National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Science and Engineering Directorate

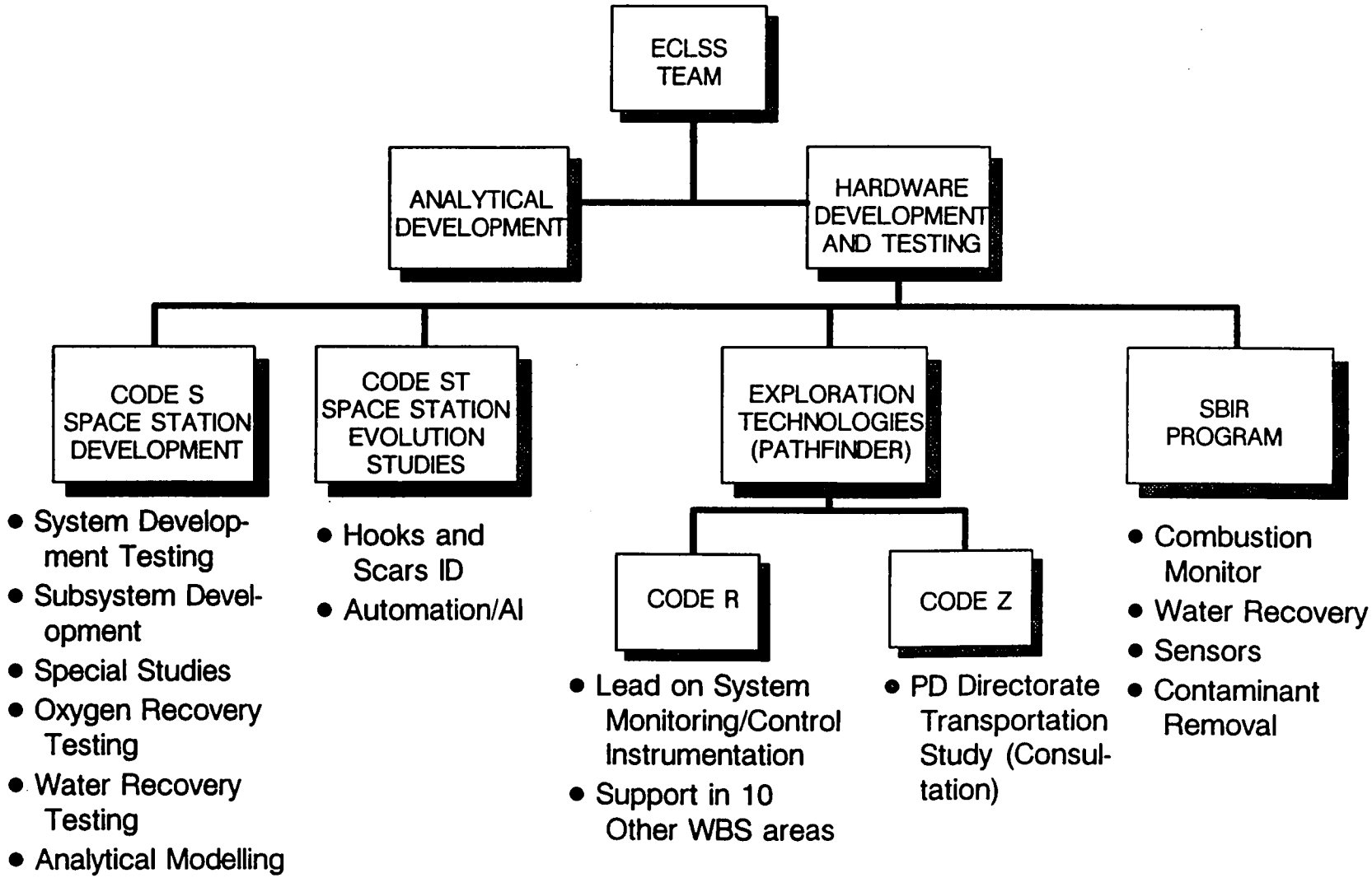
Technology for Space Station Evolution
– A Workshop

