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Subject: Advanced Life Support Research and Technology Development Metric – Fiscal Year 2005, Revision A

The attached document, "Advanced Life Support Research and Technology Development Metric – Fiscal Year 2005, Revision A," documents the calculation and results for the Advanced Life Support Research and Technology Development Metric for Fiscal Year 2005. This report is a revision of "Advanced Life Support Research and Technology Development Metric – Fiscal Year 2005," ESCG – 4470 – 05 – TEAN – DOC – 0131, which corrects a few minor typographical errors and, more importantly, adds a detailed breakdown of the vehicle equivalent system masses in Section 6. Please direct any questions or comments to A. J. Hanford at (281) 461-5391 or Anthony.Hanford@ESCG.Jacobs.com.

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Advanced Life Support Research and Technology Development Metric – Fiscal Year 2005

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1 INTRODUCTION

This document provides the official calculation of the Advanced Life Support (ALS) Research and Technology Development Metric (the Metric) for Fiscal Year 2005. As such, the values herein are primarily based on Systems Integration, Modeling, and Analysis (SIMA) Element approved software tools or reviewed and approved reference documents.

1.1 EXECUTIVE SYNOPSIS

For Fiscal Year 2005, the Advanced Life Support Research and Technology Development Metric value is 2.12 for an Orbiting Research Facility, 1.30 for a Near-Term Exploration Mission, and 1.76 for an Independent Exploration Mission.

1.2 BASIC METRIC FORMAT

The Metric is one of several measures employed by the National Aeronautics and Space Administration (NASA) to assess the Agency's progress as mandated by the United States Congress and the Office of Management and Budget. Because any measure must have a reference point, whether explicitly defined or implied, the Metric is a comparison between a selected life support system using the "best" available technologies, including those under development within the ALS Project, and an equivalently detailed baseline life support system using technology and approaches from current programs such as the Space Transportation System (STS) or the Environmental Control and Life Support System (ECLSS) from the International Space Station (ISS). More specifically, the Metric is the ratio defined by the equivalent system mass (ESM) of a life support system for a specific mission using current technologies, signified by the baseline technologies, divided by the ESM for an equivalent life support system using the "best" technologies, often called the advanced technologies here.

As defined, the Metric should increase in value as the advanced technologies become lighter, less power intensive, and require less volume. Here "best" is defined as the advanced configuration that, at the time of the Metric evaluation, provides the Metric with the highest value. This process theoretically encourages the ALS Project to research more than a single technology for each life support function and then select the most appropriate for a particular mission, which is similar to an actual process used by mission planners. Only technologies of a certain maturity level, generally of technology readiness level of 5 or higher, are selected for inclusion in the Metric to avoid assuming too much with too little data. Some promising advanced technologies at a lower technology readiness level might appear here, but those selections should be uncommon. See Table 1.2.1 for a summary of the technology readiness levels used by NASA (Henninger, *et al.*, 2002). This implies that the Metric will improve as promising technologies mature within the ALS Project and become eligible for inclusion in this calculation. Conversely, early assumptions for some technologies may be overly optimistic, so the Metric value using those technologies may decrease in the future as additional research uncovers higher than expected costs and outdated assumptions are revised.

Table 1.2.1 Technology Readiness Levels

Technology Readiness Level	Description
1	Basic principles observed and reported.
2	Technology Concept and/or application formulated.
3	Analytical and experimental critical function and/or characteristic proof-of-concept.
4	Component and/or breadboard validation in laboratory environment.
5	Component and/or breadboard validation in relevant environment.
6	System/subsystem model or prototype demonstration in relevant environment (ground or space).
7	System prototype demonstration in a space environment.
8	Actual system completed and "flight qualified" through test and demonstration.
9	Actual system "flight proven" through successful mission operations.

1.3 DESCRIPTION OF EQUIVALENT SYSTEM MASS

Equivalent system mass (ESM) is the sum of the masses of life support equipment and supplied commodities, plus the mass penalties for infrastructure support, notably power, volume, and cooling, corrected for the crewtime required to operate and maintain the life support system. See Levri, *et al.*, 2003.

ESM reduces the physical quantities describing a system or subsystem to use a single physical parameter: mass. This allows comparison of two systems with different physical parameters using a single scalar, and avoids the necessity of arbitrary weightings that reflect the prejudices of the analyst to compare, for example, a lighter subsystem to one using less power.

Conversion factors, or equivalencies, are determined for the environment and infrastructure technologies that are likely to be used for a mission. For systems requiring power, for example, examination of the power system can yield an appropriate power-mass penalty by dividing the average power-plant output for user loads by the total mass of the generating power system. Thus, for a nuclear power system on an independent lander that, on average, delivers 100 kW of electrical user power and has an overall mass of 8,708 kg, the power-mass penalty is 87 kg/kW$_e$ (0.0115 kW$_e$/kg) (Hanford, 2004a). This power-mass penalty effectively assigns a fraction of the power system mass to a power-using subsystem in place of that subsystem's power requirement. In like manner, mass penalties to account for heat rejection, called cooling here, and volume within a pressurized shell are defined.

1.4 PREVIOUS ADVANCED LIFE SUPPORT METRIC COMPUTATIONS

Previously released Metric computations, in reverse chronological order, may be found in the documents listed below. [1]

Hanford, A. J. (2004) "Advanced Life Support Research and Technology Development Metric – Fiscal Year 2004," NASA/CR-2004-208944, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, October 2004.

Hanford, A. J. (2004) "Subsystem Details for the Fiscal Year 2004 Advanced Life Support Research and Technology Development Metric," MSAD-04-0306A, Lockheed Martin Space Operations, Houston, Texas, September 2004.

Hanford, A. J. (2003) "Advanced Life Support Research and Technology Development Metric – Fiscal Year 2003," NASA/CR-2004-208939 (JSC 60455, CTSD-ADV-524), National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, 30 September 2003.

Hanford, A. J. (2003) "Advanced Life Support Research and Technology Development Metric – Fiscal Year 2002," JSC 60313 (CTSD-ADV-510), Revision A, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, 24 July 2003.

Hanford, A. J. (2003) "Advanced Life Support Research and Technology Development Metric – Fiscal Year 2002," JSC 60313 (CTSD-ADV-510), National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, 15 January 2003.

Drysdale, A. E., and Hanford, A. J. (2002) "Advanced Life Support Research and Technology Development Metric – Fiscal Year 2001," JSC 47787 (CTSD-ADV-482), National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, 17 January 2002.

Drysdale, A. E. (2001) "Update to the Advanced Life Support Research and Technology Development Metric," National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, 19 February 2001.

Drysdale, A. E., and Hanford, A. J. (1999) "Advanced Life Support Research and Technology Development Metric – Baseline" JSC 39503 (CTSD-ADV-384), National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, 19 November 1999.

Hanford, A. J., and Drysdale, A. E. (1999) "Advanced Life Support Technology Research and Development Metric – Initial Draft," LMSMSS 33045, Lockheed Martin Space Mission Systems and Services, Houston, Texas, 13 January 1999.

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[1] For electronic copies of recent documents, please see *http://advlifesupport.jsc.nasa.gov/*.

1.5 NOTES ON THE METRIC FOR FISCAL YEAR 2005

The ALS Project continues to evolve and change both in structure and focus, and these changes affect the Metric, some more strongly than others. For the current calculation, the differences in approach and organization from Fiscal Year 2004, Hanford (2004c), are minimal. Most importantly, the current calculation uses a revised version of a generalized life support spreadsheet tool, the Advanced Life Support Sizing Analysis Tool (ALSSAT) (Yeh, *et al.*, 2002, Yeh, *et al.*, 2003, Yeh, *et al.*, 2004a, Yeh, *et al.*, 2005a, and Yeh, *et al.*, 2005b). ALSSAT provided values to the current Metric calculation for all subsystems and applicable external interfaces.

Previous Metric calculations (See, for example, Drysdale and Hanford, 2002) and SIMA's official definition (See, Levri, *et al.*, 2003) include crewtime as part of equivalent mass assessments. This year, ALSSAT includes crewtime in assessments, when data is available. However, crewtime for some systems remains unavailable.

ALSSAT underwent a number of changes internally that impact the Metric, as detailed in Yeh, *et al.* (2005a) and Yeh, *et al.* (2005b). These updates affect many technologies within ALSSAT in some manner, but numerical impacts of those changes on the Metric are not individually apparent at this time. Of note, efforts over the past year, as detailed in Yeh, *et al.* (2005a) and Yeh, *et al.* (2005b), include:

1. The gas mass balances for the salad machine and crew metabolic loads are now explicitly computed instead of represented with averaged values.
2. The water mass balance for the biomass within the salad machine is now explicitly computed instead of represented with averaged values.
3. Five additional water management options were added. The new options include an International Space Station Water Recovery System without Vapor Compression Distillation with urine treated by a waste system processor, an International Space Station Water Recovery System without Vapor Compression Distillation with urine dumping, a Biological Water Recovery Subsystem without the Air Evaporation Subsystem so brine is treated by a waste system processor, a Vapor Phase Catalytic Ammonia Removal subsystem without the Air Evaporation Subsystem so brine is treated by a waste system processor, and a Vapor Phase Catalytic Ammonia Removal subsystem with Lyophilization for brine dewatering in place of an Air Evaporation Subsystem.
4. Wipes were added to the Human Accommodations External Interface. Specifically, when water is not allocated for body or hand/face cleansing, wipes are automatically assumed by ALSSAT. Moisture from the wipes may be reclaimed within the waste system if a moisture recovery technology is available. To recover moisture from wipes is optional.
5. Cryogenic oxygen storage algorithms were revised based on data from International Space Station hardware. Lacking corresponding information for cryogenic nitrogen storage, relationships based on researching cryogenic oxygen storage were substituted.
6. The power estimate for the ullage gas save pump associated with Solid Vacuum Desorption was revised.
7. Sizing routines for lithium hydroxide usage during long-duration missions were revised to correct an error. (This error did not impact the Fiscal Year 2004 Metric calculation.)
8. An initial model of the Functionalized Carbon Molecular Sieve was integrated into ALSSAT. Some data entries for this technology were missing from the available reference materials, so some quantities were estimated until more accurate information is discovered.
9. A more accurate carbon dioxide reduction subsystem based on the Sabatier was researched and implemented.
10. An Advanced Trace Contaminant Control Subsystem was researched and integrated into ALSSAT. This technology was not considered in the current calculation. [2]

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[2] Because work on ALSSAT is ongoing, some options scheduled for Fiscal Year 2005 were not completed at the time ALSSAT was made available to compute the Fiscal Year 2005 Metric. Thus, exclusion of this option and others similarly designated was not an oversight.

11. The waste stream from the food system was divided into non-biodegradable and biodegradable fractions to support waste system computations.
12. The bulk-packaged menu option within the food system was revised. As part of the new bulk-packaged food system, a bulk drink option with a dispenser and a bread machine were added. Bulk-packaged food was not considered in the current calculation.
13. The individual waste system technologies, Warm-Air Drying, Lyophilization, and Storage, were revised.
14. A second combination of waste system technologies, including lyophilization, waste compaction with a Plastic Melt Waste Compactor, and storage, was added.
15. A third combination of waste system technologies, including Sequential Batch Anaerobic Composting, Warm-Air Drying, and Storage, was added. This combination of technologies was not considered in the current calculation.

While ALSSAT continues to evolve and improve, it is believed that the current computations are sufficiently accurate to provide credible Metric values for Fiscal Year 2005.

To be consistent with last year and to reflect advances in thermal rejection technologies, the current Metric calculations apply different cooling-mass penalties to the different life support system configuration assessments for Independent Exploration Mission vehicles. Cooling-mass penalties, assuming aluminum, flow-through radiators, apply this year to life support system assessments using hardware from the baseline technology suite. Cooling-mass penalties for life support system assessments based on the advanced technology suite assume advanced hardware using composite heat-rejection technologies. This is consistent with two previous calculations (Hanford, 2003b and Hanford, 2004c). This current Metric calculation, then, showcases advantages associated with advanced thermal rejection technologies developed with ALS Project funding, providing appropriate reduced cooling-mass penalties for advanced configurations.

Finally, the Metric workshop near the end of Fiscal Year 2003 brought together analysts and management at all levels of NASA to consider the future of the Metric. Several recommendations from the discussions in that forum are included, to varying degrees, in this year's calculation. The status of the most significant are listed here.

1. Changes to the Metric will be listed or referenced in this document. Specifically, changes to the approach, methodology, or life support architecture are listed in this document, while changes to the calculation tool, ALSSAT, are recorded in software specific documentation. See Yeh, *et al.*, (2004a). However, while subjective, factors of "great influence" to the Metric related to ALSSAT are listed here. Compared to the computation from Fiscal Year 2004 (Hanford, 2004c), there are no new changes in the methodology for the Metric.
2. The Metric computation added a new Near-Term Exploration Mission whose target is Luna based upon Hanford (2005).
3. Dry food mass is excluded from the life support system for both current and advanced architectures.
4. Infrastructure equivalencies may vary over time. The infrastructure values used for this calculation appear in Hanford (2004a) or Hanford (2005). The infrastructure values for volume, power, and cooling are unchanged from the Fiscal Year 2004 Metric calculation (Hanford, 2004c) for the Orbiting Research Laboratory and the Independent Exploration Mission.
5. ALSSAT does not include stowage factors[3] for all technologies, and this is a deviation from Levri, *et al.* (2003). But, ALSSAT provides all technologies on a common basis. To date, secondary structures, or stowage factors, exist for a few technologies, but research in this area is ongoing.
6. Data for all technologies selected in this year's assessments are thought to correspond to a technology readiness level (TRL) of 5 or greater.

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[3] Stowage factors account for necessary secondary structure to mount hardware inside the vehicle. This secondary structure differs from the primary vehicle structure, or hull, which is represented by the volume-mass penalty. See Hanford (2004a) for details.

7. ALSSAT now tracks crewtime for individual technologies. These values are included in the assessments below and are included in the overall equivalent system mass values. Crewtime data for all ALSSAT technologies may be incomplete at this time.
8. ALSSAT now computes the crew metabolic waste stream as feces, urine, respiration, and perspiration based on metabolic intake, compared with using average values.
9. ALSSAT tracks thermal loads separately from power consumption, thus removing the simplifying assumption that thermal load is equivalent to power consumption. Thermal data for all ALSSAT technologies may be incomplete at this time. When unknown, the thermal load is still assumed equal to the power consumption.

1.6 CONTROL AND CONTACT INFORMATION

The ALS Project controls the Metric, and SIMA provides the Metric calculation. Subsequent releases will be made as required. Please forward comments to:

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2 BACKGROUND

2.1 SUPPORTING DOCUMENTATION

The listed SIMA reference documents provided inputs for the Fiscal Year 2005 Advanced Life Support Research and Technology Development Metric calculation. [4]

Hanford, A. J., Editor (2004) "Advanced Life Support Baseline Values and Assumptions Document," NASA/CR-2004-208941, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas.

Hanford, A. J. (2005) "A Lunar Reference Mission for Advanced Life Support," ESCG-4007-05-TEAN-DO-0082, Engineering and Science Contract Group, Jacobs Sverdrup, Houston, Texas, 08 July 2005.

Levri, J. A., Drysdale, A. E., Ewert, M. K., Fisher, J. W., Hanford, A. J., Hogan, J. A., Jones, H. W., Joshi, J. A., and Vaccari, D. A. (2003) "Advanced Life Support Equivalent System Mass Guidelines Document," NASA/TM-2003-212278, National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California.

Stafford, K. W., Jerng, L. T., Drysdale, A. E., Maxwell, S., Levri, J. A., Ewert, M. K., and Hanford, A. J. (2001) "Advanced Life Support Systems Integration, Modeling, and Analysis Reference Missions Document," JSC 39502, Revision A, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas.

Yeh, J., Brown, C., and Jeng, F. (2002) "Advanced Life Support Sizing Analysis Tool (ALSSAT) v.2.0 User's Guide," LMSEAT 34082, Lockheed Martin Space Operations, Houston, Texas.

Yeh, J., Brown, C., and Jeng, F. (2003) "Advanced Life Support Sizing Analysis Tool (ALSSAT) v.3.0," MSAD-03-0279, Lockheed Martin Space Operations, Houston, Texas.

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[4] For electronic copies of the NASA reference documents, please see *http://advlifesupport.jsc.nasa.gov/*.

Yeh, J., Brown, C., and Jeng, F. (2004) "FY04 ALSSAT Upgrade," MSAD-04-0261, Lockheed Martin Space Operations, Houston, Texas.

Yeh, J., Brown, C., and Jeng, F. (2004) "Reference Manual for the Advanced Life Support Sizing Analysis Tool (ALSSAT)," MSAD-04-0303, Lockheed Martin Space Operations, Houston, Texas.

Yeh, J., Brown, C., and Jeng, F. (2004) "Water Recovery Subsystem (WRS) Options Trade Studies Using ALSSAT," MSAD-04-0353, Lockheed Martin Space Operations, Houston, Texas.

Yeh, J., Brown, C., and Jeng, F. (2005) "FY05 ALSSAT Upgrade," MSAD-05-0098, Lockheed Martin Space Operations, Houston, Texas.

Yeh, J., Brown, C., and Jeng, F. (2005) "Advanced Life Support Sizing Analysis Tool (ALSSAT) Upgrade for FY05," ESCG-4470-05-TEAN-DOC-0141, Engineering and Science Contract Group, Jacobs Sverdrup, Houston, Texas.

These reference documents provide the primary resources for the values contained below, and, unless noted otherwise, all values are listed in or derived from these documents.

2.2 REFERENCE MISSIONS

The following missions are addressed for Fiscal Year 2005:

- Orbiting Research Laboratory: International Space Station Upgrade Mission (Stafford, *et al.*, 2001),
- Near-Term Exploration Mission: Lunar Reference Mission (Hanford, 2005), and
- Independent Exploration Mission: Mars Dual Lander Architecture (Stafford, *et al.*, 2001).

These missions are described briefly below. For additional details, please see the cited reference.

The data given applies to nominal operations. Contingency planning, though extremely important, is not sufficiently well advanced at this time for these missions, so contingencies are excluded from these calculations.

2.2.1 ORBITING RESEARCH FACILITY: INTERNATIONAL SPACE STATION UPGRADE MISSION

The International Space Station (ISS) mission is a ten-year, six-crewmember [5] mission in low-Earth orbit. For this assessment, the specifics of Earth-to-orbit transfers are not considered, nor are ISS construction operations. Rather, this assessment considers just the ESM for nominal, on-orbit operation of the life support system in the United States On-Orbit Segment (USOS) following Phase 3. [6] Extravehicular activities are assumed to be a small mission component during the day-to-day operation of the ISS after buildup is complete and are, therefore, omitted in the assessments here. [7]

The ISS Upgrade Mission follows the initial utilization phase for the complete vehicle and assumes that to use ISS for an additional ten-year mission the entire USOS life support system must be replaced with new equipment of the same or comparable technologies. This mission scenario, as addressed in the assessments below, assumes the cooling hardware will have identical properties to current ISS cooling hardware regardless of the life support system technologies used. The rationale for extending ISS beyond its initial design life is not addressed here

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[5] A crew of six is defined here not as a policy statement or a forward projection for NASA, but rather to make the ISS scenario comparable to the Independent Exploration Missions that also proposes six crewmembers.

[6] Phase 3 is also known as "assembly complete."

