A History of Spacecraft Environmental Control and Life Support Systems

K. Daues/NASA Johnson Space Center

January 6, 2006

A spacecraft's Environmental Control and Life Support (ECLS) system enables and maintains a habitable and sustaining environment for its crew. A typical ECLS system provides for atmosphere consumables and revitalization, environmental monitoring, pressure, temperature and humidity control, heat rejection (including equipment cooling), food and water supply and management, waste management, and fire detection and suppression. The following is a summary of ECLS systems used in United States (US) and Russian human spacecraft.

Atmosphere Revitalization

For Mercury, Gemini, the Apollo Command Module (CM), and the Apollo Lunar Module (LM), the carbon dioxide (CO2) removal system was primary comprised of lithium hydroxide (LiOH) canisters operating in parallel. Airflow was through only one canister. After the first canister became spent, airflow was diverted through the next parallel canister, and the spent canister is replaced. The number of canisters manifested varied with crew size and mission duration for each spacecraft. Atmospheric trace contaminants were controlled by activated charcoal located in the LiOH canisters upstream of the LiOH and filters removed airborne particulates. Cabin fans provided for ventilation. Mercury carried a carbon monoxide (CO) sensor, while Gemini and Apollo did not.

For Skylab, a two-canister molecular sieve was used for CO2 and humidity removal. Each canister was regenerative, containing Zeolite 5A for CO2 removal and Zeolite 13X for water removal. The CO2 was vacuum desorbed to space. Skylab trace contaminant gases are removed by an activated charcoal canister located in the molecular sieve unit. Filters removed airborne particulates. Venting of atmosphere between missions helped avoid long term contaminant buildup. A system using Draeger tubes monitored the buildup of CO and other trace contaminants of major concern.

For the Orbiter, CO2 removal is similar (LiOH), but the number of canisters carried depends on crew and mission requirements. Airflow is through two canisters simultaneously. The Orbiter's LiOH replacement schedule depends on size of crew. For extended missions, an amine-based Regenerable CO2 Removal System (RCRS) was used to remove CO2 and some moisture. Orbiter trace contaminant gases are removed by activated charcoal downstream of the temperature and humidity control heat exchanger. CO is converted to CO2 by an ambient temperature catalytic oxidizer (ATCO). Filters remove airborne particulates. Ammonia is absorbed by the condensate in the condensing heat exchanger.

For Spacelab, CO2 removal was performed with eight LiOH canisters on each mission. An activated charcoal canister for trace contaminant control was located in the transfer tunnel between Spacelab and the Orbiter. Spacelab-generated CO was converted to CO2 by an ambient temperature catalytic oxidizer (ATCO). Filters remove airborne particulates. Cabin fans provided for ventilation. Air vents (over/under pressure) provided relief valves.

The International Space Station (ISS) US Segment utilizes a four-bed molecular sieve for CO2 and humidity removal. This includes two regenerative desiccant beds to remove water and two regenerative Zeolite 5A molecular sieve beds to remove CO2. CO2 is heat and vacuum desorbed to space currently, but could be supplied to a Sabatier reactor if one becomes manifested on the ISS in the future. A Sabatier reactor would be used for CO2 reduction (planned as a test article). It would then convert CO2 and hydrogen (H2) to methane (CH4) and water (H2O). The Sabatier would also require a CO2 compressor. A Solid Polymer Electrolyte (SPE) device is provided for oxygen generation. [Note: A Static Feed Water Electrolysis (SFWE) using a potassium hydroxide (KOH) electrolyte was also considered.] Activated charcoal with a high temperature catalytic oxidizer is used for trace contaminant control. Filters remove airborne particulates. A Major Constituent Analyzer (MCA) in the ISS Laboratory Module (part of Atmospheric Revitalization Rack) monitors N2, O2, H2, CH4, H20 and CO2 throughout US Segment. A second MCA will be in Node 3. Cabin fans, intermodule ventilation fans, and portable local area ventilation fans support ISS ventilation. Air vents (over/under pressure) provide relief valves.