NASA

Marshall Space Flight Center
ECLSS Technology Activities

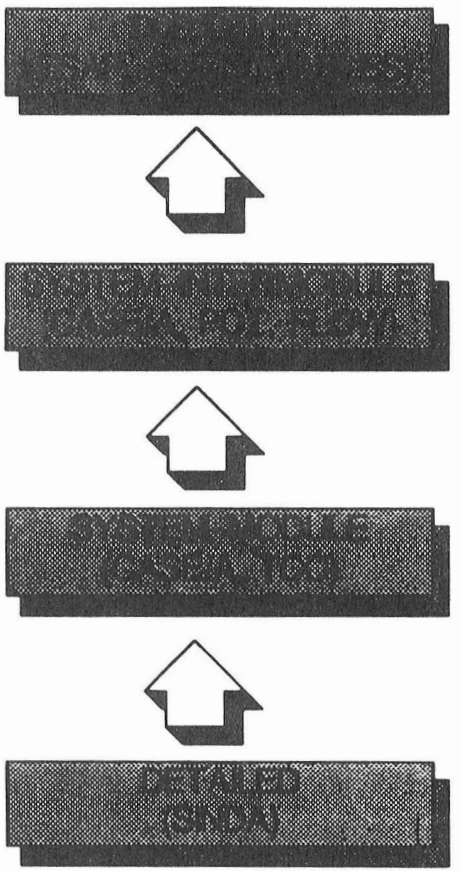
Paul Wieland
Life Support Branch/ED62

ONGOING MSFC LIFE SUPPORT ACTIVITIES



ANALYTICAL DEVELOPMENT

ECLSS MODELING APPROACH



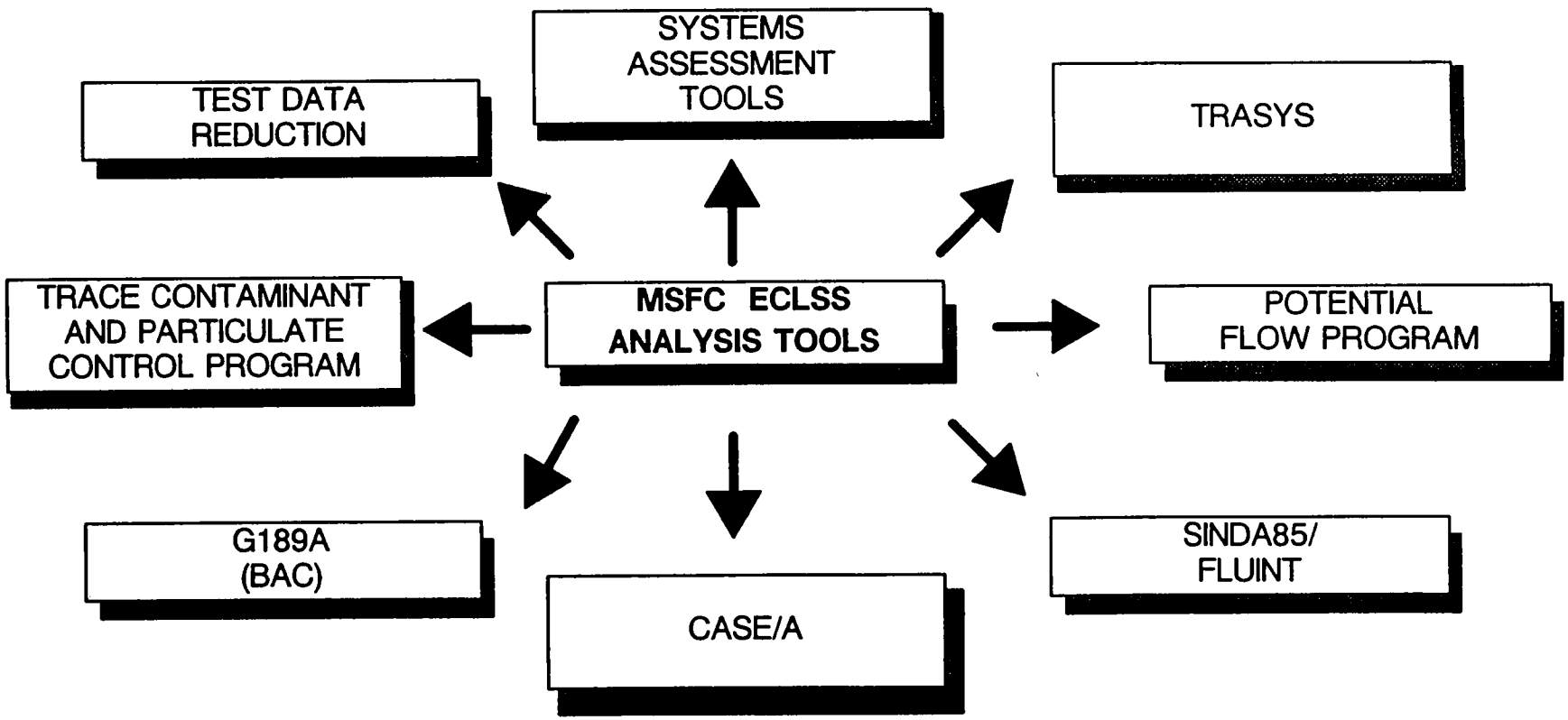
- TOP LEVEL EFFECTS
- MASS BALANCE CONSIDERATIONS ONLY
- RESOURCE ASSESSMENTS, MASS BALANCE SENSITIVITIES

- INTERACTIONS BETWEEN SYSTEMS/MODULES
- FURTHER SIMPLIFICATION OF PHYSIOCHEMICAL EFFECTS
- SYSTEM/MODULE INTERACTIONS

- INTERACTIONS BETWEEN SUBSYSTEMS/COMPONENTS OF SUBSYSTEMS
- SIMPLIFY ASPECTS OF PHYSIOCHEMICAL EFFECTS
- SUBSYSTEM INTERACTIONS

- INSIDE "BLACKBOX"
- PHYSICAL, CHEMICAL THERMODYNAMIC EFFECTS ON MICROSCOPIC LEVEL
- SUBSYSTEM/COMPONENT PERFORMANCE

ECLSS ANALYTICAL AREAS



ANALYTICAL MODEL NEEDS

- **Detailed (of components and subsystems, for subsystem design and assessment)**
  - e.g., membrane transport evaluation
    - macroscopic/microscopic theory incorporation into detailed "1st principles" models
    - extensive "phenomological level" test data to support model development
    - theory for microbial model development
    - multi-component chemical interaction models

- **System-module (for subsystem groups, design and assessment)**
  - e.g., detailed transients for water tank sizing
    - simplifications of the above models, which represent detailed processes to good fidelity
    - system interaction data
    - large/fast computers
    - CASE/A program improvements

- **System-intermodule (for validation models)**
  - e.g., pressurized volume CO_2 level prediction
    - further simplification of the above system-module models
    - large, fast computers
    - CASE/A program improvements

- **Top level (for resource assessments)**
  - e.g., resupply needs
    - better input data

EXAMPLE OF WATER RECLAMATION MODELING NEEDS

CURRENT CAPABILITIES:

- System level representations of water processing operations
  - distillation (TIMES, VCD)
  - reverse osmosis
  - multifiltration (particulate filtration, adsorption, ion exchange)
- "Curve fit" performance simulations of production rate, sensible loads, etc.
- Contaminant rejections (and therefore product water quality) from supplier–defined efficiencies

REQUIRED CAPABILITIES:

- Detailed models based on the thermodynamic and physiochemical phenoena occurring within the processes
- Impacts of physiochemical interactions
  - solute/solute
  - solute/solvent
  - solute/process
  - solvent/process
- Ability to predict transient performance and water quality

TECHNICAL CHALLENGE:

- State–of–the–art modeling limited, at best, to wastewater systems containing 2 or 3 known solutes
- Extension of bi–solute or tri–solute models to multi–solute systems is currently very limited

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HARDWARE DEVELOPMENT AND TESTING

MSFC ECLSS Hardware Development Activities

I. **Code S – Space Station Freedom**
   - A. Phase I Independent Subsystem Testing (1986–present)
   - B. Phase II Integrated Testing (1987)
   - C. Phase III Integrated Testing (1989–1990)
   - D. Subsystem Comparative Testing (BA) (1989–1990)
   - E. Operational System Tests (1989–1993)
   - F. Microbial Ecology Lab Studies

II. **Code ST – Space Station Freedom Evolution**
   - A. ECLSS Evolution and Evaluation For Hooks And Scars
   - B. Automation/Artificial Intelligence

III. **Code R – Exploration Technologies (Pathfinder)**
   - A. Sensor Development
   - B. Trace Organic Removal Process Development
   - C. Trace Contaminant Monitoring Technology Development

IV. **Code Z – Exploration Studies (Program Development Directorate)**

V. **SBIR – Small Business Innovation Research Program**
   - A. Phase I 1989 awards
     1. "Incipient Combustion Monitor for Zero Gravity Environments"
     2. "A Reagentless Separator for Removal of Inorganic Carbon From Solution"
     3. "Thin Membrane Sensors"
   - B. Phase II 1989 awards
     1. "Catalytic Water Purification Development"

VI. **University Involvement**
   - A. University of Alabama in Huntsville
   - B. University of Wisconsin
   - C. Harvard (funding: 80% ARC, 20% MSFC)
   - D. Georgia Institute of Technology

Code S – Space Station *Freedom*

Phase I Independent Subsystem Testing (1986–present)

Objectives: Verification that the subsystems operate properly and familiarization of personnel with subsystem operation, acquisition of performance data, verification of integration requirements in anticipation of later integrated testing, identification of any special problems, determination of off–nominal performance.

