NASA/TM—2003-212598

National Aeronautics and Space Administration

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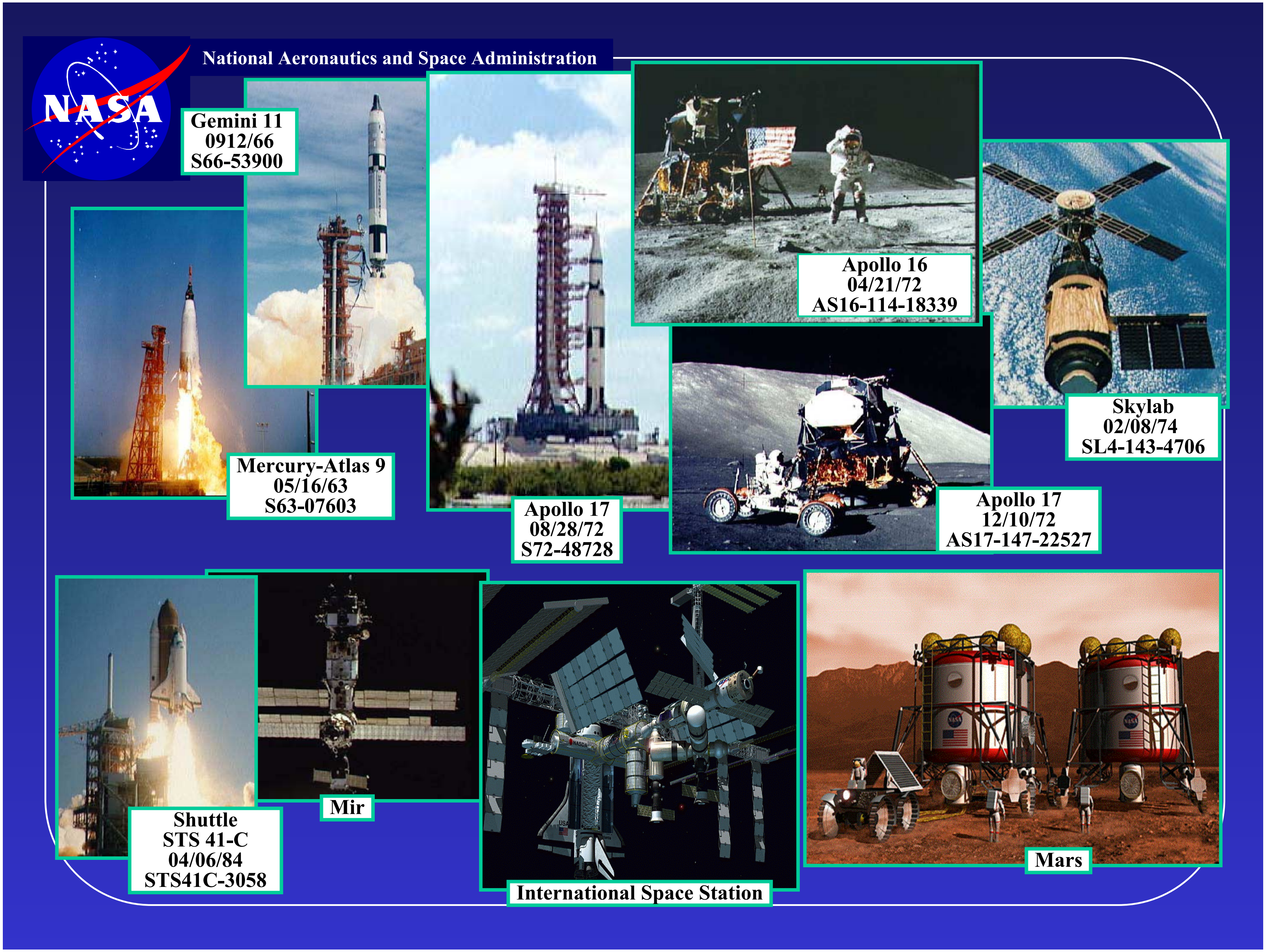
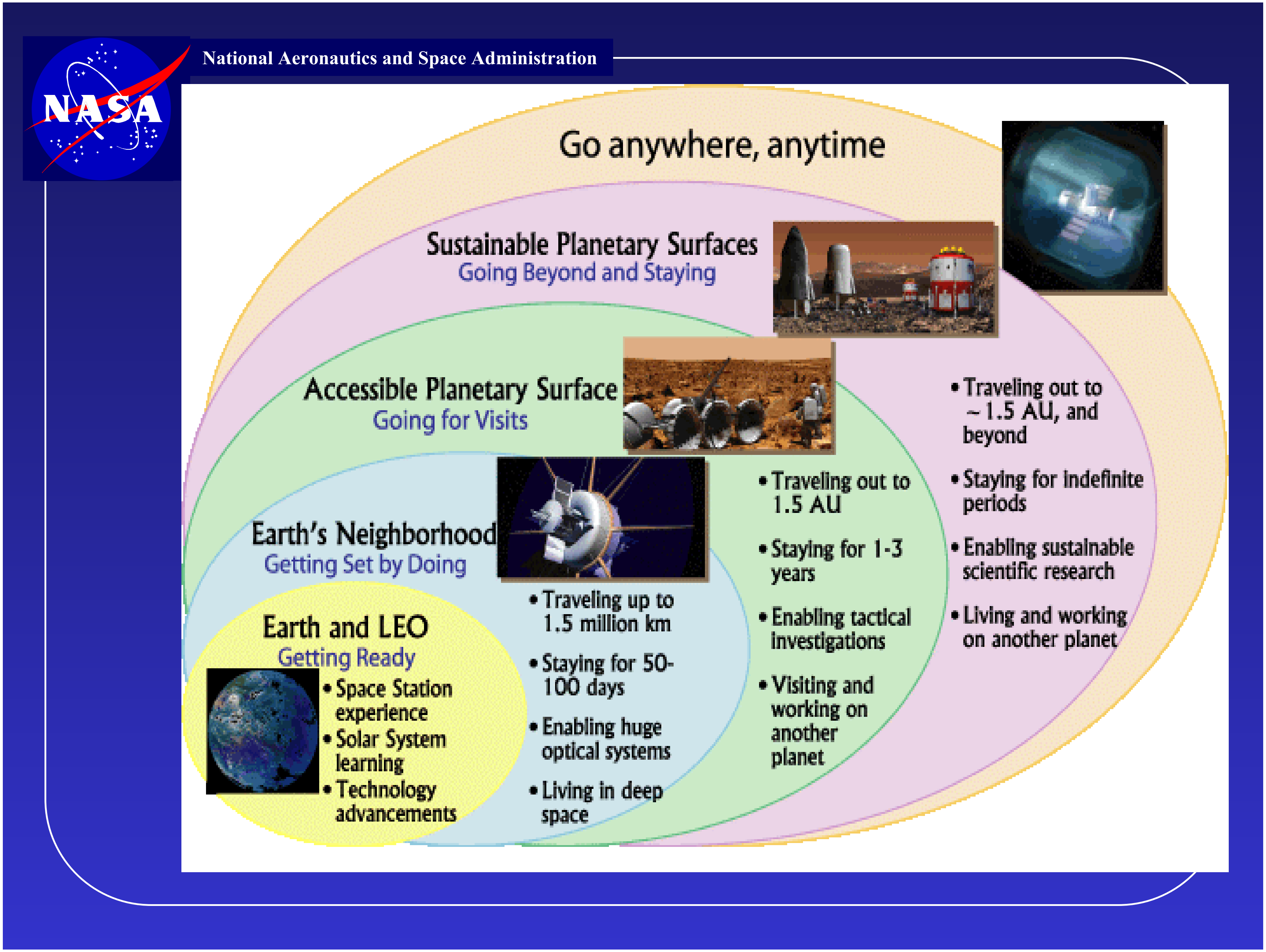

