NASA/TM—2005–214007

Designing For Human Presence in Space: An Introduction to Environmental Control and Life Support Systems (ECLSS)

Appendix I, Update—Historical ECLSS for U.S. and U.S.S.R./Russian Space Habitats

P.O. Wieland
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

July 2005

The NASA STI Program Office…in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results…even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at 301–621–0134
- Telephone the NASA Access Help Desk at 301–621–0390
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076–1320
  301–621–0390

NASA/TM—2005–214007

Designing For Human Presence in Space: An Introduction to Environmental Control and Life Support Systems (ECLSS)

Appendix I, Update—Historical ECLSS for U.S. and U.S.S.R./Russian Space Habitats

P.O. Wieland
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

National Aeronautics and
Space Administration

Marshall Space Flight Center • MSFC, Alabama 35812

July 2005

Acknowledgments

Updates to tables 1 and 2 in appendix I of NASA RP–1324 were provided by several people from NASA's Marshall Space Flight Center (MSFC) and Johnson Space Center (JSC). Their willingness to review the tables and make corrections and additions was critical to the updates.

Robyn Carrasquillo (MSFC–EV50)
Katherine Daues (JSC–EC)
John Lewis (JSC–EC6)
Jay Perry (MSFC–EV51)
Kimberlee Prokhorov (JSC–EC)
Monserrate (Monsi) Roman (MSFC–EV51)
Hank Rotter (JSC–EC)
Dave Williams (JSC–EC6)

Available from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076–1320
301–621–0390

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703–487–4650

TABLE OF CONTENTS

1. INTRODUCTION 1

2. UPDATED TABLES OF HISTORICAL ECLSS 3

APPENDIX I, UPDATE—HISTORICAL ECLSS FOR U.S. AND U.S.S.R./RUSSIAN SPACE HABITATS 4

TECHNICAL MEMORANDUM

DESIGNING FOR HUMAN PRESENCE IN SPACE: AN INTRODUCTION TO ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS (ECLSS)
Appendix I, Update—Historical ECLSS For U.S. And U.S.S.R./Russian Space Habitats

1. INTRODUCTION

NASA RP–1324 "Designing For Human Presence in Space" was written in the early 1990s to describe the process of designing environmental control and life support systems (ECLSS) for habitats in space. Included in the document were tables (appendix I) that summarize the design features and methods of performing the various life support functions for all manned spacecraft of the United States (U.S.) and the Union of Soviet Socialist Republics (U.S.S.R.)/Russia through the time of publication. Included in the table of the U.S. spacecraft were descriptions of proposed design features of Space Station *Freedom* (later the *International Space Station (ISS)*) that were not actually implemented when the *ISS* was constructed. This document provides updated tables of historical ECLSS information as described in section 2.0.

2. UPDATED TABLES OF HISTORICAL ECLSS

Tables 1 and 2 in appendix I of NASA RP–1324, "Designing For Human Presence in Space," have been updated in order to

- Correct outdated information and errors.
- Include additional information on the ECLSS used for spacecraft.
- Add information on the historical methods of thermal control for spacecraft.

Information for these revisions was provided by engineers and scientists at Marshall Space Flight Center's Environmental Control and Life Support Division and at Johnson Space Center's Crew and Thermal Systems Division.

APPENDIX I, UPDATE—HISTORICAL ECLSS FOR U.S. AND U.S.S.R/RUSSIAN SPACE HABITATS

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems.

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Atmosphere Revitalization								
CO_2 Removal	Two lithium hydroxide (LiOH) canisters operating in parallel. Airflow is through only one canister. After the first canister becomes spent, airflow is diverted through the second parallel canister, and the spent canister is replaced.	Similar to Mercury design, but sized for 2 people.	Similar to Mercury design, but sized for 3 people and mission requirements.	Similar to Mercury design, but sized for 3 people and mission requirements.	2 canister molecular sieve. Each canister was regenerable, containing Zeolite 5A for CO_2 removal and Zeolite 13X for humidity control. CO_2 and humidity was vacuum desorbed to space.	Similar to Mercury design, but the quantity of canisters carried depends on crew and mission requirements. Airflow through 2 canisters simultaneously. LiOH replacement schedule depends on size of crew. For extended missions, an amine-based regenerable CO_2 removal system (RCRS) can be used to remove CO_2 and some moisture for venting to space.	Similar to Mercury design. Eight canisters are included on each mission.	Four-bed molecular sieve. Includes two regenerable desiccant beds to remove humidity and two regenerable Zeolite 5A molecular sieve beds to remove CO_2. CO_2 is heat and vacuum desorbed to space currently, but can be supplied to a Sabatier reactor.
Gas Recovery	None	None	None	None	None	None	None	Sabatier reactor for CO_2 reduction (planned as a test article). Converts CO_2 and H_2 to CH_4 and H_2O; requires a CO_2 compressor.
O_2 Generation	None	None	None	None	None	None	None	Solid polymer electrolyte (SPE) device for oxygen generation. [Note: A static feed water electrolysis (SFWE) using a KOH electrolyte was also considered.

