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Space Station Evolution:
Beyond the Baseline

FREEDOM

Environmental Control and Life Support System Evolution Analysis

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Space Station *Freedom* ECLSS Evolution

I. Introduction: Space Station *Freedom* Evolution Impact on the ECLSS and Technology Development Needs

The Space Station *Freedom* Environmental Control and Life Support System (ECLSS) will have to accommodate the changes made to *Freedom* as it evolves over 30 years or more. Requirements will change as pressurized modules are added, crew numbers increase, and as the tasks to be performed change. This evolution will result in different demands on the ECLSS which will have to adapt to these changes. Technologies other than the baselined ones may be better able to perform the various ECLSS functions and technological advances will result in improved life support hardware better able to meet the new requirements.

Some requirements such as resupply limitations are not as stringent for *Freedom*, which is in low Earth orbit, compared to more distant missions such as returning to the Moon and venturing to Mars. But resupply is still expensive and reductions are highly desirable. For the Lunar and Mars missions resupply is essentially impossible and this aspect determines many of the requirements which differ from *Freedom's*. Since one role for *Freedom* will be to serve as a test facility for the ECLSS for Lunar and Mars missions the advances necessary for these missions can also benefit *Freedom*. Other requirements for these missions also will be more stringent in significant ways, such as reliability and autonomy of operation.

It is necessary to identify the areas where present technology is inadequate to meet the more stringent requirements in order to focus research and development efforts. This will ensure that the required technological capabilities are available when needed. Several areas where technology development is needed have been identified and this presentation will focus on these.

Space Station Evolution: Beyond the Baseline

Space Station *Freedom* ECLSS Evolution

Baseline ECLSS Design

- Changes in roles for SSF over 30 years
- Technology advances
- Test bed for Lunar/Mars mission hardware

Design Requirements for evolved ECLSS

- To prepare for these changes it is necessary to identify where technology development is needed.

- Several areas have been identified and are discussed below.

II. ECLSS Evolution Requirements

It is necessary to understand the ways in which the initial ECLSS will not meet the future requirements. By then comparing these future requirements with the technological capabilities now available, the areas where technology development is needed can be identified.

The questions to be answered are: What requirements of future missions will not be met by the initial ECLSS on *Freedom*? What technology development is needed to ensure that these requirements will be met?

Aspects of Space Station ECLSS evolution which are important and which are being evaluated, include the fluid, power, and thermal requirements of alternative technologies; the impacts of adding modules in various locations with regard to the intermodule ventilation system and maintaining acceptable concentrations of CO_2 and trace contaminants; and evaluating the evolution scenarios as more detail becomes available to determine the ECLSS requirements more specifically. This presentation will focus on the ECLSS technology development needs for Space Station *Freedom* evolution and related Lunar/Mars missions.

ECLSS Evolution Requirements

- What ECLSS requirements of future missions will <u>not</u> be met by the initial ECLSS on *Freedom*?
- What technology development is needed to ensure that these requirements will be met?
- Aspects of ECLSS evolution such as fluid, thermal, and power requirements of alternative technologies and the impacts of adding modules, are important and are being evaluated.
- This presentation will focus on technology development needs for Space Station *Freedom* evolution and related Lunar/Mars missions.