National Aeronautics and Space Administration
NASA
Gemini 11
0912/66
S66-53900
Mercury-Atlas 9
05/16/63
S63-07603
Apollo 17
08/28/72
S72-48728
Apollo 16
04/21/72
AS16-114-18339
Apollo 17
12/10/72
AS17-147-22527
Skylab
02/08/74
SL4-143-4706
Shuttle
STS 41-C
04/06/84
STS41C-3058
Mir
International Space Station
Mars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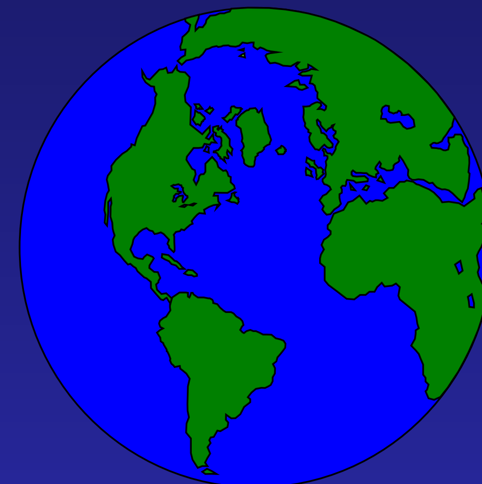
Go anywhere, anytime
Sustainable Planetary Surfaces
Going Beyond and Staying
Accessible Planetary Surface
Going for Visits
Earth's Neighborhood
Getting Set by Doing
Earth and LEO
Getting Ready
• Space Station experience
• Solar System learning
• Technology advancements
• Traveling up to 1.5 million km
• Staying for 50-100 days
• Enabling huge optical systems
• Living in deep space
• Traveling out to 1.5 AU
• Staying for 1-3 years
• Enabling tactical investigations
• Visiting and working on another planet
• Traveling out to ~1.5 AU, and beyond
• Staying for indefinite periods
• Enabling sustainable scientific research
• Living and working on another planet

Advanced Life Support



- Duplicate the functions of the Earth in terms of human life support
- Without the benefit of the Earth's large buffers --- oceans, atmosphere, and land masses
- Question is one of how small can the requisite buffers be and yet maintain extremely high reliability over long periods of time in a hostile environment
- Space-based systems must be small, therefore must exercise high degree of control

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Advanced Life Support

- Enabling technology for human exploration and development of space
- Long-duration missions dictate regenerative systems --- minimize re-supply
- Minimize mass, volume, power, thermal requirements
- Such systems will be replete with physicochemical and biological components

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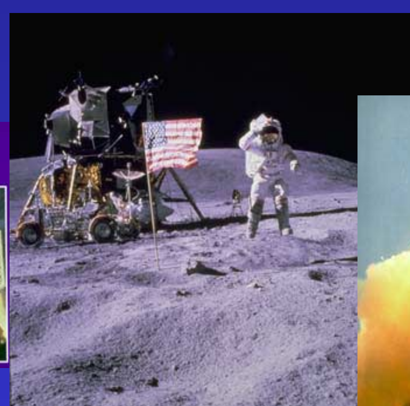
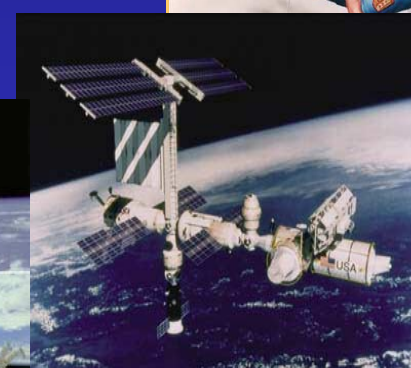
Systems Integration, Modeling, and Analysis

- **Mission objectives drive the functional requirements of Advanced Life Support technology development.**
  - **Systems Engineering enables R&TD efforts to meet the functional requirements the best way possible.**
    - **Identification and evaluation of feasible designs**
    - **Performance of technology/configuration trade studies**
    - **Optimization of operational strategies**
    - **Provide guidance for future R&TD efforts**





Progressive Capabilities

Transportation | Power | Robotic and Human Ops | Health and Safety | Space Systems

Earth's Neighborhood Capability

- Current launch systems Payload: 40mt
- In-space propulsion, Isp>1000 sec, high thrust
- Power systems, >200 w/kg
- Integrated Human/ robotic capabilities
- Crew countermeasures for 100 days
- Closure of water/air systems
- Materials, factor of 9
- IVHM - Integrated Vehicle Health Monitoring

Accessible Planetary Surface Capability

- ETO $/kg (under review) Payload: ~100mt
- In-space propulsion, Isp>3000 sec, high thrust
- Power systems, >500 w/kg
- Robotic aggregation/assembly
- Crew countermeasures for 1-3 years
- Complete closure of air/water; options for food
- Materials, factor of 20
- Micro-/Nano- avionics

Sustainable Planetary Surface Capability

- ETO $/kg (under review) Payload: 100+mt
- In-space propulsion, Isp>3000 sec, high thrust
- Sustainable power systems
- Intelligent systems, orbital and planetary
- Crew countermeasures for indefinite duration
- Closure of life support, including food
- ISRU for consumables & spares
- Materials, factor of 40
- Automated reasoning and smart sensing