Subsystems Tested:

CO_2 Removal – Four–Bed Molecular Sieve (4BMS)
Solid Amine Water Desorbed (SAWD)
Electrochemical Depolarized Cell (EDC) [planned]
Two–Bed Molecular Sieve (2BMS)

CO_2 Reduction – Sabatier
Bosch

O_2 Generation – Static Feed Electrolyzer (SFE)

Water Reclamation – Thermoelectric Integrated Membrane Evaporation System (TIMES)
Vapor Compression Distillation (VCD)

Trace Contaminant Control – Trace Contaminant Control Subsystem (TCCS)

Results: Operation and performance of the subsystems evaluated, special integration considerations identified, subsystem anomalies identified.

Code S – Space Station *Freedom*

Phase II Integrated Testing (1987)

Simplified Integrated Test – 42 hours of "open door" integrated operation (June 1987)
Metabolic Control Test – 148 hours of "closed door" integrated operation (November 1987)

Objectives: Verify proper operation of the ECLSS subsystems when integrated and gather performance data for the partial ECLS system used in the test.

Subsystems Tested: 4BMS, Sabatier, SFE, TIMES, TCCS

Results: Demonstrated the feasibility of operating and maintaining an integrated ECLS system for an extended period, provided baseline data about the stability of an ECLS system, and pointed out what developments and improvements are needed to conduct future integrated ECLS system tests. The knowledge gained is then incorporated into the design of the next generation subsystems.

The results are documented in:
"Space Station ECLSS Simplified Integrated Test Final Report" NASA TM–100363, March 1989,
and "Space Station CMIF Extended Duration Metabolic Control Test Final Report" NASA TM–100362, March 1989.

Code S – Space Station *Freedom*

Phase III Integrated Testing (1989–1990)

Simplified Integrated Test – 256 hours total of "open door" with 148 hours of integrated operation (August 1989)

Subsystems: 4BMS, Bosch, SFE, TCCS

Objectives: Investigation of system integration of the Space Station air revitalization subsystems, operation of the Bosch until cartridge "switchover" occurs.

Results: Preliminary report expected to be released in November.

Water Recovery Test – Testing of the water recovery subsystems planned for February 1990.

Subsystems: Multi-filtration, Reverse Osmosis, Water Quality Monitor (TOC), TIMES, VCD

Objectives: A major objective is to include people in the loop to provide hygiene water and to drink reclaimed potable water. Water analysis techniques are being developed and verified to ensure quality control and quality assurance during analysis of samples.

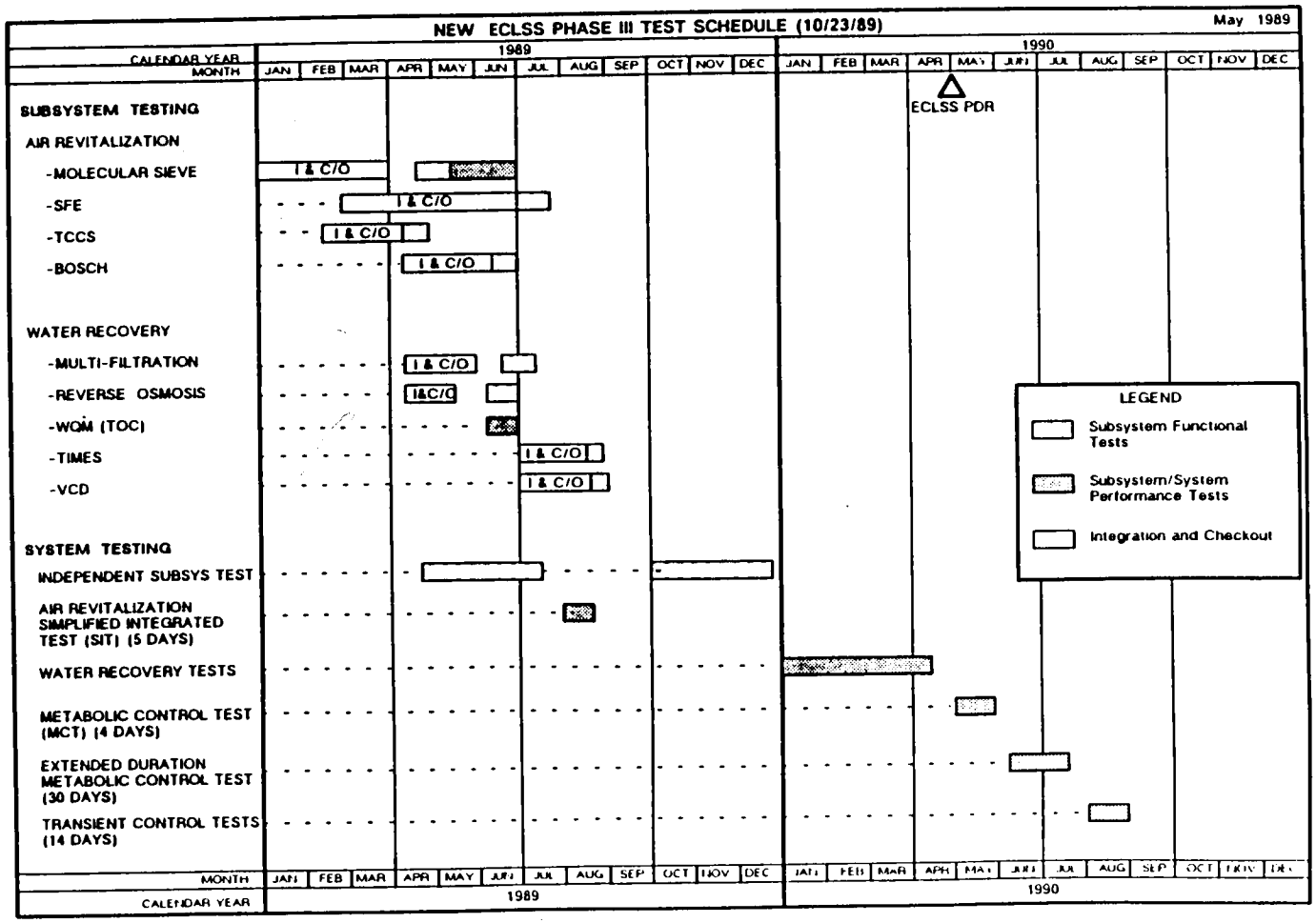
Waste water to be reclaimed includes: perspiration, respiration, urine, shower water, and water from a hand washer, a clothes washer, and a dish washer. These waste waters will be generated in the End-use Equipment Facility (EEF) which is a 100K clean room where the test subjects and equipment (exercise, etc.) are located.