For Vostok, Voskhod, Soyuz and Salyut, CO2 was removed through reaction with KOH in the oxygen regenerator (forming potassium carbonate and water). Soyuz additionally utilized LiOH beds to absorb about 20% of the CO2. Non-regenerative chemical cartridges of potassium super oxide (KO2) were used for gas recovery. KO2 was reacted with water to produce O2 and KOH. Atmospheric trace contaminants were controlled by activated charcoal and filters. Salyut additionally used a high efficiency fiberglass filter and catalytic chemical absorbents. Contaminants were also removed through reaction with constituents in the oxygen regenerator. For monitoring a gas analyzer determined the percent composition of oxygen and carbon dioxide in cabin atmosphere. Cabin fans provided for ventilation. For Salyut, cosmonauts could control air flow rate between 0.1 and 0.8 m/sec.

For Mir, CO2 removal was performed using a Vozdukh four-bed molecular sieve comprised of two regenerative silica gel desiccant beds and two regenerative CO2 removal molecular sieve beds containing an adsorbent similar to Zeolite 5A. Lithium Chloride (LiCl) or LiOH canisters were used as backup. Mir performed some CO2 reduction for experimental purposes, but most of the collected CO2 was vacuum desorbed overboard. Water electrolysis (12 cells in explosion proof containers) using a KOH electrolyte was used for O2 generation. Electrolysis water was from recovered urine supplemented by onboard stores. A Solid Fuel Oxygen Generator (SFOG) system, provided as backup, used Sodium Chlorate (NAClO3) cartridges ignited by a high temperature charge. Filters and regenerable charcoal beds and catalytic oxidizers removed CO, ammonia and methane. Charcoal beds were regenerated by vacuum for 6 hours once every 10 days and impurities were vented. Mir used a gas analyzer that determined the percentage of O2 and CO2 in the atmosphere. Sensors also monitored H2, O2 and CO. These sensors had a 1-year life. For ventilation, fans pulled air through ducts to exchange gas between modules.

The ISS Russian Segment's CO2 removal system is similar to Mir but its controller was upgraded from Mir to automatically adjust the CO2 removal rate. CO2 is vented overboard. O2 generation, trace contaminant control and ventilation systems are similar to Mir. A Russian Service Module Gas Analyzer (SMGA) is used to monitor major constituents (O2, N2, CO2, and H2O) in the Functional Cargo Block (FGB) and Service module (SM) modules. H2 is also monitored in the Logistic Single Module (LSM).

Atmosphere Composition

The atmosphere composition and cabin pressures for US and Russian spacecraft are listed in Table 1.

Table 1. US and Russian Human Spacecraft Cabin Pressures and Atmosphere Composition

Spacecraft	Composition
Mercury	100% O2 at 5 psia (34.5 kPa)
Gemini	100% O2 at 5 psia (34.5 kPa)
Apollo CM	100% O2 at 5 psia (34.5 kPa) 60% O2, 40% N2 - during launch
Apollo LM	100% O2 at 5 psia (34.5 kPa)
Skylab	Mixed O2/N2 at 5 psia (34.5 kPa) total pressure 72% O2, 28% N2 by volume
Orbiter	Mixed O2/N2 at 14.7 psia (101 kPa) total pressure 21.7% O2, 78.3% N2 Maintained at 10.2 psia prior to EVA
Spacelab	Mixed O2/N2 at 14.7 psia (101 kPa) total pressure 21.7% O2, 78.3% N2
ISS US Segment	Mixed O2/N2 at 14.7 psia (101 kPa) total pressure 21.5% O2, 78.5% N2 volume
Vostok	Sea-level atmosphere; O2/N2 mixture at 14.7 psi (101 kPa)

Voskhod	Sea-level atmosphere; O2/N2 mixture at 14.7 psi (101 kPa)
Soyuz	Sea-level atmosphere; O2/N2 mixture at a total pressure between 13.7 and 16.4 psi (94.4 and 113 kPa), with partial pressure O2 (ppO2) between 2.7 and 3.9 psi (10.5 and 15.2 kPa)
Salyut	Sea-level atmosphere; O2/N2 mixture at a total pressure between 13.5 and 16 psi (93.1 and 110 kPa), with ppO2 between 3.0 and 3.8 psi (20.5 and 25.9 kPa)
Mir	Sea-level atmosphere; up to 78% N2, 21-40% O2, with maximum ppO2 of 6.8 psi (46.9 kPa)
Russian ISS Segment	Similar to Mir

Life Support Gas Storage

For Mercury, oxygen (O2) was 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 for backup.