[7] While extravehicular activities, and the commodities they may use from the life support system, are a concern, the scenario for extravehicular activities beyond assembly complete depends heavily on many factors beyond the scope of this current assessment, so rather than add questionable assumptions, "extravehicular activities are assumed to have a small but consistent impact on all life support system architectures, and may, therefore, be omitted."

but, rather, significant justification is implicitly assumed. Alternately, this mission might apply to a new space station of comparable size and capability that follows ISS in the timeframe indicated.[8]

The baseline equipment suite assumes an appropriate life support system for the USOS Phase 3 segment using baseline technologies alone. This system includes newly fabricated equipment and it replaces the original equipment just prior to the beginning of the utilization phase of the ISS Upgrade Mission. The corresponding upgraded USOS life support system using advanced technologies provides the same capabilities as the baseline USOS Phase 3 life support system but it employs the most economical, in terms of equivalent system mass, life support technologies regardless of origin.

2.2.2 NEAR-TERM EXPLORATION MISSION: A LUNAR REFERENCE MISSION

This exploration mission consists of a single trip to one site on Luna. The analysis here assumes a standard mission profile with an overall duration of no more than 118 days (Hanford, 2005).

A Crew Exploration Vehicle carries the crew during both Earth-Luna transit segments, remaining dormant in low-Lunar orbit while the crew descends to Luna for the surface phase. The crew will transfer to a second vehicle, the Lunar Surface Access Module, to transfer from low-Lunar orbit to the surface and, ultimately, back to low-Lunar orbit at the conclusion of the surface mission. Finally, a third vehicle, the Destination Surface System, will fly to Luna and land robotically on the surface. This last vehicle provides a long-duration habitat during the surface segment. An equatorial site is assumed for this assessment. During the surface segment, extravehicular activities will be frequent, if not daily, events. Here the extravehicular activities are assumed to occupy two crewmembers for up to 8 hours per sortie, with 56 sorties scheduled during surface operations. Each vehicle is assessed for either weightless or partial gravity, according to the primary operational environment with the crew. Thus, the Crew Exploration Vehicle is studied while weightless, and the Lunar Surface Access Module and Destination Surface System are assessed assuming partial gravity.

2.2.3 INDEPENDENT EXPLORATION MISSION: MARS DUAL LANDER ARCHITECTURE

This Mars exploration mission consists of a single trip to one site on Mars. The analysis assumes a standard mission profile with outbound and return transit segments of 180 days and a surface phase of 600 days (Stafford, *et al.*, 2001). Actual missions will vary in duration according to the year or transportation opportunity, propulsion capabilities, and mission development decisions.

A Mars Transit Vehicle carries the crew during both interplanetary segments, remaining dormant in Martian orbit while the crew descends to Mars for the surface phase. A second vehicle, the Mars Descent / Ascent Lander, will fly to Mars orbit robotically. The crew will transfer to, and land in, this second vehicle. A third vehicle, the Surface Habitat Lander, will fly to Mars and land robotically on the surface. This last vehicle will house the crew during the surface segment. During the surface segment, extravehicular activities will be frequent, if not daily, events. Here the extravehicular activities are assumed to occupy two crewmembers for up to 4 hours per sortie, with 700 sorties scheduled during surface operations from the Surface Habitat Lander. After completion of the surface phase, the crew will ascend to Martian orbit in the Mars Descent / Ascent Lander and rendezvous with the waiting Mars Transit Vehicle. Each vehicle is assessed for either weightless or partial gravity, according to the primary operational environment with a crew. Thus, the Mars Transit Vehicle is studied while weightless, and the Surface Habitat Lander and the Mars Descent / Ascent Lander are assessed assuming partial gravity.

2.3 METRIC ASSUMPTIONS

Except as may be noted here, all assumptions for the Metric are derived from the reference documentation above. The infrastructure, mission parameters, computational algorithms, and most of the overall assumptions are identical to the Fiscal Year 2004 Metric values (Hanford, 2004c), where applicable. Any changes in assumptions most often arise directly or indirectly from changes and improvements in ALSSAT. See, in particular, Yeh, *et al.* (2005a) for a summary of changes to ALSSAT for Fiscal Year 2005.

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[8] While the ALS Project supports current NASA missions as requested, most ALS technologies under development will provide technological solutions for missions that are not yet defined because the technology-development cycle duration can be considerably longer than the mission-planning cycle duration. Thus, SIMA analyzes missions deemed probable even if the specific rationale for a mission is not currently apparent.

The vehicles here assume a cabin volume, for purposes of computing cabin atmospheric parameters, based on the estimated structure for each vehicle. Based on Hanford (2004a), all cabin volumes assure at least the minimal free volume for the crew. See Table 2.4.1.

To minimize the effect of infrastructure assumptions on the Metric value, similar infrastructures are assumed for each technology option. The International Space Station Upgrade Mission employs infrastructure values characteristic of International Space Station throughout, while the exploration missions assume both current and advanced technologies with some inflatable modules. With respect to these latter vehicles, the structure penalties merely account for a pressurized volume and include no additional mass for environmental radiation protection, implying instead that life support equipment is naturally resistant to radiation hazards and crew interaction with life support equipment is minimal. The volume penalties for the vehicles within the exploration missions do provide pressurized volume. See Table 2.4.3. Where applicable, specifically for the Orbiting Research Facility and the Independent Exploration Mission, these infrastructure values are identical to values assumed for the Fiscal Year 2004 Metric (Hanford, 2004c). The Near-Term Exploration Mission was evaluated during this assessment for the first time.

Support to extravehicular activities from the life support system, plus associated airlock operation costs, are included. Extravehicular mobility units and other extravehicular activity equipment are not included here. As noted above, commodity losses for extravehicular activities are carried by the subsystem primarily concerned with that commodity and are not specifically identified as extravehicular activity support costs. Any costs associated with extravehicular activity support reflect equipment unique to that function.

Some life support system designs naturally recover more water than the crew uses to support their basic metabolic and hygiene requirements. Thus, such a surplus might be a resource for other vehicle systems just as fuel cell water is a resource from Shuttle to International Space Station. Any surplus water, however, has not been included in the official Fiscal Year 2005 calculations as an additional credit except as it may offset water usage elsewhere within the life support system.

Power and cooling infrastructure costs are estimated here using nominal power and cooling loads. This approach implies that peak loads have little impact on the power and cooling systems, or that these loads can be successfully averaged when considering the entire vehicle.

Finally, the computation for Fiscal Year 2005 assumes a single-string life support system architecture for all cases. Because different technologies may require differing levels of additional equipment to assure satisfactory redundancy and reliability for an actual flight configuration, this assumption may be a significant simplification in this computation.

2.4 TECHNOLOGY ASSUMPTIONS

2.4.1 ORBITING RESEARCH FACILITY: INTERNATIONAL SPACE STATION UPGRADE MISSION

International Space Station uses aluminum modules and nodes pressurized to 101 kPa. Solar photovoltaic power generation with rechargeable batteries for energy storage provide continuous power. The external thermal control system uses a single-phase, pumped ammonia loop to transport thermal energy and rejects the thermal loads using anti-sun tracking radiators with Z-93 surface coating. The baseline hardware configuration associated with completion of Phase 3, or "assembly complete," is the assumed baseline along with an additional mission duration of ten years. For this computation, extravehicular activities are not considered. Further, the baseline provides 1.27 kg/d of potable water to payloads that is not recovered.[9] Table 2.4.2 details specific inputs for the ISS Upgrade Mission.

2.4.1.1 BASELINE LIFE SUPPORT SYSTEM TECHNOLOGY

The baseline, for the purposes of this document, is defined based on the USOS ECLSS scaled for a crew of six. See Stafford, *et al.* (2001), for details of the life support system architecture. This suite uses physicochemical technologies to regenerate air and water, while food is supplied as individual prepackaged entrees, including frozen food selections. Waste is stored without reclaiming any commodities. Thermal management employs coldplates

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[9] While this may seem wasteful, especially over a mission duration of ten years, payload wastewater may contain many constituents that the life support system's water subsystem is not designed to handle adequately. Thus, rather than limit research on International Space Station only to experiments that generate compatible wastewater, and possibly jeopardize its overall research mission and/or the crew's health through contaminating the water subsystem, it is prudent to simply dump this wastewater stream.

and condensing heat exchangers to collect sensible and latent heat loads, a single-phase fluid to transport heat, and radiators to reject heat. Clothing is supplied from Earth clean and discarded to the waste subsystem once it is deemed too dirty to wear. See Figure 2.4.1. See Section 8 for a list of acronyms used in this figure.

2.4.1.1.1 Air

The baseline air suite uses regenerable carbon dioxide removal equipment based on molecular sieve technology. The absorbed carbon dioxide is dumped overboard without recovering any commodities. The trace contaminant control system for atmospheric gases uses activated carbon, for non-combustible trace gas removal, and bacteria filter assemblies, for particulate removal, neither of which are regenerated. Further, the trace contaminant control system also removes trace combustible gases in the crew cabin. Oxygen is supplied both as pressurized gas from high-pressure stores, and as a product from electrolysis of water using solid polymer technology. The associated product hydrogen is dumped overboard. Electrolysis water is provided by the water subsystem. Nitrogen is supplied from high-pressure gas stocks. A major constituent analyzer and a fire detection and suppression system provide monitoring for air contaminants and combustion products.

2.4.1.1.2 Food

Food is provided as individual entrees from Earth. A mix of fresh, dehydrated, and full-water preserved, shelf-stable, or frozen foods are used. This system provides significant quantities of water, but also requires significant quantities of packaging. The nominal crew metabolic energy requirement for intravehicular activities only is 11.82 MJ/CM-d. Heavier workloads, such as those associated with extravehicular activities, generally require greater food intake. For this mission, the crew nominally receives 1.372 kg/CM-d [10] of food. Neglecting the dry component, the food mass as-shipped is 0.691 kg/CM-d of moisture with 0.240 kg/CM-d of disposable packaging. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Supporting technology includes conditioned cold storage and some food preparation equipment.

2.4.1.1.3 Thermal

Thermal management is divided into two systems here. The internal thermal control system includes the avionic air assemblies, which provide air-cooling for equipment, the common cabin air assemblies, which cool, dehumidify, and circulate cabin air, condensate storage, and the water flow loops for heat transport. Coldplates and heat exchangers are assumed part of other equipment, while the external thermal control system costs are assessed using the cooling-mass penalty.

2.4.1.1.4 Waste

Solid waste is stored and returned aboard the crew transfer vehicle or burned upon re-entry in an expendable resupply vehicle. This includes trash, fecal material, brine from the urine and water processing, and used filters and cartridges. The toilet is also included here under the waste subsystem.

2.4.1.1.5 Water

Urine is processed by vapor compression distillation. The brine is either returned to Earth or dumped. All grey water, including hygiene water, effluent from the vapor compression distillation, and condensate from dehumidification, is processed through a water processor. The water processor employs two multifiltration units, a volatile removal assembly, phase separators, and an ion exchange bed. A process control water quality monitor provides water quality assurance. Efficiency of recovery is high, but many expendables, mostly filter cartridges, are needed. Additional water may enter ISS directly, such as from the Shuttle’s stock of fuel cell water or as moisture contained in food, or indirectly, as a human metabolic product from the consumption of supplied food. The first mechanism is not included while the second and third mechanisms are a natural part of the overall life support commodity mass balance. Lastly, water may also come from stocks, which is the assumed source of any additional water not contained either as food moisture or arising as metabolic products from food consumption. Due to water losses for payloads, the ISS Upgrade Mission will probably be “water poor” in the nominal case without additional water stores.

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[10] The units here, kilograms per crewmember per day [kg/CM-d], denote a per person basis.

2.4.1.1.6 Human Accommodations

Clothing is delivered with the crew at the beginning of an expedition and returned to Earth with the crew at the end of each expedition. A usage rate of 0.486 kg/CM-d, in a volume of 0.00285 m^3/CM-d, is assumed.

2.4.1.2 ADVANCED LIFE SUPPORT TECHNOLOGY

In contrast to the architecture using the baseline hardware, the advanced technology suite reduces accumulated atmospheric carbon dioxide with a Sabatier carbon dioxide reduction assembly and extracts water from waste, including hygiene wipes, using lyophilization. Melt compaction provides waste volume reduction. Additionally, the advanced technology suite stores atmospheric gases as cryogens, feeds the crew with an ambient temperature pre-packaged food system, and reclaims water using a vapor phase catalytic ammonia removal water recovery system without air evaporation. An aqueous laundry recycles crew clothing. See Figure 2.4.2. See Section 8 for a list of acronyms used in this figure.

2.4.1.2.1 Air

The advanced suite uses a regenerable carbon dioxide removal assembly based on a four-bed molecular sieve technology, a Sabatier carbon dioxide reduction assembly with a gas stream compressor, and a trace contaminant control assembly based on baseline technology. Adequate water is assumed available to avoid supply penalties for any necessary oxygen and hydrogen. Specifically, Sabatier reduces carbon dioxide according to the availability of hydrogen from the oxygen generation assembly. Any carbon dioxide that is not reduced is vented to space. High efficiency particulate air filters provide particulate removal. Gases for atmospheric pressurization, specifically oxygen and nitrogen, are stored under lower pressure as cryogens compared to the high-pressure storage used within the baseline suite. Other aspects of the advanced air suite are identical to the baseline technology suite for air listed in Section 2.4.1.1.1.

2.4.1.2.2 Food

The advanced suite for food employs ambient storage, prepackaged food with comparable nutritional content to the food subsystem outlined in Section 2.4.1.1.2. This food system provides 1.147 kg/CM-d of food, or 0.466 kg/CM-d of food moisture, as-shipped, if the dry food mass is neglected. 0.264 kg/CM-d of disposable packaging is required. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Dedicated cold storage is unnecessary.

2.4.1.2.3 Thermal

The advanced suite for the thermal subsystem uses the same technologies as the baseline suite for the thermal subsystem described in Section 2.4.1.1.3.

2.4.1.2.4 Waste

The advanced suite for waste uses lyophilization to recover water from solid wastes and hygiene wipes. Reclaimed water passes to the water subsystem to remove impurities. Dry, solid waste is volume reduced using a plastic melt compactor, stored, and finally returned to Earth for ultimate disposal.

2.4.1.2.5 Water

The advanced suite for water recovery uses the vapor phase catalytic ammonia removal technology for primary water processing of both urine and grey water. Vapor phase catalytic ammonia removal uses distillation as its basic physicochemical mechanism, with additional integrated reactors for oxidation and reduction. Brine is sent to the waste subsystem for dewatering. Product water from the vapor phase catalytic ammonia removal assembly requires no further polishing, though a process control water quality monitor provides water quality assurance. Recovery efficiency with this system is high with reduced expendables compared to the baseline suite.

2.4.1.2.6 Human Accommodations

The advanced approach assumes an aqueous laundry. This will significantly increase the daily grey water load, but reduce the required mass of clothing compared to the baseline approach. While the apparent clothing usage rate to the crew remains unchanged, the laundry system cleans soiled clothing for reuse, prolonging clothing life and reducing associated waste loads.

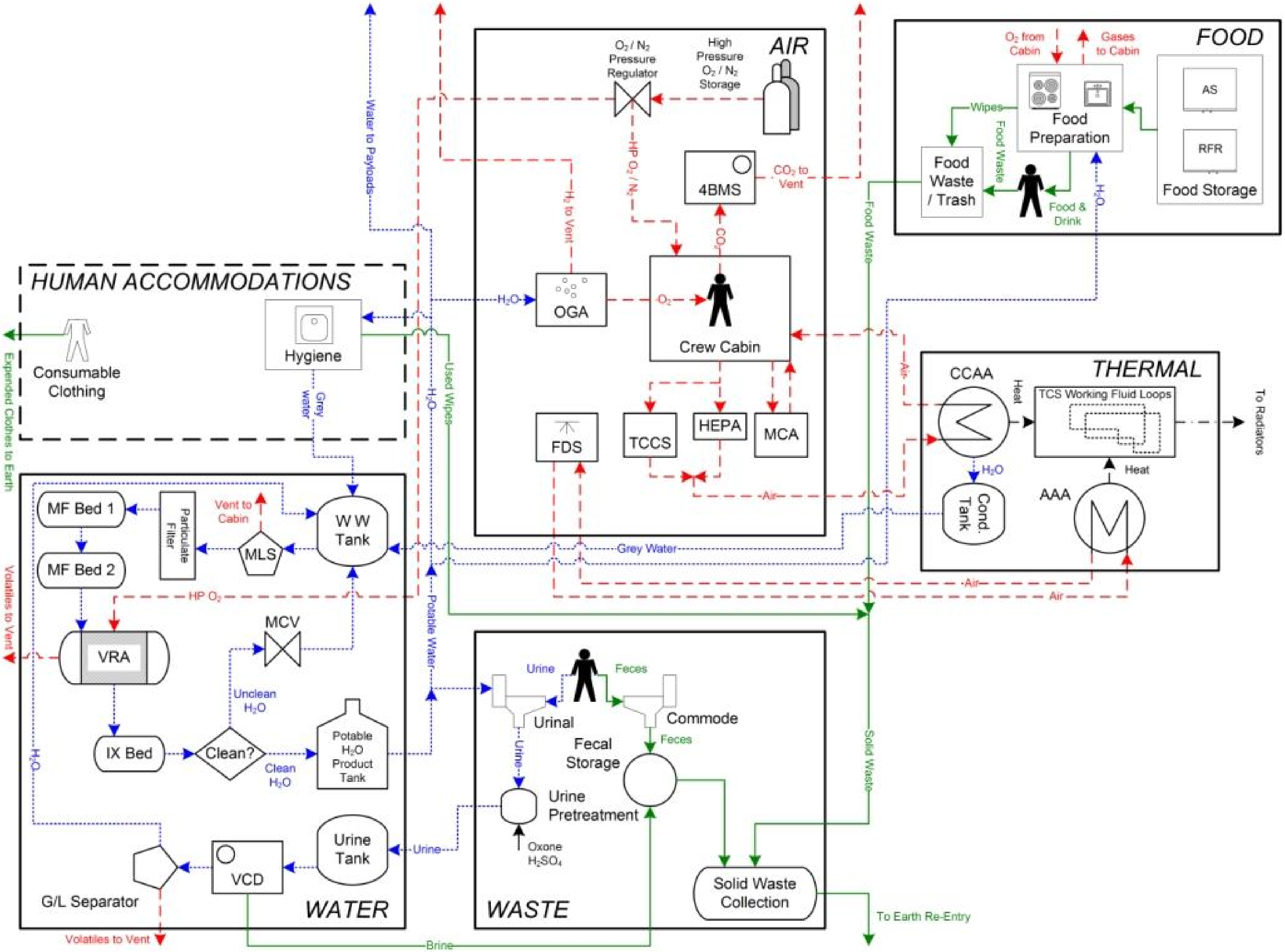

Figure 2.4.1 International Space Station Upgrade Mission using Baseline Technologies.