An Institutional Review Board (IRB) has been established in accordance with NMI 7100.8A to review protocols and procedures for ECLSS testing using human subjects. This board will address the institutional safety, medical, and legal requirements associated with human research.

Metabolic Control Test – Integrated testing planned to begin in mid-1990 for three months.

Subsystems: 4BMS, Bosch, SFE, TCCS, TIMES, RO, MF, VCD

Objectives: Integration of the Space Station air revitalization and water recovery subsystems.


NEW ECLSS PHASE III TEST SCHEDULE (10/23/89)
May 1989
CALENDAR YEAR
MONTH
1989
1990
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
ECLSS PDR
SUBSYSTEM TESTING
AIR REVITALIZATION
-MOLECULAR SIEVE
-SFE
-TCCS
-BOSCH
I & C/O
WATER RECOVERY
-MULTI-FILTRATION
-REVERSE OSMOSIS
-WQM (TOC)
-TIMES
-VCD
I&C/O
SYSTEM TESTING
INDEPENDENT SUBSYS TEST
AIR REVITALIZATION SIMPLIFIED INTEGRATED TEST (SIT) (5 DAYS)
WATER RECOVERY TESTS
METABOLIC CONTROL TEST (MCT) (4 DAYS)
EXTENDED DURATION METABOLIC CONTROL TEST (30 DAYS)
TRANSIENT CONTROL TESTS (14 DAYS)
LEGEND
Subsystem Functional Tests
Subsystem/System Performance Tests
Integration and Checkout

Code S – Space Station *Freedom*

Prime Contractor Subsystem Comparative Testing (1989–1990)

Independent Subsystem Testing (Boeing Aerospace) – beginning late 1989

Objective: Evaluation of prototype hardware of comparable maturity and with the same test conditions, for performance, safety, reliability, servicing and maintenance requirements.

Subsystems: CO_2 Removal – Four–Bed Molecular Sieve (4BMS)

CO_2 Reduction – Bosch
Sabatier

O_2 Generation – Static Feed Electrolyzer (SFE)
Anode Feed Solid Polymer Electrolyte (AFSPE)

Waste Water Reclamation

Urine Recovery – Thermoelectric Integrated Membrane Evaporation System (TIMES)
Vapor Compression Distillation (VCD)

Hygiene Water – Reverse Osmosis (RO)
Multi–Filtration (MF)

Potable Water Recovery – Multi–Filtration (MF)
Reverse Osmosis (RO)

Results: Final selections of the subsystems to be used on the Space Station *Freedom* will be based on the results of these tests.

Code S – Space Station *Freedom*

Prime Contractor Operational System Tests (1989–1993)

Concept Confirmation Tests (CCT) – 1989–1990

Testing avionics air flow control to equipment racks and fire suppressant flow control concepts.

Predevelopment Operational System Test (POST) – 1990

Early evaluation of the baseline concepts, verification of operating interfaces, acquisition of data prior to CDR.

Early Race Track (ERT) – April 1991

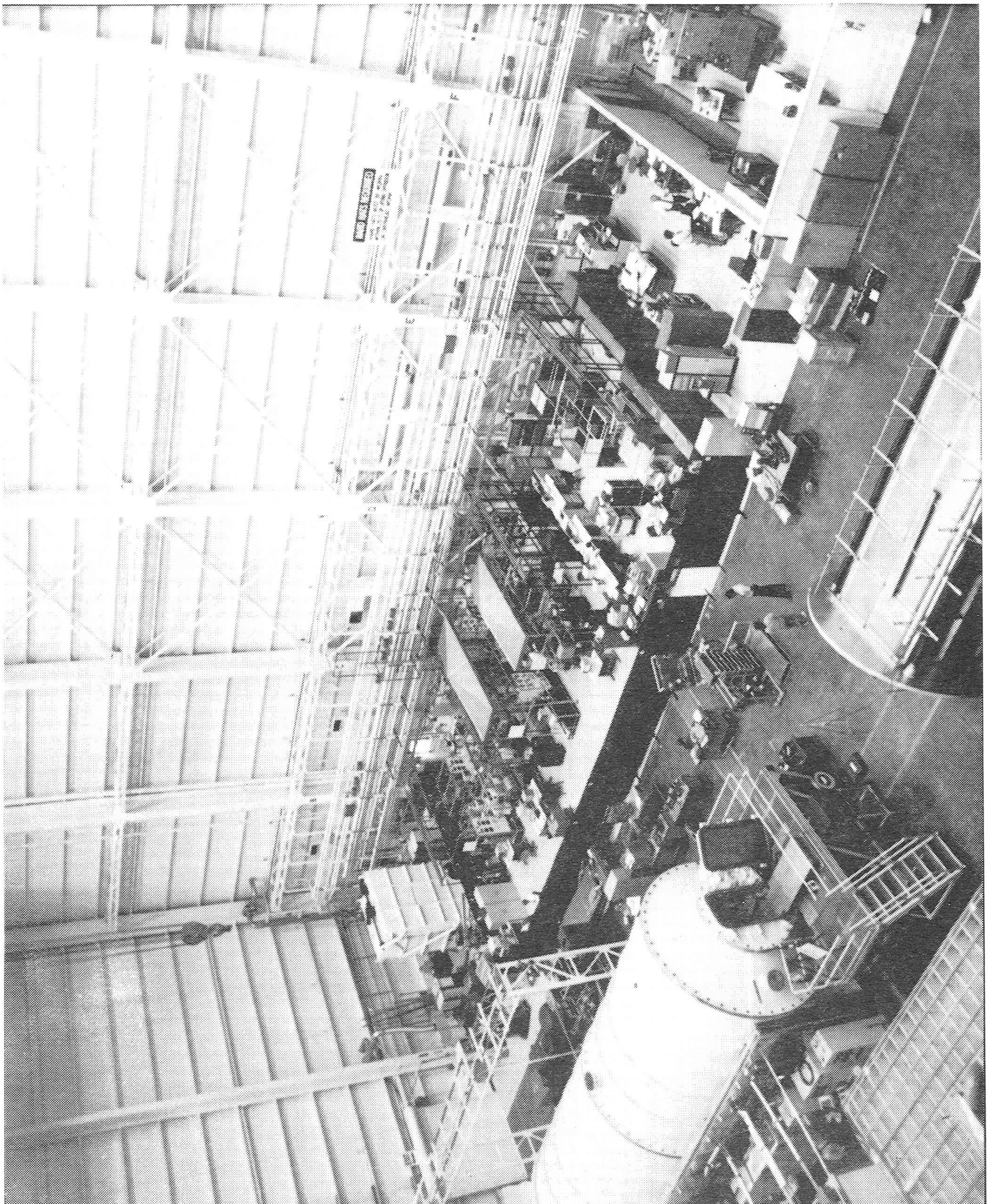
Operational evaluation of the inter-element air circulation system, verification of the ability to control ventilation requirements from centralized locations.