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Trace Contaminant Control	Activated charcoal located in the LiOH canisters upstream of the LiOH. Filters removed airborne particulates.	Similar to Mercury design, but sized for crew and mission requirements.	Similar to Mercury design, but sized for crew and mission requirements.	Similar to Mercury design, but sized for crew and mission requirements.	Activated charcoal canister located in the molecular sieve unit. Filters removed airborne particulates. Venting of atmosphere between missions helped avoid long-term contaminant buildup.	Trace contaminant gases are removed by activated charcoal downstream of the temperture and humidity control HX. CO is converted to CO_2 by an ambient temperature catalytic oxidizer (ATCO). Filters remove airborne particulates. Ammonia is absorbed by the condensate in the condensing HX.	Activated charcoal canister located in the transfer tunnel between Spacelab and the Orbiter. CO is converted to CO_2 by an ambient temperature catalytic oxidizer (ATCO). Filters remove airborne particulates.	Activated charcoal with a high-temperature catalytic oxidizer. Filters remove airborne particulates.
Atmosphere Control and Supply								
Atmosphere Composition	100% O_2 at 5 psia (34.5 kPa)	100% O_2 at 5 psia (34.5 kPa)	100% O_2 at 5 psia (34.5 kPa). 60% O_2, 40% N_2 atm. during launch.	100% O_2 at 5 psia (34.5 kPa)	Mixed O_2/N_2 at 5 psia (34.5 kPa) total pressure. 72% O_2, 28% N_2 by volume.	Mixed O_2/N_2 at 14.7 psia (101 kPa) total pressure. 21.7% O_2, 78.3% N_2. Maintained at 10.2 psia prior to EVA.	Mixed O_2/N_2 at 14.7 psia (101 kPa) total pressure. 21.7% O_2, 78.3% N_2.	Mixed O_2/N_2 at 14.7 psia (101 kPa) total pressure. 21.5% O_2, 78.5% N_2 volume. Pressure control panel.

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Atmospheric Monitoring	Carbon monoxide sensor. [1]	No on-orbit monitoring.	No on-orbit monitoring.	No on-orbit monitoring.	A system using Draeger tubes monitored the buildup of CO and other trace contaminants of major concern. [2]	No on-orbit monitoring.	No on-orbit monitoring.	Major constituent analyzer (MCA) in Lab Module (part of atmospheric revitalization rack) monitors N_2, O_2, H_2, CH_4, H_2O and CO_2 throughout U.S. segment. A second MCA will be in Node 3. [Planned but not implemented: A gas chromatograph/mass spectrometer (GCMS) for detecting the 200 contaminants defined in NHB 8060.1B.] Grab samples are collected for offline monitoring.
Gas Storage	O_2 stored as a gas at 7500 psi (51.7 MPa) in two 1.8 kg. capacity tanks. The tanks were made of 4340 carbon steel with electroless nickel plating. One tank was the primary supply, the other was backup. [5]	O_2 stored as a supercritical cryogenic fluid at 850 psi (5.86 MPa) in one spherical tank. There was a separate tank to supply the fuel cells. Two secondary cylindrical 5000 psi O_2 bottles. For emergencies there was also one small O_2 bottle attached under each ejectable seat. [6]	O_2 stored as a supercritical cryogenic fluid at 900 psi (6.20 MPa) and 180°C in two 145 kg capacity spherical Inconel Dewar tanks. The tanks were common for the ECLS and power systems. The tanks were discarded during reentry, when O_2 was supplied from a 1.7 kg capacity surge tank. [7]	21.8 kg of O_2 stored as a gas at 2700 psi (18.6 MPa) in the descent stage. In the ascent stage O_2 was stored as a supercritical cryogenic fluid at 850 psi (5.86 MPa) in two Inconel bottles. [7]	O_2 and N_2 stored as gases at 3000 psi (20.7 MPa) in six bottles each, for a total of 2779 kg of O_2 and 741 kg of N_2.	N_2 and O_2 stored as gases at 3000 psi (20.68 MPa). 4–8 spherical N_2 tanks. Metabolic O_2 is supplied by the power reactant storage and distribution system that uses supercritical cryogenic storage tanks.	N_2 stored as a gas at 3000 psi (20.68 MPa) in a spherical tank. N_2 is for leakage makeup and scientific airlock operation. O_2 source is a 100 psi (689 kPa) line from the Orbiter.	High-pressure storage of O_2 (2400 psia (16.5 MPa)) and N_2 (3000 psia (20.7 MPa)).

Note: Numbers in brackets refer to references at the end of the table.

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Cabin Ventilation	Cabin fan	Cabin fan	Cabin fans. The fans were noisy so the crew only operated them during short specified awake periods [7]	Cabin fan	3 ventilation ducts with 4 fans each. Air distributed from circular diffusers with dampers mounted flush with the floor, and from rectangular outlets with dampers and adjustable flow vanes. 3 portable fans with adjustable diffusers.	Cabin fan with ventilation ducts.	Cabin fan Air vents, over/ under pressure-relief valves.	Cabin fans, intermodule ventilation fans, and portable local area ventilation fans. Air vents, over/under pressure-relief valves.
Temperature and Humidity Control								
Atmosphere Temperature and Humidity Control	Separate suit and cabin condensing heat exchangers (CHX). Mechanically activated sponge water separator removed water from the CHX. Pilot regulated suit and cabin temperature by manually adjusting water flow rate through the suit and cabin HX's with a needle valve. [5]	Separate suit and cabin CHX's. Wicks removed water from the CHX by capillary action. Manual throttling of O_2/Coolant flow rate in suit loop to control temperature. Redundant cabin cooling loops - coolant fluid reservior, low-level coolant sensing device, 2 identical positive displacement pumps for each of 2 redundant coolant lines, and 2 regenerative heat exchangers. [6]	Suit CHX was primary method for cabin temperature and humidity control. Wicks removed water from the CHX by capillary action. Electrical heaters. [20]	Water circulated through pressure garment assembly to cool astronaut. A centrifugal water/air separator was in the total air flow path just downstream of the condensing heat exchange, and spun the condensate against a pitot tube to remove it from the air.	ATCS was located in the airlock module. A combination of air duct heaters and wall heaters, located in other Skylab areas, for heating. Four CHX's, two operating at all times. Coolanol 15 coolant.	Centralized cabin liquid/air CHX using water coolant. Air bypass ratio around CHX adjusted to control temperature. Condensate removed by slurper bar and centrifugal separator.	Similar to Orbiter design, but packaged for physical constraints and mission requirements.	Internal atmosphere control similar to Orbiter design, but packaged for physical constraints and mission requirements (as part of the common cabin air assembly (CCAA) in each major module). [18] Air and water heat exchangers cool and dehumidify the internal atmosphere. Condensate is stored in tanks.