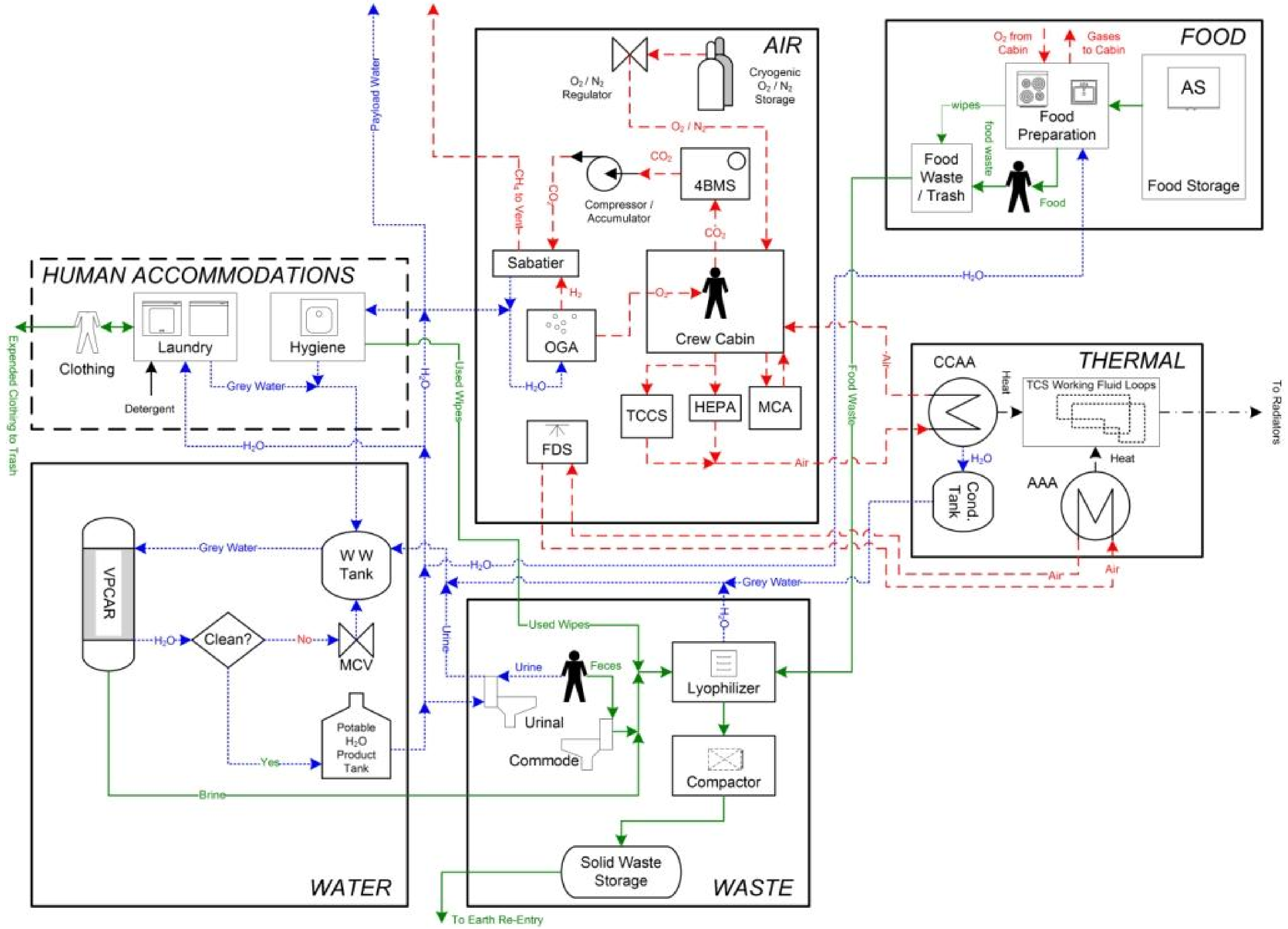

Figure 2.4.2 International Space Station Upgrade Mission using Advanced Technologies.

2.4.2 NEAR-TERM EXPLORATION MISSION: CREW EXPLORATION VEHICLE

The Crew Exploration Vehicle uses a capsule to transport the crew in Earth-Luna space. With the infrastructure values assumed, per Table 2.4.3, some cabin radiation shielding covers the entire cabin. The power infrastructure assumes fuel cells, although water from the fuel cells is not assumed. [11] The external thermal control system uses a single-phase, pumped-loop to transport thermal energy and rejects the loads using body-fitted, flow-through radiators. Extravehicular activities from the Crew Exploration Vehicle are contingency events only, so support for extravehicular activities is not included here. Table 2.4.2 details specific inputs.

2.4.2.1 BASELINE LIFE SUPPORT SYSTEM TECHNOLOGY

The baseline technology suite, for the purposes of this document, uses current storage technology to support a crew of four. See Hanford (2005) for details. The Crew Exploration Vehicle life support system, using current technologies, maintains the cabin atmosphere with high-pressure gas stores and consumable carbon dioxide removal hardware. Clean water is provided from stores, while wastes are all stored. Food is pre-packaged, requiring only minor operations before consumption. Cooling employs coldplates and condensing heat exchangers to collect heat loads, a single-phase fluid to transport heat, and radiators to reject heat. For this assessment, the applied cooling-mass penalty represents radiators constructed solely from aluminum and other metallic materials. Clothing is supplied from Earth clean and discarded to the waste subsystem once it is deemed too dirty to wear. See Figure 2.4.3. See Section 8 for a list of acronyms used in this figure.

2.4.2.1.1 Air

The baseline air suite uses non-regenerable carbon dioxide removal equipment based on lithium hydroxide. The trace contaminant control system for atmospheric gases uses activated carbon for non-combustible trace gas removal, and high efficiency particulate air filters for bacteria and particulate removal, neither of which are regenerated. Further, the trace contaminant control system also removes trace combustible gases from the crew cabin. Oxygen and nitrogen are supplied as pressurized gases from high-pressure stores. A major constituent analyzer and a fire detection and suppression system monitor for air contaminants and combustion products.

2.4.2.1.2 Biomass

The Crew Exploration Vehicle does not produce any biomass.

2.4.2.1.3 Food

The baseline suite for food uses ambient storage, prepackaged food. The nominal crew metabolic energy requirement for intravehicular activities only is 11.82 MJ/CM-d. Heavier workloads, such as those associated with extravehicular activities, generally require greater food intake. For this mission, the crew nominally receives 1.147 kg/CM-d of food, or 0.466 kg/CM-d of food moisture, as-shipped, if the dry food mass is neglected. 0.264 kg/CM-d of disposable packaging is required. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Dedicated cold storage is unnecessary. Supporting technology includes some food preparation equipment.

2.4.2.1.4 Thermal

Thermal management for the baseline configuration is divided between two systems, the Thermal Subsystem and the Cooling External Interface. The internal thermal control system includes the avionics air assembly, which provides air-cooling for equipment, the common cabin air assembly, which dehumidifies cabin air and controls air temperature, condensate storage, and thermal transport fluid loops. Coldplates and heat exchangers are physically integrated into the hardware they cool. The external thermal control system is nominally represented by the cooling-mass penalty.

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[11] *Author's note:* The Metric assessments for the Crew Exploration Vehicle before the release of an official Lunar architecture. Thus, assuming no water from fuel cells is conservative for this mission element.

2.4.2.1.5 Waste

Solid waste is stored aboard the Crew Exploration Vehicle. This includes trash, fecal material, and used filters and cartridges. The toilet is also included in the waste subsystem.

2.4.2.1.6 Water

For this assessment, the baseline water subsystem provides water solely from stores. Wastewater is also stored. A process control water quality monitor samples discharged water to assure overall water safety.

2.4.2.1.7 Human Accommodations

Clothing is launched with the crew at the beginning of this mission and returns to Earth with the crew at the end of this mission. A usage rate of 0.486 kg/CM-d, in a volume of 0.00285 m^3/CM-d, is assumed.

2.4.2.2 ADVANCED LIFE SUPPORT TECHNOLOGY

Though similar to the baseline approach above, the advanced technology suite for the Crew Exploration Vehicle stores pressurization gases as cryogens and recycles non-urine wastewater. A low-moisture content diet is also assumed. See Figure 2.4.4. See Section 8 for a list of acronyms used in this figure.

2.4.2.2.1 Air

The advanced life support suite, compared to the baseline suite in Section 2.4.2.1.1, stores gases for pressurization as cryogens instead of under high pressure. Other technologies within the advanced air suite are identical to those within the baseline technology suite for air as listed in Section 2.4.2.1.1.

2.4.2.2.2 Biomass

The biomass subsystem here is identical to the baseline suite in Section 2.4.2.1.2.

2.4.2.2.3 Food

The advanced suite for food employs ambient storage, low-moisture content, prepackaged food with comparable nutritional to the diet described in Section 2.4.2.1.3. This food system provides 0.918 kg/CM-d of food, or 0.248 kg/CM-d of food moisture, as-shipped, if the dry food mass is neglected. 0.267 kg/CM-d of disposable packaging is required. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Again, dedicated cold storage is unnecessary and supporting technology includes some food preparation equipment.

2.4.2.2.4 Thermal

The advanced life support suite for the thermal subsystem uses the same technologies as the baseline suite for the thermal subsystem described in Section 2.4.2.1.4.

2.4.2.2.5 Waste

The advanced life support suite for waste management uses the same technologies as the baseline suite for waste management described in Section 2.4.2.1.5.

2.4.2.2.6 Water

The advanced water system dumps urine but reclaims grey water using Water Recovery System technologies from the ISS ECLSS. The water processor employs two multifiltration units, a volatile removal assembly, phase separators, and an ion exchange bed. A process control water quality monitor provides water quality assurance. Efficiency of recovery is high, but many expendables, mostly filter cartridges, are needed.

2.4.2.2.7 Human Accommodations

The advanced life support approach for human accommodations uses the same approaches as the baseline human accommodations interface described in Section 2.4.2.1.7.

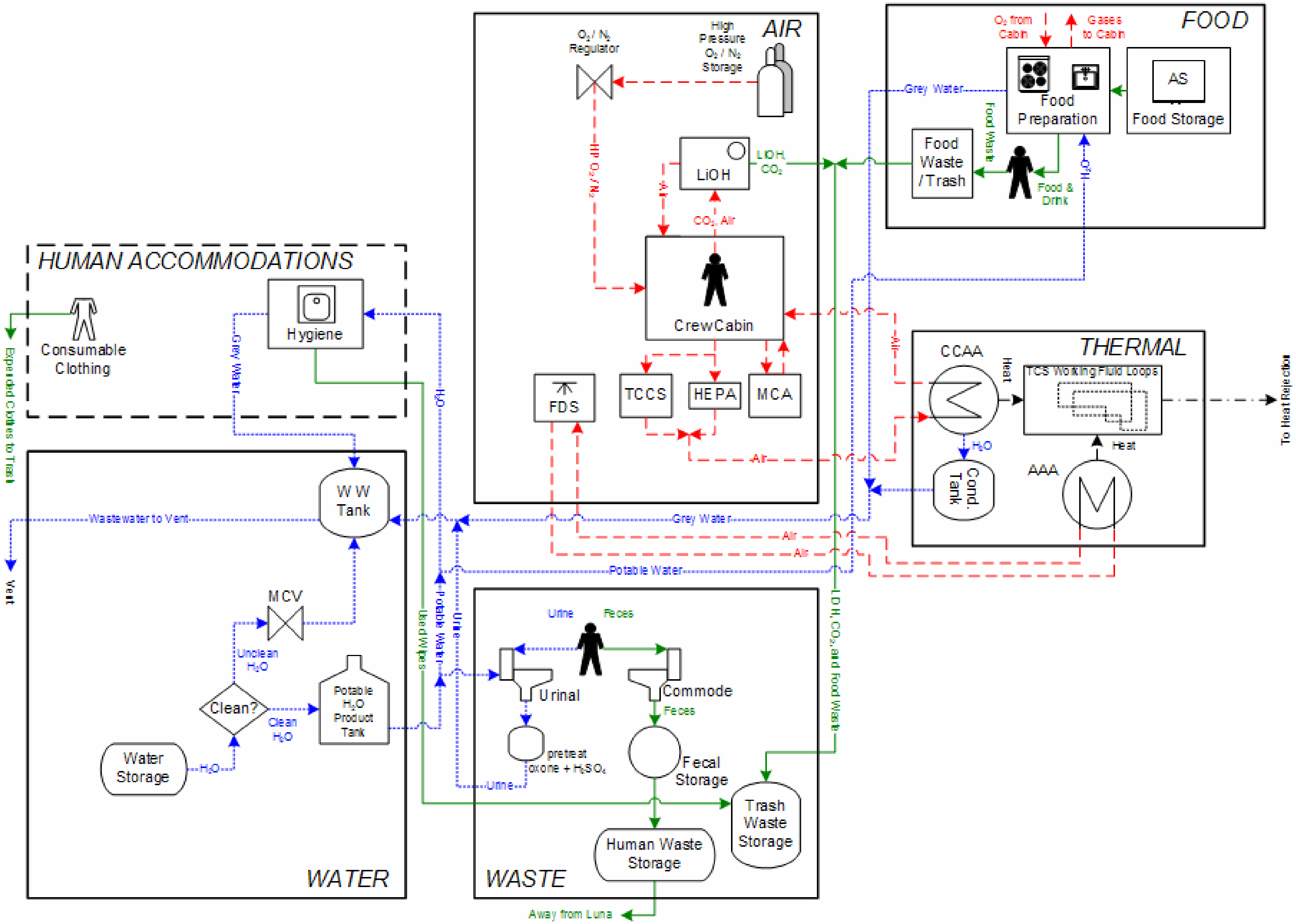

Figure 2.4.3 Crew Exploration Vehicle using Baseline Technologies.

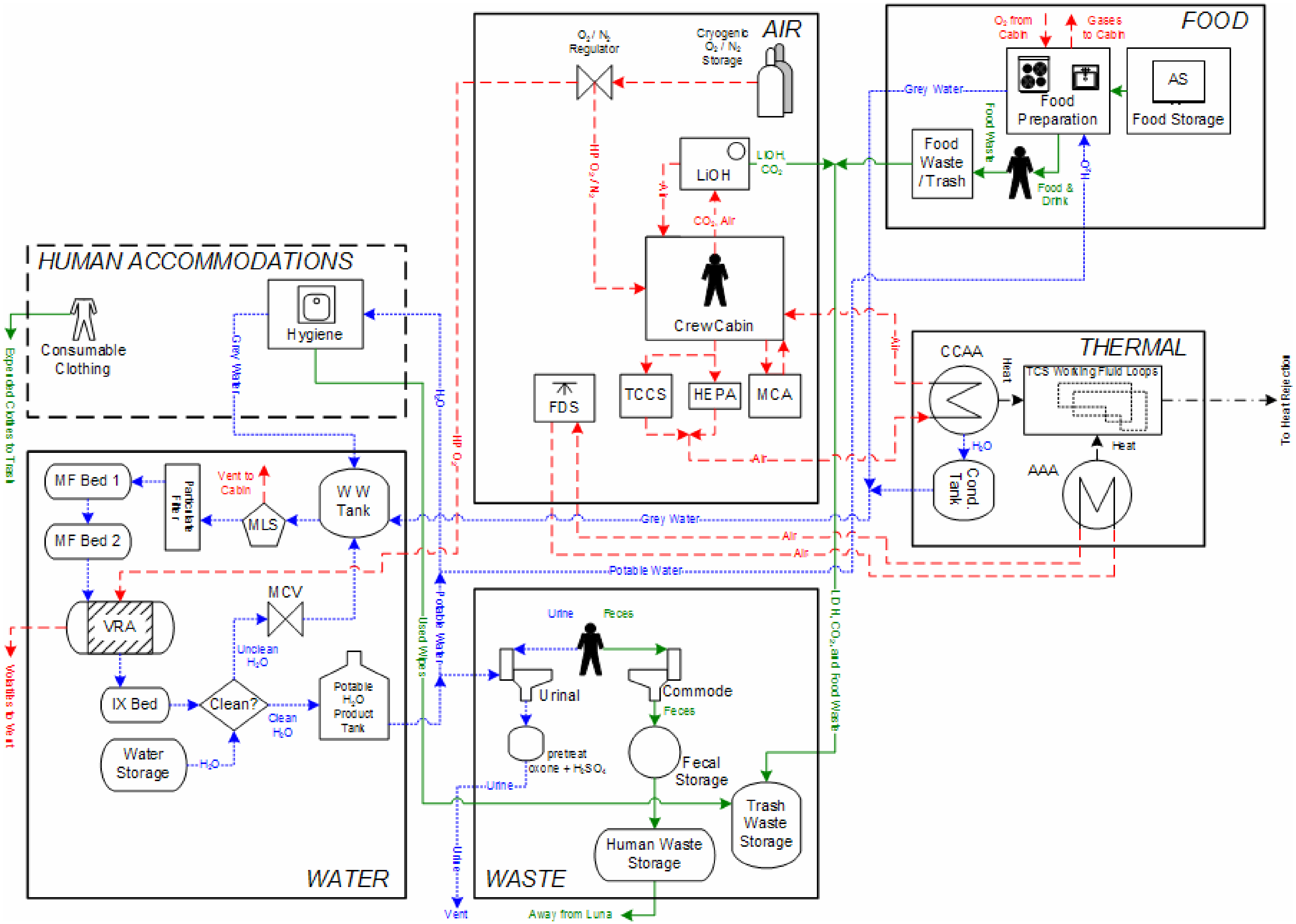

Figure 2.4.4 Crew Exploration Vehicle using Advanced Technologies.

2.4.3 NEAR-TERM EXPLORATION MISSION: LUNAR SURFACE ACCESS MODULE

The Lunar Surface Access Module transports the crew between low-Lunar orbit and the surface. With the infrastructure values assumed, per Table 2.4.3, some cabin radiation shielding covers the entire cabin. The power infrastructure assumes fuel cells, although water from the fuel cells is not assumed. [12] The external thermal control system uses a single-phase, pumped-loop to transport thermal energy and rejects the loads using body-fitted, flow-through radiators. An equatorial landing site is assumed. Table 2.4.2 details specific inputs.

2.4.3.1 BASELINE LIFE SUPPORT SYSTEM TECHNOLOGY

The baseline technology suite, for the purposes of this document, uses current storage technology to support a crew of four. See Hanford (2005) for details. The Lunar Surface Access Module life support system, using current technologies, maintains the cabin atmosphere with high-pressure gas stores and consumable carbon dioxide removal hardware. Clean water is provided from stores, while wastes are all stored. Food is pre-packaged, requiring only minor operations before consumption. Cooling employs coldplates and condensing heat exchangers to collect heat loads, a single-phase fluid to transport heat, and radiators to reject heat. For this assessment, the applied cooling-mass penalty represents radiators constructed solely from aluminum and other metallic materials. Clothing is supplied from Earth clean and discarded to the waste subsystem once it is deemed too dirty to wear. See Figure 2.4.5. See Section 8 for a list of acronyms used in this figure.

2.4.3.1.1 Air

The baseline air suite uses non-regenerable carbon dioxide removal equipment based on lithium hydroxide. The trace contaminant control system for atmospheric gases uses activated carbon for non-combustible trace gas removal, and high efficiency particulate air filters for bacteria and particulate removal, neither of which are regenerated. Further, the trace contaminant control system also removes trace combustible gases from the crew cabin. Oxygen and nitrogen are supplied as pressurized gases from high-pressure stores. A major constituent analyzer and a fire detection and suppression system monitor for air contaminants and combustion products.

2.4.3.1.2 Biomass

The Lunar Surface Access Module does not produce any biomass.

2.4.3.1.3 Food

The baseline suite for food employs ambient storage, prepackaged food. The nominal crew metabolic energy requirement for intravehicular activities only is 11.82 MJ/CM-d. Heavier workloads, such as those associated with extravehicular activities, generally require greater food intake. For this mission, the crew nominally receives 1.198 kg/CM-d of food, or 0.487 kg/CM-d of food moisture, as-shipped, if the dry food mass is neglected. 0.275 kg/CM-d of disposable packaging is required. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Dedicated cold storage is unnecessary. Supporting technology includes some food preparation equipment.