Baselined Operational System Test (BOST) – 1992

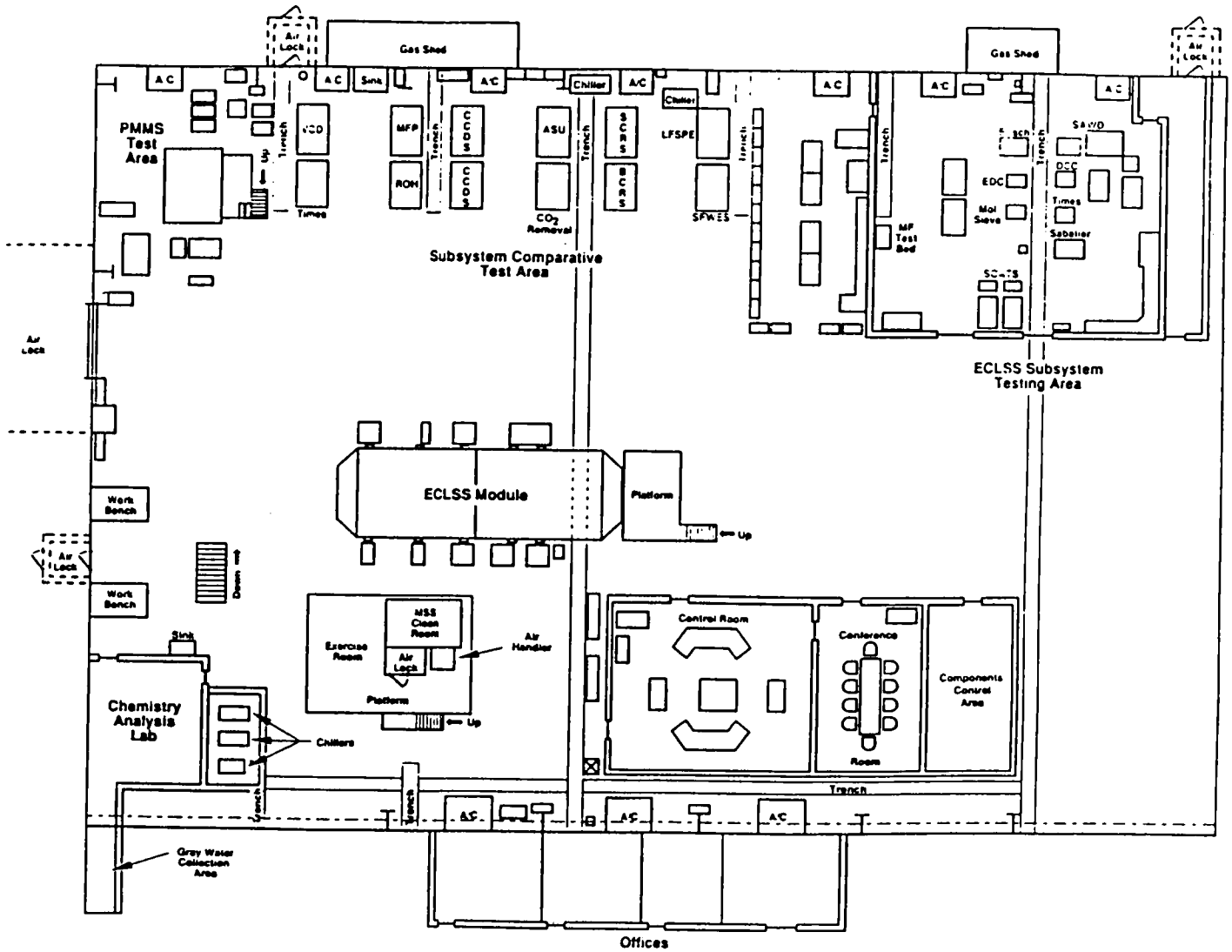
Verification of flight qualifiable hardware including a 30-day unmanned test.