For Gemini, O2 was 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 O2 bottles were provided. For emergencies there was also one small O2 bottle attached under each ejectable seat.

For Apollo CM, O2 was 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 life support and power systems. The tanks were discarded during reentry, when O2 was supplied from a 1.7 kg capacity surge tank. For Apollo LM, 21.8 kg of O2 was stored as a gas at 2700 psi (18.6 MPa) in the descent stage. In the ascent stage O2 was stored as a supercritical cryogenic fluid at 850 psi (5.86 MPa) in two Inconel bottles.

For Skylab, O2 and N2 were stored as gases at 3000 psi (20.7 MPa) in six bottles each, for a total of 2779 kg of O2 and 741 kg of N2.

For the Orbiter, O2 and N2 are stored as gases at 3000 psi (20.68 MPa) in four to eight spherical tanks. Metabolic O2 is supplied by the Power Reactant Storage and Distribution System that uses supercritical cryogenic storage tanks.

For Spacelab, N2 was stored as a gas at 3000 psi (20.68 MPa) in a spherical tank. The N2 was for leakage makeup and scientific airlock operation. The O2 source was a 100 psi (689 kPa) line from the Orbiter.

For the ISS US Segment, there is high pressure storage of O2 (1000 psia) and N2 (3000 psia).

For Vostok, Voskhod, Soyuz and Salyut, the oxygen supply was stored chemically. For Vostok, Voskhod, emergency tanks of high pressure oxygen and air were also provided for suit ventilation and cosmonaut breathing. Cosmonaut's suit could be pressurized if the cabin depressurized. For Soyuz, aside from the chemical oxygen regenerators, there was no additional gas storage. There was complete reliance on the cabin hermetic seal to prevent leakage and depressurization. For Salyut, additional cylinders of compressed air provided for leakage makeup. There was no nitrogen storage.

For Mir, backup oxygen was stored chemically as a perchlorate compound. N2 was stored as a high pressure gas. Twenty-two liters of air was stored in pressure vessels for atmospheric makeup. The ISS Russian Segment gas storage is similar to Mir and includes O2 from water electrolysis and pressurized gas in Progress vehicles.

Humidity/Temperature Control and Heat Rejection

For Mercury and Gemini, separate suit and cabin condensing heat exchangers were used. In Mercury, a mechanically-activated sponge water separator removed water from the condensing heat exchangers. The pilot regulated suit and cabin temperature by manually adjusting water flow rate through the suit and cabin heat exchanger with a needle valve. In Gemini, wicks removed water from the condensing heat exchanger by capillary action. Manual throttling of the O2/coolant flow rate in suit loop controlled temperature. Gemini had redundant cabin cooling loops with a coolant fluid reservoir, a low-level coolant sensing device, 2 identical positive displacement pumps for each of 2 redundant coolant lines, and 2 regenerative heat exchangers. Equipment was cooled by cold plates and air cooling. Cabin gas was absorb heat generated by the equipment and was cooled when it passed through the cabin condensing heat exchanger.

For Mercury, condensate was rejected to a water boiler for heat rejection and no space radiators were utilized. Gemini had a heat transport loop with Monsanto's MCS-198 (silicon ester) as the coolant for its primary method for heat rejection. External radiators were utilized.