2.4.3.1.4 Thermal

Thermal management for the baseline configuration is divided between two systems, the Thermal Subsystem and the Cooling External Interface. The internal thermal control system includes the avionics air assembly, which provides air-cooling for equipment, the common cabin air assembly, which dehumidifies cabin air and controls air temperature, condensate storage, and thermal transport fluid loops. Coldplates and heat exchangers are physically integrated into the hardware they cool. The external thermal control system is nominally represented by the cooling-mass penalty.

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[12] *Author's note:* The Metric assessments for the Lunar Surface Access Module before the release of an official Lunar architecture. Thus, assuming no water from fuel cells is conservative for this mission element.

2.4.3.1.5 Waste

Solid waste is stored aboard the Lunar Surface Access Module. This includes trash, fecal material, extravehicular activity solid wastes, and used filters and cartridges. The toilet is also included in the waste subsystem.

2.4.3.1.6 Water

For this assessment, the baseline water subsystem provides water solely from stores. Wastewater is also stored. A process control water quality monitor samples discharged water to assure overall water safety.

2.4.3.1.7 Extravehicular Activity Support

To support extensive extravehicular activities while operating independently, the Lunar Surface Access Module is assumed to carry a standard airlock even though this vehicle will see few extravehicular activities according to Hanford (2005). The life support system provides stores of water and oxygen to the extravehicular mobility units for cooling and crew consumption, and water to charge the internal liquid cooling loops. Further, carbon dioxide is removed from the airlock atmosphere using dedicated lithium hydroxide canisters. An airlock gas pump recaptures all but ten percent of the airlock atmosphere during each airlock cycle.

2.4.3.1.8 Human Accommodations

Clothing is launched with the crew at the beginning of this mission and returns to Earth with the crew at the end of this mission. A usage rate of 0.486 kg/CM-d, in a volume of 0.00285 m^3/CM-d, is assumed.

2.4.3.2 ADVANCED LIFE SUPPORT TECHNOLOGY

Though similar to the baseline approach above, the advanced technology suite for the Lunar Surface Access Module stores pressurization gases as cryogens and recycles non-urine wastewater. A low-moisture content diet is also assumed. See Figure 2.4.6. See Section 8 for a list of acronyms used in this figure.

2.4.3.2.1 Air

The advanced life support suite, compared to the baseline suite in Section 2.4.3.1.1, stores gases for pressurization as cryogens instead of under high pressure. Other technologies within the advanced air suite are identical to those within the baseline technology suite for air as listed in Section 2.4.3.1.1.

2.4.3.2.2 Biomass

The biomass subsystem here is identical to the baseline suite in Section 2.4.3.1.2.

2.4.3.2.3 Food

The advanced suite for food employs ambient storage, low-moisture content, prepackaged food with comparable nutritional content to the diet described in Section 2.4.3.1.3. This food system provides 0.959 kg/CM-d of food, or 0.259 kg/CM-d of food moisture, as-shipped, if the dry food mass is neglected. 0.278 kg/CM-d of disposable packaging is required. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Again, dedicated cold storage is unnecessary and supporting technology includes some food preparation equipment.

2.4.3.2.4 Thermal

The advanced life support suite for the thermal subsystem uses the same technologies as the baseline suite for the thermal subsystem described in Section 2.4.3.1.4.

2.4.3.2.5 Waste

The advanced life support suite for waste management uses the same technologies as the baseline suite for waste management described in Section 2.4.3.1.5.

2.4.3.2.6 Water

The advanced water system dumps urine but reclaims grey water using Water Recovery System technologies from the ISS ECLSS. The water processor employs two multifiltration units, a volatile removal assembly, phase separators, and an ion exchange bed. A process control water quality monitor provides water quality assurance. Efficiency of recovery is high, but many expendables, mostly filter cartridges, are needed.

2.4.3.2.7 Extravehicular Activity Support

The extravehicular activity support for the advanced life support system within the Lunar Surface Access Module is identical to the technologies described for the baseline extravehicular activity support suite in Section 2.4.3.1.7.

2.4.3.2.8 Human Accommodations

The advanced life support approach for human accommodations uses the same approaches as the baseline human accommodations interface described in Section 2.4.3.1.8.

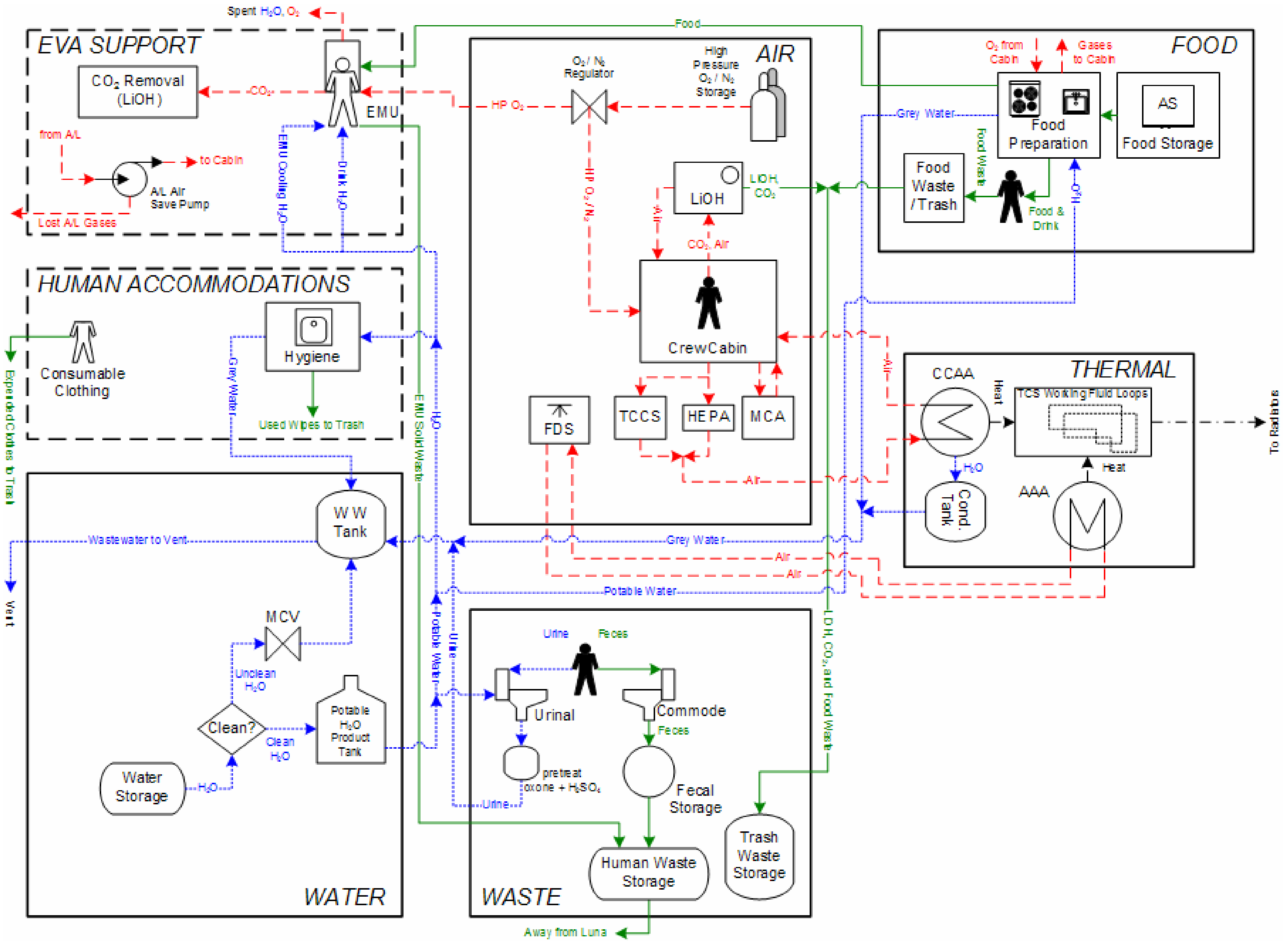

Figure 2.4.5 Lunar Surface Access Module using Baseline Technologies.

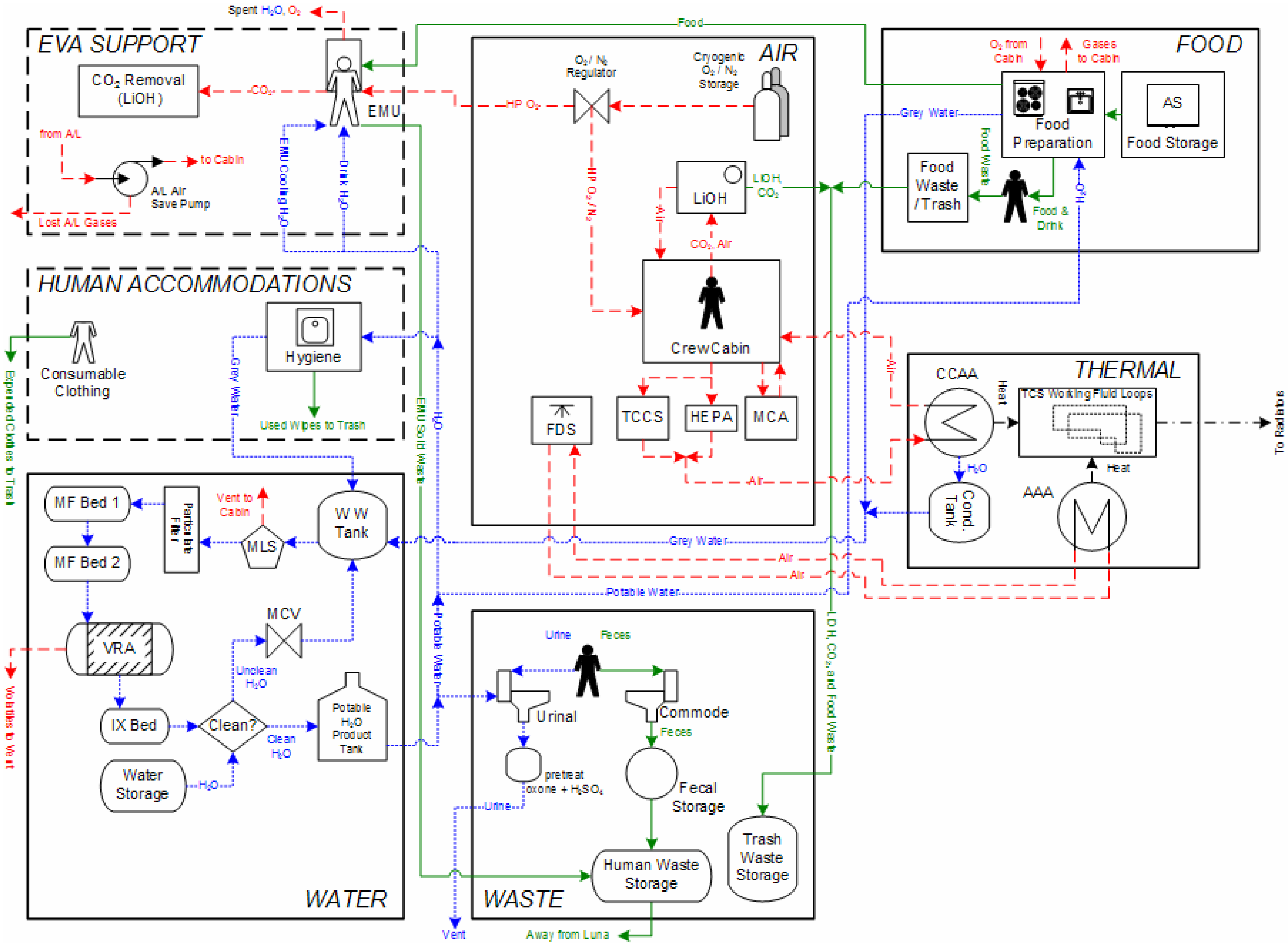

Figure 2.4.6 Lunar Surface Access Module using Advanced Technologies.

2.4.4 NEAR-TERM EXPLORATION MISSION: DESTINATION SURFACE SYSTEM

The Destination Surface System assumes a rigid International Space Station common module structure with dedicated radiation protection from polyethylene lining the walls. The crew may be housed within a hardened domain, but this is not included in the assessed infrastructure values for life support system hardware. A small nuclear reactor provides continuous power. The external thermal control system uses a single-phase, pumped loop to transport thermal energy and rejects the thermal loads using flow-through radiators. An equatorial site on the Lunar surface is assumed. Table 2.4.3 lists assumed infrastructure values while Table 2.4.2 details specific inputs for the Destination Surface System of the Near-Term Exploration Mission.

2.4.4.1 BASELINE LIFE SUPPORT SYSTEM TECHNOLOGY

The baseline technology suite, for the purposes of this document, is defined based on the USOS ECLSS scaled for a crew of six. See Hanford (2005), for details. This suite uses physicochemical technologies to regenerate air and water, while food is supplied mainly as prepackaged individual, shelf-stable entrees. Breathing and pressurization gases are provided from stores. Waste is stored without reclaiming any products from that waste. Cooling employs coldplates and condensing heat exchangers to collect heat loads, a single-phase fluid to transport heat, and radiators to reject heat. For this assessment, the applied cooling-mass penalty represents radiators constructed solely from aluminum and other metallic materials. Clean clothing is launched with the vehicle and left on the surface with the vehicle upon the departure of the crew from Luna. See Figure 2.4.7. See Section 8 for a list of acronyms used in this figure.

2.4.4.1.1 Air

The baseline air suite for the Destination Surface System uses regenerable carbon dioxide removal equipment based on molecular sieve technology, which is a four-bed molecular sieve. Absorbed carbon dioxide is dissociated from the absorbing media and exhausted from the vehicle without recovering any commodities. The trace contaminant control system for atmospheric gases uses activated carbon for non-combustible trace gas removal, and high efficiency particulate air filters for bacteria and particulate removal, neither of which are regenerated. Further, the trace contaminant control system also removes trace combustible gases from the crew cabin. Oxygen and nitrogen are supplied as pressurized gases from high-pressure stores. A major constituent analyzer and a fire detection and suppression system monitor for air contaminants and combustion products.

2.4.4.1.2 Biomass

The Destination Surface System baseline configuration does not produce any biomass.

2.4.4.1.3 Food

The baseline suite for food uses ambient storage, prepackaged food. The nominal crew metabolic energy requirement for intravehicular activities only is 11.82 MJ/CM-d. Heavier workloads, such as those associated with extravehicular activities, generally require greater food intake. For this mission, the crew nominally receives 1.150 kg/CM-d of food, or 0.467 kg/CM-d of food moisture, as-shipped, if the dry food mass is neglected. 0.264 kg/CM-d of disposable packaging is required. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Supporting technology includes some food preparation equipment.

2.4.4.1.4 Thermal

Thermal management is divided into two systems. The internal thermal control system includes the avionic air assemblies, which provide air-cooling for equipment, the common cabin air assemblies, which cool and dehumidify cabin air, condensate storage, and the water flow loops for heat transport. Coldplates and heat exchangers are assumed part of other equipment while the external thermal control system is included in the assessed cooling-mass penalty.

2.4.4.1.5 Waste

Solid waste is simply stored, without treatment, aboard the Destination Surface System. This includes trash, fecal material, brine from the urine and water processing, and used filters and cartridges. The toilet is also included in this calculation under the waste subsystem.

2.4.4.1.6 Water

Urine is processed by vapor compression distillation. The brine is stored and remains with the vehicle after the crew departs. All grey water, including hygiene water, effluent from the vapor compression distillation, and condensate from dehumidification, is processed through a water processor. The water processor employs two multifiltration units, a volatile removal assembly, phase separators, and an ion exchange bed. A process control water quality monitor provides water quality assurance. Efficiency of recovery is high, but many expendables, mostly filter cartridges, are needed. Water may enter the life support system directly, such as from moisture within prepackaged food, or indirectly, as a human metabolic product from the consumption of the prepackaged food. Water may also come from water stores.

2.4.4.1.7 Extravehicular Activity Support

The extravehicular mobility unit consumables include oxygen, for metabolic consumption and suit pressurization, and water, which is rejected to provide thermal management and consumed by the crew as drinks. Though not consumed, water also provides the working fluid for the internal cooling garment. This extravehicular mobility unit uses lithium hydroxide for carbon dioxide removal. An airlock pump, which is a compressor, reduces the airlock internal pressure to about ten percent of the cabin pressure, reducing gas losses during airlock operations. The Destination Surface System airlock also accommodates removal of carbon dioxide from the extravehicular mobility unit following extravehicular activities, and a carbon dioxide removal assembly specifically dedicated to the airlock. Atmospheric gas and water losses are actually included as part of the air and water subsystems in this calculation, and not as part of the values presented for extravehicular activity support.

2.4.4.1.8 Human Accommodations

Clothing is launched from Earth with the Destination Surface System and stays with the vehicle at the end of the surface phase. When clothing is deemed too dirty to wear, it is sent to waste storage and replaced with a clean garment from stores. A usage rate of 0.486 kg/CM-d, in a volume of 0.00285 m^3/CM-d, is assumed.

2.4.4.2 ADVANCED LIFE SUPPORT TECHNOLOGY

The advanced life support suite is similar to the baseline approach above. Cryogenic gas storage, vapor phase catalytic ammonia removal, and a low-moisture content, ambient food system are less massive than similar baseline technologies. See Figure 2.4.8. See Section 8 for a list of acronyms used in this figure.

2.4.4.2.1 Air

The advanced air suite for the Destination Surface System stores oxygen and nitrogen cryogenically. Other aspects of the advanced air suite are identical to the baseline technology suite for air listed in Section 2.4.4.1.1.

2.4.4.2.2 Biomass

The biomass subsystem here is identical to the baseline suite in Section 2.4.4.1.2.

2.4.4.2.3 Food

The advanced suite for food employs ambient storage, low-moisture content, prepackaged food with comparable nutritional to the diet described in Section 2.4.4.1.3. This food system provides 0.921 kg/CM-d of food, or 0.249 kg/CM-d of food moisture, as-shipped, if the dry food mass is neglected. 0.267 kg/CM-d of disposable packaging is required. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Again, the supporting hardware includes some food preparation equipment.

2.4.4.2.4 Thermal

The advanced suite for the thermal subsystem uses the same technologies as the baseline suite for the thermal subsystem described in Section 2.4.4.1.4.

2.4.4.2.5 Waste

The advanced suite for waste is identical to the baseline approach given in Section 2.4.4.1.5.

2.4.4.2.6 Water

The advanced water system is built around a vapor phase catalytic ammonia removal assembly to provide primary water processing of both urine and grey water. Brine is sent directly to waste storage without recovering any moisture. Product water from the vapor phase catalytic ammonia removal assembly requires no further polishing, though a process control water quality monitor provides water quality assurance.

2.4.4.2.7 Extravehicular Activity Support

The advanced suite for extravehicular activity support is identical to the baseline suite for extravehicular activity support. See Section 2.4.4.1.7.

2.4.4.2.8 Human Accommodations

The advanced life support system for human accommodations is identical to the corresponding baseline suite. See Section 2.4.4.1.8.