Manned Operational System Test (MOST) – January 1993

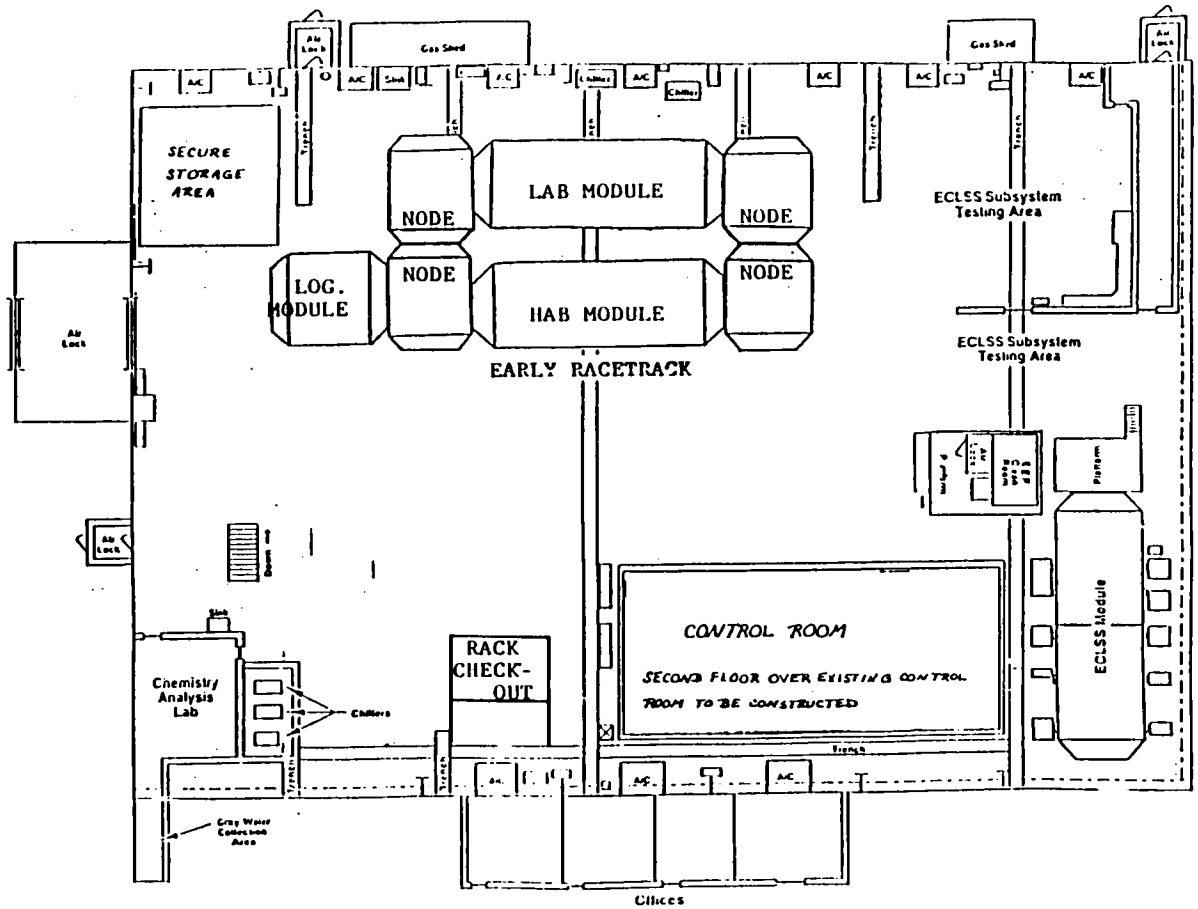
Includes a 90-day manned test. After completion of the test the subsystems will be refurbished and delivered to JSC for further testing.