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Thermal Control and Heat Rejection	Condensate rejected to water boiler for heat rejection. No space radiators.	Heat transport loop with Monsanto's MCS-198 (silicon ester) coolant was primary method for heat rejection. [21] External radiators.	Water/glycol flow system transferred heat to radiators located on the service module surface and a water boiler for the evaporation of water to space vacuum with a back pressure valve for temperature control. [20]	Water sublimator to space vacuum for water coolant loops provide crew and avionics cooling. Multilayer insulation blankets and external thermal control coatings were used to isolate structure and components from the space environment and to minimize the average temperature change. Tanks radiated part of the heat stored in them to the structure and part to the components to compensate for heat loss through the insulation blanket. [20]	Radiators mounted on the Multiple Docking Adapter and on the forward Airlock Module.	• Freon Coolant Loop provides for transfer and transport of heat loads to GSE, cooling radiators, ammonia boiler, and space vacuum flash evaporative heat sinks. Freon 21 system takes heat load of Spacelab equip, fuel cells (3), and mid-body and aft orbiter avionics. Also Freon 21 added heat to Aerosurface control hydraulics (on-orbit). SSME thrust vector and aerosurface control hydraulics is cooled via water spray boilers during launch and ascent.	• Spacelab water loops (2-redundant) interfaced with Orbiter Freon 21 loop; the water loop also takes the cabin and avionics loads to the Freon 21 Orbiter loop via air/water heat exchangers. • Spacelab Pallet coolant loop (when used) was a Freon 114 loop and interfaced with the Orbiter Freon 21 loop.	Waste heat is removed in 2 ways, through cold plates and heat exchangers, both cooled by a circulating aqueous solution loop. Waste heat is exchanged a second time to the external loop containing ammonia. The heated ammonia circulates through aluminum external radiators releasing the heat to space as infrared radiation, cooling as it circulates.

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Thermal Control and Heat Rejection (Continued)						• Flash evaporator system provides total heat rejection for vehicle during ascent (above 120,000 ft) and reentry (down to 100,000 ft), and supplementary heat rejection during orbital ops. Ammonia boilers on the Freon 21 loop are used below 100,000 ft during reentry for cooling prior to GSE connection. Water spray boiler (WSB) provides heat sink for heat loads generated by operation of the Orbiter hydraulic subsystem and APU lubricating oil system. • Radiators (2 deployable, 2 fixed - 12x15 ft) interface with the Freon 21 loop for on-orbit cooling.		

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Equipment Cooling	Cold plates and air cooling. Cabin gas absorbs heat generated by equipment and is cooled when it passes through the cabin CHX.	Similar to Mercury. 24 coldplates. [21]	Similar to Mercury.	Similar to Mercury. High-emmitance coatings were used over large portions of the cabin interior to distribute heat more uniformly. [20]	Similar to Mercury.	Air cooling, cold plates, air/liquid equipment dedicated HX's. Avionics air loop separate from cabin loop, except in aft flight deck.	• Air cooling, cold plates, liquid/liquid equipment dedicated HX's. Flow control valves set manually before flight. • Avionics (equip) air cooling was available via suction air in each Spacelab rack; the return suction was balanced prior to each flight per cooling and fire detection requirements. • Avionics air loop was separate from cabin loop. • Thermal capacitors (phase change material) were available for cold-plate mounted equipment.	Air cooling, cold plates, and equipment dedicated HX's. Air flow is controlled automatically. High heat generators are attached to custom-built cold plates. Aqueous coolant, circulated by a 17,000-rpm impeller the size of a quarter, flows through these heat-exchangers to cool the equipment.

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Water Recovery and Management								
Water Supply Quality	Potable only.	Potable only.	Potable only.	Potable only.	Potable only.	Potable only.	Not applicable.	Potable only.
Water Processing	None. Vent waste water.	None. Vent waste water.	None. Store condensate water and vent excess, or send excess to evaporator for additional cooling.	None. Store waste water. No overboard dumping of wastes on lunar surface.	None. Store waste water in tanks and vent waste when tanks are full.	None. Store waste water in a tank and vent waste when tank is full.	Not applicable.	Urine – vapor compression distillation (VCD). Potable and hygiene water: Multifiltration and ion exchange sorbent beds, and catalytic oxidation.
Water Monitoring	No on-orbit monitoring.	No on-orbit monitoring.	No on-orbit monitoring.	No on-orbit monitoring.	Iodine sampler. Water samples fixed with a linear starch reagent and compared to photographic standards.	No on-orbit monitoring.	Not applicable.	Online conductivity and free-gas monitor for the water processor. Offline monitoring of TOC and microbial count using the crew health care system (CHeCS). [19]
Water Storage and Distribution	One tank with a flexible bladder. Squeezing an air bulb (sphygmomanometer) pressurized the bladder to deliver water. Tank was filled before launch. [3]	One 7.3 liter tank containing a bladder pressurized with oxygen to deliver water. Tank was filled before launch. When tank became empty it was refilled from reserves in the service module, which separated from the main spacecraft before reentry.	Fuel cell byproduct was the principle source of potable water. Byproduct was routed to the potable tank or sent to the waste tank if the potable tank was full. Silver palladium separator removed dissolved and free H_2. Potable tank used a bladder pressurized by oxygen to deliver water.	Three (4 on Apollo 15, 16, 17) potable tanks, each with a bladder pressurized by nitrogen to deliver water. Tanks were filled before launch. Potable water was also used to cool spacecraft and extravehicular mobility units.	Ten cylindrical 600 lb. capacity stainless steel tanks fitted with pressurized steel bellows to deliver the water. One 26 lb. capacity portable tank. Tanks were filled before launch. [2]	Four 168 lb. capacity stainless steel tanks fitted with metal bellows pressurized by N_2. Drinking water is from the fuel cell byproduct.	Not applicable.	Metal bellows tank design with supply and delivery pumps. Water supplied to the distribution bus. [19]