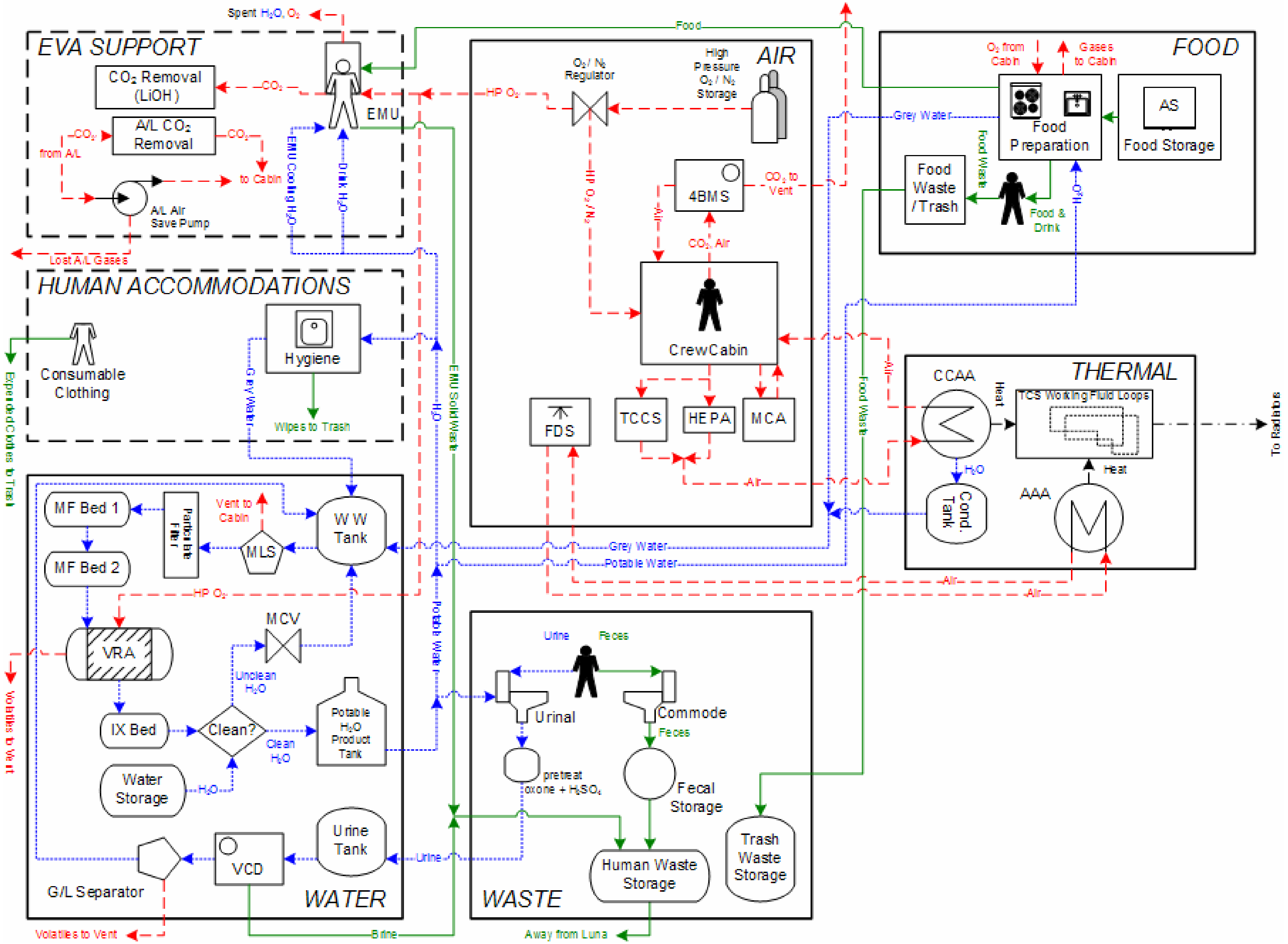

Figure 2.4.7 Destination Surface System using Baseline Technologies.

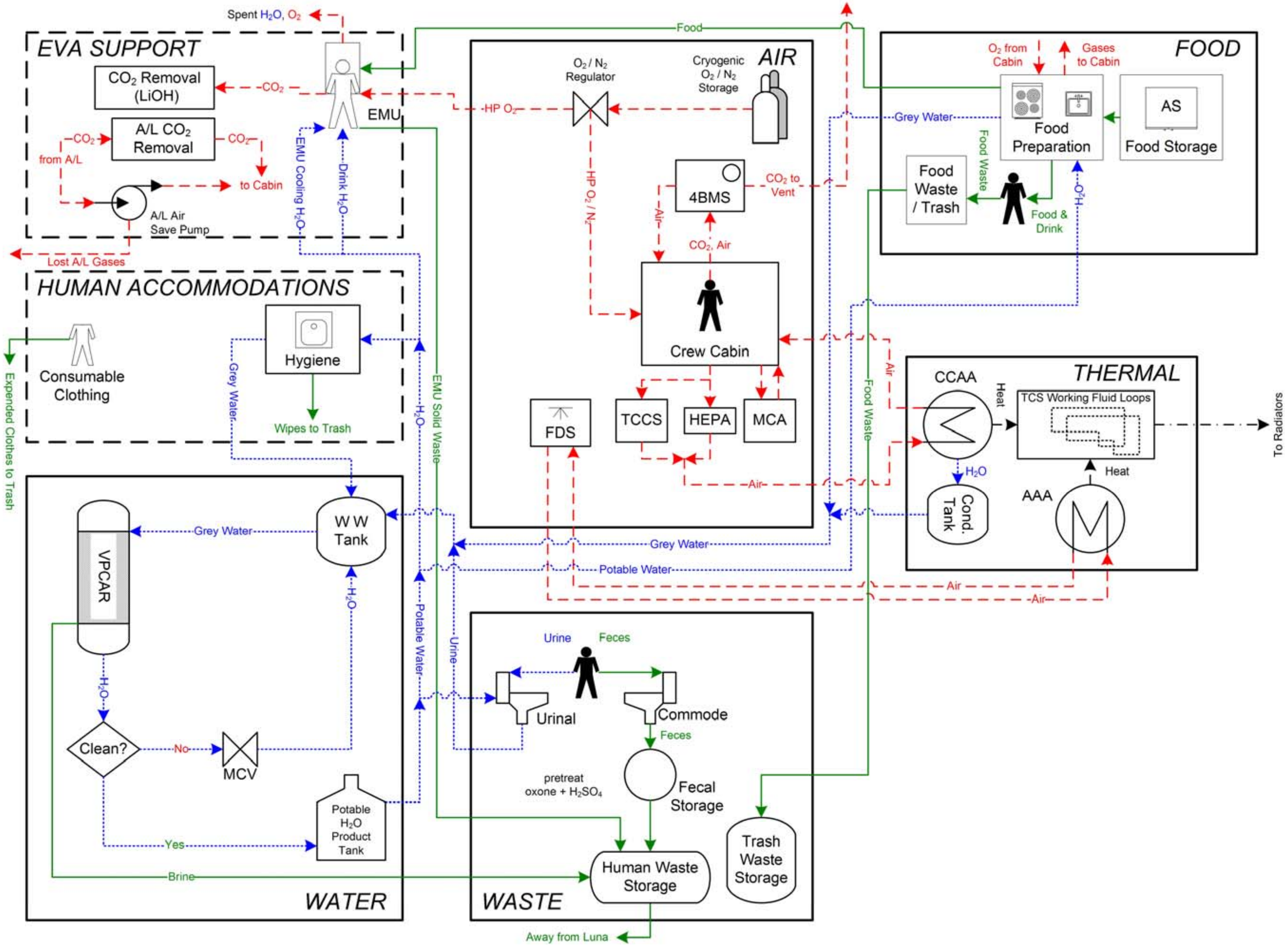

Figure 2.4.8 Destination Surface System using Advanced Technologies.

2.4.5 INDEPENDENT EXPLORATION MISSION: MARS TRANSIT VEHICLE

The Mars Transit Vehicle uses inflatable modules with radiation shielding for interplanetary travel. However, with the infrastructure values assumed, per Table 2.4.3, the cabin radiation shielding does not protect the life support equipment. [13] Thus, the volume infrastructure value reflects a pressurized, inflatable structure without radiation shielding. Power is provided by solar photovoltaic generation with minimal energy storage. The external thermal control system uses a single-phase, pumped-loop to transport thermal energy and rejects the loads using body-fitted, flow-through radiators. Extravehicular activities from the Mars Transit Vehicle are contingency events only, so support for extravehicular activities is not included here. Table 2.4.2 details specific inputs for the Mars Transit Vehicle segment of the Independent Exploration Mission.

2.4.5.1 BASELINE LIFE SUPPORT SYSTEM TECHNOLOGY

The baseline technology suite, for the purposes of this document, is defined based on the USOS ECLSS scaled for a crew of six. See Stafford, *et al.* (2001), for details. This suite uses physicochemical technologies to regenerate air and water, while food is supplied mainly as prepackaged individual entrees, including frozen food selections. Because of the long mission duration, a biomass production chamber provides salad to supplement the prepackaged food system. [14] Waste is generally stored without reclaiming any products from that waste. Cooling employs coldplates and condensing heat exchangers to collect heat loads, a single-phase fluid to transport heat, and radiators to reject heat. For this assessment, the applied cooling-mass penalty represents radiators constructed solely from aluminum and other metallic materials. Clothing is supplied from Earth clean and discarded to the waste subsystem once it is deemed too dirty to wear. See Figure 2.4.9. See Section 8 for a list of acronyms used in this figure.

2.4.5.1.1 Air

The life support system for the Mars Transit Vehicle using baseline technologies employs regenerable carbon dioxide removal equipment based on molecular sieve technology. The absorbed carbon dioxide is dumped overboard and not recovered. The trace gas contaminant system uses activated carbon, for non-combustible trace gas removal, and bacteria filter assemblies, for particulate removal. These filters are not regenerated. Further, the trace contaminant control system also removes trace combustible gases in the crew cabin. Oxygen is supplied both as pressurized gas from high-pressure stores, and as a product from electrolysis of water using solid polymer technology. The associated product hydrogen is dumped overboard. Water for electrolysis is provided by the water subsystem. Because the Mars Transit Vehicle will be “water rich” from moisture stored in food and the relatively high rate of water reclamation from grey water, most oxygen will be generated by electrolysis. Nitrogen is supplied from high-pressure gas stocks. A major constituent analyzer and a fire detection and suppression system provide monitoring for air contaminants and combustion products.

2.4.5.1.2 Biomass

The baseline suite contains a small biomass production chamber, providing salad crops as a supplement to an otherwise prepackaged food system. Though the dietary nutrients gained from salad crops are relatively minor, salads, snacks, and steamed entrees provide a psychological advantage unavailable in a completely prepackaged food system and support anticipated requirements for long-duration space missions. [15] Supporting equipment for the biomass production chamber includes a nutrient solution supply, condensate storage, and a supplemental common cabin air assembly to handle the greater humidity loading and air circulation requirements.

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[13] In fact, efficient design may use the mass of the life support hardware as partial radiation protection from the crew cabin, but any “radiation credit” may be difficult to forecast and, therefore, none is assumed here.

[14] While International Space Station Upgrade Mission is longer than the combined mission durations for all vehicles within the Mars Independent Exploration architecture, individual ISS crewmembers usually spend significantly less than a year per deployment to ISS. Thus, while fresh salad is assumed here as essential for crew physical and psychological health on extended missions, distinctions between International Space Station and this mission should be noted.

[15] Biomass production is not part of the current ISS ECLSS technology suite, so a salad machine may seem “odd” here. However, the significant rationale for a small biomass production facility like a salad machine is related to requirements for dietary diversity. Thus, a salad machine is included in both life support system configurations here to meet a requirement that is beyond those associated with historical and current vehicles.

2.4.5.1.3 Food

Food is provided as individual entrees from Earth. The baseline Mars Transit Vehicle relies on a variety of fresh, dehydrated, and full-water preserved, shelf-stable, or frozen foods. The diet is supplemented with fresh salad, snacks, and steamed entrees from a biomass production chamber. The nominal crew metabolic energy requirement for intravehicular activities only is 11.82 MJ/CM-d. Heavier workloads, such as those associated with extravehicular activities, generally require greater food intake. For this mission, the crew nominally receives 1.362 kg/CM-d. Neglecting the dry component, the food mass as-shipped is 0.685 kg/CM-d of food. In either case, 0.238 kg/CM-d of disposable packaging is required. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Supporting technology includes a dedicated cold storage and some food preparation equipment.

2.4.5.1.4 Thermal

Thermal management is divided into two systems. The internal thermal control system includes the avionic air assemblies, which provide air-cooling for equipment, the common cabin air assemblies, which cool, dehumidify, and circulate cabin air, condensate storage, and the water flow loops for heat transport. Coldplates and heat exchangers are assumed part of other equipment while the external thermal control system is included in the assessed cooling-mass penalty.

2.4.5.1.5 Waste

Solid waste is stored aboard the Mars Transit Vehicle. This includes trash, fecal material, brine from the urine and water processing, and used filters and cartridges. The toilet is also included in the waste subsystem.

2.4.5.1.6 Water

Urine is processed by vapor compression distillation. The brine is sent to waste storage. All grey water, including hygiene water, effluent from the vapor compression distillation, and condensate from dehumidification, is processed through a water processor. The water processor employs two multifiltration units, a volatile removal assembly, phase separators, and an ion exchange bed. A process control water quality monitor provides water quality assurance. Efficiency of recovery is high, but many expendables, mostly filter cartridges, are needed. Additional water may enter the life support system directly, such as from moisture within prepackaged food, or indirectly, as a human metabolic product from the metabolism of food. A third source of water is stores, but in the nominal case the Mars Transit Vehicle will probably be “water rich.”

2.4.5.1.7 Human Accommodations

Clothing is launched with the crew at the beginning of this mission and returns to Earth with the crew at the end of this mission. A usage rate of 0.486 kg/CM-d, in a volume of 0.00285 m³/CM-d, is assumed.

2.4.5.2 ADVANCED LIFE SUPPORT TECHNOLOGY

Though similar to the baseline approach above, the advanced technology suite for the Mars Transit Vehicle employs a vapor phase catalytic ammonia removal water recovery system with a dedicated lyophilization for brine dewatering, a Sabatier to reduce carbon dioxide, stores pressurization gases as cryogens, and substitutes a completely ambient food subsystem. The salad machine is retained. Additionally, an aqueous laundry recycles crew clothing. The applied cooling-mass penalty reflects lightweight radiators constructed from composite materials. See Figure 2.4.10. See Section 8 for a list of acronyms used in this figure.

2.4.5.2.1 Air

The advanced life support suite, compared to the baseline suite in Section 2.4.5.1.1, adds a Sabatier carbon dioxide reduction assembly and stores gases for pressurization as cryogens instead of under high pressure. Adequate water is assumed available to avoid a supply penalty for any necessary oxygen and hydrogen. Sabatier reduces carbon dioxide according to the availability of hydrogen from the oxygen generation assembly. Carbon dioxide that is not reduced is vented to space. Other technologies within the advanced air suite are identical to those within the baseline technology suite for air as listed in Section 2.4.5.1.1.

2.4.5.2.2 Biomass

The biomass subsystem here is identical to the baseline suite in Section 2.4.5.1.2.

2.4.5.2.3 Food

Food is provided as individual entrees with some bulk packaged items. This diet relies on a variety of ambient temperature foods and is supplemented with fresh salad, snacks, and steamed entrees from a biomass production chamber. The nominal crew metabolic energy requirement for intravehicular activities only is 11.82 MJ/CM-d. Heavier workloads, such as those associated with extravehicular activities, generally require greater food intake. For this mission, the crew nominally receives 1.138 kg/CM-d of food. Neglecting the dry component, the food mass as-shipped is 0.463 kg/CM-d with 0.262 kg/CM-d of disposable packaging. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Supporting technology includes some food preparation equipment.

2.4.5.2.4 Thermal

The advanced life support suite for the thermal subsystem uses the same technologies as the baseline suite for the thermal subsystem described in Section 2.4.5.1.4.

2.4.5.2.5 Waste

The advanced life support suite for waste management uses the same technologies as the baseline suite for waste management described in Section 2.4.5.1.5.

2.4.5.2.6 Water

The advanced water system is built around a vapor phase catalytic ammonia removal assembly to provide primary water processing of both urine and grey water. Lyophilization reclaims water from the primary processor brine, allowing almost complete water recovery. Product water from the lyophilization process passes to the primary processor. Product water from the vapor phase catalytic ammonia removal assembly requires no further polishing, though a process control water quality monitor provides water quality assurance. Overall recovery efficiency with this system is also high, with reduced expendables, compared to the baseline suite.

2.4.5.2.7 Human Accommodations

The advanced life support approach assumes an aqueous laundry. This will significantly increase the daily grey water load, but reduce the required mass of clothing compared to the baseline approach. While the apparent clothing usage rate remains unchanged for the crew, the laundry system cleans soiled clothing for reuse, prolonging clothing life and reducing associated waste loads.

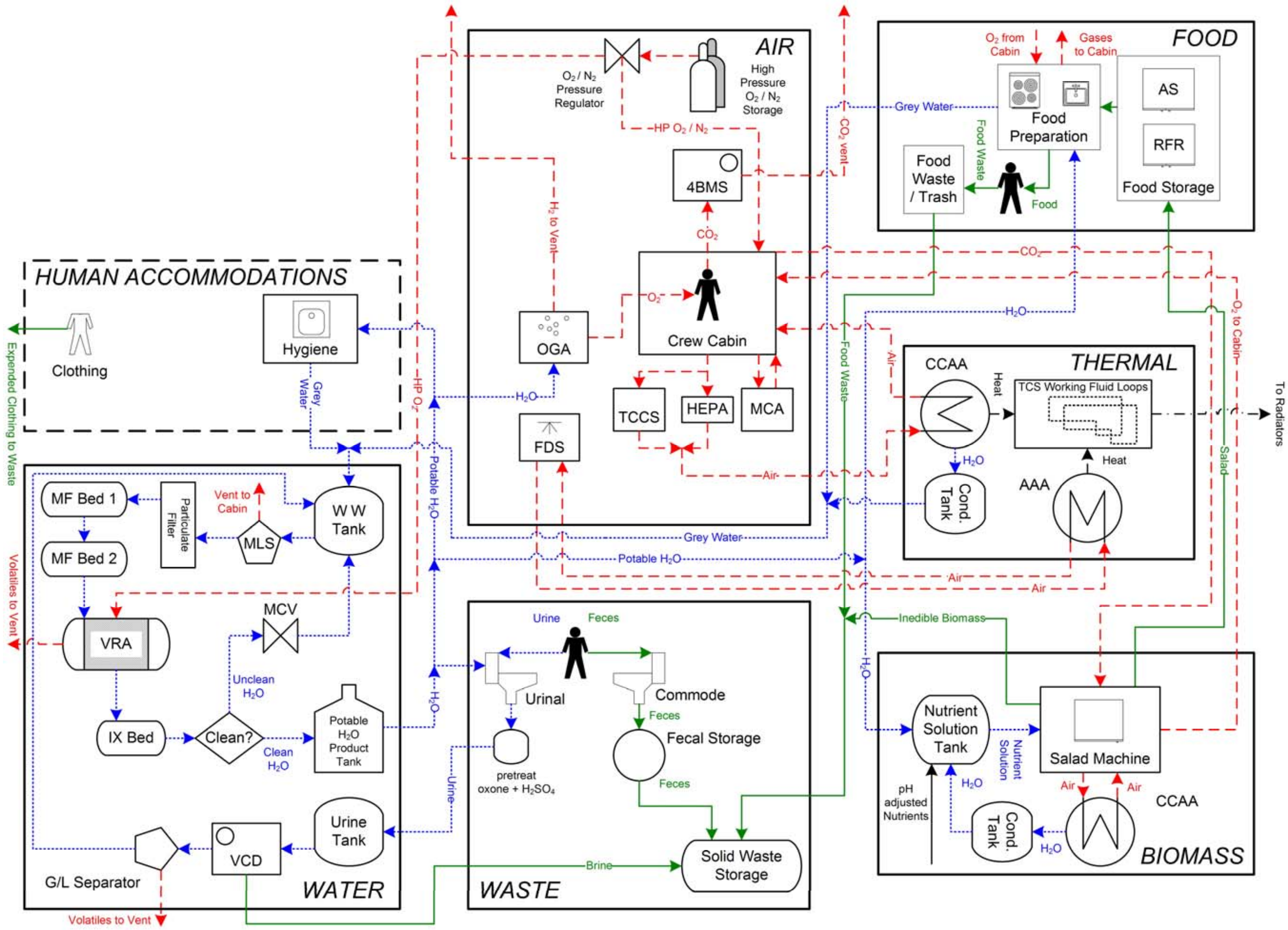

Figure 2.4.9 Mars Transit Vehicle using Baseline Technologies.

