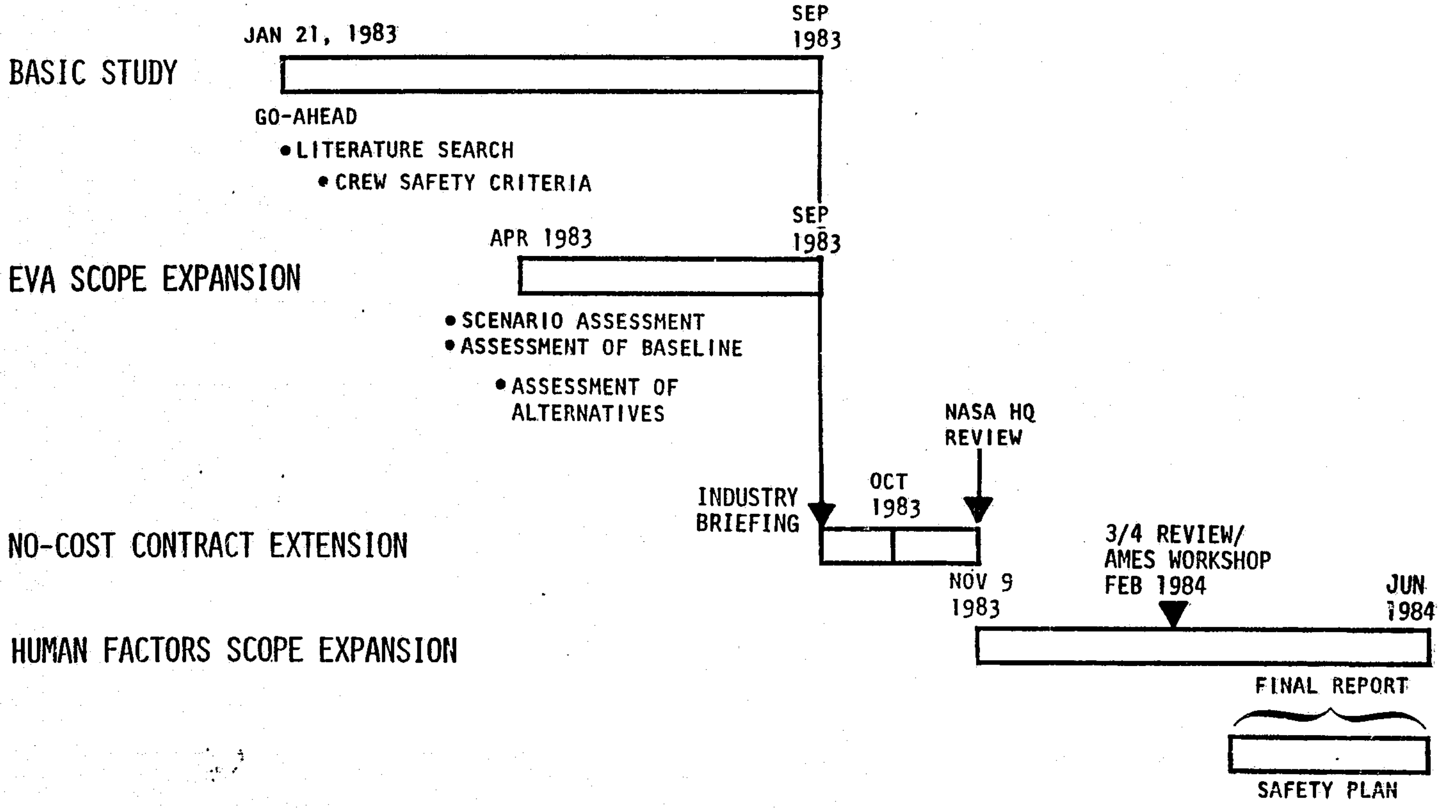
HARDWARE

PERSONNEL

- STATION SUBSYSTEMS
  - EPS
  - ECLSS
  - STRUCTURE
  - THERMAL
  - FLUIDS
  - RCS
  - IMS
  - COMM
  - GN&C
  - CREW/HAB
- EXPERIMENTS & PRODUCTION EQUIPMENT
  - EXP EQUIP. (INTERNAL)
  - EXP EQUIP. (EXTERNAL)
  - EXP EQUIP. (FREE FLIERS)
  - PROD. EQUIP. (INTERNAL)
  - PROD. EQUIP. (EXTERNAL)
  - PROD. EQUIP. (FREE FLIERS)
- TOOLS & APPLIANCES *
  - RESTRAINTS
  - FIXTURES
  - SUPPORTS
  - HAND TOOLS
  - COMM (HAND-HELD)
  - RECREATION AUDIO (HAND-HELD)
  - CREW EQUIPMENT
  - PERSONAL EQUIPMENT
- GROUND OPERATIONS SYSTEM
  - MISSION REQUIREMENTS DEV & MAINT
  - STATION CARGO MANIFESTING FACILITY
  - USER CARGO MANIFESTING FACILITY
  - LAUNCH COMPLEX
  - GROUND/AIR SUPPORT LINK
  - CONSUMABLES STORAGE & SERVICING

* THURIS ISSUES?

SCHEDULE SUMMARY



BASIC STUDY

JAN 21, 1983

SEP 1983

GO-AHEAD

- LITERATURE SEARCH
  - CREW SAFETY CRITERIA

EVA SCOPE EXPANSION

APR 1983

SEP 1983

- SCENARIO ASSESSMENT
- ASSESSMENT OF BASELINE
  - ASSESSMENT OF ALTERNATIVES

NO-COST CONTRACT EXTENSION

INDUSTRY BRIEFING

OCT 1983

NASA HQ REVIEW

NOV 9 1983

HUMAN FACTORS SCOPE EXPANSION

3/4 REVIEW/ AMES WORKSHOP FEB 1984

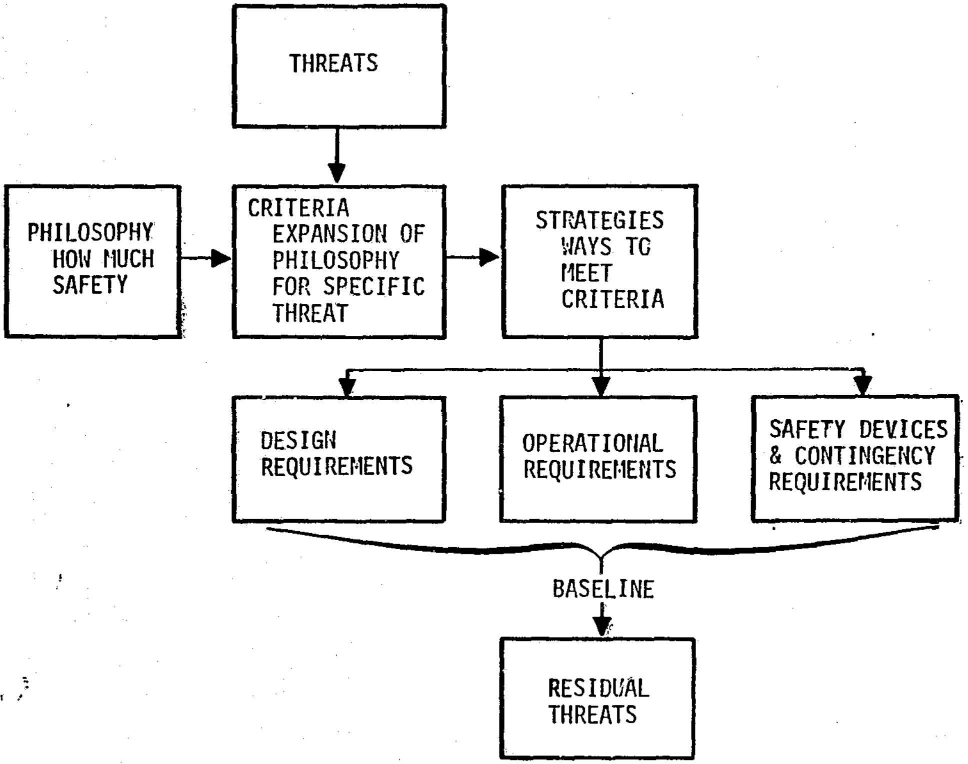
JUN 1984

FINAL REPORT

SAFETY PLAN

- PROGRAM OVERVIEW
- **THREATS & STRATEGIES**
- ALTERNATE STRATEGY
- HUMAN FACTORS OVERVIEW
- HISTORICAL PRECEDENT
- ISSUES
- SAFETY CRITERIA UPDATE
- CONCLUSIONS

STUDY APPROACH



THREATS

PHILOSOPHY
HOW MUCH
SAFETY

CRITERIA
EXPANSION OF
PHILOSOPHY
FOR SPECIFIC
THREAT

STRATEGIES
WAYS TO
MEET
CRITERIA

DESIGN
REQUIREMENTS

OPERATIONAL
REQUIREMENTS

SAFETY DEVICES
& CONTINGENCY
REQUIREMENTS

BASELINE

RESIDUAL
THREATS

SPACE STATION CREW SAFETY
THREAT LIST

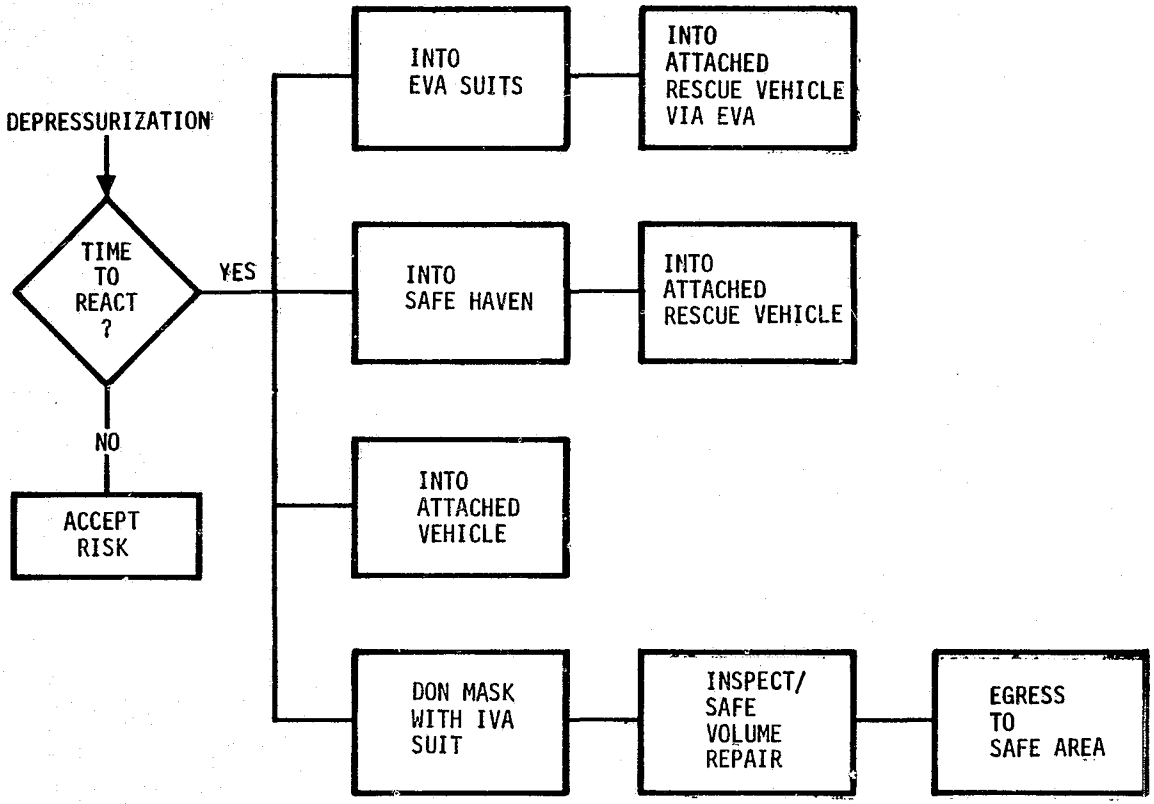
- ✓ FIRE
- LEAKAGE
- TUMBLING/LOSS OF CONTROL
- ✓ BIOLOGICAL OR TOXIC CONTAMINATION
- ✓ INJURY/ILLNESS
- GRAZING/COLLISION
- CORROSION
- MECHANICAL DAMAGE
- ✓ EXPLOSION/IMPLOSION
- ✓ LOSS OF PRESSURIZATION
- ✓ RADIATION
- OUT-OF-CONTROL IVA/EVA ASTRONAUT
- INADVERTENT OPERATIONS
- LACK OF CREW COORDINATION
- ABANDONMENT OF SPACE STATION
- ✓ METEOROID PENETRATION
- STORES/CONSUMABLES DEPLETION
- STRUCTURAL EROSION
- ORBIT DECAY
- LOSS OF ACCESS TO A HATCH
- TEMPERATURE EXTREMES
- ✓ DEBRIS
- FREE ORBIT (EVA ASTRONAUT)

SPACE STATION SAFETY PHILOSOPHY PRECEDENCE
(HOW MUCH SAFETY?)

CURRENT OPTIONS	COMMENTS
• CAUSE NO DAMAGE WHATSOEVER TO SPACE STATION AND NO INJURY TO CREW	DESIRABLE: COST TRADE
• CAUSE NO DAMAGE TO SPACE STATION BEYOND ROUTINE MAINTENANCE CAPABILITY	COST TRADE
• CAUSE NO DAMAGE TO SPACE STATION OR INJURY TO CREW WHICH WILL RESULT IN A SUSPENSION OF OPERATIONS	BASELINE PHILOSOPHY
• SPACE STATION REPAIRABLE AND OPERATIONAL WITHIN A SPECIFIED PERIOD OF TIME	MAY REQUIRE ESCAPE/RESCUE
• CREW SURVIVAL AT EXPENSE OF THE SPACE STATION	IMPLIES EVACUATION AND RESCUE AS A MINIMUM

THREAT	CAUSATIVE FACTORS	STRATEGY(IES)
DEPRESSURIZATION	UNPLANNED • PUNCTURE FROM DEBRIS • INADVERTENT CREW ACTION • INTERNAL/EXTERNAL LEAKAGE	1. CAPABILITY TO INSPECT/REPAIR INSIDE OF PRESSURE VESSEL 2. STATION MINIMUM SURVIVAL FUNCTIONS (MANDATORY OPERATIONS AT ALL TIMES) SHOULD BE COLDPLATED 3. HARDWARE FOR OTHER CRITICAL FUNCTIONS SHOULD BE CAPABLE OF BEING TURNED OFF 4. NEED TO KNOW LOCATION OF ALL PERSONNEL IN ALL MODULES 5. DISCRETE DEFINITION OF "TIME-TO-SURVIVE" NEEDED • CONTAMINATION/TOXICITY • EXPLOSIVE DECOMPRESSION • INTERIM SURVIVAL DEVICES 6. INFLATABLE PRESSURE BULKHEAD 7. PROVIDE SUBSYSTEM DESIGNERS WITH "MAXIMUM HOLE" TO SIZE LIFE SUPPORT SYSTEM WITH NUMBER OF CYCLES (PRESS/DEPRESS) STATED
	PLANNED • REMOVE CONTAMINATION • FIRE CONTROL - ALTERNATE • MAINTENANCE DEPRESSURIZATION	1. STATION SHOULD BE CAPABLE OF TBD PRESSURE VOLUME CHANGEOUTS (3 MINIMUM)

DEPRESSURIZATION ESCAPE/RESCUE OPTIONS



EFFECTS OF A FIRE IN A MODULE IN SPACE

- REMOVAL OF OXYGEN FROM MODULE
- PYROLIZE 4 TO 8 POUNDS OF SOLIDS
- GENERATION OF HEAT
  - DISTORTION OF SOLIDS
  - CAN CAUSE FIRE TO BREAK OUT ON EXTERIOR OF MODULE WALL
- REDUCED VISIBILITY
- ADDITION OF CONTAMINANTS - MOST ARE TOXIC
  - SEVERAL THOUSAND COMPOUNDS WHEN PYROLYZED IN AIR
  - CARBON MONOXIDE MORE LIKELY TO BE PRESENT THAN IN ONE-G
- OVERLOAD OF ATMOSPHERIC REVITALIZATION SYSTEM
  - ADDED STAGNATION IN ZERO-G
- PRESSURE RISE MAY BE CATASTROPHIC
- PYROLISIS PRODUCTS MAY BE FLAMMABLE
  - LEAKING CONTAINERS CAN SUPPLY FLAMMABLE BASES AFTER FIRE IS EXTINGUISHED
- CORROSIVE RESIDUE

VENTING AS A FIRE-MITIGATION STRATEGY

PROS

- MAY PRECLUDE RUPTURE
- EXHAUSTS TOXIC CONTAMINANTS
- PRECLUDES EXPLOSIVE MIXTURES
- HELPS IN CLEAN-UP OPERATIONS - AVOIDS OVERLOADING ECLSS
- FOR PURE OXYGEN, FIRE SHOULD EXTINGUISH AT ~ .13 PSIA, FOR 21% OXYGEN - FIRE SHOULD EXTINGUISH AT 2 OR 3 PSIA

CONS

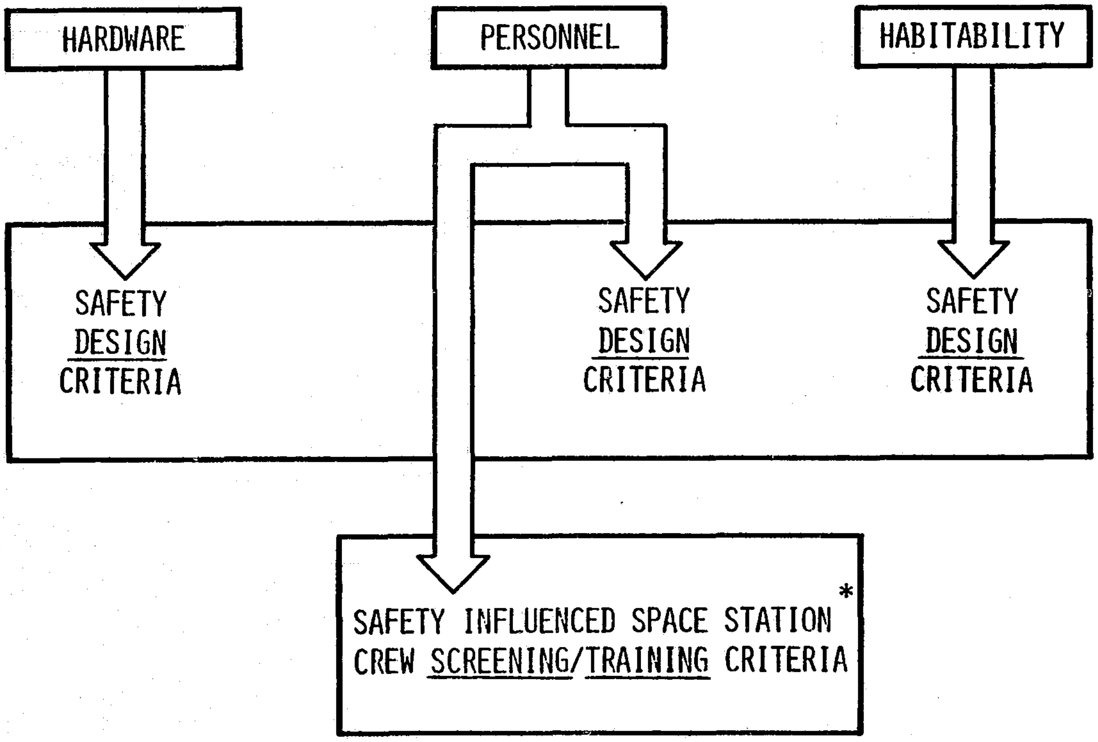
- IF FLAMMABLE LIQUIDS INVOLVED, MORE RAPID BURNING WITH POTENTIAL OF EXPLOSION AT LOWER PRESSURES.
- WHAT IS PROPER RATE OF DEPRESSURIZING A VOLUME? IT VARIES WITH SITUATION.
    - CONVECTION OF VENTING
- ALL CONNECTING PLUMBING MUST BE SEALED.
- TOO RAPID A DEPRESSURIZATION WILL CONDENSE VAPORS, PRODUCE A FOG AND MAY INTENSIFY A FIRE BECAUSE OF HIGH TURBULANCE.
- EXTERIOR DAMAGE - SUBLIMATION ON WINDOWS, RADIATORS, SENSORS, ETC.
- PROPULSIVE VENTING MAY RESULT IN TUMBLING.

THREAT IDENTIFICATION/STRATEGY DEVELOPMENT

SUMMARY

- 23 THREAT CATEGORIES HAVE BEEN DEFINED
- 8 THREATS HAVE IMPACT TO PRELIMINARY DESIGN & CANDIDATE STRATEGIES WERE DEVELOPED DURING STUDY
- 22 OF THE 23 THREAT CATEGORIES CAN BE DEALT WITH BY PROPER DESIGN SOLUTIONS
- APPROXIMATELY 70 CRITERIA IDENTIFIED TO MITIGATE THREATS
  - 50 OF THESE CRITERIA WERE COLLECTED FROM LITERATURE SEARCH
  - 20 CRITERIA - SPACE STATION - UNIQUE
  - APPROXIMATELY 240 DESIGN GUIDELINES DEVELOPED TO AID IN IMPLEMENTING THE 70 CRITERIA
- MOST THREAT STRATEGIES NEED INCORPORATION AT EARLIEST POINT IN CONFIGURATION DEVELOPMENT TO MINIMIZE DOWNSTREAM HARDWARE/OPERATIONAL IMPACT

INITIAL HUMAN FACTORS ASSESSMENTS
SAFETY CRITERIA DEVELOPMENT



*HOW IS THIS INCORPORATED INTO SPACE STATION DEVELOPMENT

PROGRAM OVERVIEW

THREATS & STRATEGIES

ALTERNATE STRATEGY

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ISSUES

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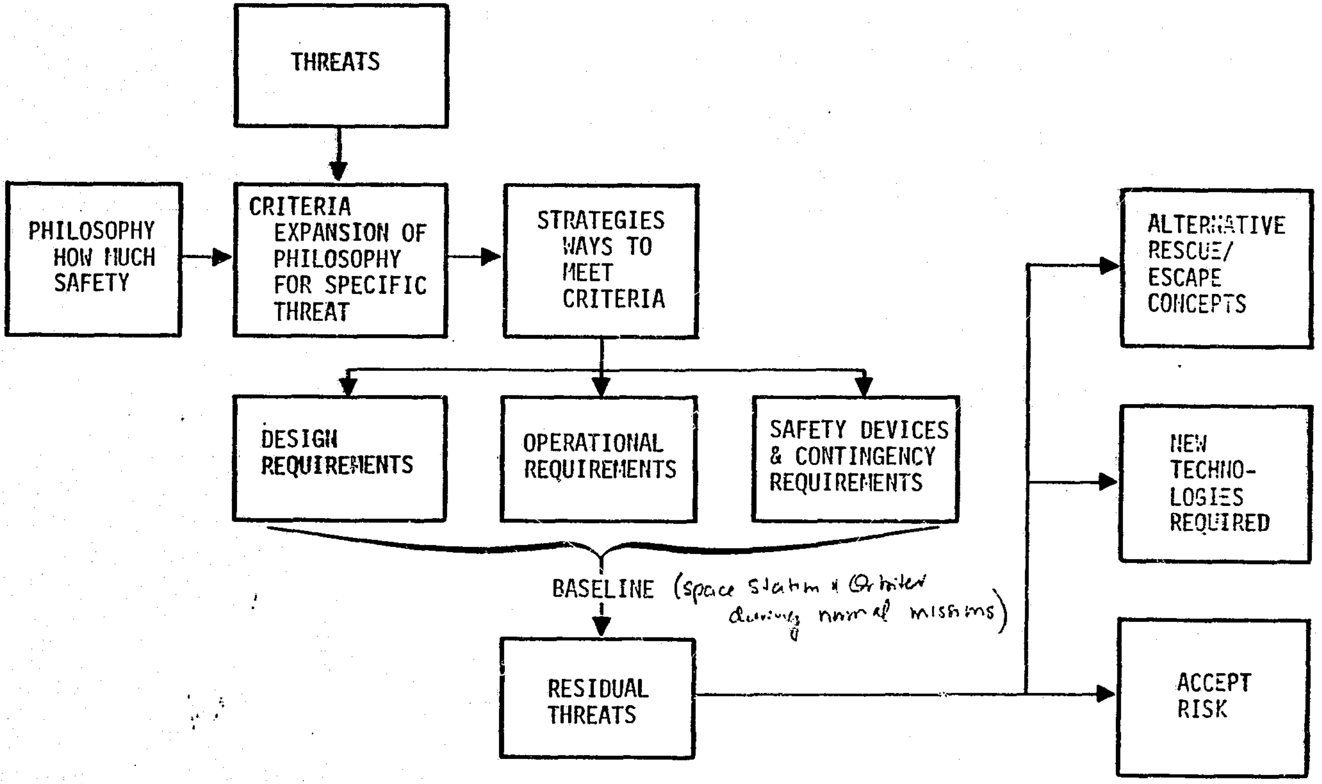
CONCLUSIONS

STUDY APPROACH



THREATS

PHILOSOPHY
HOW MUCH
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EXPANSION OF
PHILOSOPHY
FOR SPECIFIC
THREAT

STRATEGIES
WAYS TO
MEET
CRITERIA

DESIGN
REQUIREMENTS

OPERATIONAL
REQUIREMENTS

SAFETY DEVICES
& CONTINGENCY
REQUIREMENTS

BASELINE (space Station & Orbiter during normal missions)

RESIDUAL
THREATS

ALTERNATIVE
RESCUE/
ESCAPE
CONCEPTS

NEW
TECHNO-
LOGIES
REQUIRED

ACCEPT
RISK

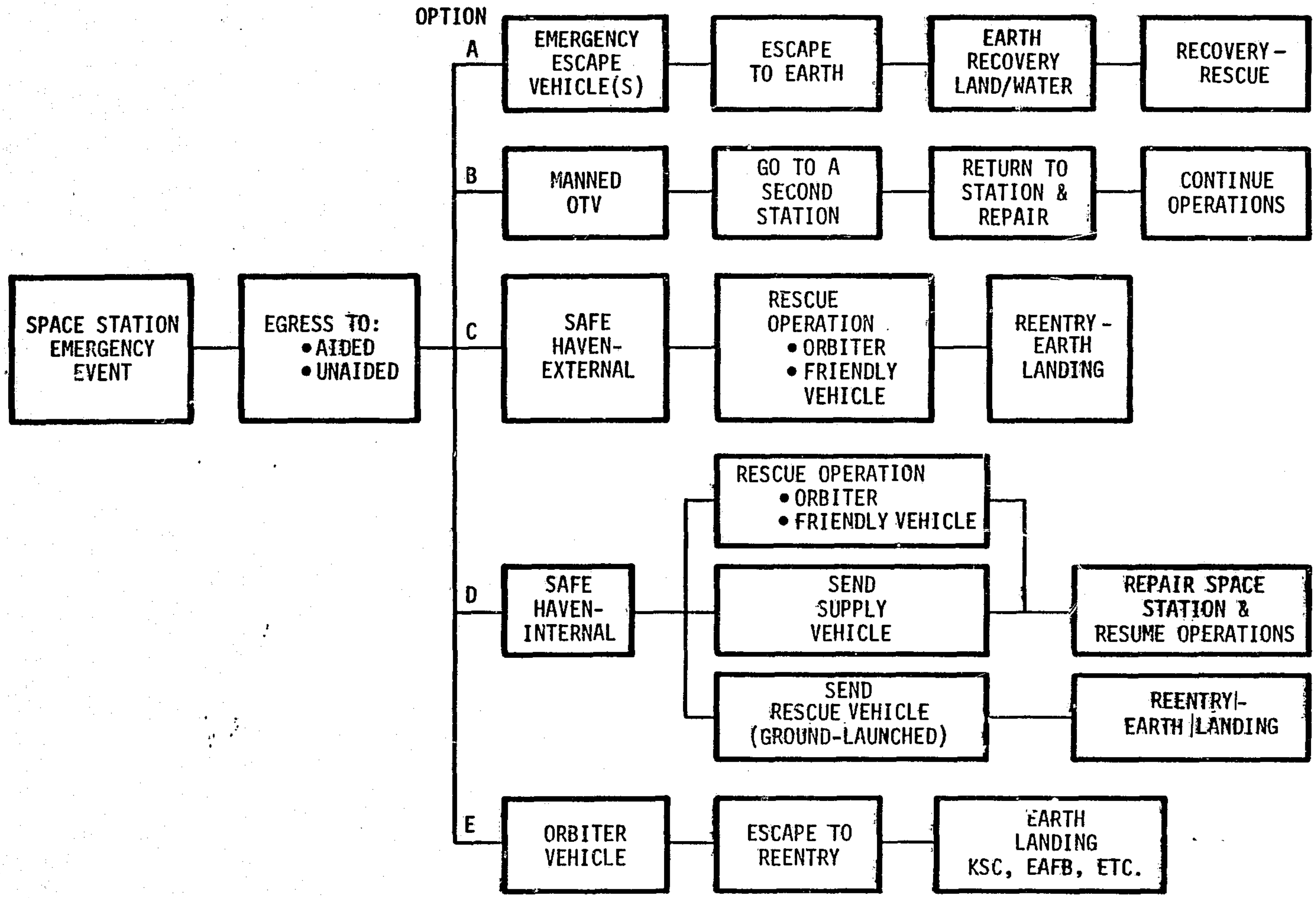
ALTERNATE STRATEGY DEFINITIONS

ESCAPE: LEAVE AREA OF THREAT WITHOUT EXTERNAL AID

RESCUE: AID FROM EXTERNAL SOURCES (EXCLUDING BASELINE)*

*BASELINE: ROCKWELL CONFIGURATION AT BEGINNING OF STUDY AUGMENTED BY NORMAL SHUTTLE RESUPPLY MISSIONS

ESCAPE AND RESCUE OPTIONS



DISCRIMINATORS FOR ESCAPE/RESCUE SYSTEM OPTIONS

OPTION	COSTS		RESPONSE TIME	CREW SIZE	TECHNOLOGY RISK	TYPE OF CALAMITIES ACCOMMODATED
	MISSION CONTINUATION	SAFETY				
A EMERGENCY ESCAPE VEHICLES	** NONE	100% (2 VEHICLES MINIMUM) $300 TO $1500M̄	VARIES (10 min TO 1-1/2 hr)	1 TO 4 PER VEHICLE	MEDIUM TO VERY HIGH	• FIRE* • TUMBLING* • MECHANICAL DAMAGE • EXPLOSION* • DEPRESSURIZATION* • METEROID PENETRATION* • DEBRIS *SELECTED
B GO TO A SECOND STATION VIA A MANNED OTV	** NONE	NO COST	VARIES (15 min TO 1-1/2 hr)	TBD	MEDIUM	ALL OF ABOVE
C SAFE HAVEN EXTERNAL	** NONE	TOTAL COST $300 TO $500M̄	<1 hr	8	VERY HIGH	ALL OF ABOVE
D SAFE HAVEN INTERNAL	TOTAL COST	NO COST	<10 min	8	LOW	ALL OF ABOVE
E ORBITER VEHICLE	NONE	<$1.0M̄/DAY	<15 min	10	VERY LOW	ALL OF ABOVE PLUS INJURY/ILLNESS

**POTENTIAL LOSS OF MISSION

WHAT WOULD CAUSE ESCAPE OF LESS THAN FULL CREW

1 MAN?	2 MEN?	3 MEN?
• SOLE SURVIVOR	• TWO SOLE SURVIVORS	• THREE SURVIVORS (REMOTE PROBABILITY) ESCAPING IMPENDING DISASTER
• PHYSICAL MEDICAL ISSUE (CUT, SOME BURNS)	• INDIVIDUAL CREWMAN MEDICAL ISSUE REQUIRING CONSTANT AID BY MEDIC • PHYSICAL • PSYCHOLOGICAL	• DECEASED
• PSYCHOLOGICAL ISSUE		
• DECEASED	• DECEASED	

PARAMETRIC EVALUATION ESCAPE, RESCUE, AND SURVIVABILITY CONCEPTS

Concept	Crew Size	Shirt-Sleeve	Technology	Development Risk	Launch Vehicles	Recovery
Escape						
Airmat	2	No	New	High	No	Water
Rib stiffened	3	Yes	New	High	No	Water
Paracone	1	No	New	High	No	Water
Moose	1	No	New	High	No	Water
Moses	2-4	No	Current	Low	No	Water/air
Encap	1	No	New	High	No	Water
Egress	1	Yes	New	Medium	No	Water
Life raft	3	No	New	High	No	Water
Lifting body	3	Yes	New	Medium	No	Water
EEOD	3	Yes	New	Medium	No	Water
Spherical heat shield	2	Yes	New	Medium	No	Water
Apollo Escape CM	2-6	Yes	Old	Very low	No	Water
Saver	1	No	New	Very high	No	Water
Rescue						
Shuttle	12	Yes	None extra	Low	***	Land
Hermes	Unk	Yes	New	Medium	Yes	Land
Apollo Rescue CSM	2-4	Yes	Current	Low (S-IB) Med (Titan)	Yes	Water
Rescue Ball	1	Yes	Current	Low	No	
Survivability*						
Cocoon	1	No	New	High	Only if needed***	Shuttle
Sortie module	12	Yes	Current	Medium		Shuttle
Space Station Module	12	Yes	Current	Medium		Shuttle
Apollo Survivability CM	8	Yes	Current	Medium		Shuttle
Modular Survivability Vehicle (MSV)	12	Yes	Current	Medium		Shuttle

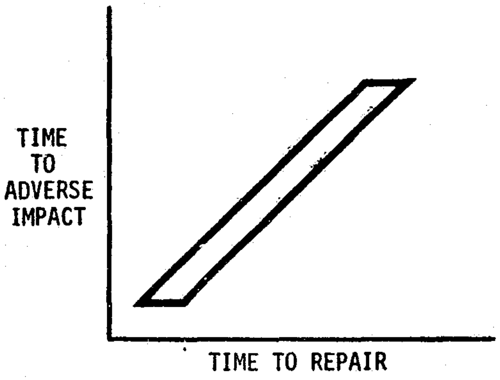
*Assumes shuttle used for rescue (10 people nominal; greater than 10 in emergency)

**Low = 2000 kg (4500 lb), high = 4000 kg (9000 lb)

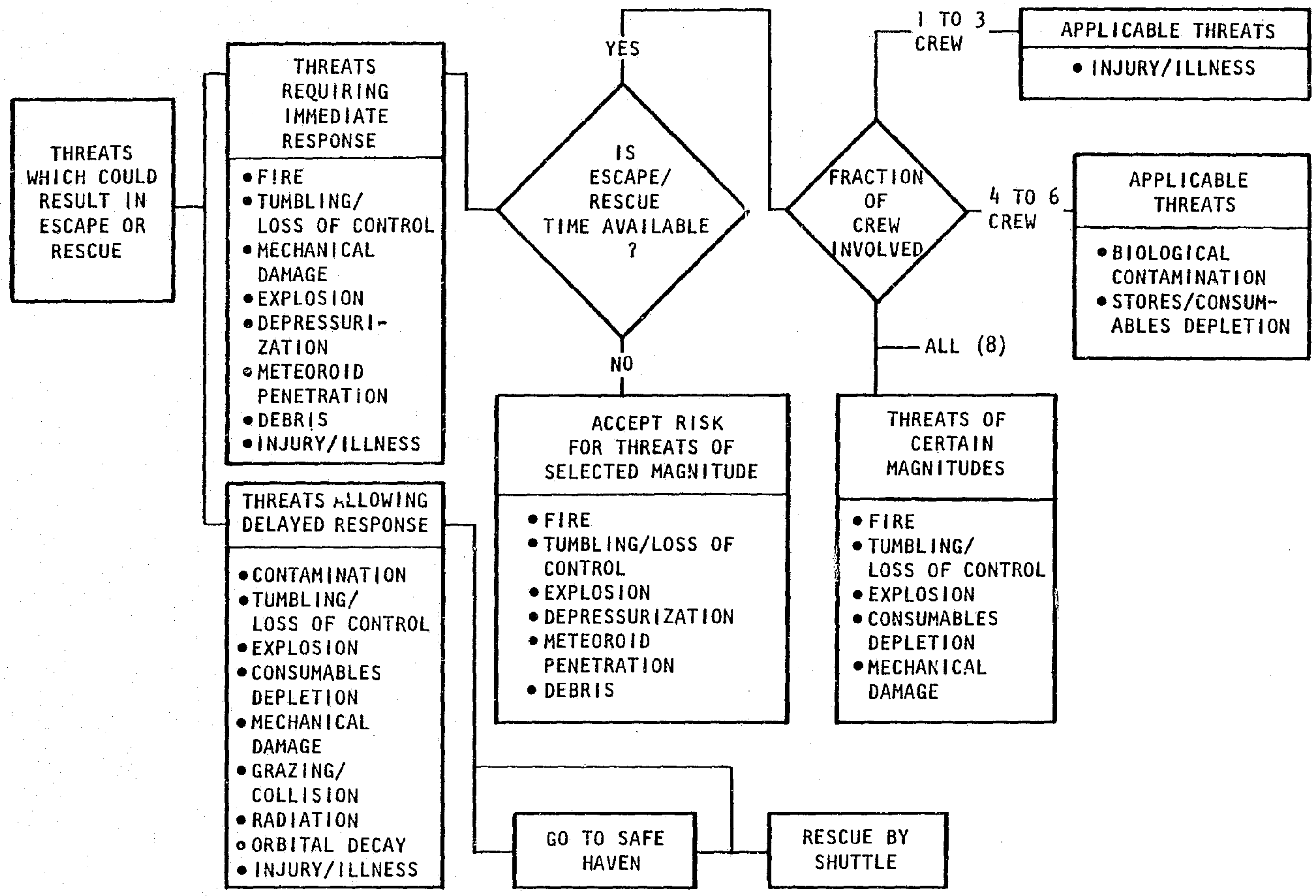
***Launch vehicles are used only if a rescue or survivability situation arises. Dedicated launch vehicles not required.

SPACE STATION CREW SAFETY
THREAT LIST

CONTROLLABLE (N/A)	IMMEDIATE NEED (IM)	DELAY ALLOWED (DEL)	
	X		FIRE
X			LEAKAGE
	X		TUMBLING/LOSS OF CONTROL
	X TO	X	BIOLOGICAL OR TOXIC CONTAMINATION
	X TO	X	INJURY/ILLNESS
		X	GRAZING/COLLISION
X			CORROSION
	X TO	X	MECHANICAL DAMAGE
	X TO	X	EXPLOSION
	X TO	X	LOSS OF PRESSURIZATION
		X	RADIATION
X			OUT-OF-CONTROL IVA/EVA ASTRONAUT
X			INADVERTENT OPERATIONS
X			LACK OF CREW COORDINATION
	X TO	X	ABANDONMENT OF SPACE STATION
	X		METEOROID PENETRATION
X		X	STORES/CONSUMABLES DEPLETION
		X	STRUCTURAL EROSION
		X	ORBIT DECAY
	X TO	X	LOSS OF ACCESS TO A HATCH
X			TEMPERATURE EXTREMES
	X		DEBRIS
X			FREE ORBIT (EVA ASTRONAUT)



THREATS REQUIRING ESCAPE/RESCUE



CANDIDATES FOR ACCEPTED RISKS

(CATASTROPHIES OF A CERTAIN MAGNITUDE)

- FIRE RESULTING FROM FUEL CELL, RCS, HYDRAULIC LINE RUPTURE
- IGNITION IN OXYGEN SYSTEM
- RCS CHAMBER OR MANIFOLD EXPLOSION
- DISINTEGRATION OF ROTATING COMPONENTS
- GENERIC SOFTWARE ANOMALY (LOSS OF STABILIZATION & CONTROL)
- LOSS OF CABIN PRESSURE
- CONTAMINATION OF BREATHING ENVIRONMENT
- STRUCTURAL FAILURE OF TANKS
- CONTACT WITH DEBRIS
- LOSS OF STABILIZATION (TUMBLING)

ALTERNATE STRATEGY - SUMMARY

- LIMITS ON USE OF BALLISTIC REENTRY ESCAPE VEHICLES
    - SIZE OF CREW ACCOMMODATED
        - IMPLICATIONS ON NUMBER OF VEHICLES REQUIRED
    - LIFE-IN-ORBIT LIMITATIONS
        - PARACHUTES
        - ORDNANCE SYSTEMS (BATTERIES)
        - OTHER DEGRADATION

      (E.G., WOULD ONE TRUST AN ESCAPE POD THAT HAD NOT BEEN USED IN 6 TO 8 YEARS?)
    - THREATS ACCOMMODATED BY BALLISTIC REENTRY ESCAPE POD
- LIMITS ON RESCUE SCENARIOS
    - WORST-CASE LIFE SUPPORT REQUIREMENTS
        - 21 DAYS
    - THREATS ACCOMMODATED
    - SIZE OF CREW ACCOMMODATED
    - SAFE HAVEN vs RESCUE
    - STORM CELLAR - MINIMUM SURVIVAL CONDITIONS FOR LIMITED PERIOD OF TIME

MAJOR OPEN ISSUES
CREW SAFETY

TECHNICAL

- SAFE HAVEN No a [illegible] but a [illegible]
    - LIMITATIONS OF MULTIPLE SAFE HAVENS CONCEPT
- DEPRESSURIZATION
    - HOW MANY VOLUME CHANGE-OUTS?
- RESOURCE MODULE CONCEPTS
    - MAINTENANCE IN AN UNPRESSURIZED MODULE IS A HIGH-RISK SITUATION
    - SINGLE MODULE IS A CONCEPTUAL SINGLE-FAILURE POINT
- DUAL EGRESS REQUIREMENT

PROGRAMMATIC

- MISSION DEFINITIZATION IS LIMITED
- TOTAL SYSTEM SAFETY vs INDUSTRIAL SAFETY
    - VARIABLE FACILITY SYNDROME (by changing cargo)
- TOTAL SYSTEM SAFETY INTEGRATION FUNCTION
- NO PROBLEM REPOSITORY FOR NON-DESIGN CRITERIA

PROGRAM OVERVIEW

THREATS & STRATEGIES

ALTERNATE STRATEGY

HUMAN FACTORS OVERVIEW

HISTORICAL PRECEDENT

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CREW SAFETY STUDY

NAS1-17242

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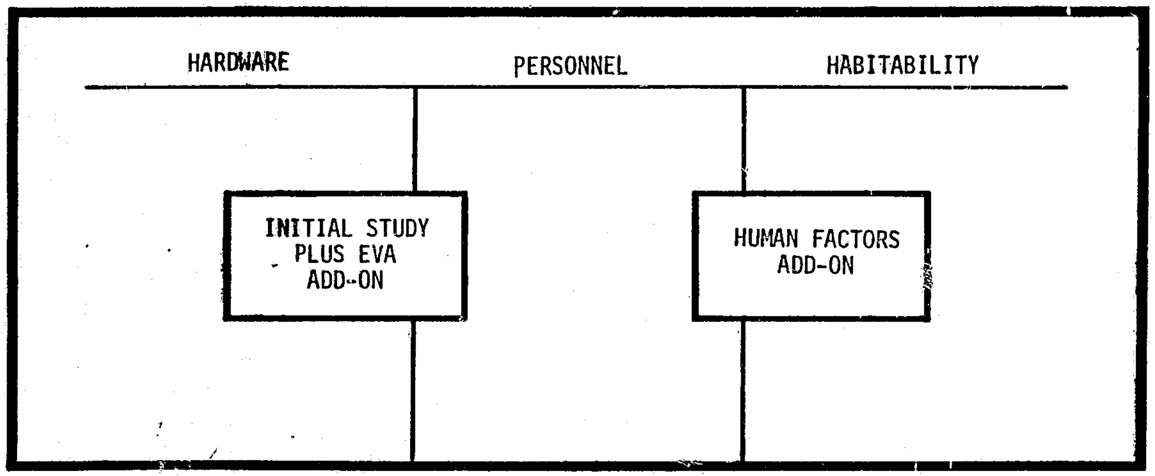


HARDWARE

PERSONNEL

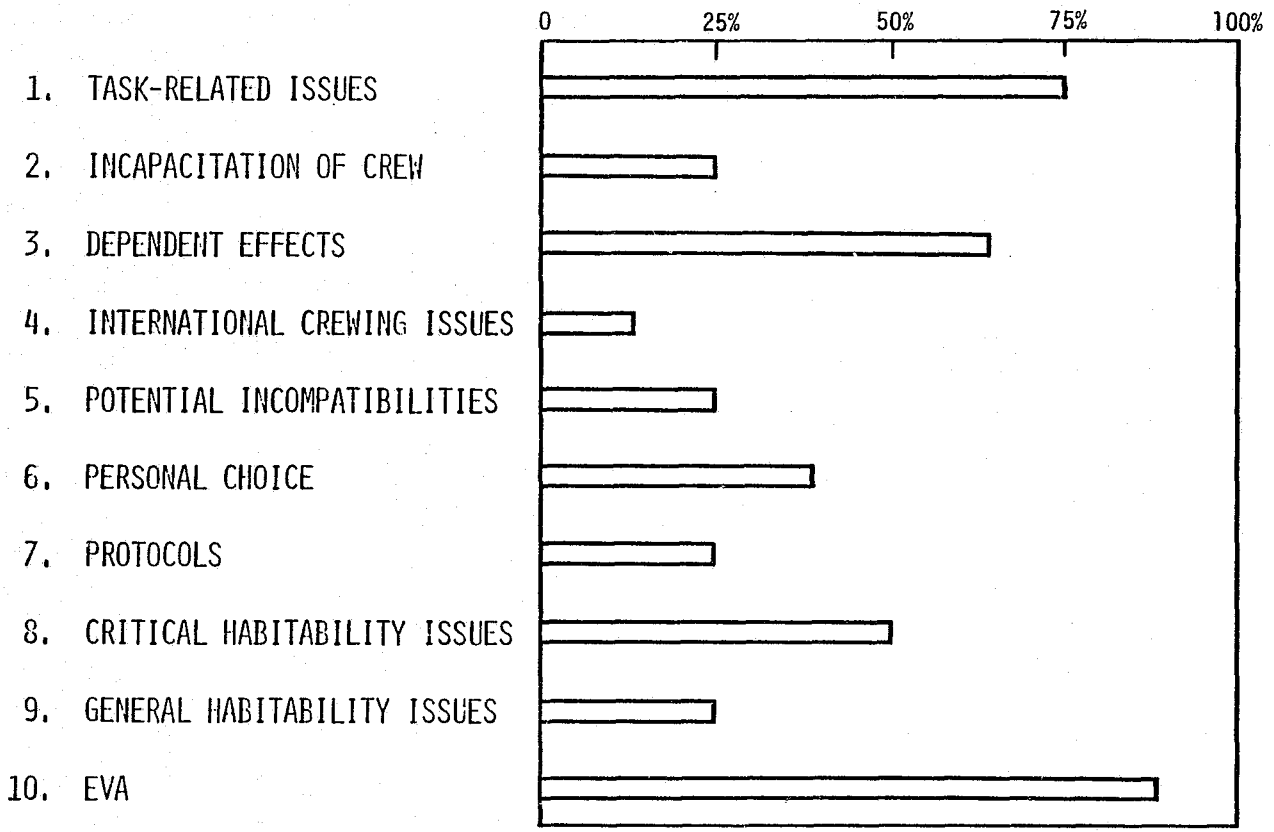
HABITABILITY

INITIAL STUDY
PLUS EVA
ADD-ON

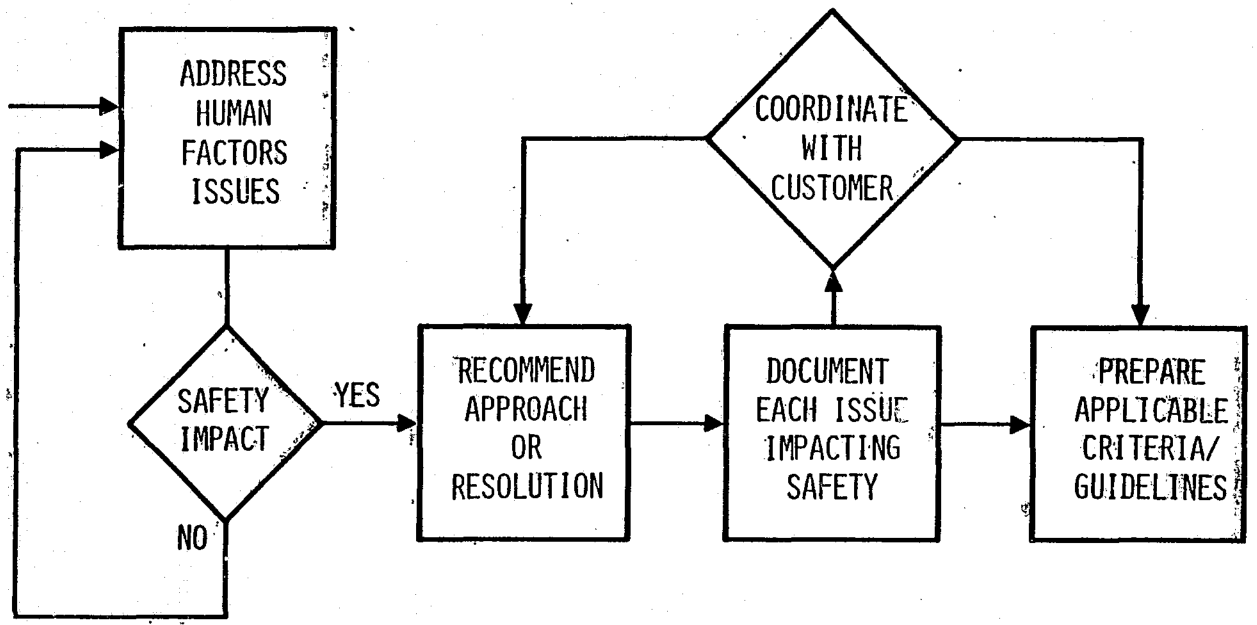
HUMAN FACTORS
ADD-ON

- OBJECTIVE:
  - IDENTIFY SAFETY ISSUES
  - PROPOSE CONTROLLING CRITERIA

SPACE STATION SAFETY
HUMAN FACTORS STATUS

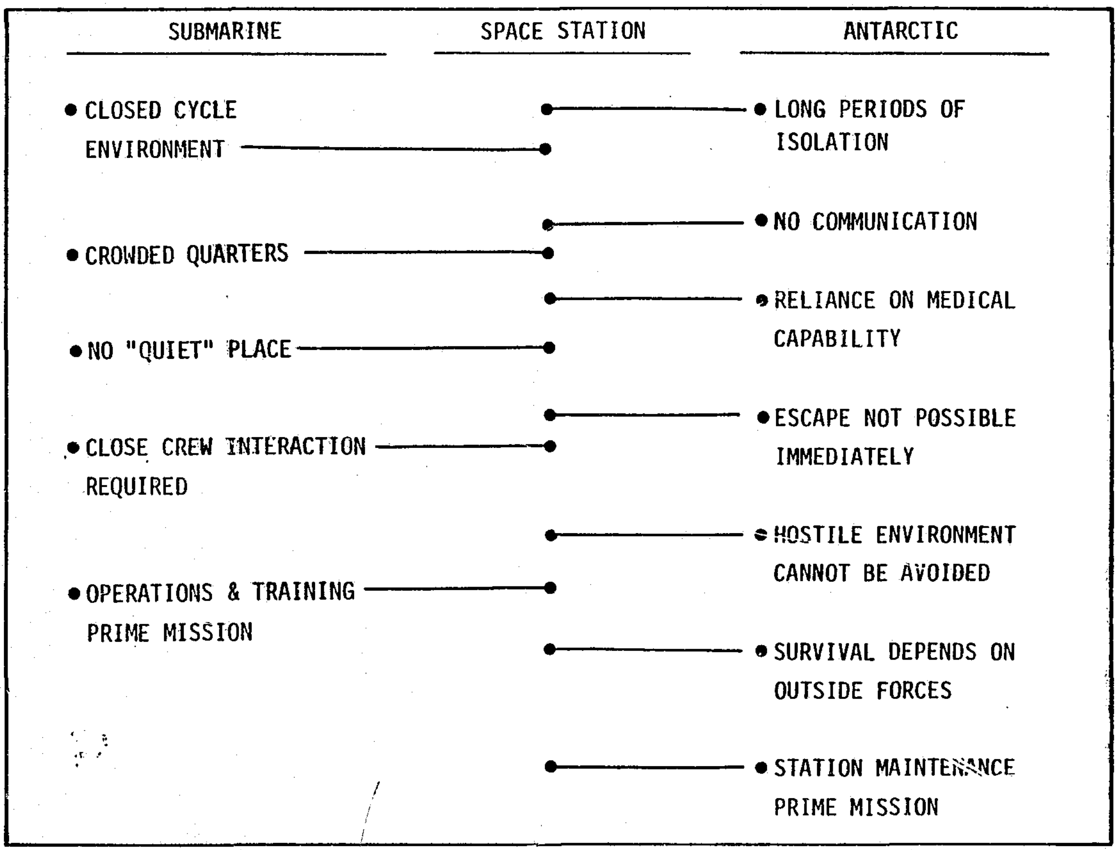


HUMAN FACTORS SAFETY STUDY APPROACH



- PROGRAM OVERVIEW
- THREATS & STRATEGIES
- ALTERNATE STRATEGY
- HUMAN FACTORS OVERVIEW
- **HISTORICAL PRECEDENT**
- ISSUES
- SAFETY CRITERIA UPDATE
- CONCLUSIONS

HISTORICAL PRECEDENT
HUMAN FACTORS ISSUES IMPACT SPACE STATION



SUBMARINE

- CLOSED CYCLE ENVIRONMENT
- CROWDED QUARTERS
- NO "QUIET" PLACE
- CLOSE CREW INTERACTION REQUIRED
- OPERATIONS & TRAINING PRIME MISSION

SPACE STATION

ANTARCTIC

- LONG PERIODS OF ISOLATION
- NO COMMUNICATION
- RELIANCE ON MEDICAL CAPABILITY
- ESCAPE NOT POSSIBLE IMMEDIATELY
- HOSTILE ENVIRONMENT CANNOT BE AVOIDED
- SURVIVAL DEPENDS ON OUTSIDE FORCES
- STATION MAINTENANCE PRIME MISSION

NOTE:
MOST SEVERE ISSUES FROM EACH ENVIRONMENT DIRECTLY APPLY TO SPACE STATION

SUBMARINE CREW EFFECTIVENESS DURING SUBMERGED MISSIONS
(60 OR MORE DAYS)

MAJOR STRESSORS:

- CONFINEMENT
- REVITALIZED AIR
- THREAT OF HYPERBARIC EXPOSURE
- FLATTENING OF CIRCADIAN RHYTHMS
- SLEEP DEPRIVATION

MINOR STRESSORS:

- PERFORMANCE DECREMENT
- DEBILITATING MORBIDITY
- DEPRESSED CREW MORALE

BEHAVIOR PATTERNS:

- MOTIVATION vs PSYCHOLOGICAL
  - WW II - 56 OUT OF 126,160 PATROLS HAD PSYCHIATRIC CASUALTIES
  - IN 1963 - 20 PER 1,000

SUBMARINE CREW EFFECTIVENESS DURING SUBMERGED MISSIONS
(60 OR MORE DAYS) (CONT)

SUMMARY COMMENTS:

- BIOLOGICAL ADAPTATION IS A COMPLEX FUNCTION OF:
  - NATURE & ENVIRONMENT SEVERITY
  - ADAPTIVE CAPACITY OF PERSONS INVOLVED
- PARAMETERS FOR SCREENING
  - EFFICIENT PERSONNEL SELECTION, SCREENING & TESTING
  - GROUP INTERACTION PROCESSES TEND TO PRODUCE COHESIVE CREWS
  - QUALITY OF LEADERSHIP INTRINSIC TO & ESSENTIAL FOR CREW INTEGRITY

REF: NAVAL SUBMARINE MEDICAL CENTER (95)

HISTORY OF MILITARY PSYCHOLOGY
(NAVAL SUBMARINE MEDICAL RESEARCH LAB)

- PSYCHOLOGY - WW II (1942-1945):
  - MAINLY MANDATED BY OPERATIONAL REQUIREMENTS OF DIESEL SUBS
  - RESEARCH IN AREAS OF HEARING, VISION & PERSONNEL SELECTION
    - PRIOR TO ESTABLISHED (NMRL) NAVY MEDICAL RESEARCH LAB

- NUCLEAR-POWERED SUBMARINES:
  - ADDITIONAL PSYCHOLOGICAL PROBLEMS IN CREW SIZE
    - INCREASED DURATION OF SUBMERGED PATROLS (FROM 3 TO 80 DAYS)
    - PSYCHOPATHOLOGICAL EFFECTS OF ISOLATION
    - INCREASED AUDITORY & VISUAL SKILLS
    - ADDED HUMAN FACTORS ASSOCIATED WITH NUCLEAR TECHNOLOGY
  - COLOR-CODED SWITCHES INCREASED COLOR PERCEPTUAL DEFICIENCY TESTS
  - EMPHASIS ON BETTER SCREENING OF PSYCHIATRIC PROBLEMS ASSOCIATED WITH MORALE DETERIORATION, PERFORMANCE DECREMENTS & DEBILITATIVE EFFECTS ON LONG-SUBMERGED MISSIONS
  - DETERMINE OPTIMAL STANDARDS FOR RED LIGHTING
  - POTENTIAL OF HEARING LOSS FROM LONGER EXPOSURE TO SOUND LEVELS
  - FIRST PROBLEMS (72-HOUR SUBMERGE)
    - HEADACHES
    - BLURRED VISION
    - DIZZINESS

HISTORY OF MILITARY PSYCHOLOGY (NAVAL SUBMARINE MEDICAL RESEARCH LAB) (CONT)

- FIRST PROBLEMS (72-HOUR SUBMERGE) (CONT)
    - MALAISE
    - PERFORMANCE DECREMENTS

- INCREASED INTERRUPTION OF DIURNAL PERIODICITY
    - IN 60- TO 70-DAY RANGE, ALLOWED "PERISCOPE LIBERTY" AT 24-HOUR PERIODS TO ALL CREW (REASSURANCE TO REAL WORLD)

- QUESTION OF: OPTIMIZING "FIT" OF MAN TO ENVIRONMENT OR ORGANIZE ENVIRONMENT TO BEST "FIT" THE MAN?

1969-1972 (NSMRL):

- CONCERN IN FOUR CONCERNED AREAS
    - HUMAN FACTORS IN SUBMARINE ESCAPE
    - PSYCHO-PHYSIOLOGICAL EFFECTS OF LONG-DURATION EXPOSURE TO SONAR "BEEPS" AT HIGH INTENSITY
    - CENTRAL NERVOUS SYSTEM INDICES OF THE NARCOTIZING EFFECTS OF EXPOSURE TO COMPRESSED GAGES
    - DRUG ABUSE IN SUBMARINE SERVICE

HISTORY OF MILITARY PSYCHOLOGY
(NAVAL SUBMARINE MEDICAL RESEARCH LAB) (CONT)

1969-1972 (NSMRL) (CONT)

- LONG CONFINEMENT ADDED MORE ILLNESSES
    - CARDIOVASCULAR
    - RESPIRATORY
    - NEOPLASTIC
- DUE TO ATMOSPHERIC TOXICANTS
- ABSENCE OF SUNLIGHT
- RESTRICTED SPACE

- MOST ALL-PERVASIVE OF QUESTIONS HAD TO DO WITH ACCUMULATIVE PSYCHO-PHYSIOLOGICAL EFFECTS OF EXPOSURE TO CO_2 AT ABOUT 1.5%
    - INTRODUCED DURING "OPERATION HIDEOUT" THAT THE CAPACITY OF CO_2 in BLOOD GAVE CALCIUM DEFICIENCY
        - COTTAGE CHEESE ADDED TO DIET & MANY TIMES WAS REQUESTED BY CREW AS AN "INSATIABLE DESIRE"

SUMMARY & FUTURE PLANNING:

- IDENTIFICATION & CONTROL OF MAJOR TOXICANTS IN ATMOSPHERE
- DEVELOP & VALIDATE AN EFFECTIVE PSYCHOLOGICAL SCREENING PROGRAM
- APPLY CONCEPT OF "SIGNIFICANT ADAPTIVE DECREMENT"
    - LD-50 (LETHAL DOSE IN 50% OF EXPOSED POPULATION) & SAD-50 (STRESSOR CLASS LD-50) - LEVELS OF TOXIC GAS, LENGTH OF DUTY CYCLE, DURATION OF SLEEP DEPRIVATION

REF: U.S. NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY (245)

ANTARCTICA

- A FACTOR CONTRIBUTING TO THE IMPORTANCE OF INTERMEMBER ATTRACTION FOR GROUP EFFECTIVENESS IS THE NATURE OF THE SETTING
  - BESIDES SPACE, ANTARCTICA IS ONE OF THE MOST HOSTILE ENVIRONMENTS INHABITED BY MAN
  - DURING THE ISOLATION PERIOD, SURVIVAL DEPENDS ON EACH STATION GROUP'S ABILITY TO HANDLE ANY EMERGENCIES THAT MIGHT ARISE
  - THIS SETTING IS RELATIVELY STRESSFUL &, UNDER CONDITIONS OF STRESS, INDIVIDUALS MAY TEND TO BECOME MORE ANXIOUS, INTERDEPENDENT & AFFILIATIVE
- ANTARCTICA SYMPTOMS FOUND TO BE:
  - DEPRESSION
  - INSOMNIA
  - ANXIETY
  - HOSTILITY
- STRESS, UNCLEAR GOALS, & A COMBINATION OF TASK & SOCIAL-EMOTIONAL ORIENTATIONS HAVE BEEN FOUND TO BE PRESENT IN THE ANTARCTICA SETTING

REFERENCE: NAVAL HEALTH RESEARCH CENTER (256)

SCREENING PROCEDURES FOR ANTARCTICA

- THREE MAJOR TYPES OF SCREENING INFORMATION USED
    - CLINICAL EVALUATION BY PHYCHOLOGISTS & PSYCHIATRISTS
    - BIOGRAPHICAL INFORMATION
    - ATTITUDE & PERSONALITY TESTS
- IN ANTARCTICA RESEARCH, BIOGRAPHICAL INFORMATION HAS BEEN USED FOR THREE PURPOSES:
    1. TO PREDICT INDIVIDUAL ADJUSTMENT OR PERFORMANCE
    2. TO DIFFERENTIATE OCCUPATIONAL SUBGROUPS IN TERMS OF EDUCATIONAL, FAMILIAL, SOCIAL & CULTURAL BACKGROUND CHARACTERISTICS
    3. TO PREDICT GROUP COHESIVENESS OR COMPATIBILITY ON THE BASIS OF DIVERSITY OR SIMILARITY IN BIOGRAPHICAL CHARACTERISTICS
- ATTITUDE QUESTIONAIRE DESCRIBING MOTIVATION FOR THE ANTARCTIC ASSIGNMENT, CONFIDENCE IN EXPEDITION LEADERSHIP, SATISFACTION WITH DUTY & REACTIONS TO COLD WEATHER, FOOD & CLOTHING WAS ADMINISTERED IN THE SCREENING PROGRAMS
- PSYCHIATRIC EVALUATIONS WERE INTENDED ONLY TO IDENTIFY & DISQUALIFY POTENTIAL PSYCHOTIC OR SERIOUSLY DISTURBED INDIVIDUALS

REF: NAVY MEDICAL NEUROPSYCHIATRIC RESEARCH (255)

LESSONS LEARNED - SKYLAB

- SKYLAB MISSIONS, AS WELL AS APOLLO/LEM, APOLLO/SOYUZ, & APOLLO/SKYLAB PROVIDED AN OPPORTUNITY TO EVALUATE THE DESIGN FEATURES & PROCEDURES THAT ARE REQUIRED TO ALLOW AN ASTRONAUT TO FUNCTION IN SPACE

FINDINGS:

- NORMAL CREW MOVEMENTS DO NOT CAUSE UNWANTED PHYSICAL DISTURBANCES IN MOST EXPERIMENTS
    - SOME LIMITATIONS STILL MAY BE REQUIRED ON CREW MOVEMENTS DURING CRITICAL PHASES OF THE EXPERIMENT
- SUGGESTS THAT IN FUTURE FACILITIES, PERMANENT HARDWARE SHOULD HAVE NO NOOKS & CRANNIES THAT WOULD PRECLUDE THE RETRIEVAL OF LOOSE ITEMS THROUGH THE "AIR-RETURN" PHENOMENON
- FUTURE DESIGNS SHOULD ALLOW THE CREW ACCESS TO ANY POINT ON THE EXTERIOR OF THE SPACECRAFT FOR PURPOSES OF INSPECTION OR UNSCHEDULED MAINTENANCE & REPAIR
- ARCHITECTURAL LAYOUT OF THE SPACECRAFT'S INTERIOR SHOULD ENSURE THAT NORMAL TRAFFIC ROUTES DO NOT INTERFERE WITH THE ACTIVITIES OF OTHER CREWMEN
- IT WAS FOUND THAT A PRE-SLEEP PERIOD OF AT LEAST ONE HOUR OF MENTALLY NONDEMANDING ACTIVITY WAS REQUIRED
    - THIS ALLOWED THE CREW TO RELAX TO THE POINT WHERE THEY COULD FALL ASLEEP

LESSONS LEARNED: SKYLAB (CONT)

- THERE WAS AN OCCASIONAL NEED FOR PRIVATE COMMUNICATIONS
    - A SECURE COMMUNICATION LINE SHOULD BE PROVIDED IN FUTURE SYSTEMS TO ELIMINATE POTENTIAL MISQUOTING OR MISUNDERSTANDING
- SLEEP COMPARTMENT VENTILATION SHOULD FLOW IN A HEAD-TO-FOOT PATTERN
- RIGID ADHERENCE TO A TWO-HOUR DAILY EXERCISE ROUTINE HAS BEEN CITED BY SOVIET AEROSPACE MEDICAL PERSONNEL AS THE PRIME FACTOR THAT ALLOWED A SALYUT-6 CREW TO RETURN TO EARTH IN STRONG PHYSICAL CONDITIONS
- THE SHOWER BATH FACILITY USES A PORTABLE SPRAY HEAD, BUT THE METHOD OF WATER REMOVAL AFTER USE WAS NOT CONVENIENT & CONSIDERABLE EFFORT & TIME WERE REQUIRED TO SET UP & TAKE DOWN THE SHOWER
- AN ENCLOSED HAND WASHER THAT WOULD ALLOW HAND INSERTION & ACTUAL "WORKING" DIRECTLY WITH THE WATER WOULD BE DESIRABLE
- CREW SHOULD BE PROVIDED WITH FAMILIAR "UP" & "DOWN" REFERENCES, PERMITTING EASY ORIENTATION, LOCATION RECOGNITION & EQUIPMENT IDENTIFICATION
- ILLUMINATION LEVELS MATCHING THOSE OF NORMAL EARTH WORKING CONDITIONS SHOULD BE PROVIDED

SPACELAB

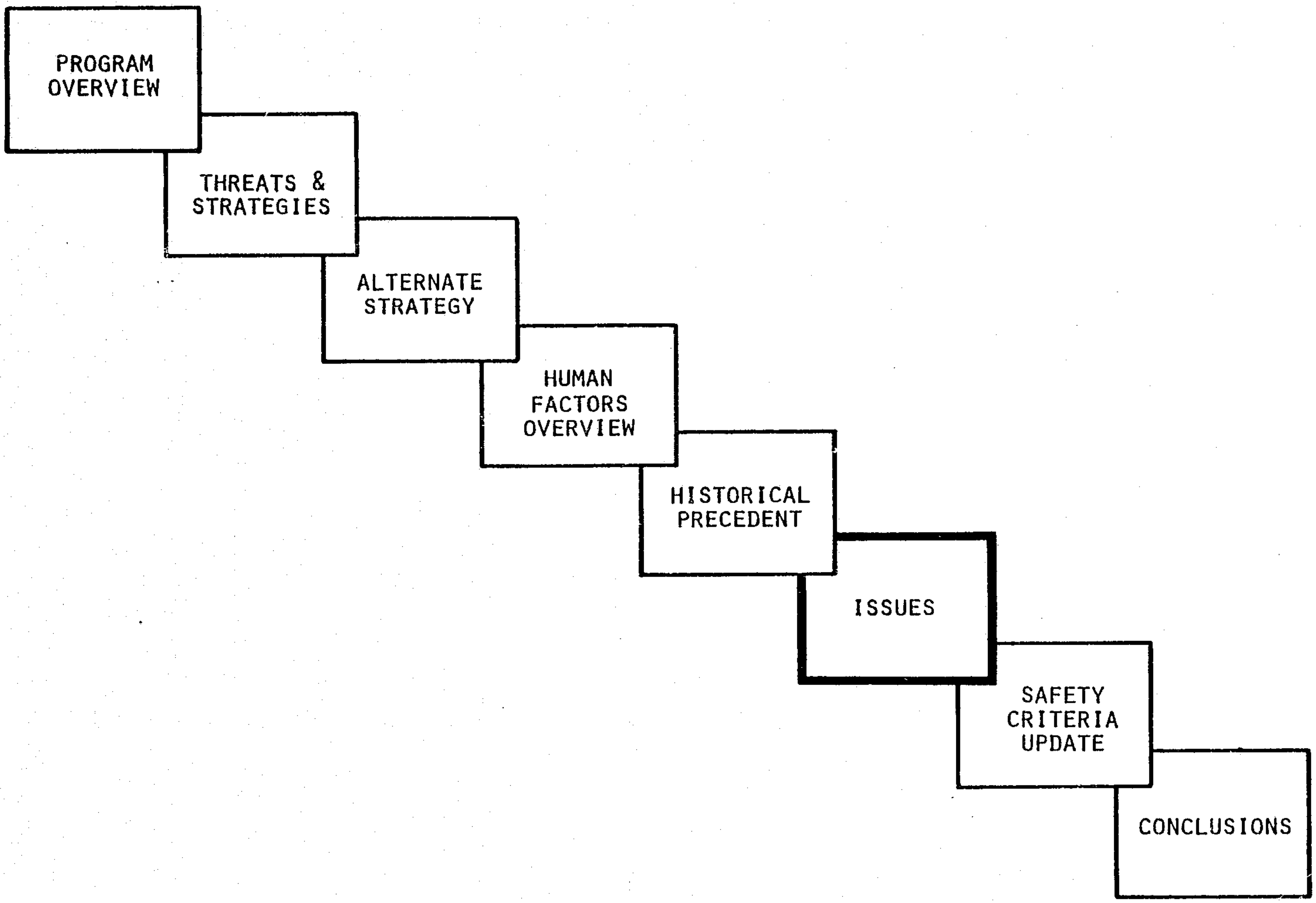
TWO-SHIFT OPERATIONS

- MULTIPROBLEMS ON FLIGHT DECK/MID DECK SATURATES QUICKLY
- BECOMES CLOCK-WATCHING ROUTINE
- AUTOMATE SOME OF THE MANEUVERS
    - SUGGESTIONS: 12-13 MANEUVERS PER SHIFT NORMAL
      20 MAXIMUM PER SHIFT

- ON TWO-SHIFT (12 & 12), A SECOND FLIGHT DECK CREWMAN NEEDED
- TREADMILL COULD NOT BE USED WHILE OTHER SHIFT ASLEEP
- B. SHAW - PRESENTED THE FOLLOWING COMMENTS:
    - HE THOUGHT IT WAS A LARGE STRAIN ON THE CREW, BUT CAN BE DONE IF REQUIRED
    - CMDR & PILOT TASKS - REQUESTED 3 PEOPLE FOR FLIGHT DECK OPERATIONS
        - THIS WOULD ENABLE THEM TO GO ON 8-HOUR DUTY CYCLES

SAFETY IMPACT

- CONCERN HERE IS FOR CONTINGENCY OPERATIONS
    - WITH THREE FLIGHT DECK CREWMEN ON 8-HOUR SHIFTS:
        - THE PILOT WOULD NOT BE TIRED
        - WOULD NOT HAVE TO AWAKEN THE OTHER CREWMEN
        - THE OFF-DUTY CREWMAN WHO IS AWAKE CAN PROVIDE ASSISTANCE FOR ANY CONTINGENCY OPERATION



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TERRITORIALISM

ISSUE

- CLASSICAL ANTHROPOMETRICS MEASURES SCOPE OF EXPECTED BODY DIMENSIONS TO PROVIDE DESIGNERS WITH DISCRETE REQUIREMENTS FOR INTERFACING EQUIPMENT DESIGN. THE PSYCHOLOGICAL NEED FOR EACH INDIVIDUAL'S INTERACTIVE "SPHERE" IS NOT EASY TO DEFINE. VIOLATION OF ONE'S PERSONAL "SPHERE" GENERATES HOSTILITIES (REAL OR PERCEIVED) BETWEEN INDIVIDUALS. THIS ISSUE TENDS TO RESIST RESOLUTION

SAFETY IMPACT

- VIOLATION OF CREWMAN'S VOLUME TENDS TO DEVELOP ANTAGONISMS THAT COULD ERUPT INTO EVENTUAL INTERCREW HOSTILITIES

APPROACH

- DEVISE MENSURATION METHODS THAT CAN DEFINE THE LIMITS OF ONE'S "SPHERE": 1. PROVIDE DESIGNERS WITH OPTIMUM DIMENSION, & 2. SCREEN OUT POTENTIAL STATION CREW PERSONNEL WHOSE SPHERE SIZE EXCEEDS THAT SELECTED FOR STATION DESIGN

ANTHROPOMETRICS

ISSUE

- PHYSICAL CAPABILITY TO HANDLE 5TH PERCENTILE FEMALE UP THROUGH 95TH PERCENTILE MALE IS DESIGN ISSUE
    - SOME OF THESE ISSUES WERE NOT READILY RESOLVABLE - WORK STATIONS LARGE ENOUGH ON ONE END OF THE SPECTRUM, YET SMALL ENOUGH FOR A 5TH PERCENTILE FEMALE TO REACH ALL CONTROLS & DISPLAYS

APPROACH

- ENSURE THAT CRITICAL & EMERGENCY CONTROLS & DISPLAYS ARE IN CORE REACH & SIGHT VOLUME

CRISIS MANAGEMENT

ISSUE

- ANNUNCIATING EVENTS FROM MANY STIMULI ARE COUNTERPRODUCTIVE
  - THE THREE MILE ISLAND INCIDENT MAY HAVE BEEN PRECIPITATED BY MULTIPLE ANNUNCIATIONS THAT CONFUSED THE OPERATORS
- SHUTTLE USES THREE-LEVEL SYSTEM
  - MASTER ALARM - HARDWIRED
  - C&W PANEL - HARDWIRED/REDUNDANCY MGT
  - BLUE LITE ALERT - SYSTEMS MANAGEMENT (SOFTWARE)
- B-1B USES ANNUNCIATION & A CENTRAL INTEGRATED TESTING SUBSYSTEM

SAFETY IMPACT

- SENSORY OVERLOAD IS PRECURSOR TO DISASTER

APPROACH

- CONTROLS & DISPLAYS SHOULD INCLUDE CONTINGENCY LEVEL INDICATORS, EDIT FUNCTIONS & MAINTENANCE ACTION READOUTS
- SCREEN FOR "UNFLAPPABLE" CREW

EMERGENCY PROCEDURES

ISSUES

- COMPLETE LOSS OF EQUIPMENT FUNCTIONS AND/OR PARTIAL DISABILITY
- REDUNDANT SYSTEMS
- NUMBER/TYPE WARNING SYSTEMS
- FIRE OR OTHER CATASTROPHIC INCIDENT
- LOSS OF PERSONNEL (DEATH) & INJURY
- EGRESS ROUTE & SAFE HAVEN
- ESCAPE & RESCUE

SAFETY IMPACT

- EMERGENCY PROCEDURE CUEING & IMPLEMENTING OVERLOAD IS RISK SITUATION

APPROACH

- ASSESS MAJOR ENVIRONMENTAL MANAGEMENT & LIFE SUPPORT SYSTEMS
- RECOMMEND REDUNDANCY WITHOUT "OVERKILL"
- IDENTIFY WARNING SYSTEMS - VISUAL & AUDIBLE
- DUAL EGRESS & SAFE HAVEN FOR EACH MODULE/CAPSULE
- PROPER PROCEDURES FOR DOCKING, EVA & INTERVEHICULAR ACTIVITIES
- ADEQUATE TRAINING OF PERSONNEL
- PORTABLE EMERGENCY EQUIPMENT

CLEANING/DISINFECTING

ISSUES:

- IDENTIFY PRIMARY & SECONDARY AREAS OF CLEANING
- GROUP BY PRIORITY, HEALTH & HYGIENE, GENERAL HOUSEKEEPING, HARDWARE, CLEAN ROOMS, ETC.
- MATERIALS & METHODS TO BE UTILIZED WITHOUT CREATING ADDITIONAL PROBLEMS
- ESTABLISH MAINTENANCE ITEMS & REGULARLY SCHEDULED ACTIVITIES
- WILL ALL CREW MEMBERS ROTATE TASKS TO PREVENT BOREDOM & CLASS DISTINCTION?

SAFETY IMPACT:

- PERSONNEL HEALTH EFFECTED BY REVITALIZED AIR SYSTEMS & CONTROL OF TOXICITY
- MORALE FACTORS DEPLETED BY ASSIGNMENTS TO SPECIFIED INDIVIDUALS
- CERTAIN LAB EXPERIMENTS MUST BE CONTROLLED TO PROTECT OTHER CREW MEMBERS
- PHYSICAL DEGRADATION DUE TO SLEEP DEPRIVATION BIOLOGICAL PROCESSES, WHICH ARE A RESULT OF ESTABLISHED ENVIRONMENTAL CONTROL METHODS
- GOOD DETERGENTS IMPACT ECLSS SYSTEM DESIGN (LiOH)

APPROACH:

- DETERMINE CLEANLINESS/DISINFECTANT LEVELS FOR ISOLATED & CONFINED LIVING/WORKING AREAS
- INVESTIGATE HIGH-TECH FILTRATION SYSTEMS TO CONTROL REVITALIZED AIR SYSTEMS
- MANDATE NO INDIVIDUAL "GRUNT" WORK, BUT SHARED CLEANING/MAINTENANCE ACTIVITIES
- INVESTIGATE ADDITIONS TO DIET AND/OR VITAMIN/MINERAL INTAKE TO "OFFSET" LOSSES IN REVITALIZED AIR

MISSION SCHEDULING

ISSUE:

- SCHEDULING CRITERIA MAY BE FORCED BY ECONOMIC (NUMBER OF SHUTTLE FLIGHTS), POLITICAL (INTERNATIONAL PARTICIPANTS), COSMIC (WINDOWS FOR EXPERIMENTS), & PERSONNEL PHYSIOLOGICAL/PSYCHOLOGICAL/Sociological ENDURANCE

SAFETY IMPACT:

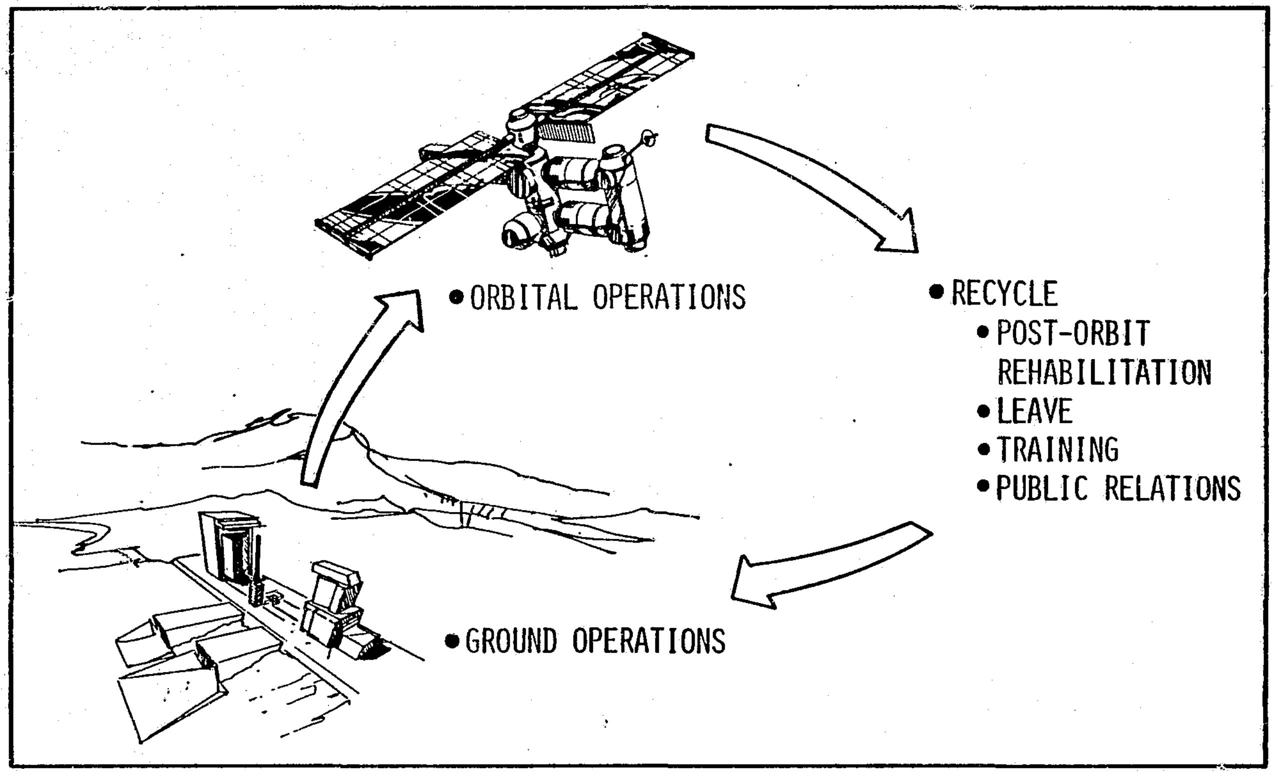
- CREW FATIGUE, ILLNESS, IRRITABILITY & TIME PRESSURES DRIVE PEOPLE TO MAKE ERRORS OR FUNCTION OUTSIDE OF EXPECTED PARAMETERS

APPROACH:

- SET UP INTEGRATED AIR-GROUND TEAMING
- CUT DOWN TOTAL PER-PERSON TIME ON ORBIT BUT APPLY EFFORT TO STATION MISSIONS
- MAKE RATIONAL ASSESSMENTS OF MAXIMUM ALLOWABLE TIME IN ORBIT RECOMMENDED PER YEAR (RADIATION, PHYSICAL DEBILITATION, PSYCHOLOGICAL ABERRATION)

WORK GROUP/SHIFT DYNAMICS

- USE "AGGREGATE" TEAM CONCEPT.

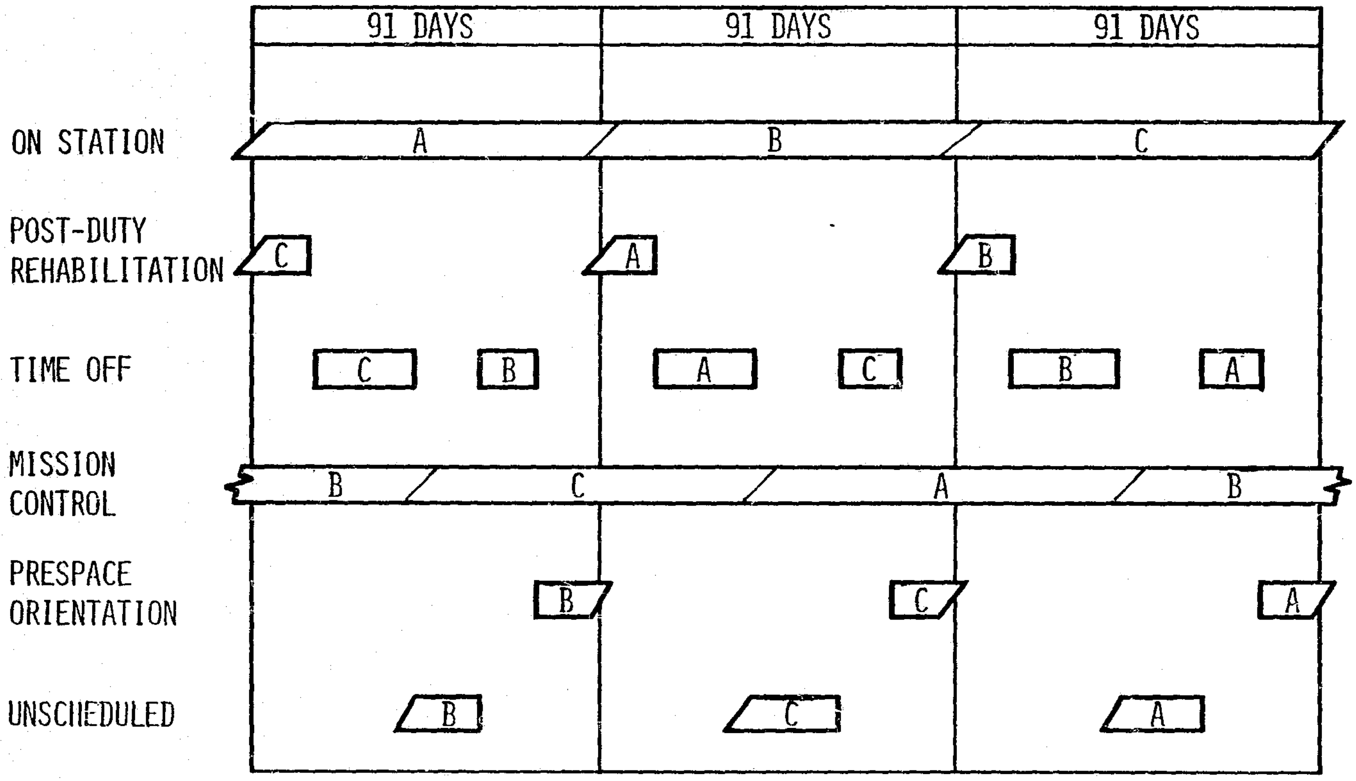


- ORBITAL OPERATIONS
- RECYCLE
  - POST-ORBIT REHABILITATION
  - LEAVE
  - TRAINING
  - PUBLIC RELATIONS
- GROUND OPERATIONS

- ONE THIRD OF TIME SPENT IN EACH MISSION SEGMENT

SPACE HABITAT SCHEDULING - PERSONNEL

THREE CREWS WOULD HANDLE ALL ASPECTS OF SPACE HABITAT



CREW CHANGEOVER

ISSUE:

- SPACE STATION IS SIZED FOR ONE CREW (8-16 PEOPLE). WHEN CREWS CHANGE OVER, WHERE WILL THE SECOND CREW BE & HOW LONG ON STATION?

SAFETY IMPACT:

- CONTINGENCY PLANNING MAY NOT BE ABLE TO HANDLE TWO CREWS

APPROACH:

- BEGIN CHANGEOVER ON GROUND
- MAINTAIN ORBITER AT STATION DURING CHANGEOVER
- PREPARE DETAIL PLAN FOR STATION CONTINGENCY OPERATIONS DURING CHANGEOVER

CROSS-TRAINING

ISSUE:

- EIGHT-MAN CREW TO HANDLE ALL SPACE STATION MAINTENANCE, OPERATIONS, USER SET-UP, MAINTENANCE & OPERATIONS REQUIRES BROAD, OVERLAPPING CAPABILITIES AMONG CREW

Required 5 crew members for EVA - 2/EVA; 1 piloting; 1/RMS; 1/Photos

SAFETY IMPACT:

- UNIQUE CRITICAL SKILLS ARE LIABILITIES IF CREWMEMBER BECOMES INCAPACITATED

APPROACH:

- SCREEN TOWARD GENERALISTS vs SPECIALISTS

- AUTOMATE, USING REDUNDANCY & SIMPLE MAINTENANCE REQUIREMENTS EQUIPMENT, EXPERIMENTS OR PRODUCTION LINES REQUIRING UNIQUE SKILLS

NOTE: APPROXIMATELY 50% OF SKYLAB CREW TIME WAS SPENT IN STATION UPKEEP, HOUSEKEEPING & REPAIR.

ACOUSTICAL IMPACTS

ISSUES:

- NOISE LEVELS FROM SPACECRAFT SYSTEMS/COMPONENTS
- PERSONNEL PHYSICAL & MENTAL EFFECTS
- BACKGROUND NOISE
- UHF NOISE
- CONTROLS, REDUCTION AND/OR ELIMINATION

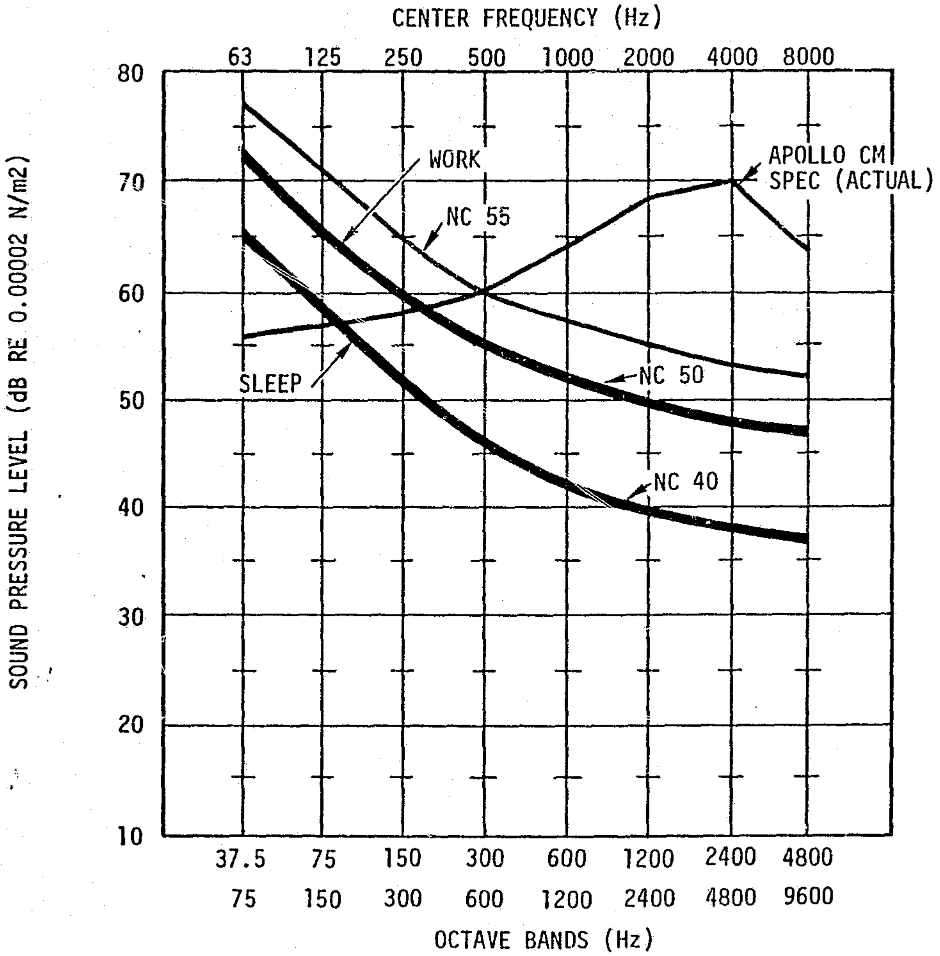
SAFETY IMPACTS:

- CREW FATIGUE, IRRITABILITY & INABILITY TO COMMUNICATE ARE RISK GENERATORS

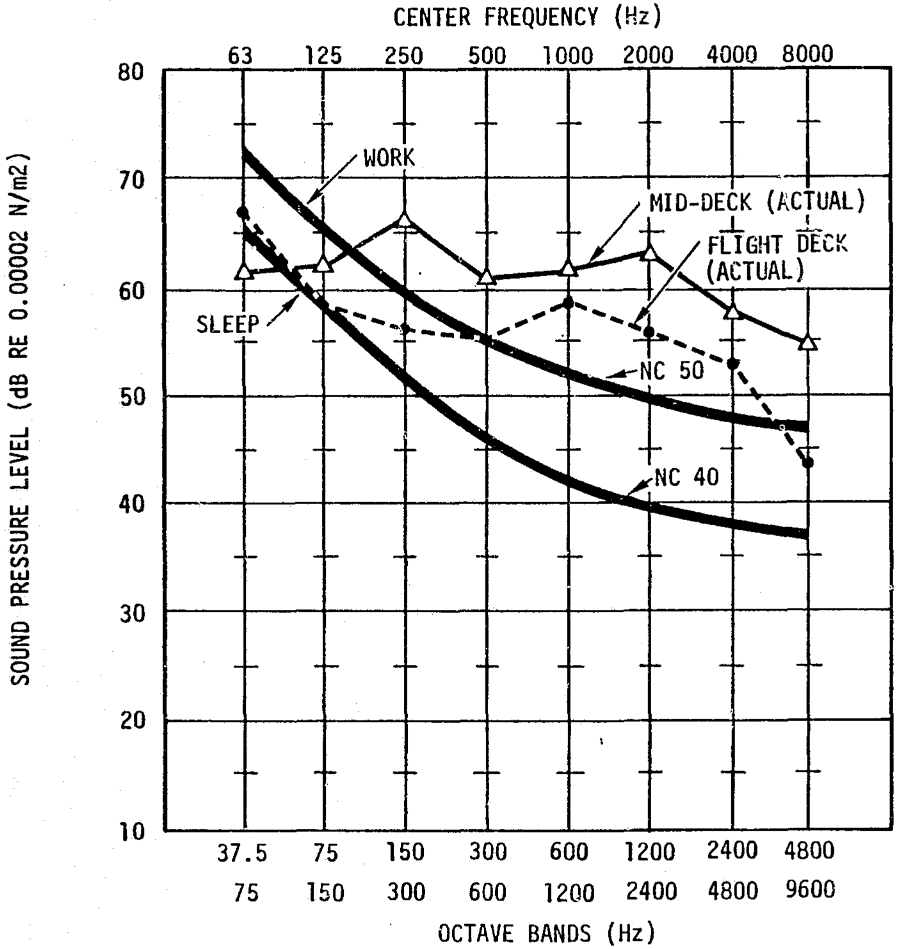
APPROACH:

- MEASURE & ASSESS ALL NOISE SOURCES FOR dB LEVEL & FREQUENCY
- INCLUDE INDIVIDUAL & ACCUMULATED NOISE
- INVESTIGATE CRITICAL AREAS OF SLEEP STATIONS & WORK AREA COMMUNICATION
- UHF MAY REQUIRE DETERMINATION FOR PHYSICAL & PSYCHOLOGICAL EFFECTS
- SLEEP AREAS SHOULD NOT BE COMPLETELY SILENT
- ADEQUATE COMMUNICATIONS MAY REQUIRE LIGHTWEIGHT HEADSETS
- SCREEN CANDIDATES FOR LOW NOISE SENSITIVITY

APOLLO ACOUSTICS



SHUTTLE ACOUSTICS



ON-ORBIT ACOUSTIC NOISE

- ALL ORBITAL VEHICLES HAVE EXPERIENCED SOME FORM OF ACOUSTIC NOISE PROBLEMS
- PREVIOUS VEHICLE NOISE PROBLEMS HAVE BEEN COMPLEX & USUALLY RESULTED IN "TRADE-OFFS" & COMPROMISES INVOLVING:
  - SPECIFICATION REQUIREMENTS RELAXATION
  - ADDED DEVELOPMENT COSTS
  - WEIGHT PENALTIES
  - SCHEDULE IMPACTS
- CONCLUSIONS/RECOMMENDATIONS
  - OPERATIONS SHOULD CONSIDER THE LIMITS NOTED IN CHARTS
  - ATTAIN A REASONABLY QUIET SPACE STATION
  - IMPOSE NECESSARY DESIGN REQUIREMENTS & SPECIFICATIONS DURING INITIAL PHASE OF PROGRAM FOR BOTH PRIMARY & SUBCONTRACTORS
  - INVESTIGATE & UTILIZE THE LATEST TECHNOLOGY IN ATTENUATION FOR ACOUSTIC DESIGN & MATERIALS

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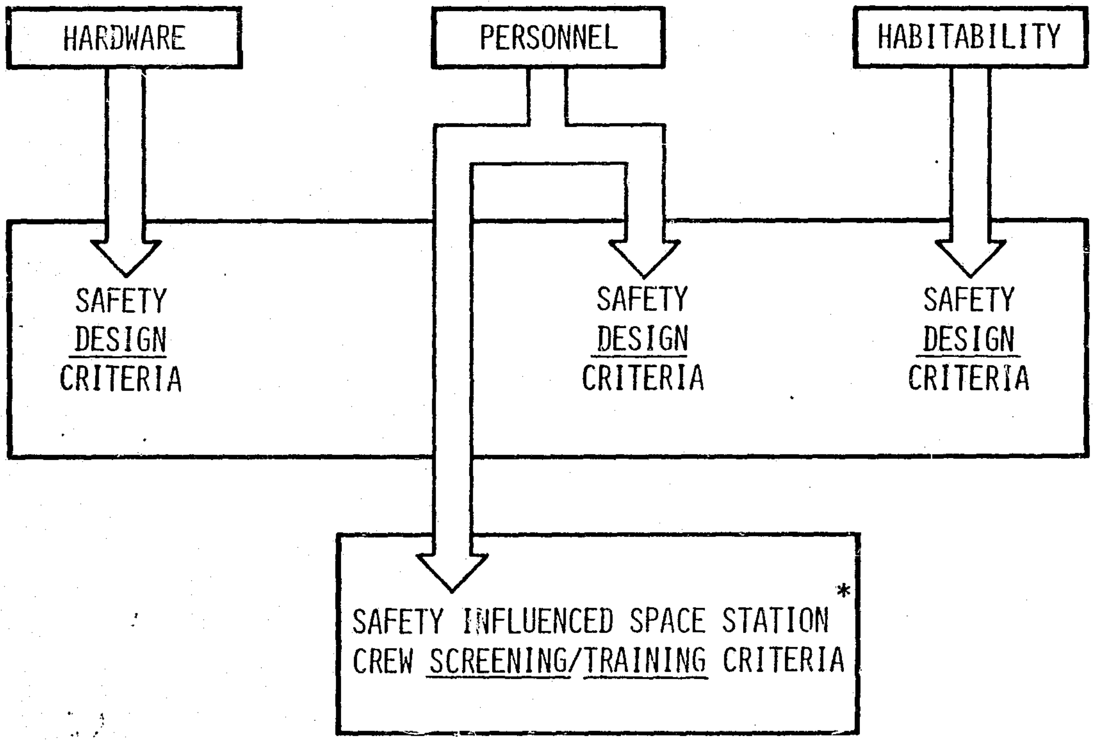
INITIAL HUMAN FACTORS ASSESSMENTS
SAFETY CRITERIA DEVELOPMENT



HARDWARE

PERSONNEL

HABITABILITY

SAFETY
DESIGN
CRITERIA

SAFETY
DESIGN
CRITERIA

SAFETY
DESIGN
CRITERIA

SAFETY INFLUENCED SPACE STATION CREW SCREENING/TRAINING CRITERIA*

*HOW IS THIS INCORPORATED INTO SPACE STATION DEVELOPMENT

CREW SAFETY CRITERIA
SUMMARY

CATEGORIES RELATING TO:	
• DAMAGE TOLERANCE	12
• CREW PROTECTION	27
• STATION INTEGRITY	11
• CONTINGENCY CONTROL	8
NEW CRITERIA	
• STATION INTEGRITY	4
• SELECTION/INDOCTRINATION (NEW HUMAN FACTORS CATEGORY)	5
TOTAL	67

NEW CRITERIA

STATION INTEGRITY

C-13 PROVISIONS SHALL BE MADE FOR INFLIGHT SERVICING, ADJUSTING, CLEANING, REMOVAL & REPLACEMENT OF OFFENDING COMPONENTS, & TESTING & REPAIRING OF ALL CRITICAL SUBSYSTEMS

C-14 WEAR ITEMS SHOULD BE LIFE-CYCLE TESTED IN A REALISTIC ENVIRONMENT

C-15 ALL PERSONNEL ITEMS SHOULD BE SCREENED FOR FLAMMABILITY & TOXICITY

C-12 SPACE STATION MODULES SHOULD BE TUMBLED TO RID THEM OF INTERNAL DEBRIS & CONTAMINANTS IMMEDIATELY PRIOR TO PREPARATION FOR LAUNCH

NEW CATEGORY OF CRITERIA
SELECTION/INDOCTRINATION

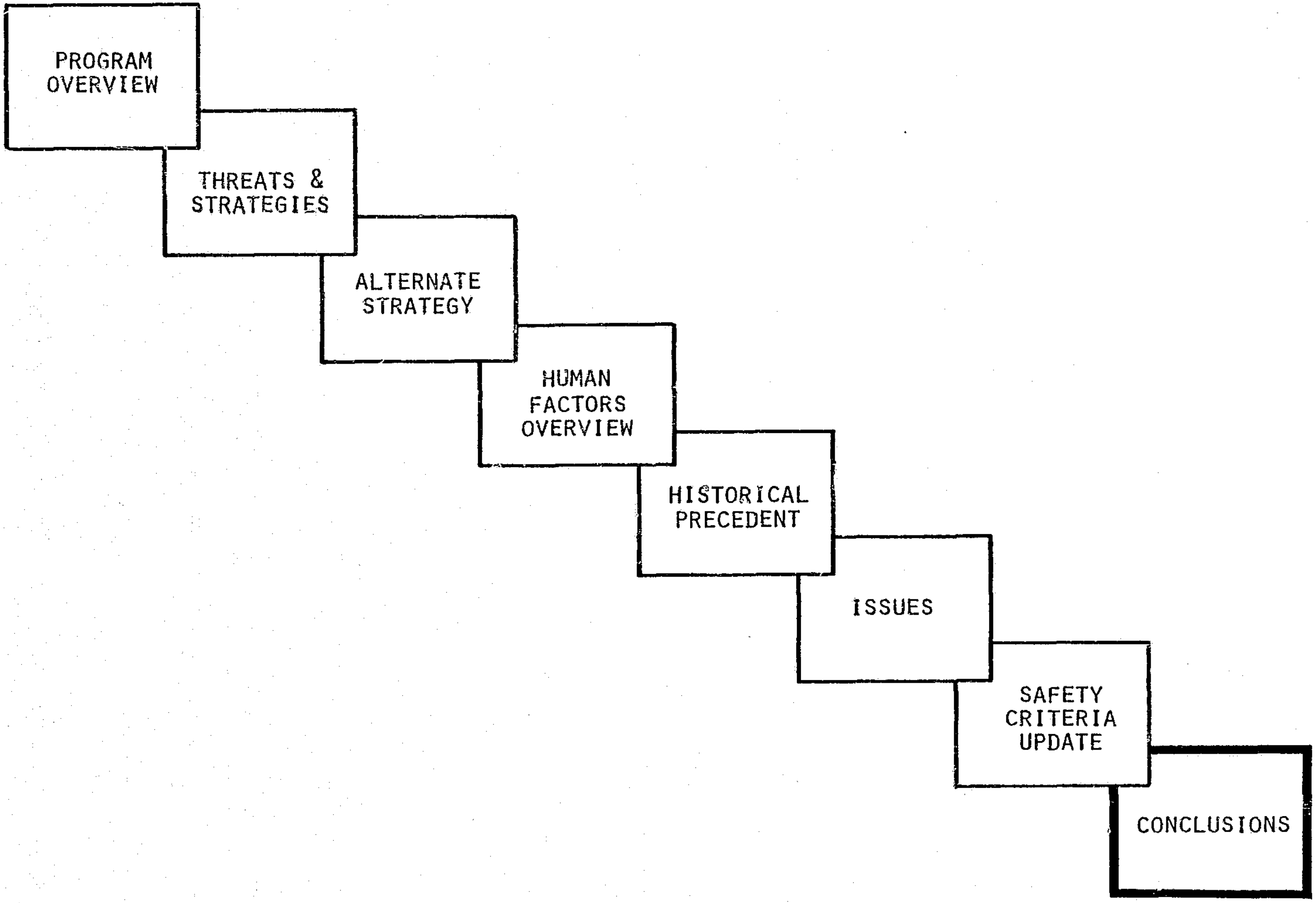
E-1 CREW SELECTION SHOULD BE BASED ON SELECTEES' CROSS-TRAINABILITY IN FIELDS OTHER THAN SPECIALTY

E-2 ORBITAL CREW SHOULD BE AN INTEGRAL PART OF THE AIR/GROUND SYSTEM ACTIVE INTERFACE WITH ON-ORBIT CREWS

E-3 STATION CREWS & TEAMING SHOULD ALLOW EQUAL THIRDS OF SCHEDULE FOR ON-ORBIT, GROUND INTERFACE OPERATIONS & RECYCLE OPERATIONS (POST-ORBIT REHABILITATION, LEAVE, ADDITIONAL TRAINING, PUBLIC RELATIONS, ETC.)

E-4 ASSURANCE SHOULD BE PROVIDED THAT EACH MISSION SEGMENT CREW IS FAMILIAR WITH: 1. STATION OPERATIONS & MAINTENANCE AS CONCERNS CRITICAL SUBSYSTEMS, & 2. PROCEDURES NECESSARY TO RENDER "SAFE" ALL EXPERIMENTS AND/OR USER PROCESSES

E-5 SCREENING CRITERIA SHOULD INCLUDE ASSESSMENT OF ATTITUDES, PHYSICAL NEEDS, PSYCHOLOGICAL NEEDS, PERSONALITY TRAITS, ABILITY TO FUNCTION UNDER STRESS, ABILITY TO ACCEPT DIRECTION, & TBD



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CONCLUSION - HUMAN FACTORS

- 48 AREAS OF IMPACT IDENTIFIED
- SAFETY CRITERIA THAT ARE NOT DESIGN CRITERIA MAY BE DIFFICULT TO INCORPORATE IN SPACE STATION PROGRAM
    - TERRITORIAL ISSUES
    - HUMAN FACTORS ISSUES THAT IMPACT MISSION OPERATIONS
    - CREW SELECTION AND SUPPORT
    - CREW TRAINING
- SPACE STATION HUMAN FACTORS AGGREGATES THE MOST SEVERE PERSONNEL STRESSORS OF ISOLATED, CONFINED ENVIRONMENTS, INCLUDING CURRENT SPACE ACTIVITIES
- EIGHT AREAS WILL BE REVIEWED IN THIS STUDY, BASED ON CONFIGURATION IMPACT IMPLICATIONS

TUESDAY

INTERNAL CONTAMINATION SESSION

by Judith Queller

Introduction

Two days of the Human Productivity meeting were devoted to presentations on and discussions of internal contamination. Internal contamination had been identified by the Program Review Committee as a potential problem requiring careful attention. It was therefore given special attention so that the various options could be discerned. On the one hand, strict control of onboard materials would simplify the problem but would represent a significant burden to the customer, both in terms of time and money. On the other hand, a more liberal policy on materials would directly benefit the customer but would necessitate better contaminant detection and removal inside the Space Station. The various issues and trades therefore needed to be defined and explored. Presentations during the two days of the Internal Contamination meeting covered an overview of internal contamination issues and concerns, past experiences including Shuttle and nuclear submarines, approaches to contamination detection and control, and discussion of the more promising approaches we might pursue.

Space Station presents us with unique conditions which permit us to rely on analogs and experiences only in a limited fashion. This is because of three sets of special circumstances. First, crew members will be subject to continuous 24-hour exposures. Therefore, 8-hour industrial threshold limit values may not be applicable. Second, the system will not be periodically refurbished (i.e. purged, ground processed). Third, we will have hazardous operations and materials which we have not previously encountered. These unique conditions require specific actions on our part. Therefore, there are basically five major areas in which we have task requirements.

1. Potential contaminants need to be identified i.e. both the sources and types of contaminants.
2. The scope and magnitude of contaminant effects need to be determined i.e. toxicological effects, microbacteriological effects and impurities.
3. Mathematical models for predictive methods need to be developed.
4. State-of-the-art and advanced technologies for monitoring contaminants and for methods of decontamination need to be identified.
5. Automated monitoring and control systems need to be designed.

Fulfilling these requirements helps us to formulate solutions for the potential internal contamination problems which face us. These solutions include the prevention of contamination, the monitoring of contaminants and the active control of contaminants.

The trace contaminant technology base is relatively firm. Mass spectrometry can be used for compound identification and gas chromotography for quantification. The hardware and design tools are available and the previous design philosophy of a conservative load model which is refined as actual data become available, is still applicable. This is true for particulate, atmospheric and bacteriological contamination.

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SPACE STATION
HUMAN PRODUCTIVITY WORKING GROUP
CONTAMINATION

BIOMEDICAL OFFICE

FEBRUARY 28, 1984

DEFINITION: CONTAMINANT → CONTAMINATE

REFERS TO THAT WHICH ON COMING INTO CONTACT WITH SOMETHING WILL MAKE IT IMPURE, UNCLEAN, OR UNFIT FOR USE; TO POLLUTE, SOIL, DECAY, INFECT, OR CORRUPT; TO **COMPROMISE** OR ADVERSELY AFFECT **BEING** AND **FUNCTION** WITH UNDESIRABLE ELEMENTS.

THIS IMPLIES THAT AN ORIGINAL CONDITION PRECEDES CONTAMINATION -- APPLICABLE TO INTENDED **SPACE STATION DESIGN**.

BASIC COMPONENTS IN CONTAMINATION:

A. **THAT WHICH IS CONTAMINATED**

- HUMAN CREW - PREEMINENTLY
- OTHER LIFE FORMS
- EQUIPMENT AND SYSTEMS ONBOARD
- PROCESSES AND ACTIVITIES

B. **CONTAMINANTS (FACTORS)**

- TYPES AND SOURCES
- EFFECTS AND CONSEQUENCES
- ASSESSMENT AND QUANTIFICATION
- CONTROL AND DECONTAMINATION

N.B.: AS IN THE HUMAN CASE, MANY ELEMENTS CAN BE EITHER OBJECT OR SOURCE OF CONTAMINATION!

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SPACE STATION
HUMAN PRODUCTIVITY WORKING GROUP
CONTAMINATION

BIOMEDICAL OFFICE
FEBRUARY 28, 1984

THE PROBLEM

THE "NEW WORLD" REVISITED

- GROWING POPULATION IN ORIGINALLY PRISTINE ENVIRONMENT
- LIMITED BASIC RESOURCES
- INCREASING AMOUNTS OF WASTE/DEBRIS INTO A FINITE CONTAINMENT
- BYPRODUCTS AND EFFLUENTS OF INDUSTRIALIZATION
- MICROBIAL THEORY REASONABLY WELL UNDERSTOOD AND OPERATIVE
- EXOTIC AND UNEXPECTED INPUTS (E.G. NUCLEAR WASTES, BIZARRE REACTIONS)
- INCOMPATIBILITIES OF VARIED INTEREST GROUPS
- MENTAL AND PSYCHIC OVERLOAD

N.B.: PROGRESS OF THESE CONTAMINATING EVENTS IN A MICROCOSM WILL FOLLOW A GREATLY **COMPRESSED TIME SCALE** WITH **LIMITED BUFFER CAPACITY**

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HUMAN PRODUCTIVITY WORKING GROUP
CONTAMINATION

BIOMEDICAL OFFICE

FEBRUARY 28, 1984

PURPOSE - TASKS

- RECOGNIZE AND EVALUATE THE PROBLEM(S) - **DESIGN SPACE STATION** ACCORDINGLY
  - IDENTIFY POTENTIAL CONTAMINANTS - SOURCES AND TYPES
  - DETERMINE SCOPE AND MAGNITUDE OF CONTAMINATION EFFECTS: TOXICOLOGICAL, MICROBIOLOGICAL, IMPURITIES
  - DEVELOP MATHEMATICAL MODELS FOR PREDICTIVE METHODS
  - IDENTIFY STATE-OF-THE-ART AND ADVANCED TECHNOLOGIES NEEDED FOR MONITORING CONTAMINANTS AND FOR DECONTAMINATION
  - DESIGN AUTOMATED MONITORING AND CONTROL SYSTEMS - LINKED TO TOX DATABASE AND MATH MODELS
  - DETERMINE OPTIMAL MEANS FOR MANAGING CONTAMINATION AND DESIGN AS INDICATED - A GLOBAL ISSUE
  - ESTABLISH ESSENTIAL BACK-UP PROVISIONS AS AUXILIARY MEDICAL DATABASE TO ASSIST RAPID DELIVERY OF APPROPRIATE MEDICAL CARE

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SOURCES AND TYPES OF CONTAMINANTS:

- FUELS AND MECHANICAL SYSTEMS
- PAYLOADS/EXPERIMENTS
- HUMAN CREWMEMBERS
- NON-HUMAN BIOLOGICALS
- MATERIALS
- ENERGIES

- CHEMICALS
- GASES
- PARTICULATES
- AEROSOLS
- MICROBIOLOGICALS
- ELECTROMAGNETIC RADIATION
- IONIZING RADIATION
- THERMAL ENERGY
- MECHANICAL ENERGY

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HUMAN TOXICOLOGIC DATA BASE

- MAJORITY OF CONCERNS FOR HUMAN CREWS
- UNIQUE **SPACE STATION** CONDITIONS
  - CONTINUOUS 24-HOUR EXPOSURE (8-HOUR TLV'S NOT APPLICABLE)
  - SYSTEM NOT PERIODICALLY REFURBISHED (PURGED, GROUND PROCESSED)
  - HAZARDOUS OPERATIONS/MATERIALS NOT PREVIOUSLY ENCOUNTERED
- LIKELIEST PROBLEMS, ORGAN SYSTEMS AFFECTED, CONSEQUENCES
- INTERRELATION WITH MEDICAL CARE SYSTEM

MICROBIOLOGICAL POTENTIAL PATHOGENS

SYSTEMS MALFUNCTION

- LIFE SUPPORT SYSTEM (ANOMALOUS, OVERLOAD)
- OPTICAL SURFACES, ELECTRONICS
- MATERIALS PROCESSING
- HOUSEKEEPING

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QUANTIFICATION OF CONTAMINANTS

- KNOWN
  - HUMAN OUTPUTS
    - RESPIRATORY
    - SKIN
    - URINARY
    - GASTROINTESTINAL
  - OTHER LIVING COMPONENTS
  - FOOD PRODUCTS, PROCESSING BYPRODUCTS
  - ONBOARD MATERIALS
  - MICROBIOLOGICALS

- LESS WELL DOCUMENTED
  - MATERIALS PROCESSING
  - MICROBIOLOGICALS - MUTANTS, VARIANTS
  - EXOTIC PHYSICO-CHEMICAL REACTIONS
  - ONBOARD INCIDENTS (I.E., SPILL, FIRE)

- PREDICTIVE MODELLING
  - REQUIRES CONTINUOUSLY UPDATED DATABASE

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SOLUTIONS:

- PREVENTION

- MONITORING
  - TECHNOLOGIES, SENSORS, ANALYZERS; DISTRIBUTION, FREQUENCY
  - DATA INTERPRETATION, DECISION
  - RESPONSE ACTUATORS

- ACTION/CONTROL
  - ALARMS
  - REDUCTION, ELIMINATION
    DECREASE INPUT, INCREASE FILTRATION/SCRUBBING, PURGE
  - ISOLATION, SHIELDING, PROTECTIVE DEVICES
  - RETREAT (SAFE HAVEN)
  - MEDICAL TREATMENT (OR SYSTEMS' EQUIVALENT)

- AUTOMATION
  MINIMIZE HUMAN REQUIREMENTS FOR CONTAMINATION CONTROL, DECONTAMINATION

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HISTORICAL LESSONS

- ALL SPACE CRAFT EXPERIENCE TO DATE
  - EMPHASIS ON LONGER DURATION
  - ATTENTION TO MORE SERIOUS/POTENTIAL PROBLEMS (E.G., HYPERGOLS, WASTE MANAGEMENT)
- SUBMARINES
- MINING
- METALLURGICAL INDUSTRIES
- CLEAN ROOMS
- MEDICAL ISOLATION
- MICROBIOLOGICAL RESEARCH AND MANUFACTURING
- EXTREME ENVIRONMENTS (E.G., BAROMETRIC PRESSURE, TEMPERATURE, HUMIDITY)

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TECHNOLOGIES REQUIRED:

INTEGRAL TO ALL OF **SPACE STATION**; COMPELLING FOR **ECLSS** AND **LOGISTICS** MODULE

- DETERMINE BEST MEANS (OR OPTIONS) FOR HANDLING EACH CASE
- IDENTIFY STATE-OF-THE-ART AND NEW TECHNOLOGIES TO IMPLEMENT
- GROUND TEST/MATH MODEL TO OPTIMIZE CONTROL
- DESIGN CONTROL AND MONITORING SYSTEMS TO MAXIMIZE AUTOMATION
- FLIGHT TEST COMPONENTS/SUBSYSTEMS WHERE FEASIBLE
- DETERMINE DEGREE OF SYSTEM CENTRALIZATION VERSUS MODULAR INDEPENDENCE
- ASSURE CAPABILITY TO UPGRADE SPACE STATION SYSTEMS

N.B.: SIZE, MASS, SPACE, COST WILL NECESSARILY CONSTRAIN TECHNOLOGIES

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FEBRUARY 28, 1984

MAJOR AGENCY **DECISIONS** FOR THE **CONTAMINATION** ISSUE

- MISSIONS AND OBJECTIVES OF SPACE STATION
- CENTRAL VERSUS DISTRIBUTIVE/MODULAR SYSTEM
- ESTABLISHMENT OF APPLICABLE TOXIC EXPOSURE TOLERANCES
- LEVEL OF AUTOMATION VERSUS HUMAN RESPONSIBILITY
- ELEMENTS AND DEGREE OF SYSTEMS CLOSURE
- WHEN TO FREEZE TECHNOLOGIES

INTERNAL CONTAMINATION ISSUES

L. ROCKOFF
2-28-84
IL #294-400-84-078

CONTAMINATION

EXTERNAL ISSUES

- WINDOWS
- MATERIAL DEGRADATION DUE TO MOLECULAR OXYGEN EXPOSURE
- HYPERGOLICS AND OTHER REACTANTS

INTERNAL ISSUES

- ✓ PARTICULATE
- ✓ ATMOSPHERIC
- BIOLOGICAL (BACTERIOLICAL)

✓ DISCUSSED IN THIS SESSION

INTERNAL ATMOSPHERIC CONTAMINATION

Contaminants Found in Shuttle Orbiter
Atmospheric Samples

Compound Identity	STS MISSION NUMBER														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Acetic Acid, n-Butyl Ester	X								X						
Acetic Acid, 2-Ethoxyethlyester	X														
Acetic Acid, Ethyl Ester						X	X								
C_4 Alkene						X									
Benzaldehyde		X													
Benzene	X	X	X		X	X									
Bromotrifluoromethane			X	X											
1-Butanal	X	X	X												
1-Butanol	X	X							X						
2-Butanone	X	X	X		X	X			X						
Butene					X										
n-Butylbenzene	X														
Carbon Dioxide							X								
Carbon Disulfide		X													
Carbon Monoxide	X	X	X		X	X	X	X	X						
Cyclohexane		X													
Decane		X													
Dichlorodifluoromethane				X											
1,1-Dichlorethene		X													
Dichloromethane	X	X	X		X	X	X		X						
1,2-Dimethylbenzene	X	X	X			X			X						
1,3-Dimethylbenzene	X	X	X		X	X	X		X						
1,4-Dimethylbenzene	X				X				X						
1,1-Dimethylethanol	X														
Ethanal	X	X	X		X	X	X		X						
Ethanol	X	X	X	X	X	X	X		X						
Ethylbenzene	X	X	X			X			X						
2-Ethylhexanal		X													
Ethyl 2-Propenyl Ether						X									
1-Heptanal	X														
Heptane		X	X												
2-Heptanone	X														
3-Heptanone	X														
Hexamethylcyclopentane		X													
Hexamethylcyclotrisiloxane	X					X			X						
1-Hexanal	X								X						
Hexane	X	X													

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Compound Identity	STS MISSION NUMBER														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Hydrogen							X								
Indan		X													
C_7 Ketone						X									
Methane	X	X	X	X	X		X	X	X						
Methanol	X	X													
2-Methyl-1,3-Butadiene	X														
Methylcyclopentane	X	X				X									
Methylethylcyclopentane			X												
6-Methyl-2-Heptanone		X													
2-Methylpentane		X													
2-Methyl-1-Propanol		X													
2-Methyl-2-Propanol		X	X			X									
4-Methyl-2-Propantanone	X		X												
Napthalene		X													
Nonane		X													
Octane		X													
1-Pentanal	X	X	X												
Pentane		X	X						X						
1-Propanal	X	X	X			X			X						
1-Propanol						X									
2-Propanol	X		X		X	X			X						
2-Propanone	X	X	X	X	X	X	X	X	X						
Prophylbenzene	X	X													
Toluene	X	X	X		X	X	X		X						
1,1,1-Trichloroethane	X	X	X			X	X	X	X						
Trichloroethene		X	X				X	X							
Triochlorofluoromethane	X	X	X				X		X						
1,1,2-Trichloro-1,2,2-Triflourethane	X	X	X	X	X	X	X	X	X						
Trimethyl Silanol		X													
C_7-Aliphatic Hydrocarbons (1)*		X													
C_8-Aliphatic Hydrocarbons (7)		X													
C_9-Aliphatic Hydrocarbons (9)		X													
C_{10}-Aliphatic Hydrocarbons (8)		X													
C_{11}-Aliphatic Hydrocarbons (8)		X													
C_{12}-Aliphatic Hydrocarbons (8)		X													
C_{13}-Aliphatic Hydrocarbons (1)		X					X								
C_{14}-Aliphatic Hydrocarbons (13)		X													

Compound Identity	STS MISSION NUMBER														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
C_8-Alkane (1)				X											
C_9-Alkane (5)				X		X									
C_{10}-Alkane (6)	X		X												
C_{11}-Alkane (5)	X		X												
C_{12}-Alkane (4)	X		X												
C_8-Olefinic Hydrocarbon (1)		X													
C_9-Olefinic Hydrocarbon (2)		X													
Silocone MN = 236									X						
Siloxane (3)					X										
Octamethylcyclotetrasiloxane						X			X						
C_3-Substituted Benzene (11)	X														
C_4-Substituted Benzene (6)	X														

PRESENT SYSTEM:

- o WHOLE GAS SAMPLES
  - o THREE TIMES DURING MISSION THE CYLINDER VALVE IS OPENED TO PERMIT THE INFLOW OF CABIN ATMOSPHERE INTO THE EVACUATED CYLINDER.
  - o THE SAMPLE IS TRAPPED UPON CLOSING THE CYLINDER VALVE.
  - o TOXICOLOGY LABORATORY PERFORMS ANALYSES AFTER THE FLIGHT.
- o GAS CHROMATOGRAPHY
  - o MASS SPECTROMETRY FOR COMPOUND IDENTIFICATION
  - o GAS CHROMATOGRAPHY FOR QUANTIFICATION.

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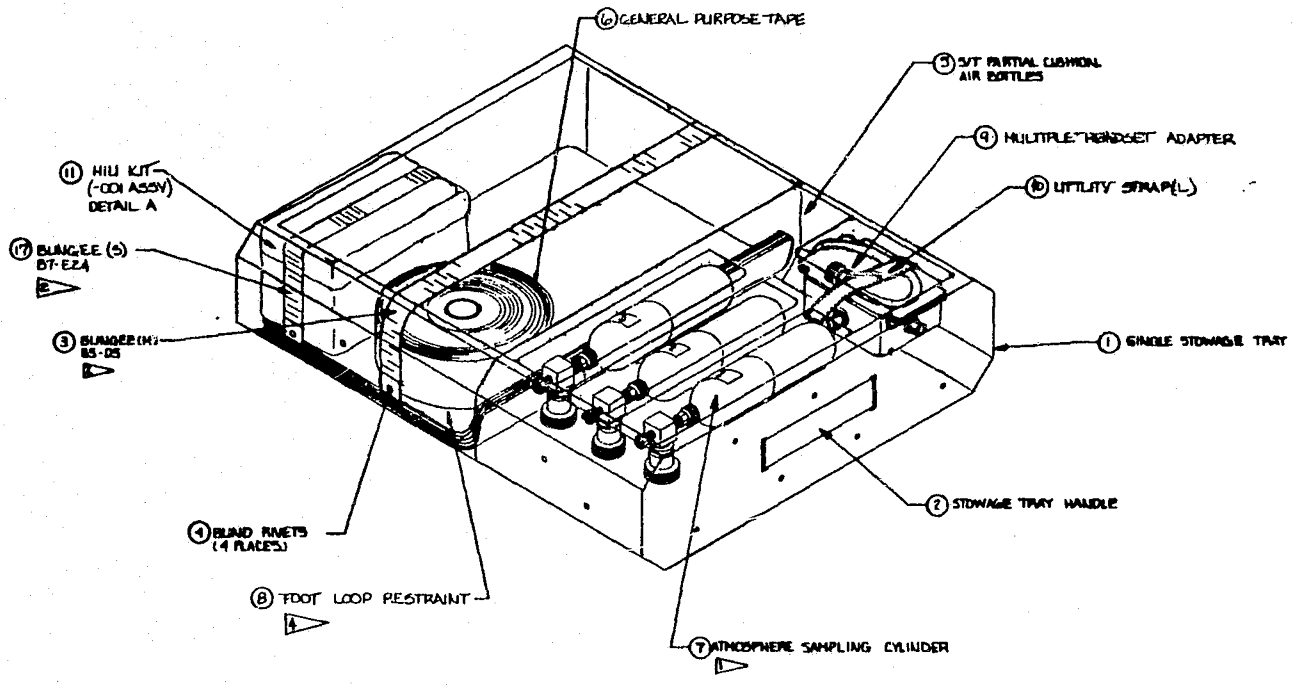

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STS-2

- SYSTEMIC POISONS EXCEEDED LIMIT BY 1.22 TIMES (MAJOR CONSTITUENT TOLUENE)
- FOUR SAMPLE BOTTLE, TENAX ABSORBER, AND CHARCOAL SAMPLE ANALYSES USED FOR EVALUATION.
- SOURCE OF TOLUENE INTRODUCED DURING GROUND OPS.

PHYSIOLOGICAL EFFECTS GROUP	SPACECRAFT MAXIMUM ALLOWABLE CONCENTRATION (SMAC) PERCENT
IRRITANTS	11.3%
CNS DEPRESSANTS	22.2%
SYSTEMIC POISONS	122.3% *
ASPHYXIANTS	6.6%

STS-3

- ANALYSIS OF 4 BOTTLES AND CHARCOAL SAMPLES SHOWED METHANE AND HALON 1301.
- FIRE SUPPRESSION HALON BOTTLE RELEASED BEFORE ENTRY PER FLIGHT RULE (SMOKE DETECTOR FAILURE).
- LEVEL WOULD EXCEED SMAC - FLIGHT RULE CHANGE TO USE OXYGEN MASK EACH TIME BOTTLE FIRED.

STS-4

- ONLY ONE BOTTLE - INADEQUATE FOR ASSESSMENT
- FIRST USE OF ATCO (AMBIENT TEMP CATALYTIC OXIDIZER)
- 100% CHARCOAL USED IN A CANISTER FOR SCRUBBING
- FREON 12 INTRODUCED WITH FIRST USE OF VPC (VAPOR PHASE COMPRESSION) FREEZER.
- BALLOONING OF INSULATION BLANKET OCCURRED.
- ODOR NOTED WHEN AIRLOCK OPENED. (UNKNOWN)
- ANALYSIS OF THE ONE SAMPLE BOTTLE SHOWED: FREON 12, HALON 1301, FREON 113 (TF), METHANE.

STS-5

- INCREASE IN CREW SIZE TO 4
- ODOR AGAIN NOTED WHEN AIRLOCK OPENED (UNKNOWN)
- ODOR NOTICED NEAR ONE OF THE LOCKERS (UNKNOWN)

STS-6

- CREW SIZE OF 4
- CREW REPORTED THAT THEY WERE SUBJECTED TO HEADACHES DURING THE FLIGHT
- AIR SAMPLES #3 AND #4 WERE COLLECTED AT THE SAME TIME
- CREW REPORTED AN ODOR NEAR THE MLR
    - CREW TURNED OFF MLR EXPERIMENT
    - POST LANDING, THE ODOR WAS TRACED TO A BURNT WIRE INSULATION FROM A SHORT IN A WIRE HARNESS IN THE HUMIDITY SEPARATOR.
- DUE TO BURNT WIRE, CHARCOAL "SCRUBBERS" ARE BEING ANALYZED FOR POSSIBLE DECOMPOSITION PRODUCTS.

STS-7

- o CABIN PRESSURE CHANGE FROM 14.7 TO 10.2 PSI AND OXYGEN CONTENT INCREASED FROM 20.9% TO 26 TO 28%. MATERIALS WERE NOT CERTIFIED AT THE HIGHER O2 CONTENT.
- o INCREASE IN CREW SIZE TO 5
- o NO SAMPLES TAKEN WHEN CABIN WAS AT 10.2 PSI.

CONCERNS:

- INSUFFICIENT SAMPLE BOTTLES TO PROVIDE THE NECESSARY DATA TO MAKE AN ADEQUATE ASSESSMENT OF THE CABIN ATMOSPHERE THROUGHOUT THE MISSION.
- USE OF SAMPLE BOTTLES FOR QUALIFICATION/VERIFICATION FOR NEW EQUIPMENT OR CHANGES IN OPERATING CONDITIONS.
- IF THE CREW CAPABILITY WERE TO BE DEGRADED (PHYSICALLY OR MENTALLY DURING THE FLIGHT) ADEQUATE POST FLIGHT DATA WOULD NOT BE AVAILABLE TO MAKE AN ASSESSMENT OF THE CAUSE AND INITIATION OF CORRECTIVE ACTION WOULD BE DIFFICULT.
- NO CONTROL ON CARRY-ON ITEMS. FIRST EXPOSURE TO CABIN ENVIRONMENT IS DURING FLIGHT WITHOUT PRIOR EVALUATION OR REAL TIME MONITORING.
- HALON 1301 LEAK/DISCHARGE COULD EXCEED SMAC LEVEL UNRECOGNIZED.
- SYNERGISTIC EFFECTS OF CABIN CONTENTS IS UNKNOWN.
- ABUSE OF LiOH CANNISTERS MAY CREATE A SINGLE POINT FAILURE, WHICH COULD RELEASE CORROSIVE/TOXIC MATERIAL.
- UNDER CURRENT SITUATIONS, MISSIONS MUST BE ABORTED IF THE DONNING OF MASKS IS REQUIRED.

CONCERNS: CONT'D

- o CABIN ATMOSPHERE CANNOT READILY BE ALTERED. CANNOT VENT TO VACUUM.
- o SPACELAB DATA - TBD

MATERIALS AND PROCESSES CONTROL
FOR
SPACE APPLICATIONS

G. A. BLACKBURN

- CONTAMINATION CONTROL IS AN INTEGRAL PART OF GOOD MATERIALS AND PROCESSES CONTROL.

- IT IS ESSENTIAL THAT MATERIALS AND PROCESSES ENGINEERING BE CONSIDERED A "TOTAL CONTROL" ELEMENT OF ANY MANNED AEROSPACE PROGRAM.

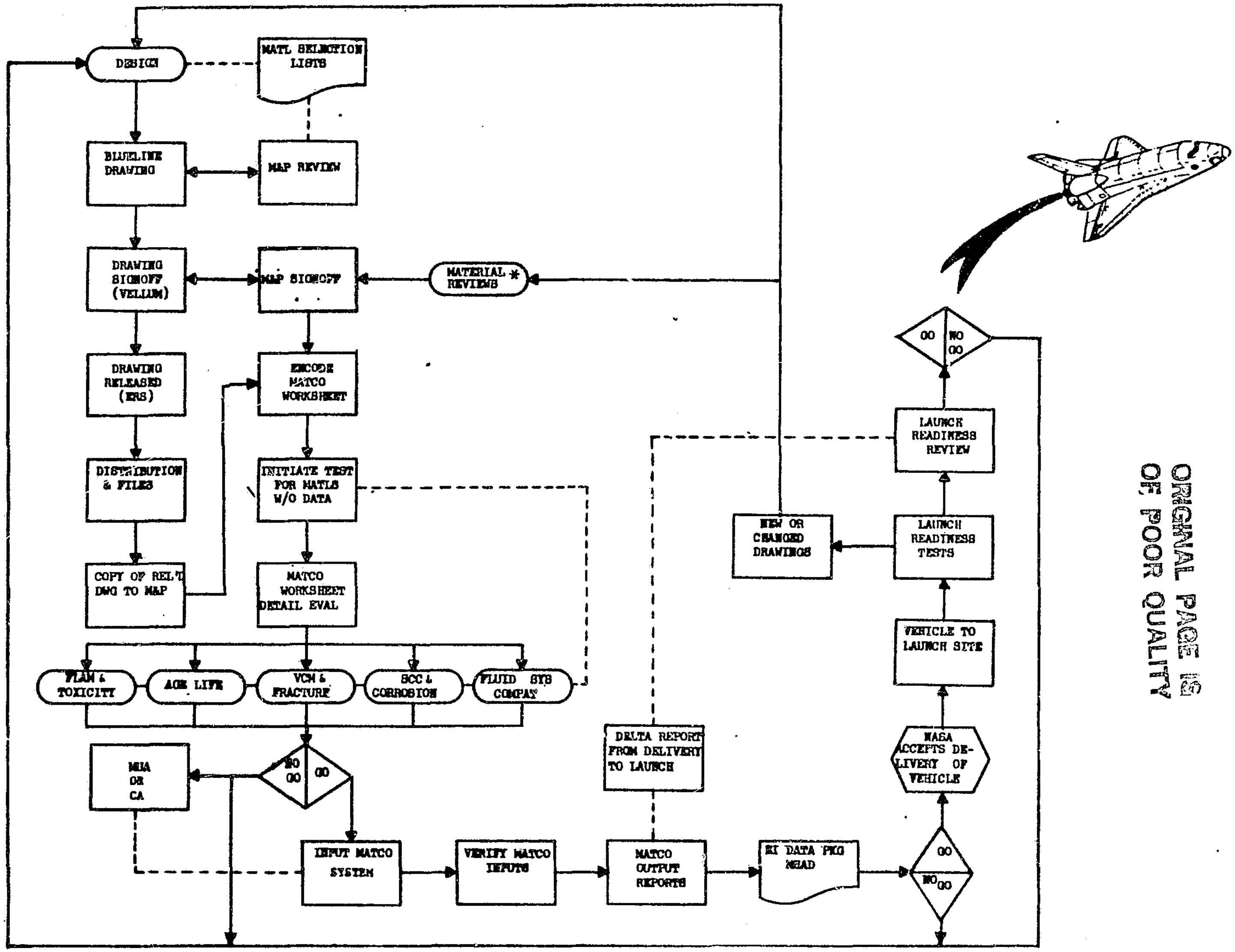
- FUTURE AEROSPACE PROGRAMS WILL REQUIRE A "SYSTEMS" PERSPECTIVE.

M&P CONTROL
FOR
SPACE APPLICATIONS

MATERIALS AND PROCESS CONTROL APPLIES TO THE PROPER SELECTION, USAGE EVALUATION, DOCUMENTATION AND THE TRACKING OF MATERIALS AND PROCESSES TO AVOID OR REDUCE THE RISKS OF SYSTEM PERFORMANCE FAILURES FROM FLAMMABILITY, TOXICITY, THERMAL/VACUUM STABILITY, CORROSION, FLUID INCOMPATIBILITIES, FATIGUE, OXYGEN IMPACT SENSITIVITIES, CONTAMINATION CONTROL, ETC.

A TOTAL MATERIAL AND PROCESS CONTROL SYSTEM CONSISTS OF TWO ELEMENTS:

1. AN ENGINEERING REVIEW/EVALUATION SYSTEM
    - PROGRAM REQUIREMENTS
    - DESIGN REVIEW/APPROVAL
    - MATERIALS/CONTAMINATION TEST PROGRAMS
    - SPECIFICATIONS
    - HAZARD REMOVALS
    - FAILURE ANALYSIS
2. AN ENGINEERING DATA MANAGEMENT AND TRACKING SYSTEM
    - MATERIALS SELECTION LISTS
    - PROPERTIES MANUAL
    - MATERIAL/CONTAMINATION IDENTIFICATION & TRACKING
    - AS/BUILT CONTROLS
    - COMPLETENESS VERIFICATION



MATERIAL CONTROL PROGRAM LOGIC

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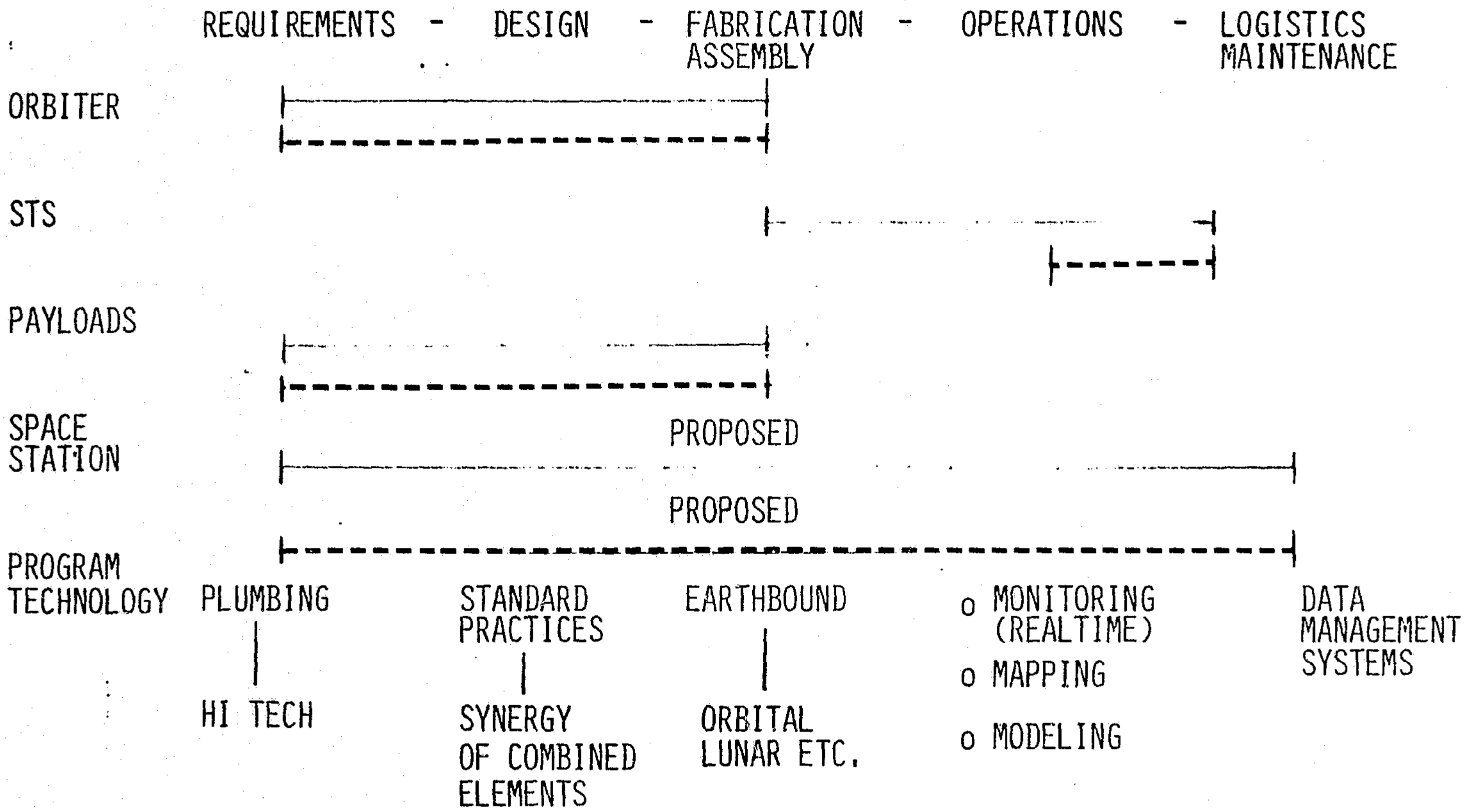
MATERIALS & PROCESSES ENGINEERING
A SYSTEMS APPROACH



REQUIREMENTS - DESIGN - FABRICATION ASSEMBLY - OPERATIONS - LOGISTICS MAINTENANCE

ORBITER

STS

PAYLOADS

SPACE STATION

PROPOSED

PROPOSED

PROGRAM TECHNOLOGY

PLUMBING
HI TECH

STANDARD PRACTICES
SYNERGY OF COMBINED ELEMENTS

EARTHBOUND
ORBITAL LUNAR ETC.

- o MONITORING (REALTIME)
- o MAPPING
- o MODELING

DATA MANAGEMENT SYSTEMS

CONTAMINATION CONTROL
ISSUES *

ISSUES	CURRENT DATA BASE TO RESOLVE	CONTROL W/CURRENT TECHNOLOGY	NEW TECHNOLOGY
o INHERENT HARDWARE CONTAMINATION LEVELS	60%	X	
o ASCENT/LAUNCH DRAG ALONG/INDUCED	20%		X
o ORBITAL DEBRIS	?		X
o OPERATIONS/CROSS CONTAMINATION	?	X	X
o MATERIALS DEGRADATION	20%	X	X
o MAINTENANCE PROCEDURES	30%	X	X
o PROBLEM ANTICIPATION/TRACKING/MONITORING	30%		X

* BASED ON APOLLO/SHUTTLE PROGRAM EXPERIENCE 1960 - 1984

MATERIALS AND PROCESSES
ISSUES *

ISSUE	CURRENT DATA BASE TO RESOLVE	CONTROL W/CURRENT TECHNOLOGY	NEW TECHNOLOGY
o ADVANCED ENGINEERING MATERIALS TRACKING DATA BASE SYSTEM	70%	X	—
o IMPROVED MATERIALS AGE LIFE DATA BASE	40%	X	X
o EFFECTS OF RADIATION ON MATERIAL PROPERTIES	30%	X	X
o INTEGRATED LOGISTICAL DATA BASES	?	X	—
o MATERIAL/CONFIGURATION MAPPING (LOCATOR)	?	X	X

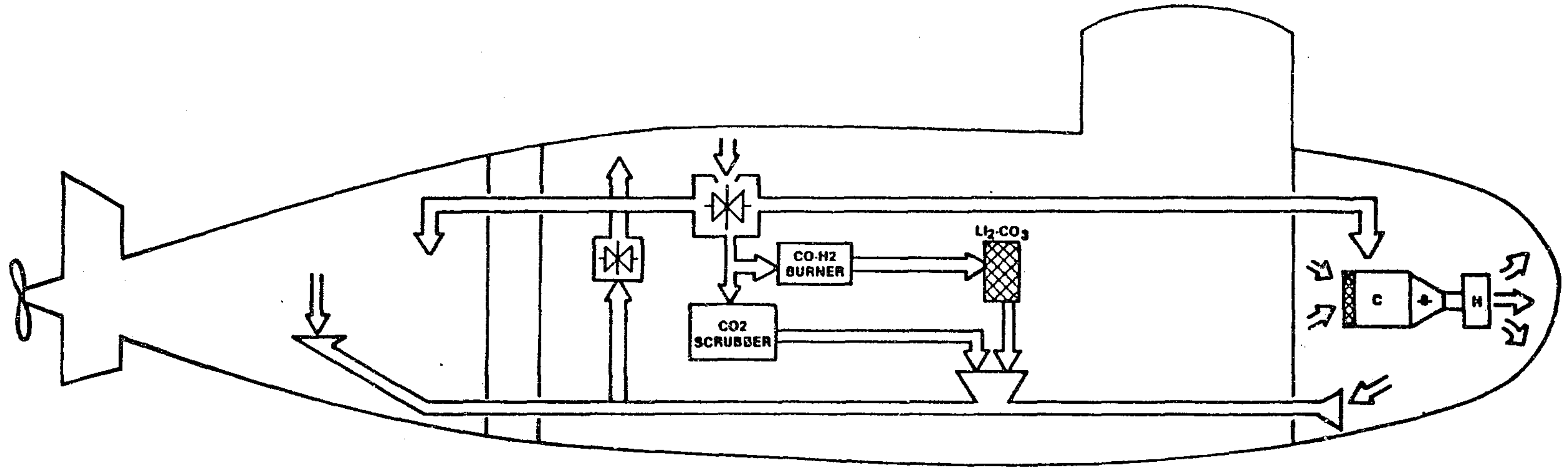
* BASED ON APOLLO/SHUTTLE PROGRAM EXPERIENCE 1960 - 1984

EXPERIENCE:

- OUR INVESTMENT IN MATERIALS & PROCESSES CONTROL PROCEDURES/ SYSTEMS HAS BEEN REPAYED BY REDUCED RISK/HAZARDS AS WELL AS TIMELY FAILURE ANALYSIS WHEN NEEDED.
- MATERIAL FAILURES AND CONTAMINATION ARE STILL A MAJOR CAUSE OF SYSTEM FAILURES.
- THE FUTURE NON-RECOVERABLE SYSTEMS SUCH AS SPACE STATION WILL DEMAND EVEN GREATER RELIABILITY, MONITORING & CONTROL.
- AT THIS TIME, WE DON'T HAVE SUFFICIENT EXPERIENCE WITH PERMANENT MANNED AEROSPACE SYSTEMS TO PROPERLY DETERMINE ALL OF THE CRITICAL USEABILITY FACTORS.

RECOMMENDATIONS:

- THERE IS AN IMMEDIATE NEED TO DEVELOP A COMPREHENSIVE MATERIALS & PROCESSES DATA BASE TO SUPPORT PHASE 'B' SPACE STATION STUDIES.
- DEVELOP A FLIGHT PROVEN "CONTAMINATION" REAL-TIME MONITORING SYSTEM.
- DEVELOP AN INTEGRATED/OPERATIONAL DATA BASE FOR A MATERIALS/MAINTENANCE/INCIDENTS TRACKING SYSTEM.



VENTILATION FLOW — SUBMERGED

I.

VENTILATION SYSTEM

WHEN THE SUBMARINE IS SUBMERGED. THE VENTILATION SYSTEM PROVIDES A CONDITIONED ATMOSPHERE IN THE SHIP WITH COMPLETE ISOLATION FROM THE OUTSIDE. A CONDITIONED ATMOSPHERE INCLUDES NOT ONLY FILTRATION AND TEMPERATURE AND HUMIDITY CONTROL, BUT ALSO AIR PURIFICATION (REMOVAL OF POTENTIALLY HARMFUL QUANTITIES OF IMPURITIES AND COMTAMINANTS) AND REVITALIZATION (ADDITION OF VITAL LIFE SUPPORT OXYGEN). THIS IS THE NORMAL MODE OF OPERATION OF THE VENTILATION SYSTEM.

THE REMAINING MODES EXCHANGE AIR BETWEEN THE SHIP'S ATMOSPHERE AND THE OUTSIDE AIR.

CARBON DIOXIDE REMOVAL SYSTEM

CARBON DIOXIDE REMOVAL PLANTS PREVENT CARBON DIOXIDE IN THE SHIP'S ATMOSPHERE FROM INCREASING TO AN UNSATISFACTORY LEVEL DURING SUBMERGED OPERATIONS. THIS IS NECESSARY SINCE THE SHIP'S PERSONNEL ARE CONTINUALLY EXPIRING CARBON DIOXIDE TO THE SHIP'S ATMOSPHERE.

BLOWERS SEND EXHAUST AIR TO THE INLETS OF THE CARBON DIOXIDE REMOVAL SYSTEM PLANTS WHEN THE SHIP IS SUBMERGED. THIS PLANT BATHES THE AIR IN A CHEMICAL SOLUTION WHICH HAS AN AFFINITY FOR CARBON DIOXIDE. MOST OF THE CARBON DIOXIDE REMAINS IN THE CHEMICAL SOLUTION, AND THE AIR IS RETURNED TO THE SPACE RELATIVELY FREE OF CARBON DIOXIDE. THE PURIFIED AIR FROM THE CARBON DIOXIDE REMOVAL PLANTS IS DISCHARGED INTO THE INLET OF A VENTILATION

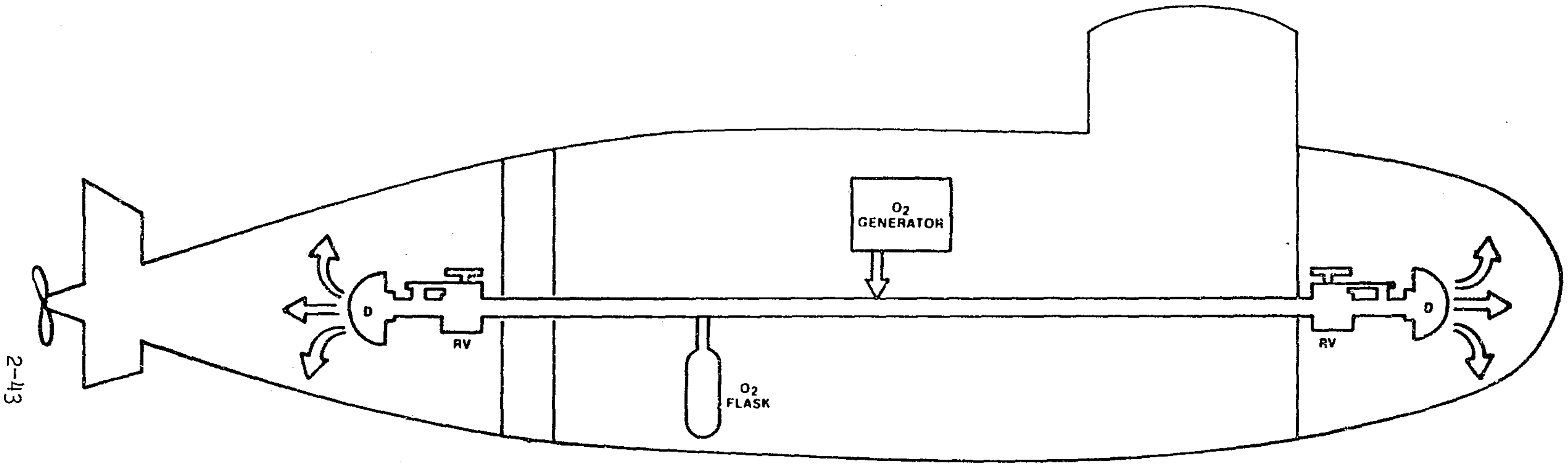
EXHAUST TERMINAL AND RETURNED TO THE SHIP'S VENTILATION SUPPLY HEADER WHERE IT IS DISPERSED THROUGHOUT THE SHIP.

CO-H2 BURNERS

THE CHEMICAL REACTION WHICH TAKES PLACE WITHIN THE CELLS OF THE MAIN STORAGE BATTERY DURING CHARGE AND DISCHARGE, PRODUCES HYDROGEN GAS WHICH IS DISPERSED INTO THE SUBMARINE ATMOSPHERE BY THE VENTILATION SYSTEM. CARBON MONOXIDE AND HYDROCARBONS FROM VARIOUS SOURCES ARE ALSO PRODUCED IN THE SHIP AND MUST BE CONTROLLED AT ACCEPTABLE LEVELS TO PREVENT EXCESSIVE BUILDUPS IN THE SHIP'S ATMOSPHERE. THE FUNCTION OF THE CO-H2 BURNERS IS TO REMOVE THESE CONSTITUENTS FROM THE ATMOSPHERE. THE VENTILATION SYSTEM SUPPLIES A REPRESENTATIVE MIXTURE OF AIR FROM THE SHIP'S EXHAUST HEADER TO THE INLET OF THE CO-H2 BURNERS. THE AIR ENTERS EACH UNIT WHERE IT IS HEATED AND, BY CATALYTIC ACTION, MOST OF THE HYDROGEN, HYDROCARBONS, AND CARBON MONOXIDE ARE BURNED. UNFORTUNATELY, SOME HYDROCARBONS WHEN BURNED PRODUCE BY-PRODUCTS WHICH ARE THEMSELVES TOXIC. THE DISCHARGE OF THE CO-H2 BURNER IS PASSED THROUGH A LITHIUM CARBONATE FILTER DESIGNED TO REMOVE THESE BY-PRODUCTS. THE AIR IS THEN DISCHARGED INTO A VENTILATION EXHAUST TERMINAL WHREE IT IS RETURNED TO THE VENTILATION SUPPLY HEADER FOR DISTRIBUTION THROUGHOUT THE SHIP.

OXYGEN SYSTEM

TO MAINTAIN THE OXYGEN CONTENT OF THE SHIP'S ATMOSHPERE AT THE PROPER LEVEL TO SUPPORT HUMAN LIFE DURING SUBMERGED OPERATIONS, OXYGEN IS PRODUCED BY TWO OXYGEN GENERATORS AND A CHLORATE CANDLE FURNACE. OXYGEN MAY BE BLED FROM STORAGE BANKS INTO THE SHIP FOR DILUTION AND DISPERSAL THROUGHOUT THE SHIP.



OXYGEN SYSTEM

II. OXYGEN SYSTEM

STANDARD DESIGN PRACTICE CALLS FOR A NORMAL SYSTEM DESIGN OXYGEN FLOW RATE OF 1.0 SCFH PER MAN. THE PRIMARY O2 SYSTEM IS CAPABLE OF PROVIDING THIS DESIGN FLOW AS A MINIMUM FOR THE DURATION OF THE MISSION (90 DAYS). PEAK O2 REQUIREMENTS MAY BE AS MUCH AS 1.65 SCFH PER MAN FOR LIMITED PERIODS OF GREATER CREW ACTIVITY.

AN O2 BACKUP SYSTEM IS PROVIDED WHICH IS CAPABLE OF PROVIDING NORMAL O2 REQUIREMENTS OV THE CREW OVER A TEN DAY PERIOD OF SUBMERGED OPERATION.

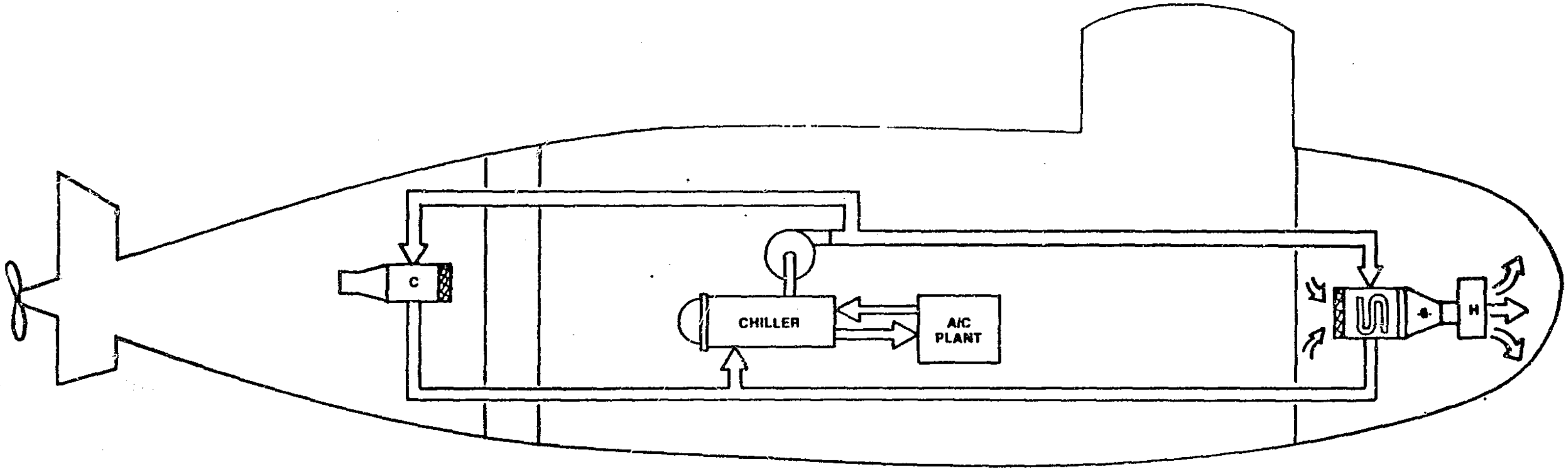
IN ADDITION, AN EMERGENCY O2 SYSTEM IS CAPABLE OF PROVIDING NORMAL O2 REQUIREMENTS OVER SHORTER PERIODS OF TIME.

THE PRIMARY SOURCE OF OXYGEN ON A NUCLEAR SUBMARINE IS AN ELECTROLYTIC OXYGEN GENERATOR WHICH SUPPLIES 3000-PSI OXYGEN TO CHARGE OXYGEN STORAGE FLASKS.

OXYGEN IS NORMALLY DISCHARGED DIRECTLY TO THE SHIP'S ATMOSPHERE THROUGH PRESSURE-REDUCING VALVES AND DIFFUSERS. THE OXYGEN FLASKS ARE CHARGED FROM SHORE AT THE START OF A PATROL AND ARE KEPT FULLY CHARGED BY THE OXYGEN GENERATOR TO PROVIDE SIX DAYS' RESERVE SUPPLY IN THE EVENT OF O2 GENERATOR FAILURE.

THE OXYGEN GENERATOR PRODUCES O2 BY THE ELECTROLYSIS OF DEMMERALIZED WATER USING ELECTORLYTIC CELLS, DISPELLING THE HYDROGEN OVERBOARD. A POTASSIUM HYDROXIDE SOLUTION TO PROVIDE CONDUCTIVITY IS USED AS THE ELECTROLYTIC SOLUTION.

CHLORATE CANDLES ARE AVAILABLE FOR A BACKUP SYSTEM AND THE STORED OXYGEN IS CLASSIFIED AS AN EMERGENCY SUPPLY.



CHILLED WATER SYSTEM

III. AIR CONDITIONING

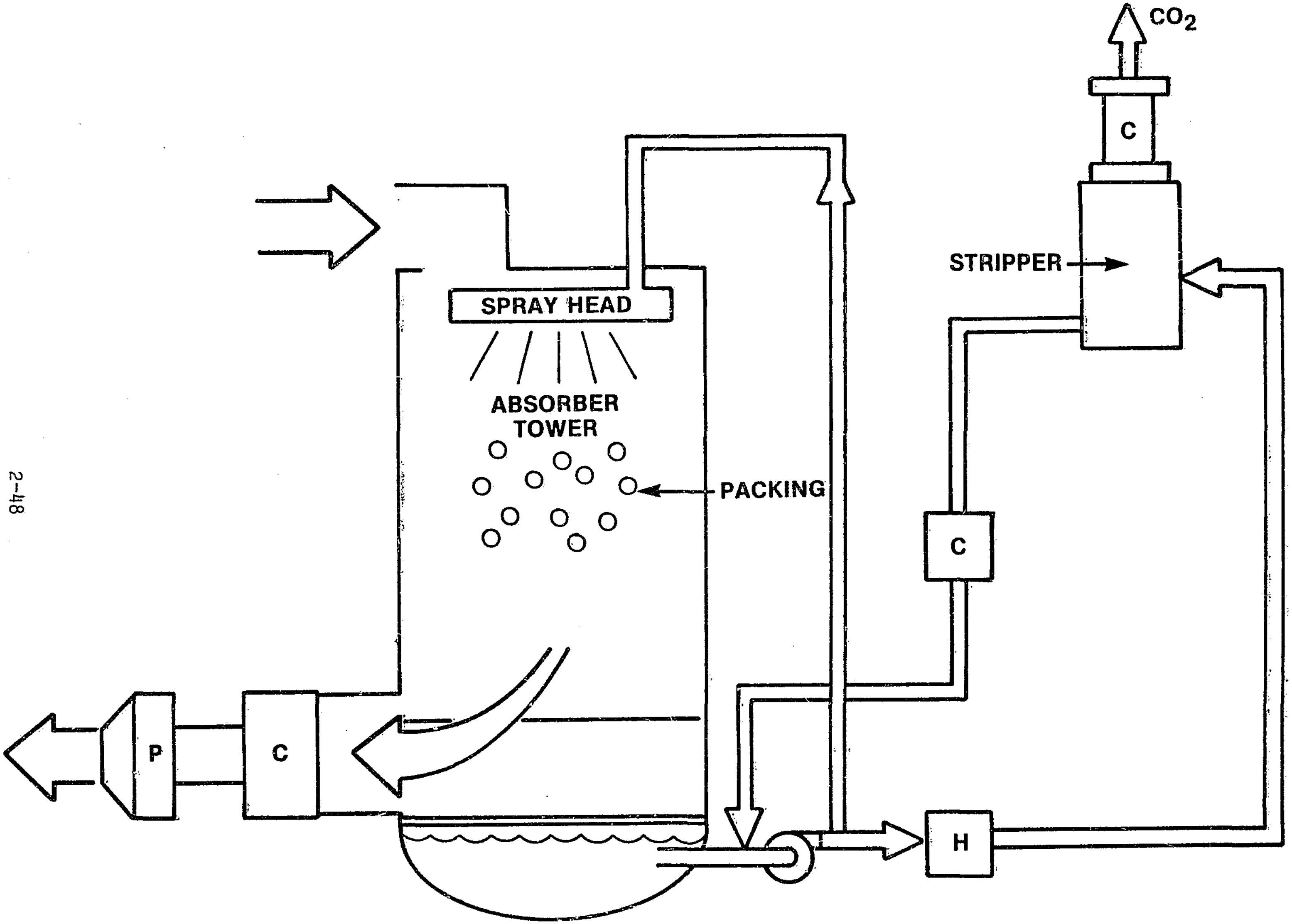
AN AIR CONDITIONING SYSTEM PROVIDES AND MAINTAINS A COOLED AND DEHUMIFIED ATMOSPHERE FOR EQUIPMENT AND PERSONNEL ON THE SHIP. THE SYSTEM CONSISTS OF R-114 AIR CONDITIONING UNITS, A CHILLED WATER SYSTEM, AND AN AIR CONDITIONING CONTROL SYSTEM.

THE R-114 AIR CONDITIONING PLANTS EMPLOY DICHLOROTETRAFLUORETHANE (R-114) AS A REFRIGERANT. THE THERMODYNAMIC PROPERTIES OF R-114 MAKE IT IDEAL AS A HEAT TRANSFER MEDIUM. R-114 IS ALSO CHEMICALLY STABLE, NON-CORROSIVE, AND NON-TOXIC. THE R-114 VAPOR COMPRESSION UNITS REMOVE HEAT PICKED UP THE CHILLED WATER SYSTEM FROM EQUIPMENT AND LIVING SPACES AND TRANSFERS THE HEAT TO SEAWATER.

A CHILLED WATER SYSTEM CIRCULATES WATER CHILLED BY THE REFRIGERANT TO COOLING COILS AND HEAT EXCHANGERS FOR AIR CONDITIONING AND EQUIPMENT COOLING. VENTILATION FANS FORCE AIR PAST THE COOLING COILS WHERE THE AIR IS COOLED AND DEHUMIDIFIED. HEAT IS TRANSFERRED FROM THE AIR TO THE CHILLED WATER IN THE COILS. OTHER COMPONENTS ARE COOLED BY CHILLED WATER FLOWING THROUGH THEIR HEAT EXCHANGERS. THE WARM CHILLED WATER RETURNS TO THE AIR CONDITIONING UNIT CHILLERS, WHRE ITS HEAT IS TRANSFERRED TO THE REFRIGERANT AND ULTIMATELY TO THE SEAWATER.

THE AIR CONDITIONING CONTROL SYSTEM SENSES TEMPERATURE AND HUMIDITY IN EQUIPMENT AND LIVING SPACES. THE SENSING DEVICES ARE PNEUMATICALLY OPERATED THERMOSTATS AND HUMIDISTATS

WHICH SENSE CHANGES IN TEMPERATURE AND HUMIDITY AND CONVERT THESE SIGNALS INTO AIR SIGNALS. RESULTING AIR SIGNALS ARE COMPARED IN LOGIC CIRCUITS WHERE THE STRONGEST DEMAND ACTUATES THE FINAL CONTROL ELEMENT TO SATISFY COOLING, DEHUMIDIFICATION, OR HUMIDIFICATION REQUIREMENTS.



CO_2 SCRUBBER

IV.

CARBON MONOXIDE REMOVAL

STANDARD PRACTICE IN SUBMARINE DESIGN CALLS FOR MAINTAINING CO_2 LEVELS AT OR BELOW 0.5%.

A PROVISION FOR BACKUP AND EMERGENCY CO_2 REMOVAL SPECIFIES A SUPPLY OF LITHIUM HYDROXIDE (LIOH).

THE PRIMARY SYSTEM FOR CO_2 REMOVAL IS THE MONETHANOL AMINE (MEA) SCRUBBER. GENERALLY, EACH SUBMARINE WILL HAVE TWO OF THESE UNITS. THE PROCESS FOR CO_2 REMOVAL IS ONE OF ABSORPTION. THE ABSORPTION AGENT IS MONETHANOLAMINE (AMINE OR MEA). THE LATEST SCRUBBERS CAN REMOVE THE INLET AIR CO_2 CONCENTRATION OF 1.5% TO ABOUT 0.2% AT THE OUTLET, AT A RATE OF 170 CUBIC FEET PER MINUTE. THE TWO SCRUBBERS TAKE SUCTION ON THE SHIP'S AIR AND ABSORB THE CO_2 IN AN AMINE SOLUTION. THE CO_2 IS REMOVED FROM THE AMINE SOLUTION AND DISCHARGED OVERBOARD. THE AMINE SOLUTION IS RE-USED IN THE SCRUBBERS.

THE CO_2 REMOVAL PLANT CONTAINS FIVE INTERRELATED SYSTEMS: AIR CIRCULATION SYSTEM, MONOETHANOLAMINE (MEA OR AMINE) CIRCULATING SYSTEM, CARBON DIOXIDE REMOVAL REMOVAL SYSTEM, AIR-CONDITIONING CHILLED WATER SYSTEM, AND AN ELECTRICAL AND INSTRUMENTATION SYSTEM.

THE AIR CIRCULATION SYSTEM FORCES ATMOSPHERIC AIR INTO THE TOWER AND DOWN THROUGH PACKING. AS THE AIR PASSES THROUGH THE TOWER, THE CO_2 IS ABSORBED BY A COOL AMINE SOLUTION, WHICH IS SPRAYED OVER THE PACKING. AT THE BOTTOM OF TOWER, A FILTER FUNNEL

LEADS THE PURGED AIR TO AN AIR PURIFIER WHERE THE AIR IS WASHED IN A SOLUTION OF FRESH WATER AND SODIUM BISULPHATE TO REMOVE THE ODOR OF AMMONIA.

THE AMINE IS CONTINUOUSLY RECYCLED THROUGH THE ABSORBER TOWER, ENTERING THE TOP THROUGH SPRAY NOZZLES, FLOWS DOWN THROUGH THE PACKING, COLLECTS IN THE BOTTOM, AND RETURNS TO THE SPRAY HEAD VIA A RECYCLING PUMP.

CO_2 IS REMOVED FROM THE AMINE BY HEATING AND STRIPPING. A SMALL AMOUNT OF THE CO_2 SATURATED AMINE IS DRAWN FROM THE BOTTOM OF THE TOWER AND ENTERS A HEAT EXCHANGER WHERE IT IS PREHEATED BY HOT, LEAN (STRIPPED) AMINE RETURNING FROM THE STRIPPER TOWER.

IN THE STRIPPER TOWER, AMINE ENTERS THE MIDDLE SECTION THROUGH SPRAY NOZZLES WHERE IT SEPARATES INTO MOISTURE AND AMINE VAPOR AND CO_2 GAS. THE AMINE VAPORS CONDENSE ON RINGS BENEATH SPRAY NOZZLES AND FLOWS DOWN TO THE BOTTOM SECTION. THE CO_2 AND A SMALL AMOUNT OF MOISTURE RISE TO THE TOP SECTION.

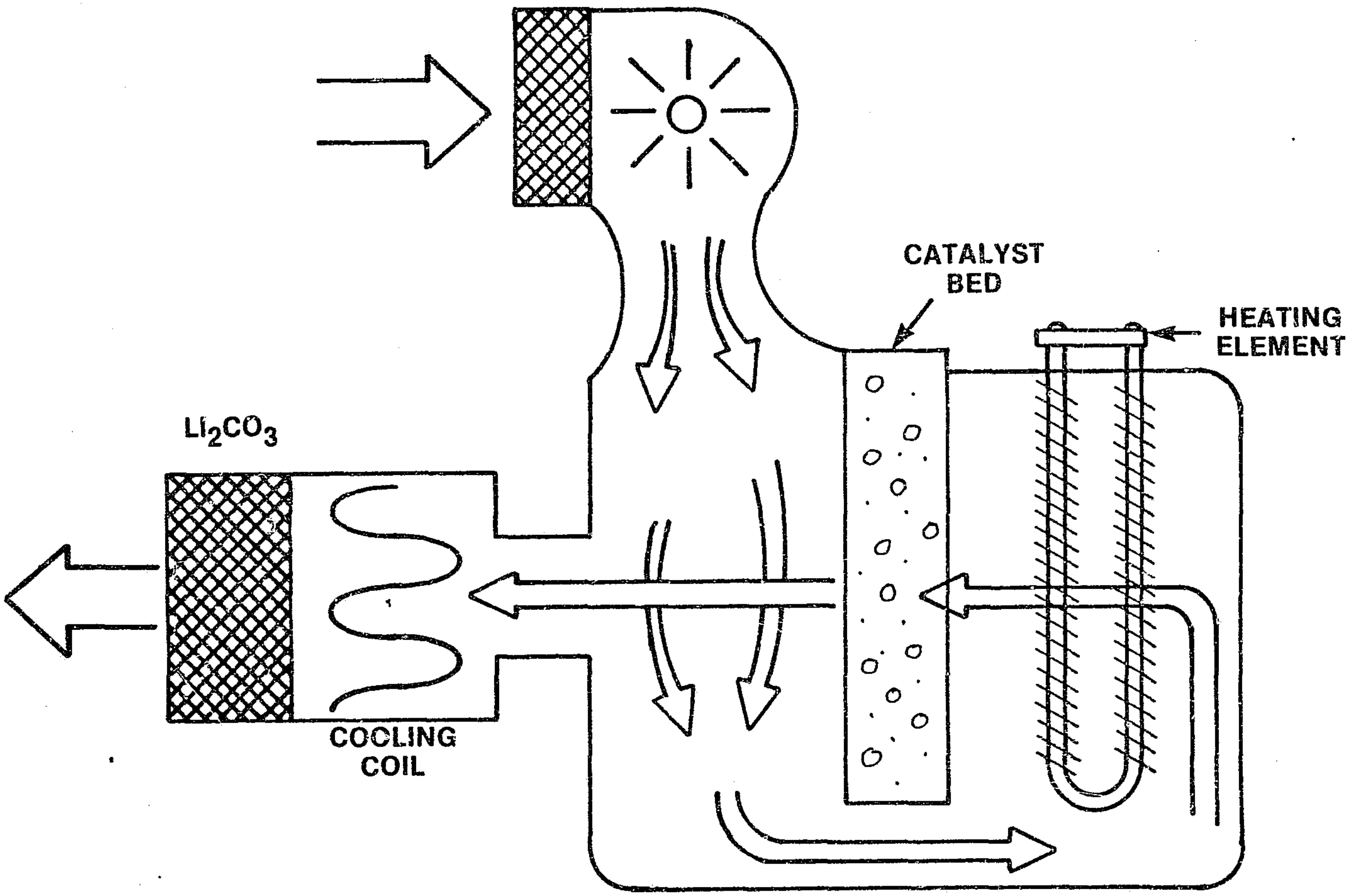
IN THE TOP SECTION, FRESH WATER TUBES CONDENSE THE MOISTURE, AND THE CO_2 PASSES TO A WATER SEPARATOR WHERE THE REMAINING MOISTURE IS REMOVED.

AFTER COMPRESSION, THE CO_2 FROM BOTH SCRUBBERS IS DISCHARGED OVERBOARD VIA SEA WATER PIPING. THE AIR-CONDITIONING CHILLED WATER COOLING SYSTEM SUPLIES WATER TO THE COOLER SECTION OF THE AIR PURIFIER, THE CO_2 COOLER, AND AN AMINE COOLER.

THE ELECTRICAL AND INSTRUMENTATION SYSTEMS CONTROL ALL ASPECTS OF THE CO_2 SCRUBBER.

CANISTERS ARE USED FOR BACKUP AND EMERGENCY CO_2 REMOVAL. IN THE BACKUP METHOD. AIR IS VENTILATED THROUGH CANISTERS OF LIOH BY A FAN AND FILTER ARRANGEMENT.

IN THE EMERGENCY MODE, THE CANISTERS ARE OPENED AND THE LIOH SPREAD ON THE FLOOR OR OTHER HORIZONTAL SURFACES WHERE NATURAL DIFFUSION ACTS TO CONTACT THE CO_2 WITH THE LIOH.



CO-H_2 BURNER

V. CARBON MONOXIDE AND HYDROGEN REMOVAL

CARBON MONOXIDE (CO) AND HYDROGEN (H_2) CONCENTRATIONS AND HYDROGEN CONTAMINANTS ARE MAINTAINED WITHIN ESTABLISHED LIMITS BY MEANS OF THE SHIPS AIR REVITALIATION SYSTEM.

CARBON MONOXIDE (CO) IS PRODUCED BY THE SMOKING OF TOBACCO, COOKING (PARTICULARLY WHEN FOOD IS BURNED), AND OVERHEATING OF ELECTRICAL EQUIPMENT. A SMALL AMOUNT OF CO IS ALSO GIVEN OFF BY THE HUMAN BODY. THE AMOUNT OF CO A PERSON CAN TOLERATE IS DEPENDENT ON THE LENGTH OF EXPOSURE. THE MAXIMUM CONCENTRATION FOR 90 DAYS CONTINUOUS EXPOSURE HAS BEEN ESTABLISHED AS 25 PARTS PER MILLION.

THE MAJOR SOURCE OF HYDROGEN (H2) IS THE SHIP'S BATTERY, WHICH GIVES OFF HYDROGEN DURING CHARGING. OTHER SOURCES ARE POSSIBLE LEAKAGE OF THE HYDROGEN BOTTLES, THE OXYGEN GENERATOR, AND THE SANITARY TANK PIPING.

NUMEROUS TYPES OF HYDROCARBONS ARE PRODUCED FROM MATERIALS SUCH AS DIESEL FUEL OIL, CLEANING SOLVENTS, LUBE OILS, COOKING FATS, CIGARETTE LIGHTER FLUID, PAINTS, AND MANY OTHER SOURCES.

DURING SUBMERGED OPERATIONS, CO-H_2 BURNERS REMOVE CARBON MONOXIDE AND HYDROGEN FROM THE SHIP'S ATMOSPHERE BY OXIDIZING CARBON MONOXIDE TO CO_2, HYDROGEN TO WATER VAPOR AND HYDROCARBONS TO CO_2 AND WATER VAPOR.

THE PURIFIED AIR IS RETURNED TO THE SHIP'S ATMOSPHERE. THE CO_2 IS REMOVED BY THE CO_2 SCRUBBERS AND THE WATER VAPOR IS CONDENSED BY THE AIR CONDITIONING COOLING COILS.

IN THE $CO-H_2$ BURNERS, A FAN DRAWS COMPARTMENT AIR INTO THE INLET DUCT THROUGH A FILTER AND INTO THE INLET SIDE OF A HEAT EXCHANGER WHERE THE AIR IS PREHEATED TO THE FIRST OF THREE LEVELS. THE AIR IS HEATED TO A SECOND LEVEL BY PASSING OVER A BANK OF ELECTRIC HEATERS, AND TO THE THIRD AND FINAL LEVEL BY BURNING HYDROGEN IN THE CATALYST BED AT A TEMPERATURE OF 600°F. THE HEAT IS PARTIALLY REMOVED FROM THE AIR STREAM AS IT PASSES THROUGH THE OUTLET SIDE OF THE ~~MAIN~~ HEAT EXCHANGER. THIS HEAT IS TRANSFERRED TO THE AIR ENTERING THE INLET DUCT OF THE HEAT EXCHANGER. BECAUSE THE HEAT EXCHANGER CANNOT REMOVE ALL THE HEAT FROM THE OUTGOING AIR, AN AFTERCOOLING COIL IS USED TO COOL THE AIR TO THE REQUIRED EXIT TEMPERATURE BEFORE IT IS DISCHARGED FROM THE UNIT.

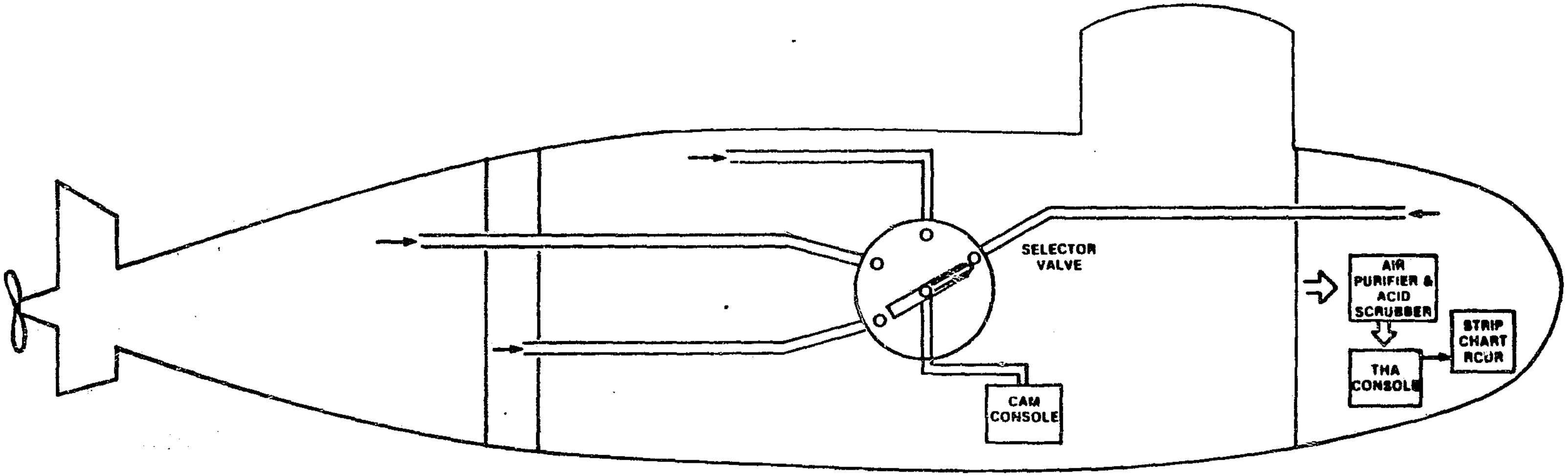
IT IS IN THE CATALYST CHARCOAL BED, CONSISTING OF 10% LIOH AND 90% HOPCALITE THAT THE CHEMICAL REACTIONS TAKE PLACE PRODUCING THE CO_2 AND H_2O. THE INCREASING AIR TEMP IS SUFFICIENT TO START THE REACTIONS. THE CHARCOAL BED IS CHANGED PERIODICALLY.

SOME PROBLEMS OCCUR WITH THE DECOMPOSITION OF HALOCARBONS WHICH MAY RESULT IN THE PRODUCTION OF ACIDE GASSES. THE OUTLET AIR IS THUS PASSED THROUGH A $LICO_3$ FILTER WHICH DECOMPOSES MOST OF THE HALOCARBONS. THE EFFICIENCY OF THE FILTER HOWEVER IS LESS THAN 100%.

VI. OTHER CONTAMINANT REMOVAL SYSTEMS

AIR PROCESSING UTILIZING ELECTROSTATIC PRECIPITATORS IS THE PRINCIPLE METHOD FOR REMOVING PARTICULATES (AEROSOLS).

ACTIVATED CHARCOAL BEDS AND HIGH EFFICIENCY FILTERS ARE ALSO IN USE THROUGHOUT THE SHIP'S VENTILATION SYSTEMS.



ATMOSPHERE ANALYZING SYSTEM

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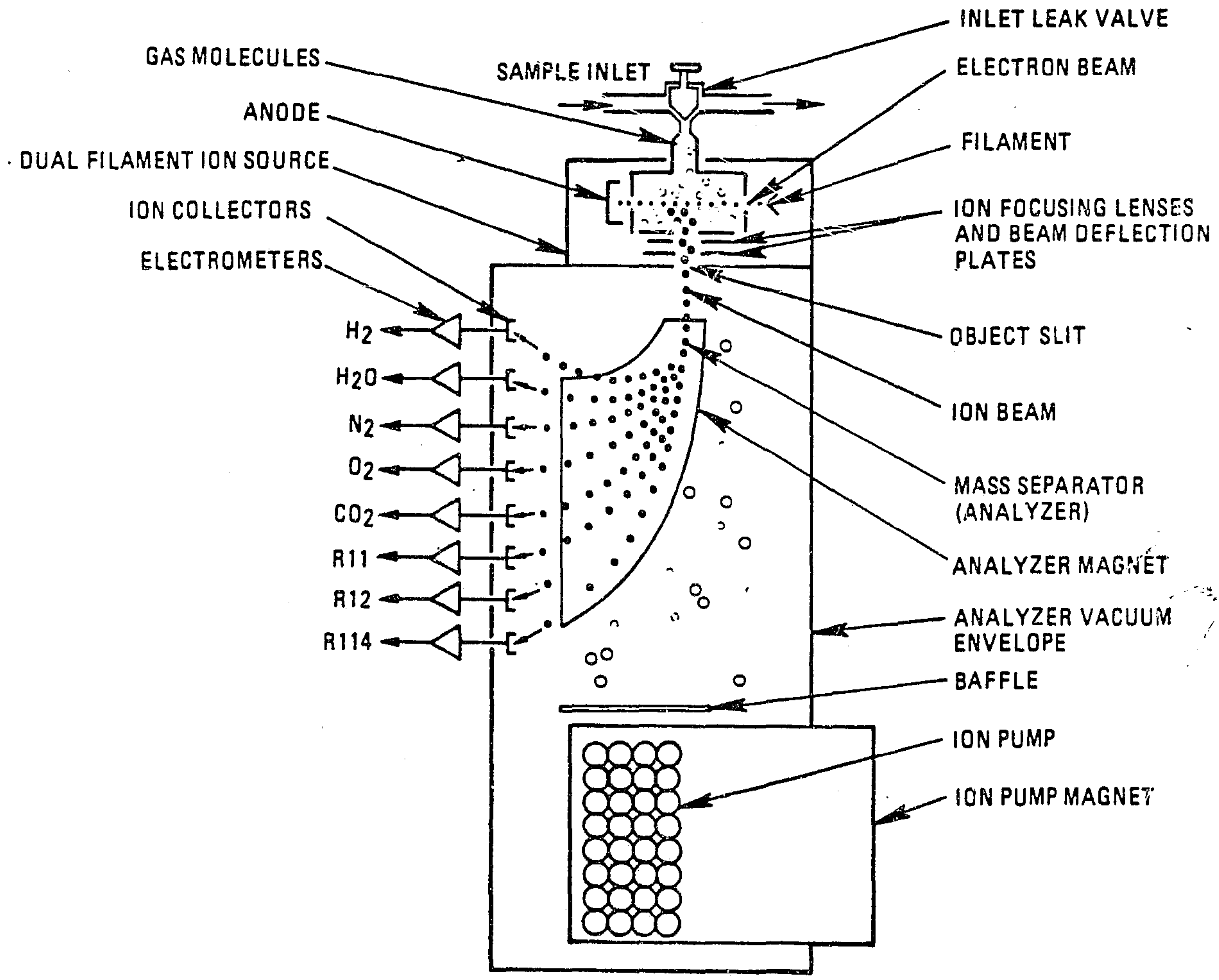
VII. ATMOSPHERE MONITORING SYSTEMS

THE ATMOSPHERE ANALYZER SYSTEMS AND THE TOTAL HYDROCARBON ANALYZER COMPRISE THE PRIMARY ATMOSPHERE MONITORING SYSTEMS FOR THE SHIP. THE ATMOSPHERE MONITORING EQUIPMENT, TERMED THE CENTRAL ATMOSPHERE MONITORING SYSTEM (CAMS) ANALYZES REPRESENTATIVE AIR SAMPLES FROM VARIOUS LOCATINS WITHIN THE SHIP THROUGH A SAMPLE SELECTOR VALVE. IN ADDITION, THE TOTAL HYDROCARBON ANALYZER IS USED TO EVALUATE THE EFFECTIVENESS OF THE INSTALLED VENTILATION SYSTEM CARBON FILTERS. THE LOCATION AND IDENTIFICATION OF ATMOSPHERIC CONTAMINANT CONCENTRATIONS BY THESE SYSTEMS IS THE BASIS FOR THE CORRECTIVE ACTION WHICH MUST BE TAKEN TO SOLVE THE CONTAMINANT PROBLEM IN THE SHIP'S ATMOSPHERE SUCH AS THE PROPER USE OF THE SCRUBBERS, BURNERS, AND O_2 GENERATORS. MANIPULATION OF THE VENTILATION SYSTEM IS ALSO NECESSARY TO CONTROL CONTAMINANTS. FOR INSTANCE, EMERGENCY EVACUATION OF A COMPARTMENT WITH SPECIAL BLOWERS MAY BE REQUIRED TO REMOVE HIGH CONCENTRATIONS OF CONTAMINANTS. PORTABLE ANALYTICAL MONITORING EQUIPMENT IS ALSO AVAILABLE.