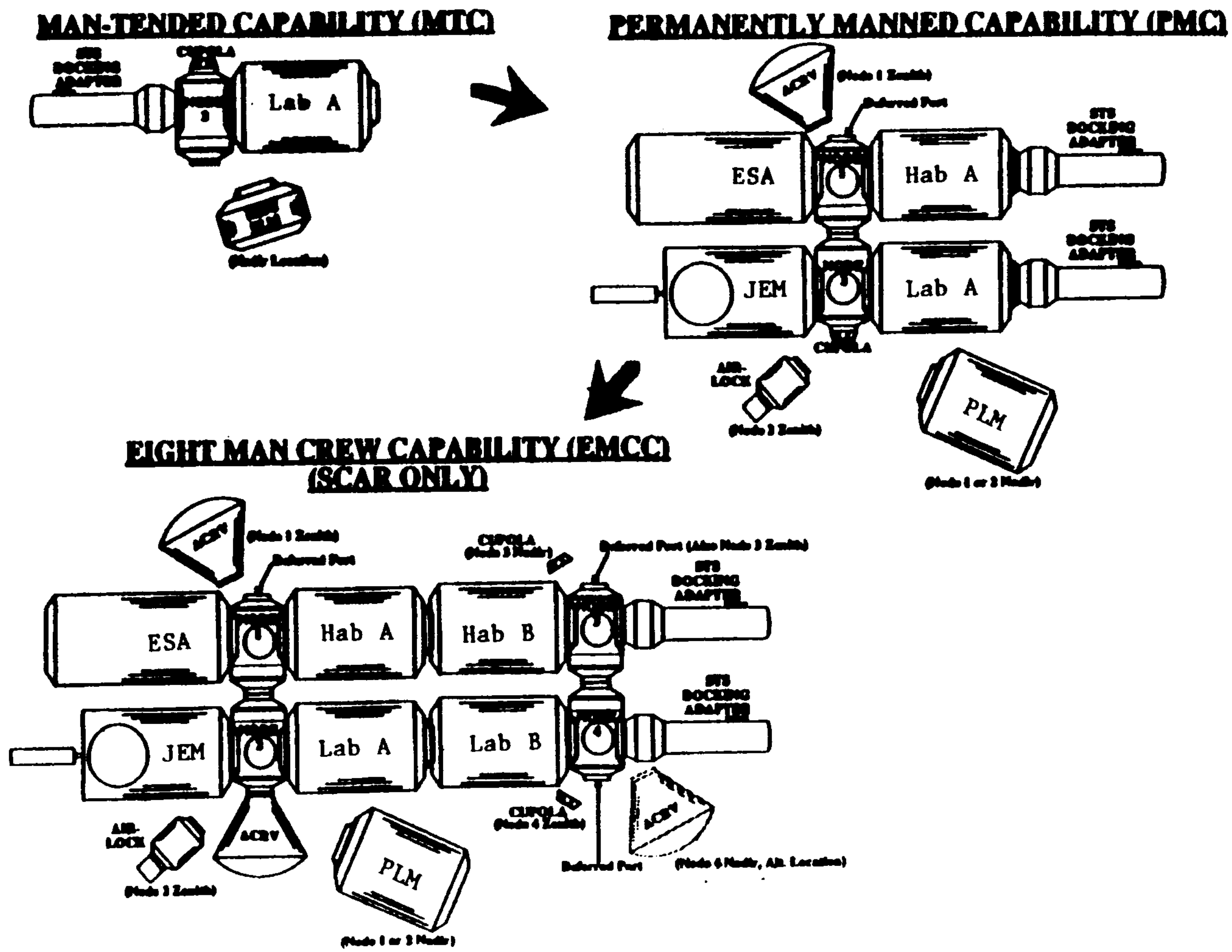
III. Space Station *Freedom* Assembly Phases

Freedom will become operational in a phased manner. The first operational phase is the MTC (Man-Tended Capability) which includes the "Lab A" module, one node, and a mini-pressurized logistics module (mini-PLM). The Shuttle is relied upon for life support functions.

The next phase is PMC (Permanently-Manned Capability) which will include the Japanese and European modules, the "Hab A" and "Lab A" modules, a second node, a full-sized PLM, and one Assured Crew Return Vehicle (ACRV). Some ECLSS functions are provided including water recovery and CO_2 removal.

At EMCC (Eight-Man Crew Capability) the "Hab B" and "Lab B" modules will be added and two additional nodes to complete a "racetrack" configuration. The O_2 loop will also be closed when the "B" modules are added.

Space Station *Freedom* Assembly Phases



IV. Space Station *Freedom* ECLSS Features

At the Permanently Manned Configuration (PMC) the water loop will be closed with the potable and hygiene water loops combined. Potable quality water will come from the Orbiter fuel cells to makeup for inefficiencies in the recycling process. The oxygen loop will be open with only CO_2 removal being performed (by a Four-Bed Molecular Sieve). The concentrated CO_2 will either be vented overboard or will be used by the propulsion system. Oxygen will be supplied from cryogenic storage tanks which will be resupplied every 90 days. All solid waste will be stored and returned to Earth. For this phase the module configuration requires the intermodule ventilation flow to be parallel into and out of each pressurized element.