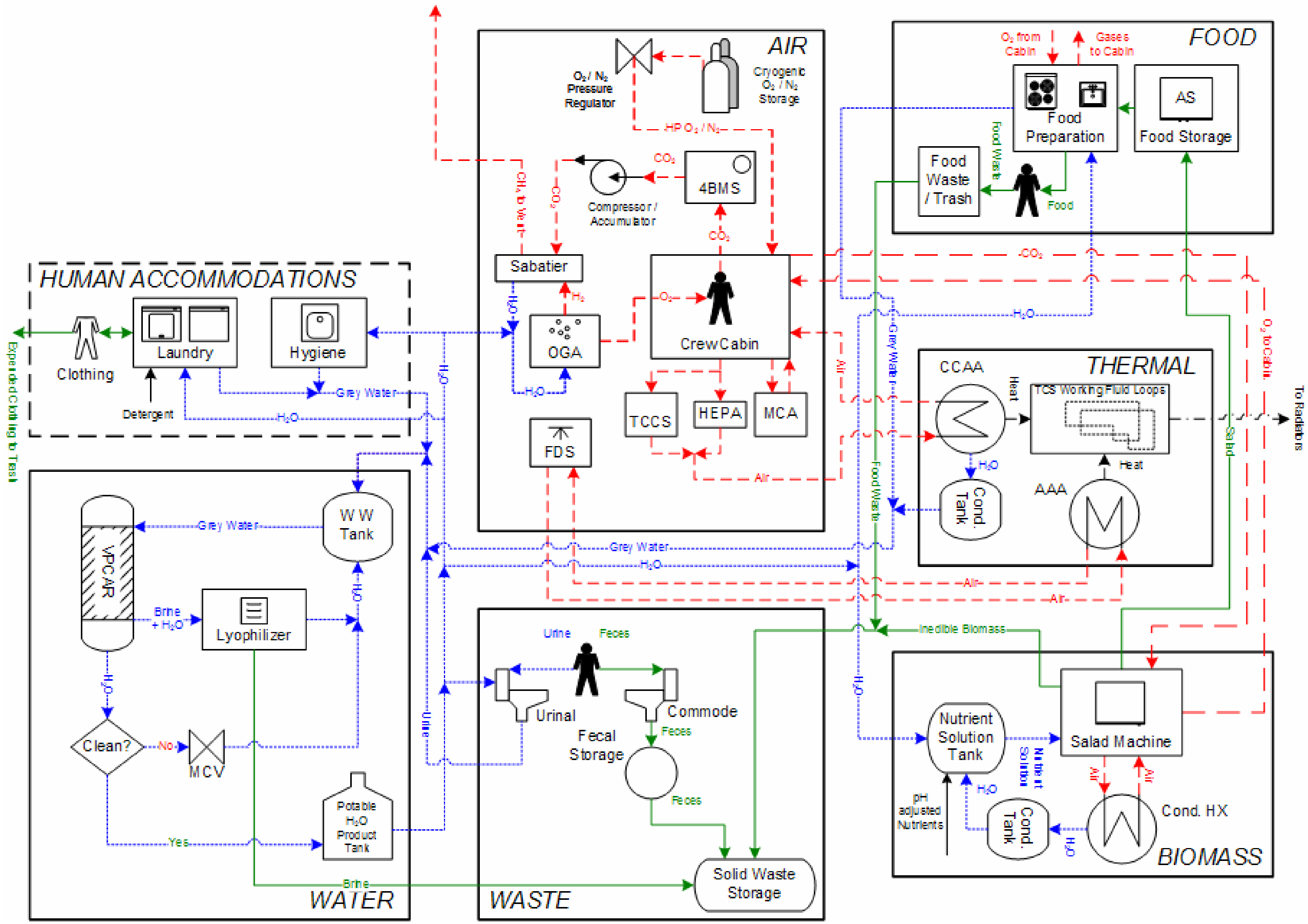

Figure 2.4.10 Mars Transit Vehicle using Advanced Technologies.

2.4.6 INDEPENDENT EXPLORATION MISSION: MARS DESCENT / ASCENT LANDER

The infrastructure penalties for the Mars Descent / Ascent Lander are associated with surface operations. This vehicle uses rigid aluminum modules per International Space Station architecture. Solar photovoltaic panels with regenerable fuel cell storage, assuming an equatorial surface site, provide power. The external thermal control system uses a single-phase, pumped loop to transport thermal energy and rejects the thermal loads using body-fitted, flow-through radiators. Again, an equatorial site on the Martian surface is assumed. While this vehicle will spend sufficient time operating in Martian orbit and, as a result, infrastructure for that phase must be considered for any viable vehicle, past experience dictates that the most severe sizing constraints are placed upon solar photovoltaic power generation and radiant cooling systems by the Martian surface environment when considering an equatorial landing site. Table 2.4.3 lists assumed infrastructure values while Table 2.4.2 details specific inputs for the Mars Descent / Ascent Lander segment of the Independent Exploration Mission.

2.4.6.1 BASELINE LIFE SUPPORT SYSTEM TECHNOLOGY

The baseline technology suite, for the purposes of this document, is defined based on current technology scaled for a crew of six. See Stafford, *et al.* (2001), for details. This suite uses physicochemical technologies to regenerate air and water, while food is supplied as individual prepackaged entrees, including frozen food selections. Waste is stored without reclaiming any commodities. Thermal management employs coldplates and condensing heat exchangers to collect heat loads, a single-phase fluid to transport heat, and radiators to reject heat. Clothing is supplied from Earth clean and discarded to the waste subsystem once it is deemed too dirty to wear. See Figure 2.4.11. See Section 8 for a list of acronyms used in this figure.

2.4.6.1.1 Air

The baseline air suite for the Mars Descent / Ascent Lander uses regenerable carbon dioxide removal equipment based on molecular sieve technology. The absorbed carbon dioxide is dumped overboard without recovering any commodities. The trace contaminant control system for atmospheric gases uses activated carbon, for non-combustible trace gas removal, and bacteria filter assemblies, for particulate removal, neither of which are regenerated. Further, the trace contaminant control system also removes trace combustible gases in the crew cabin. Oxygen is supplied both as pressurized gas from high-pressure stores, and as a product from electrolysis of water using solid polymer technology. The associated product hydrogen is dumped overboard. Electrolysis water is provided by the water subsystem. Nitrogen is supplied from high-pressure gas stocks. A major constituent analyzer and a fire detection and suppression system provide monitoring for air contaminants and combustion products.

2.4.6.1.2 Food

Food is provided as individual entrees from Earth. A mix of fresh, dehydrated, and full-water preserved, shelf-stable, or frozen foods are used. The nominal crew metabolic energy requirement for intravehicular activities only is 11.82 MJ/CM-d. Heavier workloads, such as those associated with extravehicular activities, generally require greater food intake. For this mission, the crew nominally receives 1.378 kg/CM-d of food. Neglecting the dry component, the food mass as-shipped is 0.694 kg/CM-d. In addition, 0.241 kg/CM-d of disposable packaging is required. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Supporting technology includes dedicated cold storage and some food preparation equipment.

2.4.6.1.3 Thermal

Thermal management for the Mars Descent / Ascent Lander is divided between two systems here. The internal thermal control system includes the avionic air assemblies, which provide air-cooling for equipment, the common cabin air assemblies, which dehumidify cabin air, condensate storage, and the flow loops. Coldplates and heat exchangers are assumed part of other equipment while the external thermal control system is included in the assessed cooling-mass penalty.

2.4.6.1.4 Waste

The waste system provides only for rudimentary collection and storage of waste products. The waste system includes a toilet, pretreatment to stabilize urine, and separate storage for human metabolic wastes and trash.

2.4.6.1.5 Water

Urine is processed by vapor compression distillation. The brine is sent to the waste subsystem. All grey water, including hygiene water, effluent from the vapor compression distillation, and condensate from dehumidification, is processed through a water processor. The water processor employs two multifiltration units, a volatile removal assembly, phase separators, and an ion exchange bed. A process control water quality monitor provides water quality assurance. Efficiency of recovery is high, but many expendables, mostly filter cartridges, are needed. Additional water comes from stores.

2.4.6.1.6 Extravehicular Activity Support

While extravehicular activities from the Mars Descent / Ascent Lander are essential to mission success, such activities are expected to be limited in number. Thus, the entire cabin will function as an airlock and no effort is made to recover cabin gases before depressurization, preferring instead to simply repressurize the cabin from gas stocks when the crew reoccupies the Mars Descent / Ascent Lander en route to rendezvous with the Mars Transit Vehicle. The life support system is expected to provide stores of water and oxygen to the extravehicular mobility units for cooling and crew consumption, and water to charge the internal liquid cooling loops. A dedicated carbon dioxide removal assembly removes carbon dioxide from extravehicular mobility units following an extravehicular activity.

2.4.6.1.7 Human Accommodations

Clothing is launched with the vehicle before the Mars Descent / Ascent Lander leaves Earth. This clothing will remain with the vehicle when the crew departs either for surface operations or upon returning to the Mars Transit Vehicle. This clothing is not laundered. A usage rate of 0.486 kg/CM-d, in a volume of 0.00285 m^3/CM-d, is assumed.

2.4.6.2 ADVANCED LIFE SUPPORT TECHNOLOGY

The advanced life support suite for the Mars Descent / Ascent Lander uses the same technologies as the baseline suite for the waste subsystem, extravehicular activity support, and human accommodations. The advanced life support suite uses different technologies within the air subsystem, the food subsystem, and the water subsystem. The applied cooling-mass penalty reflects advanced technologies in the form of lightweight radiators constructed from composite materials. See Figure 2.4.12. See Section 8 for a list of acronyms used in this figure.

2.4.6.2.1 Air

The air subsystem for the advanced life support suite within the Mars Descent / Ascent Lander uses a solid amine vacuum desorbed processor to remove cabin carbon dioxide loads. Oxygen is not reclaimed from the carbon dioxide. Oxygen is supplied only from stores, and all pressurization gases are supplied from cryogenic sources. Other air subsystem hardware is identical to the technologies described for the baseline air subsystem in Section 2.4.6.1.1.

2.4.6.2.2 Food

Food is provided as individual entrees. This diet relies on a variety of ambient temperature, low-moisture-content foods. The nominal crew metabolic energy requirement for intravehicular activities only is 11.82 MJ/CM-d. Heavier workloads, such as those associated with extravehicular activities, generally require greater food intake. For this mission, the crew nominally receives 0.922 kg/CM-d of food. Neglecting the dry component, the food mass as-shipped is 0.249 kg/CM-d. 0.268 kg/CM-d of disposable packaging is required. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Supporting technology includes some food preparation equipment.

2.4.6.2.3 Thermal

The thermal subsystem for the advanced life support suite within the Mars Descent / Ascent Lander is identical to the technologies listed for the baseline thermal subsystem in Section 2.4.6.1.3.

2.4.6.2.4 Waste

The waste subsystem for the advanced life support suite within the Mars Descent / Ascent Lander is identical to the technologies described for the baseline waste subsystem in Section 2.4.6.1.4.

2.4.6.2.5 Water

The water subsystem for the advanced life support suite within the Mars Descent / Ascent Lander uses vapor compression catalytic ammonia removal as the primary water processor. The brine is sent directly to solid waste storage with its moisture. A process control water quality monitor provides water quality assurance.

2.4.6.2.6 Extravehicular Activity Support

The extravehicular activity support for the advanced life support system within the Mars Descent / Ascent Lander is identical to the technologies described for the baseline extravehicular activity support suite in Section 2.4.6.1.6.

2.4.6.2.7 Human Accommodations

The human accommodations for the advanced life support system within the Mars Descent / Ascent Lander is identical to the technologies described for the baseline human accommodations suite in Section 2.4.6.1.7.

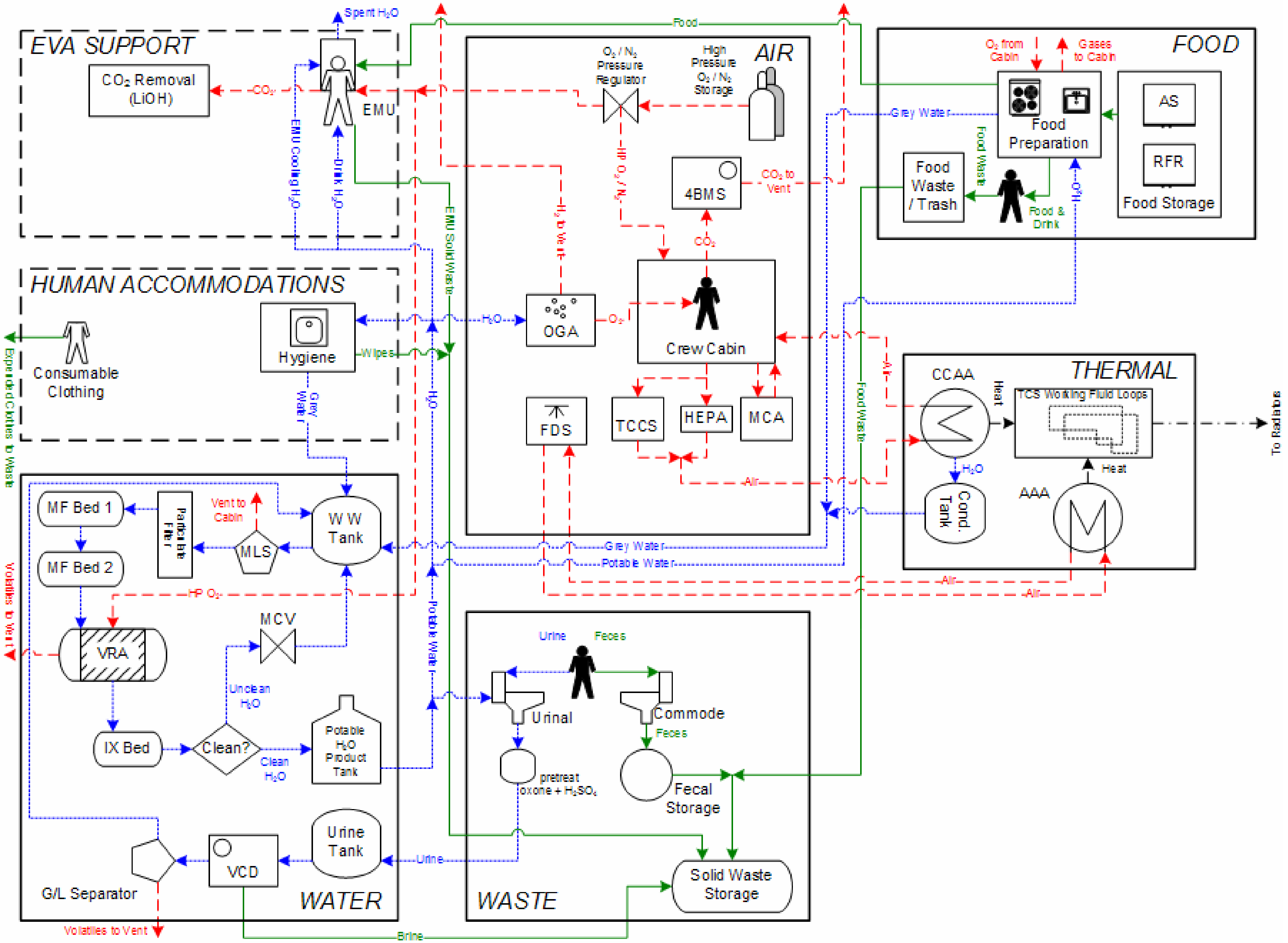

Figure 2.4.11 Mars Descent / Ascent Lander using Baseline Technologies.

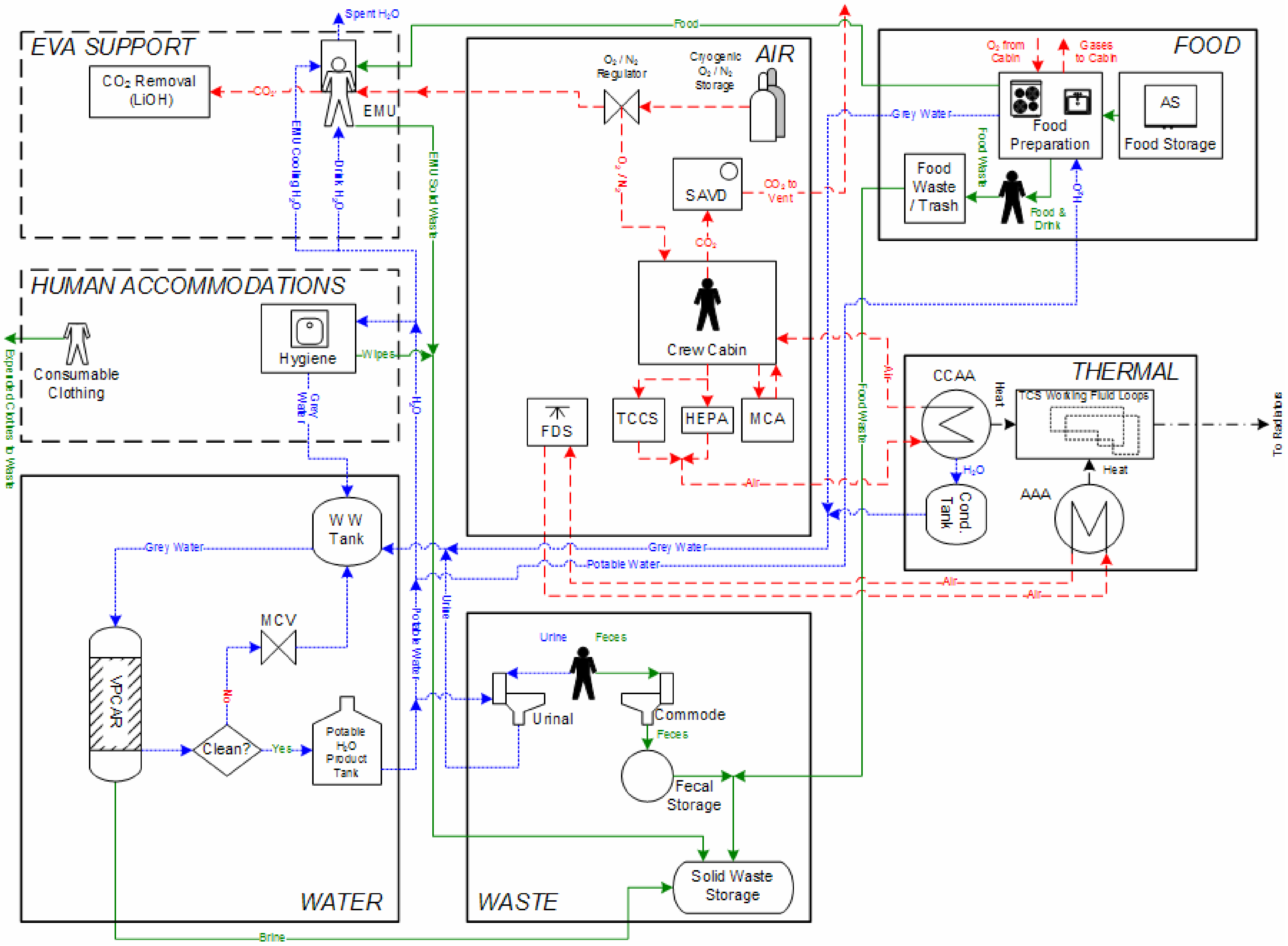

Figure 2.4.12 Mars Descent / Ascent Lander using Advanced Technologies.