THE ABILITY TO CONTROL SUBMARINE ATMOSPHERE QUALITY RESTS ON PRECISE MONITORING OF ATMOSPHERIC CONSTITUENTS. PROPER USE OF THE SCRUBBERS, BURNERS, AND OXYGEN GENERATORS IS GOVERNED BY CONCENTRATION MEASUREMENTS OF BOTH VITAL AND HARMFUL GASES IN THE SHIPS ATMOSPHERE. THIS INFORMATION IS OBTAINED FROM THE SHIPS CAMS, TOTAL HYDROCARBON ANALYSIS (THA), AND PORTABLE ANALYTICAL MONITORING EQUIPMENT.



CAMS MK I
MASS SPECTROMETER ANALYZER

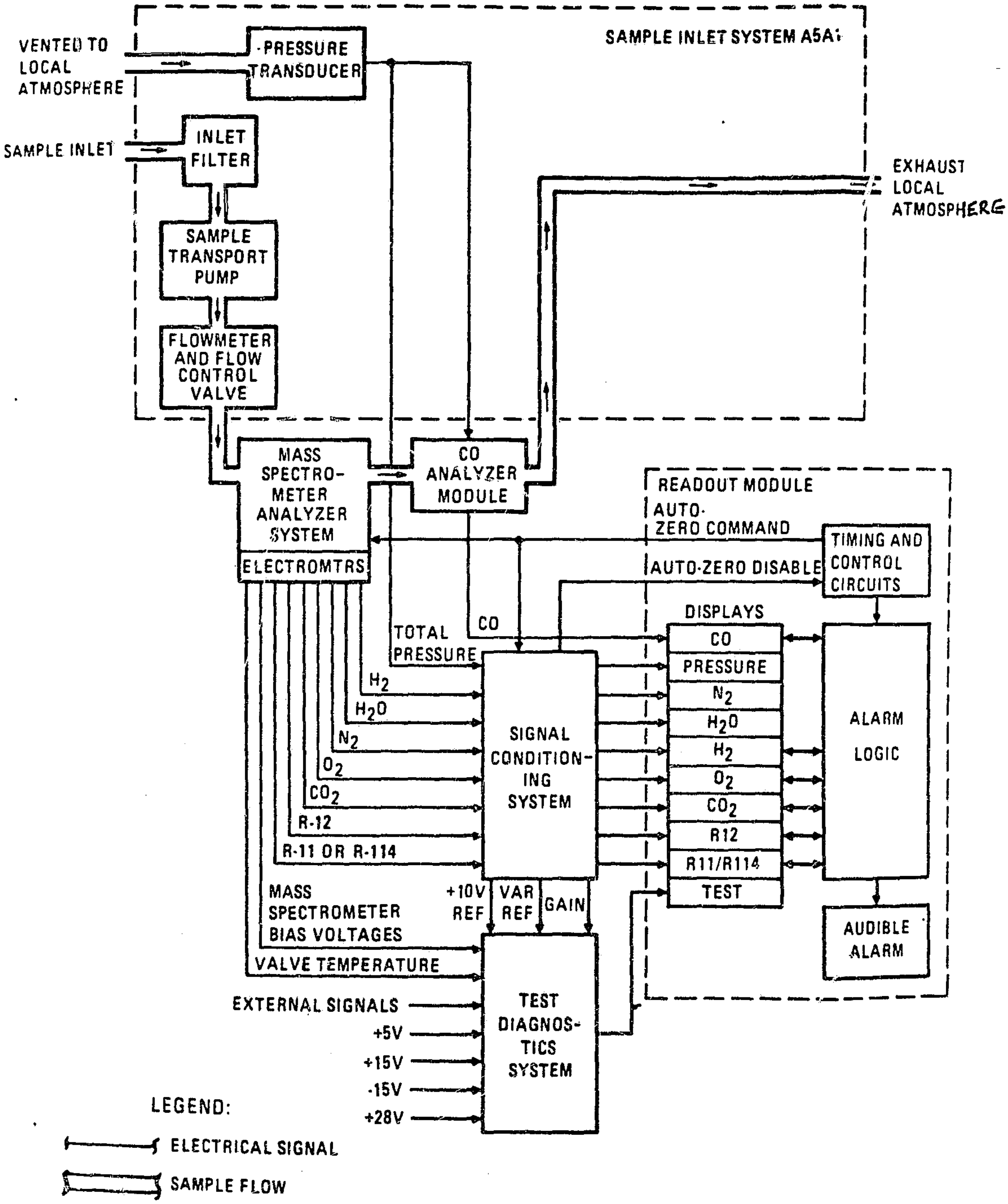
THE CAMS MONITORS AND MEASURES THE FOLLOWING CONTAMINANTS AND COMPONENTS OF THE SHIPS ATMOSPHERE:

(1) CARBON MONOXIDE	(CO)
(2) HYDROGEN	(H_2)
(3) OXYGEN	(O_2)
(4) CARBON DIOXIDE	(CO_2)
(5) NITROGEN	(N_2)
(6) WATER VAPOR	(H_2O)
(7) FREON 12	
(8) FREON 11 OR 114, AS SELECTED	

CAMS, UTILIZING THE PRINCIPLES OF MASS SPECTROSCOPY AND NON-DISPERSIVE INFRARED TO ANALYZE THE SUBMARINE'S ATMOSPHERE CONSTITUENTS, IS THE RESULT OF A NUMBER OF EXPERIMENTS WITH SUBMARINES AND THE ADVANCES IN MASS SPECTROMETRY IN THE LATE 1960'S, LARGELY BECAUSE OF THE SPACE PROGRAM.

SUBMARINES HAVE APPROXIMATELY A DOZEN LOCATIONS FROM WHICH SMALL TUBING LEADS TO A SAMPLE SELECTOR VALVE. A SAMPLE IS DRAWN THROUGH A COMPARTMENT FILTER, THROUGH THE TUBING AND SELECTOR VALVE, AND INTO THE CENTRAL ANALYZER. INDIVIDUAL COMPARTMENTS CAN BE SAMPLED BY TURNING THE SAMPLE SELECTOR VAVLE TO THE APPROPRIATE POSITION. SAMPLES ENTER ALL THE CENTRAL ANALYZERS AT ATMOSPHERIC PRESSURE.

ORIGINAL PAGE IS
OF POOR QUALITY

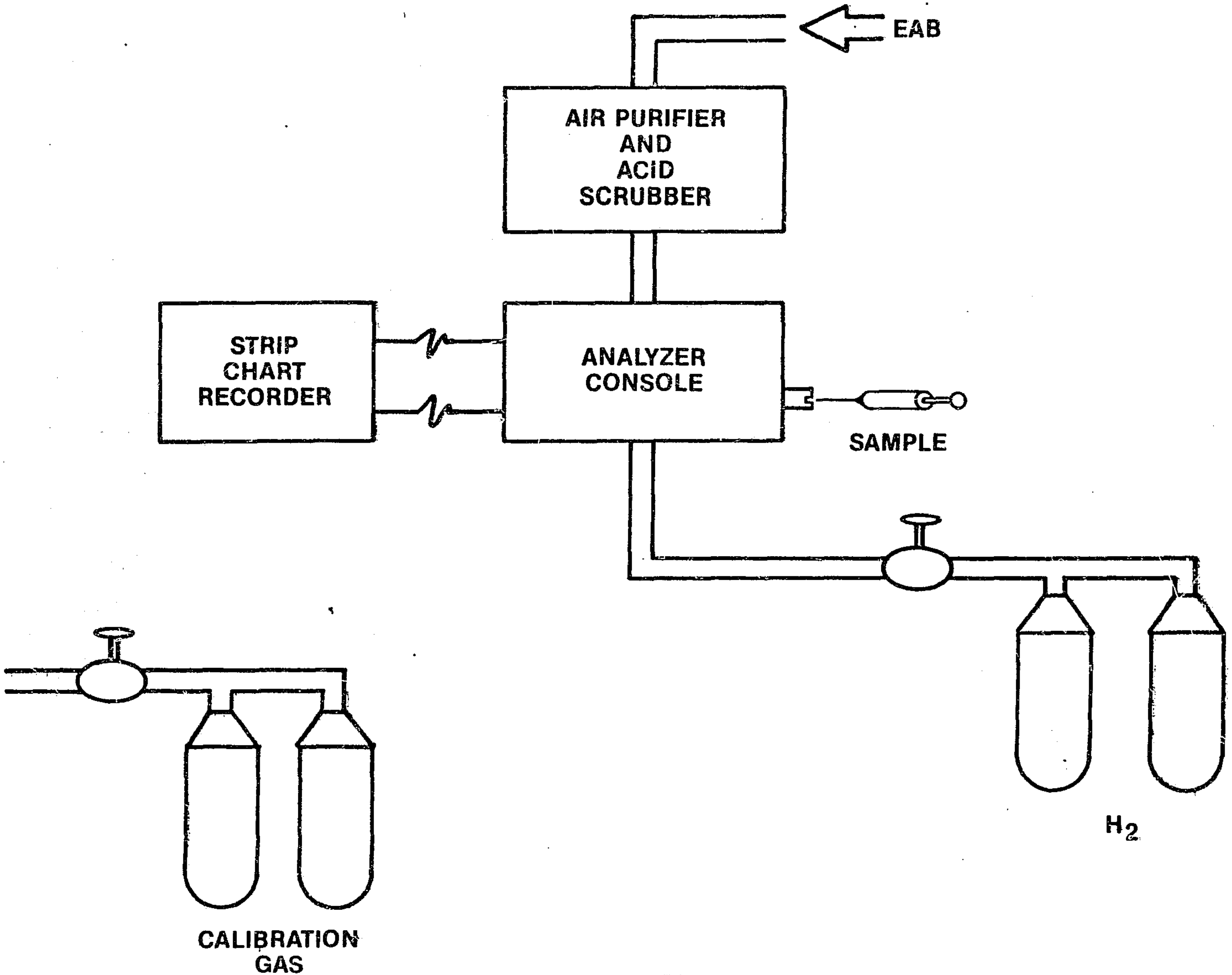


CENTRAL ATMOSPHERE MONITOR MK I

FUNCTIONAL BLOCK DIAGRAM

IN CAMS, GASEOUS SAMPLES ARE INTRODUCED INTO THE MASS SPECTROMETER THROUGH AN INLET SYSTEM WHICH REDUCES THE SAMPLE PRESSURE TO A LEVEL COMPATIBLE WITH THE ION-SOURCE OPERATING PRESSURE. THE SAMPLE IS SEPARATED AND SENT TO THE MASS SPECTROMETER PORTION OF THE INSTRUMENT. THE MAJOR PORTION OF THE INLET SAMPLE IS DIVERTED TO A NON-DISPERSIVE INFRARED ANALYZER WHICH EXAMINES THE SAMPLE FOR CARBON MONOXIDE.

THE CAMS PERFORMANCE HAS BEEN EXCELLENT. THE TWO MOST SIGNIFICANT PROBLEMS HAVE BEEN WITH THE CO ANALYZER AND THE INLET LEAK VALVE. OTHER PROBLEMS HAVE OCCURRED IN THE MASS SPECTROMETER POWER SUPPLY AND THE ION PUMP POWER SUPPLY. BOTH OF THESE POWER SUPPLIES HAVE MODIFICATION KITS WHICH CAN UPGRADE THE ANALYZERS TO PERFORM MORE SATISFACTORILY.


EAB
AIR PURIFIER AND ACID SCRUBBER
STRIP CHART RECORDER
ANALYZER CONSOLE
SAMPLE
H_2
CALIBRATION GAS

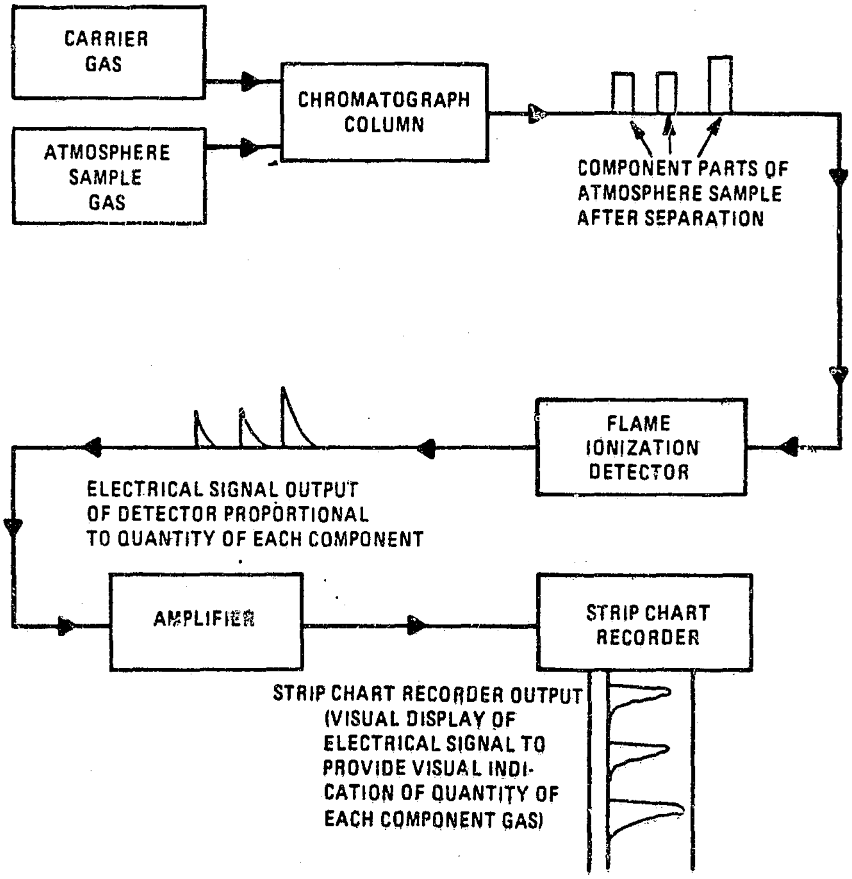
THA SYSTEM

VII. TOTAL HYDROCARBON ANALYZER

DURING SUBMERGED OPERATION, THE CLOSED ATMOSPHERE OF A SUBMARINE IS SUSCEPTIBLE TO A BUILDUP OF TOXIC AND A CORROSIVE GASES, A PORTION OF WHICH ARE HYDROCARBONS. EXAMPLES OF THE MORE COMMON HYDROCARBONS ARE METHANE (FROM CIGARETTE SMOKE AND THE SANITARY TANKS), BENZENE (FROM SOLVENTS, FUEL OIL, AND LUBE OIL), R-12 (FROM REFRIGERATION PLANTS) AND R-114 (FROM THE AIR CONDITIONING PLANTS). THE TOTAL HYDROCARBON ANALYZER (THA) MEASURES THE CONTAMINANT LEVELS OF SOME SPECIFIC HYDROCARBONS AND GROUPS THE HEAVIER HYDROCARBONS INTO A MEASURABLE QUANTITY.

THE TOTAL HYDROCARBON ANALYZER (THA) IS AN INSTRUMENT WHICH UTILIZES GAS CHROMATOGRAPHY TO INDICATE THE CONCENTRATIONS OF HYDROCARBON GASES. THE SYSTEMS CONSISTS OF AN ANLAYZER CONSOLE, WHICH SEPARATES AND MEASURES THE HYDROCARBON GASES; AN AIR PURIFIER AND ACID SCRUBBER ASSEMBLY, WHICH PURIFIES AIR FROM THE SHIP'S COMPRESSED AIR SYSTEM AND REMOVES ANY ACIDS WHICH MAY BE FORMED DURING THE PURIFICATION PROCESS; A STRIP CHART RECORDER, WHICH RECORDS THE INDICATED CONCENTRATIONS OF HYDROCARBON GASES; HYDROGEN CYLINDERS TO PROVIDE FUEL WHICH IS USED IN THE FLAME IONIZATION DETECTOR; TWO CALIBRATION GASES; AND A 100CC GLASS SYRINGE WHICH IS USED TO COLLECT GAS SAMPLES.

THE OPERATION OF THE ANALYZER CONSOLE, IN WHICH THE SEPARATION AND ANALYSIS OF A GAS SAMPLE OCCURS, IS FUNCTIONALLY DEPENDENT UPON THE SIMULTANEOUS OPERATION OF THE AIR



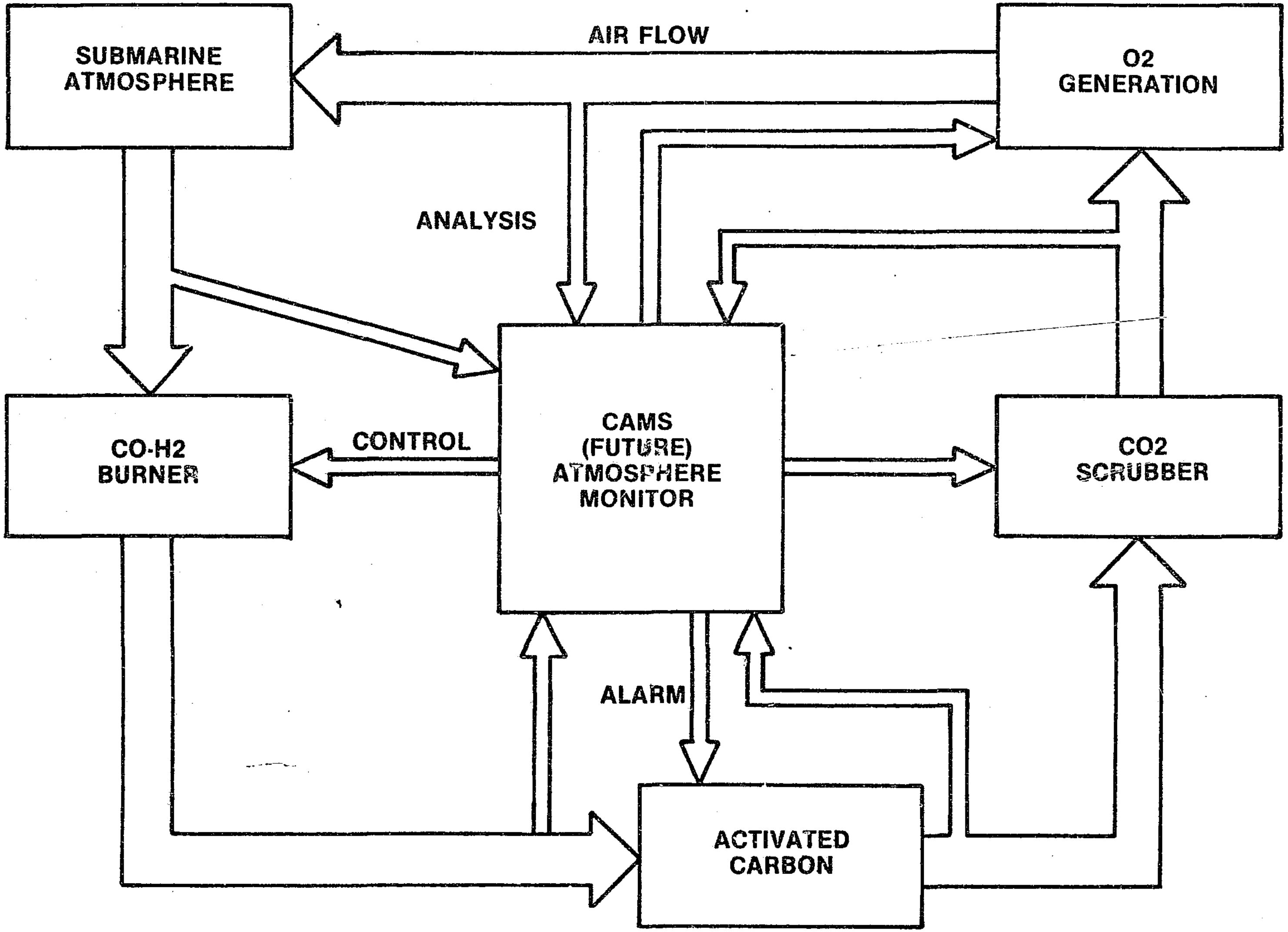
TOTAL HYDROCARBON ANALYZER

SIMPLIFIED DIAGRAM OF A GAS CHROMATOGRAMS

PURIFIER/ACID SCRUBBER. THE AIR PURIFIER/ACID SCRUBBER PROVIDES A PURE AIR SUPPLY FOR USE AS A CARRIER GAS (COLUMN AIR) AND FOR USE AS COMBUSTION AIR (FLAME AIR) USED IN THE FLAME IONIZATION DETECTOR.

THE AIR PURIFIER/ACID SCRUBBER RECEIVES AIR FROM THE EAB SYSTEM WHICH FLOWS THROUGH A HEATER AND INTO THE ACID SCRUBBER LIOH CARTIRDGE FOR REMOVAL OF ANY RESIDUAL ACIDS PRODUCED BY THE CHEMICAL REACTION OF CONTAMINANTS WITH THE AIR PURIFIER CATALYST. THE AIR, NOW FREE OF HYDROCARBON AND ACID CONTAMINANTS, FLOWS THROUGH THE AIR OUT PORT ON THE FRONT PANEL AND THROUGH THE CONNECTED HOSE TO THE AIR INLET PORT OF THE ANALYZER CONSOLE.

THIS IS WHERE THE ACTUAL BREAKDOWN AND ANLAYSIS OF GAS SAMPLES OCCURS. THERE, THE CHROMATOGRAPH COLUMN SEPARATES A MULTICOMPONENT GAS SAMPLE MIXTURE INTO ITS INDIVIDUAL COMPONENTS. A CONSTANT FLOW OF GAS, CALLED CARRIER OR COLUMN GAS, PASSES THROUGH THE COLUMN CONTINUOUSLY AND TRANSPORTS THE SAMPLE GAS THROUGH THE COLUMN. A PRECISELY MEASURED VOLUME OF THE SAMPLE GAS IS INTRODUCED INTO THE COLUMN. A FLAME IONIZATION DETECTOR, LOCATED AT THE OUTLET OF THE COLUMN, DETECTS THE CONCENTRATIONS OF THE SAMPLE GAS COMPONENTS AS THEY EMERGE FROM THE CHROMATOGRAPH COLUMN IN THE CARRIER GAS STREAM. THE ASSOCIATED ELECTRICAL SIGNAL GENERATED BY THIS PROCESS IS AMPLIFIED AND FED TO A STRIP CHART RECORDER. THE RECORDER PLOTS THE OUTPUT SIGNAL AGAINST TIME, AND THE RESULTING GRAPH IS CALLED A CHROMATOGRAM.



INTEGRATED LIFE SUPPORT MONITORING/CONTROL

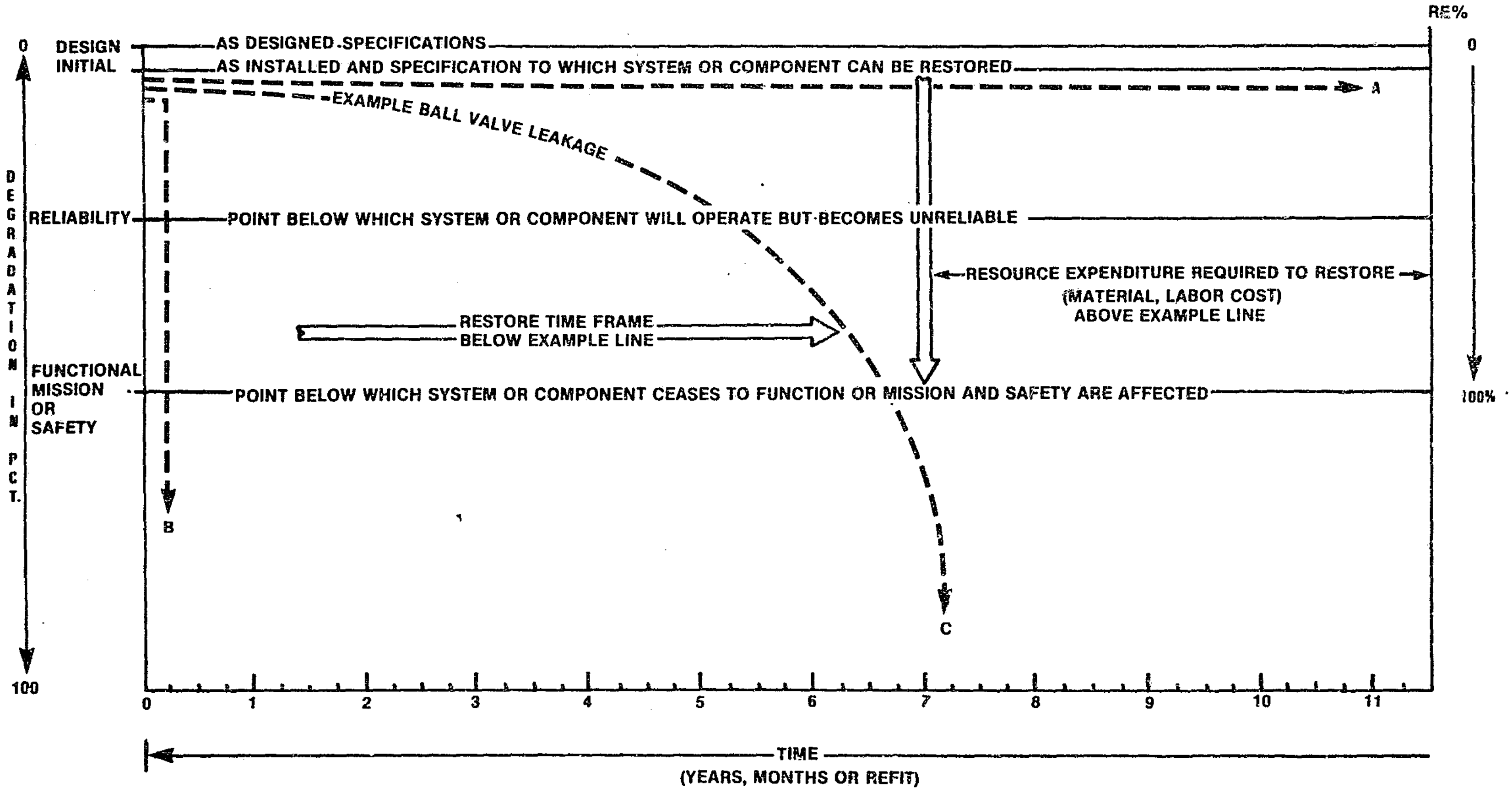
IX. INTEGRATED LIFE SUPPORT SYSTEM

AN IMPROVED CAMS HAS BEEN DEVELOPED, EVALUATED AND LABORATORY-TESTED AND IS SCHEDULED FOR QUALIFYING FOR SUBMARINE USE BY THE NAVAL RESEARCH LABORATORY AND PERKINS-ELMER CORP. THE NEW CAMS (TERMED MKII) CAN MONITOR MORE GASES, HAS A PROGRAMMABLE PROCESSOR THAT PERMITS THE SELECTION OF GASES TO BE MONITORED, AND HAS DATA-RECORDING CAPABILITIES.

THE EARLIER CAMS (MKI) IS A FIXED COLLECTOR MASS SPECTROMETER CAPABLE OF MONITORING ONLY EIGHT IONS OF PRE-SELECTED MASS TO CHARGE RATIOS.

NEW ENVIRONMENTAL CHANGES COULD REQUIRE THE NEED TO MONITOR NEW TYPES AND LEVELS OF CONTAMINANTS, THUS, A SCANNING MASS SPECTROMETER HAS BEEN DEVELOPED. THE USE OF THIS SOMEWHAT DELICATE INSTRUMENT IS NOW CONSIDERED FEASIBLE BECAUSE OF ADVANCED COMPUTER TECHNOLOGY AND INSTRUMENTATION PACKAGING. THE IMPROVED CAMS WILL MEASURE HYDROCARBONS (ELIMINATING THE NEED FOR THAS), HAVE THE CAPABILITY TO CONTINUOUSLY DISPLAY CONCENTRATION OF SELECTED GAS, ADD AND/OR DELETE CONTAMINANTS VIA COMPUTER SOFTWARE CHANGES, AND ACTIVATE AN ALARM SYSTEM FOR OUT-OF-TOLERENCE CONDITIONS.

IF PROVEN SUCCESSFUL, MINOR MODIFICATIONS COULD ALLOW AN INTEGRATED LIFE SUPPORT SYSTEM WITH APPROPRIATE ALARMS AND CONTROLS.



RELATIONSHIP OF RELIABILITY MINIMUMS
TO DEGRADATION RATE

19

X. PERFORMANCE MONITORING/CONDITION ASSESSMENT

MANY SUBMARINE LIFE SUPPORT SYSTEMS AND COMPONENTS HAVE THEIR OPERATING PERFORMANCE MEASURED, ANLAYZED FOR DEGRADATION TRENDS, AND ASSESSED FOR MATERIAL CONDITIONS IN ORDER TO CONDUCT MAINTENANCE ACTIONS PRIOR TO REACHING UNRELIABLE CONDITIONS.

THE PROCESS OF ESTABLISHING A PERFORMANCE MONITORING/MATERIAL ASSESSMENT PROGRAM INVOLVES THE SELECTION OF SYSTEMS AND COMPONENTS, THE PERFORMANCE AND MATERIAL CONDITION CRITERIA, INSPECTIONS AND MONITORING PROCEDURES, AND ANALYSIS AND ASSESSMENT TECHNIQUES. RELIABILITY MINIMUM VALUES NEED TO BE ESTABLISHED PRIOR TO ATTEMPTING TO DETERMINING WHETHER OR NOT THE PROPER PARAMETER CAN BE MEASURED TO ALLOW SOME REASONABLE TREND ANALYSIS AND PREDICTION FOR MAINTENANCE.

IN THE SAMPLE GRAPH, CURVE A INDICATES THE DEGRADATION RATE OF COMPONENTS WHERE LITTLE, OR NO MEASURABLE REDUCTION IN PERFORMANCE OR CONDITIONS IS EXPERIENCED OVER TIME. AT THE OTHER EXTREME, CURVE B SHOWS A COMPONENT SUBJECT TO INSTANTANEOUS FAILURE WITHOUT ANY PRIOR MEASURABLE DEGRADATION IN PERFORMANCE. RELIABILITY HAS NO REAL MEANING IN EITHER CASE. CURVE C ILLUSTRATES, AFTER SOME LEVEL OF DEGRADATION IS REACHED, THAT THE RATE OF DEGRADATION ACCELERATES RAPIDLY.

TOXICITY AND THE SMOKE PROBLEM: Harold L. Kaplan, Arthur F. Grand and Gordon E. Hartzell, Department of Fire Techology, Southwest Research Institute, San Antonio, TX 78284

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AMBIENT AIR CONTAMINATION--CHARACTERIZATION AND DETECTION TECHNIQUES

C. P. Nulton and H. S. Silvus

Until recently, work on indoor contamination has focused primarily on: 1) the criteria air pollutants [oxides of S, N and C, particulates and ozone]; 2) uniquely indoor contaminants [e.g., radon, formaldehyde, tobacco smoke and asbestos]; and 3) the work place pollutants for which American Conference of Governmental Industrial Hygienists (ACGIH) sets guidelines [e.g., organic solvents, metal fumes and wood dust).

Currently, concern centers on outgassing of synthetic construction and maintenance materials such as adhesives, sealants, insulation, wall coverings, cleaners, and electronic equipment inside of new, well-insulated, energy-conserving buildings. The effects of outgassing of synthetic materials in a closed system on human health and productivity is relevant to Space Station.

Indoor contaminants may cause acute reactions (e.g., poisoning by combustion products) or, more often, chronic problems develop due to low-level, long-term exposure. Southwest Research Institute (SwRI) has assisted many industrial clients in determining the source of contamination of the latter type that cause decreased worker productivity.

Chemical characterization of indoor contaminants can be divided into methods which are designed to target compounds, and those which provide for a broad range search. Typical of the former are the National Institute of Occupational Safety and Health methods that often involve either the use of solid adsorbants, or liquid impingers for sampling followed by analysis for target compounds by GC, or colorimetric detection. In cases where an organic contaminant is suspected but unknown, broader range techniques are required. Samples may be taken by pulling ambient air through adsorbants, e.g., Tenax® and Carbosieve®, which can be desorbed thermally onto GC columns for subsequent GC/MS analysis. A further refinement is to cryogenically focus the trapped organics then to volatilize them as a discrete plug onto a fused-silica capillary GC column, thus obtaining the advantages of increased resolution and overall superior chromatography.[1]

Another approach to organic sampling is the use of polyurethane foam (PUF) plugs which are relatively inert and allow for the collection of large sample volumes (e.g., 285 L/min for 4 hours). PUF samples have been used to sample for trace concentrations of relatively high molecular weight organics, e.g., PCBs, dioxins and pesticides.[2,3]

At SwRI we are characterizing the organics generated from indoor materials at ambient conditions and upon combustion. These experiments are conducted in a closed system (bell jar) with evolved organic compounds being collected on Tenax®, PUF plugs and/or liquid impingers. In one such study organic emissions from a very small electrical fire were characterized. A 5-cm^2 postion of circuit board was placed in the test vessel and a resistor (100 ohm) was overloaded causing it to flare and scorch approximately 1 cm^2 of the circuit board. The duration of the "fire" was approximately 10 seconds. The volume of the test vessel (2.8 L) was then collected on Tenax® and analyzed by GC/MS to reveal a variety of organics (Table 1) including halogenated and aromatic hydrocarbons. Analysis of system blanks also showed that the 5-cm^2 portion of circuit board emitted detectable levels of trichloroethylene and trichlorotrifluoroethane at ambient conditions.

An additional example is provided by the organic emissions from an insulation material that causes dramatic biological effects when combusted.[4] Although a wide variety of organics were characterized (Table 2), the chemical responsible for its unusual biological activity has not yet been identified.

Departing from the discussion of airborne contaminant characterization, I want to mention briefly the detection of critical levels of specific compounds or compound classes with coated quartz oscillators. Sensors of this type may be used to protect equipment as well as people.

Piezoelectric quartz crystals have been used for many years as precision frequency-determining elements in electronic oscillators. When properly cut and prepared, such crystals can maintain the frequency of an oscillator stable within a few parts per million over a nominal temperature range; with close temperature control, frequency stability on the order of parts per billion can be achieved.

The resonant frequency of a piezoelectric quartz crystal is determined by the particular mechanical mode in which the crystal operates and by certain critical dimensions characteristic of the mode. Additionally, as with any mechanical vibrating system, mass added to the surface of the crystal produces a loading effect that lowers resonant frequency. The absolute change in frequency is linearly related to added mass over a substantial range.

At Southwest Research Institute, this basic principle has been applied to measurement of the quantity of odorant in natural gas.[5] The technique employed is to apply a thin coating to the surfaces of a quartz frequency-control crystal. The materials in the coating were designed to react with tertiary butyl mercaptan (TBM), a commonly used odorant for natural gas. The crystal was connected in an electronic oscillator circuit, oscillation frequency of which was monitored by a precision electronic counter. Odorant-containing natural gas was flowed through a sample chamber surrounding the crystal (see Figure 1), and oscillator frequency changed in inverse proportion to the mass added to the crystal by reaction of the odorant with the crystal coating. By using known concentrations of odorant, it was possible to calibrate the frequency change in terms of odorant concentration.

Approximately 5 parts per million of TBM is commonly used in natural gas as odorant. The instrument described could readily quantify this concentration of odorant with a precision of ±0.5 part per million (Figure 2) and could detect changes in odorant concentration of less than 1 part per million absolute.

Quartz oscillators have a number of advantages for air monitoring including their small size, inherent sensitivity and potential for tailoring either coatings or the active quartz surface for high specificity.

Although the work I have briefly described characterizing organic air contaminants and detecting critical levels of target compounds in air is not related directly to cabin atmospheres the techniques involved become increasingly relevant to NASA as the duration of manned flights is extended and the volume and variety of on-board materials increase.

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3. Lewis, R. G. and M. D. Jackson. Anal. Chem. **54**:592, 1982.

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5. Millar, J. D., H. S. Silvus, L. M. Adams, H. J. Schattenberg III and L. L. Altpeter. Development of a Portable Instrument to Determine Odorants in Gas Distribution Lines. Presented at the International Gas Research Conference, London England, June 1983.

TABLE 1. ORGANICS ARISING FROM FLARING A RESISTOR

Class	Compound	Amount, ng
Br-containing	bromomethane	26,000
	dibromomethane	3,400
	bromobenzene	2,500
	bromoethane	<1,000
Cl-containing	1,1,1-trichloroethane	170,000
	dichlorobenzene	78,000
	trichlorotrifluoroethane	53,000
	1,1-dichloroethane	22,000
	1,1-dichloroethylene	20,000
	dichlorotrifluoroethane	6,400
	chloroform	6,400
	vinyl chloride	<1,000
Aromatic Hydrocarbons	toluene	75,000
	C_2-benzenes	36,000
	benzene	22,000
Aliphatic Hydrocarbons		~80,000
Others	benzofuran	1,800
	benzoaldehyde	1,800
	phenol	<1,000
	acetone	5,200
	methylbutynol	5,200
	methylbutanol	5,100
	methylpentanone	<1,000
	2-furancarboxaldehyde	<1,000
	dimethylethylborane	1,000
	benzonitrile	1,000
	2-propenenitrile	<1,000

TABLE 2. COMPOUNDS GENERATED BY HEATING COMMERCIAL INSULATION

Chloromethylpropane
Dichlorobenzene

Benzene
Toluene
Xylenes

Pyridine
Methylpyridine

Methylpropeneitrile
Benzonitrile
Methylbenzonitriles
Dimethylbenzonitrile

Carbon Disulfide
Methylthiophene
Methylisothiocyanate

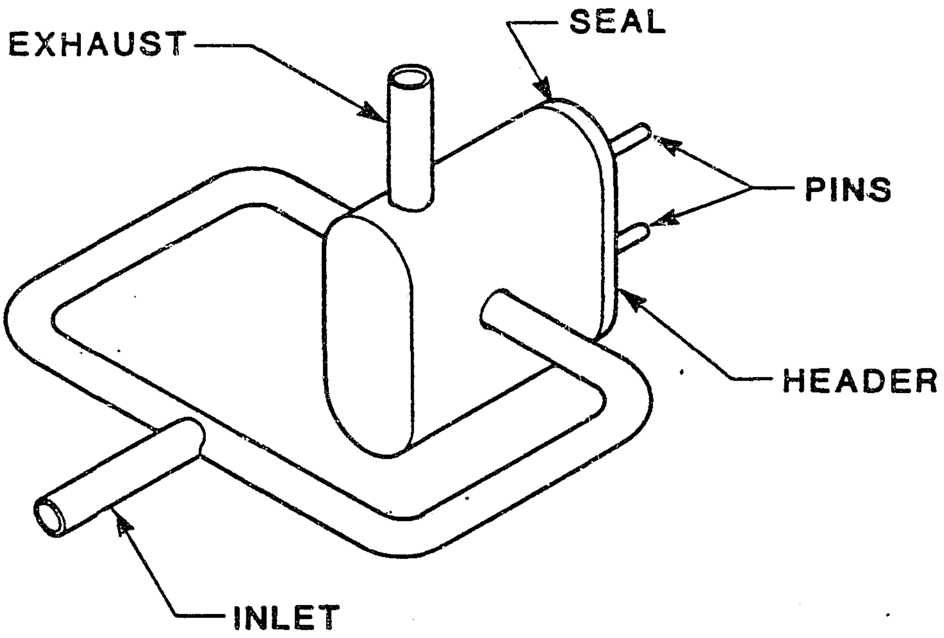


Figure 1. Experimental Arrangement for Evaluation of Quartz-Crystal Odorant Analyzer

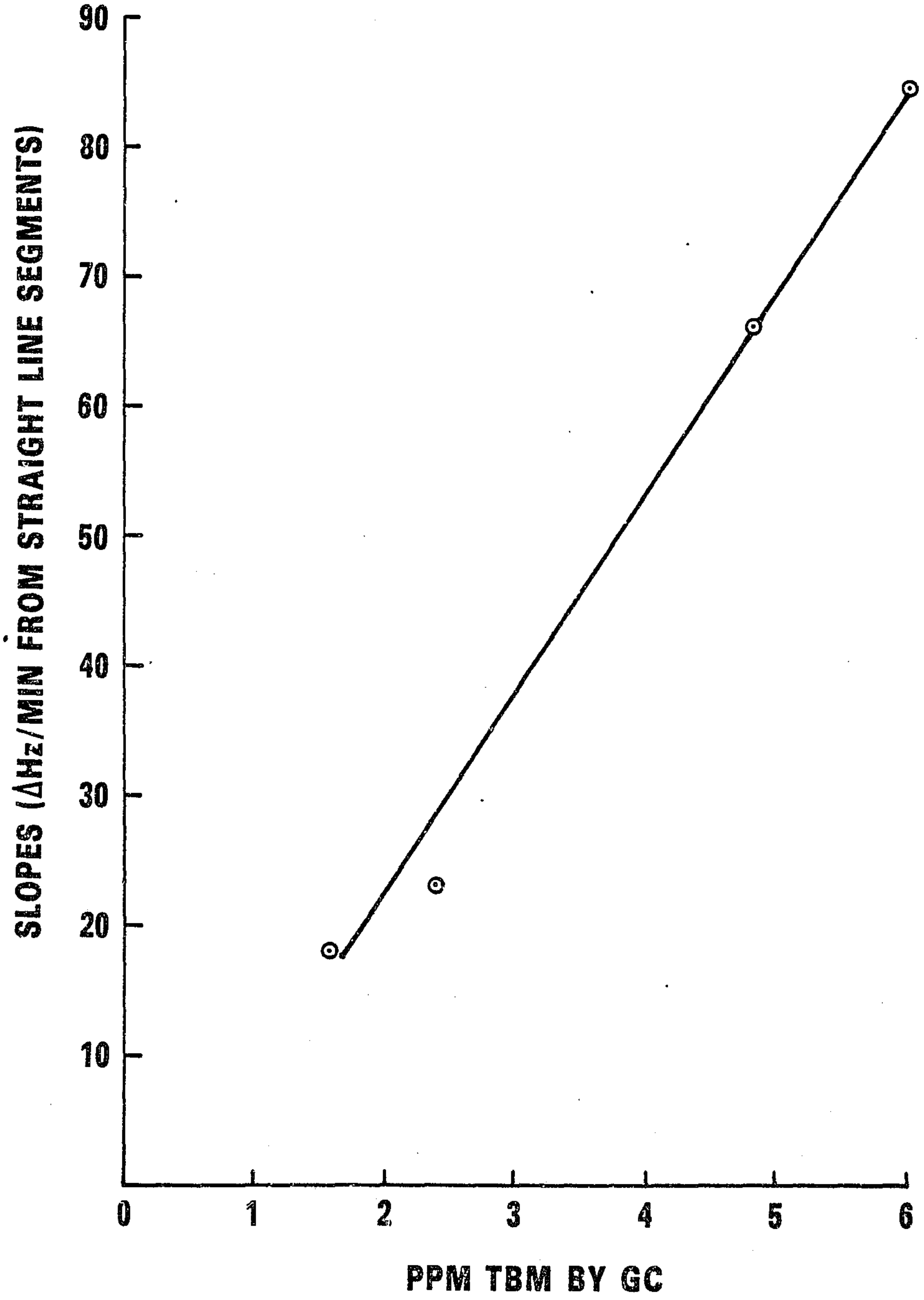


Figure 2. Response of Quartz-Crystal Sensor to Known Concentrations of Tertiary Butyl Mercaptan in Methane

National
Aeronautics and
Space
Administration

EXTENDED MISSION LIFE SUPPORT SYSTEMS

Prepared by
P. D. QUATTRONE

June, 1981

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

The material in this paper was presented at the Case For Mars Conference, Boulder, Colorado, April 30, 1981. This paper in its entirety, will be published by the Boulder Center for Science and Policy. Any inquiries for official conference papers and proceedings should be directed to:

Case For Mars
P. O. Box 4877
Boulder, CO 80306

This pre-print was prepared solely for internal use by NASA.

LIST OF ACRONYMS

ARS	Air Revitalization System
ARX-1	Air Revitalization System (Experimental) - 1 person
ASF	Amps per Square Foot
CELSS	Controlled Ecological Life Support System
C/M I	Control/Monitor Instrumentation
CRT	Cathode Ray Tube
EC/LSS	Environmental Control/Life Support Systems
EDC	Electrochemical Depolarized Concentrator
EDO	Enhanced Duration Orbiter
IARS	Independent Air Revitalization System
NSS	Nitrogen Supply Subsystem
OGS	Oxygen Generation Subsystem
PEP	Power Extension Package
R&D	Research and Development
RLSE	Regenerative Life Support Evaluation
RO	Reverse Osmosis
SF-WES	Static Feed - Water Electrolysis Subsystem
SOC	Space Operations Center
SPE-WES	Solid Polymer Electrolyte - Water Electrolysis Subsystem
SR&T	Supporting Research and Technology
SSP	Space Station Prototype
TIMES	Thermoelectric Integrated Membrane Evaporation Subsystem
VCD	Vapor Compression Distillation
WVE	Water Vapor Electrolysis

INTRODUCTION

Extended manned space missions, including interplanetary missions, will require regenerative life support systems. In order to place manned mission life support considerations into perspective, this paper will review previous manned space life support system technology, activities and accomplishments in NASA's current supporting research and technology (SR&T) program, the life support subsystem/system technologies required for an Enhanced Duration Orbiter (EDO) and a Space Operations Center (SOC), regenerative life support functions and technology required for manned interplanetary flight vehicles, and future development requirements.

BACKGROUND

The life support systems technology utilized on Projects Mercury, Gemini and Apollo used expendables: liquid oxygen (O_2) for breathing; lithium hydroxide (LiOH) canisters for carbon dioxide (CO_2) removal; activated charcoal canisters for trace contaminant removal; stored water for drinking and washing; stored freeze-dehydrated food; urine collection and storage and/or overboard dump; and collection, stabilization/treatment and storage of solid waste. These spacecraft had an atmosphere of 5 psia O_2 with no inert diluent gas.

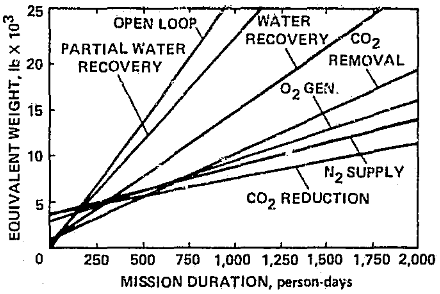
Skylab utilized a two-gas atmosphere (N_2 diluent at 1.5 psia) with a total pressure of 5 psia. Skylab also used a regenerable CO_2 removal subsystem (molecular sieve/silica gel adsorption beds).

The Space Shuttle Orbiter (Space Transportation System) ushers in a new era in American manned space vehicles. Not only is the Shuttle a reusable spacecraft, but the space cabin atmosphere is maintained at Earth ambient pressure of 14.7 psia (20% O_2 and 80% N_2). The early Shuttle flights will be seven-day flights, and the life support system flight hardware will still utilize expendables.

ADVANCED LIFE SUPPORT SYSTEMS TECHNOLOGY

Growth in space transportation capability will provide extended stay times for the Shuttle Orbiter, permanent manned facilities in low earth orbit, and ultimately, manned planetary vehicles. Regenerative life support technology is one of the rate controlling technologies for future manned space habitability including EDO, SOC and future manned planetary flight vehicles.

The use of expendables for life support, rather than regenerative techniques, for future manned missions beyond the seven-day Shuttle Orbiter, will become prohibitively expensive in terms of logistics costs. For example, the Skylab missions required the launching of 12,000 pounds of water. Regenerative systems hardware tends to be bulkier, heavier and more power consuming than short-term expendable systems. However, for some missions of only 40 person-day durations the penalties for utilizing the expendable approach will exceed any drawbacks of regenerative systems. Equivalent weight trade-off of regenerative *vs* total expendable (open loop) life support systems is shown in Figure 1.



SEQUENTIAL STEPS IN LOOP CLOSURE

DEFINITION	DESCRIPTION
PARTIAL WATER RECOVERY	HUMIDITY CONDENSATE COLLECTION
WATER RECOVERY	POTABLE WATER RECOVERY AND TREATMENT FROM URINE AND WASH WATER
CO_2 REMOVAL (NONEXPENDABLE)	REPLACEMENT OF EXPENDABLE LiOH WITH REGENERATIVE CO_2 COLLECTION TECHNIQUE
O_2 GENERATION	GENERATION OF O_2 THROUGH WATER ELECTROLYSIS USING RECLAIMED WATER
N_2 GENERATION	GENERATION OF N_2 THROUGH DISSOCIATION OF HYDRAZINE
CO_2 REDUCTION	DECREASE IN EXPENDABLE WATER BY RECOVERING PRODUCT FROM CO_2 REDUCTION (SABATIER) PROCESS

Figure 1. Regenerative vs Open Loop EC/LSS

Advanced life support systems technology, also referred to as Environmental Control/Life Support Systems (EC/LSS), consists of a number of areas including air revitalization, water reclamation, solid waste management, food service, and control/monitor instrumentation.

1. Air Revitalization System — This system integrates processes (subsystems) for: CO_2 removal, CO_2 reduction, O_2 generation, N_2 generation, humidity control, water handling, trace contaminant control, and control/monitor instrumentation for subsystem and integrated system operation.

2. Water Reclamation System — This system provides integrated processes for recovery of potable water from fuel cell water, cabin humidity condensate, wash water and urine. The system(s) must also include provisions for water quality monitoring, sterilization, and control/monitor instrumentation for subsystem and integrated system operation.

3. Solid Waste Management System — This system includes the collection, transfer, treatment and subsequent storage of treated/stabilized waste mass. Treatment processes are designed to minimize storage requirements, increasing in complexity from vacuum drying to sterilization to oxidation. Fecal water reclamation is feasible, but it is

impractical unless the solid waste treatment process can totally oxidize solid organic wastes. Fecal treatment leading to food generation is considered to be part of the Controlled Ecological Life Support System (CELSS) program and is not included in this paper.

4. Food Service System — This system involves packaging, storage and service of expendable foods for maintenance of proper human nutrition.
5. Control/Monitor Instrumentation — This technology category deals with the control, monitoring and fault diagnostic instrumentation required for reliable computer-controlled subsystem and/or system operation.

All of these technology areas, with the exception of Food Service Systems, will be discussed in this paper. This paper will emphasize the technology developments in Air Revitalization because of their relative complexity and the corresponding amount of SR&T activities completed and currently underway.

AIR REVITALIZATION

CO_2 Removal

Regenerable CO_2 removal techniques can utilize cyclic sorbers or continuous CO_2 removal processes such as an Electrochemical Depolarized Concentrator (EDC).

CO_2 Sorbers

Some solid materials such as molecular sieves or solid amines have the capability of preferentially adsorbing gases such as CO_2 on their surfaces. The adsorbed gases can then usually be desorbed by a combination of thermal and vacuum treatment processes. In all sorber system applications continuous adsorption capability is achieved only by using parallel adsorption beds which alternately cycle between adsorption and desorption operational modes.

Adsorption materials cannot provide a constant adsorption rate for any gas since the adsorption rate and capability of the material are dependent on the quantity of gas already adsorbed on the material. The adsorption rates attainable with a "nearly-spent" adsorption material are very low. As a result, the maintenance of low cabin partial pressures of the gas in question (e.g., $pCO_2 =$ 2-3 mm Hg) necessitates frequent bed recycling and large volume beds.

The molecular sieve material used for Skylab is a good CO_2 adsorber, but the material also preferentially adsorbs water vapor *vs* CO_2. Therefore, a silica gel sorber bed was required in series with the molecular sieve bed in order to preserve the CO_2 adsorption capability. The desorption cycle consisted of thermal treatment and overboard venting of the CO_2 and water vapor to space vacuum.

Solid amine CO_2 adsorption material is made from a spherical porous substrate coated with a non-volatile liquid amine. The substrate is a polymeric acrylic ester similar to plexiglas and the coating is a polyethylenimine with a molecular weight of 1800. The solid amine adsorbs CO_2 and also adsorbs water vapor.

The thermal/vacuum operational desorption mode for solid amines also involves the overboard venting of CO_2 and water vapor adsorbed on the bed(1). Such venting by any sorber subsystem may be used only on missions in which overboard CO_2 and water vapor dumping is permissible and advantageous. The solid amine sorber subsystem does, however, offer advantages over the silica gel/molecular sieve subsystem: lower weight, lower volume, reduced cabin heat load, and lower power requirements. The solid amine material has demonstrated negligible off-gassing (i.e., ammonia) with 1300 hours of endurance test time.

The solid amine CO_2 adsorber subsystem has also been proposed to be used in a steam desorbed mode (212 F, 14.7 psia), so that interfacing with a spacecraft CO_2 reduction subsystem is possible(2). Before this operational mode can be seriously considered the stability of the resin bed to a significant number of steam desorption cycles must be demonstrated, which has not occurred to date.

EDC

The EDC offers significant operational advantages and weight savings over non-regenerative techniques and sorber beds, especially at low cabin CO_2 partial pressures (2-3 mm Hg.)(3).

The EDC is an electrochemical method that continuously removes CO_2 from a flowing air stream and concentrates the CO_2 to a level useful for O_2 recovery. The CO_2 removal takes place in an electrochemical module consisting of a series of cells. Each cell (see Figure 2) consists of two electrodes separated by a matrix containing an aqueous carbonate electrolyte (Cs_2CO_3). Plates adjacent to the electrodes provide passageways for distribution of gases and electrical current. The electrochemical and chemical reactions that take place are:

Cathode:

$$O_2 + 2H_2O + 4e^- = 4OH^-$$

$$4OH^- + 2CO_2 = 2H_2O + 2CO_3^{-2}$$

Anode: (depolarized with H_2)

$$2H_2 + 4OH^- = 4H_2O + 4e^-$$

$$2CO_3^{-2} + 2H_2O = 4OH^- + 2\,CO_2$$

Overall:

$$2\,CO_2 + O_2 + 2H_2 = 2CO_2 + 2H_2O + \text{electrical energy \& heat}$$

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(1)References cited are listed at end of paper.

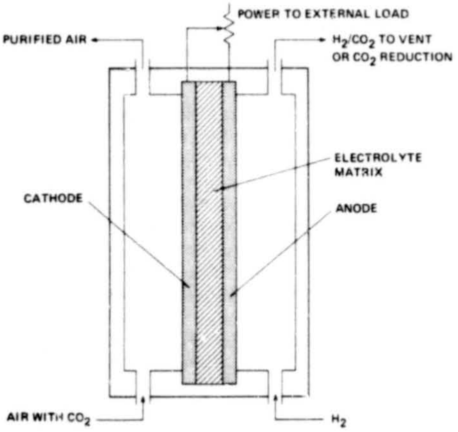

Figure 2. EDC Cell Functional Schematic

Two moles of CO_2 are theoretically transferred for one mole of O_2 consumed. This ratio represents the process efficiency, and 100% efficiency occurs when 2.75 g of CO_2 is transferred for each g of O_2 consumed. The electrical power produced by the EDC can be directly utilized by the Oxygen Generation Subsystem.

Considerable research and development work has been carried out with this concept and has resulted in increased process efficiency, demonstrated long-term performance and advanced hardware development status(4). Extended testing with EDC modules (single cells to six-person cell stacks) has exceeded over 2,000,000 cell-hours. Recent developments in the R&D program have resulted in a one-person capacity liquid-cooled module that has demonstrated a constant CO_2 removal efficiency of 91% over an inlet relative humidity range of 16-75%. In addition, this advanced module has demonstrated a static pressure differential capability of 60 psid, which is extremely important in interfacing with the Sabatier CO_2 reduction subsystem.

A three-person capacity EDC subsystem has been developed for the Regenerative Life Support Evaluation (RLSE) program (see Figure 3)(5). The EDC module in this subsystem is air-cooled, has demonstrated in excess of 72% CO_2 removal efficiency at 85% inlet relative humidity, and the CO_2 removal efficiency was increased by approximately 12% by operating the module at a 60% inlet relative humidity.

CO_2 Reduction

There are two principal methods for combining CO_2 with H_2 to form water for the eventual recovery of O_2. These are the Sabatier and Bosch processes. The factors that govern process selection deal with the availability of H_2 and the requirement for no overboard dumping of gases.

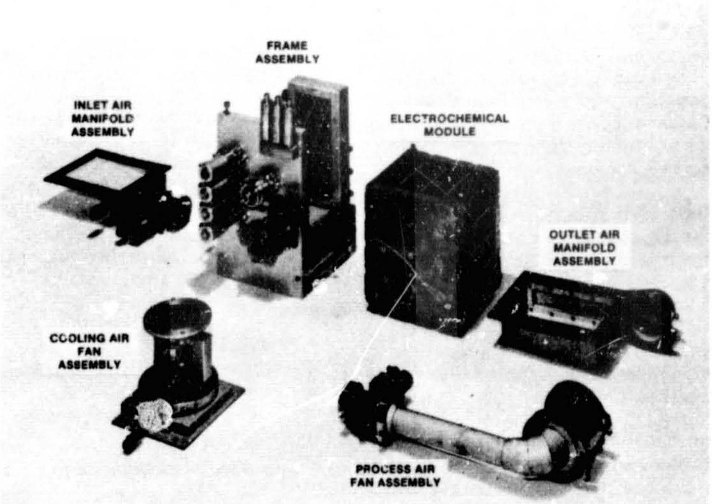

Figure 3. Three-Person RLSE CO_2 Removal Subsystem

Sabatier Process(6)

This CO_2 reduction process is ideally suited for an air revitalization system that uses a hydrazine-based N_2 generation subsystem. CO_2 and H_2 from the EDC enter the Sabatier reactor (see Figure 4) and are converted to methane (CH_4) and water per the following reaction:

$$4H_2 + CO_2 = 2H_2O + CH_4 + \text{heat}$$

The reaction occurs around 700 F and is aided by a catalyst. The water is condensed in a liquid cooled porous plaque condenser/separator. The exhaust gases, primarily CH_4, are vented overboard. Single pass high conversion efficiency (98-99%) subsystems have been developed.

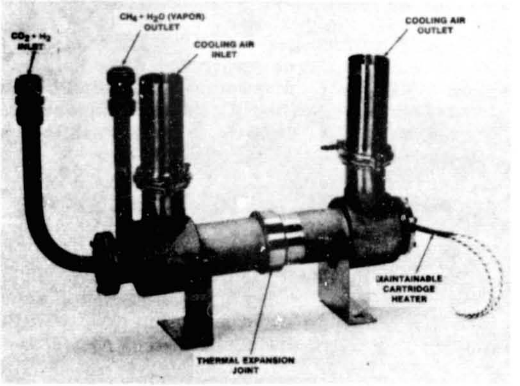

Figure 4. Sabatier Reactor

Bosch Process(7)

This CO_2 reduction process reduces CO_2 and H_2 to solid carbon (C) and water. The reaction occurs in the range of 980 - 1340 F in the presence of an iron (Fe) catalyst. The overall reaction is:

$$CO_2 + 2H_2 = C + 2H_2O + \text{heat}$$

In practice, single pass efficiencies through the Bosch reactor are less than 10%. Complete conversion is obtained by recycling the process gases with continuous deposition of carbon and removal of water vapor. The recycled gas mixture contains CO_2, carbon monoxide (CO), water vapor and CH_4. The carbon remains in the reactor and is collected in expendable cartridges. The Bosch development efforts have been limited, and a laboratory breadboard subsystem is shown in Figure 5.

In terms of equivalent weight, the Sabatier and Bosch CO_2 reduction processes trade off as shown in Figure 6 for an 8-person capacity SOC Application. The Bosch CO_2 reduction process does not trade off favorably with a Sabatier oriented ARS that uses a hydrazine-based N_2 generation subsystem. However, as cabin atmosphere leakage is reduced (less H_2 available for CO_2 reduction) and/or overboard venting of gases becomes detrimental to a mission, the Bosch process becomes attractive.

Oxygen Generation

Oxygen generation in a regenerative air revitalization system involves electrolyzing water recovered from on-

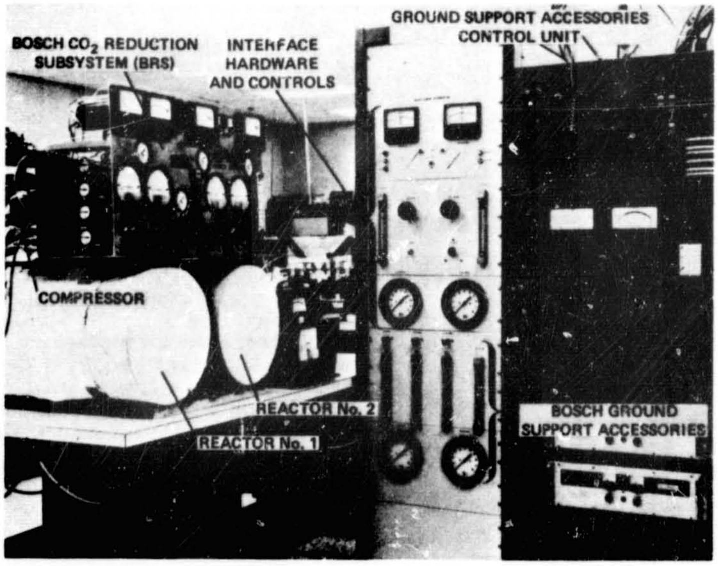

Figure 5. Bosch Laboratory Breadboard Subsystem

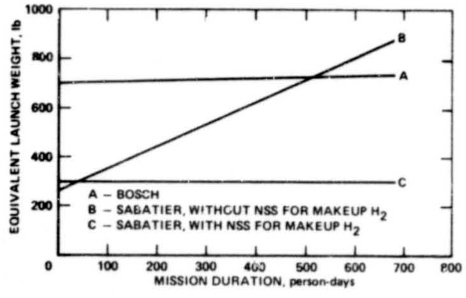

Figure 6. Comparison of CO_2 Reduction Subsystem Concepts

board waste water sources, cabin humidity condensate and from the CO_2 reduction process. In the electrolysis subsystems the electrolyte must be maintained between the electrodes, and the water that is electrolyzed must be replenished. This is not a simple task in zero gravity.

Two liquid-feed water electrolysis concepts offer the potential for minimizing and containing bulk electrolyte and maximizing the subsequent reliability and safety of the O_2 Generation Subsystem (OGS). These two concepts are the Solid Polymer Electrolyte (SPE-WES) and Static Feed (SF-WES) Water Electrolysis Subsystems.

SPE-WES(8)

The SPE-WES uses a perfluorinated sulfonic acid polymer membrane electrolyte in the electrolysis cells (see Figure 7). The electrolyte membrane is in contact with two electrodes and must be kept moist. In the case represented in Figure 7, the cathode cavity is flooded with liquid water. The electrochemical reactions that occur are:

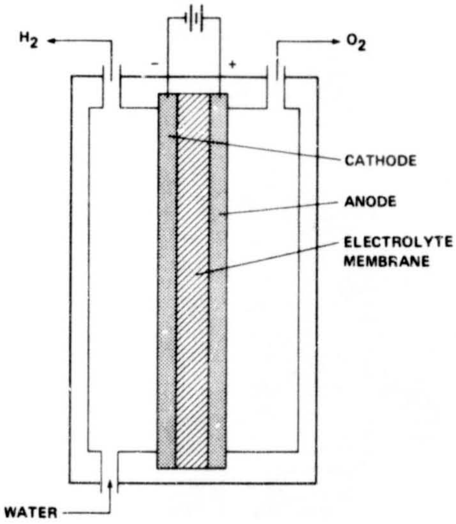

Figure 7. SPE-WES Cell Functional Schematic

Cathode:

$$4H^+ + 4e^- = 2H_2$$

Anode:

$$2H_2O = 4H^+ + 4e^- + O_2$$

A three-person capacity SPE-WES OGS that includes a twelve-cell electrolysis module (see Figure 8), has been developed for the RLSE program. This subsystem has demonstrated voltages of approximately 1.6 volts (V) at operating conditions of 180 F and a current density of 150 Amps per square foot (ASF). This subsystem offers advantages over other acid electrolyte water electrolysis technologies (low voltages and no free electrolyte in the subsystem), but it does require subsystem support components (and complexities) to deal with gas/liquid separation and removal of dissolved gases in the condensed water exhaust.

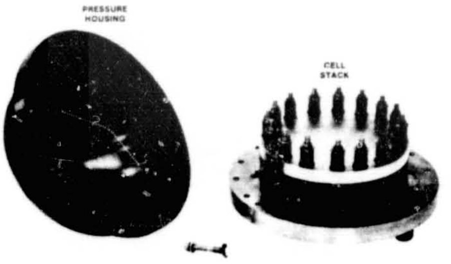

Figure 8. RLSE SPE-WES Module

SF-WES(9)

This concept utilizes static-feed water addition to an alkaline electrolyte (see Figure 9). The water is fed as vapor through the H_2 cavity to the electrolysis site (cathode/matrix/anode composite assembly). The reactions occurring in the alkaline electrolysis cells are:

Cathode:

$$4H_2O + 4e^- = 2H_2 + 4OH^-$$

Anode:

$$4OH^- = 2H_2O + O_2 + 4e^-$$

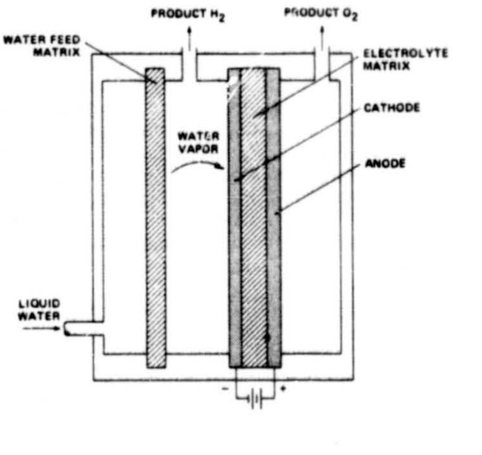

Figure 9. SF-WES Cell Functional Schematic

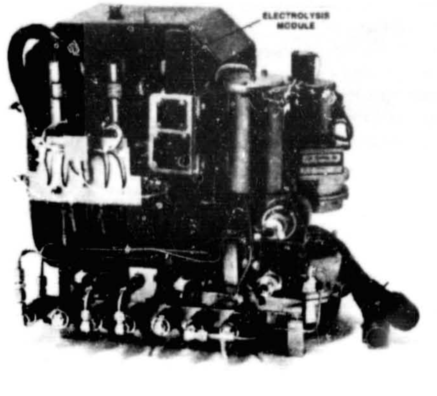

Figure 10. One-Person SF-WES OGS

Initially the water feed cavity, the water feed matrix and the cell matrix (with electrodes) contain an aqueous solution of potassium hydroxide (KOH) electrolyte at equal concentrations. When power is applied to the electrodes, water from the cell electrolyte is decomposed and the cell electrolyte concentration increases, with a resultant decrease in electrolyte vapor pressure. The vapor pressure of the electrolyte in the feed matrix causes water vapor to diffuse through the H_2 cavity and to be absorbed in the cell electrolyte matrix. This process establishes a new equilibrium based on the water requirements for electrolysis and humidification of the product gases and continues as long as electrical power is applied to the cell electrodes. When electrical power is discontinued, water vapor will continue to diffuse across the H_2 cavity until the electrolyte concentration in the cell matrix is equal to that in the water feed matrix and the water feed compartment.

The static-feed water addition concept is simple, reliable and minimizes subsystem components and controls. In addition, the use of alkaline electrolyte allows low cell voltages, which result in low power penalties. Long duration testing with the SF-WES and electrochemical modules has demonstrated voltages of 1.45-1.49V at operating conditions of 180 F and a current density of 150 ASF.

A self-contained one-person capacity SF-WES has been developed and is currently undergoing tests (see Figure 10).

Nitrogen Generation

With the advent of a two-gas space cabin atmosphere using nitrogen (N_2) as the diluent, storage and supply of N_2 for cabin leakage make-up is essential. The preferred method of providing N_2 make-up is to store the N_2 as hydrazine (N_2H_4), to catalytically dissociate the N_2H_4 into N_2 and H_2, and to separate the N_2 and H_2 gases(10). This concept is especially attractive if the Sabatier CO_2 reduction process is utilized (see Figure 6).

This Nitrogen Supply Subsystem (NSS) has a module containing catalytic dissociation and Pd/Ag passive gas separation stages. Dissociation of N_2H_4 (at 1350 F, 250 psia) involves the equilibria in the following reactions:

$$(1) \quad N_2H_4 = \tfrac{1}{3}N_2 + \tfrac{4}{3}NH_3$$

$$(2) \quad \tfrac{4}{3}NH_3 = \tfrac{2}{3}N_2 + 2H_2$$

A staging concept has been developed in order to separate the H_2 from the product N_2 and to reduce the NH_3 concentration in the product N_2 gas. A schematic demonstrating the staging concept is shown in Figure 11. All of the N_2H_4 and some NH_3 are catalytically dissociated in the first stage. The N_2, H_2 and non-dissociated NH_3 enter the first H_2 separation stage where most (90%) of the H_2 is removed and collected for use in the CO_2 reduction subsystem. The N_2 product gas stream then passes successively through

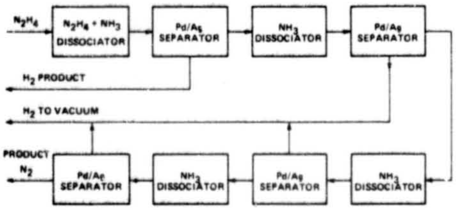

Figure 11. Nitrogen Generation Subsystem Schematic

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three additional dissociation/separation stages. This alternate dissociation/separation staging and subsequent venting of H_2 to vacuum (10%) is necessary to favor further NH_3 dissociation and thus to lower the H_2 and NH_3 concentrations in the product N_2. A nitrogen generation module that includes these stages is shown in Figure 12. Testing with this NSS hardware has demonstrated that the product N_2 stream contains less than 10 ppm NH_3 and 0.5% H_2.

Nitrogen generation using hydrazine should be considered as both a spacecraft resource or function and an air revitalization function. The hydrazine based N_2 generation approach utilizes expendable N_2H_4 (11 lb/day) to generate N_2 (9.6 lb/day) and provides H_2 (1.23 lb/day) for air revitalization. It is assumed that the NSS will be located external to the manned space cabin with bulkhead feedthroughs for product N_2 and H_2. This subsystem isolation not only contributes to safety considerations, but passive thermal control of the N_2 generation module and the use of space vacuum for byproduct H_2 would also be possible.

Trace Contaminant Control

Contaminants in a manned spacecraft emanate from both the crew and the equipment. As mission durations, vehicle sizes, crew sizes, and vehicle payload and experiment complexities increase and as spacecraft leak rates decrease, there will be a concomitant increase in concentration and variety of potential contaminants. In addition, the increased crew exposure time (with longer mission durations) will dictate a reduction in the allowable contaminant concentrations.

A spacecraft contaminant control subsystem that deals with an expected wide variety of contaminants will involve several elements including catalytic oxidation, charcoal adsorbers and chemical absorbers. No single contaminant control process is suitable for all contaminants. Some, such as CO, CH_4 and H_2, can be catalytically oxidized to CO_2 and water relatively easy. Some gases will poison oxidation catalysts and must be removed by pre-sorbent beds to protect the

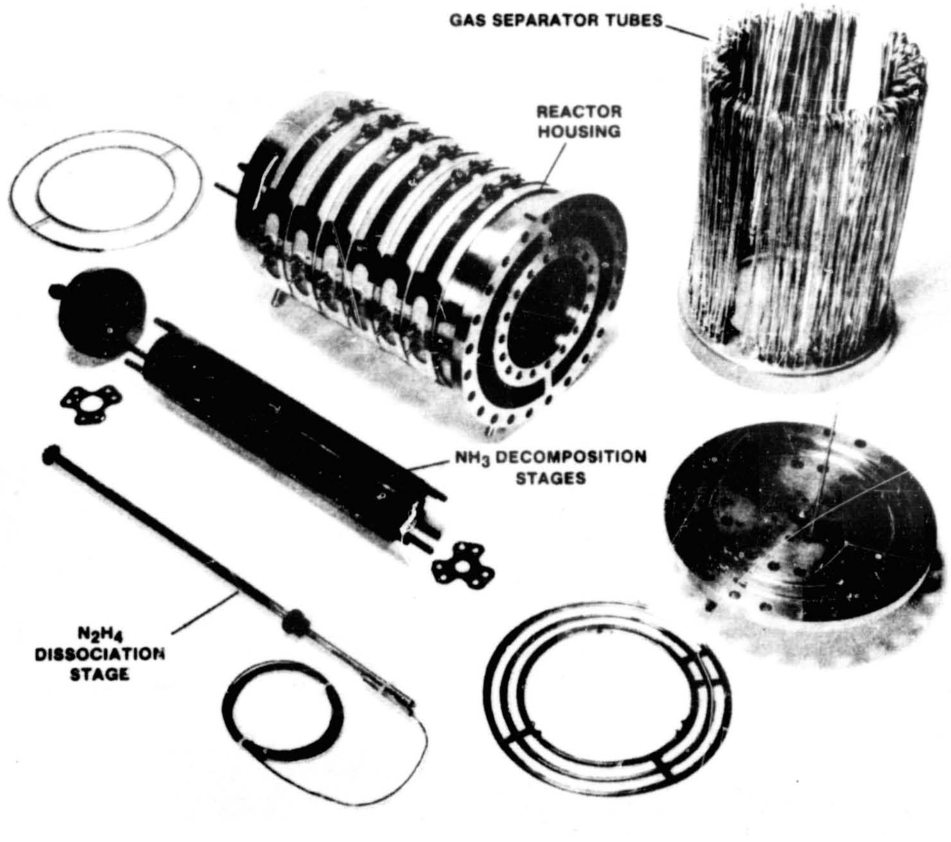


Figure 12. Advanced N_2 Generation Module

catalyst. Some gases, when oxidized, form extremely toxic substances (i.e., fluorocarbons form carbonyl fluoride) that must be removed by post-sorbent beds, and some organic materials cannot be oxidized efficiently and must be adsorbed.

A limited amount of work has been performed on adsorber/absorber characterization and on catalytic oxidation schemes. Some development efforts have also been directed toward regeneration of activated charcoal. These contaminant control R&D efforts have been very sporadic, and the technology has not progressed sufficiently to be commensurate with other regenerative air revitalization processes.

Air Revitalization System Integration

As mentioned previously, an Air Revitalization System (ARS) requires the individual subsystem technologies listed in Figure 13. An engineering breadboard integrated air revitalization system (ARX-1), including all ARS subsystem functions with the exception of contaminant control has been fabricated (see Figure 14).

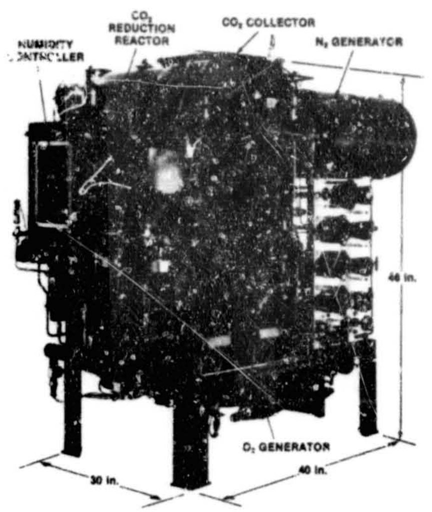


Figure 14. ARX-1

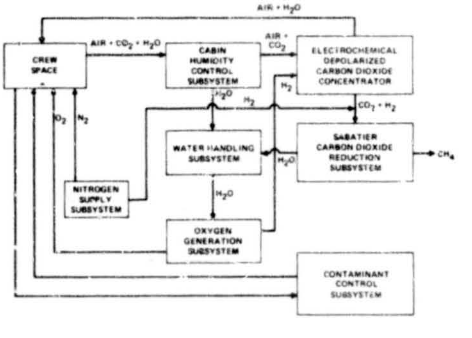


Figure 13. Air Revitalization System Block Diagram

Preliminary testing of the ARX-1 was conducted for a period of 120 days and included checkout, shakedown and endurance testing. Almost 500 hours of integrated operation at nominal steady-state conditions corresponding to a one person level were achieved. Additional testing, currently underway, will examine subsystem interactions by varying parameters such as CO_2 generation rate, humidity load, coolant temperature and power availability. One goal of this testing is to demonstrate the readiness of this integrated air revitalization system for prototype development and flight demonstration.

Control/Monitor Instrumentation

A major development goal of the advanced life support program is long duration operation with minimal servicing and maintenance by the crew and the avoidance of excessive crew training requirements. An integrated air revitalization system, for example, contains a range of electrochemical, chemical, mechanical and electrical components/subsystems; and automatic process control and monitoring are an absolute necessity.

This computer-based Control/Monitor Instrumentation (C/M I) must provide: monitoring capability; control functions including subsystem/system mode transitions; and fault diagnostics including fault prediction, fault detection, fault isolation, fault correction, and fault correction instructions. In addition, the C/M I hardware and software must be "operator error-proof."

Advanced life support C/M I developments have progressed along with current life support technology advancements. The early stages of C/M I development provided for manual or automatic operation. C/M I development has progressed through the hard-wired primary and emergency controller stage to a programmable mini-computer with a customized keyboard for operator commands, a Cathode Ray Tube (CRT) for operator/system messages, a system status panel, a system control panel, and an actuator override panel (see Figure 15).

The current stage of developmental C/M I is dedicated to the control and monitoring of engineering breadboard systems, such as the ARX-1 (see Figure 16). Test programs with advanced life support developmental hardware involve off-design, parametric and life testing. Therefore, C/M I components such as an actuator override panel are included. Advanced life support flight hardware will, of course, be dedicated to steady state operation; and the same is true for the

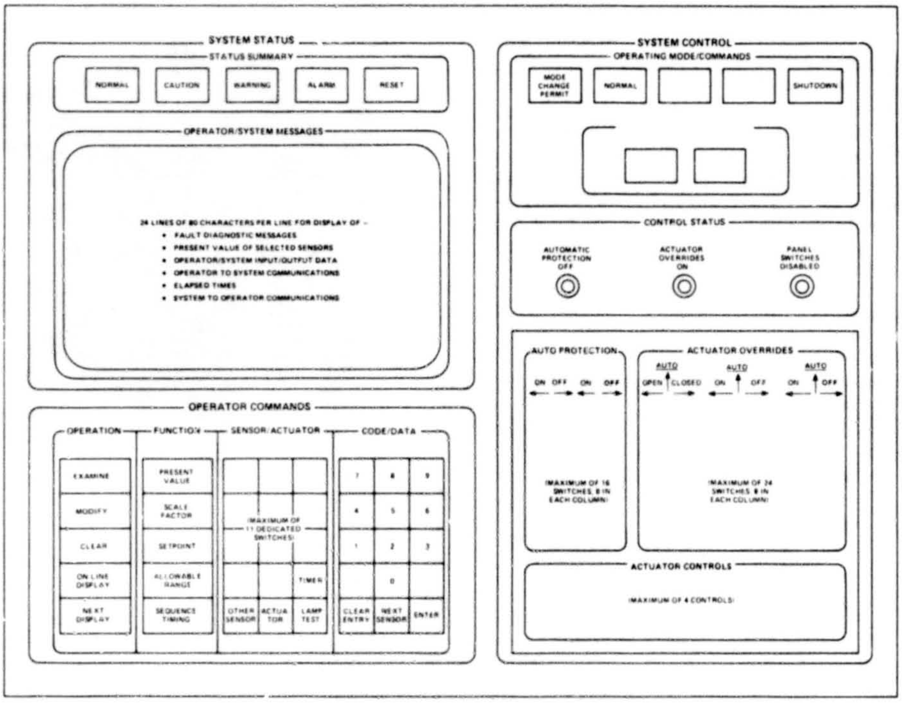


Figure 15. C/M I Control Panel

Figure 16. ARX-1 C/M I

C/M I. Therefore, flight C/M I hardware will become considerably smaller and will utilize dedicated microprocessors. A flight oriented C/M I design concept for an EDC subsystem is shown in Figure 17.

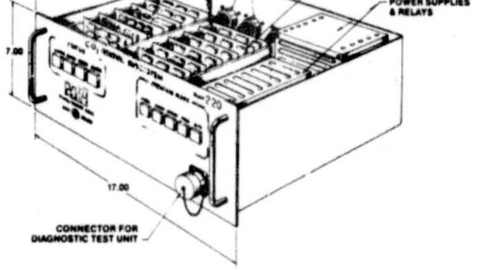
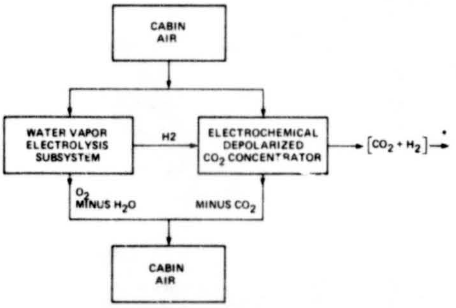


Figure 17. Flight-Oriented C/M I For CO_2 Removal Subsystem

C-3

Independent Air Revitalization System

NASA has investigated partial air revitalization systems for intermediate manned space applications. One of these is an Independent Air Revitalization System (IARS), which is perceived as a "semi-portable" ARS. The IARS includes a water vapor electrolysis (WVE) subsystem and an EDC subsystem. The IARS provides simultaneous CO_2 removal, O_2 generation and partial humidity control(11). The IARS can operate as a separate system, or it can operate as a back-up to a central ARS, described previously. A schematic of the IARS is shown in Figure 18.



*TO CO_2 REDUCTION SUBSYSTEM OR VENT

Figure 18. IARS Schematic

Water Vapor Electrolysis Subsystem

The WVE subsystem, which uses a hygroscopic electrolyte (H_2SO_4), absorbs water vapor from the cabin air stream and generates O_2 and H_2 per the following reactions:

Anode:

$$H_2O = \frac{1}{2}O_2 + 2H^+ + 2e^-$$

Cathode:

$$2H^+ + 2e^- = H_2$$

A functional WVE cell schematic is shown in Figure 19. Cabin air moisture is absorbed at the anode/electrolyte interface and the O_2 generated by electrolysis is released into the cabin air flowing through the anode compartment. Hydrogen (H_2) is generated at the cathode and is utilized at the anode of the EDC subsystem.

EDC Subsystem

The EDC subsystem technology used in the IARS has already been described in an earlier section of this paper; and the subsystem electrochemical module hardware is similar to the EDC RLSE hardware shown in Figure 3.

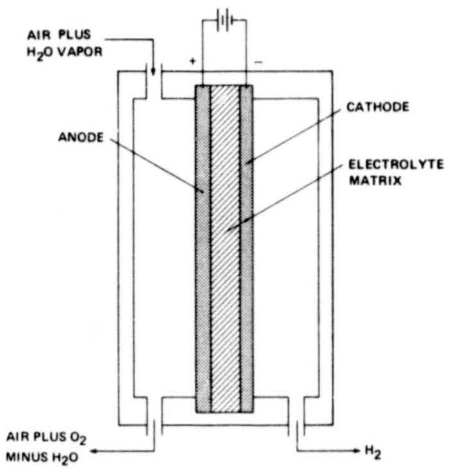


Figure 19. WVE Cell Functional Schematic

IARS Development Unit

A functional IARS development unit has been developed for the NASA RLSE program (see Figure 20), and a ninety (90) day characterization/endurance test program has been successfully completed with this three-person capacity IARS. Characterization testing included measuring the effect of cabin air pCO_2 and moisture levels on electrochemical cell performance (EDC and WVE cell voltages) and on CO_2 removal efficiency. For nominal operating conditions the EDC voltage averaged 0.4 V/cell at 20 ASF while the WVE voltage was 1.70 V/cell at 42 ASF. The CO_2 removal efficiency averaged 80% (2.2 lb. of CO_2 removed per pound of O_2 consumed). Additional testing of the above unit is scheduled.

WATER RECLAMATION

Water reclamation in a manned spacecraft is of equal importance with air revitalization. Water reclamation involves processes to reclaim water from waste water sources such as fuel cell water, cabin humidity condensate, wash water and urine. These waste water sources represent increasing degrees of contamination and will generally require reclamation processes of increasing complexity. Various processes, including multi-filtration, phase change and membrane processes, have been investigated for these applications; and limited subsystem and component development efforts have been undertaken to date.

Recovery of fecal water is considered to be difficult but feasible. Fecal water reclamation will be discussed briefly in the solid waste treatment section of this paper.

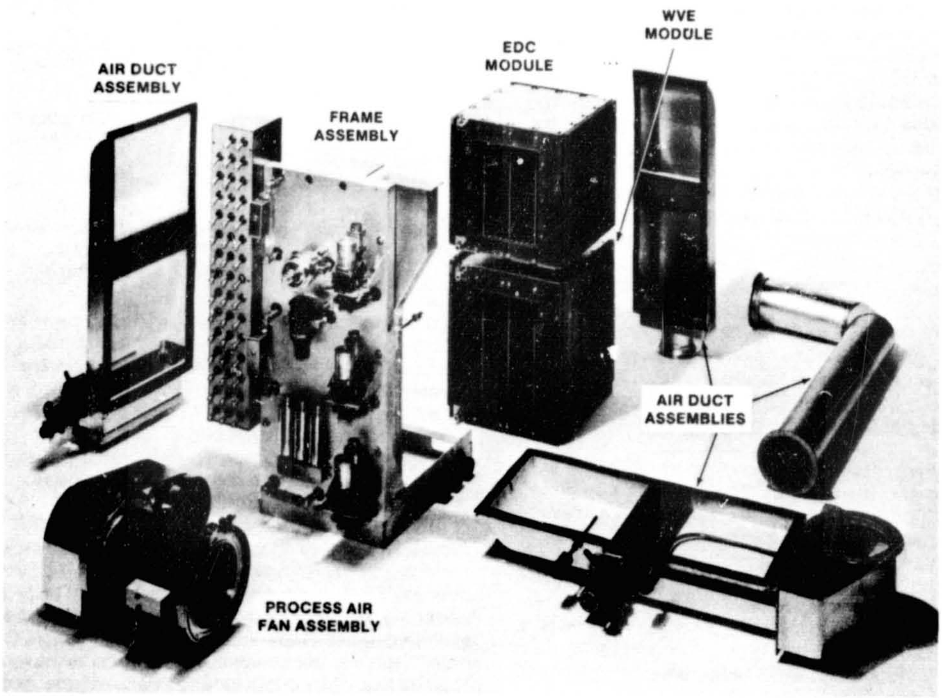


Figure 20. IARS RLSE Development Hardware

Multi-Filtration

Multi-filtration processes can be used for treating waste water containing contaminants in low concentrations (e.g., fuel cell water, cabin humidity condensate, and possibly wash water). Typically, a multi-filtration process will include a particulate/bacterial filter, an activated charcoal canister, an anion exchange resin bed, and a cation exchange resin bed(12). Very little development work has been performed in this area, and this process technology will not be discussed in further detail in this paper.

Phase Change Processes

Phase change processes that have been considered for spacecraft water reclamation from waste water sources such as urine include air evaporation, vapor compression distillation, vapor diffusion/evaporation, and a relatively new concept that uses vapor phase ammonia removal. In a distillation/condensation process, the goal is to retain the solutes (in a stabilized form) in the evaporator and to reclaim the energy involved with the vaporization process. Three of these concepts will be discussed in the following sections of this paper.

Vapor Compression Distillation

A Vapor Compression Distillation (VCD) process schematic is shown in Figure 21(13). The recovery of latent heat in the VCD process is accomplished by compressing the vapor to raise its saturation temperature and then condensing the vapor on a surface which is in thermal contact with the evaporator. The resultant

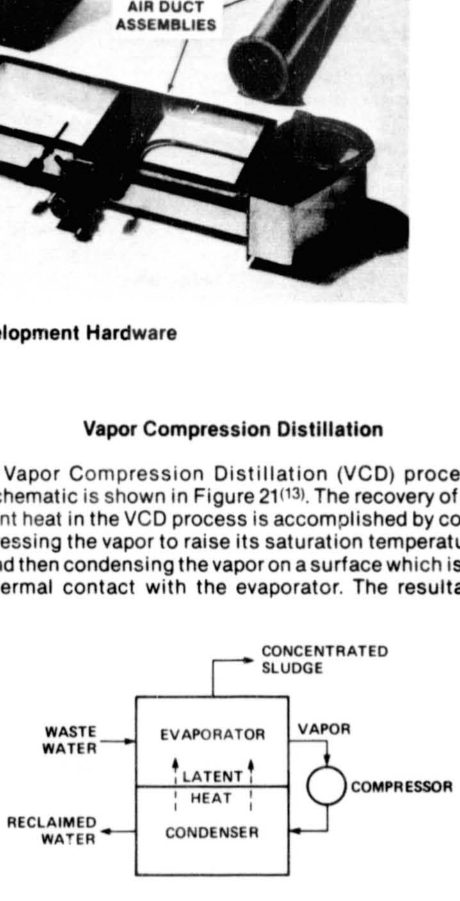


Figure 21. Vapor Compression Distillation Schematic

heat flux from the condenser to the evaporator is sufficient to evaporate an equal mass of water. Thus the latent heat of condensation is recovered for the evaporation process; and the only energy required by the process is that necessary to compress the vapor and to overcome the thermal and mechanical inefficiencies.

The VCD process occurs in a 70 to 95 F temperature range by maintaining a nominal condenser pressure of 0.70 psia. The evaporator, condenser and condensate collector are rotated at approximately 220 rpm to provide zero-gravity phase separation. The VCD components are sized to recover 96% of the water from the waste water feed by concentrating this feed stock to 50% solids. The VCD process requires pretreatment chemicals to complex with urea and to provide antifoaming in the evaporator. The product water from this subsystem requires post-treatment in charcoal and ion exchange beds in order to remove trace amounts of organic materials and dissolved NH_3, and the product water also requires the addition of small amounts of biocide to control bacterial growth.

Testing of two six-person capacity preprototype VCD units (one shown in Figure 22) has been completed with over 1000 hours of test time accumulated on each unit. Pretreated urine has been concentrated to 50% solids with water quality at projected levels (pH 5.0, conductivity of 16 μmho/cm nominal). Specific energies, expressed in watt-hours per pound of water recovered (the key VCD performance parameter), averaged from 45 to 55 W-h/lb. Additional testing of existing VCD units plus the development of an advanced development unit are underway.

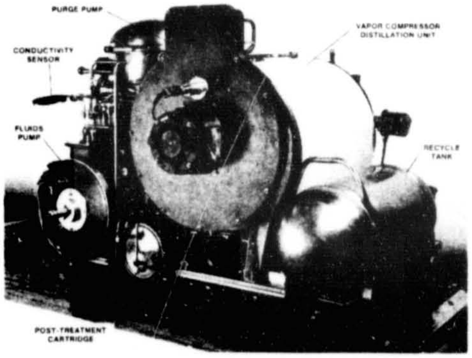


Figure 22. VCD Water Recovery Subsystem

Thermoelectric Integrated Membrane Evaporation Subsystem

A schematic of the Thermoelectric Integrated Membrane Evaporation Subsystem (TIMES) is shown in Figure 23. This concept(14) recovers the latent heat of condensation and transfers this heat to the evaporator via a thermoelectric heat pump. Waste water (urine), pretreated with a sulfuric acid/chromium trioxide solution, is heated to approximately 150 F in the thermoelectric heat exchanger, and the heated waste water is pumped through a hollow fiber polysulfone membrane evaporator module. The exterior of the module tubes is exposed to reduced pressure, and water evaporates from the tube surface and is condensed on a chilled porous plate surface in thermal contact with the cold junction surfaces of the thermoelectric heat exchanger. The heat of vaporization is provided by recycling the waste water to the heat exchanger where it is reheated and recycled. The product water from this subsystem concept requires the same post-treatment steps as those used by the VCD process. Typically the solids concentration in the recycle loop gradually increases until 95% of the original water is removed and the solids concentration is approximately 40%. At this point, the recycle tank containing the concentrated waste water sludge is removed for storage and a replacement tank is installed. The energy requirements for this process are primarily for the thermoelectric heat pump and for the subsystem pumps (recycle, cooling, and condensate).

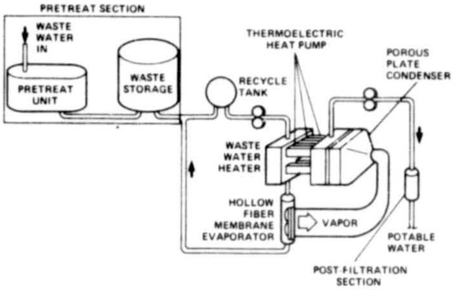


Figure 23. Thermoelectric Integrated Membrane Evaporation Subsystem Functional Schematic

A photograph of TIMES development hardware is shown in Figure 24. This subsystem has undergone limited testing and an analysis of subsystem performance cannot be made at this time.

Vapor Phase Catalytic Ammonia Removal

Ultimately, a water reclamation process that requires neither pretreatment nor post-treatment expendable chemicals would be desirable for manned spacecraft use. The vapor phase catalytic ammonia removal process offers this potential advantage(15). A schematic of the process is shown in Figure 25.

Waste water (urine) is vaporized, and the vapor stream is mixed with air or O_2 and passes through an oxidation reactor. Ammonia, urea and light organics are oxidized in this reactor. Water is condensed and separated, and the vapor phase then passes through a nitrous oxide (N_2O) decomposition reactor which converts the N_2O to N_2 and O_2. Studies with "laboratory-

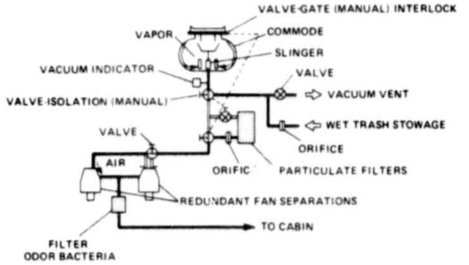


Figure 26. Solid Waste Management System/Space Shuttle

MANNED TESTING AND LIFE SUPPORT INTEGRATION

The majority of NASA's advanced life support R&D efforts have been directed at subsystem technologies or components, but there have also been efforts to integrate subsystem technologies and to perform manned chamber tests with the most advanced life support hardware available. These efforts were not directed particularly toward subsystem integration optimization, but they were directed toward manned chamber/life support subsystem hardware tests. The early manned chamber tests were performed successively at 30-, 60-, and 90-day durations(18, 19, 20) under the sponsorship of Langley Research Center.

Prototype integrated life support subsystem hardware has also been developed for "integrated systems" programs such as the Space Station Prototype (SSP) program (1971-1975)(21) and the Regenerative Life Support Evaluation (RLSE) program (1975-present) under the sponsorship of Johnson Space Center(22). This hardware has included: EDC CO_2 concentration, Sabatier CO_2 reduction, SPE water electrolysis O_2 generation, Independent Air Revitalization System (EDC CO_2 concentration and WVE O_2 generation), VCD urine water recovery subsystem, dynamic membrane wash water recovery subsystem, subsystem computerized C/M I and various components and sensors. The manned chamber tests and the testing of the SSP and RLSE hardware have been limited, but the subsystem SR&T program has benefited from both the hardware development phases and the test results.

ENHANCED DURATION ORBITER

As mentioned previously, the early Shuttle Orbiter flights will be limited to seven-day missions. In order to maximize the effective use of this Space Transportation System, Extended Duration Orbiter (EDO) missions of 30, 60 and 90 days are under active consideration. Such extended Orbiter missions will make it mandatory to reduce life support and auxiliary power (fuel cell) expendables. Significant weight savings for these missions can be realized by replacing the expendable lithium hydroxide canisters with a regenerable/continuous CO_2 removal subsystem. For longer missions, an IARS may also become applicable.

It should also be emphasized that if auxiliary power supplies such as the Power Extension Package (PEP) or a full power module (25 kW) are substituted for the Orbiter fuel cells, large O_2 and H_2 expendable requirements are eliminated; but large quantities of relatively clean fuel cell water will not be available for reclamation and subsequent use. Water reclamation from humidity condensate and wash water would then become attractive and provide weight savings.

SPACE OPERATIONS CENTER

The Space Operations Center (SOC) has been conceived as a modular space station serviced by the Space Shuttle. The SOC is a low earth orbit permanent manned facility with a 14.7 psia mixed gas atmosphere. A Shuttle resupply interval of 90 days is planned. The nominal volume for SOC is 22,000 ft^3, and the vehicle has been planned for a crew size of eight persons(23).

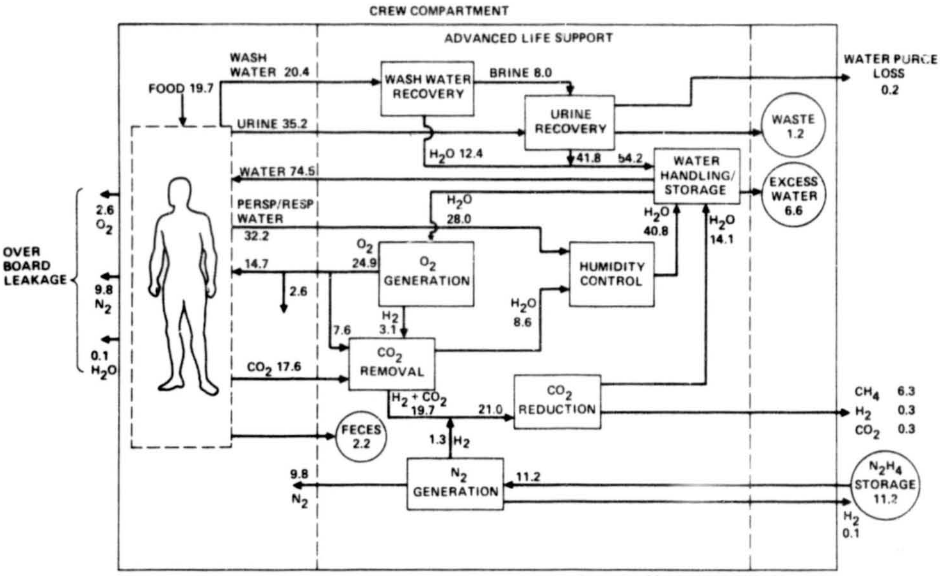
The SOC life support system is regenerative in order to minimize crew expendables. The life support system functional schematic and mass balances are shown in Figure 27. The baseline SOC life support system includes the following subsystems:

(1) liquid water electrolysis O_2 generation (solid polymer or static-feed)
(2) VCD urine water recovery
(3) hyperfiltration wash water recovery
(4) condensing heat exchanger humidity control
(5) EDC CO_2 control
(6) Sabatier CO_2 reduction
(7) hydrazine dissociation N_2 generation

The SOC life support system will regenerate all metabolic water and O_2 requirements. The only crew expendable requirement is wet food. Resupply of N_2H_4 will be required for the N_2 generation subsystem and subsequent cabin leakage make-up. Some expendables will also be required for filters, chemical beds, urine pretreatment chemicals, etc.

The SOC life support system configuration is planned so that reclaimed water from urine will be utilized primarily for O_2 production. The system will provide drinking water reclaimed from cabin humidity condensate, water vapor from the CO_2 concentrating process and water from the CO_2 reduction process. The mass balance demonstrates that surplus reclaimed water will be available beyond that required by the crew and the life support processes.

It should be emphasized that the SOC program is currently in the early definition phases, and it is possible that other life support subsystem technologies will replace the baseline subsystems in the future. The



ALL VALUES lb/day FOR 8-PERSON CREW

Figure 27. Space Operations Center Life Support System Functional Schematic and Mass Balance

controlling factors governing subsystem selection are, of course, the actual SOC project schedule and the concurrent subsystem development status.

MANNED INTERPLANETARY LIFE SUPPORT SYSTEMS

The life support functions required for manned interplanetary flight vehicles are essentially the same as those provided for Earth orbital space stations: regenerative air revitalization; water reclamation from humidity condensate, wash water and urine; and advanced solid waste management techniques.

It is anticipated that upgrading and possible substitution of subsystem technology will occur in order to increase performance capability and reliability. Subsystem selection and system integration will be dependent on the significant vehicle trade-offs that are relevant at the time of selection.

A Controlled Ecological Life Support System (CELSS) that includes food production is considered to be noncompetitive for a manned planetary flight vehicle, but a CELSS is applicable for space settlements (i.e., lunar, Mars, L_5, etc.).

FUTURE DEVELOPMENT REQUIREMENTS

The ultimate goal of NASA's advanced life support Research and Development (R&D) program is to develop the technology base for future manned space requirements. This program has been responsible for the successful developments that have been discussed in the advanced technology section of this paper.

It should be emphasized, however, that the current technology data base is not adequate for space mission planners. A significant amount of additional development activity in systems, subsystems and components must be accomplished. It should also be emphasized that the advanced life support systems technology developed to date deals with chemical processes that require proper gas/liquid separation in reduced gravity. However, none of the regenerative systems/subsystems/components described in the advanced technology section of this paper have been tested in reduced or zero gravity. Long term tests on spacecraft, such as Spacelab, are absolutely essential to the data base generation and to mission planners. Short term (approximately 30 sec) aircraft parabolic flight tests will not suffice.

NASA's advanced life support R&D program must address these issues in order to guarantee an adequate technology base for future manned space missions. An adequate technology base will not guarantee that future manned missions such as SOC or interplanetary flights will be carried out. The failure to develop the technology base *will guarantee* either that "we aren't going", or that future manned missions will require concurrent program and project hardware developments, which have historically resulted in large cost overruns (e.g., Shuttle).

In order to develop an adequate technology base, it is essential that additional R&D efforts at the following technology levels be carried out:

(1) Flight technology demonstrations

(2) System developments

(3) Subsystem developments

(4) Components/parts developments

(5) Engineering analysis/applications, system and trade studies

(6) Basic and applied research (scientific and engineering data)

These efforts are essential for air revitalization, water reclamation and solid waste management.

It is obvious from the advanced technology development section of this paper that the development status for air revitalization, water reclamation and solid waste management systems differs significantly, with air revitalization system/subsystem technology having the highest. A ten-year development plan that delineates the currently obvious additional technology level requirements for air revitalization is shown in Figure 28. This listing is not all-inclusive, but

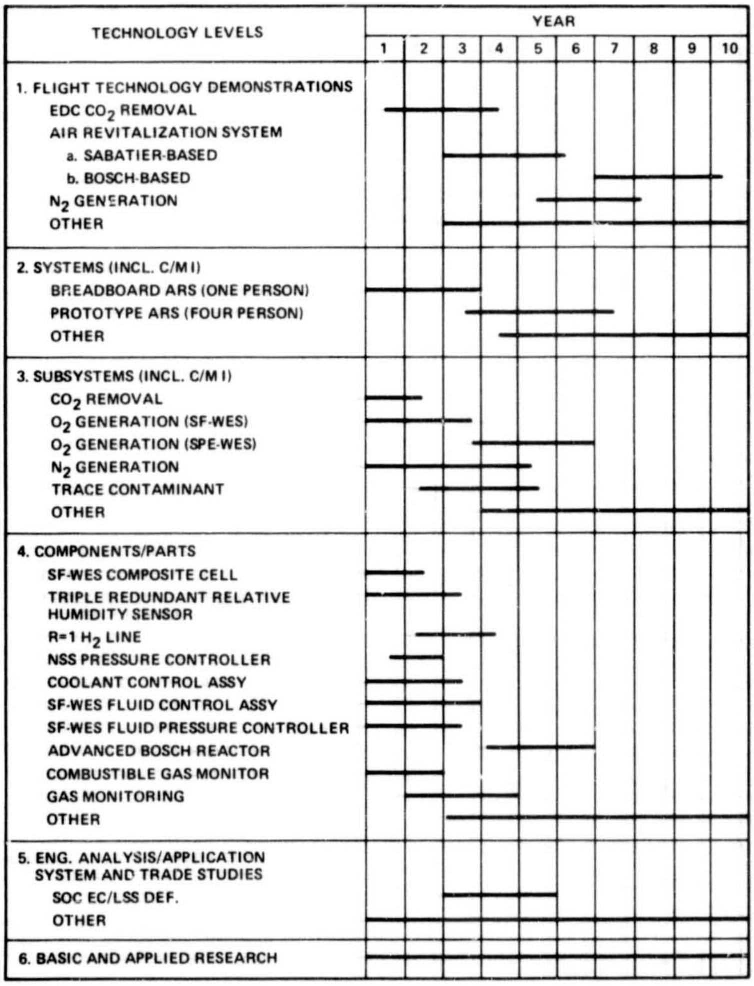


Figure 28. ARS Development Schedule According To Technology Levels

it clearly demonstrates the magnitude of R&D activity that must be performed in order to establish the required air revitalization technology base. One of the Space flight technology demonstrations identified in Figure 28 is a Sabatier based Air Revitalization System (ARS). A mock-up of this ARS flight demonstrator is shown in Figure 29.

Program planning activities are required in order to establish similar ten-year program requirements for water reclamation and solid waste management. The identified technology data gaps must, of course be filled if advanced water reclamation and solid waste management systems technology is to be selected and baselined for future manned space flight hardware.

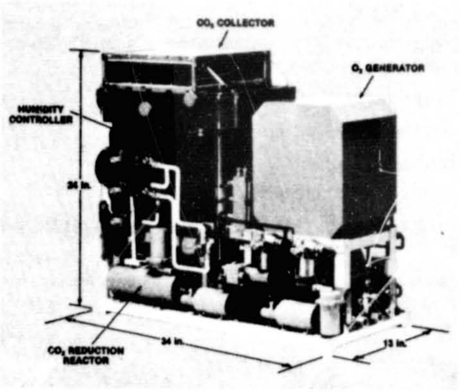


Figure 29. ARS-Space Flight Demonstrator Mock-Up

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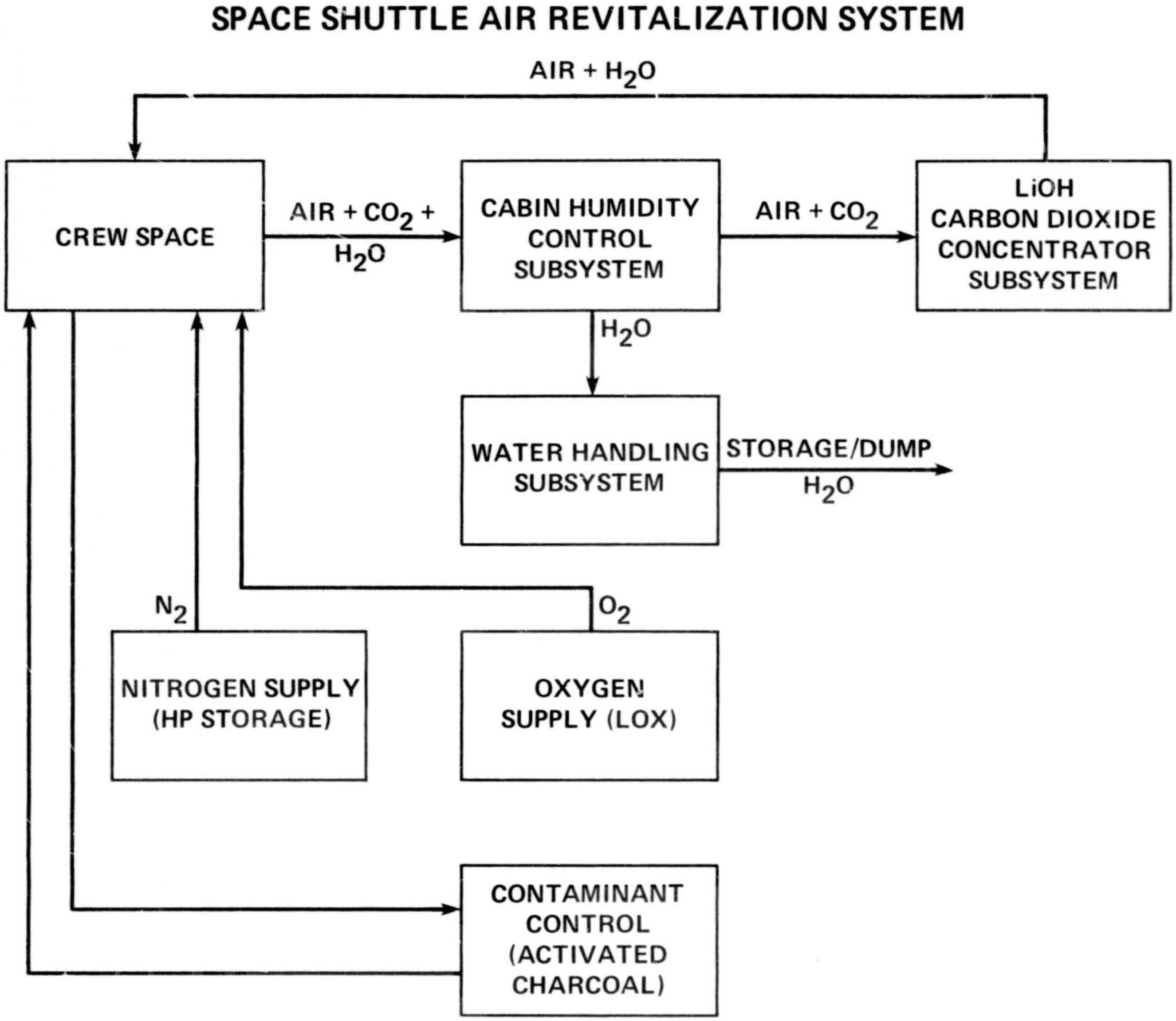
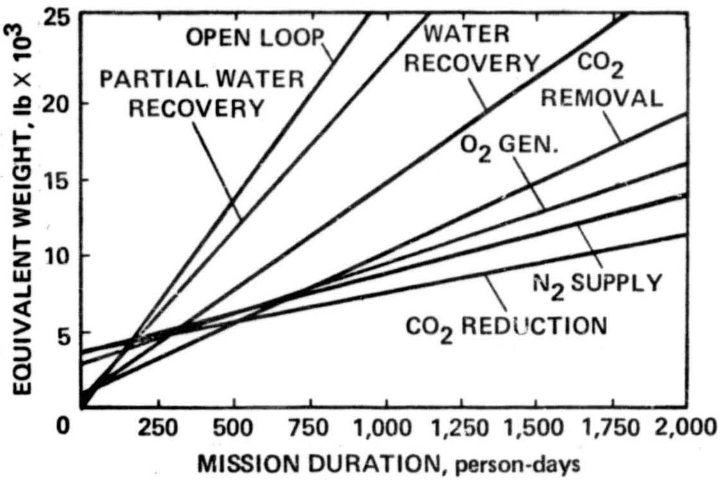


QUATTRONE FIGURE 1
SPACE SHUTTLE AIR REVITALIZATION SYSTEM

QUATTRONE FIGURE 2

REGENERATIVE vs OPEN LOOP ECLSS
TRADE-OFFZ

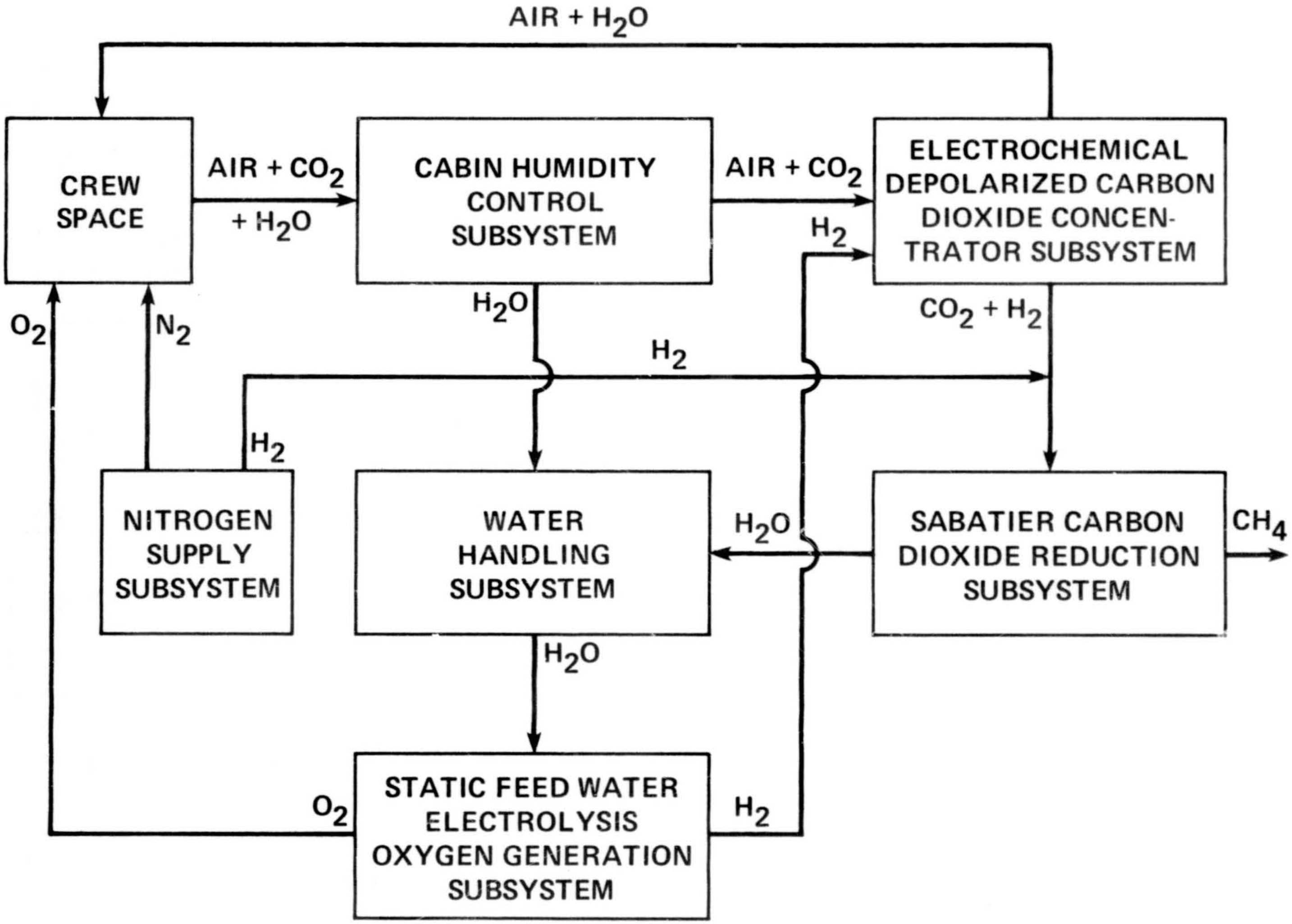
REGENERATIVE vs OPEN LOOP EC/LSS



SEQUENTIAL STEPS IN LOOP CLOSURE

DEFINITION	DESCRIPTION
PARTIAL WATER RECOVERY	HUMIDITY CONDENSATE COLLECTION
WATER RECOVERY	POTABLE WATER RECOVERY AND TREATMENT FROM URINE AND WASH WATER
CO_2 REMOVAL (NONEXPENDABLE)	REPLACEMENT OF EXPENDABLE LiOH WITH REGENERATIVE CO_2 COLLECTION TECHNIQUE
O_2 GENERATION	GENERATION OF O_2 THROUGH WATER ELECTROLYSIS USING RECLAIMED WATER
N_2 GENERATION	GENERATION OF N_2 THROUGH DISSOCIATION OF HYDRAZINE
CO_2 REDUCTION	DECREASE IN EXPENDABLE WATER BY RECOVERING PRODUCT FROM CO_2 REDUCTION (SABATIER) PROCESS

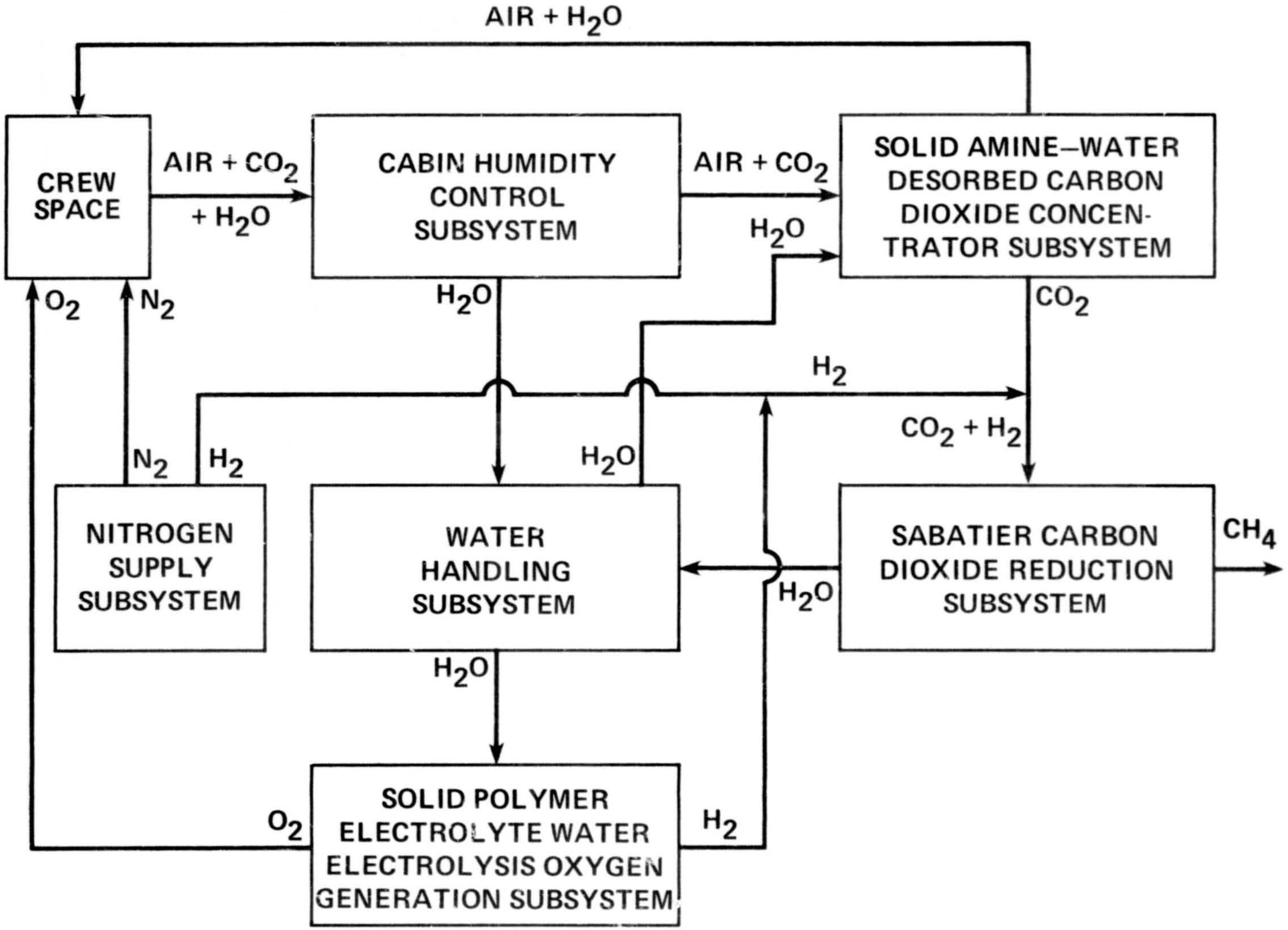
REGENERATIVE AIR REVITALIZATION SYSTEM



QUATTRONE FIGURE 3

REGENERATIVE AIR REVITALIZATION SYSTEM SCHEMATIC

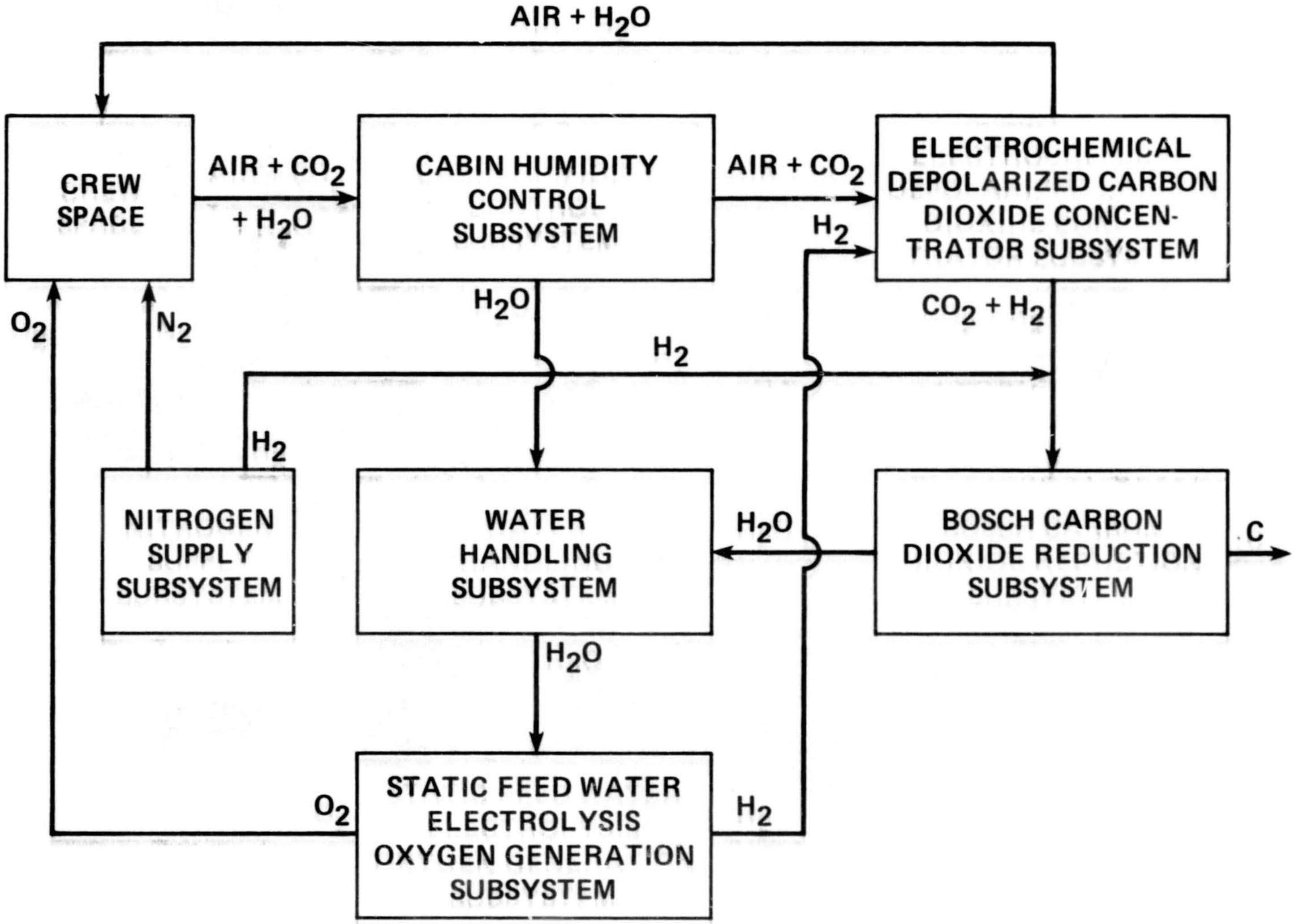
REGENERATIVE AIR REVITALIZATION SYSTEM



QUATTRONE FIGURE 4

REGENERATIVE AIR REVITALIZATION SYSTEM SCHEMATIC

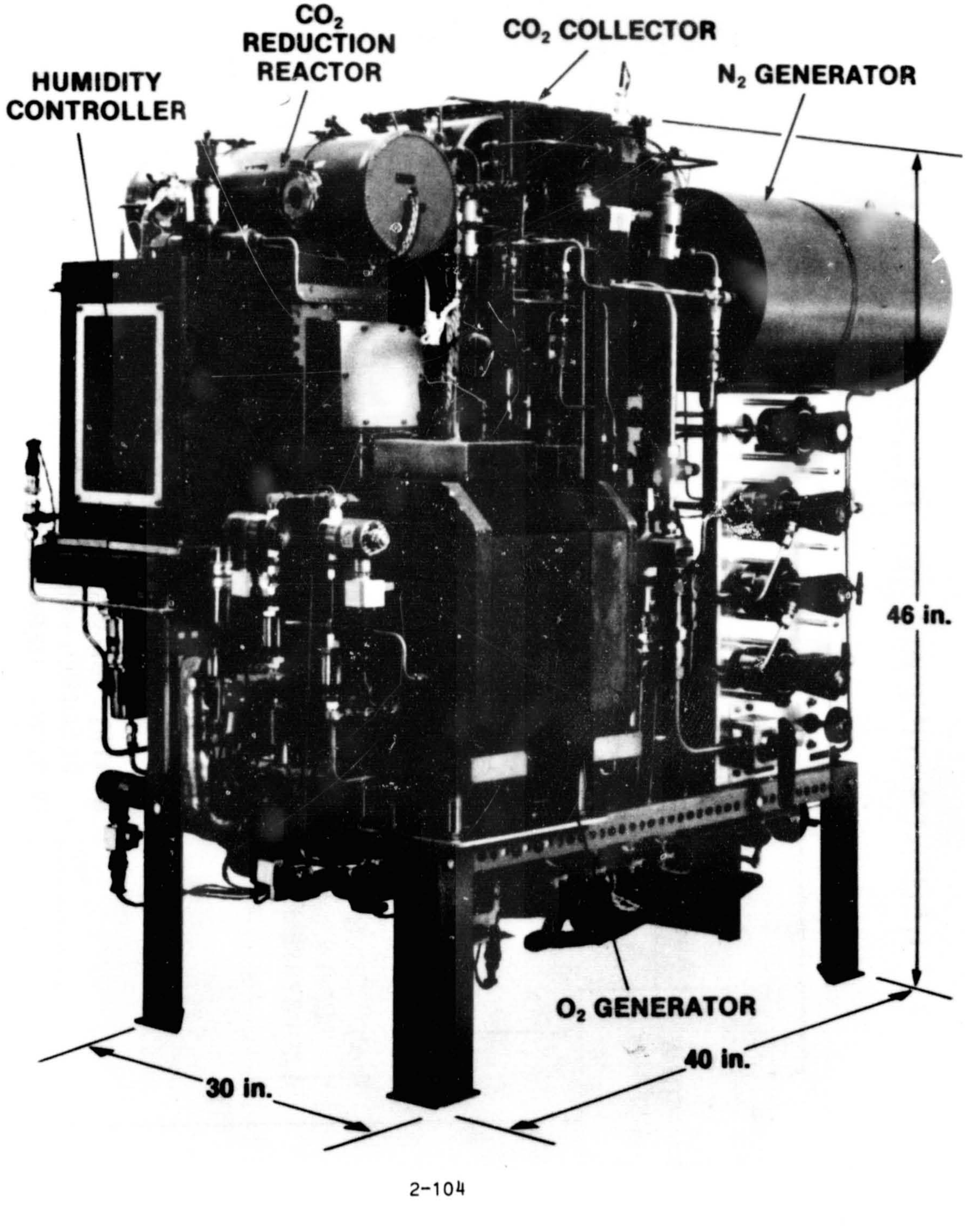
REGENERATIVE AIR REVITALIZATION SYSTEM



QUATTRONE FIGURE 5
REGENERATIVE AIR VITALIZATION
SYSTEM SCHEMATIC, NUMBER 2.

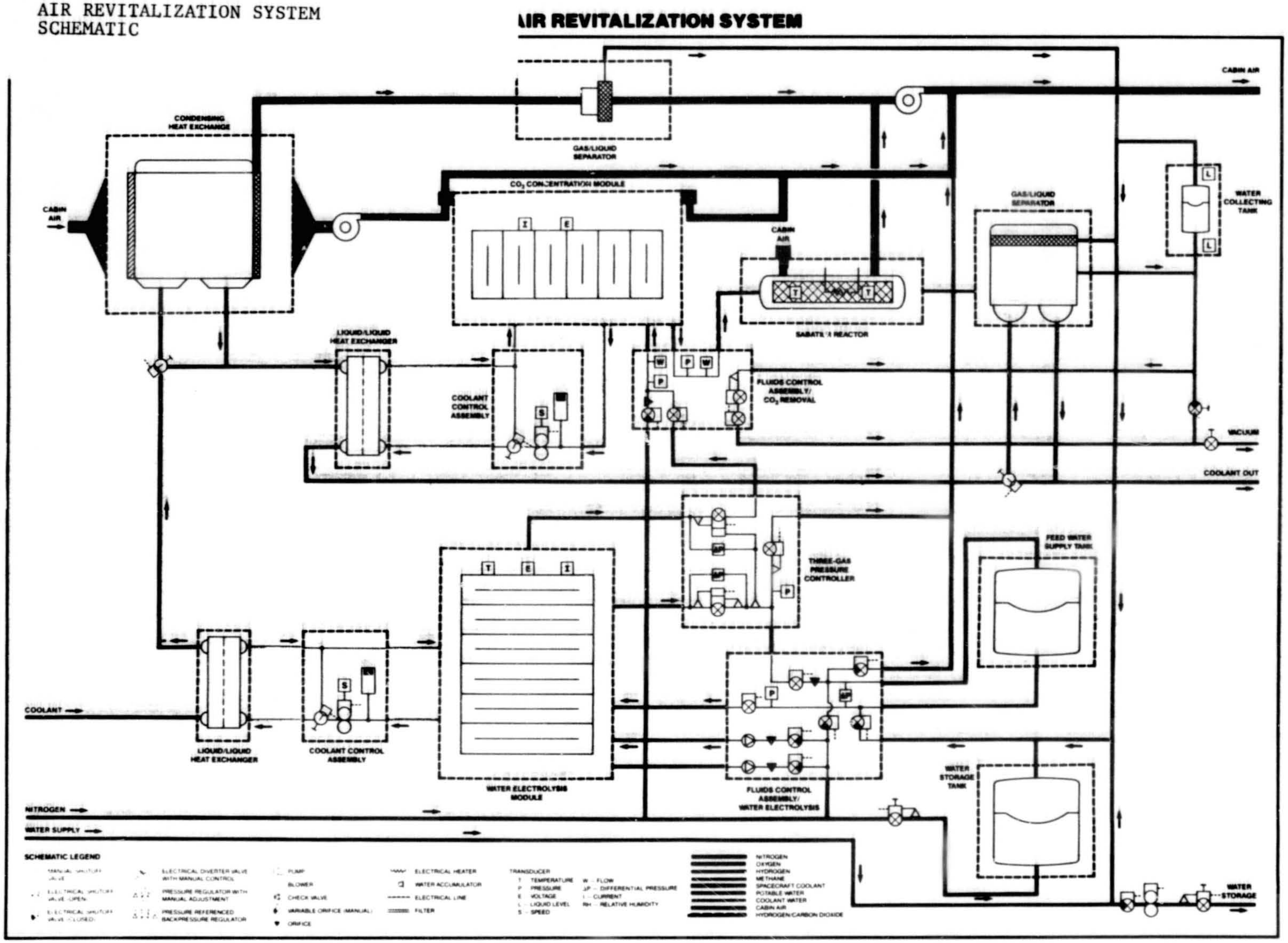
QUATTRONE FIGURE 6

EXPERIMENTAL AIR REVITALIZATION SYSTEM



QUATTRONE FIGURE 7

AIR REVITALIZATION SYSTEM
SCHEMATIC



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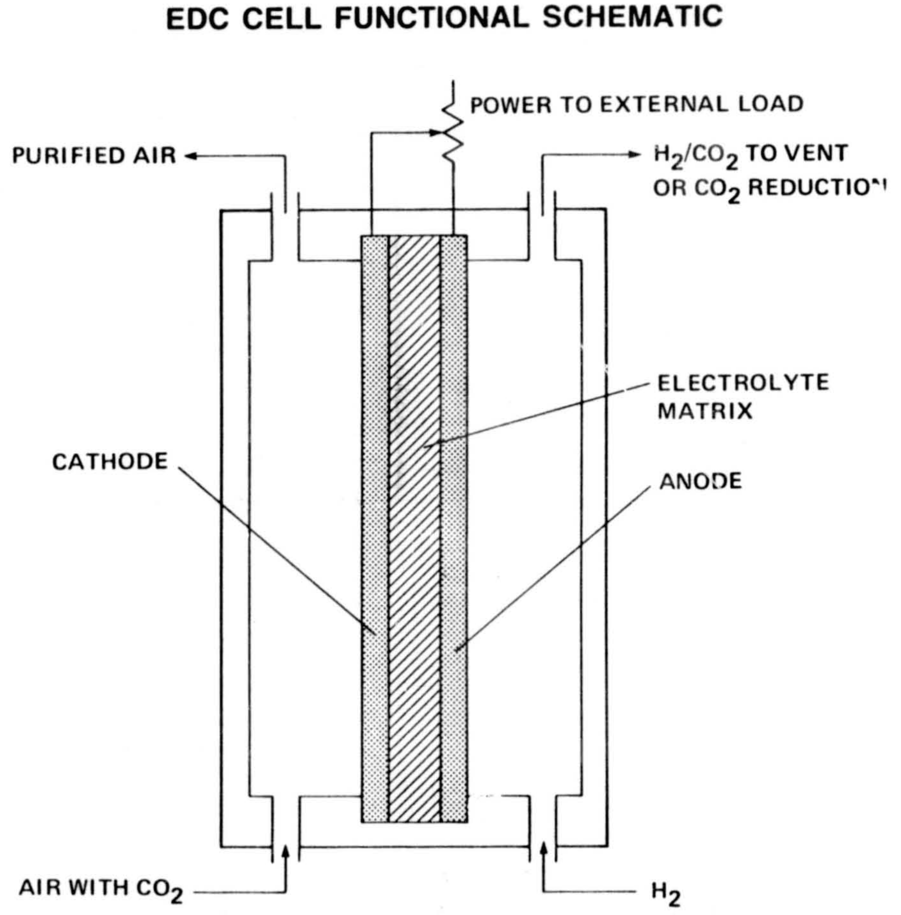
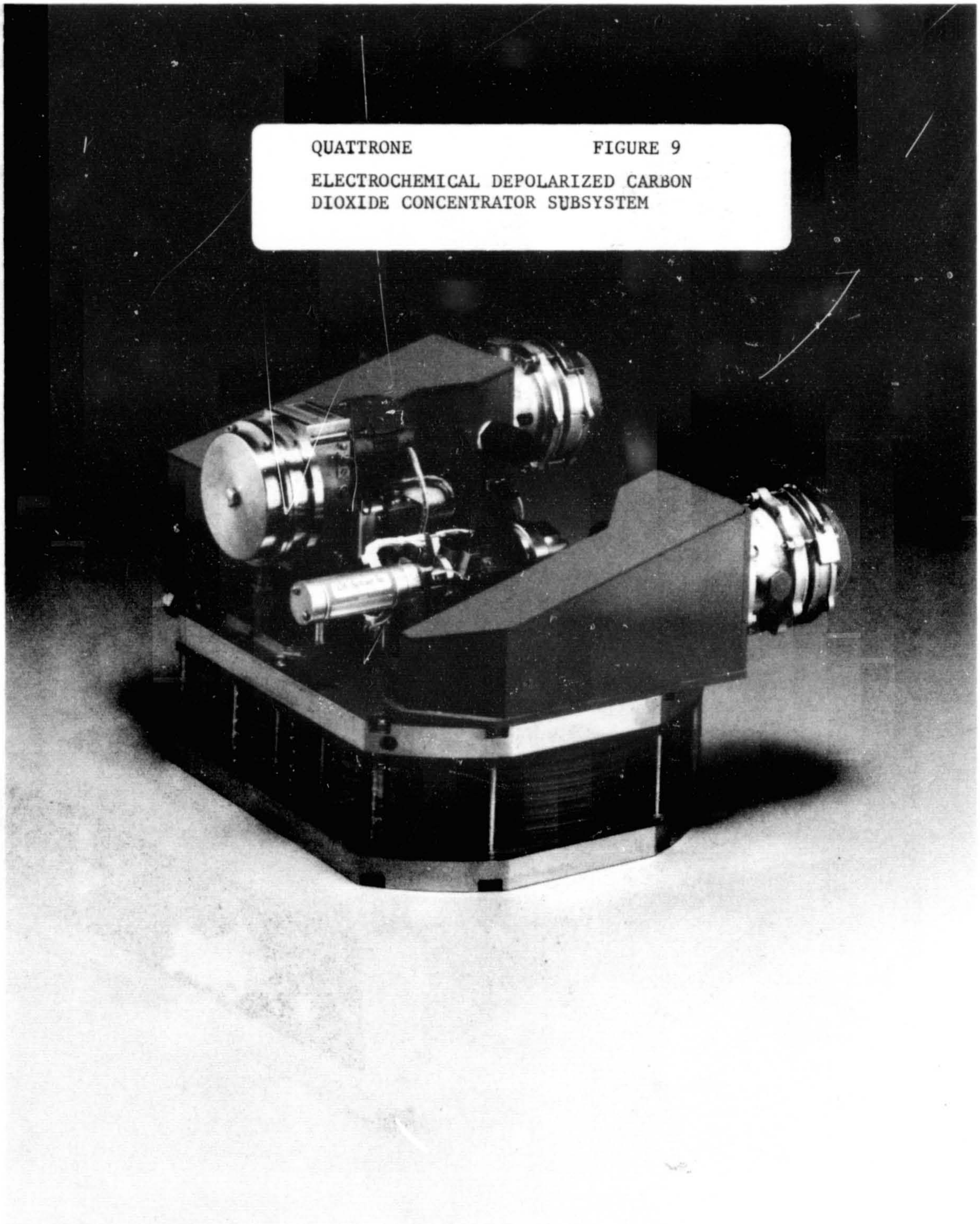
QUATTRONE FIGURE 8

ELECTROCHEMICAL DEPOLARIZED CARBON
DIOXIDE CONCENTRATOR CELL
SCHEMATIC



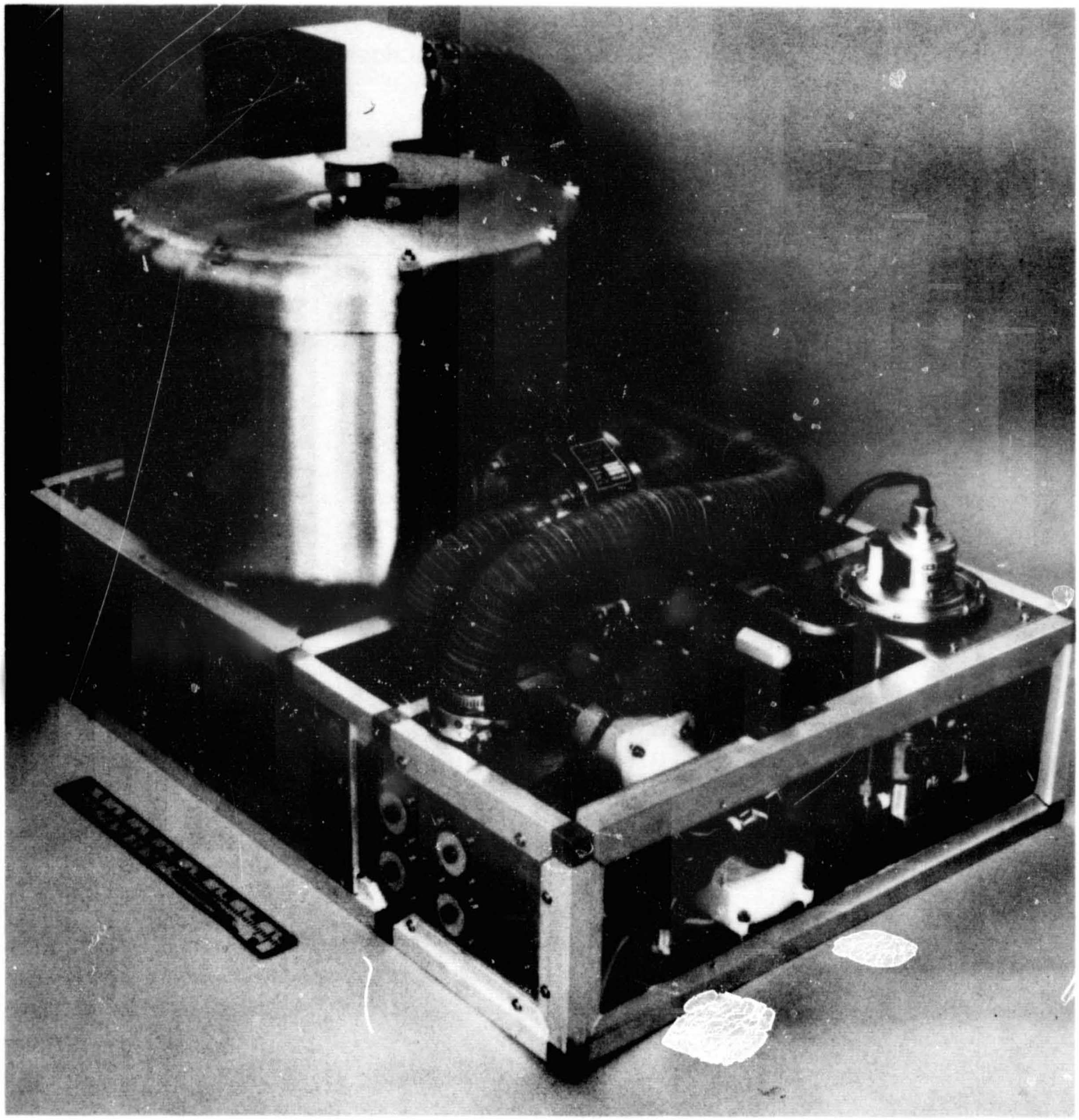


QUATTRONE FIGURE 9

ELECTROCHEMICAL DEPOLARIZED CARBON DIOXIDE CONCENTRATOR SUBSYSTEM

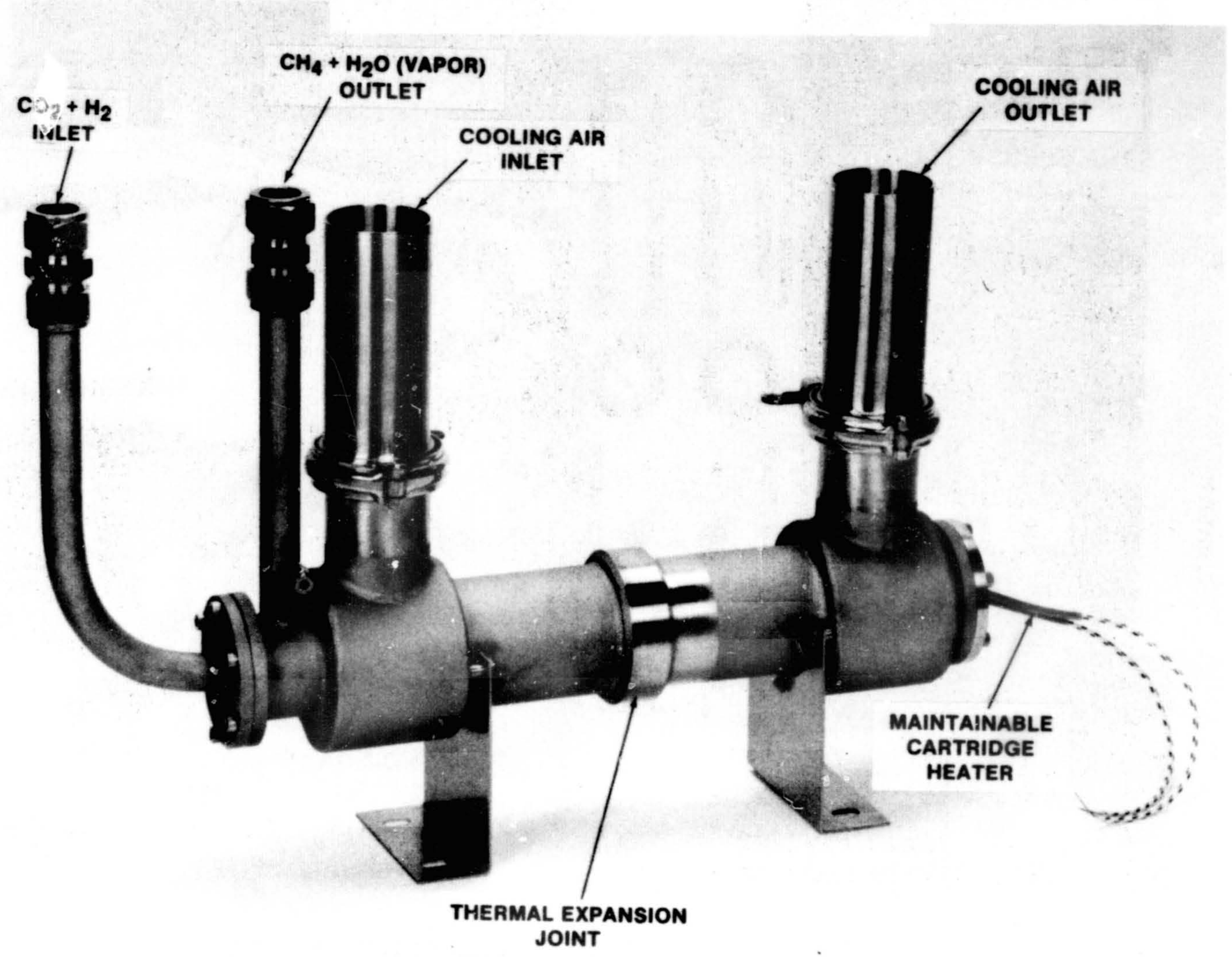
QUATTRONE FIGURE 10

SOILD AMINE-WATER DESORBED CARBON
DIOXIDE CONCENTRATOR SUBSYSTEM



QUATTRONE FIGURE 11

SABATIER CARBON DIOXIDE
REDUCTION SUBSYSTEM



BOSCH LABORATORY BREADBOARD SUBSYSTEM

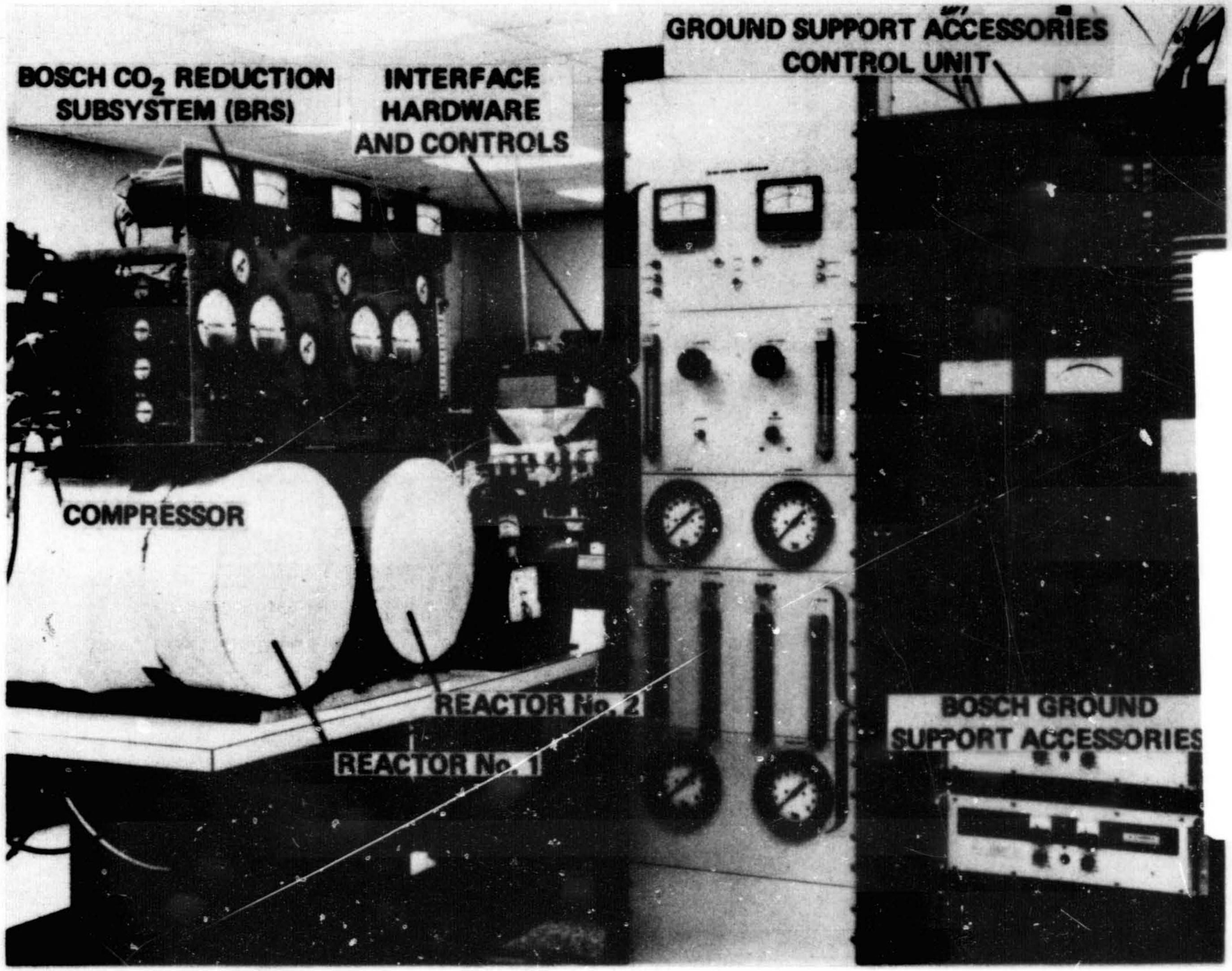


FIGURE 12

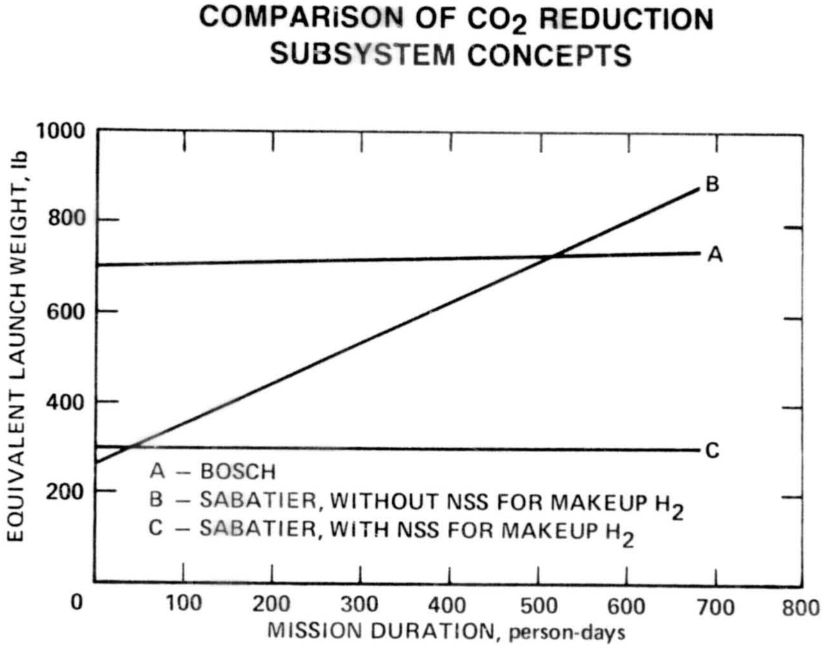
QUATTRONE

BOSCH CARBON DIOXIDE REDUCTION
SUBSYSTEM

QUATTRONE

FIGURE 13

SABATIER/BOSCH TRADE-OFF COMPARISON



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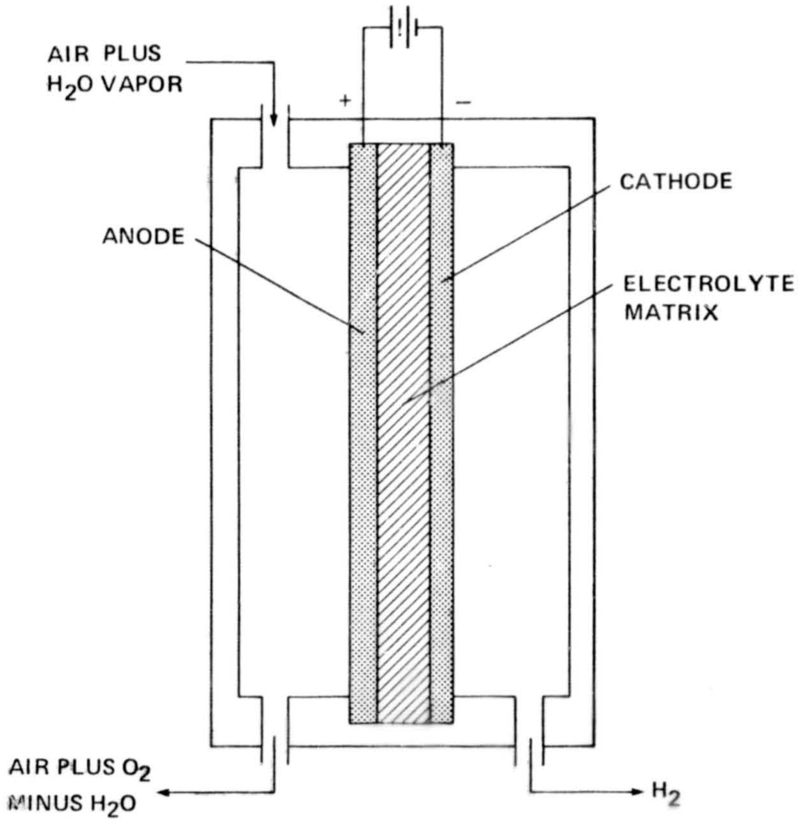
QUATTRONE FIGURE 14

WATER VAPOR ELECTROLYSIS CELL SCHEMATIC

WVE CELL FUNCTIONAL SCHEMATIC



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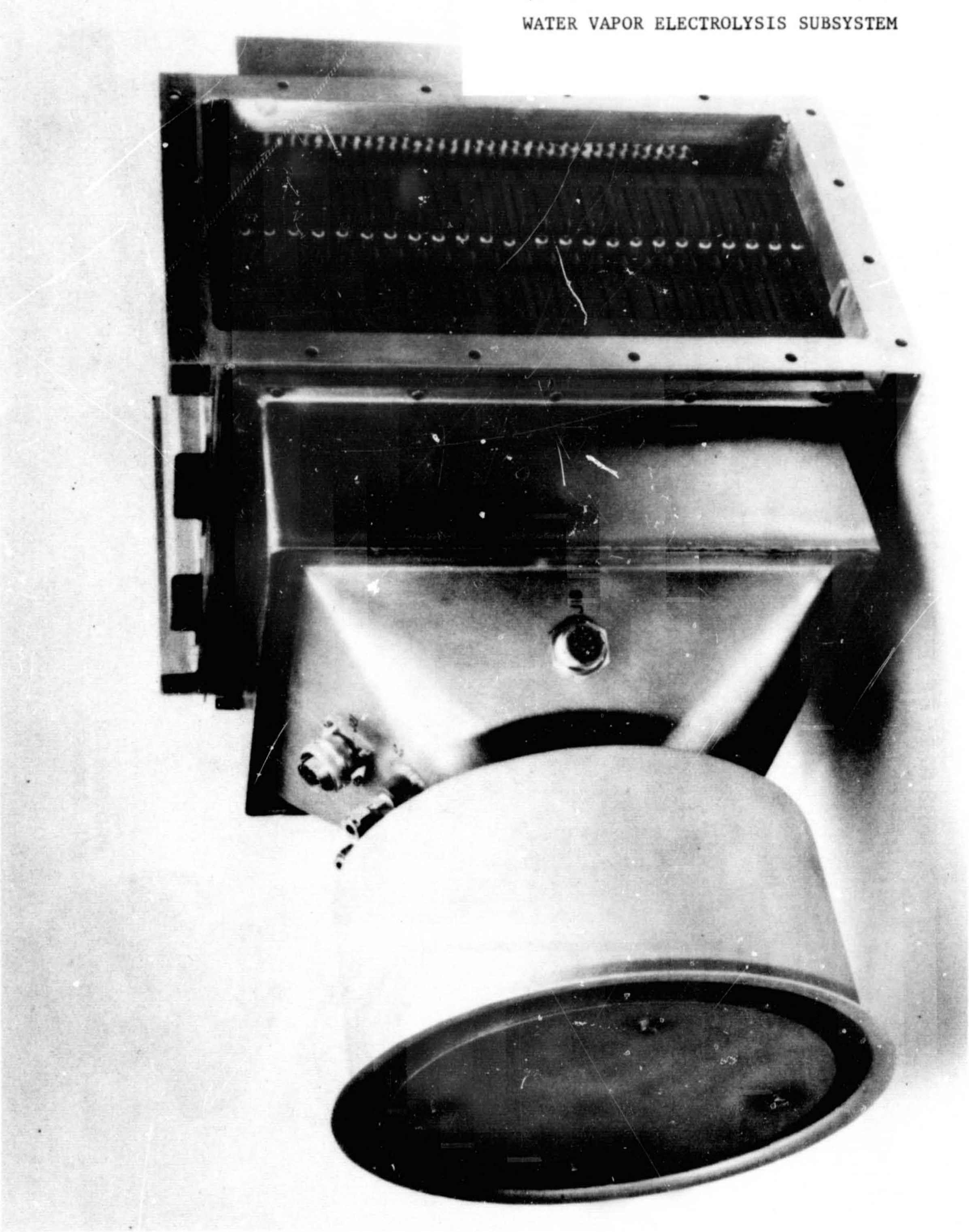
QUATTRONE FIGURE 15

WATER VAPOR ELECTROLYSIS SUBSYSTEM



IARS RLSE DEVELOPMENT HARDWARE

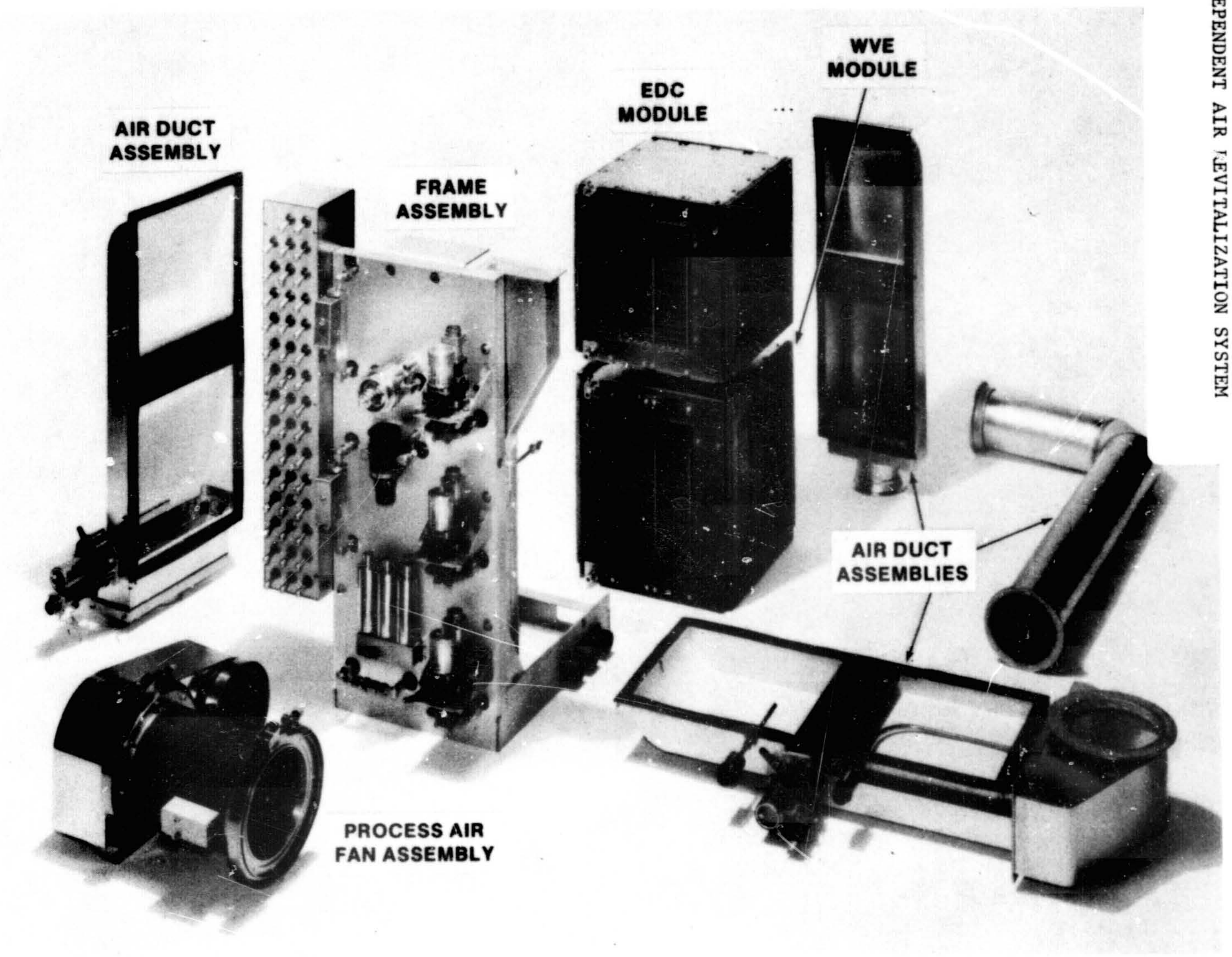


FIGURE 16
INDEPENDENT AIR REVITALIZATION SYSTEM

SF-WES CELL FUNCTIONAL SCHEMATIC

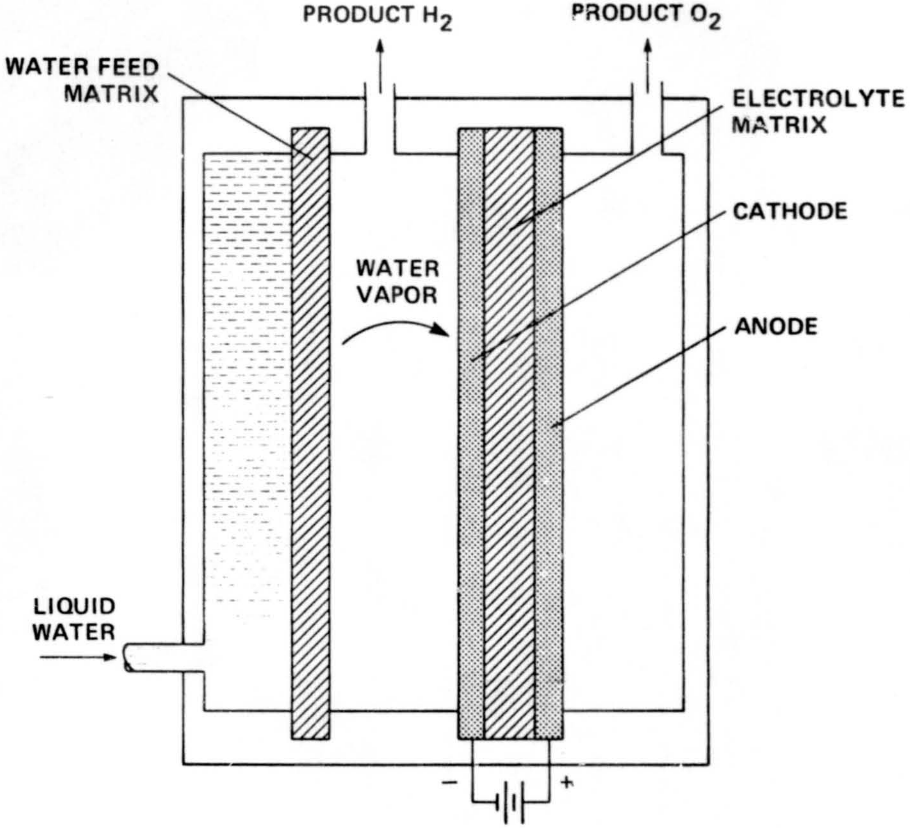
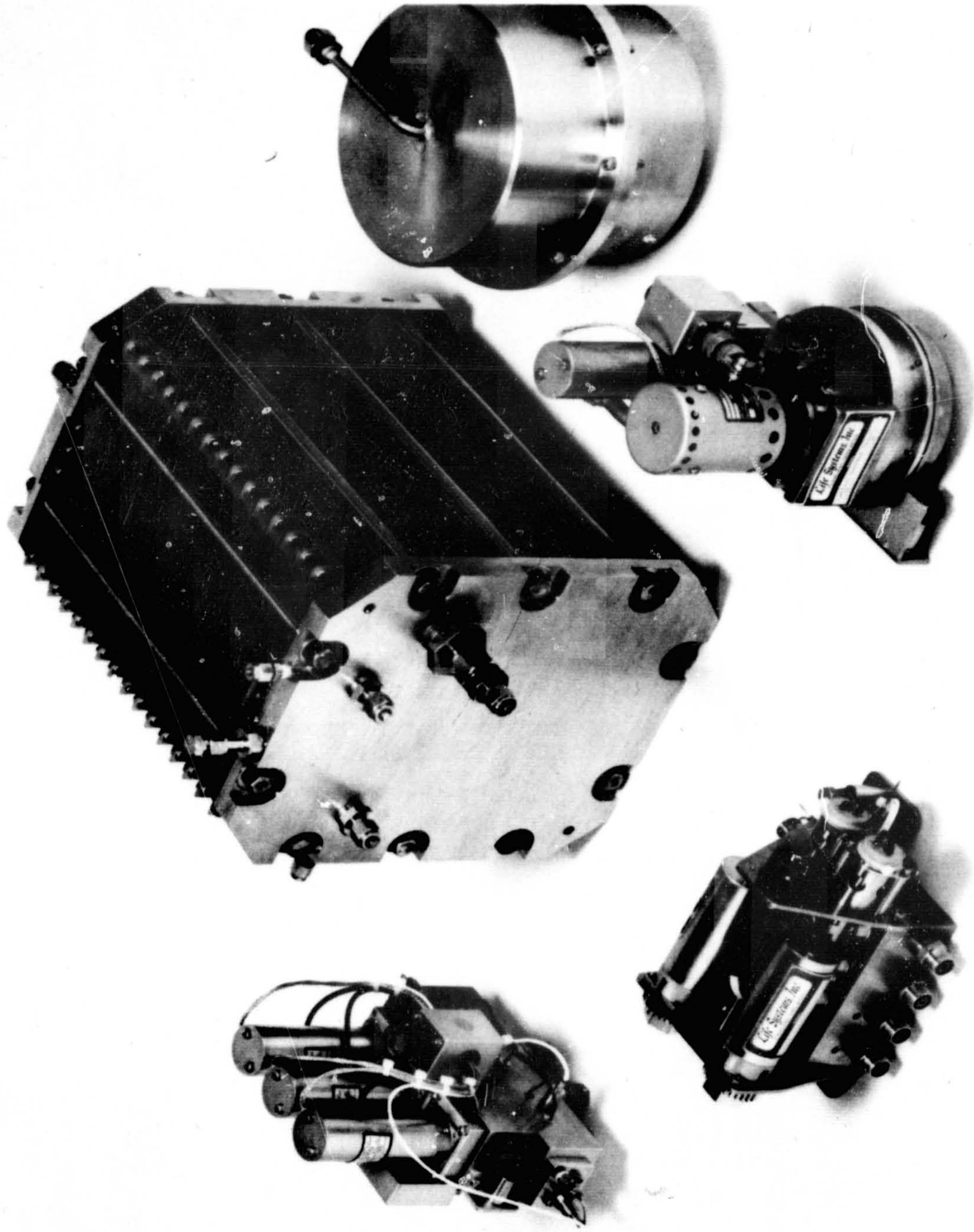


FIGURE 17

QUATRONE
STATIC FEED WATER ELECTROLYSIS CELL SCHEMATIC

QUATTRONE FIGURE 18

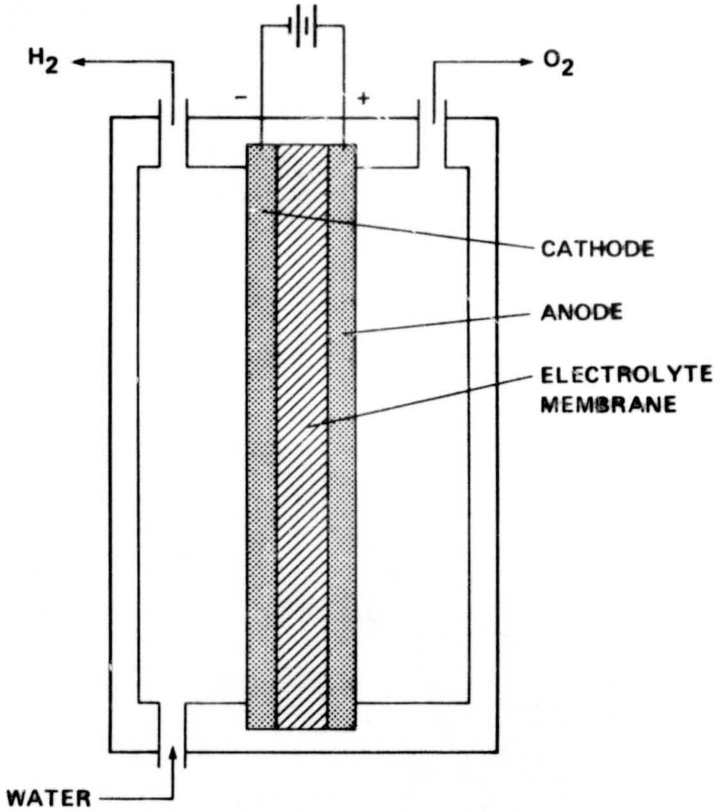
STATIC FEED WATER ELECTROLYSIS SUBSYSTEM



QUATTRONE FIGURE 19

SOLID POLYMER ELECTROLYTE WATER ELECTROLYSIS CELL SCHEMATIC

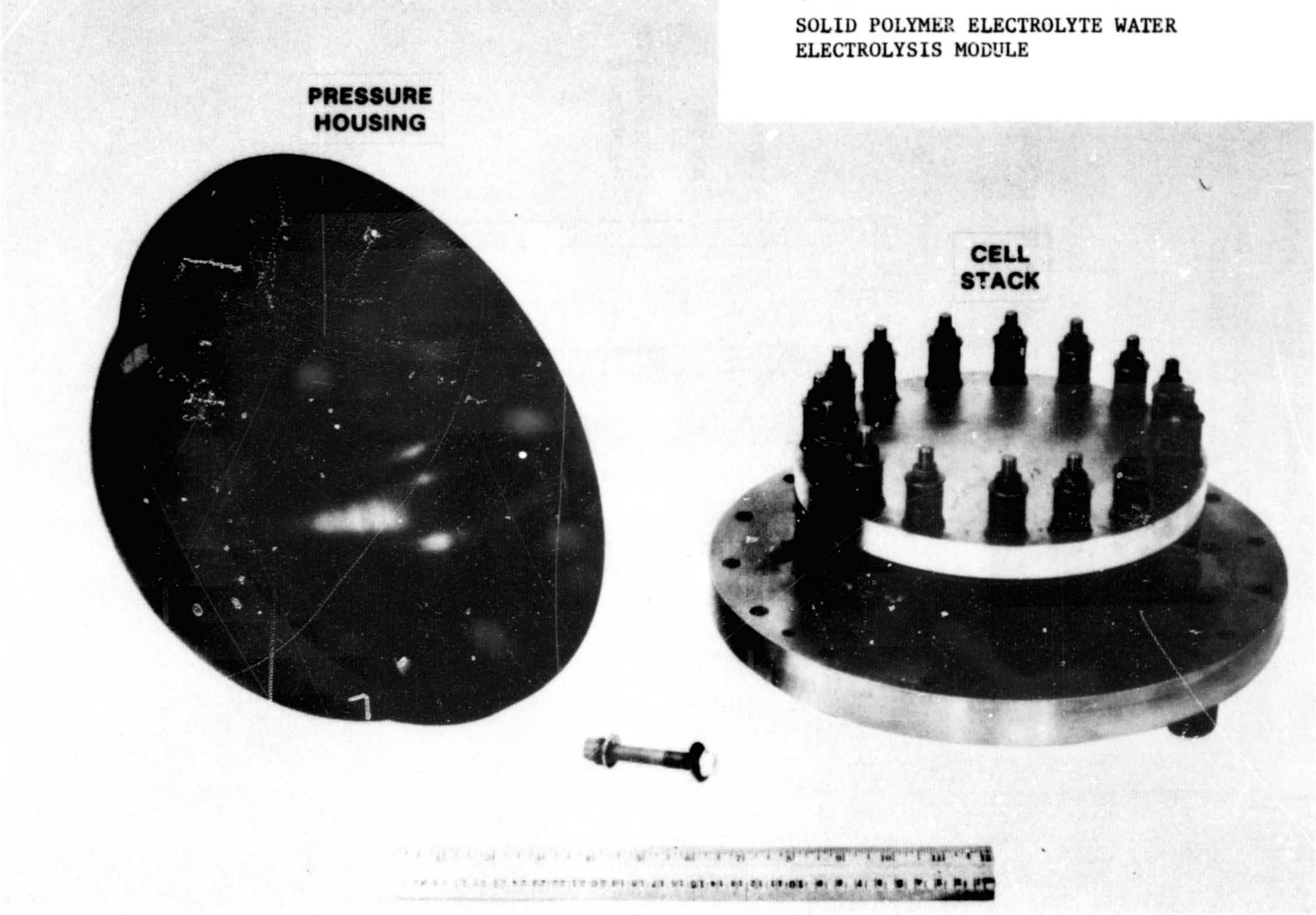
SPE-WES CELL FUNCTIONAL SCHEMATIC



RLSE SPE-WES MODULE

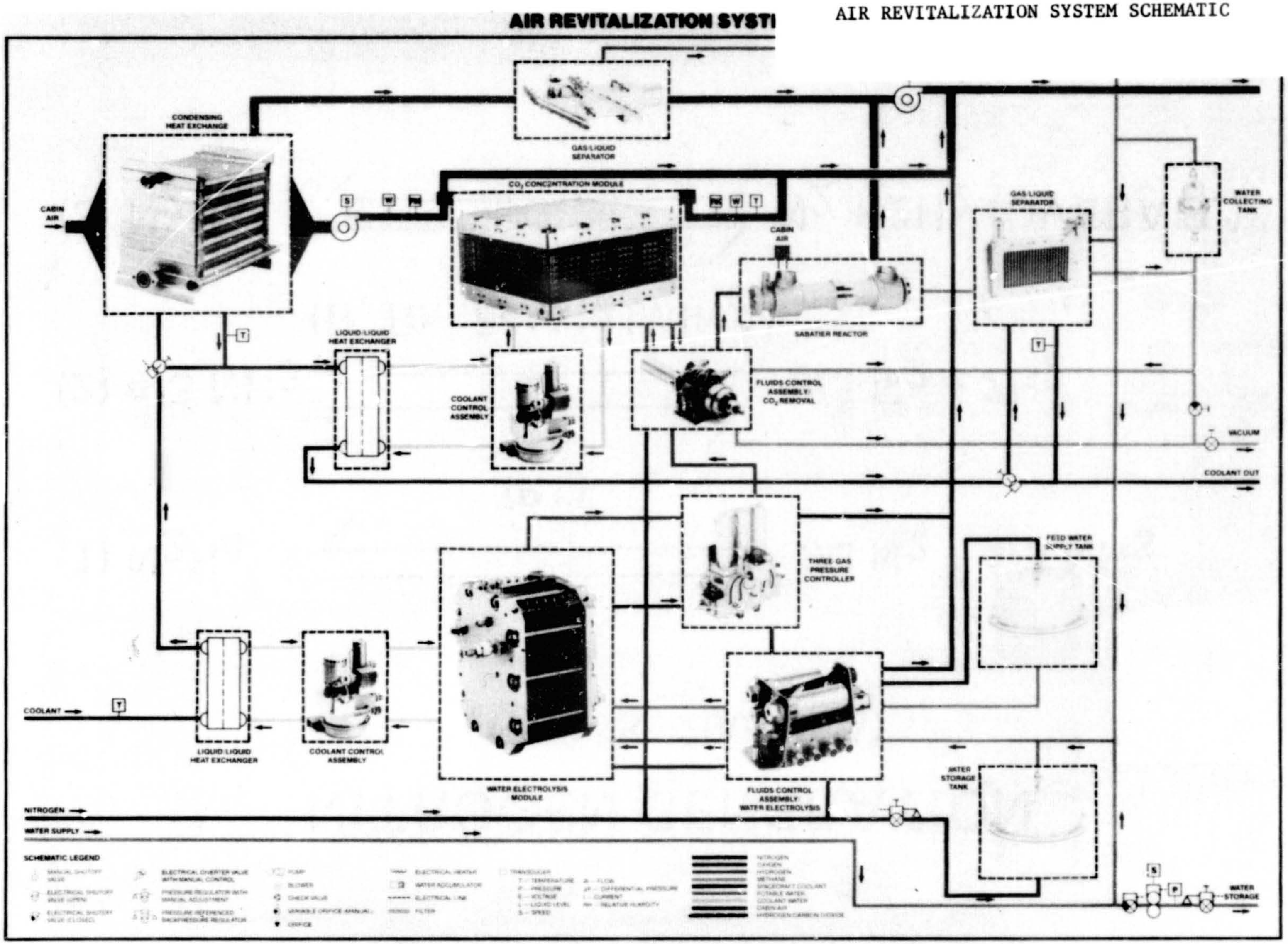
QUATTRONE FIGURE 20

SOLID POLYMER ELECTROLYTE WATER ELECTROLYSIS MODULE



QUATTRONE FIGURE 21

AIR REVITALIZATION SYSTEM SCHEMATIC



QUATTRONE FIGURE 22

NITROGEN GENERATION REACTIONS

NITROGEN GENERATION

(1000 °K; 200 PSIA)

$$\text{(1) } N_2H_4 \xrightleftharpoons[\text{(PT)}]{} 1/3\ N_2 + 4/3\ NH_3$$

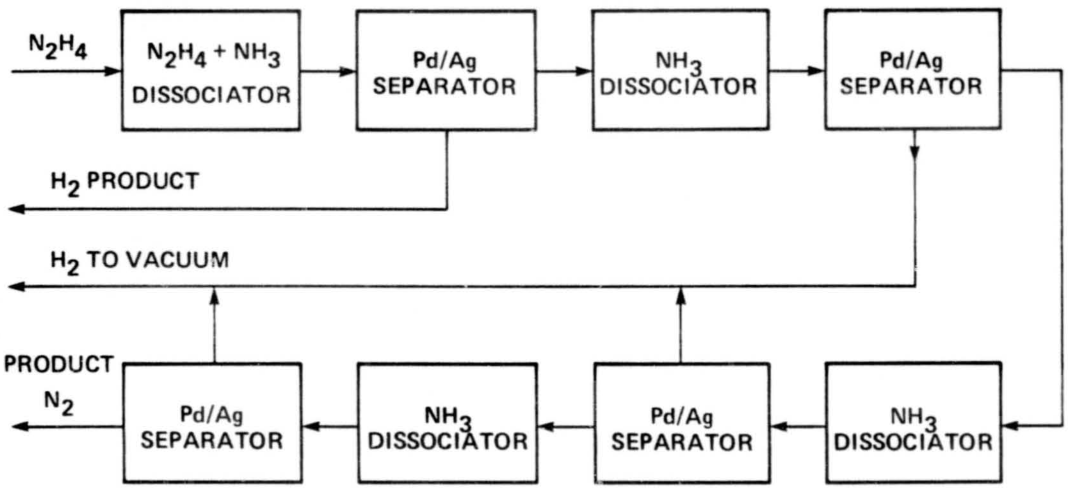
$$\text{(2) } 4/3\ NH_3 \xrightleftharpoons[\text{(Ir, Rh, Fe/ALUMINA)}]{} 2/3\ N_2 + 2H_2$$

$$\text{(3) } N_2H_4 \xrightleftharpoons{} N_2 + 2H_2 \text{ (OVERALL)}$$

QUATTRONE FIGURE 23

NITROGEN SUPPLY SUBSYSTEM STAGING SCHEMATIC

NITROGEN GENERATION SUBSYSTEM SCHEMATIC



ADVANCED N_2 GENERATION MODULE

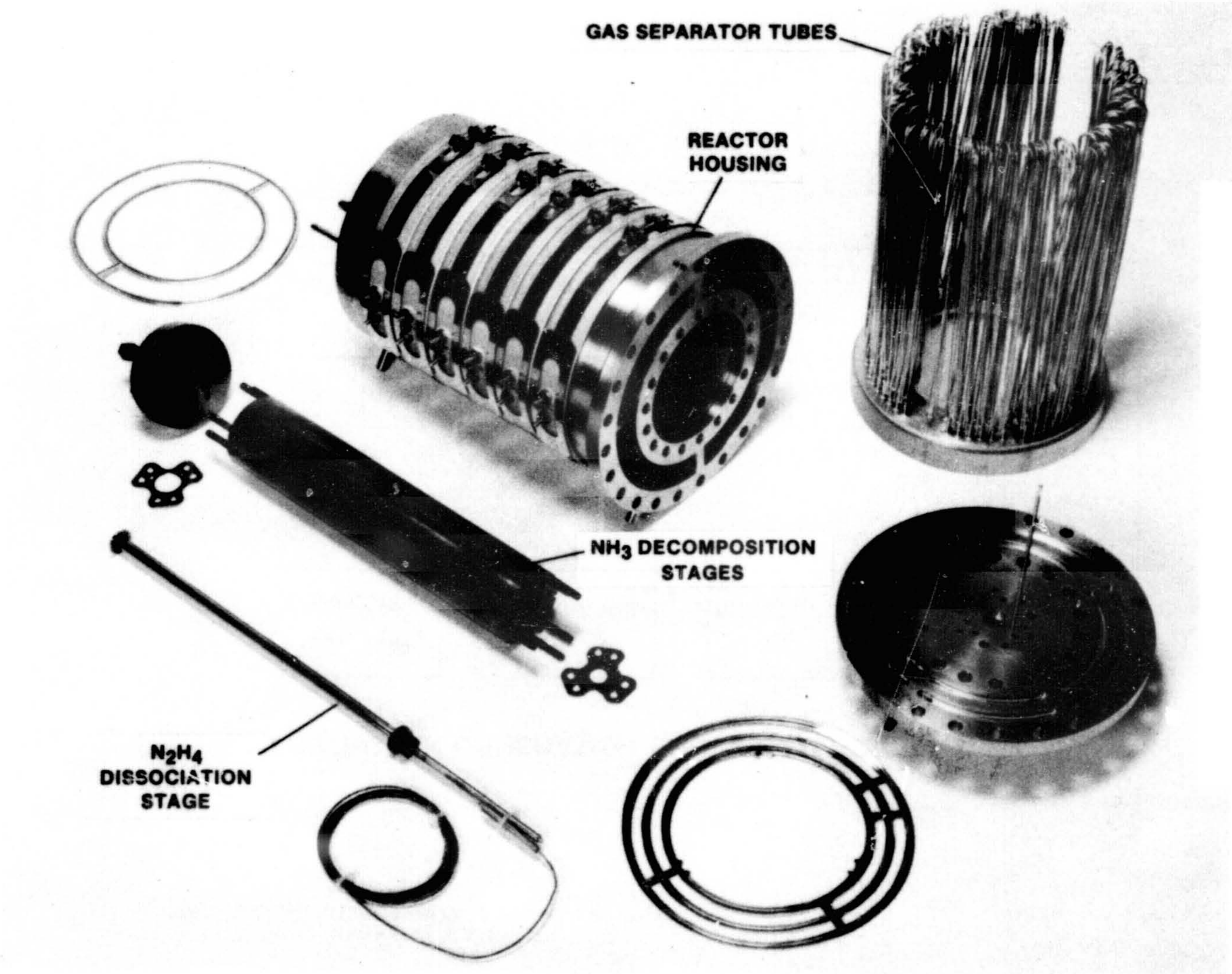
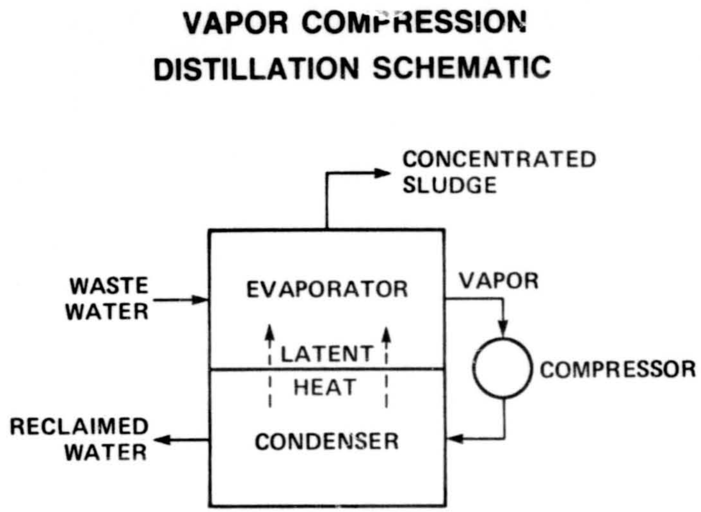


FIGURE 24

QUATTRONE NITROGEN SUPPLY SUBSYSTEM MODULE



VAPOR COMPRESSION DISTILLATION SCHEMATIC

QUATTRONE FIGURE 25

VAPOR COMPRESSION DISTILLATION SUB-SYSTEM SCHEMATIC

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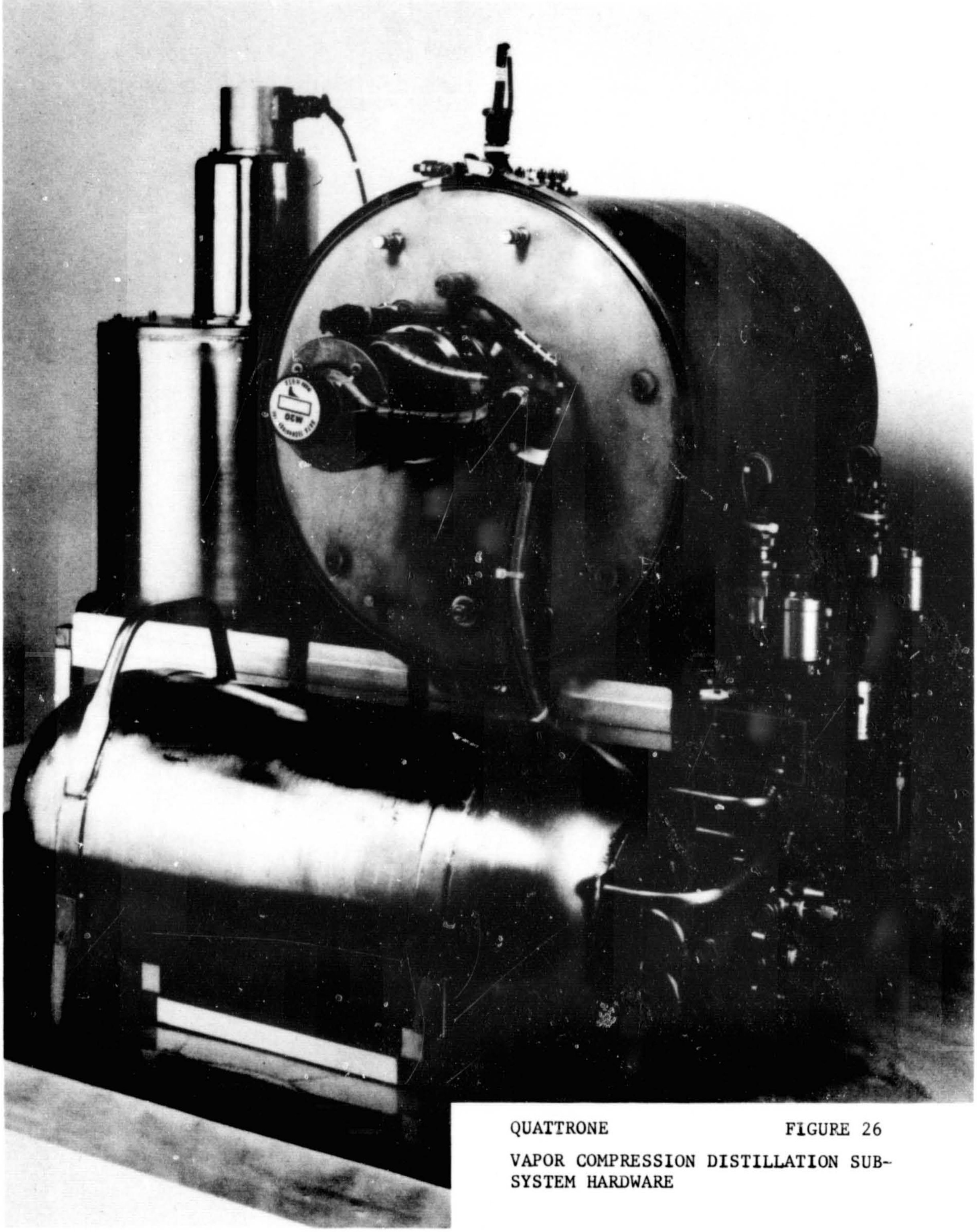
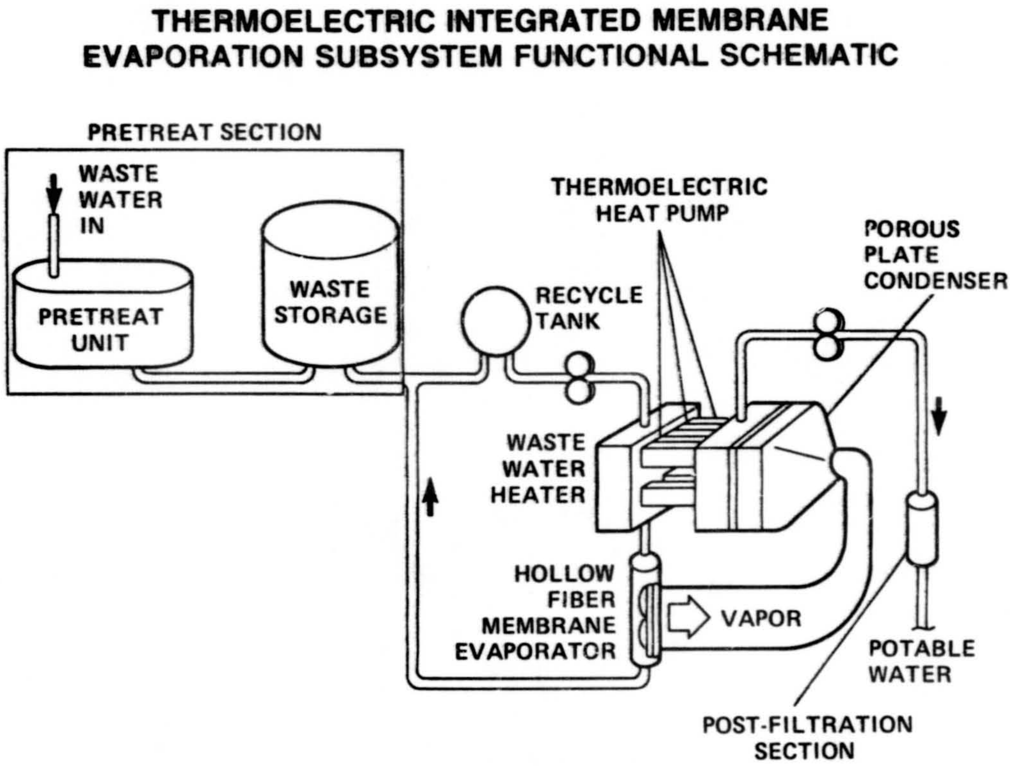


QUATTRONE FIGURE 26

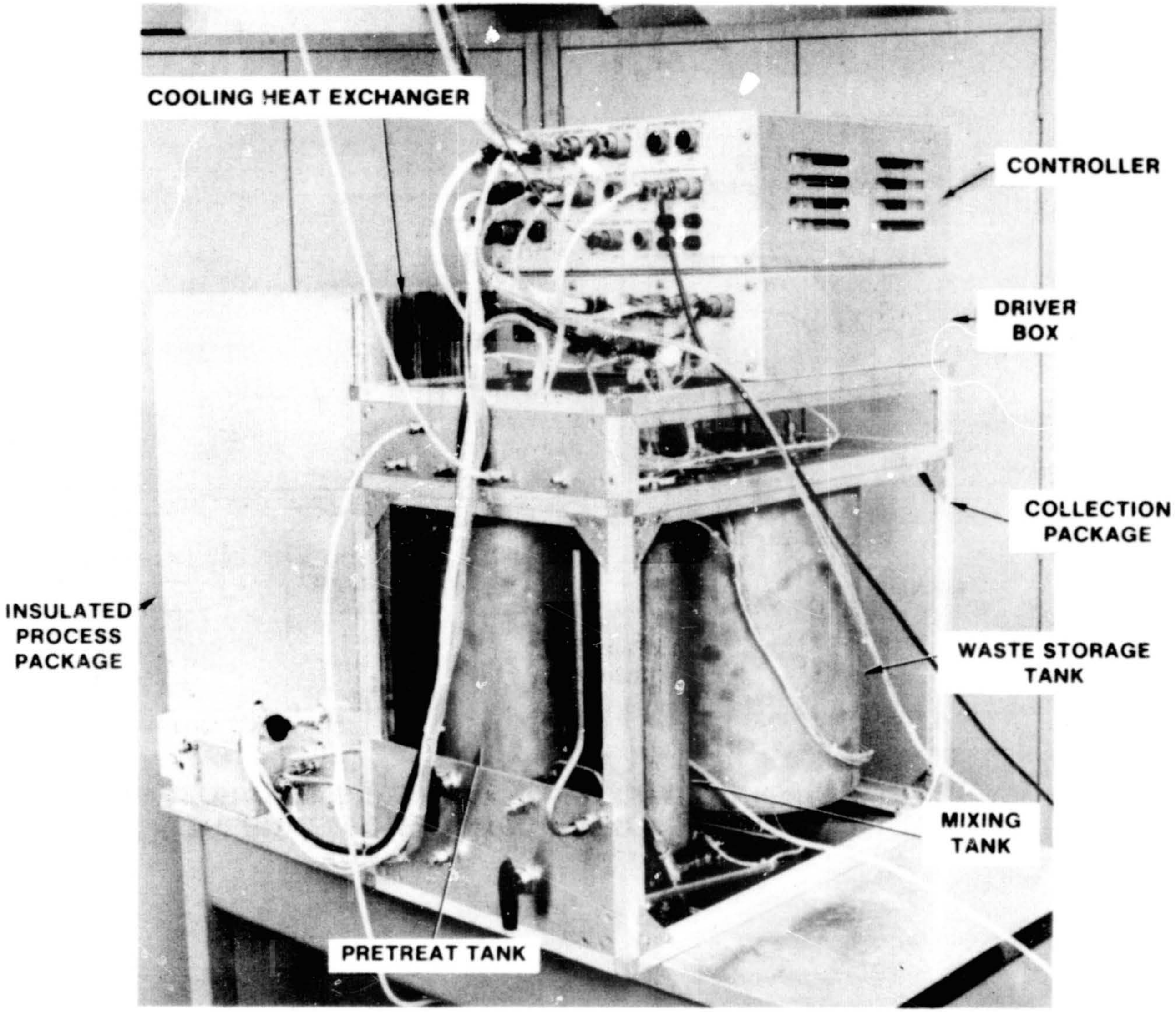
VAPOR COMPRESSION DISTILLATION SUBSYSTEM HARDWARE



THERMOELECTRIC INTEGRATED MEMBRANE EVAPORATION SUBSYSTEM FUNCTIONAL SCHEMATIC

FIGURE 27
THERMOELECTRIC INTEGRATED MEMBRANE EVAPORATION SUBSYSTEM SCHEMATIC

TIMES WATER RECOVERY SUBSYSTEM



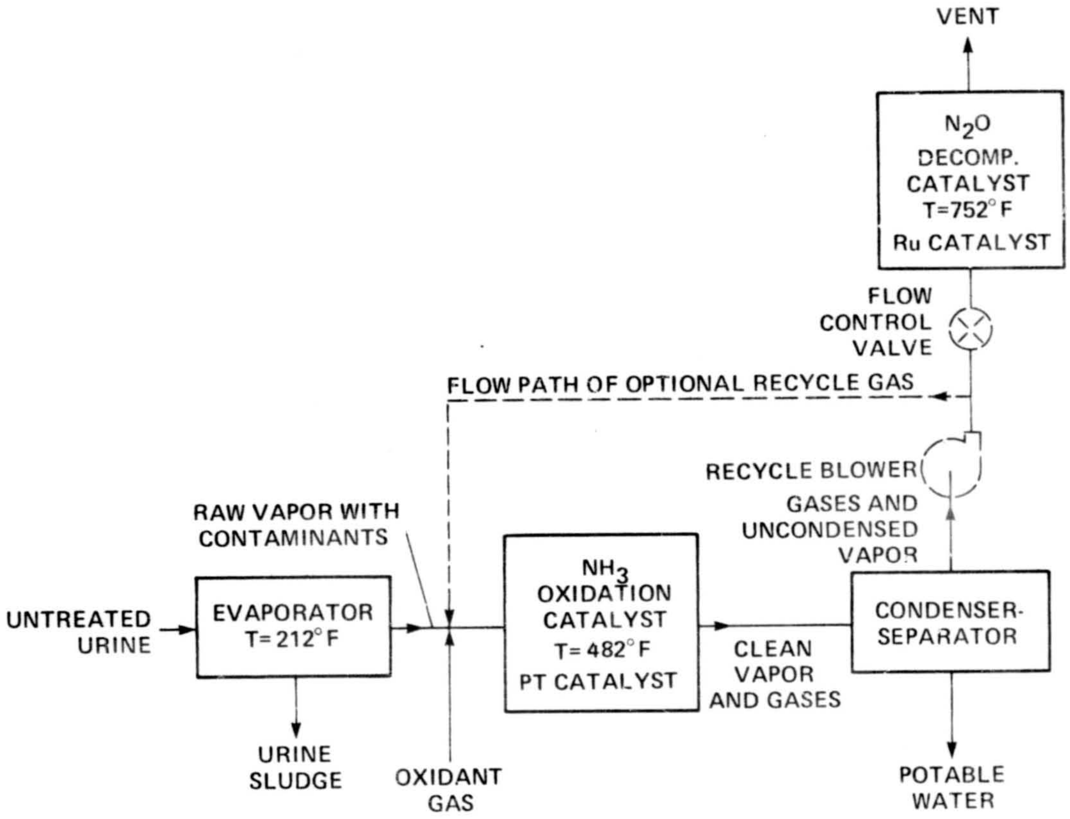
QUATRONE FIGURE 28
THERMOELECTRIC INTEGRATED MEMBRANE
EVAPORATION SUBSYSTEM HARDWARE

QUAITRONE

FIGURE 29

CATALYTIC DISTILLATION WATER RECLAMATION SUBSYSTEM SCHEMATIC

VAPOR PHASE CATALYTIC AMMONIA REMOVAL
FUNCTIONAL SCHEMATIC



SOLID WASTE MANAGEMENT SYSTEM/SPACE SHUTTLE

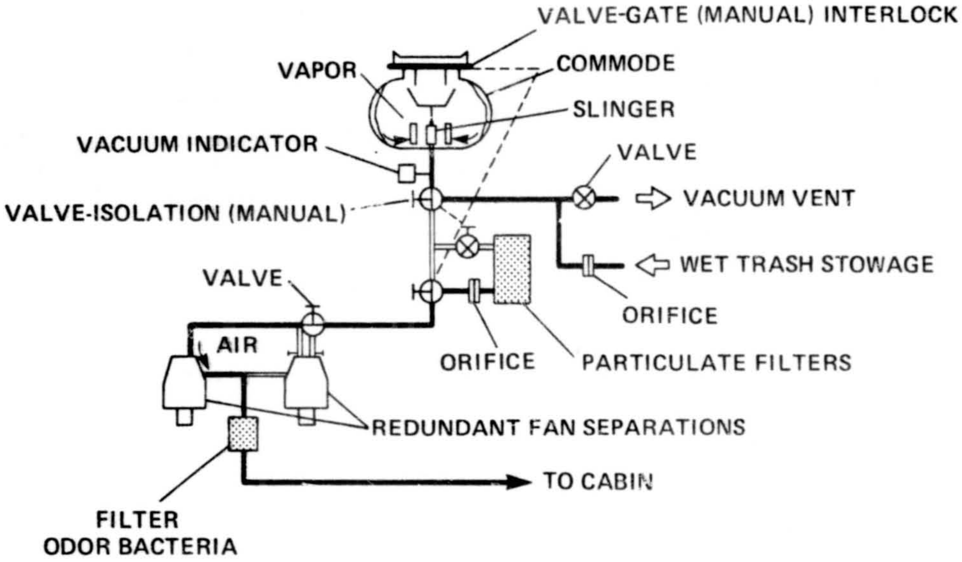


FIGURE 30
SPACE SHUTTLE SOLID WASTE MANAGEMENT SYSTEM

INTERNAL CONTAMINATION
IN THE
SPACE STATION

February 1984

Prepared for:

NASA Headquarters
Space Station Task Force
Human Productivity Working Group

INTRODUCTION

This paper discusses atmosphere trace contaminant control systems used in the past (Lunar Module and Skylab) and present (nuclear submarines and Shuttle), and makes recommendations for the future Space Station contaminant control system. The prevention and control methods used are judicious material selection, detection, and specific removal equipment. Sources and effects of contamination relating to crew and equipment are also discussed.