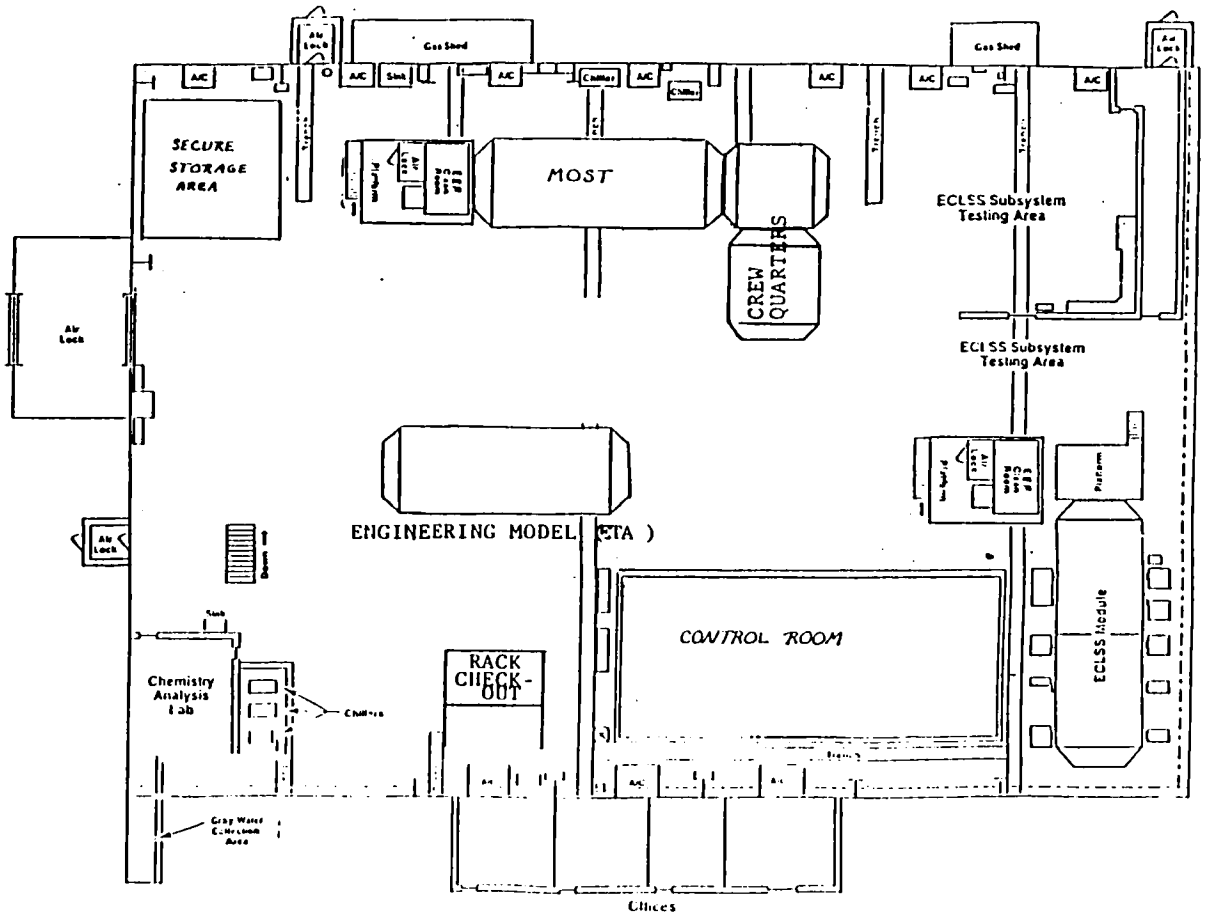
CORE MODULE INTEGRATION FACILITY



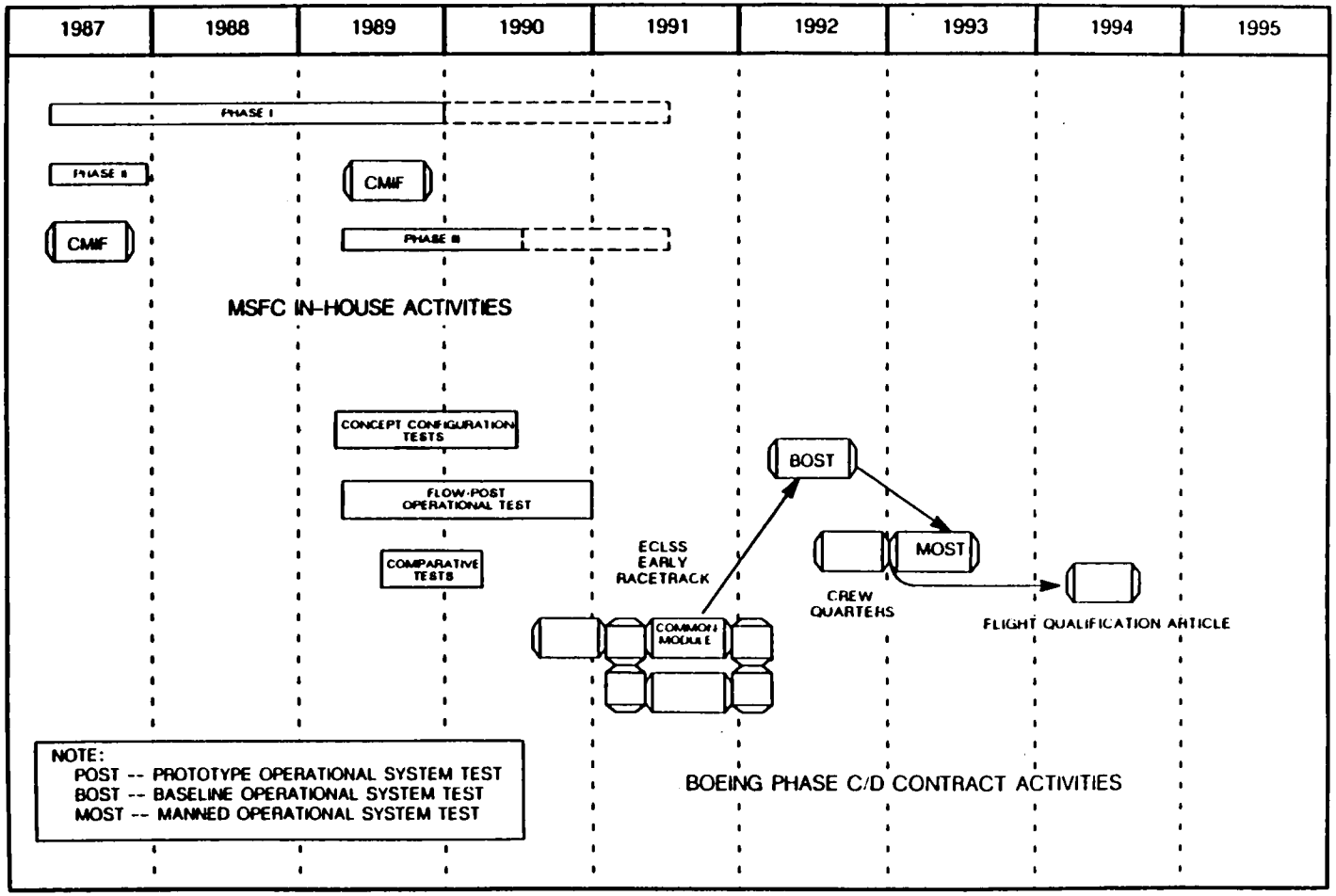
EARLY RACK TRACK LOCATION IN 4755



MOST CONFIGURATION IN 4755



ECLSS DEVELOPMENT TEST PROGRAM



Code S – Space Station *Freedom*

MSFC Microbial Ecology Lab Studies

Purpose:

(1) Provide routine sampling and microbiological identifications for ECLSS test activities.

(2) Conduct research leading to predictive models of behavior of microorganisms in the closed loop environment of Space Station *Freedom*.

(3) Provide test information on the effects of microbial growth on materials to be used on Space Station *Freedom*.

Code ST – Space Station *Freedom* Evolution

ECLSS Evolution

OBJECTIVE: This task will develop and apply the analytical tools needed to allow the ECLSS to evolve in a manner such that it meets the needs of the users over the long term, and will also identify hooks and scars required to implement the selected growth technologies.

APPROACH:
- Conduct a survey to identify ECLSS technologies with growth option potential
- Develop a prioritized list of candidates and perform an IOC hook and scar assessment
- Expand the existing analysis tools
- Perform a comparative analysis against the IOC system
- Perform cost/benefit trade studies based on the analysis

PRODUCTS:
- Interface requirements/performance characteristics/figures of merit
- Preliminary hooks and scars requirements
- CASE/A component models and documentation
- Comparative data
- Final report

STATUS: A preliminary study has been done and a contract to perform the full study is in the process of being awarded.

Code ST – Space Station *Freedom* Evolution

ECLSS Advanced Automation

OBJECTIVE: To design, test, and evaluate Knowledge Based System (KBS) components for the ECLSS which will assist the crew and increase system autonomy.

APPROACH:

- Phase 1
  - Establish the KBS requirements
  - Determine the hooks, scars, and interfaces
  - Study KBS research and techniques in NASA and industry
  - Begin initial prototyping of ECLSS advanced automation software components
- Phase 2 – Initial proof of concept design and development
- Phase 3 – Implementation and testing of the KBS on actual subsystem hardware (ECLSS test bed in Building 4755 at MSFC)

PRODUCTS:

- Documentation – reports, development plan, design & test specifications
- Hardware – Software Support Environment (SSE) compatible workstation integrated into the software development environment
- Software – ECLSS KBS with Ada knowledge based system shell, integrated with the SSE software tools
- Final system – KB system(s) ready to be integrated with ECLSS hardware and software

Code R – Exploration Technologies (Pathfinder)

MSFC is the lead for Systems Monitoring and Control Instrumentation.