For the Apollo CM, the suit condensing heat exchanger was primary method for cabin temperature and humidity control. Wicks removed water from the condensing heat exchanger by capillary action. Apollo CM equipment was cooled similarly to Mercury and Gemini. The Apollo LM used a water sublimator to space vacuum for water coolant loops to provide crew and avionics cooling. Water circulated through the pressure garment assembly to cool astronaut. The Apollo LM had high-emmitance coatings over large portions of the cabin interior to distribute heat more uniformly.

The Apollo CM used a water/glycol flow system that transferred heat to radiators located on the service module surface and a water boiler for the evaporation of water to the space vacuum with a back pressure valve for temperature control. The Apollo LM used multilayer insulation blankets and external thermal control coatings 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.

Skylab's active thermal control system was located in the airlock module. A combination of air duct heaters and wall heaters were located in other Skylab areas for heating. Four condensing heat exchangers were provided, two operating at all times. Coolanol 15 was the coolant for Skylab. Skylab equipment was cooled similarly to Mercury, Gemini and Apollo. Skylab had radiators mounted on the Multiple Docking Adapter and on the forward Airlock Module.

The Orbiter uses a centralized cabin liquid/air condensing heat exchanger utilizing water as coolant. The air bypass ratio around condensing heat exchanger is adjusted to control temperature. Condensate is removed by a slurper bar and centrifugal separator. Spacelab and ISS US Segment systems are similar to the Orbiter design, but packaged for physical constraints and mission requirements. On ISS it is part of the Common Cabin Air Assembly in each major module where air and water heat exchangers cool and dehumidify the internal atmosphere. On ISS condensate is stored in a tank.

For equipment cooling, the Orbiter, Spacelab and the ISS US Segment use air cooling, cold plates, and air/liquid equipment-dedicated heat exchangers. The Orbiter's avionics air loop is separate from the cabin loop, except in aft flight deck. Spacelab control valves were set manually before flight and avionics 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. In Spacelab, thermal capacitors (using phase change material) were available for coldplate mounted equipment. ISS US Segment air flow is controlled automatically. High heat generators are attached to custom-built cold plates. Cold water circulated by a 17,000-rpm impeller the size of a quarter, courses through these heat-exchangers to cool the equipment.

The Orbiter's Freon Coolant Loop provides for the transfer and transport of heat loads to ground support equipment, cooling radiators, ammonia boiler, and space vacuum flash evaporative heat sinks. The Freon 21 system takes the heat load of the Spacelab equipment, three fuel cells, mid-body and aft Orbiter avionics, and adds heat to Aerosurface control hydraulics (on-orbit). The Space Shuttle Main Engines (SSME) thrust vector and aerosurface control hydraulics are cooled via water spray boilers during launch and ascent. A 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 operations. Ammonia boilers on the Freon 21 loop are used below 100,000 ft during reentry for cooling prior to ground support equipment connection. Water Spray Boiler (WSB) system provides a heat sink for heat loads generated by operation of the Orbiter hydraulic subsystem and auxiliary power unit (APU) lubricating oil system. Radiators (2 deployable, 2 fixed - 12x15 ft) interface with the Freon 21 loop for on-orbit cooling. Two redundant Spacelab water loops 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. The Spacelab Pallet coolant loop (when used) was a Freon 114 loop and interfaced with the Orbiter Freon 21 loop.

ISS US Segment waste heat is removed through cold plates and heat exchangers, both cooled by a circulating water loop. Waste heat is exchanged a second time to another loop containing ammonia. The heated ammonia circulates through aluminum external radiators releasing the heat as infrared radiation and cooling as it flows.

Vostok used a liquid-air condensing heat exchanger. Condensate was trapped by porous wicks between the heat exchanger tubes. Temperature was adjusted by automatic regulation of the air flow rate through heat exchanger. The cosmonaut could set temperature and humidity. The temperature range was between 12 (54° F) and 25°C (77°F), 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. The dehumidifier operated cyclically. Air inlet to dehumidifier opened after humidity rose above 70%. The air inlet automatically closed when humidity reached 35% ± 5%. The Voskhod and Sozuz designs are similar. The Soyuz liquid coolant is a water/glycol mixture and humidity was controlled primarily by the condensing heat exchanger. Condensate is 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 O2 regenerator.