EFFECTS OF TRACE CONTAMINANTS

Trace contaminants can affect the crew, equipment and experiments.

Effects On The Crew

The compounds found in the trace contaminants can be divided into categories based on their major toxic effects. These categories, with examples are(1):

1. Irritants: aldehydes, ketones and esters.
2. Asphyxiants: carbon monoxide, carbon dioxide*, fluorinated hydrocarbons* and methane*.
3. Central Nervous System Depressants: aliphatic hydrocarbons and alcohols.
4. Systemic Poisons: chlorinated hydrocarbons and aromatic hydrocarbons.

---

*Displaces oxygen at high concentrations

An indication of the toxic risk from a given atmospheric contaminant is the ratio of its concentration (C) to its SMAC (Spacecraft Maximum Allowable Concentration) value. The relative toxic hazard index (RTHI) value of compound X would be expressed as $C_x/SMAC_x$. Any atmospheric contaminant that exceeds its SMAC value ($RTHI > 1$) would be considered to be at an unacceptably high level.

To some extent, multiple atmospheric contaminants that are in the same toxicological category exert an additive effect. The sum of all RTHI values in one toxicological category of an atmospheric sample can be referred to as the total relative toxic hazard index (TRTHI). It may be expressed mathematically as follows:

$$TRTHI = C_1/SMAC_1 + C_2/SMAC_2 + C_3/SMAC_3 + C_n/SMAC_n$$

C_x = concentration of chemical
$SMAC_x$ = SMAC value of chemical

The level of toxicity can be subjectively graduated from nuisance valve, to reduced productivity, to health hazard, to life threatening.

Contamination may affect the drinking water supply, food storage and preparation equipment and air circulation equipment.

An additional hazard of some contaminants is their property as fuel for propagation of fire and explosion. Examples are H_2, CO, and CH_4.

Effects on Equipment

Monomolecular layers on microchips can affect the conductivity of electrical paths and capacitance of elements. Surface degradation and adverse corrosion can occur as well as clogging of microporous membranes, filters and operations. Optical surfaces are particularly vulnerable.

Effects on Experiments

Cross contamination can occur in biological experiments which can affect growth and fatality rates, thereby coloring conclusions referring to cause and effect. Non-biological experiments can also be influenced by contamination. Crystal growth, plating, flow reduction, and assembly can be affected.

SOURCES OF CONTAMINATION

Contaminants have been found to be generated by the crew vehicle equipment, experiments, operations, food and human waste disposal, cleaning fluids, and repairs.

Crew

Principal sources of contaminants from man are expired air, urine, feces, flatus, perspiration, vomitus and saliva (sneezing). Major contaminants generated by metabolic processes of the crew are: CO_2, NH_3, CO, H_2S, H_2, CH_4, organic acids and mercaptans. In addition, bacteria, virus, fungus, skin particles and hair and nail clippings will occur.(2),(3)

Equipment

Compounds generated by equipment generally have relatively high vapor pressure and are outgassed from solid materials and lubricants. Although NASA has done an outstanding job eliminating most of these contaminants in NASA owned equipment, experimenters and developers of manufacturing processes may not be able to conform to the guidelines presented in NHB 8060.1B,"Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion," September 1981.(4)

Experiments and Crew Activities

Experiments can release inorganic, organic, viral and bacteriological contaminants.

Contaminants will probably be released during food preparation, food and human waste disposal, and crew cleansing.

Accidents, Fire, Explosion, and Spillage

In addition to contaminants present during normal operations, one must consider the toxic atmospheres resulting from such upset conditions as fire or equipment failure, as well as the products of thermal decomposition due to overheating of electrical and hydraulic equipment. Carbon monoxide and aldehydes are frequent breakdown products in equipment fires. Thermal degradation of plastics will yield monomers and large chain fragments such as methyl alcohol, hydrochloric and hydrofluoric acids, and hydrogen cyanide.(5).

Accidents may occur during servicing of satellites, leading to an EVA astronaut's exposure to rocket fuels and oxidizers. These contaminants may then be brought into the station on EMU clothing or tools.

PAST CONTAMINANT CONTROL

Lunar Module

The lunar module contaminant control system consisted of particulate filters and activated carbon, for odor control, both packaged in the LiOH cartridges used to control CO_2. The pressure suits worn by the crew also aided contaminant control.

Langley (MDAC) 90-Day Manned Test - 1970

Objectives of the 90-day operational manned test involved the evaluation of an advanced regenerative life support system similar to that of an orbiting scientific laboratory under closed-door conditions. These objectives included determination of long-term operating characteristics and power requirements of individual subsystems and the total system; measurement of mass and thermal balances; determination of the ability of the test crew to operate, maintain, and repair onboard equipment; measurement of chemical and microbial equilibrium of the closed life support system; assessment of the effect of confinement on the psychological and physiological characteristics of the test crew; and collection of data to assist in determining the role of man in performing in-flight experiments.(6)

This test operated with no materials passed into or out of the test chamber. The composition of the atmosphere during the manned operation was determined on a continuous basis and by individual samples taken at frequent intervals. Analysis was done by chromatograph on direct samples. Concentrated samples were also obtained by freeze-out techniques and sent through the gas chromatograph to determine the presence of organic compounds. Inorganic compounds were measured by wet chemical analysis on samples taken daily.(7)

Contaminants were controlled during the 90-day test by employing a 1.5 cfm toxin burner (integrated with a Sabatier reactor for thermal efficiency), along with particulate filters, solid amine CO_2 control, molecular sieve CO_2 control and a condensing heat exchanger. The cabin air was almost free of contaminants during the unmanned and manned periods preceding the 90-day test. During the 90-day test there were no inorganic compounds noted. There were no NO_x compounds until NH_3 reached 0.5 ppm. The NO_x disappeared when the toxin burner was shut down, indicating NO_x was formed from NH_3 in the toxin burner.

Analysis of the CO_2 just upstream of the Sabatier reactor showed the presence of Freon 113. The average detected concentration of Freon 113 varied from 9.0 ppm, when the solid amine unit was operating, to 33.8 ppm, when the molecular sieve unit was operating. Acetone and ethyl alcohol were also detected in the CO_2 at low concentrations. These results indicate that the CO_2 scrubbers were able to remove some of the trace contaminants.

Skylab

The Skylab environmental control system had considerable capability to scrub the cabin air of generated contaminants. Principal elements of the system were the charcoal canisters in the molecular sieve unit and waste management systems, the condensing heat exchangers, and the Linde 13X and 5A molecular sieve material.

The molecular sieve and charcoal canisters performed their design function of removing odors, as well as removing contaminants. The only means available to evaluate the performance of the odor removal system was via crew comments, but all three crews indicated that the system performed very well.

Ground tests in which air laden with various concentrations of trace contaminants was passed through special test bed molecular sieves, qual unit molecular sieves and a Gemini condensing heat exchanger indicated that molecular sieve material had 100% removal efficiency for all contaminants tested with the exception of H_2 and CO as shown in Table 1. No removal capability was noted for these two gases. The condensing heat exchanger had some capability for contaminant removal, especially for Coolanol 15.

TABLE 1
SKYLAB CONDENSING HEAT EXCHANGER AND MOLE-SIEVE CONTAMINANT REMOVAL EFFICIENCY

	Contaminant	Test Inlet Concentration, ppm	Removal Efficiency, Percent	
			CHX	Mole-Sieve
1.	Hydrogen	900	(1)	0
2.	Ammonia	60	(1)	100
3.	Methyl Chloride	20	(1)	100
4.	Freon 12	500	(1)	100
5.	Benzene	5	8.7	100
6.	Freon 113	500	(1)	100
7.	Xylene	50	(1)	100
8.	Toluene	50	(1)	100
9	Acetone	500	(1)	100
10.	Isopropyl Alcohol	100	(1)	100
11.	Acetaldehyde	50	2.6	100
12.	Methyl Isobutyl Ketone	10	33	100
13.	Dichloromethane	25	(1)	100
14.	Carbon Monoxide	75	(1)	0
15.	Methyl Chloroform	90	15.2	100
16.	Methyl Ethyl Ketone	100	1.1	100
17.	Coolanol 15	50	89	100

(1) Not tested.

PRESENT CONTAMINANT CONTROL

Shuttle and Spacelab

The Shuttle and Spacelab trace contaminant control systems each include activated LiOH canisters, a condensing heat exchanger and a carbon monoxide oxidizer.

Four atmospheric samples were collected at approximately 12-hour intervals in the orbiter crew cabin during the 56-hour STS-1 mission on April 12-14, 1981.(8) Post-mission gas chromatographic/mass spectrometer analysis showed 57 different chemical contaminants; 38 were structurally identified. The total quantity of gases in each toxicological category was below the SMAC value of any one of its constituents. The only categories of gases that approached the SMAC value for any one gas in their category were the systemic poisons and asphyxiants. However, in both cases, these values were below the concentration of gases with the lowest SMAC value. The catalytic oxidizer for CO control was not present on the STS-1 mission.

Submarines

In view of the convergence of the requirements for spacecraft and submarine life support systems a study, jointly funded by the Navy NAVSEC and NASA was prepared by Hamilton Standard in 1974(9).

In this study, for submarines, activated carbon was selected to control trace contaminants, as well as odors, hydrocarbons and "Freon" spills. On present submarines, aerosols are controlled with strategically placed filters and electrostatic precipitators. A Hopcalite catalyst operated at high temperature is now used to control CH_4, H_2 and CO.

Detection of trace contaminants on submarines is accomplished by a Perkin-Elmer Central Atmosphere Monitoring System (CAMS) which uses a mass spectrometer to monitor all trace contaminants except CO. An infrared analyzer monitors CO.

SPACE STATION

Contaminants expected in the Space Station can be divided into the following main categories:

- Those present during normal operation
  - Contaminants generated by the crew and equipment
  - Contaminants generated by experiments and manufacturing
- Contaminants generated by fire and explosion

As demonstrated by previous Skylab flights and STS-1, the combination of prevention (selection of materials), proper waste handling, and minimal removal equipment resulted in odor-free flight on Skylab and no contaminant reaching its SMAC value on STS-1.

However, it is expected that the desire to open the station to a broad user community will necessitate some relaxation of NHB 8060.1B. Therefore, higher levels of particulate and gaseous contaminants will be generated, requiring control equipment which is more sophisticated and has larger throughput than that used on Skylab and Shuttle.

In addition, the cabin volume and crew size will increase in proportion to the space station size while cabin air leakage can be expected to decline, particularly for non or low EVA activity missions.

As a result, the need to control low molecular weight contaminants, particularly CH_4, will require a high temperature (600°F) catalyst.

The high temperature catalytic oxidizer developed by Hamilton Standard is relatively insensitive to the normal humidity levels found in the environment. Additional base sorbent beds such as $LiCO_3$ should be placed upstream of the catalyst bed to protect it from acid gases such as SO_2, H_2S and HCl. A base sorbent bed should be placed downstream of the high temperature catalyst to stop acid gases which may be produced in that catalyst bed, such as HCl and HF.

As noted earlier, the condensing heat exchanger can be used to control some of the trace contaminants, such as ammonia, methyl isobutyl ketone, methyl chloroform and benzene which have been demonstrated in laboratory tests to be removed in the condensate water. This water must then be filtered to remove these contaminants if it is to be reused.

Particulates and aerosols can be controlled using absolute filters placed upstream of the fan and a condensing heat exchanger to remove particles greater than 0.3 microns including bacteria. The absolute filter prevents growth in the activated carbon and condensing heat exchanger. Debris traps should be placed upstream of the absolute filters to stop coarse particles (wet and dry) which make up the bulk of the particulate matter and may quickly clog the absolute filter.

Post-Fire Atmosphere Cleanup

In the event of a fire within the space station, the routine procedures for controlling and extinguishing the blaze should include shutting down the environmental control equipment in or serving the affected section. This action helps to lower the oxygen concentration in the area of the fire and restricts the distribution of the combustion products in the atmosphere to a local area around the fire site.

Once the fire is extinguished, the local atmosphere must be cleaned to remove suspended particulate materials and objectionable or toxic gases generated by the combustion before the ECLSS is returned to duty in order to prevent spreading the fire-generated contaminants to other parts of the station. Portable oxygen systems or other self-contained breathing apparatus should be included in the on-board emergency equipment.

One method of cleaning the fire-contaminated atmosphere would be to dump it by depressurizing the affected section. Depressurization involves added risk such as the bends if the crew had no other area in which to seek protection. In addition, depressurization of a large section of the space station will require the replacement of the N_2 and O_2 required. For example, a 5000 ft^3 section will contain 300 lbs of N_2 at standard conditions. In addition, there is a possibility of contaminating experiments or sensors outside the pressurized volume.

A portable post-fire air purification unit proposed by Hamilton Standard for use in U.S. Navy ships can provide the required cleanup capability without any interface with the ECLSS. The unit is entirely self-contained and requires only a source of electric power to operate its fan. It can reduce the level of carbon monoxide in a 5000 cubic foot enclosed volume from a fatal one-hour exposure level of 5000 parts per million to a safe one-hour inhalation level of less than 500 parts per million in about 20 minutes.

To clean up a contaminated compartment, the unit need only be allowed to run unattended within the closed volume until contaminant levels are sufficiently reduced as indicated by the ECLSS Monitor and Control sensors in the compartment or until visual and olfactory observations indicate the removal of smoke and odors.

SUMMARY

Skylab and Shuttle results have indicated that the combination of materials selection, onboard removal devices, and preflight offgassing tests can be an effective means of controlling spacecraft contaminant levels.

The following are recommendations for atmospheric contamination control on Space Station:

1. The maximum allowable levels of contaminants should be established by NASA.

2. An effective materials screening program should be carried out to eliminate materials with offgassing characteristics above established criteria; i.e., NASA should produce a list of acceptable materials.

3. Contaminants should be selectively monitored using a CAMS or similar unit.

4. A simple, standard procedure should be developed to test the flammability and outgassing of flight payloads and experiments. Standard cabinets should be considered, especially designs which accommodate special sorbent beds and interface with the catalytic oxidizer so that unique contaminants can be efficiently controlled.

Table 2 defines the elements of a contaminant control system envisioned for a Space Station. Additional equipment or designed-in, controlled cabin leakage may later be required.

TABLE 2
TYPICAL SS CONTAMINANT CONTROL SYSTEM

ITEM	TO CONTROL
Absolute Filters	Particulates, Bacteria and Aerosols
Condensing Heat Exchanger	Humidity Control (Moisture) and Water Soluble Compounds
CO_2 Removal Hardware	Carbon Dioxide Level
Activated Charcoal (Treated and Untreated)	High Molecular Weight Hydrocarbons and Ammonia
High Temperature Catalytic Oxidizer with Pre- and Post-Filters	Cabin Monoxide, Hydrogen and Low Molecular Weight Hydrocarbons; acid gases and products of oxidation

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INTERNAL CONTAMINATION:
SPACE STATION
LIFE SUPPORT ALTERNATIVES

Prepared for: Space Station Human Productivity Working Group

28 February 1984

Chris [illegible]

CONTAMINATION CONTROL ALTERNATIVES

1. **Business as usual (preventative)**
   - NHB 1700.7A (safety policy)
   - NHB 8060.1B (flammability, odor, offgassing)
2. **Relax prevention guidelines**
3. **Revise prevention approach to soften burden on users; increase on-board control**

THREE QUESTIONS FOR CONTAMINANT CONTROL

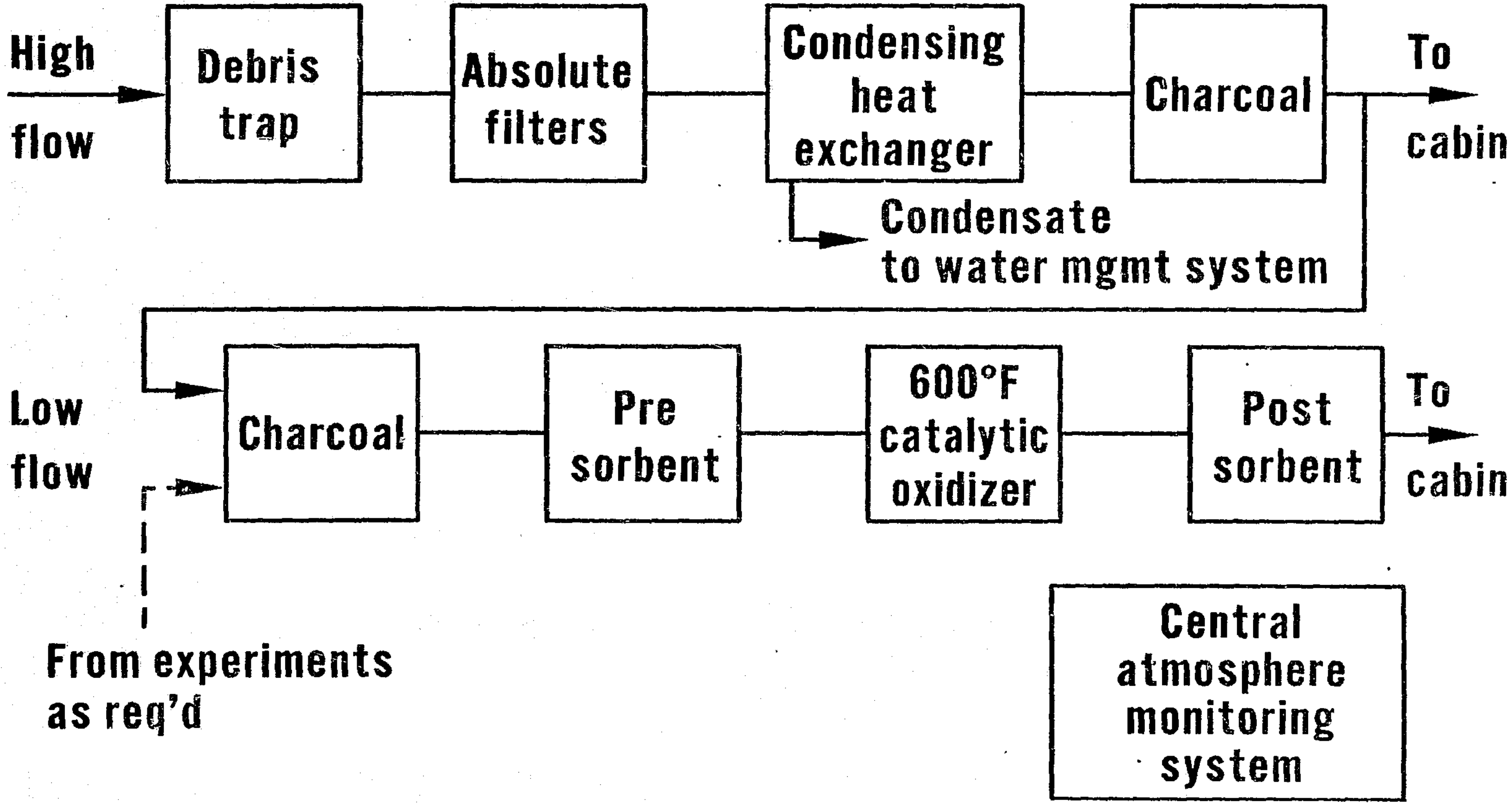
1. What is the contaminant?
2. What is its allowable level?
3. What is its production rate?

Having answers to these questions is key to controlling the contaminant.

CONTAMINATION AND HUMAN PRODUCTIVITY

- Effects on the crew
  - Categories/levels
- Sources of contaminants
  - Crew, equipment, experiments, accidents
- Non-venting regenerative life support for Space Station

TYPICAL TRACE CONTAMINANT CONTROL SYSTEM



High flow

Debris trap

Absolute filters

Condensing heat exchanger

Charcoal

To cabin

Condensate to water mgmt system

Low flow

Charcoal

Pre sorbent

600°F catalytic oxidizer

Post sorbent

To cabin

From experiments as req'd

Central atmosphere monitoring system

SOME FLAMMABILITY/CONTAMINANT SCREENING IS MANDATORY

Without screening, Space Station payloads/ experiments need:

- Isolated, fireproof module(s)
- Independent ECLS system(s)
- Over-designed contaminant control scheme with conservatively frequent filter/sorbent changes

The burden on station designers and the risk to the crew are inappropriate. Some screening is mandatory.

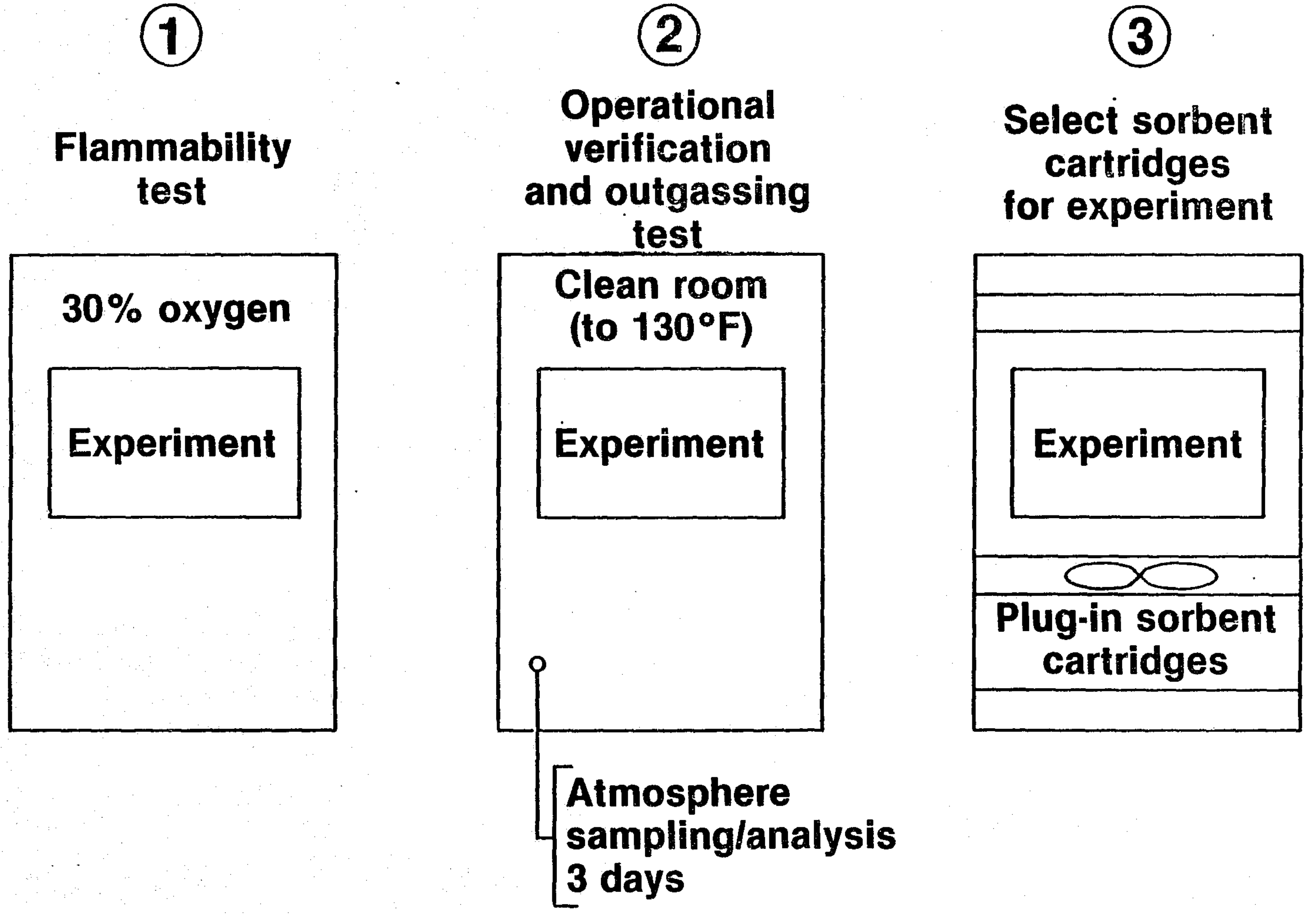
CUSTOMER - FRIENDLY CONTAMINATION CONTROL

1. NASA publish a list of approved materials

2. NASA publish a list of prohibited materials

3. NASA establish a "customer service" center with assigned payload "sponsors" to soften burden on users

USER'S EXPERIMENT/PAYLOAD CHECKOUT & SCREENING AT NASA FACILITIES



① **Flammability test**

30% oxygen

Experiment

② **Operational verification and outgassing test**

Clean room (to 130°F)

Experiment

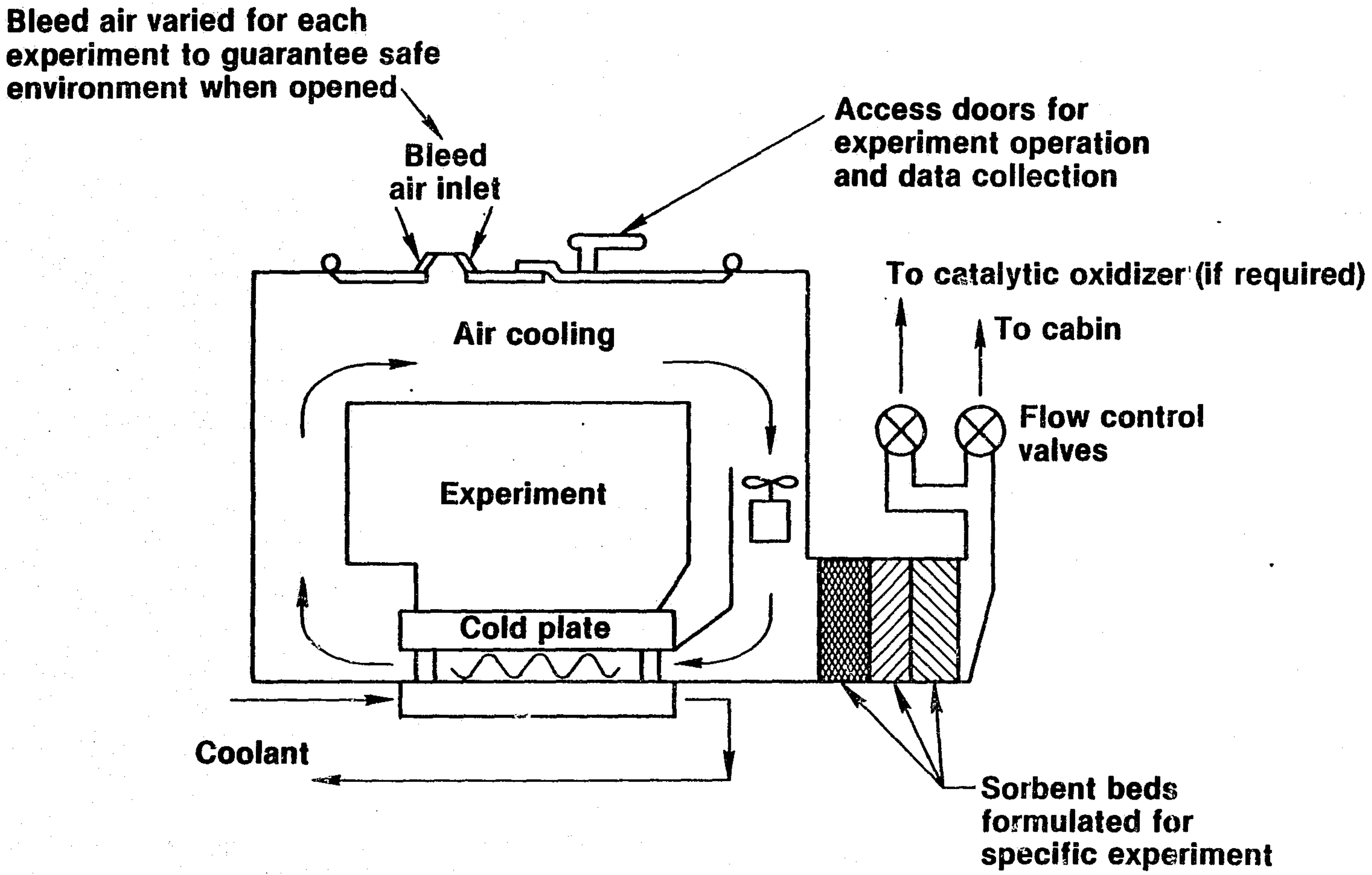
Atmosphere sampling/analysis 3 days

③ **Select sorbent cartridges for experiment**

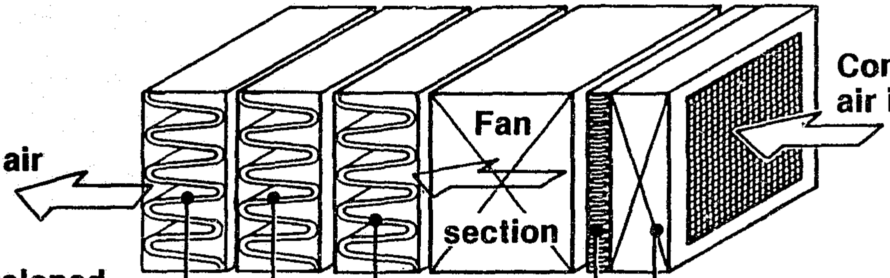
Experiment

Plug-in sorbent cartridges

STANDARD CABINET FOR EXPERIMENTS SUSCEPTIBLE TO OFFGASSING



SMOKE/TOXIC GAS AIR PURIFICATION UNIT



Contaminated air inlet

Clean air outlet

HS developed catalyst (10% PT on Al_2O_3) for oxidation of CO and H_2

Coarse particulate (>2 micron) removal unit, vortex-separator

Charcoal for removal of organics (hydrocarbons) and phosphoric acid impregnated charcoal for removal of basic gases (NH_3, amines)

Fine particulate (>0.3 micron) removal, electrostatic filter media

Sodasorb for removal of CO_2 and acid gases (HCL, HCN, HF, NO_2, SO_2, etc.)

SPACE STATION

TRACE CONTAMINANT CONTROL

SPACECABIN CONTAMINANT SOURCES

SOURCE	CONTAMINANT
o MAN	- METABOLIC PRODUCTS: CO_2, NH_3, CO, H_2S, H_2 CH_4, ORGANIC ACIDS, MERCAPTANS - BACTERIOLOGICAL CONTAMINANTS
o SPACECRAFT SUBSYSTEMS, EXPERIMENT EQUIPMENT AND PAYLOADS	- WIDE VARIETY OF ALCOHOLS, ALDEHYDES, AROMATICS, ESTERS, ETHERS, CHLOROCARBONS, FLUOROCARBONS, HALOCARBONS, HYDROCARBONS, KETONES, ACIDS
o EMERGENCY SITUATIONS: FIRE, SPILLS, EQUIPMENT FAILURES	- CO, CO_2, HYDROCARBONS, AROMATICS, ACID GASES, OXIDES OF N_2, SO_2, NH_3, ALCOHOLS, FORMALDEHYDE
o ANIMAL AND PLANT EXPERIMENTS	- METABOLIC, BACTERIOLOGICAL

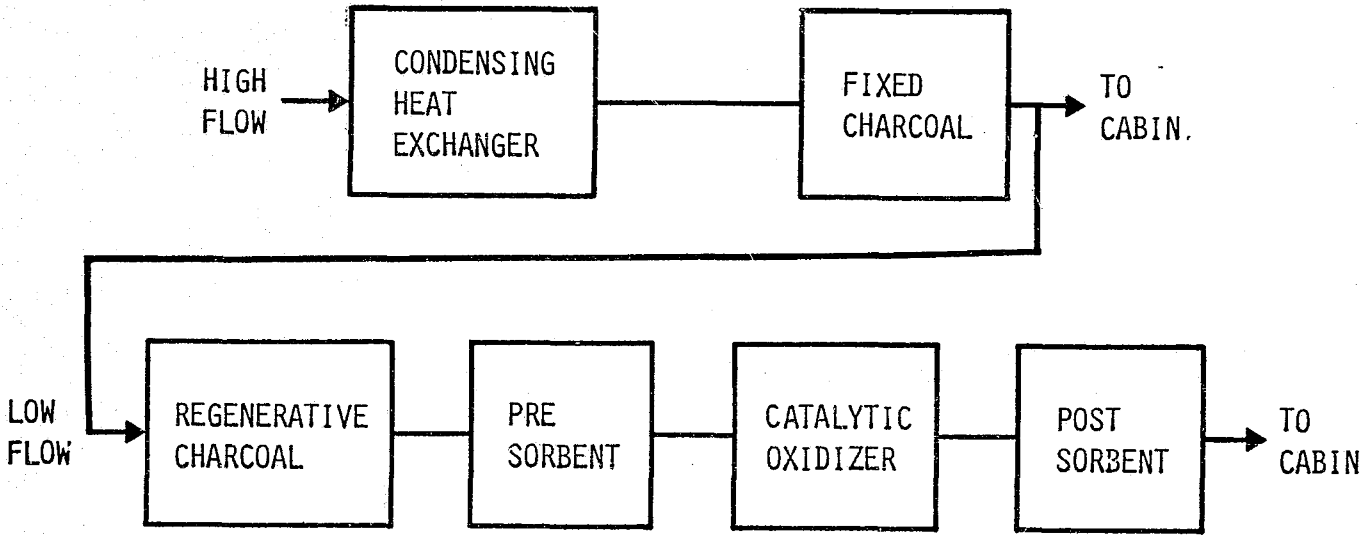
TECHNOLOGY BASE

- DEFINITION OF ACTIVATED CHARCOAL SORPTION CHARACTERISTIC FOR A WIDE VARIETY OF CONTAMINANTS AND CHARCOALS
- DEVELOPMENT OF ANALYTICAL TOOLS FOR PREDICTING CHARCOAL SORPTION AND SIZING OF BED
- DEVELOPMENT OF IN-FLIGHT CHARCOAL BED REGENERATION METHODS USING HEAT AND VACUUM
- DEFINITION OF CONDENSING HEAT EXCHANGER REMOVAL CAPACITY
- DEFINITION OF HIGH TEMPERATURE CATALYTIC OXIDIZER PERFORMANCE CHARACTERISTICS AND PRE AND POST SORBENT REQUIREMENTS
- DEFINITION OF PRE AND POST SORBENT BED PERFORMANCE
- DEVELOPMENT OF ROOM TEMPERATURE CATALITIC OXIDIZER BED
- DEVELOPMENT OF ACID GAS REMOVAL BED
- DEVELOPMENT OF AMMONIA REMOVAL SORBENT
- DEVELOPMENT OF FORMALDEHYDE REMOVAL SORBENT

CONTAMINANT CONTROL SYSTEM ELEMENTS

DEVICE	CONTROLS
FIXED CHARCOAL BED	LOW MOLAR VOLUME WELL ABSORBED CONTAMINANTS
REGENERATIVE CHARCOAL BED	HIGH MOLAR VOLUME MODERATELY WELL ABSORBED CONTAMINANTS
PHOSPHORIC ACID IMPREGNATED CHARCOAL	AMMONIA
CONDENSING HEAT EXCHANGER	HIGHLY SOLUBLE CONTAMINANTS
ROOM TEMPERATURE CATALYTIC OXIDIZER	CARBON MONOXIDE, HYDROGEN
HIGH TEMPERATURE CATALYTIC OXIDIZER	POORLY ABSORBED HYDROCARBONS
PRE AND POST SORBENT	ACID GASSES, SULFUR COMPOUNDS

TYPICAL CONTAMINANT CONTROL SYSTEM CONFIGURATION



APPROACH TO CONTAMINANT CONTROL

- DEFINE CONTAMINANT LOAD MODEL AND PRODUCTION RATES
- DEFINE SPACECRAFT MAXIMUM ALLOWABLE CONCENTRATIONS (SMAC)
- ESTABLISH FIXED CHARCOAL BED SIZE FOR EACH CONTAMINANT
- DEFINE NEED FOR REGENERATIVE BED
- DEFINE CONTAMINANTS NOT HANDLED BY FIXED AND REGENERATIVE BEDS
- SIZE SPECIAL SORBENT BEDS OR CATALYTIC OXIDIZERS
- OPTIMIZE SYSTEM CONSIDERING CONTAMINANT LOAD AND SYSTEM INTERACTION

CONTAMINANT LOAD MODEL DEFINITION

DATA SOURCES

- o WSTF MATERIALS OFFGASSING TESTS
- o SPACE COMPONENTS OFFGASSING TESTS
- o PAYLOAD EQUIPMENT OFFGASSING TESTS
- o MANNED SPACECRAFT CONTAMINANT MONITORING (GROUND AND FLIGHT)
- o GROUND BASED MANNED SIMULATOR TESTS
- o LITERATURE AND TEST DATA FOR METABOLIC CONTAMINANTS

DATA COMPILATION

- o DETERMINATION OF PAYLOAD GENERATION RATES PER UNIT WEIGHT
- o ESTIMATE OF TOTAL PAYLOAD WEIGHT
- o DETERMINATION OF SPACE SYSTEMS GENERATION RATES PER UNIT WEIGHT
- o METABOLIC LOADS FROM CREW SIZE
- o COMPOSITE CONTAMINANT LOAD

SPACECRAFT MAXIMUM ALLOWABLE CONCENTRATIONS

- ESTABLISHED BY NASA JSC MEDICAL DIRECTORATE
- DOCUMENTED IN NHB 8060.113 FOR UP TO 7 DAYS
- SOME CONTAMINANTS NOT INCLUDED IN NHB 8060.113
- SEVERAL CONTAMINANTS HAVE VERY LOW ALLOWABLE LEVELS

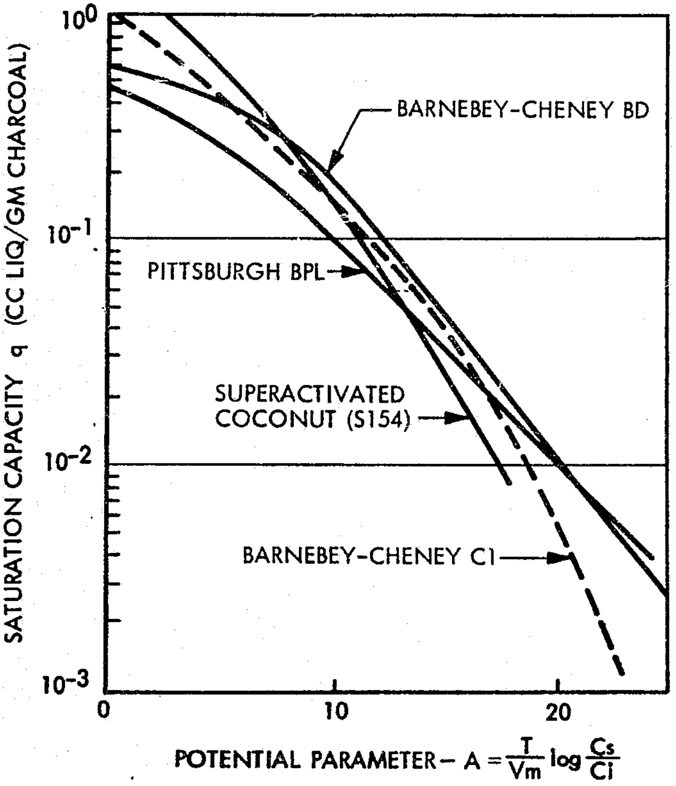
CHARCOAL BED SIZING

- CHARCOAL BED INCLUDES SATURATED ZONE PLUS ABSORPTION ZONE
- CAPACITY DEPENDS ON CONTAMINANT CHARACTERISTICS
  - TEMPERATURE
  - MOLAR VOLUME
  - VAPOR PRESSURE
  - INLET CONCENTRATION

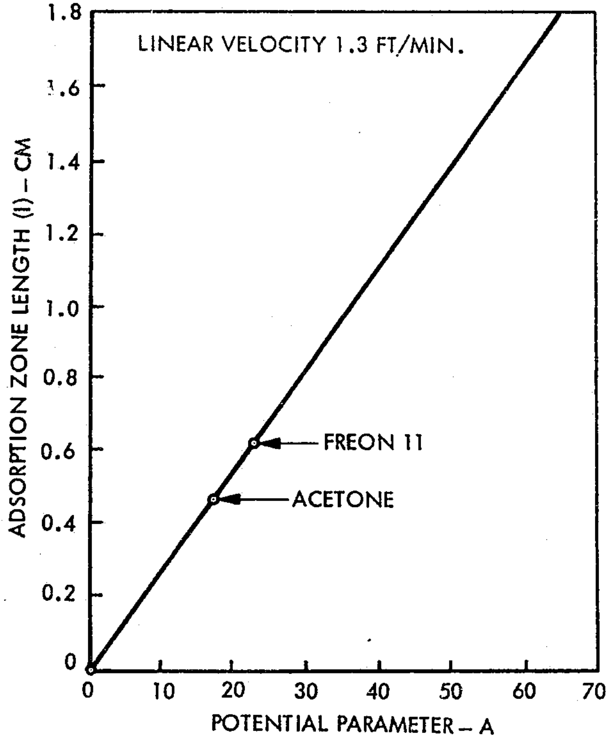
  "A" VALUE
- "A" VALUE PLUS EXPERIMENTALLY DETERMINED POTENTIAL PLOT PROVIDES SATURATION CAPACITY
- ADSORPTION ZONE LENGTH IS ADDED TO SATURATED ZONE TO DETERMINE TOTAL BED SIZE
- BED SIZE ADJUSTED FOR COADSORPTION
- SIZING ACCOMPLISHED BY COMPUTER PROGRAM (ICHAR)

TYPICAL CHARCOAL PERFORMANCE CHARACTERISTICS

POTENTIAL PLOT FOR VARIOUS CHARCOALS



ADSORPTION ZONE LENGTHS FOR VARIOUS CONTAMINANTS



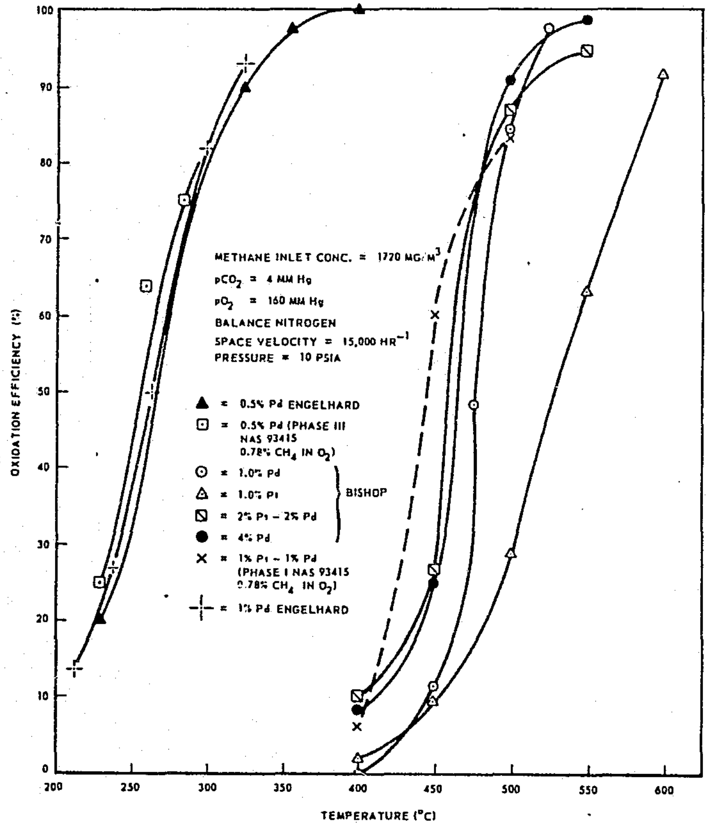
CATALYTIC OXIDIZER SIZING

- ESTABLISH CONTAMINANTS THAT REQUIRE OXIDATION FOR CONTROL
- DETERMINE NEED FOR HIGH OR LOW TEMPERATURE CATALYTIC OXIDIZER
- SELECT MOST EFFECTIVE CATALYST FROM TEST DATA
- DETERMINE FLOW RATE, RESIDENCE TIME AND CATALYST BED SIZE
- OPTIMIZE INSULATION REQUIREMENTS VERSUS BED SIZE

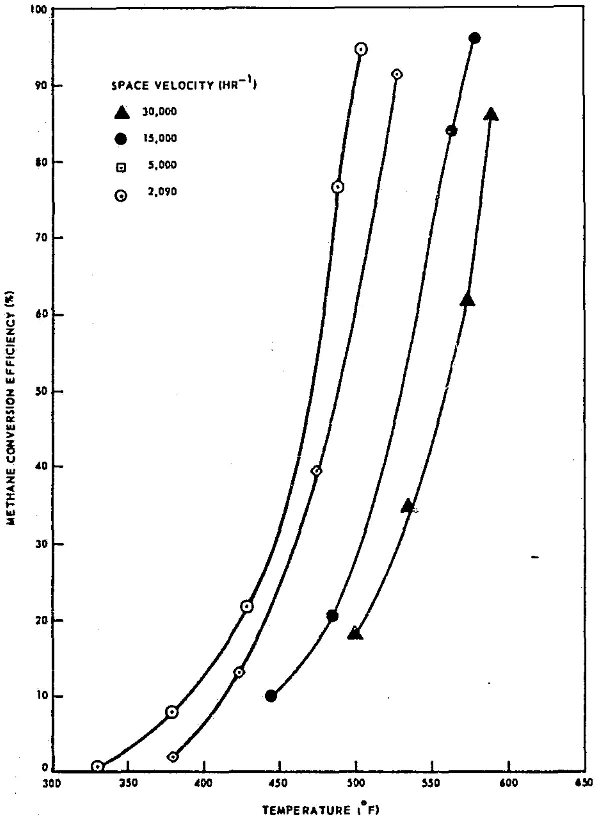
SPACE STATION PROGRAMS

TYPICAL CATALYTIC OXIDIZER PERFORMANCE CHARACTERISTICS

CONVERSION EFFICIENCY FOR VARIOUS CATALYSTS



CONVERSION EFFICIENCY FOR VARIOUS RESIDENCE TIMES



SPECIAL SORBENT BED SIZING

- USED FOR AMMONIA, ACID GASES AND OTHER SPECIAL CONTAMINANTS
- BED SIZE DETERMINED BY
  - ALLOWABLE CONCENTRATION
  - TOTAL CONTAMINANT GENERATION RATE
  - EXPERIMENTALLY DETERMINED CONTACT TIME
  - MISSION DURATION
- GENERALLY INTEGRATED INTO FIXED CHARCOAL BED
- LITHIUM HYDROXIDE AND POTASSIUM HYDROXIDE IMPREGNATED CHARCOAL USED FOR ACID GASES
- ACID IMPREGNATED CHARCOAL USED FOR AMMONIA
- CHROMATE IMPREGNATED CHARCOAL USED FOR FORMALDEHYDE

SPACE STATION PROGRAMS

ANIMAL AND PLANT RESEARCH PAYLOAD PROBLEMS

PROBLEMS

- o WASTE REMOVAL AND STORAGE
- o BACTERIOLOGICAL CROSS CONTAMINATION

SOLUTIONS

- o COMPLETE ISOLATION OF CREW AND EXPERIMENTS BY USE OF SEPARATE ENVIRONMENTAL SYSTEMS
- o USE OF HIGH EFFICIENCY BACTERIOLOGICAL FILTERS
- o USE OF ONLY SPF ANIMALS
- o USE OF ISOLATION TRANSPORTERS FOR WASTE REMOVAL AND STORAGE
- o USE OF SPECIALLY DESIGNED ISOLATION WORK STATIONS (GLOVE BOX DESIGN)

EMERGENCY UPSET CONTAMINANT REMOVAL

- SAFE HAVEN CREW SHELTER
- EMERGENCY CONTAMINANT REMOVAL SYSTEM REMOTELY ACTIVATED
- PORTABLE BREATHING APPARATUS
  - OXYGEN LINE
  - SUPEROXIDE BREATHER
- CABIN DECOMPRESSION AND REPRESSURIZATION

CONCLUSIONS

- TRACE CONTAMINANT CONTROL TECHNOLOGY BASE IS RELATIVELY FIRM
- HARDWARE AND DESIGN TOOLS ARE AVAILABLE
- PREVIOUS DESIGN PHILOSOPHY STILL APPLICABLE

  I.E., CONSERVATIVE LOAD MODEL REFINED LATER AS ACTUAL OFFGASSING DATA ARE AVAILABLE
- MAJOR CONCERNS
  - CATALYTIC OXIDIZER (NEED VS. DANGER)
  - CONTAMINANTS WITH VERY LOW ALLOWABLE CONCENTRATIONS
  - IMPACT OF RELAXING MATERIALS REQUIREMENTS

WEDNESDAY, FEBRUARY 29

N85-29551

GAS CHROMATOGRAPHY:
POSSIBLE APPLICATION OF ADVANCED INSTRUMENTATION DEVELOPED FOR SOLAR SYSTEM EXPLORATION TO SPACE STATION CABIN ATMOSPHERES

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Gas chromatography (GC) technology has been under development for flight experiments in solar system exploration for some years. GC is a powerful analytical technique where relatively simple devices can separate individual components from complex mixtures and then make very sensitive quantitative and qualitative measurements. It is particularly suited to monitoring samples containing mixtures of fixed gases and volatile organic molecules. GC has been used on the Viking mission in support of life detection experiments and on the Pioneer Venus Large Probe to determine the composition of the venusian atmosphere. A flight GC is currently being developed to study the progreess and extent of STS astronaut denitrogenation prior to extravehicular activity. Advanced flight GC concepts and systems for future solar system exploration are also currently under study. Studies include miniature ionization detectors and associated control systems capable of detecting from ppb up to 100 percent concentration levels. Further miniaturization is being investigated using such techniques as photolithography and controlled chemical etching in silicon wafers. Novel concepts such as ion mobility drift spectroscopy and multiplex gas chromatography are also being developed for future flight experiments. These powerful analytical concepts and associated hardware are ideal for the monitoring of cabin atmospheres containing potentially dangerous volatile compounds and could be applied with minimal development.

TABLE 1

PIONEER VENUS LGC RESULTS

SAMPLE NUMBER	1	2	3
ALTITUDE,KM	51.6	41.7	21.6
PRESSURE,BARS	0.7	2.9	17.8
GAS		% CONCENTRATION	
CO_2	95	96	96
N_2	4.6	3.5	3.4
H_2O	<0.06	0.52	0.14
		ppm	
O_2	44	16	
Ar	60	64	67
CO	32	30	20
Ne	8	11	4
SO_2	<600	180	185

Figure 1: Pioneer Venus short column chromatogram of 24 km sample, showing raw data points. Solid line shows detector signal at a range of 0.7 to 1.6 mV. Dashed line shows detector signal at a range of 0.7 to 900 mV. Inset at right is expanded view of SO_2 peak.

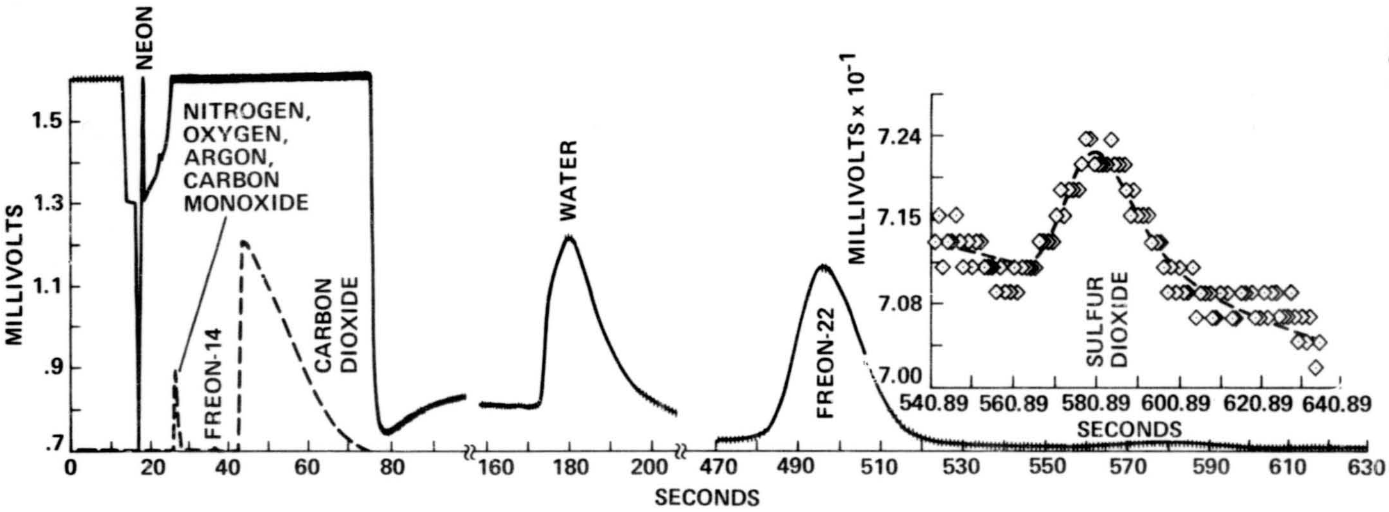

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Figure 2: Pioneer Venus long column chromatogram of 24 km sample, showing raw data points. Solid line shows detector signal at a range of 0.6 to 1.5 mV. Dashed line shows detector signal at a range of 0.6 to 90.6 mV. Inset at left is expanded view of Neon peak.

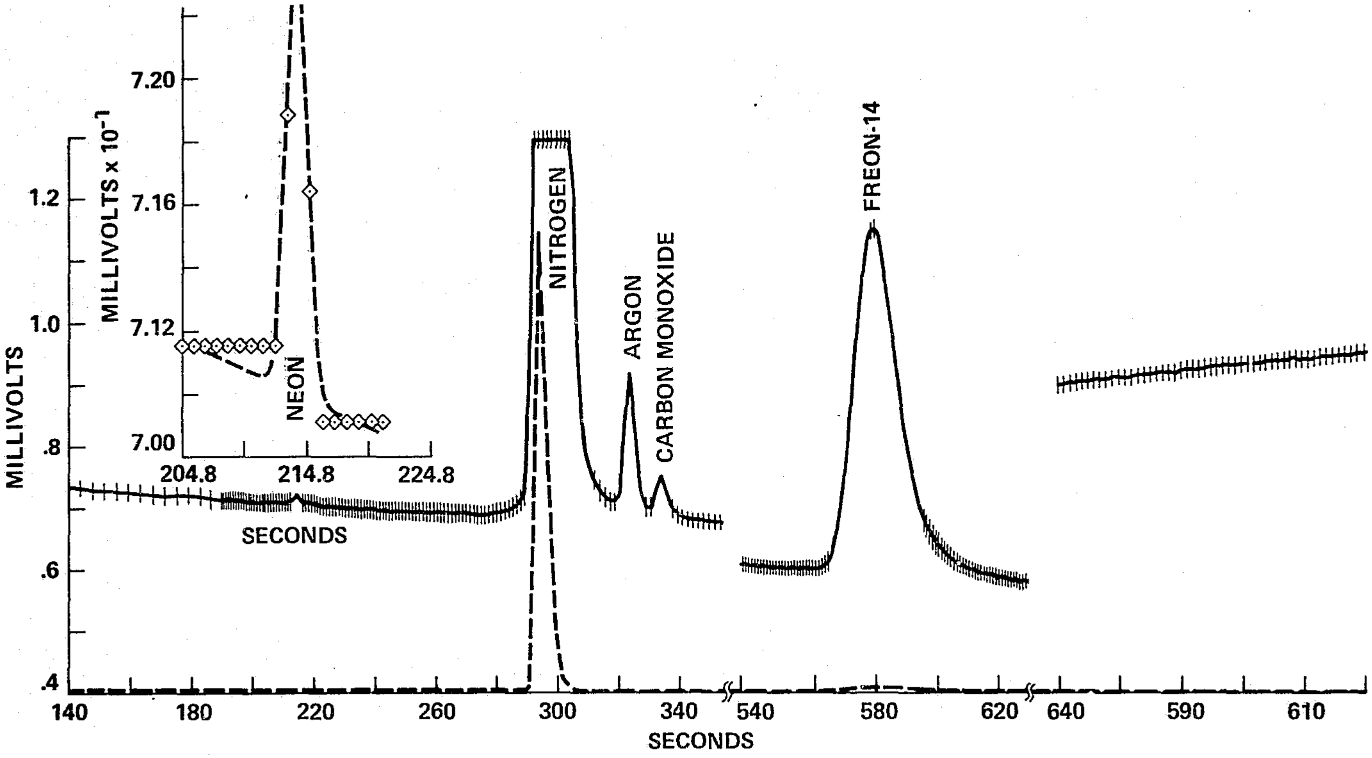
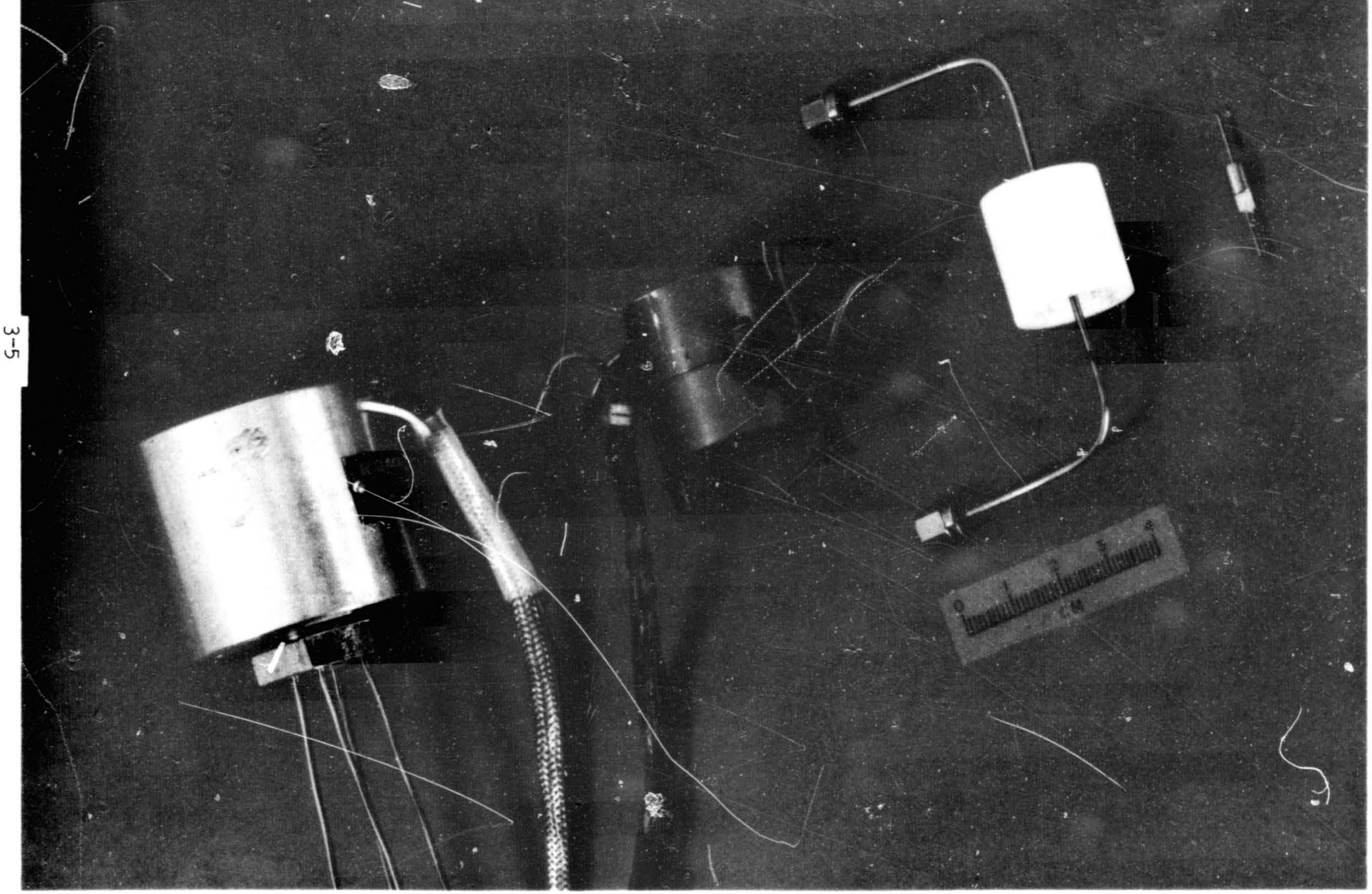


Figure [illegible] Evolution of Gas Chromatographic Detectors.
From top to bottom   Commercial Thermoconductivity Detector (TCD), Viking GEX TCD,   Mockup of commercial Metastable Ionization Detector (MID),   ARC miniature MID (Woeller)



GC / IMDS

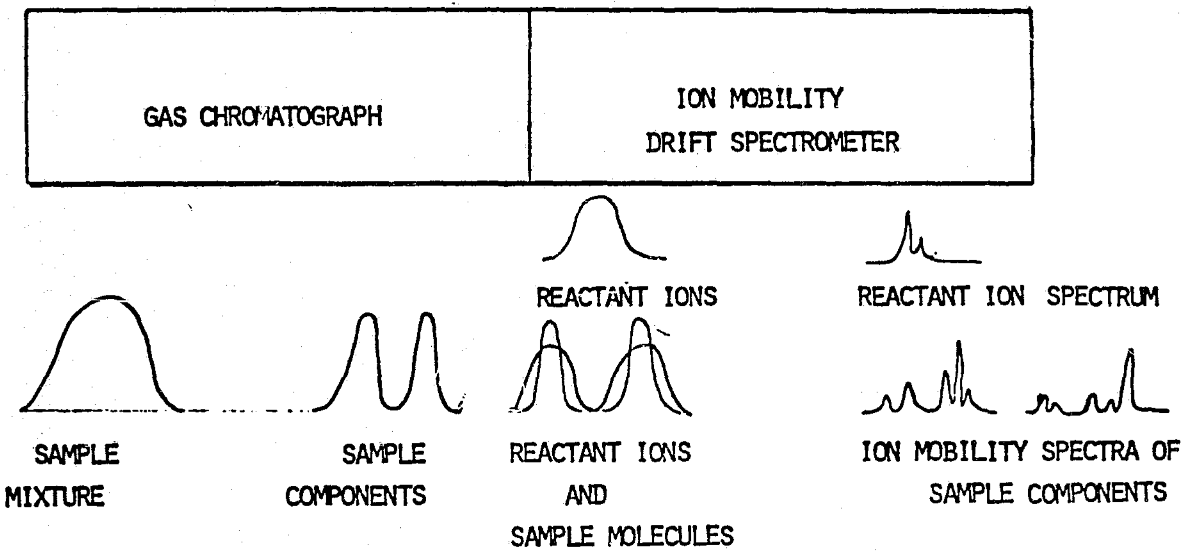


Figure 4: Gas Chromatograph separates components of sample mixture. IMDS reactant ions ionize each sample component as it elutes from the GC column forming product ions. These product ions are separated in the drift tube according to their size and structure forming Ion Mobility Spectra of the sample components.

Figure 5: Top: Typical positive reactant ion spectrum (background). Bottom: IMDS spectra of three heptylhalides. Although similiar in structure, the heptylhalides produce distinctly different spectra.

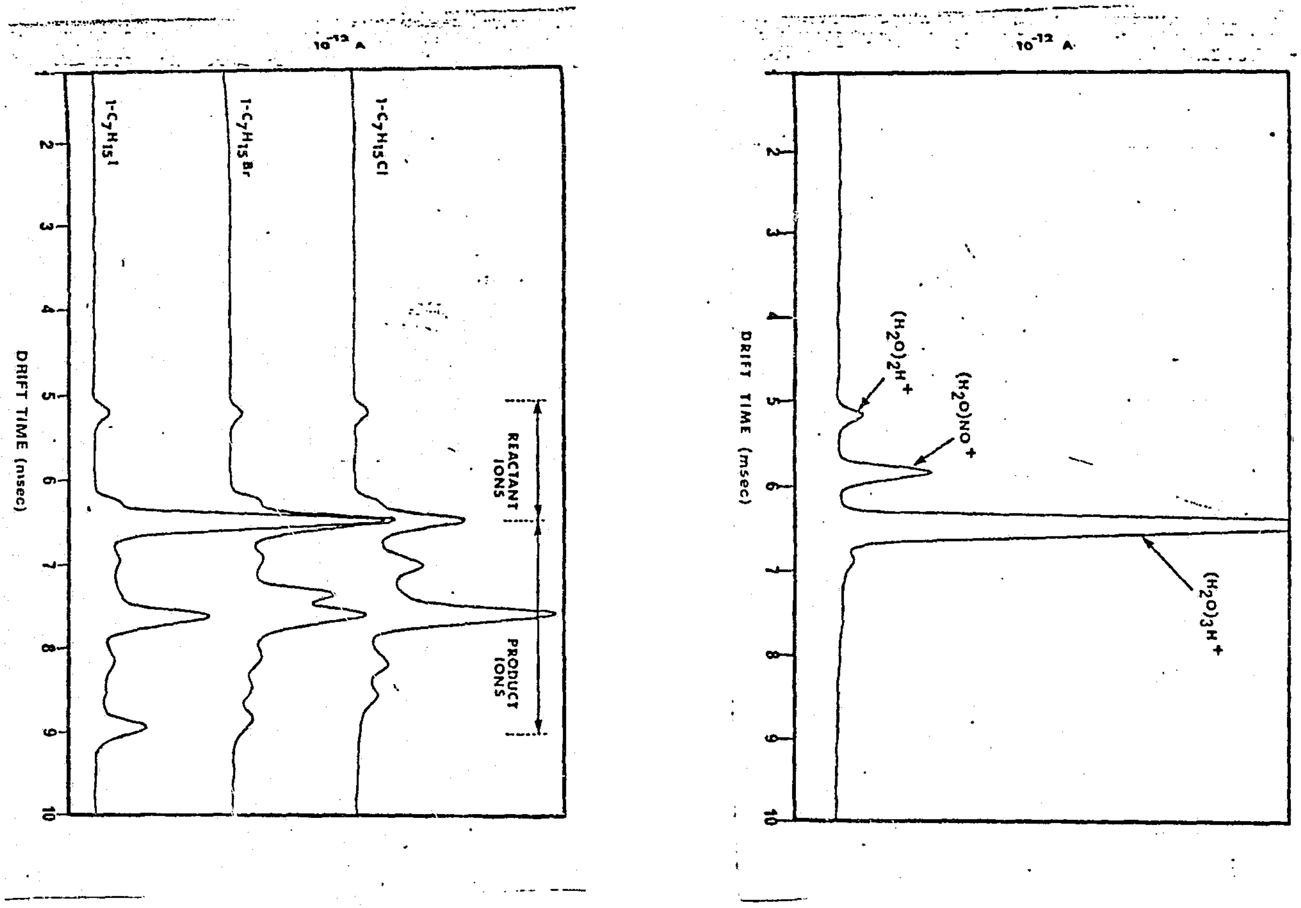


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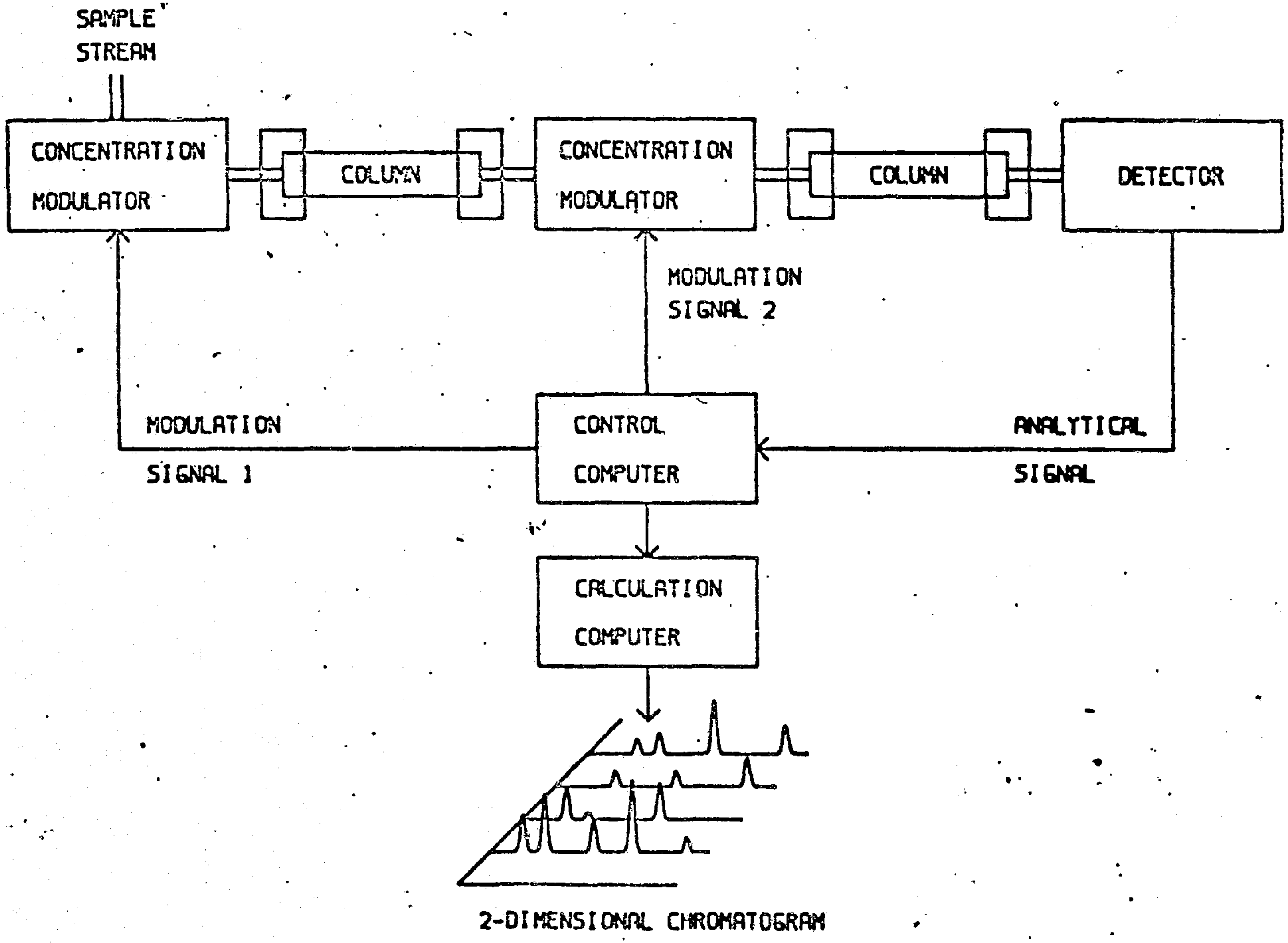
Figure 6: Block Diagram of Two-Dimensional Multiplex Gas Chromatographic System. Computer controls sample introduction using two concentration modulators and analyzes detector output to produce 2-dimensional chromatogram.



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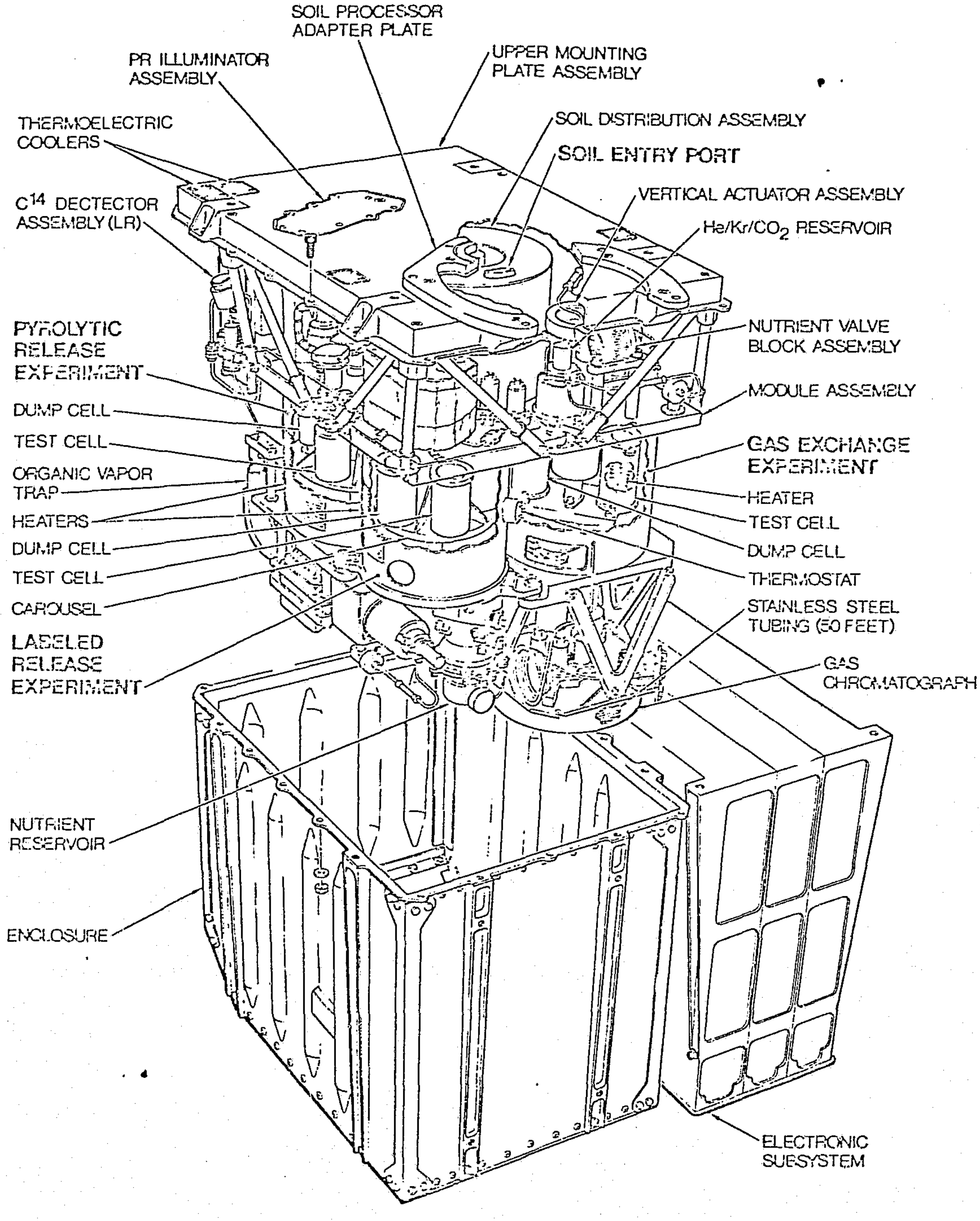
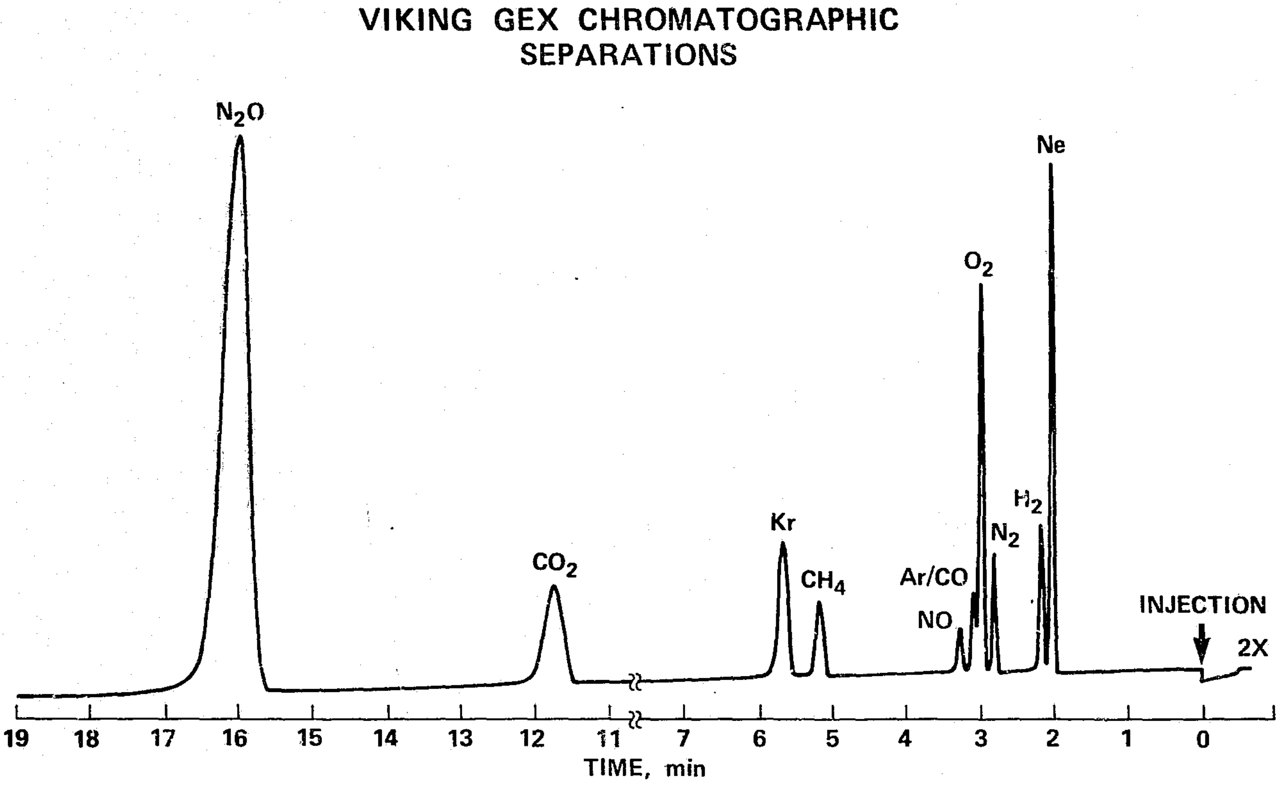


Figure 7. Exploded View of Instrument Packaging



VIKING GEX CHROMATOGRAPHIC SEPARATIONS

Figure 8.

VL-1 GAS CHANGES IN GEX HEADSPACE

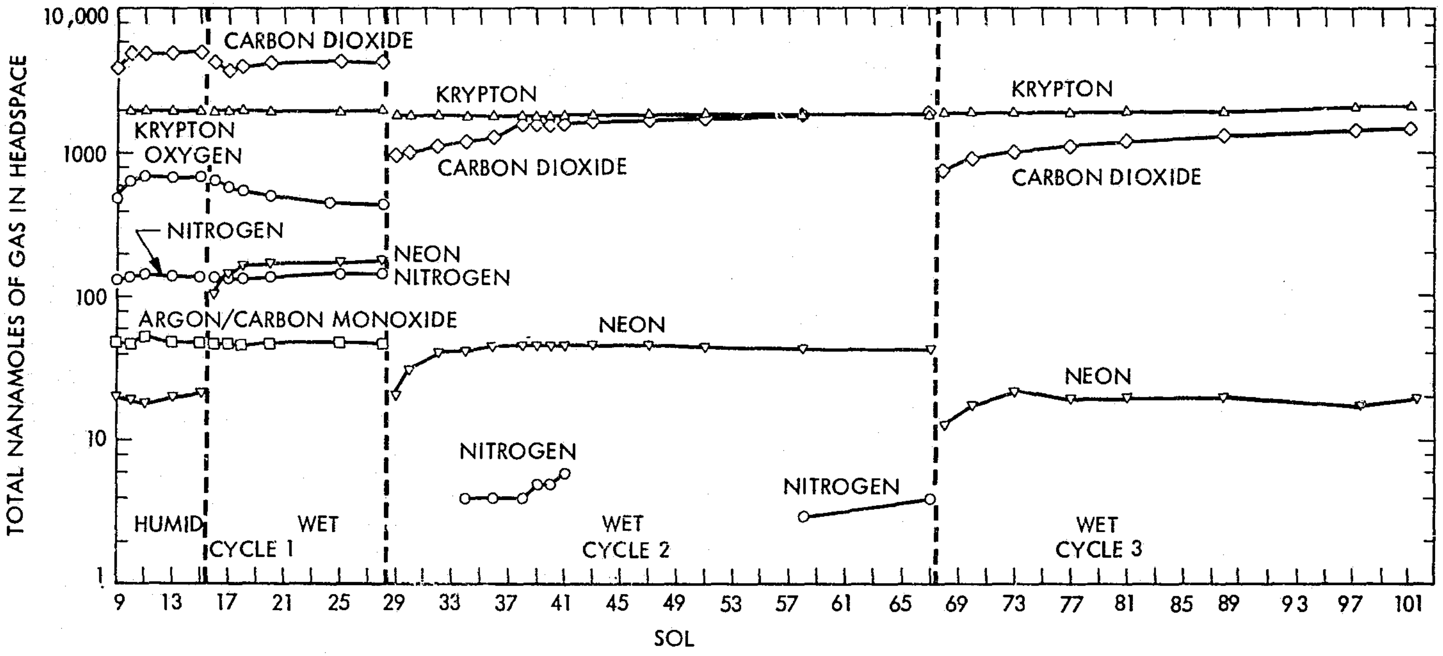


Figure 9

PIONEER VENUS
GAS CHROMATOGRAPHIC ATMOSPHERIC ANALYZER

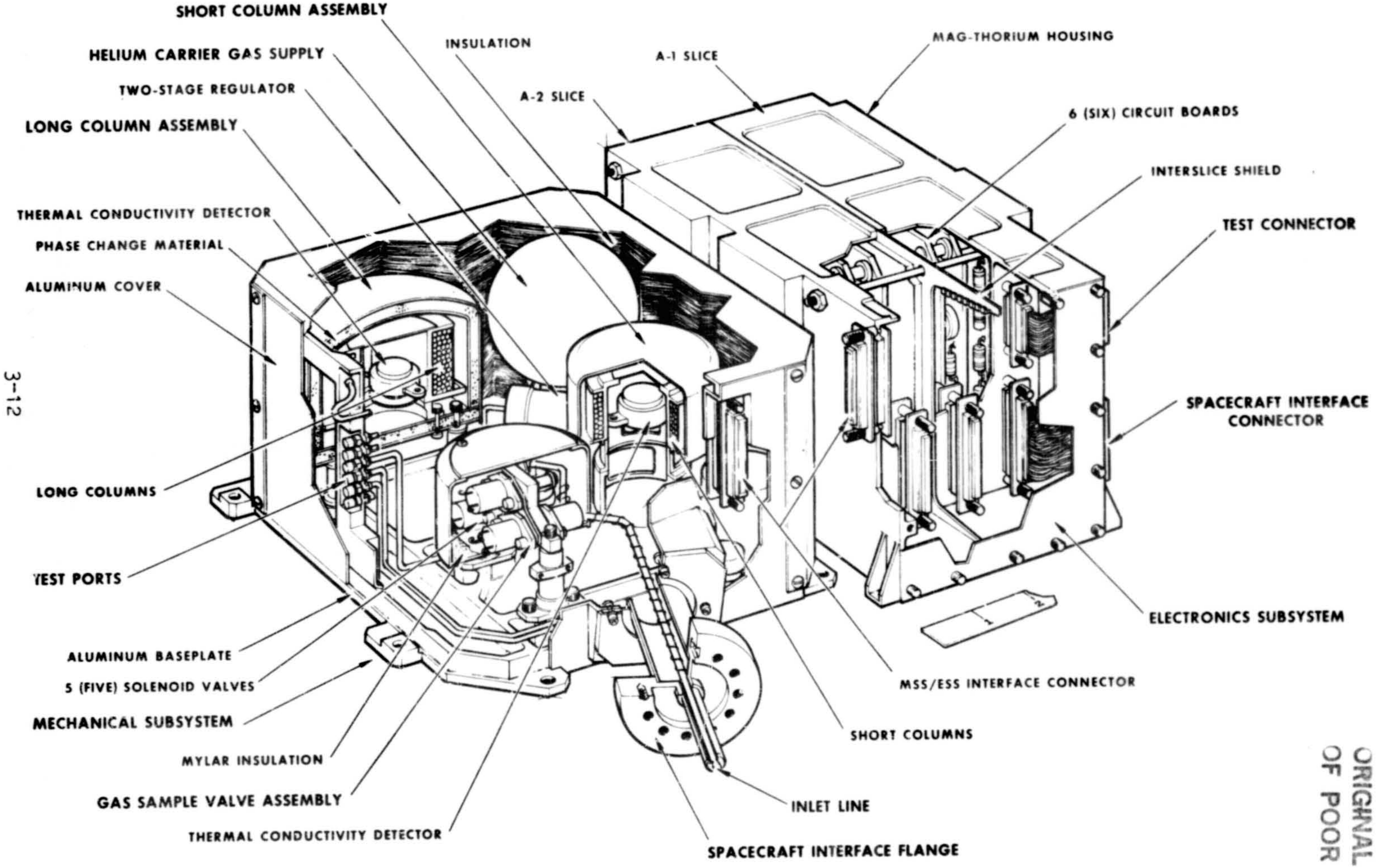
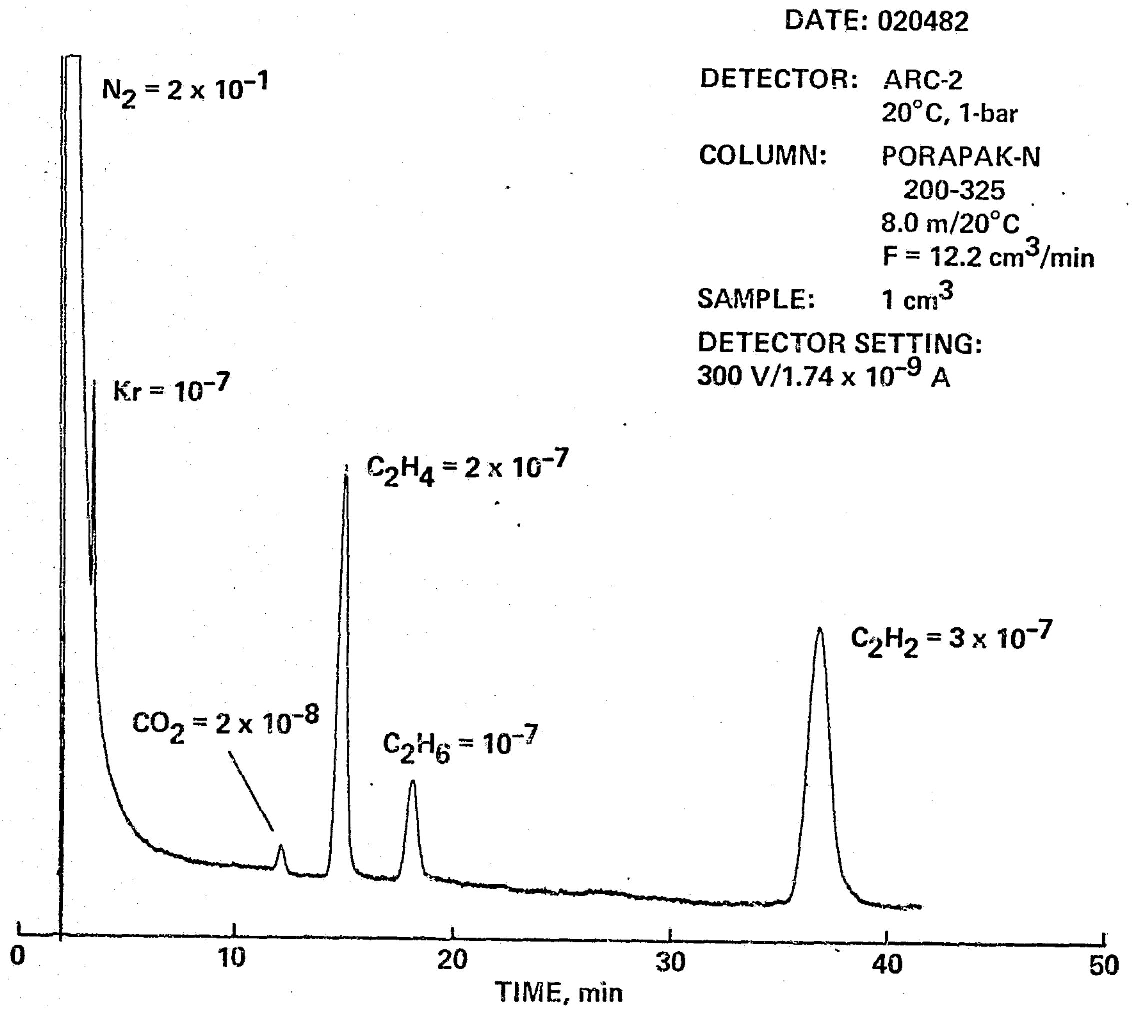


Figure 10



CHROMATOGRAM DEMONSTRATING CAPABILITY OF CURRENT TECHNOLOGY TO MEASURE SPECIES IN THE PARTS-PER-BILLION RANGE (E.G., CO_2 AT 20 PPB)

Figure 11

MODULATED VOLTAGE METASTABLE IONIZATION DETECTOR

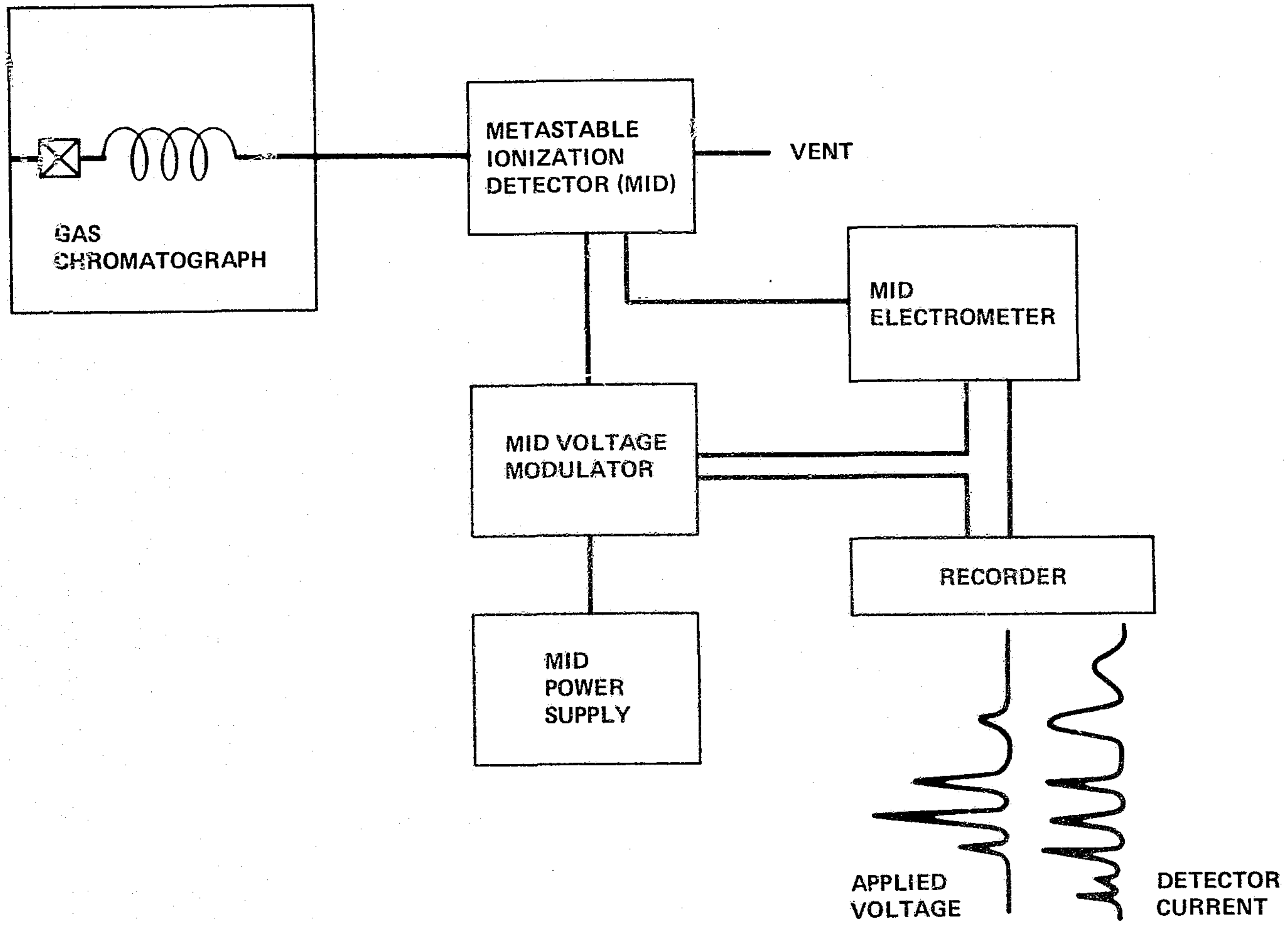


Figure 12

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LABORATORY PROTOTYPE MICRO GAS CHROMATOGRAPH

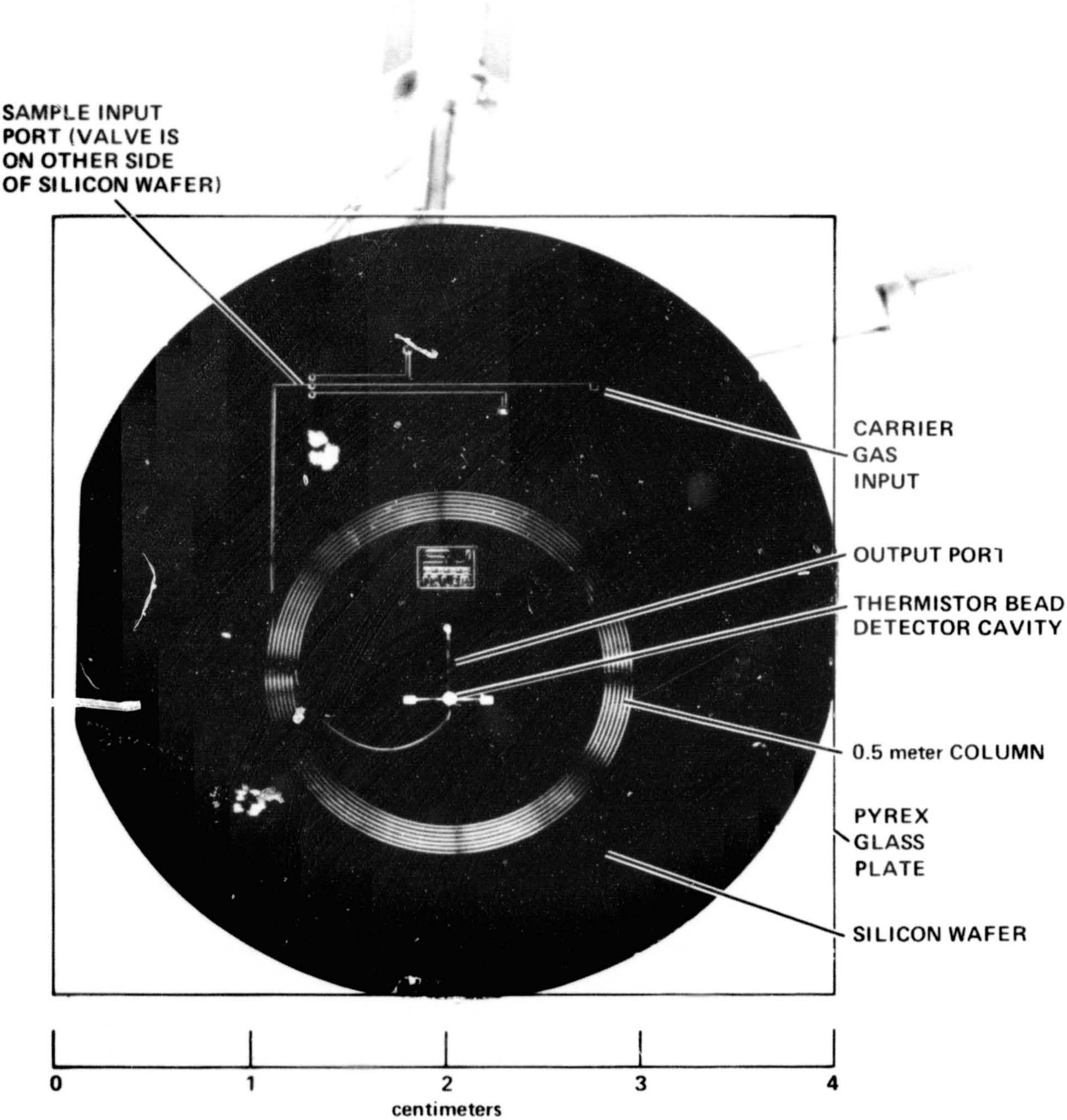


Figure 13

N85-29552

2/28/84

Mass Spectrometry Technology at the Jet Propulsion Laboratory (JPL)

by

Charles E. Giffin

INTRODUCTION

The purpose of this presentation is to inform the members of the NASA Human Productivity Working Group about recent developments in the field of mass spectrometery taking place at the Caltech Jet Propulsion Laboratory. The pertinent research and development is aimed at producing an ultra-high sensitivity mass spectrograph for both spaceflight and terrestrial applications. The unique aspect of the JPL developed technology is an integrating focal plane ion detector that obviates the need for spectral scanning since all ions over a wide mass range are monitored simultaneously. The ion detector utilizes electro-optical technology and is therefore referred to as an Electro-Optical Ion Detector (EOID). A technical description of the JPL MS/EOID, some of the current applications, and its potential benefits for internal contamination analysis are discussed below.

MS/EOID TECHNOLOGY

Figure 1 illustrates the comparison between a scanning mass spectro<u>meter</u> and a non-scanning mass spectro<u>graph</u>. Simply put, the spectrometer can monitor only one ion species at a time while the spectrograph monitors simultaneously all ion species illuminating the focal plane. For high sensitivity, the spectrometer utilizes an electron multiplier for an ion detector which can achieve the ability to detect single ions passing through the image slit. Classically, the mass spectrograph has used a photoplate to simultaneously monitor all the ion species along the focal plane but required approximately 10,000 ions to generate a detectable image in the photographic emulsion. The duty cycle (i.e., the fraction of time spent measuring individual ion currents during a spectral scan period) of a scanning mass spectrometer can be as low as 0.01% per mass peak over a mass range of 20:1. The mass spectrograph has a 100% duty cycle. Hence several orders of magnitude increase in spectral sensitivity can be achieved with a spectrograph fitted with an ion detector capable of detecting single ions. The EOID achieves this requirement.

Figure 2 illustrates the EOID concept. Ions exiting the magnetic field of a mass spectrograph impinge on a two dimensionsal microchannel electron multiplier array (MCA). For each ion entering a microchannel 10^4 electrons exit the channel and are accelerated to the phosphored surface of a fiber optic vacuum window. Approximately 100 photons are generated for each impinging electron giving an overall ion-to-photon gain of 10^6. The photons are guided fiber optically to a self-scanned linear photodiode array (PDA) where signals are integrated, converted back to electrons and sent to a computer. Figure 3 is a photograph of "ion" images appearing on the exit face of the fiber optic window arising from a sample of perfluoro-iso-octane (MW = 438 amu).

Figure 4 is a schematic representation of the MS/EOID hardware implementation. The focal plane is 12.7 cm long and is viewed by five 1024 element PDAs interdigitated fiber-optically for mechanical reasons. Hence the MS/EOID has 5120 individual detector elements (photodiodes) continuously observing the mass spectral signal. Each photodiode is inactive for only 8.3μs while it is being readout to the computer. Spectral integration time can be varied from several tens of milliseconds to tens of seconds. Figure 5 is a summary of the existing "miniaturized" MS/EOID specifications and Figure 6 is a photograph of the instrument.

APPLICATIONS

Inherent in the MS/EOID concept is the potential for both high sensitivity as well as rapid transient response. Different applications may stress one over the other and in some cases both are required. In general, however, the preservation of complete spectral information while detecting ion currents with single ion sensitivity has opened up some interesting fields of research.

An application stressing sensitivity is that of amino acid analysis from protein molecules sequenced by the Edman degradation chemical process. Determination of the protein structure is accomplished by successively clipping amino acids, one by one off the protein molecule in the sequenator, and analyzing each sample for the prominent amino acid in that residue. Liquid chromotography coupled with UV detection is typically used. This is both time consuming and not very sensitive (30 minutes for an LC run and ~1 ng detectability). An automated MS/EOID is currently under development at JPL that has an analysis time of one minute and a detectability approaching 1 pg. Figure 7 is a block diagram of the system and Figures 8 and 9 are representative data. Efficient sample acquisition and transport together with sample contamination are areas of concern being presently worked.

An MS/EOID instrument system is currently under development that requires both fast transient response and and high sensitivity. This system will be utilized for the real-time analysis of ambient aerosols and biological particles in air. This system concept is shown schematically in Figure 10. Ambient aerosol particles are extracted from the air and formed into a beam by a differentially pumped capillary/skimmer system. As the particles strike a hot rhenium filament, they are volatilized and the plume of vapor is subsequently ionized by an electron beam. The burst of ions thus genrated (in a time span of ~100-200 μs) is accelerated into the mass analyzer, separated according to mass, and integrated by the EOID. Complete mass spectra from each volatilized/ionized particle can be read out at intervals as closely spaced as 40 ms. Figures 11 and 12 are data gathered from 1.7 μm diameter potassium biphthalate particles and three different bacterial particles <u>without</u> the benefit of MS/EOID. In these cases approximately 1000 particles per peak were required to generate the statistics necessary to quantitate the ion intensity measurements using a quadrupole mass filter in the manual scan mode. The MS/EOID for the particle analysis research is currently being assembled and will be operational by early spring. A laser ionization method is also under development and will be studied in detail after the MS/EOID is interfaced to the particle beam inlet system.

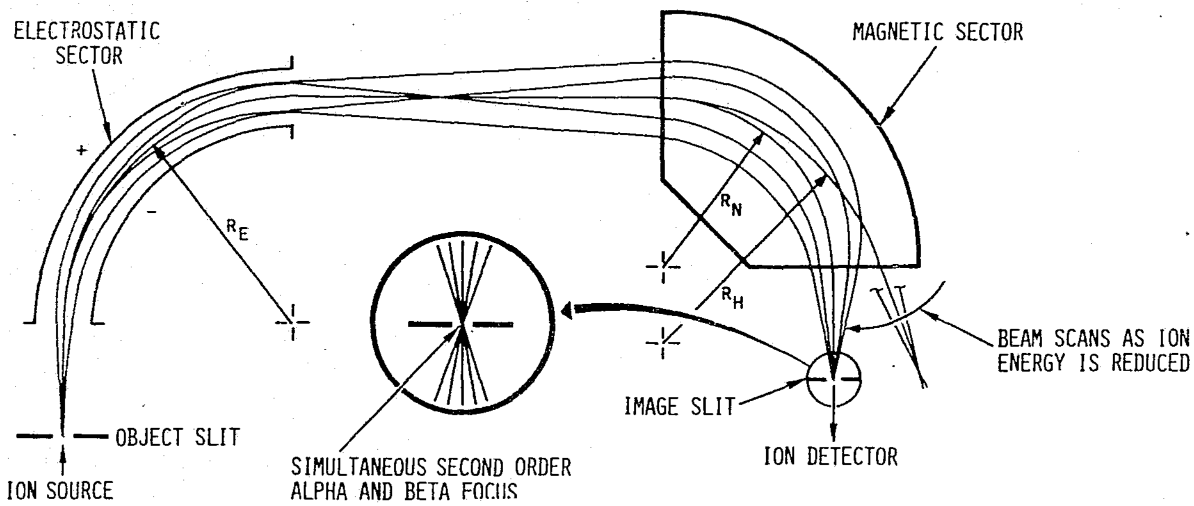
APPLICATION TO SPACE STATION INTERNAL CONTAMINATION

It is the author's opinion that the potential role MS/EOID could play in the area of internal contamination would be as a quantitiative analysis tool for the elucidation of atmospheric contaminants aboard Space Station. With the hundreds of contaminants found over the years in spacecraft environments, it would appear that combined gas chromotography-mass spectrometery offers the best chance for accurately assessing potentially hazardous conditions in the environment.

The existing MS/EOID at JPL covers a much broader mass range than is required (a maximum mass limit of 300 amu should be adequate). A small MS/EOID at the University of Minnesota (built for upper atmosphere ballon borne measurements) is too small with a maximum mass limit of 50 amu. Preliminary calculations show that if one limits the focal plane length to 6.4 cm a medium size MS/EOID could be constructed covering a mass range from 15 amu to 300 amu while taking advantage of the latest state-of-the-art high resolution microchannel electron multiplier array and photodiode array devices available on the market.

The rational for using an MS/EOID over a more conventional mass spectrometer is speed of response coupled with high sensitivity. Were a micro GC column (silicon wafer type) developed that could effect the required separation of contaminant species then the MS/EOID would likely be the only mass spectrometer that could measure the spectra of the very narrow (fractional second) peaks eluting from the GC. Because of its small size, the silicon wafer GC also utilizes very small sample aliquots thus requiring a high sensitivity detector for the quantitiatve measurement of trace species.

DOUBLE FOCUSING MASS SPECTROMETER



DOUBLE FOCUSING MASS SPECTROGRAPH

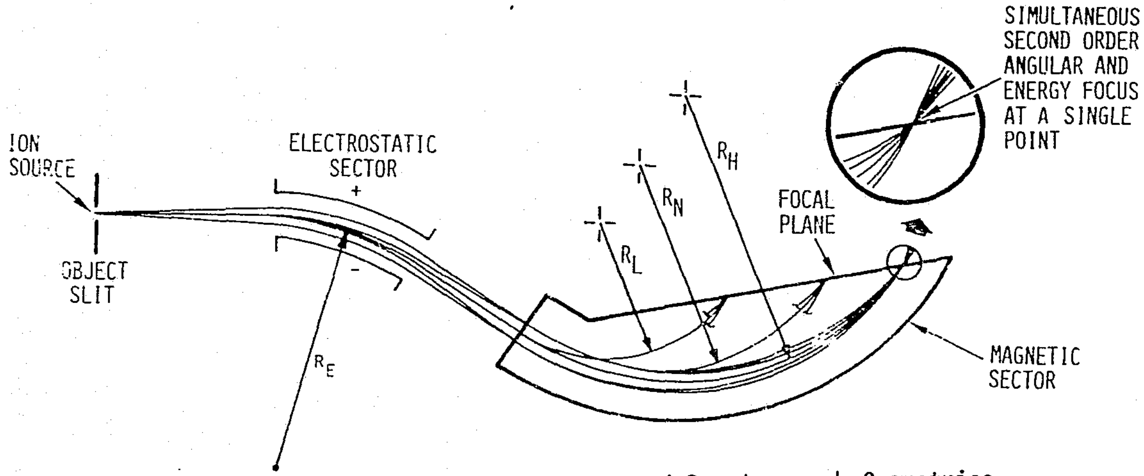


Figure 1 - Comparison of Spectrometer and Spectrograph Geometries

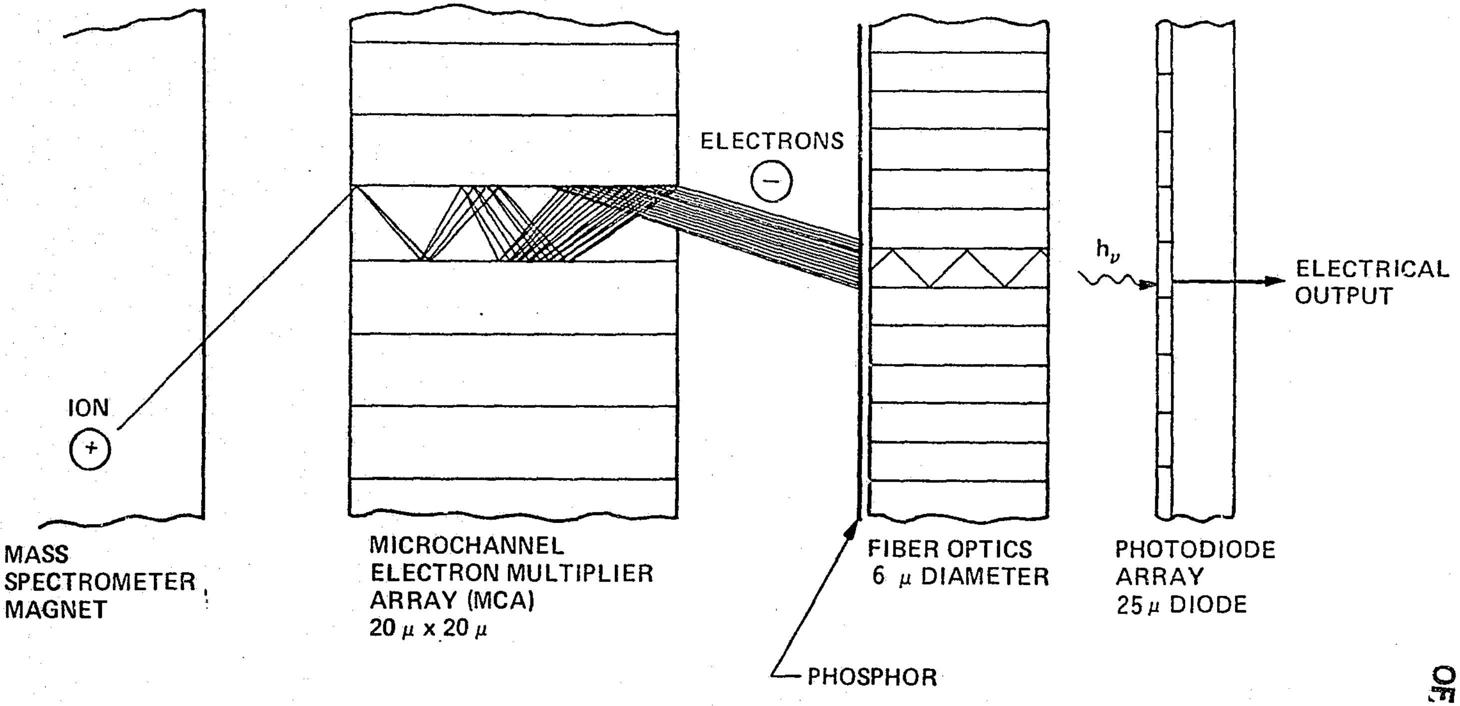


Figure 2 - Electro-Optical Ion Detector Schematic

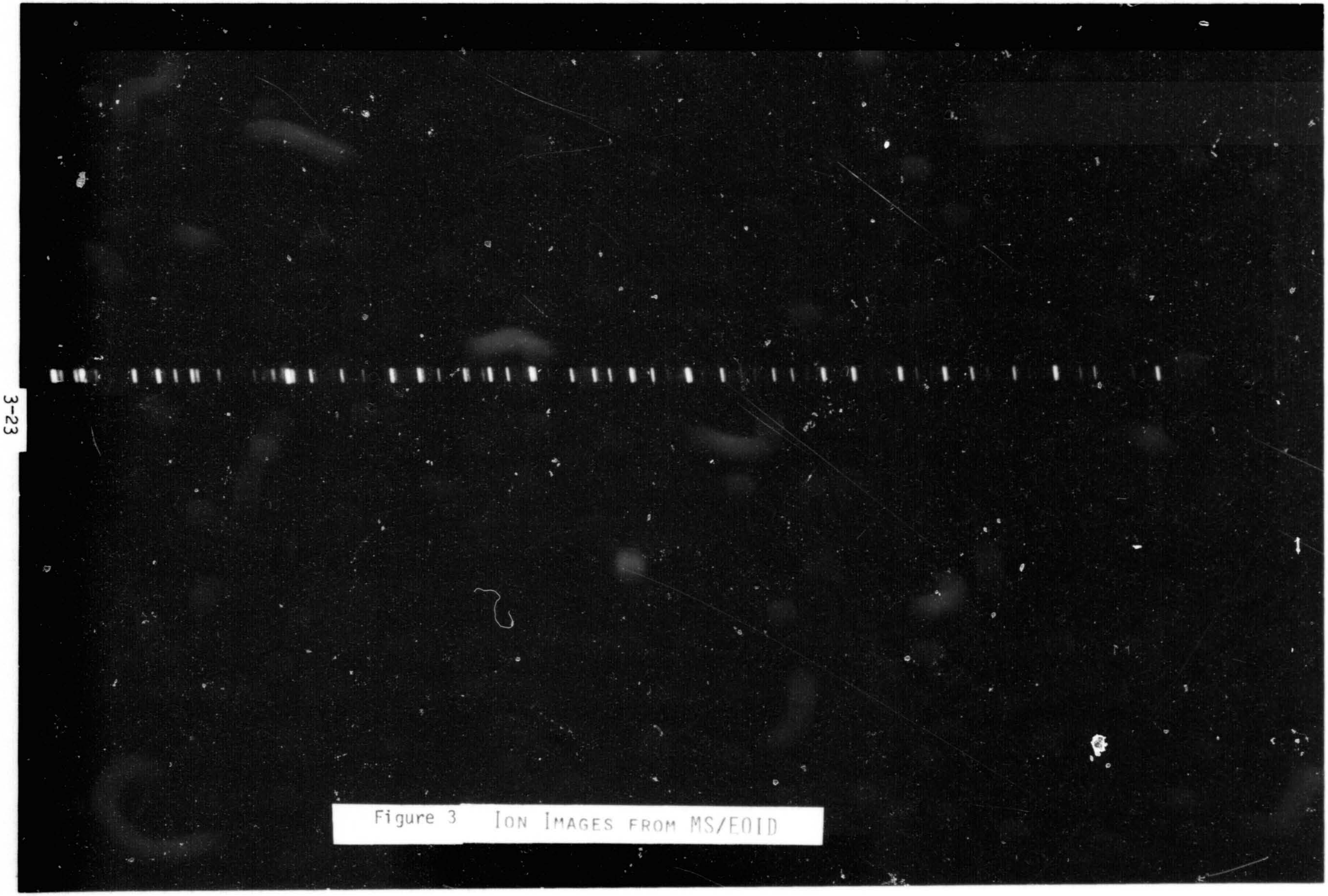


Figure 3 ION IMAGES FROM MS/EOID

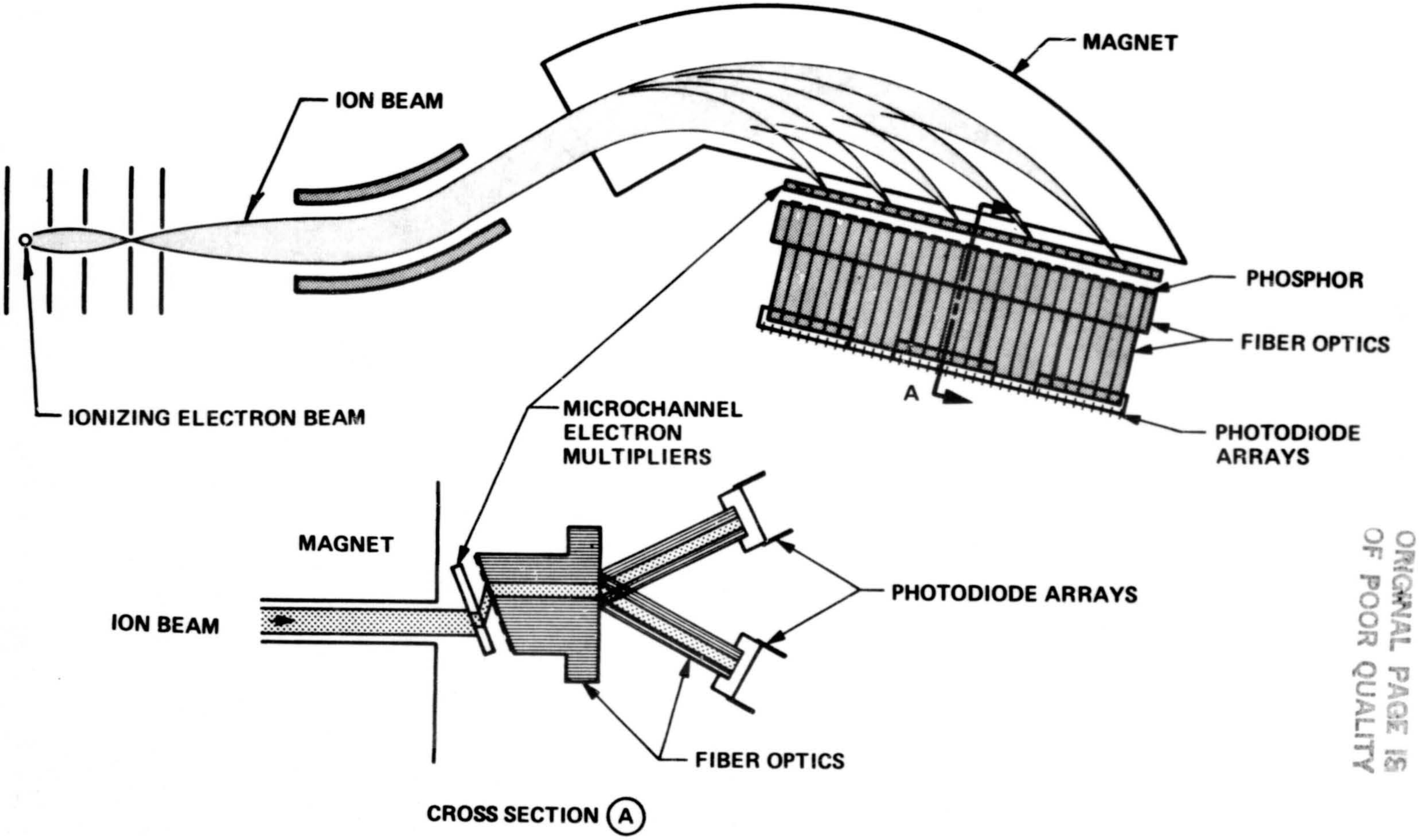


Figure 4 MS/EOID IMPLEMENTATION SCHEMATIC

MS/EOID PERFORMANCE

• MASS RANGE	25 - 500 AMU
• MASS RESOLUTION	$(M/\Delta M)_{10\%} = 515$
• DYNAMIC RANGE	1.5×10^4
• SPECTRAL READOUT TIME	40 MILLISECONDS
• DETECTABILITY (WITH 100:1 SPECTRAL DYNAMIC RANGE)	$\sim 1 \times 10^{-15}$ GRAM*

*APPROXIMATELY EQUIVALENT TO 0.1 μM DIAMETER PARTICLE OF UNIT DENSITY

Figure 5

DOUBLE FOCUSING FOCAL PLANE MASS SPECTROGRAPH WITH AN ELECTRO-OPTICAL ION DETECTOR

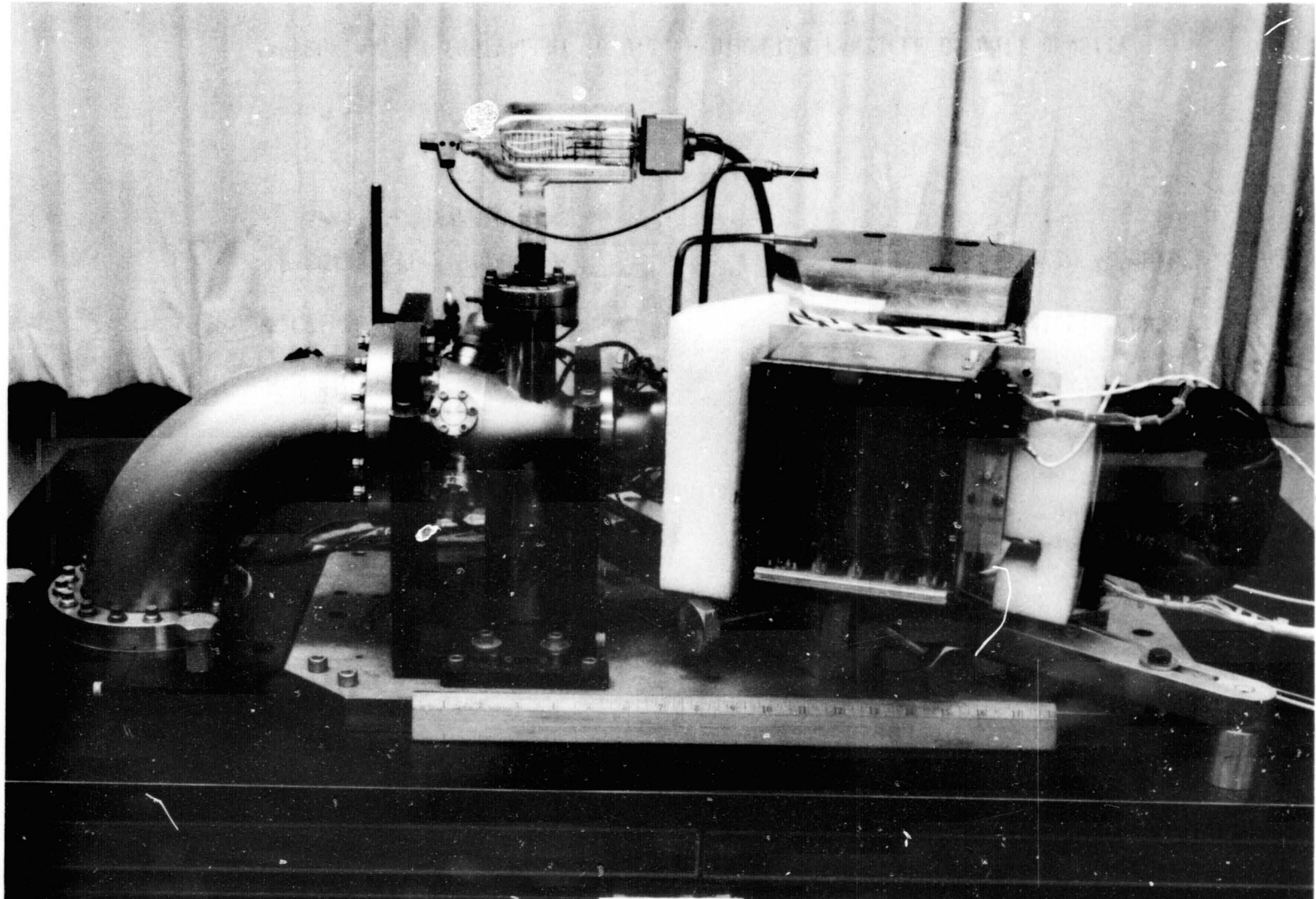


Figure 6

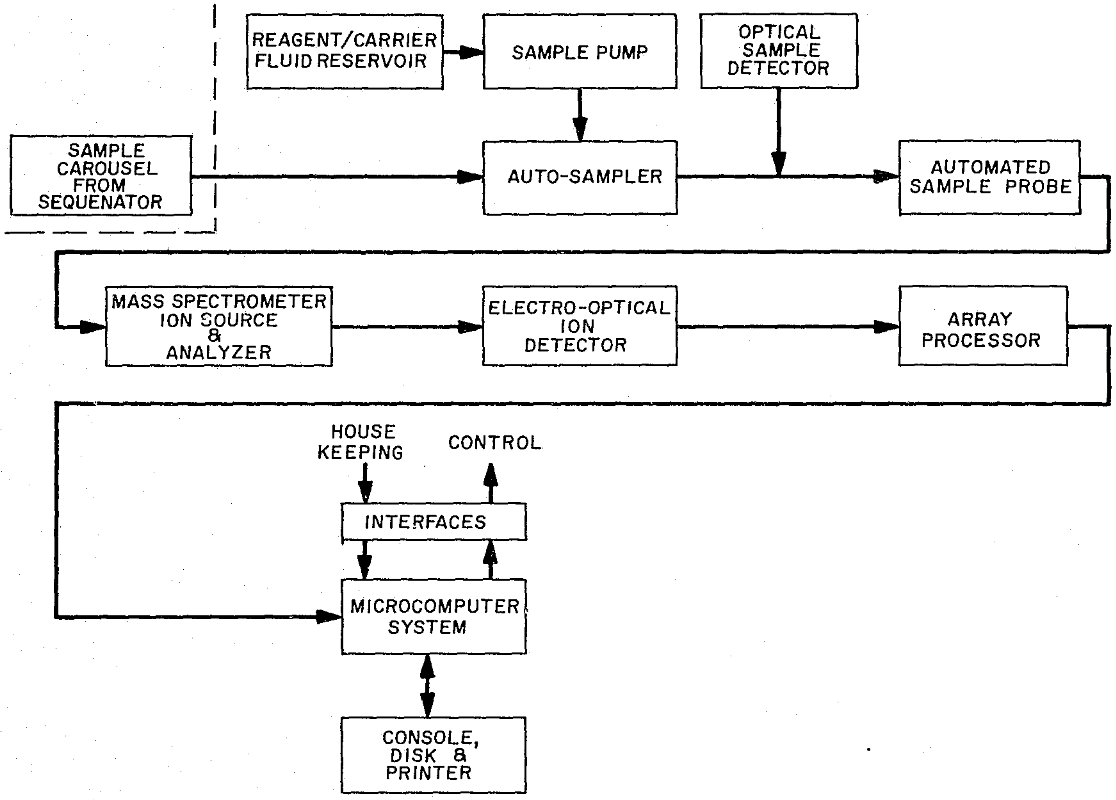


Figure 7: Mass Spectrograph System for Amino Acid Analysis

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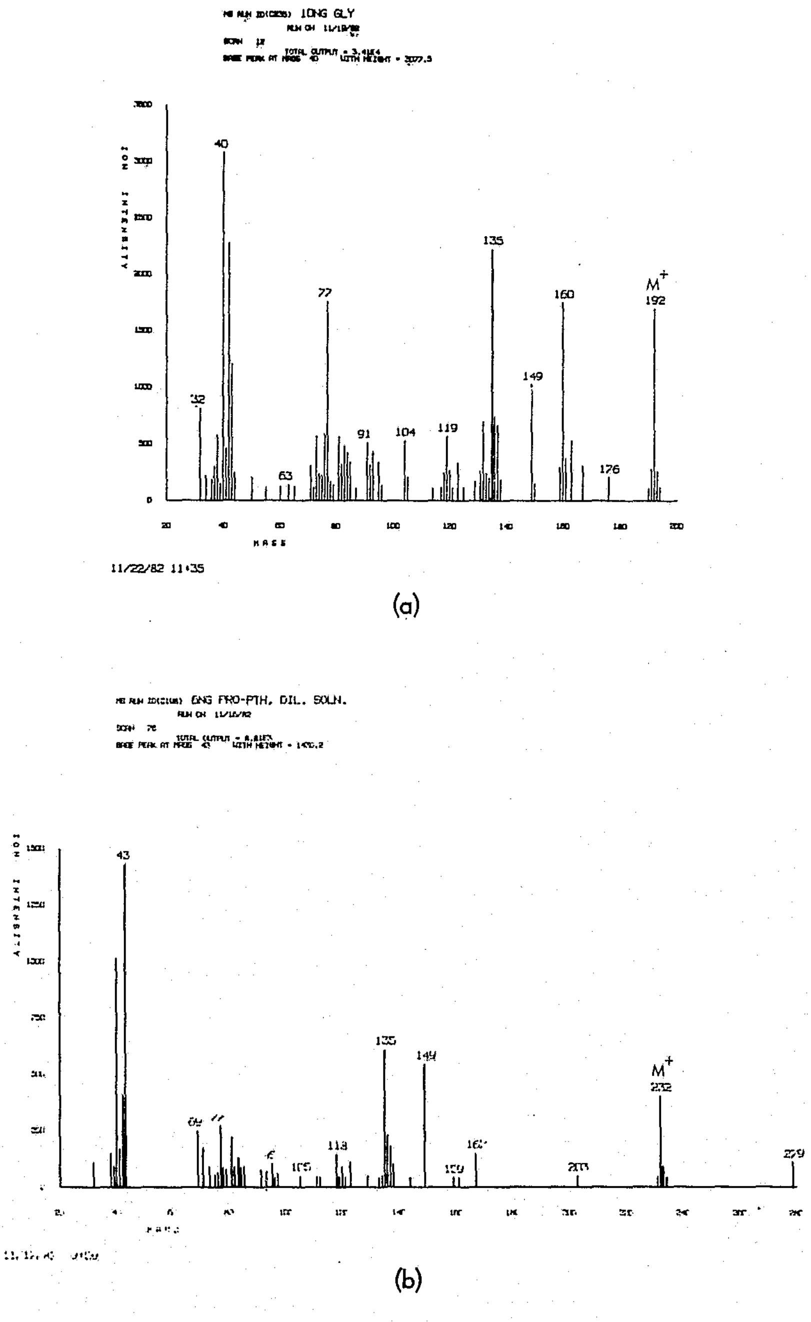
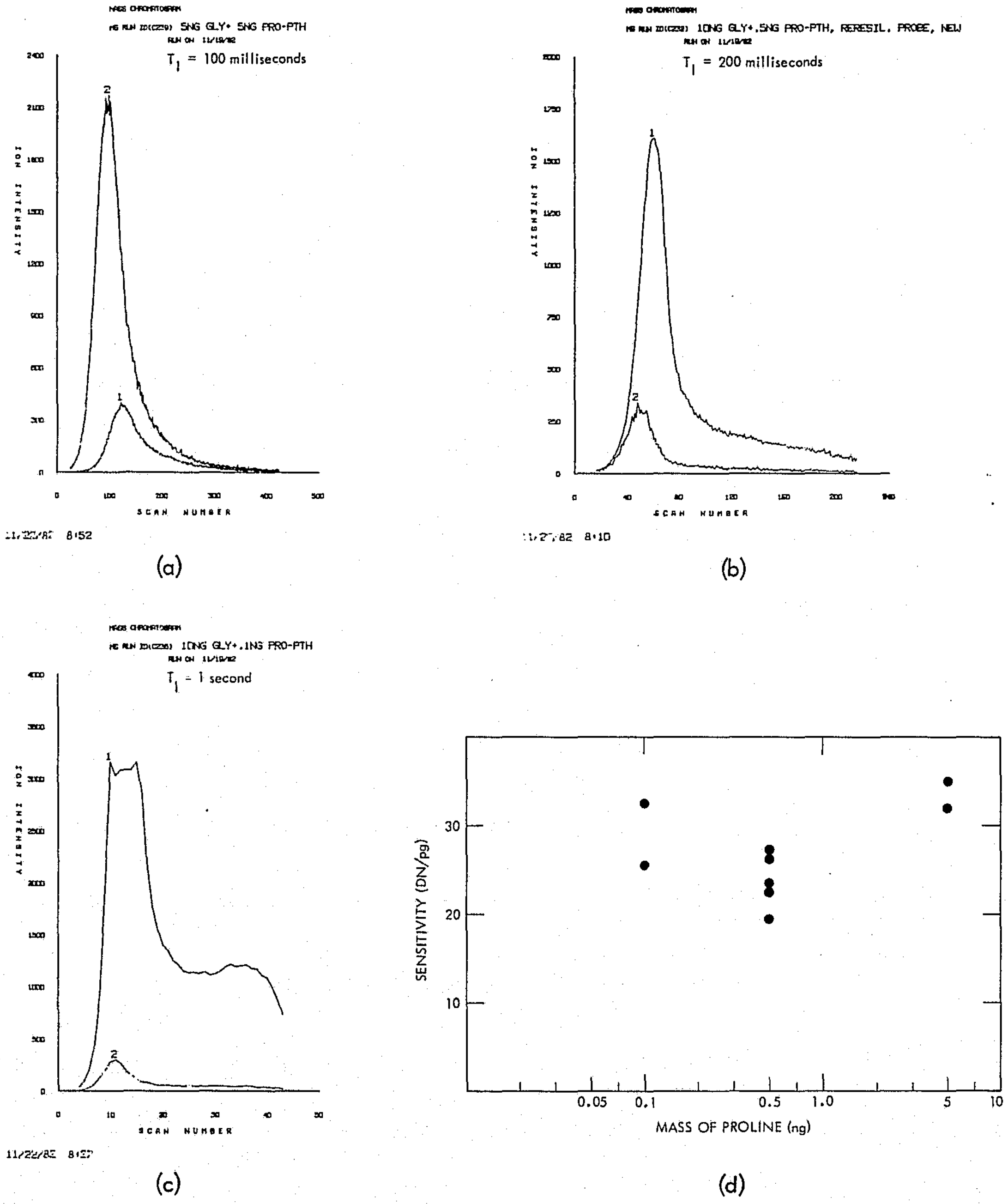


Figure 8 Representative Line Spectra;
(a) Glycine-PTH, (b) Proline-PTH,
(c) Leucine-PTH



(a)

(b)

(c)

(d)

Figure 9 Glycine/Proline-PTH Elution Characteristics and Sensitivity
Curve #1: m/e = 192, Curve #2: m/e = 232,
T_I = Spectral Integration Time

PAMS WITH ELECTRO-OPTICAL ION DETECTION

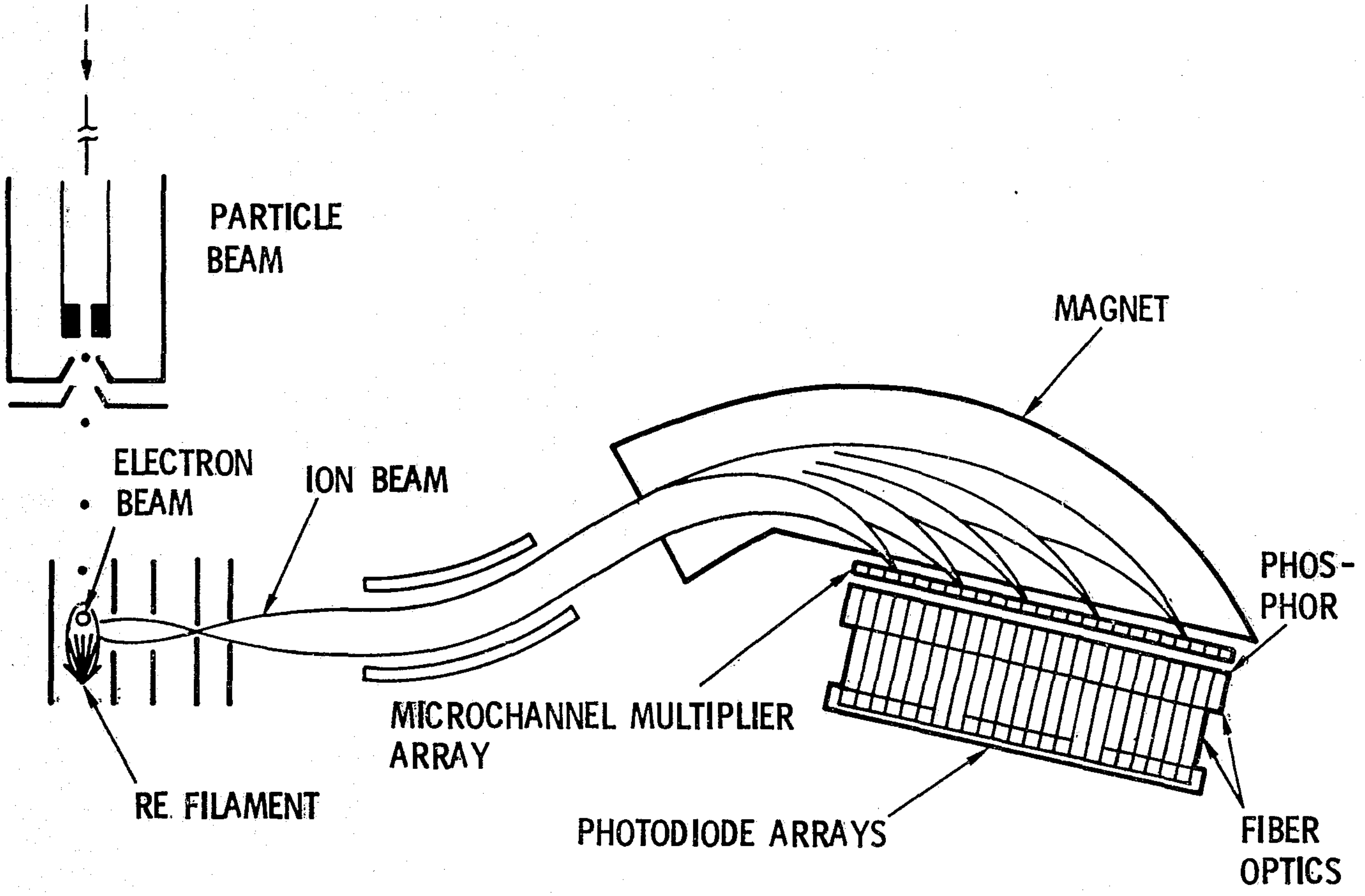


Figure 10

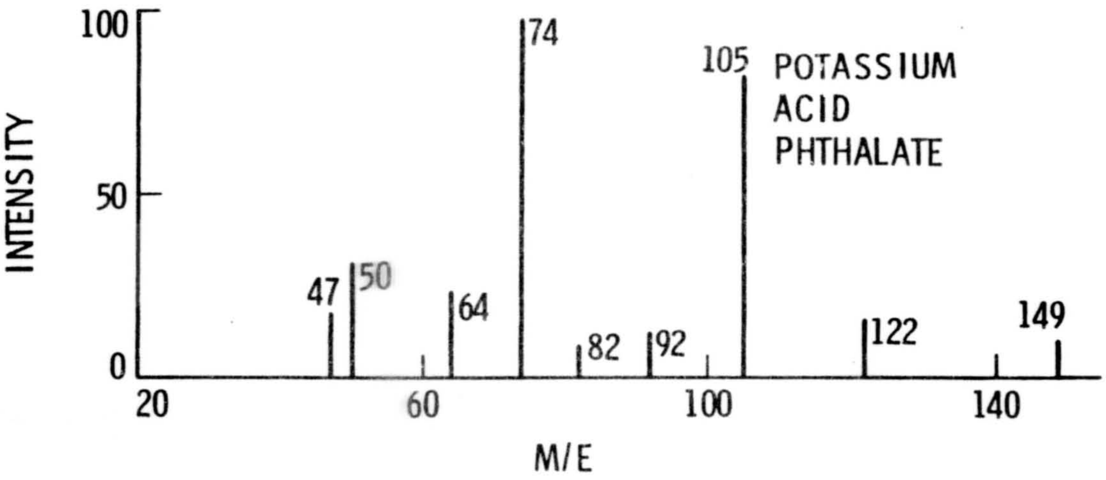


Figure 11a Mass spectrum obtained from potassium biphthalate particles of 1.7 μm diameter.

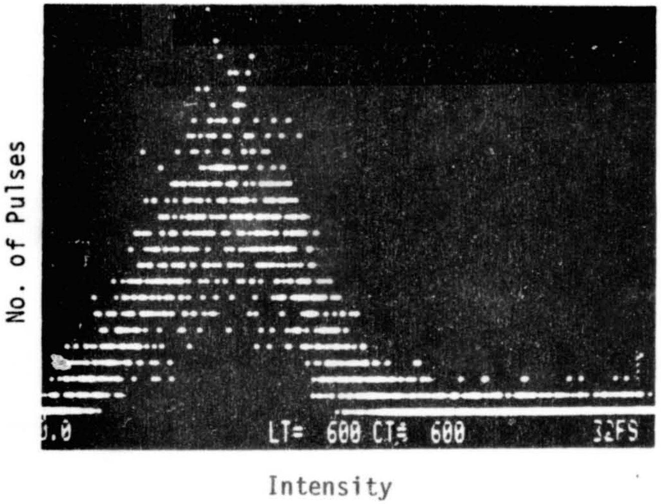


Figure 11b Pulse height Distribution of ion pulses at 50 amu resulting from 1.7 μm diameter KBP particles.

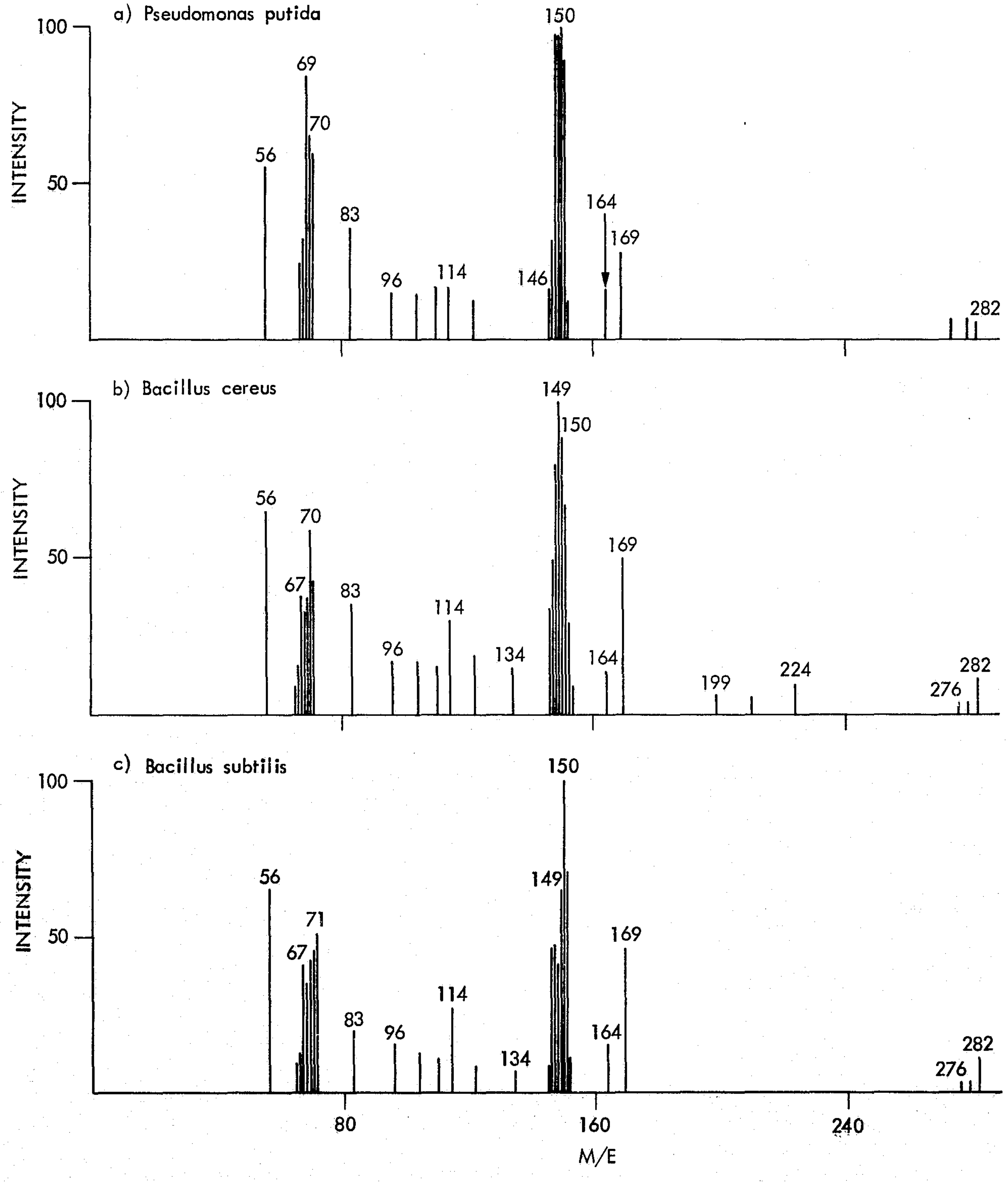


Figure 12 MASS SPECTRA FROM BACTERIAL PARTICLES

ATMOSPHERE MONITORING REQUIREMENTS

INSTRUMENTATION REQUIREMENTS DEPEND ON MONITORING NEEDS

WHAT IS THE ACTION PROTOCOL?

- WHAT ACTIONS CAN BE TAKEN?
- WHAT INFORMATION IS NEEDED?
- WHO DECIDES ON ACTION?

INFORMATION REQUIREMENTS

- COMPOUND TYPE
- QUANTITATION
- RATE OF BUILD-UP

SOURCES AND CAUSES OF ATMOSPHERIC CONTAMINATION

- SYSTEM DESIGN
- MATERIALS
- MALFUNCTIONS

ATMOSPHERE MONITORING REQUIREMENTS (CONT'D)

RESULTING ATMOSPHERIC CONDITIONS

- POSSIBLE COMPOUND TYPES
    - ORGANIC
    - INORGANIC
    - ANTICIPATED
    - STRANGERS
- TOXICITY RANGE
- CONTAMINANT MIXTURES
- DYNAMICS

WHAT CONSTITUTES ADEQUATE PROTECTION?

WHAT PRICE IS ACCEPTABLE?

- DOLLARS
- SPACECRAFT DEMANDS
- SYSTEM DEMANDS
- PROGRAM DEMANDS

INSTRUMENT REQUIREMENTS

PERFORMANCE

COMPOUNDS

IDENTIFICATION

DETECTION LIMIT

DYNAMIC RANGE

INTERFERENCES

ANALYSIS TIME

INFORMATION OUTPUT

ACCURACY

OPERATING MODES

DEMANDS

POWER

WEIGHT

SIZE

CONFIGURATION

INTERFACES

DATA FORMAT

OPERATOR INVOLVEMENT

RELIABILITY

MAINTAINABILITY

INSTRUMENTATION -- SINGLE DEVICES

GAS CHROMATOGRAPHY

-- GOOD SENSITIVITY
-- RELATIVELY SLOW
-- BROAD COMPOUND COVERAGE
-- GOOD MIXTURE CAPABILITY
-- IDENTIFICATION NOT ASSURED
-- STRANGERS CANNOT BE IDENTIFIED
-- MODERATE SPACECRAFT DEMANDS
-- RELATIVELY LOW COST
-- FLIGHT HARDWARE EXPERIENCE

MASS SPECTROMETRY

-- GOOD SENSITIVITY
-- EXCELLENT SPEED
-- BROAD COMPOUND COVERAGE
-- GOOD MIXTURE CAPABILITY FOR KNOWN COMPOUNDS ONLY
-- IDENTIFICATION LESS DEPENDENT ON CALIBRATION
-- STRANGERS CAN BE IDENTIFIED IF ISOLATED
-- REASONABLE SPACECRAFT DEMANDS DEPENDING ON CONFIGURATION
-- MODERATE COST
-- EXTENSIVE FLIGHT HARDWARE EXPERIENCE

INSTRUMENTATION -- SINGLE DEVICES (CONT'D)

OTHER SINGLE DEVICES

INFRA RED--

- NOT AS WIDELY USED
- GENERALLY LESS SENSITIVE
- MODERATE MIXTURE CAPABILITY

NON DISPERSIVE IR
CHEMILLUMINESCENT
ELECTROCHEMICAL
} SPECIFIC COMPOUNDS ONLY

INSTRUMENTATION -- TANDEM DEVICES

GAS CHROMATOGRAPH/MASS SPECTROMETRY

-- WIDELY ACCEPTED FOR MIXTURE AND ATMOSPHERIC ANALYSIS
-- PROVIDES MIXTURE SEPARATION AND POSITIVE IDENTIFICATION
-- GOOD SENSITIVITY
-- BROAD COVERAGE
-- STRANGER IDENTIFICATION
-- RELATIVELY SLOW
-- MORE SIGNIFICANT SPACECRAFT DEMANDS
-- EXPENSIVE
-- FLIGHT HARDWARE EXPERIENCE

TANDEM MASS SPECTROMETRY (CID)

-- POTENTIALLY FASTER THAN GCMS
-- SOMEWHAT LESS SEPARATION CAPABILITY
-- LESS PROVEN THAN GCMS
-- LESS SUITABLE FOR RELIABLE, LONG TERM MONITORING
-- SUBSTANTIAL SPACECRAFT DEMANDS
-- NO FLIGHT HARDWARE EXPERIENCE

SPECIFIC COMPOUND ISSUES

MAJOR CONSTITUENTS:

-- N_2, O_2, H_2O, CO_2

-- MAY BE ADDRESSED EFFECTIVELY BY DIRECT MASS SPECTROMETRY

-- SHOULD BE A DEDICATED DEVICE

-- REQUIRES A DIFFERENT ANALYZER FOR OPTIMIZED PERFORMANCE

CARBON MONOXIDE:

-- DIFFICULT FOR GCMS

-- PROBABLY DESERVES A DEDICATED DEVICE

-- NDIR IS THE BEST APPROACH

-- ELECTROCHEMICAL MAY BE ACCEPTABLE

OTHER INORGANIC COMPOUNDS:

-- NO_x, SO_2, HALOGENS, ACIDS

-- SPECIAL PROBLEMS FOR GCMS

-- DEDICATED GC A POSSIBILITY

-- OTHER DEDICATED DETECTORS

ATMOSPHERE MONITORING EXPERIENCE

TWO GAS SENSOR DEVELOPMENT:

- 60 DAY MANNED CHAMBER TEST
- 90 DAY MANNED CHAMBER TEST
- OTHER APPLICATIONS

LABORATORY TRACE CONTAMINANT SENSOR:

- ACCUMULATOR CELL/MASS SPECTROMETER

CENTRAL ATMOSPHERE MONITORING SYSTEM -- CAMS MK I:

- MASS SPECTROMETRY OF MAJOR AND SELECTED CONSTITUENTS

CONTAMINANT AND ATMOSPHERIC SENSOR

FLIGHT TRACE CONTAMINANT SENSOR:

- CONCEPTUAL DESIGN OF FLIGHT ACCUMULATOR CELL/MS

SPACELAB TRACE GAS ANALYZER:

- GCMS BASED ON VIKING GCMS TECHNOLOGY
- UTILIZED ACCUMULATOR CELL TECHNOLOGY

CENTRAL ATMOSPHERE MONITORING SYSTEM -- CAMS MK II:

- MICROPROCESSOR CONTROLLED SCANNING MASS SPECTROMETER

TGA PROGRAM HISTORY

1975 BREADBOARD FEASIBILITY PROGRAM
1976 DATA SYSTEM DEVELOPMENT
1977 GCMS INTERFACE STUDIES
JAN 1978: INITIATED FLIGHT HARDWARE PROGRAM
AUG 1978: PRELIMINARY DESIGN REVIEW
AUG 1979: CRITICAL DESIGN REVEIW
JUN 1981: ENGINEERING TEST UNIT DELIVERED
JUL-SEPT 1981: ETU EVALUATION AT NASA/JSC
OCT 1981: ETU RETURNED FOR MODS
FEB 1982: QUAL UNIT DESIGN COMPLETED
APR 1982: PROGRAM CANCELLED

SPACELAB PREMISES

TRACE CONTAMINANT MONITORING ORIGINALLY REQUIRED

NECESSARY DUE TO:

- REDUCED MATERIAL TESTING
- LESS MATERIAL CONTROL

PRIMARY CONCERN-- SLOW BUILD-UP OF ORGANIC CONTAMINANTS

EIGHT ORGANIC COMPOUND CLASSES AND CARBON MONOXIDE

UP TO 30 DAY CONTINUOUS EXPOSURE

PERIODIC ANALYSIS

GROUND BASED DATA ANALYSIS

SINGLE POINT MONITORING

SHUTTLE ASSUMED TO BE A SAFE HAVEN

IMMEDIATE SHUTTLE RETURN POSSIBLE

TGA MISSION REQUIREMENTS

LOCATION:

- SPACELAB EXPERIMENT RACK

MISSION DURATION:

- 7 DAYS NOMINAL
- 30 DAYS MAXIMUM

ANALYSIS RATE:

- ONCE EVERY 6 HOURS
- REPETITIVE

REPLENISHMENT:

- FOUR 7 DAY MISSIONS
- ONE 30 DAY MISSION

DATA STORAGE:

- ONE ANALYSIS CYCLE
- DATA DOWNLINKED ON COMMAND

TGA INSTRUMENT DESCRIPTION

GAS CHROMATOGRAPH-MASS SPECTROMETER

BASED ON VIKING TECHNOLOGY

TWO STAGE SAMPLE ENRICHMENT

DUAL GC COLUMNS:

- ORGANIC COMPOUNDS
- CARBON MONOXIDE

GCMS INTERFACES:

- FLOW SPLIT (ORGANICS)
- PALLADIUM ALLOY SEPARATOR (CO)

DOUBLE FOCUSING MAGNETIC SECTOR MS

ION PUMP VACUUM SYSTEM

MICROPROCESSOR CONTROLLED

DIGITAL RECORDER DATA STORAGE

DOWNLINKED MASS SPECTRAL DATA

GROUND BASED DATA ANALYSIS

IN FLIGHT CALIBRATION WITH INTERNAL STANDARD.

TGA PERFORMANCE SPECIFICATION

COMPOUNDS:

- 8 CLASSES OF ORGANICS
- 40 COMPOUNDS SPECIFIED
- CARBON MONOXIDE

DETECTION LIMIT:

- 0.5 PPM FOR BENZENE

FULL SCALE:

- 1000 PPM (NOMINAL)

REPEATABILITY:

(1 TO 1000 PPM) -- +/- 20%

ANALYSIS CYCLE TIME:

(ORGANICS) -- 90 MINUTES

(CO) -- 30 MINUTES

WARM UP TIME: 25 MINUTES

POWER OFF PERIOD: 100 HOURS

TGA COMPOUNDS

	M	S_R	REQUIRED DETECTION LEVEL	MINIMUM DETECTION LEVEL
ALCOHOLS				
METHANOL	32	0.45	20.1	2.5
N-BUTANOL	74	0.38	4.9	2.0
N-PROPANOL	60	0.5	19.9	1.7
ISOBUTANOL	74	0.54	4.9	1.4
ISOPROPANOL	60	0.7	20.0	1.2
ALDEHYDES				
ACETALDEHYDE	44	0.29	5.0	3.4
ACROLEIN	56	0.29	0.02	3.0
BUTYRALDEHYDE	72	0.29	24.8	2.6
PROPIONALDEHYDE	58	0.54	25.0	1.6
ALIPHATICS				
1,3-BUTADIENE	54	0.63	50.0	1.4
1-BUTENE	56	1.04	99.8	0.8
ISOPRENE	68	0.54	99.8	1.5

TGA COMPOUNDS (CONT'D)

	M	S_R	REQUIRED DETECTION LEVEL	MINIMUM DETECTION LEVEL
AROMATICS				
ETHYLBENZENE	106	2.8	9.8	0.22
MESITYLENE	120	2.0	1.5	0.39
N-PROPYLBENZENE	120	3.0	4.9	0.20
STYRENE	104	1.3	9.9	0.49
M-XYLENE	106	1.0	9.9	0.63
BENZENE	78	1.5	0.5	0.49
TOLUENE	92	1.3	9.8	0.52
P-XYLENE	106	1.1	9.9	0.62
ESTERS				
BUTYLACETATE	116	2.9	20.0	0.30
ETHYLACETATE	88	2.0	26.4	0.34
ISOBUTYLACETATE	116	2.5	15.0	0.24
N-PROPYLACETATE	102	2.1	19.9	0.30

TGA COMPOUNDS (CONT'D)

	M	S_R	REQUIRED DETECTION LEVEL	MINIMUM DETECTION LEVEL
HALOCARBONS				
CARBON TETRACHLORIDE	152	0.32	0.16	1.6
CHLOROBENZENE	112	1.2	3.7	0.51
DICHLOROBENZENE	146	1.2	2.5	0.21
METHYLCHLORIDE	50	0.62	4.8	1.5
METHYLCHLOROFORM	132	0.34	0.18	1.7
TETRACHLOROETHYLENE	164	0.82	2.5	0.61
TRICHLOROETHYLENE	130	0.38	0.19	1.5
VINEYLIDENE CHLORIDE	96	1.0	0.5	0.66
1,2-DICHLOROETHANE	98	0.14	4.9	4.7
DICHLOROFLUOROMETHANE	102	2.2	49.9	0.29
METHYLENE CHLORIDE	84	0.83	12.4	0.85
HETEROCYCLICS				
1,4-DIOXANE	88	1.6	2.5	0.43
TETRAHYDROFURAN	72	0.88	9.8	0.87

TGA COMPOUNDS (CONT'D)

	M	S_R	REQUIRED DETECTION LEVEL	MINIMUM DETECTION LEVEL (1)
<u>KETONES</u>				
METHYLETHYLKETONE	72	1.3	4.7	0.59
METHYLISOBUTYLKETONE	100	1.4	4.9	0.46
<u>INORGANICS</u>				
CARBON MONOXIDE	28	1.0	13.0	

(1) PROJECTED DETECTION LEVEL ASSUMING A 10% RELATIVE ION INTENSITY MUST BE DETECTED WHEN THE GC CURVE IS AT 50% OF PEAK VALUE.

TGA INTERFACE SPECIFICATIONS

POWER: 150 WATTS AVERAGE
12 WATTS STANDBY

WEIGHT: 145 POUNDS

SIZE: 4 CUBIC FEET

CONFIGURATION: 19 INCH RACK MOUNT
15.7 INCHES HEIGHT

INPUT POWER: 28 V PRIMARY
28 V ESSENTIAL

CARRIER GAS VENT: SORBED ON PALLADIUM
OXYDIZED TO WATER

DATA INTERFACES:

DATA--HRM EXPERIMENT CHANNEL
DOWNLINK COMMAND--RAU CHANNEL
TIMING-- RAU GMT
RAU USER CLOCK

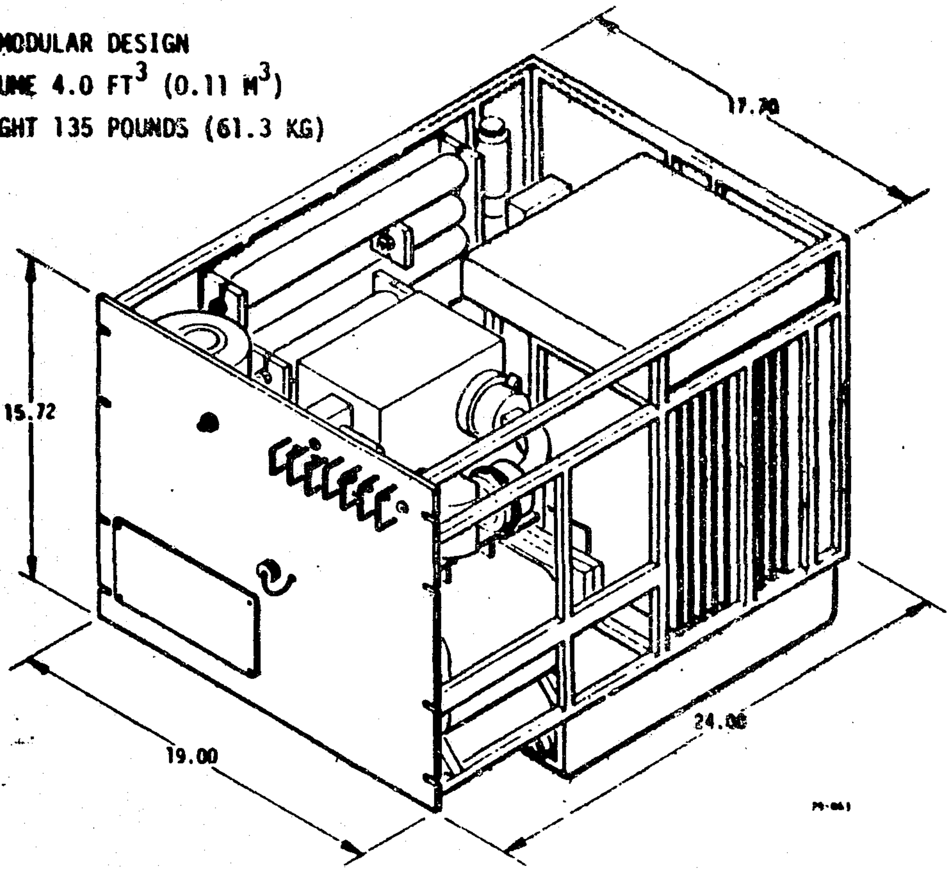
COOLING AIR: 41 KG/HR

OPERATOR: TURN ON ANALYSIS START
PERIODIC/REPETITIVE

GROUND SUPPORT: TIME ZERO UMBILICLE

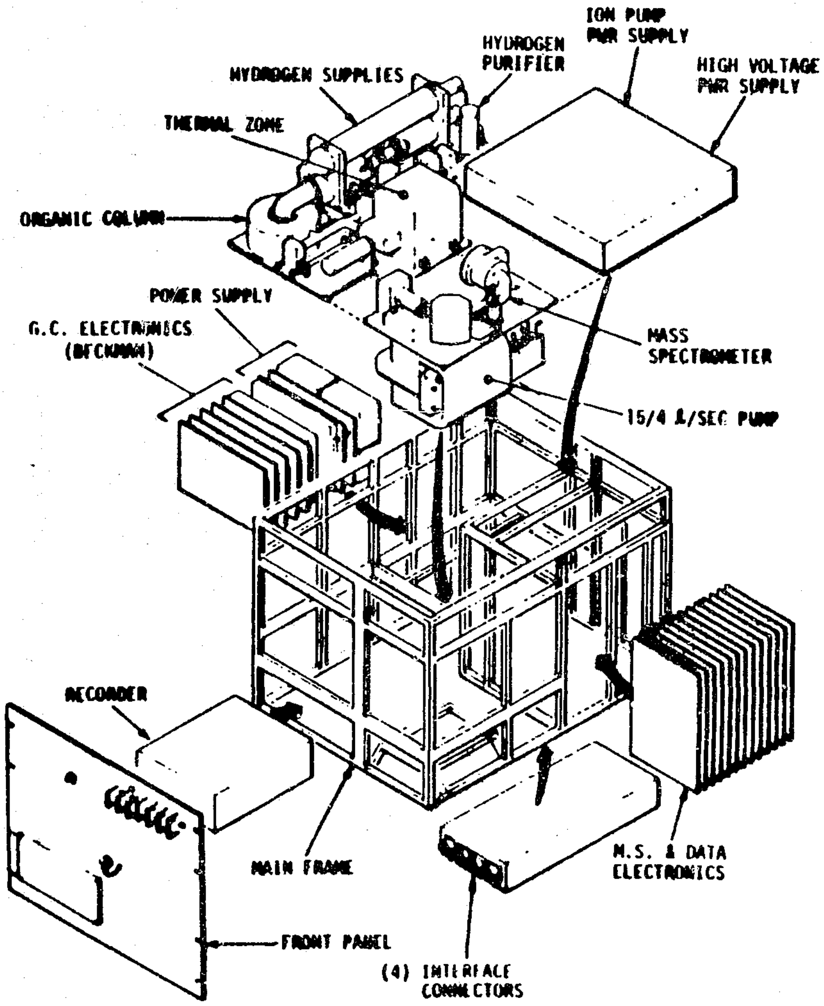
TGA PACKAGE

- COMPACT MODULAR DESIGN
    - VOLUME 4.0 FT^3 (0.11 M^3)
    - WEIGHT 135 POUNDS (61.3 KG)

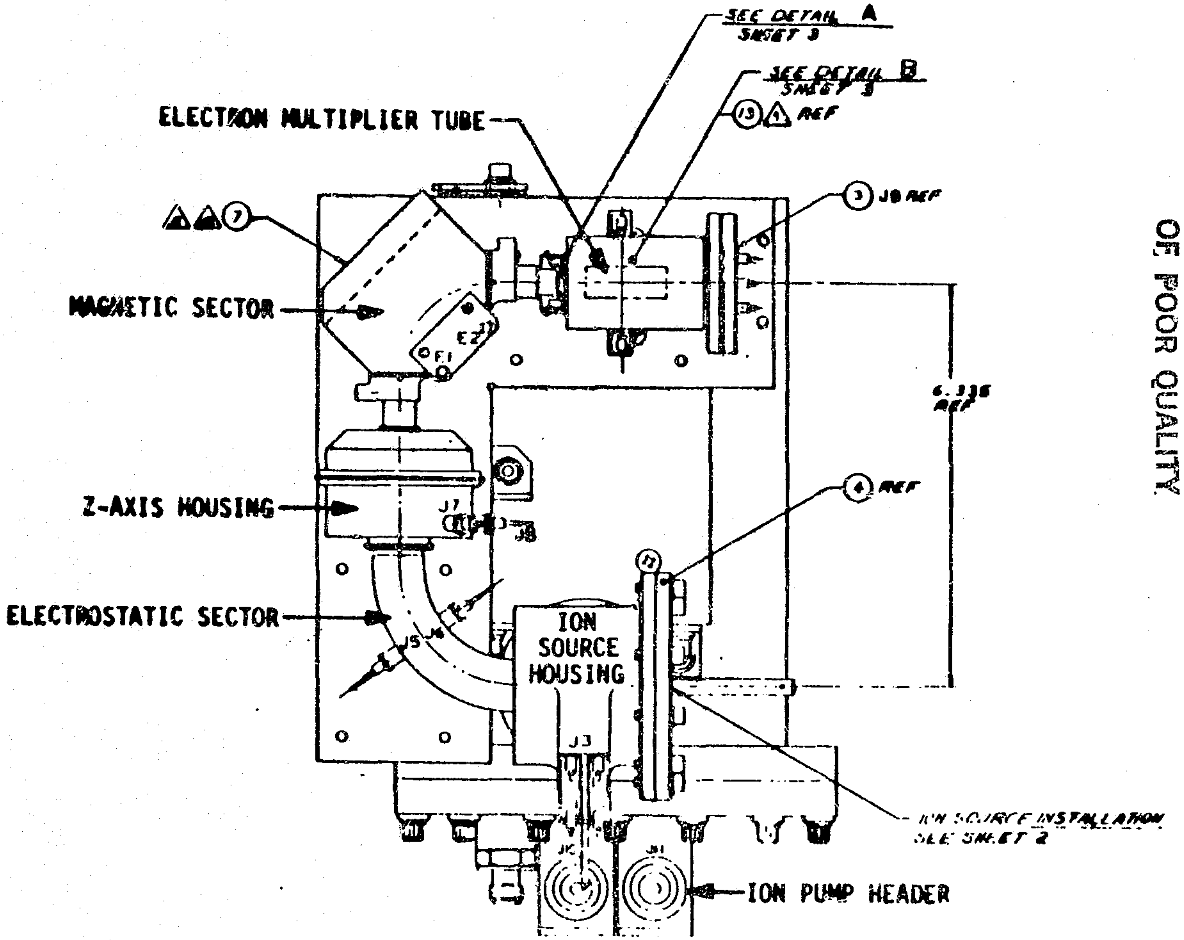


- DESIGNED FOR 19.00" ELECTRONIC RACK MOUNT

TGA SYSTEM MECHANICAL ASSEMBLY



M.S. SUBSYSTEM TOP ASSEMBLY
TOP VIEW



TGA PARAMETERS (CONTINUED)

CARBON MONOXIDE COLUMN-- (CONTINUED)

- TEMP -- 50-100°C AT 10°C/MIN
- OTHER -- SAME AS ORGANIC
- SEPARATION -- NOT FULLY RESOLVED FROM NITROGEN TAIL

CARRIER GAS SUPPLY --

- VOLUME -- 100 ATM LITERS
- PRIMARY PRESSURE -- 1500 PSI
- DELIVERY PRESSURE -- 200 PSI

CALIBRATION GAS--

- FLUOROBENZENE (INT. STANDARD)
- CARBON MONOXIDE } EVERY FOURTH ANALYSIS
- CO WITH OXYGEN-18 } EVERY FOURTH ANALYSIS

TGA PARAMETERS

GC SUBSYSTEM

ACCUMULATOR CELLS--

- #1 -- 0.5 G TENAX GC
  - 0.1 G SPHEROCARB
- #2 -- 0.05 G TENAX GC
  - 0.02 G SPHEROCARB
- ENRICHMENT -- 300:1

ORGANIC COLUMN--

- TYPE -- CAPILLARY
- LENGTH -- 0.375 MM ID
- MATERIAL -- STAINLESS STEEL
- STATIONARY PHASE -- WITCONOL
- CARRIER GAS -- HYDROGEN
- FLOW RATE -- 2 CC/MIN
- TEMP -- 40-120°C AT 2 /MIN HOLD AT 120°C
- RANGE -- METHANOL TO ORTHODICHLOROBENZENE
- SEPARATION -- ORTHO AND META XYLENE; PEAK WIDTH -- 7-10 S HPWH

CARBON MONOXIDE COLUMN--

- TYPE -- PACKED
- LENGTH -- 4.5 M
- DIAMETER -- 0.75 MM
- STATIONARY PHASE -- MOLE SIEVE 5A

TGA PARAMETERS (CONTINUED)

MASS SPECTROMETER

TYPE -- DOUBLE FOCUSING MAGNETIC SECTOR

GEOMETRY -- 90^{o} - 90^{o} NIER-JOHNSON

MAGNETIC SECTOR RADIUS -- 1.5 IN

MAGNET -- 7 KG PERMANENT

MV PRODUCT -- 32,000

MASS RANGE -- 24-250 AMU

RESOLUTION -- 20% VALLEY AT 240

SCAN SPEED -- 4.4 S/DECADE

SENSITIVITY -- 2 x 10-6 AMPS/TORR

ION SOURCE -- DUAL FILAMENT --
-- 50 CC/S
-- 225 ^{o}C

ION CURRENT DETECTOR --
ELECTRON MULTIPLIER
BOX AND GRID TYPE
GAIN--10^{4}

TGA PARAMETERS (CONTINUED)

ION PUMP

TYPE -- DIODE
DIFFERENTIAL SPUTTERING

CONFIGURATION -- SPLIT ANODE

SPEED -- 4 L/S FOR AIR
15 L/S FOR AIR

VOLTAGE -- 4 KV

GAS LOAD -- 0.08 TORR-CC/S

TGA TECHNICAL STATUS

GENERALLY MET EXPECTED PERFORMANCE FOR ORGANIC COMPOUNDS

DIFFICULT WITH THE GCMS INTERFACE FOR CARBON MONOXIDE

HYDROGEN SAFETY ISSUES RESOLVABLE

MINOR CHEMICAL REACTIVITY

ENGINEERING PROBLEMS FULLY RESOLVED

POSSIBLE SPACE STATION PREMISES

LONGER TERM EXPOSURE MAY REQUIRE LOWER CONCENTRATION LIMITS

WIDER RANGE OF COMPOUND TYPES INCLUDING INORGANICS

RAPID CATASTROPHIC EVENT ASSESSMENT

ANSWERS NEEDED ON BOARD

MORE COMPLEX EVENT PROTOCOL

- MAY REQUIRE MORE INFO
- GREATER INSTRUMENT FLEXIBILITY

GREATER ANTICIPATORY CAPABILITY?