RTOP #591-34-61 System Monitoring, contract with MDSSC
"real-time sensor" development
chemical composition monitoring technology

RTOP #591-34- ECLSS Evolution and Advanced Instrumentation, new contract
continuation of 591-34-61 effort

RTOP #591-34- Trace Contaminant Monitoring

In support of 10 other WBS categories MSFC has one water recovery technology task.

RTOP #591-34-21 Water Recovery, contract with MDSSC, subcontracted to Sievers Research trace organic removal water reclamation (funded through Ames)

CODE R PATHFINDER
NASA CENTER ROLES – P/C CLLS OFFICE

	ARC	JPL	JSC	LaRC	MSFC
1.1 PHYSICAL/CHEMICAL LIFE SUPPORT					
1.1.1 THERMAL CONTROL	S		L		S
1.1.2 AIR REVITALIZATION	S	S	L		S
1.1.3 WATER MANAGEMENT	L	S	S		S
1.1.4 SOLID WASTE MANAGEMENT	L	S	S		S
1.1.5 FOOD MANAGEMENT	S		L		S
1.2 PORTABLE LIFE SUPPORT SYSTEMS					
1.2.1 THERMAL CONTROL SYSTEMS	SEE EVA/SUIT				
1.2.2 ATMOSPHERE CONTROL	PROJECT PLAN				
1.2.3 MONITORING & CONTROL	FOR DETAILS				
1.2.4 SYSTEM INTEGRATION					
1.3 SYSTEMS CONTROL					
1.3.1 SYSTEMS MONITORING & CONTROL INSTR.	S				L
1.3.2 SYSTEMS CONTROL STRATEGY	L				S
1.4 SYSTEM INTEGRATION					
1.4.1 SYSTEM REQUIREMENTS	S	S	L		
1.4.2 P/C BIO SYSTEMS	L	S			
1.4.3 SYSTEMS ANALYSIS & ASSESSMENT	L	S	S	S	S
1.4.4 VALIDATION & VERIFICATION	L		S		S
1.4.5 SYSTEM TESTS	L		S		S
1.4.6 HUMAN-RATED TESTS	S		L		S

L = LEAD CENTER
S = SUPPORT CENTER

Code R – Exploration Technologies (Pathfinder)

Sensor Development Needs

- Water Quality Monitor (WQM) – on-line
  - Specific contaminants/mechanical properties
  - Improvement in Trace Organic Contaminant (TOC) sensitivity
- Water Quality Monitor (WQM) – off-line
  - Automation
- Trace gas analyzer
  - Automation
  - Turn-around time
- Specific hazardous gas sensors
  - Hydrogen
  - Methane
  - Other hazardous payload substances

Code R – Exploration Technologies (Pathfinder)

Other Need Areas

- Different Subsystem Selection Because of:
  - Space Station shortfalls
  - Design differences – e.g., propulsion other than O_2/H_2, venting allowed, 90-day resupply, photovoltaic power supply, etc.
  - Different weighting factors and priorities
    - power
    - weight
    - volume
    - other
  - New technology breakthroughs
    - automation improvements
    - improvements/maturing of existing P/C processes
    - advancements in P/C processes
    - CELSS

- System Differences
  - Mission scenarios different from the Space Station
  - Local resource usage capability
  - Mission isolation with no resupply

Code Z – Exploration Technologies

PD Directorate Transportation Studies Support

- Review Technical Content of Contract Studies
- Act as an Advisor to PD Personnel
- Support Reviews
- Provide PD/Contractor Personnel SSF Data and Consultation

Phase I Small Business Innovation Research Contract's

1. TITLE: **"Incipient Combustion Monitor for Zero Gravity Environments"**
   CONTRACT: TBD (SBIR '89 Phase I) CONTRACTOR: ADA Technologies, Inc.
   PERIOD OF PERFORMANCE: 1/90 – 7/90

   GOAL: To investigate the feasibility of using a dynamic expansion condensation nuclei chamber for the detection of submicron particles emitted when combustible materials are heated.

2. TITLE: **"A Reagentless Separator for Removal of Inorganic Carbon from Solution"**
   CONTRACT: TBD (SBIR '89 Phase I) CONTRACTOR: Umpqua Research Co.
   PERIOD OF PERFORMANCE: 1/90 – 7/90

   GOAL: To investigate removing inorganic carbon by first converting it to CO_2 using a solid–phase acidic material and then separating it using a CO_2 permeable membrane degasser.

3. TITLE: **"Thin Membrane Sensors"**
   CONTRACT: TBD (SBIR '89 Phase I) CONTRACTOR: Resource Technologies Group, Inc.
   PERIOD OF PERFORMANCE: 1/90 – 7/90

   GOAL: To investigate the feasibility of using a thin membrane sensor with controllable electrical properties to detect a variety of chemical and biological agents.

Phase II Small Business Innovation Research Contract's

TITLE: **"Removal of Contaminants From Experiment Waste Water Using Immobilized Enzymes"**
CONTRACT: NAS8-37642 (SBIR '87 Phase I) CONTRACTOR: Umpqua Research Co.
PERIOD OF PERFORMANCE: Phase I: 1/88 - 7/88, Phase II: 1/90 - 12/91

GOAL: To investigate the use of immobilized enzymes to enhance the removal of low molecular weight organic contaminants from the Process Materials Management System (PMMS) and ECLSS wastewaters

PHASE I RESULTS:

- Two enzymes were focused on:
  - urease (for removal of urea)
  - alcohol oxidase (for removal of methanol, ethanol, and related contaminants)
- Both enzymes successfully immobilized the contaminants
- Good performance was demonstrated

PHASE II PROPOSAL:

- Continue development to:
  - optimize enzyme preparation and immobilization methodologies
  - investigate synergistic effects through co-immobilization of complementary enzymes
  - investigate additional enzymes to broaden the range of contaminants removed
  - develop and test alternate reactor designs
  - perform long term parametric and life testing
  - fabricate and deliver prototype reactors to the MSFC for testing
- Contract awarded 12/89

University Involvement

University of Alabama in Huntsville –
"Identifying Critical Monitoring Tests for Recycled Water Systems"

University of Wisconsin –
Developing a Predictive Model of the Ecological Behavior of Microorganisms
Developing Techniques and/or Equipment Which Facilitate Rapid Monitoring of Microorganisms

Harvard (funding: 80% ARC, 20% MSFC) –
"Processes Involved in Microbial Biofilm Formation in Water Reclamation Systems for the Orbiting Space Station"

Georgia Institute of Technology –
"CO_2 Reduction Subsystem Combustion Kinetics"