Salyut used a liquid-air condensing heat exchanger. Temperature could be set by cosmonaut between 15 (59°F), and 25°C (77°F). The 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. The active thermal control system in the Kvant Module had only one thermal loop, designed to be connected to either of the Mir core's two active thermal control loops if need be. Salyut utilized external radiators.

Mir used a liquid-air condensing heat exchanger. Two internal thermal control loops (a cooling loop and a heating loop) were charged with "Temp" coolant (an alcohol [or ethylene glycol] and water mixture). A redundant piping system was included with each loop. Loop temperature was controlled automatically. Mir has no large-surface areas thermal radiators with a fluid interface. Humidity control was maintained by adding 1.2 liters of water/crewperson/day to the atmosphere. The ISS Russian Segment temperature and humidity control system is similar to Mir’s. Mir avionics were cooled by heat exchangers and by air pulled from the cabin. Each method provided about 50% of the cooling. A condensator, with freon as the working fluid, removed moisture that condensed on the equipment.

Water Management

For Mercury, Gemini, the Apollo Command Module (CM), and the Apollo Lunar Module (LM), Skylab, and the Orbiter, potable water was stored and not processed for reuse. Mercury, Gemini waste water was vented to space. The Apollo CM stored condensate water and vented the excess, or sent excess to the evaporator for additional cooling. The Apollo LM stored waste water as no overboard dumping of wastes on lunar surface was allowed. Skylab stored waste water in tanks and vented waste when the tanks were full. The Orbiter also stores waste water in a tank and vents waste water when the tank is full. The ISS US Segment potable and hygiene water is recycled utilizing a multifiltration and ion exchange sorbent beds, and catalytic oxidation. The ISS US Segment can also process urine for water reclamation using vapor compression distillation.

For Mercury, water quality depended on the quality of the public water system in Cocoa Beach, Florida. Bacteria control depended on the residual disinfectant (chlorine) in the public supply. For microbial control chlorine added to the water before launch for Gemini and the Apollo CM. For the Apollo CM chlorine at a concentration of 0.5 mg/liter was maintained by adding (via syringe injection) 22 ml of sodium hypochlorite solution every 24 hours. For the Apollo LM, iodine added before launch and there was no on-orbit biocide addition. A pre-flight 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. For Skylab, the iodine level was maintained between 0.5 and 6.0 mg/liter by periodic injection of a 30 g/l potassium iodide solution. The Orbiter adds iodine from microbial check valves (MCV). MCV passively adjusts iodine concentration between 2 and 6 mg/l. The ISS US Segment also adds iodine from microbial check valves and heat sterilization at 120°C for 10 minutes is planned as part of the water processing cycle.

No on-orbit monitoring of water quality was used on US spacecraft, except for the use of an iodine sampler on Skylab where water were samples fixed with a linear starch reagent and compared to photographic standards. And the ISS US Segment uses an on-line conductivity and free-gas monitor for the water processor. Off-line monitoring of total organic carbon and microbial count can be performed by the Crew Health Care System.

For Mercury, one tank, filled before launch, with a flexible bladder was used for water storage. Squeezing an air bulb pressurized the bladder to deliver water.

For Gemini, one 7.3 liter tank containing a bladder pressurized with oxygen was used to deliver water. The 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.

For the Apollo CM, fuel cell byproduct was the principle source of potable water. Byproduct water was routed to the potable tank or sent to the waste tank if the potable tank was full. A silver palladium separator removed dissolved and free hydrogen. The potable water tank used a bladder pressurized by oxygen to deliver water. The Apollo LM, used three (four on Apollo 15, 16, 17 LMs) potable tanks for storage, each with a bladder pressurized by nitrogen to deliver water. The tanks were filled before launch. The potable water was also used to cool spacecraft and extravehicular mobility units.