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Water System Microbial Control	Water quality depended on the quality of the public water system in Cocoa Beach, Fl. Bacteria control depended on the residual disinfectant (chlorine) in the public supply. [4]	Chlorine added to the water before launch.	Chlorine at a concentration of 0.5 mg/liter maintained by adding (syringe injection) 22 ml of sodium hypochlorite solution every 24 hours.	Iodine added before launch. No on-orbit biocide addition. A preflight analysis was performed to predict when the iodine concentration would fall below 0.5 mg/liter during each mission. When this predicted time was reached during the mission a bacteria filter was added upstream of the water dispenser.	Iodine maintained between 0.5 and 6.0 mg/liter by periodic injection of a 30 g/l potassium iodide solution.	Iodine from microbial check valves (MCV). MCV passively adjusts iodine concentration between 2 and 6 mg/l.	Not applicable.	Iodine from microbial check valves. Heat sterilization at 120°C for 10 minutes is planned as part of the water processing cycle.

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Waste Management								
Fecal/Urine Handling	In-suit urine collection bag stored urine until end of mission. No provisions for fecal handling. No provisions for urine handling on first Mercury mission.	Feces were collected in bags and stored. Bags taped to buttocks. Urine was collected using the urine transfer system, which consisted of a rubber cuff connected to a flexible bag. Urine could be directed to the boiler tank to assist with spacecraft heat rejection.	Feces were collected in bags and stored. Bags taped to buttocks. Bag was kneaded to mix a liquid bactericide with the feces. Urine was voided directly overboard through urine receptacle assembly or collected using the urine transfer system, which consisted of a rubber cuff connected to a flexible bag. For Apollo 15–17, urine was collected and stored, then vented daily.	Fecal containment system was identical to Apollo command module (CM) system. Primary difference from CM waste management system was no overboard dumping of urine on lunar surface.	Feces were collected in gas permeable bags attached under a form-fitting seat, then vacuum dried and stored. Urine was collected using individual receivers, tubing, and disposable collection bags. [2]	Commode/Urinal - Feces are collected in the commode storage container , where they are vacuum dried, and held. Urine is sent to a waste water tank which is vented when full.	Utilizes Orbiter facilities.	Commode/urinal-feces are collected in a bag and compacted in a cylindrical canister for storage and disposal (in a Progress resupply module). A VCD urine processor is part of the waste & hygiene compartment planned for Node 3, and will be capable of automatic transfer or of accepting urine via a EDV portable water container to allow transfer from the Russian segment.
Fire Detection and Suppression								
Suppressant	Water from the food rehydration gun. [8] Capability to depressurize cabin by manually opening cabin outflow valve.	Similar to Mercury design. Maximum of 3 cabin depresses could be accommodated by the on-board oxygen supply.	Water from the food rehydration gun and a portable aqueous gel (hydroxymethyl cellulose) extinguisher, which could expel 0.06 m^3 of foam in 30 sec. Capability to depressurize cabin.	Similar to Apollo CM design.	Portable aqueous gel (hydroxymethyl cellulose) extinguishers, which could expel 0.06 m^3 of foam in 30 sec. [9] Capability to depressurize cabin.	Halon 1301. Three remote Halon bottles (one per avionics bay) and three portable Halon bottles, two located on the middeck and one on the flight deck. Capability to depressurize cabin.	Halon 1301. A Halon bottle with distribution lines located in each equipment rack. Two portable Halon extinguishers. Capability to depressurize cabin.	CO_2. Portable CO_2 extinguishers. Capability to depressurize cabin.

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)
Detection	Crew senses [8]	Crew senses	Crew senses	Crew senses	Ultraviolet detectors	Ionization smoke sensors	Ionization smoke sensors	Photoelectric smoke detectors mounted in ventilation ducting, payload racks, and in the cabin. Also, for payloads and situations where a smoke detector cannot be used, data parameter monitoring is used that relies on temperature (or other) sensors with software monitoring for out-of-limits indication of a fire event.

Table 1. Historical summary of U.S. spacecraft environmental control and life support systems (Continued).

Subsystem	Mercury	Gemini	Apollo CM	Apollo LM	Skylab	Orbiter	Spacelab	International Space Station (U.S. Segment)

References:

General reference—Martin, Charles, and A.K. McCormick III, "Environmental Control and Life Support System (ECLSS) Historical Data Summary: Apollo Through Space Station Freedom," MDC 92W5038, McDonnell Douglas Space Systems Company, December 1992.