2.4.7 INDEPENDENT EXPLORATION MISSION: SURFACE HABITAT LANDER

The Surface Habitat Lander assumes an inflatable module without radiation protection with the implied assumption that life support hardware is hardened versus environmental radiation loads. The crew may be housed within a hardened domain, but this is not included in the assessed infrastructure values for life support system hardware. A small nuclear reactor provides continuous power. The assumed value corresponds to a 100 kW_e nuclear reactor on an independent lander, but an actual system for this mission will likely be much smaller, both in capacity and overall mass, so the infrastructure value assumed is an approximation of the actual system. The external thermal control system uses a single-phase, pumped loop to transport thermal energy and rejects the thermal loads using body-fitted, flow-through radiators. An equatorial site on the Martian surface is assumed. Table 2.4.3 lists assumed infrastructure values while Table 2.4.2 details specific inputs for the Surface Habitat Lander segment of the Independent Exploration Mission.

2.4.7.1 BASELINE LIFE SUPPORT SYSTEM TECHNOLOGY

The baseline technology suite, for the purposes of this document, is defined based on the USOS ECLSS scaled for a crew of six. See Stafford, *et al.* (2001), for details. This suite uses physicochemical technologies to regenerate air and water, while food is supplied mainly as prepackaged individual entrees, including frozen food selections. Because of the long mission duration, biomass production chamber provides salad to supplement the prepackaged food system. [16] Waste is generally stored without reclaiming any products from that waste. Cooling employs coldplates and condensing heat exchangers to collect heat loads, a single-phase fluid to transport heat, and radiators to reject heat. For this assessment, the applied cooling-mass penalty represents radiators constructed solely from aluminum and other metallic materials. Clean clothing is launched with the vehicle and left on the surface within the vehicle upon the departure of the crew from Mars. See Figure 2.4.13. See Section 8 for a list of acronyms used in this figure.

2.4.7.1.1 Air

The baseline air suite on the Surface Habitat Lander uses regenerable carbon dioxide removal equipment based on molecular sieve technology. The absorbed carbon dioxide is dumped overboard without recovering any commodities. The trace contaminant control system for atmospheric gases uses activated carbon, for non-combustible trace gas removal, and bacteria filter assemblies, for particulate removal, neither of which are regenerated. Further, the trace contaminant control system also removes trace combustible gases in the crew cabin. Oxygen is supplied both as pressurized gas from high-pressure stores, and as a product from electrolysis of water using solid polymer technology. The associated product hydrogen is dumped overboard. Electrolysis water is provided by the water subsystem. Nitrogen is supplied from high-pressure gas stocks. A major constituent analyzer and a fire detection and suppression system provide monitoring for air contaminants and combustion products.

2.4.7.1.2 Biomass

The baseline suite contains a small biomass production chamber, providing salad crops as a supplement to an otherwise prepackaged food system. Though the dietary nutrients gained from salad crops are relatively minor, salads, snacks, and steamed entrees provide a psychological advantage unavailable in a completely prepackaged food system and support anticipated requirements for long-duration space missions. [17] Supporting equipment for the biomass production chamber includes a nutrient solution supply, condensate storage, and a supplemental common cabin air assembly to handle the greater humidity loading and air circulation requirements.

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[16] While International Space Station Upgrade Mission is longer than the combined mission durations for all vehicles within the Mars Independent Exploration architecture, individual ISS crewmembers usually spend significantly less than a year per deployment to ISS. Thus, while fresh salad is assumed here as essential for crew physical and psychological health on extended missions, distinctions between International Space Station and this mission should be noted.

[17] Biomass production is not part of the current ISS ECLSS technology suite, so a salad machine may seem “odd” here. However, the significant rationale for a small biomass production facility like a salad machine is related to requirements for dietary diversity. Thus, a salad machine is included in both life support system configurations here to meet a requirement that is beyond those associated with historical and current vehicles.

2.4.7.1.3 Food

Food is provided as individual entrees from Earth. This system relies on a variety of fresh, dehydrated, and full-water preserved, shelf-stable, or frozen foods. The diet is supplemented with fresh salad, snacks, and steamed entrees from a biomass production chamber. The nominal crew metabolic energy requirement for intravehicular activities only is 11.82 MJ/CM-d. Heavier workloads, such as those associated with extravehicular activities, generally require greater food intake. For this mission, the crew nominally receives 1.362 kg/CM-d of food. Neglecting the dry component, the food mass as-shipped is 0.685 kg/CM-d with 0.238 kg/CM-d of disposable packaging. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Supporting technology includes dedicated cold storage and some food preparation equipment.

2.4.7.1.4 Thermal

Thermal management is divided into two systems. The internal thermal control system includes the avionic air assemblies, which provide air-cooling for equipment, the common cabin air assemblies, which cool and dehumidify cabin air, condensate storage, and the water flow loops for heat transport. Coldplates and heat exchangers are assumed part of other equipment while the external thermal control system is included in the assessed cooling-mass penalty.

2.4.7.1.5 Waste

Solid waste is simply stored, without treatment, aboard the Surface Habitat Lander. This includes trash, fecal material, brine from the urine and water processing, extravehicular activity wastes, and used filters and cartridges. The toilet is also included in this calculation under the waste subsystem.

2.4.7.1.6 Water

Urine is processed by vapor compression distillation. The brine is stored and remains with the vehicle after the crew departs. All grey water, including hygiene water, effluent from the vapor compression distillation, and condensate from dehumidification, is processed through a water processor. The water processor employs two multifiltration units, a volatile removal assembly, phase separators, and an ion exchange bed. A process control water quality monitor provides water quality assurance. Efficiency of recovery is high, but many expendables, mostly filter cartridges, are needed. Water may enter the life support system directly, such as from moisture within prepackaged food, or indirectly, as a human metabolic product from the consumption of the prepackaged food. Water may also come from water stores. Due to the high frequency of extravehicular activities, the Surface Habitat Lander will probably be “water poor” in the nominal case without additional stores.

2.4.7.1.7 Extravehicular Activity Support

The extravehicular mobility unit consumables include oxygen, for metabolic consumption and suit pressurization, and water, which is rejected to provide thermal management and consumed by the crew as drinks. Though not consumed, water also provides the working fluid for the internal cooling garment. This extravehicular mobility unit uses lithium hydroxide for carbon dioxide removal. An airlock pump, which is a compressor, reduces the airlock internal pressure to about ten percent of the cabin pressure, reducing gas losses during airlock operations. Hardware to generate oxygen specifically for extravehicular activities, oxygen recharge compressor assembly, [18] is also included. Additionally, carbon dioxide from the extravehicular mobility unit is dumped to dedicated hardware following an extravehicular activity, and the airlock provides a dedicated carbon dioxide removal assembly to support activities within the airlock. Atmospheric gas and water losses are actually included as part of the air and water subsystems in this calculation, and not as part of the values presented for extravehicular activity support.

2.4.7.1.8 Human Accommodations

Clothing is launched from Earth with the Surface Habitat Lander and stays with the vehicle at the end of the surface phase. When clothing is deemed too dirty to wear, it is stowed with the other dirty clothing and replaced with a clean garment from stores. A usage rate of 0.486 kg/CM-d, in a volume of 0.00285 m^3/CM-d, is assumed.

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[18] The oxygen recharge compressor assembly (ORCA) is an ISS technology for compressing oxygen to serve extravehicular mobility units.

2.4.7.2 ADVANCED LIFE SUPPORT TECHNOLOGY

The advanced life support suite differs significantly from the baseline approach above. Cryogenic gas storage, vapor phase catalytic ammonia removal, and an ambient food system are less massive than similar baseline technologies, while Sabatier, lyophilization, and an aqueous laundry help to close various life support commodity loops within the vehicle. As above, the salad machine is retained in the advanced suite. The applied cooling-mass penalty reflects lightweight radiators constructed from composite materials. See Figure 2.4.14. See Section 8 for a list of acronyms used in this figure.

2.4.7.2.1 Air

The advanced air suite within the Surface Habitat Lander, compared to the baseline suite detailed in Section 2.4.7.1.1, adds a Sabatier carbon dioxide reduction assembly with a gas stream compressor and stores pressurization gases as cryogens. Adequate water is available to avoid a supply penalty for any necessary oxygen and hydrogen. Specifically, Sabatier reduces carbon dioxide according to the availability of hydrogen from the oxygen generation assembly. Any carbon dioxide that is not reduced is vented to space. Other aspects of the advanced air suite are identical to the baseline technology suite for air listed in Section 2.4.7.1.1.

2.4.7.2.2 Biomass

The biomass subsystem here is identical to the baseline suite in Section 2.4.7.1.2.

2.4.7.2.3 Food

Food is provided as individual, ambient storage, prepackaged entrees in the advanced food suite. The diet is supplemented with fresh salad, snacks, and steamed entrees from a biomass production chamber. The nominal crew metabolic energy requirement for intravehicular activities only is 11.82 MJ/CM-d. Heavier workloads, such as those associated with extravehicular activities, generally require greater food intake. For this mission, the crew nominally receives 1.138 kg/CM-d of food. Neglecting the dry component, the food mass as-shipped is 0.463 kg/CM-d with 0.262 kg/CM-d of disposable packaging. The corresponding specialized food storage structure adds an additional 0.860 kg/CM-d. Supporting technology includes some food preparation equipment.

2.4.7.2.4 Thermal

The advanced suite for the thermal subsystem uses the same technologies as the baseline suite for the thermal subsystem described in Section 2.4.7.1.4.

2.4.7.2.5 Waste

The advanced suite for waste uses lyophilization to recover moisture from waste. Reclaimed water is returned to the water subsystem as grey water.

2.4.7.2.6 Water

The advanced water system is built around a vapor phase catalytic ammonia removal assembly to provide primary water processing of both urine and grey water. A dedicated lyophilization processor reclaims water from the primary processor brine, allowing almost complete water recovery. Product water from the lyophilization processor passes to the primary processor. Product water from the vapor phase catalytic ammonia removal assembly requires no further polishing, though a process control water quality monitor provides water quality assurance.

2.4.7.2.7 Extravehicular Activity Support

The advanced suite for extravehicular activity support is identical to the baseline suite for extravehicular activity support. See Section 2.4.7.1.7.

2.4.7.2.8 Human Accommodations

The advanced life support system assumes an aqueous laundry. This will significantly increase the daily grey water load, but reduce the required mass of clothing compared to the baseline approach. While the actual clothing usage rate remains unchanged, the laundry system cleans soiled clothing for reuse, prolonging clothing life and reducing associated waste loads.

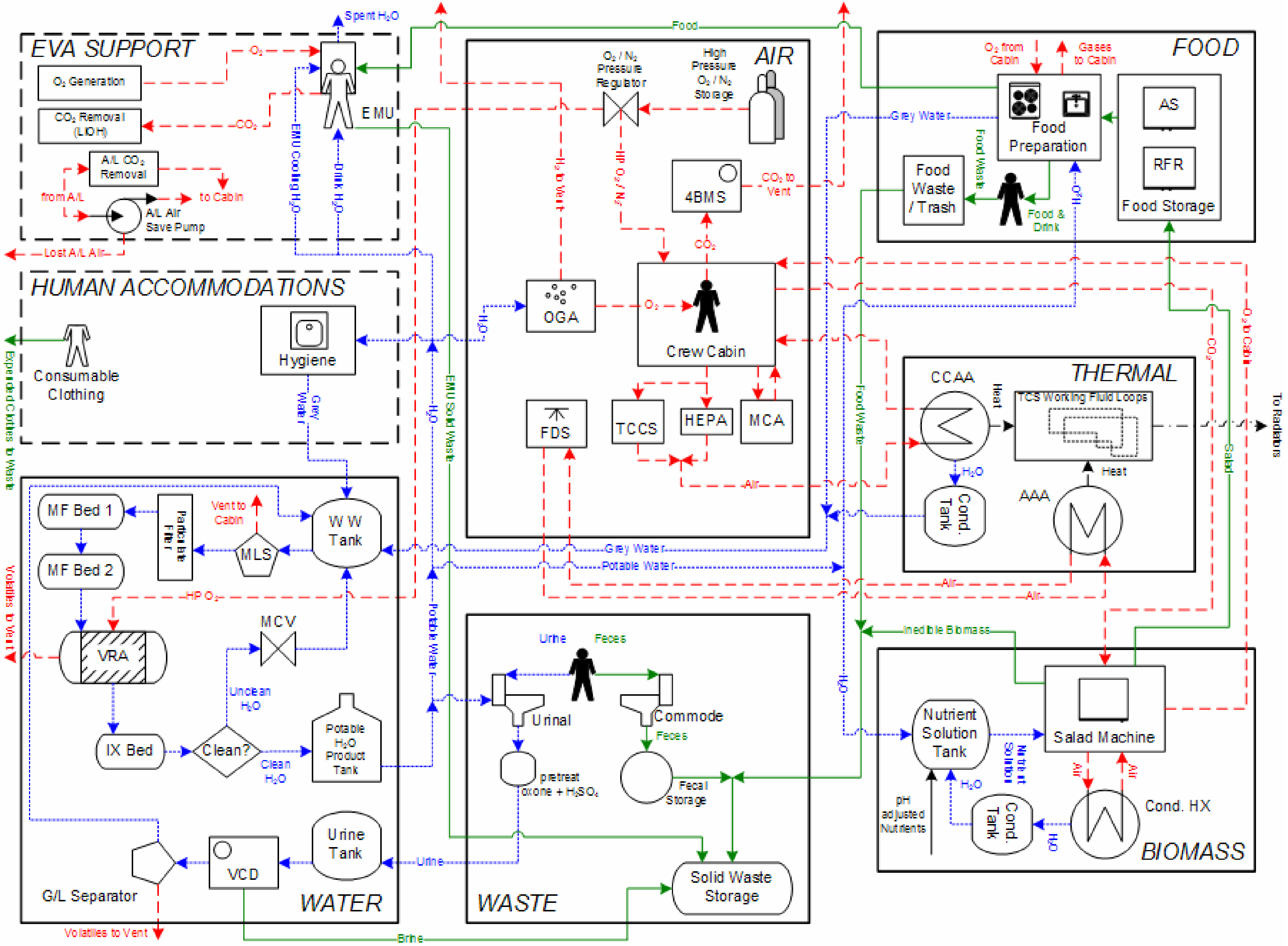

Figure 2.4.13 Surface Habitat Lander using Baseline Technologies.

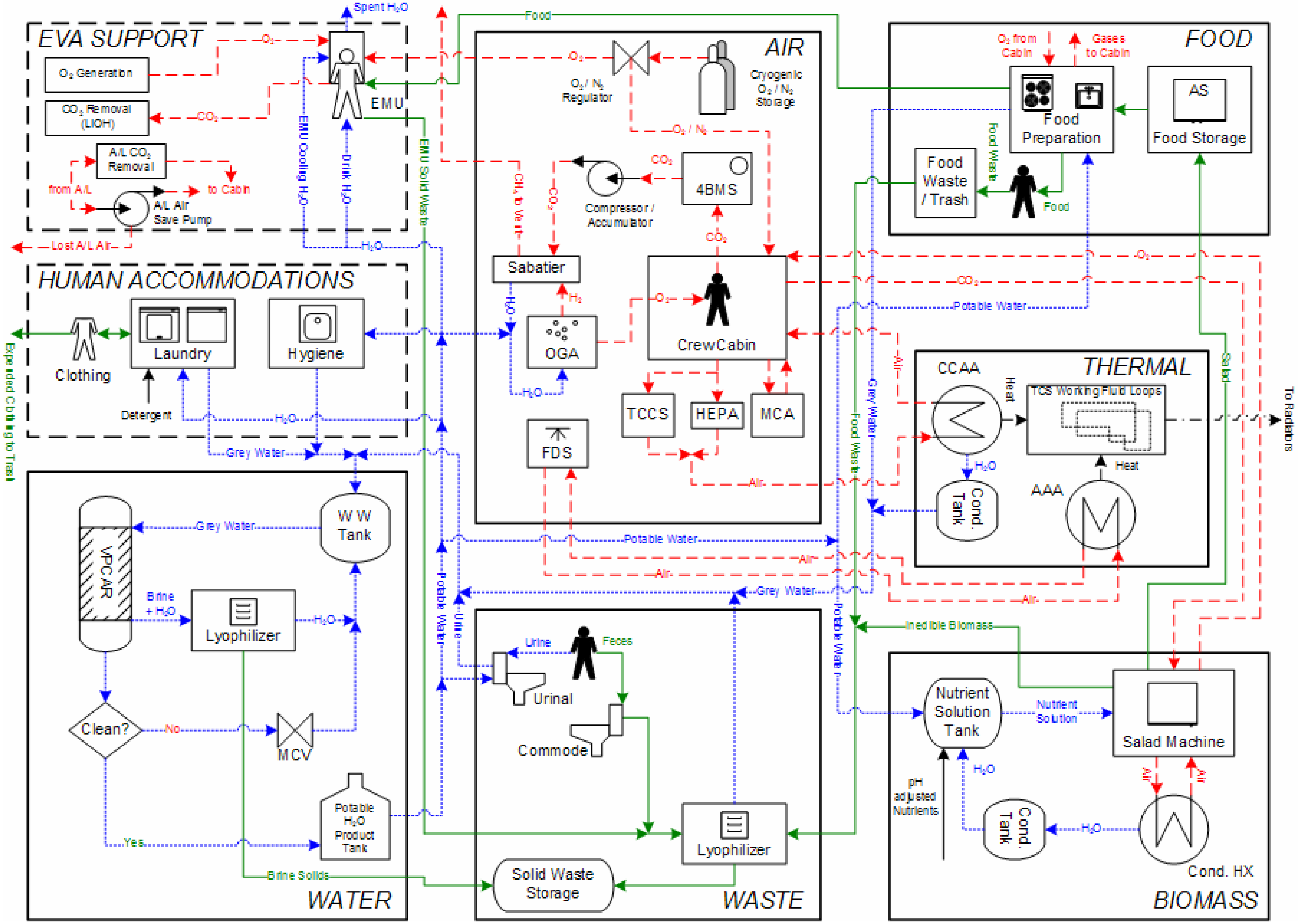

Figure 2.4.14 Surface Habitat Lander using Advanced Technologies.