For the Eight-Man Crew Configuration (EMCC) the water loop will be closed as for PMC. In addition, the O_2 loop will also be closed with CO_2 reduction by a Sabatier Subsystem and O_2 generation by a Static Feed Water Electrolysis Subsystem. In order to minimize the amount of "scarring" required to close the O_2 loop, the closed loop hardware will be contained in the "B" modules and the 4BMS in the "A" modules will become backups. As during PMC all solid waste will be stored and returned to Earth. With the addition of two more nodes connecting the "B" modules to make a "racetrack" the intermodule ventilation flow can be in series, which has some advantages, for this configuration, over parallel flow.

Space Station *Freedom* ECLSS Features

Permanently Manned Capability (PMC)

- Closed Water Loop with combined potable and hygiene water reclamation (makeup water will be obtained from the Orbiter fuel cells)
- CO_2 Removal will be performed by Four–Bed Molecular Sieves with the concentrated CO_2 vented or sent to the propulsion system
- O_2 will be supplied from cryogenic storage tanks
- All solid waste will be returned
- Open module pattern

Eight–Man Crew Capability (EMCC)

- Closed Water Loop with combined potable and hygiene water reclamation (makeup water will be obtained from the Orbiter fuel cells)
- CO_2 Removal will be performed by Four–Bed Molecular Sieves with the concentrated CO_2 delivered to a CO_2 reduction subsystem (Sabatier) for O_2 recovery
- O_2 will be generated by electrolyzing water (Static Feed Water Electrolysis Subsystem)
- Scarring will be minimized by having the closed O_2–loop hardware in the “B” modules, the 4BMS in the “A” modules will then become backup
- All solid waste will be returned
- Racetrack module pattern

V. Impacts on the ECLSS of Evolution Beyond EMCC

The distinctions and impacts on the ECLSS can be identified by evaluating two representative evolution scenarios: research facility and transportation node. The research facility is dedicated to scientific and commercial development research, with experiments inside the lab modules, mounted externally, and assembled externally as free flyers or for transfer to deep space. The transportation node is oriented toward assembly, maintenance, and repair of transfer vehicles for Lunar and Mars missions, with less research occurring.

Common factors of these evolution scenarios include an increase in the number of people with up to 30 for some scenarios, an increase in the number of EVA's performed to 52 to 250 per year of 8 hours each, additional modules and pressurized volume for laboratory or habitat space and logistics modules, increased power production to operate experiments or vehicle maintenance facilities, and safe haven considerations.

The details of these factors differ for each scenario, but the overall effects on the ECLSS are similar and can be summed up as: increased capability to process higher rates of mass, improved performance to operate more efficiently, and added functions to perform additional tasks such as solid waste processing.

Specific impacts on the ECLSS include: reducing the need for expendables such as reagents or filters, increasing the reliability of the hardware such as by eliminating rotating components, optimizing recovery of mass such as by eliminating venting or brine waste, and increasing autonomy of operation so the crew can use their time more productively.

Impacts on the ECLSS of Evolution Beyond EMCC

Common factors of the evolution scenarios
- Increased number of people (15 to 30 depending upon the scenario)
- Increased EVA (52 to 250 per year)
- Additional modules and pressurized volume (short modules plus nodes, logistics modules, "pocket" labs, etc.)
- Power availability (depends upon user requirements and production capacity)
- Safe haven considerations

Overall effects on the ECLSS requirements
- Increased capability
- Improved performance
- Added functions

Impacts on ECLSS design
- Reducing the need for expendables
- Increasing reliability of hardware
- Optimizing recovery of mass
- Increasing autonomy of operation

VI. Technology Development Needs

In several areas the ECLSS requirements for the growth scenarios exceed the capabilities of present ECLS technologies and additional development will be needed in order to ensure that future ECLSS requirements can be met.

Based on the experience with developing the ECLSS for *Freedom* and on evaluations of scenarios for future missions, ECLSS technology requirements for the evolving *Freedom* and future missions are being identified at MSFC.