General reference—Diamant, Bryce L., and W. R. Humphries, "Past and Present Environmental Control and Life Support Systems on Manned Spacecraft," SAE Paper No. 901210, 20th International Conference on Environmental Systems, Williamsburg, VA, July 9-12, 1990.

1) Silvestri, Goffredo, et al.: *Quest for Space*. New York, NY, Crescent Books, 1986.

2) Hopson, G.D., Littles, J.W., and Patterson, W.C.: "Skylab Environmental Control and Life Support Systems." ASME Paper 71-AV-14, Life Support and Environmental Control Conference, San Francisco, CA, July 12-14, 1971.

3) Calvin, Melvin, and Gazenko, Oleg G., eds.: *Foundations of Space Biology and Medicine*. Volume 3, NASA N76-26831, 32, 34, 36 and 37, Washington DC, 1975.

4) Willis, Charles E., and Schultz, John R.: "Spacecraft Water Systems Disinfection Technology: Past, Present and Future Needs." SAE Paper No. 871487, 17th Intersociety Conference on Environmental Systems, Seattle, WA, July 13–15, 1987.

5) Samonski, Frank H., Jr.: "Technical History of the Environmental Control System for Project Mercury." NASA TN D-4126, Washington, DC, 1967.

6) Watkins, Harold D.: "Basic Gemini ECS Keyed to 14-Day Flight" *Aviation Week & Space Technology*, August 19, 1963, p.52–69.

7) "Biomedical Results of Apollo", NASA Lyndon B. Johnson Space Center, N76-12690, 91, 93, 94, Houston, TX 1975.

8) Mackowski, Maura J.: "Safety on the Space Station." *Space World*, March 1987, p. 22–24.

9) "Skylab Operational Data Book, " MSFC-01549, December 1970.

10) Hamilton Standard, "Final Report—Soviet Space Life Support Systems." U.S. Government Contract 85-N987400-000, Windsor Locks, CT, November 1985.

11) Bluth, B.J., and Helppie, Martha: *Soviet Space Stations As Analogs*, Second edition, Report under NASA Grant NAGW-659, Washington, DC, 1987.

12) Volynkin, Yu. M., and Yazdovskiy, V.I.: "The First Manned Space Flights." N63-15658, Translated by the Air Force Systems Command Foreign Technology Division, Wright-Patterson AFB, OH, 1962.

13) Pochkayev, I., Serebrov, A., and Ul'yanov, V.: "Special Feature: The Mir Space Station." *U.S.S.R. Space Life Sciences Digest*, Issue 10, 1987.

14) Gil'berg, L.A.: "Living and Working in Space." NASA Technical Translation. NASA TT F-17075, Washington, DC, July 1967.

15) Voronin, G.I., Guenin, A.M., and Fomin, A.G.: "Physiological and Hygienical Evaluation of Life Support Systems of the Vostok and Voskhod Spacecarft." Bjurstedt, Hilding, ed. *Proceedings of the Second International Symposium of Basic Environmental Problems of Man in Space*, New York, Springer-Verlag, 1967.

16) Loginov, Sergei N., Associate Professor of the Department of Life Support Systems, College of Cosmonautics, Moscow Aviation Institute, Lecture at the University of Alabama in Huntsville, June 25–27, 1990.

17) Wieland, P.O., "Living Together in Space: The Design and Operation of the Life Support Systems on the International Space Station," NASA/TM-1998-206956/Volume II, January 1998.

18) Williams, D., J. Lewis, R. Carrasquillo, R. Reysa, and G. Gentry, SAE 2002-01-2494, "International Space Station Environmental Control and Life Support System Status: 2001-2002", 32nd International Conference on Environmental Systems, July 2002, San Antonio, TX.

19) Carrasquillo, R.L., "Status of the Node 3 Regenerative ECLSS Water Recovery and Oxygen Generation Systems", SAE 2003-01-2590, 33rd International Conference on Environmental Systems, July 2003, Vancouver, BC.

20) JSC-09423, Apollo Program Summary Report, April 1975.

21) Gemini Press Reference Book, http://www.apollosaturn.com/geminiNR/sec4.htm.

Table 2. Historical summary of Russian spacecraft environmental control and life support systems.

Subsystem	Vostok	Voskhod	Soyuz	Salyut	Mir	International Space Station (Russian Segment)
Atmosphere Revitalization						
CO_2 Removal	CO_2 is removed through reaction with KOH in the oxygen regenerator (forming potassium carbonate and water). [3]	Similar to Vostok design.	Similar to Vostok design. In addition, LiOH beds are used to absorb about 20% of the CO_2. [10]	Similar to Soyuz design.	Vozdukh 5-bed regenerable device with 2 desiccant beds and 3 CO_2 removal beds. Cyclic operation to remove excess moisture from the air before removing CO_2. LiCl (or LiOH) canisters used as backup. [11, 18]	Similar to Mir. Controller upgraded from Mir to automatically adjust the CO_2 removal rate. [17]
Gas Recovery	Nonregenerative chemical cartridges of potassium super oxide (KO_2). KO_2 is reacted with water to produce O_2 and KOH. [3]	Similar to Vostok design.	Similar to Vostok design.	Similar to Vostok design.	Some CO_2 reduction for experimental purposes, but most of the collected CO_2 is vacuum desorbed overboard.	CO_2 vented overboard.
O_2 Generation	Nonregenerative chemical cartridges of potassium super oxide (KO_2). KO_2 is reacted with water to produce O_2 and KOH. [3]	Similar to Vostok design.	Similar to Vostok design.	Similar to Vostok design.	Water electrolysis (12 cells in explosion proof containers) using a KOH electrolyte for O_2 generation. Electrolysis water is from recovered urine supplemented by onboard stores. [11, 18] Backup is solid fuel oxygen generator (SFOG) that used Lithium perchlorate cartridges ignited by high- temperature charge. [18]	Similar to Mir, but water is from stores only (no urine processor).