MULTI-POINT SAMPLING

TGA IMPROVEMENTS/MODIFICATIONS

ELIMINATE THE CO COLUMN
- -- REDUCE COMPLEXITY

GLASS OR SILICA COLUMN
- -- REDUCE REACTIVITY PROBLEMS

INCREASED SAMPLE ENRICHMENT
- -- PERMITS LOWER LEVEL DETECTION
- -- DUAL ENRICHMENT MODES

MULTIPLE GC COLUMN OPERATING MODES
- -- FLOW RATES
- -- TEMPERATURE PROGRAMMING

DIRECT MS AND/OR ACCUMULATOR CELL MS MODE
- -- FASTER ANALYSIS OF HIGHER LEVEL CONSTITUENTS

ON BOARD DATA ANALYSIS
- -- REVERSE SEARCH
- -- TIE TO ELUTION TIME

MULTI-POINT SAMPLING
- -- TEFLON TRANSPORT LINES
- -- SAMPLE CARTRIDGES

TGA IMPROVEMENTS/MODIFICATIONS (CONT'D)

ELIMINATE TAPE RECORDER
- SOLID STATE MEMORY

BATTERY BACK-UP FOR VACUUM

CARRIER GAS RECOVERY

UPDATED DESIGN AND PACKING
- SPACE STATION INTERFACES
- MODULAR FOR MAINTAINABILITY
- UPDATED COMPONENT SELECTION

SOME PROBLEMS ASSOCIATED WITH TRACE CONTAMINANT REMOVAL SYSTEMS FOR SPACECABINS

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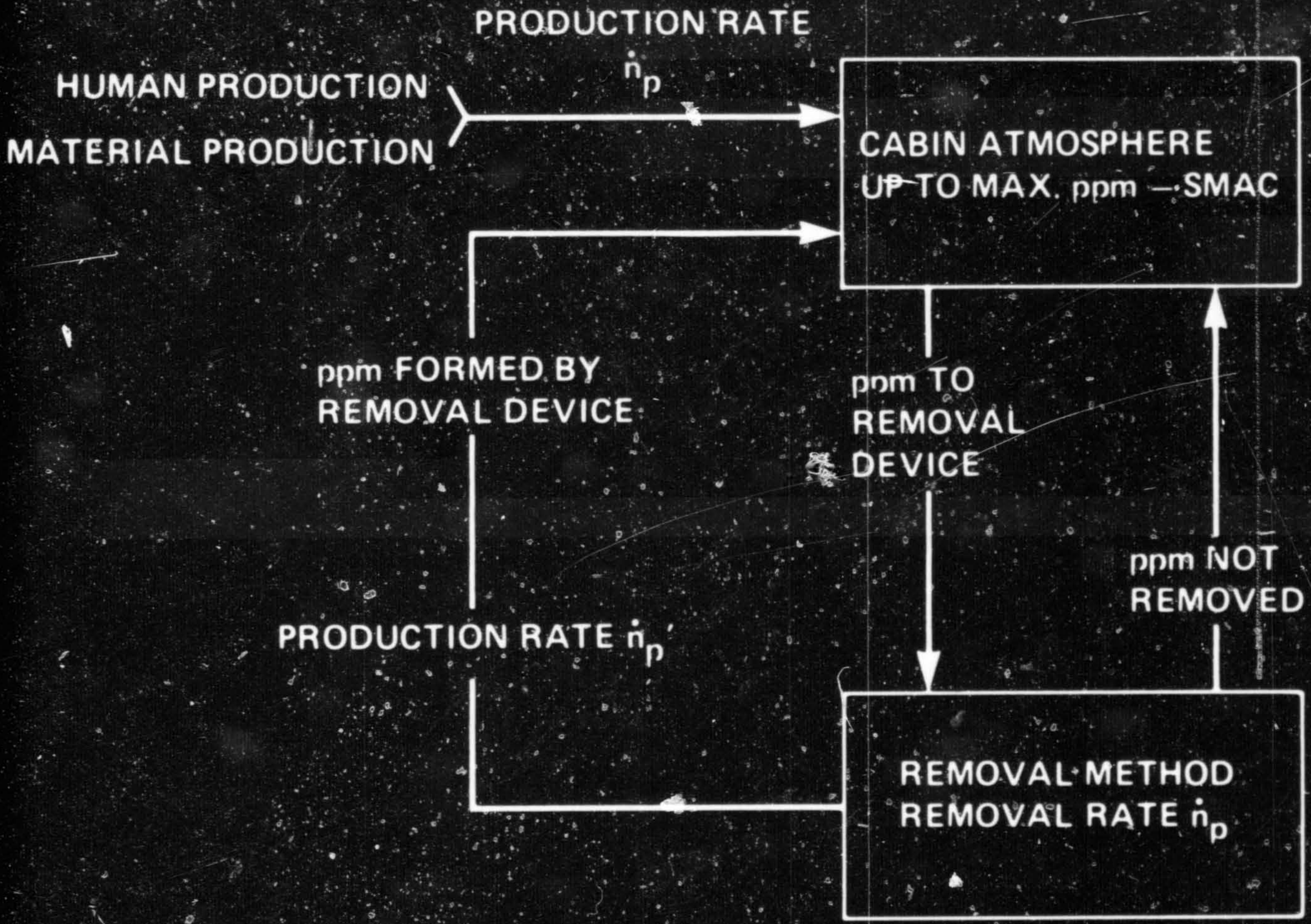
INTRODUCTION

This talk summarizes some of the potential problems associated with acid gas sorbents, activated charcoal beds and the catalytic oxidizer proposed for spacecabin trace contaminant control.

CONTAMINANT FLOW CYCLE IN CLOSED ATMOSPHERIC SYSTEM



HUMAN PRODUCTION

MATERIAL PRODUCTION

PRODUCTION RATE $\dot{n}_p$

CABIN ATMOSPHERE
UP TO MAX. ppm — SMAC

ppm FORMED BY
REMOVAL DEVICE

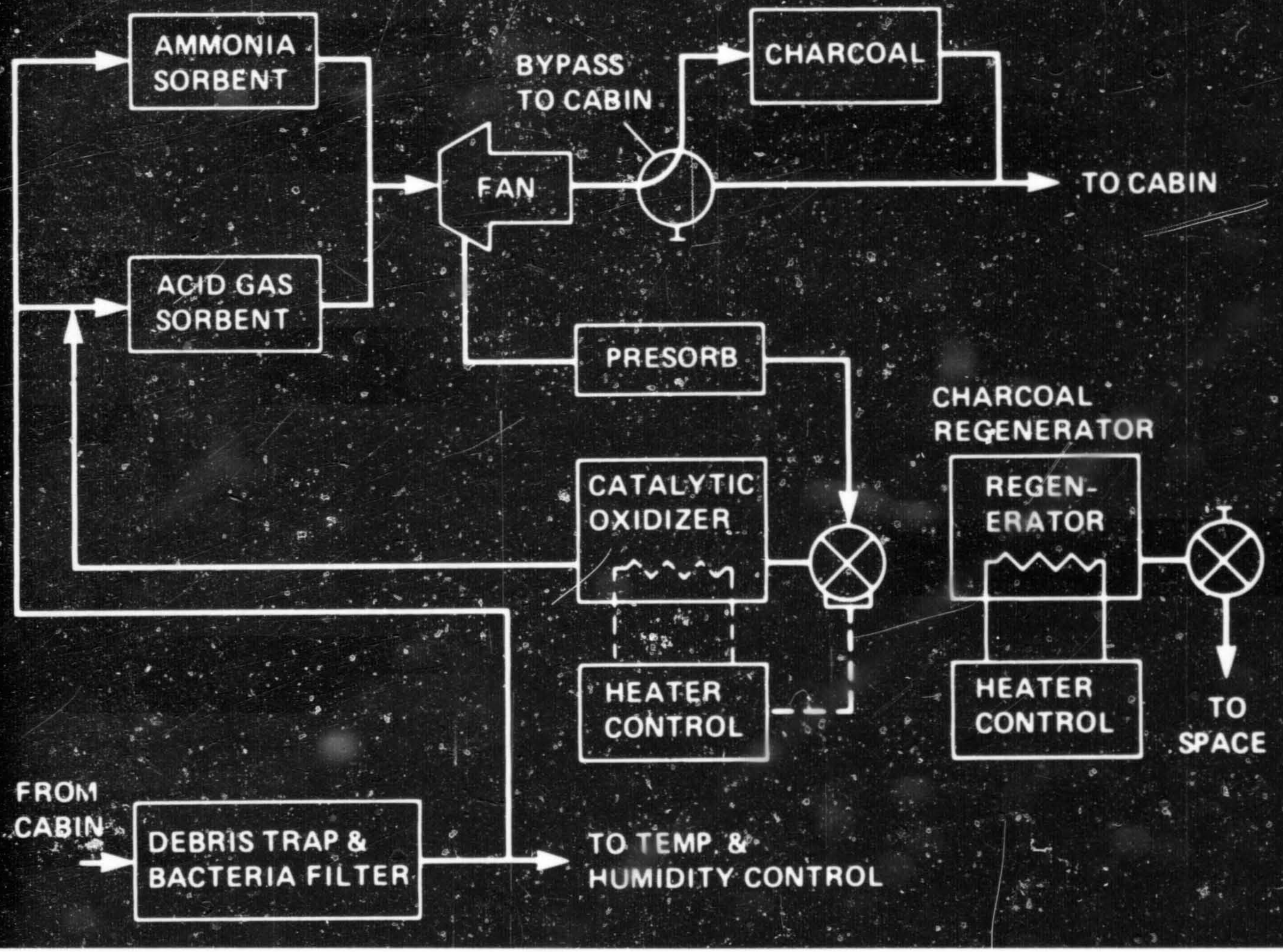
PRODUCTION RATE $\dot{n}_p'$

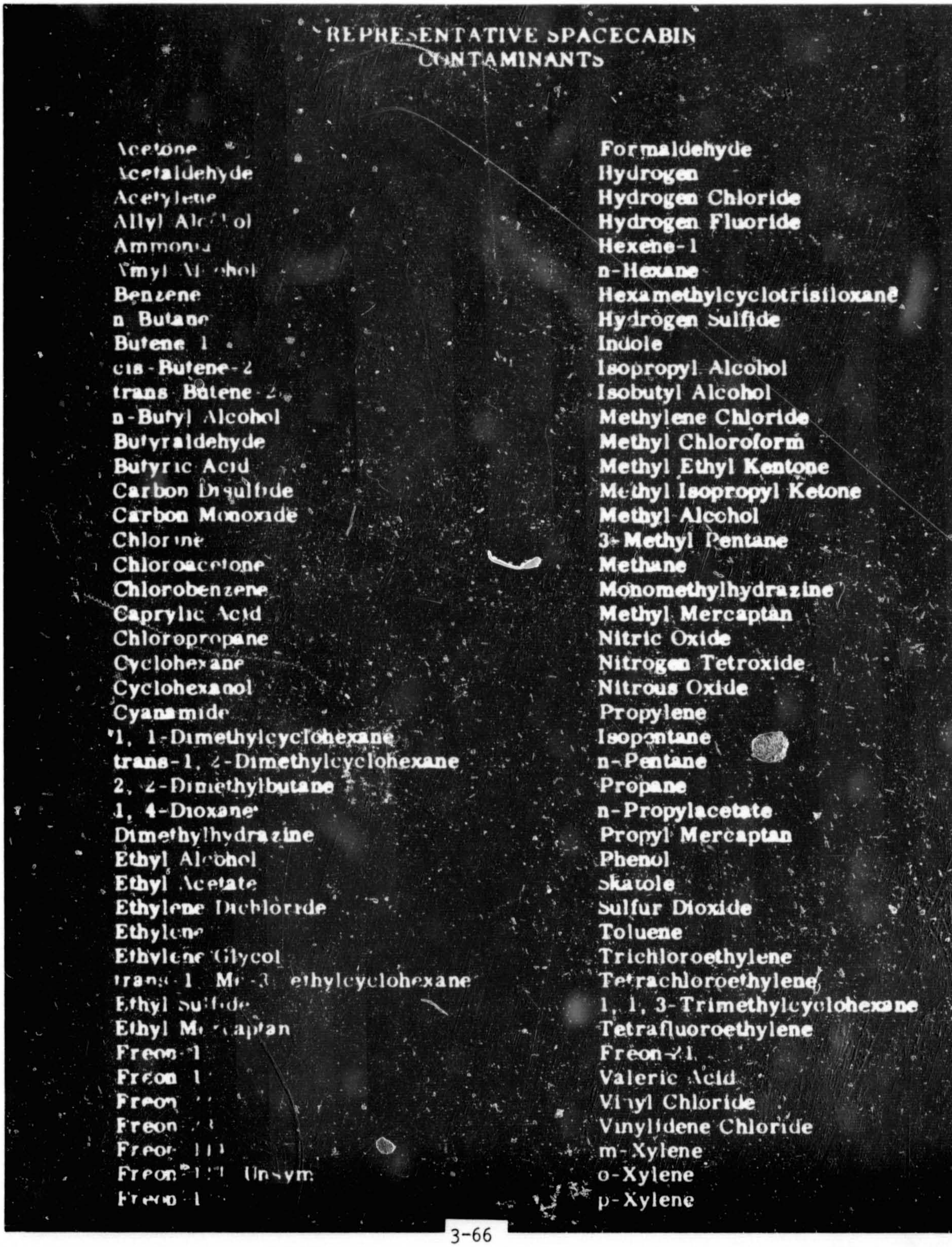
ppm TO
REMOVAL
DEVICE

ppm NOT
REMOVED

REMOVAL METHOD
REMOVAL RATE $\dot{n}_p$

TRACE CONTAMINANT CONTROL SYSTEM PROPOSED FOR A SPACE STATION





REPRESENTATIVE SPACECABIN CONTAMINANTS

Acetone
Acetaldehyde
Acetylene
Allyl Alcohol
Ammonia
Amyl Alcohol
Benzene
n Butane
Butene 1
cis-Butene-2
trans Butene-2
n-Butyl Alcohol
Butyraldehyde
Butyric Acid
Carbon Disulfide
Carbon Monoxide
Chlorine
Chloroacetone
Chlorobenzene
Caprylic Acid
Chloropropane
Cyclohexane
Cyclohexanol
Cyanamide
1, 1-Dimethylcyclohexane
trans-1, 2-Dimethylcyclohexane
2, 2-Dimethylbutane
1, 4-Dioxane
Dimethylhydrazine
Ethyl Alcohol
Ethyl Acetate
Ethylene Dichloride
Ethylene
Ethylene Glycol
trans-1 Me[illegible]-3 [illegible]ethylcyclohexane
Ethyl Sulfide
Ethyl Mercaptan
Freon-1[illegible]
Freon 1[illegible]
Freon [illegible]
Freon [illegible]
Freon 11[illegible]
Freon 1[illegible] Unsym.
Freon-1[illegible]

Formaldehyde
Hydrogen
Hydrogen Chloride
Hydrogen Fluoride
Hexene-1
n-Hexane
Hexamethylcyclotrisiloxane
Hydrogen Sulfide
Indole
Isopropyl Alcohol
Isobutyl Alcohol
Methylene Chloride
Methyl Chloroform
Methyl Ethyl Kentone
Methyl Isopropyl Ketone
Methyl Alcohol
3-Methyl Pentane
Methane
Monomethylhydrazine
Methyl Mercaptan
Nitric Oxide
Nitrogen Tetroxide
Nitrous Oxide
Propylene
Isopentane
n-Pentane
Propane
n-Propylacetate
Propyl Mercaptan
Phenol
Skatole
Sulfur Dioxide
Toluene
Trichloroethylene
Tetrachloroethylene
1, 1, 3-Trimethylcyclohexane
Tetrafluoroethylene
Freon-21
Valeric Acid
Vinyl Chloride
Vinylidene Chloride
m-Xylene
o-Xylene
p-Xylene

BOILING POINTS OF SPACECRAFT CONTAMINANTS

Component[1]	Normal Boiling[2] Point, °C
Acetronitrile (C_2H_3N)	81.8
Benzene (C_6H_6)	80.1
t-Butanol ($C_4H_{10}O$)	82.9
Cyclohexane (C_6H_{12})	80.7
1,2-Dichloroethane	83.7
O-Dichlorobenzene ($C_6H_4Cl_2$)	179.0
Ethyl Acetate ($C_4H_8O_2$)	77.1
Freon 12	-30
Freon 113	48.2
Furan (Furfuran) (C_4H_4O)	32
Isopropanol (C_3H_8O)	82.5
Methyl Chloroform (1,1,1 Trichloroethane) ($C_2H_3Cl_3$)	74.2
Methylethylketone (C_4H_8O)	79.6
Vinyl Chloride (C_2H_3Cl)	-13.8

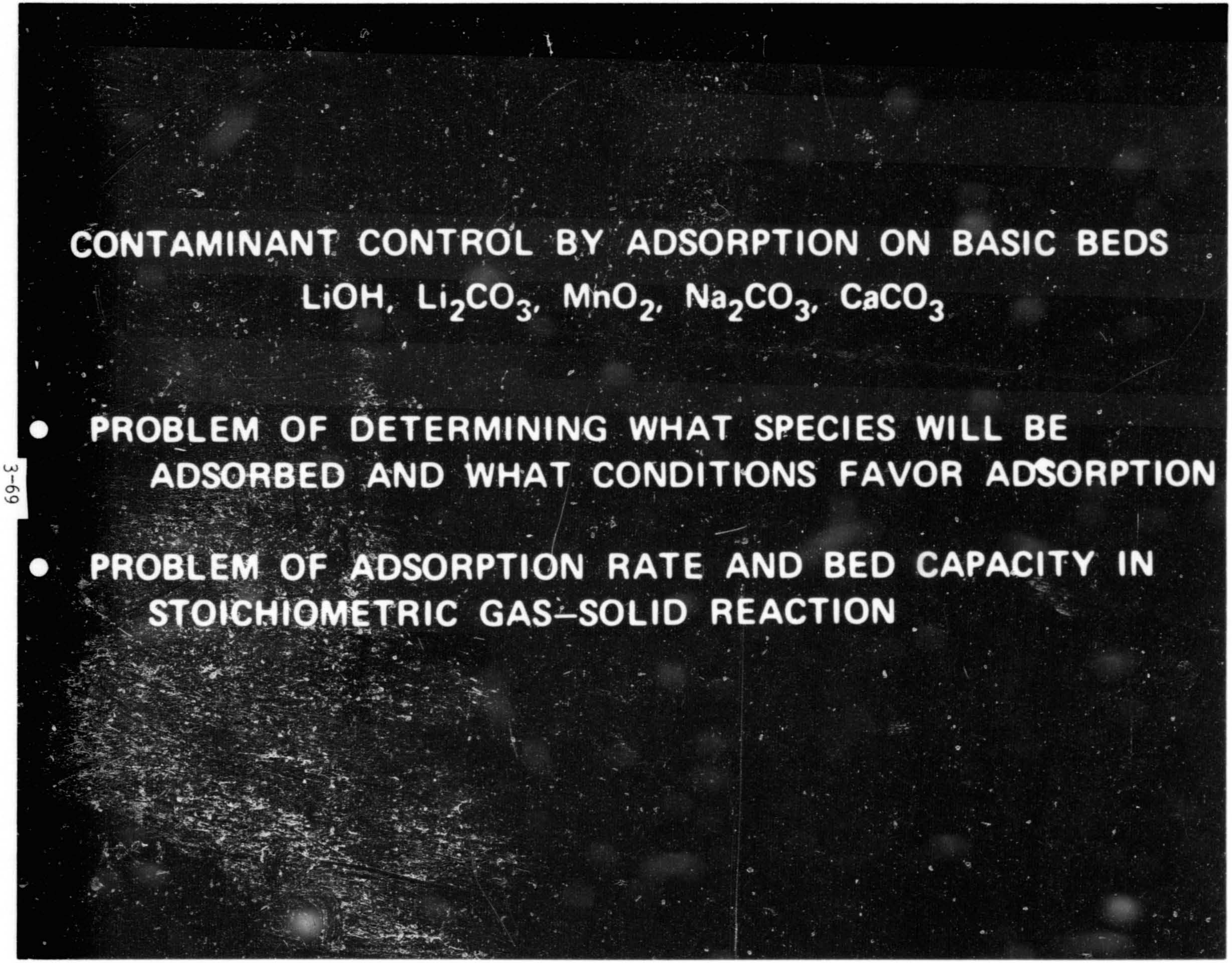
(1) Green, B. D. and J. I. Steinfeld, SPIE Vol. 99, Third European Electro-Optics Conference (1976), P. 32

(2) CO_2 condenses (to solid) at -78.5°C at 1 atm

BASIC ADSORBENT BEDS AS ATMOSPHERIC CONTAMINANT REMOVAL DEVICES

- BASIC ADSORBENT BEDS HAVE BEEN SHOWN TO REMOVE – CO_2, HCl, H_2S, Cl_2 AND SO_2 WITH SOME EFFECTIVENESS AND TO BE INEFFECTIVE FOR NO_2, CH_3SH, AND CHF_3 (FREON 23)

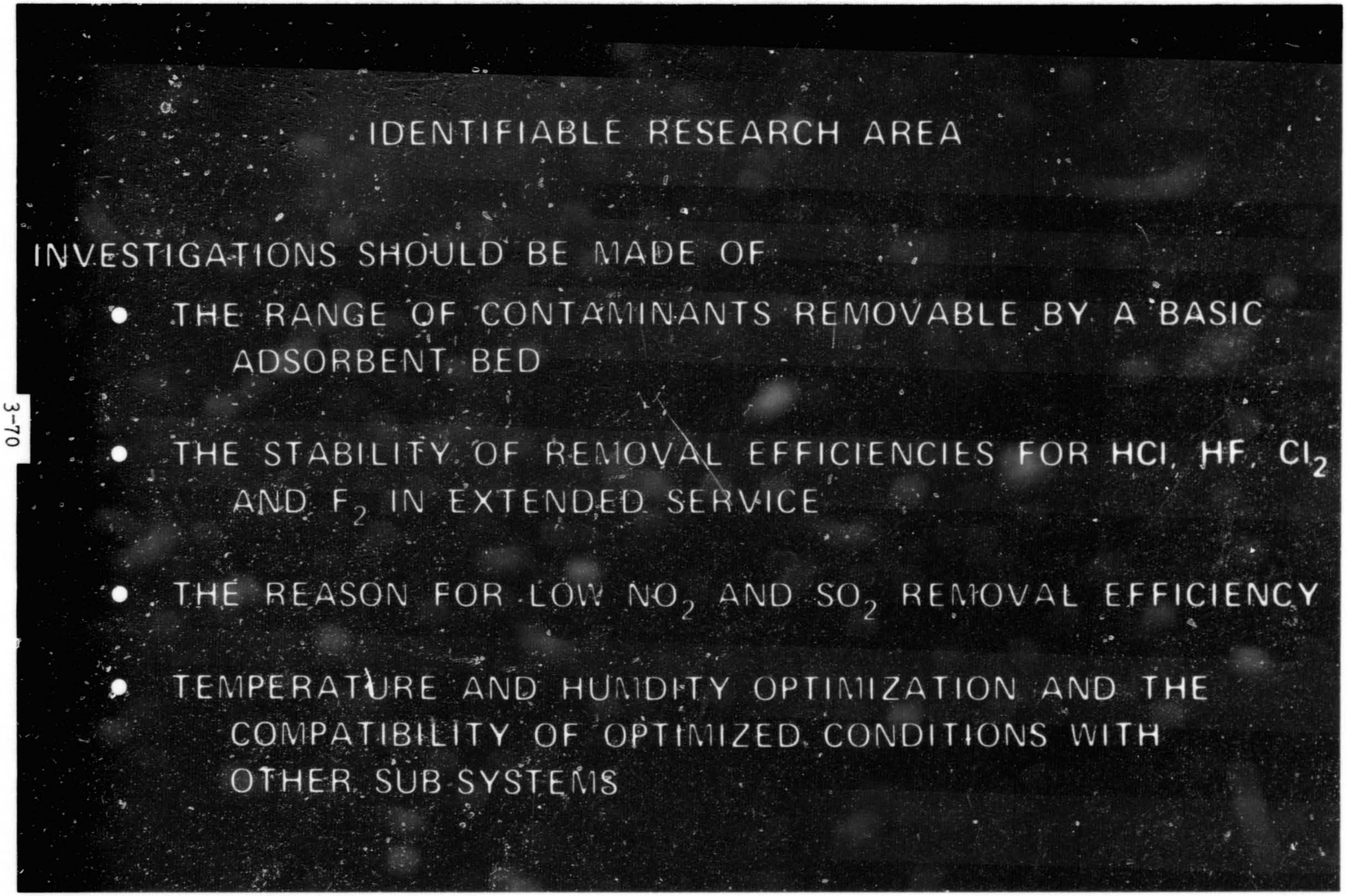
- DATA ON ADSORPTION OF ALL CONTAMINANTS ON BASIC BEDS IS INCOMPLETE WITH RESPECT TO EFFECT OF TEMPERATURE, CO_2 CONC, HUMIDITY, CONTAMINANT CONCENTRATION, REACTION RATES, AND BED CAPACITIES – NO DATA IS AVAILABLE FOR MANY CONTAMINANTS



CONTAINMINANT CONTROL BY ADSORPTION ON BASIC BEDS

LiOH, Li_2CO_3, MnO_2, Na_2CO_3, $CaCO_3$

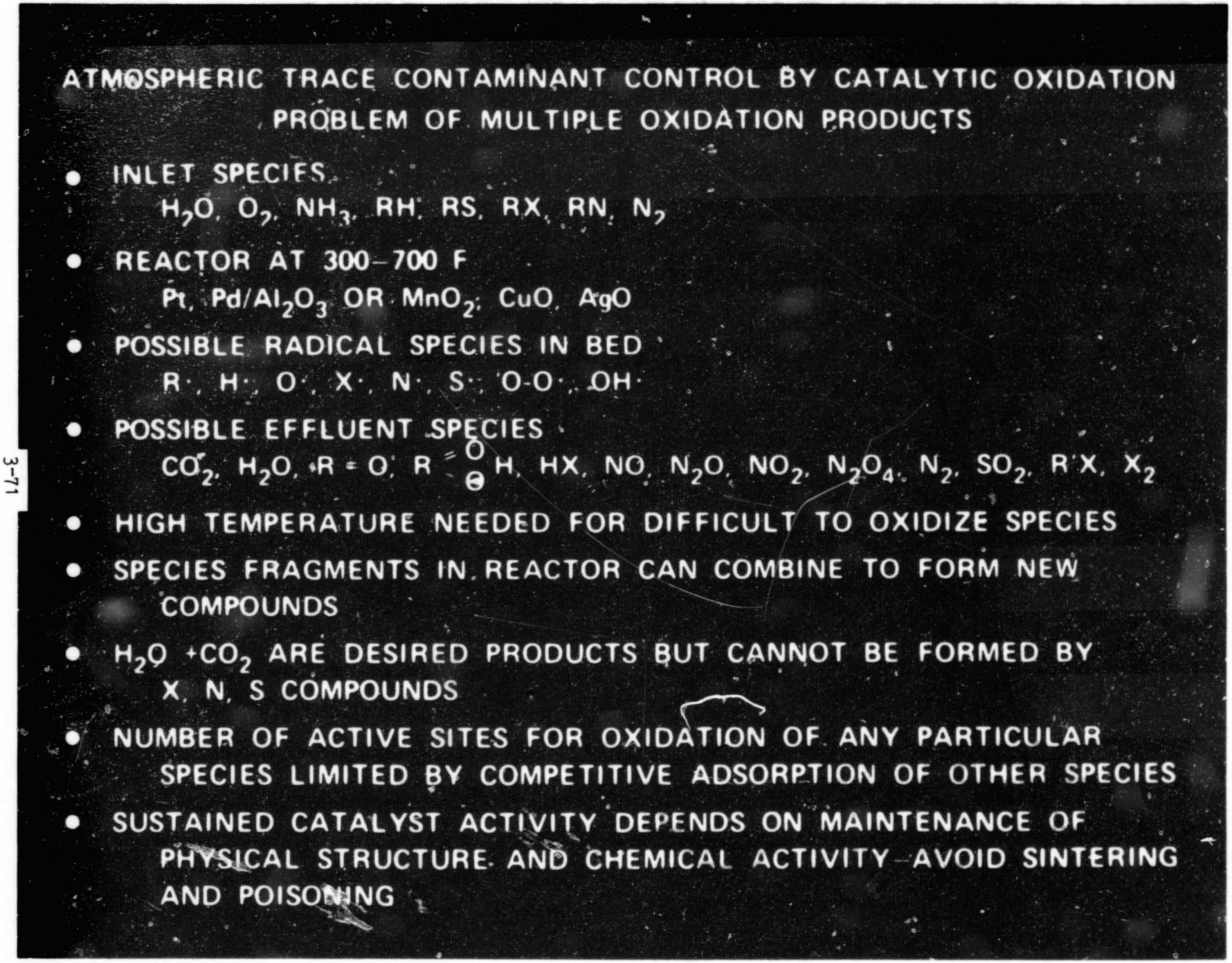
- PROBLEM OF DETERMINING WHAT SPECIES WILL BE ADSORBED AND WHAT CONDITIONS FAVOR ADSORPTION
- PROBLEM OF ADSORPTION RATE AND BED CAPACITY IN STOICHIOMETRIC GAS–SOLID REACTION



IDENTIFIABLE RESEARCH AREA

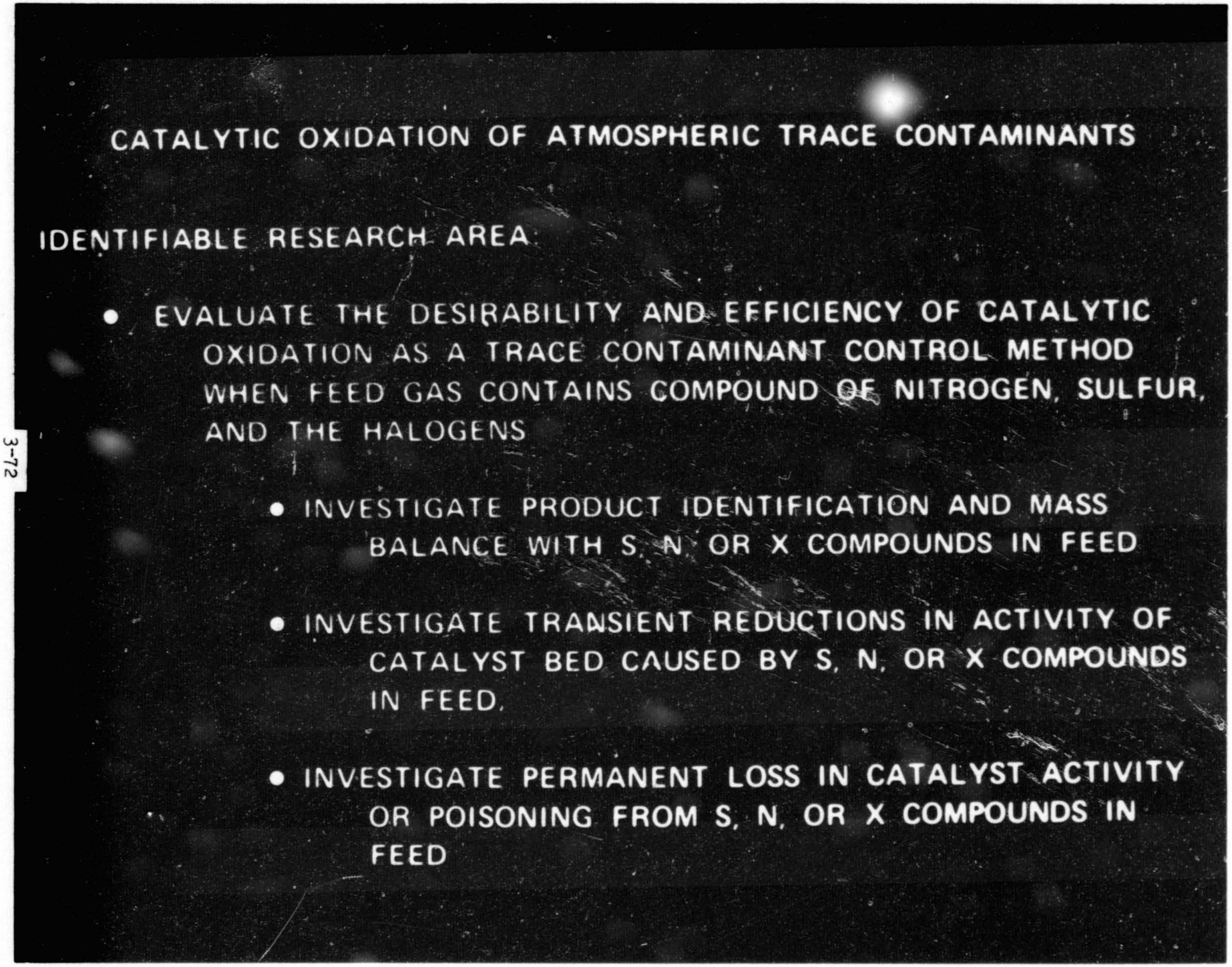
INVESTIGATIONS SHOULD BE MADE OF

- THE RANGE OF CONTAMINANTS REMOVABLE BY A BASIC ADSORBENT BED
- THE STABILITY OF REMOVAL EFFICIENCIES FOR HCl, HF, Cl_2 AND F_2 IN EXTENDED SERVICE
- THE REASON FOR LOW NO_2 AND SO_2 REMOVAL EFFICIENCY
- TEMPERATURE AND HUMIDITY OPTIMIZATION AND THE COMPATIBILITY OF OPTIMIZED CONDITIONS WITH OTHER SUB-SYSTEMS



ATMOSPHERIC TRACE CONTAMINANT CONTROL BY CATALYTIC OXIDATION
PROBLEM OF MULTIPLE OXIDATION PRODUCTS

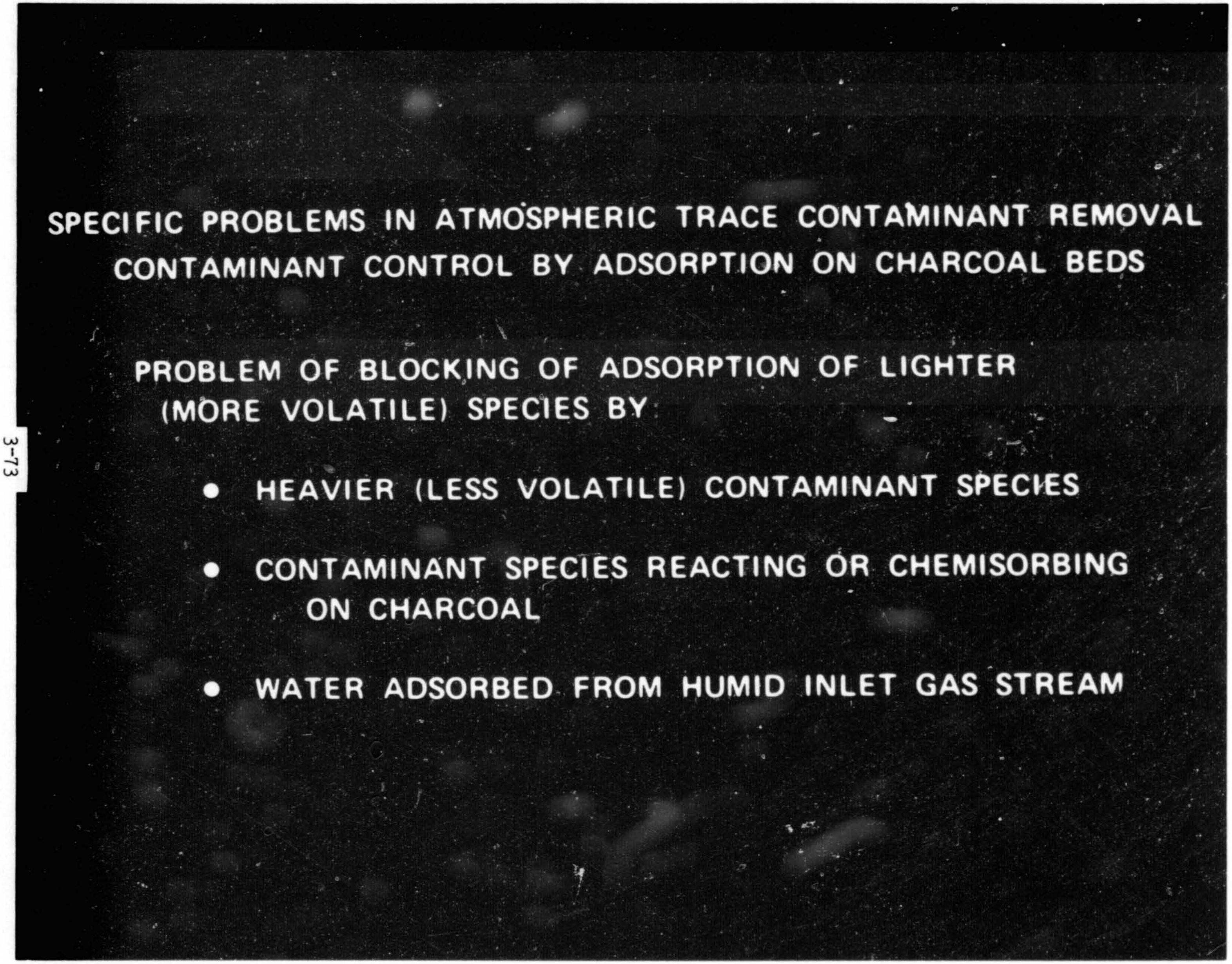
- INLET SPECIES
  H_2O, O_2, NH_3, RH, RS, RX, RN, N_2
- REACTOR AT 300–700 F
  Pt, Pd/Al_2O_3 OR MnO_2, CuO, AgO
- POSSIBLE RADICAL SPECIES IN BED
  R·, H·, O·, X·, N·, S·, O-O·, OH·
- POSSIBLE EFFLUENT SPECIES
  CO_2, H_2O, R = O, $R\overset{O}{\underset{\Theta}{=}}H$, HX, NO, N_2O, NO_2, N_2O_4, N_2, SO_2, R'X, X_2
- HIGH TEMPERATURE NEEDED FOR DIFFICULT TO OXIDIZE SPECIES
- SPECIES FRAGMENTS IN REACTOR CAN COMBINE TO FORM NEW COMPOUNDS
- H_2O +CO_2 ARE DESIRED PRODUCTS BUT CANNOT BE FORMED BY X, N, S COMPOUNDS
- NUMBER OF ACTIVE SITES FOR OXIDATION OF ANY PARTICULAR SPECIES LIMITED BY COMPETITIVE ADSORPTION OF OTHER SPECIES
- SUSTAINED CATALYST ACTIVITY DEPENDS ON MAINTENANCE OF PHYSICAL STRUCTURE AND CHEMICAL ACTIVITY–AVOID SINTERING AND POISONING



CATALYTIC OXIDATION OF ATMOSPHERIC TRACE CONTAMINANTS

IDENTIFIABLE RESEARCH AREA:

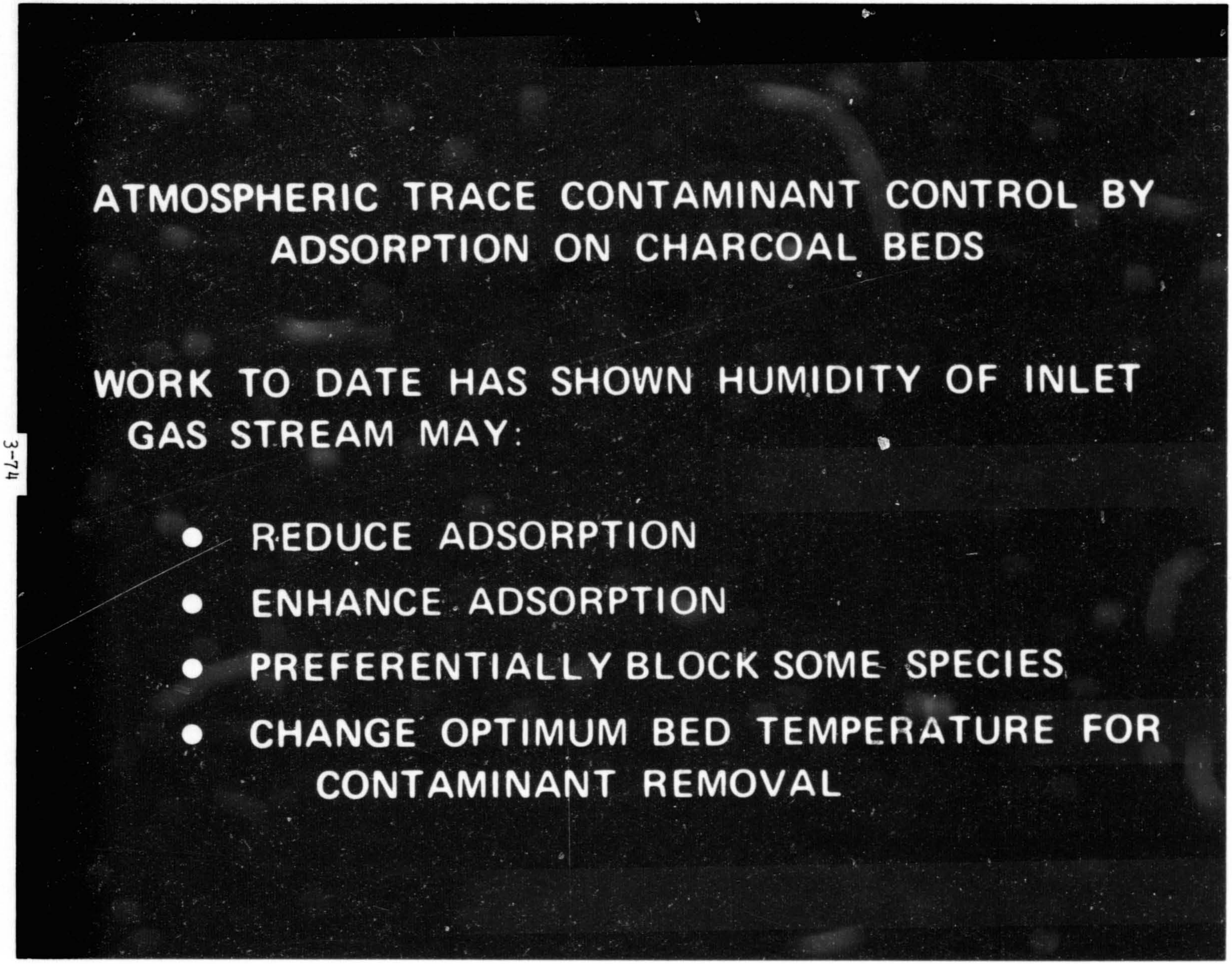
- EVALUATE THE DESIRABILITY AND EFFICIENCY OF CATALYTIC OXIDATION AS A TRACE CONTAMINANT CONTROL METHOD WHEN FEED GAS CONTAINS COMPOUND OF NITROGEN, SULFUR, AND THE HALOGENS
  - INVESTIGATE PRODUCT IDENTIFICATION AND MASS BALANCE WITH S, N, OR X COMPOUNDS IN FEED
  - INVESTIGATE TRANSIENT REDUCTIONS IN ACTIVITY OF CATALYST BED CAUSED BY S, N, OR X COMPOUNDS IN FEED.
  - INVESTIGATE PERMANENT LOSS IN CATALYST ACTIVITY OR POISONING FROM S, N, OR X COMPOUNDS IN FEED



SPECIFIC PROBLEMS IN ATMOSPHERIC TRACE CONTAMINANT REMOVAL
CONTAMINANT CONTROL BY ADSORPTION ON CHARCOAL BEDS

PROBLEM OF BLOCKING OF ADSORPTION OF LIGHTER (MORE VOLATILE) SPECIES BY:

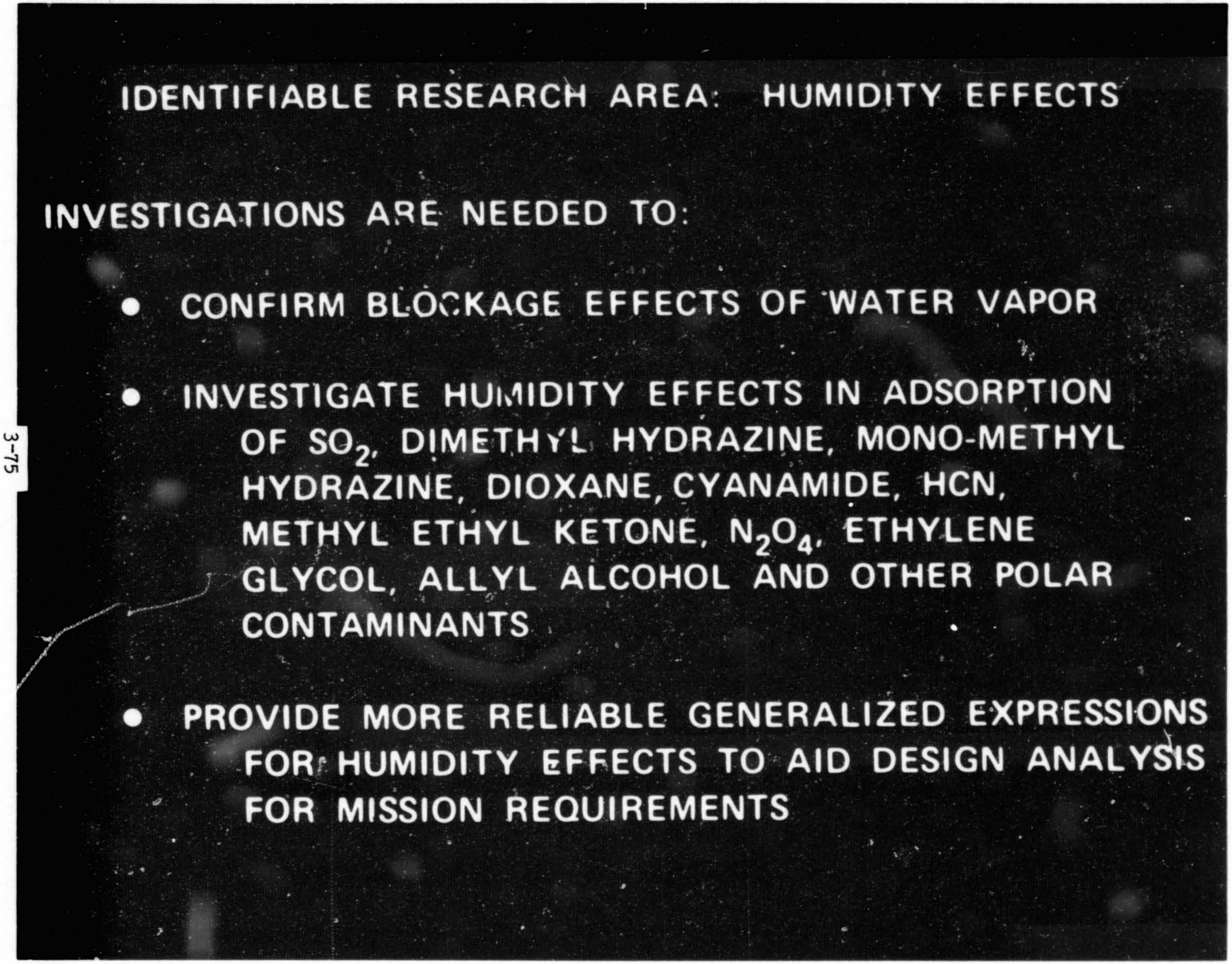
- HEAVIER (LESS VOLATILE) CONTAMINANT SPECIES
- CONTAMINANT SPECIES REACTING OR CHEMISORBING ON CHARCOAL
- WATER ADSORBED FROM HUMID INLET GAS STREAM



ATMOSPHERIC TRACE CONTAMINANT CONTROL BY ADSORPTION ON CHARCOAL BEDS

WORK TO DATE HAS SHOWN HUMIDITY OF INLET GAS STREAM MAY:

- REDUCE ADSORPTION
- ENHANCE ADSORPTION
- PREFERENTIALLY BLOCK SOME SPECIES
- CHANGE OPTIMUM BED TEMPERATURE FOR CONTAMINANT REMOVAL



IDENTIFIABLE RESEARCH AREA: HUMIDITY EFFECTS

INVESTIGATIONS ARE NEEDED TO:

- CONFIRM BLOCKAGE EFFECTS OF WATER VAPOR
- INVESTIGATE HUMIDITY EFFECTS IN ADSORPTION OF SO_2, DIMETHYL HYDRAZINE, MONO-METHYL HYDRAZINE, DIOXANE, CYANAMIDE, HCN, METHYL ETHYL KETONE, N_2O_4, ETHYLENE GLYCOL, ALLYL ALCOHOL AND OTHER POLAR CONTAMINANTS
- PROVIDE MORE RELIABLE GENERALIZED EXPRESSIONS FOR HUMIDITY EFFECTS TO AID DESIGN ANALYSIS FOR MISSION REQUIREMENTS

NEED FOR FURTHER RESEARCH ON ATMOSPHERIC TRACE CONTAMINANT CONTROL METHODS

- NO ONE METHOD CAN DO COMPLETE TASK
- IMPORTANT PROBLEMS REMAIN LARGELY UNSOLVED. PREDICTION OF EFFECTS OF CONTAMINANT MIXTURES, HUMIDITY VARIATION AND OFF-DESIGN LOADS, BED REGENERATION AND LONG-TERM ACTIVITY
- MORE DEFINITIVE EXPERIMENTS ARE NEEDED TO PROVIDE THE DESIGN DATA NECESSARY FOR CONTAMINANT CONTROL SYSTEMS WITH:
  - HIGHER RELIABILITY FACTOR
  - BETTER USE OF WEIGHT AND VOLUME AVAILABLE
  - LOWER POWER PENALTY
  - GREATER MARGIN FOR COMFORT AND HEALTH
- INTERFACE MUST BE MAINTAINED BETWEEN CONTROL METHODS RESEARCH AND MATERIALS AND PHYSIOLOGICAL RESEARCH AND DESIGN ENGINEERING

CONTAMINATION CONTROL FOR INCREASED CREW PRODUCTIVITY

FEBRUARY 29, 1984

Space Station Task Force
Human Productivity Group
NASA Ames Research Center
Moffett Field, CA 94035

D.B. Heppner
C.W. Miller

SCOPE OF PRESENTATION

- Contaminant Sources and Loading - Air/Water
- Contaminant Control - Air
- Contaminant Control - Water
- Other Factors Affecting Productivity
- Issues

SPACE STATION CONTAMINANT SOURCES — AIR

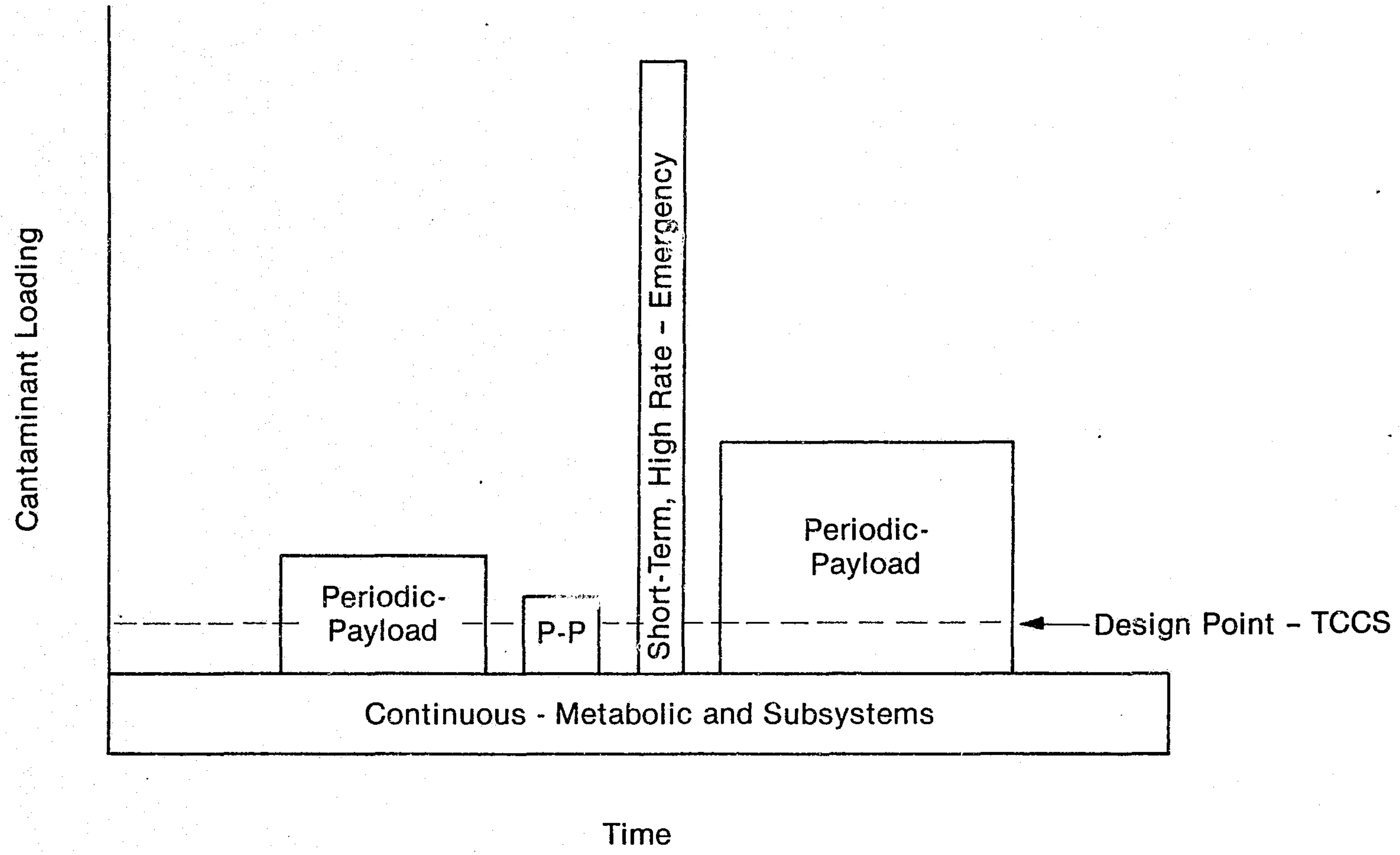
CONTAMINANT	SOURCE	LOADING
Metabolic Products: CO_2, NH_3, CO, H_2S, H_2, CH_4, Organic Acids, Mercaptans, Bacteriological Contaminants.	Crew & Animal	Continuous
Wide Variety of Alcohols, Aldehydes, Aromatics, Esters, Ethers, Chlorocarbons, Fluorocarbons, Halocarbons, Hydrocarbons, Ketones, Acids.	Subsystems & Payloads	Continuous & Periodic
CO, CO_2, Hydrocarbons, Aromatics, Acid Gases, Oxides of N_2, SO_2, NH_3, Alcohols, Formaldehyde.	Emergencies - Spills, Equipment Failures, Fire	Short Term, High Rate

SPACE STATION CONTAMINANT SOURCES — WATER

			Dissolved Solids				
Water Source	Quantity Per Person-Day (lb)	Suspended Solids (PPM)	Inorganics (PPM)	Organics (PPM)	Total (PPM)	Urea (PPM)	Micro-Organism
Fuel Cell	As required	0(a)	10 to 424	0(a)	10 to 424	0	No
Condensate		0(b)	12(b)	4(b)	16(b)	No	Yes(b)
		10 to 600(a)	20 to 350(a)	25 to 87(a)	45 to 450(a)	0 to 5(a)	Yes
without SDAS	7.15(e,f,g,h)						
with SDAS	14.15(d,e,f,g,h)						
Shower	5(f),8(g,h)	160(i)	90(i)	1,030(i)	1,120(i)	15(i)	Yes
		650(j)	270(j)	800(j)	1,070(j)	260(j)	Yes
Handwash	7(f),4(g,h)	110(i)	60(i)	1,020(i)	1,080(i)	10(i)	Yes
Laundry	27.5(f,g,h)	210(i)	180(i)	1,010(i)	1,190(i)	5(i)	Yes
Dish Wash		9,000(i)	580(i)	500(i)	1,080(i)	0	Yes
CO_2 Reduction Water	1.80					0	No
EVA Wastewater (lb/8 hr EVA)	9.68(f,g,h)	(Same as Condensate)					
Urine	3.31(f,g,h)	38,000	12,500(k)	29,200(k)	41,700(k)	16,300(k)	Yes
Urinal Flush	1.09(f,g,h)						
Fecal Water	Not Identified						
Standard							
Wash Water Standard(l)					≤1,500	≤50	≤10
Potable Water Standard(l)					≤ 500		≤10
Potable Water Standard(m)					14	0	

(a) References noted in ( )

CONTAMINANT LOADING PROFILE (TYPICAL)



CONTAMINANT CONTROL — AIR

- CO_2 Removal
  - SDAS vs. EDC
  - EDC vs. LiOH
- H_2O Removal
  - Water Vapor Electrolysis
  - Condensing Heat Exchanger
  - Desiccant
- Trace Contaminant Control
  - Normal, Loading Removal
  - High Contaminant Loading Removal
- Microbial
  - Surface Wipe

REGENERATIVE CO_2 REMOVAL

COMPARISON ELECTROCHEMICAL VS STEAM DESORBED AMINE[a]

PRIOR COMPARISONS

Year	Organization	CO_2 Removal Subsystem Selected
1970	Ham. Std.	EDC equiv. wt. less than half IR-45 amine. Also cited amine problems: bed expansion/ contraction, steam/CO_2 separation, steam generation, long term degradation.
1971	Rockwell	EDC selected over amines based on weight, power and heat rejection (⅓ other techniques) and ideally integrates with fuel cell and propulsion system.
1972	NASA JSC/ Ham. Std.	Selected EDC for SSP.
1973	McDonnel Douglas	EDC selected over amine based on lower weight, volume and power.
1976	NASA	Selected EDC for RLSE.
1979	NASA JSC	Selected EDC for Space Operations Center.

ASSUMPTIONS

1. 4-Person Subsystem
2. 2.2 lb CO_2/Person Day
3. Inlet $pCO_2 = 3.0$ mm Hg
4. Flight Prototype Level
5. Spares Not Included
6. Penalties, lb/W

Power: 0.71 (AC)
0.59 (DC)

Heat Rej: 0.18 (Liq.)
0.44 (Air)

COMPARISON RESULTS

Category	EDC	SDAS	Comments
Fixed Hardware Wt., lb	92	139	All components incld. in both
Power Wt. Penalty, lb	49	577	461 of 577 for steam gen. & heat loss
Heat Rej. Wt. Penalty, lb	145	394	EDC rejects heat to liquid, amine to air
Subtotal	286	1,110	Amine 3.6 times greater than EDC
O_2 Generation Penalty, lb	309	0	EDC integrates with H_2, O_2 & H_2O utilities
Humidity Control Penalty, lb	102	770	Amine dumps 8 x H_2O vapor into cabin
Water Processing Penalty, lb	27	206	Cabin condensate processing penalty
Total Eg. Wt., lb	724	2,086	Difference even greater as pCO_2 spec-dec.
Operation Cont. or Cyclic	Either	Cyclic	Amine continuously cycles cabin RH, T
Vary CO_2 Removal Rate	Yes	No	EDC tolerates crew changes
Maintainability	Cell	Canister	EDC maintainable at lower level
Humidifier Load, lb H_2O/day	4	32	Increases redundant dehumidifiers
Water Recov. Sys. Load, H_2O/day	4	32	Amine 8 times EDC
Noise	Negl.	Large	On/off amine compressor noisy

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a. Details found in Life Systems' TR-604, 7/11/83, and SAE Paper No. 831120.

REGENERATIVE vs. NON REGENERATIVE CO_2 REMOVAL COMPARISON OF ELECTROCHEMICAL vs. LITHIUM HYDROXIDE

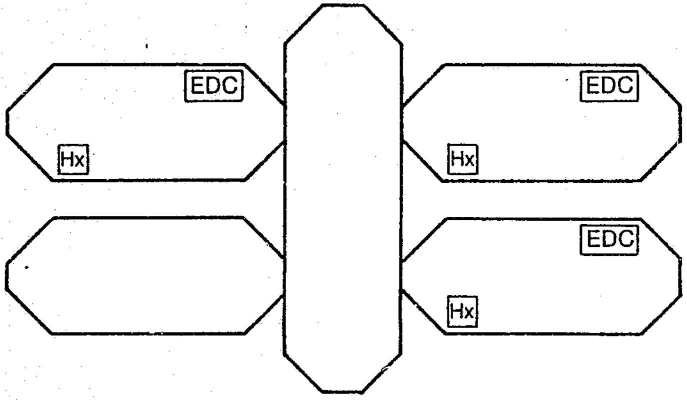
	EDC	LiOH
Weight	724 lbs(1)	3600 lbs(2)
Volume	2.4 ft^3	100 ft^3
Power	0.14 kW	0.03 kW
Crew Time	0	105 hrs.(3)
Resupply Weight	0	1523 lbs
Resupply Volume	0	51.3 ft^3

(1) Weight includes penalty for power, heat rejection, O_2 generation, humidity control, and water processing.

(2) Weight includes penalty for power.

(3) Crew time was calculated assuming changing seven canisters per day requiring ten minutes to locate canister, log out, remove exhausted canister, install new canister and stow old canister.

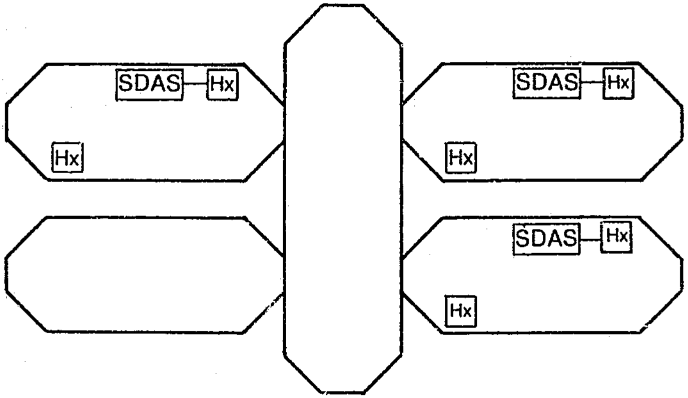
WATER VAPOR REMOVAL — SYSTEMS CONSIDERATION



Water Vapor Loading

	lb/man-day
Metabolic	4.02
Hygiene	0.94
Food Preparation	0.06
Experiments	1.00
Laundry	0.13
Sub-Total	6.15
EDC	1.00
Total	7.15

Heat Exchangers Required 1 per Module



Water Vapor Loading

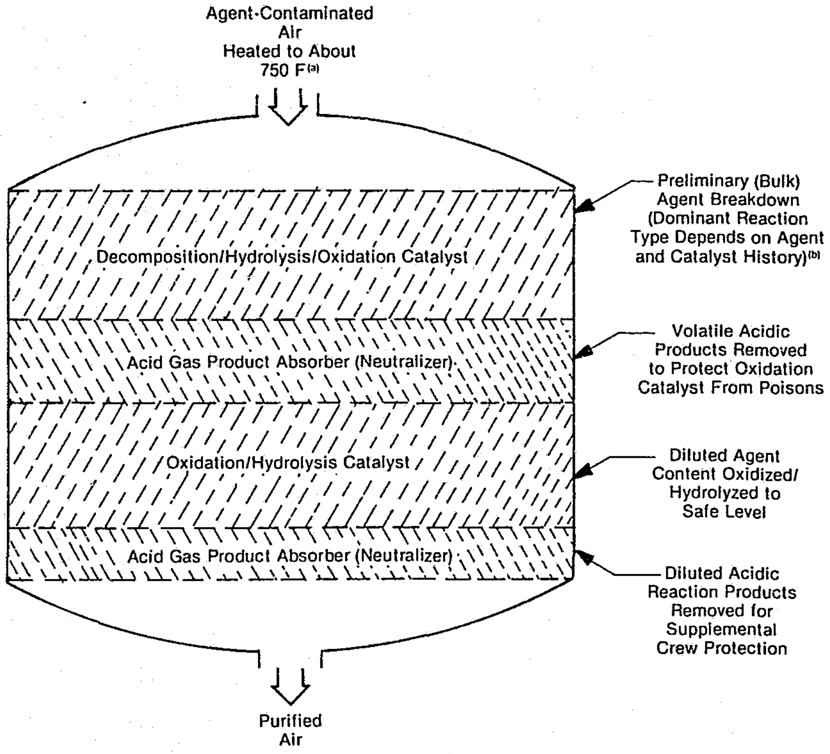
	lb/man-day
Metabolic	4.02
Hygiene	0.94
Food Preparation	0.06
Experiments	1.00
Laundry	0.13
Sub-Total	6.15
SDAS	8.00
Total	14.15

Heat Exchangers Required 1 per Module plus
1 per SDAS

CONTAMINANT CONTROL TECHNIQUES EVALUATED BY LIFE SYSTEMS

- Catalytic Oxidation
- Corona Discharge
- Regenerative Adsorption
- Thermal Decomposition
- Laser Decomposition
- Combustion
- Chemical Decomposition
- Microwave/Plasma Decomposition
- Membranes

BASELINE SEQUENTIAL CATALYTIC OXIDATION CONCEPT

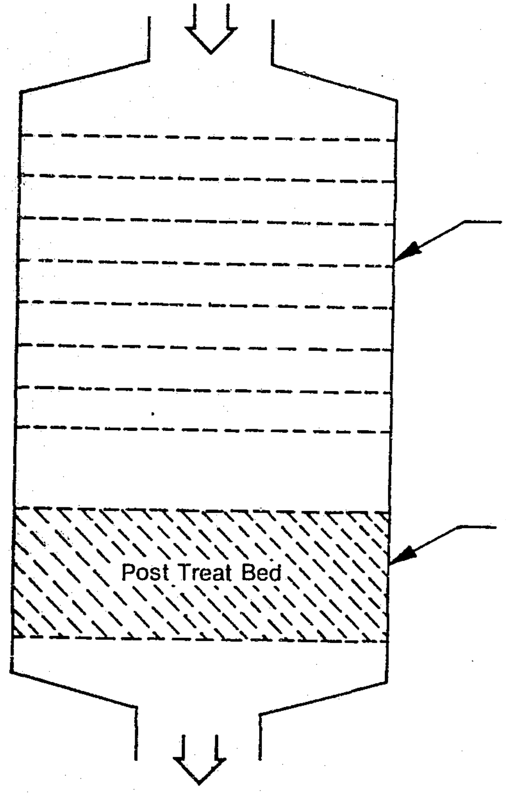


(a) Some agent breakdown will occur during heatup. Potentially installing a portion of the absorber material upstream of the first bed will further improve longevity.

(b) First catalyst bed expected to provide alternate decomposition modes even after primary mode (oxidation) is destroyed.

CORONA DISCHARGE REACTOR/ POST-TREAT CONCEPT

Agent-Contaminated
Air



Agents Oxidized/
Decomposed in High
Voltage Corona
Created at Series of
Electrodes

Removes Potentially
Toxic Byproducts

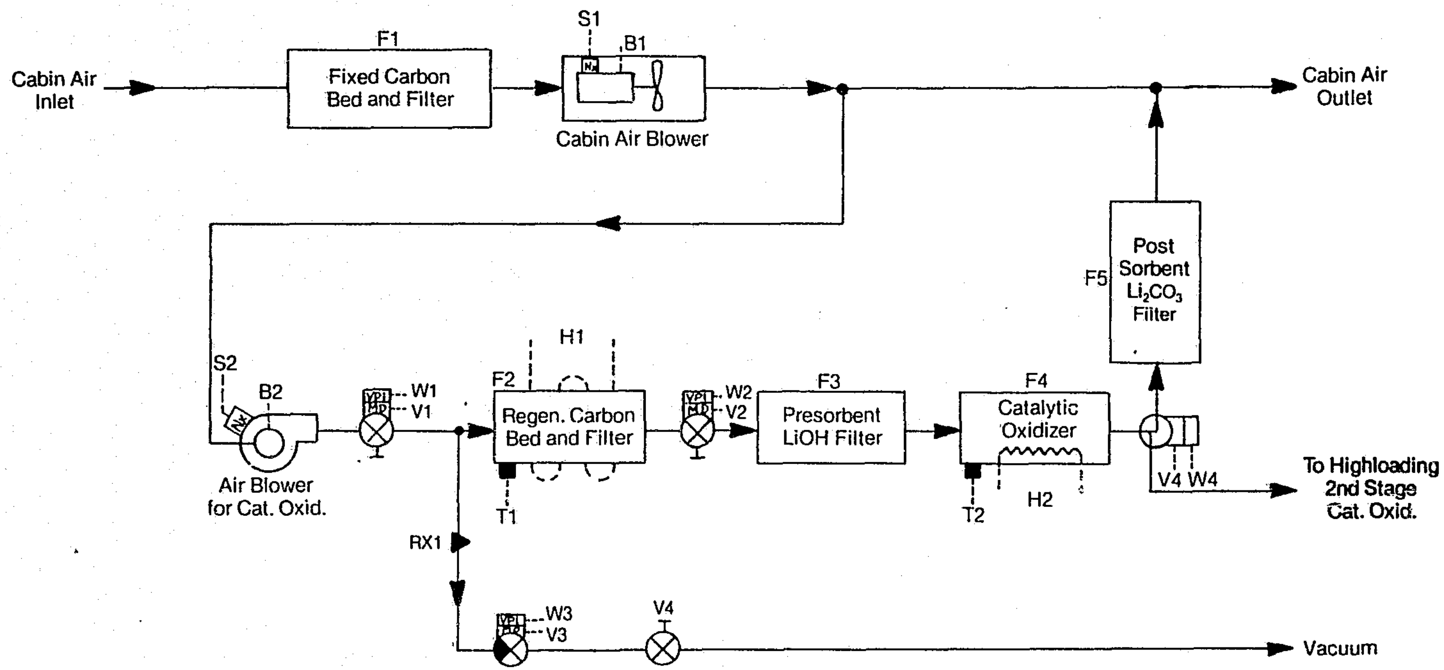
Purified
Air

FOCUS OF CORONA DISCHARGE INVESTIGATIONS

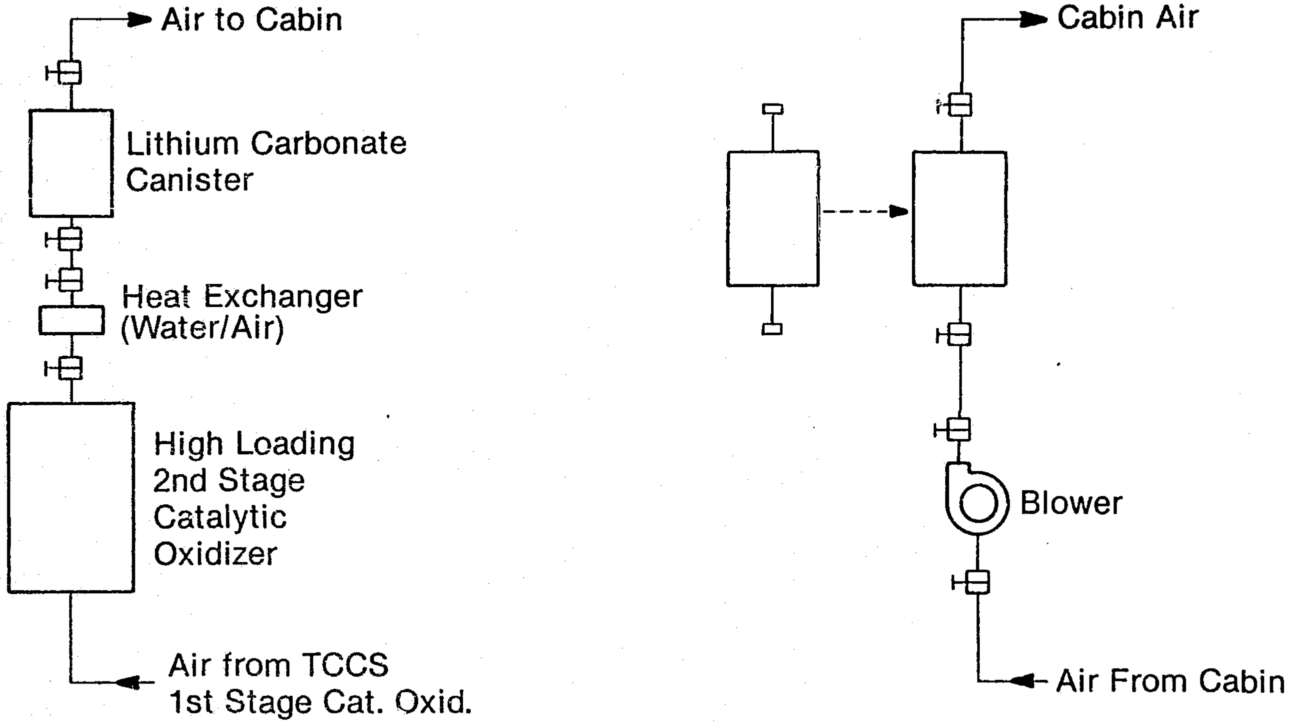
- Available Data
  - Very Little Data Available
  - Currently Existing Laboratory Reactors Not Amenable to Scaleup
  - Post-Treat Concept Not Explored to Date

- Focus of Present Work
  - Design Lab Scale Breadboard Reactor Compatible With Scaleup
  - Expand Data Base Considerably
  - Improve Process Performance
  - Investigate Post-Treat Concept(s)

TRACE CONTAMINANT CONTROL SUBSYSTEM FOR NORMAL LOADING REMOVAL



TRACE CONTAMINANT CONTROL FOR HIGH LOADING REMOVAL



TCCS SIZING FOR SPACE STATION

Subsystem	Normal	High Loading Canister	High Loading Catalytic Oxidation
Weight, lb	105	TBD	26
Power, W (continuous)	165	100	140
Volume, ft^3	8.3	TBD	0.8
Resupply (90 days)			
Weight, lb	250	TBD	TBD
Volume, ft^3	9.8	TBD	TBD

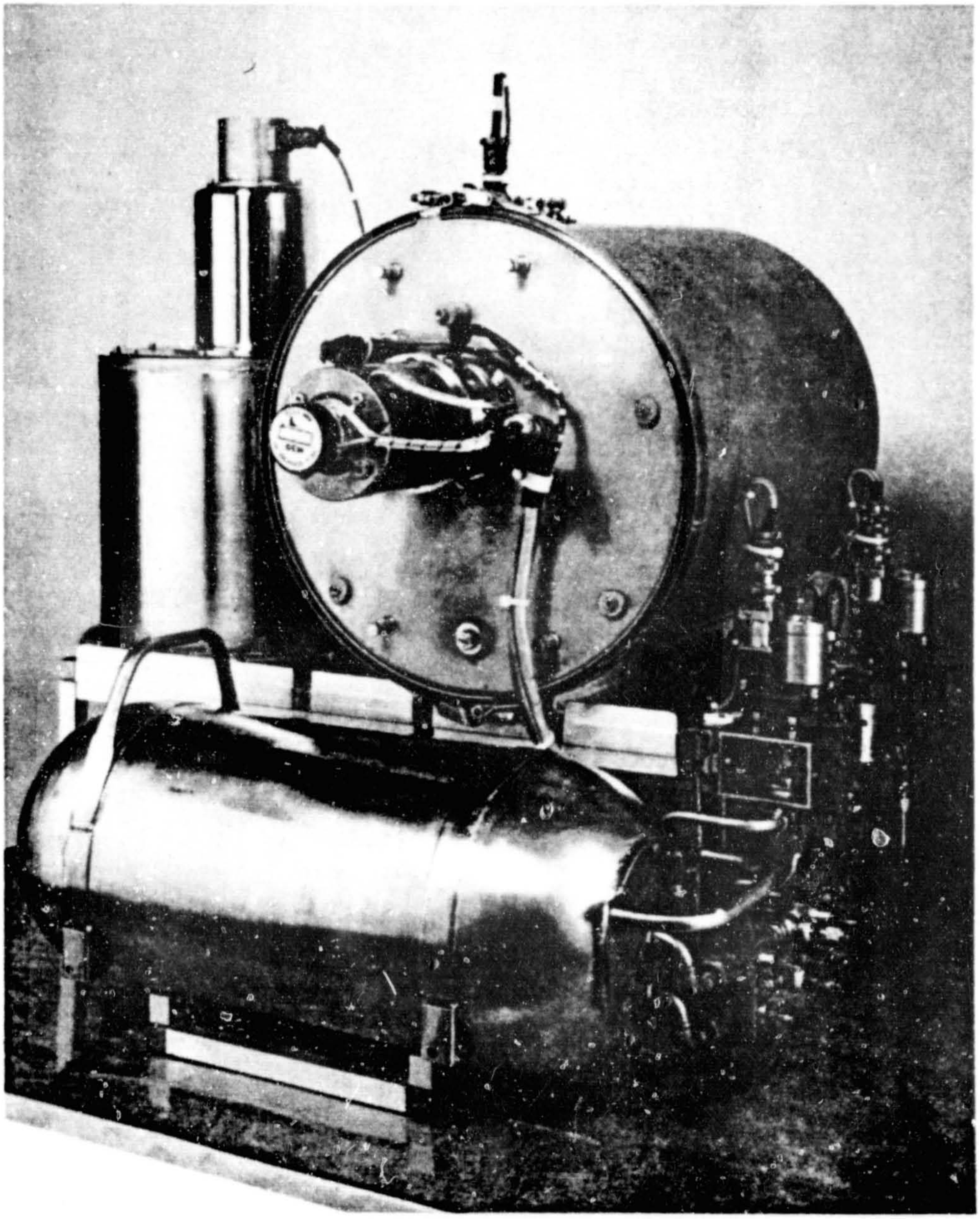
CONTAMINANT CONTROL — WATER

- Biocide Addition
- Microbial Checkvalve
- UV/Ozonation
- Phase Change Water Recovery
- Filtration Water Recovery
- Open Loop Regenerative Fuel Cell

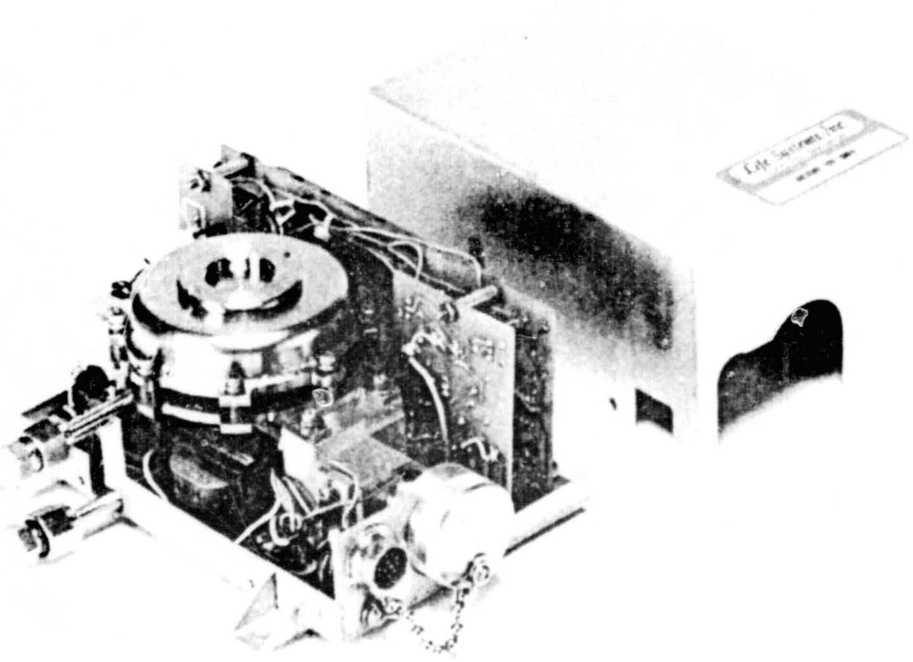
WATER CONTAMINANT CONTROL OPTIONS

Sources	Treatment	Quality
Fuel Cell	Biocide Addition	Potable
Condensate CO_2 Reduction EVA CO_2 Reduction	Multifiltration, Biocide Addition	Potable
Shower Handwash	Filtration Water Recovery, Microbial Check Valve, Biocide Addition	Reuse
Laundry Dishwash Urine Urinal Flush	Phase Change Water Recovery, Multifiltration, Biocide Addition	Reuse
Reuse	UV/Ozonation, Biocide Addition	Potable
Reuse	Open Loop Regenerative Fuel Cell, Biocide Addition	Potable

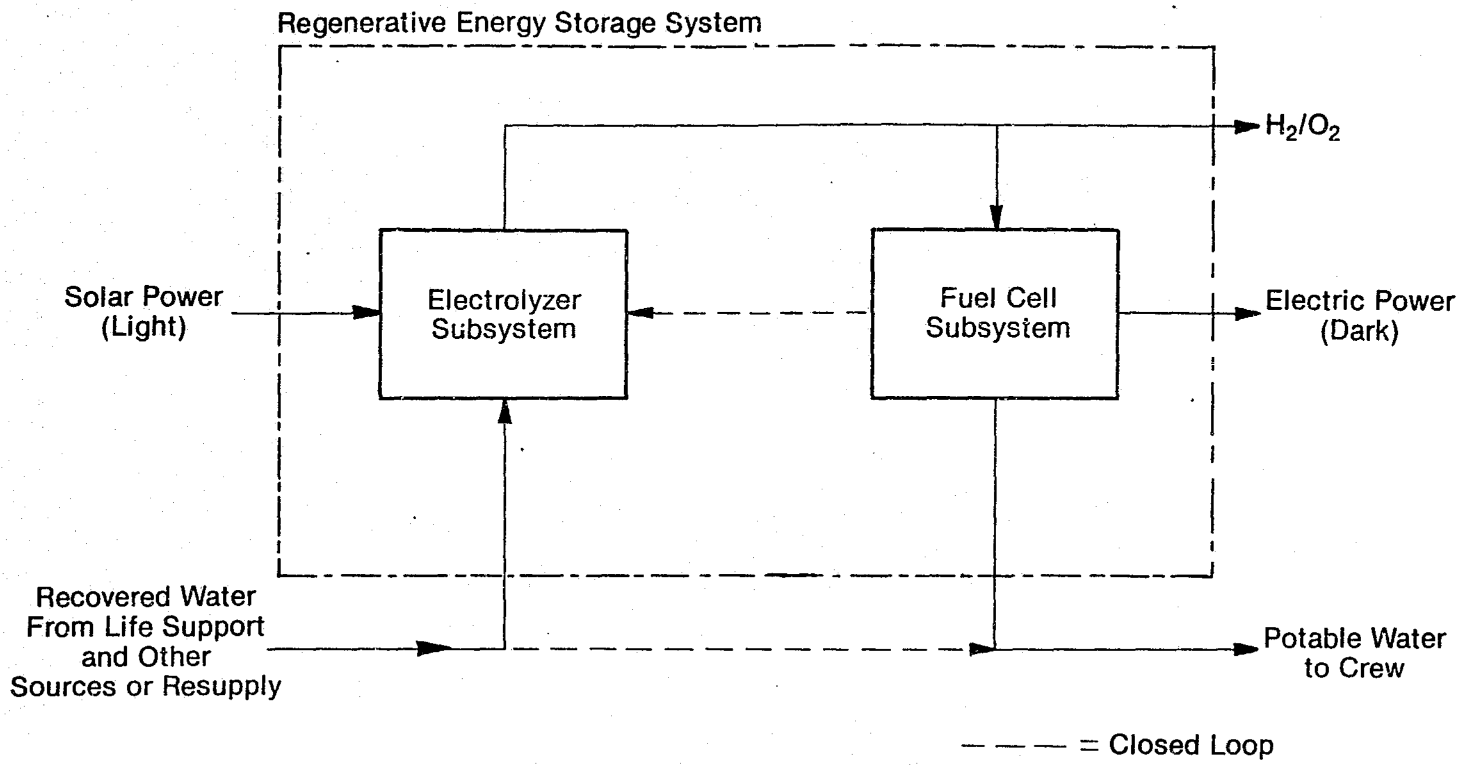
PHASE CHANGE WATER RECOVERY — VAPOR COMPRESSION DISTILLATION SUBSYSTEM



BIOCIDE ADDITION AND MONITORING UNIT



OPEN LOOP REGENERATIVE FUEL CELL — FOR SECONDARY WATER TREATMENT



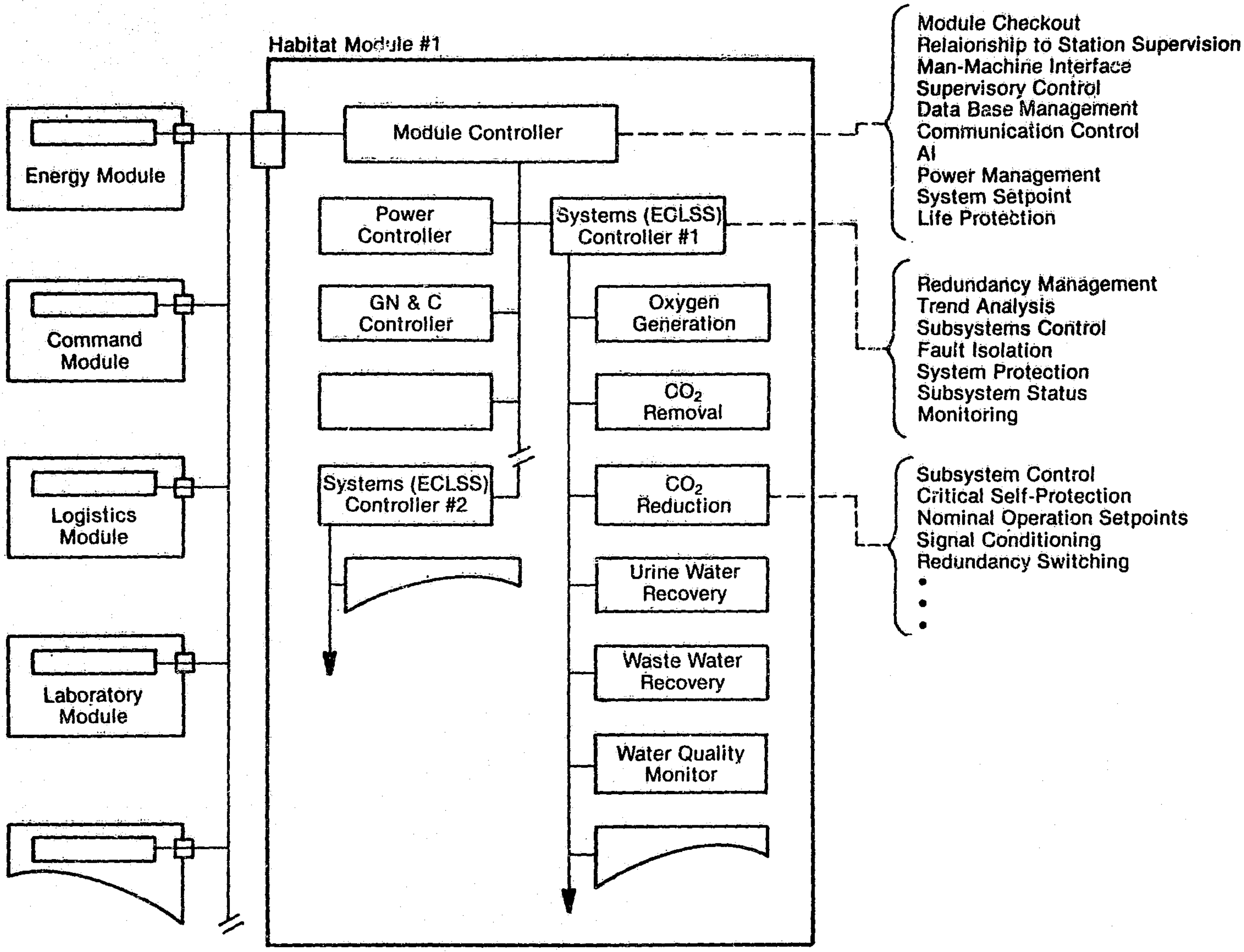
OTHER FACTORS AFFECTING PRODUCTIVITY

- Automation
  - Subsystem Interaction
  - Man in Loop

- Mechanical Integration
  - Subsystem
  - System

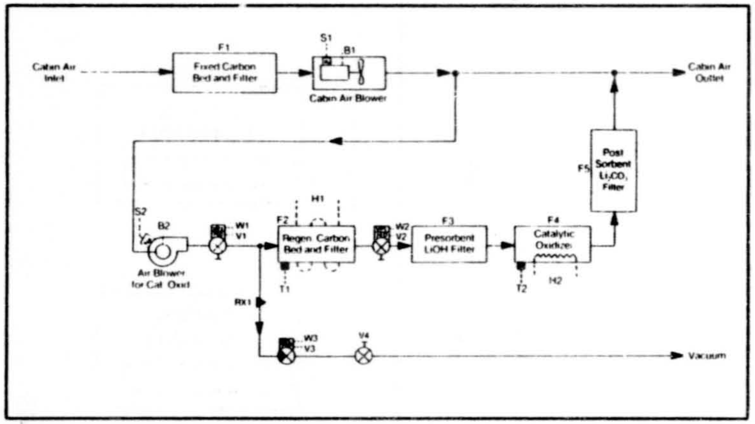
- Crew Time
  - LiOH
  - TCCS Cannister Design

SPACE STATION AUTOMATION CONCEPT



SUBSYSTEM INTEGRATION

Trace Contaminant Control Subsystem



Sensors

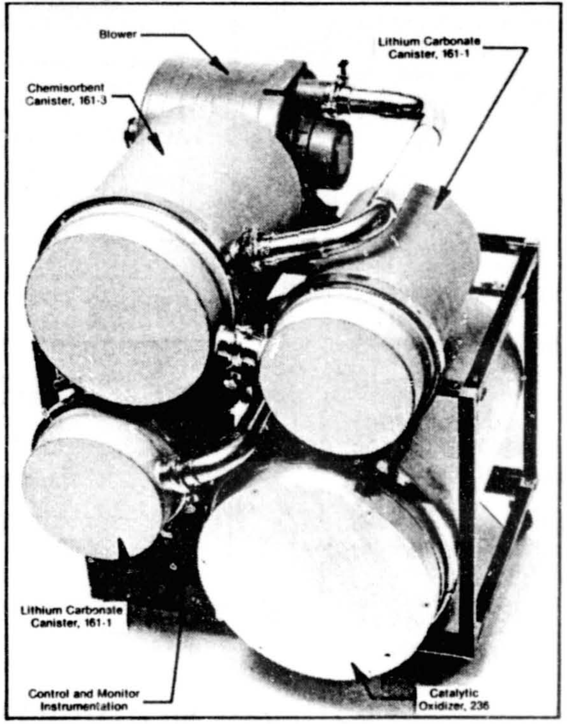
Description	Qty	Subsystem Symbol
Speed Sensor for Fixed Carbon Blower	1	S1
Speed Sensor for Regen. Carbon Blower	1	S2
Regen. Carbon Bed Temperature	2	T1
Catalytic Oxidizer Temperature	2	T2
Total	6	

Actuators

Description	Qty	Symbol
Blower, Cabin Air	1	B1
Blower, Cat. Oxid.	1	B2
Heater, Regen. Carbon	1	H1
Heater, Cat. Oxid.	1	H2
Valves, Carbon Bed Isolation	2	V1,V2
Valve, Vacuum	1	V3
Total	7	

MECHANICAL ENGINEERING INTEGRATION

Packaging



MECHANICAL COMPONENTS INTEGRATION PROGRAM

Sponsored By:
Ames, Lewis,
JSC: Crew & Power,
Life Systems

PURPOSE: Save Money By

1. Decreasing Subsystem Complexity
2. Decreasing Wt, Vol., Power,...
3. Increasinng Reliability

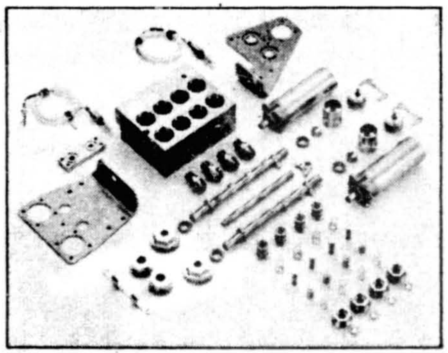
STATUS:

- 5 - Completed
- 1 - in Development
- 3 - Planned

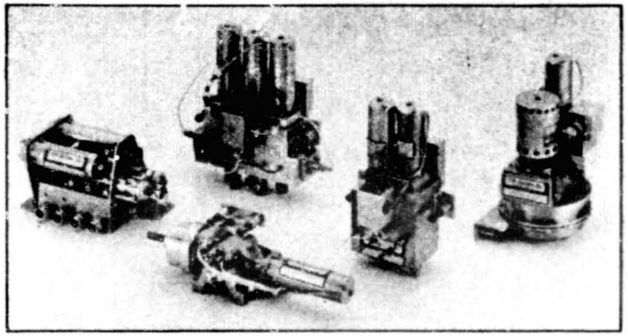
Avg. Results	% Red:
No. Components	83
Power	68
Weight	83
Volume	83
No. Connections	64

No.	Mechanical Integration	Units Produced	Testing Hours	Testing Cycles
1	3-Fluids Pressure Controller	7	15,000	11,800
2	Coolant Control Assembly	7	11,500	8,600
3	Fluids Control Assembly (EDC)	3	20,000	14,000
4	Fluids Control Assembly (SFE)	8	2,400	1,000
5	2-Fluids Pressure Controller	1	0	0

- 18 Components → 1
  - 7 - Two-way Valves
  - 2 - Check Valves
  - 4 - Filters
  - 3 - Orifices
  - 2 - Press. Trans.
- 24 W → 2
- 11.4 lb → 4
- 400 in^3 → 200



Assembled: 4.8 x 3.0 x 3.5 In



Next Steps:

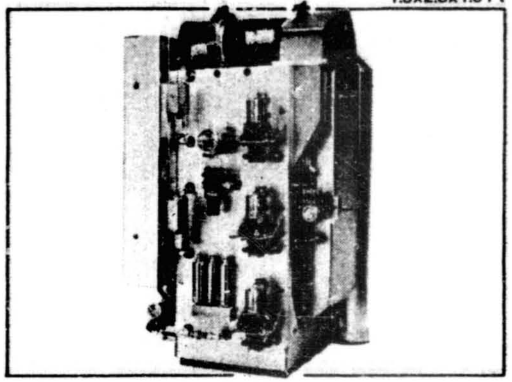
1. Applicability of Super Plastics
   - Injection Molding To Save $
   - Considerably Lighter Weight
2. Increase Maintainability
   - Onboard Replacement Unit

12 YEARS OF CONTINUOUS INTEGRATED ARS EXPERIENCE

Air Revitalization System Development	Timeframe 73	74	75	76	77	78	79	80	81	82	83	84	85	86	CO_2 Rem.	CO_2 Red.	O_2 Gen.	Dehumidification	N_2 Gen.	Capacity
Lab. Breadboard	—	—													EDC	Sab.	SFE	-	-	1
Lab. Breadboard		—	—												EDC	Bos.	-	-	-	4
Flight Breadboard (EARS)			—	—											EDC	-	WVE	WVE	-	1
Lab. Breadboard			—	—	—										EDC	Bos.	SFE	-	-	4
Lab. Breadboard					—	—									EDC	Sab.	SFE	-	-	1
✓ Flight Breadboard (ARX-1)						—	—	—	—	—	—				EDC	Sab.	SFE	Slupper	N_2H_4	1
✓ RLSE Preprototype (IARS)						—	—	—	—	—					EDC	-	WVE	WVE	-	3
✓ Flight Experiment Mockup								—	—						EDC	Sab.	SFE	Slupper	-	1
✓ Engineering Model										—	—	—	—		EDC	Sab.	SFE	Slupper	-	1
✓ Flight Demonstration												- -	- -	- -	EDC	Sab.	SFE	-	-	1

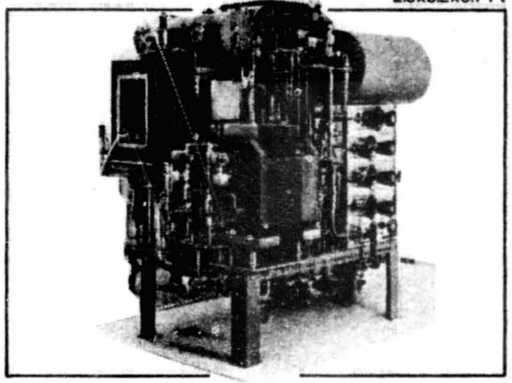
✓ = Subsystems no longer retained as separate entities.

1.5x2.8x1.5 Ft



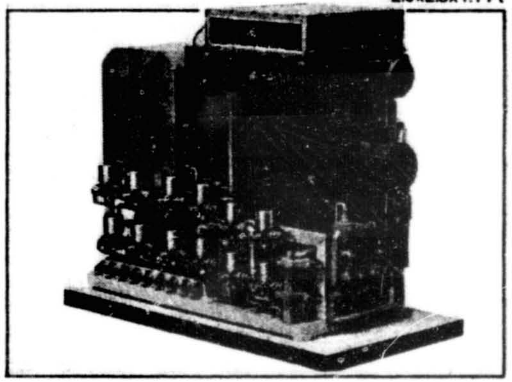
- CO_2 Removal
- O_2 Generation
- Dehumidification

2.3x3.2x3.7 Ft



- CO_2 Removal
- O_2 Generation
- Dehumidification
- CO_2 Reduction
- N_2 Generation

2.0x2.8x1.1 Ft

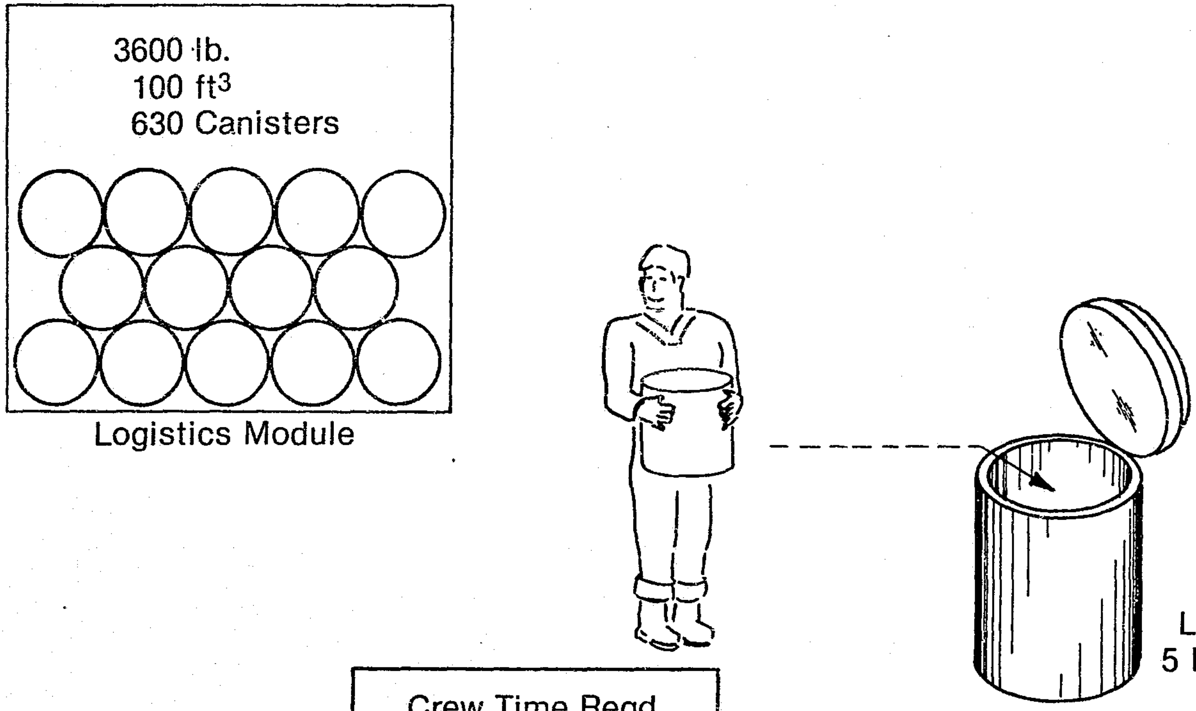


- CO_2 Removal
- O_2 Generation
- Dehumidification
- CO_2 Reduction

Result: Life Systems Has Indepth Knowledge Of:
- ARS Functional & Component Performances
- Process Dymanics
- Water Handling: Feed & Condensate
- Interactions Between Controllers
- Importance of Simplifying
- Software Requirement & Development Times

ALSO: WE ARE INTEGRATING THE SFE AND SHUTTLE ORBITER FUEL CELL INTO RFCS BREADBOARD

CONTAMINANT CONTROL TECHNIQUE AFFECTS CREW PRODUCTIVITY



LiOH Canister
Storage (90 Days)

3600 lb.
100 ft^3
630 Canisters

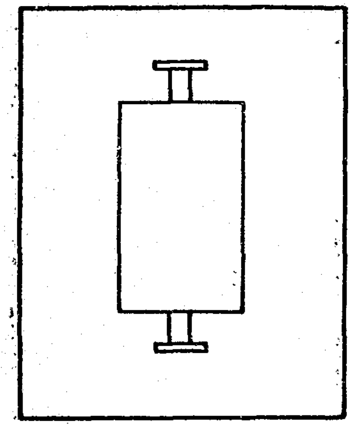
Logistics Module

LiOH Use
5 Locations

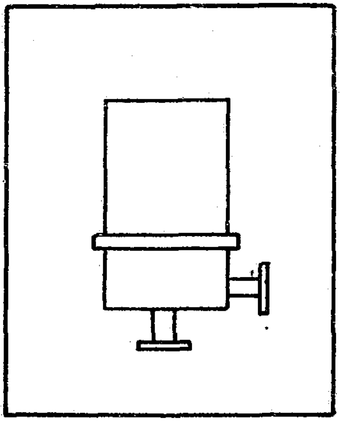
Crew Time Reqd.

10 min/Canister
7 Canister/Day
105 hr/90 Days

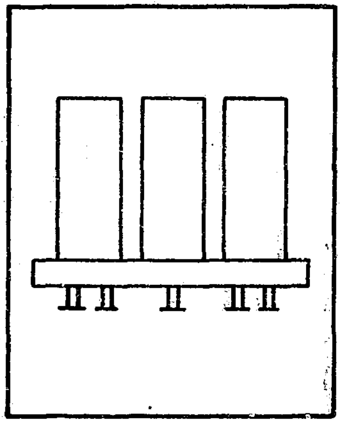
CANISTER OPTIONS VS. CREW TIME



Canister With
2 Clamps



Canister With
1 Clamp



Multiple Canisters
With Common
Manifold

ISSUES REGARDING CONTAMINATION CONTROL

Sources — Space Station Design and Selection of Materials and Subsystems

Loading — Multiple Capacity Equipment for Normal and High Loading

Control Techniques — Additional Studies, Evaluation and Testing

Productivity Factors — Automation, Mechanical Integration, Crew Time

C-6

SPACE STATION TASK FORCE

HUMAN PRODUCTIVITY PROGRAM DEFINITION

D.E. CRAMER

HUMAN PRODUCTIVITY: WHAT IS IT?

THE USE OF MAN TO ATTAIN UTILITARIAN OBJECTIVES IN THE SPACE STATION SYSTEM

HUMAN PRODUCTIVITY: WHY NOW?

- EARLIER ATTEMPTS TO START A SPACE STATION PROGRAM HAD NO SUCH THRUST
- PRESENT SPACE STATION PLANNING IS CHARACTERIZED BY:
  - TECHNICAL ACTIVITIES TIED CLOSELY TO MISSION REQUIREMENTS -- USER NEEDS ACKNOWLEDGED
  - COMMERCIAL THEME MORE PROMINENT
  - COMMERCIAL USERS HAVE MORE DETAILED REQUIREMENTS
  - CUSTOMER DEMAND FOR HIGH EFFICIENCY AND AFFORDABILITY
- CURRENT NATIONAL CONCERN OVER U.S. PRODUCTIVITY
- NASA'S GOAL TO BECOME "A LEADER IN THE DEVELOPMENT AND APPLICATION OF ADVANCED TECHNOLOGY AND MANAGEMENT PRACTICES WHICH CONTRIBUTE TO SIGNIFICANT INCREASE IN BOTH AGENCY AND NATIONAL PRODUCTIVITY"

HUMAN PRODUCTIVITY: PROGRAM GOAL

TO OPTIMIZE HUMAN PRODUCTIVITY ON THE SPACE STATION WITHIN THE EXISTING RESOURCES AND OPERATIONAL CONSTRAINTS

HUMAN PRODUCTIVITY FLIGHT OBJECTIVES

- DEVELOP HABITABILITY WHICH:
  - SUSTAINS HUMAN PRODUCTIVITY ABOVE 90% OF INITIAL PERFORMANCE THROUGHOUT A TOUR OF 90 DAYS
- MAXIMIZE IVA CREW TIME:
  - CURRENT GOAL: 9 HOURS/DAY EXCLUDING WEEKENDS
- ESTABLISH EVA WHICH IS:
  - ROUTINE
  - RELIABLE
  - CONVENIENT
  - AND ABOVE ALL – CAPABLE
  - CURRENT GOAL: 8 HOURS/DAY FOR 4 CREW MEMBERS
- MAXIMIZE USE OF SHUTTLE TO VALIDATE NEW SYSTEMS

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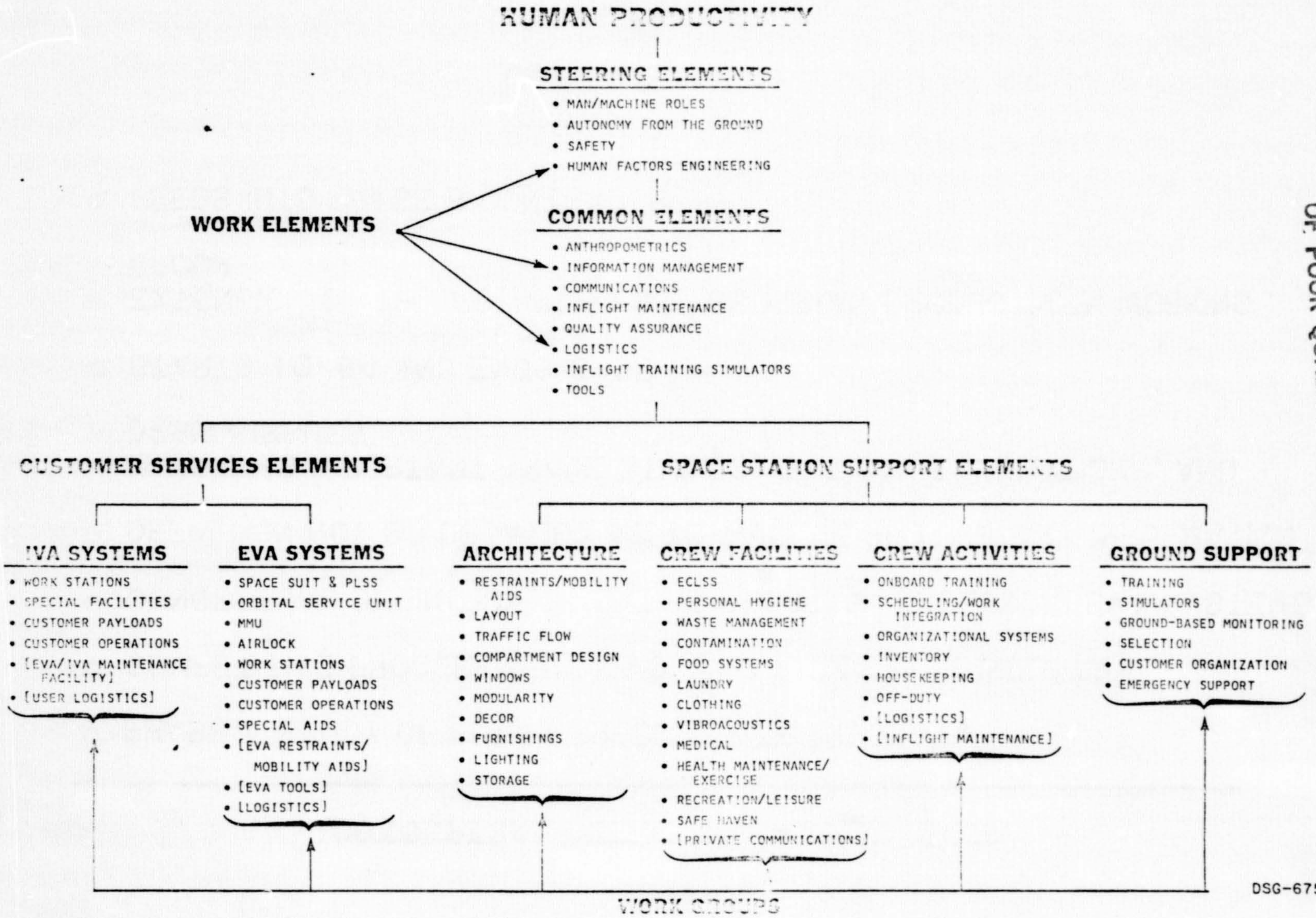
HUMAN PRODUCTIVITY: PROGRAM STRATEGY (I)

- INTEGRATE CREW-RELATED ACTIVITIES AND FACILITIES INTO A
  SINGLE,
  WELL INTEGRATED, AND
  COORDINATED PROGRAM
- CONDUCT ITERATIVE COST/TRADE STUDIES
- IDENTIFY COST EFFECTIVE PROGRAM ELEMENTS
- INCREASE SAFETY AND PRODUCTIVITY OF HUMAN OPERATIONS
- MATCH RESOURCES

HUMAN PRODUCTIVITY: PROGRAM STRATEGY (II)

- PROVIDE FOR WELL ORGANIZED CUSTOMER INVOLVEMENT
- DEVELOP A MULTI-CENTER ACTIVITY
- PROVIDE A FORUM FOR CENTER, INDUSTRY, AND UNIVERSITY INTERACTION
- ACCOMMODATE GROWTH AND EVOLUTION
- CARRY OUT AN EARLY, DETAILED DEFINITION


HUMAN PRODUCTIVITY
STEERING ELEMENTS
• MAN/MACHINE ROLES
• AUTONOMY FROM THE GROUND
• SAFETY
• HUMAN FACTORS ENGINEERING
WORK ELEMENTS
COMMON ELEMENTS
• ANTHROPOMETRICS
• INFORMATION MANAGEMENT
• COMMUNICATIONS
• INFLIGHT MAINTENANCE
• QUALITY ASSURANCE
• LOGISTICS
• INFLIGHT TRAINING SIMULATORS
• TOOLS
CUSTOMER SERVICES ELEMENTS
SPACE STATION SUPPORT ELEMENTS
IVA SYSTEMS
• WORK STATIONS
• SPECIAL FACILITIES
• CUSTOMER PAYLOADS
• CUSTOMER OPERATIONS
• [EVA/IVA MAINTENANCE FACILITY]
• [USER LOGISTICS]
EVA SYSTEMS
• SPACE SUIT & PLSS
• ORBITAL SERVICE UNIT
• MMU
• AIRLOCK
• WORK STATIONS
• CUSTOMER PAYLOADS
• CUSTOMER OPERATIONS
• SPECIAL AIDS
• [EVA RESTRAINTS/ MOBILITY AIDS]
• [EVA TOOLS]
• [LOGISTICS]
ARCHITECTURE
• RESTRAINTS/MOBILITY AIDS
• LAYOUT
• TRAFFIC FLOW
• COMPARTMENT DESIGN
• WINDOWS
• MODULARITY
• DECOR
• FURNISHINGS
• LIGHTING
• STORAGE
CREW FACILITIES
• ECLSS
• PERSONAL HYGIENE
• WASTE MANAGEMENT
• CONTAMINATION
• FOOD SYSTEMS
• LAUNDRY
• CLOTHING
• VIBROACOUSTICS
• MEDICAL
• HEALTH MAINTENANCE/ EXERCISE
• RECREATION/LEISURE
• SAFE HAVEN
• [PRIVATE COMMUNICATIONS]
CREW ACTIVITIES
• ONBOARD TRAINING
• SCHEDULING/WORK INTEGRATION
• ORGANIZATIONAL SYSTEMS
• INVENTORY
• HOUSEKEEPING
• OFF-DUTY
• [LOGISTICS]
• [INFLIGHT MAINTENANCE]
GROUND SUPPORT
• TRAINING
• SIMULATORS
• GROUND-BASED MONITORING
• SELECTION
• CUSTOMER ORGANIZATION
• EMERGENCY SUPPORT
WORK GROUPS

DSG-675

CONCEPTUAL DEFINITION - WHAT IS IT?

- PHASE A STUDY OF HUMAN PRODUCTIVITY PROGRAM
- COMPETITIVE PROCUREMENT INVOLVING AEROSPACE INDUSTRY
- CONCEPTUAL DEFINITION OF ENTIRE PROGRAM, EXCLUDING EVA SYSTEMS
- DEFINITION NOT SO DETAILED AS TO INVOLVE PROPRIETARY INFORMATION
- IDENTIFIES IMPORTANT TRADE STUDIES, CRITICAL ASSUMPTIONS, AND DESIGN ISSUES
- STARTS 10/84 AND ENDS 6/85
- EXTENSION OF THE ACTIVITIES OF THE HUMAN PRODUCTIVITY WORKING GROUP
- FEEDS INTO PHASE B CONTRACTS

CONCEPTUAL DEFINITION - WHY DO IT?

THE HUMAN PRODUCTIVITY PROGRAM IS NEW -- A DEFINITION IS REQUIRED:

- TO PROVIDE INFORMATION/REQUIREMENTS INTO PHASE B STUDIES
- TO IDENTIFY LONG LEAD TECHNOLOGY
- TO IDENTIFY RESPONSIBILITY FOR WORK ELEMENTS
- TO COORDINATE THE DEVELOPMENT OF CREW FACILITIES AND ACTIVITIES
- TO LAY THE FOUNDATION FOR A COST EFFECTIVE APPROACH TO IMPROVING HUMAN PRODUCTIVITY

CONCEPTUAL DEFINITION - PROCESS

INCLUDES ALL OF THE HUMAN PRODUCTIVITY PROGRAM:

- ○ EXCLUDING EVA SYSTEMS WHICH ARE COVERED IN SEPARATE, PARALLEL CONTRACTS
- ○ EMPHASIS ON BREADTH NOT DEPTH
- ○ DEFINITION IS ITERATIVE STARTING WITH "STEERING" WORK ELEMENTS

PROCESS INVOLVES THE FOLLOWING DIVISIONS:

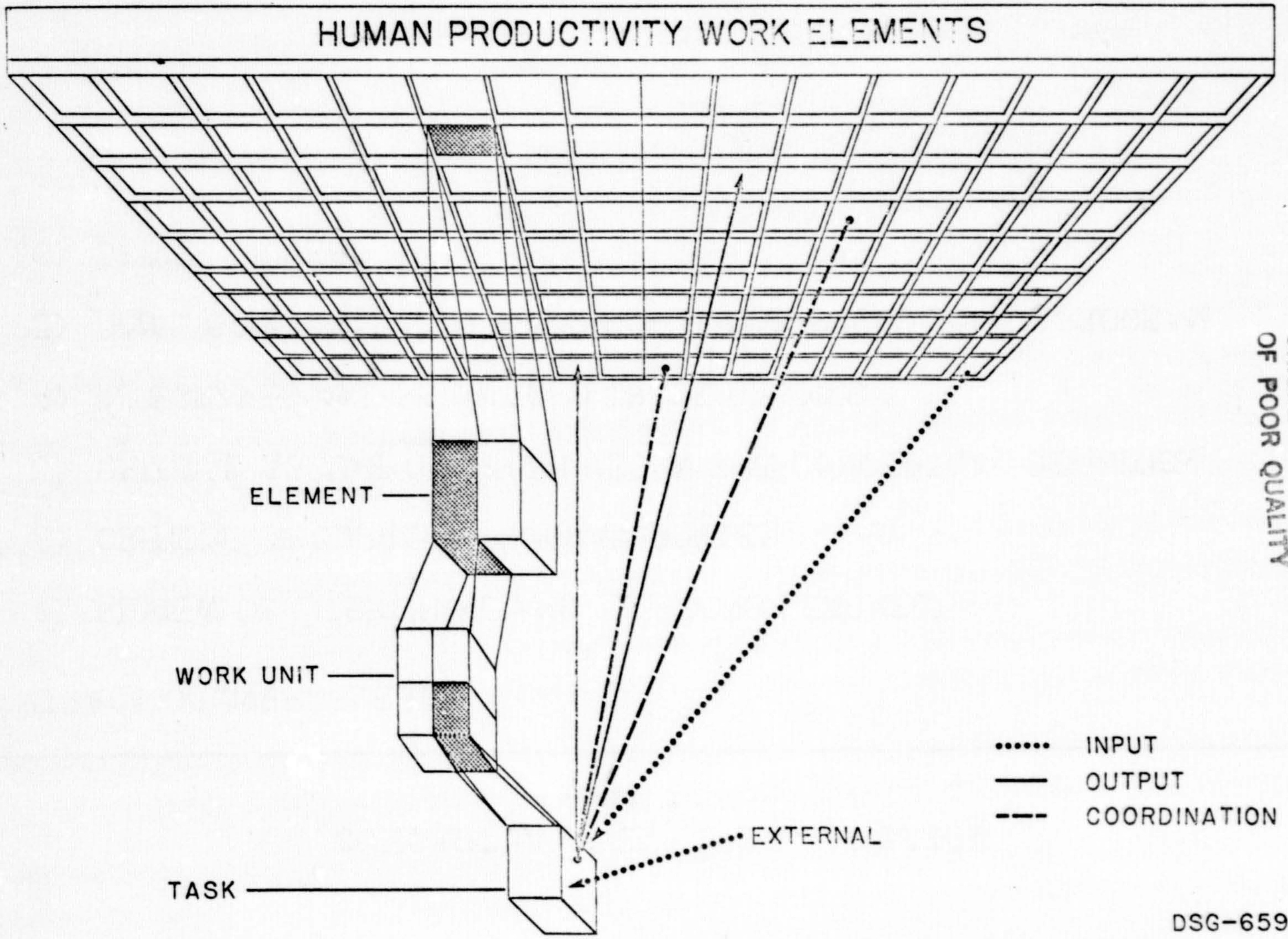
- ○ WORK ELEMENTS INTO WORK UNITS
- ○ WORK UNITS INTO TASKS
- ○ PRIMARY EMPHASIS ON TASK LEVEL:
  - OBJECTIVE
  - DELIVERABLE
  - APPROACH
  - INPUTS
  - ELEMENT COORDINATION
  - ELEMENT DELIVERABLE DISTRIBUTIONS
  - ENGINEERING TRADE STUDIES
  - REQUIRED MANPOWER
  - SPECIAL REQUIREMENTS
  - REQUIREMENTS REFERENCE
  - START DATE
  - COMPLETION DATE

CONCEPTUAL DEFINITION - PROCESS
(Continued)

CONTRACT DELIVERABLES:

1) REVIEW OF LITERATURE AND "LESSONS LEARNED"
2) CRITIQUE OF CURRENT PROGRAM CONTENT
3) CRITICAL ASSUMPTION INVOLVED IN THE CONCEPTUAL DEFINITION
4) INTEGRATED AND PRIORITIZED TRADE STUDIES
5) FINAL CONCEPTUAL DEFINITION OF HUMAN PRODUCTIVITY PROGRAM
6) DESIGN DRIVERS

HUMAN PRODUCTIVITY PROGRAM DEFINITION PROCESS



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CONCEPTUAL DEFINITION - SCHEDULE

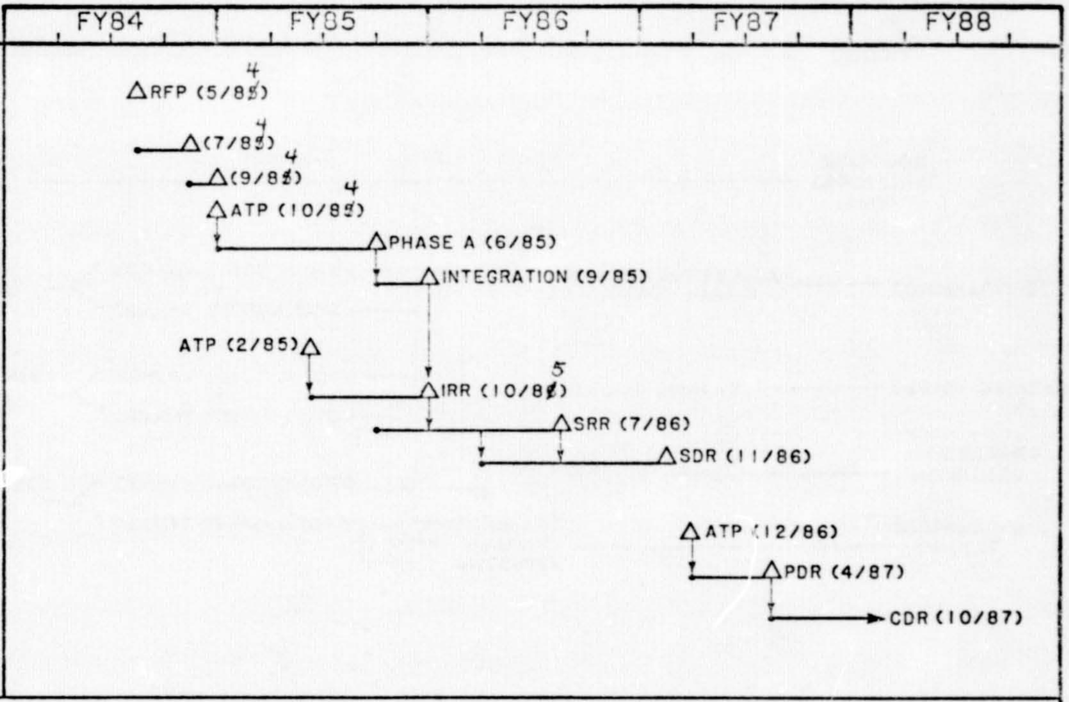
PHASE A HUMAN PRODUCTIVITY DEFINITION

- PREPARATION
- EVALUATION
- SELECTION
- DEFINITION
- NASA INTEGRATION

PHASE B SPACE STATION DEFINITION

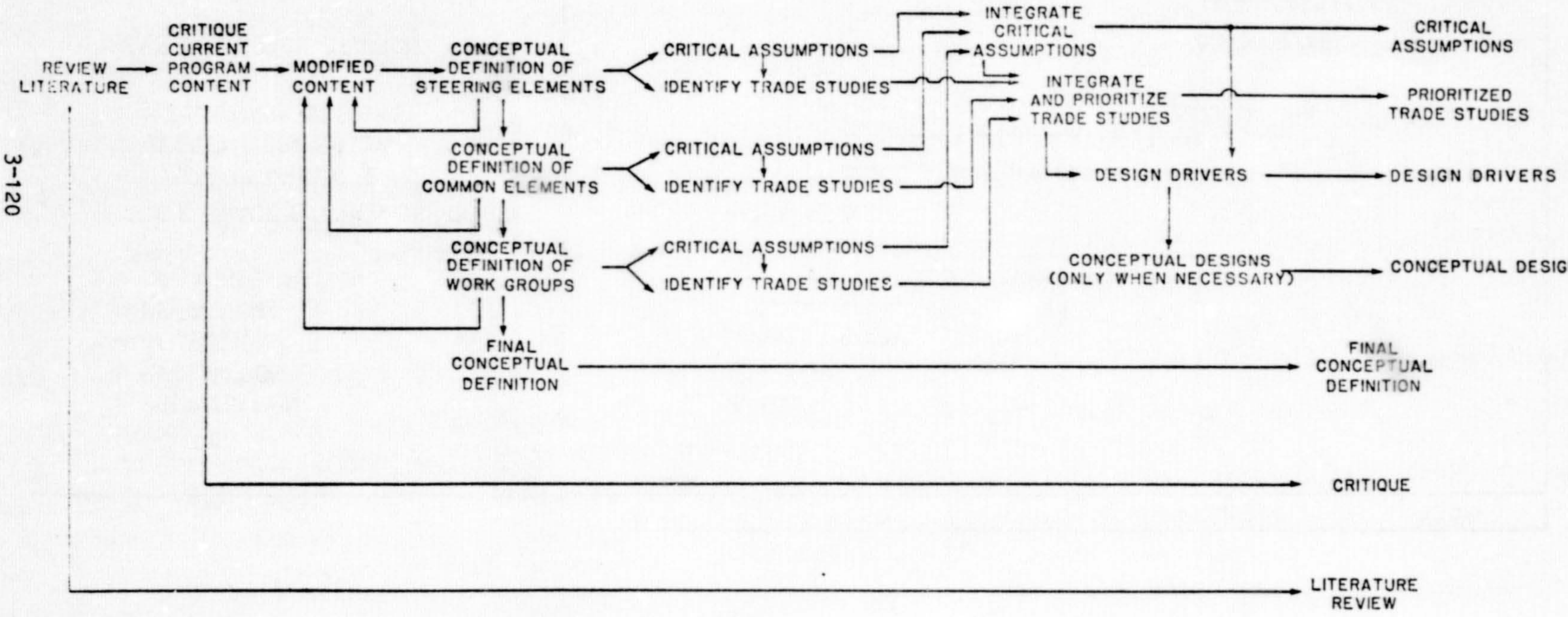
- SYSTEMS ANALYSIS
- ELEMENT DEFINITION
- PRELIMINARY DESIGNS

PHASE C/D SPACE STATION

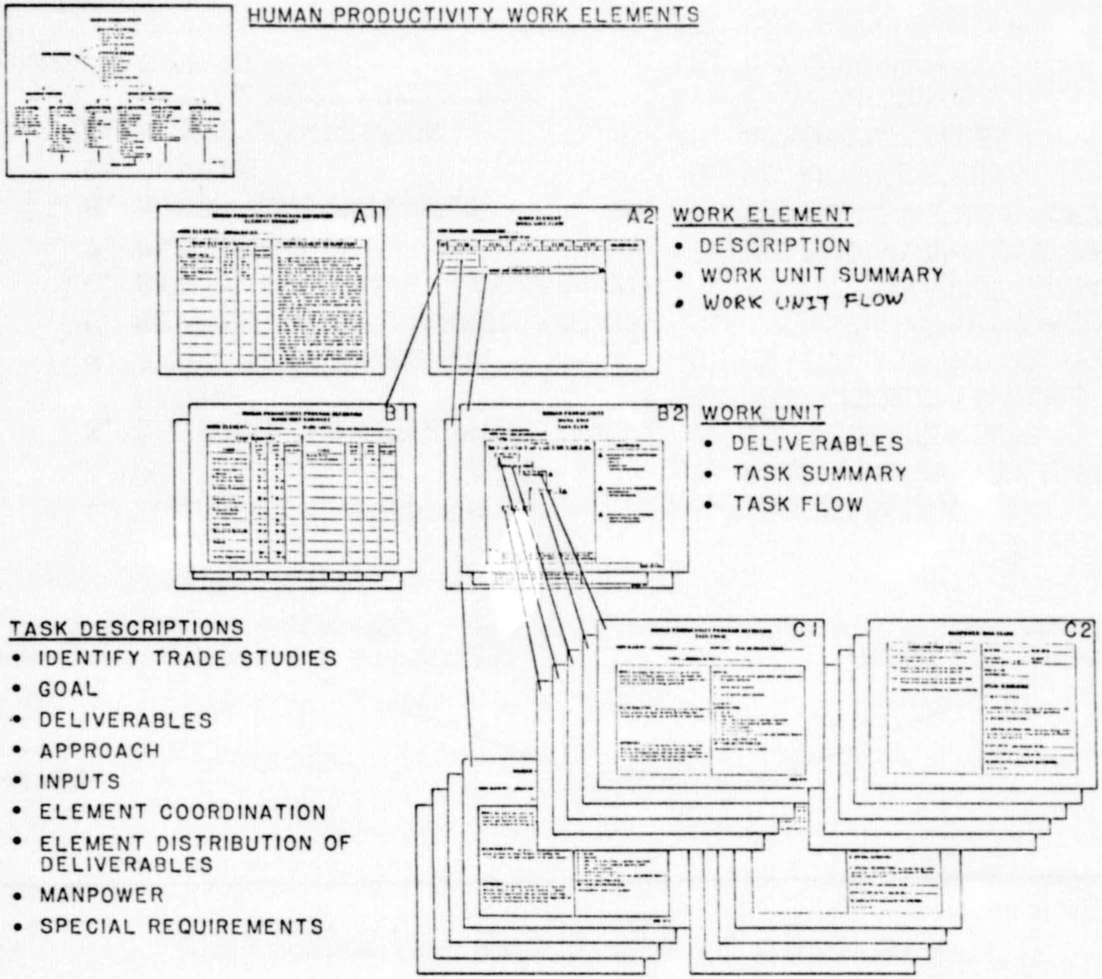


RFP – REQUEST FOR PROPOSAL
ATP – AUTHORITY TO PROCEED
IRR – INTERFACE REQUIREMENTS REVIEW
SRR – SYSTEMS REQUIREMENTS REVIEW
SDR – SYSTEMS DESIGN REVIEW
PDR – PRELIMINARY DESIGN REVIEW
CDR – CRITICAL DESIGN REVIEW

HUMAN PRODUCTIVITY PROGRAM - CONCEPTUAL DEFINITION



HUMAN PRODUCTIVITY PROGRAM - DEFINITION PROCESS



HUMAN PRODUCTIVITY WORK ELEMENTS

WORK ELEMENT
- DESCRIPTION
- WORK UNIT SUMMARY
- WORK UNIT FLOW

WORK UNIT
- DELIVERABLES
- TASK SUMMARY
- TASK FLOW

TASK DESCRIPTIONS
- IDENTIFY TRADE STUDIES
- GOAL
- DELIVERABLES
- APPROACH
- INPUTS
- ELEMENT COORDINATION
- ELEMENT DISTRIBUTION OF DELIVERABLES
- MANPOWER
- SPECIAL REQUIREMENTS

DSG-691

CONCEPTUAL DEFINITION - EXAMPLE

WORK ELEMENT: VIBROACOUSTICS

WORK UNITS:

NOISE AND VIBRATION CONTROL

TASKS:

1. INVENTORY OF SOURCES
2. INDIVIDUAL SOURCE MODELS
3. DISTRIBUTED SOURCE PREDICTION MODEL
4. AIRBORNE TRANSMISSION
5. REVERBERATION CHARACTERISTICS
6. STRUCTURE-BORNE TRANSMISSION
7. PATH MODEL
8. ABSORPTIVE MATERIALS
9. DAMPING
10. ACTIVE SUPPRESSION
11. SYSTEM NOISE PREDICTION/ CONTROL

NOISE AND VIBRATION EFFECTS

TASKS:

1. NAS CONSULTATION
2. PRESSURE/GRAVITY EFFECTS
3. TTS MEASUREMENTS
4. INTELLIGIBILITY IN NOISE
5. EVA/IVA HEARING PROTECTION
6. PRESSURE/GRAVITY/BACKGROUND EFFECTS ON VOICE SIGNAL
7. VOICE COMMAND SYSTEM PERFORMANCE
8. COMMUNICATION DEVICES EVA/IVA
9. COGNITIVE EFFECTS
10. ANNOYANCE/SLEEP
11. EVA/IVA TASKS
12. CREW SURVEY
13. CONTINUED NAS CONSULTATION

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DSG-690

HUMAN PRODUCTIVITY PROGRAM DEFINITION
ELEMENT SUMMARY

WORK ELEMENT: VIBROACOUSTICS

WORK ELEMENT SUMMARY

WORK UNITS	START DATE	STOP DATE	MANPOWER/ MAN-YEARS
Noise and Vibration Effects	4th Qtr FY 84	End FY 89	
Noise and Vibration Control	FY 85	End FY 89	

WORK ELEMENT DESCRIPTION

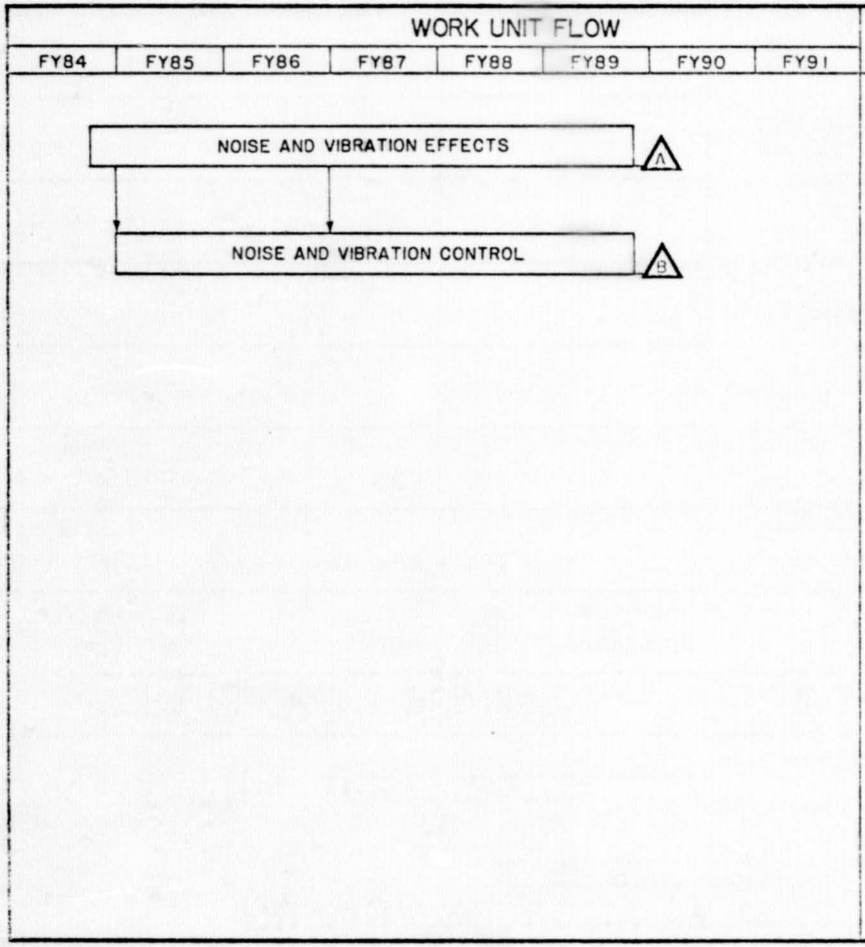
The objective of the bibroacoustic work element is to develop a strategy which facilitates effective communication of human speech and controls noise generation and exposure on board the Space Station. To meet this objective, we we must better characterize the generation and transmission characteristics of noise aloft and the physiological effects of noise exposure in space. Two basic approaches will be used: (1) The development of cost-effective acoustic engineering control measures and (2) the development of communication aids and countermeasures. Of these two approaches, the development of engineering control measures is the preferred method.

Terrestrial data bases provide information on the effects of noise on auditory thresholds, intelligibility, task performance, comfort and sleep. However, vibroacoustic data bases need to be developed for the space environment because the present approach which relies on terrestrial analogs may not be adequate. In lieu of adequate flight data, terrestrial data will be used in strategy development which will subsequantly be updated based upon in-flight experience.

The overall objective of this work element is to develop the most cost-effective combination of engineering controls and communication aids and countermeasures.

HUMAN PRODUCTIVITY PROGRAM DEFINITION
WORK UNIT FLOW

WORK ELEMENT: VIBROACOUSTICS



DELIVERABLES

A
- HEARING EXPOSURE LIMIT VALUES
- REQUIRED COMMUNICATION SPECIFICATIONS
- VIBROACOUSTIC PERFORMANCE CRITERIA
- SLEEP COMPARTMENT NOISE LEVELS

B
- VIBROACOUSTIC SOURCE PREDICTION MODEL
- VIBROACOUSTIC PATH PREDICTION MODEL
- VIBROACOUSTIC CONTROL STRATEGIES

DSC-615

B I

HUMAN PRODUCTIVITY PROGRAM DEFINITION
WORK UNIT SUMMARY

WORK ELEMENT: Vibroacoustics WORK UNIT: Noise and Vibration Effects

TASK SUMMARY

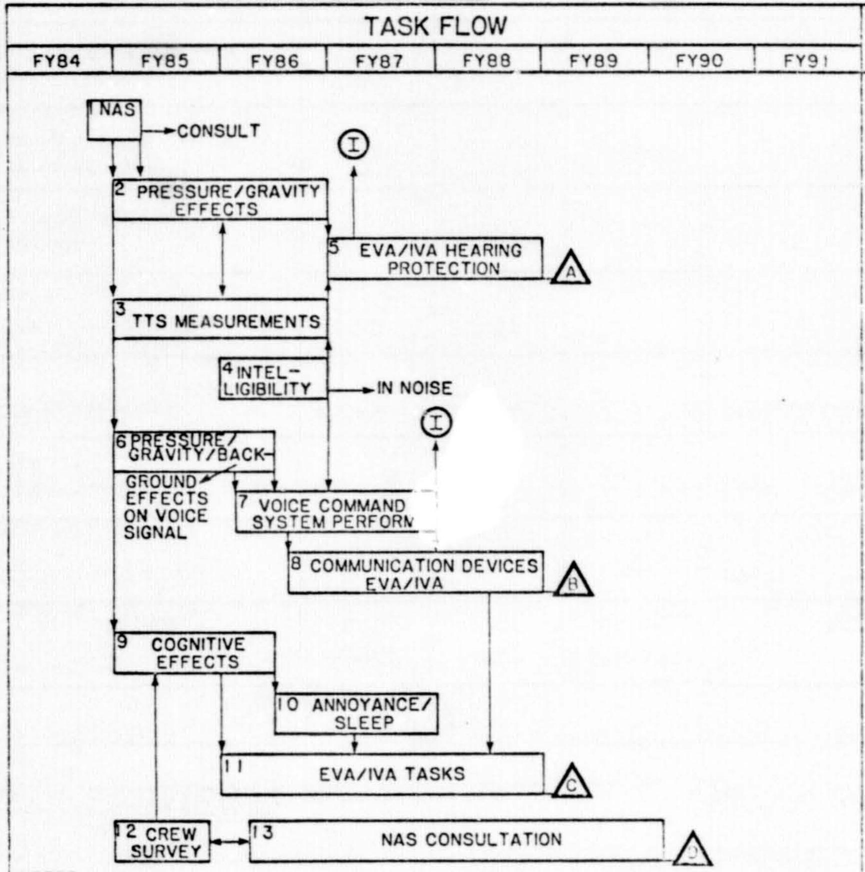
TASKS	START DATE	STOP DATE	MANPOWER/ MAN-YEARS	TASKS	START DATE	STOP DATE	MANPOWER/ MAN-YEARS
NAS Consultation	4th Qtr FY 84	2nd Qtr FY 85		EVA/IVA Tasks	FY 86	FY 89	
Pressure/Gravity Effects	FY 85	FY 87		Crew Survey	FY 85	4th Qtr FY 85	
TTS Measurements	FY 85	FY 87		NAS Cont'd Consult.	FY 86	FY 90	
Intelligibility in Noise	FY 86	FY 87					
EVA/IVA Hearing Protection	FY 87	FY 89					
Pressure/Gravity/ Background Effects on Voice Signal	FY 85	3/4 FY86					
Voice Command System Performance	FY 86	FY 88					
Communication Devices EVA/IVA	3/4 FY86	FY 89					
Cognitive Effects	FY 85	3/4 FY86					
Annoyance	3/4 FY86	FY 88					

HUMAN PRODUCTIVITY
WORK UNIT
TASK FLOW

B2

WORK ELEMENT: VIBROACOUSTICS
WORK UNIT: NOISE AND VIBRATION EFFECTS
TASK:

TASK FLOW



NOTES:
I- INPUT TO NOISE AND VIBRATION CONTROL
THESE ARE THE INPUTS CONCERNING COMMUNICATION IN TWO SENSORY MODULITIES

DELIVERABLES

A HEARING EXPOSURE LIMIT VALUES
- NON-HAZARDOUS
- COMMUNICATIONS
- HEARING PROTECTION DEVICES REQUIREMENTS

B REQUIRED COMMUNICATION SPECIFICATION FOR:
- AIDED
- UNAIDED
- EVA/IVA
- VOICE COMMAND
- ALARM

C VIBROACOUSTIC PERFORMANCE CRITERIA

D SLEEP COMPARTMENT ACCEPTANCE NOISE LEVELS
- BACKGROUND
- TRANSIENTS

HUMAN PRODUCTIVITY PROGRAM DEFINITION
WORK UNIT SUMMARY

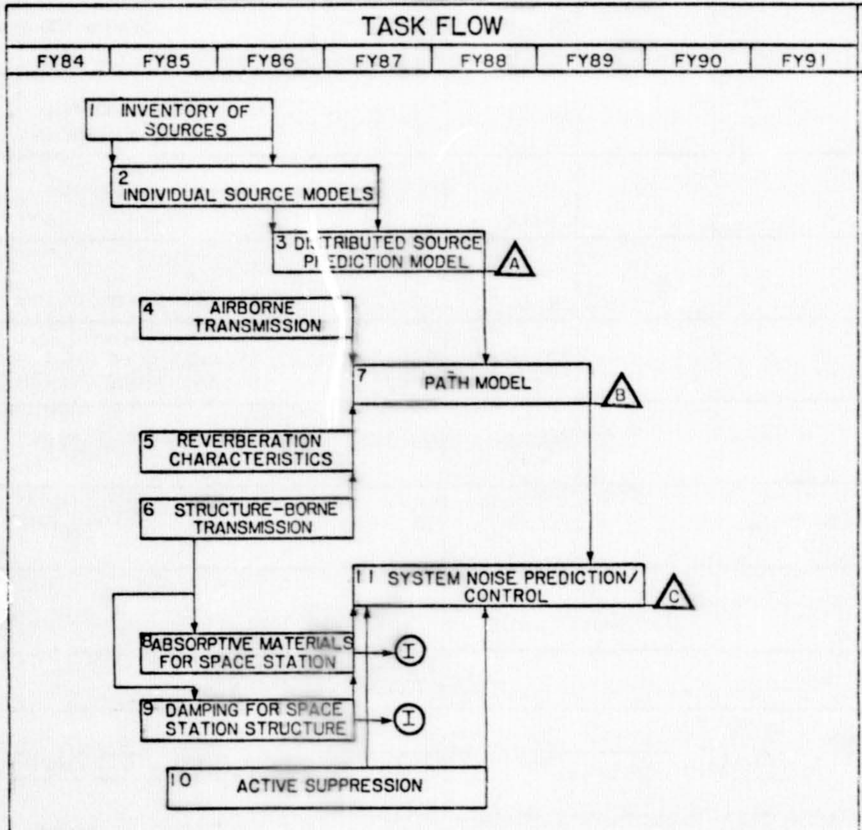
WORK ELEMENT: Vibroacoustics WORK UNIT: Noise and Vibration Control

TASK SUMMARY

TASKS	START DATE	STOP DATE	MANPOWER/ MAN-YEARS	TASKS	START DATE	STOP DATE	MANPOWER/ MAN-YEARS
Inventory of Sources	3/4 FY 84	3/4 FY 86		System Noise Prediction/Control	FY 87	FY 90	
Individual Source Models	FY 85	3/4 FY 87					
Distributed Source Prediction Model	3/4 FY 86	3/4 FY 88					
Airborne Transmission	FY 85	FY 87					
Reverberation Characteristics	FY 85	FY 87					
Structure-Borne Transmission	FY 85	FY 87					
Path Model	FY 87	3/4 FY 89					
Absorptive Materials	FY 85	FY 87					
Damping	FY 85	FY 87					
Active Suppression	3/4 FY 85	3/4 FY 88					

HUMAN PRODUCTIVITY
WORK UNIT
TASK FLOW

WORK ELEMENT: VIBROACOUSTICS
WORK UNIT: NOISE AND VIBRATION CONTROL
TASK:



DELIVERABLES

△ A VIBROACOUSTIC SOURCE PREDICTION MODEL
- INTENSITY
- SPECTRA
- INTERMITTANCY
- TEMPORAL CHARACTERISTICS

△ B VIBROACOUSTIC PATH PREDICTION MODEL
- REVERBERATION
- SPATIAL DISTRIBUTION

△ C VIBROACOUSTIC CONTROL STRATEGIES
- SOURCE SPECIFICATIONS
- OPERATING CONSTRAINTS

NOTES:

I- TASKS 8 AND 9 WILL BE COORDINATED WITH GROUPS DEALING WITH SUCH SAFETY ISSUES AS TOXICITY FLAMMABILITY. FOR THIS REASON THESE TASKS MUST BEGIN EARLY SO THAT SAFETY FACTORS MAY BE ADDRESSED IN A TIMELY MANNER.

HUMAN PRODUCTIVITY PROGRAM DEFINITION
TASK FORM

WORK ELEMENT: Vibroacoustics

WORK UNIT: Noise and Vibration Control

TASK: Inventory of Sources

GOAL: Determine the anticipated type of noise sources (e.g.) fans, pumps, etc.), estimate the number and nature of noise sources per module and the total acoustical energy generated.

DELIVERABLE(S): An inventory of the anticipated noise sources on Space Station including the acoustic spectrum and use profile of each source.

APPROACH: Carefully review Shuttle, Spacelab, Skylab, Salyut, etc. as useful analogs. Space Station configurations and operations will then be studied to estimate the nature and magnitude of the various anticipated noise sources.

INPUTS:

1. Information on noise generation and transmission in space vehicles.
2. Known noise sources.
3. Anticipated noise sources.

ELEMENT COORDINATION:

1. ECLSS
2. Thermal
3. IVA - Work Stations; customer payloads
4. EVA - Airlock; orbital service unit
5. Personal hygiene
6. Health maintenance
7. Safe haven
8. Attitude and Orbital Control

ELEMENT DISTRIBUTION OF TASK DELIVERABLES:

Intermediate work unit product.

MANPOWER/MAN-YEARS

ENGINEERING TRADE STUDIES

(1) Distribution of noise sources relative to human activities

(2) Engineering alternatives to meet the functions associated with noise sources

(3) Utilization alternatives to meet the functions associated with noise sources

(4) Engineering alternatives to source isolation

GENERIC: __________ TEST BED: __________

FOCUSED TECHNOLOGY: 2 MY FLIGHT TEST: __________

PROTOTYPE TECHNOLOGY: __________

SPECIAL REQUIREMENTS

1. NEW FACILITIES:

2. UNIQUE SKILLS: Knowledge of acoustics, and Space Station Systems and their operations

3. SPECIAL HARDWARE:

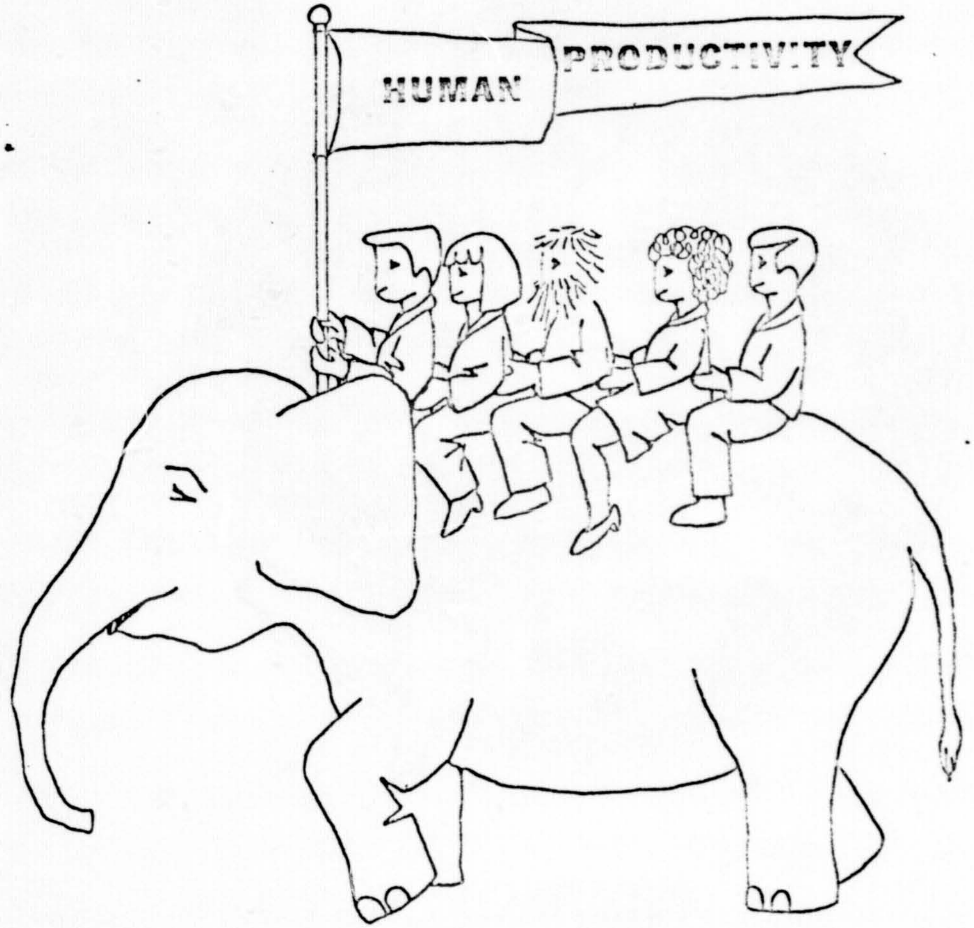
4. SPECIAL INFORMATION: Detailed design information on noise generating machinery in Shuttle, Skylab, and Spacelab

START DATE: 4th Quarter FY 84

COMPLETION DATE: Mid FY 86

REQUIREMENTS DOCUMENT REFERENCE:

6.11.2.2.1B


HUMAN PRODUCTIVITY

THE HUMAN ROLE IN SPACE
(THURIS)

Harry L. Wolbers, PhD
Thuris Study Manager
(714) 896-4754

VGG374

THE HUMAN ROLE IN SPACE

Three Factors to Consider

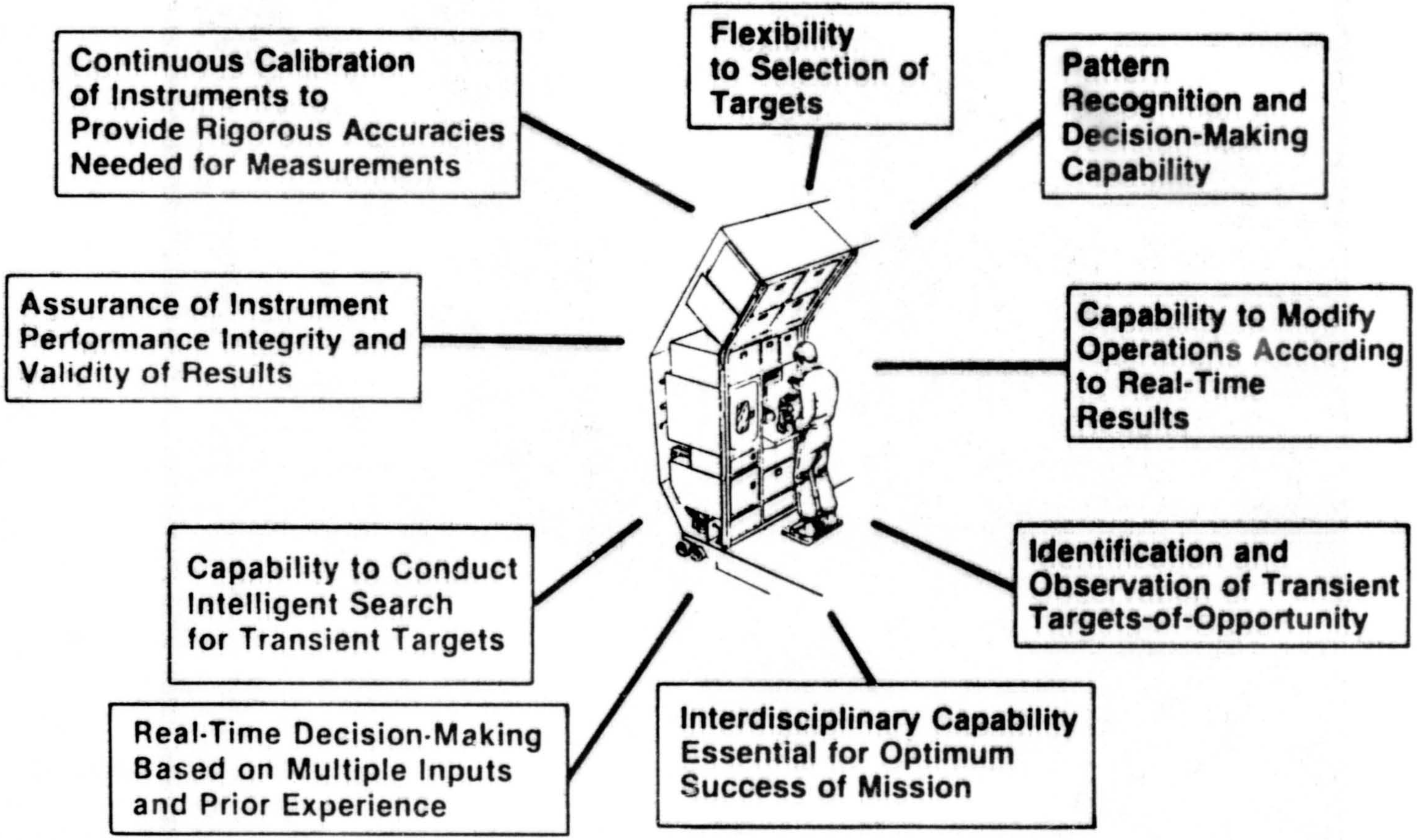
- **Performance** —
  - Where Along the Continuum From Direct Human Intervention, to Teleoperators, to Remotely Actuated and Controlled Systems, to Independent (Self-Actuating/Self-Healing Operations), Can The System Requirements Best Be Met?
- **Cost** —
  - If Alternative Implementation Concepts Are Feasible, Which Is the Most Cost Effective?
- **Risk** —
  - What is the Success Probability, or Conversely, What Is the Risk or Impact of System Failure?