Now **2010+** **2020+** **2030+**

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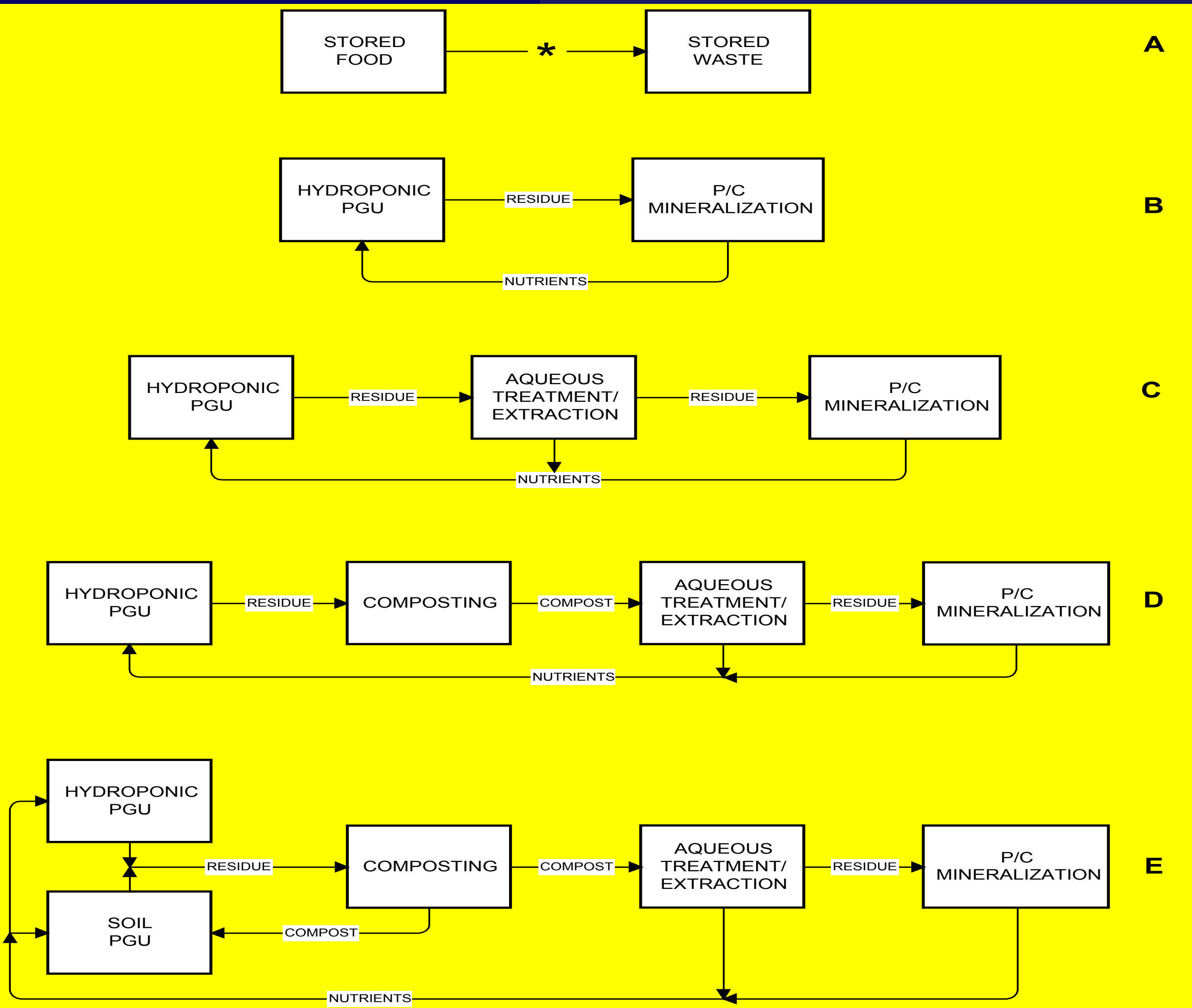
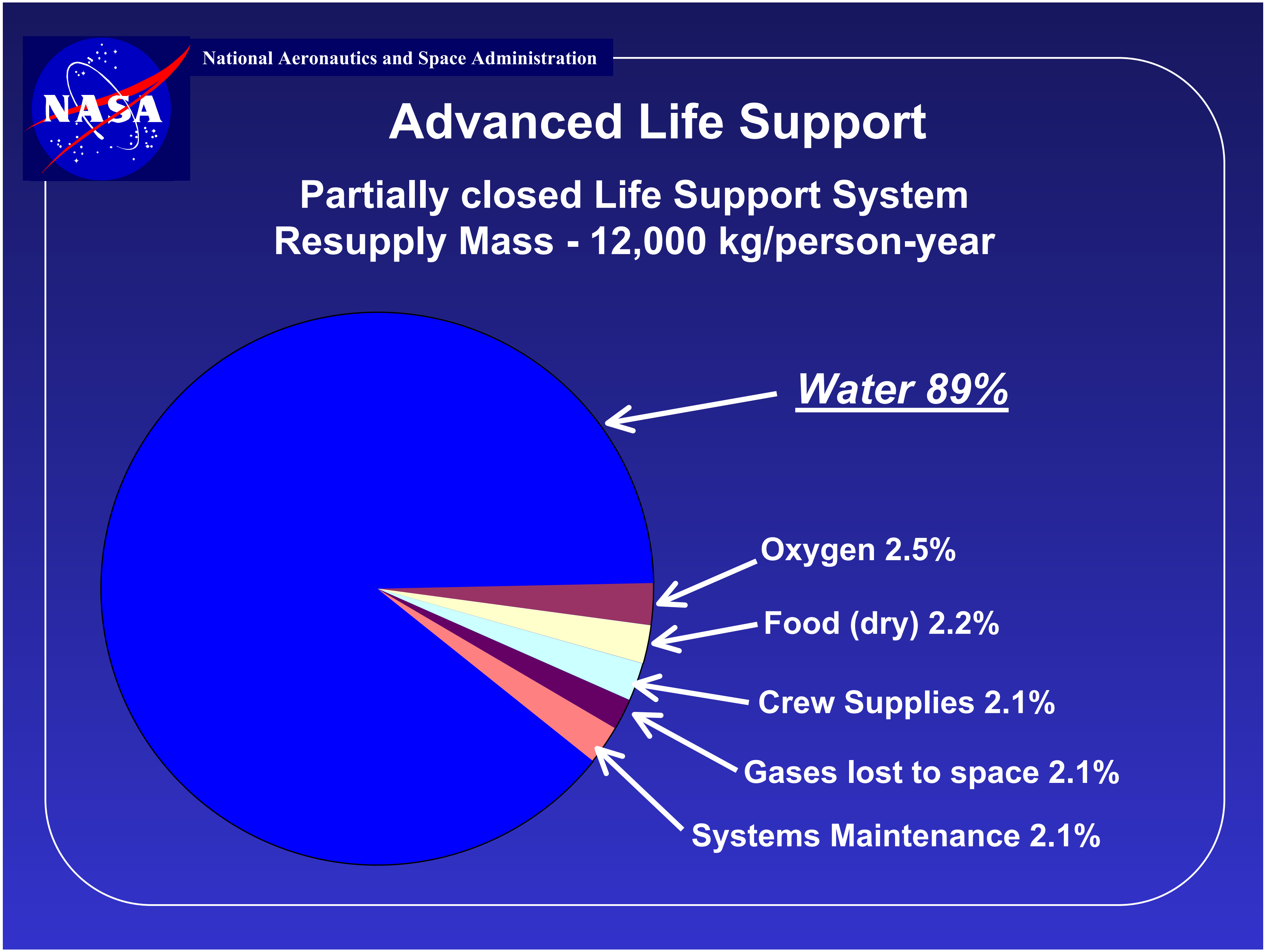