Skylab used ten cylindrical 600 lb. capacity stainless steel tanks fitted with pressurized steel bellows to deliver the water. It also had one 26 lb. capacity portable tank. The tanks were filled before launch. The Orbiter has four 168 lb. capacity stainless steel tanks fitted with metal bellows pressurized by nitrogen. Drinking water is from the fuel cell byproduct. The ISS US Segment uses a metal bellows tank design with supply and delivery pumps. Water is supplied to the distribution bus.

For Vostok, Voskhod, and Soyuz, potable water was stored and not processed for reuse. On Salyut 6 and 7, potable water was recovered from condensate. Waste water was pumped into storage columns containing ion exchange resins and activated charcoal, and then sent through filters containing fragmented dolomite, artificial silicates, and salt. Minerals were then added, including calcium, magnesium, bicarbonate, chloride, and sulfate. Mir had three water purification systems. Condensate was recovered by the same process used on Salyut 6, 7. Hygiene/kitchen water was recovered (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. This Mir system could recover 21 liters of water at one time. Electrolysis water was recovered from urine by vapor-diffusion distillation. This Mir system could generate 5.4 liters/day. The ISS Russian Segment water processing system was similar to Mir. The only water quality monitoring provided on Russian spacecraft was measurements taken by water analyzers include pH and salinity on Mir and a conductivity monitor on the ISS Russian Segment.

Vostok, Voskhod, and Soyuz had similar water storage and distribution systems. Water was held in a container made of two layers of elastic polyethylene film. The container was hermetically sealed inside a metal cylinder. Low pressure created by the crewperson's mouth was enough to induce water flow from the polyethylene container. Each crewperson was allotted 2.2 l/day of water. Salyut used the Rodnik ("spring") system to filter water supplied from tanks with a total volume of over 400 liters. Mir system was similar to the Salyut design and had tanks that used pressurized bladders to deliver water. The ISS Russian Segment system was similar to Mir.

For microbial control, Vostok, Voskhod, and Soyuz used a silver preparation added to the water, which was boiled before launch. On Salyut, Mir and the ISS Russian Segment water was heated and ionic silver was introduced electrolytically to achieve a concentration of 0.2 mg/l.

Food

For the first suborbital flights in the Mercury Program no food was provided. During John Glenn’s was the first US astronaut to eat food in space. He was supplied with applesauce in a tube. Later bite-sized cubes of a high calorie mixture of protein, high-melting-point fat, sugar, and fruit or nuts were added on Mercury missions.

During Gemini crews were provided with food for 2500 kcal per person. This consisted of concentrated foods, bite-sized cubes and food squeezed from tubes. The food packaging had high water vapor and O2 barrier properties.

The Apollo CM food system was initially like Gemini, then dehydrated food, food in retort pouches, canned products, and irradiated food were added with increased variety and improved quality. Apollo astronauts used utensils for the first time in space. The Apollo LM provided food bars.

Skylab was the first US spacecraft to have freezers, refrigerators and food warmers. Crews had a varied diet chosen from 72 foods with a 6-day cycle menu. Most food was packaged in aluminum cans to maintain 2-year shelf life. Supplies included some frozen and thermostablized items, high-caloric-density bars, ice cream, and specialties such as filet mignon and lobster.

The Orbiter’s food system includes a galley with a rehydration station and a convection oven. A single package design of food and beverage was introduced as well as commercial-off-the-shelf food items. There are over 150 orbiter food and beverage options. Examples include fruits, salad spread, pudding, cookies, sweet/sour beef, rice pilaf, asparagus, scrambled eggs, beef patty, and tortillas.

On joint NASA/Russian Mir missions half the food was provided by the US and half by Russia. The food was similar to Orbiter food but with a 9-month shelf life (routinely extended). Russian food packaging included cans, metal tubes, and plastic overwrapped in foil. Mir had two food heaters and rehydration equipment and Orbiter brought a potable suitcase food warmer. The Orbiter and Progress vehicles resupplied Mir food stores and brought fresh fruit, vegetables and snacks.