VGD999

PRESENCE OF CREW WAS ESSENTIAL TO SKYLAB MISSION SUCCESS

- Assembled and Set Up Equipment
- Conducted Pre-Operations Tests (Checkout) of Experiment Equipment
- Performed Interactive Operations — Real-Time Display and Data Analysis to Determine Next Operation
- Management — Changed Ops Plans Due to "Surprises"
- Conducted Malfunction Tests
- Maintained and Repaired Subsystems
- Modified Instruments
- Analyzed and Interpreted Results
- Conducted Ground/Space Cooperative Tests
- Made Visual Observations — Discrimination
- Developed "Work-Arounds" — Heat Shield, Solar Array Deployment
- Recovered Payloads
- Assembled Large Experiments/Equipment From Parts
- Recovered Film

CAPABILITIES PROVIDED BY MAN



Continuous Calibration of Instruments to Provide Rigorous Accuracies Needed for Measurements

Flexibility to Selection of Targets

Pattern Recognition and Decision-Making Capability

Assurance of Instrument Performance Integrity and Validity of Results

Capability to Modify Operations According to Real-Time Results

Capability to Conduct Intelligent Search for Transient Targets

Identification and Observation of Transient Targets-of-Opportunity

Real-Time Decision-Making Based on Multiple Inputs and Prior Experience

Interdisciplinary Capability Essential for Optimum Success of Mission

SAR IMAGE — SANTA BARBARA CHANNEL

VGG375

OCEANOGRAPHIC EFFECTS DISCOVERED FIRST FROM MANNED SPACECRAFT

EDDIES

- Existence at Coastal Boundaries (Gemini)
- Size Variability in Confined Seas (Apollo)
- Distribution Along Current Edges (Skylab)
- Kelvin-Helmholtz and Von Karman Vortices — Island Wakes (Apollo and Skylab)
- Scale Variability (Skylab)
- Surface Manifestation of Warm and Cold Core Eddies (Skylab and ASTP)
- Coalescence (Skylab)
- Associated Cloud Formations (Skylab)

FRONTS

- Surface Manifestations of Fronts (Gemini — ASTP)
- Fronts and Thermal Boundaries (ASTP)
- Mesoscale Turbulence at Frontal Boundaries (Skylab)
- Plankton Distribution (Skylab)
- Wave/Front Interaction (Skylab)

OCEANOGRAPHIC EFFECTS DISCOVERED FIRST FROM MANNED SPACECRAFT

VGG376

INTERNAL WAVES

- Distribution Along Shelf Break (Apollo 6)
- Configuration Over Shelf (Apollo 6)
- Existence In the Open Ocean (Skylab)
- Extent and Configuration Along Ocean Fronts (Skylab)

OCEAN SWELL

- Refraction and Absorption at Current Boundaries (Skylab)
- Refraction In Fjords (Skylab)
- Dissipation at Upwelling Boundaries (Skylab)

UPWELLING

- Configuration of Upwelling Boundaries (Apollo, Skylab)

CURRENTS

- Current Confluence and Retention of Identity (Skylab)

VFX882

BENEFITS OF MAN IN ORBIT

Scientist/Observer

- Real-Time Data Analysis
- Multiple Sensor Use
- Sensor Mode/Parameter Selection
- Cooperation With Principal Investigator
- Target Selection

Development Engineer

- Sensor Operation
- Sensor Evaluation
- Component Testing

Technical Operations Specialist

- Equipment Setup, Checkout, Maintenance, Calibration
- Servicing of Sensor and Equipment Consumables

VFX881

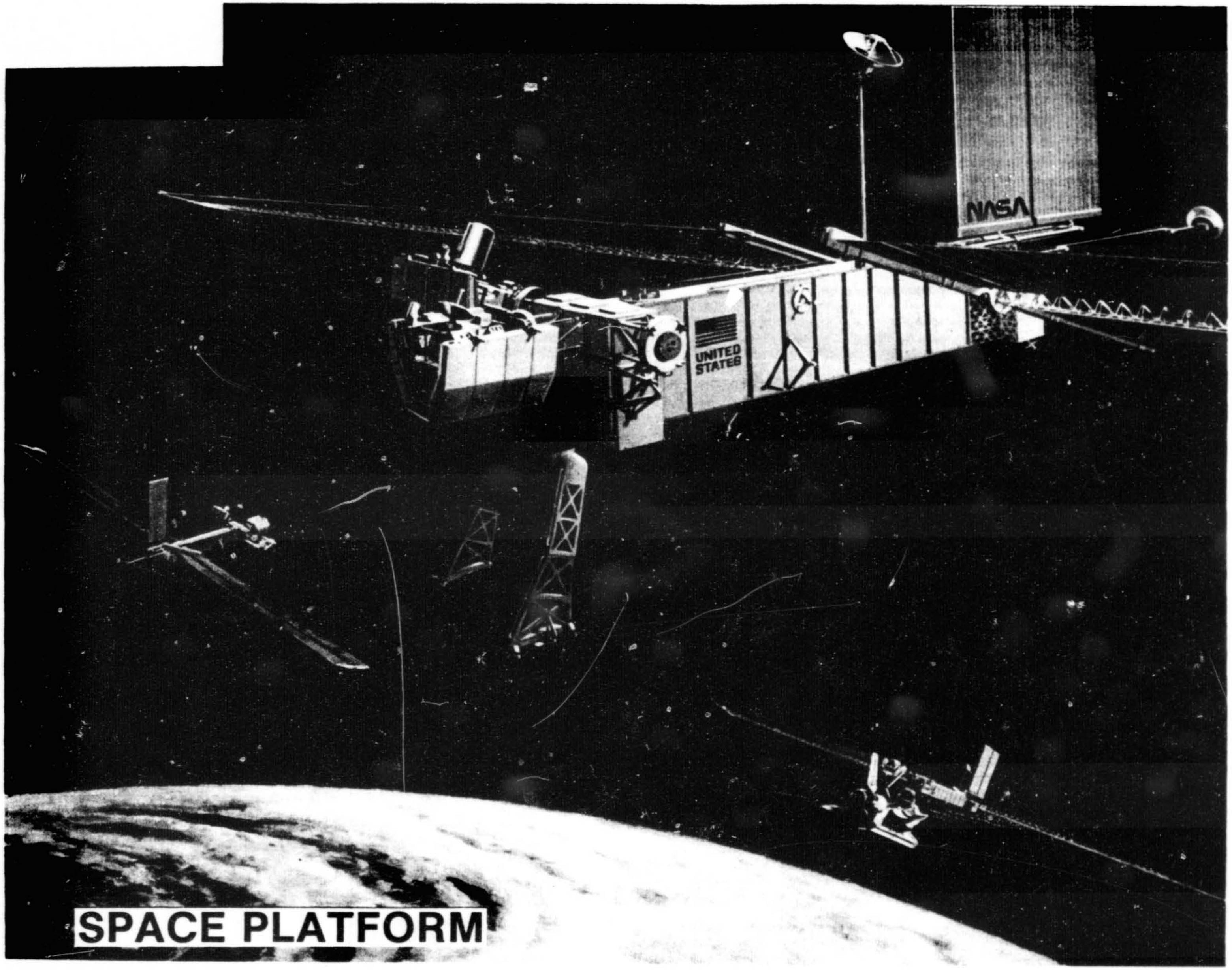
CONCERNS OF MAN IN ORBIT

Safety of Flight

- External Environment
- Physiological Limits
- Psychological Stress
- Onboard Safety

Performance Degradation

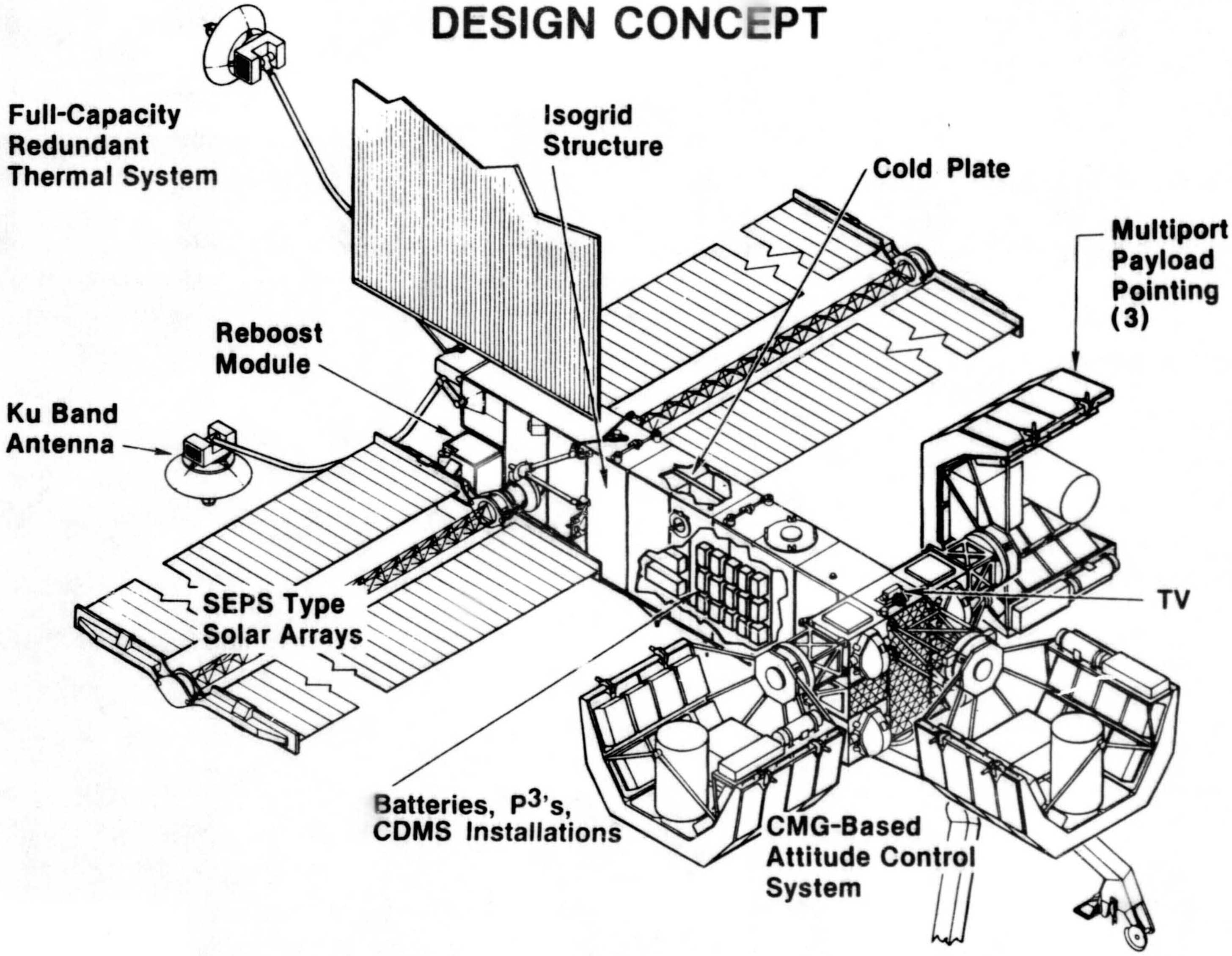
- Acceleration Disturbances
- Effluent Release
- Repetitive Duty Cycles



SPACE PLATFORM

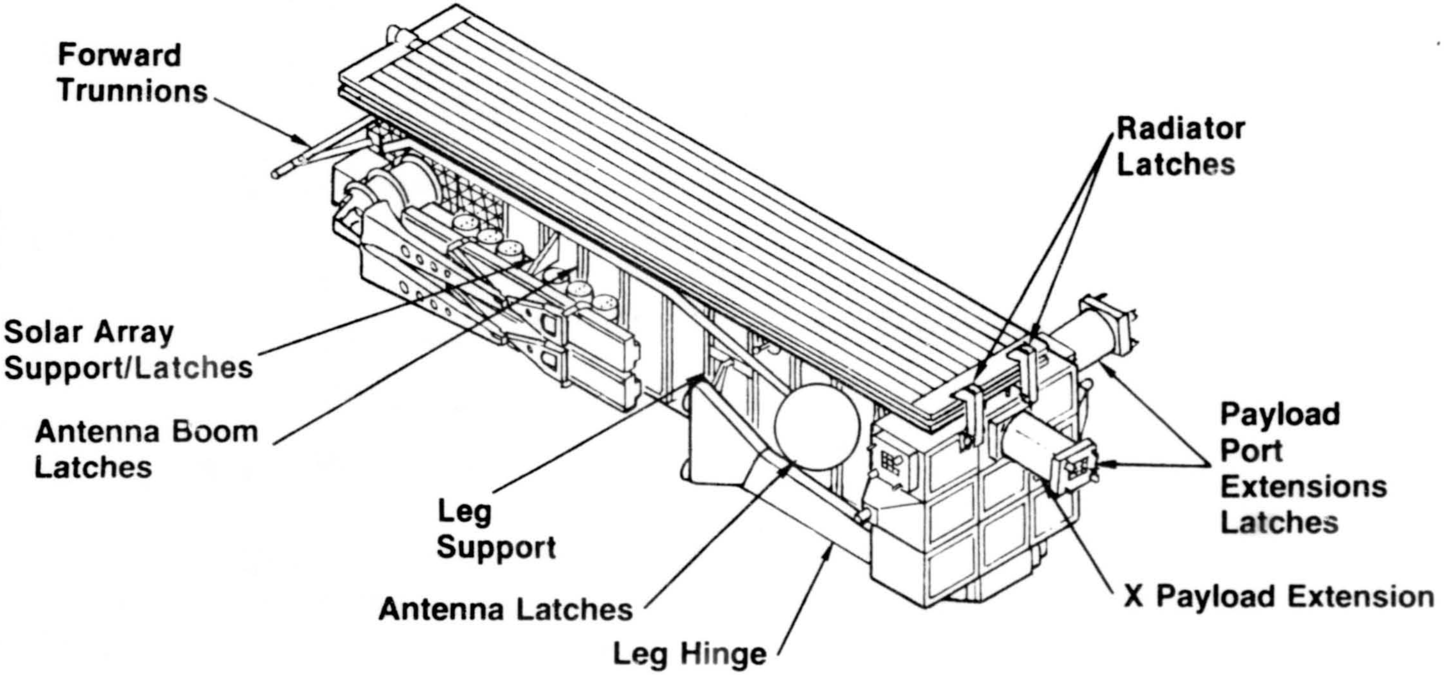
SPACE PLATFORM SYSTEM
DESIGN CONCEPT

VFT332



VFF601N

CANDIDATES FOR EVA ACTIVATION



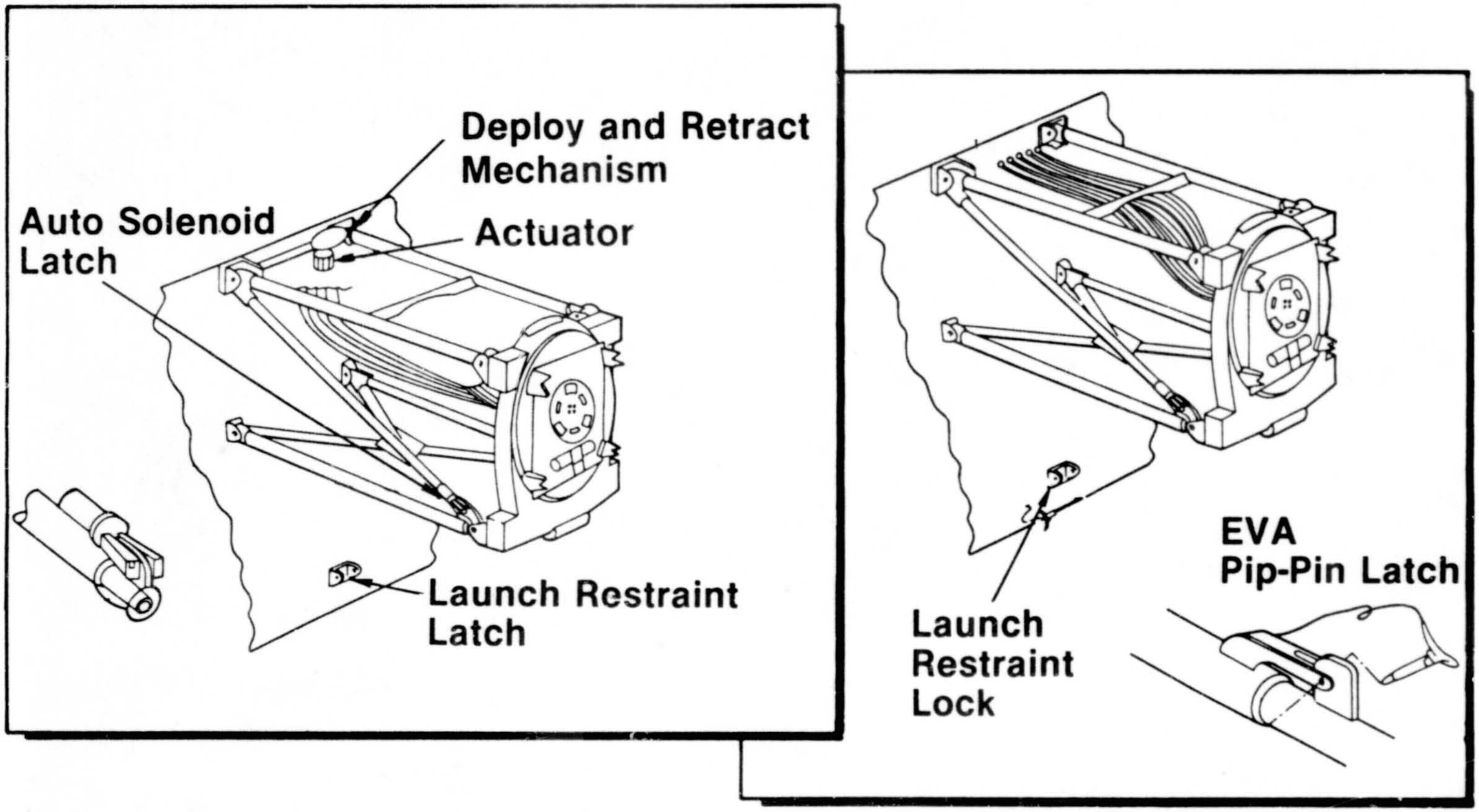
- Latches/Supports Required for Ascent/Descent Only
- Costs — EVA Versus Mechanisms

EVA VERSUS MECHANISMS

- **Initial Survey Found 15 Candidate Mechanisms That Could be Done by an EVA Crewman**
- **Survey Criteria:**
  - Low Activation Cycles
  - No Free-Flight Activation Requirement
  - EVA Activation is Safe
- **Candidates:**
  - Forward Launch Supports (1 Total)
  - Solar Array Launch Latches (2 Total)
  - Radiator Latches (3 Total)
  - +Y and −Y Berthing Ports (4 Total)
  - Aft Berthing Port (3 Total)
  - Ku Band Antenna (2 Total)

PAYLOAD BERTHING PORT (X-AXIS)

VGB362



Remotely Actuated Deployment Mechanism

Manually Actuated (EVA) Deployment Process

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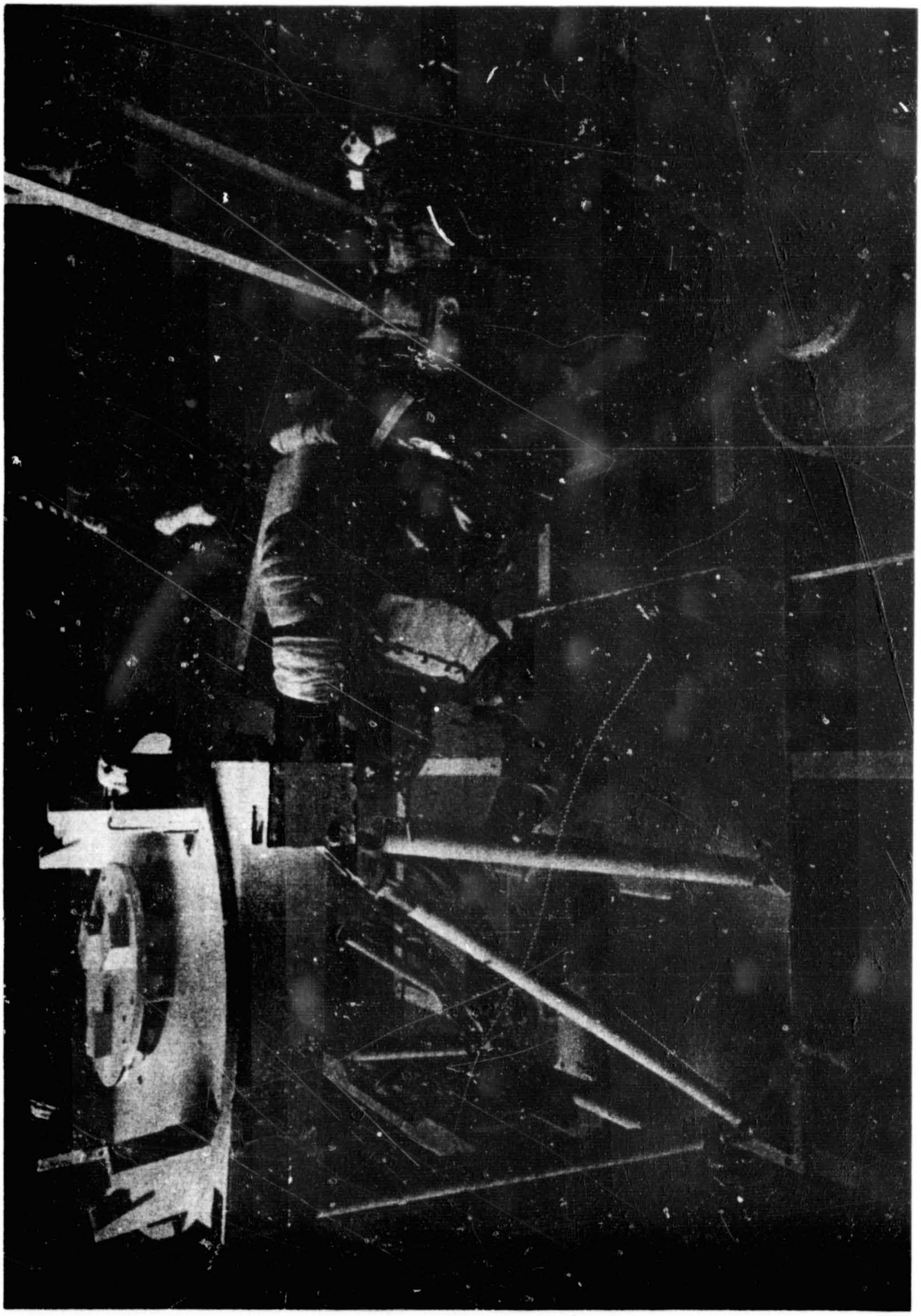

EVA VS MECHANISMS

VGB353

- **Reduction of Automatic Mechanisms**

• Forward Launch Support	$133K
• Solar Array Launch Latches	1051K
• Radiator Launch Restraints	401K
• +Y and -Y Berthing Port Mechanisms	266K
• Aft Berthing Port Mechanisms	344K
• Antenna Launch Latch	211K

TOTAL COSTS FOR 15 MECHANISMS = $2406K

- **Manual Activation to Perform the Functions of the Above-Stated Mechanisms Involves 2 EVA Crewman Approximately 2.5 Hours Which is Well Within the Capability of EVA Operations**

EVA Costs (Per EVA Crewman) = $60K-100K, Depending on EVA Support Equipment*

$60K X 2 Crewman = $120K

$100K X 2 CREWMAN = $200K

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*Per MMU Users Guide, Martin Marietta Report MCR-78-517 (Contract NAS9-14593)

16

CRITERIA FOR SELECTING COMMERCIAL MISSIONS

VGB376

- High Market Value
- High Value Per Pound
- Not Labor Intensive
- Requires Unique Properties of Space
- Low Probability of Rapid Technological Obsolescence

VGB325

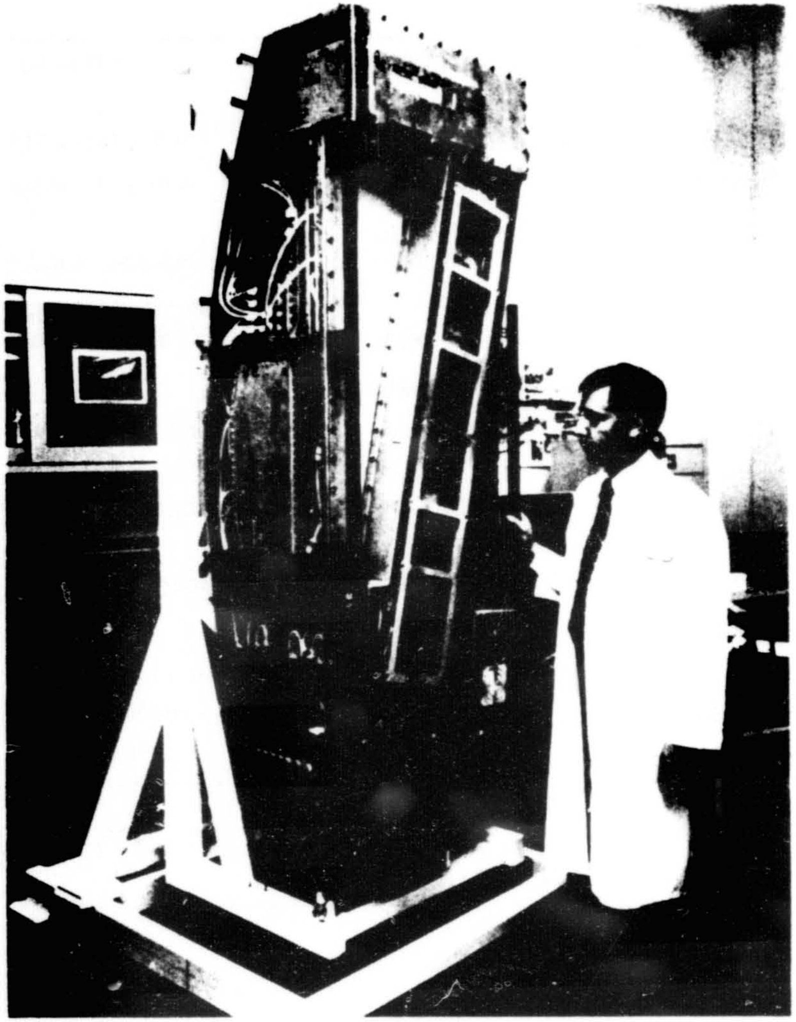
CANDIDATE PHARMACEUTICAL PRODUCTS

12 TYPICAL

Typical Products	Beneficial Medical Application	Function/Status	Annual Patients (USA)
α_1 Antitrypsin	Emphysema	Research Quantities Only Now	100,000
Antihemophilic Factors VIII and IX	Hemophilia	100% Terminal by Age 40	20,000
Beta Cells	Diabetes	Possible Single-Dose Cure	600,000
Epidermal Growth Factors	Burns	Replacement Skin Grafting	150,000
Erythropoietin	Anemia	Replacement Transplants/ Transfusions	1,600,000
Immune Serum	Viral Infections	EOS Provides Higher Purity	185,000
Interferon	Viral Infections	Potential May Be Unlimited	>10,000,000
Granulocyte Stimulating Factor	Wounds	Research Quantities Only Now	2,000,000
Lymphocytes	Antibody Production	Replace Antibiotics/Chemotherapy	600,000
Pituitary Cells	Dwarfism	Currently Not Curable	850,000
Transfer Factor	Leprosy/Multiple Sclerosis	Potential for Other Applications	550,000
Urokinase	Blood Clots	Low Development Costs	1,000,000

VFY053

ELECTROPHORESIS OPERATIONS IN SPACE



Flight Dates Under Joint Endeavor Agreement

STS	4	JUN	1982
STS	6	APR	1983
STS	7	JUNE	1983
STS	8	AUG	1983
STS	14	JUN	1984
STS	19	OCT	1984

Results From First STS Flights

1. 700 Times Increase in Yield
2. Quantitatively Repeatable Separation
3. Validated Design Concepts
4. Value of Manned Participation Confirmed

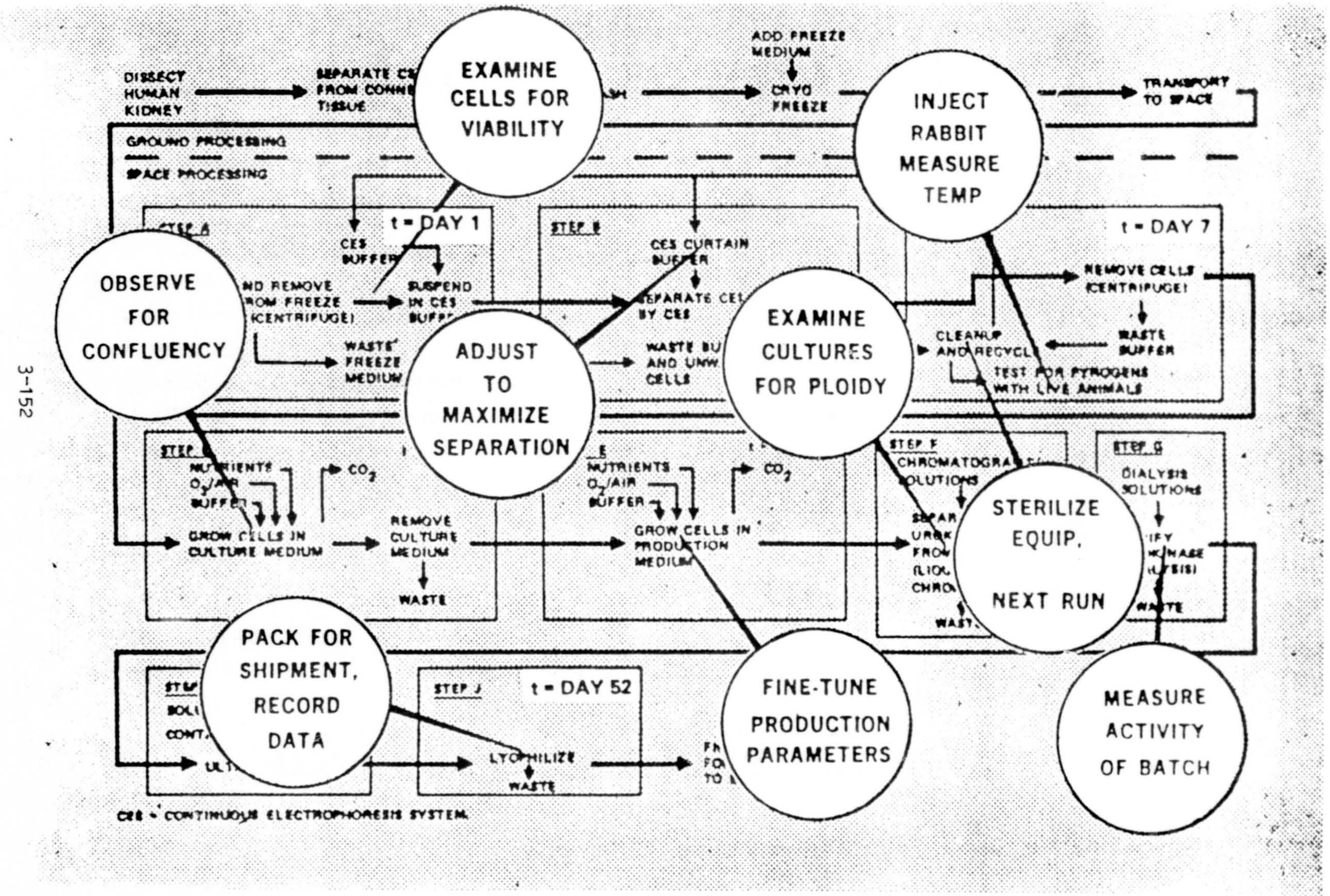
STS-4 EOS OPERATIONS SUMMARY

VGB351

	28 June 1982	30 June 1982
Raw Parameters		
Total Operating Time	6.5 Hours	8 Hours
Total Number of CPU Operator Calls	27	28
Scheduled Calls	19	22
Unscheduled Calls	8	6
Total Number of Key-Board Inputs Required	99	83
Scheduled Calls	48	72
Unscheduled Calls	51	11
Averaged parameters		
Operator Calls/Hour	4	3
Scheduled Calls	3	3
Unscheduled Calls	1	1
Keyboard Inputs/Hour	15	10
Scheduled Calls	3	3
Unscheduled Calls	6	2
Operator Call Response Time	27 Sec	43.7 Sec

Manned Presence Essential to Reduce Risk of Failure

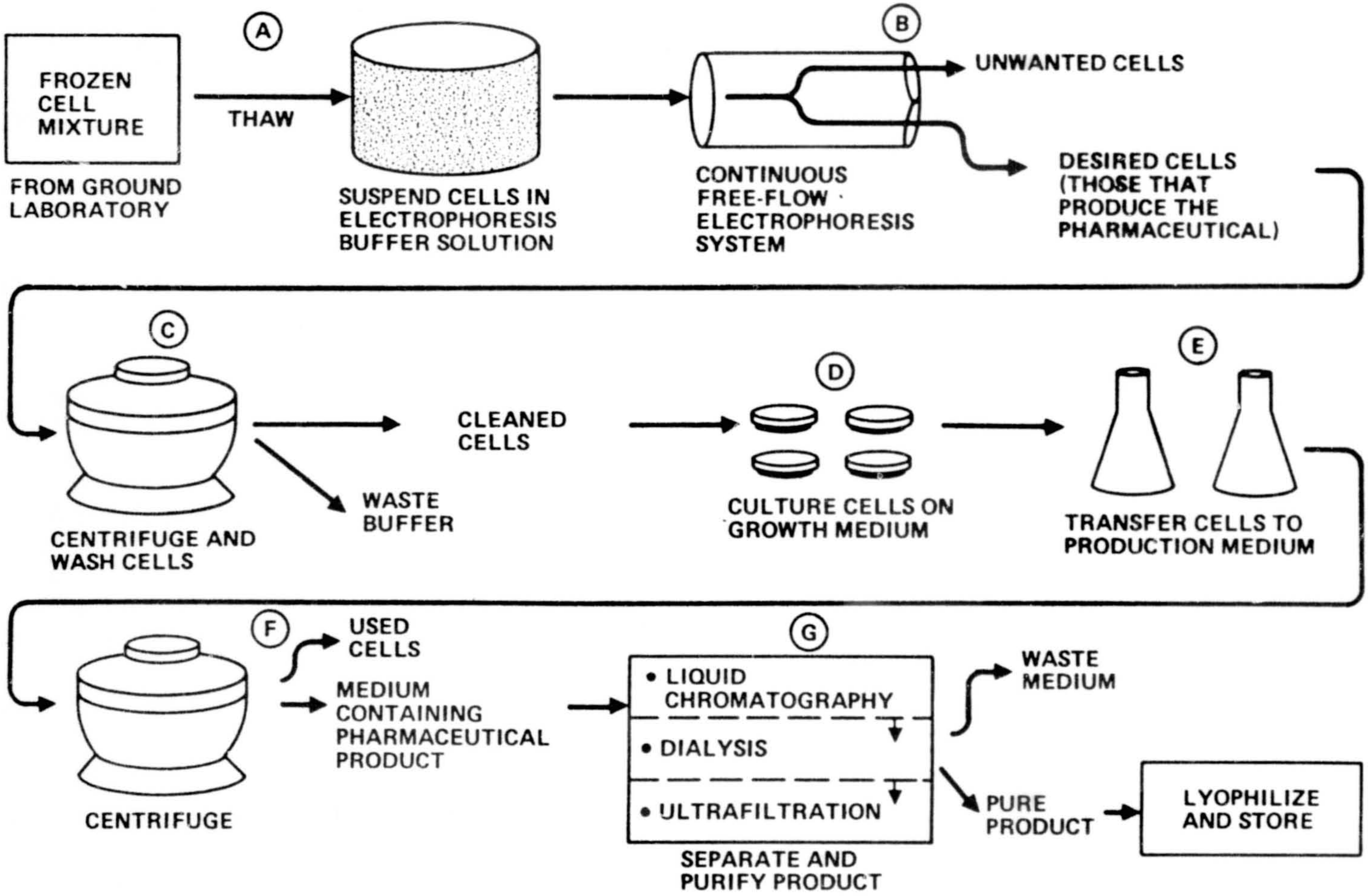
ROLE OF MAN IN UROKINASE PROCESS DEVELOPMENT AND OPTIMIZATION



VFL135N

TYPICAL SPACE PHARMACEUTICAL PILOT PLANT

(Manned Involvement: Circled Letters)



FROZEN CELL MIXTURE

FROM GROUND LABORATORY

Ⓐ THAW

SUSPEND CELLS IN ELECTROPHORESIS BUFFER SOLUTION

Ⓑ CONTINUOUS FREE-FLOW ELECTROPHORESIS SYSTEM

UNWANTED CELLS

DESIRED CELLS (THOSE THAT PRODUCE THE PHARMACEUTICAL)

Ⓒ CENTRIFUGE AND WASH CELLS

CLEANED CELLS

WASTE BUFFER

Ⓓ CULTURE CELLS ON GROWTH MEDIUM

Ⓔ TRANSFER CELLS TO PRODUCTION MEDIUM

Ⓕ CENTRIFUGE

USED CELLS

MEDIUM CONTAINING PHARMACEUTICAL PRODUCT

Ⓖ SEPARATE AND PURIFY PRODUCT

- LIQUID CHROMATOGRAPHY
- DIALYSIS
- ULTRAFILTRATION

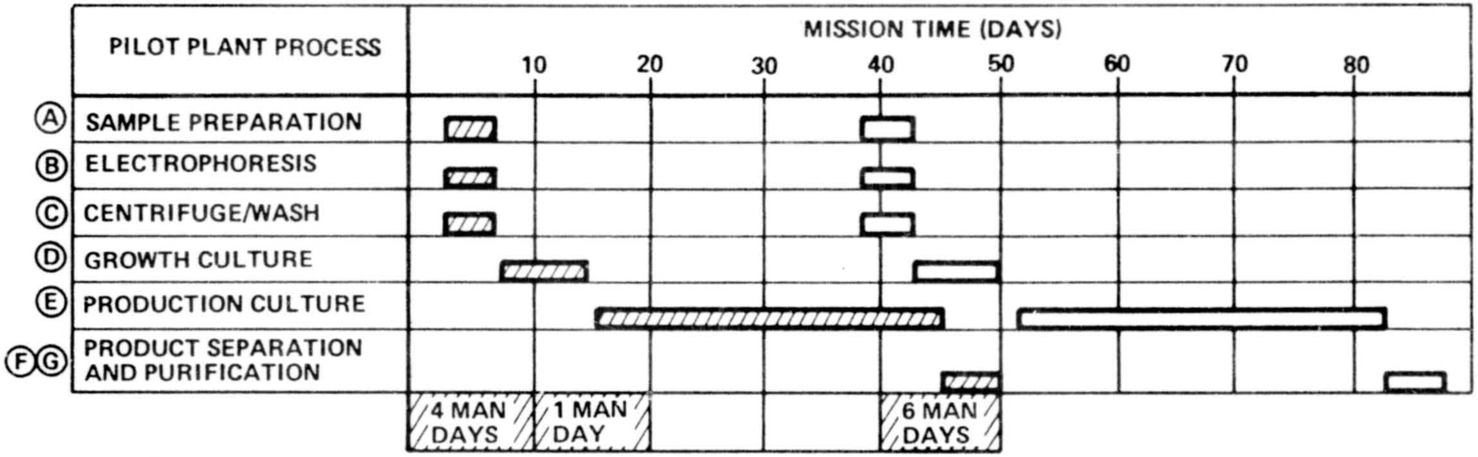
WASTE MEDIUM

PURE PRODUCT

LYOPHILIZE AND STORE

VFL136N

TYPICAL TIMELINE PHARMACEUTICAL PILOT PLANT AND CREW OPERATIONS



Ⓐ Thaws Cell Mixture and Suspends in Electrophoresis Buffer Solution

Ⓑ Introduces Cell Suspension Into Electrophoresis Unit and Collects Separated Products

Ⓒ Discards Unwanted Products. Centrifuges Wanted Cells a Number of Times — Resuspending Cells in Fresh Wash Water Between Centrifugations

Ⓓ Prepares Cell Cultures on Growth Medium in Culture Plates

Ⓔ Transfers Cell Colonies to Production Medium and, After Approximately 30 Days, Removes Cells by Centrifugation

Ⓕ Separates Pharmaceutical From Production Medium Via Successive Processes (e.g., Liquid Chromatography, Dialysis, and Ultrafiltration)

Ⓖ Lyophilizes Pure Pharmaceutical and Stores

ATTRIBUTES OF A MANNED SPACE STATION

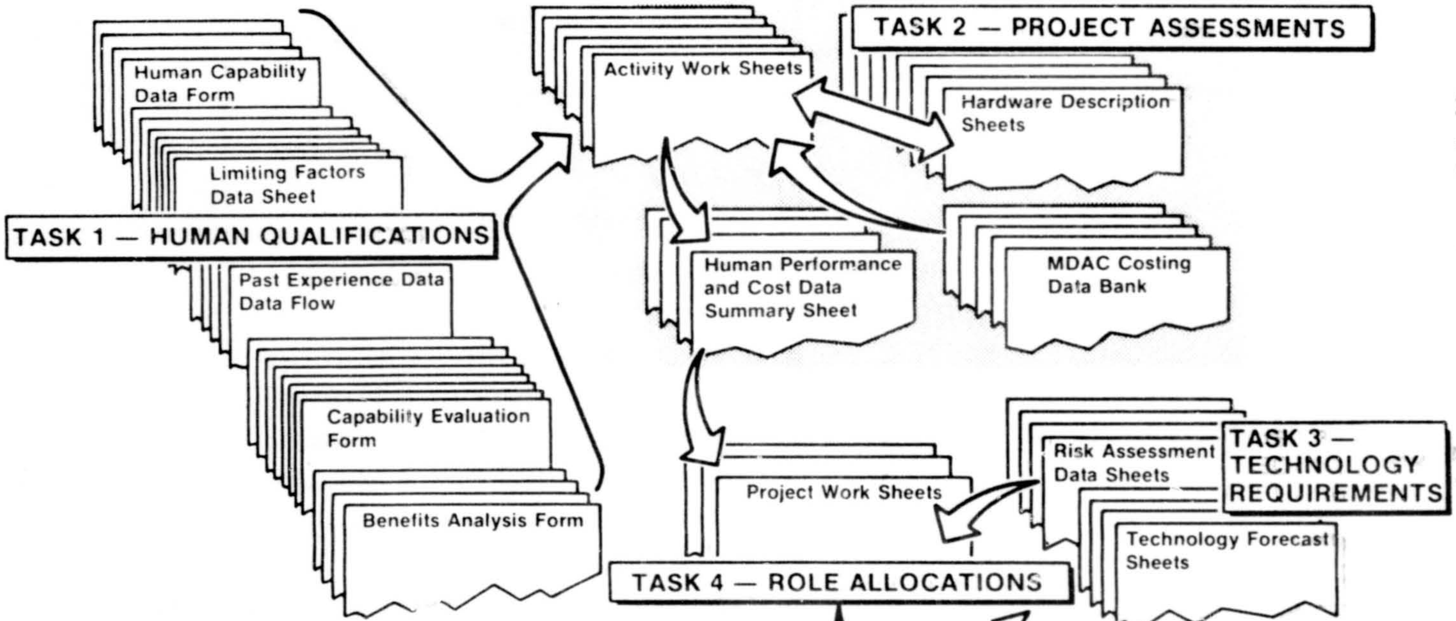
- Schedule Compression — Reduced Cost and Risk
- Combines Best Features of Unmanned Free-Flyer and Sortie Mission, e.g.,
  - Onboard Step-by-Step Development Sequence
  - Less Automation
  - Reduced Cost — No Free-Flyer Support Subsystems, Fewer Shuttle Launches
  - Common Support Equipment
  - Unlimited Data Gathering — Test Conduct Time — Flexibility
  - Infrequent Event — Seasonal Coverage
- Flight Crew Capabilities — Modifications/Repair/Replacement/Assembly
  - Visual Observations
  - Real-Time Sensor Adjustments
  - Analyzing Data
  - Pointing Control
  - Targets of Opportunity
  - Failure Diagnosis/Repair
  - EVA for Structural Assembly — Equipment Adjustments
  - Iterative Operations
  - Learning Curve Benefits

Man Responds Creatively as Unanticipated Events or Problems Arise

- Contribution of Man in Space is Historical Fact

VGG338

STUDY METHODOLOGY



Study Goal – Rational Methodology For Optimizing Human Role in Space

Criteria – Performance — Cost — Risk

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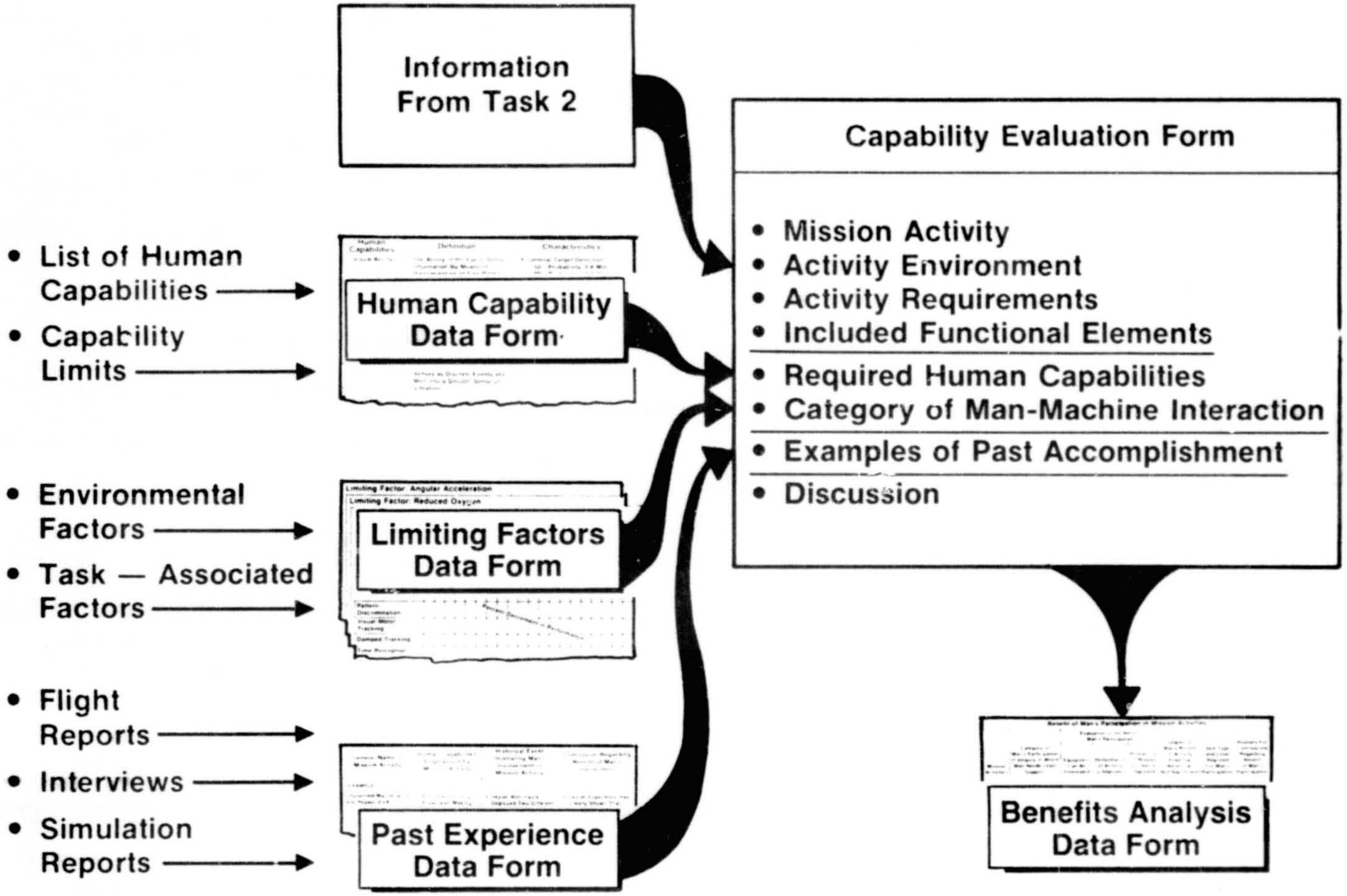
VGG372

THURIS STUDY SCHEDULE

Study Tasks	Study Months												Total Man-Months
	1	2	3	4	5	6	7	8	9	10	11	12	
1.0 Human Qualifications	1	1											2
2.0 Specific Project Assessments	2	2	2	2	2	2	2						14
2.1 Project Analysis	▨	▨											
2.2 Mission Time Lines			▨	▨									
2.3 Support Requirements					▨	▨							
2.4 Econometrics						▨	▨						
2.5 Evaluation						▨	▨						
3.0 Technology Requirements								2					2
4.0 Human Roles in Space									2				2
Study Documentation										2	1	1	4
Totals (Contract Funds)	3	3	2	2	2	2	2	2	2	2	1	1	24
Milestones	ATP					Midterm Briefing					Final Briefing	Final Reports	

TASK I — HUMAN QUALIFICATIONS FOR SPACE ACTIVITIES

VGG343



Information From Task 2

Capability Evaluation Form

- Mission Activity
- Activity Environment
- Activity Requirements
- Included Functional Elements
- Required Human Capabilities
- Category of Man-Machine Interaction
- Examples of Past Accomplishment
- Discussion

- List of Human Capabilities →
- Capability Limits →

Human Capability Data Form

- Environmental Factors →
- Task — Associated Factors →

Limiting Factors Data Form

- Flight Reports →
- Interviews →
- Simulation Reports →

Past Experience Data Form

Benefits Analysis Data Form

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TYPICAL LIST OF BASIC HUMAN CAPABILITIES

VGG345

A. Sensory/Perceptual

- Visual acuity
- Detection and discrimination of brightness
- Color detection and discrimination
- Depth perception at close range
- Static depth perception at a distance
- Peripheral visual detection and discrimination
- Visual accommodation
- Detection and discrimination of tone
- Detection and discrimination of sound intensity
- Localization of sound
- Detection of tone duration
- Auditory detection and discrimination of motion
- Discrimination of tone patterns
- Detection of light touch
- Tactile recognition
- Discrimination of texture
- Detection and discrimination of force against limb
- Recognition of location of limb
- Detection and discrimination of movement of limb
- Detection and discrimination of angular acceleration
- Detection and discrimination of linear acceleration
- Detection and discrimination of vibration
- Detection of heat and cold
- Perception of pain
- Olfaction

B. Cognitive

- Decision-making
- Problem solving (invention)
- Association (long- and short-term memory)
- Deduction
- Induction
- Guided performance
- Learned procedure
- Perceptual set
- Reading
- Speaking
- Writing
- Speech perception
- Recording
- Time perception
- Assessment of volume of space
- Discrimination of complex pattern
- Complex visual generalization and discrimination

C. Psychomotor

- Arm/hand/finger control of force
- Arm/hand/finger control of speed of motion (including reaction time)
- Leg control of force
- Control of mass in motion (loop behavior)
- Damped tracking (visual)
- Visual-motor tracking

D. Motor

- Arm/hand/finger manipulation
- Body positioning

HUMAN CAPABILITY

CATEGORY – SENSORY/PERCEPTUAL CAPABILITIES
SENSORY MODALITY – VISION

HUMAN CAPABILITY	DEFINITION	CHARACTERISTICS	LIMITING FACTORS	REFERENCES
BRIGHTNESS DETECTION AND DISCRIMINATION (CONT)			– REGION OF RETINA STIMULATED – LEVEL OF ILLUMINATION ON TEST	
COLOR DISCRIMINATION	HUE DISCRIMINATION – THE ABILITY TO DETECT THE SMALLEST DIFFERENCE IN WAVELENGTH OF TWO TEST FIELDS BRIGHTNESS DISCRIMINATION – DEFINED ABOVE SATURATION DISCRIMINATION – THE ABILITY TO DETECT SMALL DIFFERENCES IN THE PERCENTAGE OF WHITE LIGHT IN TWO FIELDS OF IDENTICAL HUES	BLUE – 2.5 nm GREEN – 1.0 nm YELLOW – 3.3 nm ORANGE – 1.5 nm RED – 20.0 nm TOO DIFFICULT TO MEASURE FOR ACCURATE THRESHOLDS	• COLOR OF LIGHT SOURCE • COLOR OF LIGHT REFLECTED FROM NEARBY SURFACES • LEVEL OF ILLUMINATION • SURFACE REFLECTIVITY CHARACTERISTICS	1, 6, 11, 15, 17
DEPTH PERCEPTION AND DISCRIMINATION	THE ESTIMATE OF THE DISTANCE OF AN OBJECT FROM THE OBSERVER, OR THE RELATIVE DISTANCE OF TWO OR MORE OBJECTS, OR THE DIFFERENCE IN PARALLAX CORRESPONDING TO THE MINIMUM DISTANCE TWO OBJECTS CAN BE DISPLACED ALONG THE LINE OF SIGHT AND STILL BE RECOGNIZED AS BEING AT DIFFERENT DISTANCES	JUDGMENT OF ABSOLUTE DISTANCE IS VERY INACCURATE JUDGMENT OF RELATIVE DISTANCE IS VERY ACCURATE ANGULAR DIFFERENCES AS SMALL AS 2 sec OF PARALLAX CAN BE DETECTED EFFECTIVE USE OF UNAIDED STEREOPSIS (BINOCULAR DISPARITY) IN DEPTH PERCEPTION LIMITED TO A DISTANCE OF 15 TO 20 ft. BEYOND 20 ft, JUDGMENT OF DEPTH OR DISTANCE IS PRIMARILY DEPENDENT ON MONOCULAR CUES	• DISTANCE OF OBJECTS FROM THE EYE • ABSENCE OF OBJECTS OF KNOWN SIZE FOR COMPARISON • ATMOSPHERIC CONDITIONS • ILLUMINATION INTENSITY • STIMULUS SIZE • MONOCULAR VERSUS BINOCULAR CUES	6, 13, 17, 18

LIMITING FACTORS

VGL578

Stress Factor: Space Adaptation Syndrome (Exposure to Weightlessness)

Human Capabilities Impacted	Duration of Exposure						
	Less Than 3 Hours	3-12 Hours	12-24 Hours	24-48 Hours	48-72 Hours	72-96 Hours	More Than 96 Hours
Threat to Life or Consciousness	None	None	None	Neg	Neg	Neg	None
Visual Acuity	None	Mod	Neg	Neg	Neg	None	None
Depth Perception	None	Mod	Neg	Neg	Neg	None	None
Visual Accommodation	None	Mod	Mod	Neg	Neg	None	None
Tactual Discrimination	None	Mod	Mod	Neg	Neg	None	None
Discrimination of Angular Acceleration	Neg	Mod	Sig	Sig	Sig	Sig	Sig
Cognition	None	Sig	Sig	Mod	Neg	Neg	None
Memory	None	Neg	Neg	None	None	None	None
Evaluation	None	Mod	Sig	Mod	Neg	None	None
Arm/Hand/Finger/Control of Force and Speed of Motion	Mod	Sig	Sig	Sig	Mod	Neg	None
Visual-Motor Tracking	Mod	Sig	Sig	Mod	Neg	Neg	None
Arm/Hand/Finger Manipulation	None	Sig	Sig	Mod	Mod	Neg	None
Body Positioning	Mod	Sig	Sig	Mod	Mod	Neg	None

Impact Code (Decrease in Observed Capability)	
None	(None)
Negligible	(Neg)
Moderate	(Mod)
Significant	(Sig)

MANNED SPACEFLIGHT EXPERIENCE

VGL398

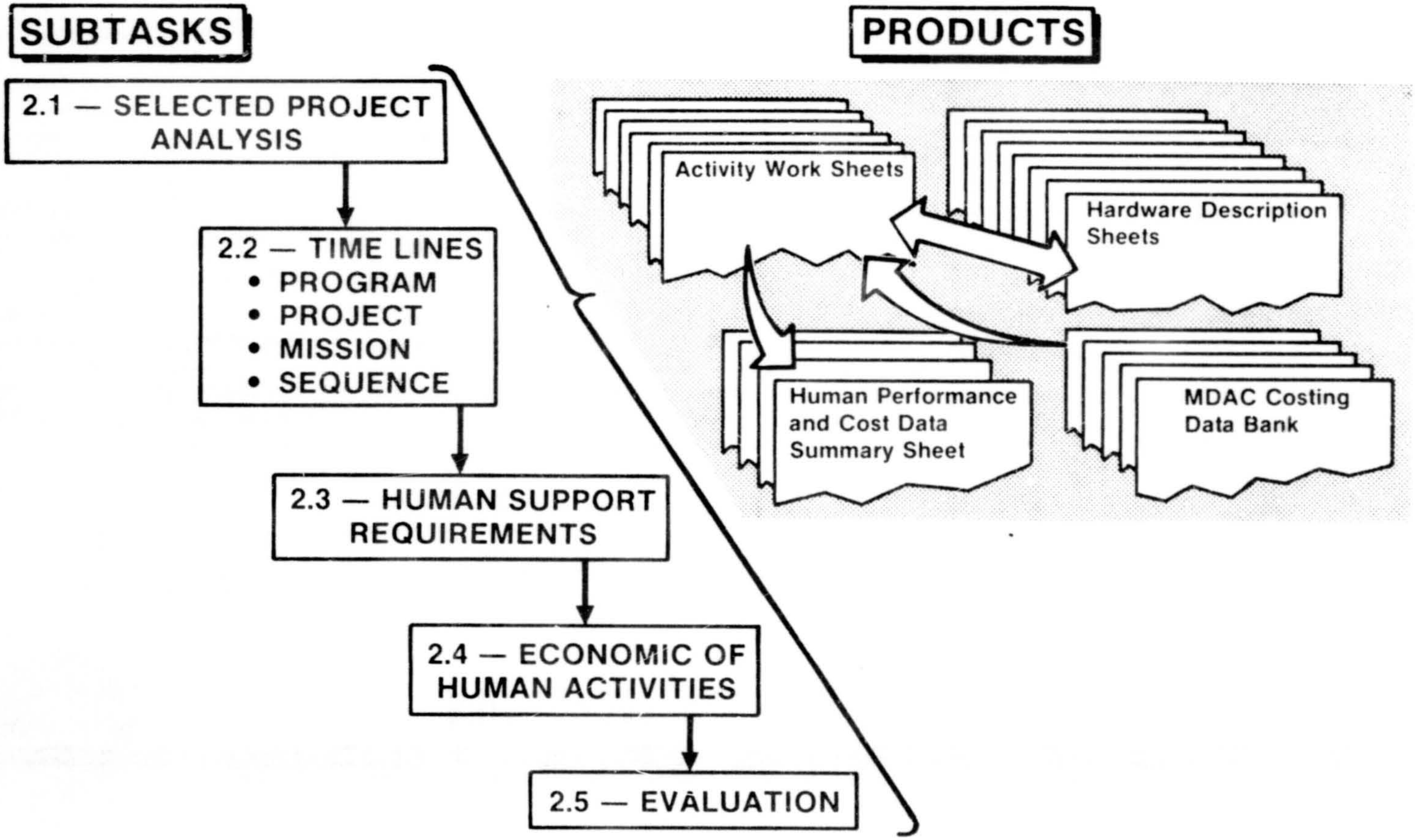
MISSION ACTIVITY	GENERIC ACTIVITIES INCLUDED	COMMENTS	DOCUMENT
• OVERRIDE CONTROL ACTIVATED TO OPEN SHUTTER ON STAR TRACKER	• IDENTIFY ABNORMALITIES • ANALYZE DATA • DEFINE PROCEDURES/SCHEDULES • IMPLEMENT PROCEDURES/SCHEDULES • MEDIATIONAL PROCESSING	• STAR TRACKER SHUTTERS NOT CYCLING OPEN AND CLOSED AS EXPECTED • CREW ANALYZED PROBLEM, SHUTTER NOT RESPONDING TO AUTO CONTROL • MANUAL OVERRIDE OF SHUTTER BY CREW SOLVED PROBLEM	STS-1 ORBITER MISSION REPORT JSC 17378 AUGUST 1981
• RESET OPEN RMS TV CIRCUIT BREAKER	• ACTIVATE/INITIATE SYSTEM OPERATION • OPERATE SYSTEM • INSPECT/OBSERVE • CONNECT ELECTRICAL INTERFACE • INSPECT/OBSERVE • ANALYZE DATA	• DURING DAY 2 RMS OPERATIONS, THE RMS WRIST/ELBOW TV CAMERA CIRCUIT BREAKER OPENED • CREW RESET BREAKER • RESETTING BREAKER DID NOT SOLVE PROBLEM • TROUBLESHOOTING ISOLATED PROBLEM TO EXCESSIVE CURRENT DRAW BY ELBOW TV CAMERA	STS-2 ORBITER MISSION REPORT JSC 17959 FEBRUARY 1982
• METRIC CAMERA (GERMAN EXPERIMENT) FAILED ON STS-9/SL-2 • SECOND CASSETTE JAMMED ON 25TH FRAME OF 400 • DATA LINK BETWEEN JSC, CAMERA FIRM IN GERMANY, AND FLIGHT CREW SET UP • JSC GROUND CREW DEVISED, FIXED, AND WALKED FLIGHT CREW THROUGH PROCEDURES TO REPAIR JAM • CAMERA PUT BACK ON LINE BY FLIGHT CREW	• IDENTIFY ABNORMALITIES • DEACTIVATE/TERMINATE SYSTEM OPERATION • RELEASE LATCH • REMOVE/OPEN COVERING • INSPECT/OBSERVE • COMMUNICATE INFORMATION • CORRELATE DATA • GATHER TOOLS/EQUIPMENT • RESOLVE ABNORMALITIES • REPLACE/CLOSE COVERING • CLOSE LATCH • ACTIVATE/INITIATE SYSTEM OPERATION • REPLACE TOOLS/EQUIPMENT	• STS-9/SL-1 • METRIC CAMERA (GERMAN) SECOND FILM CASSETTE JAMMED • JSC GROUND LINKED TO ZEISS CAMERA IN GERMANY AND TO STS-9/SL-1 CREW • REPAIR PROCEDURES WORKED OUT IN REAL TIME AT JSC • RELAYED TO CREW TO EFFECT REPAIR	AVIATION WEEK AND SPACE TECHNOLOGY DECEMBER 19, 1983
• SOYUZ 23 (OCT 1976) AUTOMATIC DOCKING FRUSTRATED SOYUZ 24 (FEB 1977) MANUAL DOCKING ACHIEVED	• ADJUST/ALIGN ELEMENTS • CONFIRM/VERIFY PROCEDURES/SCHEDULES • CORRELATE DATA • DETECT CHANGE IN STATE OR CONDITION • TRACKING (CONTINUOUS ADJUSTMENT) • POSITION MODULE • INSPECT/OBSERVE	• SOYUZ 24 DOCKED MANUALLY WITH SALYUT 5 • SOYUZ 23 WAS "FRUSTRATED" (FAILED) WITH ITS AUTOMATIC DOCKING SYSTEM IN EARLIER ATTEMPT	SPACEFLIGHT VOL 19, NO. 5 MAY 1977

BENEFIT OF MAN'S PARTICIPATION IN MISSION ACTIVITIES

		Evaluation of the Benefit of Man's Participation					
Life Science Mission Activities	Recommended Man/Machine Category	Equipment Can Be Eliminated	Performance of Activity Is Improved	Probability of Mission Success is Improved	Assessment of Onboard Participation	Skill Type and Level Required for Man's Participation	Reasons for Conclusions Regarding Benefits of Man's Participation
Monitor Rat Colony	Supported	●	●	●	Beneficial	Biological Technician	Man Onboard Can Treat Sickness and Remedy Malfunctions
Replenish Supplies	Manual	●	—	●	Beneficial	Minimal Training	Equipment Mass and Volume Significantly Increased by Automation
Remove and Process Urine Samples	Supported	●	—	●	Beneficial	Biological Technician	Increase in Equipment Mass and Complexity If Samples Automatically Processed
Measure Mass of Rat	Augmented	●	●	●	Essential	Minimal Training	Extremely Difficult to Design Intra-Habitat Mass Measurement System
Acquire, Process, and Store Rat Blood Samples	Augmented	—	●	●	Essential	Biological Technician	No Feasible Method Is Available for Blood Sample Acquisition Without Man
Sacrifice Rats and Acquire Tissue Samples	Supported	—	●	●	Essential	Skilled Scientist/ Technician	Exposure of Rats in Habitats to Lethal Chemical Preservative Not Realistic Alternative

VGG352

TASK 2 — SPECIFIC PROJECT ASSESSMENT



SUBTASKS

2.1 — SELECTED PROJECT ANALYSIS

2.2 — TIME LINES
- PROGRAM
- PROJECT
- MISSION
- SEQUENCE

2.3 — HUMAN SUPPORT REQUIREMENTS

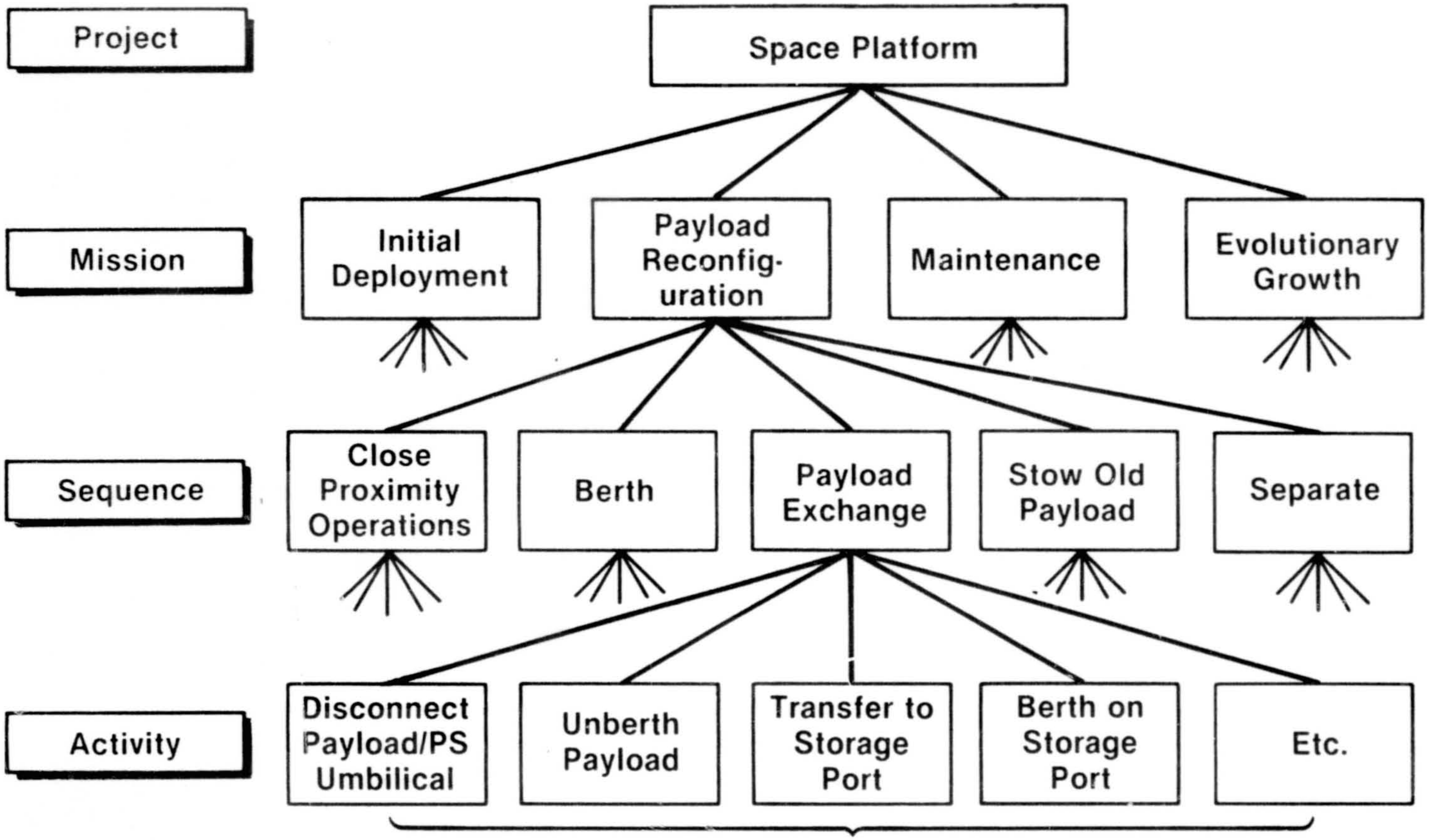
2.4 — ECONOMIC OF HUMAN ACTIVITIES

2.5 — EVALUATION

PRODUCTS

VGL917

SPACE PLATFORM PROJECT ANALYSIS



Project

Mission

Sequence

Activity

Space Platform

Initial Deployment

Payload Reconfiguration

Maintenance

Evolutionary Growth

Close Proximity Operations

Berth

Payload Exchange

Stow Old Payload

Separate

Disconnect Payload/PS Umbilical

Unberth Payload

Transfer to Storage Port

Berth on Storage Port

Etc.

25 Generic Activities
Derived From Space Platform Analysis

VGL402

GENERIC SPACE ACTIVITIES

1. Activate/Initiate System Operation
2. Adjust/Align Elements
3. Allocate/Assign/Distribute
4. Analyze/Compute Data
5. Apply Biomedical Sensor
6. Communicate Information
7. Confirm/Verify Procedures/Schedules/Operations
8. Connect/Disconnect Electrical Interface
9. Connect/Disconnect Fluid Interface
10. Correlate Data
11. Deactivate/Terminate System Operation
12. Decode Data
13. Define Procedures/Schedules/Operations
14. Deploy Appendage
15. Detect Change in State or Condition
16. Display Data
17. Encode Data
18. Extract Data
19. Gather Tools/Equipment
20. Handle/Inspect/Examine Living Organisms
21. Identify Abnormalities
22. Implement Procedures/Schedules
23. Inspect/Observe
24. Measure (Scale) Physical Dimensions
25. Mediational Processing
26. Perform Fine Motor Manipulations
27. Plot Data
28. Position Module
29. Release/Secure Mechanical Interface
30. Remove/Open Covering
31. Remove Biomedical Sensor
32. Remove Module
33. Replace/Close Covering
34. Replace/Clean Surface Coatings
35. Replace Tools/Equipment
36. Replenish Materials
37. Retract Appendage
38. Store/Record Data
39. Tracking (Continuous Adjustment)
40. Transport Loaded
41. Transport Unloaded

GENERIC SPACE ACTIVITIES (CONT)

VGL919

Activities	Source					
	AXAF	(1) Skylab	(2) Space Platform	Space Station	(3) Armis Study (MIT)	Life Sciences Laboratory
1. Activate/Initiate System Ops	●	●	●	●	●	●
2. Adjust/Align Elements		●		●	●	●
3. Allocate/Assign/Distribute		●	●	●	●	●
4. Analyze/Compute Data		●	●	●	●	●
5. Apply Biomedical Sensor		●		●	●	●
6. Communicate Information	●	●	●	●	●	●
7. Confirm/Verify Proced/Sched/Ops		●	●	●	●	●
8. Connect/Disconnect Elec Interface		●	●	●	●	●
9. Connect/Disconnect Fluid Interface		●	●	●	●	
10. Correlate Data		●	●	●	●	●
11. Deactivate/Terminate Sys Ops	●	●	●	●	●	●
12. Decode Data			●	●	●	
13. Define Proced/Sched/Ops		●	●	●	●	●
14. Deploy Appendage	●	●	●	●	●	
15. Detect Change in State or Cond		●		●	●	●
16. Display Data		●	●	●	●	●
17. Encode Data			●	●	●	
18. Extract Data			●	●	●	●
19. Gather Tools/Equipment	●	●	●	●	●	●
20. Handle/Inspect/Examine						●
21. Identify Abnormalities		●	●	●	●	●

(1) Includes EREP and ATM Activities

(2) Includes Activities Derived From the Analysis of Space Platform GroundSystem Data Management Study

(3) Includes 330 Generic Functional Elements Derived From the Geosynchronous Platform, Advanced X-Ray Astrophysics Facility, Teleoperator Maneuvering System and Space Station

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GENERIC SPACE ACTIVITIES

Activities	Source					
	AXAF	(1) Skylab	(2) Space Platform	Space Station	(3) Armis Study (MIT)	Life Sciences Laboratory
22. Implement Proced/Sched		●	●	●	●	●
23. Inspect/Observe		●	●	●	●	●
24. Measure (Scale)		●			●	
25. Mediational Processing		●		●		●
26. Perform Fine Motor Manip		●		●		●
27. Plot Data		●	●	●		●
28. Position Module	●	●	●	●	●	●
29. Release/Secure Mech Interface	●	●	●	●	●	●
30. Remove/Open Covering		●	●		●	●
31. Remove Biomedical Sensor		●		●	●	●
32. Remove Module	●	●	●	●	●	●
33. Replace/Close Covering		●	●		●	●
34. Replace/Clean Surf. Coat.	●		●			●
35. Replace Tools/Equipment	●	●	●	●	●	●
36. Replenish Materials	●	●		●	●	●
37. Retract Appendage	●	●	●	●	●	
38. Store/Record Data		●	●	●	●	●
39. Tracking (Cont Adjust.)				●	●	●
40. Transport Loaded	●	●	●	●	●	●
41. Transport Unloaded	●	●	●	●	●	

(1) Includes EREP and ATM Activities

(2) Includes Activities Derived From the Analysis of Space Platform GroundSystem Data Management Study

(3) Includes 330 Generic Functional Elements Derived From the Geosynchronous Platform, Advanced X-Ray Astrophysics Facility, Teleoperator Maneuvering System and Space Station

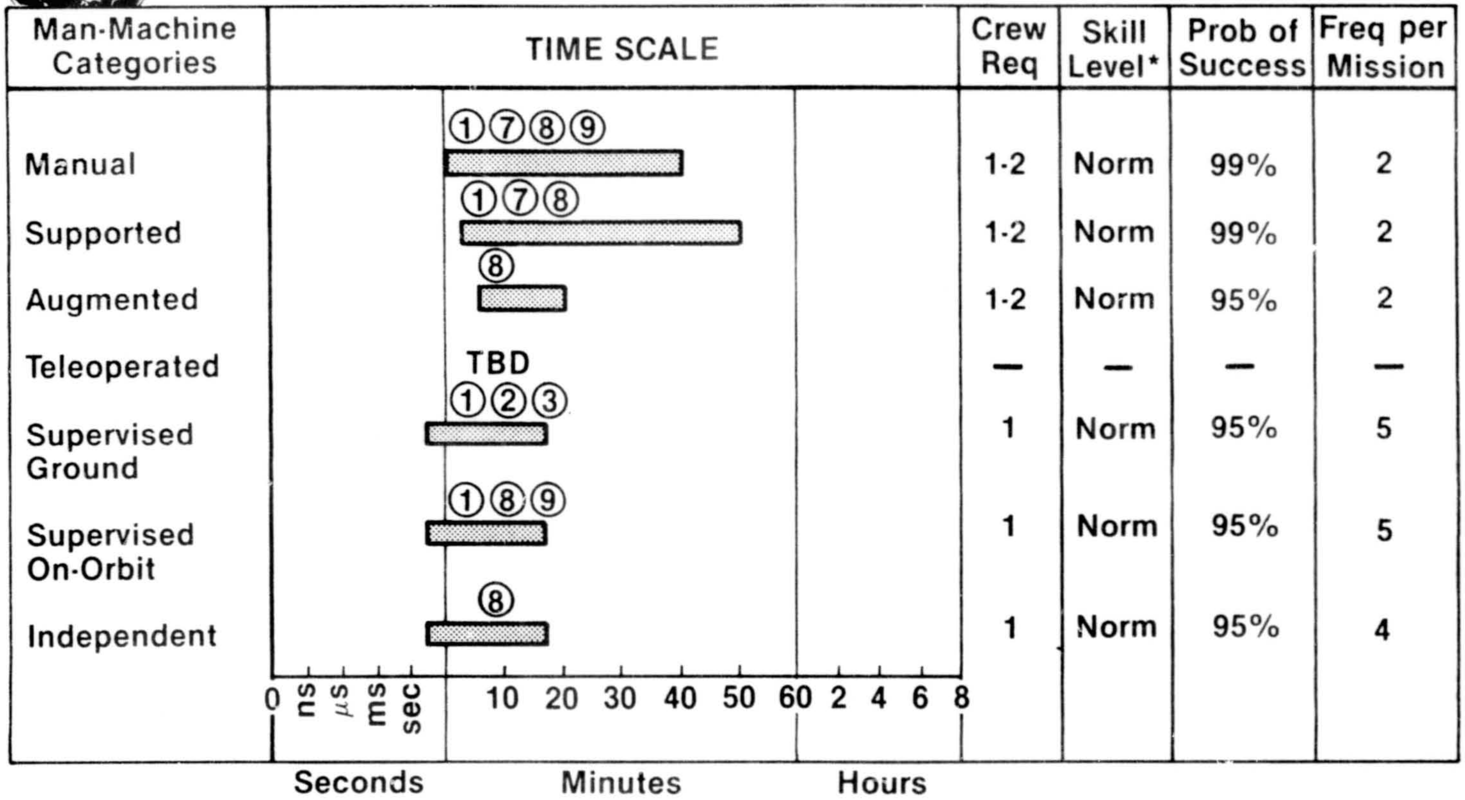
CATEGORIES OF MAN-MACHINE INTERACTION

VGL403

MANUAL	Unaided IVA/EVA, With Simple (Unpowered) Hand Tools
SUPPORTED	Requires use of Supporting Machinery or Facilities to Accomplish Assigned Tasks (e.g., Manned Maneuvering Units and Foot Restraint Devices)
AUGMENTED	Amplification of Human Sensory-Motor Capabilities (Powered Tools, Exo-Skeletons, etc)
TELEOPERATED	Use of Remotely Controlled Sensors and Actuators Allowing the Human Presence to Be Removed From the Work Site (Remote Manipulator Systems, Teleoperators, Telefactors)
SUPERVISED	Replacement of Direct Manual Control of System Operation With Computer Directed Functions Although Maintaining Humans in Supervisory Control From Ground-Based or Orbital Based Work Stations
INDEPENDENT	Basically Independent Self Actuating, Self-Healing Operations but Requiring Human Intervention Occasionally (Automation and Artificial Intelligence)

VGL393

DEPLOY APPENDAGE



Man-Machine Categories	TIME SCALE	Crew Req	Skill Level*	Prob of Success	Freq per Mission
Manual	①⑦⑧⑨	1-2	Norm	99%	2
Supported	①⑦⑧	1-2	Norm	99%	2
Augmented	⑧	1-2	Norm	95%	2
Teleoperated	TBD	—	—	—	—
Supervised Ground	①②③	1	Norm	95%	5
Supervised On-Orbit	①⑧⑨	1	Norm	95%	5
Independent	⑧	1	Norm	95%	4

*<u>Skill Level</u>

Normal Skills (Norm) — Task Falls Within the Realm of Standard Training/Basic Knowledge

Specialized Skills (Spec) — Task Requires Special Training or Specific Knowledge of the Activity

VGL404

REFERENCE SOURCES

① McDonnell Douglas Astronautics Company, Alternative System Design Concept Study (Space Platform/Power System), Contract NAS8-33955, DR Numbers 1-16, July, 1982

② Space Platform Ground System Study — Final Report, 7/21/82, Ford Aerospace and Communications Corporation. (Subcontract to MDAC Under NAS8-33955)

③ Space Station Program Description Document — Book Number 6, Appendix B, Operations Studies, Second Level White Pages, 8/83, Space Station Operations Working Group, NASA-KSC

⑦ Space Maintenance and Contingency Operations Simulation Neutral Buoyancy Testing (NB-51) — Final Report, MDC H0190, MDAC-HB, 5/83

⑧ McDonnell Douglas Astronautics Company Engineering Estimate

⑨ National Aeronautics and Space Administration, Johnson Space Center, Mission Planning and Analysis Division, The 25-Kilowatt Power System — Baseline Reference Mission, JSC 17066, February 1981

COST FACTOR ASSIGNMENT TO MAN-MACHINE INTERACTION CATEGORIES

VGL401

Cost Factors	Categories of Man-Machine Interaction					
	Manual	Supported	Augmented	Teleoperated	Supervised	Independent
1. Prorated Facility Costs	●	●	●	●	●	●
2. Prorated Transp Costs	●	●	●	●	●	
3. Orbital Supt Equip Costs	●	●	●	●	●	
4. Automated Equip Costs						●
5. Gnd Supt Equip Costs				●	●	●
6. Gnd Supt Operations				●	●	●
7. Training Requirements	●	●	●	●	●	
8. Software Support Costs			●	●	●	●
9. Crew Rotation Rates	●	●	●	●	●	
10. Duty Cycles	●	●	●	●	●	
11. Operation Times	●	●	●	●	●	●
12. Logistics Requirements	●	●	●	●	●	
13. Emergency Provisioning	●	●	●	●	●	
14. Hazardous Ops Provisioning	●	●	●			

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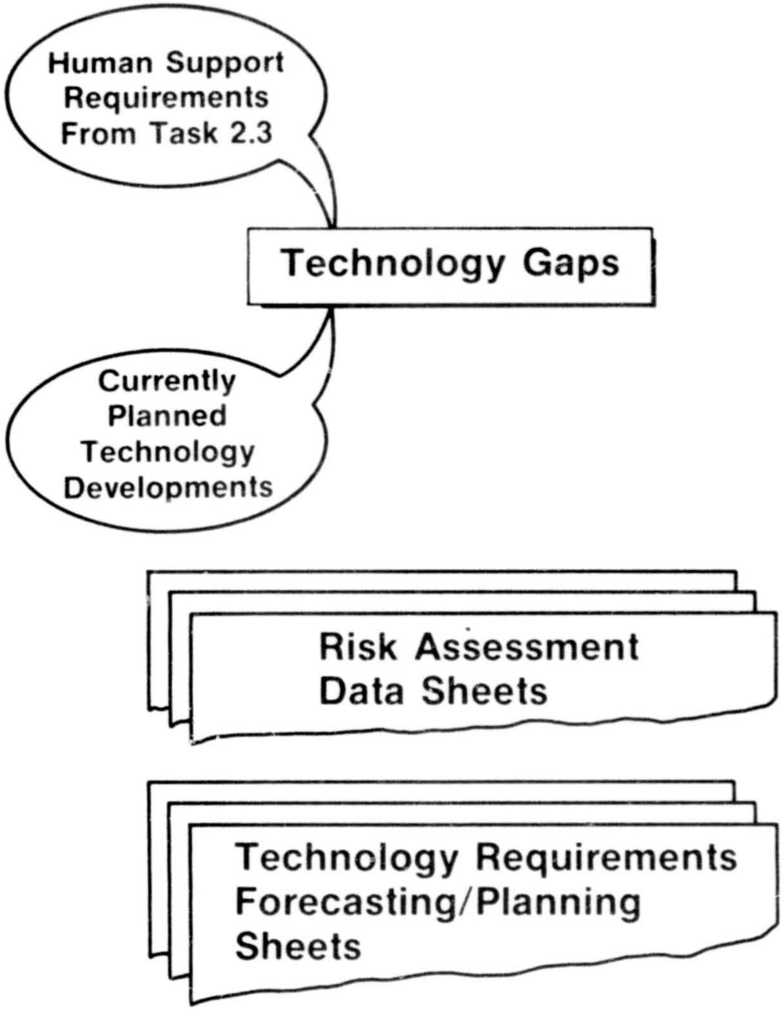
VGG363

TASK 3 — TECHNOLOGY REQUIREMENTS

- Technology Gaps
- Technology Risk Assessment
- Technology Plan



Human Support Requirements From Task 2.3

Technology Gaps

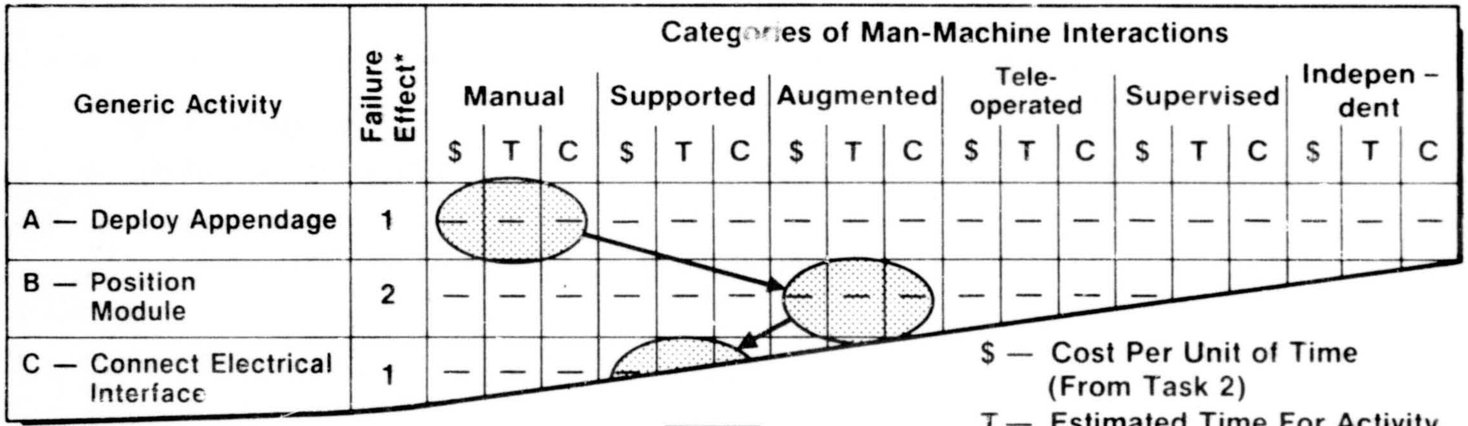
Currently Planned Technology Developments

Risk Assessment Data Sheets

Technology Requirements Forecasting/Planning Sheets

TASK 4 — ROLE ALLOCATIONS

VGG339



Generic Activity	Failure Effect*	Categories of Man-Machine Interactions																	
		Manual			Supported			Augmented			Tele-operated			Supervised			Indepen-dent		
		$	T	C	$	T	C	$	T	C	$	T	C	$	T	C	$	T	C
A — Deploy Appendage	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B — Position Module	2	—	—	—	—	—	—	—	—	—	—	—	—	—					
C — Connect Electrical Interface	1	—	—	—	—														

*Failure Effect Rating
1 = Mission Loss
2 = Minimal Data Return
3 = Significant Data Return
4 = Minor Effect

$ — Cost Per Unit of Time (From Task 2)

T — Estimated Time For Activity (From Task 2)

C — Confidence of Estimate (Risk) — (From Task 3)

Select Lowest Expected Cost Path

- Compute ($)(T)/(C)
- Test: $T \leq T_{max}$, $C \geq C_{min}$

VGL394

STUDY ACCOMPLISHMENTS TO DATE

106 Reference Documents Reviewed to Date

Task 1 — Completed
- Documentation of Human Capabilities/Limitations
- Historical Precedents and Operational Experiences

Task 2 — In Process
- Six Space Project Areas Reviewed
- Generic List of 41 Basic Activities Developed
- Timeline Profiles and Mission Impact Factors Established for 20 of 41 Activities
- Preliminary Listing of Human Support Equipment Completed
- Early Start on Economic Assessment of Human Activities in Space
- Fourteen Factors Impacting Costs Identified
- Philosophy for Allocating Costs Established

Tasks 3 and 4 — No Work Scheduled as yet per Study Plan

THURSDAY

SEMINAR ON
SPACE STATION HUMAN PRODUCTIVITY

OVERVIEW:
HUMAN FACTORS ISSUES IN SPACE STATION ARCHITECTURE

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(415) 965-5385   FTS 448-5385

MARCH 1, 1984

N85-29558

SPACE STATION PROGRAM STATUS

3/1/84

"NO DESIGN DECISIONS
HAVE BEEN MADE"

Hans Mark 2/10/84

TWO YEARS OF INTENSIVE STUDY
1984 - 1985

TARGET FIRST LAUNCH DATE: 1991

JOHNSON SPACE CENTER (JSC):
LEAD CENTER FOR DEVELOPMENT

AMES RESEARCH CENTER (ARC):
- SPACE HUMAN FACTORS OFFICE FORMED (9/83)
- AERO-SPACE HUMAN FACTORS DIVISION FORMED IN REORGANIZATION OF MVSRD (2/84)

SPACE STATION PROGRAM ASSUMPTIONS

1. ALL PARTS OF STATION WILL BE LAUNCHED IN SHUTTLE PAYLOAD BAY - ~14'-0" MAX. O.D. X ~45' MAX. LENGTH.

2. STATION WILL FLY IN LOW EARTH ORBIT, (LEO) ~200-300 MILE ALTITUDE AT LOW INCLINATION, ~28.5°.

3. SOLAR PHOTOVOLTAIC POWER, ~75 KW.

4. ZERO-GRAVITY (NO ARTIFICIAL G.).

5. BUDGET FOR INITIAL OPERATING CAPABILITY (I.O.C.) IS $8.0 BILLION OVER ~8 YEARS, AND INCLUDES 2 UNMANNED PLATFORMS, SVCE. STRUCT. EVA, MMUS & OMS/TMS

CONCEPT DEVELOPMENT GROUP I.O.C. MODEL:

1. AUTONOMY:
   - 90 DAYS WITHOUT STS REVISIT
   - 5 DAYS W/O ROUTINE GROUND SUPPORT
   - 24 HOURS W/O ANY COMM. FROM GROUND
2. CREW:
   - 6 - 8 PEOPLE ON 90 DAY TOURS
   - MIXTURE OF PILOT, MISSION & PAYLOAD TYPES
3. COMMAND & CONTROL:
   - COMPLETELY DISTRIBUTED TO EACH MODULE
   - NO "BRIDGE"
4. SAFETY:
   - "SINGLE PERCEIVED LEVEL", WITH DISTR. SAFE HAVENS TO SUPPORT ENTIRE CREW FOR 21 DAYS.

1) SPACE HUMAN FACTORS

- FOR <u>WORKING</u> & <u>LIVING</u> ENVIRONMENTS
- "<u>MAXIMIZE HUMAN PRODUCTIVITY</u>":
  - CREW PERFORMANCE
  - IVA TIME AVAILABLE FOR PAYLOADS
  - ROUTINE EVA → 1,000 HOURS/YEAR
- <u>NEW SPACE MISSION CHARACTERISTICS</u>:
  - LONG DURATION, REPEATED TOURS OF DUTY
  - PERMANENT HABITATION WITH AUTONOMY
  - HIGH LEVELS OF AUTOMATION, MAN/MACHINE INTERACTION & USE OF ROBOTICS
- <u>COMMERCIALIZATION</u>:
  - COTTAGE INDUSTRY OR MASS PRODUCTION?
  - DIVERSE ACTIVITIES

2) ARCHITECTURE

"Architecture is a social art. It becomes an instrument of fate because it not only caters to requirement but also shapes and conditions our responses. It can be called reflective because it mirrors a program of conduct and living. At the same time this art of a planned environment does more, it also programs our daily conduct and our entire civilized life. It modifies and often breaks earlier established habit."

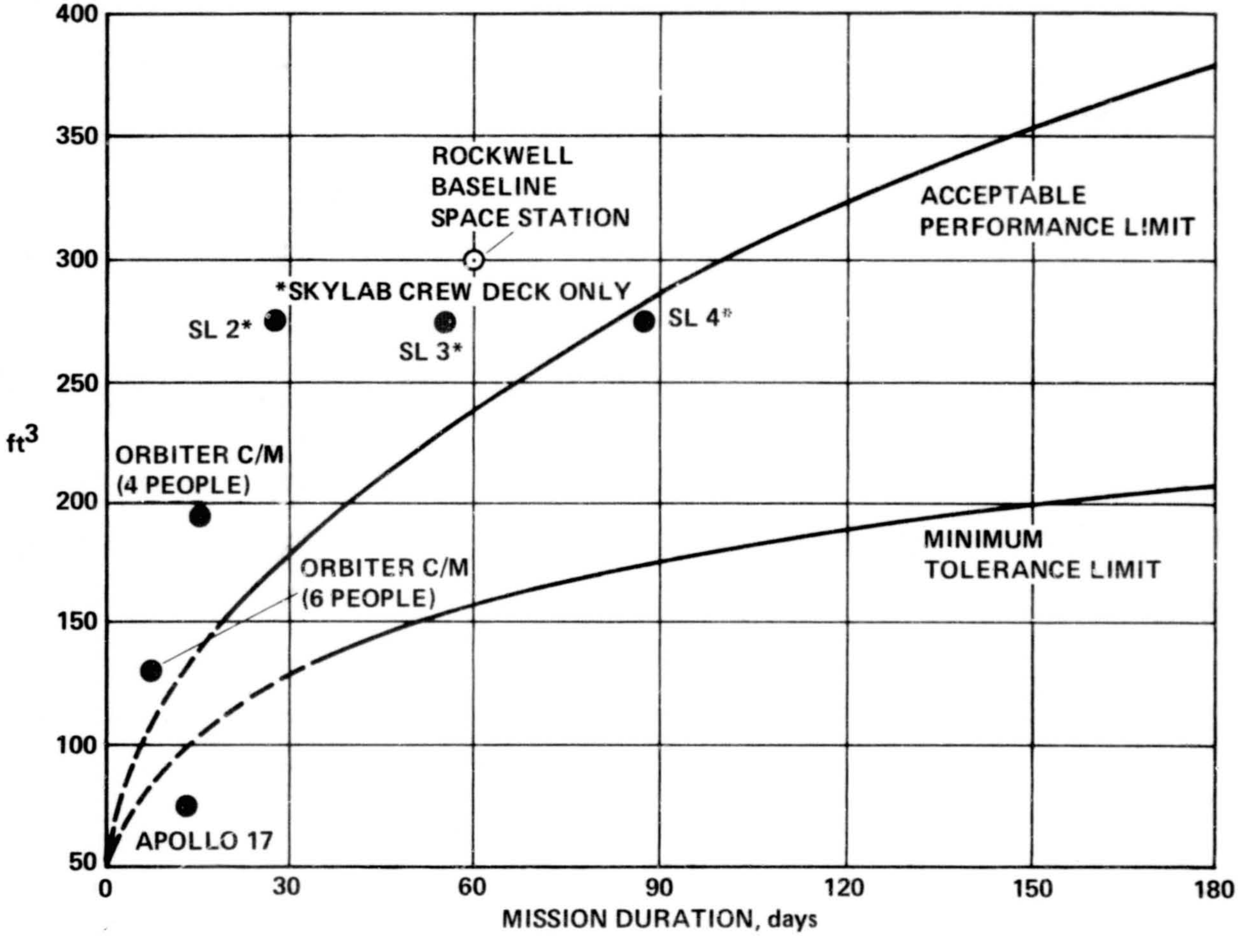
— Richard Neutra, SURVIVAL THROUGH DESIGN,
(Oxford University Press) 1954. Page 314.

3) VOLUME

- MOST CRITICAL SINGLE H.F. ISSUE:
  - MOST CONSTRAINED BY EXTERNAL LIMITS.
  - AFFECTS ENTIRE HABITABILITY BASELINE.
  - CELENTANO CURVES.
- EFFORTS TO REDUCE COSTS BY MINIMISING VOLUME PRESENT A FALSE ECONOMY.
- EFFECTS OF INADEQUATE VOLUME:
  - FORCE MINIATURIZATION OF MANY ITEMS.
  - PRECLUDE MUCH "OFF-THE-SHELF" HARDWARE.
  - IMPEDE, IMPAIR OR PREVENT ON-ORBIT MAINTENANCE.
  - DRIVE UP DESIGN, ENGINEERING, FABRICATION & INTEGRATION COSTS BEYOND THE INITIAL SAVINGS.
  - DIMINISH CREW PERFORMANCE & COMFORT.

6

J. T. CELENTANO: HABITABLE VOLUME REQUIREMENTS PER PERSON



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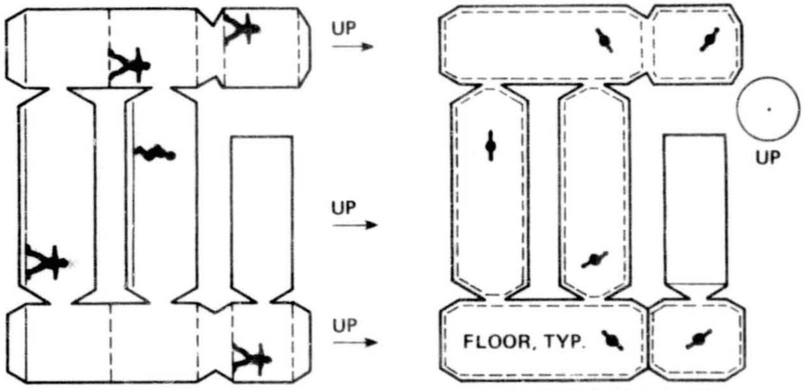
4) REFERENCE ORIENTATION

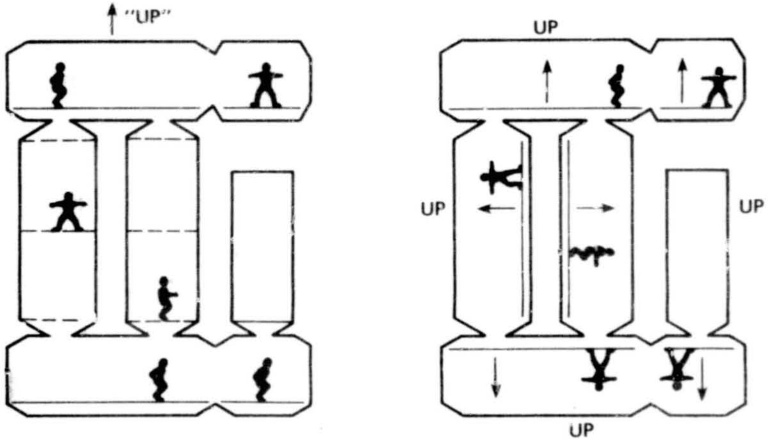
- ONE POINT
  (SOVIET EVA PROTOCOL)
- TWO POINT
  (LOCAL VERTICAL IN SKYLAB OWS, SPACELAB)
- THREE POINT (2-D)
  (RAFT TYPE STATION ASSEMBLY)
- FOUR POINT (3-D)
  ("DELTA" CONFIGURATION
- PLANAR (S.O.C. TYPE) STATION OPTIONS

PLANAR SPACE STATION REFERENCE ORIENTATION OPTIONS



1 SHORT AXIS UP

2 FLOORS ALL COPLANAR



3 LONG AXIS UP
(ORIGINAL S.O.C., J.S.C.)

4 UP AWAY FROM CENTER

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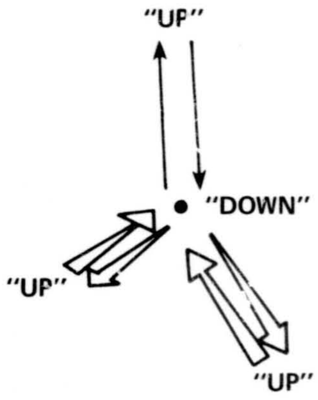
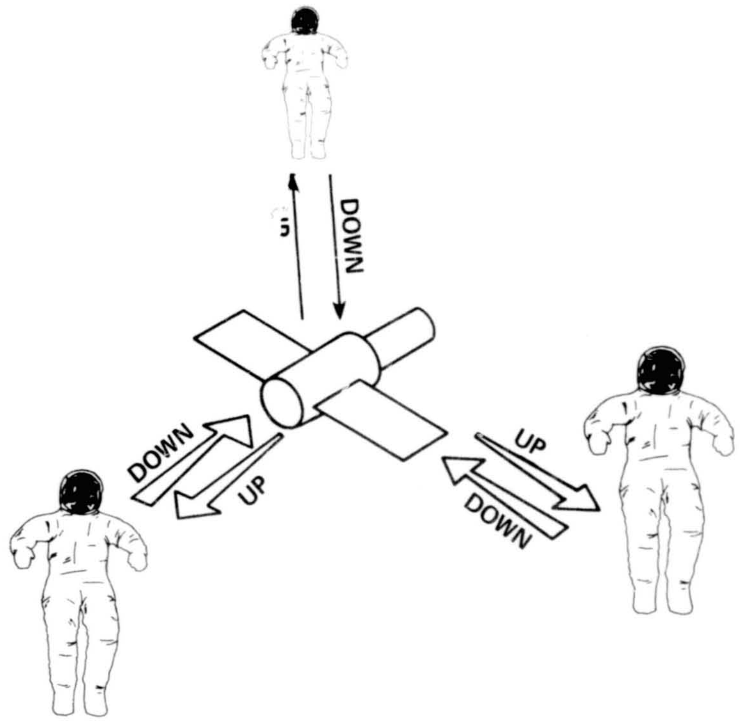


ONE POINT
REFERENCE ORIENTATION



REPORTED SOVIET EVA PROTOCOL
FOR TETHERED OPERATIONS

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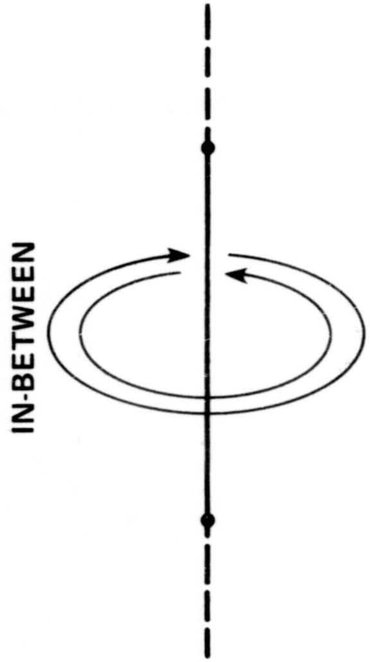
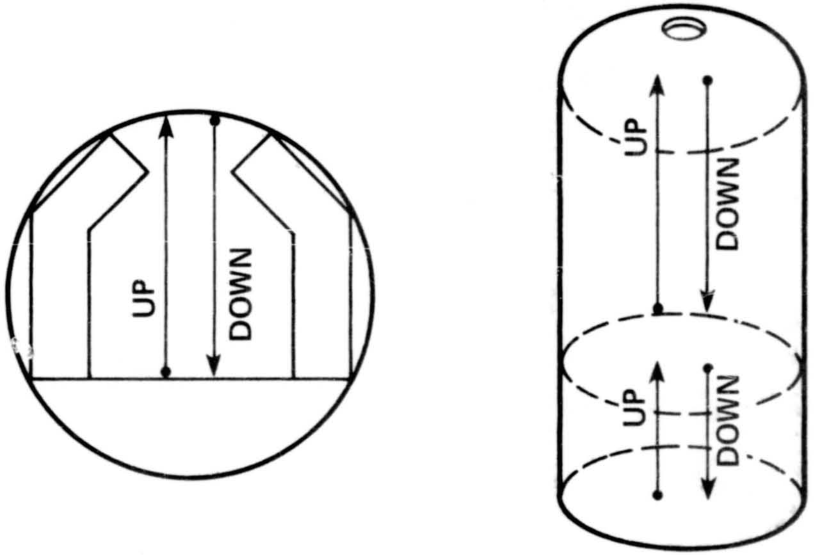


TWO POINT
REFERENCE ORIENTATION



SPACELAB

SKYLAB

"LOCAL VERTICAL"
IN SKYLAB AND
SPACELAB

NASA—Ames Research Center
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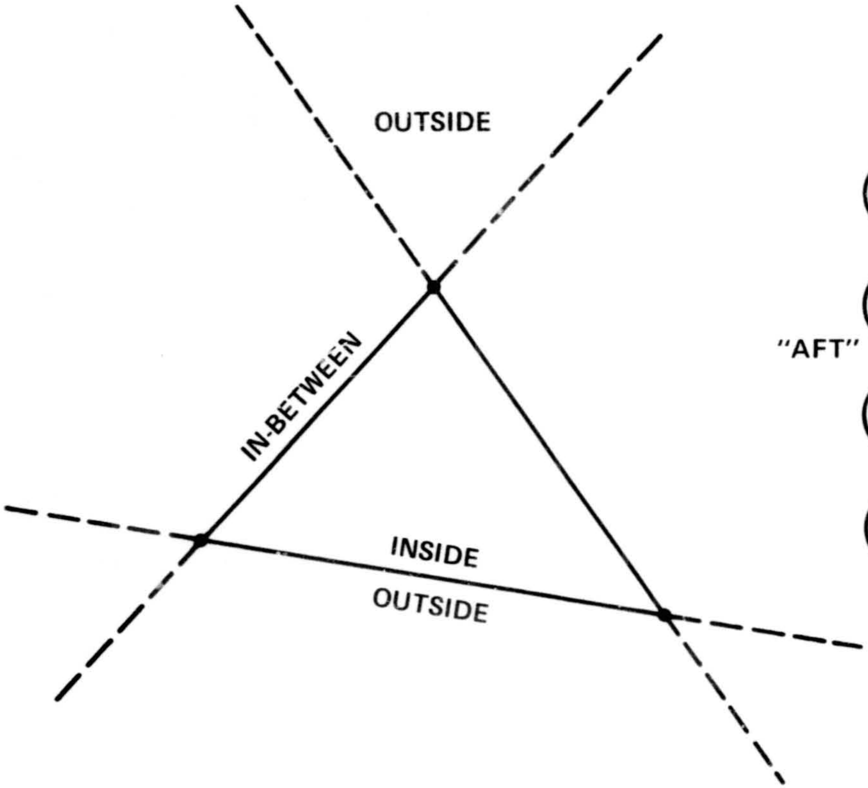
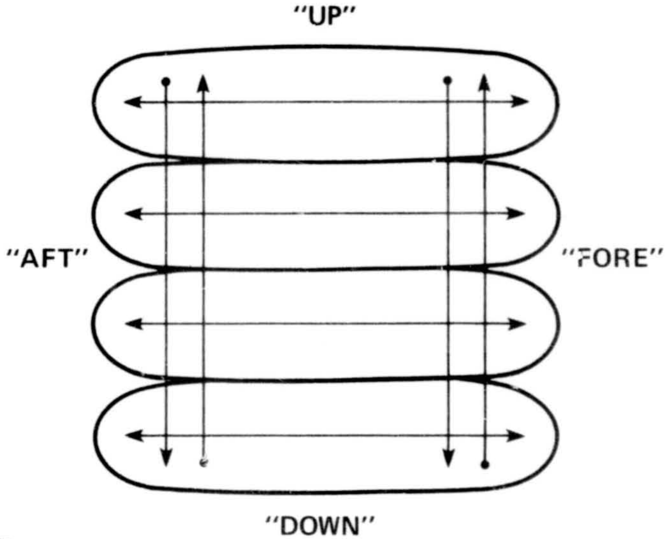


THREE POINT
REFERENCE ORIENTATION



"VERTICAL RAFT"
SPACE STATION

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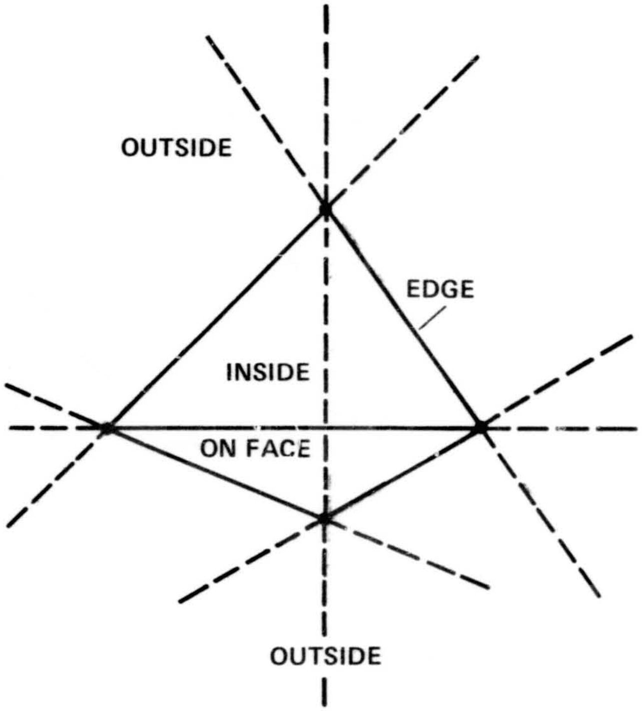
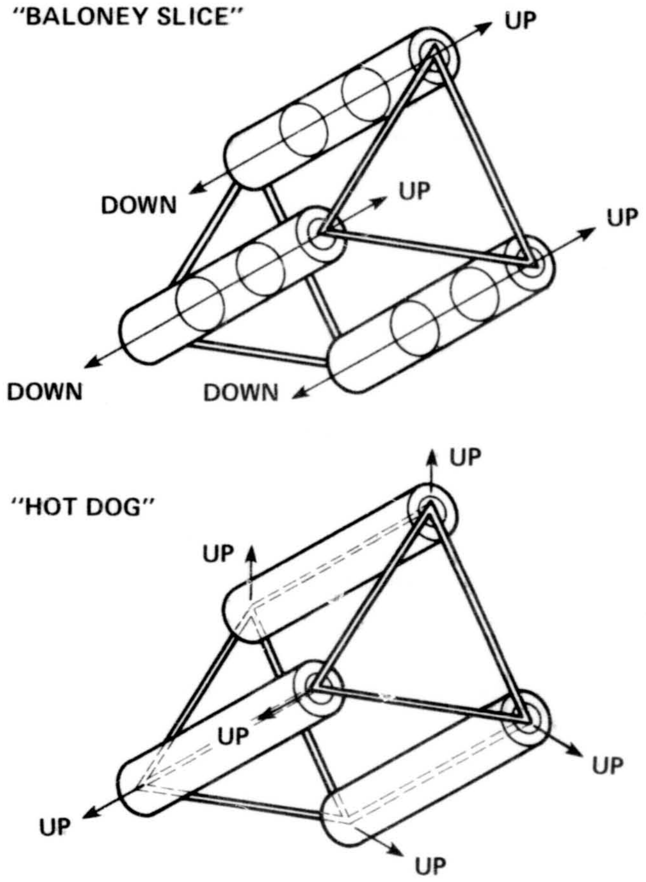


FOUR POINT
REFERENCE ORIENTATION



JSC "DELTA"
CONFIGURATION

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Space Human Factors Office

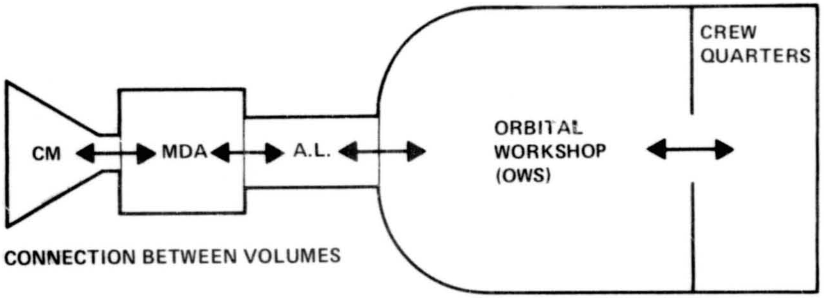
5) CIRCULATION

- SKYLAB EXPERIENCE SHOWS 3 ASPECTS:
  1. <u>CONNECTION</u> BETWEEN VOLUMES
  2. <u>PENETRATION</u> THROUGH VOLUMES
  3. <u>DIVISION</u> OR <u>SEPERATION</u> OF VOLUMES

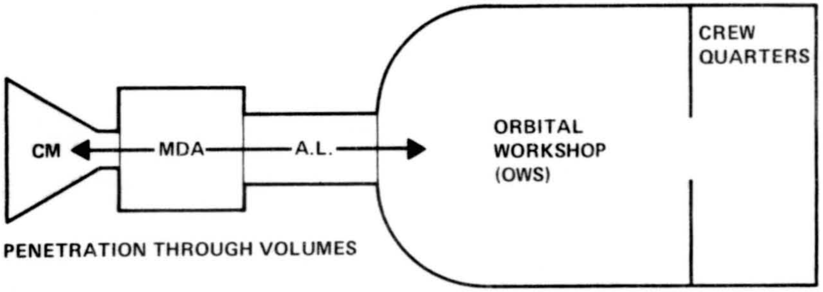
- BIOLOGICAL ANALOGIES – TRADITION IN CITY PLANNING
  - SCALELESSNESS & COMPLEXITY
  - FIGURE/GROUND AMBIGUITY
  - CENTER/END VS CENTER/PARTS CIRCULATION

- FIVE <u>CIRCULATION CONDITIONS - DEFINITIONS</u>
  1. ACCESS
  2. MULTIPLE ACCESS
  3. EGRESS
  4 DUAL EGRESS
  5. DUAL REMOTE EGRESS

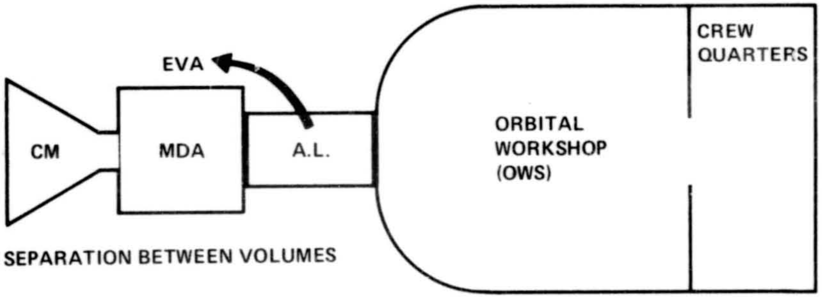
SKYLAB CIRCULATION CHARACTERISTICS



CONNECTION BETWEEN VOLUMES



PENETRATION THROUGH VOLUMES



SEPARATION BETWEEN VOLUMES

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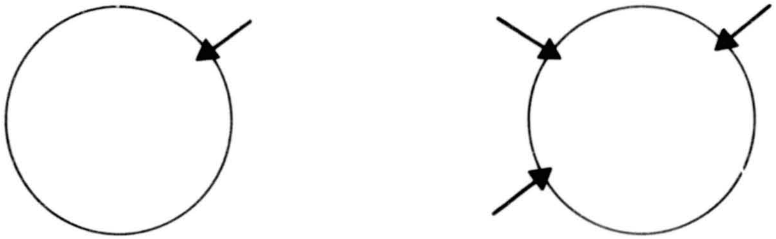
ACCESS AND EGRESS DEFINITIONS

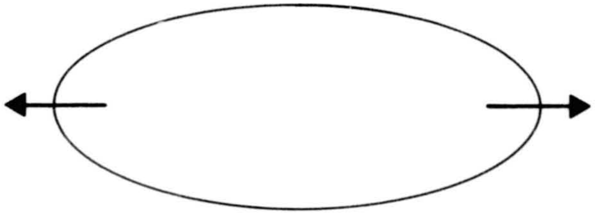


(a) ACCESS

(b) MULTIPLE ACCESS

(c) EGRESS

(d) DUAL EGRESS



(e) DUAL REMOTE EGRESS

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6) PRIVACY

- MANDATORY FOR "STAYING SANE IN SPACE"
- INDIVIDUAL CONTROL (PERSONAL DOMAIN)
  VITRUVIUS'S DEFINITION: "INVITATION"
- COMMUNITY CONTROL BY
  "LOCKS" & SEPERATIONS BETWEEN DOMAINS
  1. ENTRY LOCK
  2. DIRECT EVA ACCESS TO EXTERIOR
  3. BUFFER BETWEEN PRIVATE DOMAINS
  4. LOCK TO PRIVATE CREW QUARTERS
  5. LOCK TO COMMON AREAS
  6. EXTERIOR SEPERATIONS & CLEARANCES
     – INFLUENCE ON INTERIOR FUNCTIONS

7) GROUP GATHERING PLACES

1. WARDROOM
   - GALLEY ?
   - DINING
   - RECREATION / ENTERTAINMENT
   - WORK AREA

2. GROUP WORK STATIONS
   - STS RMS & AFT PILOT STATION
   - NEED FOR OFFICE ON SKYLAB
   - LABORATORY MODULES

3. EXERCISE / HEALTH FACILITY

4. SMALL GROUP / CONFERENCE / DEN
   - DOUBLE AS SOLAR STORM RADIATION SHELTER ?

8) VISUAL SYSTEMS 1

- WINDOWS FOR WORK
  - RENDEZ-VOUS & DOCKING
  - CELESTIAL OBSERVATION
  - EARTH OBSERVATION
- WINDOWS FOR ENTERTAINMENT
  - MOST POPULAR PASTIME ON SKYLAB WAS WATCHING EARTH SLIP BY.
- WINDOW LOCATION, TYPE, SIZE, SHAPE & OPTICAL QUALITY – CRITICAL
- CLOSED CIRCUIT T.V. & VIDEO
  - TO WHAT EXTENT CAN THEY SUBSTITUTE FOR WINDOWS?
- WINDOWS ADMIT UNWANTED RADIATION

VISUAL SYSTEMS 2

- <u>LIGHTING:</u>
  - SPECIFIC TASK LIGHTING
  - AMBIENT BACKGROUND LIGHTING
- <u>ARTIFICIAL LIGHTING:</u>
  - SOME STUDIES SHOW LONG TERM EXPOSURE CONTRIBUTES TO FATIGUE & IRRITABILITY.
  - USE OF SUNLIGHT FOR INTERIOR ILLUMINATION
- <u>EXTERIOR ILLUMINATION:</u>
  - SUPPORT EVA WORK CONTINUOUSLY THROUGH NIGHTSIDE?
  - EVA CONTROL OF LUMINAIRES?

9) VIBROACOUSTICS

- SKYLAB WAS SO QUIET, THE SLIGHTEST NOISE WOULD AWAKEN SLEEPING CREWMEN, FORCING SINGLE SHIFT OPERATION.

- SHUTTLE FLIGHT DECK IS SO LOUD, HEADSETS MUST BE WORN FOR CONVERSATION.

- COUNTERMEASURES:
  - ISOLATION OR ATTENUATION AT SOURCE
  - ABSORPANT SURFACES
  - SOUND BARRIERS/BULKHEADS BETWEEN COMPARTMENTS IN A MODULE
  - POSITIVE ISOLATION BETWEEN MODULES.

- AUDIO SYSTEMS

10) STRUCTURES: SHELLS

- MODULE PRESSURE SHELL CONSTRUCTION CAN <u>INFLUENCE</u> <u>HABITABILITY</u> <u>AND H.F.</u>
  - RIBBED VS. SMOOTH INTERIOR WALL
    - → CONNECTIONS FOR INTERIOR STRUCTURE
    - → WINDOW FRAMING, SIZE, SHAPE, LOCATION
    - → DUST & CONTAMINANT ACCUMULATION
- END CAP GEOMETRY
  - <u>SUPPORT</u> BERTHING PORTS, MECHANISMS, WINDOWS, TANKS
  - <u>METHOD OF FABRICATION</u>
    - SHEAR SPUN SECTION
    - TRAPAZOIDAL GORES
    - HEXAGONAL GORES
  - <u>FORM</u>: ELLIPTICAL, CONICAL OR SPHERICAL

11) MECHANISMS

- BERTHING MECHANISM IMPORTANCE CANNOT BE IGNORED, IT IS PROFOUND.
- CURRENT BERTHING MECH. CONCEPT WAS DEVELOPED AT JSC FOR APOLLO/SOYUZ (ASTP):
  - SINGLE-VECTOR, SIMULTANEOUS ALIGNMENT
  - WORKED WELL FOR APOLLO

<u>BUT</u>

- SPACE STATION MECHANISM MUST PERFORM MORE & DIFFERENT FUNCTIONS:
  - GEOMETRIC FLEXIBILITY
  - 15 - 20 VARIED UTILITY CONNECTIONS
  - SYSTEM OF BERTHING LOGIC
  - MAINTENANCE & UPGRADES BETWEEN PORTS

12 UTILITIES

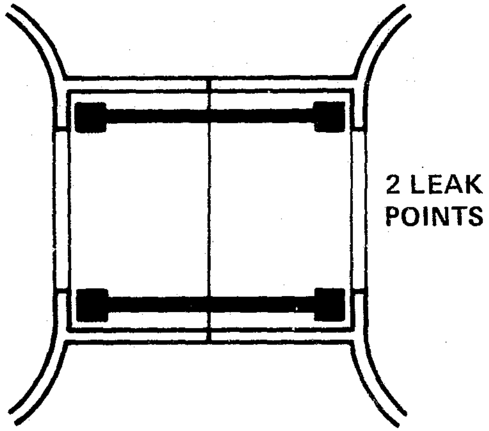
- DISTRIBUTION & CONNECTION WILL BE THE MOST DIFFICULT INTERIOR DESIGN & PHYSICAL SYSTEM INTEGRATION PROBLEM.
- CASE STUDY OF PLUMBING JOINTS (POTENTIAL LEAK & MAINTENANCE POINTS
  - — MANUAL CHANNEL: 2 JOINT UNITS/PIECES
  - — REMOTE ACTUATED: 5 JOINT UNITS/PIECES
- LDR CASE STUDY (MDAC) 3-D TRUSSES
  - — ASSEMBLED (MANUAL) EVA
  - — DEPLOYED (AUTOMATED)
- REMOTE/AUTOMATIC CONNECTIONS MAY BE APPRORIATE ONLY FOR FREQUENT OR HAZARDOUS UNITS OR MODULES OR OPERATIONS

UTILITY CONNECTION CASE STUDY

RESULTS OF TRIANGULAR-TETRAHEDRAL SPACE STATION STUDY:

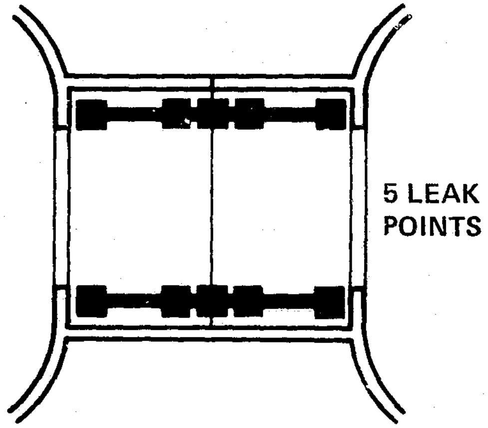
MANUAL CHANNEL CONNECTION:

2 JOINT UNITS/PIECES – PREASSEMBLED CHANNEL INSTALLED BY HAND



REMOTE ACTUATED CONNECTION:

5 JOINT UNITS/PIECES – PREINSTALLED UTILITIES DEPLOYED AUTOMATICALLY



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13) FUNCTION

- DEFINITION OF FUNCTION
- CLARITY OF FUNCTION
- ORGANIZATION OF FUNCTIONS
- DO FUNCTIONS EQUATE TO MODULES?
- CAN FUNCTION DICTATE GEOMETRY?

A Preliminary Human Factors Planning and Design Outline of Parameters Related to Space Station Windows and CCTV Monitoring[*]

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Abstract

This paper presents a preliminary discussion of parameters considered to be important in designing windows for space station from a human factors point of view. The following window parameters are discussed: number, frontal area and shape, location in relation to the configuration of station modules, field of view angles, ambient interior illumination control, closed circuit TV operations, and preliminary design specifications. Not discussed are such topics as mechanical strength or weight, installation, breakage threat, abrassion resistance, etc. Space station windows should not require any break-throughs in new optical technology.

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[*] Paper presented at Space Station Human Productivity working group meeting, February 27 - March 2, 1984, Ames Research Center-NASA, Moffett Field, CA. 94035.

N85-29559

Introduction

This paper presents an outline with commentary on selected aspects of space station windows and remote television monitoring. The fundamental question may be asked at the outset:

Are Windows Needed?

Of course this question has to do with the issue of whether the crew can carry out their duties as well by means of remotely controlled TV cameras as they can by viewing through windows. This is a complex question which has been discussed for years. The literature which compares human visual capabilities with those of closed circuit television hardware appears to favor human vision when everything is considered. This literature is not reviewed here. It is instructive to note that windows have been included on every previous manned space flight of both the Soviet Union and the United States. Astronauts Truly and Crippen remarked about the value of space vehicle windows. They state, "A wealth of scientific information was gleaned from the hand held photography of the heavens and the earth taken from these six (Skylab) windows. However, quite often there was not a window available to view a desired objective.... Every attempt should be made to provide spacecraft of the future with enough windows of good optical quality to always offer a view of earth and space." A review of many post-flight debriefings of the American missions and other material has convinced this writer of the critical importance of windows.

Their major functions are listed here:

1. Permits outside visual observations.
   a) rendezvous/docking with other objects
   b) space station build-up/repair/(future) modification
   c) emergency/rescue operations
   d) earth surface experiments/monitoring
   e) celestial experiments
   f) experiment hardware moving and stowage using remote manipulators

2. Permits limited visual observations from outside to inside. For instance in the event of a communication system failure gestures/non-verbal communication would still be possible.

3. Can make it possible to "see through" a module from outside.

4. Allows natural sunlight to enter for possible use.

5. Contributes to general habitability of the living/working environment by virtue of the natural beauty of the heavens and earth viewed from orbital altitude and by the ability of a window to permit the viewer ready "visual escape" from the relatively small and confining habitat.

6. Contributes to the mental health of the crew by providing immediate visual and "psychological" access with the earth.

7. Can contribute to the physical health of the crew by providing access to natural solar radiation.

Subject Outline

Primary Design Issues
(Discussed here)

1.1 Number of windows per module
1.2 Frontal area and shape of each window
1.3 Location of each window in each module in relation to station configuration
1.4 Field of view angles of each window (function of 1.2 and 1.3)
1.5 Ambient interior illumination control
1.6 Operations better suited for CCTV than windows
1.7 Preliminary design specifications

Secondary Design Issues
(Not discussed here)

2.1 Optical characteristics of each window to permit execution of each required function
3.1 Solar radiation filtering requirements (UV, visible, IR)
4.1 Maintenance requirements (cleaning/polishing interior & exterior surfaces)
5.1 Internal heat balance considerations
6.1 Internal "habitability" considerations (need for visual escape, crew reassurance to the real world, shorter day/night cycle and circadian entrainment, etc.)
7.1 Visual accommodation considerations over time
8.1 Stimulus to human creativity

1.1 Number of Windows Per Module

In order to determine the required number of windows per module from a human factors design point of view one should take the following factors into account. Not considered in this paper are such considerations as the mechanical strength or weight of glass, specific means for installing it into the space station, leakage-related problems, or other threat impact issues. Also, factors such as the abrasion-resistance of glass is of importance here only to the extent that periodic maintenance must be planned in order to restore the windows to some acceptible condition. Clearly, the more windows there are the more such maintenance will be required. Finally, it is assumed that the optical quality of each window will be adequate to support the particular task(s) that will be carried out using the window. The host of problems associated with poor optical design will not be discussed here.

1.1.1 Established need for external visibility during space station build-up period. Certain configurations of modules of a completed space station may block the external field of view from a given window so that another window would be called for in that module. Because of weight, strength, and other penalties, it is possible that a temporary CCTV might be used in place of a window during the construction phase.

1.1.2 Established need for field of view (FOV) overlap from two or more windows. Certain operations may require simultaneous multi-crew coordination from different windows. Can it be demonstrated that both crewmen will be enhanced in their ability to perform the required tasks because of this simultaneous viewing capability?

1.1.3 Established need for having "blind spots" only in non-critical areas. CCTV monitoring could be used to provide "fill-in" surveillance in these areas.

1.1.4 Established need for admitting solar radiation into the space station over a sufficiently large area (total) area. Certain experiments as well as the crew may require natural sunlight inside the space station.

1.2 Frontal Area and Shape of Each Window

As with the other window design characteristics discussed here, window area and shape have been determined mainly on the basis of structural engineering constraints rather than by human factors related needs. A particularly stong case must be made by the human factors design professional if he intends to depart from so-called "standard" window shapes and sizes.

As used here, the term "area" refers to the physical dimensions of the window's transparent surface. The perceived shape of any window is determined by eye distance and head orientation relative to the window (cf. Figs. 7-9).

Of course an upper limit will be reached in window area set by strength and other considerations. There is a need to find creative solutions in regard to enlarging or minifying window area visual effects. Can lenses (or fiber optics) be used in this way, perhaps to expand a patch of sunlight once it has entered a smaller window? Should windows be made of non-flat material such as the bubble canopys used on WW-II bomber and fighter aircraft?

A wide variety of window shapes have been used to date in America's manned space vehicles. The Mercury, Gemini, and Apollo vehicles all had small, irregularly shaped windows which provided only minimal external visibility. The Skylab vehicle had round windows. The astronaut could literally touch his nose to the glass which permitted a relatively wide external field of view (Figs. 2-5). The shuttle vehicle had forward windows remarkably similar in shape to those in today's commercial airplanes. At the top rear of the crew compartment are two square windows 19.75" on a side (with small radius corners) and at the rear bulkhead are two horizontally oriented rectangular windows measuring 14.25" wide. Their vertical dimension nearest the vehicle's centerline is 10.75" and farthest from the centerline is 9". They are recessed over 3" from the surrounding wall surface. To the author's knowledge no one has specifically analyzed the influence that this wide variety of windows may have had on how adequately the crew carried out their assigned tasks (Fig. 10). Anthropometric studies were conducted for the shuttle's rear work station windows in terms of eye to window distance to aid in planning for location of surrounding structure.

Before proceeding it is necessary to comment on the Design Eye Point (DEP) for a space station window. The DEP is the location of the two eyes relative to the window which will provide a desired external visibility envelope when looking through the window. This design approach was borrowed from airplane cockpit design. In the case of the space station's windows, the DEP must take into account not only eye to glass separation distance but also head-body orientation since the viewer will be in zero gravity conditions and may or may not have body restraint available. There will, therefore, need to be an azimuthal reference (A_z) included which will represent the angle between the local vertical of the window (0°) and the longitudinal axis of the head with 0° at the top and measuring in the clockwise direction. Why will this A_z parameter be needed? Because the monocular and binocular visual field of the viewer may be larger or smaller than the FOV of the window depending upon head orientation and eye to window separation distance (see Figs. 11-15). It may be possible to maximize the total external visual field through a window by specifying a certain head orientation.

The following factors are considered relevant to designing the frontal area and shape of space station windows. .

1.2.1 Number of persons per window. Can a need be shown for two or more viewers to look out of the same window at the same time? Of course window area and shape are closely related. A circular window with an area of one square meter will have a diameter of only 56.4 cm which will not permit more than one viewer (centered), but a rectangular window of the same area (but 20 cm by 500 cm) could accommodate as many as six viewers side by side. How each of the viewers is oriented relative to one another also will determine how many people can use the same window simultaneously.

1.2.2 Eye to window surface distance. Obviously, the nearer the viewer can get to the window the larger will be his external field of view (angle) (cf. Figs. 11-15). The nominal eye to window surface distance for the aft bulkhead window in shuttle was 55 cm (22 inches). Field of view plots for an eye distance of only 10.4 inches showed that the maximum angular field of view width out this window for the 50 % man (binocular viewing) was about 62° (monocular) and about 80° (binocularly) (See Fig. 8). Moving back farther would reduce this angle significantly. Future anthropometric design considerations should accommodate a crew ranging in size from the 5th percentile female to the 95th percentile male.

Calculations have shown that the outer edges of a docking vehicle may well disappear outside the window's field of view at a certain separation distance even with the eyes located very near the window's surface (see Figs. 1,6). If this happens it will be necessary to provide additional range and range-rate dynamic cues for the astronaut to use. Such cues might include carefully planned surface patterns and other detail of known size that provide orientation and texture information about the vehicle being approached.

Another important consideration is placement of wall-mounted equipment and other structure near each window. It is known that the volumetric work-envelope requirements of the body in weightlessness differs from those in a one-g environment. Provision should be made to permit the viewer to locate his eyes near the window for extended periods of time without neck muscle strain.

1.2.3 Maximum field of view needed from the window. Certain tasks involving external visibility through windows will call for wider visual fields than others. Certain windows may need to be "dedicated" to specific functions with all of their field of view, optical transmission, and other characteristics pre-established to support the required function(s).

An ultra-wide field of view may be desireable in future space stations in situations in which visual judgments need to be made of the "structural" continuity of a very long module. Such a module may be only partially visible when viewed through a narrow window but which would be totally visible when viewed through a wide angle window.

Several comments are in order concerning the shape of the windows. It is likely that most windows will be used for a wide variety of purposes and that shape of the aperture will not be particularly important. However, it is possible that during the approach, docking, and other close-proximity operations with another vehicle or module window outline shape could be important. Consider a round window. Roll attitude of a distant approaching vehicle could not be readily determined within such a window shape without an additional reticle, head up display, or other aid. In addition, the viewer's body orientation would be harder to determine when viewing through a round window. A square or rectangular window outline would provide such attitude information.

If it is found that crew "self orientation" to a local vertical is needed, then correctly shaping and orienting all windows alike could help to provide these verticality cues just as wall-to-wall intersection lines do in the one-g (earth) environment.

1.2.4 Established need for high optical quality. Much the same arguement as given above (1.2.3) applies here. For example, if celestial observations will be carried out it may be justified to specify an "astronomy" window with all of the necessary optical characteristics.

1.2.5 Window thickness (depth) requirements. The thicker is the total window assembly the smaller will be the available external field of view for a given eye to window separation distance. Also relevant here are the total number of panes used in each window. Generally, the more panes the lower is the total light transmission and the greater is the possibility of multiple reflections (sometimes known as the "string-of-pearls" effect).

1.2.6 Established need for internal module ionizing radiation shielding. Unless the window assembly provides adequate cosmic radiation protection itself (at least comparable with surrounding walls), the fewer windows the better (all else equal).

1.2.7 Established criticality of maintaining clean windows. The larger the windows the greater will be the required maintenance (time/energy) "costs." In addition, certain shaped windows may require special cleaning implements. For example, a window having a small radius corner may prevent some implements from reaching all the way to the window frame. Such considerations may justify a limited number of space station window sizes and shapes.

1.2.8 Possibility/probability of needing to replace windows on-orbit. Windows may be damaged (cracked, scratched, unable to maintain an internal pressure over time). The frontal area of a becomes available. It also may be necessary to replace an existing window(s) as new technology makes improvements available.

1.2.9 Possibility of reflection of sunlight into a window from a near-by surface. Certain space station surface contours and sun angle orientations may produce very high intensity reflections into a window. Such reflected light could produce multiple reflections within multiple window panes, temporary visual impairment from so-called "flash blindness", and could alter the

heat load inside the station.
Since the human pupil of the eye requires from two to four seconds to contract completely to very high brightness scenes, an unexpected solar reflection could leave the viewer visually incapacitated for some period of time (see section 1.5).

1.3 Location of Each Window in Each Module in Relation to Overall Station Configuration

In general, much the same considerations given above with regard to the number, size, and shape of the space station windows applies here as well. This issue is complex and calls for a careful prioritization of crew duties. There likely will be competition for wall space. Whether a window is installed rather than a cabinet or equipment should be dictated by a carefull consideration of the long-term needs of the space station as well as a thorough knowledge of the capabilities and limitations of human vision and CCTV. Thus, while one might justify having no windows at all over the short-term, it is becoming increasingly obvious that having the ability to look out is very important. It is suggested that having this capability will become even more meaningful the longer the crew is on-board for psychological and social reaons.

A general design guideline should be kept in mind when considering the placement of each window in relation to the overall space station configuration, namely, the window designer must take into account all that is known about the capabilities and limitations of the human visual system. Take the perception of space for instance. There are a number of cues to distance and orientation present in most viewing situations (accommodation; convergence; light and shading, shadows, surface texture and gradients, motion parallax, flow fields, perspective transformations, occlusion of the farther object by the nearer, edge and corner configurations, redundancy, absolute size, etc.). The very high contrast environment of space will eliminate some of these cues while the relatively great viewing distances will eliminate or reduce others. The point is that window placement should attempt to plan for what cues will be available from the earth/sky background as well as from the other modules of the space station which will provide potentially useful distance ranging and translation rate cues.

Not discussed here are various engineering design factors such as module rib-spacing, radius of curvature of the walls, weight penalty, or other such subjects. The following general factors are presented to help plan for where to locate each window in a module.

1.3.1 Space station build-up sequence and module shape, number, and size. Window placement in each module may be partially dictated by the need to use each window during the construction phase of the space station. It is possible that CCTV may perform the desired viewing functions better from temporary locations than providing fixed windows at locations which may become "non-functional" or of reduced utility later when the space station is completed.

1.3.2 Module internal layout design. Windows must be located with regard to their proximity to internal equipment that may require human monitoring and to fixed walls and/or other structure. Human anthropometric measurements as well as full scale mock-ups should define the necessary maximal and minimal separation distances.

If it appears that natural sunlight can be used for general interior illumination purposes an approach might be to locate a relatively large window at the end of the module and orient the module with the window pointing toward the sun. The shaft of light running the length of the module could then be "tapped" by inserting a reflecting (diffuse) surface at any location desired.

1.3.3 Necessity for sunlight at certain internal locations. It is conceivable that certain on-board tasks would benefit by being illuminated by natural sunlight. Window placement should take this possibility into account.

The opposite situation also exists, namely, those areas within the space station that must be shielded from sunlight such as sleeping areas.

1.3.4 Personal privacy needs should be considered. Window placement should consider the needs of the crew's personal privacy in "staterooms" and "heads." If a stateroom has a window it should be capable of being temporarily shuttered (see Section 1.5).

1.3.5 External visibility from multiple windows simultaneously. It may be desireable to use full visual field human vision (e.g., during the final stages of a docking/berthing operation). If a single window will not permit this wide a single field of view perhaps the use of two (or more) adjacent windows would suffice.

1.4 Field of View Angles of Each Window

The angular width and height of each window is determined by window size and shape and the eye to window distance. Laboratory research has shown the importance of having stable visual references within the observer's field of view during those times when he must judge precise absolute and differential motions. For the final stages of docking, for example, a special purpose alignment system such as is used on the shuttle (COAS) plays an important stabilization role. However, if the astronaut can hold his head in a constant position relative to the window frame, the fixed frame will serve the same purpose without the need for additional (input) power or special optical display hardware.

The field of view of each window may be effectively varied by moving the position of the eyes relative to the window. Computerized plots made for the deployment of payloads on shuttle using the remote manipulator arm provided valuable insight into how these fields of view change with head movement.

The recommended minimal window field of view width is 120° arc since this will provide for full binocular visual field stimulation. That is, the region of the visual field that is mediated by the right eye will be fully overlapped by that region of the visual field that is mediated by the left eye. If significant head rotation is anticipated (rather than just eyeball rotation within the eye socket), then this minimal horizontal angle should be increased accordingly.

1.4.1 Optimal eye location behind a window to yield maximum field of view with minimal head movement. It can be shown that for a given size and shape window, there is an optical location for the eyes in terms of minimizing head movements yet keeping the target in sight.

1.4.2 Provision for allowing the eyes to be positioned very near the window's surface. Despite possible problems of window surface scratching and abrasion and moisture condensation from the crew's breath, it is strongly recommended that the area surrounding each window be designed with minimal interferrence for the shoulders and upper torso to permit him to come up close to the windows' surface when necessary.

1.5 Ambient Interior Illumination Control

There is a rather extensive literature which shows the critical importance of providing adequate illumination to support the performance of various tasks. This is no less the case on the space station. The availability of full sunlight makes possible the application of "light pipe" technology to bring sunlight to a desired interior location directly rather than via photovoltaic cells transduction. Direct solar radiation at mean solar distance = 1.99 (+/- .02) cal cm^{-2} min^{-1}. The mean luminance of the solar disc viewed from orbital altitude = 2.02 x 10^5 stilb (= 5.88 x 10^8 foot Lamberts). Solar illuminance at mean solar distance (outside earth's atmosphere) = 1.37 x 10^5 lux (lumen m^{-2}). The lack of a local light- scattering atmosphere surrounding the space station produces an extremely high contrast between the blackness of space and the solar disc or objects illuminated by sunlight. This high contrast may call for special optical filtering at the windows, particularly for operations which must be carried out over long periods of time. Neutral density optical coatings, crossed polarizing filters, photochromic filters, and other kinds of light-controlling means are presently available. Several preliminary planning factors are given below.

1.5.1 Established need for having natural (full spectrum) sunlight available inside the space station. It is possible that various biological, medical, physical, and psychological experiments will require natural sunlight. Permanent windows having special glass will need to be installed to support these experiments. It is suggested that each module have at least one such window which transmits as wide a wavelength band as possible but that a "snap-on" spectral blocking filter also is provided for these particular windows.

1.5.2 Established utility of sunlight in health maintenance of the crew. It is known that calcium loss from the bone in weightlessness continues to be a major problem. It is also known that vitamin D from certain wavelengths of natural sunlight facilitate the absorption of calcium by the gastrointestinal tract. It may be justified to require periodic "sunlight therapy" on space station. If so, special optical glass will be required for the windows.

1.5.3 Established validity of using natural sunlight inside the space station to supplement or replace artificial illuminants. It is possible that on-board power generation requirements might be reduced through the creative use of fiber optics and/or reflective surfaces to redirect sunlight into and through the interior of the space station.

1.5.4 Established validity of using sunlight to enhance the habitability of the space station's living and working areas. Most people enjoy looking out of windows at out-of-door scenes. A careful review of in-flight voice communications from earlier space flights has shown the importance of having windows for reasons other than to support experiments.

1.5.5 Established need for having a test-bed for evaluating new means for controlling sunlight. It is conceivable that new technology will be developed for controlling ambient illumination for terrestrial applications. Having windows on space station will make testing of this new technology possible as long as the windows possess adequate transmission in the IR, visible, and UV wavelength bands.

1.6 Operations Better Suited for CCTV Than Windows

Justifications commonly given for using closed circuit TV monitoring include: operating environments which may be hostile to the human, operations which call for mobility and/or surveillance in small areas too restricted for for. Experience gained from recent shuttle flights has proven the utility of remotely aimed and controlled TV cameras. The remote manipulator (cherry picker) arm was able to be positioned precisely at full extension by means of a TV camera attached to its end.

A prudent approach to the matter of how best to provide for the visualization of external space station operations would seem to be to provide a carefully integrated combination of CCTV and windows. Computer-aided 3-D perspective views of the completed space station for each vantage of concern should be produced so as to determine whether a window or CCTV camera is the best solution. Following are some general factors to consider in deciding whether CCTV should be employed in place of permanent windows on space station.

1.6.1 Necessity of having a "video" record of activities for later analysis. The CCTV camera's output may be stored on-board the space station and/or transmitted to earth.

1.6.2 Requirement for operating in the space environment over prolonged periods of time. While an astronaut could visually monitor external operations through a window, a properly positioned CCTV camera could also. Energy, weight, and volume tradeoff studies should be performed to justify use of either alternative.

This factor also includes those physical characteristics of the space environment that are harmful to man (ionizing radiation, low temperature, low pressure) but which may be designed against for the CCTV system.

1.6.3 Requirement for "seeing" into very small and poorly lit areas. A properly designed CCTV system with its own illumination source(s) can permit visual access into volumes far smaller than that of the suited astronaut.

1.6.4 Operations where image magnification (zoom) are required. High quality optical magnifying lenses are now available with which to achieve wide ranges of field of view and magnification with minimal distortion and light loss. It should be noted, however, that range and range rate cues will be either missing altogether or severely distorted by a zoom system unless additional information is provided within the field of view.

1.6.5 Requirement to "see" ongoing operations but where physical impact is possible. It is best to sacrifice a TV camera (if absolute necessary) and not a person.

1.6.6 Requirement for a very long optical baseline. Certain future on-orbit operations may require ultra-large baselines as during the construction of very large antenna or solar cell arrays. Use of inertially stabilized CCTV systems positioned relative to each other (with appropriate retroreflective auto-alignment systems) over large separation distances could play a useful role here. It is difficult to see how the space station could be configured to provide this type of function no matter where the windows were placed.

1.7 Preliminary Design Specifications

FOV (width; $A_z = 0°$)...................... 120°
(Height; $A_z = 0°$)..................... 80°

Shape (general)...................... Rectangular or

	Square
Transmission (general purpose viewing)	80% (400 - 725 nm)
(skin photo-therapy)	t.b.d.
("full spectrum" applications)	approx.340-850 nm
Design Eye Point (separation distance) ($A_z = 0°$)	12" (mean)
(min., max. distance)	1"; task dep.
Line of Sight (angular) Deviation	0.5 mr (note 1)
Optical Quality (general)	optical grade A (no bubbles)
Protective Shield (outside)	if possible
(inside)	yes
Light Shade (complete light cut-off capability?)	yes
(variable neutral density capability?)	yes (0 - 100%)
(colored filters available?)	t.b.d.

Note. 1. This deviation requirement should apply for all head positions and over the total FOV. The 0.5 mr maximum allowable radial error should be computed as the root-mean-square of the azimuth and elevation component errors.

Summary

While it may be concluded that windows on space station will be required to support a wide variety of work and leisure time activities, their specific design should take into account at least those human factors issues addressed above. It also should be pointed out that in order to not overlook critical "interaction" effects which are liable to occur whenever humans interact with other humans and with equipment each of the above factors also should take into account the following:

work vs. leisure time activities
small vs. large interior volume availability
long vs. short term occupancy
inflexible vs. flexible interior configurability
major vs. minor physiological stressor(s) present
major vs. minor psychological stressor(s) present

The importance of providing for optimal human vision in space flight has been adequately demonstrated over the past twenty five years. Now is the time to plan for the overall best design for the windows on space station.

BASIC FIELD OF VIEW ANGLE VARIABLES

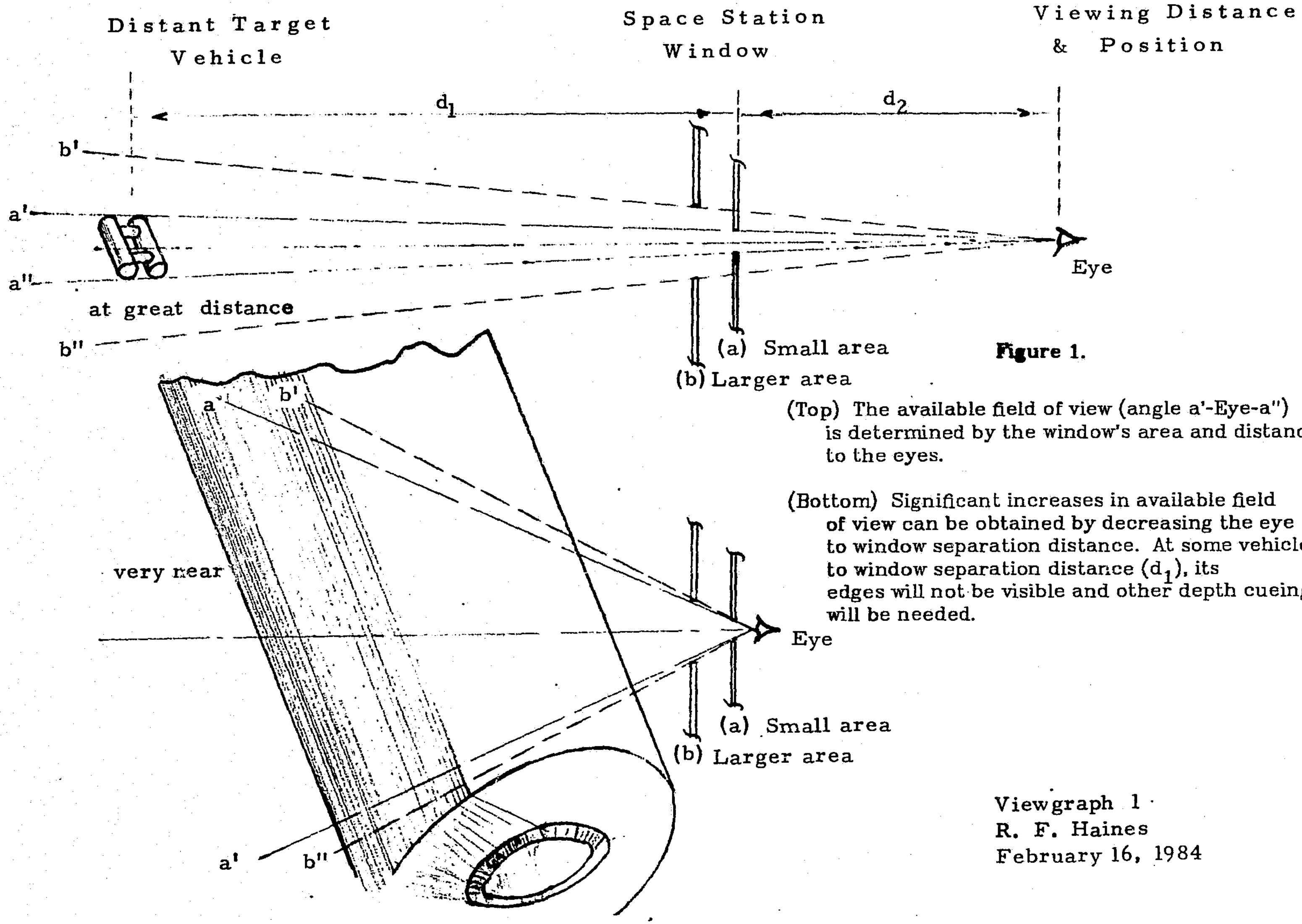
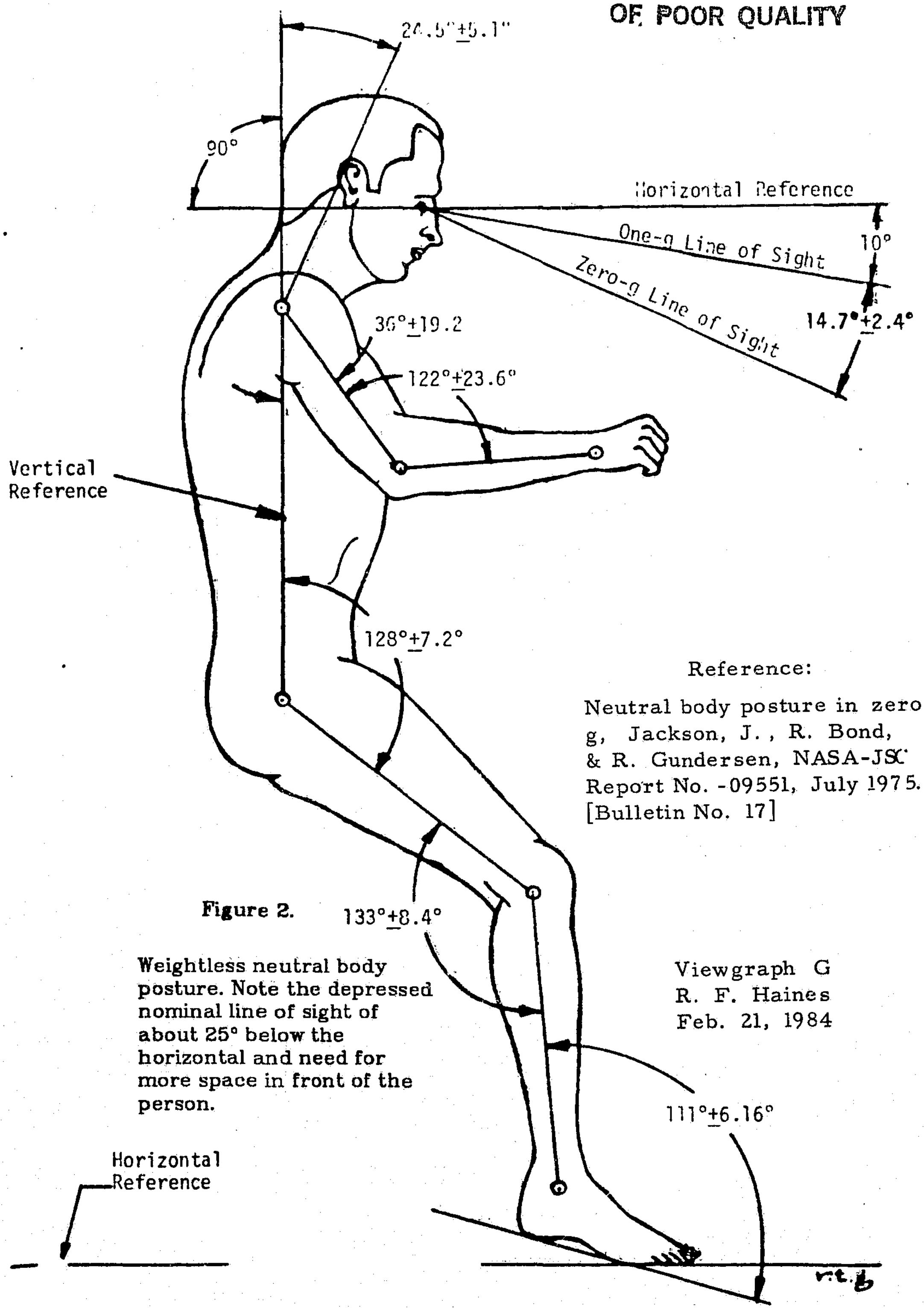


Figure 1.

(Top) The available field of view (angle a'-Eye-a") is determined by the window's area and distance to the eyes.

(Bottom) Significant increases in available field of view can be obtained by decreasing the eye to window separation distance. At some vehicle to window separation distance (d_1), its edges will not be visible and other depth cueing will be needed.

Viewgraph 1
R. F. Haines
February 16, 1984



Reference:

Neutral body posture in zero-g, Jackson, J., R. Bond, & R. Gundersen, NASA-JSC Report No. -09551, July 1975. [Bulletin No. 17]

Figure 2.

Weightless neutral body posture. Note the depressed nominal line of sight of about 25° below the horizontal and need for more space in front of the person.

Viewgraph G
R. F. Haines
Feb. 21, 1984

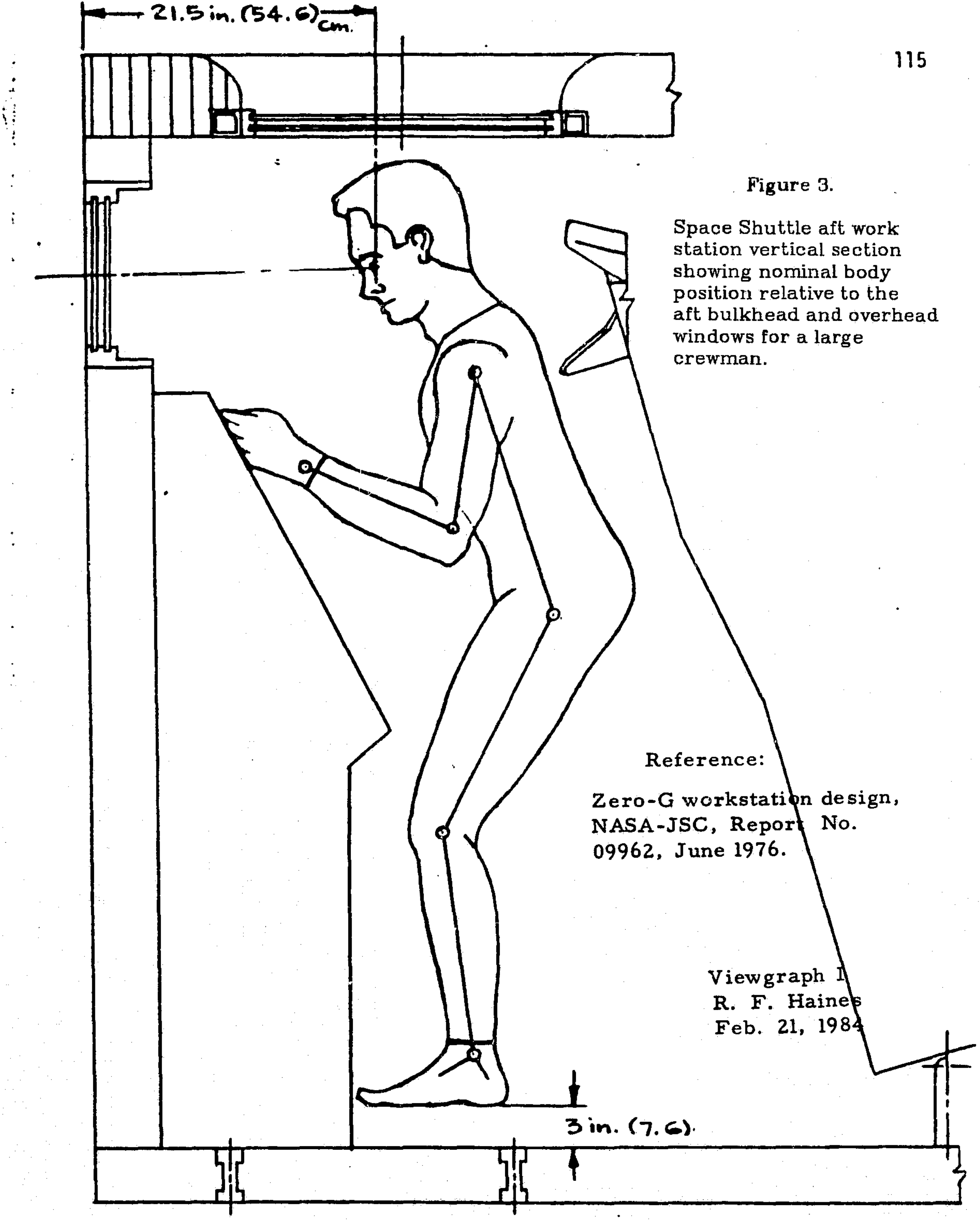


Figure 3.

Space Shuttle aft work station vertical section showing nominal body position relative to the aft bulkhead and overhead windows for a large crewman.

Reference:

Zero-G workstation design, NASA-JSC, Report No. 09962, June 1976.

Viewgraph I
R. F. Haines
Feb. 21, 1984

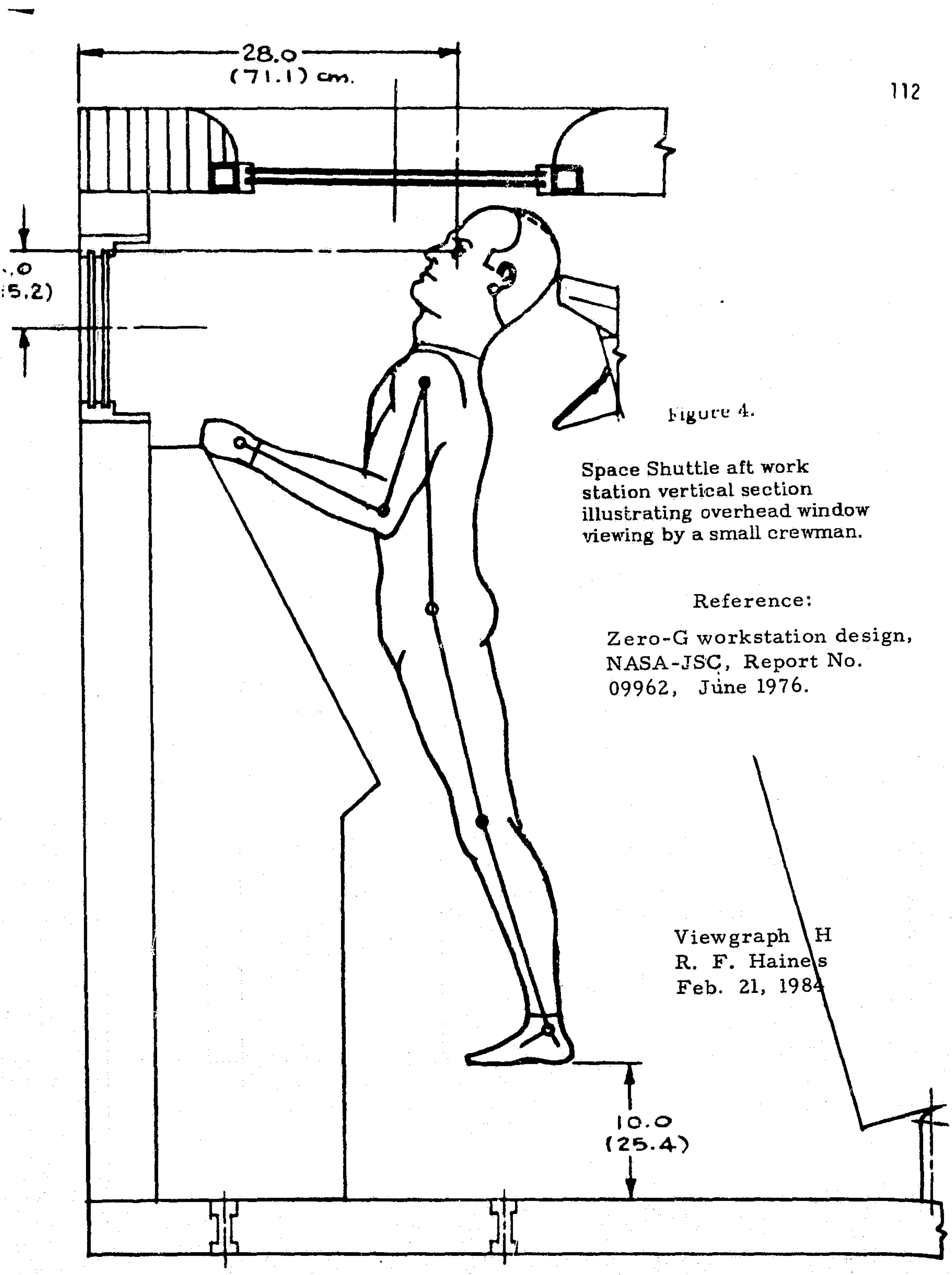


Figure 4.

Space Shuttle aft work station vertical section illustrating overhead window viewing by a small crewman.

Reference:

Zero-G workstation design, NASA-JSC, Report No. 09962, June 1976.

Viewgraph H
R. F. Haines
Feb. 21, 1984

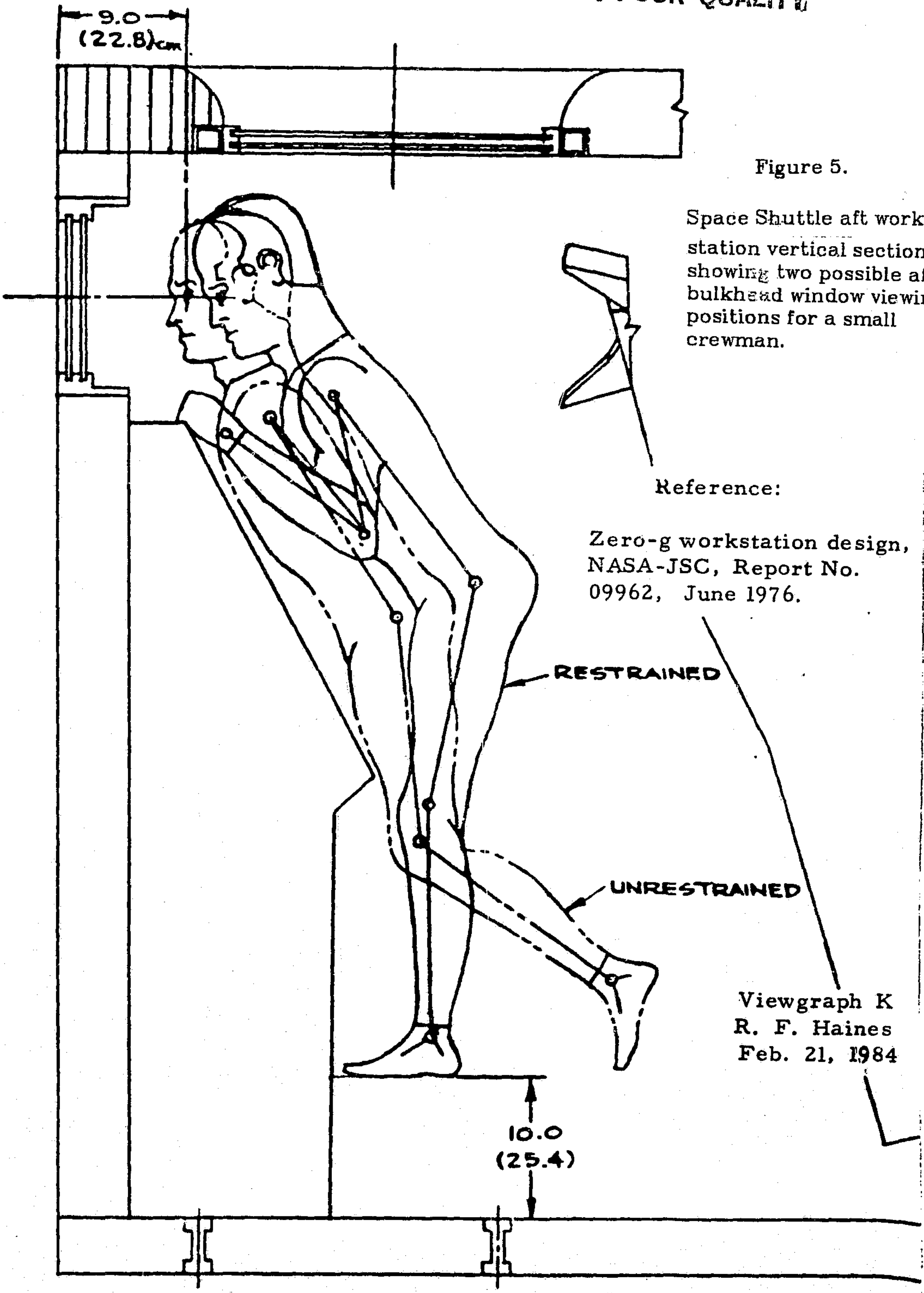


Figure 5.

Space Shuttle aft work station vertical section showing two possible aft bulkhead window viewing positions for a small crewman.

Reference:

Zero-g workstation design, NASA-JSC, Report No. 09962, June 1976.

Viewgraph K
R. F. Haines
Feb. 21, 1984

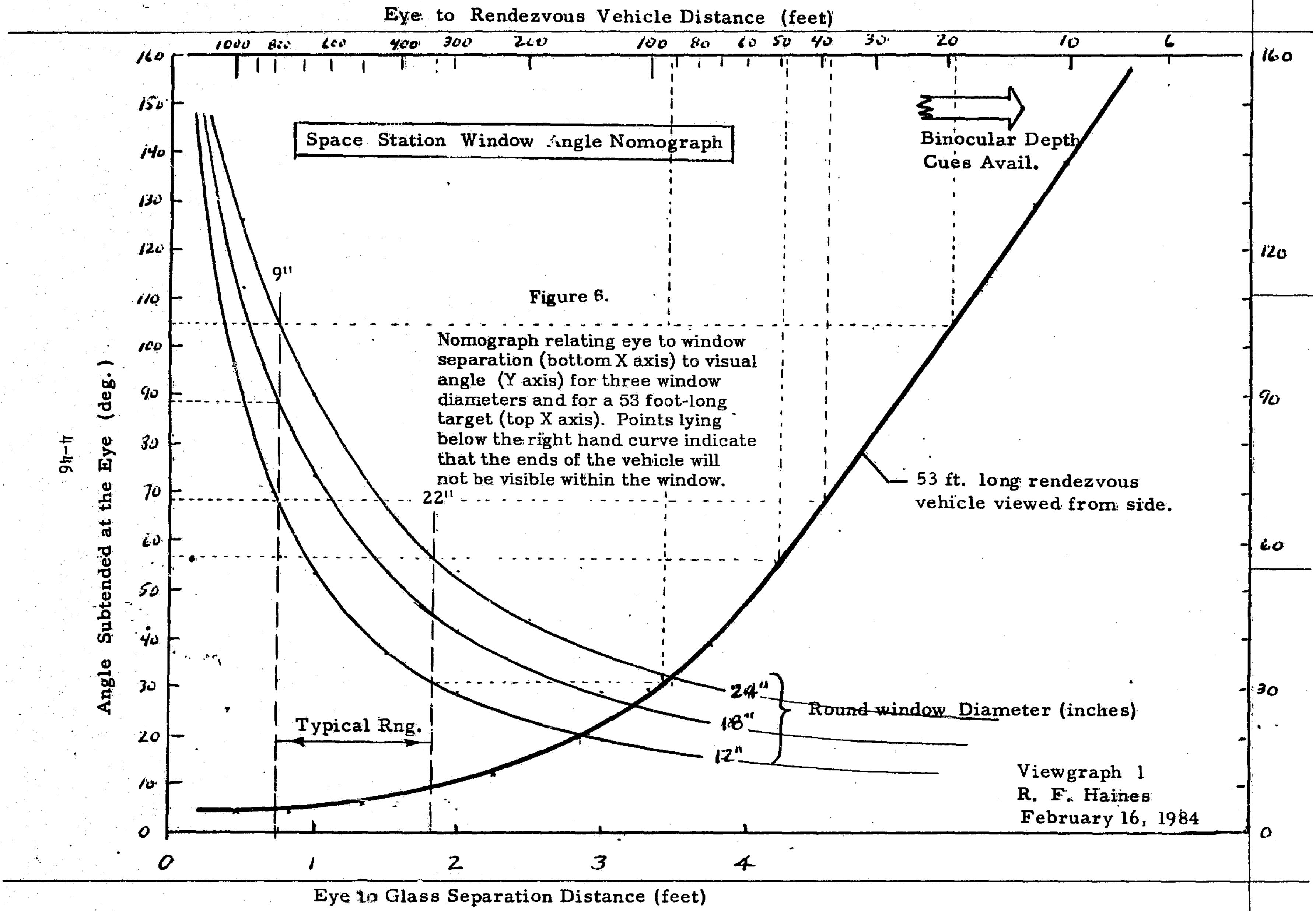


Figure 6.

Nomograph relating eye to window separation (bottom X axis) to visual angle (Y axis) for three window diameters and for a 53 foot-long target (top X axis). Points lying below the right hand curve indicate that the ends of the vehicle will not be visible within the window.

Viewgraph 1
R. F. Haines
February 16, 1984

AITOFF'S EQUAL AREA PROJECTION OF THE SPHERE

RADIUS OF PROJECTED SPHERE EQUALS ONE DECIMETER

AFT WINDOW FIELD-OF-VIEW

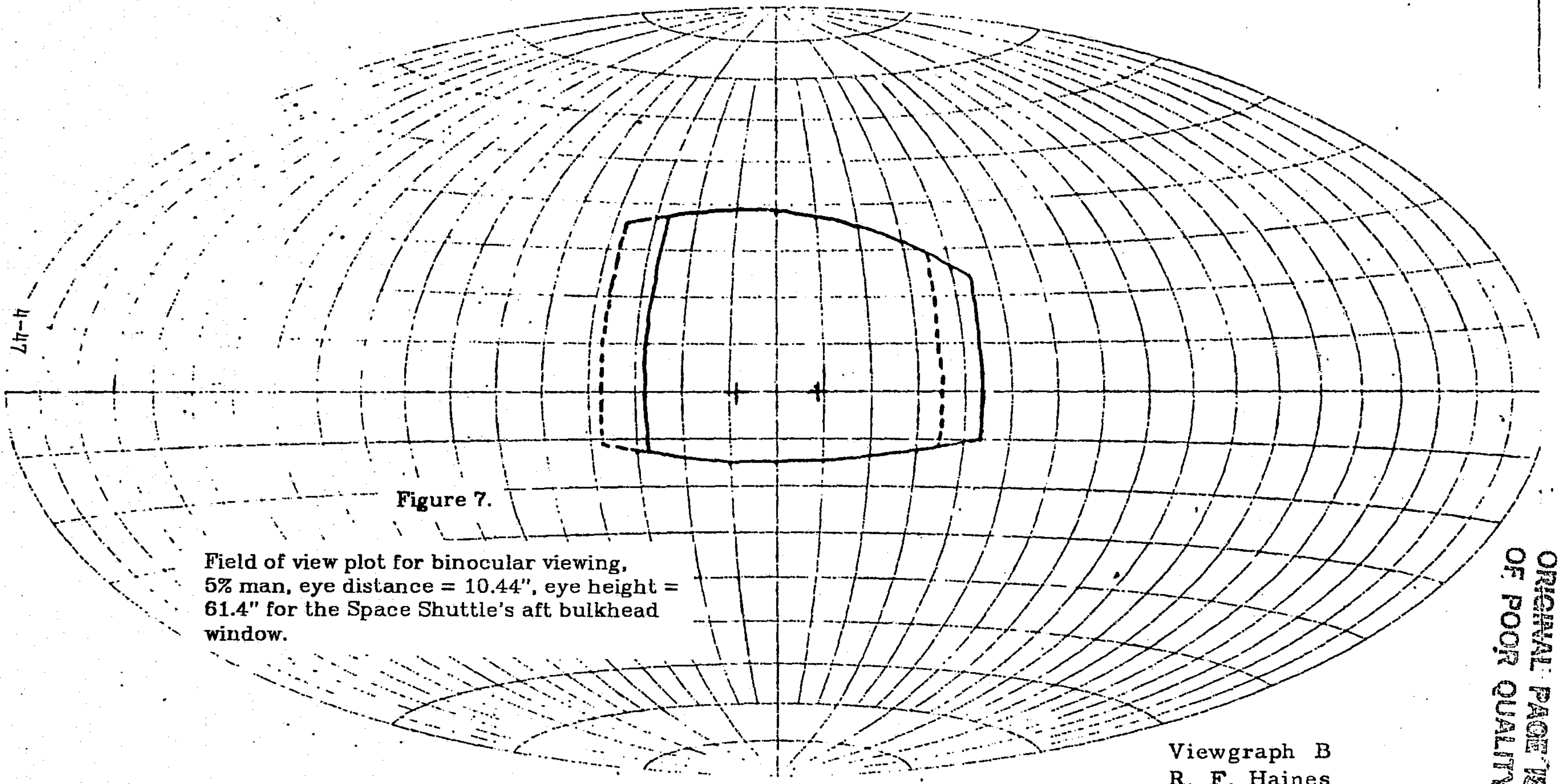


Figure 7.

Field of view plot for binocular viewing, 5% man, eye distance = 10.44", eye height = 61.4" for the Space Shuttle's aft bulkhead window.

Space Shuttle

Viewgraph B
R. F. Haines
Feb. 21, 1984

AITOFF'S EQUAL AREA PROJECTION OF THE SPHERE

RADIUS OF PROJECTED SPHERE EQUALS ONE DECIMETER

AFT WINDOW FIELD-OF-VIEW

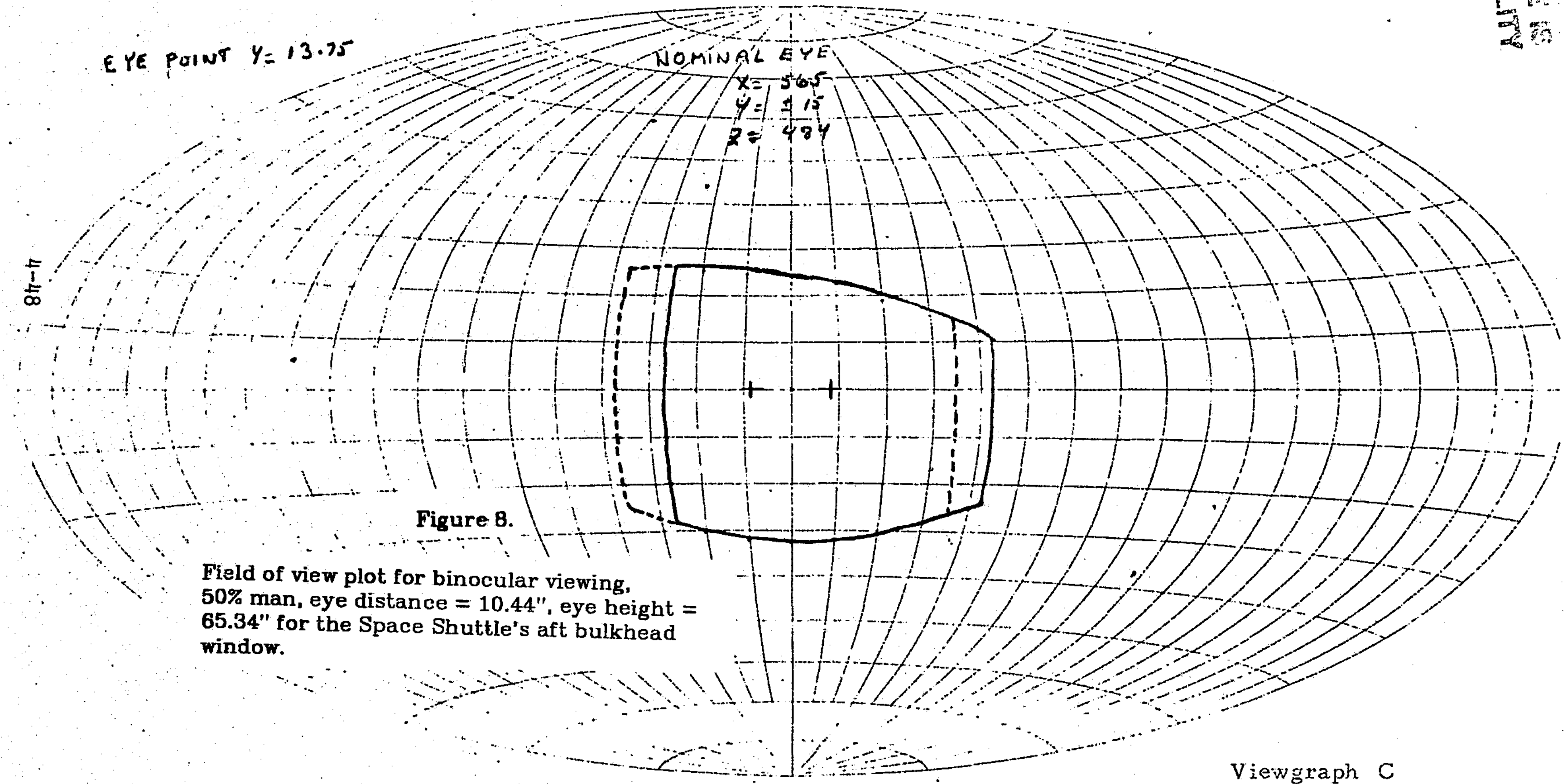


Figure 8.

Field of view plot for binocular viewing, 50% man, eye distance = 10.44", eye height = 65.34" for the Space Shuttle's aft bulkhead window.

Space Shuttle

Viewgraph C
R. F. Haines
Feb. 21, 1984

AITOFF'S EQUAL AREA PROJECTION OF THE SPHERE

RADIUS OF PROJECTED SPHERE EQUALS ONE DECIMETER

AFT WINDOW FIELD-OF-VIEW

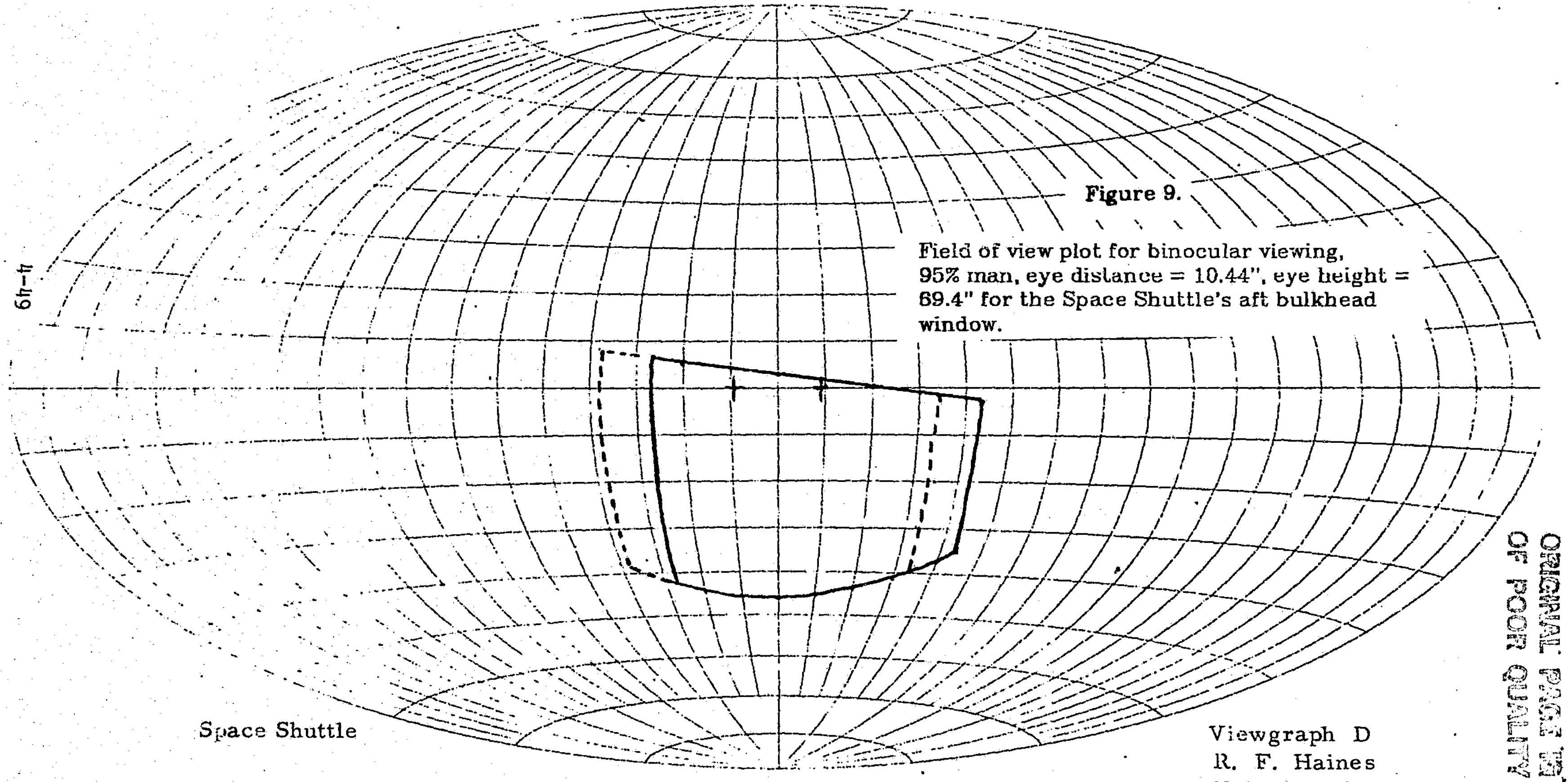


Figure 9.

Field of view plot for binocular viewing, 95% man, eye distance = 10.44", eye height = 69.4" for the Space Shuttle's aft bulkhead window.

Space Shuttle

Viewgraph D
R. F. Haines
Feb. 21,1984

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309

Space Shuttle
Rear Bulkhead Window

AITOFF'S EQUAL AREA PROJECTION OF THE SPHERE

RADIUS OF PROJECTED SPHERE EQUALS ONE DECIMETER

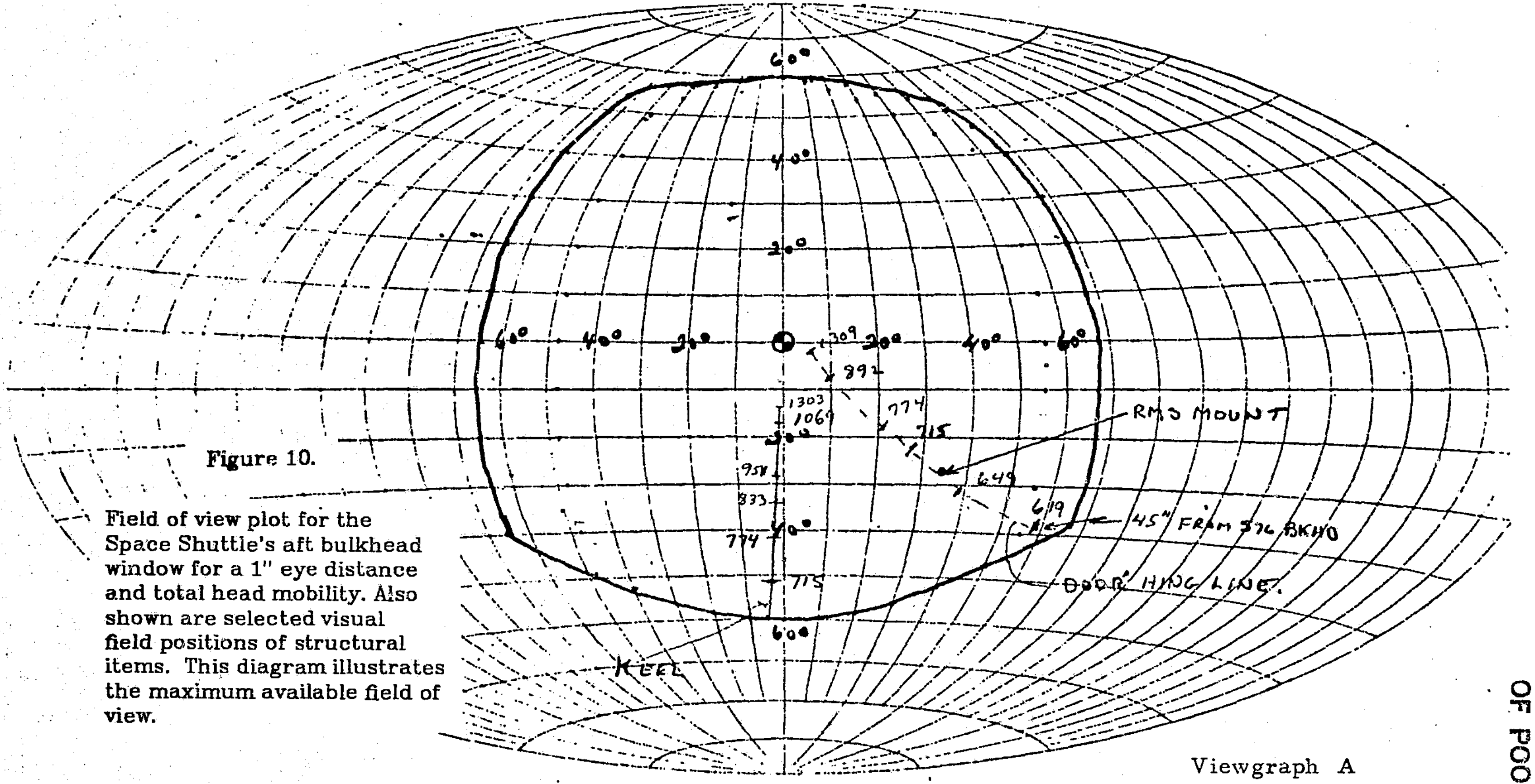


Figure 10.

Field of view plot for the Space Shuttle's aft bulkhead window for a 1" eye distance and total head mobility. Also shown are selected visual field positions of structural items. This diagram illustrates the maximum available field of view.

Viewgraph A
R. F. Haines
Feb. 21, 1984

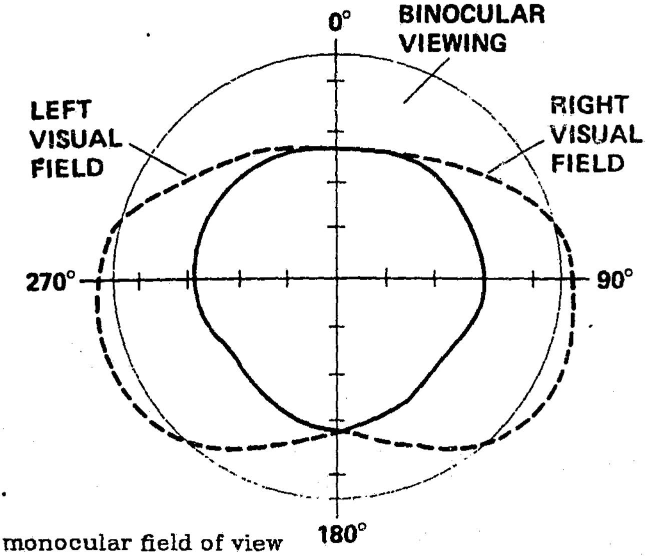
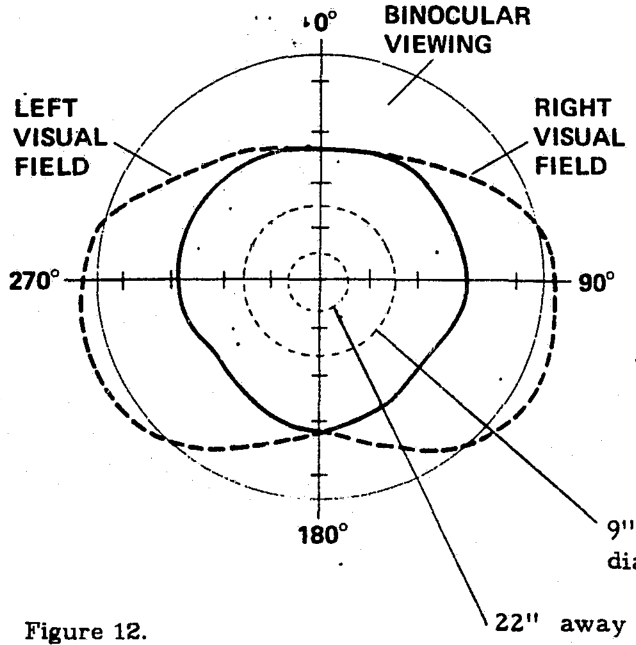


Figure 11.

Total binocular and monocular field of view of the human. The intersection of the horizontal and vertical lines is the line of sight. Each tick = 20°. The central area is the binocular visual field where both eyes receive corresponding images.

Viewgraph
R. F. Haines
February 21, 1984



9" away from a 12" diameter round window.

22" away from a 12" diameter round window.

Figure 12.
Field of view for two viewing distances and a 12" diameter round window relative to the binocular visual field.

Viewgraph
R. F. Haines
February 21, 1984

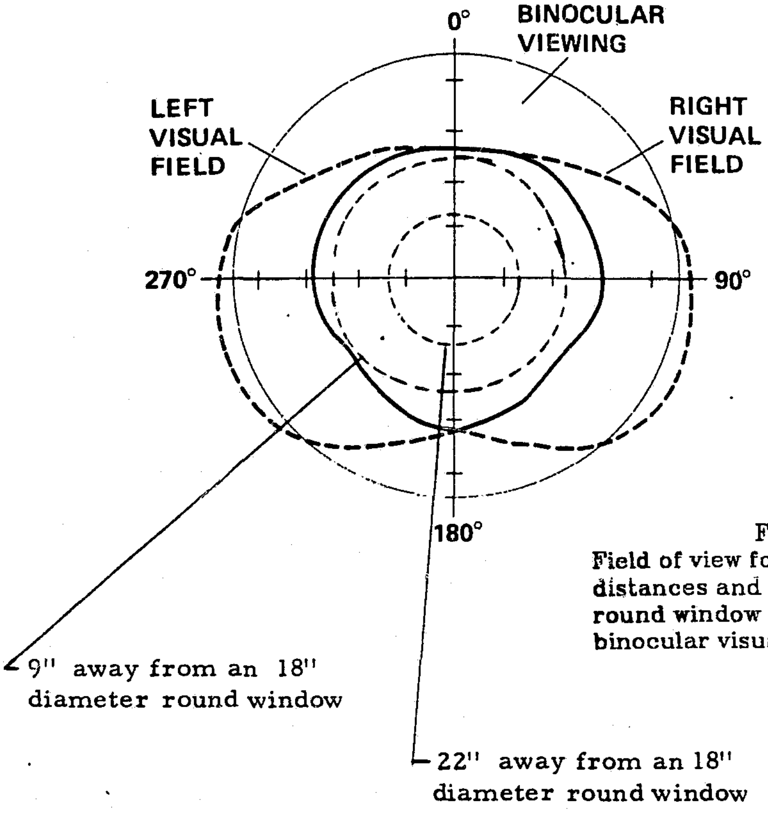


Figure 13.
Field of view for two viewing distances and an 18" diameter round window relative to the binocular visual field.

Viewgraph
R. F. Haines
February 21, 1984

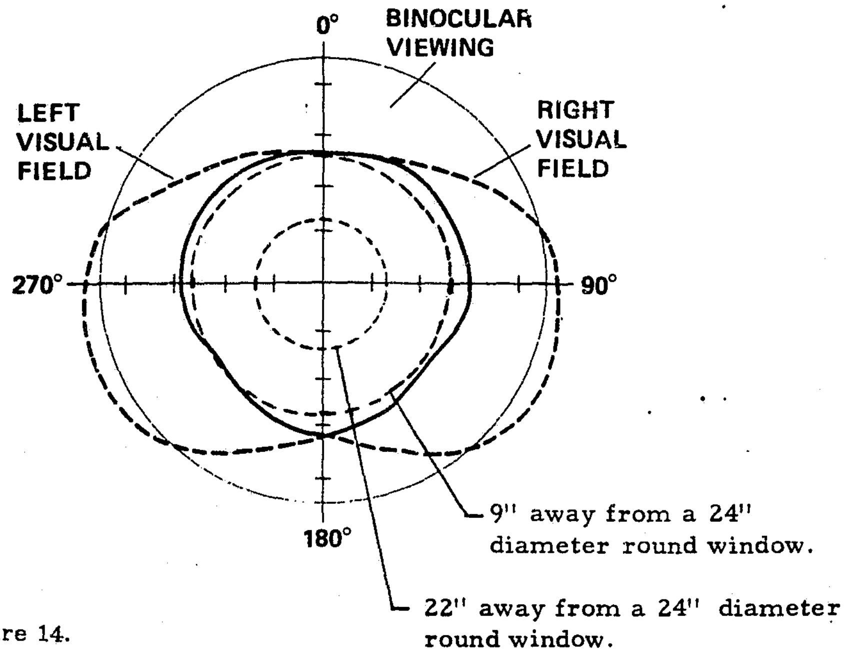


Figure 14.
Field of view for two viewing distances and a 24" diameter round window relative to the binocular visual field.

Viewgraph
R. F. Haines
February 21, 1984

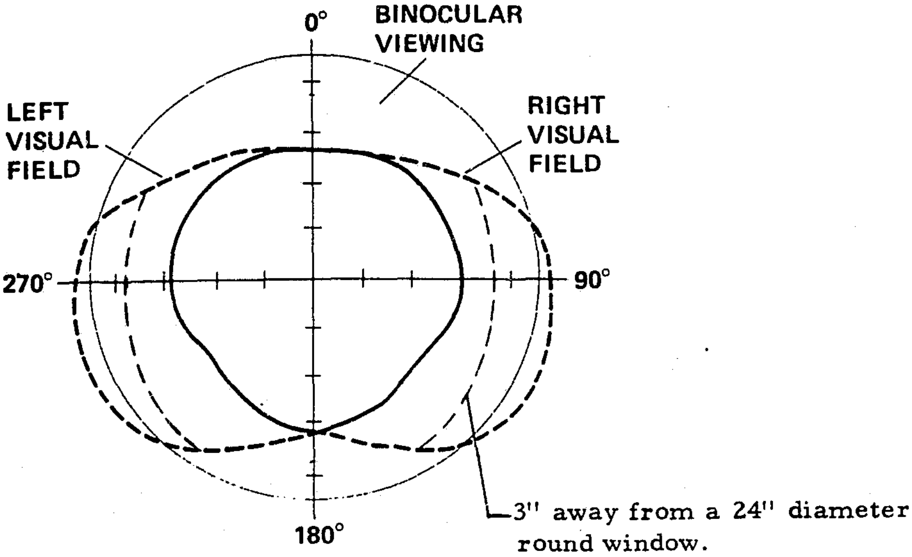


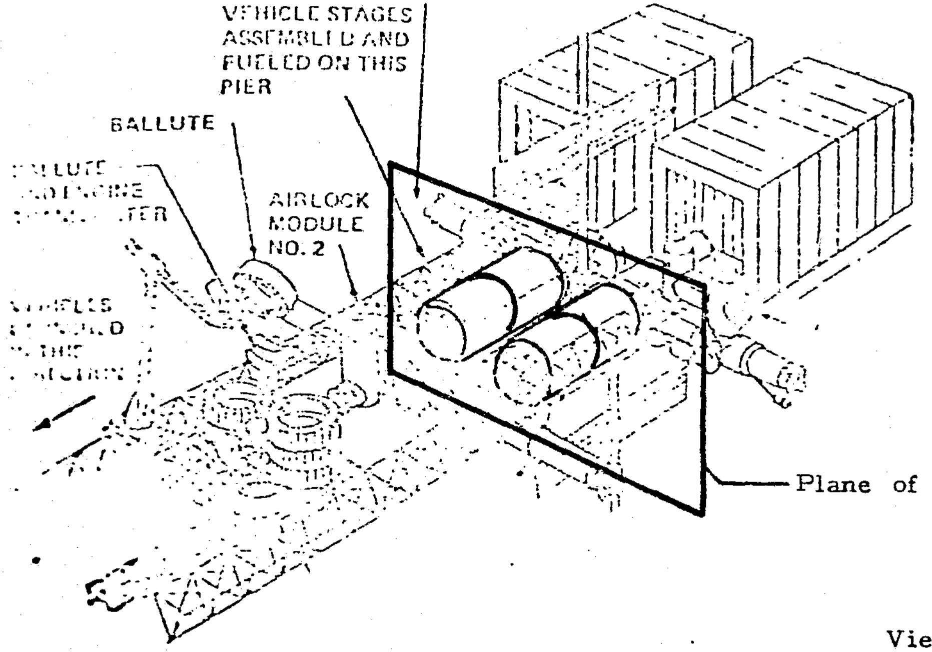
Figure 15.
Field of view for a 3" eye to window viewing distance and a 24" diameter round window relative to the binocular visual field.

Viewgraph
R. F. Haines
February 21, 1984

15

BOEING CONCEPT - OVERALL CONFIGURATION

Figure 16.
Illustration of plane cutting two parallel cylindrical modules.

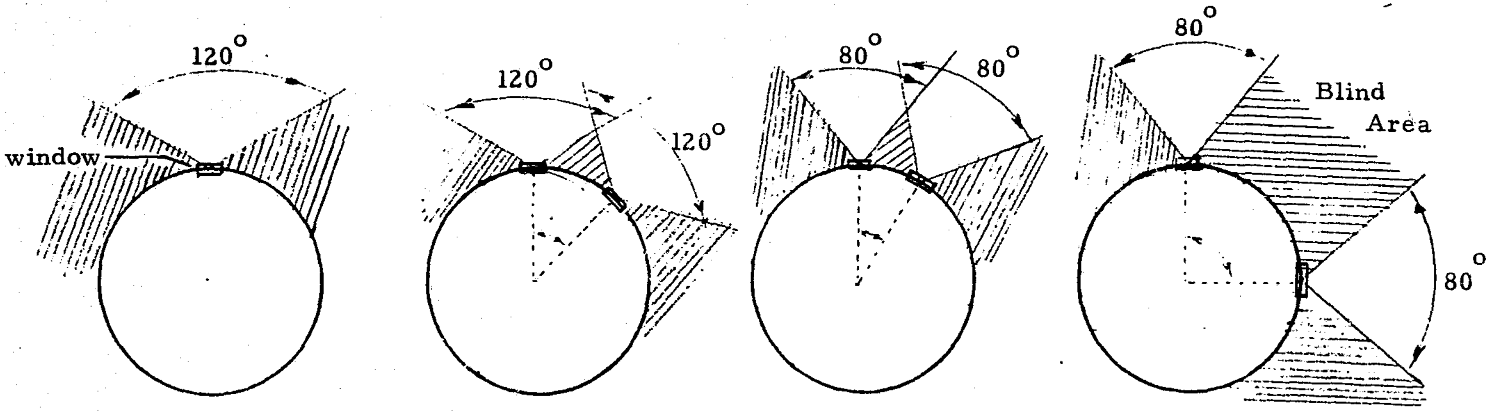


Plane of section

Viewgraph
R. F. Haines
February 21, 1984

EXTERNAL VISIBILITY OVERLAP

(Each Circle Represents Module Section)



One Window

Two Windows (45° spacing)

Two Windows (30° spacing)

Two Windows (90° spacing)

Figure 17.
Diagram to illustrate overlapping fields of view for various window angular widths and spacings. Note that the two factors may be traded off with each other to minimize blind areas (cross-hatched).

To minimize blind areas:

- Increase field of view angle per window
- Decrease window to window spacing
- Both of the above

Note: Field of view angle is <u>not</u> directly related to window area.

Viewgraph
R. F. Haines
February 16, 1984

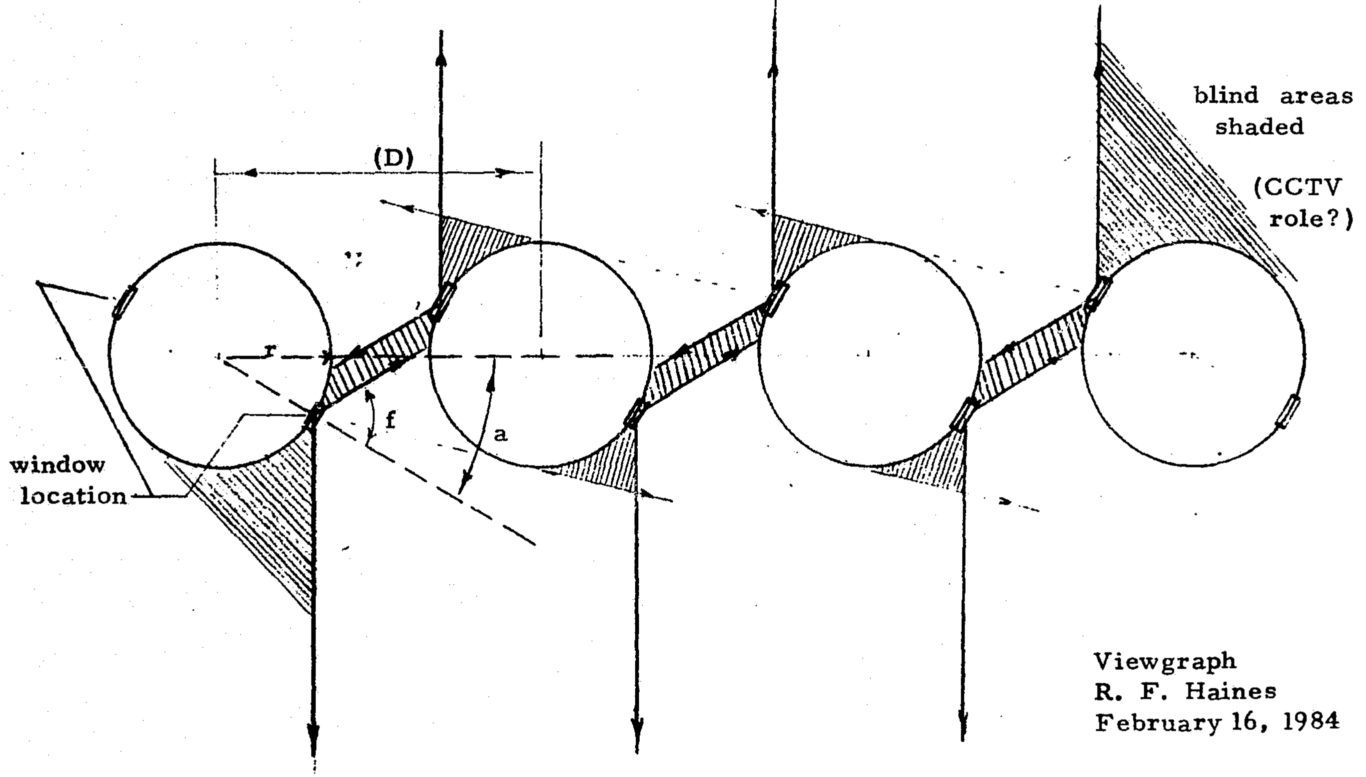
WINDOW FIELDS OF VIEW FOR IN-LINE MODULES

(Each Circle Represents a Module Section)

Key Variables:

D = Intermodule spacing = 3 r
a = window orientation angle off axis = 30°
r = module radius = r
f = field of view half-angle = 60°

Figure 18.
Diagram of four in-line modules each **having** two windows 180° apart as **shown.** Four design variables are also indicated. Closed circuit TV may be useful to "see" into otherwise blind **areas.**



Viewgraph
R. F. Haines
February 16, 1984

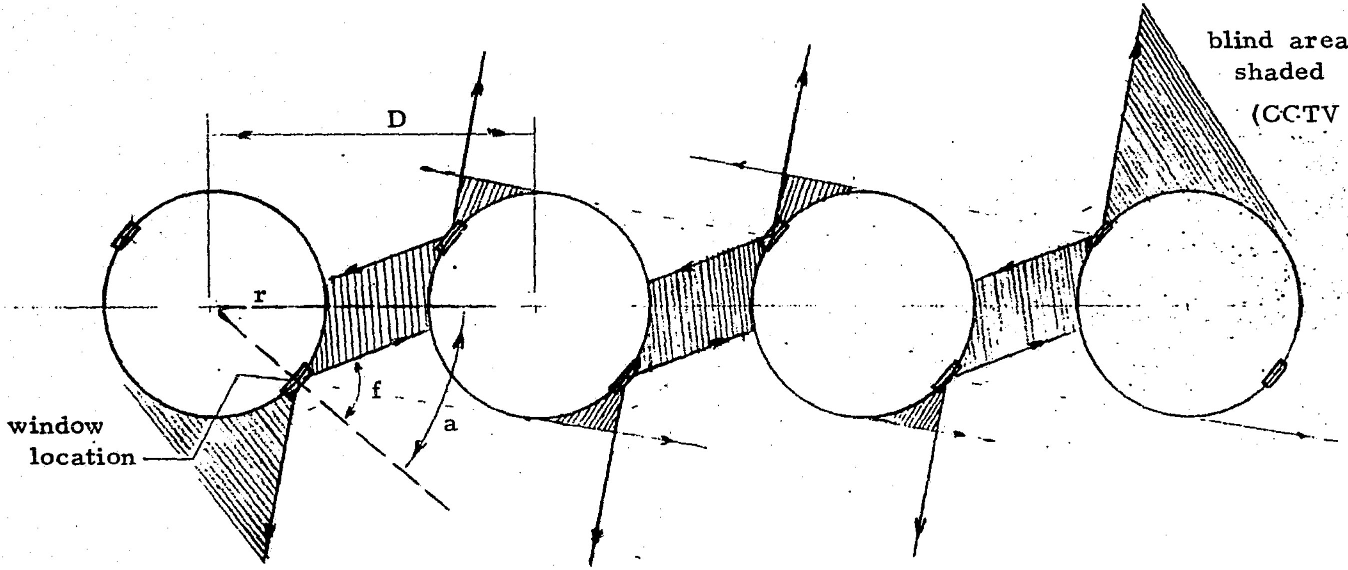
WINDOW FIELDS OF VIEW FOR IN-LINE MODULES

(Each Circle Represents a Module Section)

Key Variables:

D = intermodule spacing = 3 r
a = window orientation angle off axis = 45^o
r = module radius = r
f = field of view half-angle = 60^o

Figure 19.
Diagram of four in-line modules each having two windows 180° apart as shown. Compare this field of view configuration with that of Figure 18.