* = Incorporation of food regeneration in ALS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NASA
Advanced Life Support
Partially closed Life Support System
Resupply Mass - 12,000 kg/person-year
Water 89%
Oxygen 2.5%
Food (dry) 2.2%
Crew Supplies 2.1%
Gases lost to space 2.1%
Systems Maintenance 2.1%

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Water Processing

- Goal is to develop a processing system that is capable of generating potable water.
- Current baseline recycles only a fraction of the water at the cost of expendables and power.
- Future technologies (VPCAR, biological processors) have to be optimized for microgravity compatibility.

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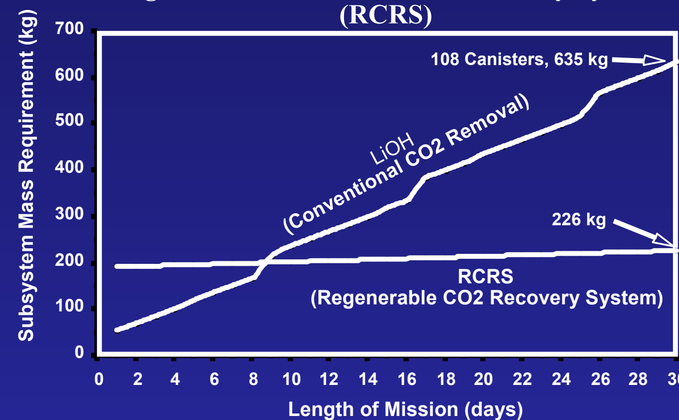
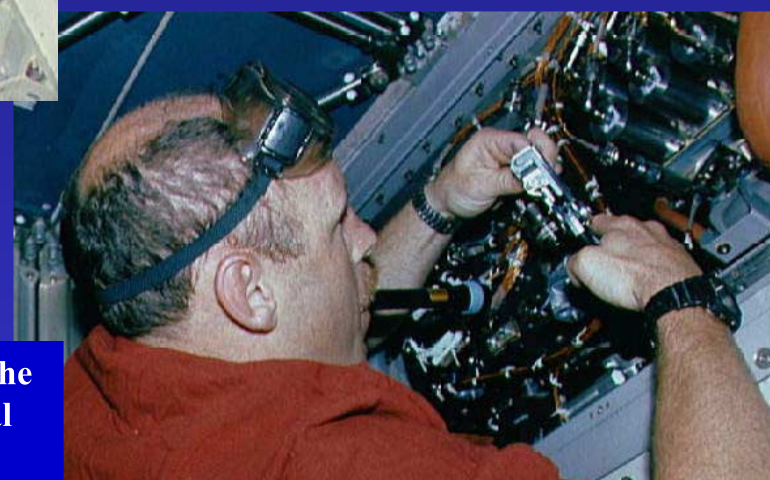
Air Revitalization Systems

Commander Lousma replaces
ARS LiOH
canisters on middeck
S82-28921 03/31/82

Mass Savings Using a Regenerative Physicochemical Subsystem: Shuttle Regenerable Carbon Dioxide Recovery System (RCRS)





Mission Pilot Ken Bowersox repairing the Regenerative Carbon Dioxide Removal System wiring.
07/09/92 STS050-20-012

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Why Advanced CO_2 Removal Technologies?

- The ISS CO_2 removal subsystem has the highest power penalty of any ISS life support subsystem (~ 3200 W-hr/kg CO_2). Current technology has a thermodynamic efficiency of about 3%.

- Current CO_2 removal & reduction technology in closed-loop mode (with Sabatier/oxygen recovery) will require ~ 5400W-hr/kg CO_2.

- Life scientists are calling for lower CO_2 levels on International Space Station.
  - ISS requirement is 7000 ppm, compared to ~400 ppm Earth-normal
  - Achieving lower concentrations translates directly into more energy consumption.
  - Power will be an extremely critical resource for a Mars transit vehicle.
  - The Mars Reference Mission would use a solar-powered transit vehicle with total estimated available power of 30 kW; 12 kW for ECLS

- Develop CO_2 removal technology that consumes 10x less power than current Space Station technology for same performance.
  (or maintains substantially lower concentrations of CO_2 for no increase in power)

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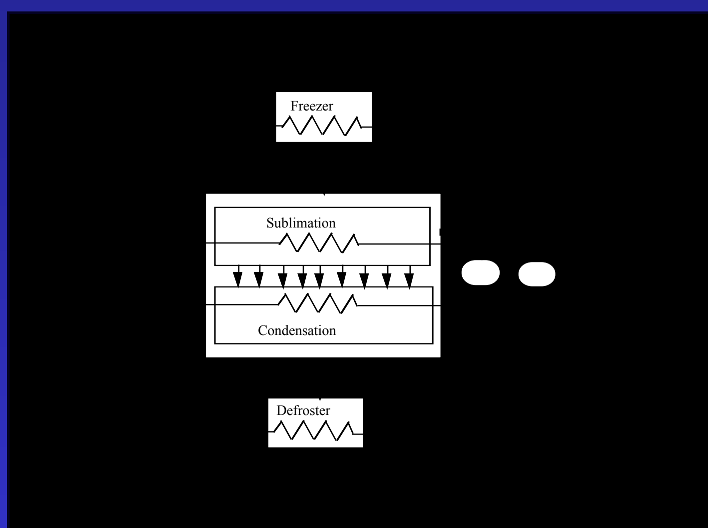
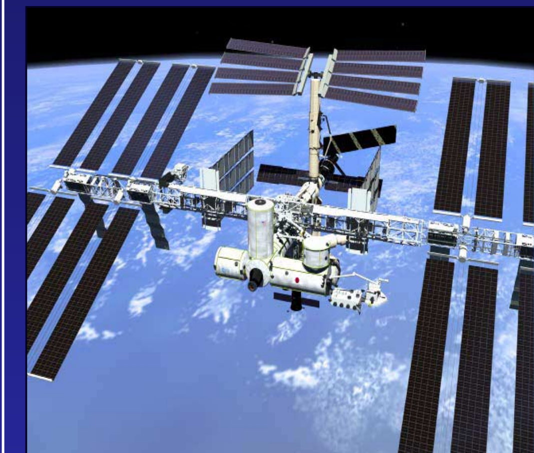
Solid Waste Resource Recovery Systems: Lyophilization