Note: Numbers in brackets refer to references at the end of the table.

Table 2. Historical summary of Russian spacecraft environmental control and life support systems (Continued).

Subsystem	Vostok	Voskhod	Soyuz	Salyut	Mir	International Space Station (Russian Segment)
Trace Contaminant Control	Activated charcoal and filters. Contaminants also removed through reaction with constituents in the oxygen regenerator. [3]	Similar to Vostok design.	Similar to Vostok design.	Activated charcoal, high efficiency fiberglass filter, and catalytic chemical absorbents. Oxygen regenerator also removes contaminants. [12]	Filters and regenerable charcoal beds and catalytic oxidizers removed CO, ammonia and methane. Charcoal beds regenerated by vacuum for 6 hours once every 10 days. Impurities vented. [11, 18]	Similar to Mir. Ambient temperature catalytic filter for methane and hydrocarbon removal. Nominal regeneration cycle every 20 days (though can be every 10 days). Two units operating with one being regenerated every 10 days. Regeneration time is 4–5 hours heating and 7–8 hours cooling.
Atmosphere Control and Supply						
Atmosphere Composition	Sea-level atmosphere - O_2/N_2 mixture at 14.7 psi (101 kPa).	Sea-level atmosphere - O_2/N_2 mixture at 14.7 psi (101 kPa).	Sea-level atmosphere. O_2/N_2 mixture at a total pressure between 13.7 and 16.4 psi (94.4 and 113 kPa), with ppO_2 between 2.7 and 3.9 psi (10.5 and 15.2 kPa).	Sea-level atmosphere. O_2/N_2 mixture at a total pressure between 13.5 and 16 psi (93.1 and 110 kPa), with ppO_2 between 3.0 and 3.8 psi (20.5 and 25.9 kPa).	Sea-level atmosphere. Up to 78% N_2, 21-40% O_2. Maximum ppO_2 is 6.8 psi (46.9 kPa). [18]	Similar to Mir (and USOS). Also dP/dt sensors. ppO_2 2.82 psia (146 mmHg) to 3.35 psia (173 mmHg) with a concentration of no more than 24.8%. Total pressure 14.2 to 14.9 psia (734 to 770 mmHg)
Atmospheric Monitoring	Gas analyzer determined percent composition of oxygen and carbon dioxide in cabin atmosphere. No other on-orbit atmosphere monitoring. [3]	Similar to Vostok design.	Similar to Vostok design.	Similar to Vostok design. Several gas analyzers distributed around the station. [12]	Similar to Salyut design. Used a gas analyzer that determined the percentage of O_2 and CO_2 in the atmosphere. Sensors also monitored H_2, O_2 and CO. Sensors had a 1-year life. [18]	Russian service module gas analyzer (SM GA) to monitor major constituents (O_2, CO_2, and H_2O) in the FGB and SM modules. H_2 is also monitored in the life support module (LSM).

Table 2. Historical summary of Russian spacecraft environmental control and life support systems (Continued).

Subsystem	Vostok	Voskhod	Soyuz	Salyut	Mir	International Space Station (Russian Segment)
Gas Storage	Oxygen supply stored chemically. Emergency tanks of high-pressure oxygen and air for suit ventilation and cosmonaut breathing. Cosmonaut's suit could be pressurized if the cabin depressurized. No nitrogen storage. Cabin hermetic seal was designed for zero leakage. [14]	Similar to Vostok design.	Aside from the chemical oxygen regenerators, there was no additional gas storage. Complete reliance on the cabin hermetic seal to prevent leakage and depressurization. [16]	Oxygen supply stored chemically. Cylinders of compressed air for leakage makeup. No separate N_2 or O_2 storage. [12]	Backup oxygen stored chemically as lithium perchlorate compound. N_2 stored as a high-pressure gas. Twenty-two liters of air stored in pressure vessels for atmospheric makeup. [11, 18]	No N_2 storage on the Russian segment. Gases stored on the Progress resupply modules: 180L O_2 on Progress, 144L O_2 on Progress M–1.
Cabin Ventilation	Cabin fan	Cabin fan	Cabin fan	Cabin fans. Cosmonauts could control air flow rate between 0.1 and 0.8 m/sec. [12]	Fans pull air through ducts to exchange air between modules. [15]	Same as Mir.

Table 2. Historical summary of Russian spacecraft environmental control and life support systems (Continued).