Viewgraph
R. F. Haines
February 16, 1984

SEMINAR ON SPACE STATION HUMAN PRODUCTIVITY

HUMAN FACTORS ISSUES IN SPACE STATION ARCHITECTURE

March 1, 1984

JOHNSON SPACE CENTER CONFIGURATIONS

Jim Lewis

Crew Station Design Section, SP-22

Man-Machine Analysis Branch

Man-Systems Division

Johnson Space Center (JSC)

Houston, Texas 77058

(713) 483-4161
FTS 525-4161

Pair (.1 = Hab. 1)
(.2 = Hab. 2)

HABITABILITY

FACILITIES

HAB MODULES	TYPE OF FLOORPLAN	*# OF CREW	GALLEY ORIGINAL, HALF, FULL	PERSONAL HYGIENE SM. ST. SKLB E1 & E2	HEALTH MAINT/MED STRAIGHT SQUARED	PRIVATE QUARTERS ORG. CDG ECONOMIZED	WARDROOM STANDARD EXPANDED	EXPANDED STOWAGE Y/N	CDMS Y/N
1	Longitudinal	4	Orig.	—	St.	0	—	N	N
1X	Cross-Sect.	4	0 (X-Sect.)	—	St (X-Sect.)	0 (X-Sect.)	—	N	N
1A	L	4	0	St.	—	0	—	N	N
1B (Bent)	L	4	0 (Bent)	—	St.	0	—	N	N
001.1	L	8	0	—	St.	CDG	—	Y	N
002.1	L	8	0	—	Sq.	CDG	—	N	Y
003.1	L	8	0	St.	St.	CDG	—	Y	N
004.1	L	8	0	—	Sq.	CDG	—	N	Y
005.2	L	8	half	—	—	CDG	Expanded	N	Y
006.1	L	8	full	—	Sq.	CDG	—	N	Y
007.1	L	8	full	Sky.	St.	CDG	—	N	Y
008.1	L	8	full	Sky.	St.	CDG	—	N	Y
009.2	L	6	half	Small	—	CDG	Standard	Y	Y
010.1	L	8	full	Expanded 1	St.	CDG	—	N	Y
011.1	L	8	full	Expanded 1	St.	CDG	—	N	Y
012.1	L	8	full	Expanded 1	St.	Economized	—	N	Y
014.2	L	6	half	Expanded 2	—	Economized	Expanded	Y	Y

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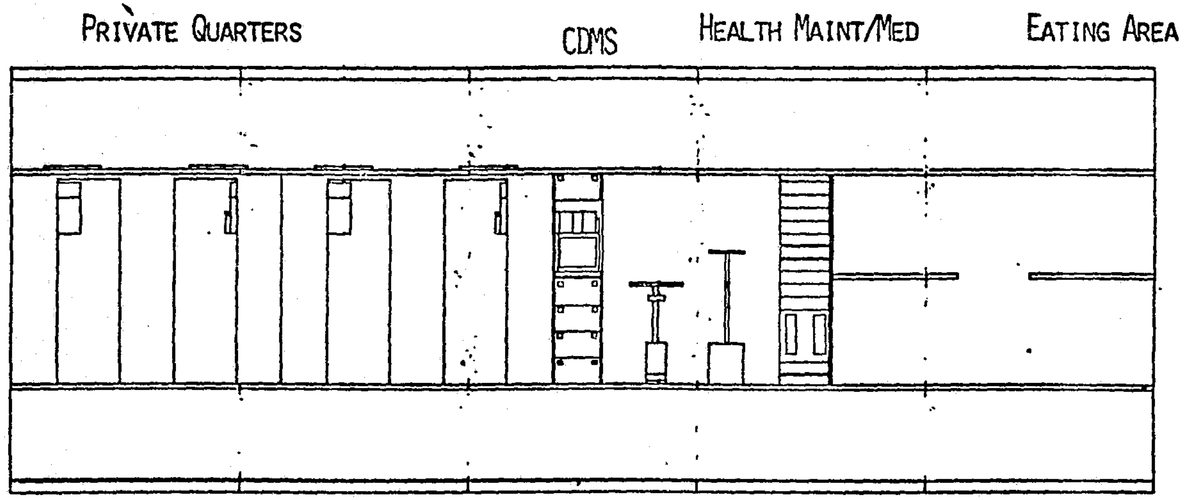
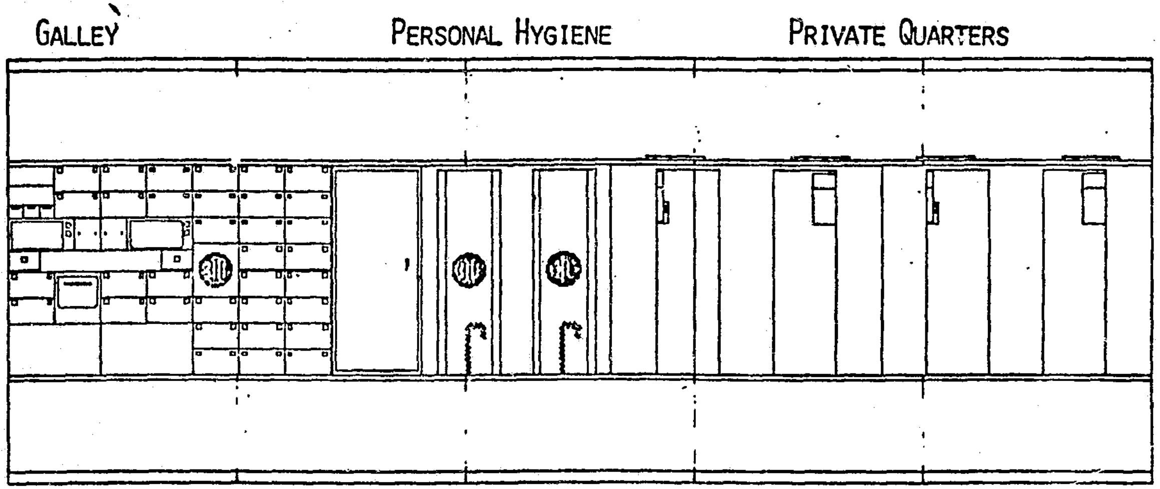
					REMARKS				
WORK AREA Y/N	"SIT DOWN" EATING Y/N	OFFICE Y/N	#SEGMENTS	*SEGMENT SIZE (EACH)		CV. FT./ PERSON			
N	Y (4)	N	2	9'					
N	Y (4)	N	2	9'					
N	Y (4)	N	2	9'					
N	Y (4)	N	2	9'					
N	N	N	4	9'					
N	N	N	3	9'					
N	Y (4)	N	4	9'					
N	Y (8)	N	3	(3)9'+5'	Hab. 1+				
Y	Y (8)	Y	3	(3)9'+5'	Hab. 2"				
N	Y (8)	N	3	(3)9'+5'	Same as + 004.1 with full galley				
N	Y (8)	N	4	9'	Hab. 1				
N	Y (8)	N	4	9'	Hab. 1 Identical to 007. with galley and HMF/PHF switched				
Y	Y (4)	Y	4	9'	Hab. 2				
N	Y (8)	N	4	9'	Identical, with galley & HMF/PHF switched				
N	Y (8)	N	4	9'					
N	Y (8)	N	5	88" each	Hab. 1				
Y	Y (6-12)	Y	5	88" each	Hab. 2				

RIGHT SIDE VIEW HABMOD #1



MOD 012

LEFT SIDE VIEW HABMOD #1



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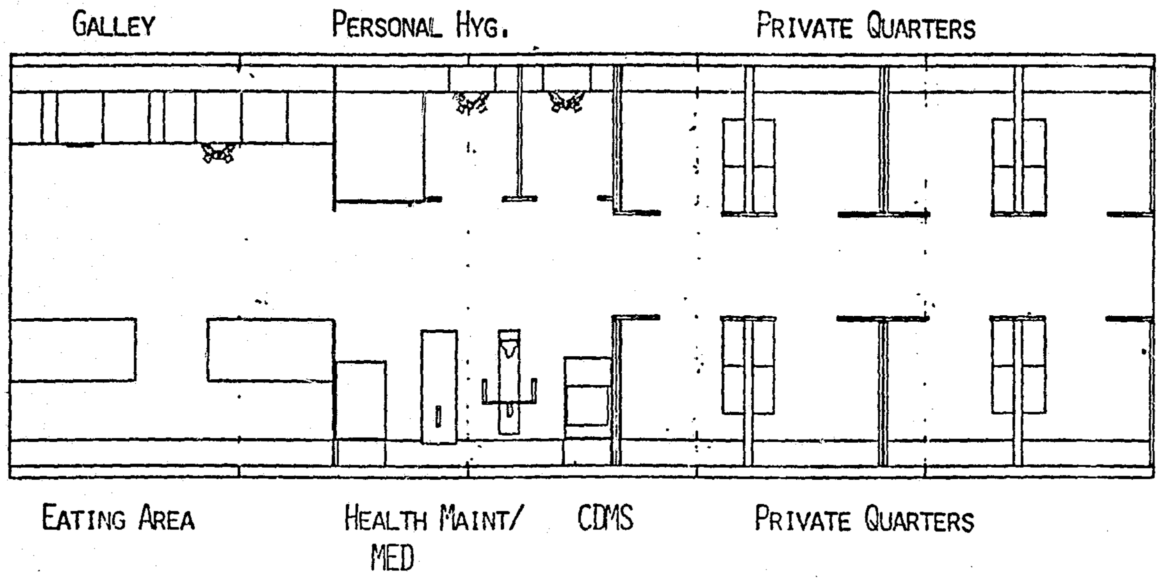
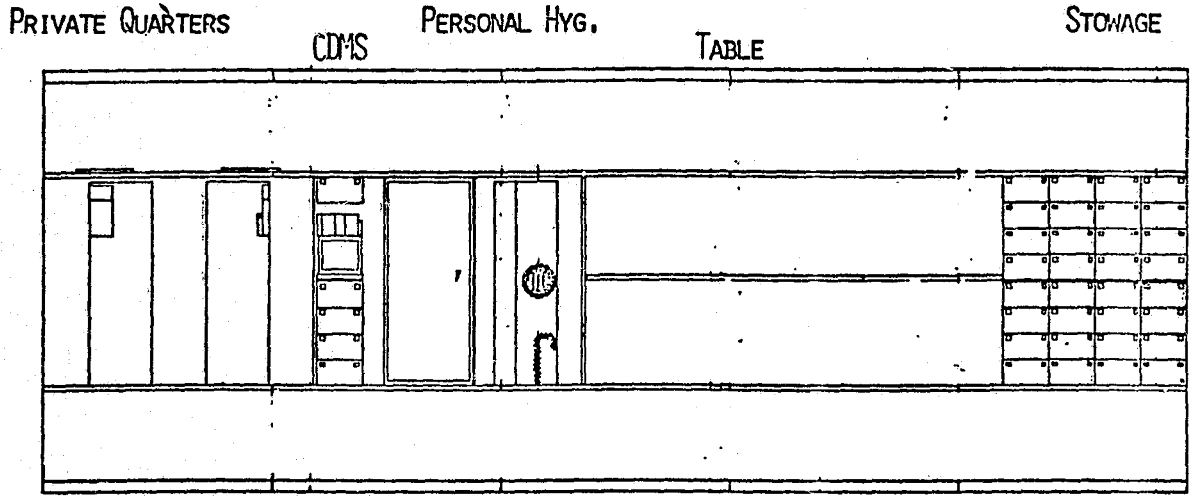
TOP VIEW HABMOD #1



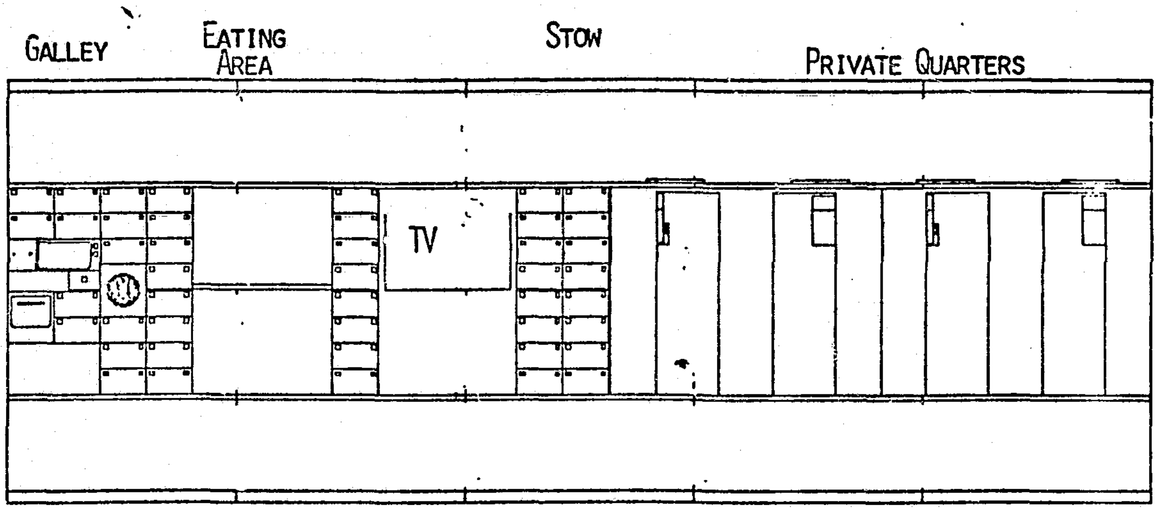
PLAID

RIGHT SIDE VIEW HABMOD #2



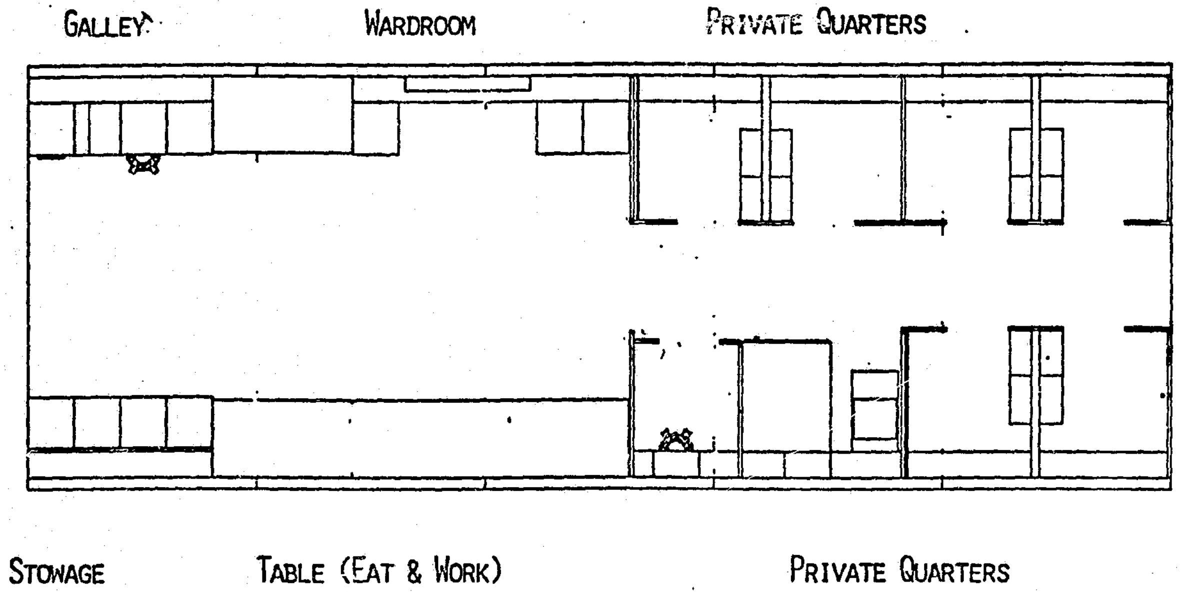
MOD 014

LEFT SIDE VIEW HABMOD #2



MOD 014

TOP VIEW HABMOD #2



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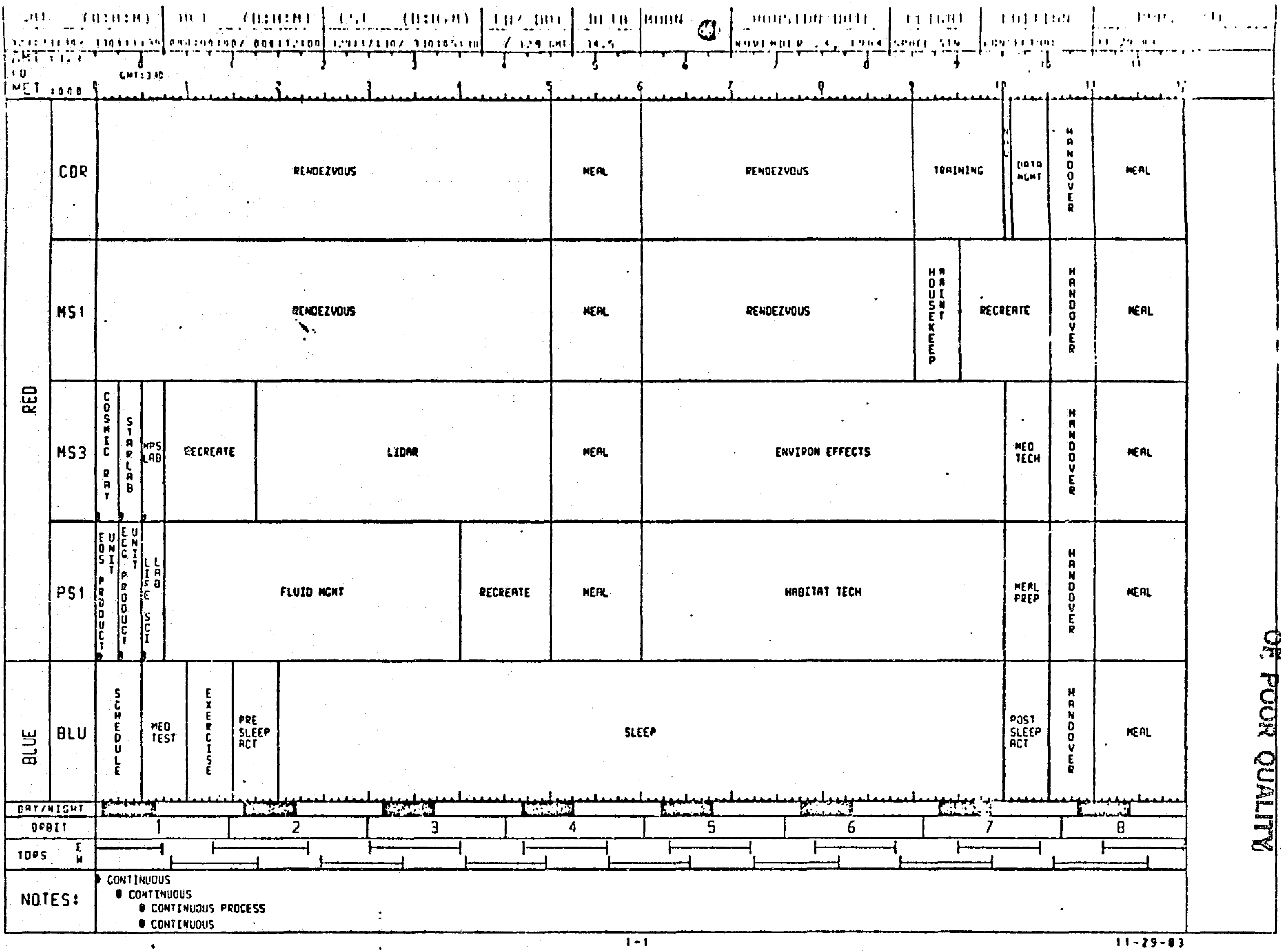

Figure 4.10-1. Conceptual 48-hour Space Station Timeline

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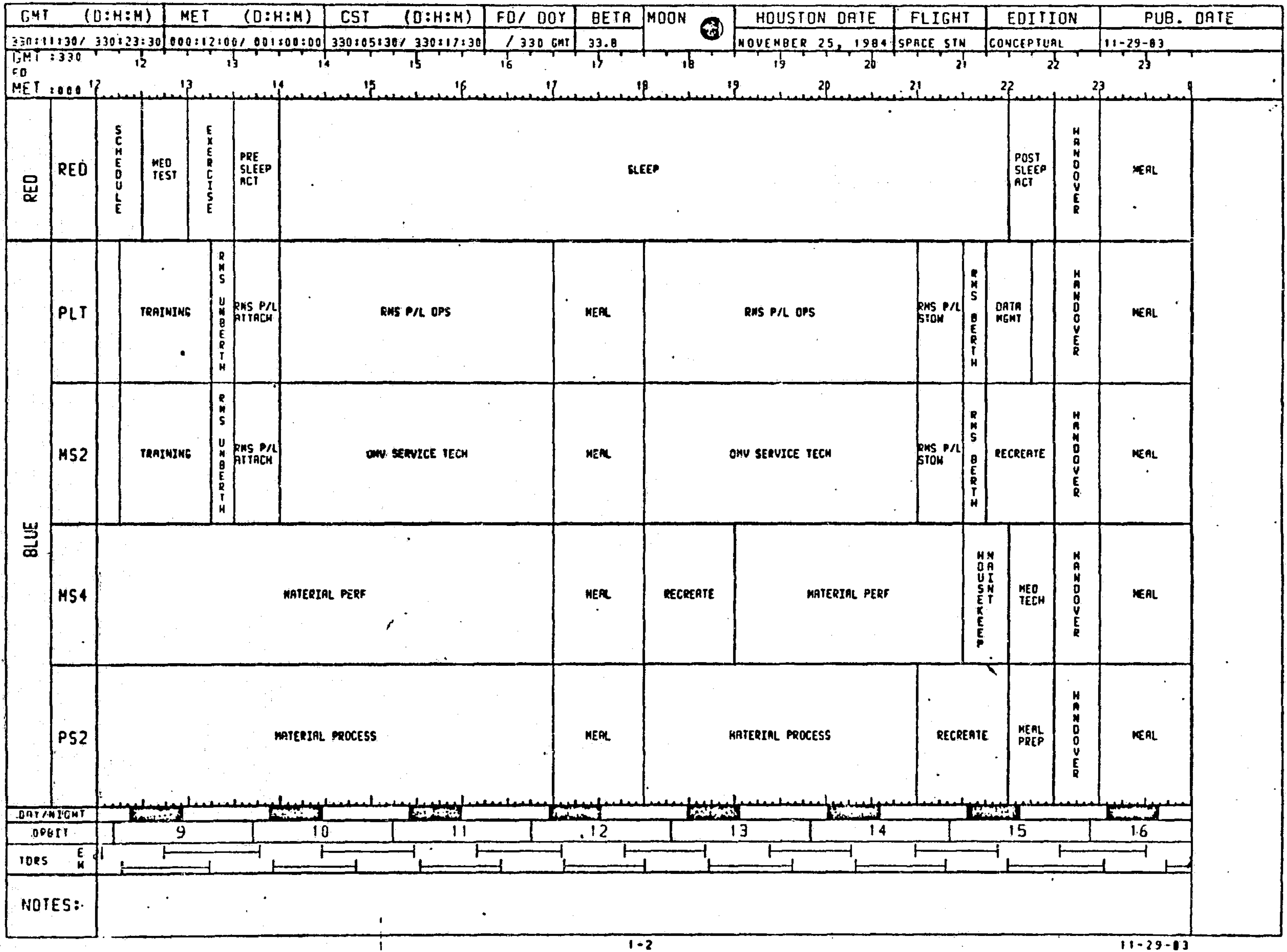

Figure 4.10-2. Conceptual 48-hour Space Station Timeline

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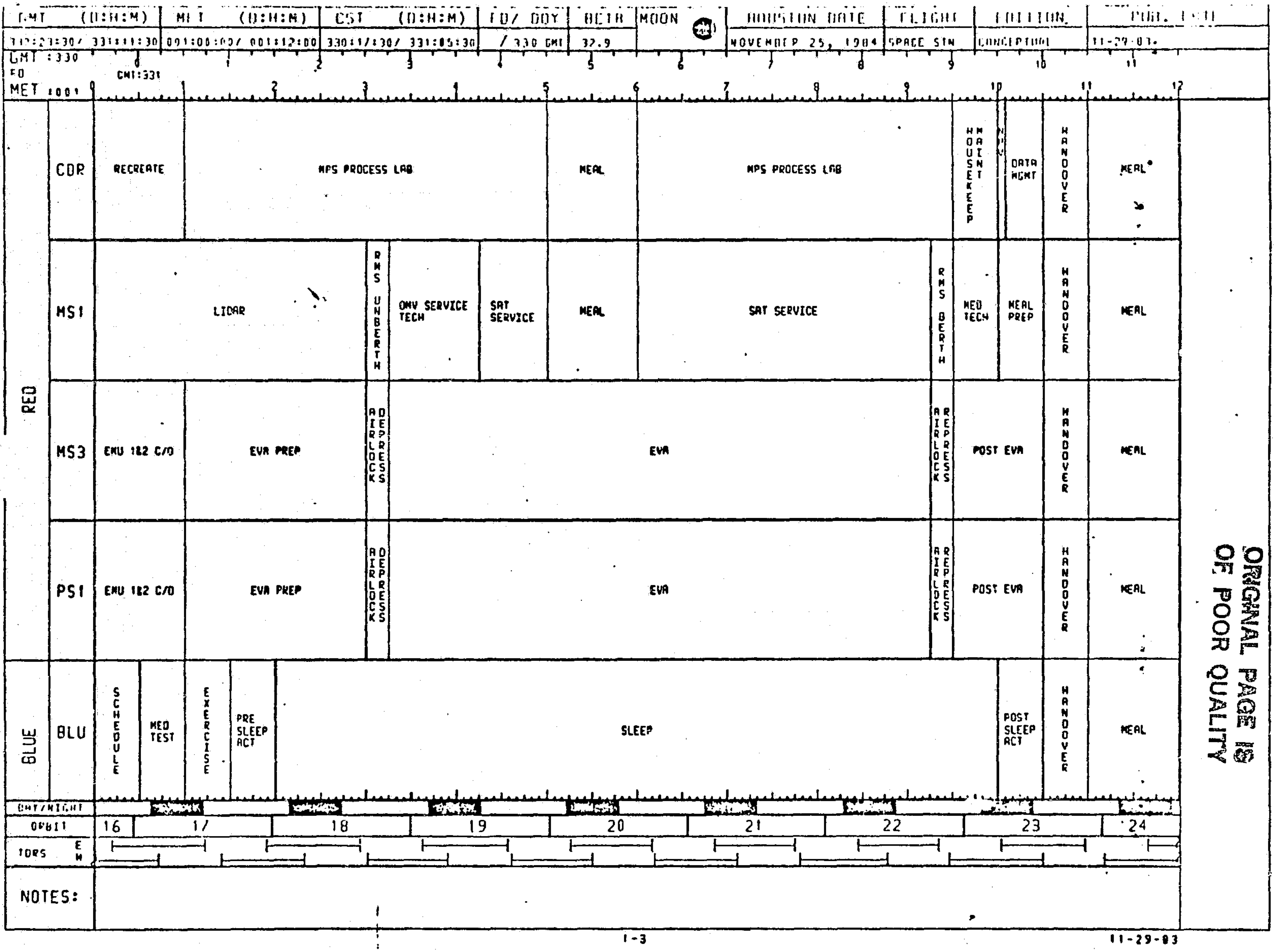

Figure 4.10-3. Conceptual 48-hour Space Station Timeline

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GMT (D:H:M)	MET (D:H:M)	CST (D:H:M)	FD/ DOY	BETA	MOON	HOUSTON DATE	FLIGHT	EDITION	PUB. DATE
331:11:30/ 331:23:30	001:12:00/ 002:00:00	331:05:30/ 331:17:30	/ 331 GMT	31.9	◑	NOVEMBER 26, 1984	SPACE STN	CONCEPTUAL	11-29-83

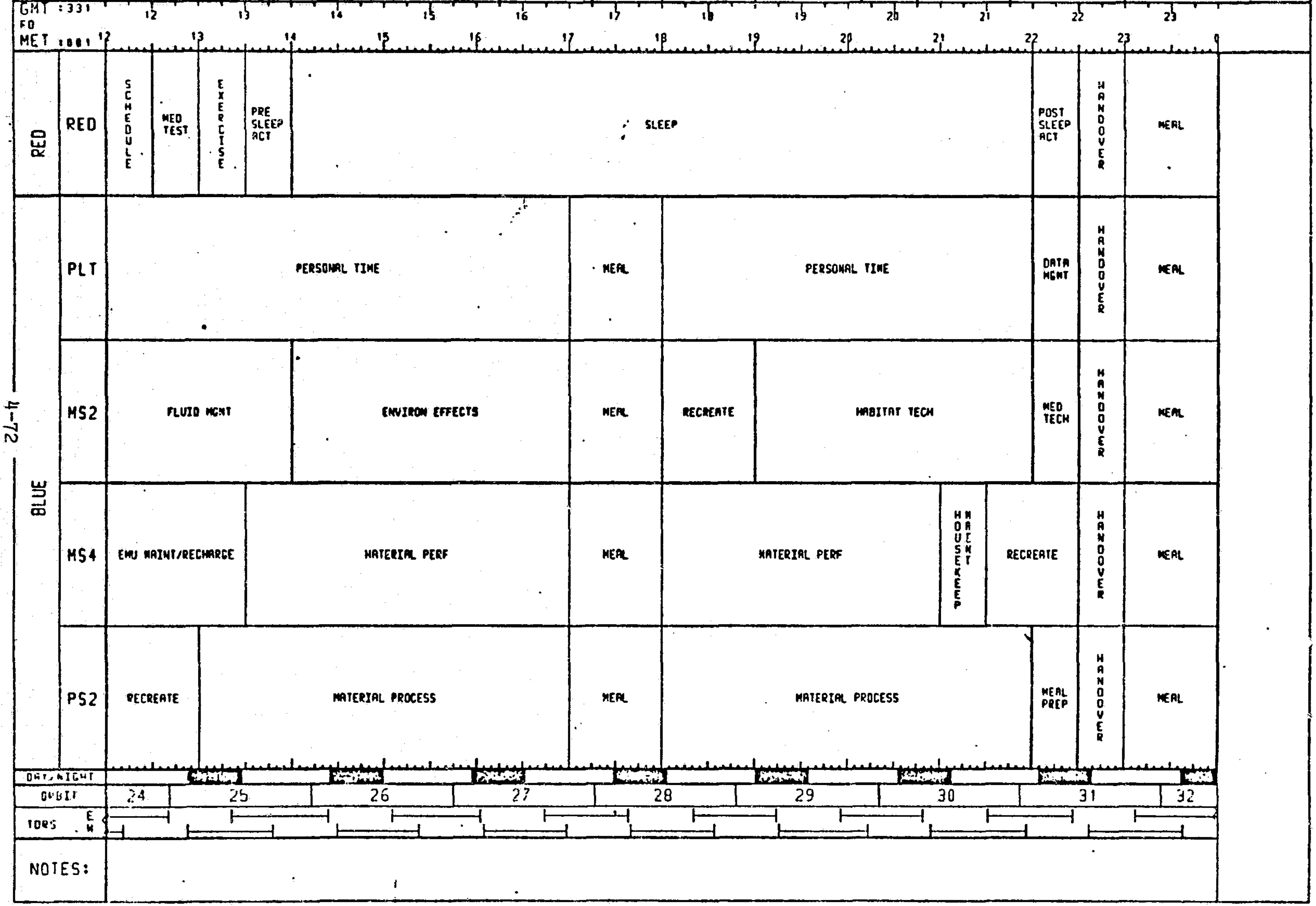


Figure 4.10-4. Conceptual 48-hour Space Station Timeline

SPACE STATION AUTOMATION ASSESSMENT

MAN-MACHINE TRADEOFF STUDY

PASADENA, CALIFORNIA 91109

ABE FEINBERG
WAYNE ZIMMERMAN

MARCH 1, 1984

CONTENTS

BACKGROUND

- APPLICATION OF ADVANCED SPACE TECHNOLOGY INVOLVED THE PRIVATE SECTOR (E.G., BIOMEDICINE, SOLAR POWER PLANTS, ALTERNATE ENERGY SOURCES, ETC.).
- NEW TECHNOLOGY APPLICATIONS REQUIRED A BETTER UNDERSTANDING OF ACTUAL HUMAN TASKS/INTERFACES.
- THERE WAS A NEED TO SYSTEMATICALLY DEFINE HUMAN INTERFACES.
- FOR THOSE AREAS WHERE AUTOMATION LOOKED PROMISING, THERE WAS A NEED TO ESTABLISH A SOUND MEANS OF ASSESSING HUMAN/MACHINE TRADEOFFS (I.E., SYSTEM EFFICIENCY TRADEOFFS).
- DOE RESEARCH RELATED TO REMOVING WORKERS FROM HAZARDOUS ENVIRONMENTS - SPECIFICALLY UNDERGROUND COAL MINING.
- SPACE STATION EFFORT COMMENCED JANUARY 1984.

BASIC APPROACH

- ESTABLISH TASK PROBLEM AREAS IN NEW TECHNOLOGY VIA INTERVIEWS OR ACTUAL INDUSTRIAL ENGINEERING STUDIES (E.G., INTERVIEWS WITH OPERATORS, OR IDENTIFYING HIGH TASK TIME DRIVERS).
- DEVELOP LIST OF POTENTIAL AUTOMATION CANDIDATES.
- PERFORM TASK AND SYSTEM CRITICAL PATH ANALYSES, SUPERIMPOSE POTENTIAL AUTOMATION CANDIDATES, AND ASSIGN ATTRIBUTES TO ASSESS IMPACTS FOR EACH AREA (E.G., COST, TASK EFFICIENCY IMPROVEMENT, SAFETY IMPROVEMENT, ETC.).
- COMFIRM IMPACTS OF ATTRIBUTES BY TALKING TO EXPERTS.
- DEVELOP CONCEPTUAL DESIGNS AND COSTS NECESSARY TO IMPLEMENT AUTOMATION CANDIDATES.
- ASSESS COST BENEFITS (I.E., WEIGH THE COST OF AUTOMATING AGAINST THE BENEFITS GAINED).
- RANK AUTOMATION CANDIDATES AS A FUNCTION OF MOST FAVORABLE RESPONSE TO ATTRIBUTES AND OVERALL COST BENEFITS.

PROCESS

- IDENTIFY KEY SPACE STATION MODULES
- DEVELOP MOVING BASELINE FOR DETERMINING SPACE STATION COMPONENT AUTOMATION OPTIONS
- PERFORM TASK ASSESSMENT
- DEVELOP ATTRIBUTES FOR ASSESSING COSTS AND BENEFITS OF ASSIGNING TASKS TO TECHNOLOGIES
- PREPARE LIST OF POTENTIAL TRADEOFFS

AF WFZ 4
3/1/84

SELECTION OF KEY MODULES FOR FY 1984 TRADEOFF STUDY

MODULE	LEVEL OF INTEREST
UTILITY	HIGHEST
DOCKING	HIGHEST
LOGISTICS	HIGH
LABORATORY	HIGH
HABITAT	MODERATE
REMOTE ARM	MODERATE

CRITERIA/ATTRIBUTES FOR TASKS AND TECHNOLOGY ASSIGNMENTS

(TENTATIVE)

SAFETY

MISSION AND OPERATIONS TIME

PAYLOAD

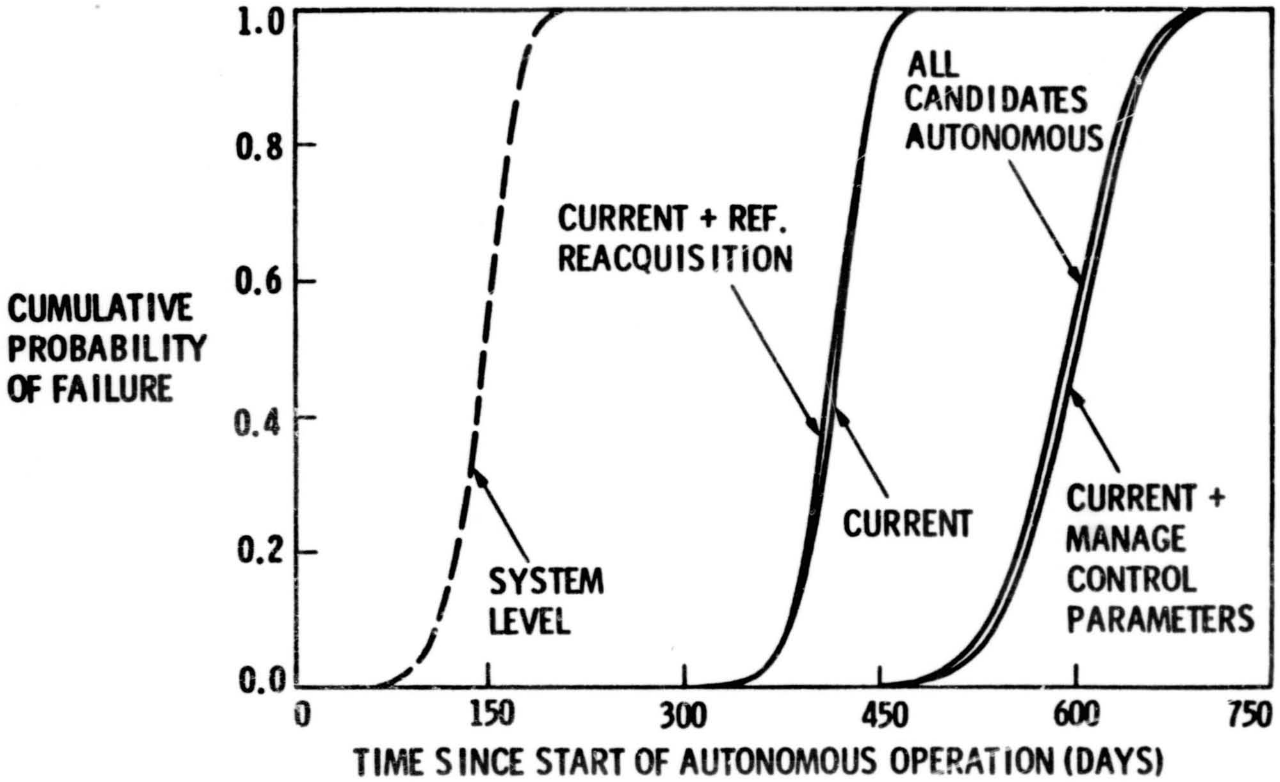
POWER

RELIABILITY

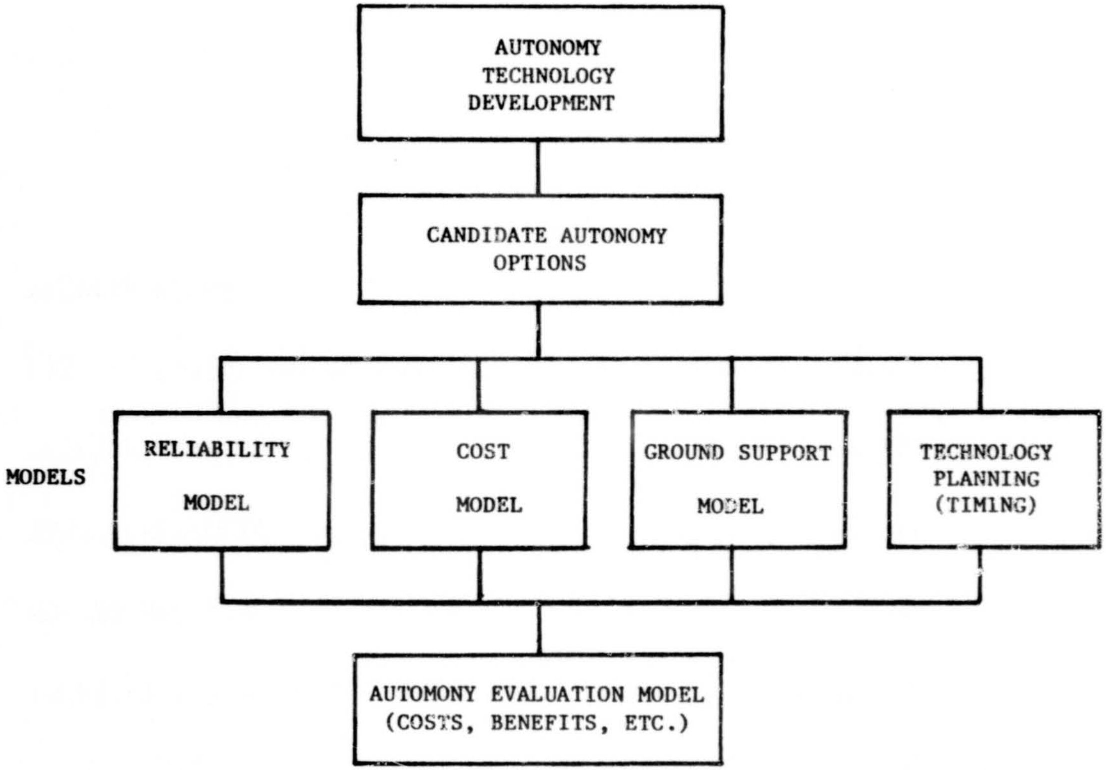
R&D TIME

COST

EXAMPLE: AUTONOMY IMPACT ON RELIABILITY



AUTONOMY EVALUATION



AUTONOMY TECHNOLOGY DEVELOPMENT

CANDIDATE AUTONOMY OPTIONS

MODELS

RELIABILITY MODEL

COST MODEL

GROUND SUPPORT MODEL

TECHNOLOGY PLANNING (TIMING)

AUTOMONY EVALUATION MODEL (COSTS, BENEFITS, ETC.)

JHS/AS/WFZ 8
3/1/84

SCHEDULE

TASK	SCHEDULED COMPLETION
IDENTIFY KEY MODULES	COMPLETED
MOVING BASELINE	3/31/84
TASK ASSESSMENT	4/30/84
DEVELOP ATTRIBUTES	5/31/84
LIST POTENTIAL MAN/MACHINE TRADEOFFS	7/31/84
PREPARE REPORT	9/30/84

N85-29562

February 28, 1984

SOME IDEAS AND QUESTIONS REGARDING SPACE STATION DESIGN FOR HUMAN USE

Sharon Skolnick, B.I.D., M.Ed.

As a designer and writer, I appreciate the creative thinking of the late Buckminster Fuller, who once referred to the earth as 'a spaceship on a gravity leash.' When astronaut Bruce McCandless recently separated from his umbilical cord and floated free, it seemed like a birth-- as though the gravity leash had been dropped and a new, human planet had been born.

If the earth is a spaceship, we are all astronauts. Fragile, tough, self-regulating and cyclically operating, we jump on and off of our planet all of the time, without needing to be rooted like plants. But too many people forget how interwoven with earth we are, how consistently we need not only food, warmth and a roof, but nurturing, meaning, spiritual sustenance, love, and human touch-- and humor.

What has struck me over and over when I hear reports from the scientists and pilots who have reached outer space is the laughter: the jokes these people crack, and the stunned, poetic reaction to the beauty they see, the whole earth in space. And how philosophical and inspired many of them become. This in spite of living in cramped tin cans with levers and buttons and flashing lights.

To optimize a long term outer space environment, I think we need to research and draw upon what is really human and humane; what individual

Raymond Loewy, William Snaith Associates, Industrial Designers in New York City. I was the only woman on the product design team. Though the others may have seen my colorful banners, multilevel strap-in tables, hanging plants and grow-lights as "feminine" and "untechnical", I am a female human and I addressed my design skills and analytical thought to the humanity of the passengers, the spirit of fun and play in a new kind of space. It is exciting to be able to present the idea now, 15 years later, when humanism and high tech are starting to interface.

Just because we are entering the realm of science fiction doesn't mean we need to stick with set designs, or send people out to live in a Greyhound bus station. On the other hand, the appointments of a luxury ocean liner, all polished woods and gleaming brass and palm trees, may be inappropriate where minimal weight has to do maximum work.

I think we need nests in the trees for a high flyers: private organic spaces if the outer shell is vast and cylindrical and people are floating; or else group gathering areas of large dimensions if the general milieu is tight little spaces. We need touches of whimsy, of softness, and lots of places for the individual to put or choose personal objects and images, to make the station homey for that person.

The human animal is not a machine. Maybe we need to study the animals' environments too.

Some specific suggestions my friends and I have come up with to humanize a space environment include:

-- Natural, not plastic, materials. Natural fabrics on the walls, with banks of subtly colored lights the passenger can change at will, since color is so persons require and desire to keep them healthy, happy, productive and secure. What colors, shapes, spaces, what kinds of order or clutter make us feel good, therefore becoming more stable, optimistic and efficient.

I believe two places to look for applicable answers are the indigenous cultures of planet earth, shelter design and living patterns of native people: Plains and Southwest Indians, nomadic Semitics and Asians, and Polynesian sailors who spent long months on the high seas with their families, their thatched shelters, their domestic animals and some coconut trees.

That's one place to look, because people who can make a human environment from available materials in an economic, ergonomic way, while at the same time keeping their spiritual energies focused through meaningful ritual and reverence, have much to teach the high tech world.

The other place with some answers may be the prisons. What does not make for a human environment? What is oppressive, dulling, psychologically upsetting of balance, dehumanizing? How to avoid those traps on a mini-planet orbiting in space may let us know, ultimately, how to stop torturing human beings in various kinds of institutions on earth. It looks like environmental research for space could have some global repercussions as well, if it could be approached from an ethically high place.

Obviously the answers are not all going to come from the engineers and ergonomics experts and corporate white males over 50, or we wouldn't be here today.

When I designed a three-dimensional weightless cafeteria for the space station set to go into orbit in 1985, the year was 1969 and the place was psychologically important for peace of mind. Pattern templates to create light patterns at will.

-- A lot of plant material and grow-lights, some plants growing in earth, so the smell and feel of earth is present. A few uncaged, well-behaved animals, shuttle-pets: birds; dogs; cats; turtles; fish...

-- Use of natural wood for built-in furnishings.

-- Muted, rear screen still-picture projection from a large library of paintings, textiles, sculptures and photographs, chosen by the individual or group to express current interests, ease tensions and share cultural images of personal value. One person might need to see a beach, another a Manhattan urbanscape, while a third might feel good in the presence of a punk painting or old masterpiece.

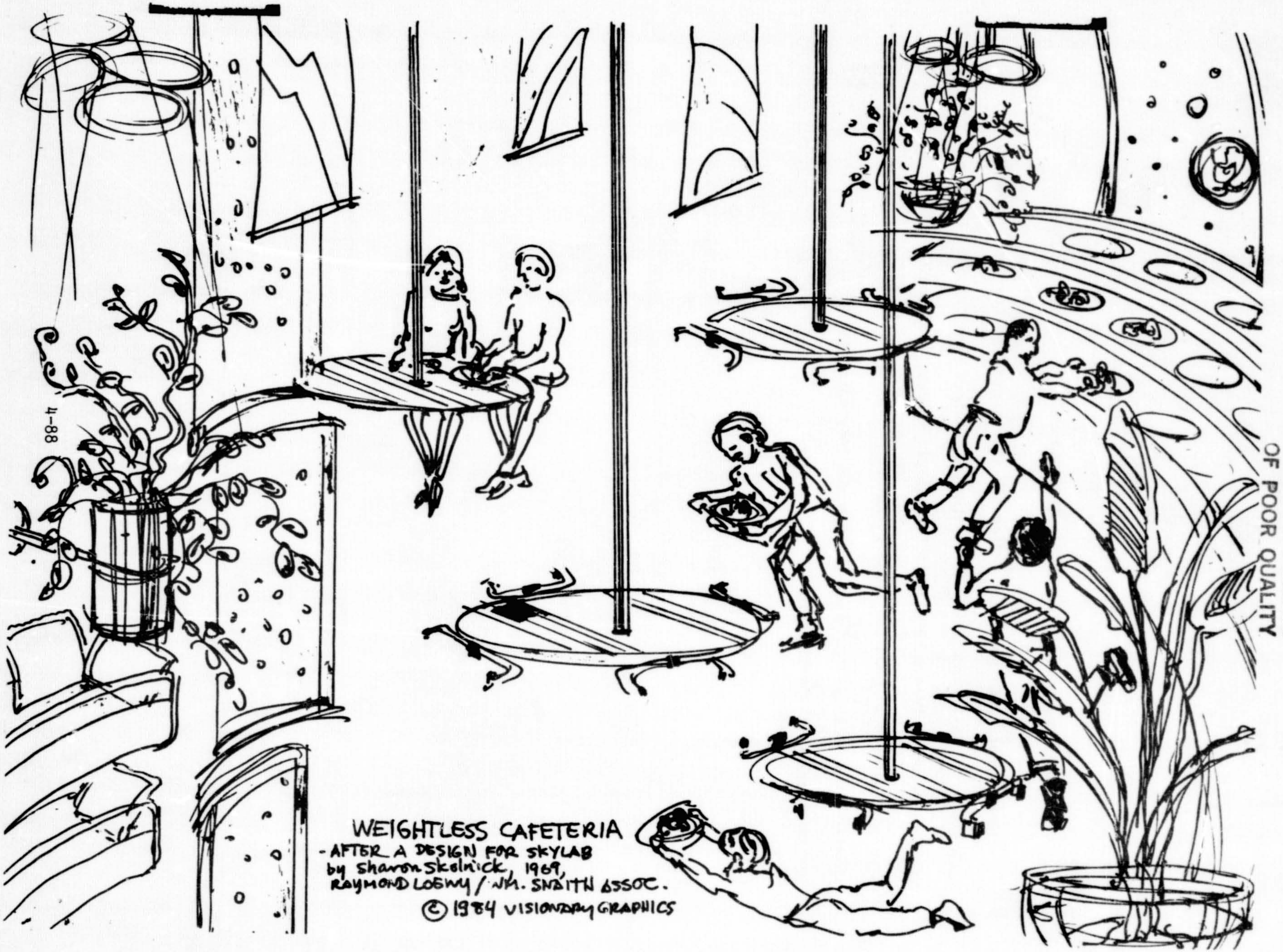
-- A huge rear screen hemisphere might be used for total environmental effect: redwood forest or desert, as well as for movies, video and educational images for group conferences.

-- Ultimately, I can see the space station becoming its own little planet, with green plants growing on the outside surface under a greenhouse-like atmospheric outer shell. Why not grow food locally?

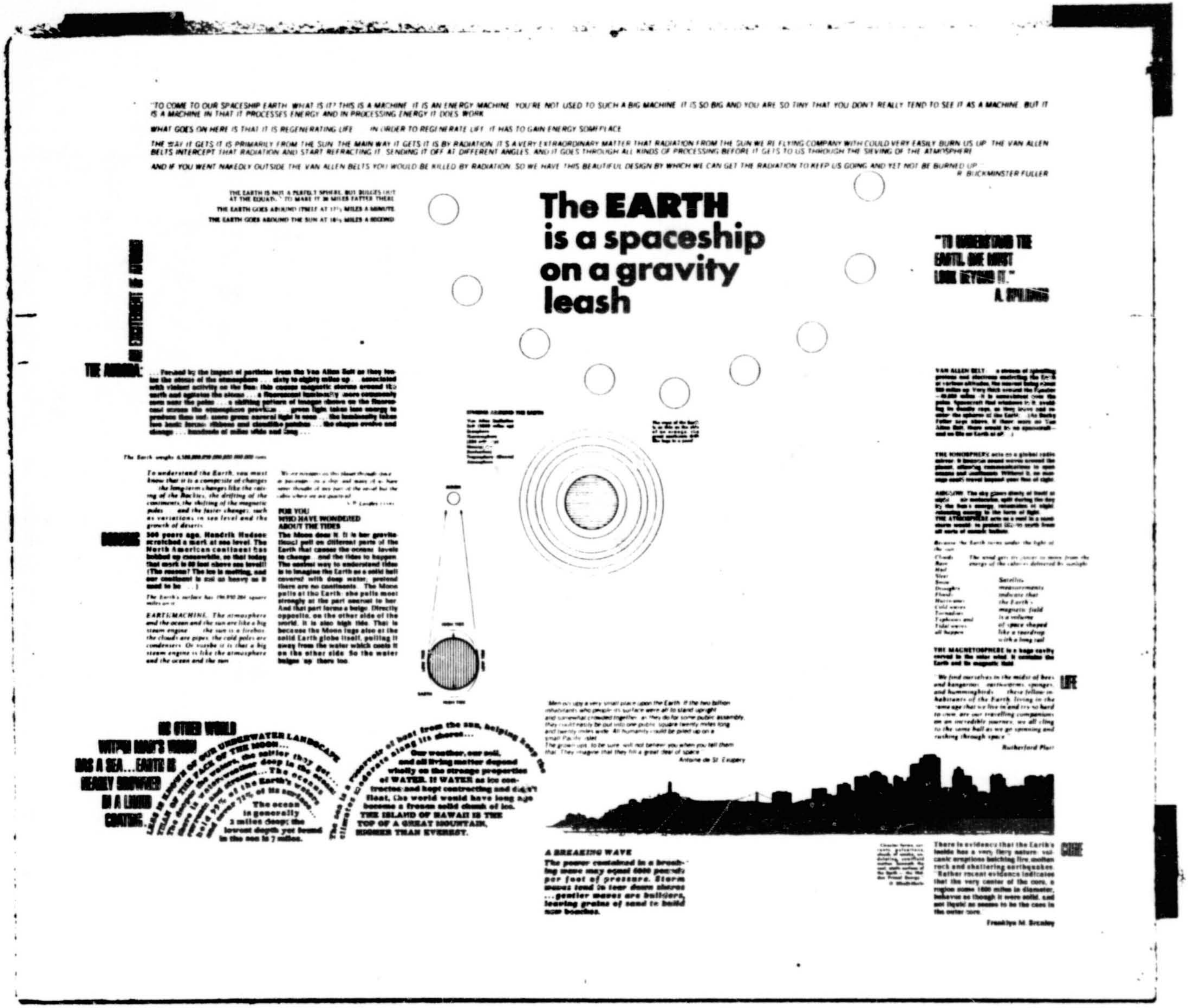
These little offshoots of earth could be wonderful, healthful spas for healing of mind/body/spirit as well as commercial and scientific pursuits. To achieve and sustain that kind of reality, I think the aims not only have to be of the highest human kind, but the accessability of the station needs to be universal as well. This should not be a haven for the elite, but should be a sanctuary and thrill for all kinds of people: women, men, elders, kids, the handicapped, all cultures, all colors, all opinions.

That's what earth is, after all-- or could be.

I hope your consultants are indigenous people and healers and artists, people with a respect for nature's cycles and ancient human wisdom. This is a great opportunity to create a truly wholistic place, the fruit of global knowledge of what is good for human beings gathered in one revolving, evolving sphere. This is a great chance. I hope you take advantage of it, and I thank you for hearing my thoughts.



WEIGHTLESS CAFETERIA
- AFTER A DESIGN FOR SKYLAB
by Sharon Skolnick, 1969,
RAYMOND LOEWY / WM. SNAITH ASSOC.
© 1984 VISIONARY GRAPHICS



"TO COME TO OUR SPACESHIP EARTH. WHAT IS IT? THIS IS A MACHINE. IT IS AN ENERGY MACHINE. YOU'RE NOT USED TO SUCH A BIG MACHINE. IT IS SO BIG AND YOU ARE SO TINY THAT YOU DON'T REALLY TEND TO SEE IT AS A MACHINE. BUT IT IS A MACHINE IN THAT IT PROCESSES ENERGY AND IN PROCESSING ENERGY IT DOES WORK.

WHAT GOES ON HERE IS THAT IT IS REGENERATING LIFE ... IN ORDER TO REGENERATE LIFE IT HAS TO GAIN ENERGY SOMEPLACE.

THE WAY IT GETS IT IS PRIMARILY FROM THE SUN. THE MAIN WAY IT GETS IT IS BY RADIATION. IT'S A VERY EXTRAORDINARY MATTER THAT RADIATION FROM THE SUN WE'RE FLYING COMPANY WITH COULD VERY EASILY BURN US UP. THE VAN ALLEN BELTS INTERCEPT THAT RADIATION AND START REFRACTING IT, SENDING IT OFF AT DIFFERENT ANGLES, AND IT GOES THROUGH ALL KINDS OF PROCESSING BEFORE IT GETS TO US THROUGH THE SIEVING OF THE ATMOSPHERE.

AND IF YOU WENT NAKEDLY OUTSIDE THE VAN ALLEN BELTS YOU WOULD BE KILLED BY RADIATION. SO WE HAVE THIS BEAUTIFUL DESIGN BY WHICH WE CAN GET THE RADIATION TO KEEP US GOING AND YET NOT BE BURNED UP ..."

R. BUCKMINSTER FULLER

THE EARTH IS NOT A PERFECT SPHERE, BUT BULGES OUT AT THE EQUATOR TO MAKE IT 26 MILES FATTER THERE

THE EARTH GOES AROUND ITSELF AT 17½ MILES A MINUTE

THE EARTH GOES AROUND THE SUN AT 18½ MILES A SECOND

The EARTH is a spaceship on a gravity leash

"TO UNDERSTAND THE EARTH, ONE MUST LOOK BEYOND IT."

A. SPILHAUS

THE AURORA:

To understand the Earth, you must know that it is a composite of changes ... the long-term changes like the raising of the Rockies, the drifting of the continents, the shifting of the magnetic poles ... and the faster changes, such as variations in sea level and the growth of deserts.

300 years ago, Hendrik Hudson scratched a mark at sea level. The North American continent has bobbed up meanwhile, so that today that mark is 60 feet above sea level! (The reason? The ice is melting, and our continent is not as heavy as it used to be ...)

EARTH/MACHINE. The atmosphere and the ocean and the sun are like a big steam engine ... the sun is a firebox, the clouds are pipes, the cold poles are condensers. Or maybe it is that a big steam engine is like the atmosphere and the ocean and the sun.

FOR YOU WHO HAVE WONDERED ABOUT THE TIDES

The Moon does it. It is her gravitational pull on different parts of the Earth that causes the oceans' levels to change ... and the tides to happen. The easiest way to understand tides is to imagine the Earth as a solid ball covered with deep water; pretend there are no continents. The Moon pulls at the Earth: she pulls most strongly at the part nearest to her. And that part forms a bulge. Directly opposite, on the other side of the world, it is also high tide. That is because the Moon tugs also at the solid Earth globe itself, pulling it away from the water which coats it on the other side. So the water bulges up there too.

NO OTHER WORLD WITHIN MAN'S VISION HAS A SEA ... EARTH IS NEARLY SMOTHERED IN A LIQUID COATING.

LESS IS KNOWN OF OUR UNDERWATER LANDSCAPE THAN OF THE FACE OF THE MOON ... The deeper the waters, the saltier they get ... There is underwater weather deep in the oceans ... The oceans hold 97% of the Earth's waters ... cover 71% of its surface ...

The ocean is generally 3 miles deep; the lowest depth yet found in the sea is 7 miles.

The sea is a reservoir of heat from the sun, helping keep the climates moderate along its shores ...

Our weather, our soil, and all living matter depend wholly on the strange properties of WATER. If WATER as ice contracted and kept contracting and didn't float, the world would have long ago become a frozen solid chunk of ice.

THE ISLAND OF HAWAII IS THE TOP OF A GREAT MOUNTAIN, HIGHER THAN EVEREST.

"Men occupy a very small place upon the Earth. If the two billion inhabitants who people its surface were all to stand upright and somewhat crowded together, as they do for some public assembly, they could easily be put into one public square twenty miles long and twenty miles wide. All humanity could be piled up on a small Pacific islet.

The grown-ups, to be sure, will not believe you when you tell them that. They imagine that they fill a great deal of space."

Antoine de St. Exupery

A BREAKING WAVE

The power contained in a breaking wave may equal 6000 pounds per foot of pressure. Storm waves tend to tear down shores ... gentler waves are builders, leaving grains of sand to build new beaches.

THE MAGNETOSPHERE is a huge cavity carved in the solar wind. It contains the Earth and its magnetic field.

Because the Earth turns under the light of the sun

Clouds
Rain
Hail
Sleet
Snow
Droughts
Floods
Hurricanes
Cold waves
Tornadoes
Typhoons and
Tidal waves
all happen

The wind gets its power to move from the energy of the calories delivered by sunlight.

Satellite measurements indicate that the Earth's magnetic field is a volume of space shaped like a teardrop with a long tail.

LIFE

"We find ourselves in the midst of bees and kangaroos, earthworms, sponges, and hummingbirds ... these fellow inhabitants of the Earth, living in the same age that we live in and try so hard to own, are our travelling companions on an incredible journey; we all cling to the same ball as we go spinning and rushing through space."

Rutherford Platt

CORE

There is evidence that the Earth's inside has a very fiery nature: volcanic eruptions belching fire, molten rock and shattering earthquakes. "Rather recent evidence indicates that the very center of the core, a region some 1600 miles in diameter, behaves as though it were solid, and not liquid as seems to be the case in the outer core."

Franklyn M. Branley

EXHIBIT PANEL, "ASTRONOMIA" PERMANENT EXHIBIT, HAYDEN PLANETARIUM, N.Y.C.
1968 GORDON ASHBY DESIGN ASSOC., SAN FRANCISCO
RESEARCH & GRAPHICS: SHARON SKOLNICK

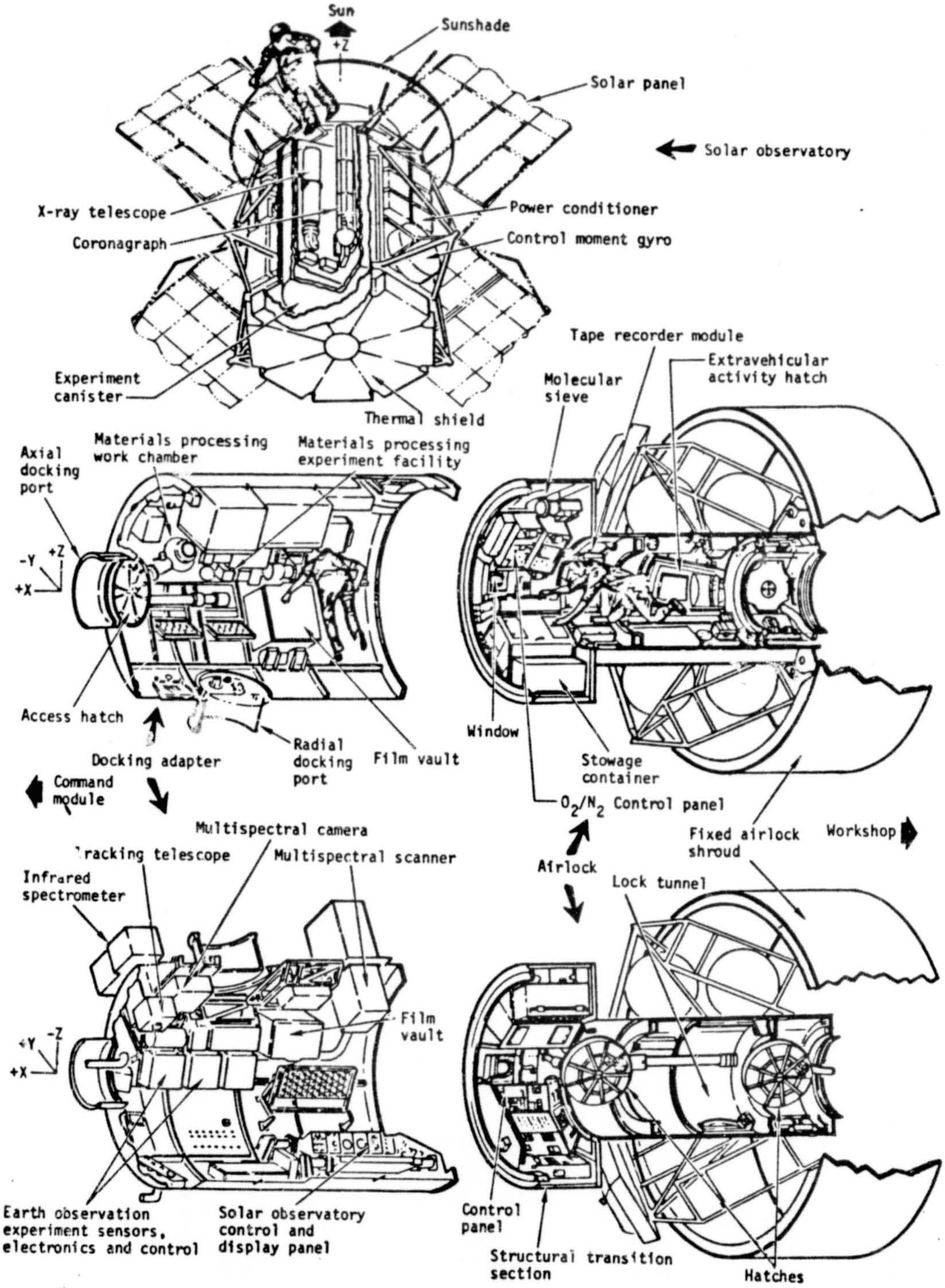


Figure 2-2.- Cutaway view of modules and launch configuration.

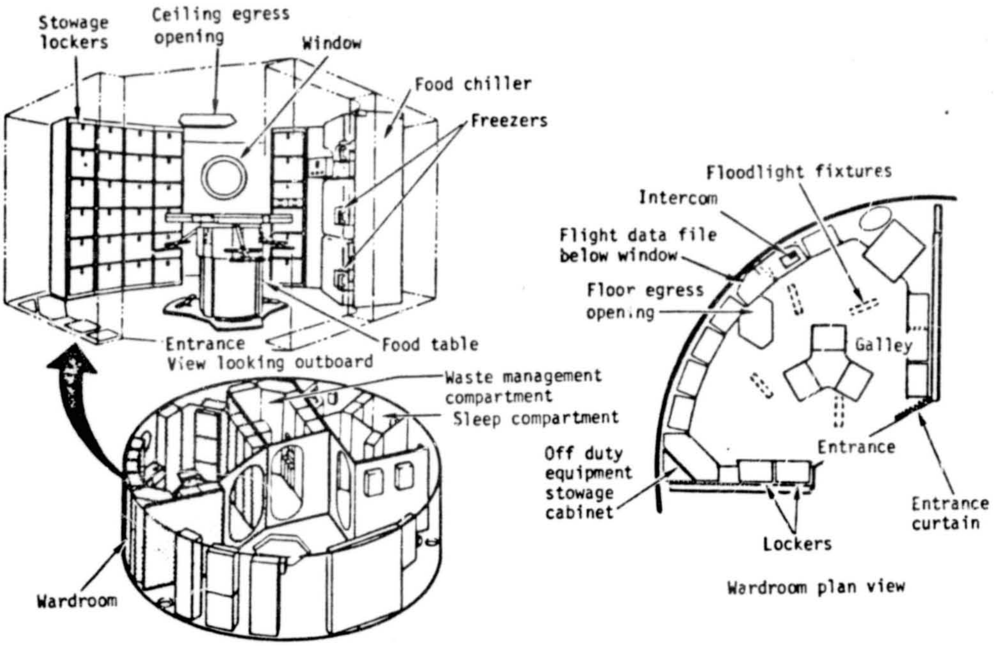


Figure 10-4.- Wardroom arrangement.

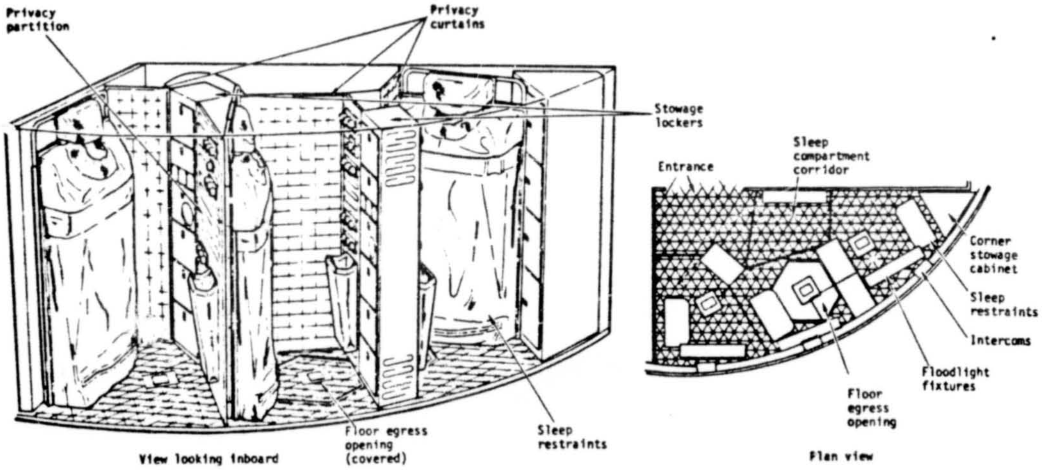


Figure 10-7.- Sleep compartment arrangement.

SPACE STATION
HUMAN PRODUCTIVITY WORKING GROUP
February 27 - March 2, 1984
Ames Research Center
Building 239 Room B39

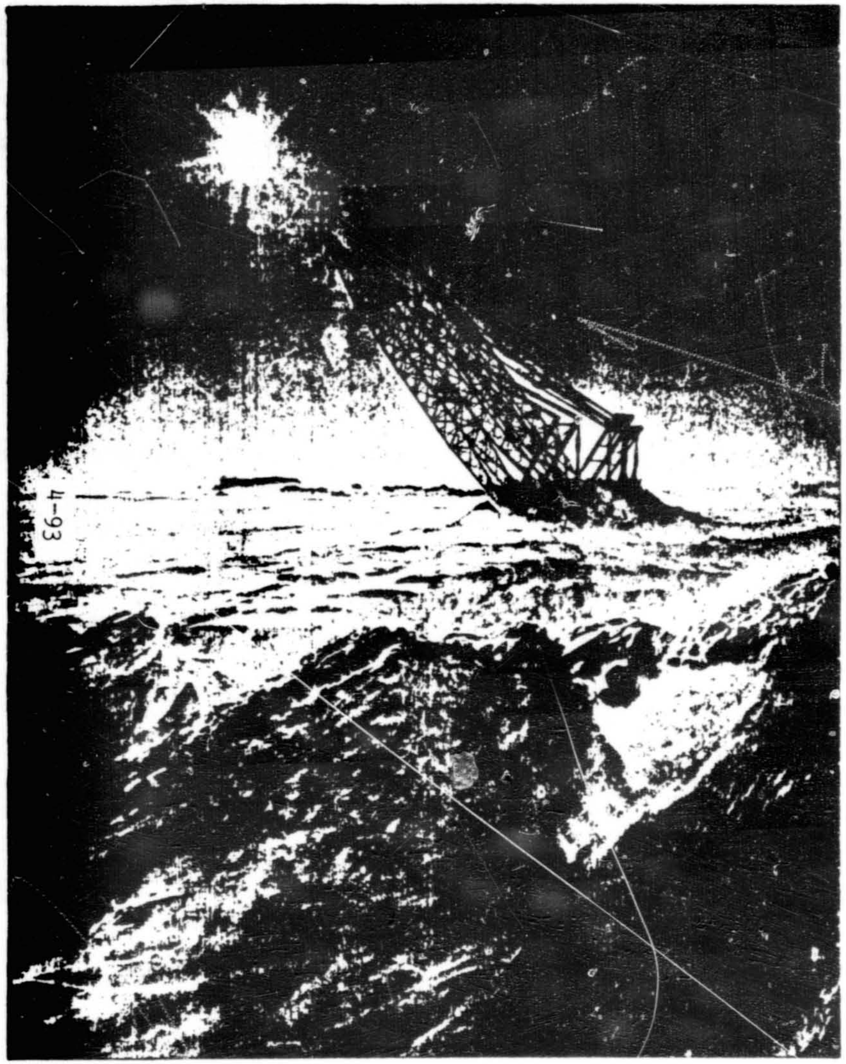
HUMAN PRODUCTIVITY EXPERIENCE AND UNDERSEA HABITAT DESIGN

BY

Thomas C. Taylor

John S. Spencer

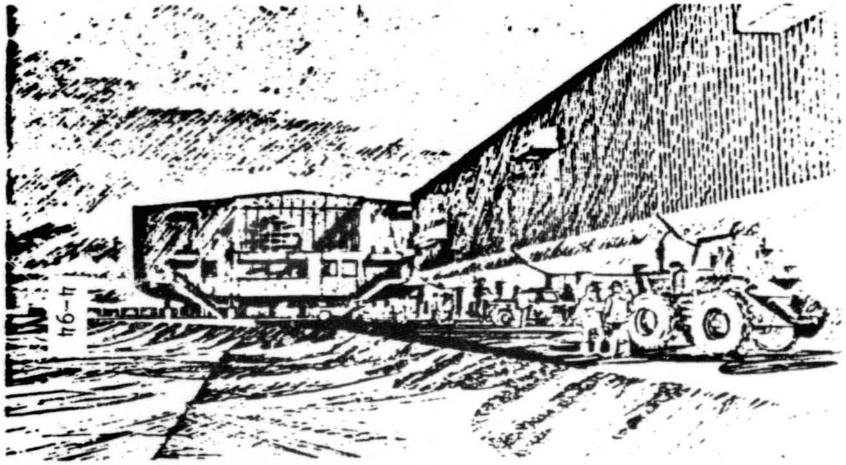
Prudhoe Bay Operations

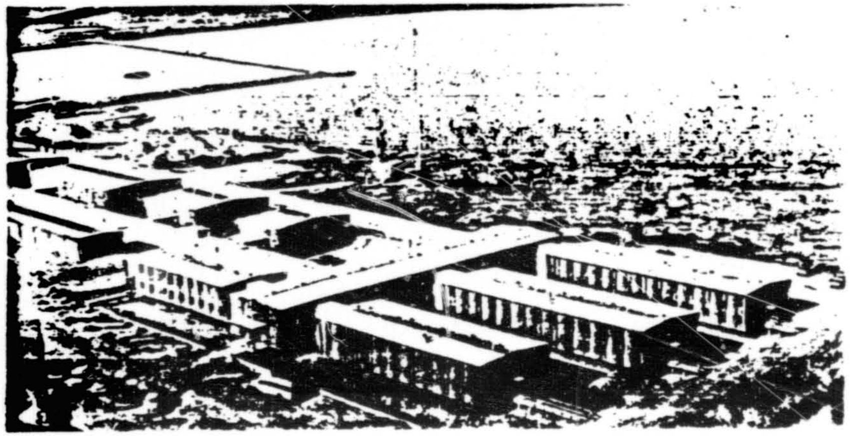


LESSONS LEARNED

- FINANCIAL DRIVER
- HABITATION
- RISK REDUCTION
- TRANSPORTATION
- EQUIPMENT
- MARKET DEVELOPMENT
- OTHER ELEMENTS

North
Slope
Alaska:





HABITATION LESSONS LEARNED

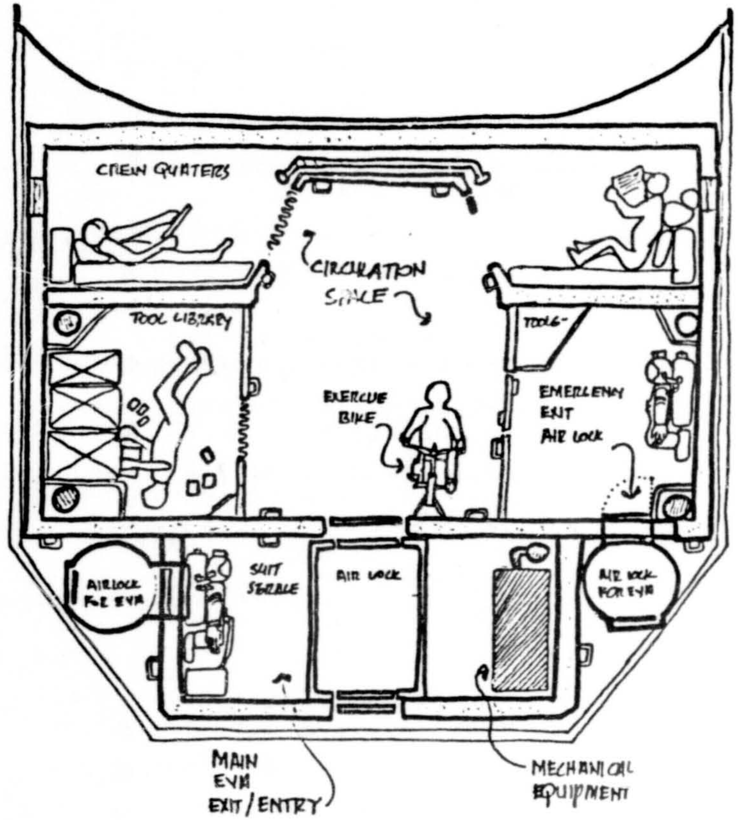
- GOOD DESIGN PAYS DIVIDENDS
- DESIGN MUST GO BEYOND HUMAN FACTORS CONSIDERATION
- FOOD IS IMPORTANT MORALE FACTOR
- PRIVACY IMPORTANT
- HUMAN PRODUCTIVITY SUCCESS CAN BE MEASURED BY CONSTRUCTION OPERATIONS
- NEGATIVE SOCIAL INDICATORS ALSO VISIBLE

INTERIOR DESIGN COMPARISON - ALASKA CONSTRUCTION CAMPS

Actual Observed Experience
1975 - 1978

WELL DESIGNED INTERIOR	MARGINAL HUMAN FACTORS DESIGN
● Good lighting	● Poor lighting
● Acoustical provisions	● No acoustical provisions
● Group gathering locations	● Group meetings in rooms
● Exercise and recreation Facilities provided	● Exercise and recreation Facilities limited

EFFECTS	EFFECTS
● Pleasant and positive overall Feeling from surroundings	● Cramped feeling
● Inhabitants changed work Clothes before dinner	● Inhabitants usually ate In work clothes
● Several security staff For 600 inhabitants	● Approximately 1 uniformed Security staff for each 30 inhabitants
● Room doors without locks	● Room doors with locks
● Interior sprinkler system added	● Inhabitants slept with Arctic Parka over feet and near boots
● Food served cafeteria style	● Food with portions served by staff
	● Noticeably more drugs, gambling, Alcohol, and camp damage problems
	● Some cases of arson

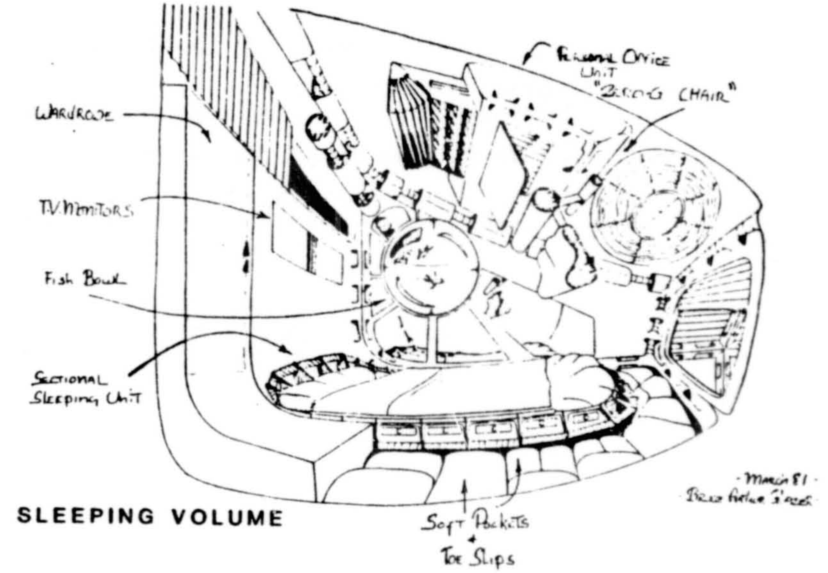


HABITATION MODULE

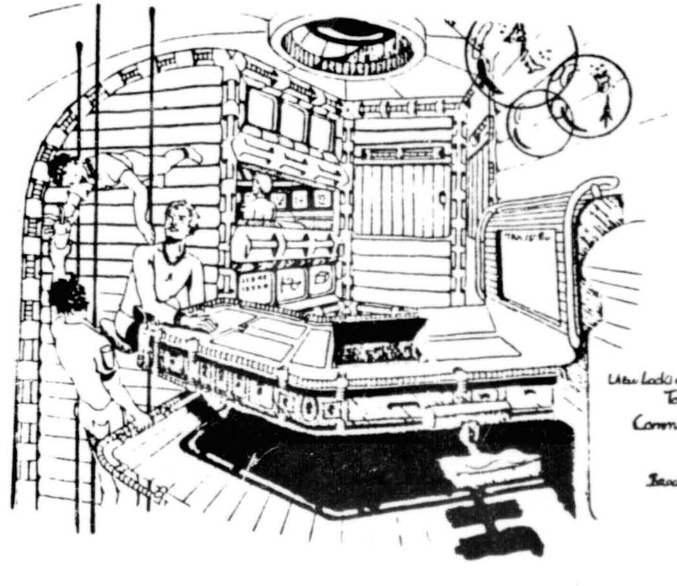
SECTION A-A
1/4"-1'-0"

1981 SHDA

HABITATION SPACE FOR SIX ASTRONAUTS FROM 3 TO 6 MONTHS - SHUTTLE CREW LAY-OVER OR EMERGENCY HABITATION.



SLEEPING VOLUME



View Looking Across Galley Towards Command Center

1981
Bruce Arthur Glaser

DESIGN STUDY

HABITABILITY CRITERIA

by Carol J. Amato

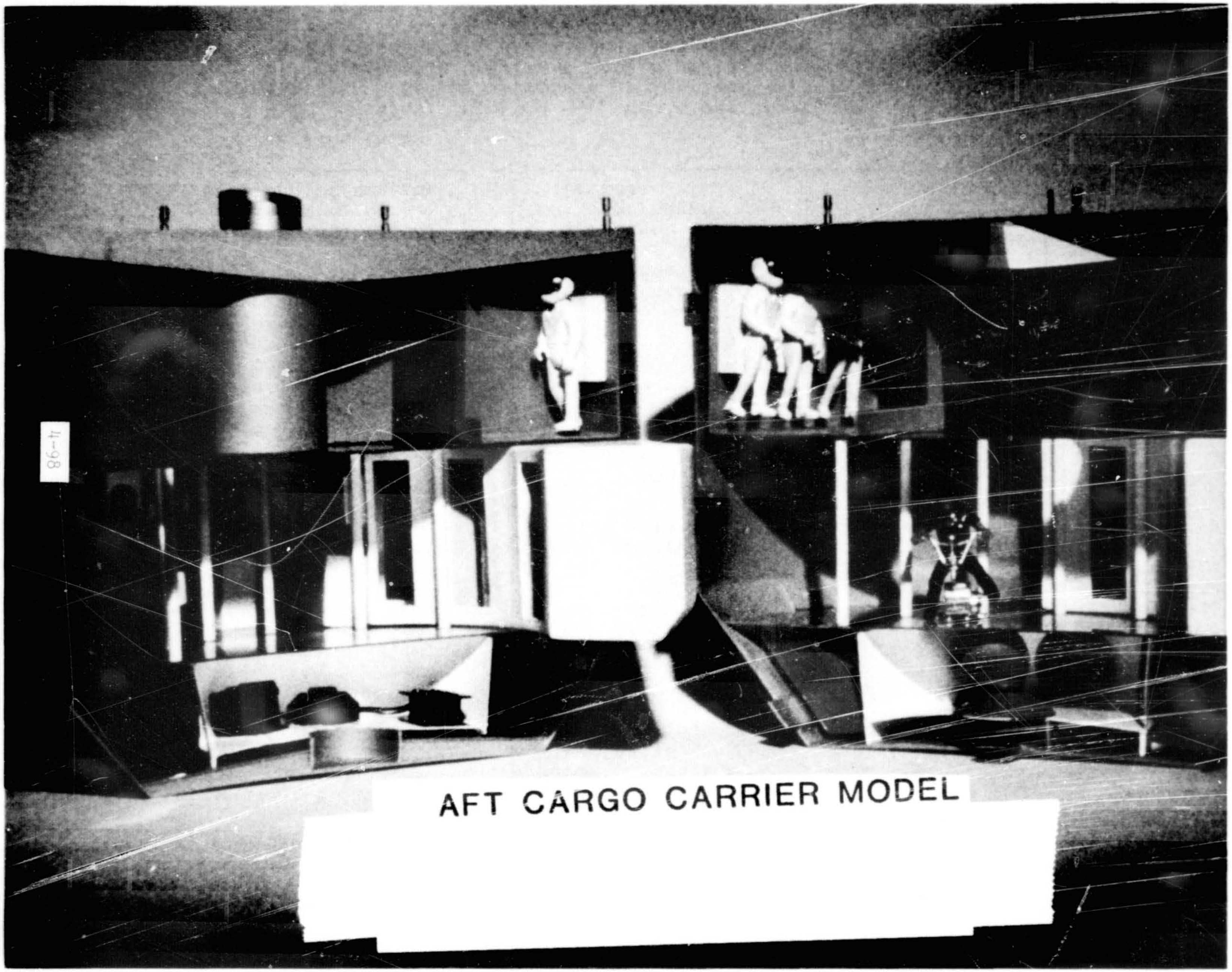
	PSYCHOLOGICAL/ BIOLOGICAL	CULTURAL	SOCIAL	GENERAL PHYSICAL
Single Nationality Crews	Nature of Mission Duration Motivation Mobility Sense of Orientation Adaptability Flexibility Sensory Stimulation Variability Personal Identification Personal Turf Change and Surprise Environmental Enhancement Growth and Change Sense of Security Work/Free Schedules Presence of Family View of Outside Escape Procedures Known Need to "Get Away" Living Things (pets, etc) Room for Job Advancement Solipsism Effect Shimanigasi Syndrome	Crew Characteristics Which Language Dominates? Holistic Medicine Approach Cultural Self-Evolution Colonist Superiority Complex Toward Terrans Hierarchical vs. Egalitarian Pacifism vs. Militarism	Social Areas Activity Arrangement Loner vs. Social Personalities Male/Female Roles Required Social Interaction Sports (Individual and Group) Arts Entertainment Age Distribution a Must	Safety Ease of Movement Comfort Volume/ Person/ Activity Gravity Situation Life Support Ease of Maintenance Exercise
Multi-National Crews	Architectural Preferences Aesthetic Values and Choice of Surroundings Living Things (Pets, Plants) Variation of Routine	Basic Anthropological Knowledge of Other Cultures as a Requirement Decision-making Process		

CULTURAL REFERENCES

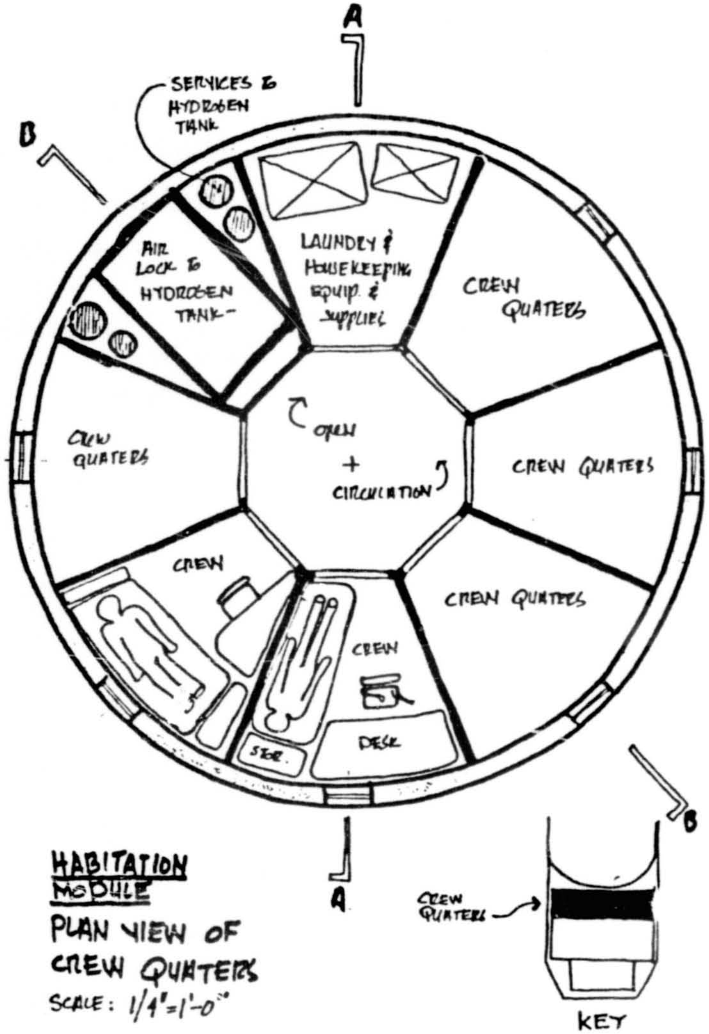
World View Ethnic Cooking Religious Practices
Sex Practices Family Structure Marriage Practices
Political Orientation Hygiene Habits Male/Female Roles
Economic Orientation Kinship and Descent Patterns
Pacifism Vs. Militarism Concept of Private Ownership
Child-Raising Practices Attitudes on Sickness and Death

MILITARY PERSONNEL
(ADDITIONAL CONSIDERATIONS)

Officers vs. Enlisted
(No hierarchy?)
Violence as Good
Military Wife Syndrome



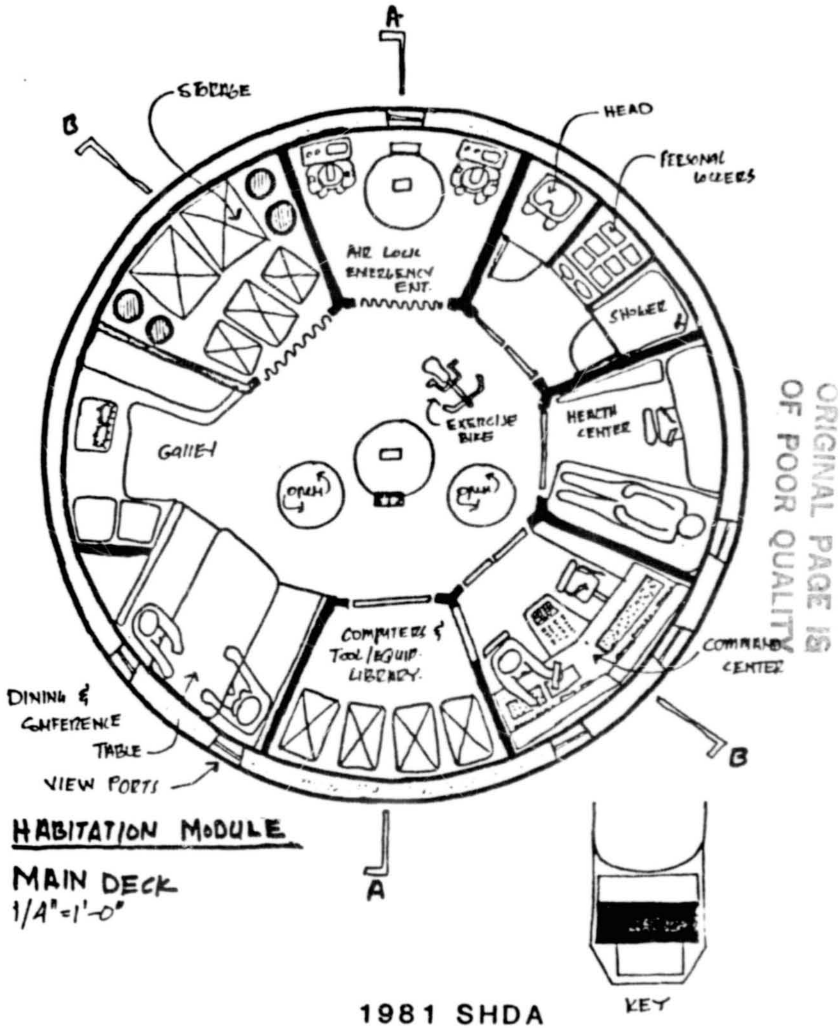
AFT CARGO CARRIER MODEL



HABITATION MODULE

PLAN VIEW OF CREW QUATERS

SCALE: 1/4"=1'-0"



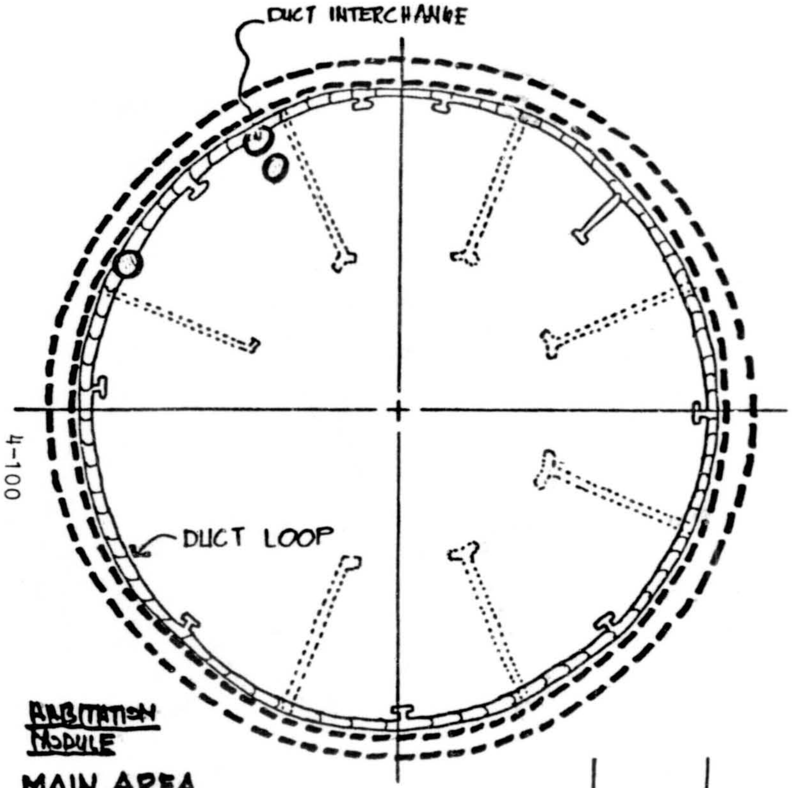
HABITATION MODULE

MAIN DECK

1/4"=1'-0"

1981 SHDA

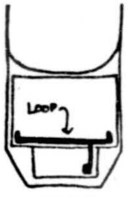
UTILITY CONSIDERATIONS



HABITATION MODULE

MAIN AREA
MECHANICAL DUCT
DISTRIBUTION PATTERN

SCALE: 1/4"=1'-0"



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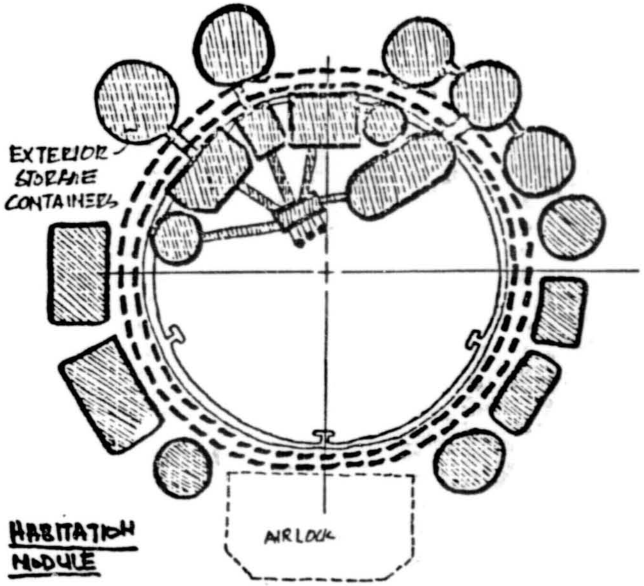


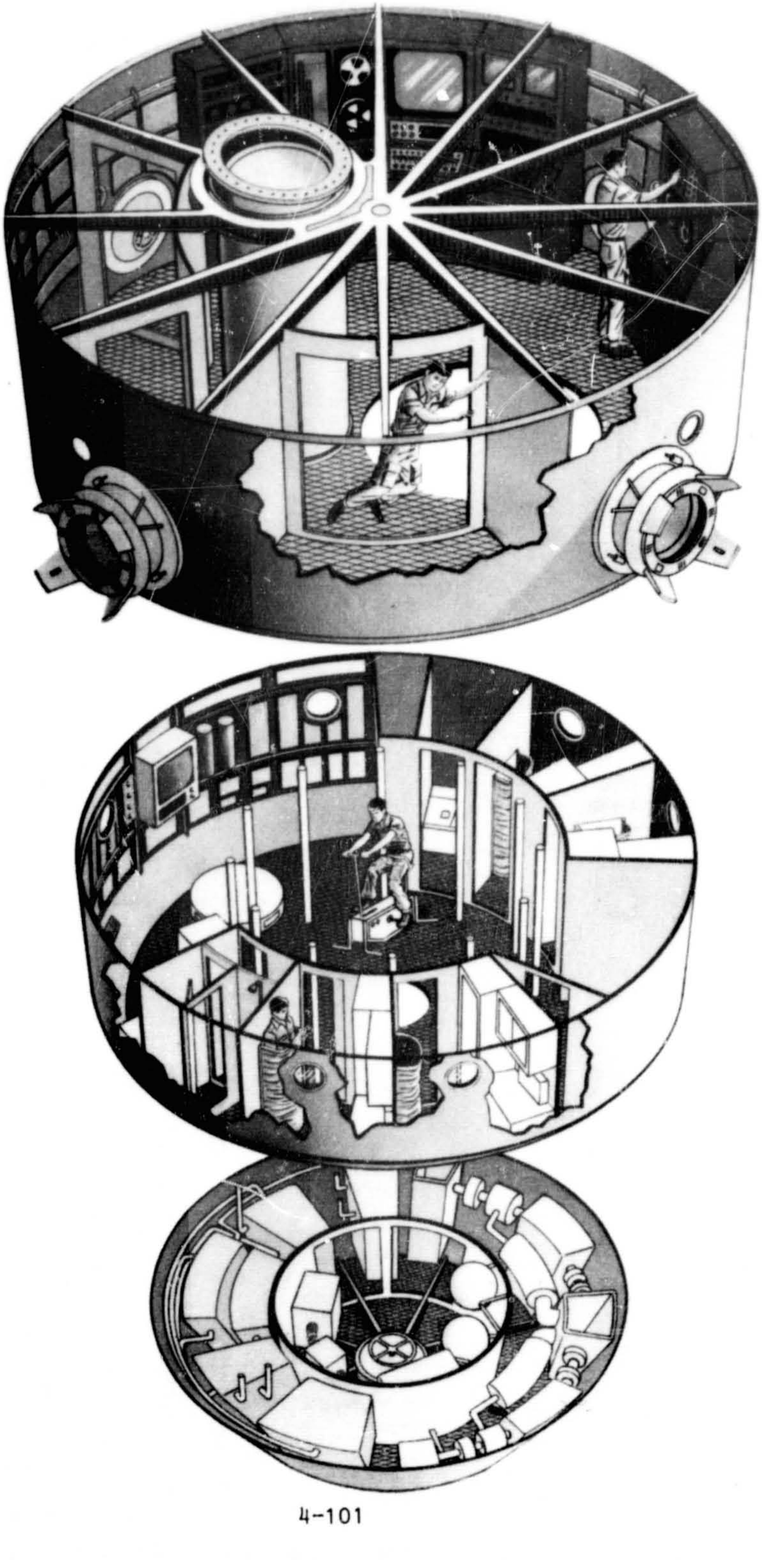
HABITATION MODULE

SERVICE/MECHANICAL AREA
EQUIPMENT-DUCT DISTRIBUTION

SCALE: 1/4"=1'-0"

KEY

1981 SHDA



Western Regional Undersea Laboratory

• the program

On July 1, 1980, the Institute for Marine and Coastal Studies at USC signed a cooperative agreement with the National Underseas Research Project Office of NOAA for funding to initiate a long-term underwater scientific research program at Santa Catalina Island, California, utilizing saturation diving and an underwater habitat.

• saturation diving

Saturation diving allows extended periods at the work site without intermediate decompression times. Non-work periods are spent in an underwater structure anchored to t[illegible] bottom near the work site, which serves a[illegible] both home and laboratory. The WRUL Pr[illegible]gram is designed to give mission times [illegible] to 14 days. Missions will commence and en[illegible] on dry land beside an on-site, fully staffe[illegible] hyperbaric chamber.

• time frame

The first operational mission is expected [illegible] start in late 1982. It is anticipated there w[illegible] [illegible] 12 to 16 missions per year. Interested [illegible]vestigators should submit their propo[illegible] [illegible] months in advance of their [illegible] date to allow for the peer re[illegible]

Announcement of the Initiation of a University of Southern California (USC)/National Oceanic and Atmospheric Administration (NOAA) cooperative undersea research program at the USC Catalina Marine Science Center (CMSC).

• objectives

The primary goal of the WRUL Program is to expand marine research in the Pacific region of the U.S. The program will support basic and applied marine science by making available a saturation diving facility in temperate waters. Additionally, the location of the habitat within a preserve under the control of the university administration allows, indeed promotes, long term studies. The WRUL staff and facilities will be made available to those research projects that qualify through the peer review process.

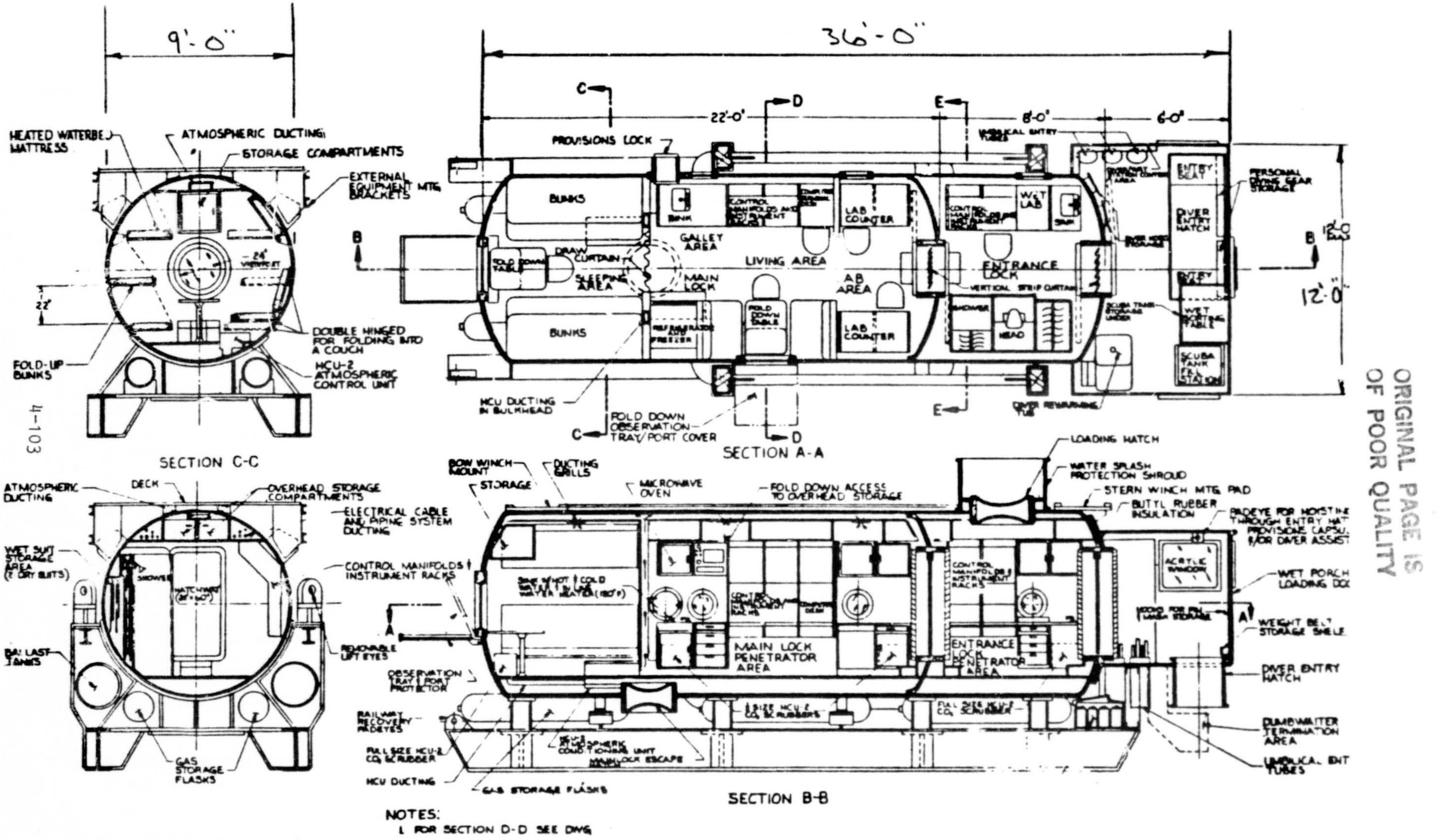
Possible areas of investigation include

- Marine fisheries
- Marine ecology
- Oceanography
- Marine pollution
- Sea floor properties and processes
- Human physiology
- Nautical archaeology
- Marine geology
- Energy resources

The proposed WRUL system will be guided in its design and operation by a philosophy of safety (with ABS certification), simplicity of operation, and utilization of existing facilities, all within a modest operating budget.

the habitat

- Size - 8 meters long by 3 meters diameter
- Depth range - 16 to 50 meters sea water
- Mission crew - 4
- Support via shore umbilical
- Excursion range:
  Horizontal - 100 m untethered, 300 m tethered
  Vertical - 8 to 80 meters sea water
- One large observation port
- Breathing gas - air or nitrox (reduced O2 percentage)
- Mission duration - 5 to 14 days
- Contains wet and dry laboratory space
- Flexible configuration to meet investigator requirements



SECTION C-C

SECTION A-A

SECTION E-E

SECTION B-B

NOTES:
1. FOR SECTION D-D SEE DWG

UNDERSEA HABITAT

ORIGINAL PAGE IS
OF POOR QUALITY

UNDERSEA HABITAT STUDY

Crew Size: 4-5
Mission Length: 2 weeks

HABITABILITY CRITERIA
USC UNDERSEA LABORATORY

by Carol J. Amato

PSYCHOLOGIAL/BIOLOGICAL

- Nature of Mission
- Duration
- Motivation
- Mobility
- Sense of Orientation
- Adaptability

- Flexibility
- Sensory Stimulation
- Variability
- Personal Identification
- Personal Turf
- Change & Surprise
- Environmental Enhancement
- Sense of Security
- Work/Free Schedules
- View of Outside
- Escape Procedures Known
- Need to "Get Away"
- Living Things (fish tank)
- Aesthetic Values
- Variation of Routine

CULTURAL

- Crew Characteristics
- Basic Knowledge of Cultural Habits of Other Crew Members

CULTURAL DIFFERENCES

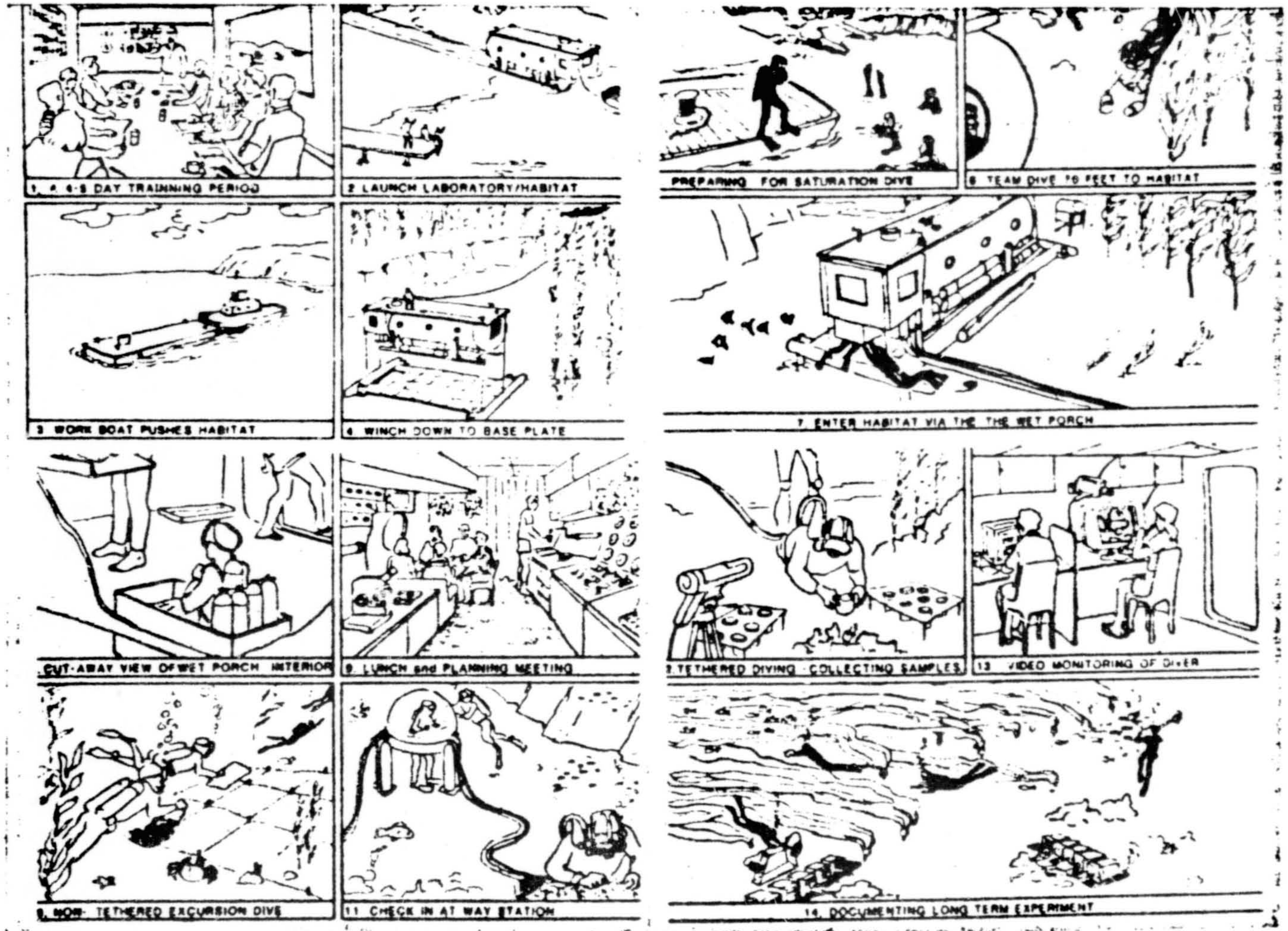
- World View
- Dietary Habits
- Hygiene Habits
- Political Orientation
- Religious Practices

SOCIAL

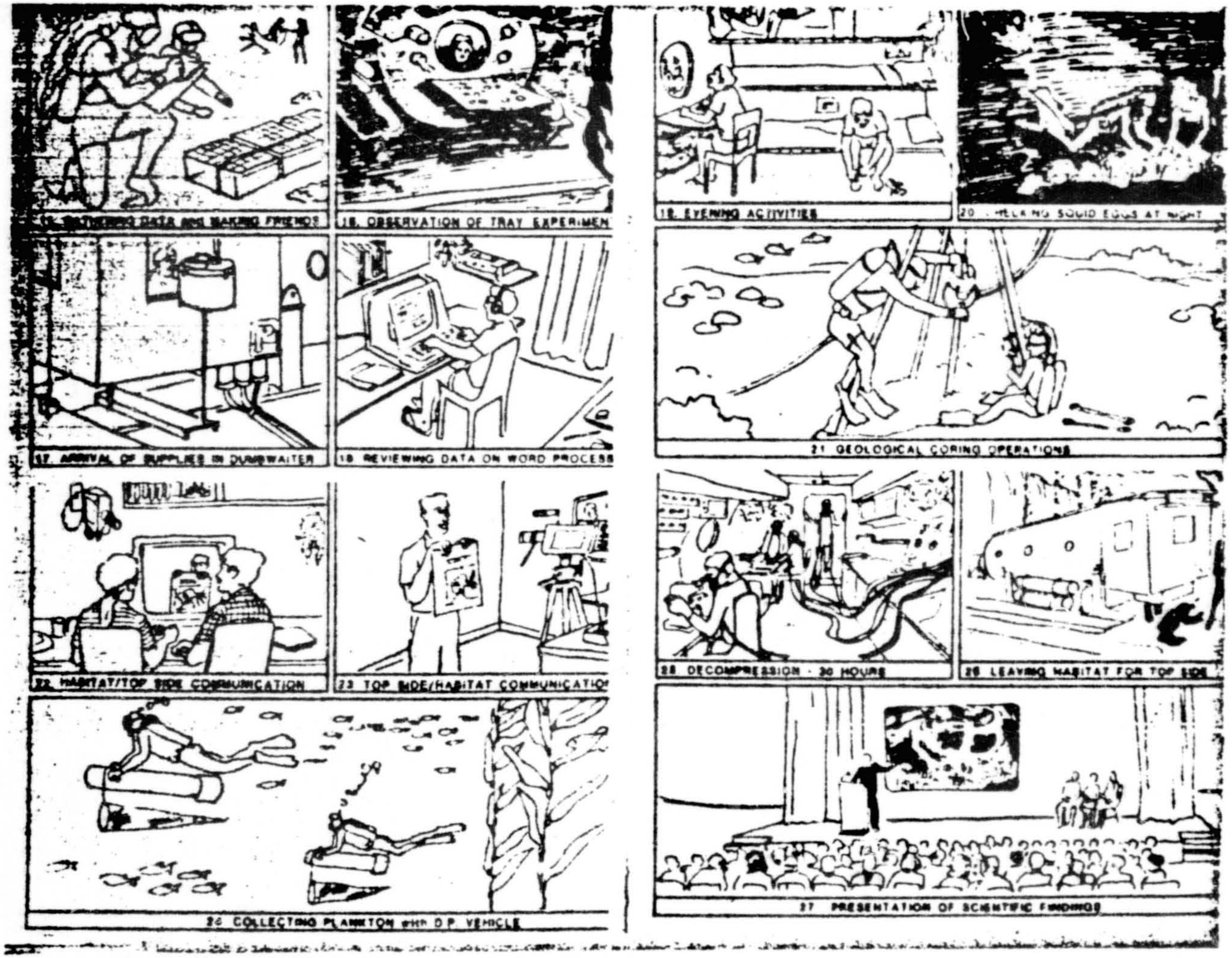
- Social Areas
- Activity Arrangement
- Loner Vs. Social Personalities
- Male/Female Roles
- Required Social Interaction
- Entertainment

GENERAL PHYSICAL

- Safety
- Ease of Movement
- Comfort
- Volume/Person/Activity
- Life Support
- Ease of Maintenance



STORY BOARD OF SEA HABITAT EXPERIENCE



STORY BOARD OF SEA HABITAT EXPERIENCE

PUBLICATIONS

List of Publications - The following publications are available upon request from the author, Thomas C. Taylor, Taylor & Associates, Inc., P.O. Box 1547, Wrightwood, CA 92397, (619-249-6882).

*1. Taylor, T.C. (1980), "Commercial Operations for the External Tank in Orbit," Eighteenth Goddard Memorial Symposium, Washington, D.C., AAS 80-89, March 1980.

2. Taylor, T.C. (1980), "SPS Primary Structure by Another Method," Presentation at the D.O.E. SPS Conference in Lincoln, NE, 17 April 1980.

3. Witek, N.J. and Taylor, T.C. (1980), "Global Benefits of the Space Enterprise Facility Using the External Tank," IAF Tokyo, Paper 80-IAA-46.

4. Witek, N.J. and Taylor, T.C. (1980), "The External Tank as a Large Space Structure Construction Base," IAF Tokyo, Paper IAF-80-A-41.

*5. Taylor, T.C.(1981), "A Commercial Construction Base using the External Tank," 2nd AIAA Conf. on Large Space Platforms, Feb. 2-4, 1981, AIAA-81-0460.

*6. Tewell, J.F., Anderson, J.W. and Taylor, T.C. (1981), "Platform Operations Using the External Tank," 2nd Conf. on Large Space Platforms, San Diego, CA, Feb. 2-4, 1981, AIAA-81-0461.

*7. Taylor, T.C. (1981), "A Modest Habitation Facility in Low Earth Orbit," Fifth Princeton/AIAA/SSI Conf. on Space Manufacturing, May 18-21, 1981, Paper No. 53.

*8. Taylor, T.C. (1981), "A Modest Habitation Facility in Low Earth Orbit," Rome IAF, IAF-81-40.

9. Taylor, T.C. (1981), "Future Potential Uses of Spacelab for Manned Orbital Facilities," Rome IAF, IAA-81-227.

10. Taylor, T.C. (1982), "Orbital Facility Operations Through an Assured Market Sceanrio," Paris IAF, IAF-82-33.

11. Mobley, T.B. and Taylor, T.C. (1982), "The ET in Orbit as a Space System Material Resource," Paris IAF, IAF-82-392.

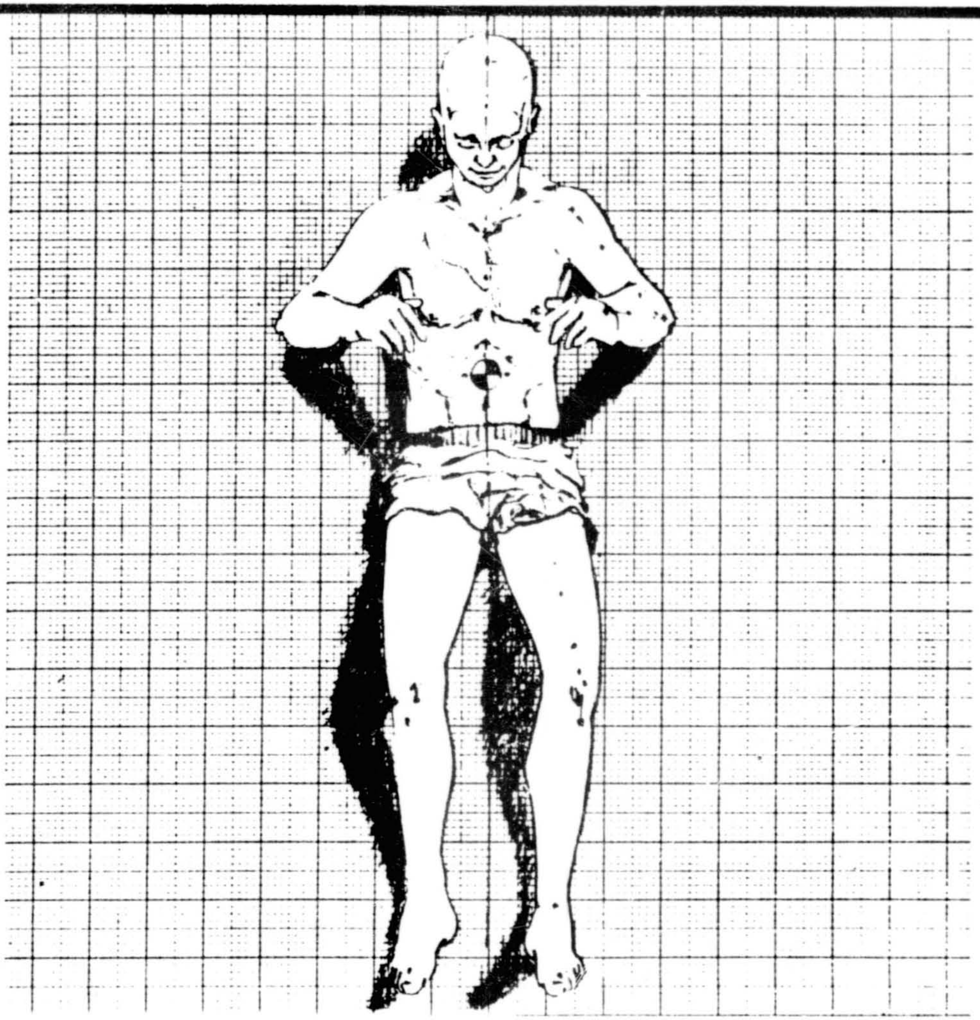
12. Mitchell, P.M. and Taylor, T.C. (1984), "Low Cost Science and Astronomy Platforms in Orbit," AIAA 22nd Aerospace Sciences Meeting, Reno, NV, Jan. 9-12, 1984.

***COMMERCIAL HUMAN PRODUCTIVITY RELATED**

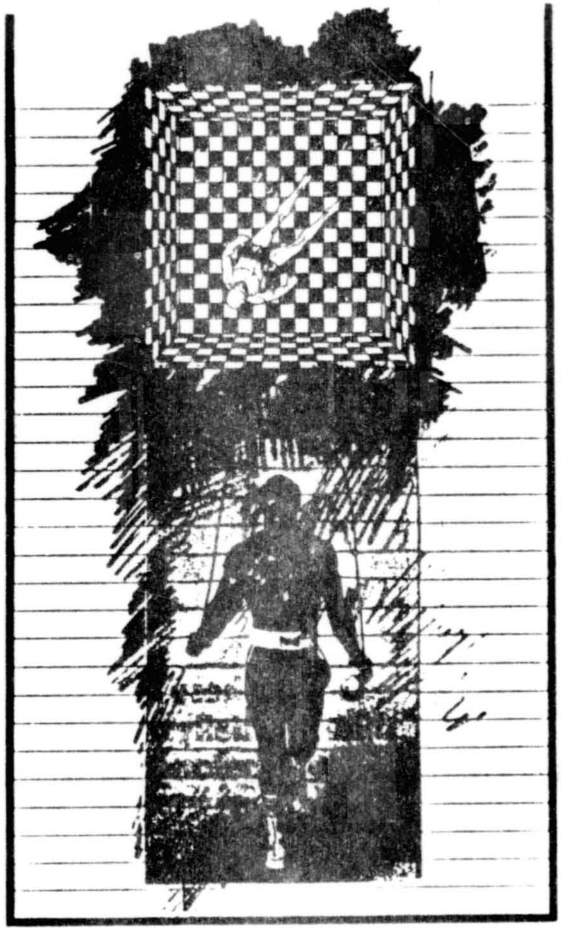
Considerations for Space Station Interior Architecture

Brand Griffin

Neutral Body Postures



Contrasting Environments

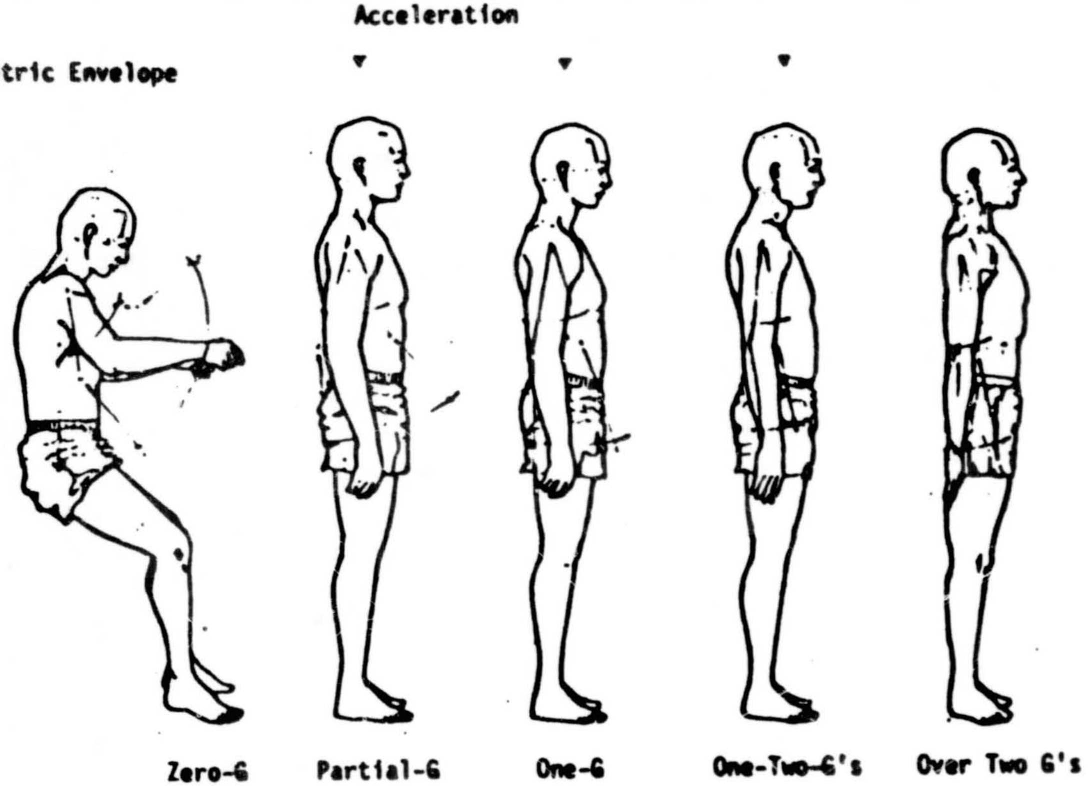


Acceleration Gradient

88-1112

Variable:

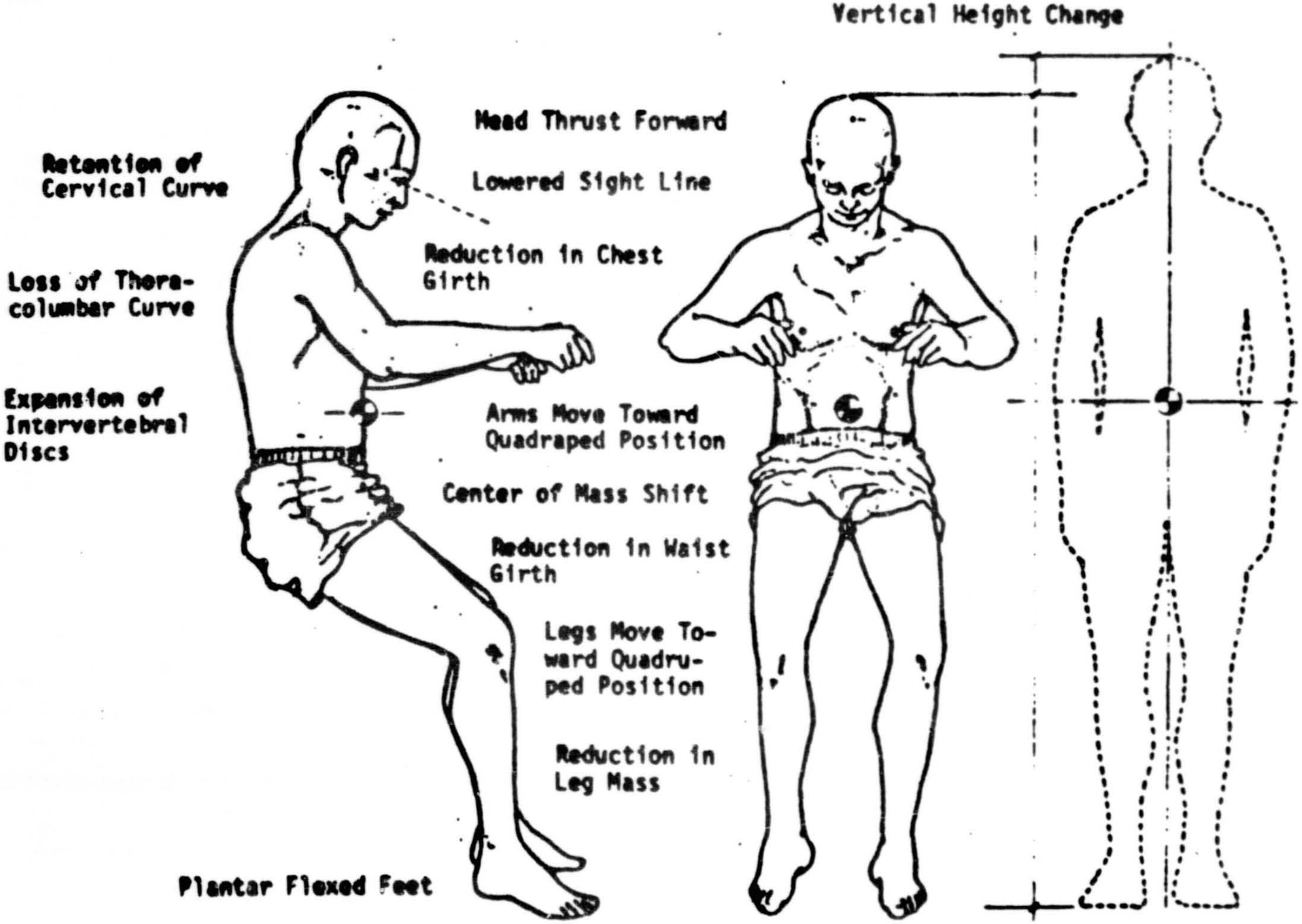
Anthropometric Envelope
(Nominal)



Implications:

1. Location of controls.
2. Intravehicular and extravehicular garment fit.
3. Angular speed of limbs.

Anatomical Change in Zero-G



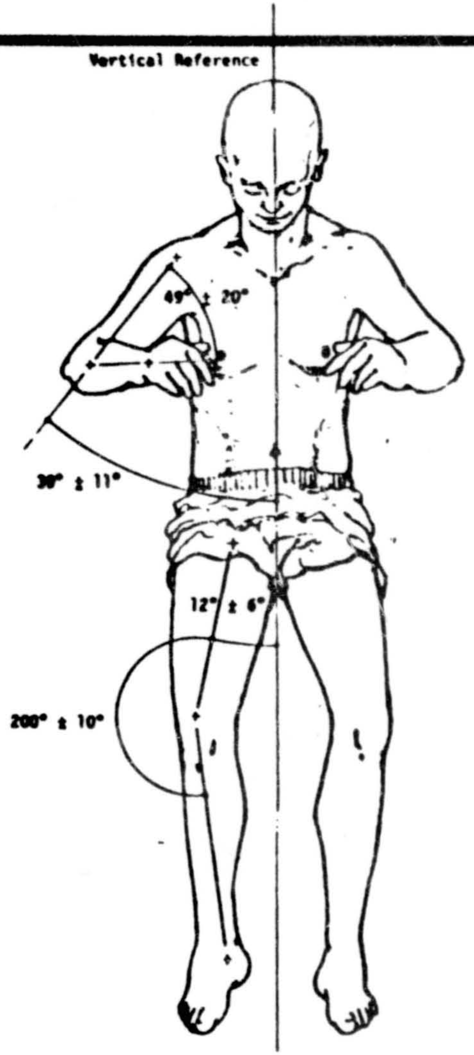
Space Station

NASA

88-1114

Male Angular Relationships

Ventril View



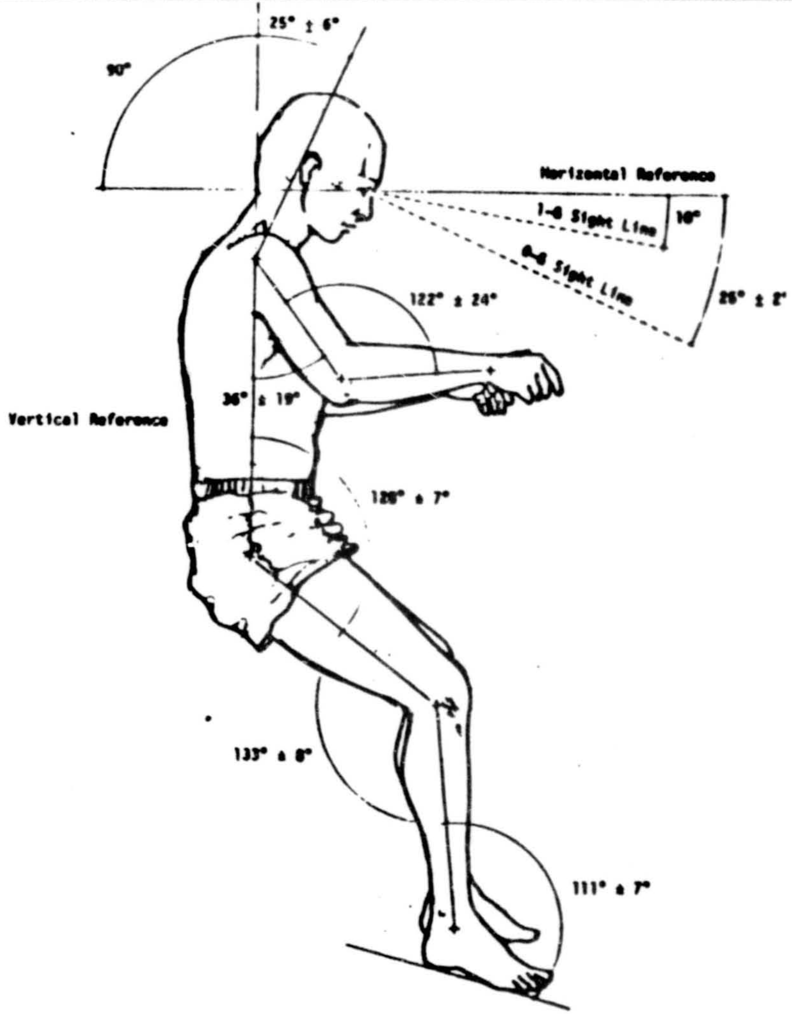
Space Station

NASA

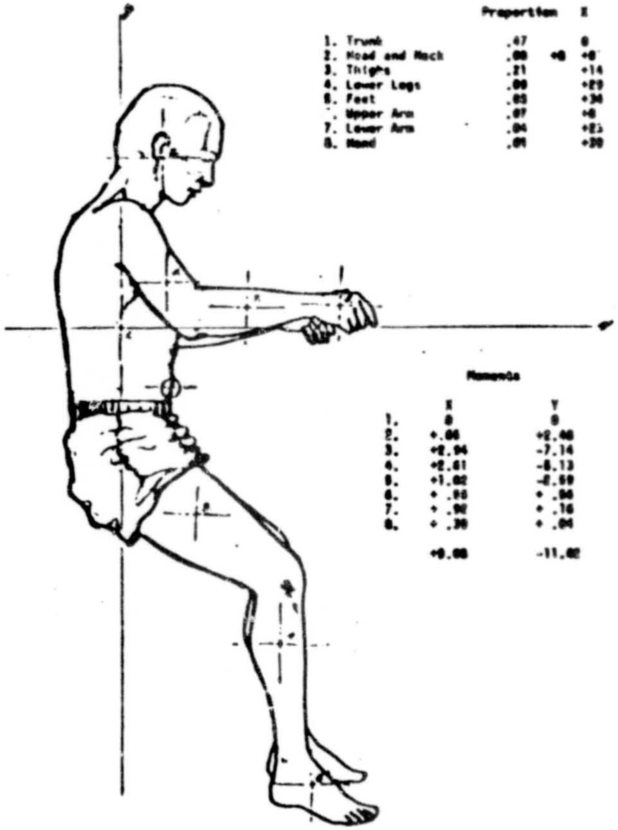
86-1113

Male Angular Relationships

Profile View



Center of Mass (Segmental Method)



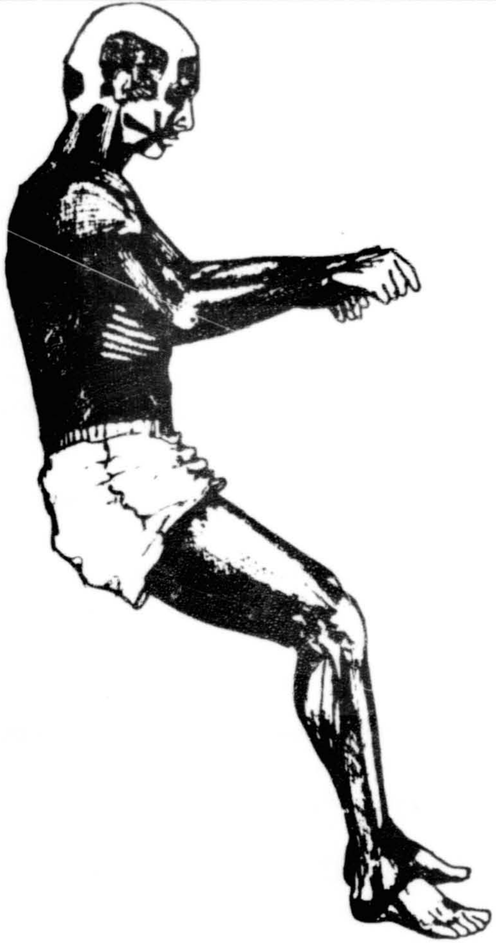
		Proportion		X	Y
1.	Trunk	.47		0	0
2.	Head and Neck	.08	+8	+8	+31
3.	Thighs	.21		+14	-34
4.	Lower Legs	.09		+29	-67
5.	Feet	.03		+34	-83
6.	Upper Arm	.07		+8	+8
7.	Lower Arm	.04		+23	+4
8.	Hand	.01		+30	+4

Moments

	X	Y
1.	0	0
2.	+.64	+2.48
3.	+2.94	-7.14
4.	+2.61	-6.13
5.	+1.02	-2.49
6.	+ .56	+ .56
7.	+ .92	+ .16
8.	+ .30	+ .04
	+9.08	-11.02

NOTE: Proportional to fluid shift and duration of exposure to zero-g, the c.g. will move in the +y direction.

Neutral Body Posture
Muscular Considerations



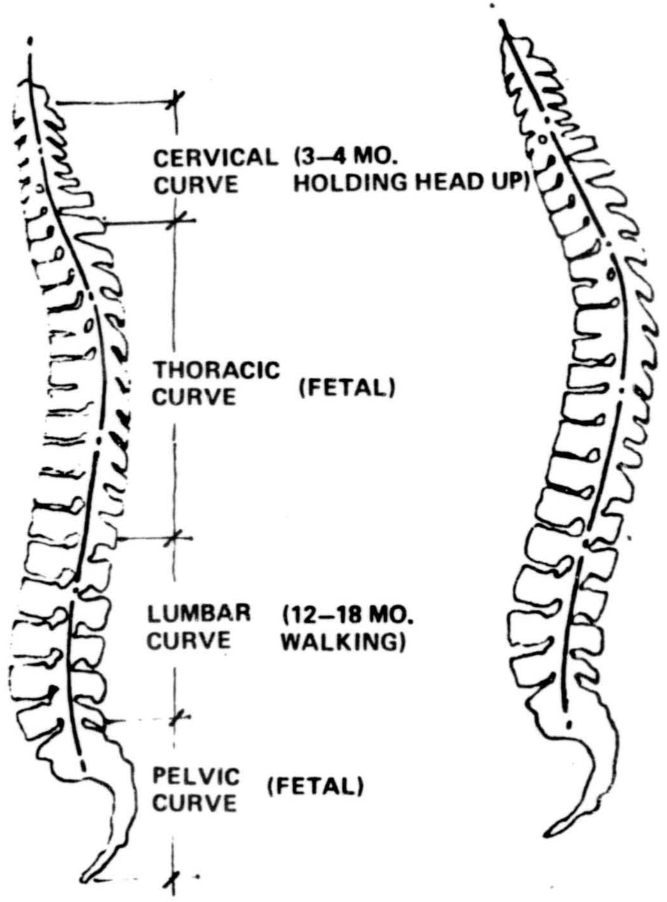
C-7

Neutral Body Posture/Skele

Space Station

SS-1133

Zero-G Change to the Vertebrae Column



Space Station

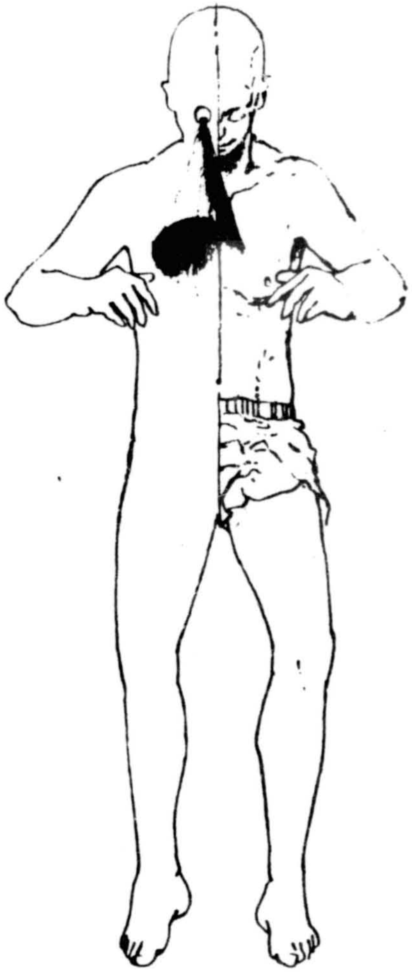
Neutral Body Posture/Pulmonary

NASA

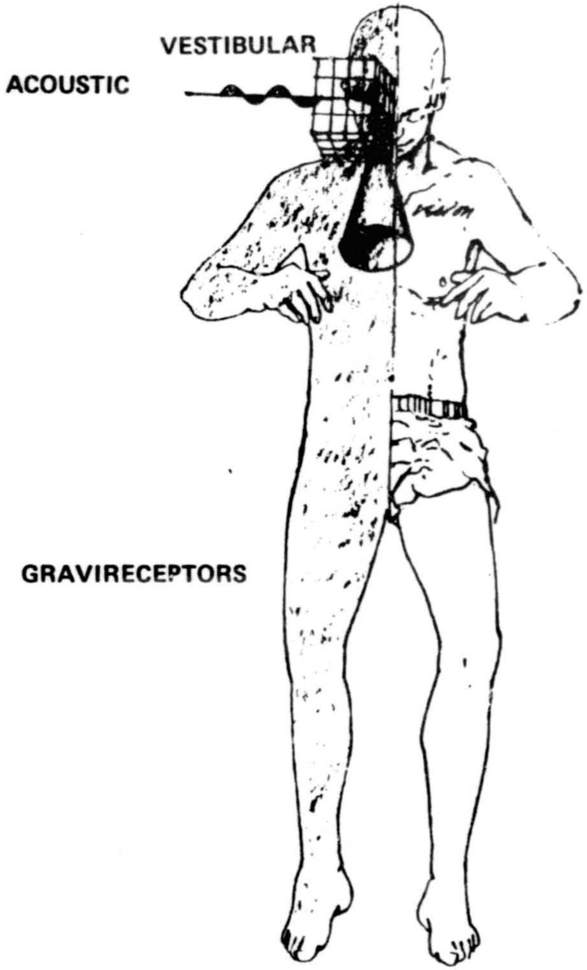
SS-1127

Neutral Body Posture/Cardiovascular

Neutral Body Posture/Vision



Neutral Body Posture/Orientation



Neutral Body Posture and EVA Suit Fit

Space Station

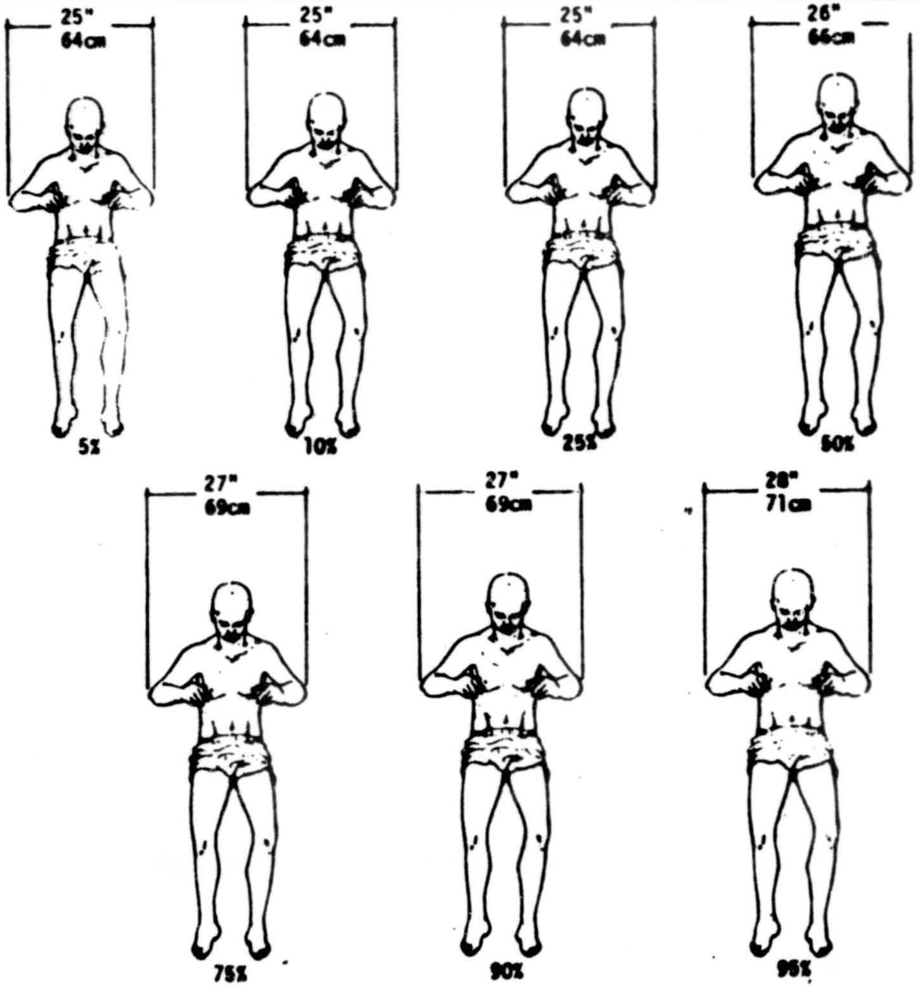
NASA

88-1116

Nominal Dimensions of Male Neutral Body Posture

Envelope by Percentile Groups

Ventral Views

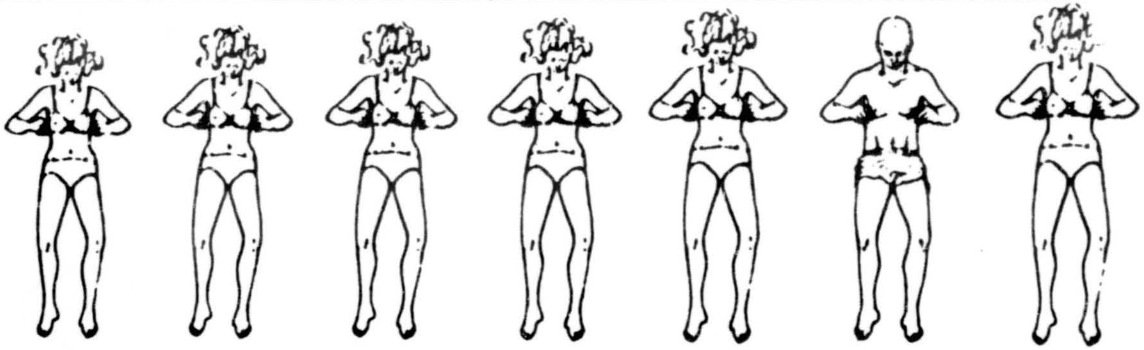


Space Station

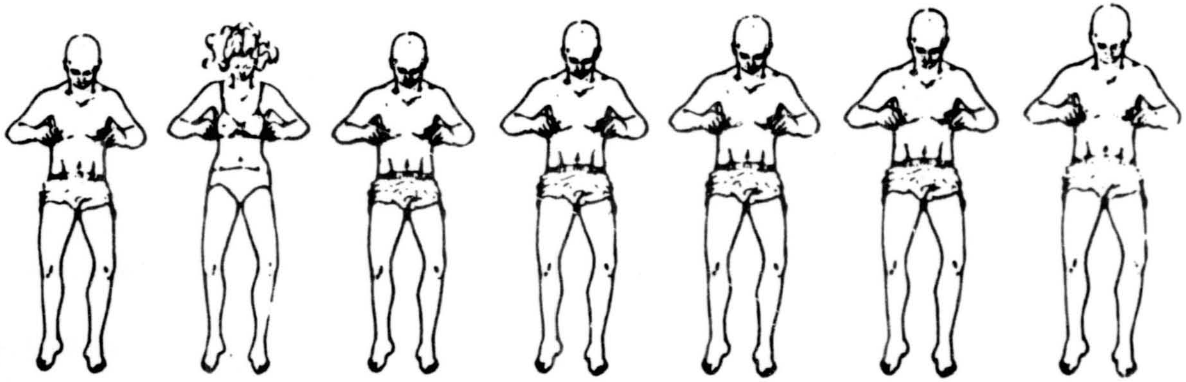
Male and Female N.B.P. Arranged by Height from Projected Astronaut Populations

NASA

86-1110

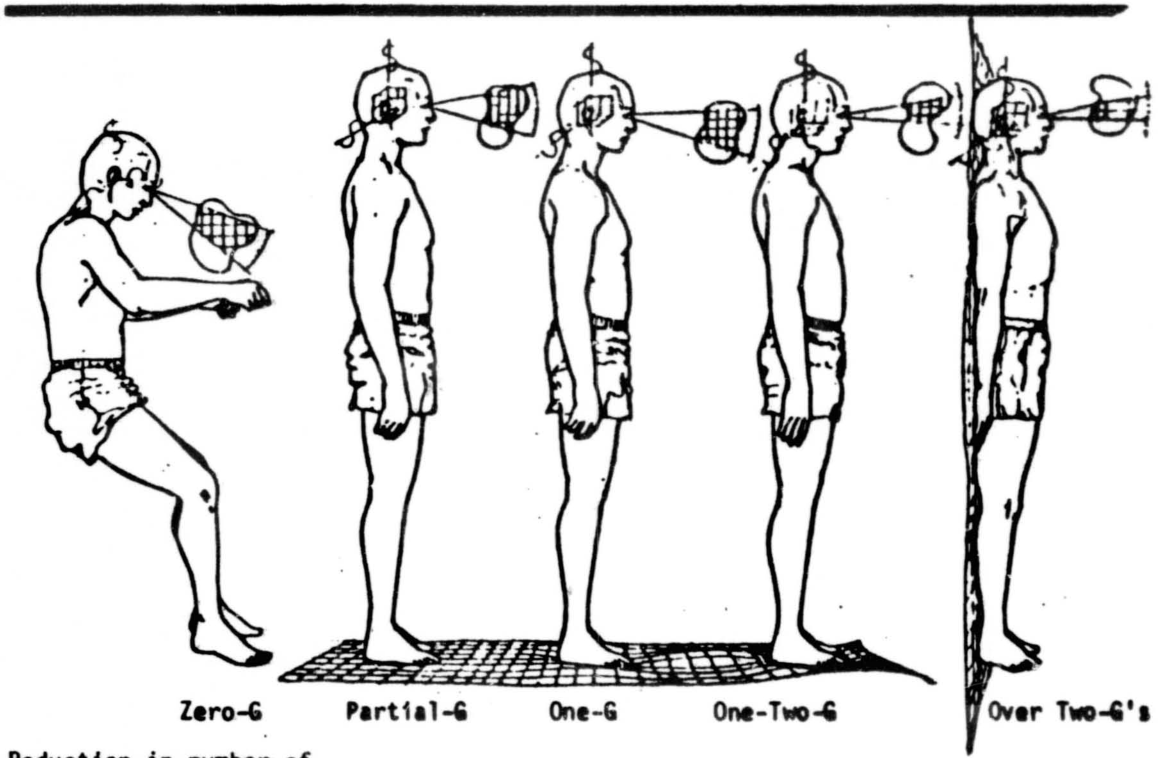


PERCENTILE	5%	10%	25%	50%	75%	5%	90%
N.B.P "	54	54	56	58	59	60	61
1-6 "	60.0	60.8	62.5	64.1	65.8	66.2	67.2



PERCENTILE	10%	95%	25%	50%	75%	90%	95%
N.B.P	61	61	62	63	64	66	67
1-6	67.3	68	68.5	70.2	71.6	73.0	74.3

Comparitive Orientation Analyzers



Reduction in number of afferent impulses used for orientation.

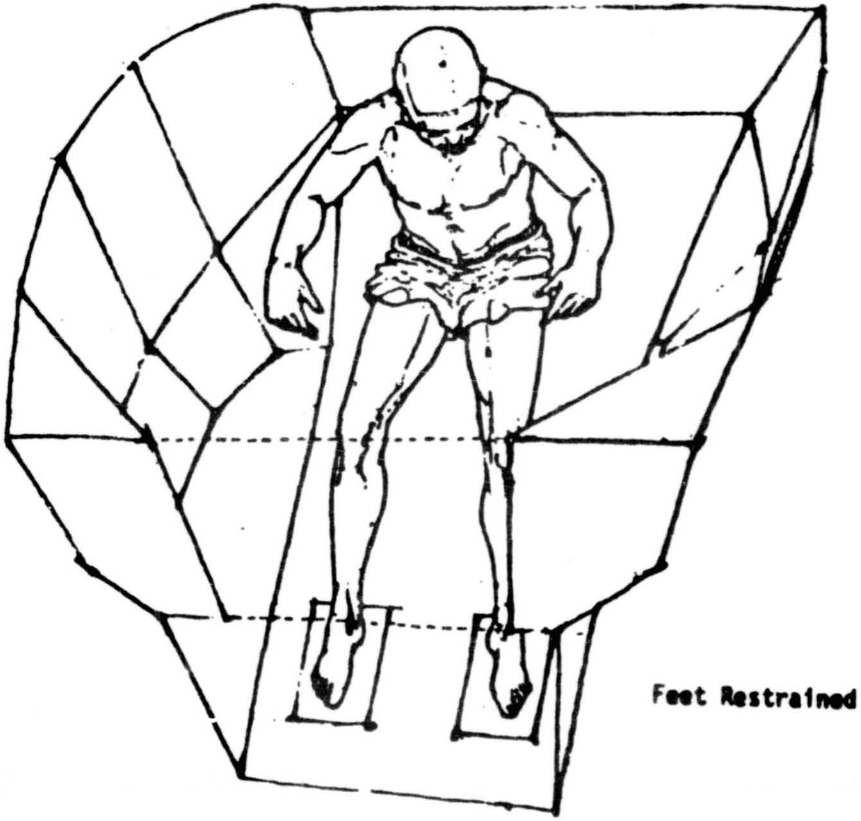
1. No otolith functions.
2. No cutaneous (proprioceptive--must be imposed).

Tunnel Vision reduces field of sight.

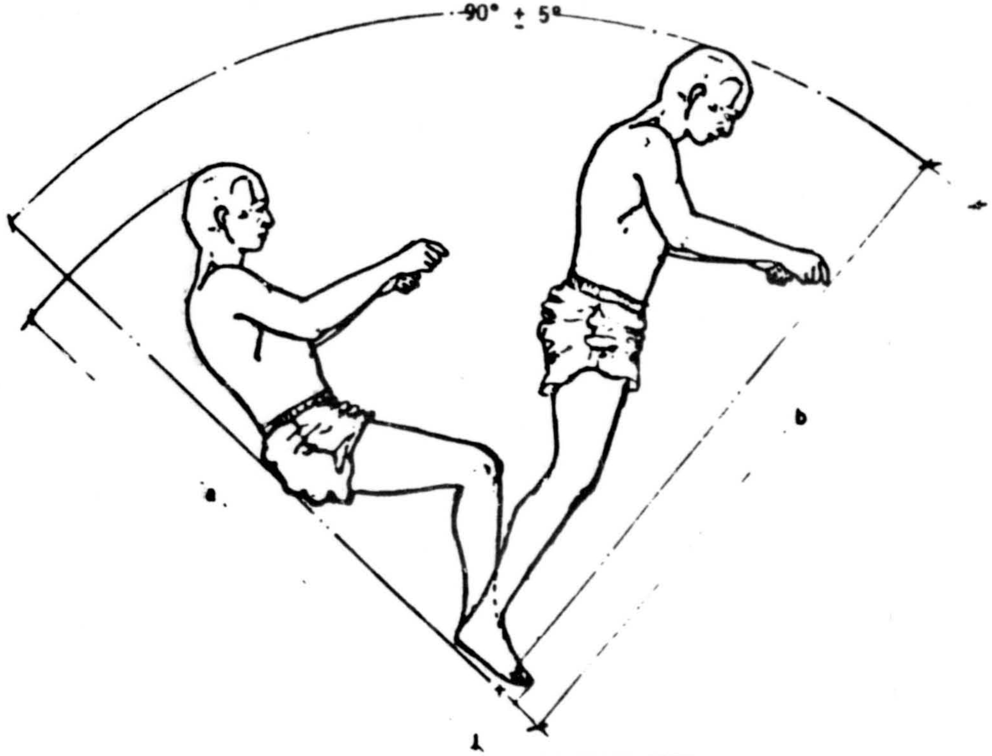
Space Station

NASA

Work Station Diagram for the Dynamic Zero-G Envelope



Dynamic Zero-G Envelope



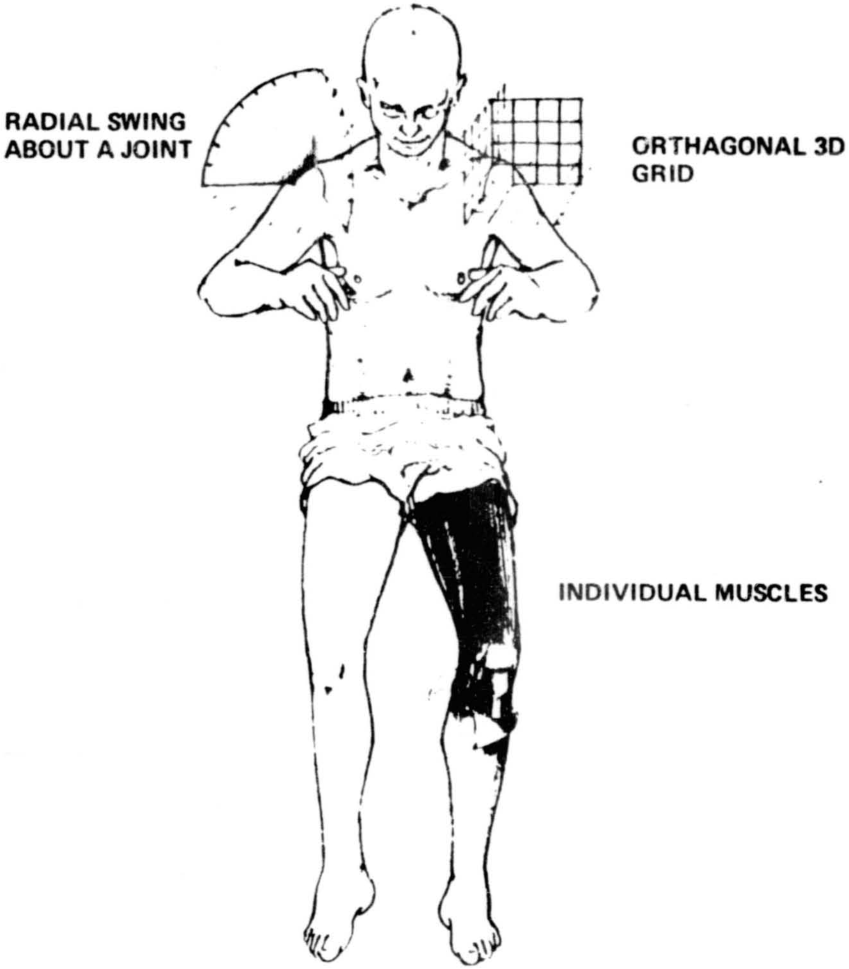
NOMINAL LIMITS OF MOVEMENT FROM
RESTRAINED FOOT POSITION

	MALE							FEMALE						
	5%	10%	25%	50%	75%	90%	95%	5%	10%	25%	50%	75%	90%	96%
a"	58	59	60	62	75	64	65	53	53	55	57	58	59	61
b"	65	66	67	69	70	71	72	59	59	61	63	64	66	67

Space
Station

NASA
SS-1132

Quantifying Work from Neutral Body Datum



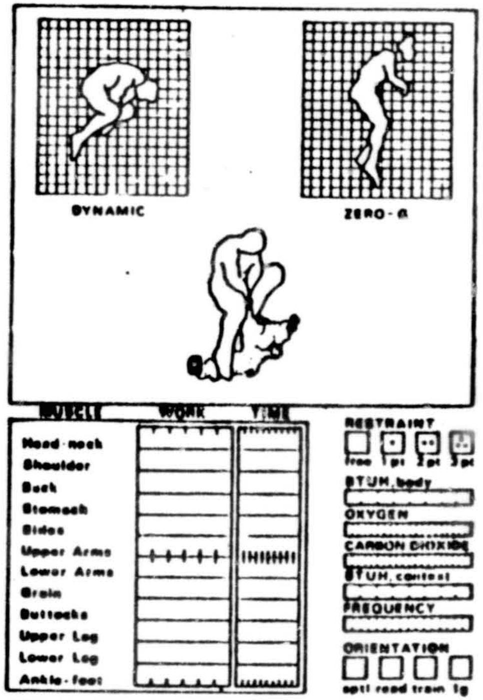
Space Station

NASA

88-1100

Zero-G Activity Analysis

(Donning and Doffing IVA Wear)



Work diagram - graphic portrayal of individual muscle work superimposed on N.B.P.

Profile, unit extreme posture exhibited for that activity

Nominal view - 3D representation of activity

Body description by major muscle groups

Desired restraint necessary for efficient performance.

Heat produced by activity

Quantity of O_2 consumed

Quantity of CO_2 produced

Heat produced by equipment and other crewmembers within the immediate vacinity

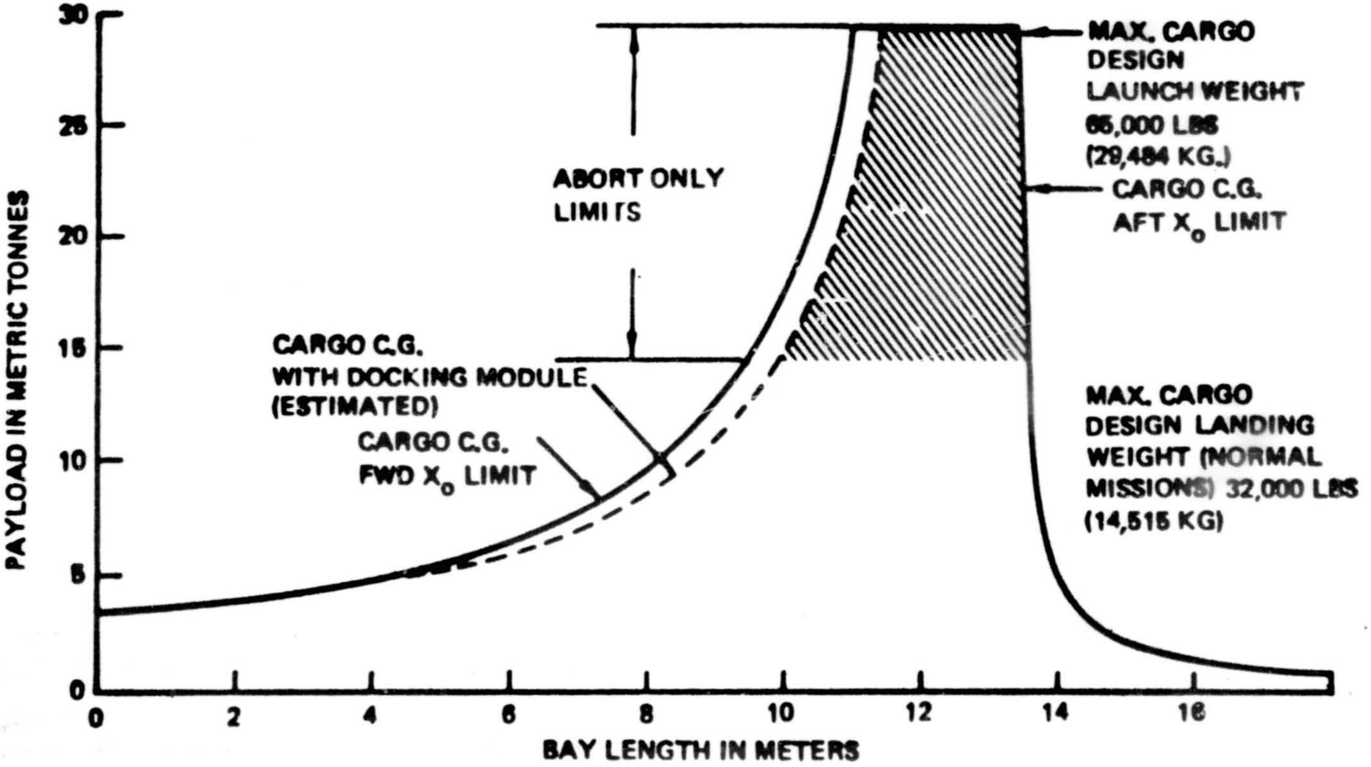
No. of times the activity is performed in 24 hour period

Orientation required for that activity

Work exerted by muscle groups for that activity - calibration based on measurement through cybex isokinetic dynamometer, infared photography, EMG or photogrametry

Time each muscle group is working

Shuttle Center of Gravity

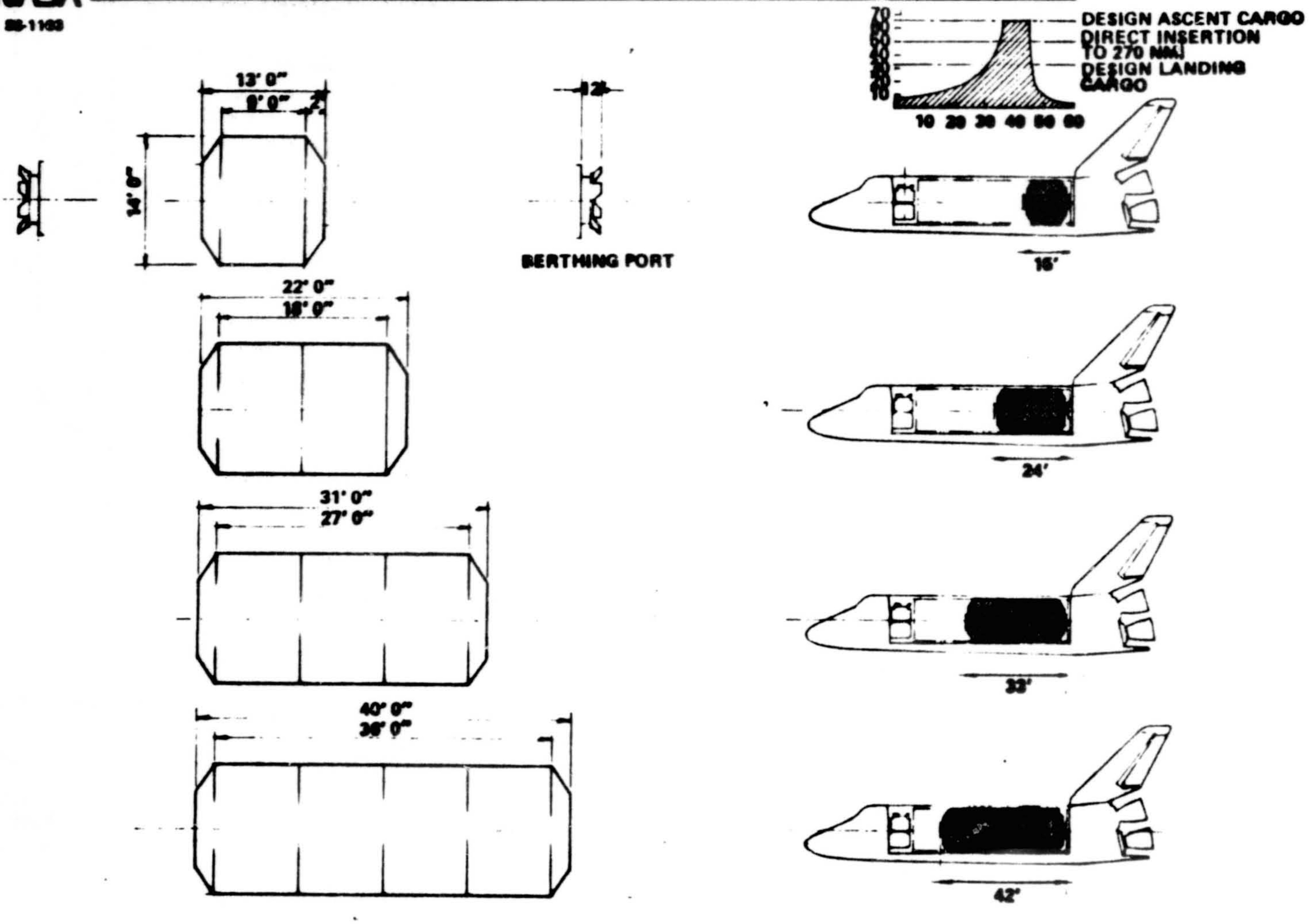


Space Station

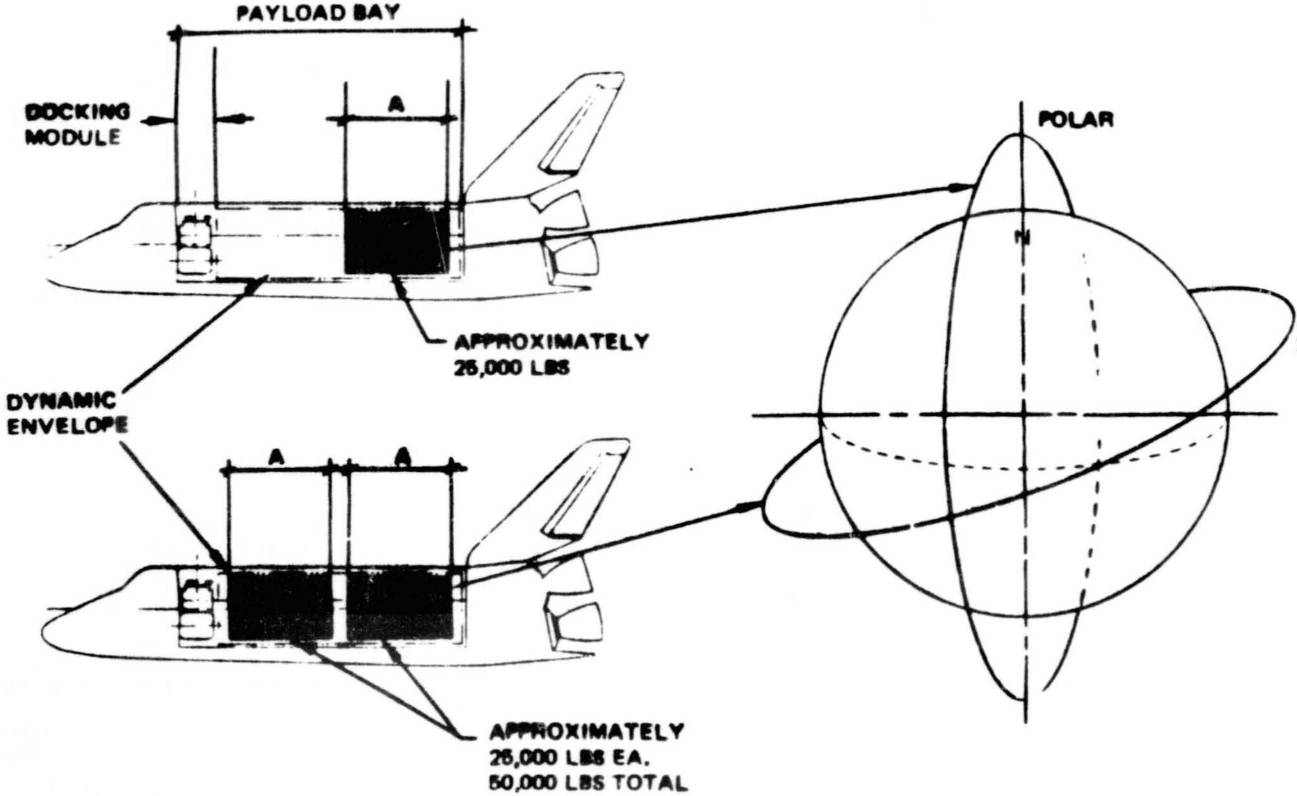
NASA

SS-1103

Module Length



Module Sizing Rationale
Incremental Architecture



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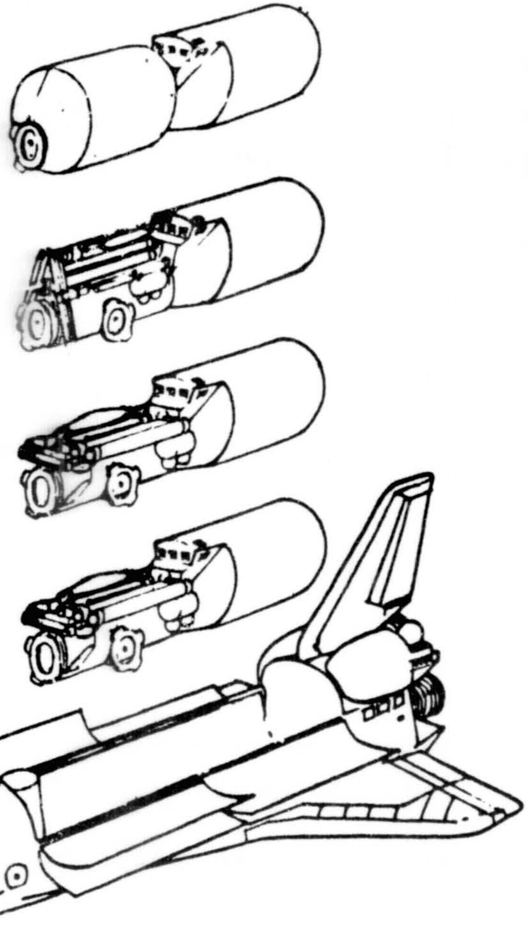
Delivery Options



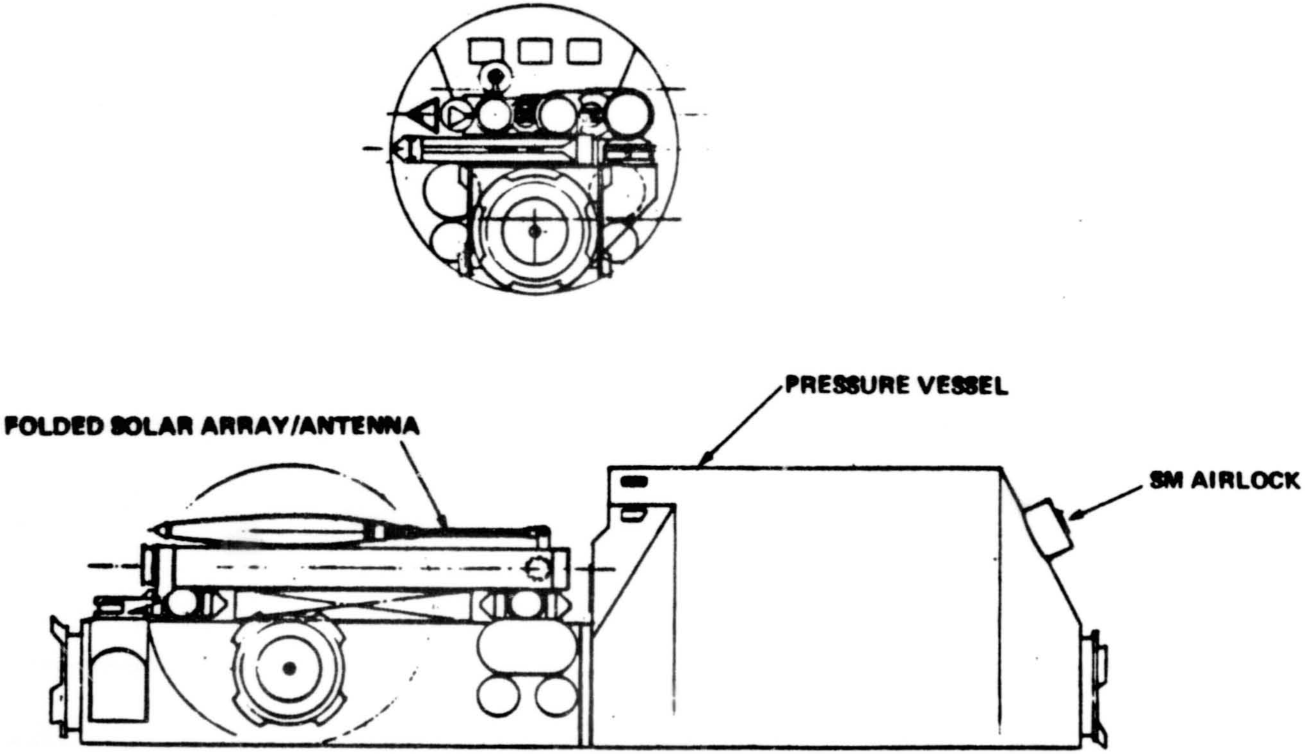
TWIN PRESS VESSELS

SINGLE LAUNCH SPACE STA.