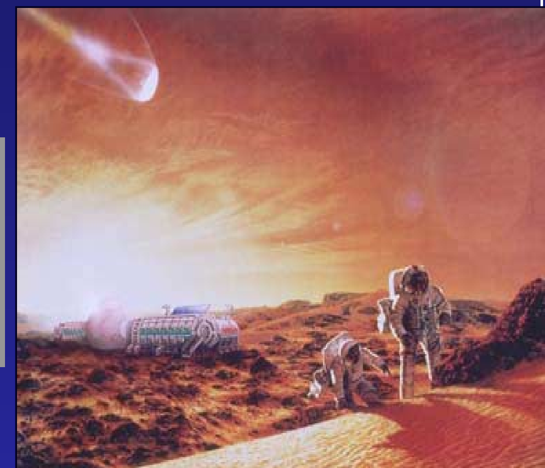
- **Low pressure, low temperature process** **(potential for low power operation).**
- **Complex solids pumping or handling techniques are not required.**
- **The technique should not produce CO_2, NO_x, SO_x, or any other undesirable oxidation byproducts** **(gases generated are primarily water vapor).**
- **The final product is a stable dried material with 1 to 3% H_2O.**
- **The approach is fully regenerable, meaning that the process requires no consumables, only energy.**



ISRU Technologies for Mars Life Support



Self-Sufficiency Options for Life Support



Complete regeneration
No leaks
Total closure (100%)

Relatively relaxed closure and leakage requirements, reliance on local resources (ISRU)

Design Drivers are

- **Reduced mass and power**
- **Increased safety and reliability**

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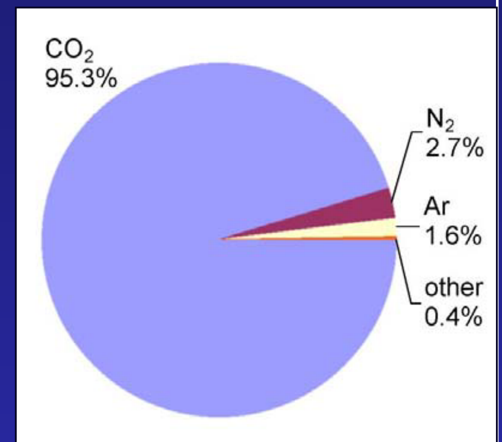
Atmospheric Resources of Mars

Mars Pathfinder, 1997



Mars atmosphere composition

- Pressure: ~1% of Earth's
- Temperature: 180 – 290 K (equatorial)
- Dusty, windy

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N_2 Consumables / Make-up for Mars Life Support

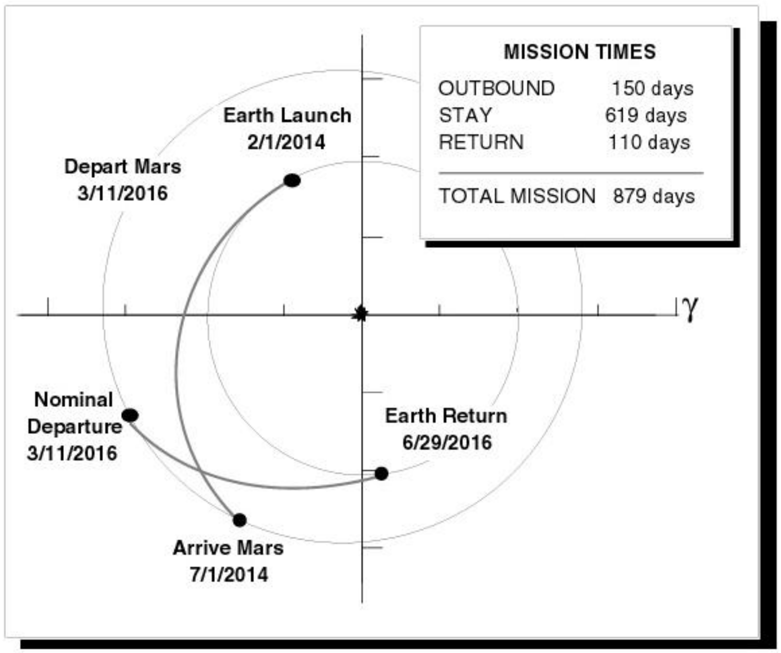

Figure 3-4 Fast-transit mission profile

NASA SP 6107, Mars Reference Mission, 1997.

- <u>Transit Leakage Losses:</u>
- 0.1 kg/day leakage,
- 260 days = 26 kg N_2

- <u>Surface Leakage Losses:</u>
- 0.1 kg/day leakage,
- 619 days = 62 kg N_2

- <u>Surface/Airlock Losses:</u>
- 1 kg/cycle, 2 cycles/day,
- 619 days = 1200 kg N_2

- <u>Total Mission N_2 Losses:</u>
- ~1.3 tonnes N_2 lost
- (2x safety factor = 2.6 tonnes)

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Integrated Test beds

Why do we need integrated test beds?