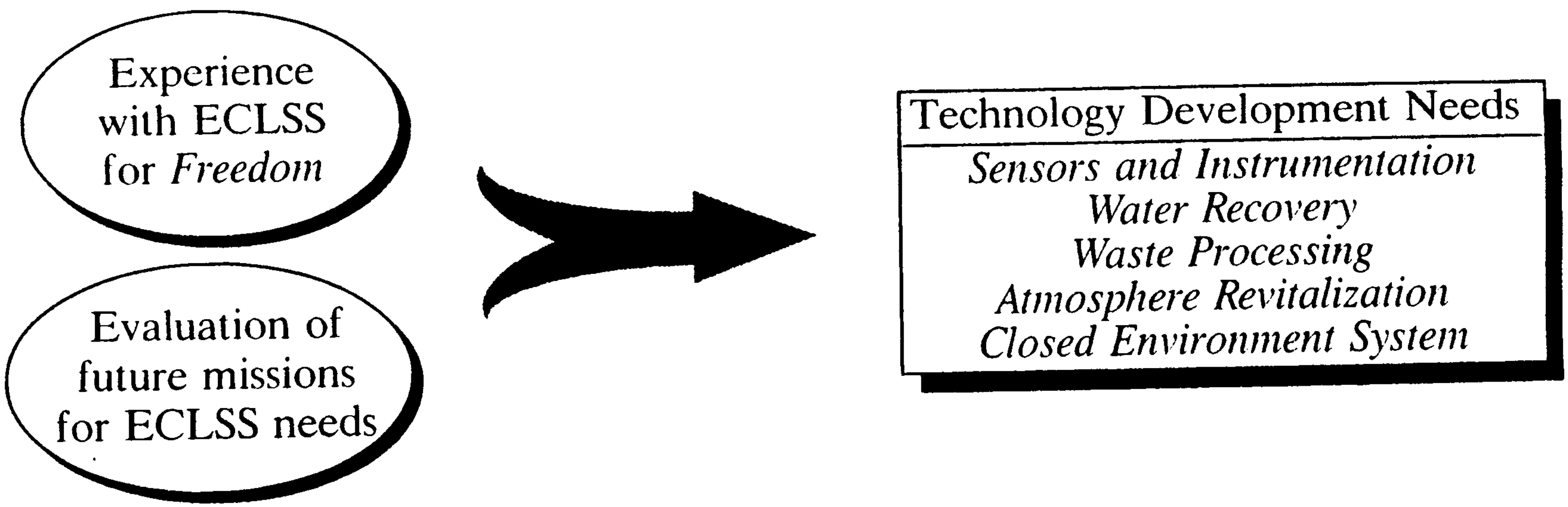
The technology development needs that have been identified at this time fall into five areas:

Sensors and Instrumentation
Water Recovery
Waste Processing
Atmosphere Revitalization
Closed Environment Systems

These needs have been prioritized and recommendations have been made for inclusion in the Office of Space Flight Technology Requirements Document.

The high and medium priority technology development needs are described below.

Technology Development Needs



- These needs have been prioritized and technologies recommended for inclusion in the Office of Space Flight Technology Requirements Document.
- The high and medium priority technology development needs are described below.

VI. Technology Development Needs (cont.)

Sensors and Instrumentation

Ensuring acceptable quality of recycled water is a major challenge for Space Station *Freedom* and will be an even greater challenge for Lunar/Mars missions. Great strides have been made at MSFC with the recent water recovery testing. Fifteen volunteers, who literally contributed their sweat, drank the purified water in a blind taste test which also included municipal water. Most thought the recycled water tasted better. Continued testing is expected to demonstrate that the water can be recycled repeatedly. Before the volunteers drank the water, however, numerous laboratory analyses were performed to ensure acceptable purity. On a long duration mission, especially to the Moon or Mars, we won't have the benefit of a laboratory full of analysis equipment. Nor will we want to wait a day or two to find out if the water is acceptable. For these reasons, on-line real-time instruments are needed to monitor microorganisms and chemicals. Two specific technology needs are described below.

Technology Development Needs (cont.)