On the ISS frozen foods (e.g., entrees, vegetables, baked goods, grains, and desserts), refrigerated foods (e.g., fruit, vegetables, and dairy items), ambient foods (e.g., thermostabilized, irradiated, aseptic-fill, shelf-stable natural form food, and rehydratable beverages) and commercial-off-the-shelf food are provided. ISS has a convection oven for heating foods. There is a 30-day pre-selected menu plus added food for in-flight changes. The packing system for the daily menu food is based on single-service, disposable containers to eliminate the need for a dishwasher. The Orbiter and Progress vehicles resupply ISS food stores and bring fresh fruit, vegetables and snacks.

Waste Management

On Mercury an in-suit urine collection bag stored urine until the end of the mission. There were no provisions for fecal handling. Note that there were no provisions for urine handling on first Mercury mission. On Gemini, feces were collected in bags and stored. Bags had to be taped to buttocks to use. Urine was collected using the urine transfer system, which consisted of a rubber cuff connected to a flexible bag. The urine could be directed to the boiler tank to assist with spacecraft heat rejection.

For the Apollo CM and LM, feces were collected in bags and stored. Bags had to be taped to buttocks to use. The bag was kneaded to mix a liquid bactericide with the feces. Urine was voided directly overboard through a 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. The primary difference between CM and LM waste management systems was that no overboard dumping of urine was allowed on lunar surface for the LM system.

On Skylab, 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.

The Orbiter utilizes a commode/urinal system. 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.

The ISS US Segment also utilizes a commode/urinal system. Feces are collected in a bag and compacted in a cylindrical canister for storage and disposal (in a Progress resupply module). A urine processor is part of the waste and hygiene compartment planned for Node 3, and will be capable of automatic transfer or of accepting urine via a portable water container to allow transfer from the Russian Segment.

For Vostok, Voskhod, and Soyuz, urine and feces were 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. On Salyut feces were collected in hermetically sealed metal or plastic containers, which were ejected to space about once a week. The urine collector, separate from the main commode, was a cup-and-tube device with a disposable plastic insert and filter. Mir and the ISS Russian Segment used a commode for urine and feces collection. Urine was sent to the recovery processor after passing through an air/liquid separator. Concentrated urine was stored in a tank until disposal. Waste from food and water went to a waste collection unit. Solid wastes were disposed by Progress vehicle reentry.

Fire Detection and Suppression

Detection: Mercury, Gemini and Apollo depended on crew senses for fire or smoke detection. Skylab used ultraviolet detectors. The Orbiter and Spacelab use ionization smoke sensors. The ISS US Segment uses 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. On Salyut CO2 detectors doubled as smoke detectors. Mir had optical sensors and the ISS Russian Segment uses improved optical sensors.

Suppression: Mercury could use water from the food rehydration gun and had the capability to depressurize the cabin by manually opening cabin outflow valve. Gemini's system was similar to the Mercury design and a maximum of three cabin depressurizations could be accommodated by the on-board oxygen supply. The Apollo and Skylab systems could use water from the food rehydration gun and a portable aqueous gel (hydroxy-methyl cellulose) extinguisher, which could expel 0.06 m3 of foam in 30 seconds. They also had the capability to depressurize the crew cabin. The Orbiter and Spacelab uses Halon 1301 as a fire suppressant. The Orbiter has three remote Halon bottles, one per avionics bay, and three portable Halon bottles, two located on the middeck and one on the flight deck. Spacelab had a Halon bottle with distribution lines located in each equipment rack and two portable Halon extinguishers. The Orbiter and Spacelab also have the capability to depressurize the crew cabin. The ISS US Segment uses CO2 has the fire suppressant, has portable CO2 extinguishers and can depressurize the cabin. Mir and the ISS Russian segment use portable extinguishers and the crew can open valves to extinguish fires in inaccessible areas.

SOURCES:

1) P.O. Wieland, 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 US.S.R./Russian Space Habitats (July 2005)

2) Helen W. Lane and Dale A. Schoeller, Nutrition in Spaceflight and Weightlessness Models (2000)

3) NASA Facts, Space Food, FS-2002-10-079-JSC (October 2002)