- Allows for validating a subsystem in a relevant environment
- Subsystems get exposed to off-nominal loads which allows for testing the limits that the system can effectively tolerate
- Effect of the test article on the optimal functioning of other subsystems
- Subsystems get exposed to real streams which can not be simulated in laboratory studies

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INTEGRITY

Integrated Human Exploration Mission Simulation Facility

SUMMARY

- Human exploration missions are very complex and risky – duration and distance from Earth
- Integration issues are difficult to identify
- Individual technologies & systems have inherent risk
- Integration of all systems & procedures on the ground will allow risk to be more effectively managed
- Integrated procedures can be developed and validated

- Definition of "missions" provides focus for R&D
- INTEGRITY is a cost-effective way to prepare for future human exploration missions beyond low earth orbit
- INTEGRITY will facilitate:
  - ✓ Development of improved management techniques, including cost & risk estimation
  - ✓ International, Commercial, Academic partnering
  - ✓ Education & Public involvement
  - ✓ Re-invigorate NASA workforce
    - Recruiting tool

Visitors' viewing area

24 April 2003

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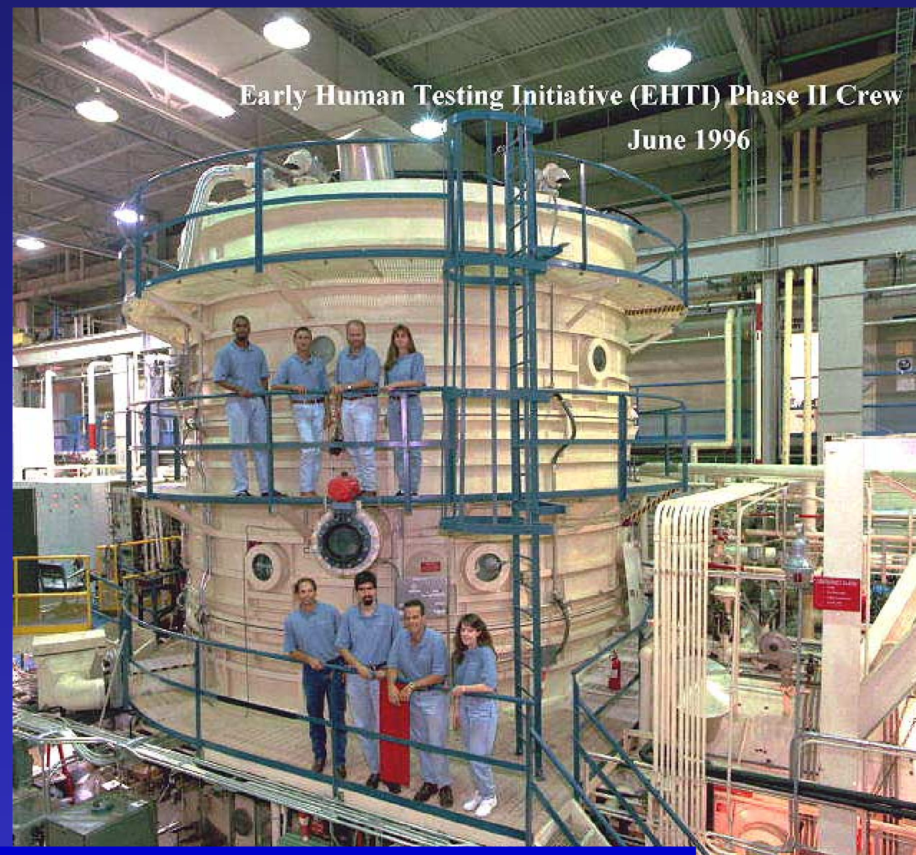
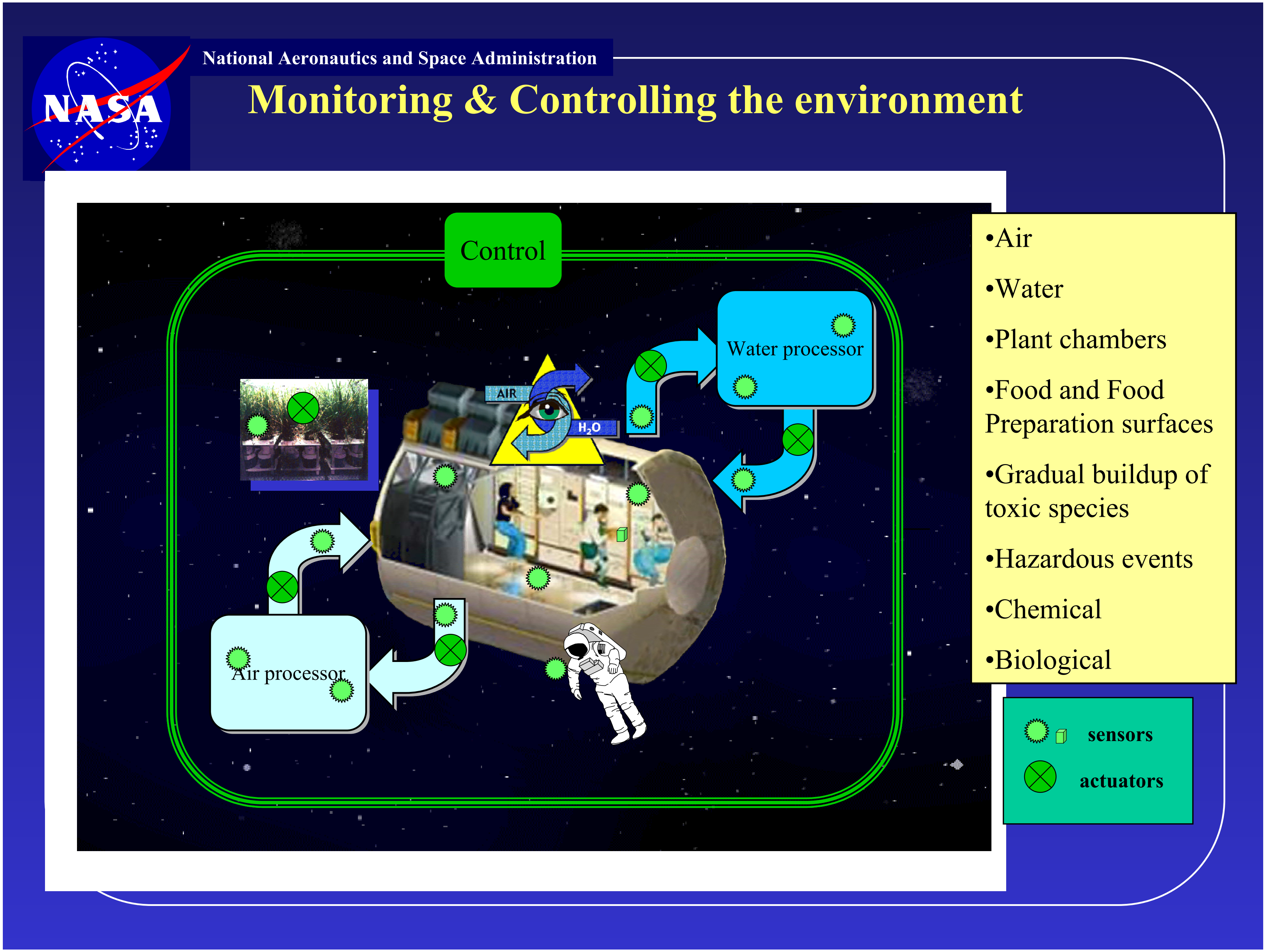
Advanced Life Support