Sensors and Instrumentation

Technology Need: On–Line Real–Time Microorganism and Chemical Monitor

Present Status: Present methods of microorganism monitoring are labor intensive, require large sample volumes, require large volumes of sterile reagents and nutrient solutions, generate biologically active wastes, and require 48 hours or more to confirm results. Chemical monitoring methods also are typically labor intensive and must be calibrated for specific compounds.

Technical Goal: A rapid, automated method which does not require large amounts of expendables is needed.

Technology Need: On–Line Monitor of Total Organic Carbon and Specific Organic Constituents in Water

Present Status: Total Organic Carbon (TOC) content is a significant parameter to determine the quality water. Present methods are limited in sensitivity and are not able to detect, identify, or quantify the constituents which contribute to the TOC content.

Technical Goal: An analyzer is required which can detect, identify, and quantify the constituents contributing to the TOC content. Of the 500 μg/l TOC allowable in potable water, at least 80% must be quantified to fully assess the medical acceptability of the water.

VI. Technology Development Needs (cont.)

Sensors and Instrumentation (cont.)

Monitoring of atmosphere quality, both major constituents and trace contaminants, is essential, but present methods require about 90 minutes to identify and quantify trace contaminants. A rapid method (10 minutes or less) with better resolution, range, and size than the present GC/MS is needed. Also the ability to monitor low mass compounds and identify O_2, CO_2, CH_4, and H_2 is needed. One method which may be able to meet the requirements is the ion trap MS/MS.

Technology Development Needs (cont.)
Sensors and Instrumentation

Technology Need: Improved Monitoring of Major Constituents and Trace Contaminants

Present Status: The present state-of-the-art method is the gas chromatograph/mass spectrometer method which requires about 90 minutes to analyze a sample and has limited resolution.

Technical Goal: Rapid (10 minutes or less) analysis of atmosphere samples with better resolution, range, and size than a GC/MS is needed. The capability of monitoring low mass compounds is necessary, as well as identifying O_2, CO_2, CH_4, and H_2. One method which can potentially meet these goals is the ion trap MS/MS.

VI. Technology Development Needs (cont.)

Water Recovery

In addition to water quality monitoring, improvements are also needed in processing waste water. Specifically, higher recovery efficiencies and reduction in expendables are needed. Two methods which are recommended for further development are the Air Evaporation System and Reverse Osmosis. The potential benefits of these methods are described below.

Technology Development Needs (cont.)

Water Recovery

Technology Need: Improved Water Recovery from Urine

Present Status: The baseline method of processing urine on *Freedom* is the Vapor Compression Distillation (VCD) subsystem which has an efficiency of 85 to 90%. The VCD contains precise, rotating components and flexible peristaltic pump tubing which are potential weaknesses with regard to long-term reliability.

Technical Goal: A higher rate of water recovery is needed to reduce resupply and storage penalties. The Air Evaporation System (AES) method has a recovery rate approaching 100% and has an inherently higher reliability than the VCD because of fewer moving parts. Improvements in the AES are needed with regard to power consumption and wick changeout.

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Technology Development Needs (cont.)

Water Recovery (cont.)

Technology Need: Improved Water Recovery from Waste Potable and Hygiene Water

Present Status: The baseline method of processing waste potable and hygiene water on *Freedom* is multifiltration which requires the use of expendable "unibeds." The recovery rate is 100%, but the expendables weigh 1 to 2% of the water processed.

Technical Goal: A method which requires <u>no</u> expendables is needed to reduce resupply and storage penalties. The Reverse Osmosis (RO) method has the potential to achieve a high recovery rate without requiring expendables. Improvements in the RO membrane are needed in order to:
(1) Improve fouling resistance to obtain water recovery efficiencies approaching 100% (the present efficiency is about 95%),
(2) Remove low molecular weight organic molecules, and
(3) Increase the high temperature tolerance to allow sterilization in place in the event of microorganism contamination.

VI. Technology Development Needs (cont.)

Waste Processing

Any mass (gas, liquid, solid, or heterogeneous) that is vented or stored is a liability by increasing the amount of mass that must be resupplied or stored from the beginning of a mission. Methods of processing these wastes to convert them into useable forms are required.

Technology Development Needs (cont.)