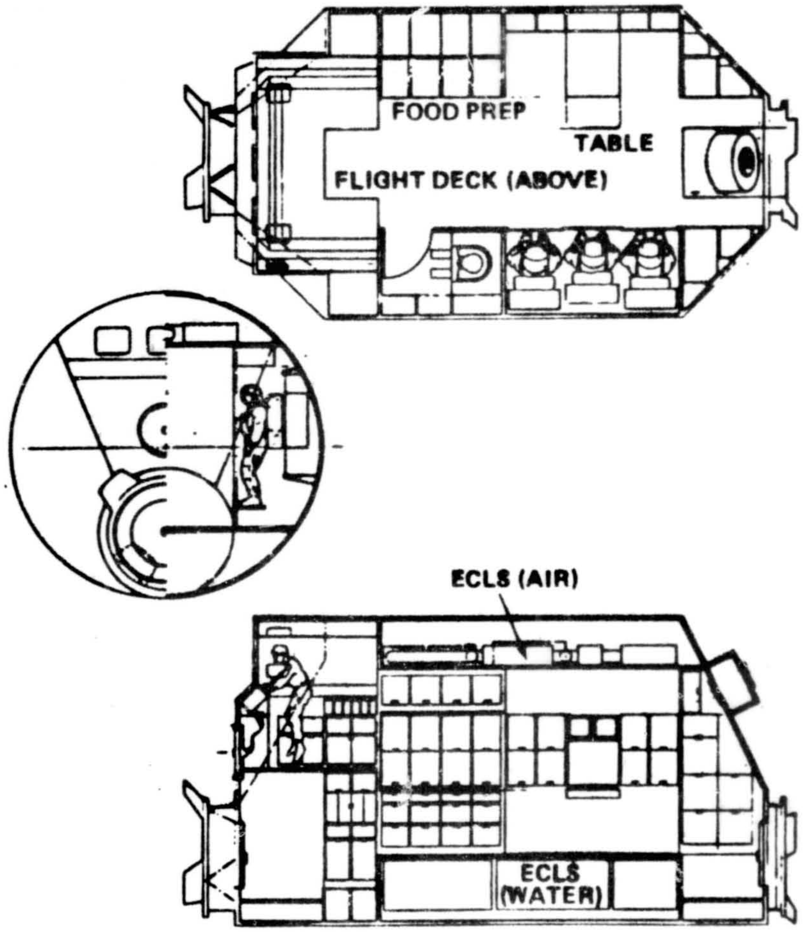
COMMAND/CONTROL MODULE

CREW QUARTERS

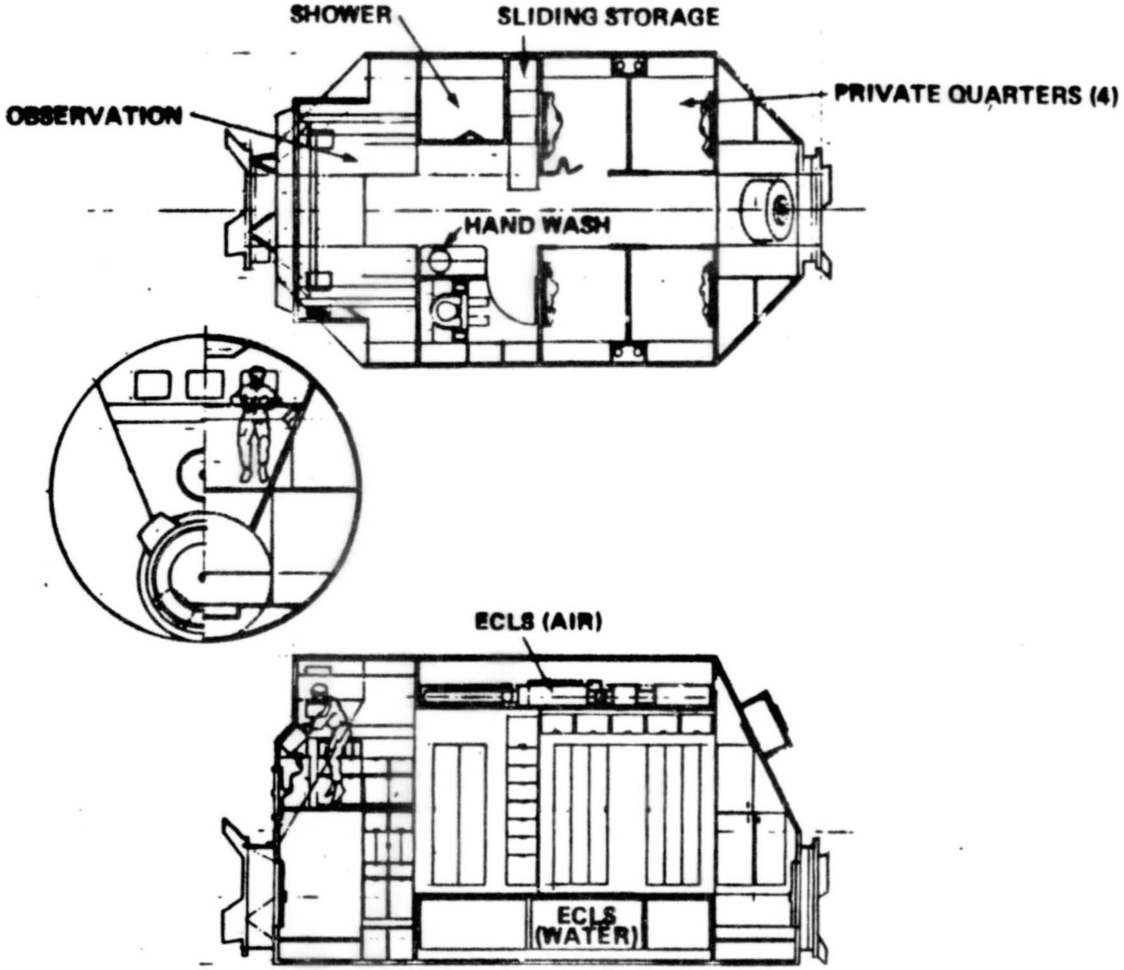
External View Alternative Module



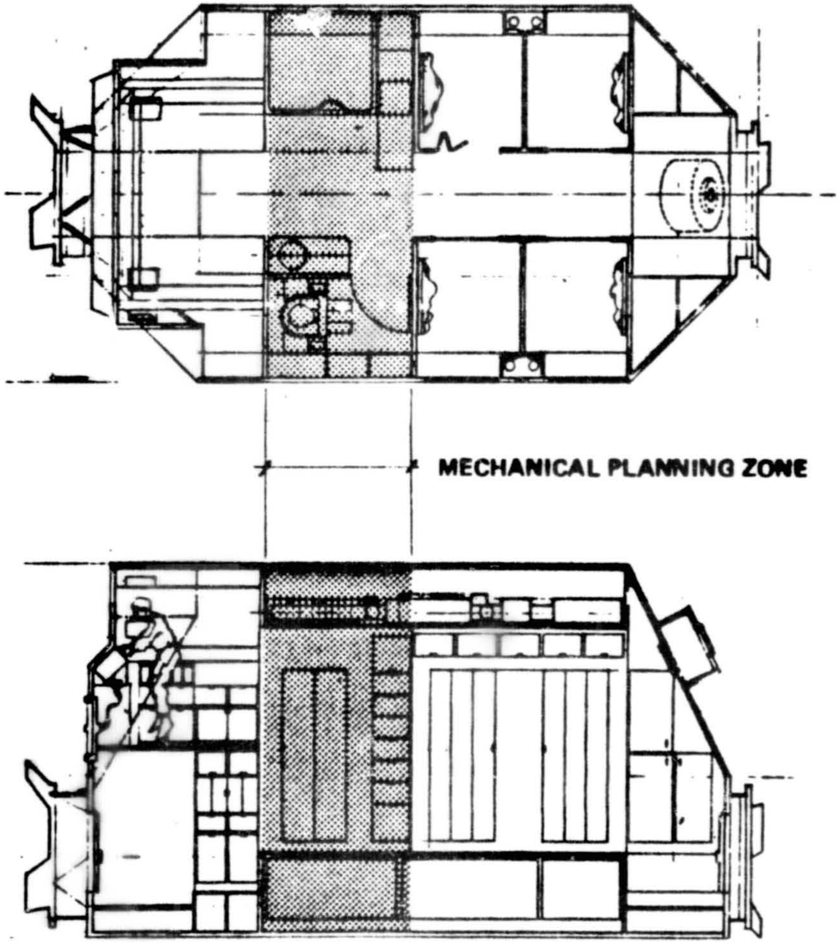
Command/Control Module



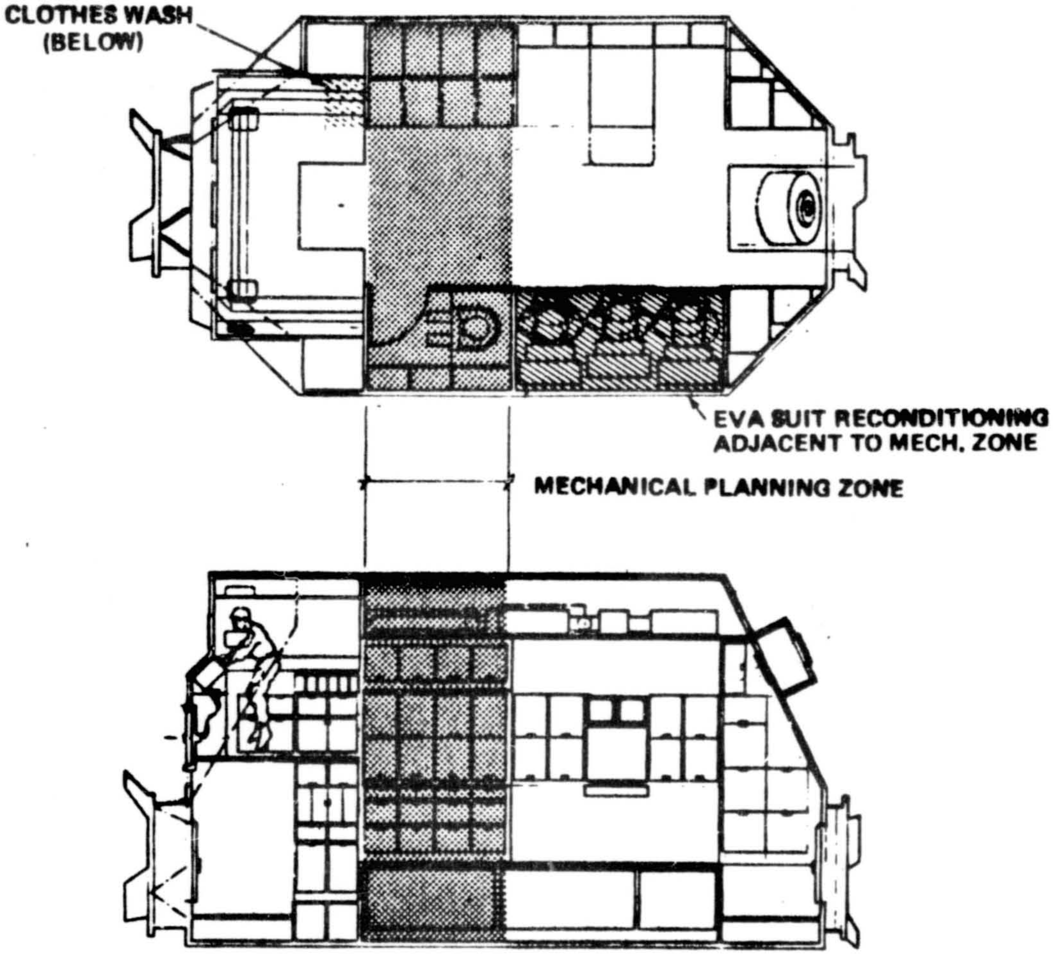
Crew Quarters Module



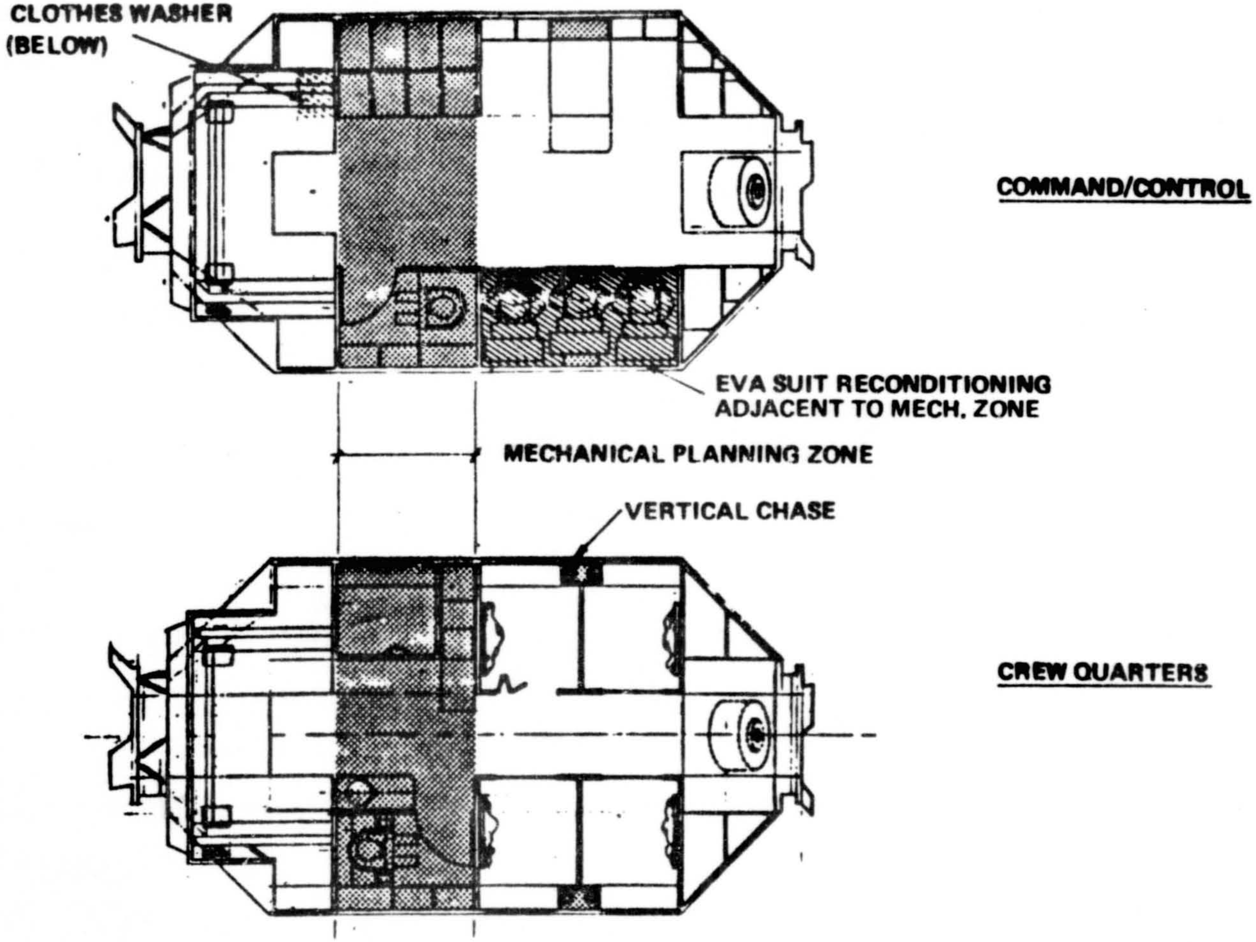
Crew Quarters Mechanical Zone



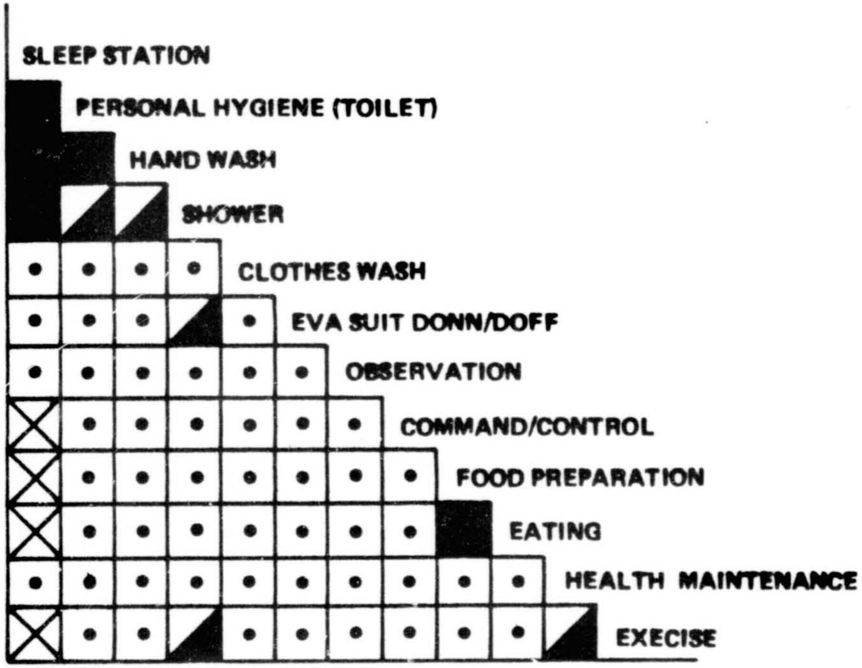
Command/Control Mechanical Zone



Comparative Mechanical Zone Placement



Adjacency Matrix



	SLEEP STATION	PERSONAL HYGIENE (TOILET)	HAND WASH	SHOWER	CLOTHES WASH	EVA SUIT DONN/DOFF	OBSERVATION	COMMAND/CONTROL	FOOD PREPARATION	EATING	HEALTH MAINTENANCE
SLEEP STATION											
PERSONAL HYGIENE (TOILET)	■										
HAND WASH	■	■									
SHOWER	■	◪	◪								
CLOTHES WASH	●	●	●	●							
EVA SUIT DONN/DOFF	●	●	●	◪	●						
OBSERVATION	●	●	●	●	●	●					
COMMAND/CONTROL	☒	●	●	●	●	●	●				
FOOD PREPARATION	☒	●	●	●	●	●	●	●			
EATING	☒	●	●	●	●	●	●	●	■		
HEALTH MAINTENANCE	●	●	●	●	●	●	●	●	●	●	
EXECISE	☒	●	●	◪	●	●	●	●	●	●	◪

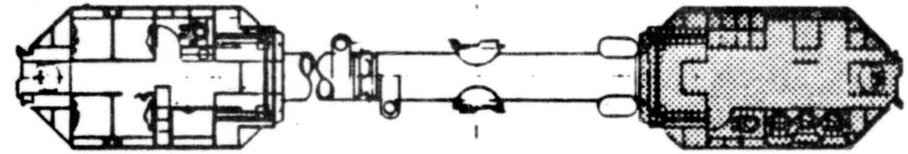
■ CLOSE PROXIMITY

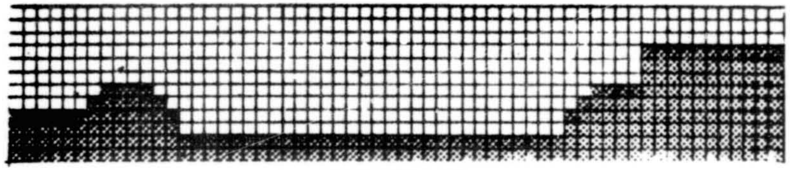
◪ MODERATE PROXIMITY

☒ SEPARATION

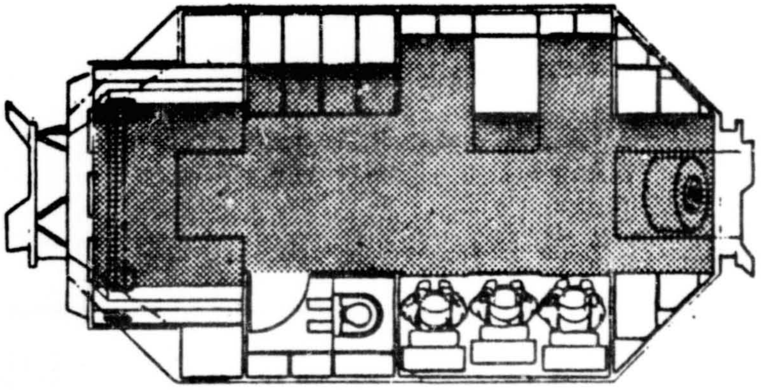
● NO PREFERENCE

Open Space, Command/Control Module



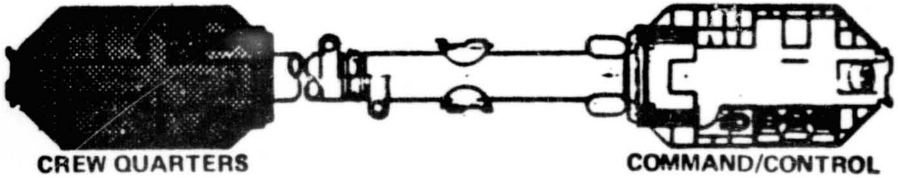


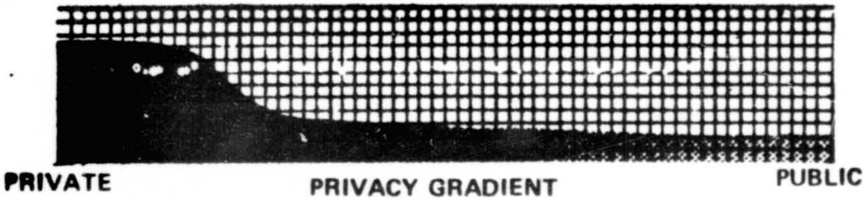
OPEN SPACE

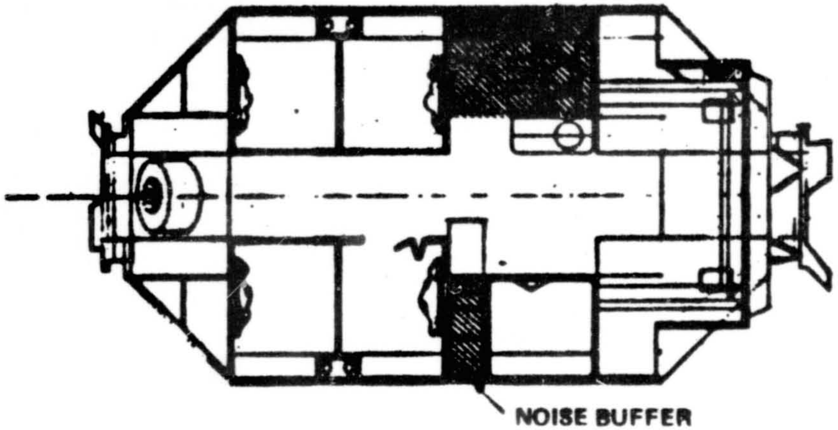


COMMAND/CONTROL MODULE

Privacy Gradient





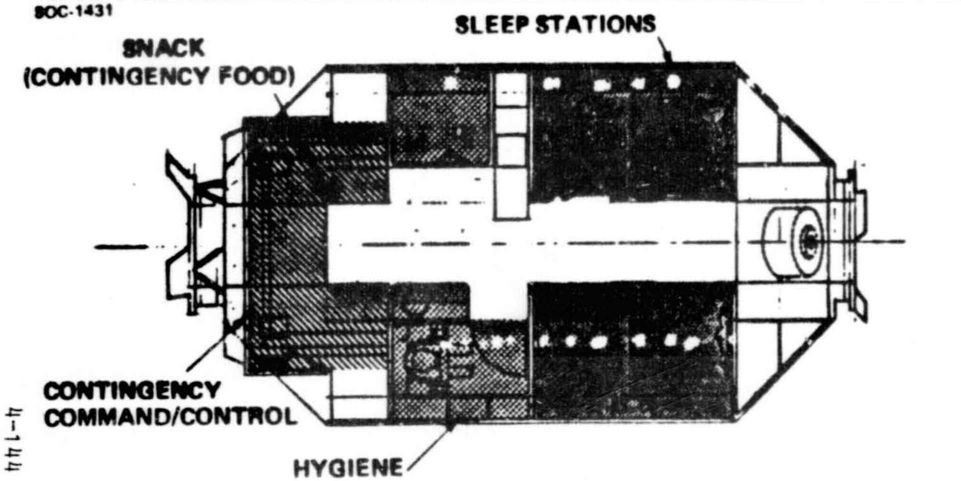


CREW QUARTERS MODULE

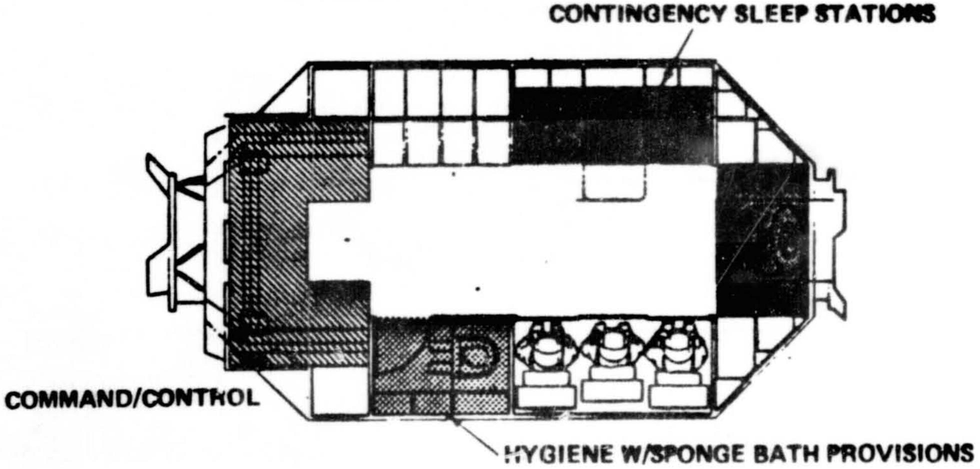
SPACE
OPERATIONS
CENTER

Redundancy

NASA
SOC-1431



CREW QUARTERS



COMMAND/CONTROL

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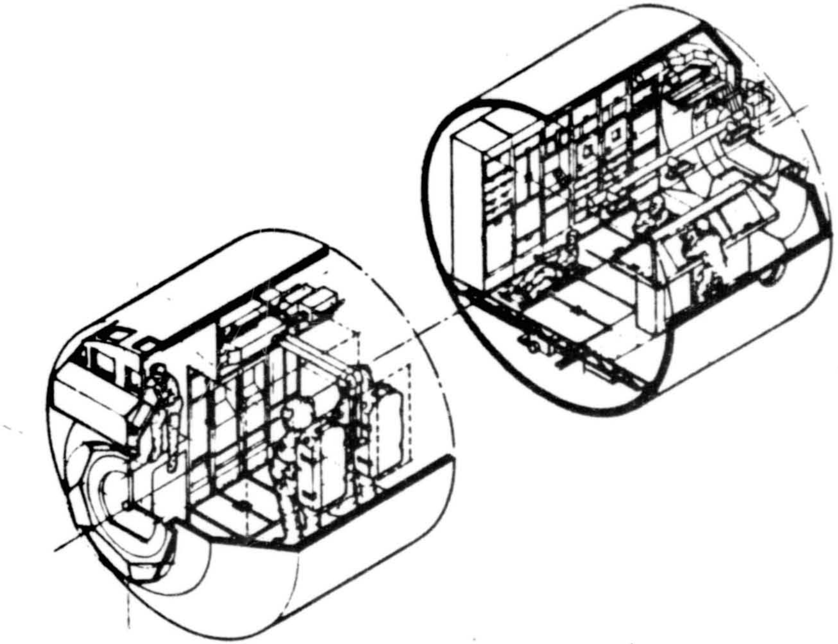
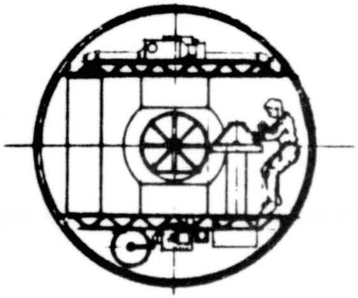
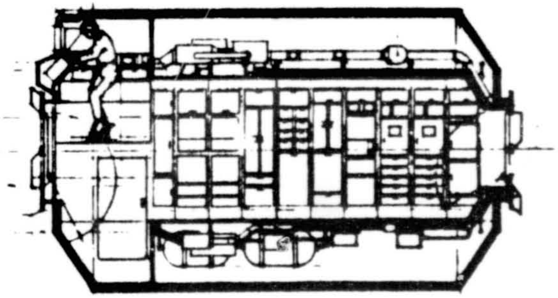
Space Station Common Module
(Active)

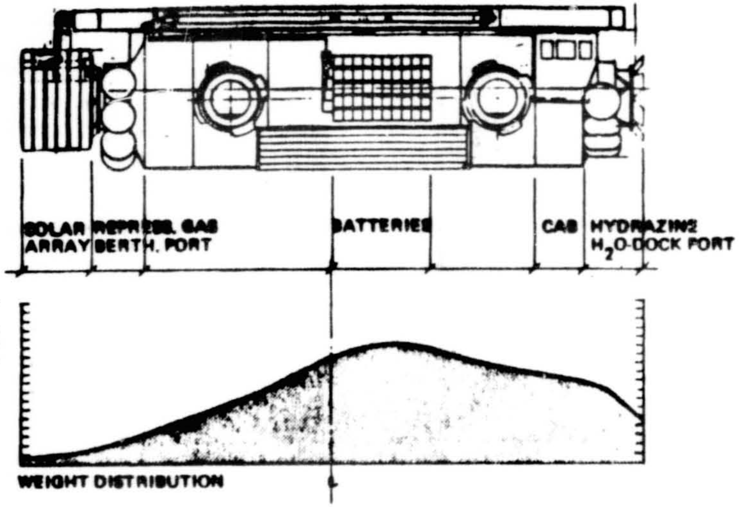




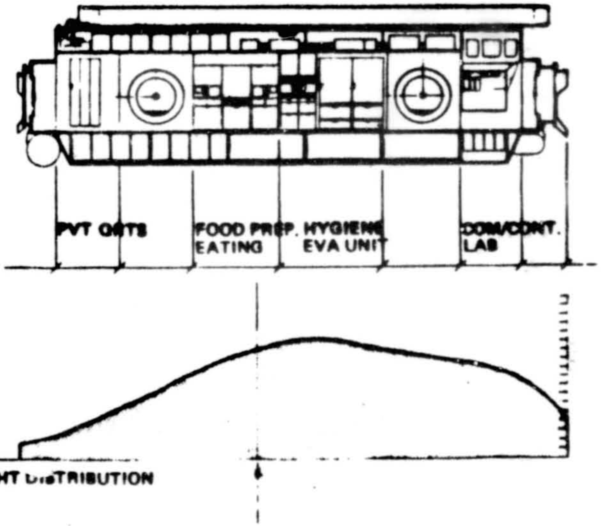


LARGE SPACE SYSTEMS
LSS-034

Habitable Service Module Weight Distribution



EXTERNAL CONFIGURATION

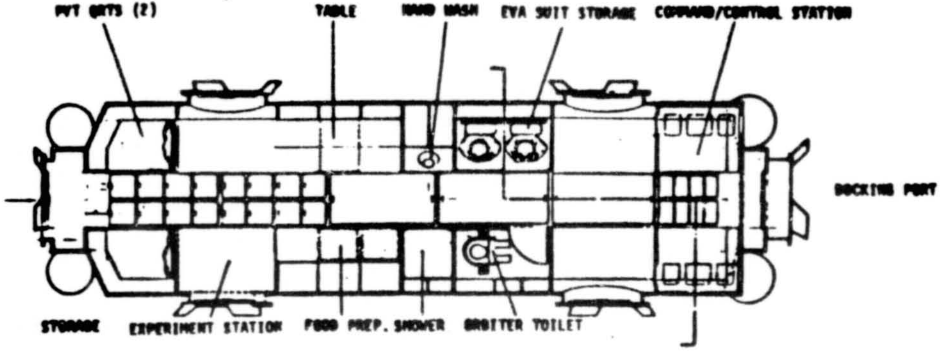


INTERNAL LAYOUT

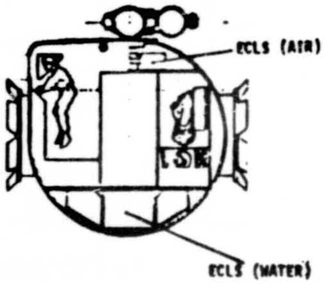
Habitable Service Module, Interior Layout

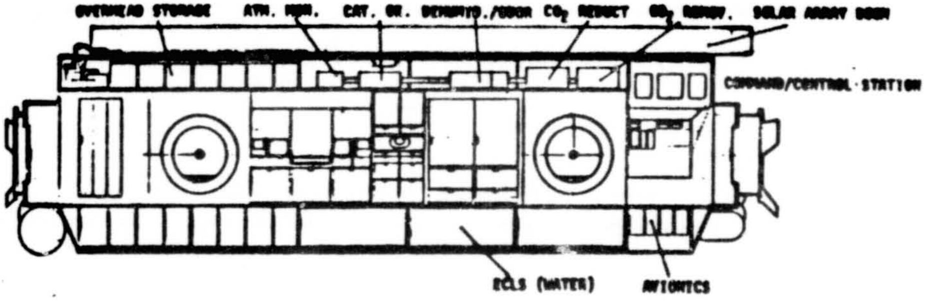
(2 Man Configuration)

SECTION VIEW



PLAN VIEW

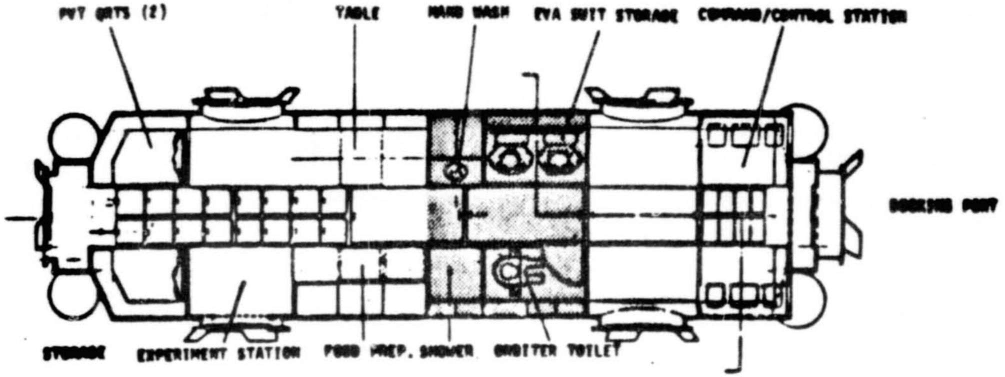




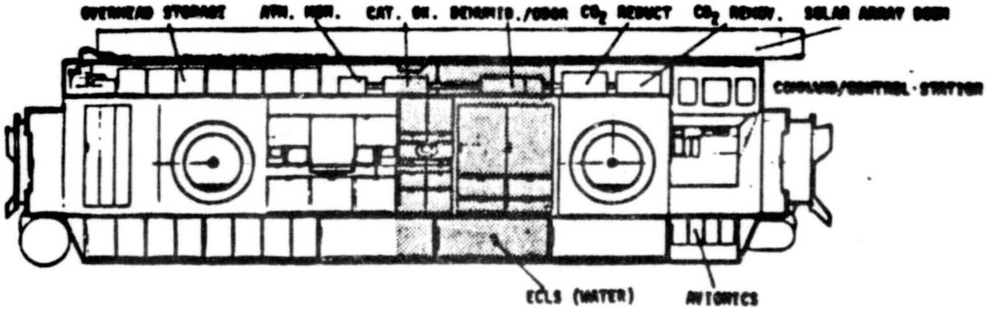
INBOARD PROFILE VIEW

Hygiene/EVA Suit Storage Zone

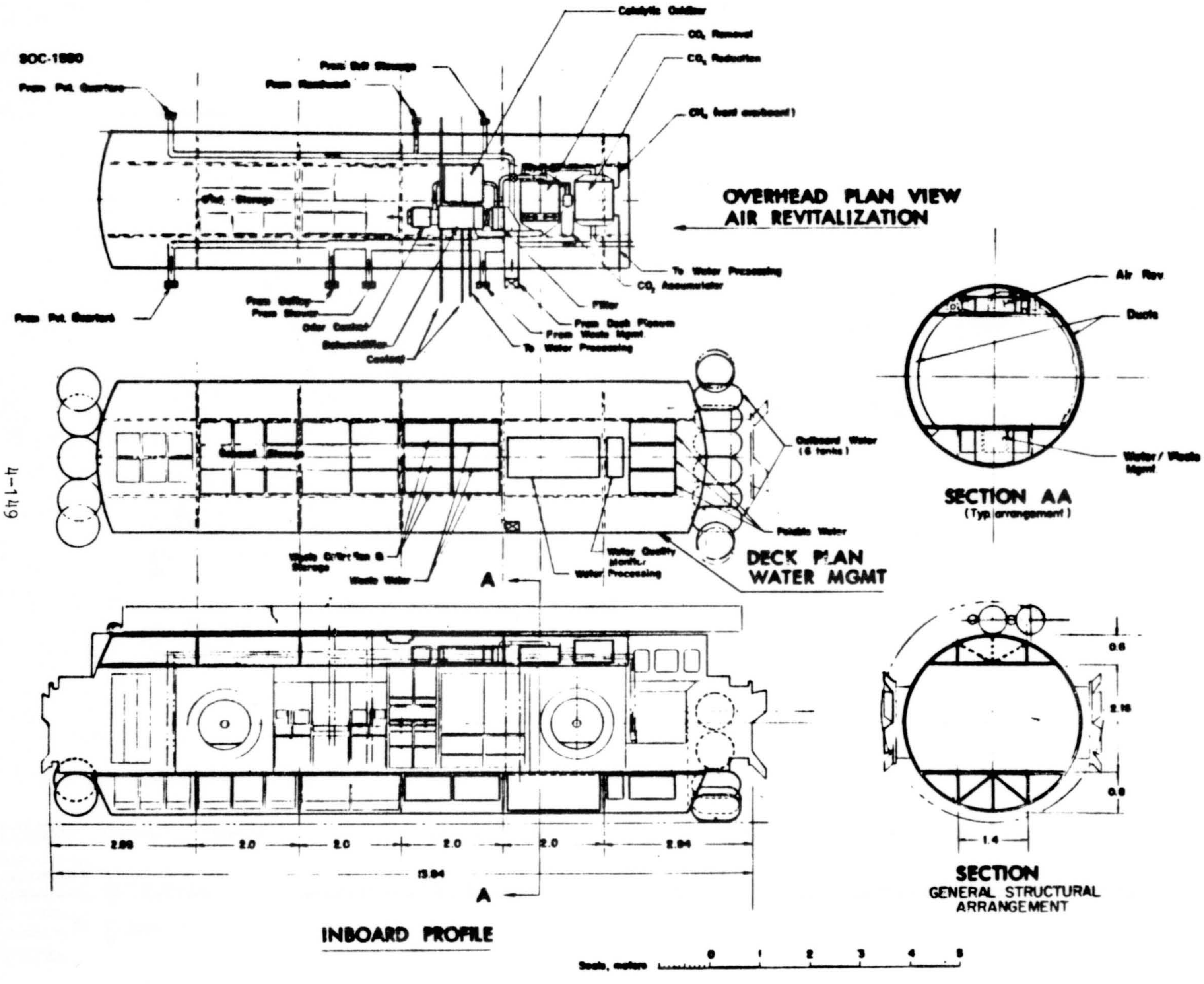
LSS-936



PLAN VIEW



INBOARD PROFILE VIEW

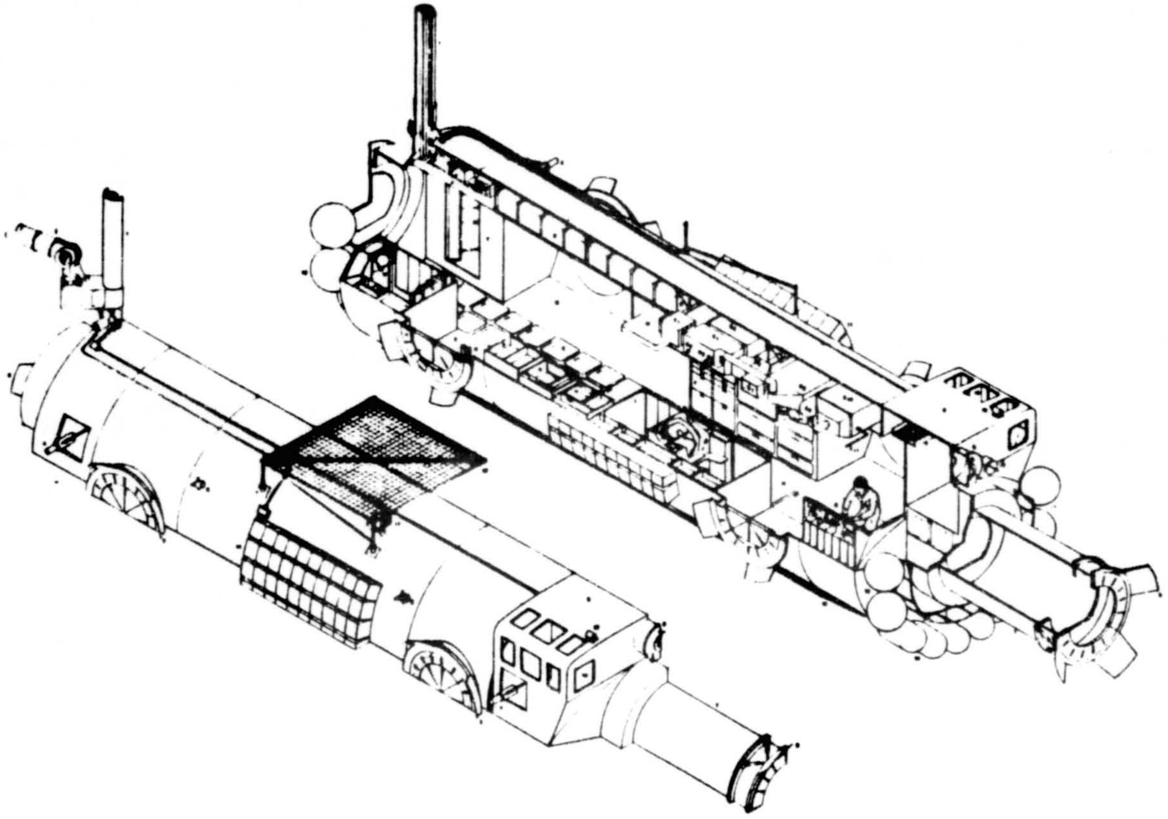

SOC-1980
From Pot. Quarters
From Handwash
From Sci Storage
Catalytic Oxidizer
CO₂ Removal
CO₂ Reduction
CH₄ (vent overboard)
Pot. Storage
OVERHEAD PLAN VIEW
AIR REVITALIZATION
To Water Processing
CO₂ Accumulator
Filter
From Dash Plenum
From Waste Mgmt
To Water Processing
Coolant
Dehumidifier
Odor Control
From Shower
From Galley
From Pot. Quarters
Air Rev
Ducts
Water / Waste Mgmt
SECTION AA
(Typ arrangement)
General Storage
Outboard Water
(6 tanks)
Potable Water
Waste Collect'n &
Storage
Waste Water
Water Quality
Monitor
Water Processing
DECK PLAN
WATER MGMT
A
A
0.6
2.16
0.6
1.4
SECTION
GENERAL STRUCTURAL
ARRANGEMENT
2.88
2.0
2.0
2.0
2.0
2.94
13.94
INBOARD PROFILE
Scale, meters
0
1
2
3
4
5

Space Station

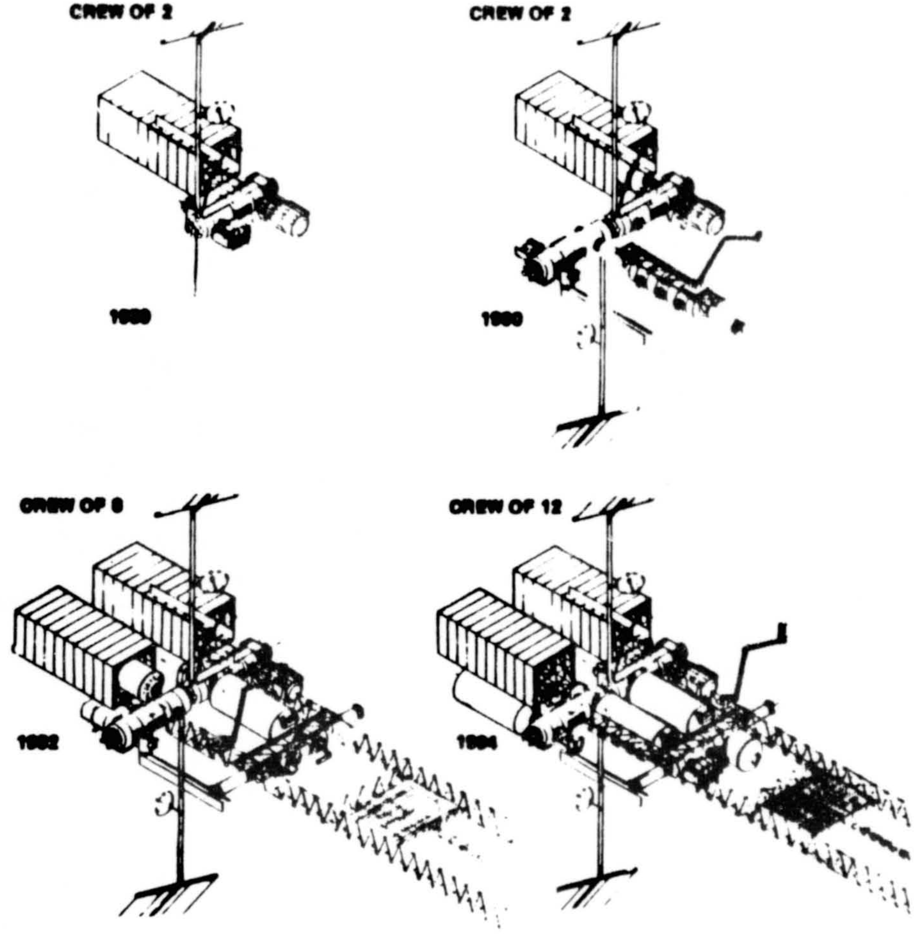
NASA

85-434

Hybrid Module/Interior-Exterior



Mission Derived Build-up Sequence



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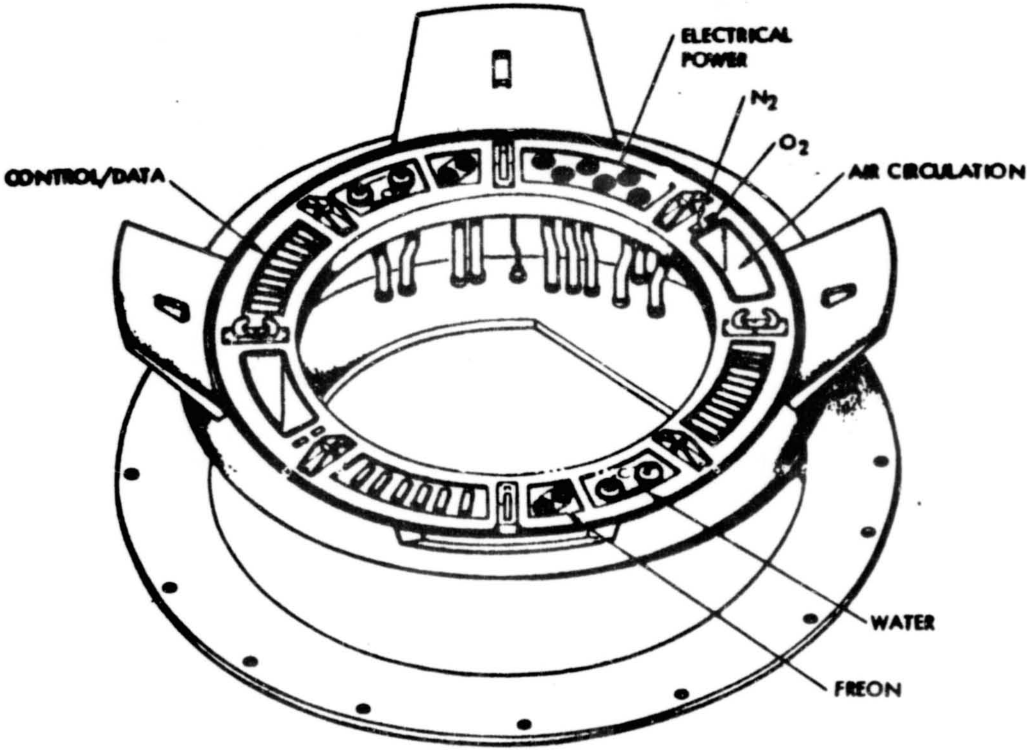


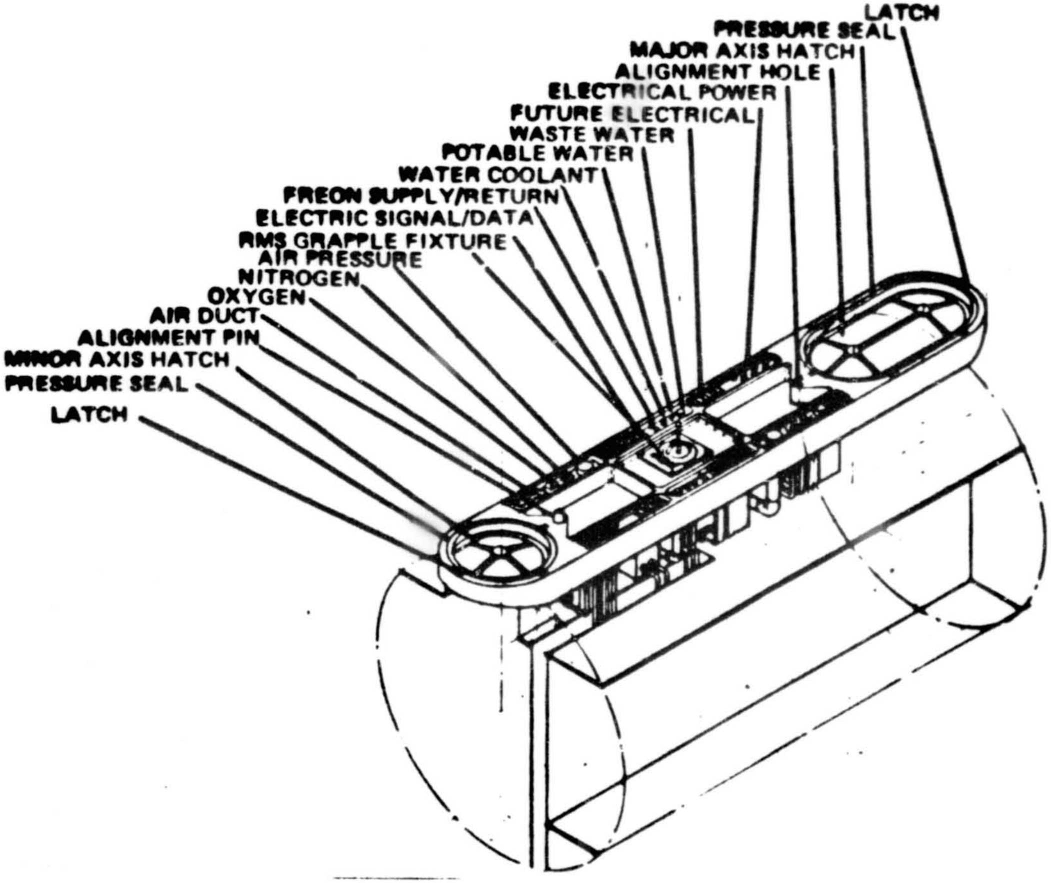
Space Station Module to Module Interface

Space Station

Berthing Interface Unified Architecture

NASA

86-708

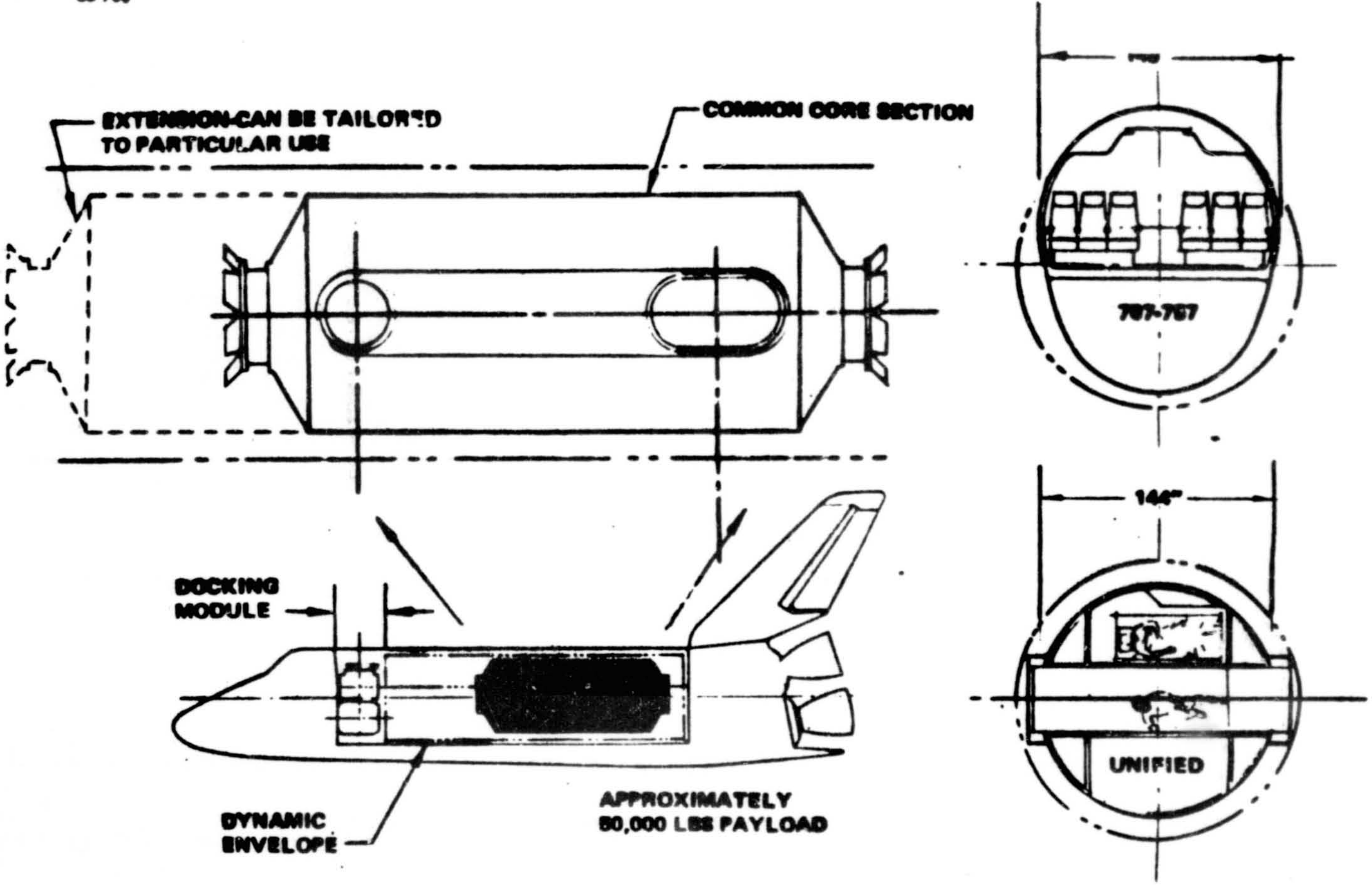


Space Station

NASA

Module Sizing Rationale
Unified Architecture

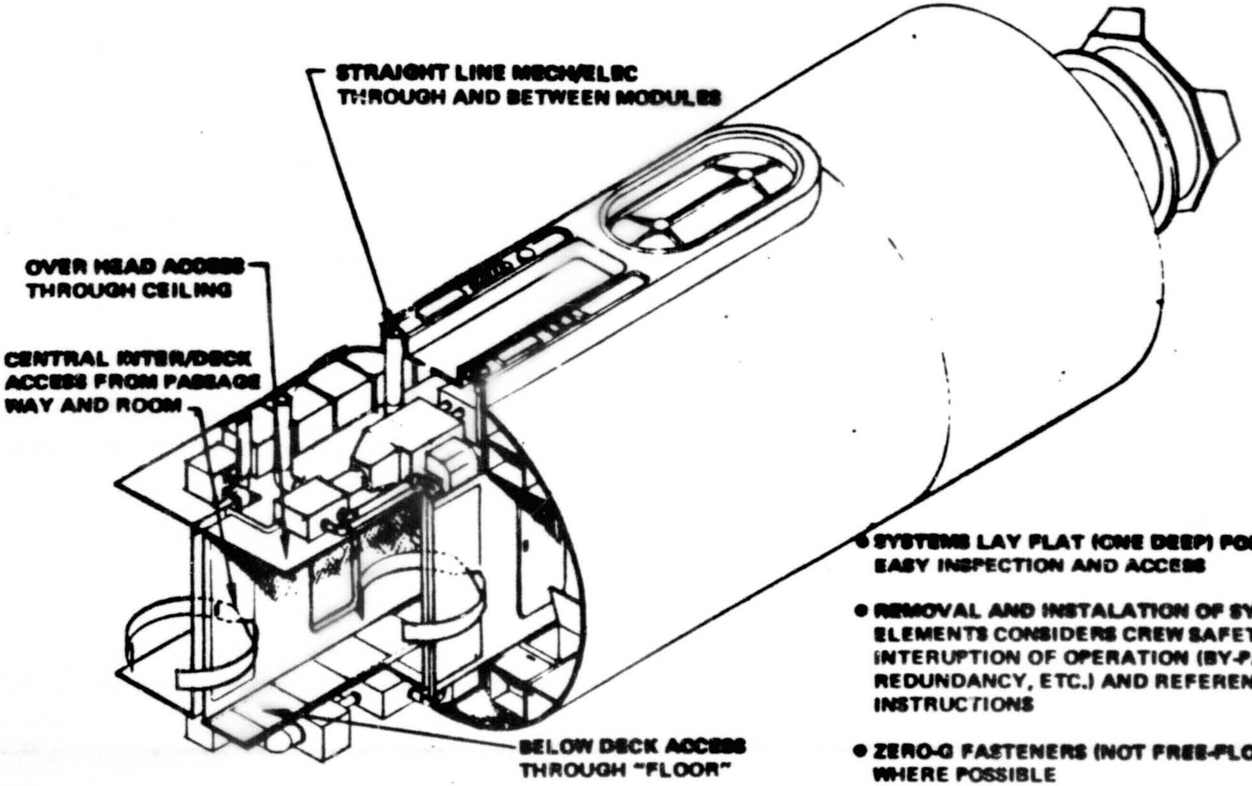
SS-706



Space Station

On-Orbit Subsystem Accessibility

NASA SS-706

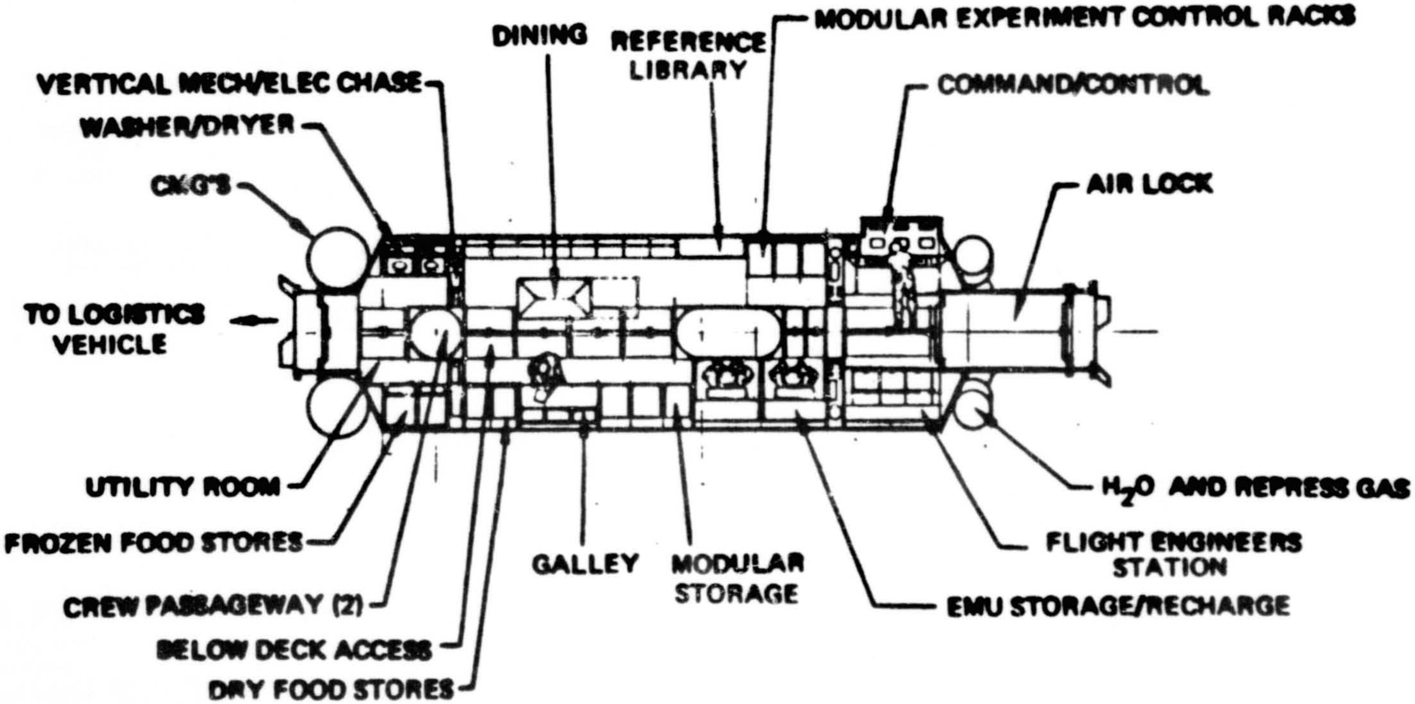


- SYSTEMS LAY FLAT (ONE DEEP) FOR EASY INSPECTION AND ACCESS
- REMOVAL AND INSTALATION OF SYSTEM ELEMENTS CONSIDERS CREW SAFETY, INTERUPTION OF OPERATION (BY-PASS, REDUNDANCY, ETC.) AND REFERENCE INSTRUCTIONS
- ZERO-G FASTENERS (NOT FREE-FLOATING) WHERE POSSIBLE

Space Station

NASA 88-710

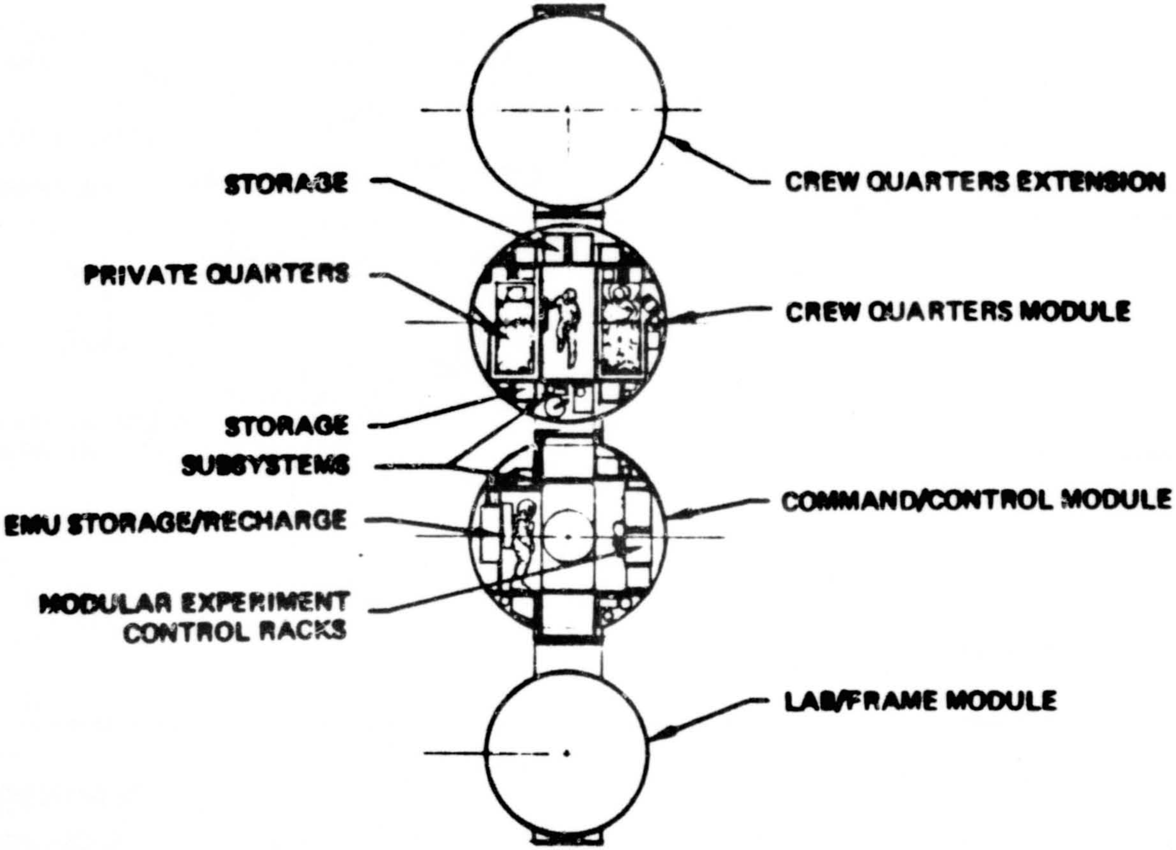
Unified Module Shown in Command/Control Layout



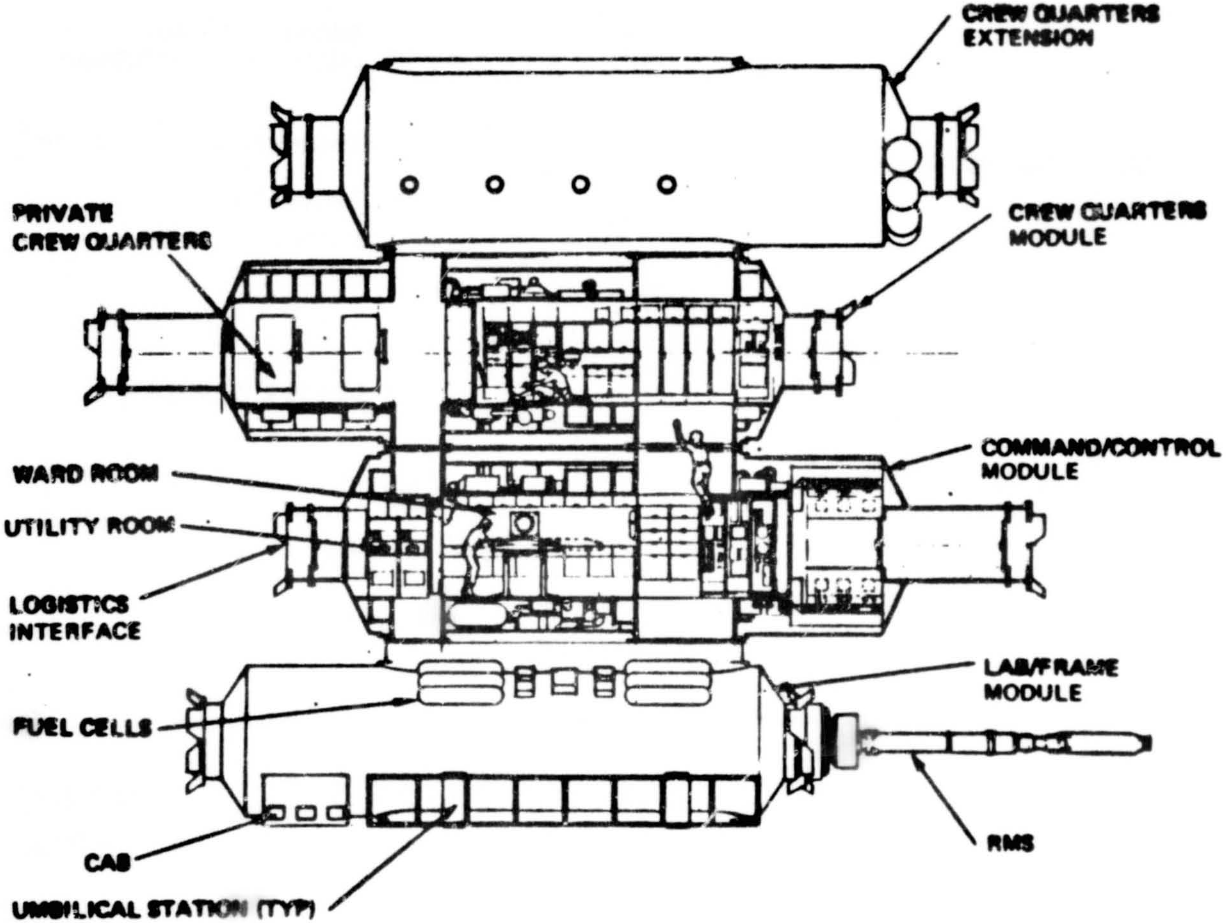
Space
Station

Transverse Section Unified Architecture

NASA
85-711



Section View of Crew Quarters and Command/Control Modules

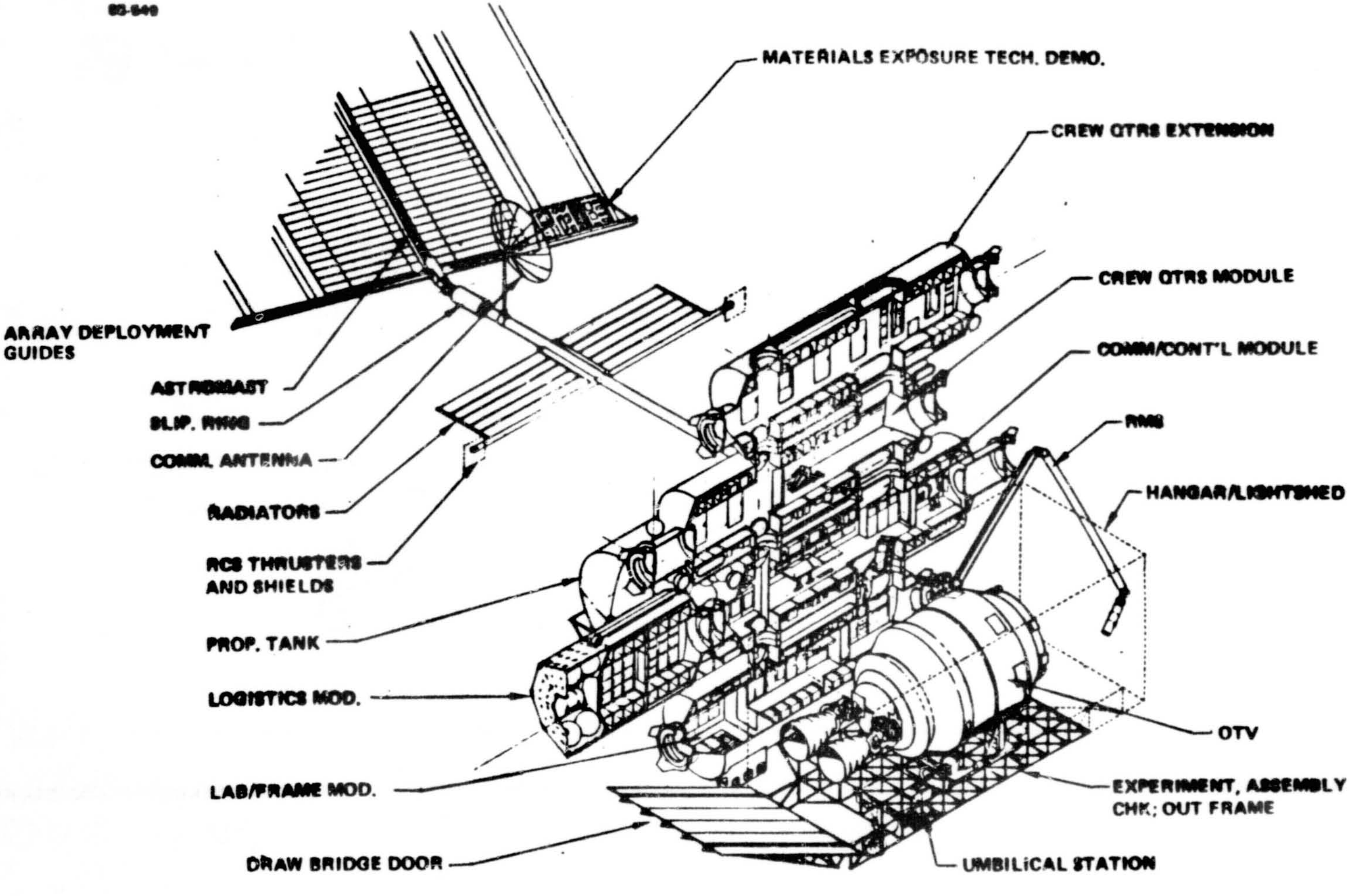


Space Station

NASA

Cutaway View of Unified Space Station Architecture

[illegible]



SPACE
OPERATIONS
CENTER
NASA
SOC-1466

Adjacency Matrix

SLEEP STATION											
PERSONAL HYGIENE (TOILET)	■										
HAND WASH	■	■									
SHOWER	■	◢	◢								
CLOTHES WASH	•	•	•	•							
EVA SUIT DONN/DOFF	•	•	•	◢	•						
OBSERVATION	•	•	•	•	•	•					
COMMAND/CONTROL	☒	•	•	•	•	•	•				
FOOD PREPARATION	☒	•	•	•	•	•	•	•			
EATING	☒	•	•	•	•	•	•	•	■		
HEALTH MAINTENANCE	•	•	•	•	•	•	•	•	•	•	
EXECISE	☒	•	•	◢	•	•	•	•	•	•	◢

■ CLOSE PROXIMITY

◢ MODERATE PROXIMITY

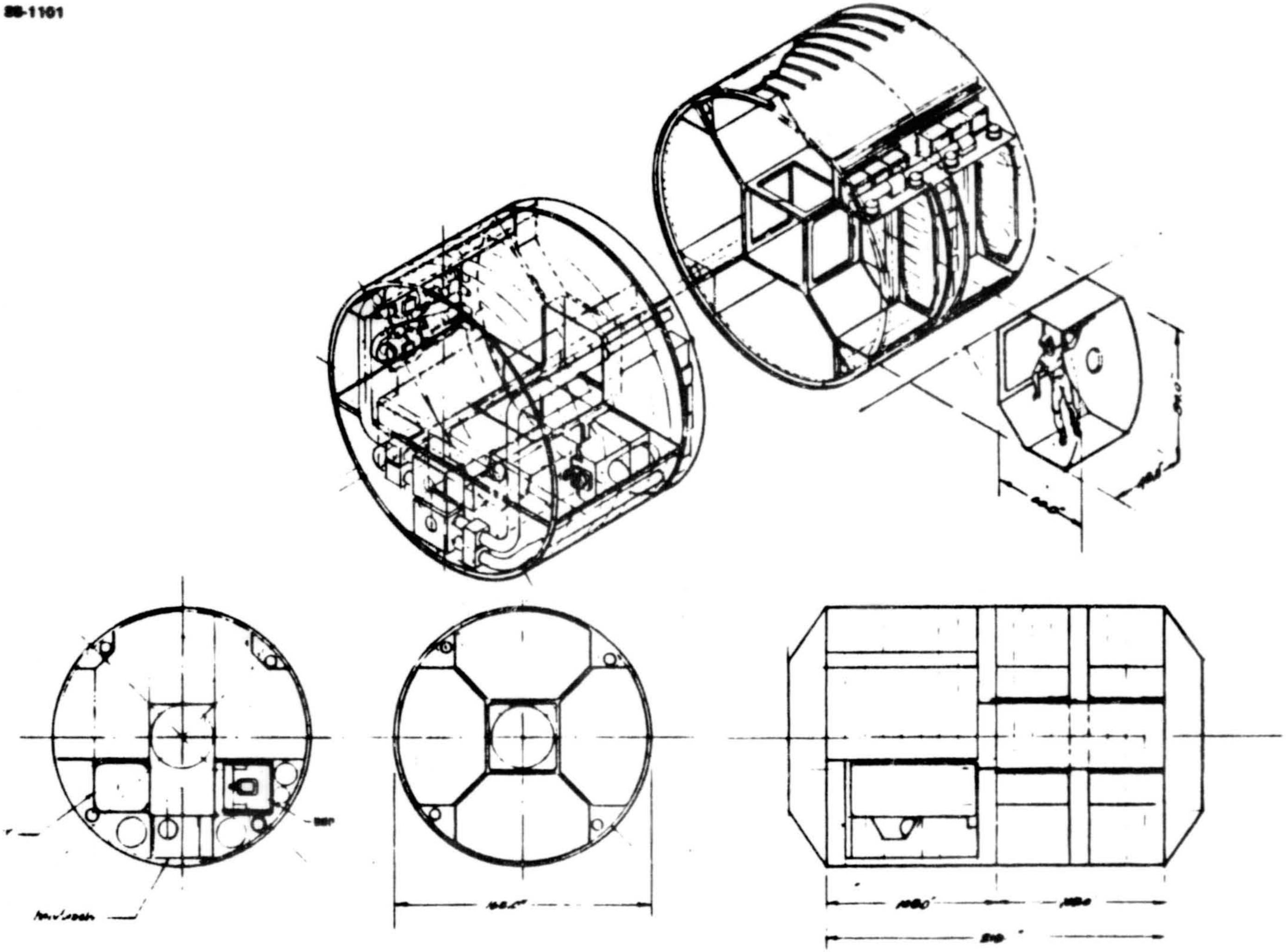
☒ SEPARATION

• NO PREFERENCE

Space
Station

NASA
86-1101

Space Station Common Module (Quiet)

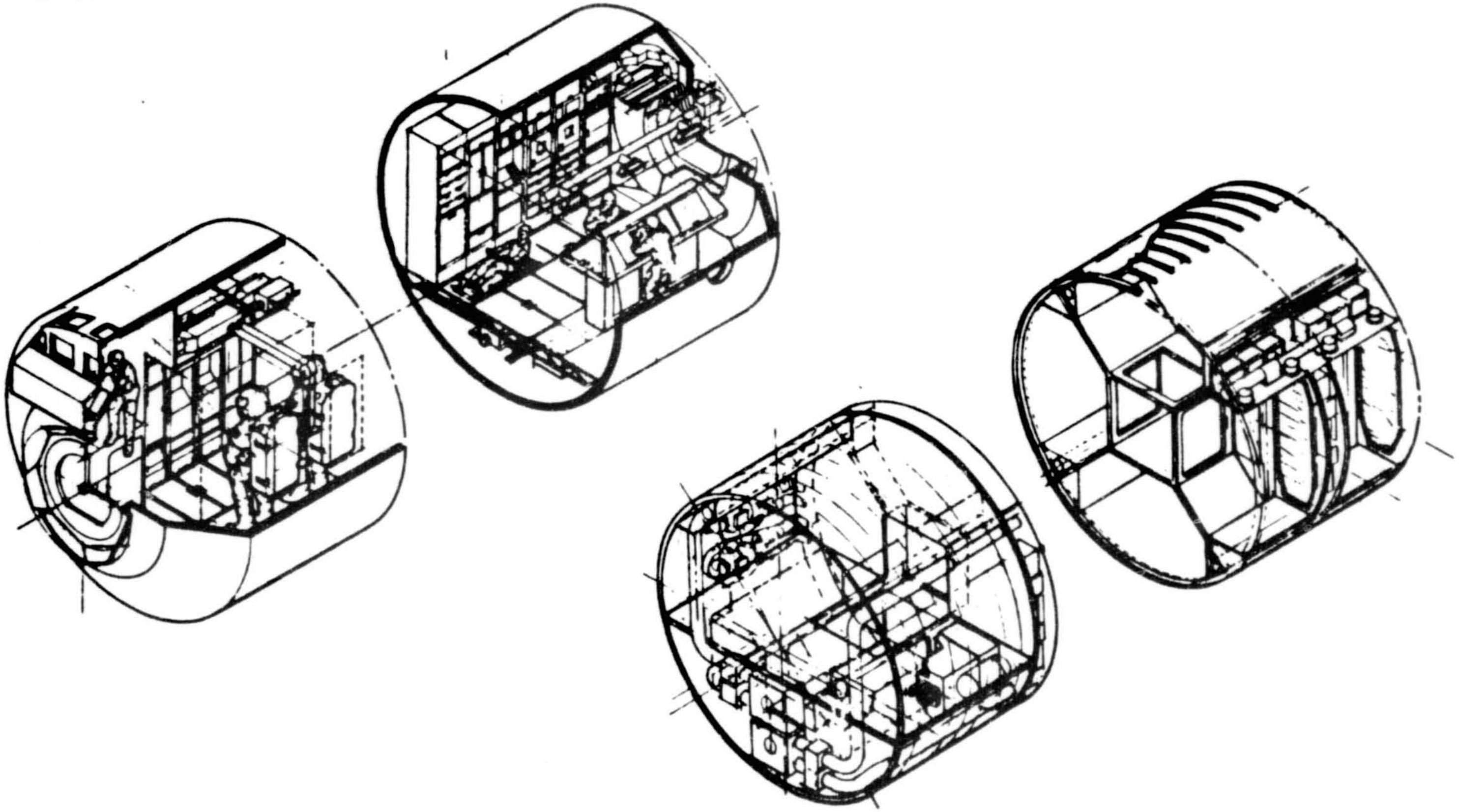


Space
Station

Space Station Common Module

NASA

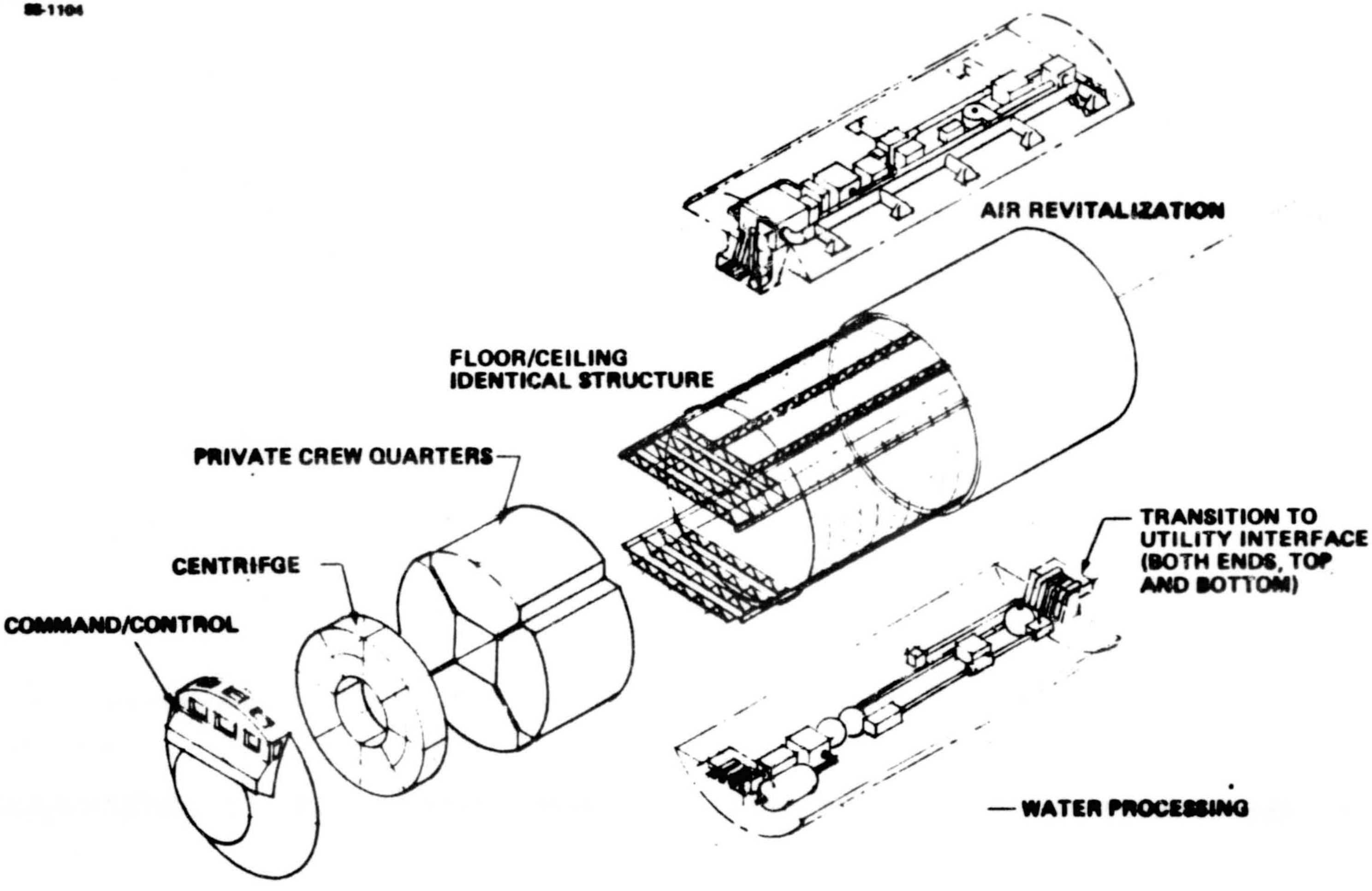
88-1162



ACTIVE

QUIET

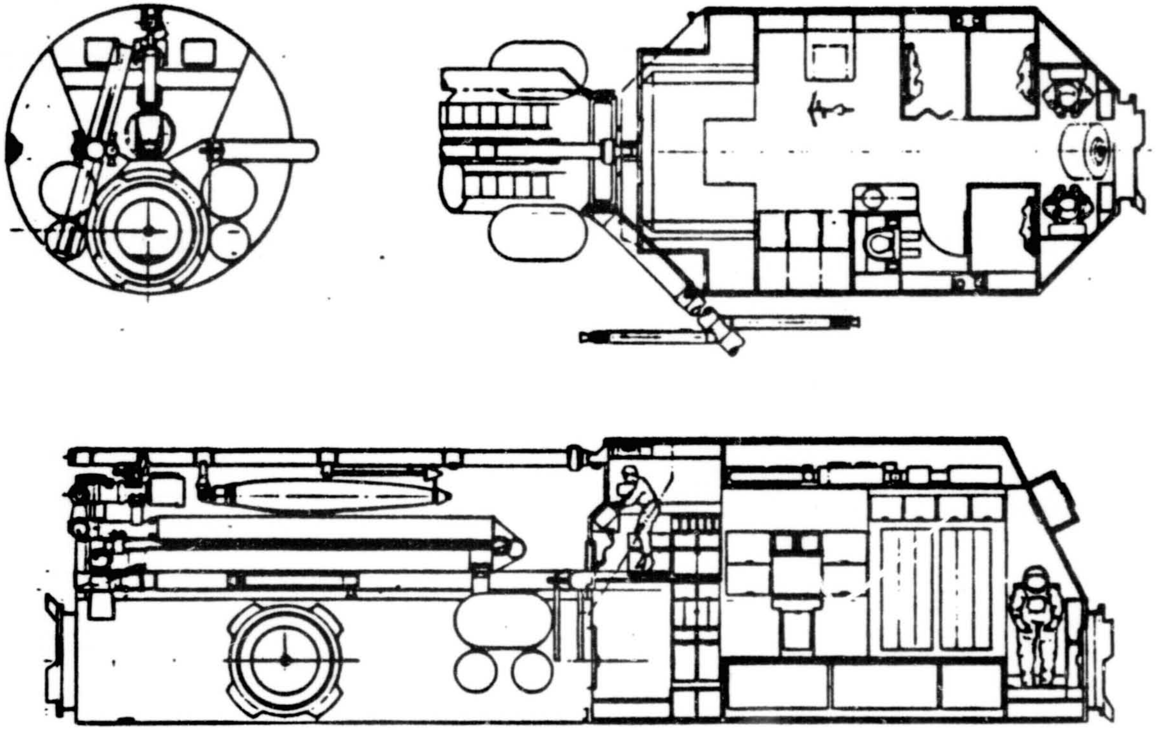
Common Module Elements



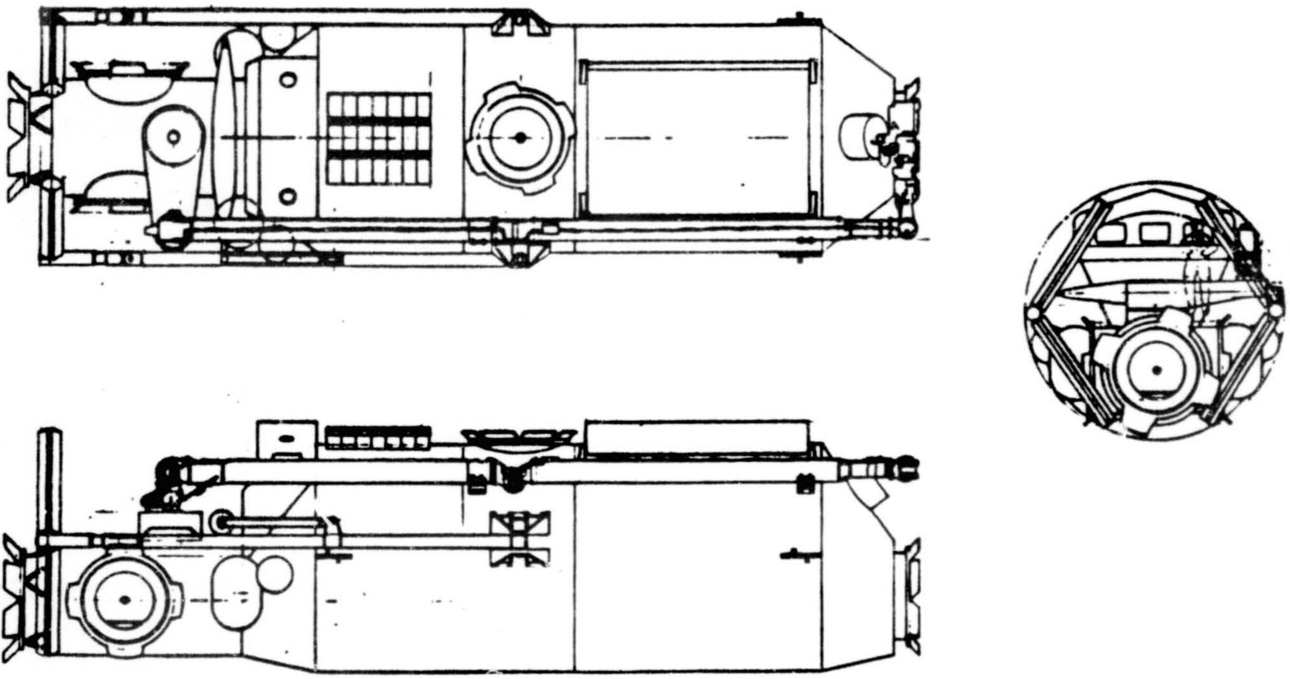
SPACE
OPERATIONS
CENTER

Interior, Single Launch Space Station

NASA
SOC-1424



Reduced Diameter Single Launch Space Station



47%

Habitable Service Module Evolution

DECREASING INITIAL COST →

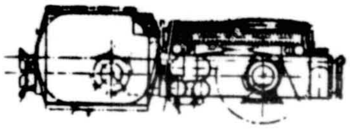
SOC REFERENCE SERVICE MODULE

DESIGNED TO SUPPORT FUNCTION WITH A HABITABLE MODULE; NOT A "SAFE HAVEN"

EMERGENCY EQUIPMENT ADDED

CREW PROVISIONS ADDED TO PERMIT EMERGENCY SURVIVAL

FIRST ATTEMPT REPACKAGING



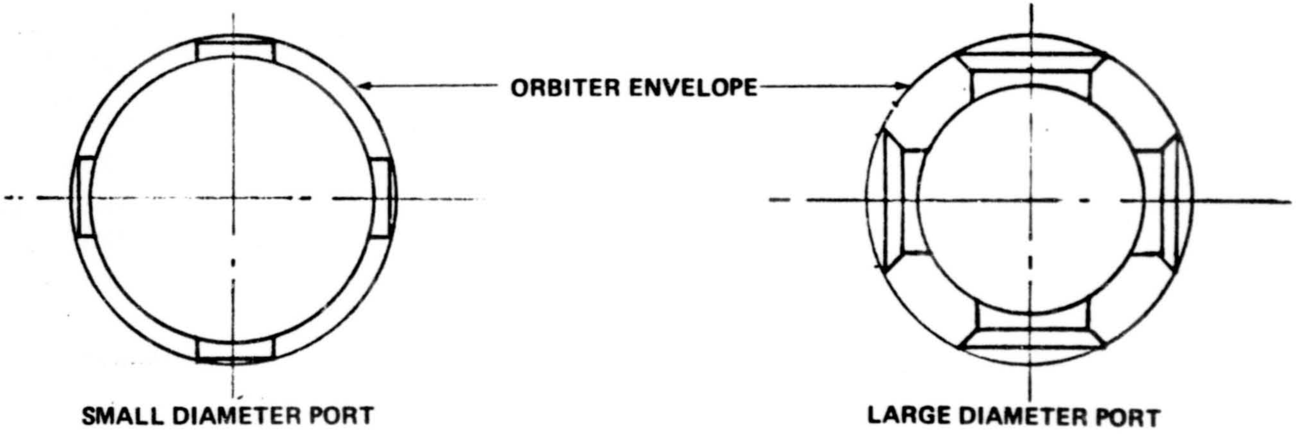
TWO-DIAMETER DESIGN ACCOMMODATES TWO PEOPLE BUT DEPLOYMENT IS COMPLEX

SECOND REPACKAGING

3.5-METER DIAMETER ACCOMMODATES THREE PEOPLE WITH SIMPLIFIED DEPLOYMENT

Docking and Berthing Ports

ASSUMING A "GIVEN" DESIGN FOR A DOCKING PORT:



SMALL PORT PERMITS LARGER DIAMETER MODULE BUT MAY MAKE DOCKING/BERTHING MORE DIFFICULT.

LARGE PORT PERMITS EASIER DOCKING/BERTHING BUT REDUCES DIAMETER OF MODULE.

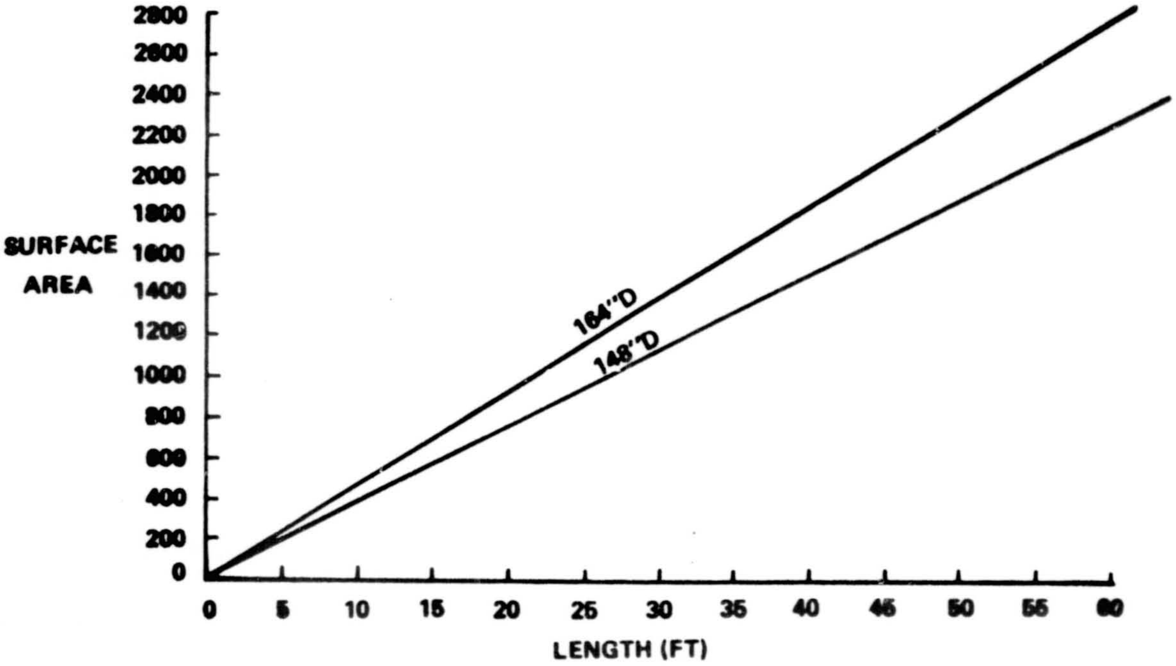
PORT DESIGN NEEDS TO BE ESTABLISHED EARLY IN PROGRAM

Space Station

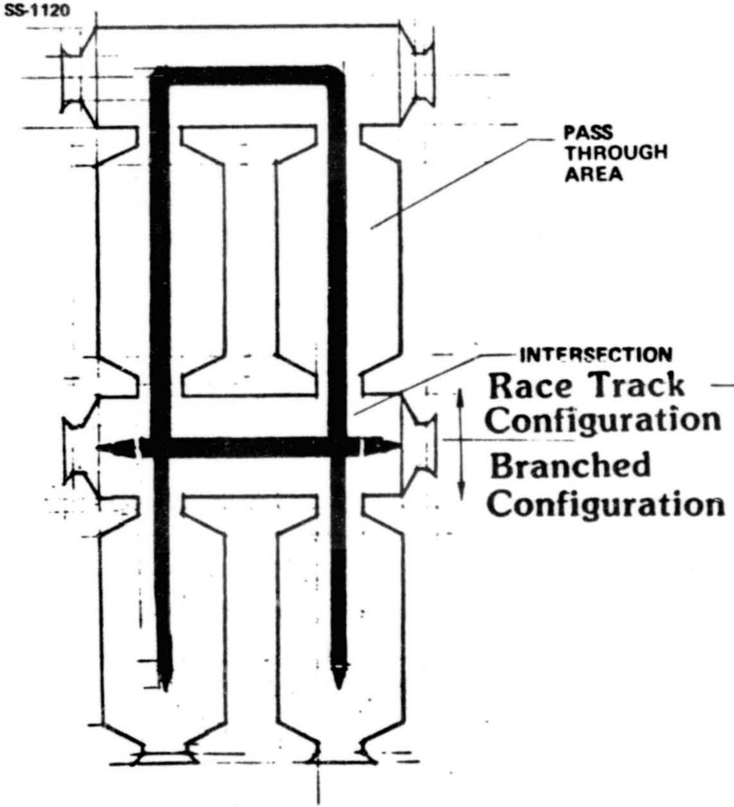
Surface Area Comparison for Two Space Station Modules

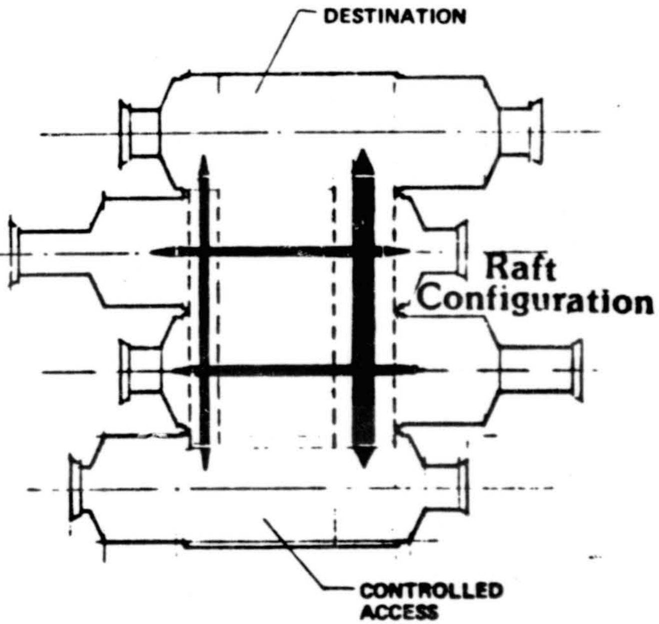
NASA

88-1165



IVA Circulation





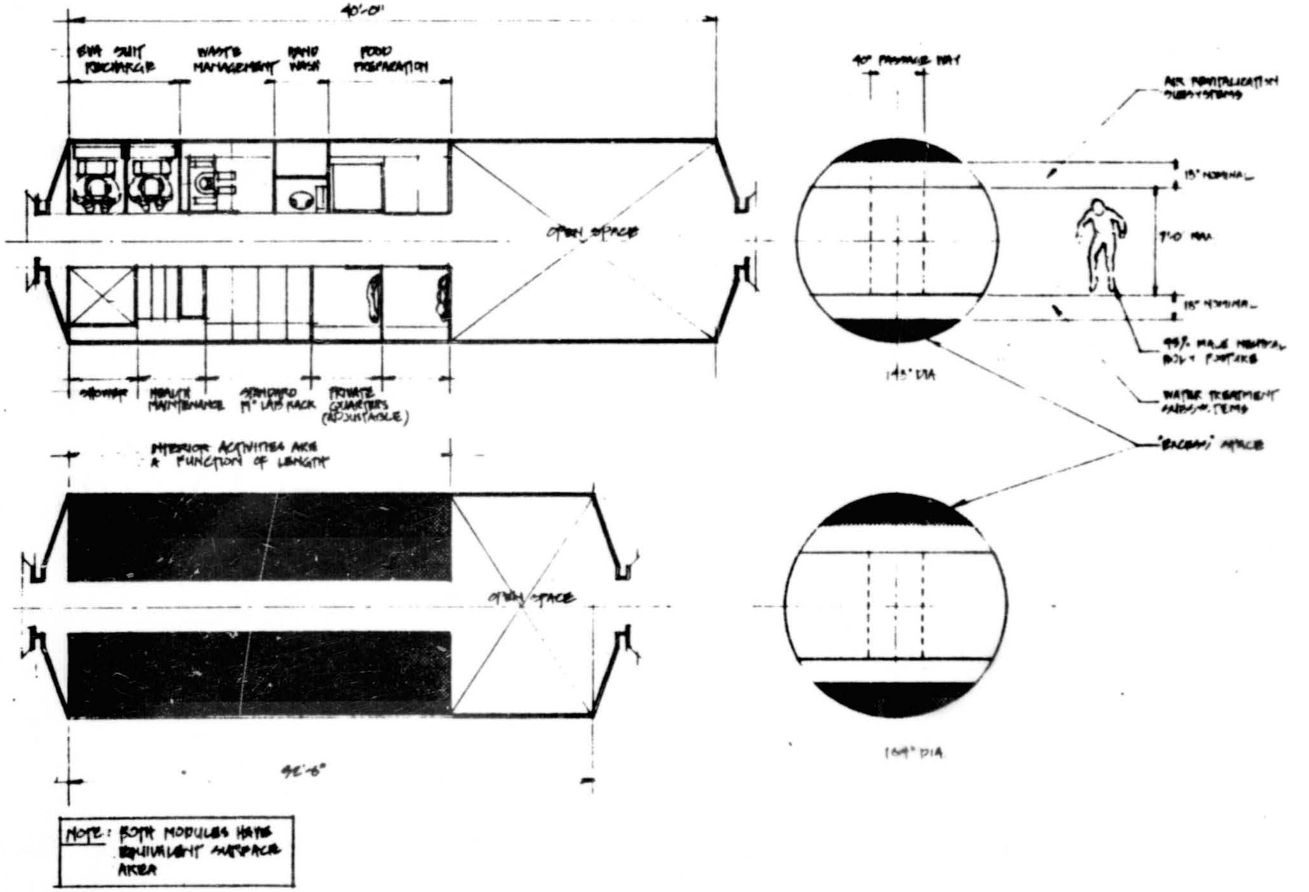
AXIAL CIRCULATION

- RACE TRACK—ALL AREAS ARE PASS THROUGH
- BRANCHED—CAN ARRANGE PRIVACY ALONG AXIS AWAY FROM CORE

TRANSVERSE CIRCULATION

- MINIMUM INTERRUPTION TO ACTIVITIES IN MODULE
- BETTER PRIVACY GRADIENT (CONTROLLED ACCESS)

Volumetric Efficiency



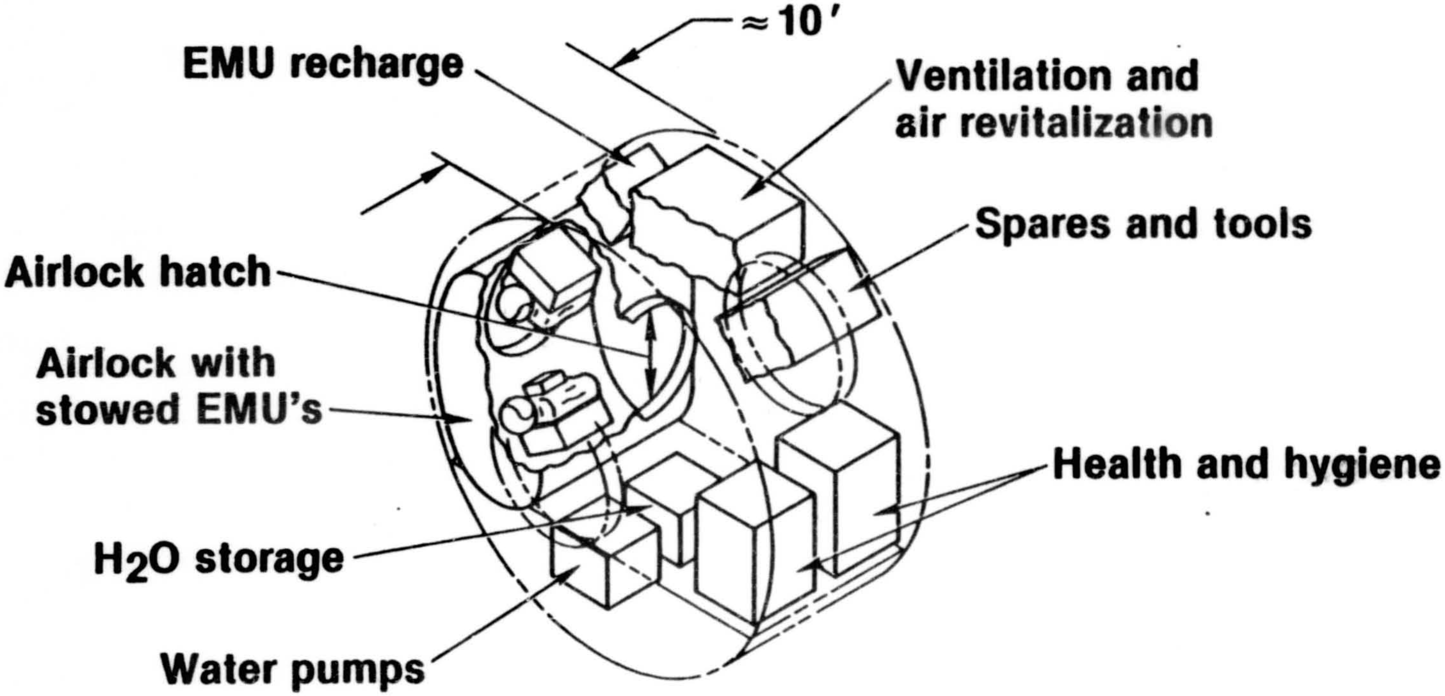
NOTE: BOTH MODULES HAVE EQUIVALENT SURFACE AREA

HUMAN FACTORS IN SPACE STATION ARCHITECTURE:

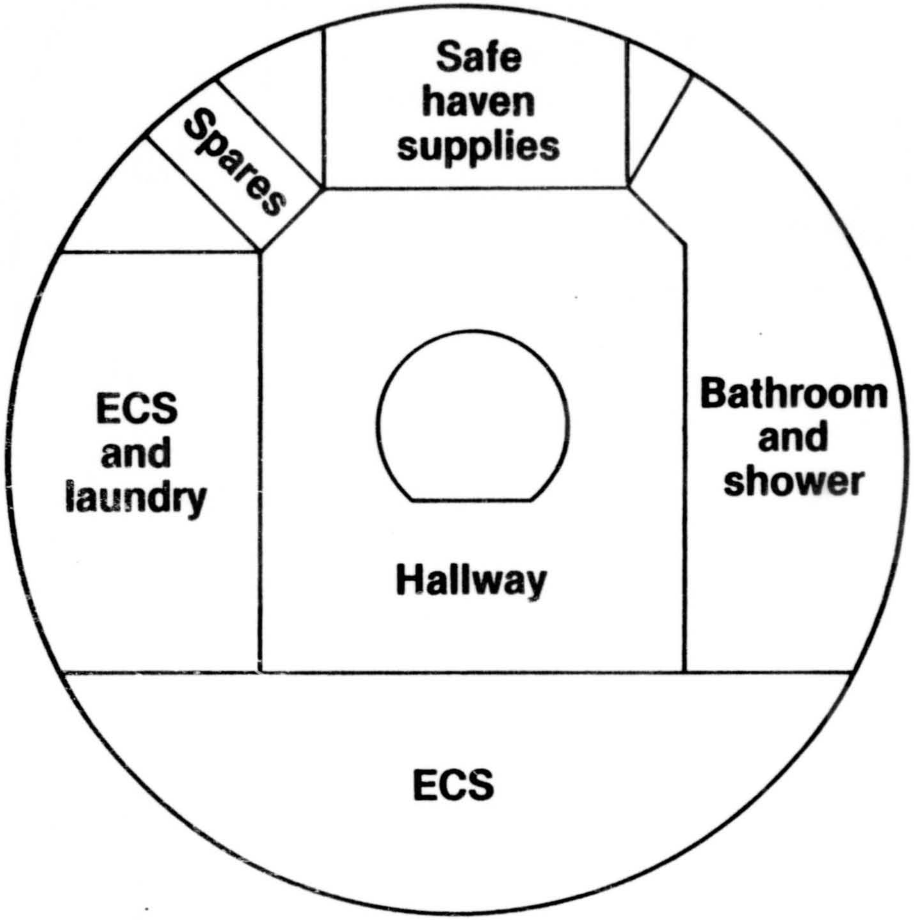
THE ECLSS MODULE CONCEPT

Prepared for: Space Station Human Productivity Working Group
1 March 1984

INITIAL ETCLS MODULE WITH AIRLOCK

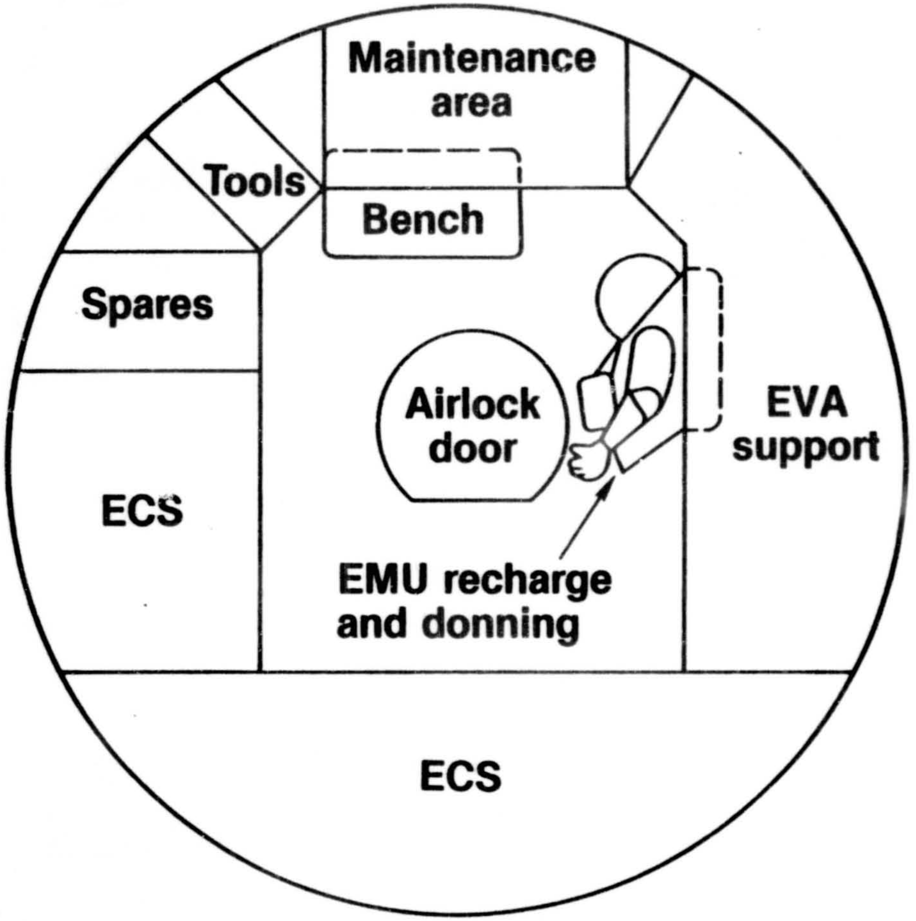


POTENTIAL ECLS MODULE EQUIPMENT GROUPING (ECS/Hygiene/Laundry)

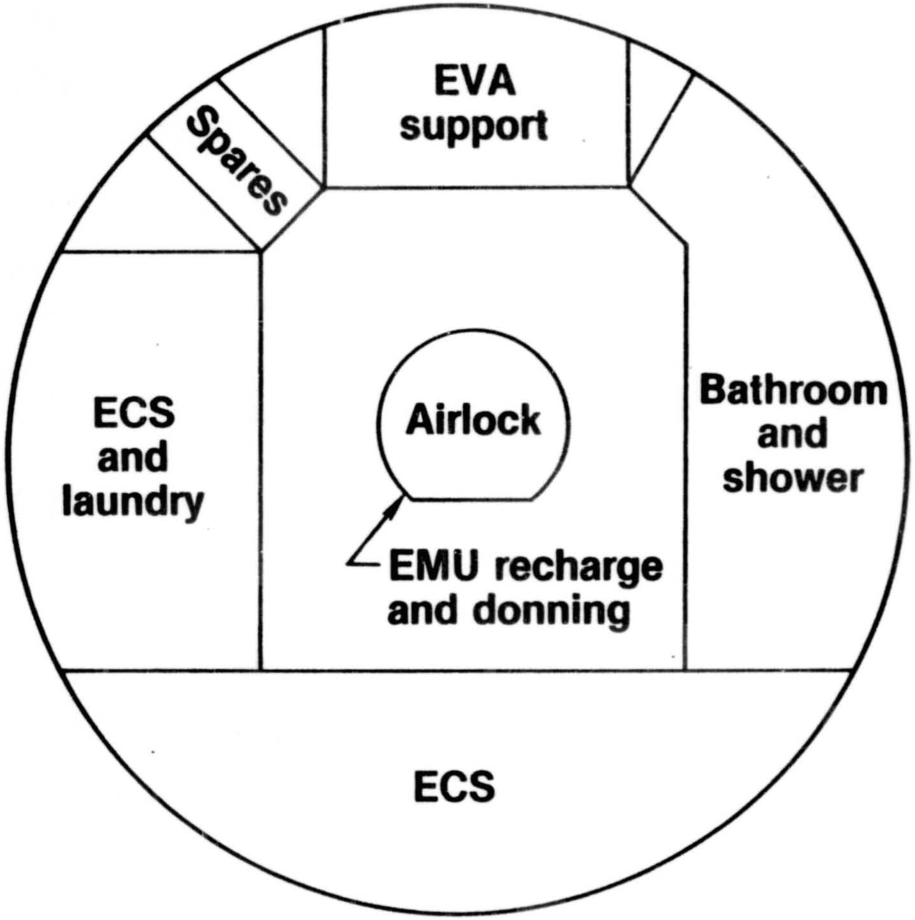


POTENTIAL ECLS MODULE EQUIPMENT GROUPING

(ECS/EVA Support)



POTENTIAL ECLS MODULE EQUIPMENT GROUPING (ECS/Hygiene/Laundry/EVA Support)



NOISE IS REDUCED

Sources of Noise in the Primary Vehicle Module

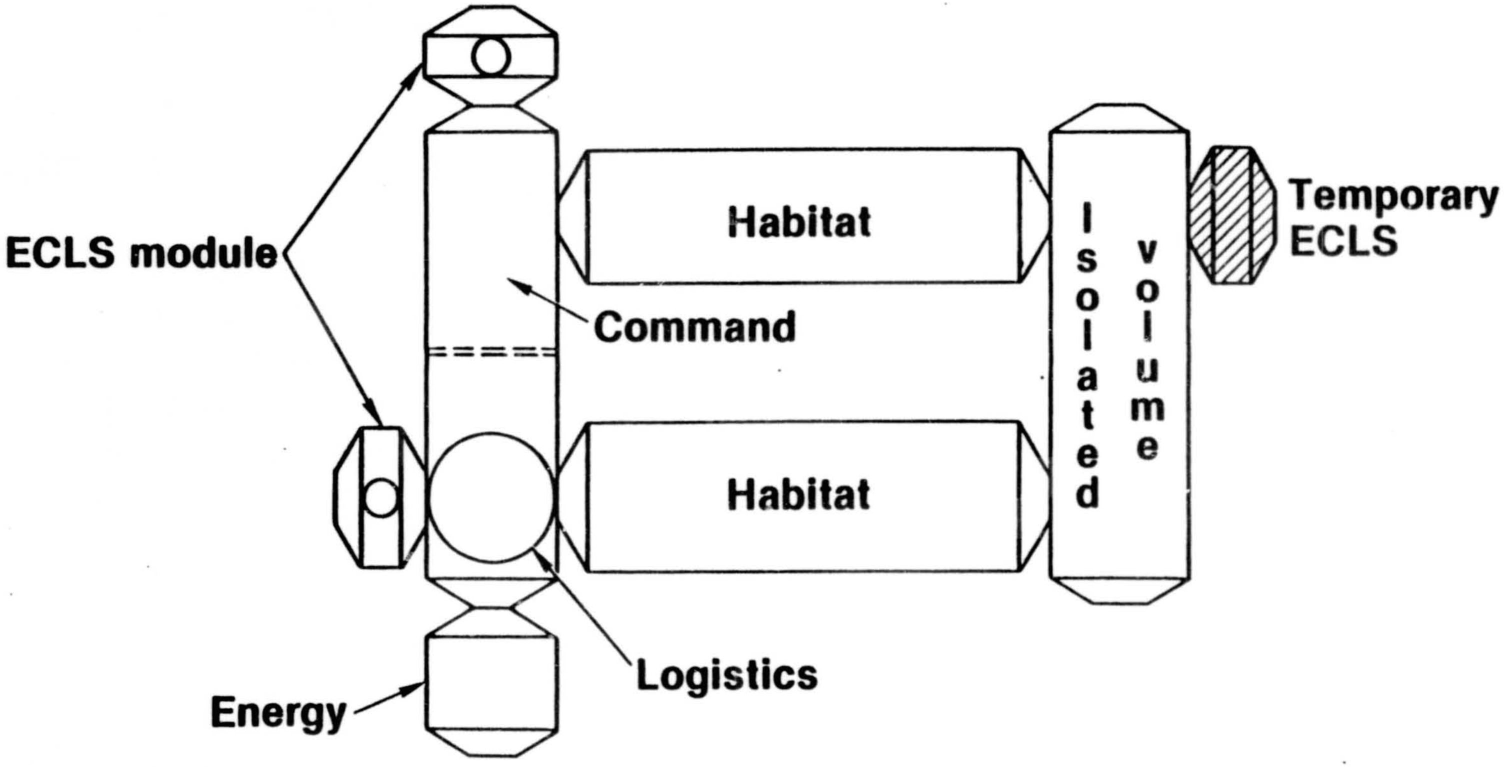
Distributed ECLS

- Ventilation fans
- Process air fans
- Fluid pumps
- Compressors
- Water processor
- Toilets
- Shower
- Trash compactor
- Clothes washer/dryer
- EMU operations
- Valves

ECLS Module

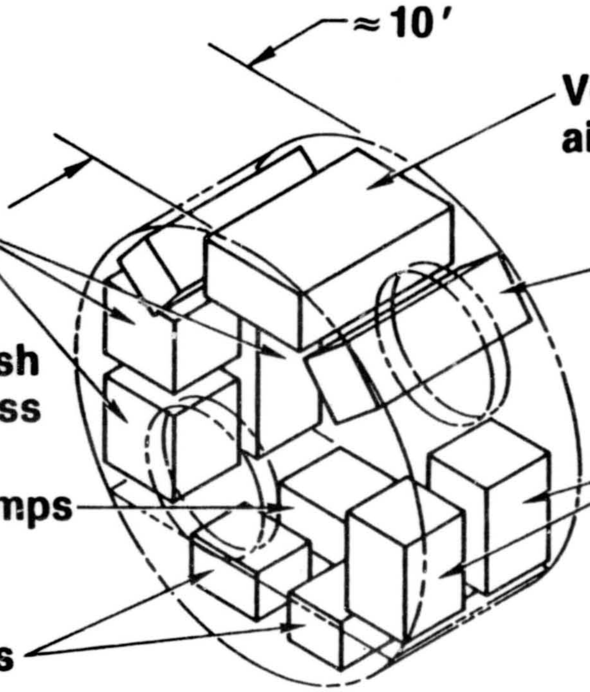
- Ventilation fans

AN ECLS MODULE PROVIDES OPERATIONAL FLEXIBILITY



Scenario: Temporary animal experiments

“CLOSED LOOP” ETCLS MODULE



Ventilation and air revitalization

Evolutionary hardware
- Shower
- Clotheswash
- H_2O process

Spares and tools

Health and hygiene

H_2O storage and pumps

Hazardous gas compartment
- CO_2 reduction
- Electrolysis

MODULE-TO-MODULE BULKHEAD INTERFACES

- Air
- Oxygen
- Nitrogen
- Carbon dioxide

- Coolant water
- Potable water
- Condensate
- Wash water
- Wastewater

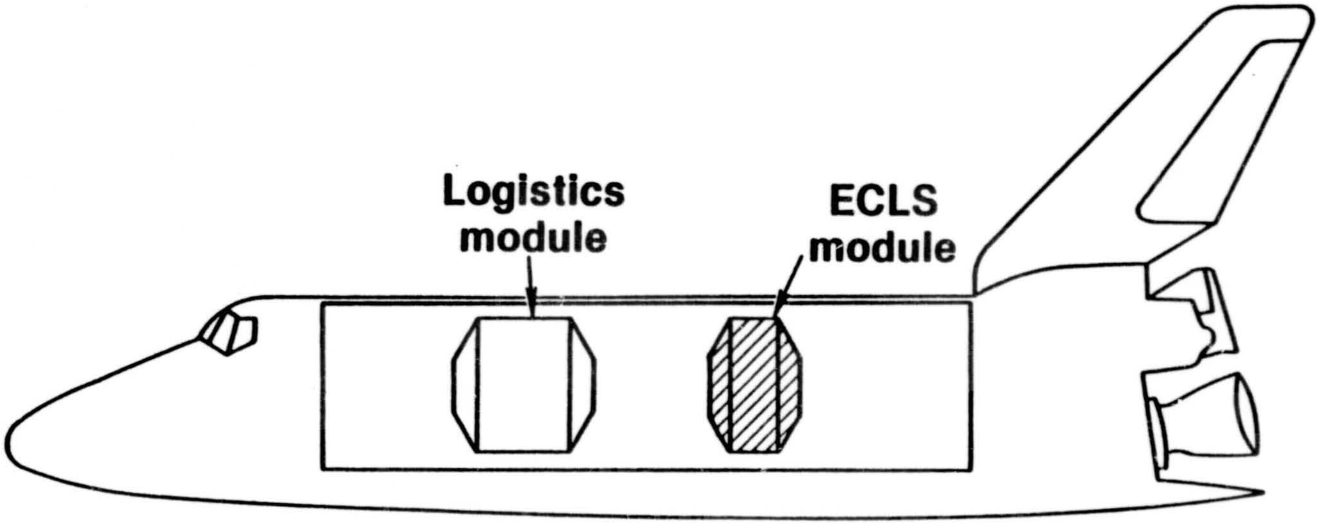
- Power bus
- Data bus

COMMON BULKHEAD DESIGN CONSIDERATIONS

Advantages/disadvantages

- Space Station
  - Design
  - Configuration
- Facility/facility services
- GSE

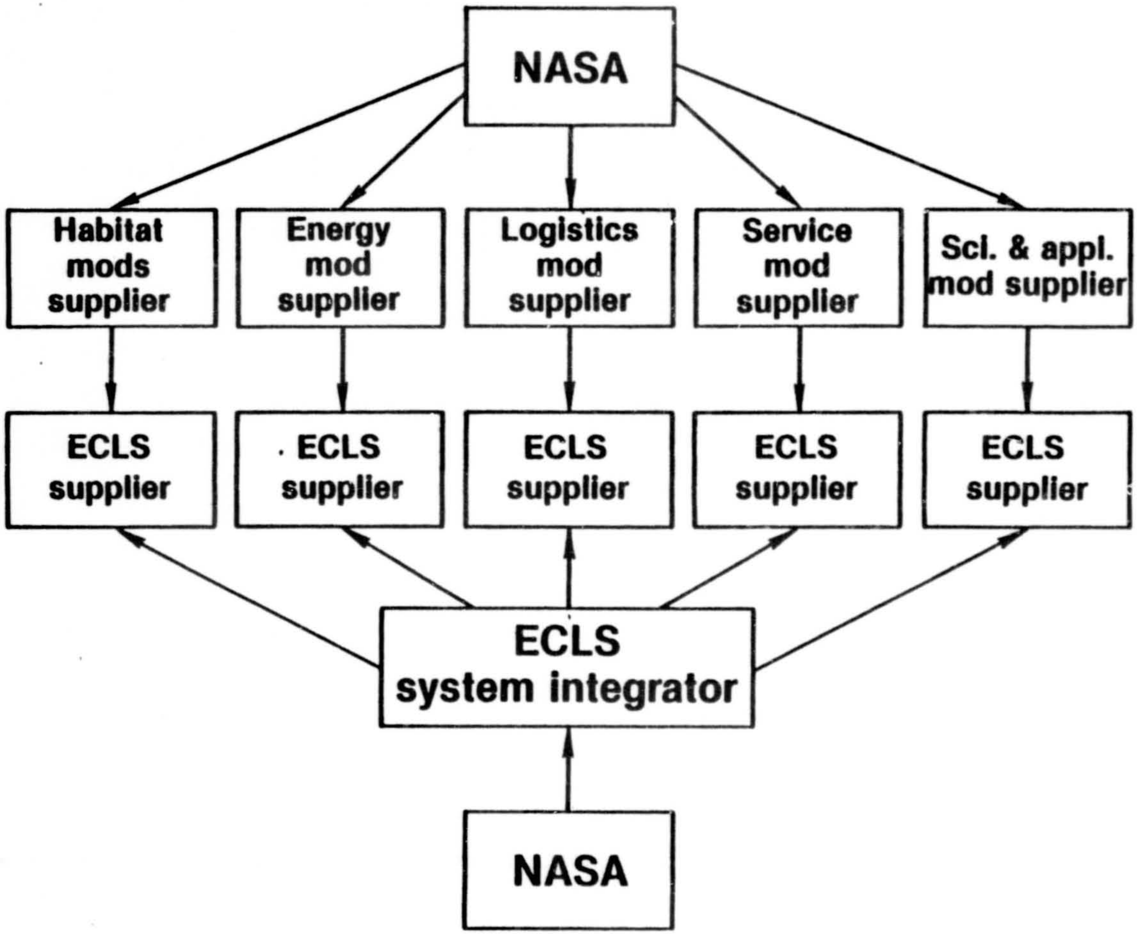
AN ECLS MODULE PROVIDES OPERATIONAL FLEXIBILITY



Scenario: Return to earth for retrofit/refurbishment

ECLS MANAGEMENT BECOMES MORE EFFECTIVE

Distributed ECLS



NASA

Habitat mods supplier

Energy mod supplier

Logistics mod supplier

Service mod supplier

Sci. & appl. mod supplier

ECLS supplier

ECLS supplier

ECLS supplier

ECLS supplier

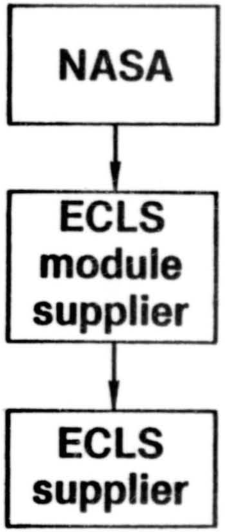
ECLS supplier

ECLS system integrator

NASA

- Costly, complex management

ECLS Module



NASA

ECLS module supplier

ECLS supplier

- Simple, direct management

SEPARATE ECLS MODULE ADVANTAGES/DISADVANTAGES

8401B010

+ CENTRALIZED ECLS BENEFITS
  - ECLS BECOMES NON-ISSUE FOR OTHER MODULES
  - LESS ECLS EQUIPMENT/COST
  - REDUCED LOGISTICS MODULE ECLS WEIGHT/VOLUME
  - FACILITATES TWO BATHROOMS

+ MOVABLE/RETURNABLE/GROWABLE/ISOLATABLE

+ FACILITATES NASA PROCUREMENT

+ ISOLATES NOISE

+ FACILITATES TWO AIRLOCKS

+ FACILITATES RETAINING TWO SEGMENT COMMON MODULE

+ USES COMMON STRUCTURE – SINGLE SEGMENT

+ FACILITATES SHUTTLE MANIFESTING AND SPACE STATION ASSEMBLY

? PROBABLY AN INITIAL LAUNCH PENALTY

? COST ADVANTAGE/DISADVANTAGE – PROBABLY EQUAL FOR IOC
ADVANTAGE FOR GROWTH STATION

IMPACT OF THE ECLS MODULE ON HUMAN PRODUCTIVITY

- MANAGEMENT OF ECLS IMPLEMENTATION BECOMES MORE EFFICIENT
- OPERATIONAL CHECKS AT KSC ARE SIMPLIFIED AND DRAMATICALLY REDUCED
- RETROFIT/REFURB MAY BE MORE EASILY PERFORMED ON THE GROUND BY EXPERTS
- INTERRELATED FUNCTIONS ARE LOCATED TOGETHER
- INTERMITTENT NOISES AND ODORS ARE ISOLATED
- LESS HARDWARE SIMPLIFIES MAINTENANCE
- ON-ORBIT SERVICING DOESN'T INTERFERE WITH PRODUCTIVE ACTIVITIES

HABITABILITY
SLEEP ACCOMMODATIONS

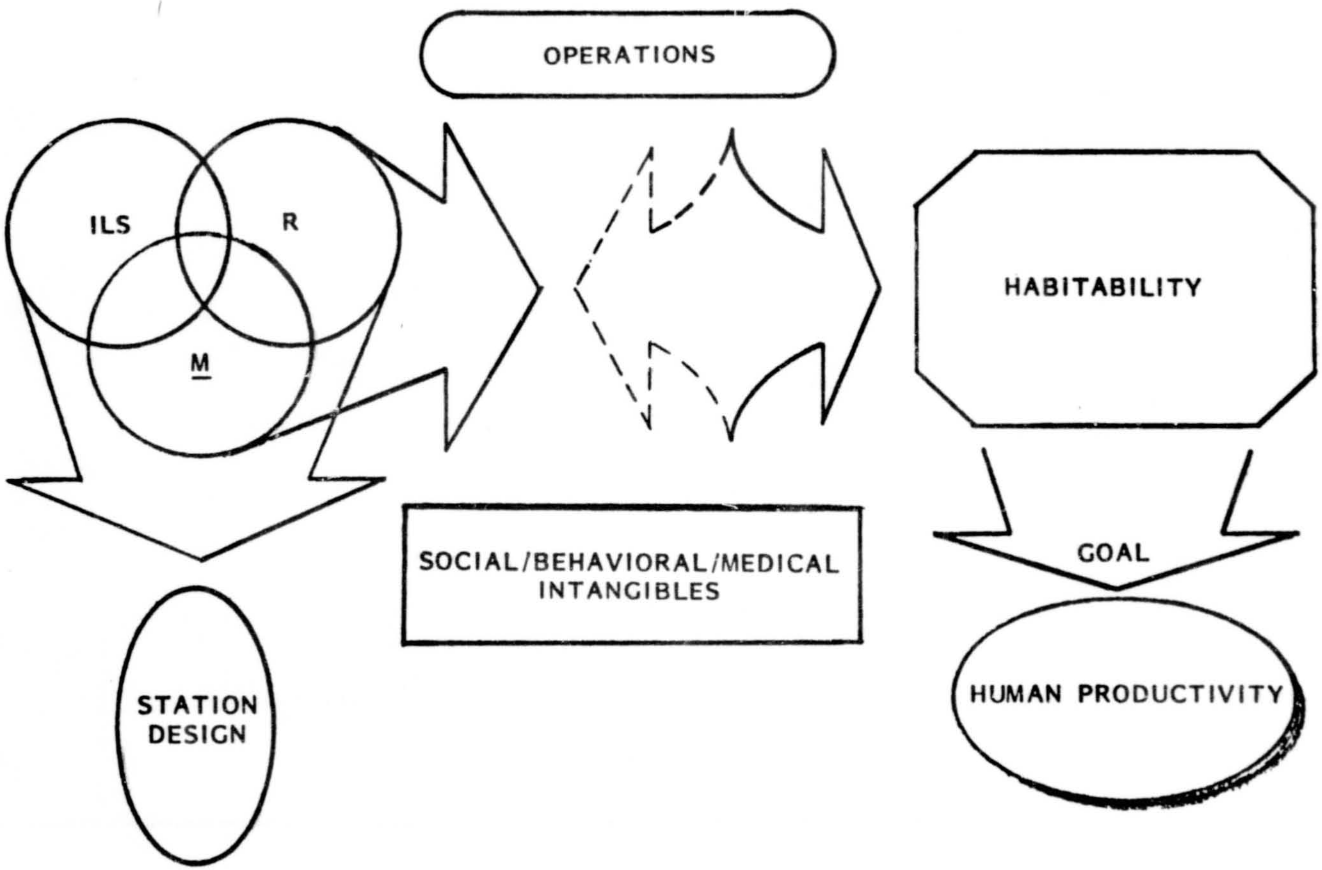
PRESENTATION TO

SPACE STATION TASK FORCE

1 MARCH 1984

H. T. FISHER, SUPERVISOR

SELECTED STATION INFLUENCING FACTORS

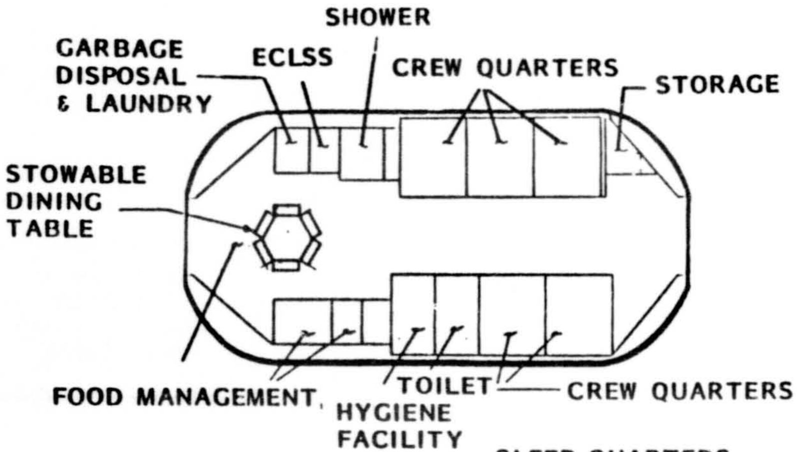


WARDROOM - GENERAL REQUIREMENTS

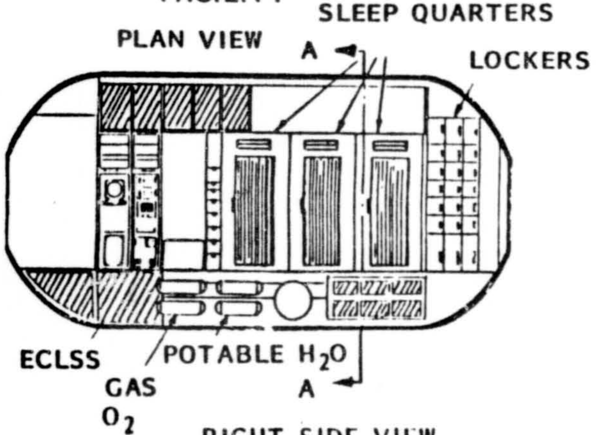
WARDROOM HABITABILITY GENERIC FUNCTIONS

A. SLEEPING ACCOMMODATIONS
B. REST PLACE
C. ENTERTAINMENT EXTENSION
D. DRESSING AREA
E. PERSONAL ITEM STOWAGE
F. BODY RESTRAINT OPTION
G. COMMUNICATIONS
H. TOTAL PRIVACY
I. EXTERNAL VIEWING
J. GROOMING PROVISIONS
K. WRITING WORK AREA
L. SOUND ISOLATION

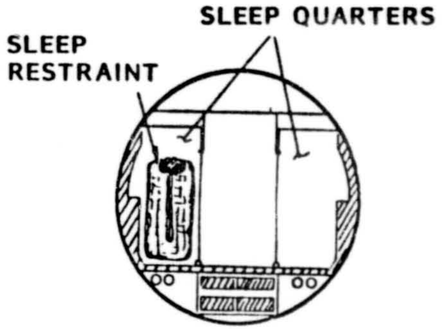
SLEEP QUARTERS CONCEPT A



PLAN VIEW

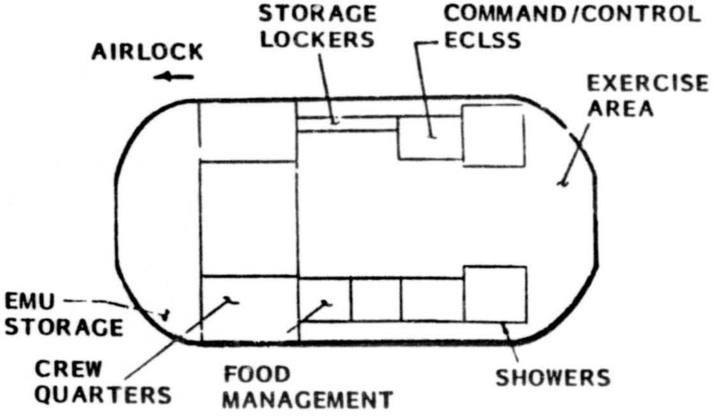


RIGHT SIDE VIEW

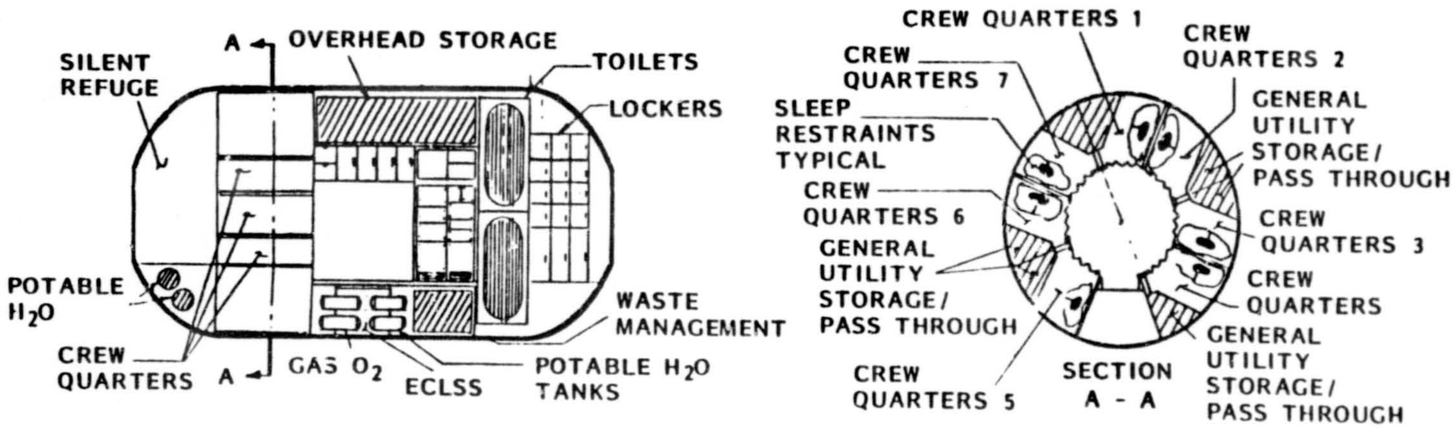


SECTION A - A

SLEEP QUARTERS CONCEPT B

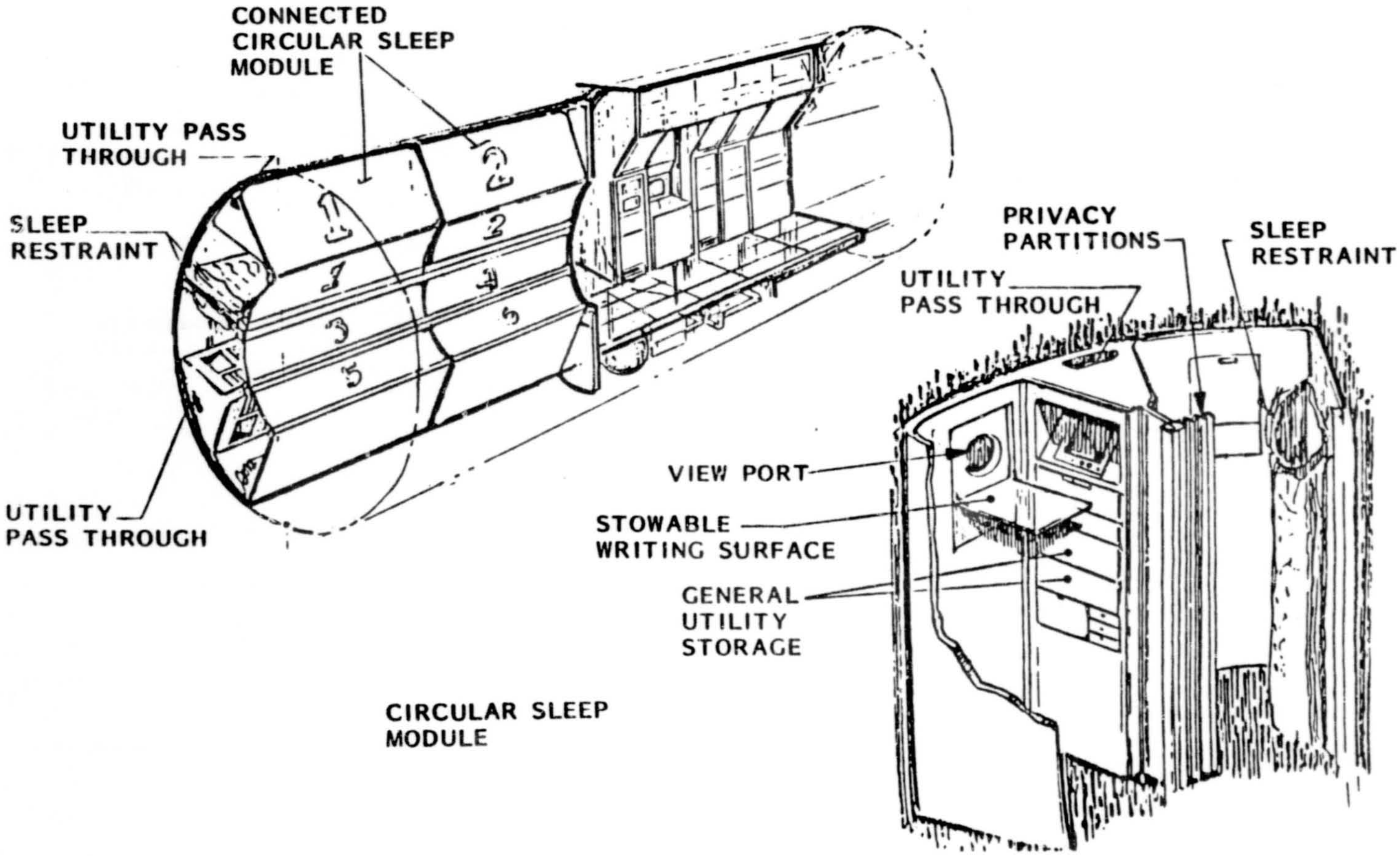


CIRCULAR SLEEP MODULE



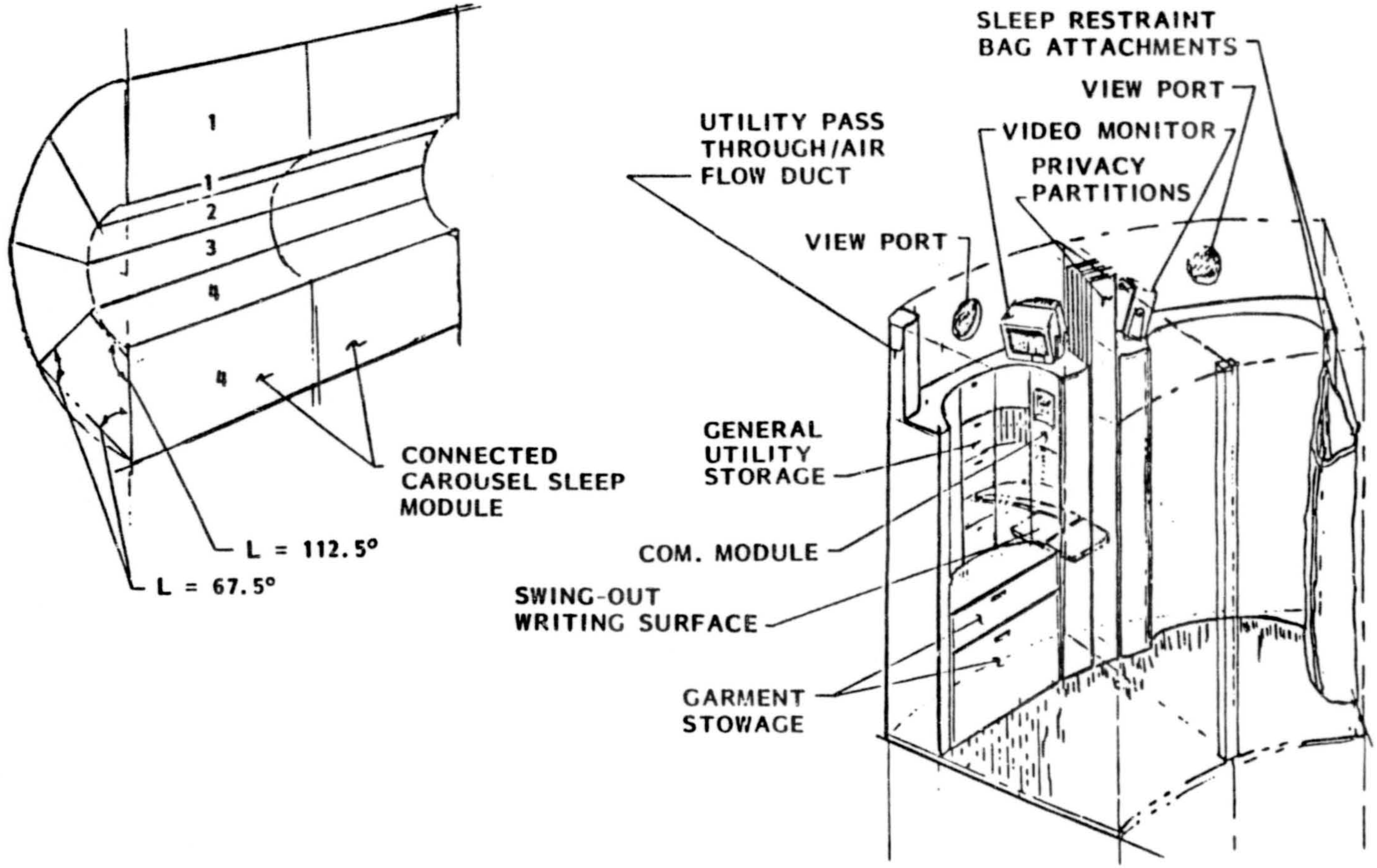
ORIGINAL PAGE IS OF POOR QUALITY

SLEEP QUARTERS CONCEPT

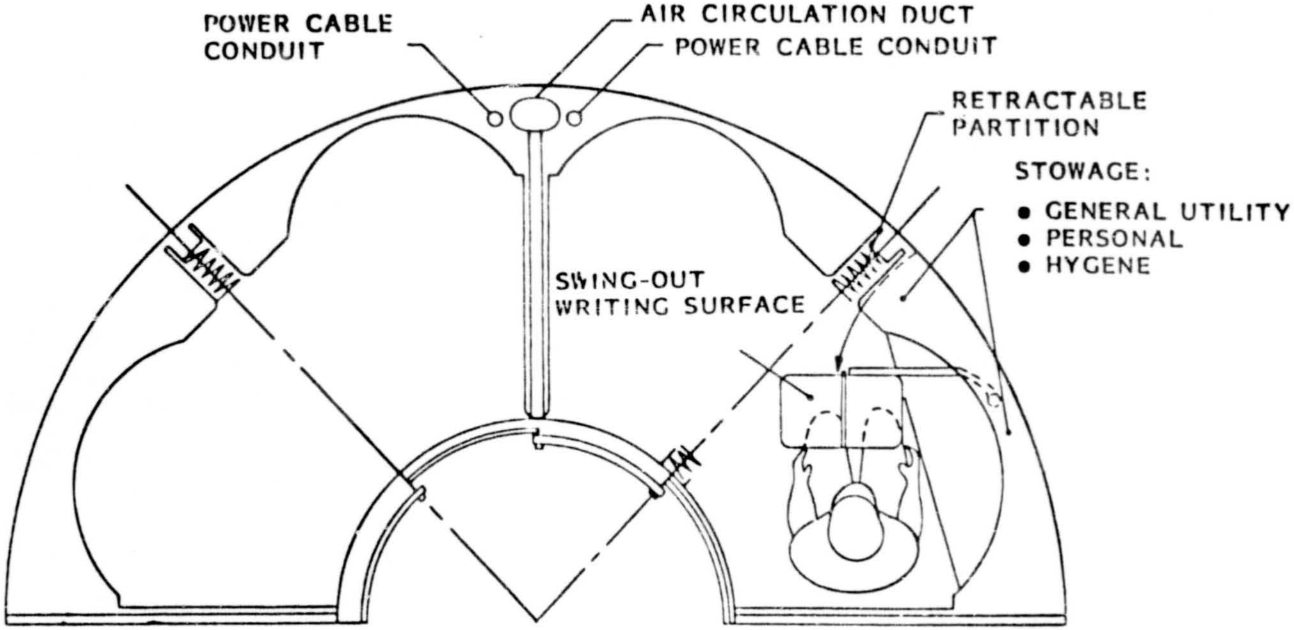


CIRCULAR SLEEP MODULE

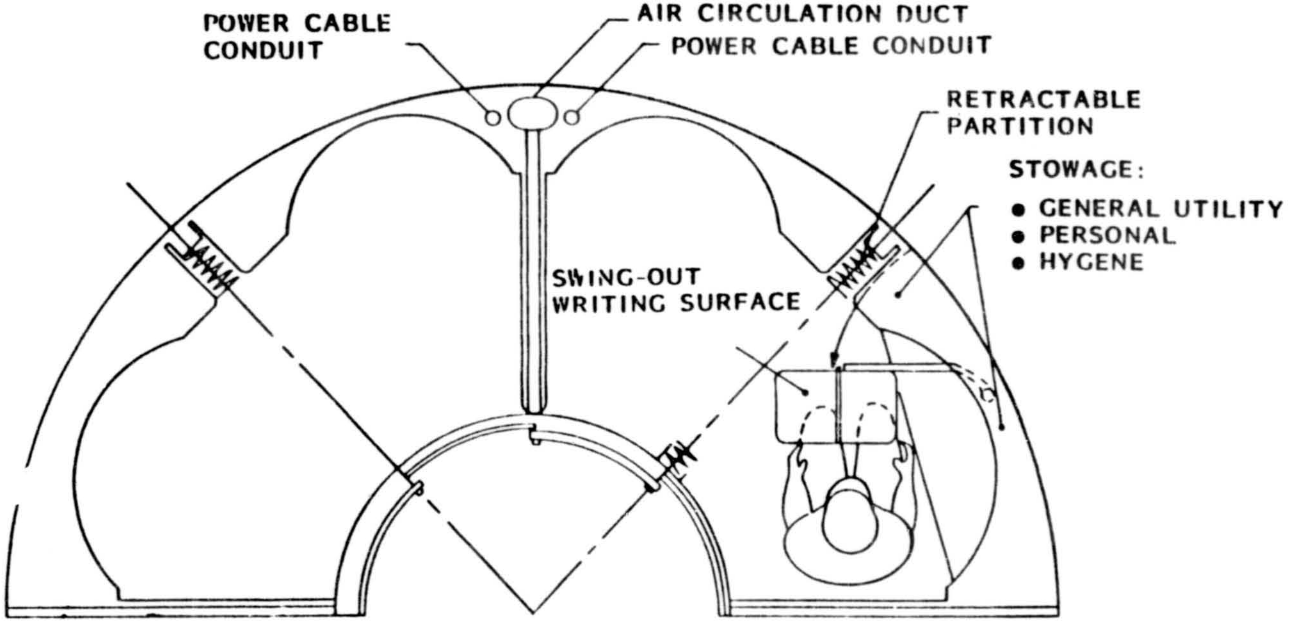
SLEEP COMPARTMENT—BUNK AREA DETAILS



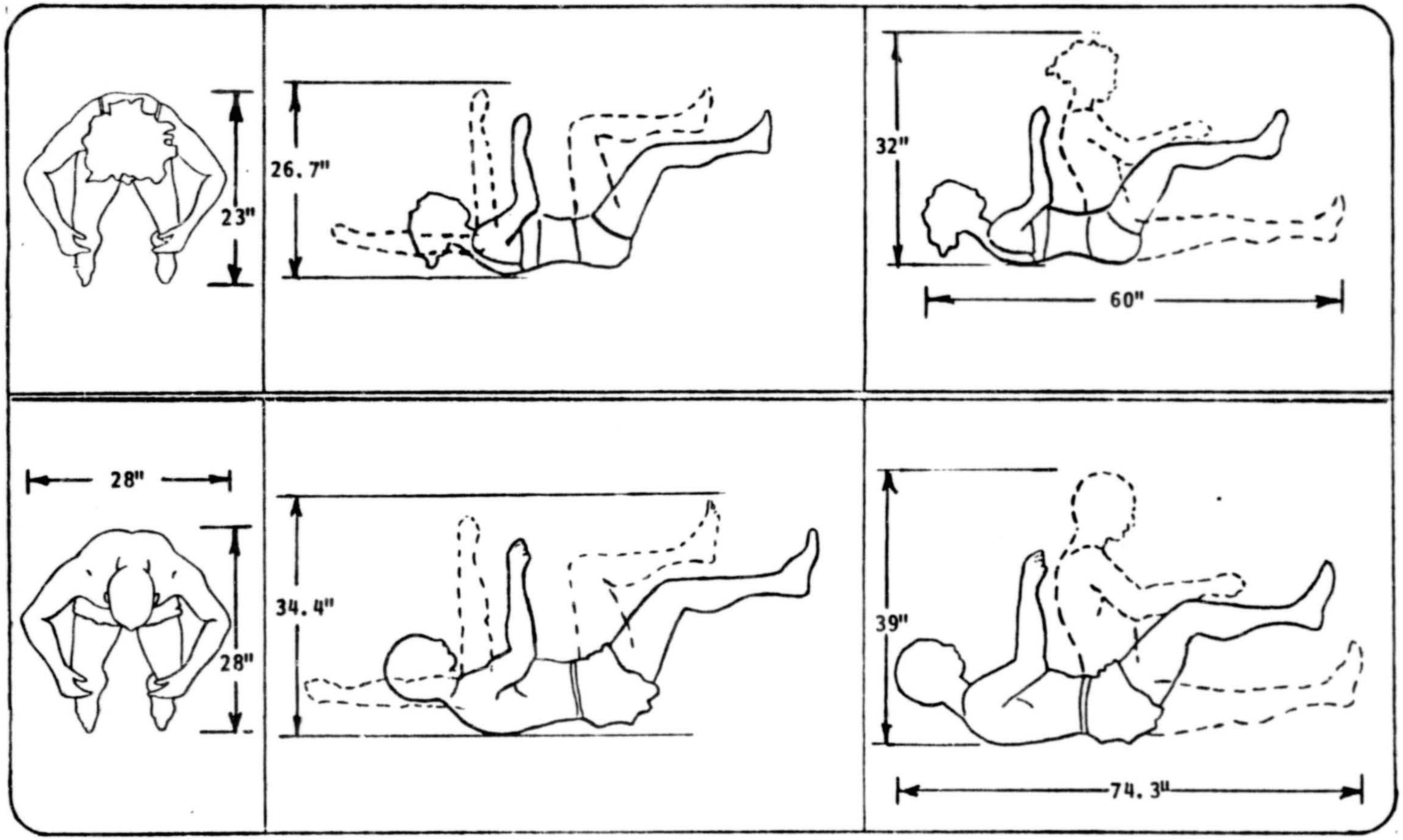
SLEEP BUNK—PLAN VIEW



SLEEP BUNK—PLAN VIEW

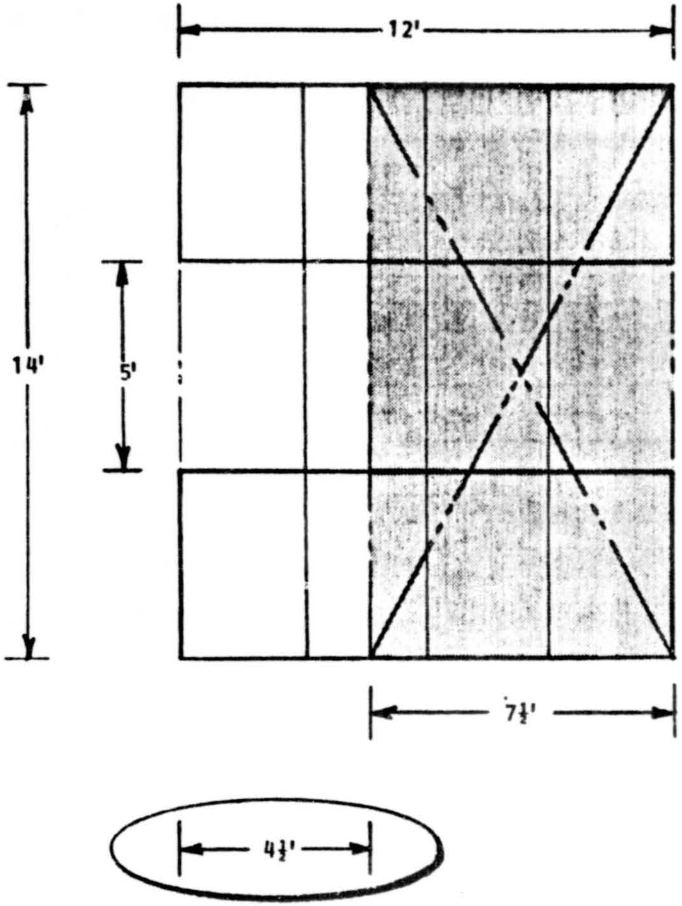


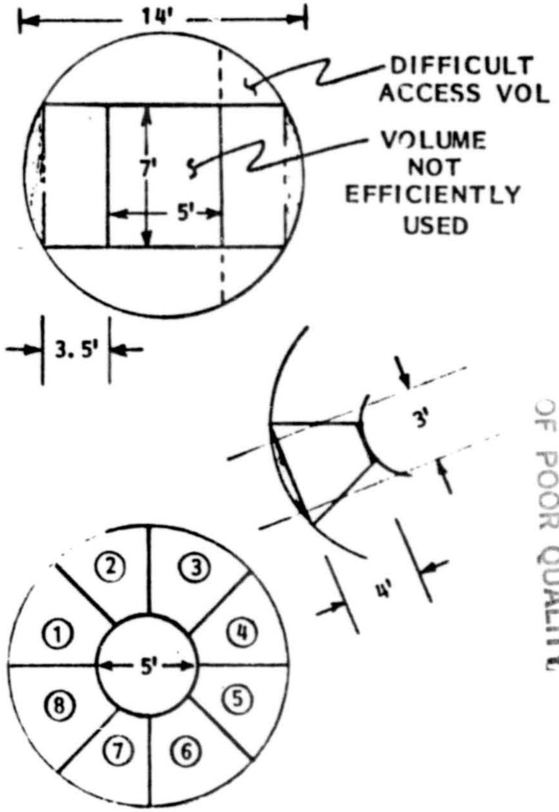
SLEEP/REST VOLUMETRIC FOR 5th TO 95th%tile FEMALES/MALES*



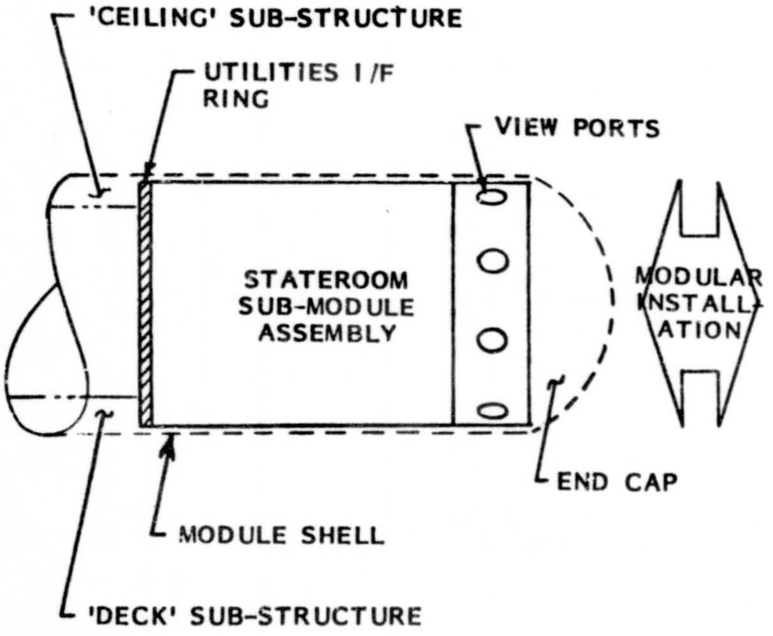
* BASED ON NASA PUB 1024

VERTICAL VS HORIZONTAL WARDROOM





WARDROOM SUB-MODULE - "MODULARITY"



A. WARDROOM IS SUB-MODULE ASSEMBLY

B. ASSEMBLY IS STAND-ALONE UNIT
- PERMITS PARALLEL MFG
- FLEXIBILITY IN SCHED. INSTALLATION

C. ASSEMBLY IS SIMPLE BARREL CONFIGURATION
- EIGHT (8) SEGMENTS
- INDIVIDUAL SEGMENT MANUFACTURING

D. UTILITIES I/F RING
- SIMPLE I/F TO UTILITIES
- 360° POTENTIAL I/F TO RING
- RING ACCEPTS:
  - ECLSS PLENUM DUCTING (LOOP)
  - SIGNAL/DATA LINES (IN/OUT)
  - POWER CABLES
- STAND-ALONE UNIT - BOLTS ON
- INDIVIDUAL MANUFACTURING

TOP TOP-TIER ADVANTAGES OF THE SARA* CONCEPT

A. OVER 100 CU FT PER CREWPERSON

B. HORIZONTAL (EARTH-LIKE) SLEEP/REST ACCOMMODATIONS

C. SINGLE WARDROOM CAN OPEN TO ADJACENT WARDROOM
- DOUBLES 'OPEN AREA'
- ADJACENT WARDROOM ALWAYS VACANT ASSUMING:
  - 2 OR 3 SHIFT OPS OR
  - LESS THAN 8 CREW (e.g., 4)
- PERMITS 2 PEOPLE TO FACE ONE-ANOTHER IF OTHER WARDROOM TEMPORARILY USED

D. ADDED 'OPEN AREA' FURTHER AVAILABLE AS EACH WARDROOM FACES:
- OPEN CORRIDOR 60 IN DIAMETER
- OPPOSITE WARDROOM (NOT BEING USED) - OPEN AREA

E. WARDROOM SUB-ASSEMBLY (8 WARDROOMS) ONLY 91 IN LONG (OVERALL)
- SEVEN (7) FT. INTERNAL
- ONE (1) IN. END PLATES + INSULATION
- FOUR (4) IN. FOR UTILITIES I/F RING

F. SIMPLIFIED SUB-ASSEMBLY MODULAR CONCEPT
- FABRICATION
- INSTALLATION

G. PORTHOLES ARE ALL IN ONE NARROW CIRCUMFERENTIAL 'RING SEGMENT' - STRUCTURAL ADVANTAGE

H. LESS LENGTH USED (X AXIS) THAN VERTICAL 'BUNKS'
- SAVES 20% OF SHORT MODULE LENGTH!

* SLEEP AND REST ACCOMMODATIONS

MICHAEL KALIL

DESIGN OF CONFINED ENVIRONMENTS

PRESENTATION MADE AT AMES RESEARCH CENTER
MOFFIT FIELD, CALIFORNIA

MARCH 1, 1984

I. DESIGN VOCABULARY AND HISTORY

- A. THE REPETITION OF FORMS IN RELATIONSHIP TO LAND BASED STRUCTURES AND SPACE BOUND OBJECTS
- B. THE COMPOSITION OF SHELTER AND ITS QUALITIES IN REGARD TO HUMAN NEEDS

II. PROTOTYPE FOR EXPERIMENTATION OF LIVING/HOME ENVIRONMENT

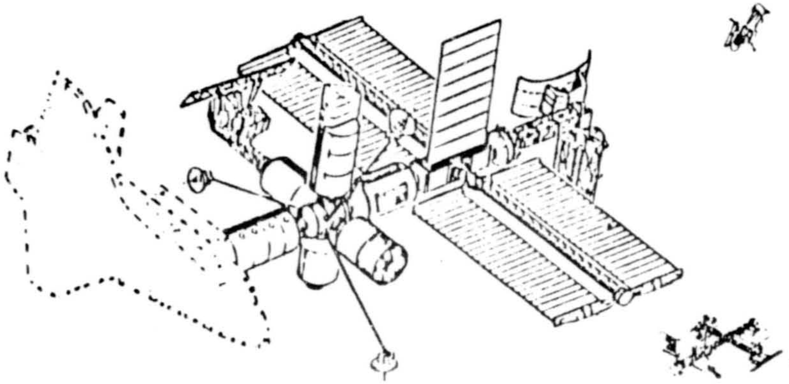
- A. DESIGN PHILOSOPHY
  - 1. DETERMINING BASIC HABITABILITY NEEDS
  - 2. CREATING A FORM THAT RETAINS THE BASIC NEEDS WITHIN A STRUCTURE THAT UTILIZES CURRENT TECHNOLOGY
- A. DESIGN CONCEPT - FLOOR PLANE
  - 1. MODULES AND THEIR ABILITIES TO REVEAL, CONCEAL OR TRANSFORM TO MEET THE NEEDS OF HABITABILITY
  - 2. ELECTRONICS AND THEIR CAPACITY TO MANIPULATE THE ENVIRONMENT TO THE FUNCTIONS AND THE COMFORTS OF THE USER

III. PROTOTYPE FOR EXPERIMENTATION OF WORK/OFFICE ENVIRONMENT

PROJECT RETAINS DESIGN PHILOSOPHY AND SYSTEMS AS DESCRIBED ABOVE AND EXPANDS TO ENCOMPASS FUNCTIONALITY OF EXECUTIVE RESPONSIBILITIES IN REGARD TO COMMUNICATIONS, CONFERENCE, ACCESS TO INFORMATION AND CREATIVE PRODUCTION.

307 EAST 76th STREET NEW YORK 10021 **212 861-1467**

VGM068



CUSTOMER AND MISSION INFLUENCES ON SPACE STATION ARCHITECTURE

Fritz Runge

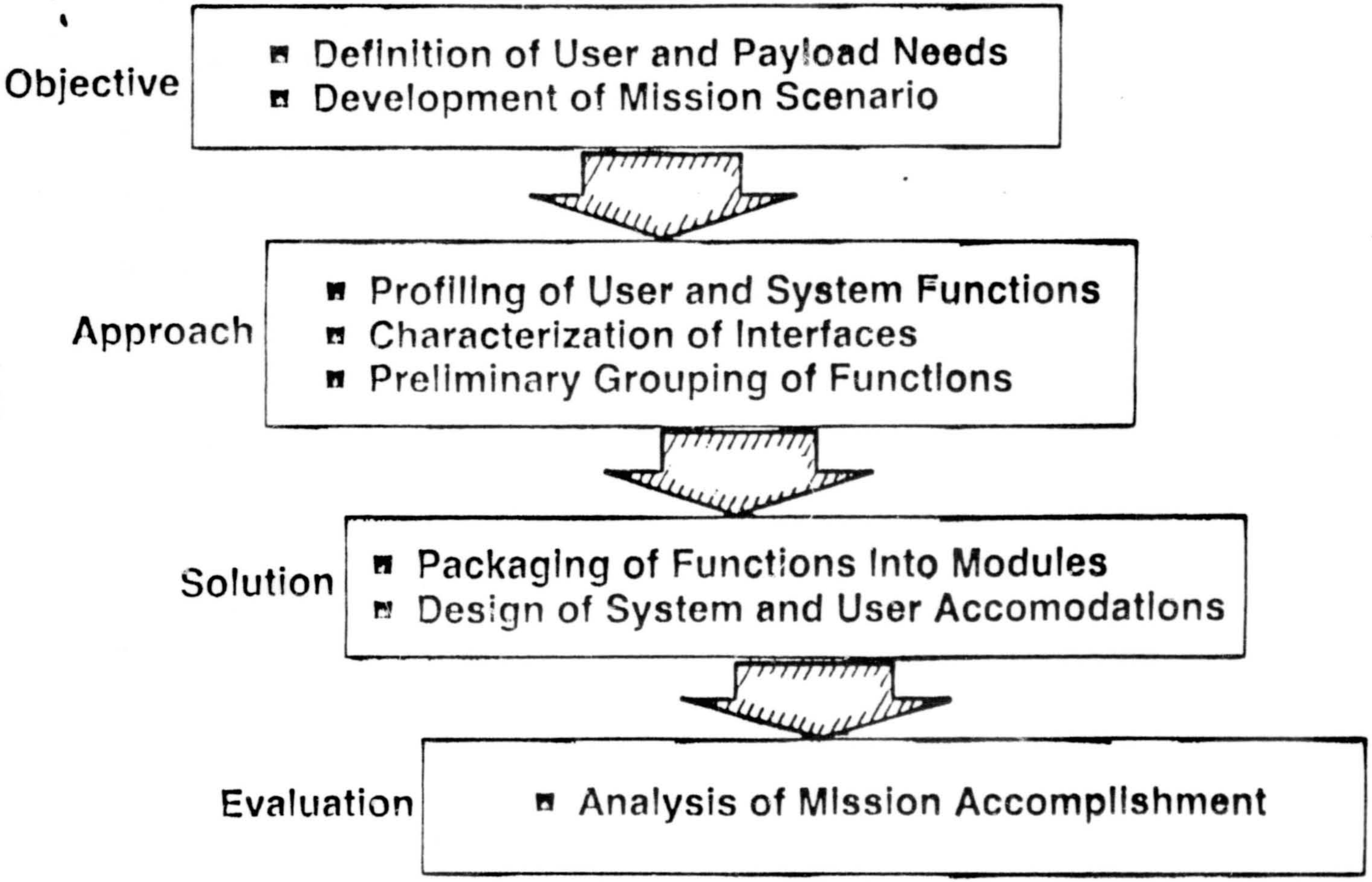
VFV802

ARCHITECTURAL CONSIDERATIONS IN A SPACE STATION

• Uses (Missions)	Science, Applications, Commerce, Defense (Integrated and Isolated)
• Occupants	Scientists, Engineers, and Technicians
• Activities	Interior: Habitation, Control, Research, Production, Maintenance, Logistics with IVA Exterior: Berthing, Sensing, Assembly/Checkout, Maintenance, and Logistics with EVA
• Interfaces	Shuttle, Attached Payloads, Free-Flight Payloads, and Long- and Short-Range Excursion Vehicles
• Utilities	Atmosphere, Water, Power, Data, Communications, Thermal
• Locomotion	Orientation, Reboost, Manipulation, Excursion
• Environments	Exterior: Low Earth Orbit and Operations Interior: Life Sustaining and Protecting Stage and Payload Storage
• Technology/Cost	Budget-Dependent: Development vs Operations

VGB597

DEVELOPMENT OF SPACE STATION ARCHITECTURE



Objective
- Definition of User and Payload Needs
- Development of Mission Scenario

Approach
- Profiling of User and System Functions
- Characterization of Interfaces
- Preliminary Grouping of Functions

Solution
- Packaging of Functions Into Modules
- Design of System and User Accomodations

Evaluation
- Analysis of Mission Accomplishment

MANNED PLATFORM ACTIVITY SPECTRUM

VGM113

(Science) (Technology) (Commercial)
(National and International)

Interior

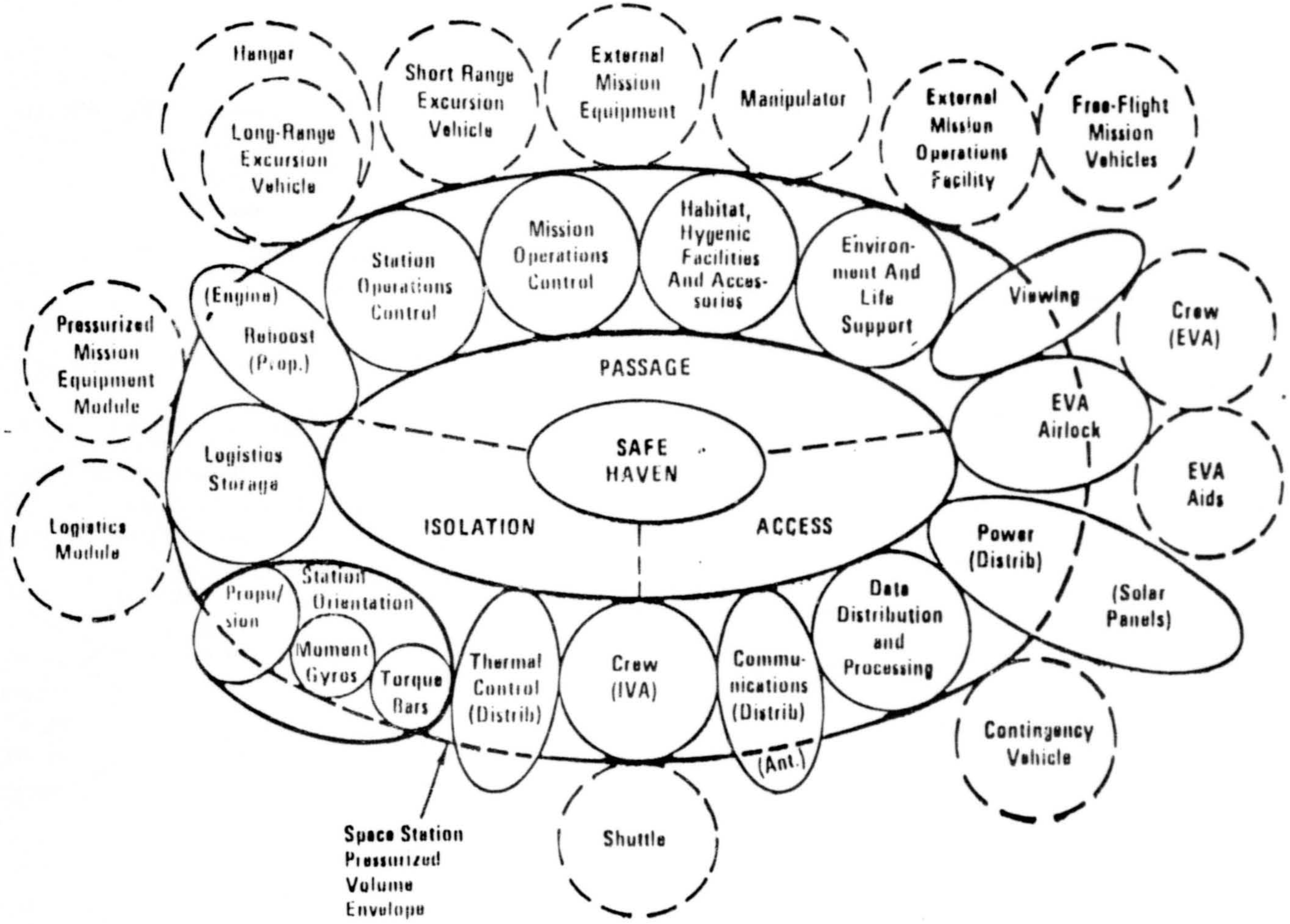
- Payload Operations
  - Life Science
  - Material Processing Applications
  - Technology Demonstrations
- Control Center(s) for:
  - Interior Operations
  - Exterior Operations/Accessories
  - Exterior Payloads
  - Maneuvering Vehicles
- Habitation/Recreation
- Maintenance/Logistics
- Traffic (Daily Routine and Periodic
- Safe Haven
- Exterior Viewing
  - Operations
  - Sight-Seeing

Exterior

- Attached Payload Operations
  - Science Instruments
  - Applications Instruments
  - Large Space Systems
  - Development of:
    - — Technology (Prototypes, Performance Measurement)
    - — Operations (Assembly, Alignment, EVA)
  - Assembly Accessories
  - Hi-Alt-Vehicle Buildup/Stowage/ Launch Spacecraft Servicing
- Attached/Detached Payload Operations (Tended/Tethered/ Teleoperatored)
  - Material-Processing
  - Free Flyers
  - Rendezvous Testing, Tow/Dock Services and Low-G Payloads
  - Co-Orbiting Platform
- Sustaining Resource Installations
- Shuttle Interaction Operations

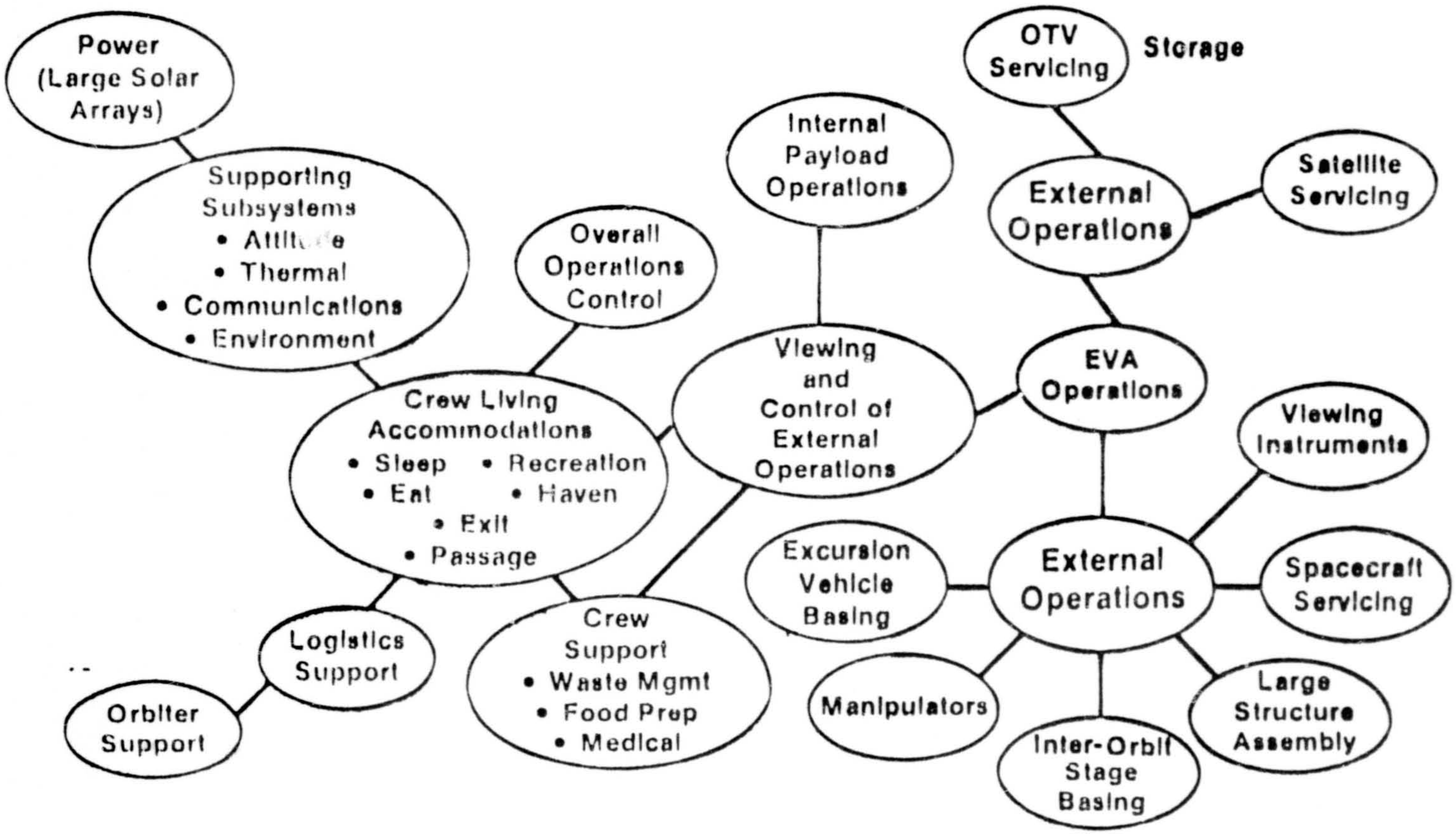
VFV803

BASIC SPACE STATION ELEMENTS



FVX303

INITIAL FUNCTIONAL GROUPING



Power (Large Solar Arrays)

Supporting Subsystems
- Attitude
- Thermal
- Communications
- Environment

Overall Operations Control

Internal Payload Operations

OTV Servicing

Storage

External Operations

Satellite Servicing

Crew Living Accommodations
- Sleep
- Eat
- Recreation
- Haven
- Exit
- Passage

Viewing and Control of External Operations

EVA Operations

Viewing Instruments

Excursion Vehicle Basing

External Operations

Spacecraft Servicing

Logistics Support

Orbiter Support

Crew Support
- Waste Mgmt
- Food Prep
- Medical

Manipulators

Inter-Orbit Stage Basing

Large Structure Assembly

REQUIREMENTS FULFILLMENT CONGREGATION
(HIGH-MODULARITY CONCEPT)

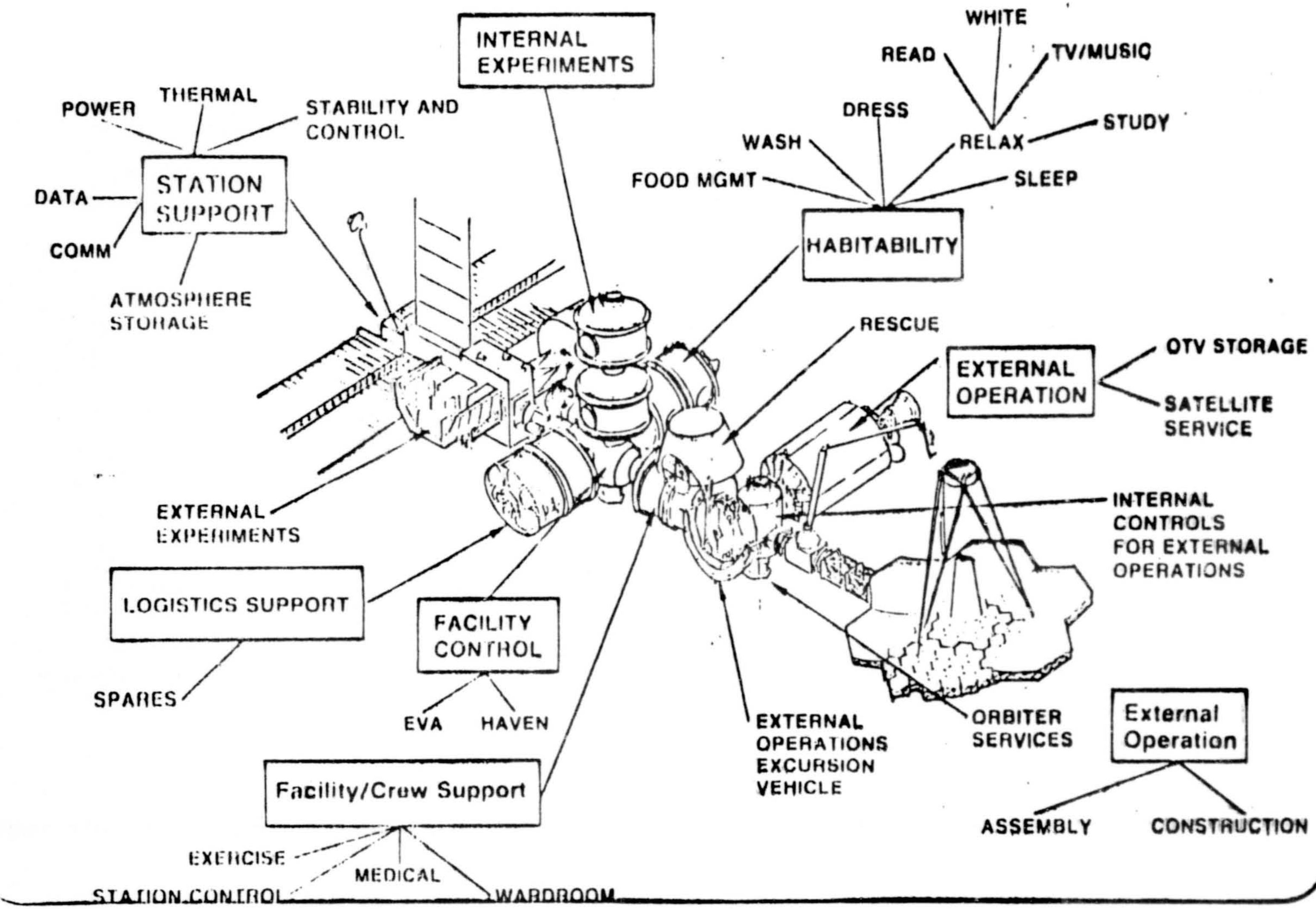
VFR079

• POWER (11 – 25 kW) • COMM/DATA • THERMAL RADIATION • ATTITUDE CONTROL • ALTITUDE REBOOST • EXTERIOR PAYLOAD INSTALLATIONS	SUBSYSTEMS MODULE (SPACE PLATFORM)
• CENTRAL BUILDUP PORTS & PASSAGE • UTILITIES DISTRIBUTION • LIFE SUSTENANCE (90 DAYS)	CENTRAL SUPPORT AND BUILDUP MODULE
• BASIC CREW (2) ACCOMODATIONS • MINI-CONTROL CENTER • SAFE HAVEN	BASIC CREW MODULE
• LOGISTICS – CREW SUPPLIES – PAYLOADS – PAYLOAD SUPPLIES – MANNED PLATFORM AND SPACE PLATFORM SPACES	INTERIOR ACCESS LOGISTICS MODULE

• EXPANDED CREW ACCOMODATIONS AND CONTROL CENTER	HABITAT MODULE
• EXPANDED EXTERIOR PAYLOAD INSTALLATION	EXTERIOR OPERATION MODULE
• EXPANDED INTERIOR PAYLOAD INSTALLATION	DEDICATED PRESSURE PAYLOAD MODULE
• SUBSYSTEM UPGRADES	IVA INSTALLED SUBSYSTEM MODULE
• LOGISTICS ASCENT – PLANNED – UNPLANNED	SHUTTLE (90 DAY CYCLE) EXPENDABLE LAUNCH VEHICLE
• EMERGENCY STATION ABONDONMENT	REENTRY CAPSULE
• EXTENDED REACH LOADING	PLATFORM MOUNTED REMOTE MANIPULATOR

SPACE STATION ELEMENTS

VFX302



INTERNAL EXPERIMENTS

STATION SUPPORT
POWER
THERMAL
STABILITY AND CONTROL
DATA
COMM
ATMOSPHERE STORAGE

HABITABILITY
FOOD MGMT
WASH
DRESS
RELAX
READ
WHITE
TV/MUSIC
STUDY
SLEEP

RESCUE

EXTERNAL OPERATION
OTV STORAGE
SATELLITE SERVICE

INTERNAL CONTROLS FOR EXTERNAL OPERATIONS

EXTERNAL EXPERIMENTS

LOGISTICS SUPPORT
SPARES

FACILITY CONTROL
EVA
HAVEN

EXTERNAL OPERATIONS EXCURSION VEHICLE

ORBITER SERVICES

External Operation
ASSEMBLY
CONSTRUCTION

Facility/Crew Support
EXERCISE
MEDICAL
STATION CONTROL
WARDROOM

VGF312

CONFIGURATION ASPECTS OF PAYLOAD ACCOMMODATIONS

Payload Type	Location Type
■ Internal	Pressurized Module
• Built-In	
• Transient	
■ External	
• Non-Viewing	Any Berth
• Viewing	
— Stellar	Space-Directed
— Solar	
— Earth	Earth-Directed
• Large Assembly	Large Free Volume
• Periodically Serviceable	Close-In Access Aids Possibly Enclosed
• Small Reusable Stages	Semi-Remote Berth
• Large Reusable Stages	Semi-Remote Berths (Near Station Centerline)
• Large Propellant Storage	

Constraints

- Approach/Exit Movement Corridors
- Solar Array Shadowing
- Radiator Reflections
- Manipulator Access (Shuttle/Space Station)
- Multiple Orbiter Berthing Ports
- Interim Berthing During Assembly or Exchange

Exterior Payload Operations/Time Impact Configuration Significantly

ARCHITECTURE OPTIONS FOR PAYLOAD ACCOMMODATIONS

VGM110

Laboratory Module(s) (Interior Payloads)

- Lab Functions Only
- Lab and Crew Qtrs Hybrid
- Lab and Sta-Control Hybrid
- Dedicated Types
- General Purpose Types
- Short Module
- Long Module/Unpartitioned
- Long Module/Partitioned
- Some Long, Some Short
- Accessories:
  Built-In Radiator
  Scientific Airlock

Service Center (Exterior Payloads)

- Integrate With Multiple Docking Adapter
- Separate Multi-Berth Unit (Trusswork) (Tunnel)
- One Unit/10 Berths (All-In-One)
- Two Units/5 Berths (i.e. Modular)
- Incorporates Big Manipulator
- Incorporates Radiators
- Articulating (For Broad Op's Flexibility)
- Central, Top or End-Mounted
- Rotating Berths For Maximum Viewing Payload, or Assembly Op's Flexibility
- Hangar Provisions (Pressurized/ Unpressurized)

SPECTRUM OF SERVICES SCENARIOS (RELATED TO SPACE STATION)

VGF194

- User Types and Service Locations:

	On Station	Off Station
• Space Station Attached Payloads	✓	
• Free Flying Spacecraft	✓	Via TMS
• Teleoperator Maneuvering System	✓	Via TMS
• Space Platform	?	Via TMS
• Space Platform Attached Payloads	?	Via TMS
• Reusable Orbit Transfer Vehicles	✓	
• ROTV-Boosted Free-Flying Spacecraft	✓	
• ROTV-Boosted Servicer	✓	

SPACE STATION SERVICE CENTER

Objective

- Provide a Broad Range of Enabling and Sustaining Services to Resident and Transient Payloads

Service Functions (in Graduated Capability/Time)

- Berthing
- Activation
- Deployment
- Diagnosis
- Alignment
- Replenishment
- Enclosure
- Replacement
- Modification
- Assembly
- Stowage
- Checkout and Launch
- Manipulation
- Maintenance
- Surface Treatment

Types of Payloads (Nasa, DoD, Commercial, Foreign)

- Self-Propelled Spacecraft
- Propulsion-Staged Spacecraft
- Teleoperator Maneuverer
- Orbit Transfer Vehicle(s)
- Reusable Orbit Transfer Vehicle
- Palletized Payloads) (Resident/Non-Resident)
    - Science
    - Earth Applications
    - Technology
- Space Platforms (?)