Lunar - Mars Life Support Project

**Phase I: 15-day, 1-Person Test
March 1995**



Phase II: 30-day, 4-Person Test - June 1996
Phase IIA ISS: 60-day, 4-Person Test - January 1997
Phase III: 90-day, 4-Person Test - September 19, 1997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NASA
Monitoring & Controlling the environment
Control
Water processor
AIR
H_2O
Air processor
•Air
•Water
•Plant chambers
•Food and Food Preparation surfaces
•Gradual buildup of toxic species
•Hazardous events
•Chemical
•Biological
sensors
actuators

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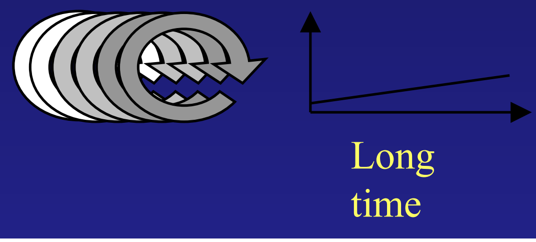
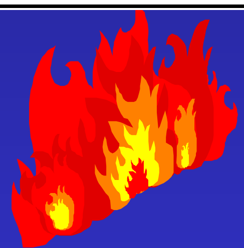


COMPOUND	DETECTION LIMIT
PRIORITY 1	PPM
Acetaldehyde	0.1
Formaldehyde	0.01
Methanol	0.2
Dichloromethane	0.03
Perfluoropropane (F218)	10
Acetone	1
Octamethylcyclotetrasiloxane	0.05
2-Propanol	3
Freon 82	5



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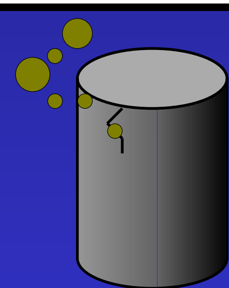

*microgravity combustion not shown

Gradual buildup of harmful chemical or microbials

Hazardous event such as fire or leakage

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Ground-based Commercial technology





- High mass
- High power requirement
- High operator skill
- High capability
- May require gravity

- Lower mass
- Lower power requirement
- Low operator skill
- Low capability
- May require gravity

•Breakthroughs needed to achieve high capability and low mass/power plus autonomy

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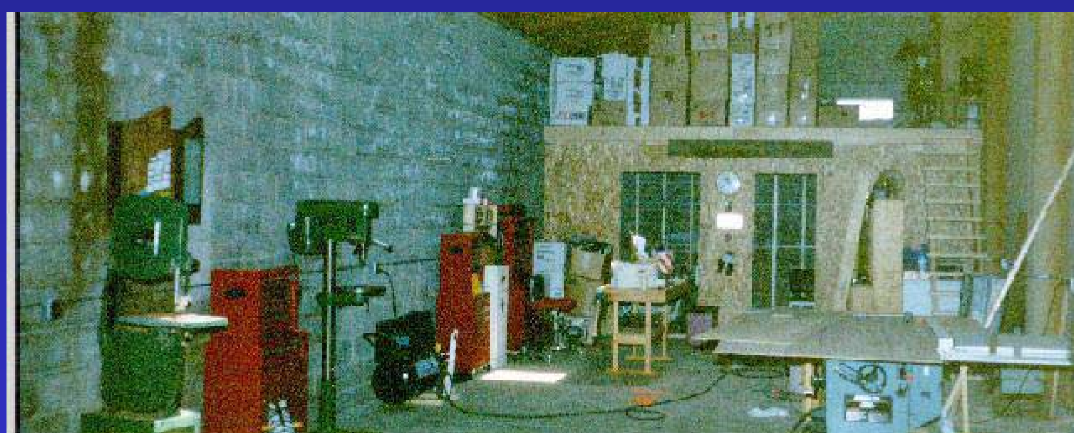
Optimizing Size vs Capability



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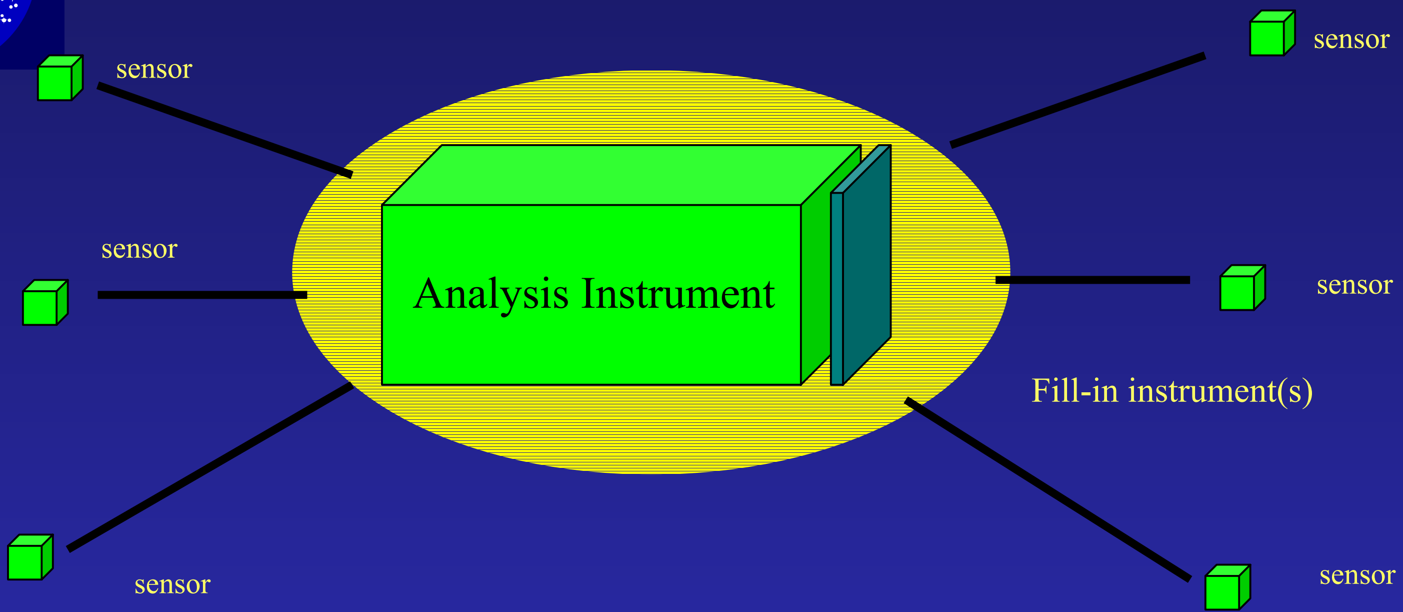
AEMC Vision: Hierarchical monitoring/control