Waste Processing

Technology Need: Processing of Wastes to Recover Mass

Present Status: Gaseous wastes will be vented from *Freedom*. Solid wastes and hazardous liquid wastes will be stored for return to Earth. These methods result in loss of recoverable mass and require crew involvement in storing and transporting waste materials.

Technical Goal: Advanced methods of processing waste gases, liquids, and solids and heterogeneous wastes are required to recover water and gases. This would also reduce the amount of storage and resupply required.

VI. Technology Development Needs (cont.)

Atmosphere Revitalization

Controlling the level of trace contaminants to maintain low concentrations is very important for long duration missions, due to potential hazards of long term exposure to even small concentrations of some contaminants. The present method relies on adsorption on activated charcoal, catalytic oxidation, and absorption on LiOH. The power and resupply penalties of this method make it unsuitable for Lunar and Mars missions, and very expensive for *Freedom*. Smoke control presently relies on containing the smoke in a single module and venting the atmosphere after a major smoke event. This is acceptable on *Freedom* where the crew can return to Earth if the contingency atmosphere is used up, but for a Lunar or Mars mission this approach could be disastrous. A regenerable method of removing trace contaminants, including smoke, quickly and reliably is needed.

Technology Development Needs (cont.)

Atmosphere Revitalization

Technology Need: Trace Contaminant Removal and Smoke Control

Present Status: The present trace contaminant removal method is activated charcoal, catalytic oxidation, and LiOH pre– and post–sorbent beds. This approach, while effective, requires high temperatures and, for long duration missions, large quantities of LiOH and charcoal sorbent materials. This method has only limited capabilities with regard to cleanup after a fire or spill of hazardous substances. Presently, smoke control relies on containing the smoke in a single module and venting the atmosphere after a major smoke event.

Technical Goal: Regenerable sorbents for trace contaminant control and smoke removal with improved abilities to desorb to space vacuum are needed.

VI. Technology Development Needs (cont.)

Atmosphere Revitalization (cont.)

At EMCC *Freedom* will have a closed O_2 loop, but with the Sabatier reactor for CO_2 reduction mass will be lost as CH_4. The Bosch reactor and the Carbon Formation Reactor are two methods by which the hydrogen can be recovered (as water) leaving only solid carbon. Even though solid waste remains, this is a step toward complete recovery of mass. Additional development is required in order to perfect the Bosch and CFR reactors.

The efficiency of the Bosch and CFR reactions is adversely affected by inert gases (N_2) in the concentrated CO_2 supply. The present 4BMS product CO_2 contains about 2% N_2. A method of reducing this level to less than 1% is needed to increase the performance of the CO_2 reduction subsystem.

Technology Development Needs (cont.)

Atmosphere Revitalization (cont.)

Technology Need: Improved Recovery of O_2 From CO_2

Present Status: The baseline AR for *Freedom* in the PMC is the Four–Bed Molecular Sieve for CO_2 removal only, and venting of the CO_2 to space. For the EMCC a Sabatier CO_2 reduction subsystem will produce methane (to be vented or used for propulsion) and water (to be electrolyzed or added to the potable water supply). The mass loss due to venting methane can be substantial and requires resupply of water to make up the hydrogen loss.

Technical Goal: Closure of the O_2 loop requires recovering O_2 from CO_2 and hydrogen from the CO_2 reduction process. The Bosch and Carbon Formation Reactor are two methods of doing this which leave only solid carbon as a residue. Further work is needed to perfect them including researching reactor kinetics to better understand the reaction processes.

Technology Need: Improved Separation of Inert Gases From CO_2

Present Status: Presently the concentrated CO_2 produced by the Four–Bed Molecular Sieve contains about 2% inert gases (primarily N_2) which reduce the efficiency of the CO_2 reduction subsystems.

Technical Goal: Removal of inert gases to levels below 1% by membrane separation or other methods is needed to allow optimum performance of the CO_2 reduction subsystem.

VI. Technology Development Needs (cont.)

Closed Environment System

Some technology needs apply to the closed environment system as a whole.

The ECLSS for *Freedom* contains many rotating components: pumps, blowers, rotating drums, etc. which generate noise. Long duration missions such as *Freedom* and Lunar/Mars missions will have lower allowable noise levels than previous missions due to physiological effects of exposure to continuous noise. Insulation can reduce the amount of noise transmitted but reducing the amount of noise generated would reduce the need for insulation and simplify packaging and maintenance procedures. Noise also indicates inefficiencies and energy losses.