SPACE STATION SERVICE CENTER (CONT.)

Major Configuration Elements

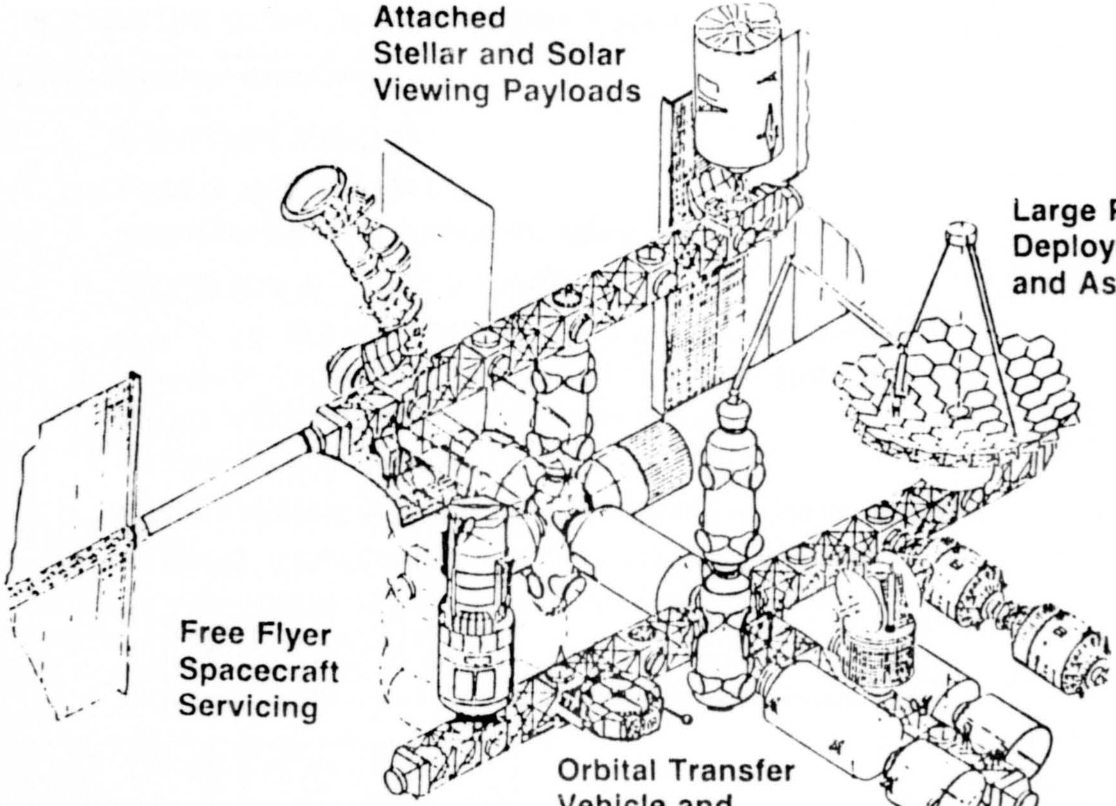
- Servicing Control Centers (General and Dedicated)
- Articulated, Truss Beams(s) with Berthing Ports
- Power, Data and Communications Distribution
- Liquid, Gas Storage and Distribution Systems
- Manipulator(s): Major and Localized — Minor Types
- Enclosure(s): Permanent and Portable
- EVA Access/Assistance Equipment
- Interior Stowage (Replacement/Modification items)
- Exterior Stowage (Interim and Long Term Berthing)
- Tool and Supplies Stowage
- Diagnostic and Checkout Equipment
- Work Bench Areas
- Directed Lighting

Configuration Constraints

- Extensive Crew Visibility of Operations
- Safe Rendezvous and Exit Flight Corridors
- Efficient Shuttle RMS Loading Access or Handover
- Extensive Payload (Berth) Separation for Viewing or Movement Freedom
- Minimal Solar Array Shadowing and Radiator Reflection

VGF602

ATTACHED PAYLOAD AND MULTI-SERVICE CENTER



Attached Stellar and Solar Viewing Payloads

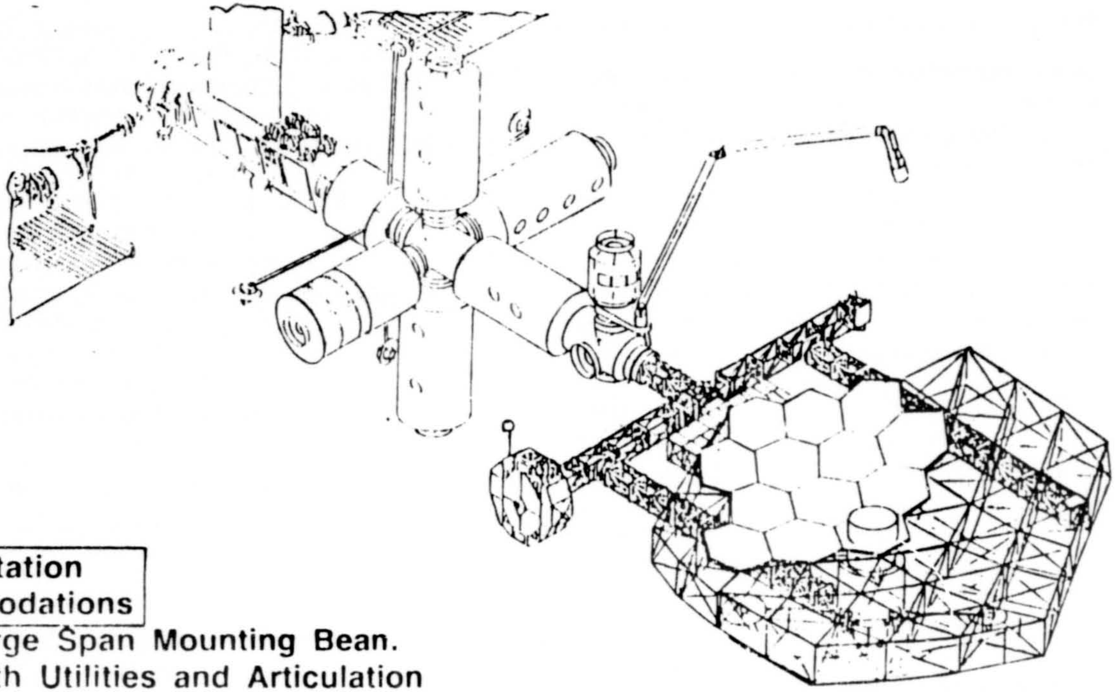
Large Payload Deployment and Assembly

Free Flyer Spacecraft Servicing

Orbital Transfer Vehicle and Payload Assembly and Refueling

VGM112

LARGE DIAMETER REFLECTOR ASSEMBLY



Space Station Accommodations

- Large Span Mounting Bean. With Utilities and Articulation
- Long Reach Manipulator
- Interim Stowage Locations For Construction Elements
- Operational Viewing
- Internal Control Center
- EVA Crew Capabilities
- Possible Enclosure/Contamination Shield Provisions

VGK162

SPACE STATION MISSIONS
EARLY SET (1991-93)

Missions Externally Attached to SS Base (Or Co-Orbiting Platform)

SAA	0001	Cosmic Ray Nuclei
SAA	0002	Space Plasma Physics
SAA	0003	Solar Optical Telescope
SAA	0004	Shuttle IR Telescope Facility
SAA	0006	Starlab
SAA	0201	LIDAR Facility
SAA	0306	CELS Pallet
COM	1202	EOS Production Units
COM	1203	ECG Production Units
COM	1105	Communications Test Lab
TDM	2010	Materials Performance
TDM	2060	Deployment/Assembly/Construction
TDM	2070	Structural Dynamics
TDM	2080	Design Verification
TDM	2210	Large Space Antenna Technology
TDM	2260	Earth Observation Instrument
TDM	2310	Fluid Management Technology
TDM	2410	Attitude Control Technology
TDM	2420	Figure Control Technology
TDM	2460	Telepresence and EVA Technology
TDM	2470	Interactive Human Factors
TDM	2510	Environmental Effects Technology
TDM	2560	Satellite Servicing Technology
TDM	2570	OTV Servicing Technology

Missions Accommodated Inside SS Laboratory Modules

SAA	0307	Life Science Laboratory
COM	1201	MPS Lab #1
TDM	2020	Materials Processing
TDM	2520	Habitation Technology
TDM	2530	Medical Technology
TDM	2580	On-Board Operations Technology

Free-Flyer Missions Serviced At/By SS Base

SAA	0012	Space Telescope
SAA	0013	Gamma Ray Observatory
SAA	0014	X-Ray Timing
SAA	0016	Solar Max Mission
SAA	0017	AXAF
SAA	0019	Far UV Spectroscopy

Planetary Missions Supported at SS Base

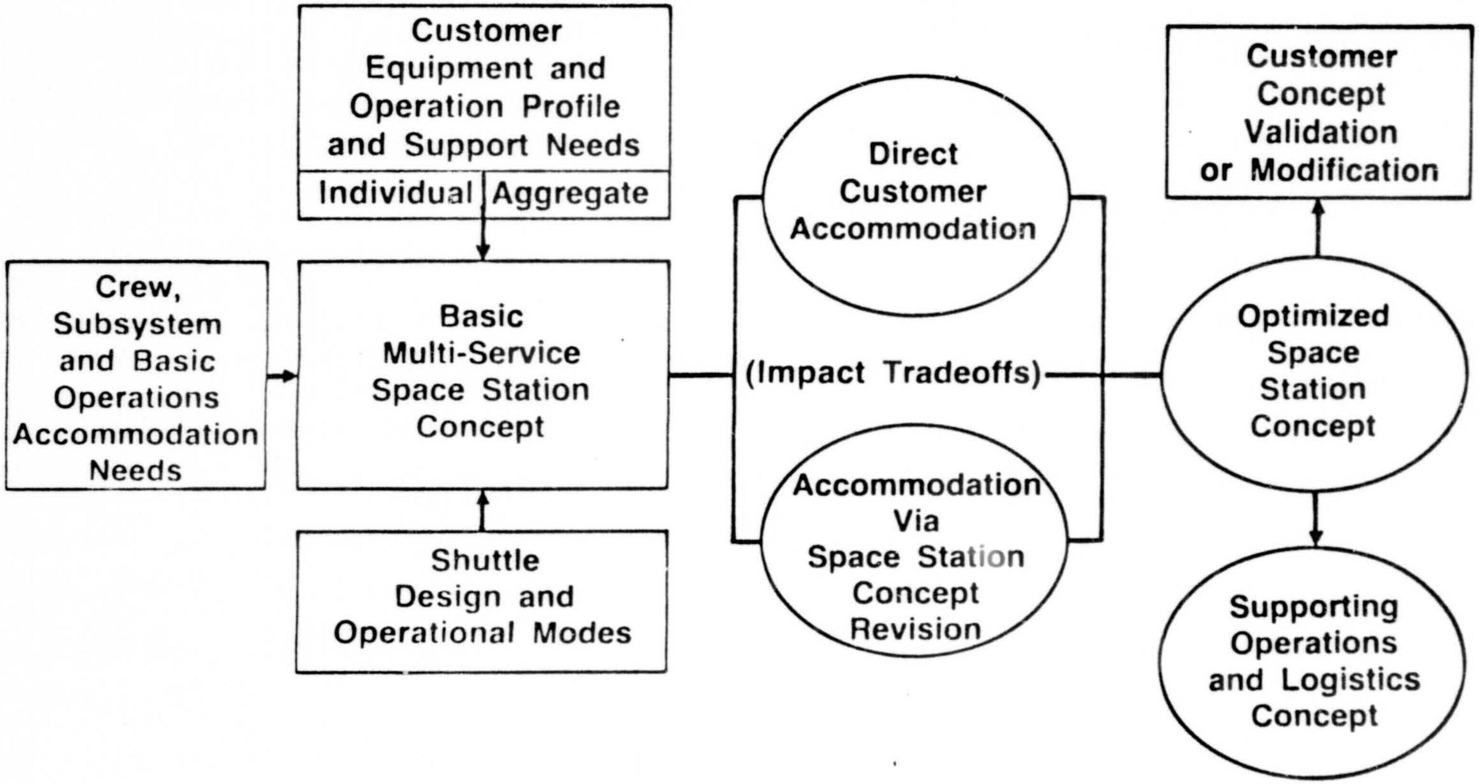
SAA	0102	Lunar Geochemical Orbiter
SAA	0105	Titan Probe

Missions Supported By Polar Platform

SAA	0202	Earth Sciences Research
COM	1019	Stereo Multi-Linear Array

CUSTOMER ACCOMMODATION CONSIDERATIONS IN ARCHITECTURE

VGM111



Customer Equipment and Operation Profile and Support Needs

Individual | Aggregate

Crew, Subsystem and Basic Operations Accommodation Needs

Basic Multi-Service Space Station Concept

Shuttle Design and Operational Modes

Direct Customer Accommodation

(Impact Tradeoffs)

Accommodation Via Space Station Concept Revision

Customer Concept Validation or Modification

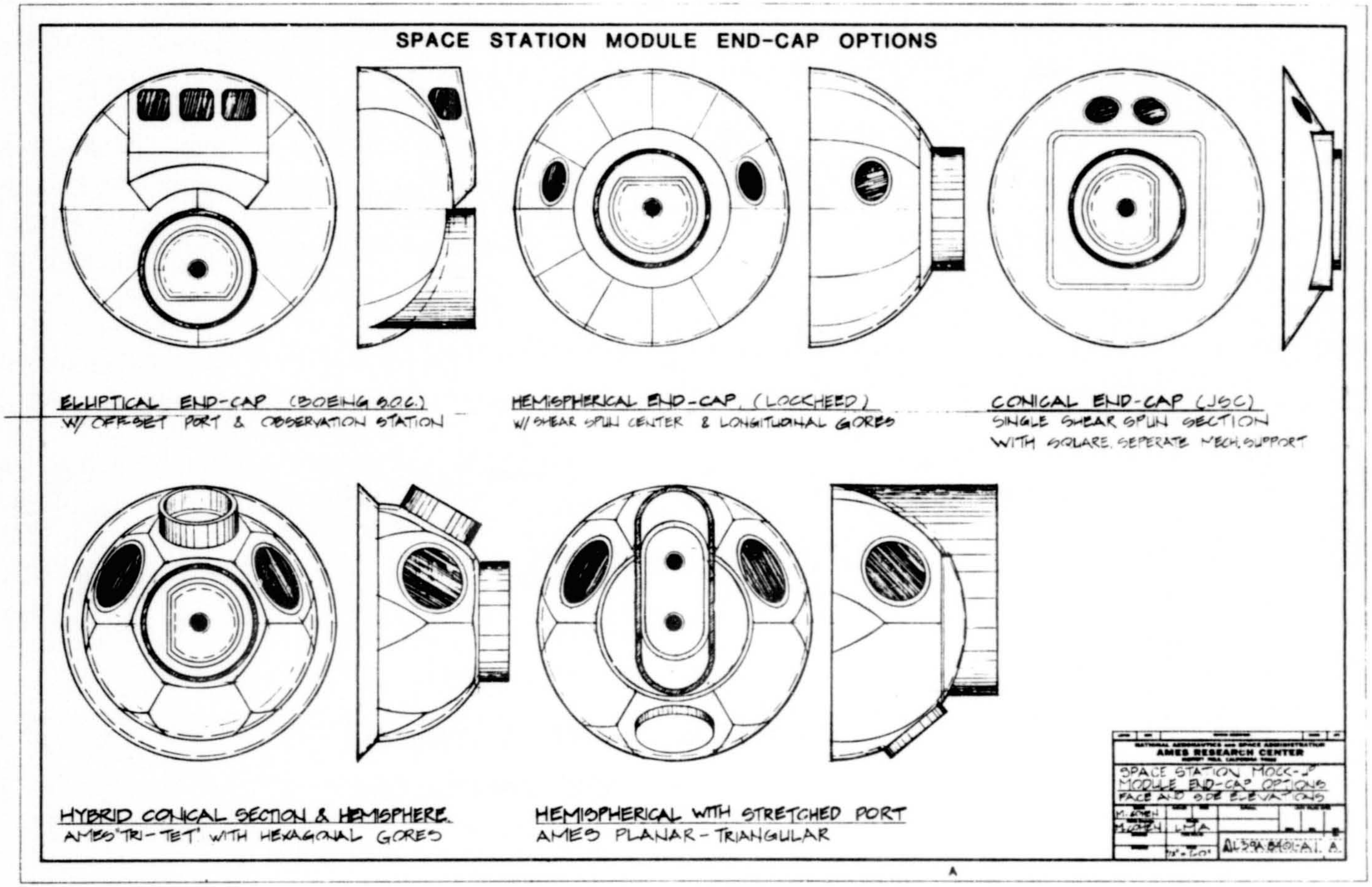
Optimized Space Station Concept

Supporting Operations and Logistics Concept

FRIDAY

AMES MOCK-UP IDEAS
FOR SPACE HUMAN FACTORS RESEARCH

MARC M. COHEN
ARCHITECT
MARCH 2, 1984


SPACE STATION MODULE END-CAP OPTIONS
ELLIPTICAL END-CAP (BOEING S.O.C.)
W/ OFFSET PORT & OBSERVATION STATION
HEMISPHERICAL END-CAP, (LOCKHEED)
W/ SHEAR SPUN CENTER & LONGITUDINAL GORES
CONICAL END-CAP (JSC)
SINGLE SHEAR SPUN SECTION
WITH SQUARE, SEPERATE MECH. SUPPORT
HYBRID CONICAL SECTION & HEMISPHERE.
AMES "TRI-TET" WITH HEXAGONAL GORES
HEMISPHERICAL WITH STRETCHED PORT
AMES PLANAR-TRIANGULAR
AMES RESEARCH CENTER
SPACE STATION MOCK-UP
MODULE END-CAP OPTIONS
FACE AND SIDE ELEVATIONS
LMA
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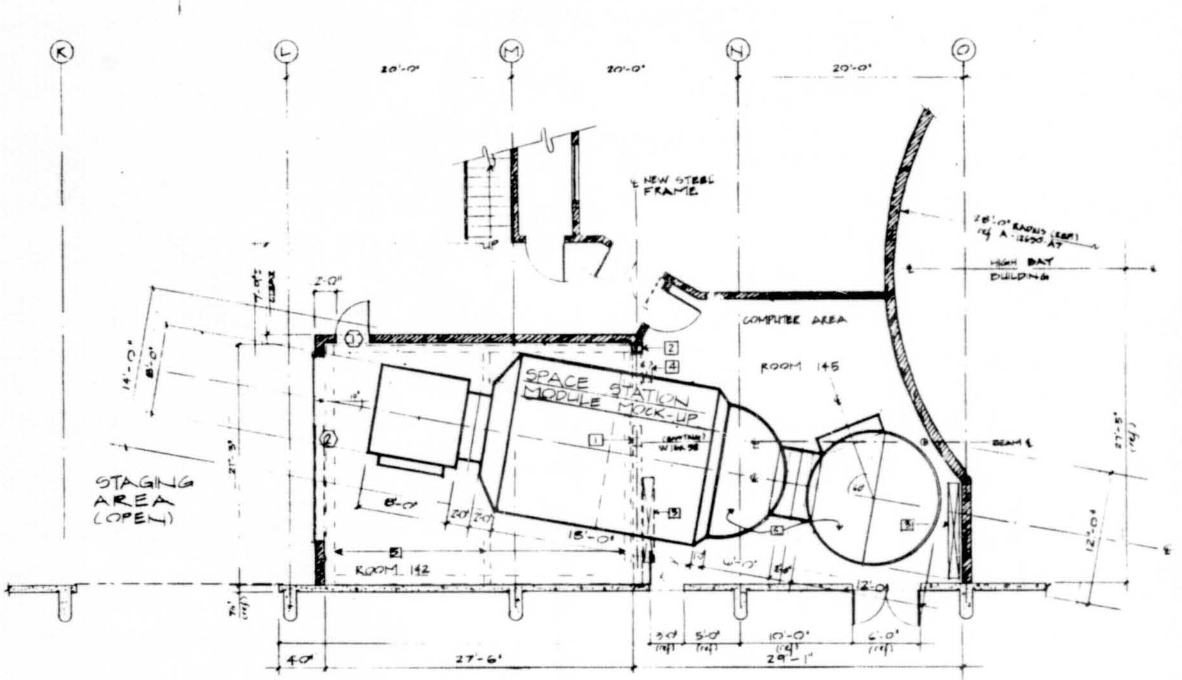


SPACE HUMAN FACTORS LABORATORY SCHEMATIC FLOOR PLAN (MAXIMUM FLOOR AREA UTILIZATION)

NOTES

1. REMOVE (E) 6"x12" WOOD COLUMN. SUPPORT W16x58 W/ TEMPORARY POST
2. INSTALL STEEL MOMENT RESISTING OR BRACED FRAME TO SUPPORT ROOF LOADS, W16x58 BEAM & TO RESIST LATERAL LOADS.
3. RELOCATE (E) SUPPLY AIR DUCT FROM CENTER WALL TO SOUTH WALL
4. REMOVE & CAP (E) SUPPLY AIR DUCT
5. REMOVE ALL (E) ELEC. RACEWAYS RUNNING EAST/WEST
6. RELOCATE FIRE SPRINKLER HEADS AS REQ'D. BY DUCT RELOCATION

LEGEND:

EXISTING 6" STUD WALL TO BE REMOVED	┅┅┅
EXISTING 6" STUD WALL TO REMAIN	▬
EXISTING CONCRETE WALL TO REMAIN	═

KEY.

①	3'-0" x 7'-0" SOLID CORE DOOR
②	16' x 16' (NOMINAL) INSULATED & GASKETED ROLL-UP DOOR

A	4/9/84	MOMENT FRAME LINE WEIGHT	HMC	[illegible]

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA

MODIFICATION OF BUILDING N-239A, RMS 142 & 145
SPACE HUMAN FACTORS LAB
WITH MODULE MOCK-UP

HAL COHEN
HAL COHEN
LMTA
NOV. 9, 1983
1/4" = 1'-0"
A L39A-8301-A1 A

N85-29568

SIMULATION FOR HUMAN FACTORS RESEARCH

DAVID NAGEL

AEROSPACE HUMAN FACTORS RESEARCH DIVISION

NASA-AMES

MARCH 2, 1984

A CENTRAL QUESTION: FIDELITY

VERY RECENT TRENDS IN AERONAUTICAL SIMULATION

- For Training: lower fidelity
- For R&D: greater fidelity (including full mission)

CRITERIA FOR TRAINING DEVICES:

TRAINING EFFECTIVENESS

- Usual Methods of Evaluation
  - Transfer of training (costly & rare!)
  - Judged effectiveness (generally fidelity - perhaps irrelevant)
- In Aviation, Little Empirical Support for Incremental Effectiveness of Hi VS Lo Fidelity (& Very High Cost)
- Increased Emphasis on Training System Effectiveness - Not Training Device Effectiveness
- Developing Strategy is to Concentrate on Low Cost Devices, & Improved "Instructors" & Curricula Using Advanced Instruction Notions

  (knowledge of results, adaptive systems, perceptual learning, S/R, & motivational principles, knowledge engr, ...)

CRITERIA FOR R&D DEVICES:

ABILITY TO GENERALIZE RESULTS

- Usual Methods of Evaluation
  - Engineering fidelity
  - Psychological fidelity
- In Aviation, Great Deal of Evidence Linking Fidelity to "Effectiveness"
- Problems
  - Engineering fidelity costly & sometimes extremely difficult to achieve.
  - Psychological fidelity is multidimensional (perceptual, cognitive, social, workload, ...)
  - Some necessary human measurement models don't exist.
  - Fidelity criteria typically are unknown, costly to determine (requires verification in flight, similar to transfer paradigms)

AVIATION R&D SIMULATION

- Resulting Trend is to Rely on Empirical Results (re-effectiveness) and Increasing Task & Mission Fidelity

FULL SYSTEM/FULL MISSION SIMULATION FOR HUMAN FACTORS RESEARCH

- In Aviation
  - Becoming increasingly indispensable tool for variety of human factors studies (operational problems, crew-system integration, ...)
- In Space
  - True full mission simulation very costly.
  - Fidelity of mockups should reflect a priori requirements for degree of confidence needed.
  - Full system (not mission), part system, & lower degrees of fidelity may be enough for many study areas.

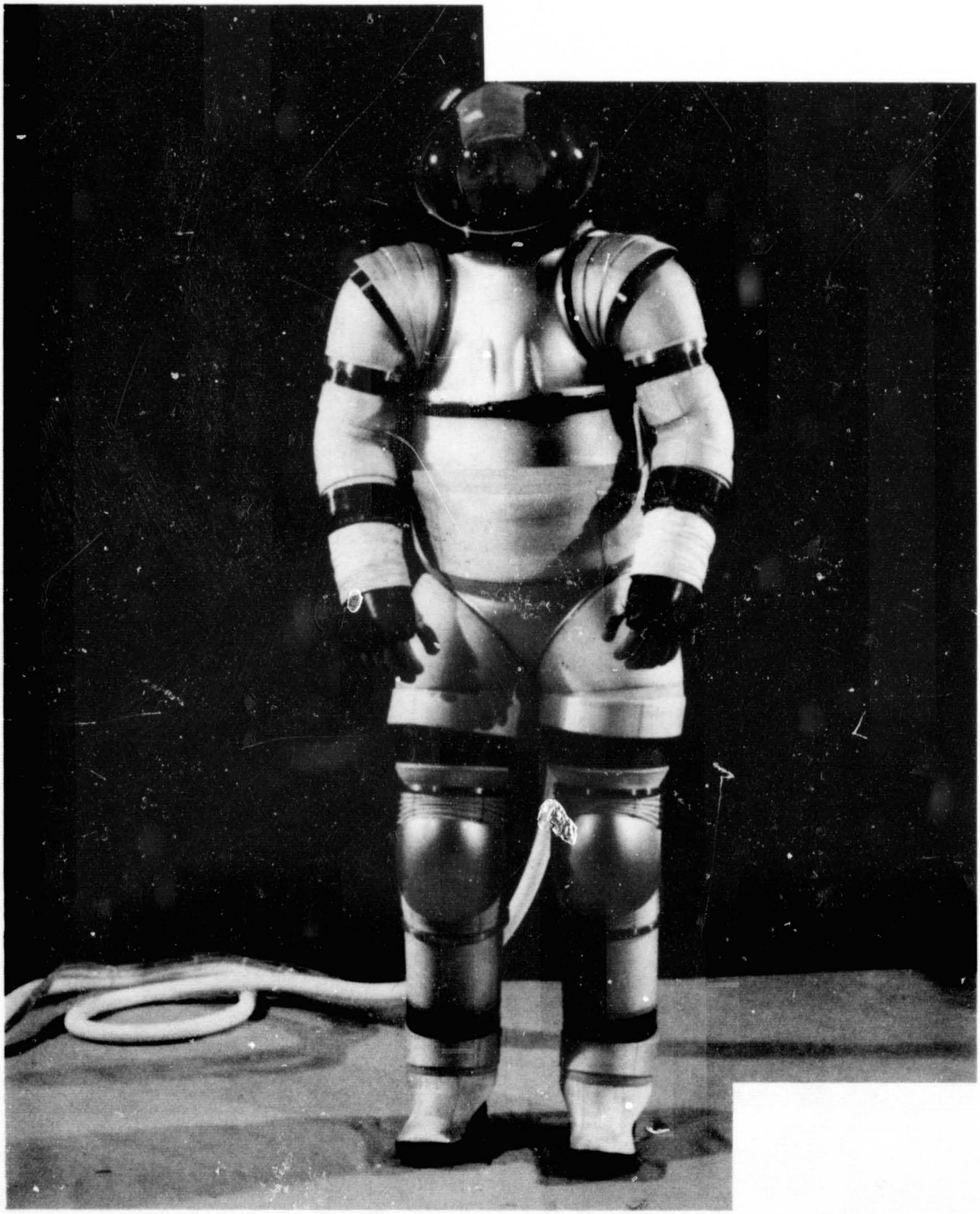
AMES RESEARCH CENTER -- AERO-SPACE HUMAN FACTORS DIVISION

AX-5 DESIGN OBJECTIVES

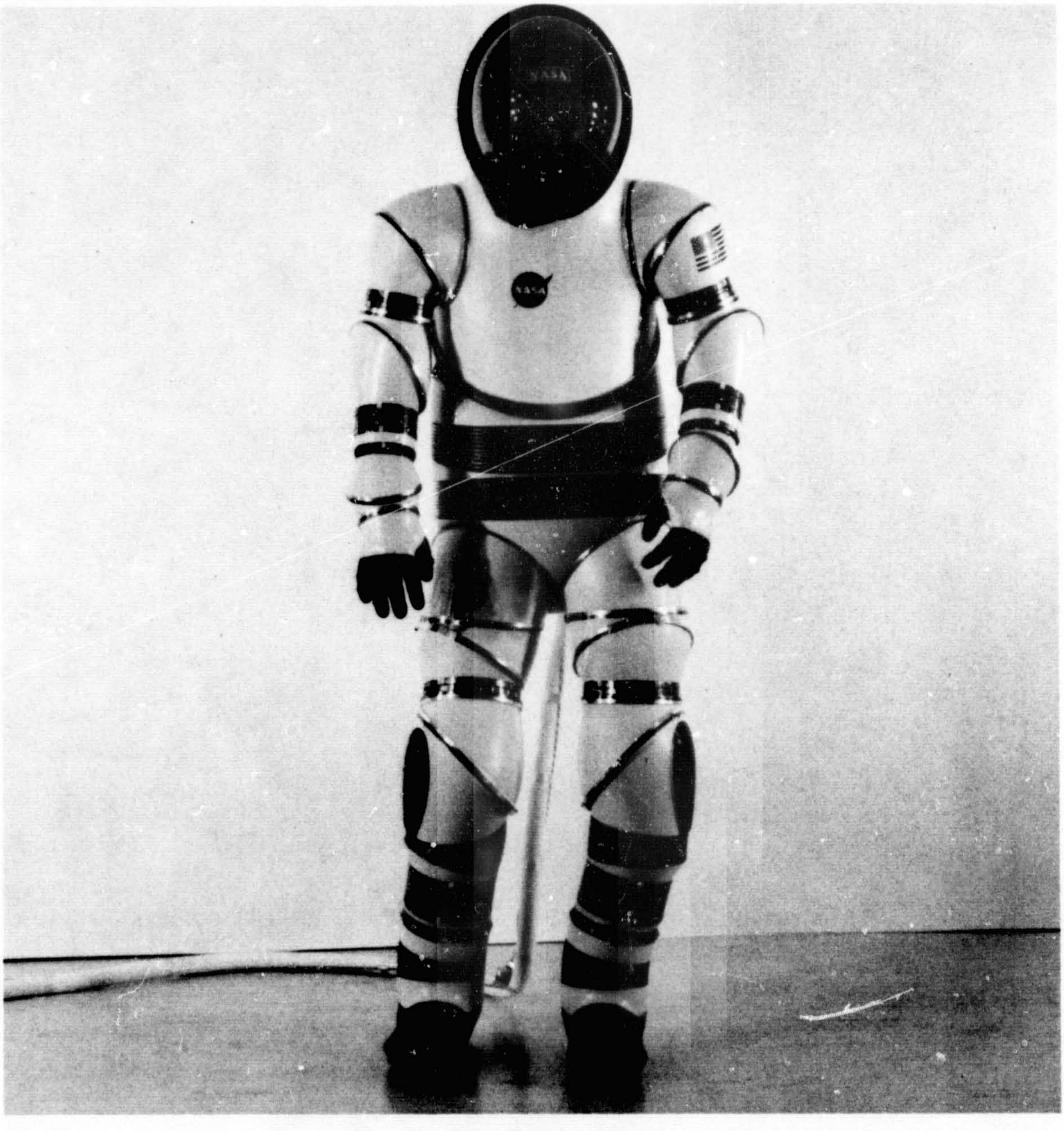
- PERFORMANCE
  - 14.7 PSI PRESSURE
  - HIGH MOBILITY
  - LOW TORQUE JOINTS
  - LOW LEAKAGE (<50SCC/MIN)
  - COMFORT
  - EASE OF DONNING/DOFFING

- MECHANICAL DESIGN
  - ALL HARD STRUCTURES
  - MULTIPLE WALL W/MATERIALS OPTIONS
  - [redacted]
  - [redacted]
  - DRY LUBRICANTS
  - TOTAL MODULARITY
  - LOW MAINTENANCE/LONG LIFE JOINTS
  - HAZARD PROTECTION
    - RADIATION
    - DEBRIS
    - PROPELLANTS
    - THERMAL
    - SHARP CORNERS
  - MANUFACTURING REPEATABILITY

FIRST VARIATION ON AX-5 DESIGN



SECOND VARIATION ON AX-5 DESIGN



LSS-1224

Space Station Models, Mockups, and Simulators

by

Keith H. Miller
Alan Osgood

Space Station Human Productivity Working Group Meeting
NASA-Ames Research Center
February 27–March 2, 1984

- Types of Boeing models, mockups and simulators
- Classes of models, mockups and simulators
- Use of models in 767 program
- Use of models, mockups, and simulators for Space Station Program

Types of Boeing Models, Mockups, and Simulators

- **Stationary work stations** – Flight decks, E-3A multipurpose consoles, communications consoles, gunner stations etc.
- **Larger work areas** – Galleys, cargo handling, E-3A & E-4B mission crew areas, maintenance areas
- **Leisure areas** – Airplane passenger cabins, lavatories, E-3A & E-4B rest areas
- **Complete facility** – Airplane, office and production areas

Space Station

Classes of Models, Mockups and Simulators

LSS-1227

Class	Use	Users
Models	– Compare variety of concepts	Staff and engineering
1/100th–1/[illegible]0th scale	– Area layout and access	
1/10–1/4th scale	– Personnel accommodation	
Full scale mockups	– Progressive development of design	
Class 1	– Foam core, wood & paper of overall configuration	Staff and engineering
Class 2	– Subsystems mockup (plumbing, wiring)	
"Lighted" mockup	– Lighting, display and control	
Class 3	– Real equipment & materials (not qualified)	Manufacturing
Engineering simulators	– Develop and test design and procedures	Engineering
Developmental	– Single task or subsystem	
Configuration	– Integrated tasks, and subsystems	
Training devices	– Train and test personnel	Training
Part task trainers	– Single task	
Procedures trainers	– Integrate tasks	
Training simulators	– Realistic situation	

Characteristics of Models

- Inexpensive side by side comparison of concepts and designs
  - Humans much better at comparative judgments than absolute judgments
  - Provides 3-D views and perspective
  - Easy to transport

- Used by technical staff, engineering, marketing research and public relations

- Range of model scales
  - 1/100th–1/20th scale – Area layout and access
  - 1/10th–1/4th scale – Component layout and personnel accommodation

- Evaluations of interior layouts and color schemes closely approximate evaluations of actual interiors

Use of Models for 767 Program

- Verification of value of models for design evaluation
- Evaluation of alternative passenger cabin configurations
- Prediction of 767 market share in competitive markets
- Demonstration of 767 passenger appeal to airlines

Computerized Human Factors Tools

- Analyses for anticipated user groups
    - Conducted before hardware built
- Anthropometry
    - Accessibility of controls
- Vision
    - Readability of displays
    - Vision through windows
- Timeline evaluation

Approach for Space Station

- Maximize use of CADCAM
  - Concept development and evaluation
  - Early problem identification and resolution
- Maximize use of models
  - Comparison of alternative concepts
  - Initial development of procedures
  - Initial training
- Use partial mockups, subsystem simulators, and part task trainers to maximum utility
- Minimize demands on complete mockups, engineering simulators and training simulators

FISHER

MOCKUPS AND HUMAN PRODUCTIVITY STUDIES

Presentation To

SPACE STATION
HUMAN PRODUCTIVITY WORKING GROUP MEETING

NASA AMES

2 MARCH 1984

THE MAGIC OF MOCKUPS AND THE MYSTIQUE OF HUMAN PRODUCTIVITY

Presentation To

SPACE STATION

HUMAN PRODUCTIVITY WORKING GROUP MEETING

NASA AMES

2 MARCH 1984

OBJECTIVE

TO PRESENT IDEAS FOR GROUP CONSIDERATION/DISCUSSION

RELATIVE TO:

- MOCKUP CANDIDATES
- MOCKUP UTILIZATION
- MOCKUP DEVELOPMENT SCHEDULES/SEQUENCE

SPACE STATION PROGRAMS

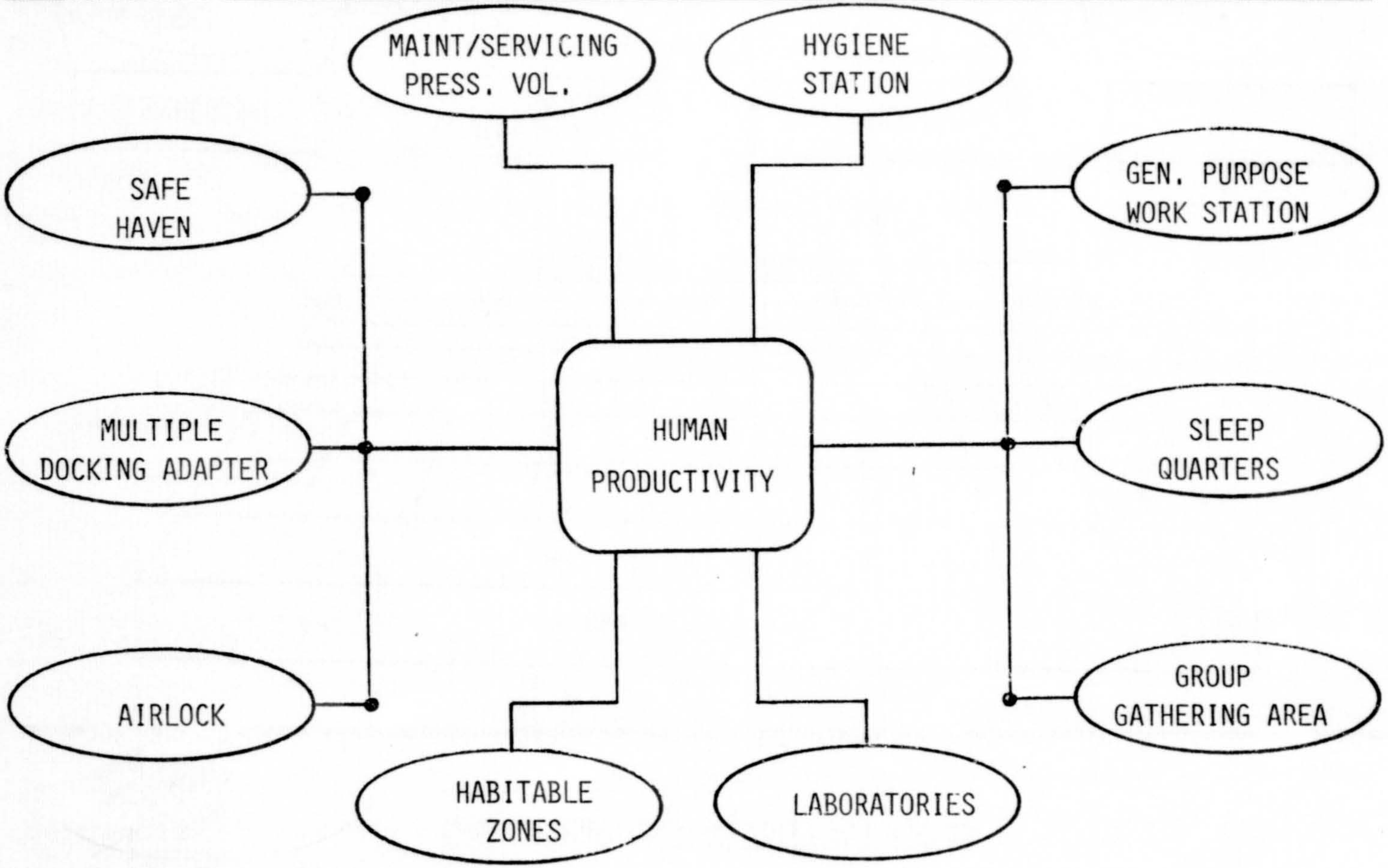
NASA AMES* SUGGESTED MOCKUP TOPICAL COVERAGE

1. VOLUME
2. ORIENTATION
3. CIRCULATION
4. PRIVACY
5. GROUP GATHERING
6. VISUAL SYSTEMS
7. LIGHTING
8. VIBRO/ACOUSTICS
9. FUNCTIONAL ORGANIZATION
10. OTHER

* Mr. Marc Cohen - ARC

MOCKUP CANDIDATES WHICH AID IN HUMAN PRODUCTIVITY

INVESTIGATIONS AND ASSESSMENT



HUMAN PRODUCTIVITY

MAINT/SERVICING PRESS. VOL.

HYGIENE STATION

SAFE HAVEN

MULTIPLE DOCKING ADAPTER

AIRLOCK

GEN. PURPOSE WORK STATION

SLEEP QUARTERS

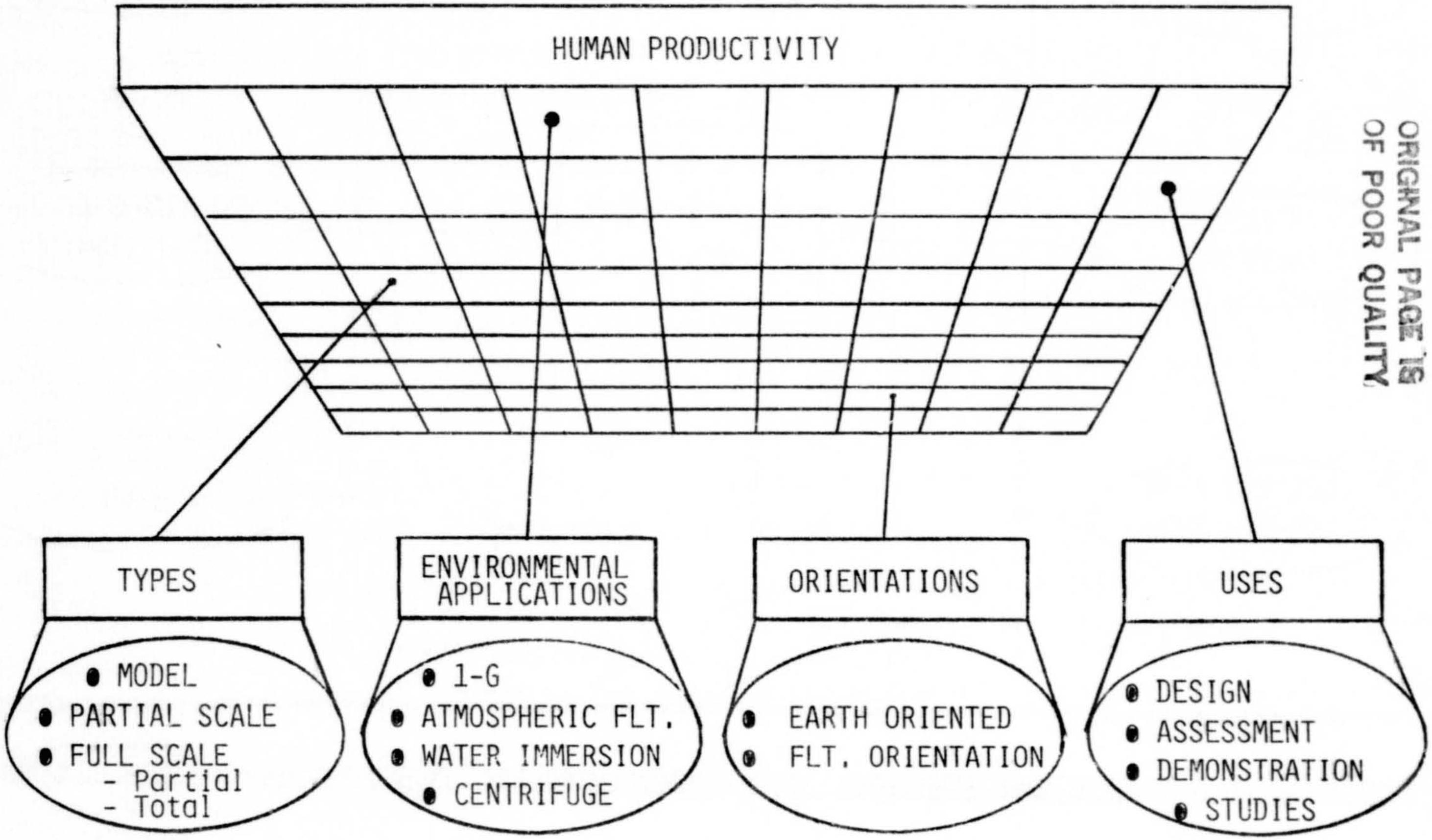
GROUP GATHERING AREA

HABITABLE ZONES

LABORATORIES

SPACE STATION PROGRAMS

MOCKUP CONSIDERATIONS



HUMAN PRODUCTIVITY

TYPES
- MODEL
- PARTIAL SCALE
- FULL SCALE
  - Partial
  - Total

ENVIRONMENTAL APPLICATIONS
- 1-G
- ATMOSPHERIC FLT.
- WATER IMMERSION
- CENTRIFUGE

ORIENTATIONS
- EARTH ORIENTED
- FLT. ORIENTATION

USES
- DESIGN
- ASSESSMENT
- DEMONSTRATION
- STUDIES

MOCKUP CANDIDATES AND USES

SAFE HAVEN ZONE(S)

1. ACTIVITY VOLUMETRICS
2. EMERGENCY ECLSS ITEMS & CONTROL/MONITOR
3. 'ZONE' VOLUMETRICS FOR UP TO X CREW
4. RESCUE INTERFACES
5. RESCUE DEVICES STOWAGE
6. EMERGENCY EQUIPMENT STOWAGE/ACCESS
7. COMMUNICATION PANEL/DEVICE LOCATION
8. VIEW PORT(?)
9. FOOD PREPARATION, STOWAGE & WASTE
10. HYGIENE CONDUCT & WASTE HANDLING
11. CONTAMINATION CONTROL
12. EMERGENCY SLEEP PROVISIONS
13. VENTILATION & ODOR CONTROL
14. PERSONNEL ACCOUTREMENTS
15. PRIVACY
16. GENERAL STOWAGE & ACCESS
17. EMERGENCY ITEM CHECK & ACCESS
18. MEDICAL & FIRST AID SUPPLIES/STOWAGE
19. OTHER

GENERAL PURPOSE WORKSTATION(S)

1. DESIGN FOR 0-G FEATURES/USE
2. RE-LOCATION POTENTIAL
3. BASIC STATION RECONFIGURABILITY
4. SIZE & LAYOUT
5. UTILIZATION VOLUMETRICS
6. ANTHROPOMETRIC UTILIZATION- POPULATION (?)
7. AMBIENT ILLUMINATION IMPACT
8. SEE-OVER VS DECK-TO-CEILING/OVERHEAD
9. MAINTENANCE ACCESS - OPTIONS
10. CABLE RUN(S) AND INTERFACES
11. COOLING/VENTILATION & DUCTING INTERFACES
12. MODULARITY & COMMONALITY
13. BASIC DISPLAY/CONTROL LAYOUT
14. INTRA-STATION D&C COMMONALITY
15. CREW USER EASE & SIMPLICITY
16. 'ISOLATION' FEATURES AS REQUIRED
17. STATION STATUS INDICATION
18. EMERGENCY WARNING & COMMUNICATION
19. OTHER

SPACE STATION PROGRAMS

MOCKUP CANDIDATES AND USES

MAINT/SERVICING (PRESS.) AREA

1. ACTIVITY VOLUMETRICS
2. PACKAGE TRANSFER - IV TO EV OR EV TO IV
3. SPACECRAFT ELEMENT ENTRY/EXIT VOLUME
4. SPACECRAFT ORU ENTRY/EXIT VOLUME
5. INTERNAL LAYOUT/ARRANGEMENT/ARCHITECTURE
6. INTERFACE TO AIRLOCK
7. AREA SUB-ZONE LAYOUT
8. I/F TO SPARES/STOWED ITEMS
9. STOWED ITEM VOLUMETRICS
10. CREW WORK STATION(S)
11. CREW WORK STA. MAINTENANCE ACCESS
12. CONTAMINATION MANAGEMENT
13. EMERGENCY PROVISIONS & STOWAGE
14. UNIQUE WORK STATION FEATURES
15. TOOLS/AIDS STOWAGE/ACCESS & CLEANING
16. ITEM PROTECTION OR ISOLATION
17. SPECIAL ITEM HANDLING DEVICES/ITEMS
18. EQUIPMENT/ITEM/ORU TRANSFER DEVICES
19. EMERGENCY ECLSS PANEL ACCESS & WARNING
20. SAFE HAVEN INTEGRATION (?)
21. OTHER-MANY!

SLEEP QUARTERS AREA

MOCKUP CANDIDATES AND USES

MULTIPLE DOCKING ADAPTER

1. VOLUMETRICS
   - PKG & MODULE PASS-THRU
   - S/C ELEMENT PASS-THRU
   - ACTIVITY VOLUMETRICS
   - SUIT DON/DOFF VOLUME (8 CREW?)
   - ITEM TRANSFER DEVICES VOLUME
2. CREW FUNCTIONS
3. INTERNAL ORIENTATION LAYOUTS
4. INTERNAL ACCOUTREMENTS
5. ILLUMINATION
6. HATCH SWING & STOWAGE
7. WINDOW LOCATIONS
8. CONTROL PANEL LOCATIONS
9. EMERGENCY PROVISIONS/DEVICES
10. CONTAMINATION CONTROL TECHNIQUES
11. EMERGENCY ECLSS
12. OTHER

AIRLOCK

1. VOLUMETRICS
   - PKG & MODULE PASS-THRU
   - S/C ELEMENT PASS-THRU
   - ACTIVITY VOLUMETRICS
   - SUIT DON/DOFF VOLUME (8 CREW?)
   - ITEM TRANSFER DEVICES VOLUME
   - EVA TOOLS & AIDS STOWAGE
2. CREW FUNCTIONS
3. CREW TRANSFER - ABLE & INCAPACITATED
4. INTERNAL ORIENTATION LAYOUTS
5. INTERNAL ACCOUTREMENTS
6. ILLUMINATION
7. HATCH SWING & STOWAGE
8. WINDOW LOCATIONS
9. CONTROL PANEL LOCATIONS
10. EMERGENCY PROVISIONS/DEVICES
11. CONTAMINATION CONTROL TECHNIQUES
12. EMERGENCY ECLSS
13. ALTERNATE USES
    - o HYPERBARIC CHAMBER & SUB-AIRLOCKS
    - o SAFE HAVEN

MOCKUP CANDIDATES AND USES

HYGIENE STATION

1. ACTIVITY VOLUMETRICS
2. TOILET CONFIGURATION
3. CLEANSING FEATURES
   - SHOWER
   - WASH BOWL
4. ACCESS VOLUMETRICS
5. MAINTENANCE ACCESS VOLUME
6. CONTAMINATION CONTROL/CONTAINMENT
7. WASTE PRODUCT HANDLING
8. WASTE PRODUCT 'STOWAGE' & TRANSFER
9. WET ITEM HANDLING/MANAGEMENT
10. VENTILATION
11. VIBRO/ACOUSTICS (DIFFICULT IN M/U)
12. AESTHETICS
13. PRIVACY
14. COMFORT & CONVENIENCE
15. ARRANGEMENT ALTERNATIVES-GROWTH
16. ODOR CONTROL/MANAGEMENT
17. ITEM(S) STOWAGE - VARIOUS
18. OTHER

FOOD STATION

1. ACTIVITY VOLUMETRICS
2. FOOD/DRINK PREPARATION ACCESS
   - EASE OF PREPARATION (FULL MEAL/SNACK)
   - MULTIPLE CREW ACCESS(?)
   - ZONE DIFFERENTIATION
   - OTHER
3. STATION ARRANGEMENT
4. AESTHETICS & PLEASANTNESS OF SURROUND
5. MULTIPLE CREW ACCOMODATIONS
6. EATING FACILITY ACCOUTREMENTS
7. CONTAMINATION CONTAINMENT/CONTROL
8. ODOR CONTROL & VENTILATION
9. COMFORT FEATURES
10. VIBRO/ACOUSTRICS (DIFFICULT IN M/U)
11. WASTE PRODUCT HANDLING
12. WASTE PRODUCT 'STOWAGE' & TRANSFER
13. FOOD STOWAGE VOLUME & ACCESS/LOGISTICS
14. WASTE COMPACTING(?)
15. BACTERIAL CONTROL/MANAGEMENT
16. GENERAL ITEMS STOWAGE/ACCESS
17. OTHER - MANY!

MOCKUP CANDIDATES AND USES

HABITATION ZONE(S)

1. ACTIVITY VOLUMETRICS
2. TRAFFIC PATTERNS & FLOWS
3. ORIENTATION
4. ENTRY/EXIT FROM 1 ZONE TO 2ND(TRANSITION)
5. ACCESS VOLUMETRICS
6. MAINTENANCE ACCESS VOLUMETRICS
7. TRANSLATION AIDS
8. UNIQUE CREW ACCOMODATION ACCOUTREMENTS
9. ILLUMINATION
10. EMERGENCY ECLSS PANEL ACCESS & WARNING
11. RECONFIGURABILITY
12. ATTRACTIVE 'FURNISHINGS' & DECOR
13. COLOR & AESTHETICS
14. WINDOW(S) &/OR VIEW PORTS
15. CONTAMINATION CONTROL/MANAGEMENT
16. SAFE HAVEN INTEGRATION(?)
17. BASIC STATION COMMUNICATIONS ACCESS
18. OTHER

GROUP GATHERING AREA

1. ACTIVITY VOLUMETRICS
2. GROUP I/F AND INTERACTION LAYOUT
3. ACCOMMODATIONS/FURNISHINGS/ACCOUTREMENTS
4. BASIC LAYOUT/ARCHITECTURE & ORIENTATION
5. WINDOWS OR VIEW PORTS
6. ITEM STOWAGE, SET-UP & TEAR-DOWN
7. TRAFFIC PATTERNS & FLOWS
8. PARTITIONING/RE-PARTITIONING
9. ISOLATION/PRIVACY
10. AESTHETICS
11. ILLUMINATION
12. VIBRO/ACOUSTICS(DIFFICULT IN M/U)
13. VENTILATION
14. EMERGENCY ECLSS PANEL ACCESS
15. COMMUNICATION PANEL ACCESS & WARNING
16. MULTI-PURPOSE UTILIZATION FEATURES
17. OTHER

MOCKUP CANDIDATES AND USES

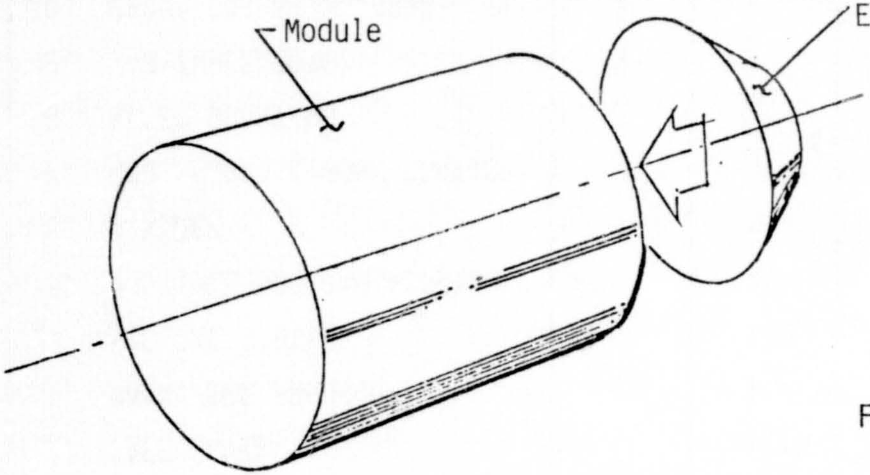
LABORATORIES

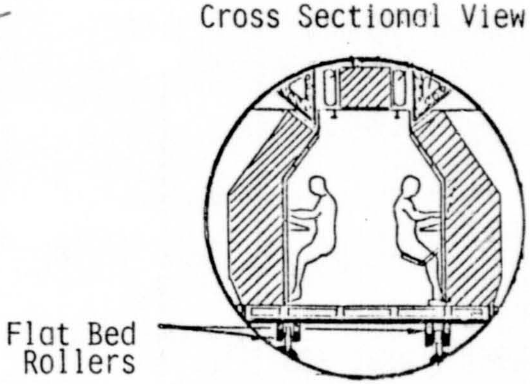
1. ACTIVITY
2. INTERNAL LAYOUT
3. LAMINAR FLOW WORK BENCH (TYP)
4. EXPERIMENTS INTEGRATION
5. EXPERIMENT RACKS INSTALL/LAYOUT
6. CONTAM. PROTECT/MGMT/ISOLATION
7. SAFETY PRECAUTIONS
8. EMERGENCY PROVISIONS
9. EQUIPMENT/SUPPLIES STOWAGE
10. SAMPLE CHANGEOUT FACILITIES
11. EXPERIMENT REPLENISHMENT
12. OBSERVATION PROVISIONS
13. ILLUMINATION LOCATION/INTENSITY
14. WORK STATION LAYOUT/LOCATION
15. CONTROL PANEL LOCATION/LAYOUT
16. BODY POSITION RESTRAINTS
17. TRANSLATION/TRANSFER DEVICES
18. MAINTENANCE ACCESS PROVISIONS
19. COMMUNICATIONS (STD/EMERGENCY)
20. INTERNAL ACCOUTREMENTS
21. EXTERNAL WINDOW ARRANGEMENT
22. RECONFIGURABILITY
23. UTILITIES INTERFACES
24. VIBRO/ACOUSTICS
25. PERTURBATIONS IMPACT
26. OTHER

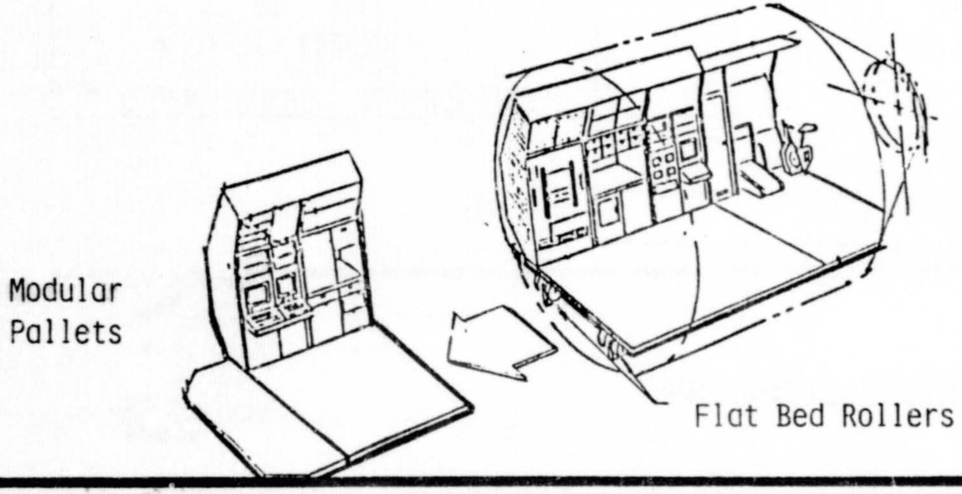
MOCKUP FIDELITY

	MATERIALS				
	SOFT FOAMCOR	FOAMCOR/ WOOD	WOOD OR FIBERGLASS	METAL	COMBINATIONS
1. GEN. PURPOSE MODULE SHELL					
• 9 FT. LENGTH			X	X	
• 18 FT. LENGTH			X	X	
2. SAFE HAVEN		X	X		USE ITEM 1 (REMOVE/REPLACE)
3. MAINT/SER PRESSURE VOL.		X			" " " " "
4. HYGIENE STATION	X	X	X	X	" " " " "
5. MULTIPLE DOCKING ADAPTER		X	X	X	
6. AIRLOCK		X	X		
7. GEN. PURPOSE WORK STATION	X	X			" " " " "
8. SLEEP QUARTERS	X	X			" " " " "
9. HABITABLE ZONES	X	X			" " " " "
10. GROUP GATHERING AREA	X	X			" " " " "
(11) LABORATORIES		X	X	X	UNIQUE

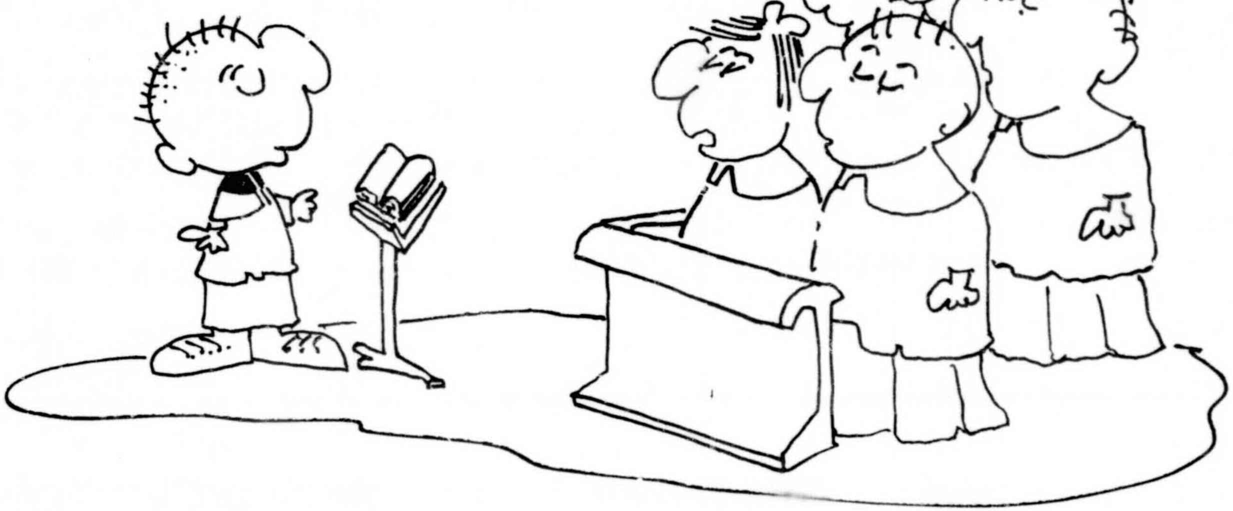
INTERIOR PALLET MODULAR INSERTION/REPLACEMENT







WHAT VALUE MOCKUPS



(PREACHING TO THE CHOIR)

AESTHETIC CONCERNS IN HUMAN PRODUCTIVITY

1. CAN THE EFFECTIVENESS OF THE CREW BE INCREASED BY ENVIRONMENTAL FACTORS SUCH AS:
    - DECOR
    - MATERIALS SELECTION
    - ENVIRON. VARIABILITY
    - COMFORT
    - CLEANLINESS
    - FEELING OF SPATIAL FREEDOM
2. IT IS THOUGHT THAT INTRODUCING ASETHETIC & COMFORT FACTORS INTO THE SPACE STATION ENVIRONMENT MAY RESULT IN:
    - INCREASED EFFICIENCY
    - POSITIVE ATTITUDE MAINTENANCE
    - INCREASED OUTPUT
    - FEWER ERRORS
3. IT IS SUGGESTED THAT THE IMPACT OF THESE FACTORS ON HUMAN PRODUCTIVITY OVER A 90 DAY PERIOD IN A CONFINED ENVIRONMENT (E.G., MOCKUP/SIMULATOR) WARRANTS NEAR-TERM CONCENTRATED NASA STUDY

GENERAL MOCKUP UTILIZATION

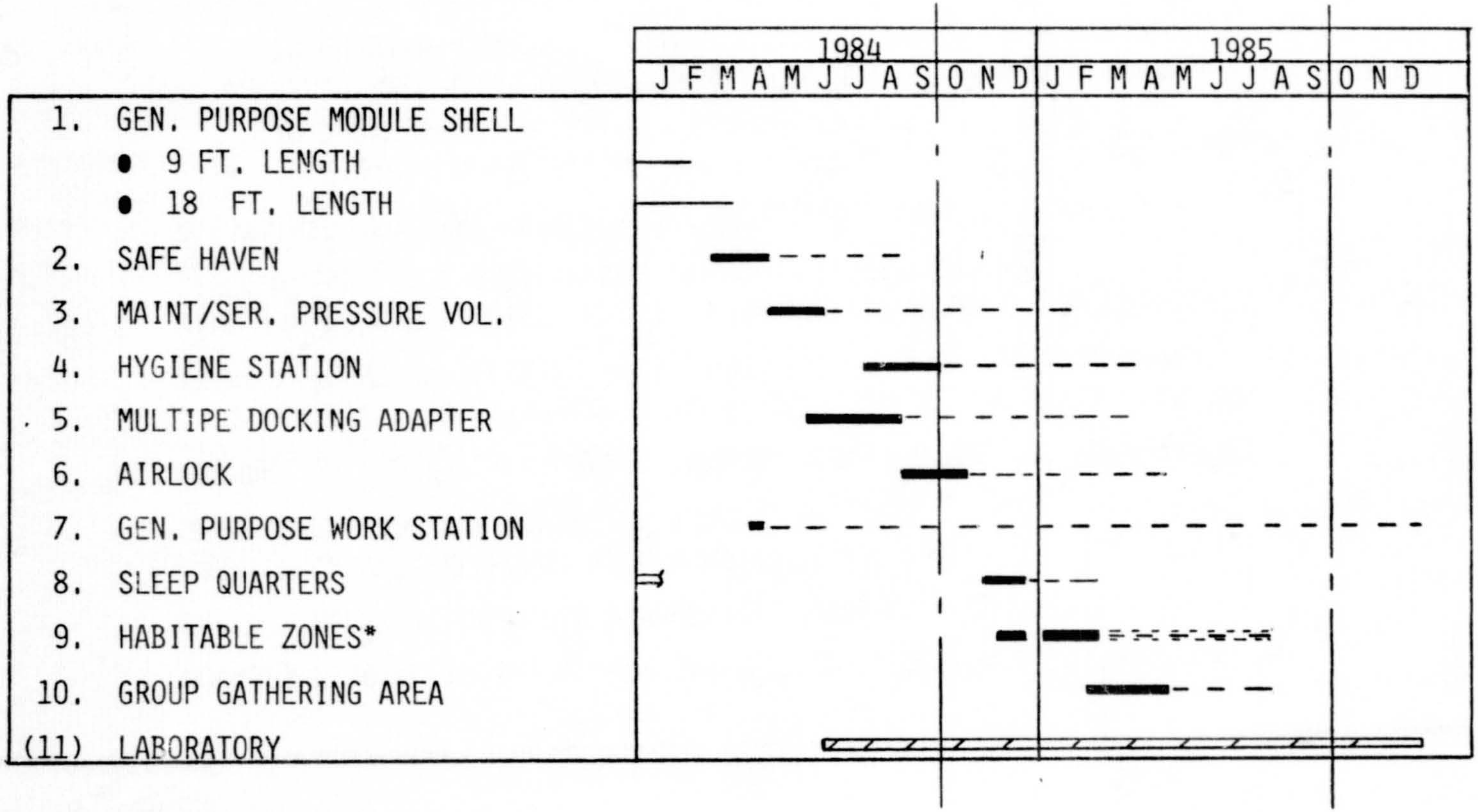
1. MANAGEMENT VISIBILITY IDENTIFICATION
2. 3-DIMENSIONAL "SOLID" REPRESENTATION
3. DESIGN VERIFICATION TOOL
4. CUSTOMER/CONTRACTOR COMM EVAL. TECHNIQUE
5. PUBLIC RELATIONS FACILITY
6. DESIGN ENGINEERING EVALUATION TOOL
7. FORM & FIT ANALYSES
8. ALTERNATE LAYOUT ASSESSMENTS
9. MAINTENANCE ACCESS EVALUATIONS
10. EQUIPMENT ARRANGEMENT STUDIES
11. CABLE RUN PATH ANALYSES
12. CABLE LAY-UP MOCKUP DEVELOPMENT
13. ILLUMINATION FIXTURE LOCATION STUDIES
14. LIGHTING (SPOT/FLOOD) EXAMINATION
15. ANTHROPOMETRIC ASSESSMENTS
16. MAN-MACHINE INTERACTION EVALUATIONS
17. MULTI-ACTIVITY INTERACTION ANALYSES
18. INSTALLATION/REMOVAL TASK STUDIES
19. LOGISTICS ITEM TRANSFER DEMONSTRATIONS
20. RE-CONFIGURE/SHAPING - INTERNAL
21. SUB-COMPARTMENT RE-ARRANGEMENT ANALYSES

GENERAL MOCKUP UTILIZATION (con't)

22. STOWAGE COMPARTMENT LAYOUT STUDIES
23. SUIT DON/DOFF VOLUMETRIC ANALYSES
24. EMERGENCY ITEM ACCESS
25. FUNCTION TIME-LINE ANALYSES
26. EMERGENCY PROCEDURE CONDUCT DEMOS
27. TRANSLATION AID ASSESSMENT
28. COLOR/DECOR EVALUATIONS
29. TRAFFIC FLOW EXAMINATION
30. HATCH SWING & STOWAGE STUDY
31. LAYOUT ORIENTATION EVALUATIONS
32. BODY ORIENTATION ASSESSMENTS
33. CREW ENTRY-EXIT ANALYSES (INTERNAL)
34. WINDOW/VIEW-PORT SIZING/LOCATION
35. FURNISHINGS ARRANGEMENT & LAYOUT
36. WORK STATION INSTALLATION EXAMINATION
37. CONTAM. MGMT. & TECHNIQUE HANDLING STUDY
38. SAFE HAVEN INTEGRATION EVALUATIONS
39. MAXIMUM CREW LOADING VOLUME ANALYSES
40. BODY POSITION/RESTRAINT DEVICE LOCATION
41. CREW FUNCTION SIMULATION
42. OTHER

SPACE STATION PROGRAMS

CANDIDATE DEVELOPMENT SCHEDULE



1. GEN. PURPOSE MODULE SHELL
   - 9 FT. LENGTH
   - 18 FT. LENGTH
2. SAFE HAVEN
3. MAINT/SER. PRESSURE VOL.
4. HYGIENE STATION
5. MULTIPE DOCKING ADAPTER
6. AIRLOCK
7. GEN. PURPOSE WORK STATION
8. SLEEP QUARTERS
9. HABITABLE ZONES*
10. GROUP GATHERING AREA

(11) LABORATORY

* Potential Longer Duration Study

SPACE STATION PROGRAMS

CONCLUSIONS

1. MOCKUPS PIVOTAL TO INVESTIGATION, RESEARCH, DESIGN & INTEGRATION
2. CERTAIN ELEMENTS OF HUMAN PRODUCTIVITY CAN BE ASCERTAINED
3. EARLY MOCKUP DEVELOPMENT WILL SUBSTANTIALLY AID IN STATION REQTS. DEVELOPMENT AND CONFIGURATION EVOLUTION
4. PRIMARY VOLUMETRICS FOR BASIC INTERNAL STATION NOT YET ESTABLISHED
5. IT IS CRITICAL TO ESTABLISH (EARLY) SAID VOLUMETRIC REQTS. FOR THE STATION 'LEST ENGINEERING DOES IT FOR US' AND WE 'LOSE AGAIN'
6. WILL THE MOCKUP STUDIES RESULT IN VOLUMETRIC ALLOCATIONS EXCEEDING THE CURRENT SPACE STATION CDG ESTIMATES/LIMITATIONS ?
7. A COMBINED INDUSTRY MOCKUP STUDY DATA BASE CAN'T BE IGNORED
    - 'OLE B.C.' MIGHT BECOME THE I/F BATTLE GROUND TO BRING THIS TO THE FORE
    - REASONABLE COOPERATION/INTERACTION BY THE COMBINED STATION INTERESTED AEROSPACE COMMUNITY COULD RESULT IN A STRONG POSITION
8. INDUSTRY DEVELOPED MOCKUPS USUALLY HAVE A DEGREE OF PROPRIETARY FEATURES WHICH MAKES OPEN SHARING DIFFICULT
9. NASA MOCKUP DEVELOPMENT & USE WILL PERMIT CERTAIN LONG-TERM INVESTIGATIONS TO BE UNDERTAKEN WHICH ARE VERY IMPORTANT TO THE PROGRAM

EXPERIENCES
WITH
NEUTRAL BUOYANCY TESTING
MOCKUPS

PRESENTED TO:
SPACE STATION
HUMAN PRODUCTIVITY
WORKING GROUP

MARCH 2, 1984

PRESENTED BY:
BOB DELLACAMERA
(714) 896-5224

NASA QUESTION:

CAN AN EVA CREWMAN REMOVE AND REPLACE ELECTRICAL CONNECTORS ON TIMING UNIT?

NB-51

SPACE PLATFORM CONTINGENCY OPERATIONS

QUICK LOOK TEST REPORT #1 DATE: AUGUST, 1982

NEUTRAL BUOYANCY SIMULATION

SPACE PLATFORM CONTINGENCY OPERATIONS

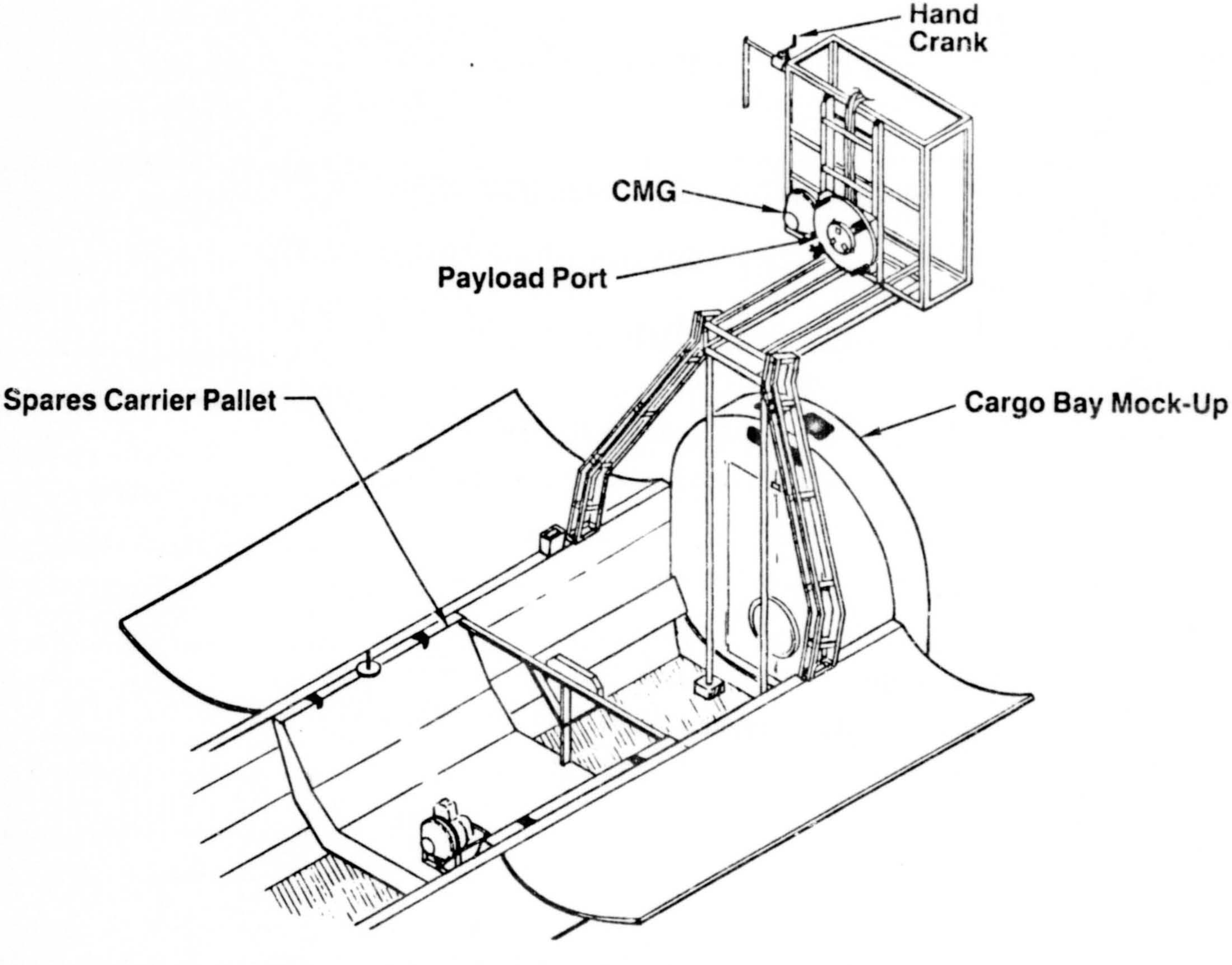
TASK 1. AFT PAYLOAD PORT DEPLOYMENT/RETRACTION

TASK 2. CONTROL MOMENT GYRO(CMG) REMOVAL/REPLACEMENT

TASK 3. MANUAL HAND CRANK APPENDAGE DEPLOYMENT

SPACE PLATFORM NEUTRAL BUOYANCY MOCK-UP

VFW323



NB-51

SPACE MAINTENANCE AND CONTINGENCY OPERATIONS SIMULATION

QUICK LOOK TEST REPORT #2 DATE: NOVEMBER 1982

NEUTRAL BUOYANCY SIMULATION

SPACE MAINTENANCE AND CONTINGENCY OPERATIONS SIMULATION

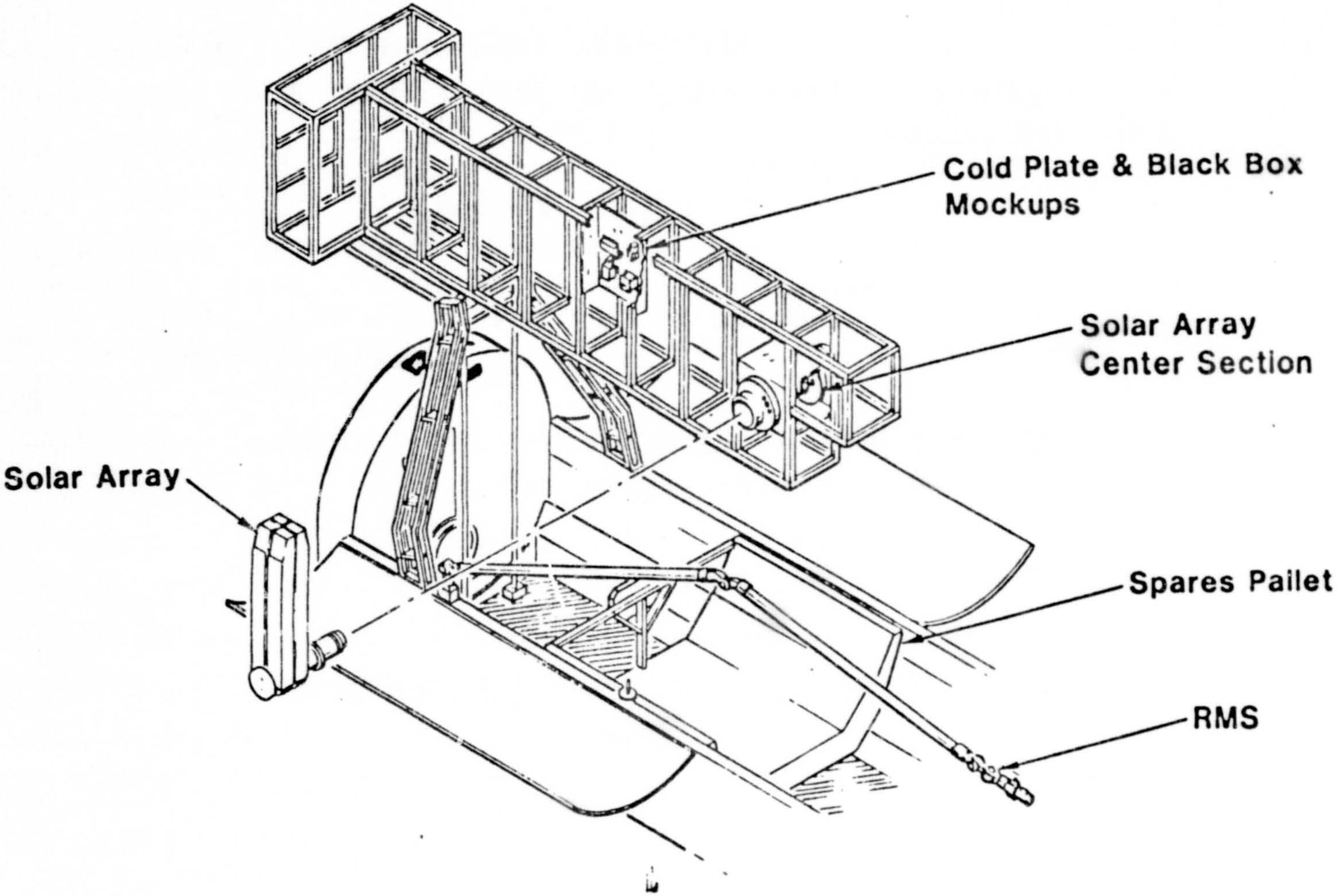
TASK 1. SOLAR ARRAY WING EXCHANGE

TASK 2. COLD PLATE MOUNTED BLACK BOX EXCHANGE
- ADJUSTABLE FOOT RESTRAINT EVALUATION
- BATTERY INSTALLATION
- FLUID DISCONNECT MATE/DEMATE
- OVERCENTER LATCH/BLIND MATING ELECTRICAL CONNECTOR
- D-SERIES (RECTANGULAR), ELECTRICAL CONNECTOR DEMATE/MATE
- CIRCULAR CONNECTOR (STANDARD AND COAX) DEMATE/MATE

TASK 3. SOLAR ARRAY BLANKET BOX EXCHANGE

VFX925

SPACE PLATFORM NEUTRAL BUOYANCY MOCK-UP



NB-51

SPACE MAINTENANCE AND SERVICING SIMULATIONS

QUICK LOOK TEST REPORT #3 DATE: SEPTEMBER 1983

TASK ACTIVITIES:

TASK 1. MANUAL HAND CRANK APPENDAGE DEPLOYMENT

TASK 2. COLD PLATE MOUNTED ORU EXCHANGE
- SINGLE FOOT ADJUSTABLE FOOT RESTRAINT EVALUATION
- SMALL BOX (50 LB) OVER CENTER LATCH FASTENING CONCEPT
- MEDIUM BOX (150 LB) COARSE THREAD CAPTIVE FASTENERS
- LARGE BOX (250 LB) FINE THREAD CAPTIVE FASTENERS

TASK 3. CONNECTOR TOOLS/ADJUSTABLE FOOT RESTRAINT EVALUATIONS

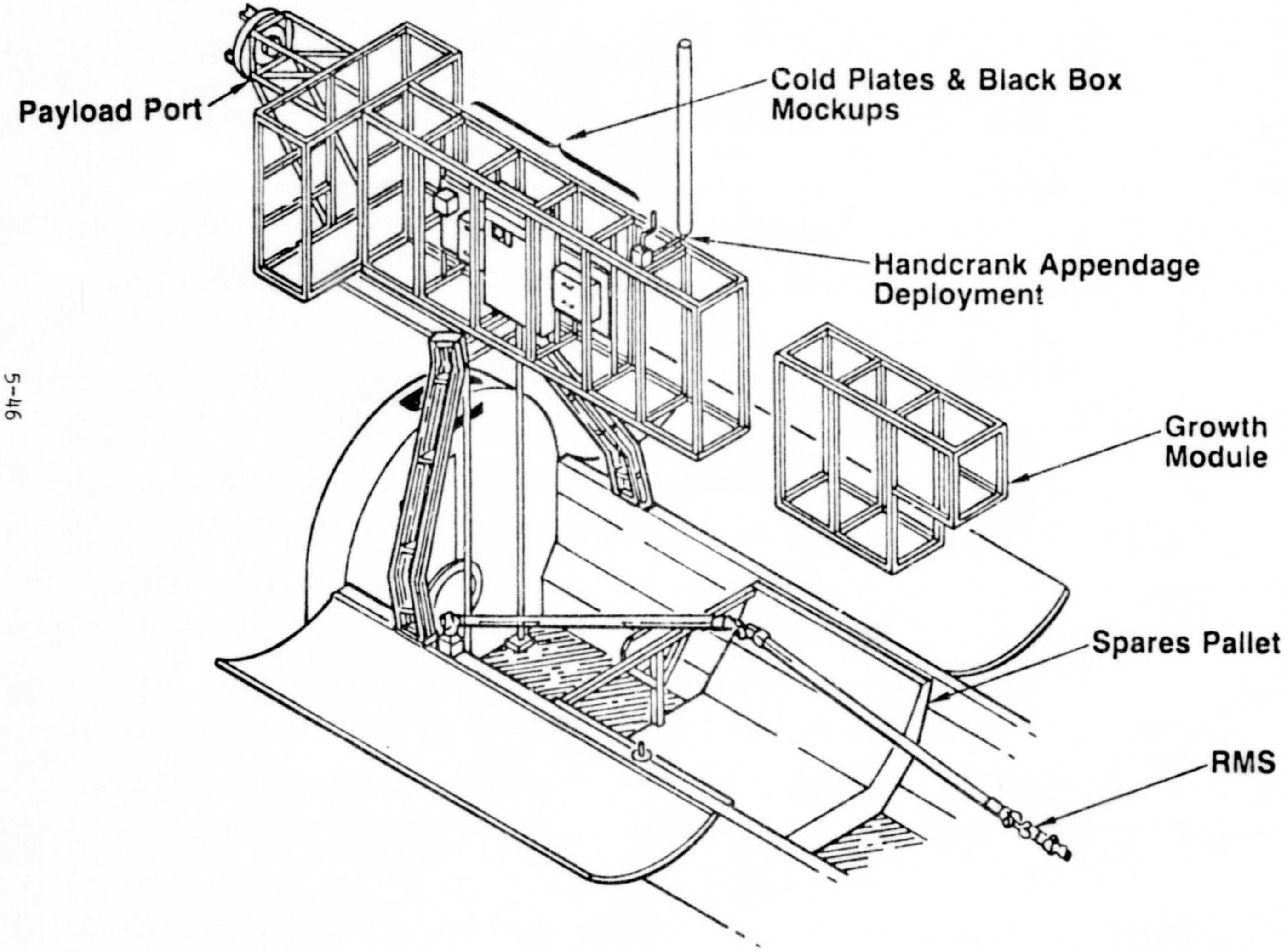
TASK 4. CONTINGENCY OPERATIONS
- MANUAL APPENDAGE JETTISON
- FLUID TRANSFER SIMULATION

TASK 5. STRUCTURAL MODIFICATION - PAYLOAD PORT STRENGTHENING

TASK 6. SATELLITE GROWTH ACTIVITY

VEB969

SPACE PLATFORM NEUTRAL BUOYANCY MOCK-UP
SEPTEMBER TEST SERIES



SUMMARY OF NEUTRAL BUOYANCY TESTING

- SIGNIFICANT RESULTS
  - DEMONSTRATED EVA CREWMAN FINE MOTOR ACTIVITIES ARE ACHIEVABLE WHEN SIMPLE AIDS WHICH ENHANCE PERFORMANCE CAPABILITIES ARE PROVIDED.
  - DISCOVERED THAT CERTAIN TASKS WERE ACCOMPLISHED WITH LESS EFFORT WHEN THE EVA CREWMAN WAS AFFORDED ADDITIONAL MOBILITY BY RESTRAINTS OTHER THAN FIXED FOOT RESTRAINT PLATFORMS.
  - ILLUSTRATED MANUAL TRANSLATION OF LARGE MASS ITEMS IS FEASIBLE, BUT MECHANICAL AIDS SHOULD BE PROVIDED TO ASSIST EVA TRANSLATIONAL OPERATIONS.
  - DURING THE INSTALLATION PROCESS OF REPLACEABLE UNITS, APPLICATION OF ALIGNMENT INDICATORS (I.E., PINS, PLACARDS, GUIDES, ETC.) PROVIDES SIGNIFICANT ASSISTANCE TO THE EVA CREWMAN. THIS IS ESPECIALLY EVIDENT AS MASS AND SIZE INCREASE.

ROCKWELL EXPERIENCE
APPLICATIONS TO AMES SPACE STATION MOCKUP HABITABILITY/PRODUCTIVITY STUDIES

PRESENTATION TO NASA
AMES RESEARCH CENTER
MOFFET FIELD, CALIFORNIA

MARCH 2, 1984

J. A. ROEBUCK
CREW/HABITATION GROUP
SYSTEMS ENGINEERING
SPACE STATION PROGRAM

PURPOSE OF BRIEFING

- ASSIST NASA/AMES RESEARCH CENTER WITH PLANNING FOR SPACE STATION MOCKUP STUDIES
- REVIEW MOCKUP LESSONS FROM ROCKWELL SPACECRAFT STUDIES
  - APOLLO-LEM THROUGH SPACE SHUTTLE
  - EARLY SPACE STATION
- ILLUSTRATE TYPICAL AND UNIQUE MOCKUP TECHNOLOGY APPLICATIONS

POTENTIAL USES FOR SPACE STATION MOCKUPS

- VERIFY REQUIREMENTS DURING DESIGN

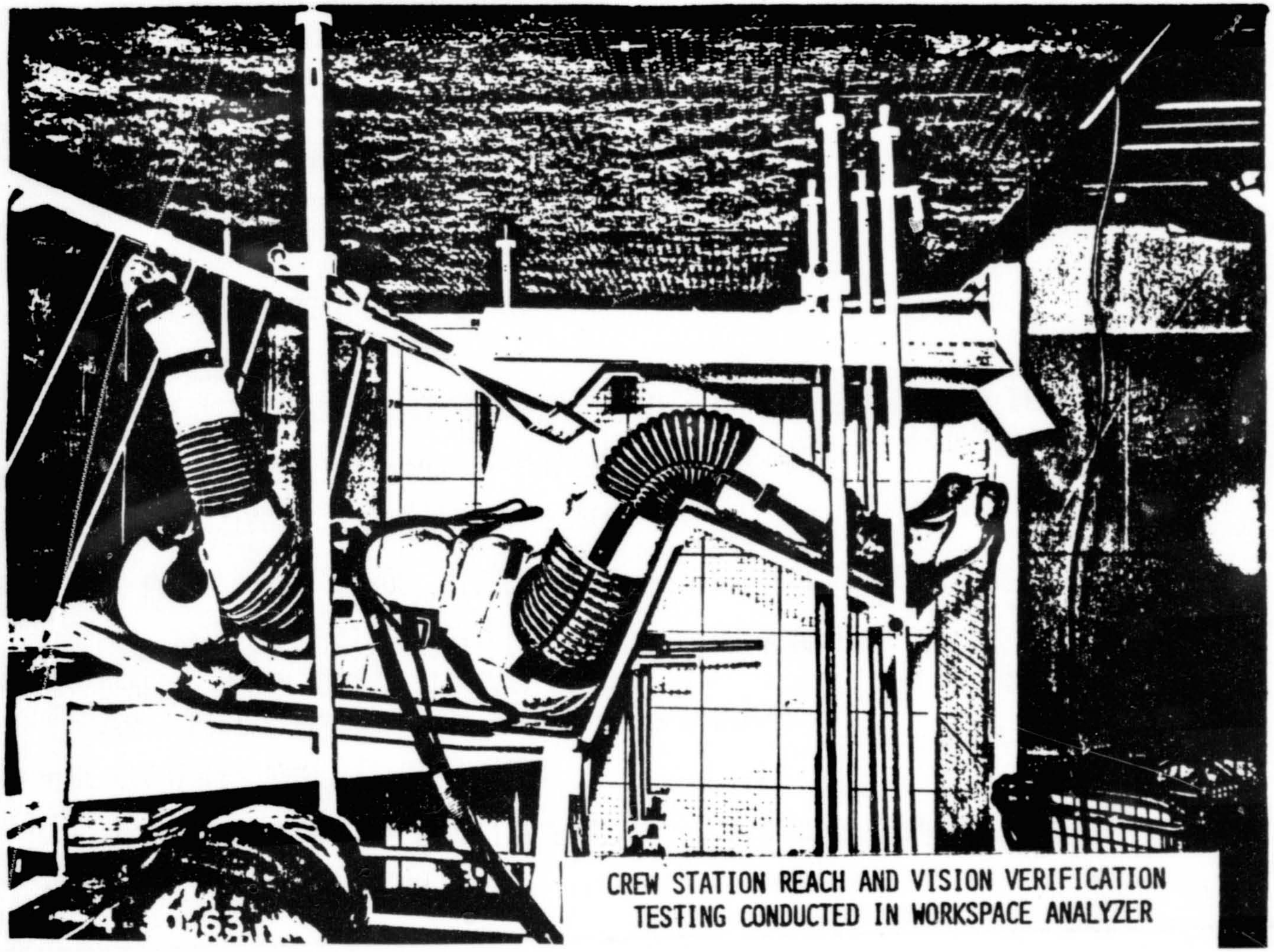
—OR—

- DEVELOP NEW REQUIREMENTS (BEFORE IMMERSION AND PARABOLIC FLIGHTS)

	AGENCY	
AREAS OF CONCERN	CONTRACTOR	NASA/AMES
□ CONTROL/DISPLAY LAYOUTS, FORMATS	•	●
□ WORK STATION DESIGN—REACH, CLEARANCE, FORCE	•	•
□ ADEQUATE LIGHTING, MARKINGS, COLOR	•	●
□ REFINE REACH, VISION, CLEARANCE MODELS FOR DRAWINGS/ COMPUTER ANALYSIS	•	•
□ INGRESS/EGRESS PATHWAYS, AIDS	•	●
□ HABITABILITY/PRODUCTIVITY STUDIES (LONG TERM)	•	●
□ MAINTENANCE AND PARTS EXCHANGE	•	•
□ INTERFERENCES—CORRECTIONS	•	•
□ NEW DETAILS, COMPLEX SHAPE DEVELOPMENTS	•	•
□ WIRING AND DUCTING ROUTINGS DEVELOPMENT	•	•
□ EMERGENCY OPERATIONS (IVA & EVA)	•	•
■ PUBLIC AWARENESS SUPPORT—DOCUMENTARY FILMS, VIDEO TAPES, TV INTERVIEWS & NEWS	•	●

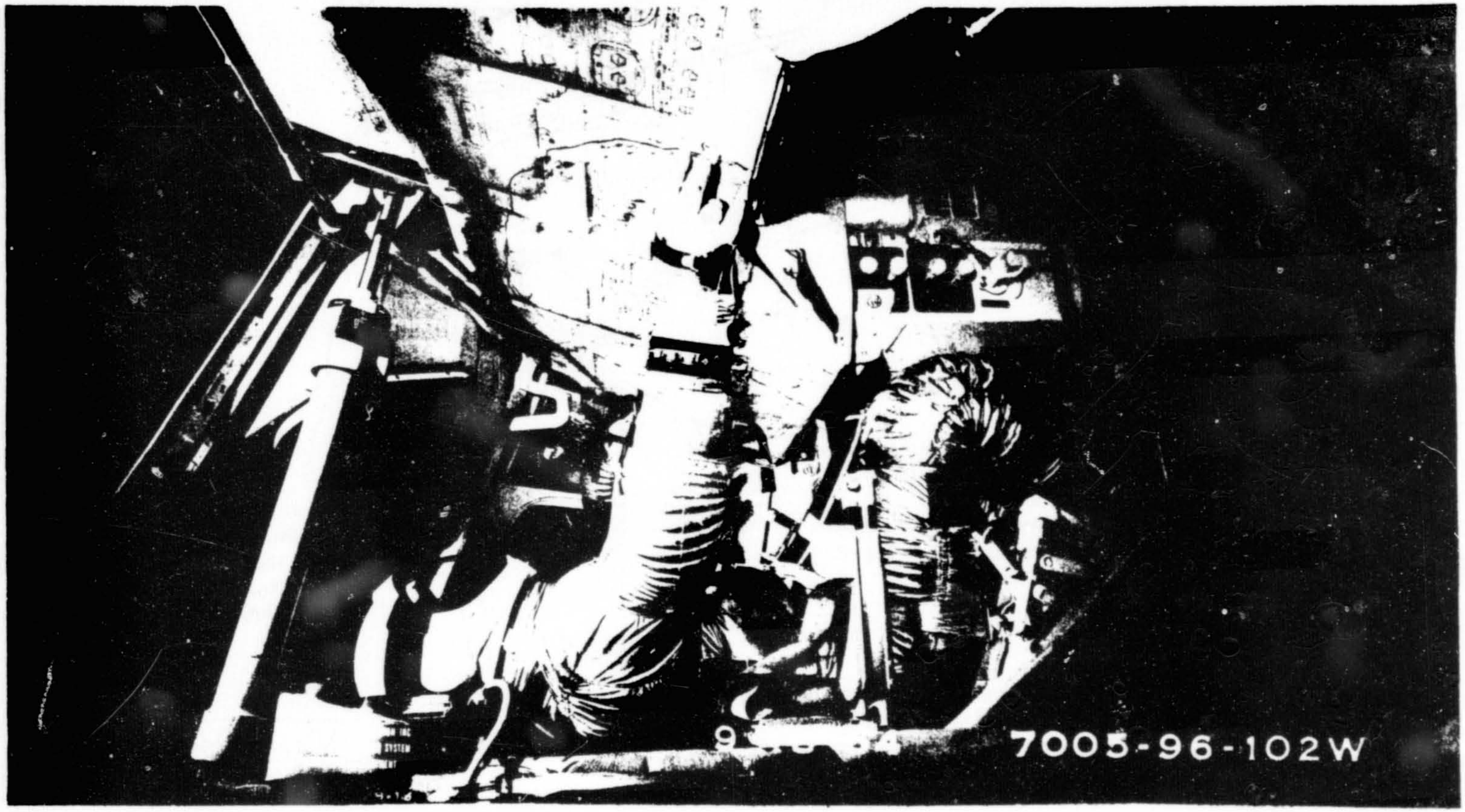
RECOMMENDATIONS—GENERAL

- DON'T GET FANCY TOO SOON
  - GROSS WORKSPACE, LOW FIDELITY FIRST
  - BUILD UP GRADUALLY, CAREFULLY
- BE FLEXIBLE, VARY KEY DIMENSIONS
  - DON'T SETTLE FOR ONE EASY ANSWER—SEEK MINIMUMS
  - DEVELOP A FEW PARAMETRIC DATA POINTS
  - PROVIDE TILT & ROLL CAPABILITY (ZERO-G SIMULATION)
- SEEK LARGE RANGE OF BODY SIZES & SKILLS IN SUBJECT SELECTION
- MEASURE DISTANCE, TIME, ANGLES, FORCES
  - THINK ABOUT DESIGNER NEEDS—CAN SHAPES BE DRAWN?
- EVALUATE VISIBILITY & LIGHTING—CAN INFORMATION BE READ, PARTS BE DISTINGUISHED? PROVIDE NUMBERS
- EXERCISE THE SPACE; CHECK FOR
  - SAFETY—PROJECTIONS, HAZARDS
  - PRODUCTIVITY—CONVENIENCE, VOLUME, REACH, TIME
  - HABITABILITY—HOW LONG CAN YOU LIVE IN IT?
    - ON-DUTY TIME
    - OFF-DUTY TIME



CREW STATION REACH AND VISION VERIFICATION TESTING CONDUCTED IN WORKSPACE ANALYZER

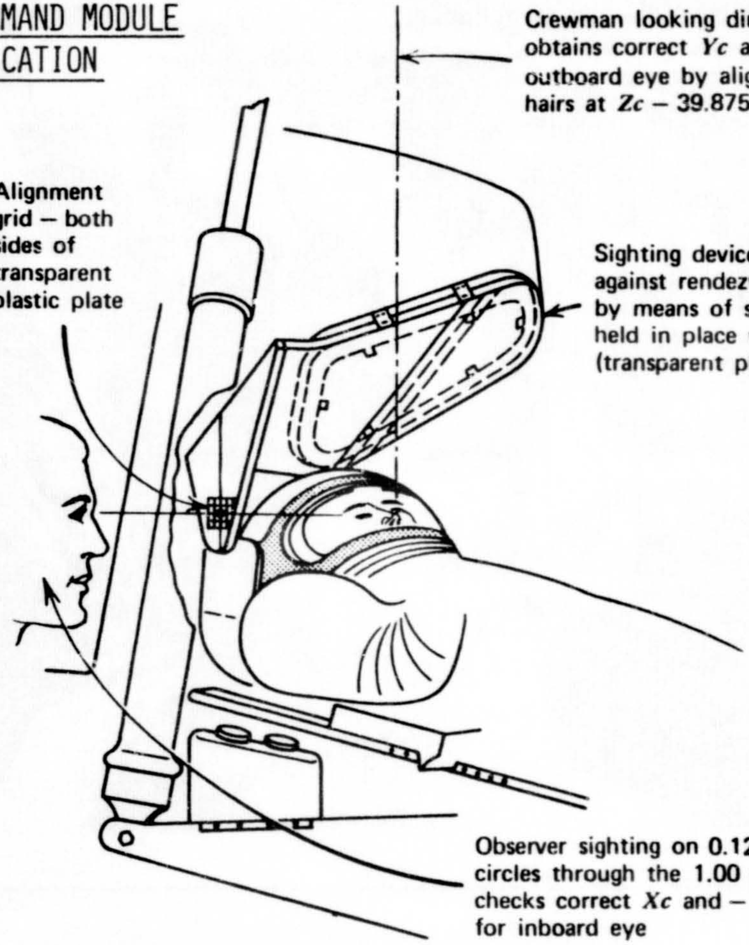
REACH ENVELOPE MEASUREMENTS AND CLEARANCE EVALUATIONS



APOLLO COMMAND MODULE MOCKUP EXAMPLE

PARALLEL PLANE GRIDS ON TRANSPARENCY FOR EYE POSITION MEASUREMENTS

APOLLO COMMAND MODULE APPLICATION



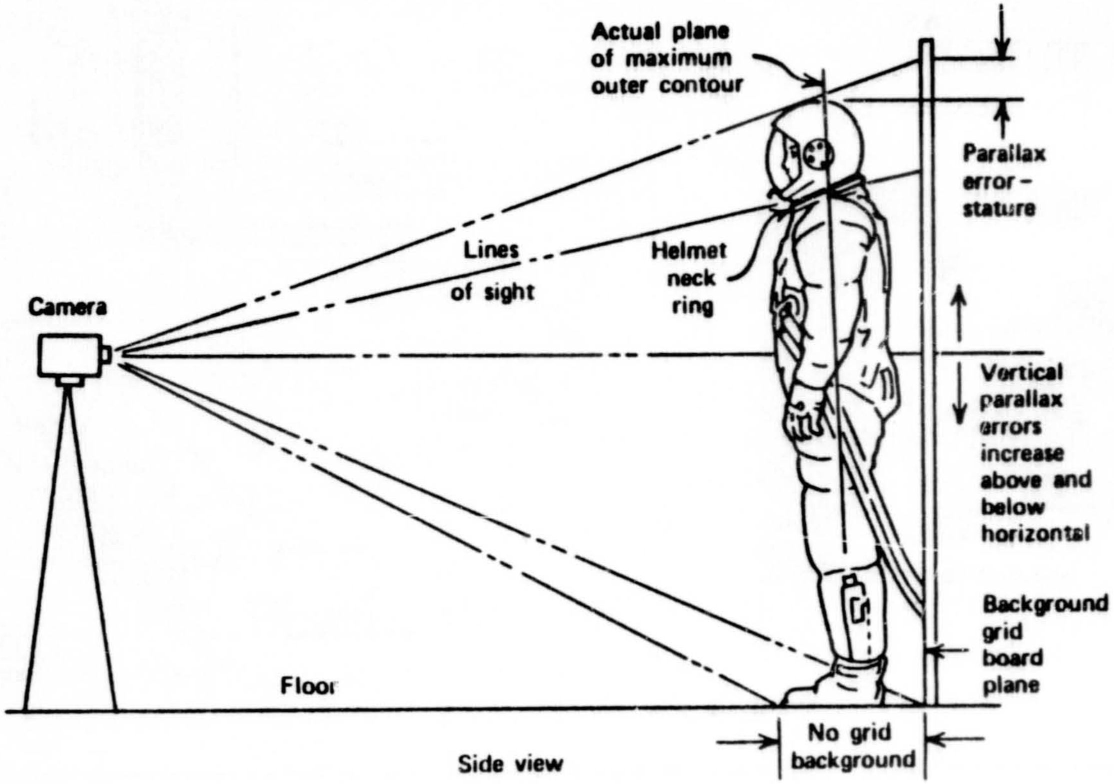
Crewman looking directly forward (+Xc) obtains correct Yc and Zc location of outboard eye by alignment of cross hairs at Zc – 39.875 and Yc – 25.75

Alignment grid – both sides of transparent plastic plate

Sighting device correctly positioned against rendezvous window retainer by means of small square pads, and held in place with screw clamps (transparent plastic material)

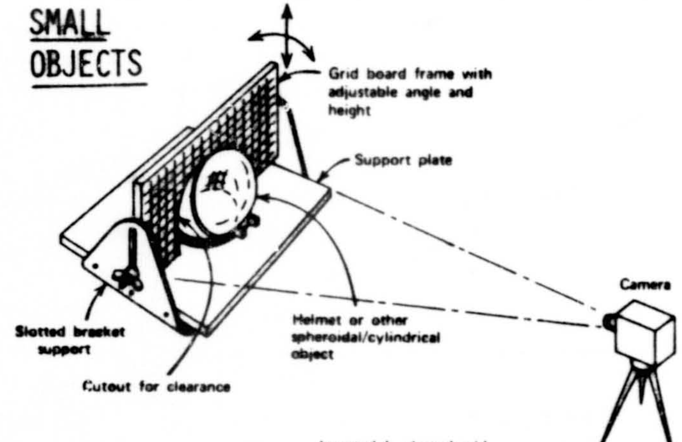
Observer sighting on 0.12 diameter circles through the 1.00 sq. grid, checks correct Xc and – Zc position for inboard eye

BACKGROUND GRID PARALLAX ERRORS

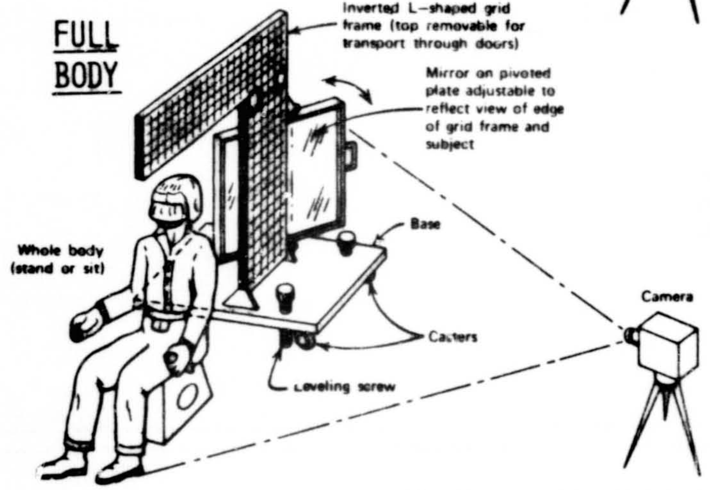


LOW-PARALLAX GRID FRAME SYSTEM

SMALL OBJECTS



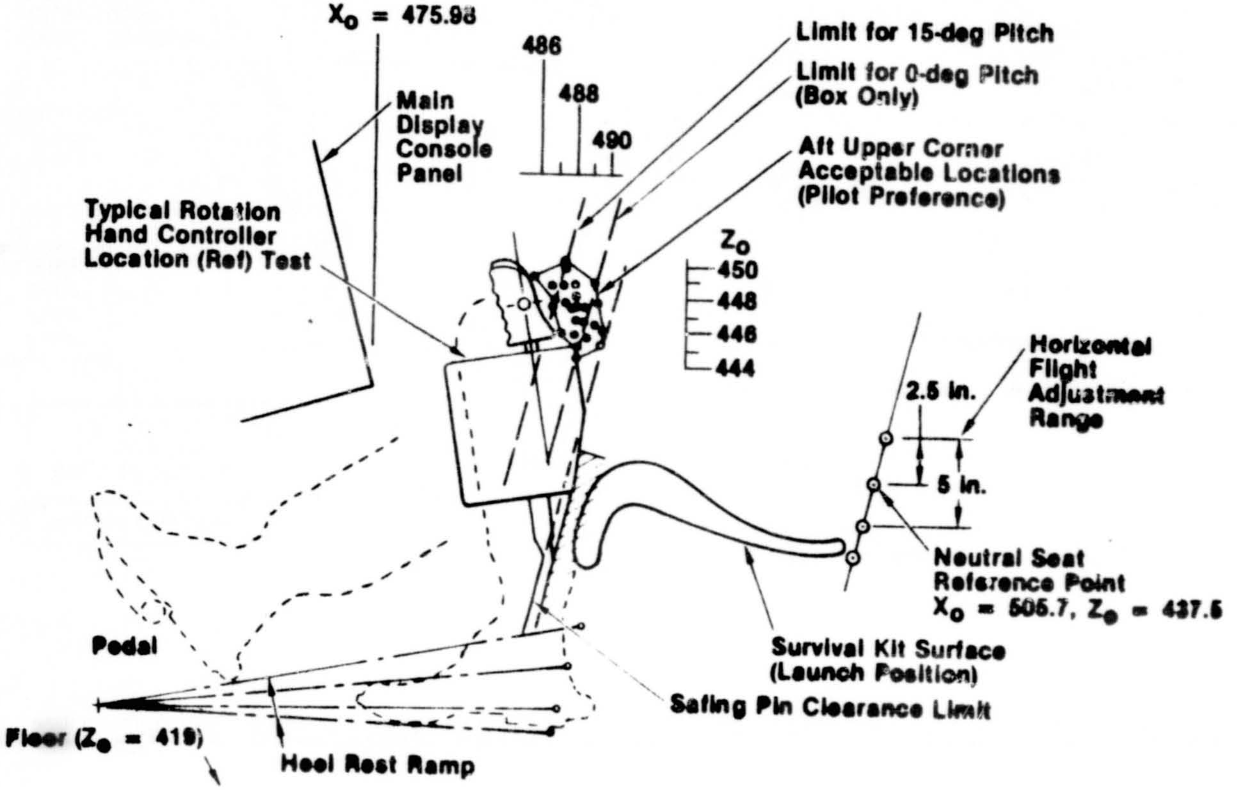
FULL BODY



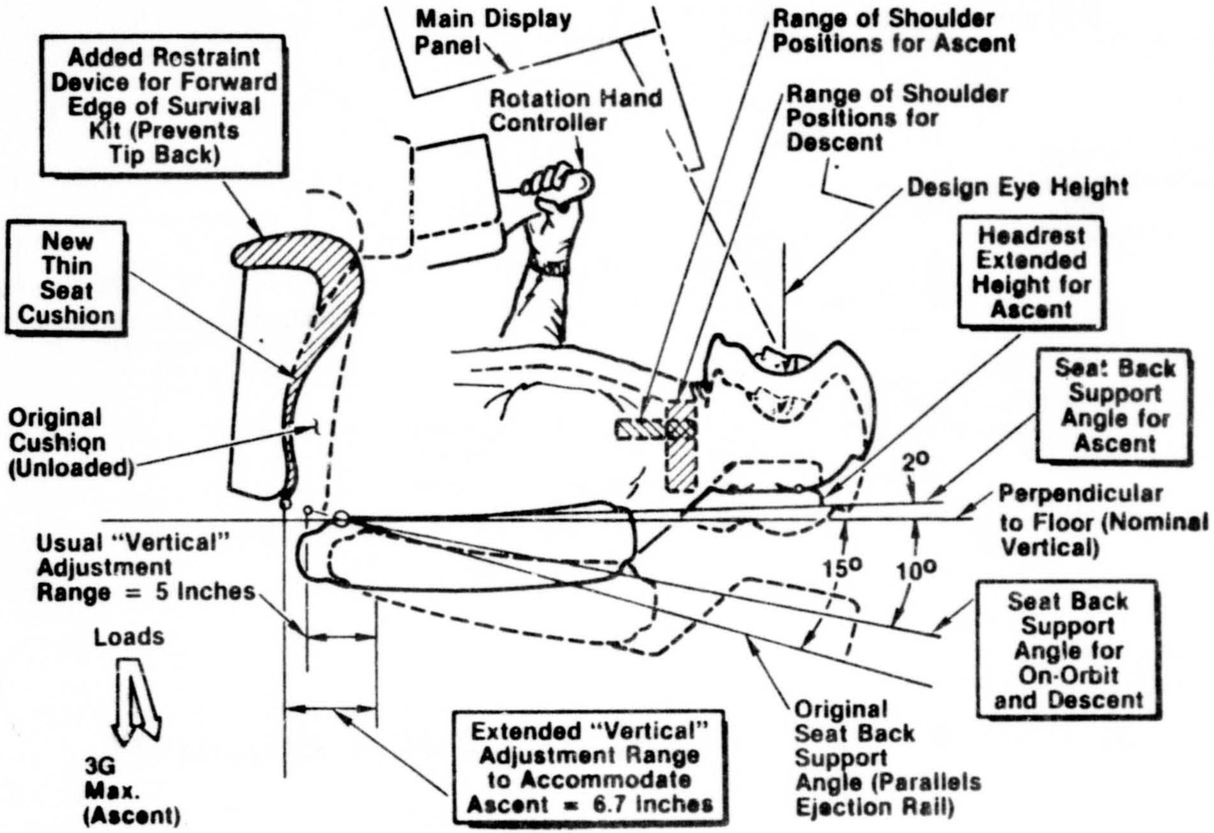
APPLICATION TO MOCKUP EVALUATION

- GRID ON FOME-COR
- MOUNTED WITH TAPE
- IN PLANES OF MAX. DIAMETERS

Rotation Hand Controller Adjustment Range



Ejection Seat Modifications for Shuttle Ascent Mode



Added Restraint Device for Forward Edge of Survival Kit (Prevents Tip Back)

New Thin Seat Cushion

Original Cushion (Unloaded)

Usual "Vertical" Adjustment Range = 5 Inches

Loads

3G Max. (Ascent)

Main Display Panel

Rotation Hand Controller

Range of Shoulder Positions for Ascent

Range of Shoulder Positions for Descent

Design Eye Height

Headrest Extended Height for Ascent

Seat Back Support Angle for Ascent

2°

Perpendicular to Floor (Nominal Vertical)

15°

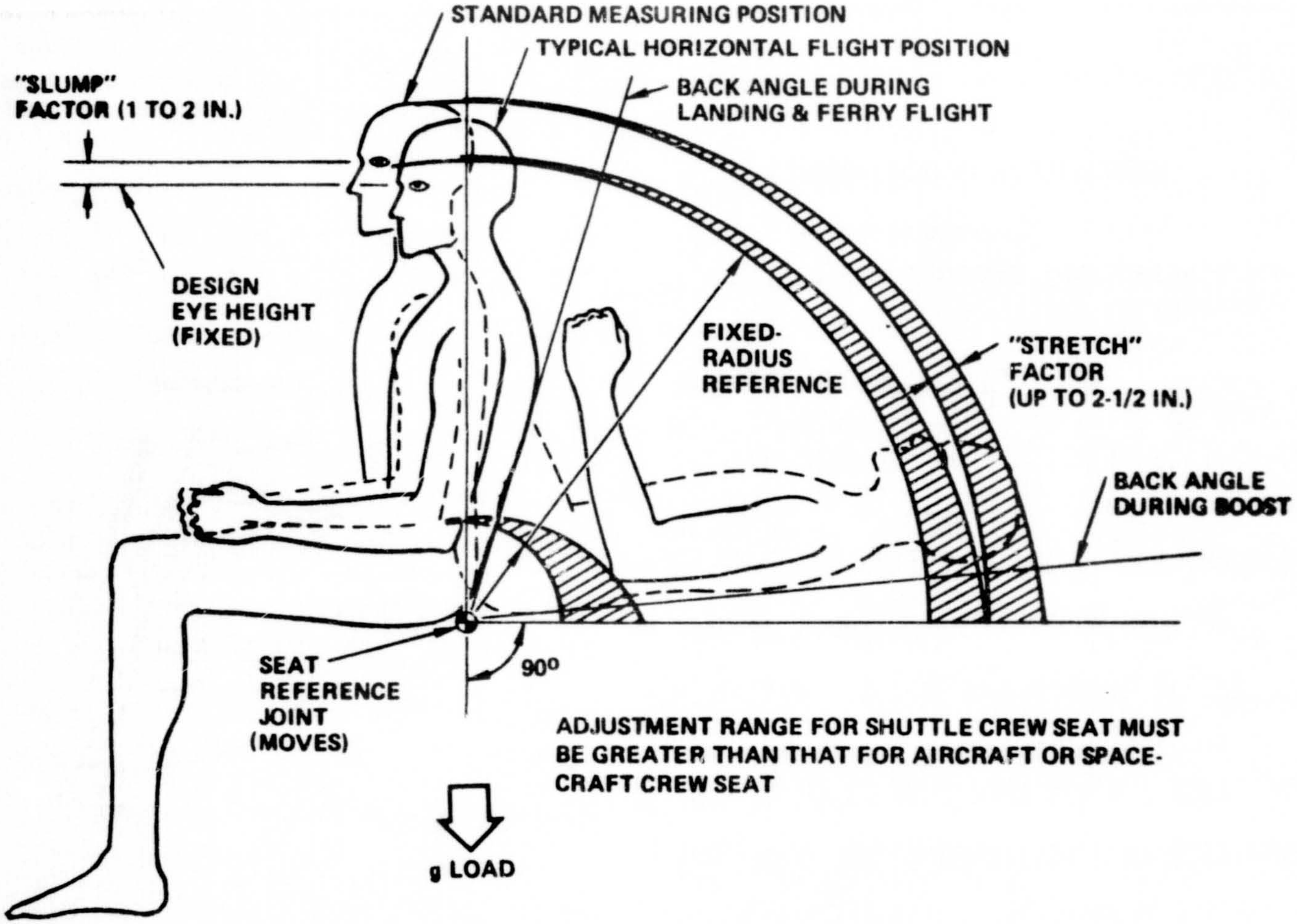
10°

Seat Back Support Angle for On-Orbit and Descent

Original Seat Back Support Angle (Parallels Ejection Rail)

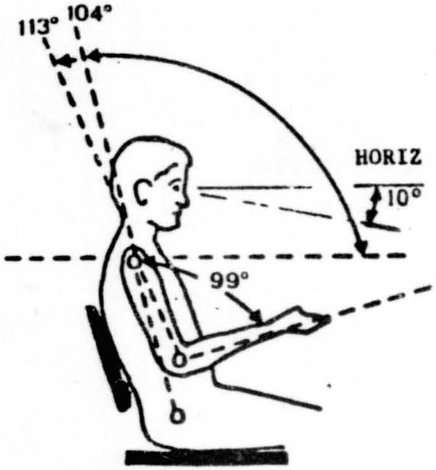
Extended "Vertical" Adjustment Range to Accommodate Ascent = 6.7 Inches

TRUNK LENGTH AND EYE-TO-SEAT CHANGES WITH BODY ATTITUDE



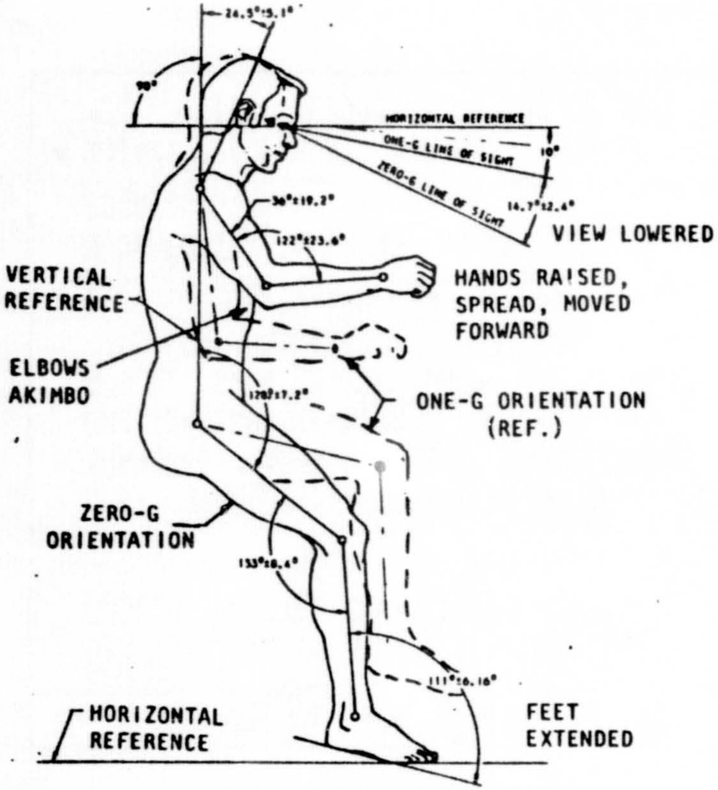
ADJUSTMENT RANGE FOR SHUTTLE CREW SEAT MUST BE GREATER THAN THAT FOR AIRCRAFT OR SPACECRAFT CREW SEAT

TYPICAL VDT WORKSTATION "MEAN BODY POSTURE" IN EARTH NORMAL ENVIRONMENT



- SEAT/BACK ANGLES CONDITIONED BY BODY LOADS
- GRAVITY HOLDS ARMS DOWN AGAINST BODY, HANDS LOW - APPROXIMATELY TABLE HEIGHT
- HEAD NEAR VERTICAL FOR MINIMAL EFFORT
- LINE OF SIGHT SLIGHTLY BELOW HORIZON
- NATURAL SEPARATION OF CRT SCREEN AND KEYBOARD OR OTHER CONTROLS
- OPTIMAL WORK STATIONS NOT YET PROVIDED IN MOST INDUSTRY SETTINGS IN SPITE OF MANY STUDIES. FOR EXAMPLE:
    - TYPEWRITER KEYBOARD RECTANGULAR LAYOUT STANDARD (NOT OPTIMUM FOR WRIST ACTION)
    - INSUFFICIENT ADJUSTMENTS

WEIGHTLESSNESS IMPACT ON VDT WORKSTATION DESIGN REQUIREMENTS



MESSAGE: RESEARCH NEEDED TO DEFINE LONG-TERM HUMAN-COMPUTER INTERFACES IN SPACE

- NEW PREFERRED ARM ANGLES
- NEW PREFERRED SHOULDER ANGLES
- NEW LINE OF SIGHT REFERENCE
- NEW LEG CLEARANCE REQUIREMENTS
- NEW RESTRAINTS TO BE DETERMINED
  - RESIST PUSH-OFF FORCES ON KEYS
  - NEW CONSTRAINTS ON REACH ENVELOPE
- PROBABLE REORIENTATION OF KEYBOARDS
- POTENTIAL CRT-KEYBOARD INTERFERENCE
- POSSIBLE NEED FOR FINGER GRIPS/GUIDES
- POSSIBLE LIGHTER LOADS ON KEYS/TOUCH SENSORS
  - LIGHT-PEN OPTION

MOCKUP TILT & ROLL BENEFITS EVALUATION

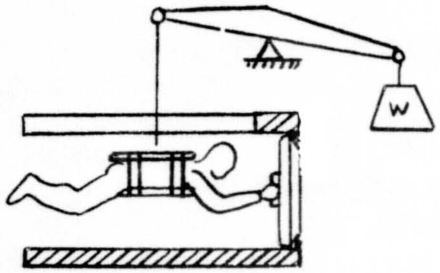
★ ROCKWELL EXPERIENCE HAS VERIFIED VALUE OF 1-G MOCKUP ORIENTATION OPTIONS:

ORIENTATION & PROGRAM APPLICATIONS	BENEFIT
• SIMULATE LAUNCH ATTITUDE (NOSE UPWARD)—APOLLO, SHUTTLE CREW COMPARTMENT	• BODY STRETCH:HEAD, HAND & EYE POSITION ACCURACY • INGRESS/EGRESS SIMULATING UNUSUAL POSITION
• HORIZONTAL ATTITUDE SIMULATION OF TUNNEL TRANSFER, PARTS HANDLING, POST-LANDING ORBITER EGRESS—NORMAL AND EMERGENCY—APOLLO, SHUTTLE CREW COMPARTMENT, ASTP TRANSFER TUNNEL	• EASE OF HORIZONTAL MOVEMENT, MINIMIZE CONTACTS WITH FLOOR & SIDES (ZERO-G SIM.) • CORRECT ATTITUDE FOR ORBITER EGRESS, RETURN FLIGHT
• 360° IN SAGITTAL PLANE—SIMULATION OF BODY MOTION IN STRAPS ON APOLLO COUCH—ROTATION TABLE	• FIRST APPROXIMATION OF HEAD AND KNEE MOTION (ONE-G)
• ROTARY SPACE STATION SIMULATION—MOCKUP LIVING QUARTERS ON END OF ARM	• EVALUATE CORIOLIS EFFECTS • EVALUATE VARIABLE G-FIELD EFFECTS

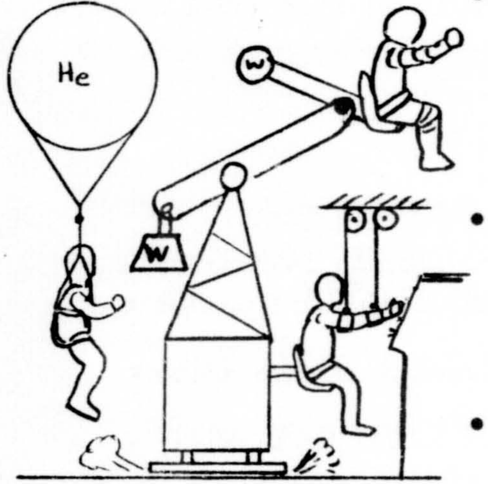
ZERO-G SIMULATION BODY SUPPORTS

- BODY SUPPORTS REQUIRED TO EXPLOIT DIFFERING MOCKUP ORIENTATIONS:

TYPICAL SYSTEMS



- CABLE SUPPORT WITH BODY SANDWICH PANELS, COUNTER WEIGHTS
  - APOLLO TUNNEL TRANSFER: HATCH PROBE & DROGUE REMOVAL
  - EVA AND IVA SIMULATION



- HELIUM BALLOON AND PARACHUTE HARNESS
  - EVA SIMULATION
- NEGATOR SPRINGS, CABLES AND CUFFS ON ARMS
  - IVA SIMULATION OF WEIGHTLESSNESS
- AIR-BEARING SUPPORT FLOORS, COUNTER-BALANCED CHAIRS

SUMMARY

- RECOMMENDED USAGES FOR AMES RESEARCH OFFERED
- BRIEF SAMPLE OF SPECIAL MOCKUP USAGE TECHNIQUES PRESENTED
- MOCKUP TECHNOLOGY INVOLVING HUMAN INTERFACES HAS IMPROVED DURING 20 YEARS OF SPACECRAFT EXPERIENCE—NOW AVAILABLE FOR SPACE STATION
    - ✓ APOLLO-LEM
    - ✓ LUNAR FLYER
    - ✓ EARLY SPACE STATION
    - ✓ SHUTTLE
    - ✓ APOLLO-SOYUZ TEST PROGRAM

  } SPACE STATION SYSTEMS

- KEY CONCERNS IN MOCKUP EVALUATIONS
    - ○ COST-EFFECTIVE LEVELS OF FIDELITY
    - ○ VARIABLE VOLUME & SHAPE CAPABILITY
    - ○ MEASUREMENTS WHICH CAN BE USED FOR GRAPHIC ANALYSIS
        - ✓ LAYOUT DRAWINGS
        - ✓ COMPUTER MODELING
        - ✓ TIME DATA
    - ○ ACCURATE, COST-EFFECTIVE MEASUREMENT METHODS AND SUBJECT SELECTION
        - ✓ PHOTOS—GRIDS
        - ✓ HAND MEASURES
        - ✓ VISUAL ALIGNMENT AIDS
        - ✓ DEFINE SUBJECT'S BODY DIMENSIONS & MOBILITY

Space Station

The Role of Mock-Ups in the Development of Orbital Replaceable Units (ORU)

Human Productivity Working Group
Ames Research Center – NASA
March 2, 1984

Gary A. Johnson
Crew Systems

Large Modular Orbital Replaceable Unit (ORU)

ORBITAL REPLACEABLE UNIT - ORU

- AN ORU IS ANY UNIT SPECIFICALLY DESIGNED FOR REPLACEMENT WHILE IN ORBIT
- TYPES:
  - COMPONENT (E.G., SOLAR ARRAYS, CMGS, INDIVIDUAL ELECTRONIC BOXES, ANTENNAS)
  - MODULAR - A COLLECTION OF RELATED UNITS IN SINGLE PACKAGE FOR TO OPTIMIZE MAINTAINABILITY (E.G., BATTERIES, THERMAL CONTROL PUMP PACKAGE, SELECTED GROUPS OF ELECTRONIC BLACK BOXES) - MAY HAVE INTEGRAL COLDPLATE
- NUMBER AND RATIO OF TYPES IS A FUNCTION OF THE PARTICULAR SPACECRAFT (I.E., SPACE STATION, SPACE PLATFORM, LEO FREE FLYER, GEO FREE FLYER)

3

LARGE MODULAR ORU APPLICABILITY

- MAINTENANCE
- GROWTH
- UPGRADING
- ASSEMBLY

LARGE ORU REPLACEMENT TESTS

PURPOSE:

TO DEVELOP AND VALIDATE HARDWARE DESIGN AND OPERATIONS FOR ON-ORBIT REPLACEMENT OF LARGE MODULAR ORU'S. THESE TESTS WILL PROVIDE GENERIC DATA FOR ANY SPACECRAFT IN WHICH LARGE ORU'S ARE AN OPTION, SUCH AS SPACE STATIONS AND SPACE PLATFORMS

TEST METHODS:

- O 1-G TESTS - SHIRTSLEEVE SUBJECTS WITH SIMPLE PENDULUM AND COUNTERBALANCE SUSPENSION - NO RMS (AT TRW)
- O NEUTRAL BUOYANCY TESTS - PRESSURE-SUITED SUBJECTS WITH PARTIAL SP FRAME, RMS, MFR, AND MMU (AT MSFC)

LARGE ORU REPLACEMENT TESTS

OBJECTIVES:

1-G TESTS:

- VERIFY MECHANICAL OPERATION OF ORU STRUCTURAL, FLUID AND ELECTRICAL CONNECTIONS
- PRELIMINARY EVALUATION OF HANDLING, GUIDING, ACCESS FEATURES
- DEVELOPMENT OF NEUTRAL BUOYANCY TEST PROCEDURES

NEUTRAL BUOYANCY TESTS:

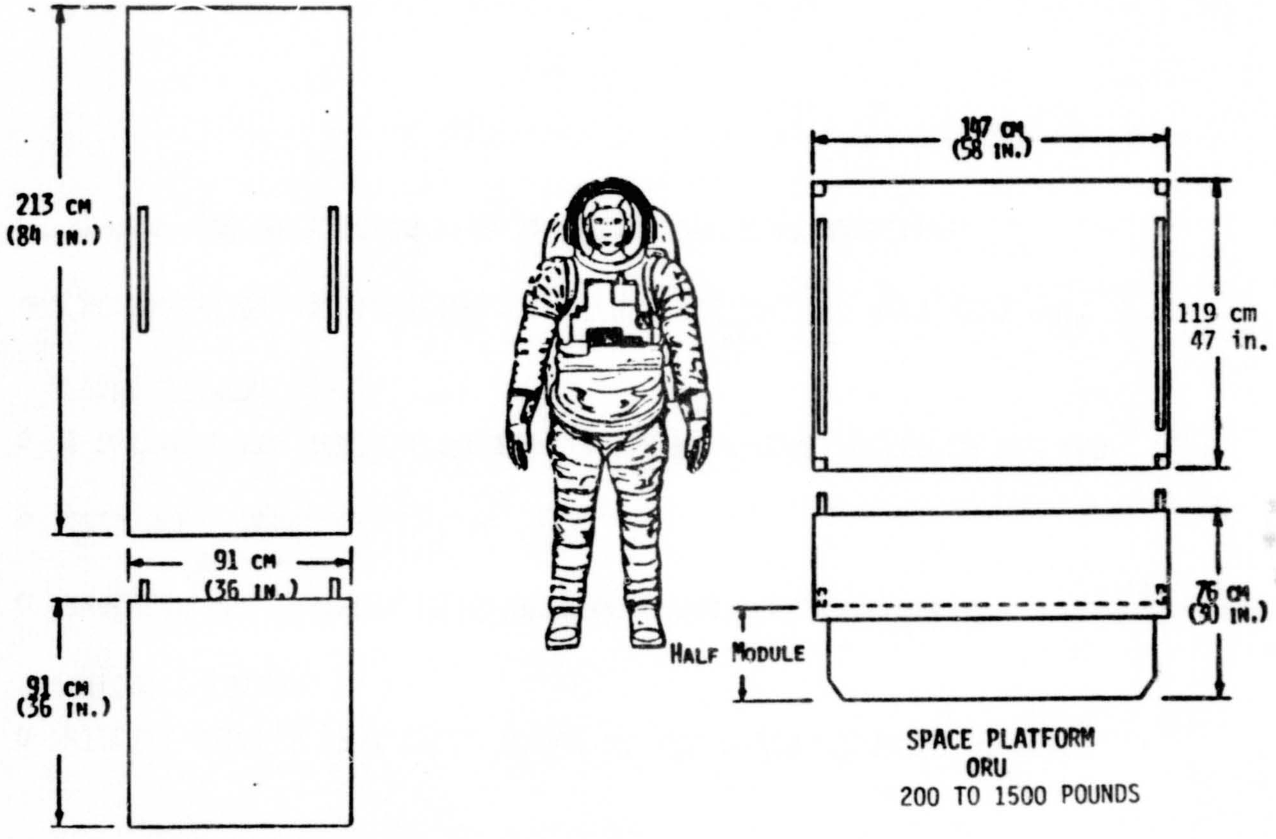
- DEVELOP AND VERIFY ORU/EVA/RMS/MFR/MMU INTERFACES
- VERIFY HANDLING, INSERTION, AND REMOVAL OF LARGE HIGH DENSITY MODULES
- VERIFY MANUAL OPERATION OF STRUCTURAL, FLUID AND ELECTRICAL ATTACHMENT MECHANISMS
- VERIFY ACCESS, VISION, TORQUE, FEEDBACK, AND SAFETY PARAMETERS
- OBTAIN TASK AND TASK ELEMENT TIMES
- DEVELOP AND VERIFY BODY POSITIONS AND BODY RESTRAINTS
- VERIFY COMPATIBILITY OF CREW SAFETY TETHERING AND EQUIPMENT TETHERING OPERATIONS WITH ORU OPERATIONS
- VERIFY FUNCTION OF MODULE ALIGNMENT GUIDES
- INVESTIGATE TEMPORARY PARKING OPERATIONS

6

APPROACH USED TO DEVELOP ORU REPLACEMENT OPERATIONS

- UTILIZE RESULTS FROM SPACE TELESCOPE AND OTHER PROGRAMS TO AVOID UNIQUE SOLUTIONS
- ANALYSIS AND ENGINEERING LAYOUTS OF OPERATIONS/PROCEDURES
- 1/20 SCALE MODEL EVALUATION
- 1-G (UNSUITED) TESTS USING FULL SCALE FOAM-CORE MOCKUP OF ORU AND FRAME SEGMENT
- 1-G (UNSUITED) TESTS USING FULL SCALE NEUTRAL BUOYANCY TEST UNIT
- NEUTRAL BUOYANCY TESTS WITH SUITED SUBJECTS AT NASA/MSFC

MODULAR ORU

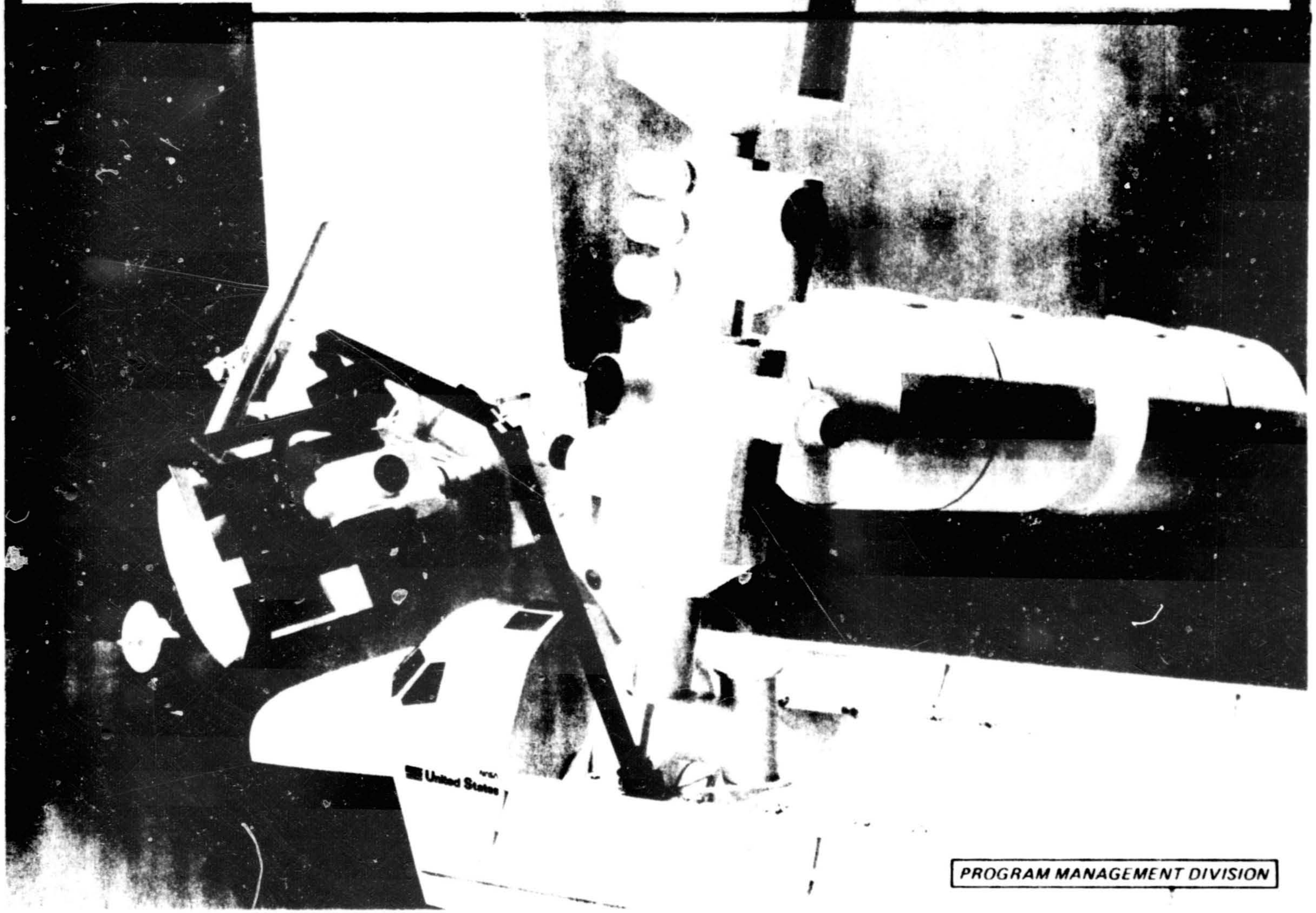


SPACE TELESCOPE
SCIENTIFIC INSTRUMENT
800 POUNDS

SPACE PLATFORM
ORU
200 TO 1500 POUNDS

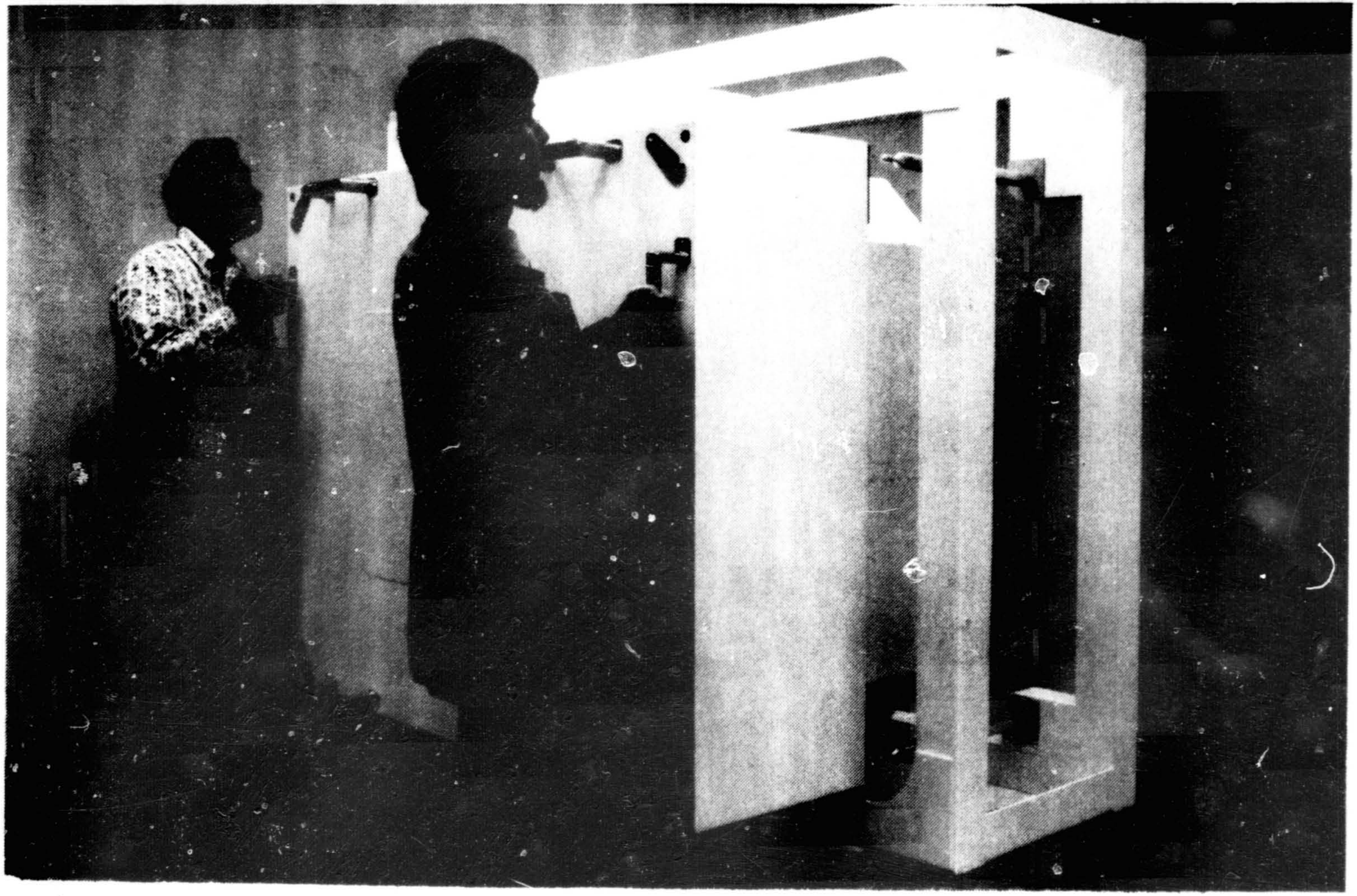
8

PORT ORU REPLACEM

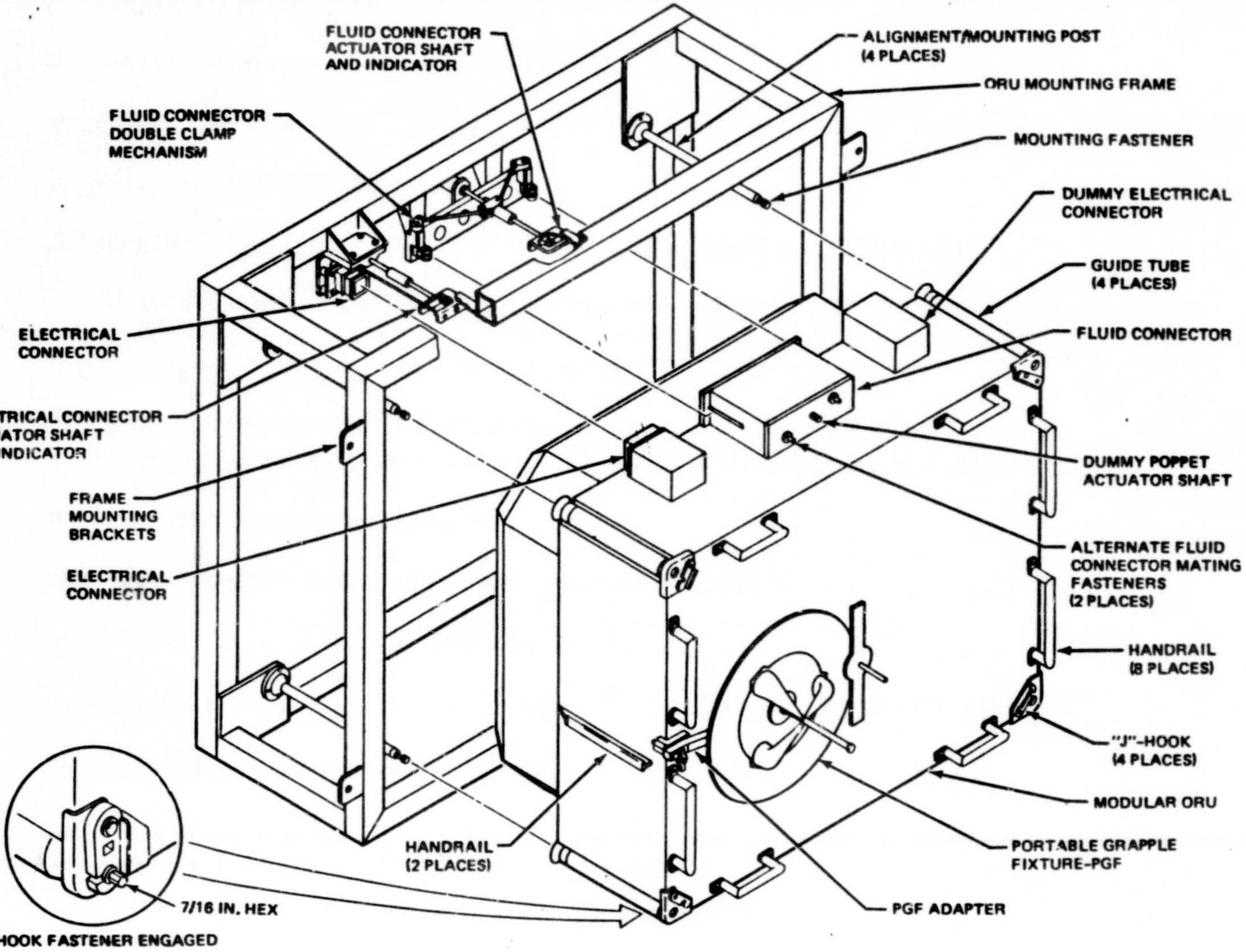


PROGRAM MANAGEMENT DIVISION

MODULAR ORU MOCKUP



MODULAR ORU AND ORU MOUNTING FRAME

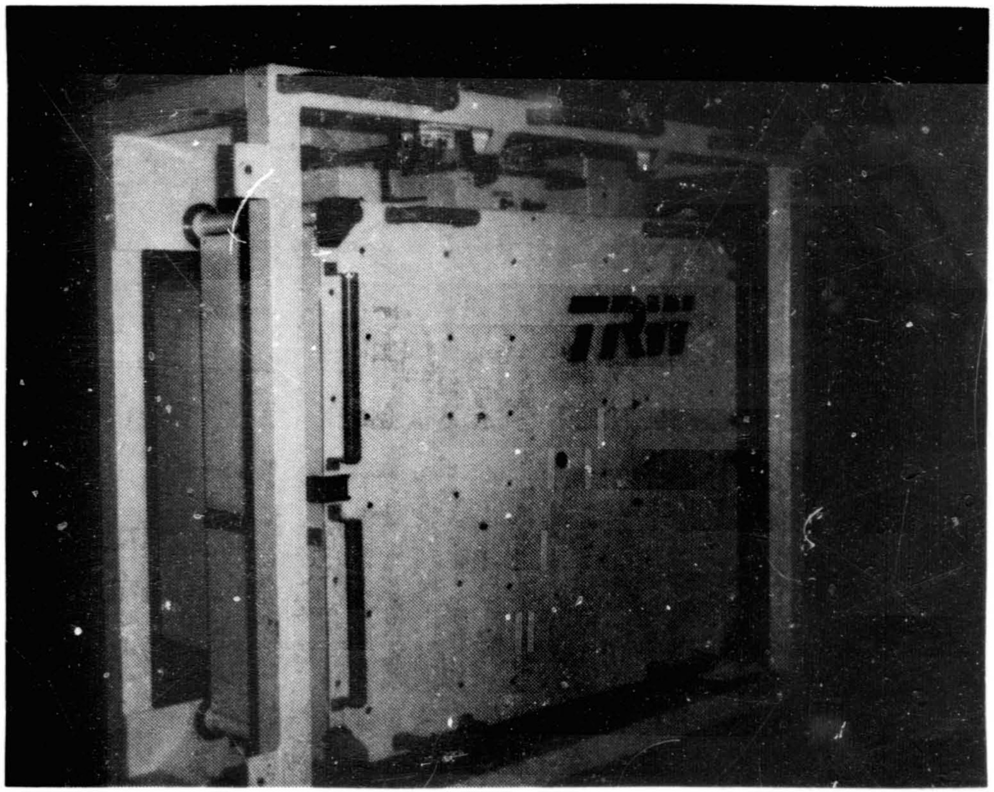


ORU HARDWARE AND OPERATIONS
DESIGN FEATURES

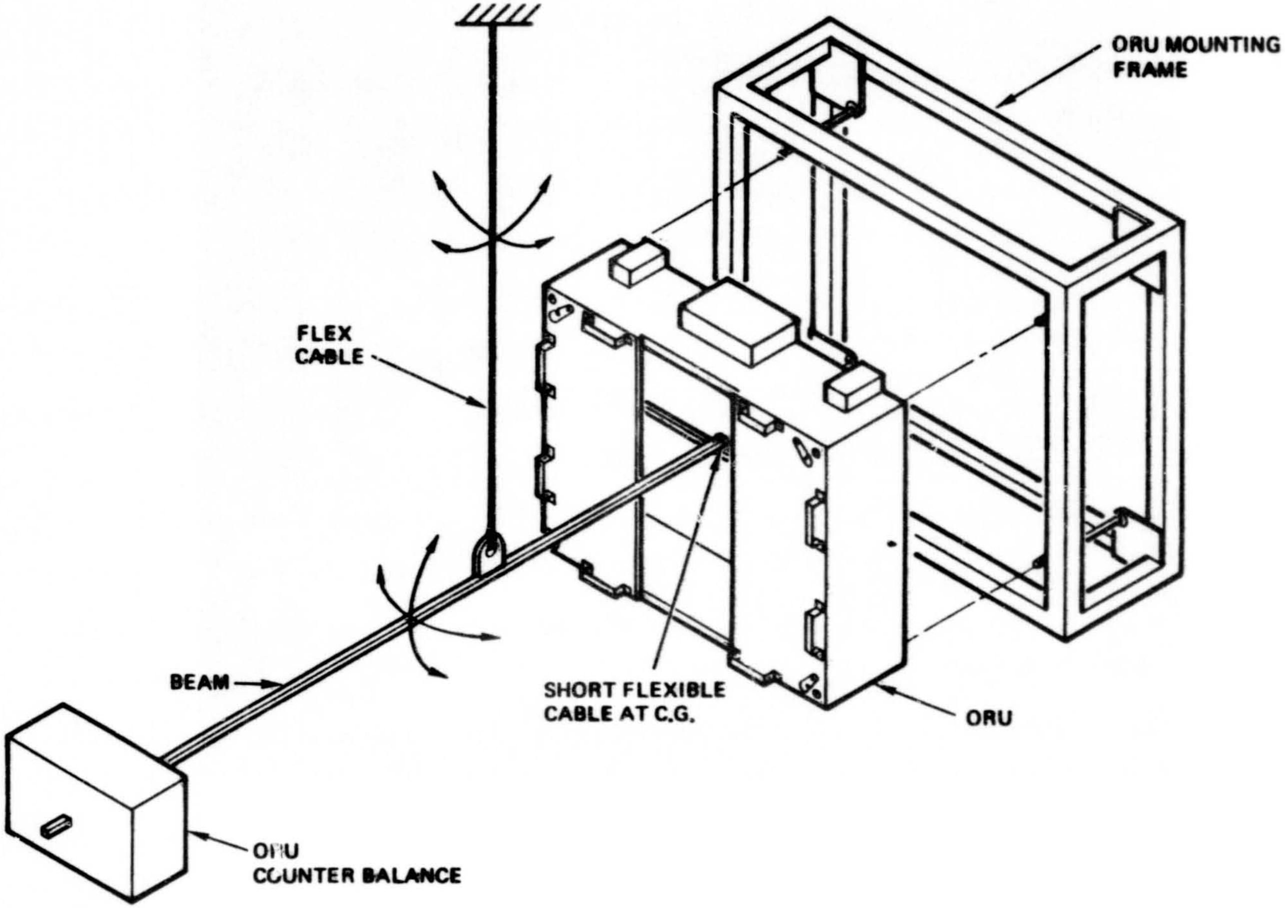
- O VISIBILITY/ACCESS COMPATIBLE WITH SUITED CREWMEN
- O ADAPTER PROVIDED FOR PORTABLE RMS GRAPPLE FIXTURE FOR MODULE TRANSFER
- O STANDARD NASA HANDHOLDS AND FOOT RESTRAINTS
- O SHARP CORNERS, EDGES AND PROTRUSIONS ELIMINATED
- O ALL LOOSE EQUIPMENT TETHERED
- O STANDARD MUSHROOM RATCHET WRENCH USED FOR ALL FASTENERS AND ACTUATORS (7/16" HEX - DOUBLE-PLUS HEIGHT)
- O "J"-HOOK FASTENERS (TEMPORARY RESTRAINT INHERENT)
- O NO ENGAGEMENT OF THREADED FASTENERS (BASELINE)
- O RUNNING FRICTION IN ALL TOOL OPERATED FASTENERS AND ACTUATORS
- O ALIGNMENT GUIDES FOR MODULE
- O STATUS (MATE/DEMATE) INDICATORS FOR FLUID AND ELECTRICAL CONNECTOR
- O OPERATION MARKINGS FOR ACTUATORS
- O ADAPTER PROVIDED FOR DOCKING MMU TO ORU WITH ROTATION JOINT FOR ADDRESSING TASKS

/3

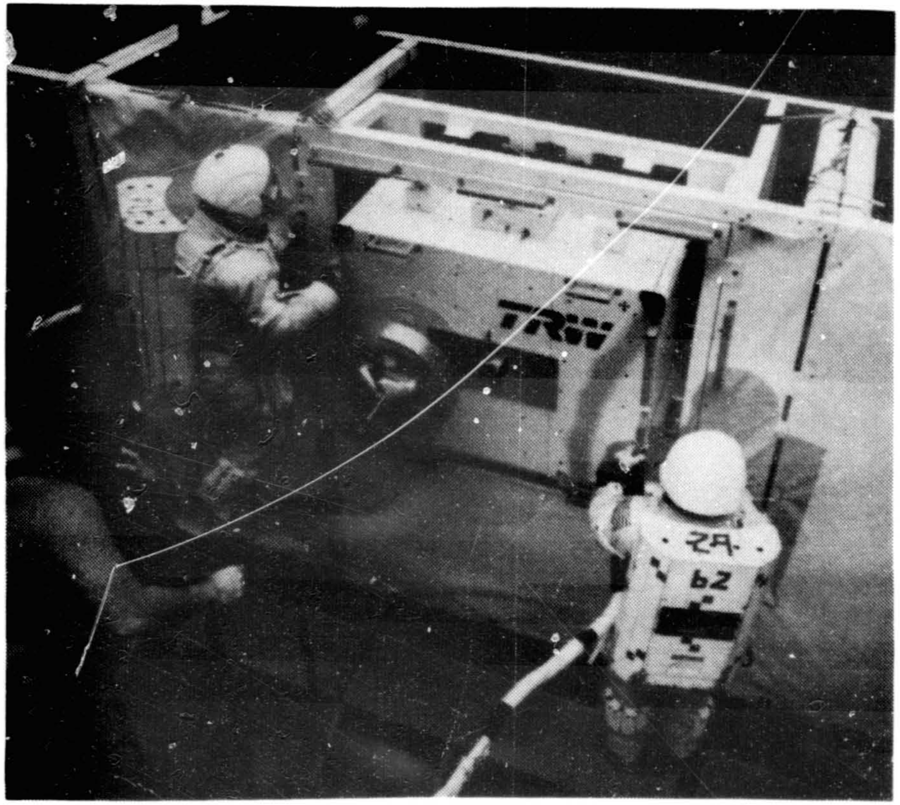
MODULAR ORU NEUTRAL BUOYANCY TEST UNIT



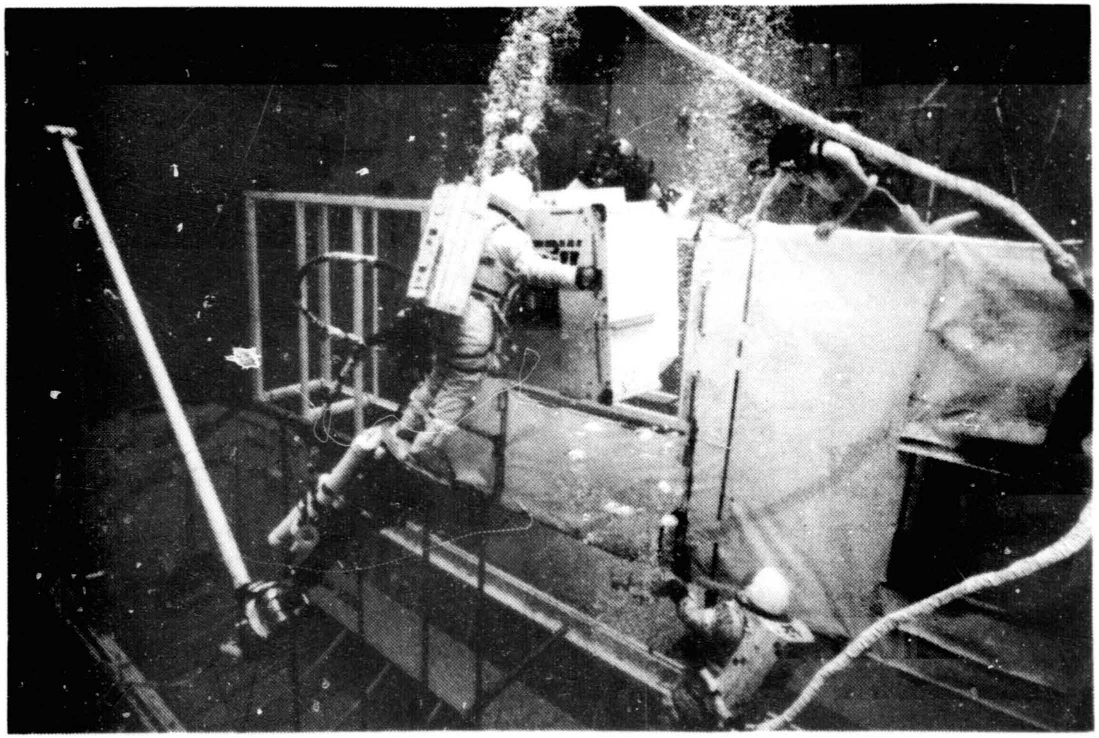
MODULAR ORU
1-G PENDULUM TEST



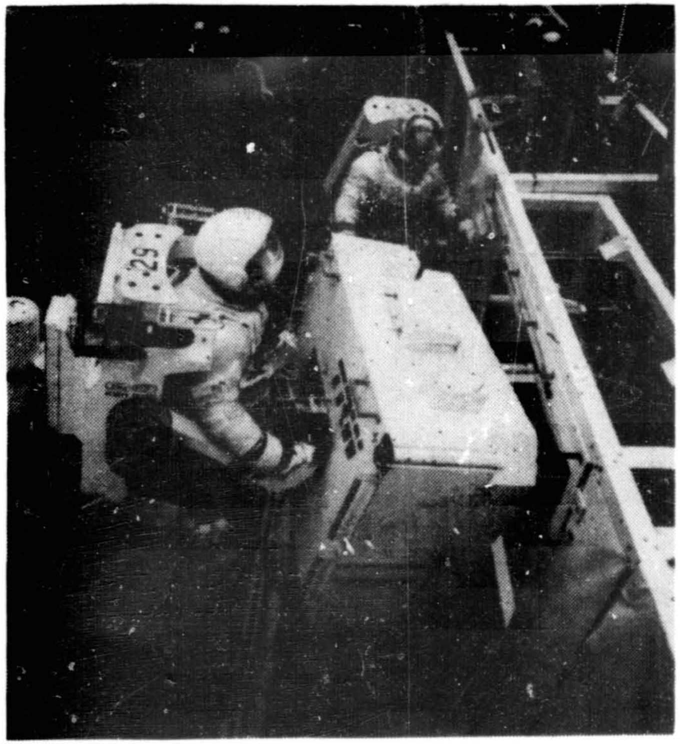
INSTALLATION OF MODULAR ORU USING PORTABLE FOOT RESTRAINTS



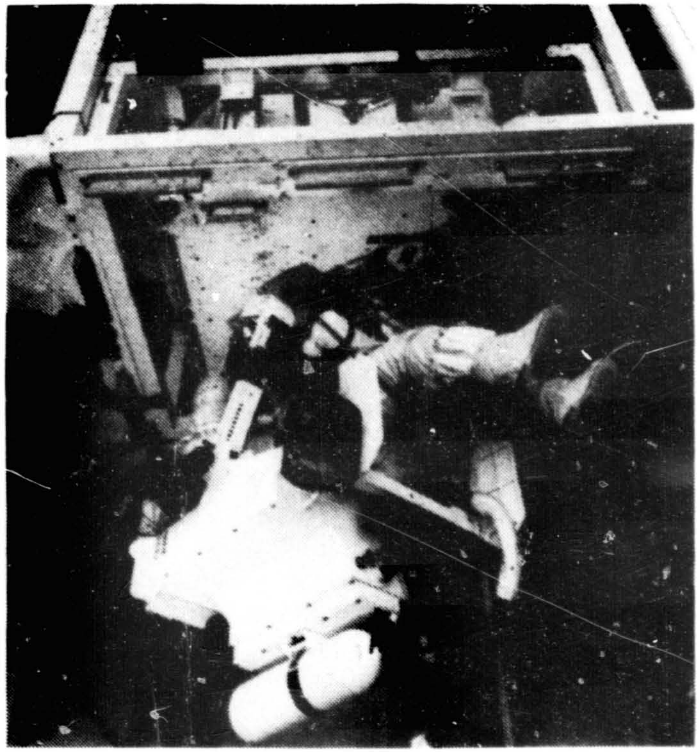
REMOVAL OF MODULAR ORU USING MFR



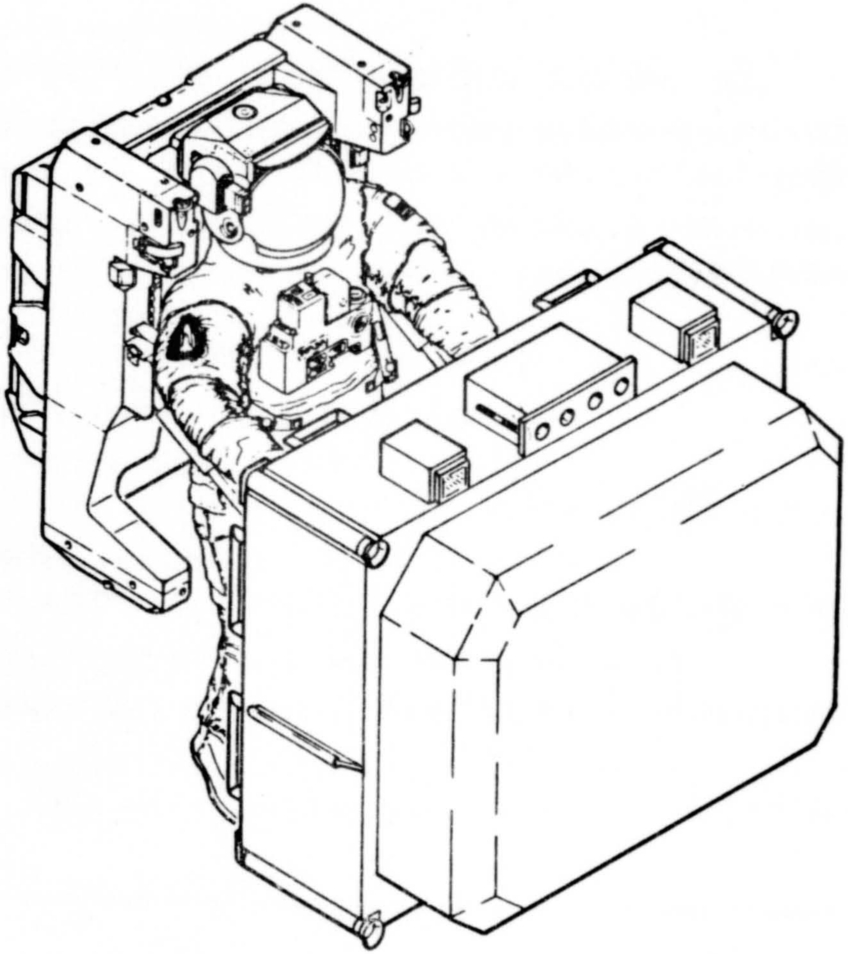
INSTALLATION OF ORU USING MMU



ROTATING MMU TO ADDRESS ORU FASTENERS



MANNED MANEUVERING UNIT (MMU)
WITH MODULAR ORU



NEUTRAL BUOYANCY TEST RESULTS

- ALL THREE MODES (PFR, MFR, MMU) FEASIBLE FOR REPLACEMENT OF LARGE MODULES
- MFR MODE MOST EFFICIENT - WHERE RMS ACCESS IS AVAILABLE
- POST/TUBE ALIGNMENT IS EFFECTIVE - NO BINDING
- J-HOOK MECHANICAL FASTENERS - EASY TO OPERATE AND PROVIDE TEMPORARY RESTRAINT
- HAND TOOL DRIVEN ELECTRICAL AND FLUID CONNECTOR MATE/DEMATE MECHANISMS ARE EFFECTIVE
- TETHER APPROACH FOR PARKING IS FEASIBLE -
- ALL OPERATIONS ARE COMPATIBLE WITH A7L TEST SUIT - SHUTTLE PRESSURE SUIT WOULD ENHANCE OPERATIONS
- FOOT RESTRAINTS ARE MORE EFFECTIVE AND SAFER THAN HANDHOLDS-ONLY, FOR LARGE MODULE HANDLING - ONE CREWMAN IN FOOT RESTRAINT IS ADEQUATE
- TORQUE (25 FT/LBS) AND NUMBER OF TURNS (3-5) ON FASTENERS AND HEX DRIVES COMPATIBLE WITH RATCHET WRENCH/HANDHOLD APPROACH
- ONE INCH HEX HEIGHT PREFERRED OVER "DOUBLE-HEIGHT" (1/2 IN.) - BETTER TOOL STABILITY

NEUTRAL BUCYANCY TEST RESULTS (CONT)

- ONE-MAN OPERATIONS ARE FEASIBLE FOR ALL THREE MODES BUT TWO-MAN OPERATIONS ARE PREFERRED FOR MODULE CONTROL IN PFR MODE
- MMU/ORU/PRESSURE SUIT INTERFACES CAN BE DEVELOPED IN NBF - FREE FLYING DYNAMICS NEED COMPUTER AND 6 DOF SIMULATION
- ANALYTICAL AND MOCKUP DETERMINATION OF FOOT RESTRAINT LOCATIONS IS EFFECTIVE
- SOME DIFFICULTY IN MATING ALTERNATE FLUID CONNECTOR BOLTS - LEARNING CURVE
- TASK TIMES
- UTILIZATION OF FOAM-CORE MOCKUPS ARE VERY EFFECTIVE IN DEVELOPING HARDWARE AND PROCEDURES
- SIMPLE COUNTERBALANCE PENDULUM (1-G) TESTS ARE EFFECTIVE IN PRELIMINARY TESTING OF ALIGNMENT AND ATTACHMENT HARDWARE FOR LARGE MODULES
- NEUTRAL BUOYANCY TESTS SHOULD INCLUDE SAFETY TETHERS, MINI WORK STATION (MWS) AND WORK TETHERS TO ENHANCE FIDELITY
- SIGNIFICANT AMOUNT OF GENERIC DATA ON EVA,RMS, MFR, AND MMU OPERATIONS OBTAINED

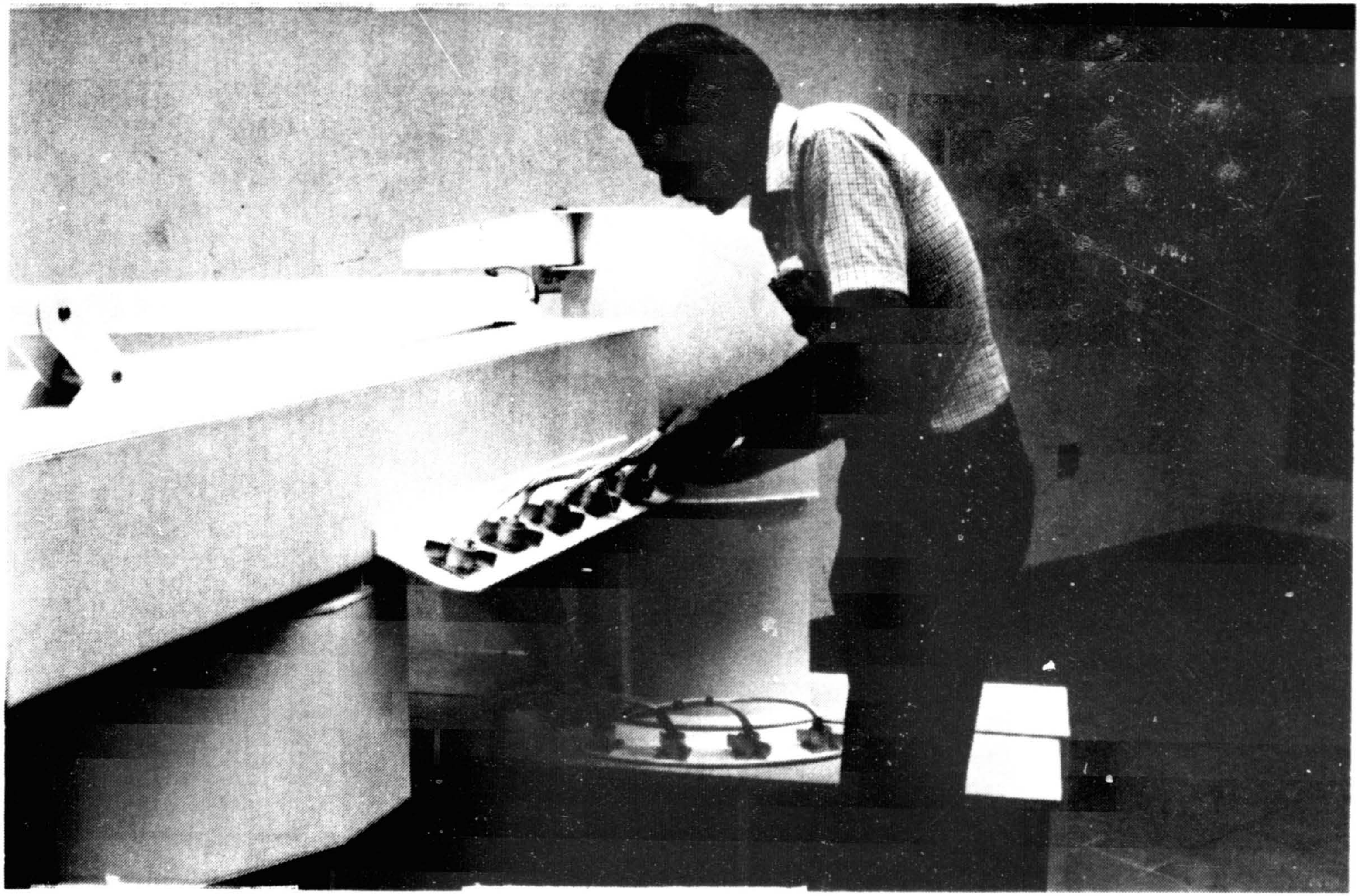
C-7

5-85

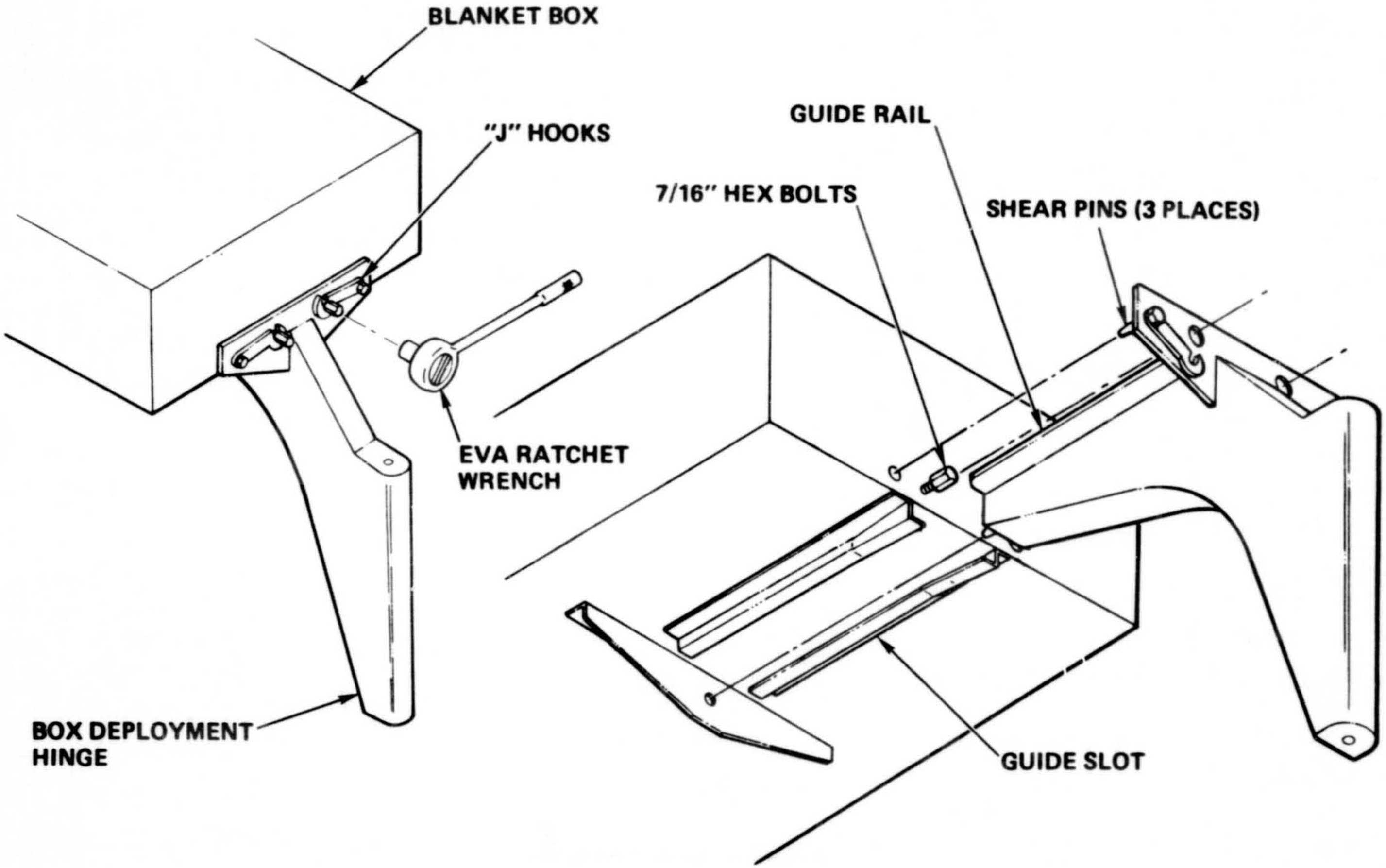
Solar Array Subsystem

SOLAR ARRAY MOCKUP

ELECTRICAL CONNECTOR MATING

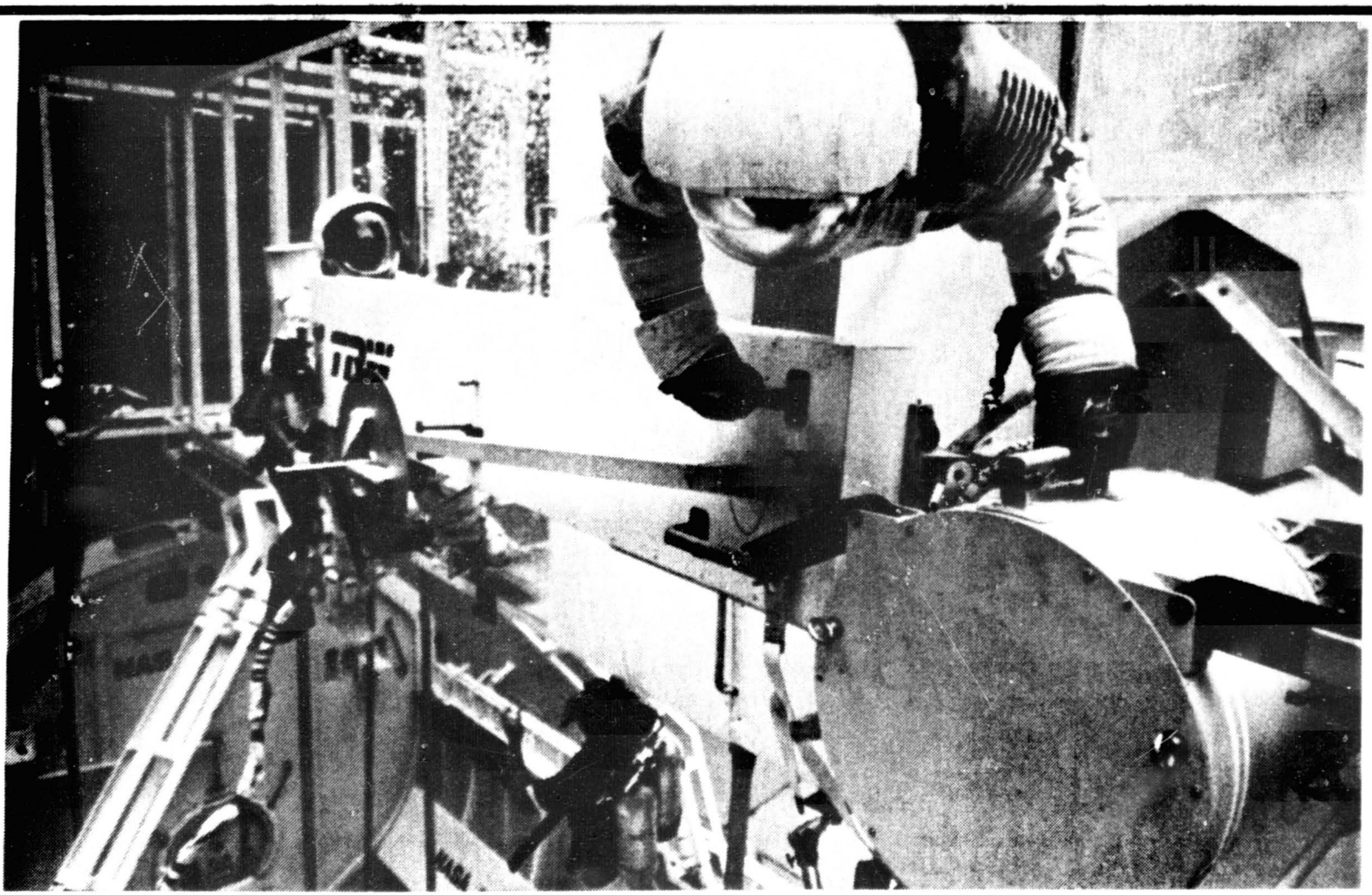


BOX TO WING MECHANICAL INTERFACE

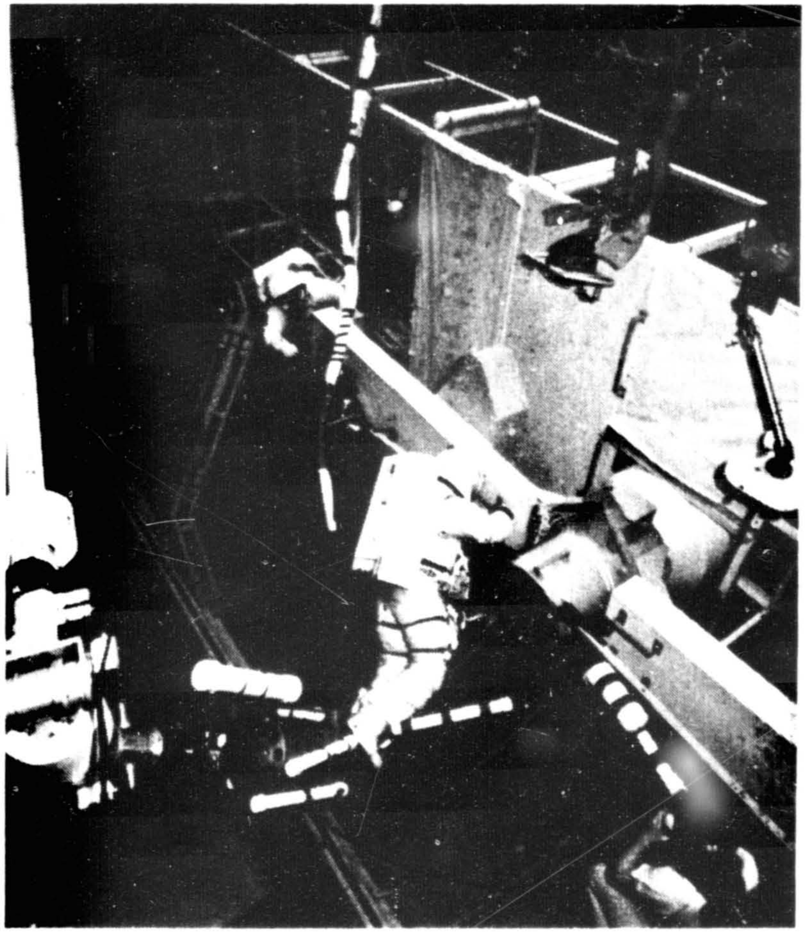


S/A BOX REMOVAL

CREWMEN AT BOTH ENDS



NEUTRAL BUOYANCY TEST
BLANKET BOX CHANGEOUT USING MANIPULATOR FOOT RESTRAINT



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16. Abstract

As NASA prepares plans to develop a space station, one of the major human factors study tasks is to develop an approach to crew safety. NASA has always been a leader in the field of safety consciousness and recognizes that safety will be the key to reliability and human productivity in the space station.

In evaluating safety strategies, it is also necessary to recognize both qualitatively and quantitatively how this space station will be different from all other spacecraft. It is recognized that the major difference between a space station and previous spacecraft is the role of human factors and extra-vehicular activity (EVA). In the project, a model of the various human factors issues and interactions that might affect crew safety is developed.

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