- Analysis Instrument: eg GCIMS, GCMS, FTIR
  - Analyzes for almost everything
  - Complex, expensive (although low mass)
  - Probably only one on board
  - "Fill-in" covers the few things that the Analysis Instrument doesn't cover (eg, formaldehyde, O_2, CO_2…)
    - eg TDL, SERS
- Sensor is simpler, cheaper, more robust
  - May be fixed or portable
  - Much more capable than off the shelf
  - eg Enose, Bioarray

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Some Top level Issues for Wastes Processing

- Gas-liquid Separation
  - All P/C, Bio water treatment systems
  - Humidity control systems
- Solid-liquid Interactions
  - Settling problems in Bio and P/C systems
  - Optimal functioning of P/C systems
- Thermal Control
  - Heat Rejection
  - Heat Transport

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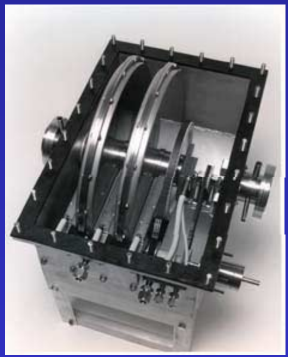
Water Recovery Systems Flight Verification Topics

- Thermal properties of thin fluid films
- Two phase flow in open chambers
- Splashing in liquid/gas boundaries
- Centrifugal separations, what occurs during start and stop events
- Pumping of saturated fluids
- Surface tension directed flow stability



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Water Recovery Systems Flight Verification Topics (Cont.)

- Reaction kinetics in packed beds, effects of channeling and condensation
- Stability of packed beds during launch
- Deterioration of packed beds during operation
- Lubrication of rotating gears

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Issues for Plant Growth Systems

- Delivery of adequate water and oxygen to rooting systems
- Recovery and recycling of transpired water from plant systems (typically can expect ~5 L $m^{2/}$day)
- Liquid / gas phase separation issues for both water delivery and retrieval systems
- Maintain adequate air flow around leaves and "soil" surface to offset lack of thermal stirring

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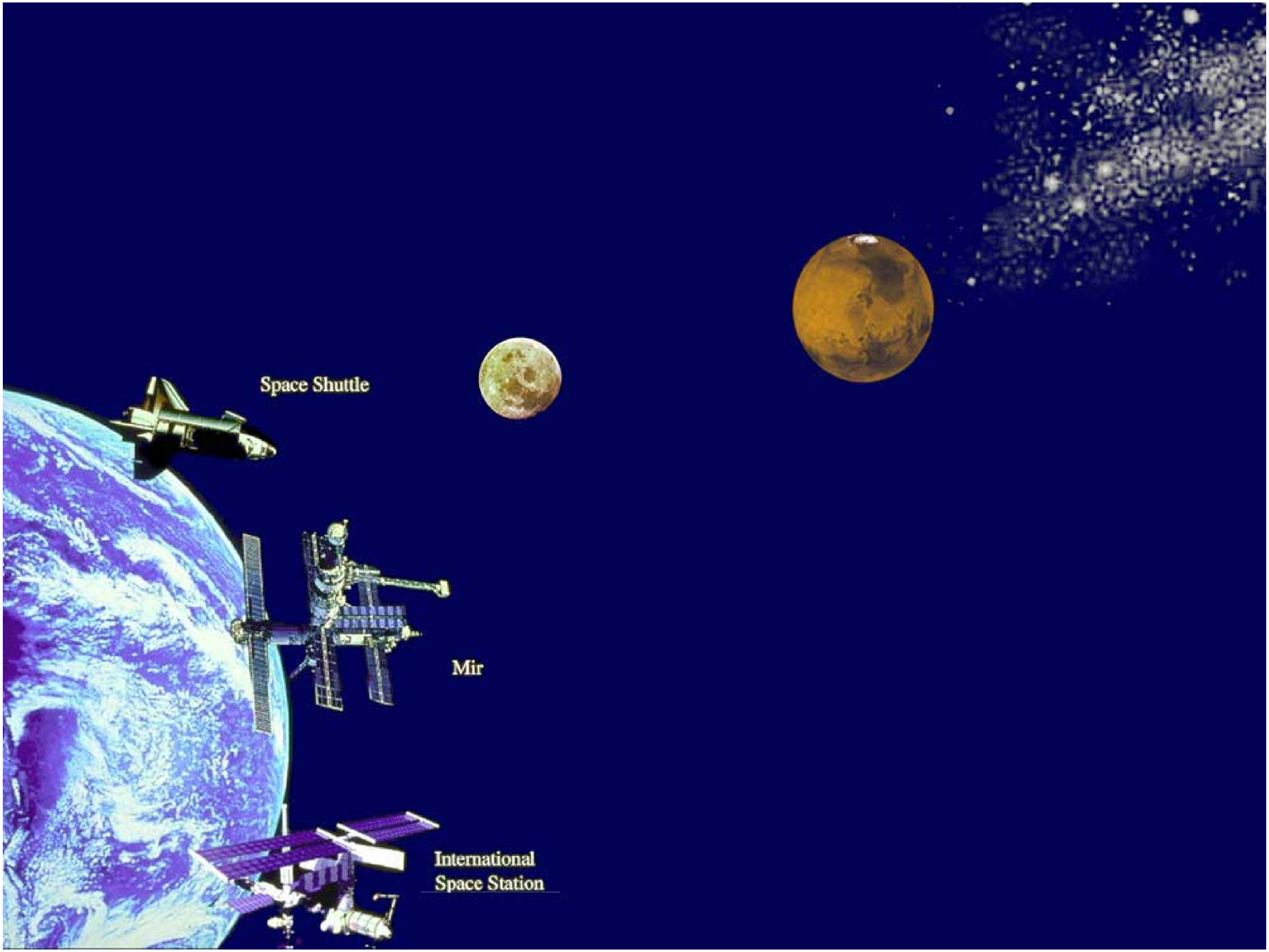
Some Top level Issues that Prevail

- Particles issues in air filtration systems
  - Fine particles in air treatment systems (CDRA)
  - Settling issues ad clogging (Bends in systems)
  - Gravity effects
- Sensors and Monitoring Systems
  - Particulate pre-filtering (MCA)
  - Fine particles in miniaturized monitoring systems
- Health issues associated with PM_{10} and less?


Space Shuttle
Mir
International
Space Station