Technology Development Needs (cont.)

Closed Environment System

Technology Need: Component Noise Reduction

Present Status: Presently, sound insulation material is used to minimize noise from pumps, fans, compressors, and other rotating equipment. Long duration missions such as *Freedom* and Lunar/Mars missions will have lower allowable noise levels than previous missions due to physiological effects of exposure to continuous noise. Noise also indicates inefficiencies and energy losses.

Technical Goal: Rotary equipment which generates little noise and requires little or no sound insulation.

VI. Technology Development Needs (cont.)

Closed Environment System (cont.)

Minimization of leakage is very important on long duration missions and allowable leakage limits will decrease. The capability of detecting leaks ranging from 0.05 to 1.0 lb/day is needed. Also the ability to identify the location of a leak is needed.

Particulate contaminants can also be a significant problem and improvements are needed over the present time-consuming microscopic examination process. On *Freedom* the process will be partly automated but additional improvements are needed to monitor specific size ranges of particles (0.5 to 10 microns, 10 to 100 microns, etc.), the mass density, and the total count.

Technology Development Needs (cont.)

Closed Environment System (cont.)

Technology Need: Leak Detection

Present Status: Current leak detection methods for the Space Shuttle Orbiter are a dP/dT sensor on orbit and a pressure decay test during preflight checkout. For *Freedom* the mass loss will be calculated from the total pressure and temperature. Identification of the location of a leak is not automatically performed.

Technical Goal: An advanced leak detection system capable of detecting leakage ranging from 0.05 to 1.0 lb/day is needed. The capability of identifying the location of a leak is also needed.

Technology Need: Particulate Contamination Monitor

Present Status: Present methods used on the Shuttle rely on crew detection by microscopic examination, which is a time consuming process. On *Freedom* a light scattering diode laser will measure the total count in the 0.5 to 100.0 micron range on a continuous basis and microscopic examination will be done periodically (e.g., weekly).

Technical Goal: A particulate monitor is needed which can monitor specific size ranges of particles (e.g., 0.5 to 10 microns and 10 to 100 microns), the mass density, and the total count.

VII. Technology Development Priorities

The technology development needs reviewed here are the ones which have been identified as "high" or "medium" priority.

The "high" priority development needs are:

- On-Line Real-Time Microorganism and Chemical Monitor
- Processing of Wastes to Recover Mass
- Trace Contaminant Removal and Smoke Control
- Component Noise Reduction

The "medium" priority development needs are:

- On-Line Monitor of Total Organic Carbon and Specific Organic Constituents in Water
- Improved Monitor of Major Constituents and Trace Contaminants
- Improved Water Recovery from Urine: Air Evaporation Subsystem
- Improved Water Recovery from Waste Potable and Hygiene Water: Advanced Reverse Osmosis
- Improved Recovery of O_2 from CO_2
- Improved Separation of Inert Gases from CO_2
- Leak Detection
- Particulate Contamination Monitor

It is recommended that development efforts be focused on these, especially the "high" priority ones, to meet the requirements of *Freedom* as it evolves over its thirty-year lifetime.

Technology Development Priorities

Priority	Technology Development Need
	Sensors and Instrumentation
High	On–Line Real–Time Microorganism and Chemical Monitor
Medium	On–Line Monitor of Total Organic Carbon and Specific Organic Constituents in Water
Medium	Improved Monitor of Major Constituents and Trace Contaminants
	Water Recovery
Medium	Improved Water Recovery from Urine: Air Evaporation Subsystem
Medium	Improved Water Recovery from Waste Potable and Hygiene Water: Advanced Reverse Osmosis
	Waste Processing
High	Processing of Wastes to Recover Mass
	Atmosphere Revitalization
High	Trace Contaminant Removal and Smoke Control
Medium	Improved Recovery of O_2 from CO_2
Medium	Improved Separation of Inert Gases from CO_2
	Closed Environment System
High	Component Noise Reduction
Medium	Leak Detection
Medium	Particulate Contamination Monitor