Subsystem	Vostok	Voskhod	Soyuz	Salyut	Mir	International Space Station (Russian Segment)
Temperature and Humidity Control						
Atmosphere Temperature, Humidity Control and Heat Rejection	Liquid-air condensing heat exchanger. Condensate trapped by porous wicks between the heat exchanger tubes. Temperature adjusted by automatic regulation of air flow rate through heat exchanger. Cosmonaut could set temperature and humidity of craft. Temperature range was between 12 and 25°C, and relative humidity was between 30 and 70%. Humidity was controlled primarily by a dehumidifier containing a silica gel drying agent impregnated with lithium chloride and activated carbon. Dehumidifier operated cyclically. Air inlet to dehumidifier opened after humidity rose above 70%. Air inlet automatically closed when humidity reached 35 ± 5%. [13]	Similar to Vostok design.	Liquid-air condensing heat exchanger. Temperature adjusted by automatic regulation of air flow rate through heat exchanger. Liquid coolant was a water/glycol mixture. Cosmonaut could set temperature and humidity of craft. Temperature range was between 12 and 25°C, and relative humidity was between 30 and 70%. Humidity was controlled primarily by the condensing heat exchanger. Condensate was trapped by porous wicks between the heat exchanger tubes. The primary role of the chemical water absorbents became control of the oxygen production rate of the O_2 regenerator. [3]	Liquid-air condensing heat exchanger. Temperature could be set by cosmonaut between 15 and 25°C. Coolant was an antifreeze-type fireproof liquid. Porous wicks trapped moisture between tubes of the heat exchanger. Condensate was collected in a moisture trap and periodically pumped out manually by the cosmonauts. [14] The active thermal control (ATC) system in the Kvant Module had only one loop. The Kvant Module's thermal loop was designed to be connected to either of the Mir Core's 2 ATC loops if need be. External radiators.	Liquid-air condensing heat exchanger. Two internal thermal control loops charged with Temp (alcohol [ethylene glycol [17]] and water mixture) coolant - a cooling loop and a heating loop. A redundant piping system is included with each loop. Loop temperature is controlled automatically. No large-surface areas thermal radiators with a fluid interface. [11, 18]	Two redundant internal thermal loops are filled with Triol, water with a 30 percent solution of glycerin, which lowers the freezing point to –7°C. Triol also contains antifreeze, biocide, and ultraviolet-light-sensitive additives to aid in leak detection. Internal loops are considered cooling loops. Two redundant external thermal loops are filled with polymethyl siloxane. External thermal loops interface with internal loops. External thermal loops are called heating loops. These loops interface with the body-mounted radiators which contain ammonia heat pipes.

Table 2. Historical summary of Russian spacecraft environmental control and life support systems (Continued).

Subsystem	Vostok	Voskhod	Soyuz	Salyut	Mir	International Space Station (Russian Segment)
Equipment Cooling	**	**	**	**	Avionics is cooled by heat exchangers and by air pulled from the cabin. Each method provides about 50% of the cooling. A condensator, with freon as the working fluid, removes moisture that condenses on the equipment. [11, 18]	Thermal loops from the various Russian modules are connected to the science power platform (SPP) central heat rejection system. This increases the heat rejection capability due to the integrated large radiators. Batteries are air cooled only.
Water Recovery and Management						
Water Supply Quality	Potable only.	Potable only.	Potable only.	Potable only.	Potable, hygiene, and electrolysis grade. [11]	Similar to Mir.
Water Processing	None	None	None	Salyut 6,7 - Potable water is recovered from condensate. Waste water is pumped into storage columns containing ion exchange resins and activated charcoal, then sent through filters containing fragmented dolomite, artificial silicates, and salt. Minerals are then added, including calcium, magnesium, bicarbonate, chloride, and sulfate. [12]	1. Condensate recovered by the same process used on Salyut 6, 7 and delivered to the water processor. 2. Water processor recovered hygiene/kitchen water, for hygiene use only, by a system of filters (containing fragmented dolomite, artificial silicates and salts), activated charcoal and ion exchange resins. Minerals (calcium, magnesium, bicarbonate, chloride and sulfate) were then added. Could recover 21 liters of water at one time. 3. Electrolysis water recovered from urine by vapor diffusion distillation. Could generate 5.4 liters/day. [11, 18]	Similar to Mir, but without recovery of water from urine. Also, condensate collected in the USOS can be processed through the Russian water processor (SRVK) with the aid of the condensate feed unit (CFU).

Table 2. Historical summary of Russian spacecraft environmental control and life support systems (Continued).

Subsystem	Vostok	Voskhod	Soyuz	Salyut	Mir	International Space Station (Russian Segment)
Water Monitoring	**	**	**	**	Measurements taken by water analyzers include pH and salinity. [11]	Conductivity monitor. Samples collected for chemical and microbial analyses.
Water Storage and Distribution	Water held in a container made of two layers of elastic polyethylene film. Container was hermetically sealed inside a metal cylinder. Low pressure created by the crewman's mouth was enough to induce water flow from the polyethylene container. Each crewman was allotted 2.2 l/day of water. [3]	Similar to Vostok design.	Similar to Vostok design.	Rodnik ("spring") system filters water supplied from tanks with a total volume of over 400 liters. [12]	Similar to Salyut design. Tanks use pressurized bladders to deliver water. [11] Soft storage containers (EDV's) that hold 22 L also used.	Similar to Mir.
Water Supply Microbial Control	Silver preparation added to water, which was boiled before launch. [3]	Similar to Vostok design.	Similar to Vostok design.	Water heated and ionic silver introduced electrolytically to achieve a concentration of 0.2 mg/l. [12]	Similar to Salyut design.	Same as Mir.
Waste Management						
Fecal/Urine Handling	Urine and feces entrained in an air stream and collected. Design of the urine/feces receiving unit permitted simultaneous collection of urine and feces even when clothed in a space suit.	Similar to Vostok design.	Similar to Vostok design.	Feces are collected in hermetically sealed metal or plastic containers, and ejected to space about once a week. The urine collector, separate from the main commode, is a cup-and-tube device with a disposable plastic insert and filter.	Commode for urine and excrement collection. Urine is pretreated after passing through an air/liquid separator. Pretreated urine stored in a bladder containing polyvinyl formaldehyde (a stabilizer) until electrolysis or disposal. [18] Solid wastes disposed by Progress vehicle reentry. Waste from food also stored until disposal. [18]	Similar to Mir, but urine is collected in EDVs for disposal in a Progress module. No recovery of water from urine.

Table 2. Historical summary of Russian spacecraft environmental control and life support systems (Continued).

Subsystem	Vostok	Voskhod	Soyuz	Salyut	Mir	International Space Station (Russian Segment)
Fire Detection and Suppression						
Suppressant	**	**	**	**	Portable extinguishers. Can extinguish fires in inaccessible areas. [11, 18]	Two different portable extinguishers: Backpack style same as used on MIR, and new handheld style. Water-based with foaming agent. Two modes spray or foam. Foam for behind panels, spray for open cabin area.
Detection	**	**	**	CO_2 detectors doubled as smoke detectors. [12]	Optical sensors. [11]	Improved optical sensor in the service module. FGB and DC–1 modules have ionization detectors.

** Information limited or unavailable.

References:

1) Silvestri, Goffredo, et al.: *Quest for Space*. New York, NY, Crescent Books, 1986.

2) Hopson, G. D., Littles, J.W., and Patterson, W.C.: “Skylab Environmental Control and Life Support Systems.” ASME Paper 71-AV-14, Life Support and Environmental Control Conference, San Francisco, CA, July 12-14, 1971.

3) Calvin, Melvin, and Gazenko, Oleg G., eds.: *Foundations of Space Biology and Medicine*. Volume 3, NASA N76-26831, 32, 34, 36 and 37, Washington DC, 1975.

4) Willis, Charles E., and Schultz, John R.: “Spacecraft Water Systems Disinfection Technology: Past, Present and Future Needs.” SAE Paper No. 871487, 17th Intersociety Conference on Environmental Systems, Seattle, WA, July 13–15, 1987.

5) Samonski, Frank H., Jr.: “Technical History of the Environmental Control System for Project Mercury.” NASA TN D-4126, Washington, DC, 1967.

6) Watkins, Harold D.: “Basic Gemini ECS Keyed to 14-Day Flight” *Aviation Week & Space Technology*, August 19, 1963, p. 52–69.

7) “Biomedical Results of Apollo”, NASA Lyndon B. Johnson Space Center, N76-12690, 91, 93, 94, Houston, TX 1975.

8) Mackowski, Maura J.: “Safety on the Space Station.” *Space World*, March 1987, p. 22–24.

9) “Skylab Operational Data Book, “ MSFC-01549, December 1970.

10) Hamilton Standard, “Final Report-Soviet Space Life Support Systems.” U.S. Government Contract 85-N987400-000, Windsor Locks, CT, November 1985.

11) Bluth, B.J., and Helppie, Martha: *Soviet Space Stations As Analogs*, Second edition, Report under NASA Grant NAGW-659, Washington, DC, 1987.

12) Volynkin, Yu. M., and Yazdovskiy, V.I.: “The First Manned Space Flights.” N63-15658, Translated by the Air Force Systems Command Foreign Technology Division, Wright-Patterson AFB, OH, 1962.

13) Pochkayev, I., Serebrov, A., and Ul’yanov, V.: “Special Feature: The Mir Space Station.” *U.S.S.R. Space Life Sciences Digest*, Issue 10, 1987.

14) Gil’berg, L.A.: “Living and Working in Space.” NASA Technical Translation. NASA TT F-17075, Washington, DC, July 1967.

15) Voronin, G.I., Guenin, A.M., and Fomin, A.G.: “Physiological and Hygienical Evaluation of Life Support Systems of the Vostok and Voskhod Spacecarft.” Bjurstedt, Hilding, ed. *Proceedings of the Second International Symposium of Basic Environmental Problems of Man in Space*, New York, Springer-Verlag, 1967.

16) Loginov, Sergei N., Associate Professor of the Department of Life Support Systems, College of Cosmonautics, Moscow Aviation Institute, Lecture at the University of Alabama in Huntsville, June 25–27, 1990.

17) Wieland, P. O., “Living Together in Space: The Design and Operation of the Life Support Systems on the International Space Station,” NASA/TM-1998-206956/Volume II, January 1998.

18) NASA, Lyndon B. Johnson Space Center, Mission Operations Directorate, Space Flight Training Division, Systems Training Branch, TD501, “A Russian Space Station: The Mir Complex”, February 10, 1994.

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
July 2005

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems (ECLSS)
Appendix I, Update—Historical ECLSS for U.S. and U.S.S.R./Russian Space Habitats

5. FUNDING NUMBERS

6. AUTHORS
P. O. Wieland

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

8. PERFORMING ORGANIZATION REPORT NUMBER
M–1142

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/TM—2005–214007

11. SUPPLEMENTARY NOTES
Prepared by the Spacecraft and Vehicle Systems Department, Engineering Directorate

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 54
Availability: NASA CASI 301–621–0390
http://trs.nis.nasa.gov/
https://www2.sti.nasa.gov/login/wt/

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Human exploration and utilization of space requires habitats to provide appropriate conditions for working and living. These conditions are provided by environmental control and life support systems (ECLSS) that ensure appropriate atmosphere composition, pressure, and temperature; manage and distribute water, process waste matter, provide fire detection and suppression; and other functions as necessary.

The tables in appendix I of NASA RP–1324 “Designing for Human Presence in Space” summarize the life support functions and processes used onboard U.S. and U.S.S.R/Russian space habitats. These tables have been updated to include information on thermal control methods and to provide additional information on the ECLS systems.

14. SUBJECT TERMS
life support, ECLSS, space habitats, *ISS*, *International Space Station*, thermal control, spacecraft

15. NUMBER OF PAGES
28

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

National Aeronautics and
Space Administration
IS04
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama
35812