2.4.8 MISSION PARAMETERS

The most significant overall mission parameters, based on Stafford, *et al.* (2001), Hanford (2005), and Hanford (2004a), are provided in Table 2.4.1. Specifically, these values quantify the mission segment duration, crew cabin volume, number of pressurized modules, and additional thermal loads aside from those associated with the life support system. For example, such loads may represent avionics, experiments, or other functions not associated with life support. For these calculations, sixty percent of the thermal loads are removed from the crew cabin via the condensing heat exchanger, with coldplates removing the other forty percent.

Table 2.4.1 Advanced Mission Parameters

Mission	Number of Pressurized Modules	Total Crew Cabin Volume [m³]	Additional Thermal Loads [kW$_{th}$]	Mission or Segment Duration [d]
Orbiting Research Facility: International Space Station Update Mission	6	1,330	121.0	3,650
Near-Term Exploration Mission:				118
Crew Exploration Vehicle	1	22.0	1.0	14
Lunar Surface Access Module	1	21.5	1.0	6
Destination Surface System	1	39.6	1.0	98
Independent Exploration Mission:				~960 [19]
Mars Transit Vehicle	2	110	5.5	360
Mars Descent / Ascent Lander	1	25.5	1.0	30
Surface Habitat Lander	2	110	8.5	600

Specific input values for each parameter of the ALSSAT menus are listed in Table 2.4.2. ALSSAT entries that are not listed here are zero or are not used to compute the current Metric values.

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[19] The duration of the total surface element is 600 days and the Surface Habitat Lander is sized for the full mission. In reality, the crew will probably spend a few days in the Mars Descent / Ascent Lander both just after landing and just before liftoff. The total duration for this vehicle is 30 days.

Table 2.4.2 Specific Input Values for Metric Mission Parameters in the Advanced Life Support Sizing Analysis Tool (ALSSAT)

Parameter	Units	International Space Station Upgrade Value	Crew Exploration Vehicle Value	Lunar Surface Access Module Value	Destination Surface System Value
Mission Definition					
Number of Crewmembers	CM	6	4	4	4
Manned Mission Duration	[d]	3,650	14	6	98
No. of Dockings Requiring PMA Pressurization per Mission	--	0	0	0	0
Will contingency considerations be included in this mission?	--	No	No	No	No
Vehicle Definition Parameters					
Number of Modules	modules	6	1	1	1
Maximum Atmospheric Leakage per Module	[kg/d•mod]	2.24×10^{-3}	2.24×10^{-3}	2.24×10^{-3}	2.24×10^{-3}
Total Pressurized Atmospheric Volume	[m³]	1,330	22.0	21.5	39.6
Total PMA Atmosphere Volume	[m³]	0	0	0	0
Interior Atmosphere Definition (Manned)					
Nominal Total Atmosphere Pressure	[kPa]	101.3	65.5	65.5	65.5
Nominal Atmosphere Oxygen Partial Pressure	[kPa]	21.3	19.7	19.7	19.7
Nominal Atmosphere Water Vapor Partial Pressure	[kPa]	1.2	0.7759	0.7759	0.7759
Nominal Atmosphere Carbon Dioxide Partial Pressure	[kPa]	0.4	0.4	0.4	0.4
Nominal Crew Inputs					
Oral Hygiene Water	[kg/CM-d]	0.363	0.5	0.5	0.5
Hand / Face Wash Water	[kg/CM-d]	4.082	1.5	1.5	1.5
Urinal Flush Water	[kg/CM-d]	0.494	0.494	0.494	0.494
Laundry Water [20]	[kg/CM-d]	12.474	0	0	12.474
Water Supplied by Fuel Cells	[kg/d]	0	0	0	0
Shower Water	[kg/CM-d]	0	0	0	0
Dishwashing Water	[kg/CM-d]	0	0	0	0
Drinking Water	[kg/CM-d]	2.000	3.5	3.5	3.5
EHS Sample Water [21]	[kg/d]	1.272 [22]	0	0	0

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[20] When a laundry is part of the life support system. Otherwise this value is zero.

[21] This represents water to payloads that is not recovered.

[22] This is equivalent to 0.212 kg/CM-d.

Table 2.4.2 Specific Input Values for Metric Mission Parameters in the Advanced Life Support Sizing Analysis Tool (ALSSAT) (continued)

Parameter	Units	International Space Station Upgrade Value	Crew Exploration Vehicle Value	Lunar Surface Access Module Value	Destination Surface System Value
Thermal Control System, Vehicle Characteristics					
Characteristic Vehicle Length	[m]	51	1.70	2.00	2.02
Characteristic Vehicle Radius	[m]	2.2	2.50	1.85	2.50
Thermal Control System, Internal Thermal Control System Fluid Loop					
ITCS Inlet Temperature	[K]	275.00	275.00	275.00	275.00
ITCS Outlet Temperature	[K]	308.15	308.15	308.15	308.15
ITCS Working Fluid	--	Water	Water	Water	Water
Avionics from Cold Plates [23]	[kW$_{th}$]	48.4	0.4	0.4	0.4
Avionics from Heat Exchanger (HX) [23]	[kW$_{th}$]	72.6	0.6	0.6	0.6
Percentage from Cold Plates	as a fraction	0.4	0.4	0.4	0.4
Thermal Control System, ITCS Loop Characteristics					
ITCS Pump Efficiency (eta)	dimensionless	0.45	0.45	0.45	0.45
ITCS Line Diameter (Outside Diameter)	[m]	0.0635	0.009525	0.009525	0.009525
ITCS Effective Line Length Multiplier	dimensionless	10	10	10	10
Thermal Control System, Physical Constants					
Maximum Insolation	[kW$_{th}$/m^2]	1.414	1.414	1.414	1.414
Solar Incident Angle	[degrees]	90	90	30	30
Albedo	dimensionless	0	0	0.067	0..067
View Factor of Ground	dimensionless	0	0	0.5	0.5
Additional Service	[m]	2.0	2.0	2.0	2.0
Liquid Tankage Mass Penalty	as a fraction	0.10	0.10	0.10	0.10
Factor for Valves and Fittings in TCS Lines	as a fraction	0.15	0.15	0.15	0.15
Accumulator Volume Factor	as a fraction	0.30	0.30	0.30	0.30
Phase Change Material Container Mass	as a fraction	0	1.00	1.00	1.00
Volume Factor for Re-Entry Containment	as a fraction	0	0.25	0.25	0.25
Percentage of Re-Entry for Aero-Brake	as a fraction	0	0.75	0.75	0.75
Percentage of FES Ducting Assumed	as a fraction	0	1.00	1.00	0

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[23] The avionics heat load here represents all other vehicle hardware besides life support hardware.

Table 2.4.2 Specific Input Values for Metric Mission Parameters in the Advanced Life Support Sizing Analysis Tool (ALSSAT) (continued)

Parameter	Units	International Space Station ISS Upgrade Value	Crew Exploration Vehicle Value	Lunar Surface Access Module Value	Destination Surface System Value
External Interfaces, EVA Support					
Will oxygen required by EVA be generated?	--	n/a	n/a	No	No
Total Number of EVAs per Day	[sorties/d]	0	0	2	2
Total Number of EVAs per Mission	[sorties]	0	0	4	56
EVA Duration	[h]	0	0	8	8
Crewmembers per EVA	[CM/sortie]	0	0	2	2
Airlock Volume	[m³]	0	0	4.25	4.25
Airlock Free Gas Volume	[m³]	0	0	3.7	3.7
Airlock Gas Losses per Cycle	[%]	0	0	10	10
Oxygen Consumption	[kg/CM-h]	0	0	0.15	0.15
Nominal EMU Waste Water Recovery	[%]	0	0	50	50
EVA Drinking Water	[kg/CM-h]	0	0	0.24	0.24
Cooling Water Losses	[kg/CM-h]	0	0	0.19	0.19
Maximum Absorbency Garment	[kg/CM-EVA]	0	0	0.173	0.173
Waste Water Absorbed by Maximum Absorbency Garment	[kg/CM-EVA]	0	0	0.55	0.55
External Interfaces, Human Accommodations					
Mass of Clothing without a Laundry Facility	[kg/CM-d]	0.486	0.486	0.486	0.486
Volume of Clothing without a Laundry Facility	[m³/CM-d]	2.85×10^{-3}	2.85×10^{-3}	2.85×10^{-3}	2.85×10^{-3}
Mass of Clothing with a Laundry Facility	[kg/CM-d]	0.02	n/a	n/a	0.07
Volume of Clothing with a Laundry Facility	[m³/CM-d]	1.173×10^{-4}	n/a	n/a	4.105×10^{-4}
External Interfaces, Integrated Control					
Please select a sensory control level.	dimensionless	Low Tech	Low Tech	Low Tech	Low Tech
Computational Parameters					
Maximum Allowable Iteration Count	dimensionless	1,000	1,000	1,000	1,000
Maximum Change at Convergence	dimensionless	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}

Table 2.4.2 Specific Input Values for Metric Mission Parameters in the Advanced Life Support Sizing Analysis Tool (ALSSAT) (continued)

Parameter	Units	Mars Transit Vehicle Value	Mars Descent / Ascent Lander Value	Surface Habitat Lander Value
Mission Definition				
Number of Crewmembers	CM	6	6	6
Manned Mission Duration	[d]	360	30	600
No. of Dockings Requiring PMA Pressurization per Mission	--	0	0	0
Will contingency considerations be included in this mission?	--	No	No	No
Vehicle Definition Parameters				
Number of Modules	modules	2	1	2
Maximum Atmospheric Leakage per Module	[kg/d•mod]	2.24×10^{-3}	2.24×10^{-3}	2.24×10^{-3}
Total Pressurized Atmospheric Volume	[m³]	110	25.5	110
Total PMA Atmosphere Volume	[m³]	0	0	0
Interior Atmosphere Definition (Manned)				
Nominal Total Atmosphere Pressure	[kPa]	70.3	70.3	70.3
Nominal Atmosphere Oxygen Partial Pressure	[kPa]	21.3	21.3	21.3
Nominal Atmosphere Water Vapor Partial Pressure	[kPa]	1.2	1.2	1.2
Nominal Atmosphere Carbon Dioxide Partial Pressure	[kPa]	0.4	0.4	0.4
Nominal Crew Inputs				
Oral Hygiene Water	[kg/CM-d]	0.363	0.363	0.363
Hand / Face Wash Water	[kg/CM-d]	4.082	4.082	4.082
Urinal Flush Water	[kg/CM-d]	0.494	0.494	0.494
Laundry Water [24]	[kg/CM-d]	12.474	0	12.474
Water Supplied by Fuel Cells	[kg/d]	0	0	0
Shower Water	[kg/CM-d]	2.722	0	2.722
Dishwashing Water	[kg/CM-d]	0	0	0
Drinking Water	[kg/CM-d]	2.000	2.000	2.000
EHS Sample Water [25]	[kg/d]	0	0	0

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[24] When a laundry is part of the life support system. Otherwise this value is zero.

[25] This represents water to payloads that is not recovered.

Table 2.4.2 Specific Input Values for Metric Mission Parameters in the Advanced Life Support Sizing Analysis Tool (ALSSAT) (continued)

Parameter	Units	Mars Transit Vehicle Value	Mars Descent / Ascent Lander Value	Surface Habitat Lander Value
Thermal Control System, Vehicle Characteristics				
Characteristic Vehicle Length	[m]	5.6	3.61	5.6
Characteristic Vehicle Radius	[m]	2.5	1.5	2.5
Thermal Control System, Internal Thermal Control System Fluid Loop				
ITCS Inlet Temperature	[K]	275.00	275.00	275.00
ITCS Outlet Temperature	[K]	308.15	308.15	308.15
ITCS Working Fluid	--	Water	Water	Water
Avionics from Cold Plates [26]	[kW_{th}]	2.2	0.4	3.4
Avionics from Heat Exchanger (HX) [26]	[kW_{th}]	3.3	0.6	5.1
Percentage from Cold Plates	as a fraction	0.4	0.4	0.4
Thermal Control System, ITCS Loop Characteristics				
ITCS Pump Efficiency (eta)	dimensionless	0.45	0.45	0.45
ITCS Line Diameter (Outside Diameter)	[m]	0.0127	0.009525	0.0127
ITCS Effective Line Length Multiplier	dimensionless	10	10	10
Thermal Control System, Physical Constants				
Maximum Insolation	[kW_{th}/m^2]	1.414	1.414	1.414
Solar Incident Angle	[degrees]	90	30	30
Albedo	dimensionless	0	0.1	0.1
View Factor of Ground	dimensionless	0	0.5	0.5
Additional Service	[m]	2.0	2.0	2.0
Liquid Tankage Mass Penalty	as a fraction	0.10	0.10	0.10
Factor for Valves and Fittings in TCS Lines	as a fraction	0.15	0.15	0.15
Accumulator Volume Factor	as a fraction	0.30	0.30	0.30
Phase Change Material Container Mass	as a fraction	1.00	1.00	1.00
Volume Factor for Re-Entry Containment	as a fraction	0.25	0.25	0.25
Percentage of Re-Entry for Aero-Brake	as a fraction	0.75	0.75	0.75
Percentage of FES Ducting Assumed	as a fraction	1.00	1.00	1.00

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[26] The avionics heat load here represents all other vehicle hardware besides life support hardware.

Table 2.4.2 Specific Input Values for Metric Mission Parameters in the Advanced Life Support Sizing Analysis Tool (ALSSAT) (concluded)

Parameter	Units	Mars Transit Vehicle Value	Mars Descent / Ascent Lander Value	Surface Habitat Lander Value
External Interfaces, EVA Support				
Will oxygen required by EVA be generated?	--	n/a	No	Yes
Total Number of EVAs per Day	[sorties/d]	0	1	2
Total Number of EVAs per Mission	[sorties]	0	1	700
EVA Duration	[h]	0	4	4
Crewmembers per EVA	[CM/sortie]	0	6	2
Airlock Volume	[m³]	0	25.5	4.25
Airlock Free Gas Volume	[m³]	0	23.75	3.7
Airlock Gas Losses per Cycle	[%]	0	100	10
Oxygen Consumption	[kg/CM-h]	0	0.15	0.15
Nominal EMU Waste Water Recovery	[%]	0	50	50
EVA Drinking Water	[kg/CM-h]	0	0.24	0.24
Cooling Water Losses	[kg/CM-h]	0	0.19	0.19
Maximum Absorbency Garment	[kg/CM-EVA]	0	0.173	0.173
Waste Water Absorbed by Maximum Absorbency Garment	[kg/CM-EVA]	0	0.55	0.55
External Interfaces, Human Accommodations				
Mass of Clothing without a Laundry Facility	[kg/CM-d]	0.486	0.486	0.486
Volume of Clothing without a Laundry Facility	[m³/CM-d]	2.85×10^{-3}	2.85×10^{-3}	2.85×10^{-3}
Mass of Clothing with a Laundry Facility	[kg/CM-d]	0.03	n/a	0.02
Volume of Clothing with a Laundry Facility	[m³/CM-d]	1.759×10^{-4}	n/a	1.173×10^{-4}
External Interfaces, Integrated Control				
Please select a sensory control level.	dimensionless	Low Tech	Low Tech	Low Tech
Computational Parameters				
Maximum Allowable Iteration Count	dimensionless	1,000	1,000	1,000
Maximum Change at Convergence	dimensionless	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}

2.4.9 INFRASTRUCTURE COSTS/EQUIVALENCIES

Infrastructure equivalencies, from Hanford (2005) and Hanford (2004a), are assumed as shown in Table 2.4.3 for each mission vehicle. The corresponding infrastructure technologies are noted above with each mission. With regard to both volume, which accounts for vehicle structure, and power, which represents power generation, both the baseline and advanced technology suites use the same infrastructure equivalencies.

Table 2.4.3 Advanced Mission Cost Equivalencies

Mission	Volume [kg/m^3]	Power [kg/kW$_e$]	Cooling [27] [kg/kW$_{th}$]
Orbiting Research Facility: **International Space Station Update Mission**	66.7	476.0	323.9
Near-Term Exploration Mission:			
Crew Exploration Vehicle	131.9	341.5	19.4
Lunar Surface Access Module	49.6	179.6	56.0
Destination Surface System	100.0	226.0	53.6
Independent Exploration Mission:			
Mars Transit Vehicle	9.16	237.0	40.0/ 30.0
Mars Descent / Ascent Lander	66.7	228.0	145.0/ 121.0
Surface Habitat Lander	9.16	87.0	145.0/ 121.0

For cooling, two equivalencies appear in Table 2.4.3 for each vehicle within the Independent Exploration Mission. The first cooling equivalency simulates current cooling technology using aluminum, flow-through radiators. This first equivalency is applied to assessments using the baseline technology suite. The second cooling equivalency represents advanced radiators that are under development for life-support thermal loads. This second equivalency is applied to assessments using the advanced technology suite. All cooling equivalencies here are listed in Hanford (2004a). Note that the differences between the cooling infrastructure values reflect only changes in thermal hardware material, and not changes in overall thermal management architecture.

For the International Space Station Update Mission, the same cooling equivalency, based upon current ISS cooling technology and architecture, is used for estimates employing both life support system technology suites. This approach is equivalent to assuming that ISS cooling technology is unlikely to change regardless of which technologies supply life support functions within ISS.

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[27] When two infrastructure equivalencies are listed for cooling, the first assumes current technology using aluminum, flow-through radiators, while the second assumes advanced technologies with some form of lightweight radiators.

3 ADVANCED LIFE SUPPORT RESEARCH AND TECHNOLOGY DEVELOPMENT METRIC

3.1 SUBSYSTEM TECHNOLOGY DATA

The tables below list overall subsystem attributes for the various vehicles and missions considered in this Metric computation. Except as noted above, these classifications are consistent with advanced terminology as presented within Hanford (2004a) and Stafford, *et al.* (2001). See Section 6 for assessments at the assembly-level.

Table 3.1.1 Orbiting Research Facility: International Space Station Upgrade Mission using Baseline Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW$_e$]	Cooling [kW$_{th}$]	Crewtime [CM-h]	ESM [kg]
Air	33,085	34.97	4.399	2.815	129.58	38,517
Biomass	0	0.00	0.000	0.000	0.00	0
Food	31,304	129.74	4.272	4.272	0.00	43,375
Thermal	763	2.70	0.769	0.769	20.28	1,573
Waste	3,917	107.93	0.014	0.014	0.00	11,127
Water	25,677	13.82	1.322	1.322	0.00	27,657
Extravehicular Activity Support	0	0.00	0.000	0.000	0.00	0
Human Accommodations	22,799	79.59	0.000	0.000	0.00	28,107
Totals	**117,545**	**368.75**	**10.776**	**9.192**	**149.86**	

The total life support system ESM for the International Space Station Upgrade Mission using baseline technologies, rounded to the nearest 10 kg, is 150,360 kg. The computed crewtime-mass penalty for this assessment is 0.724 kg/CM-h.

Table 3.1.2 Orbiting Research Facility: International Space Station Upgrade Mission using Advanced Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW$_e$]	Cooling [kW$_{th}$]	Crewtime [CM-h]	ESM [kg]
Air	10,420	14.04	4.556	2.974	129.58	14,531
Biomass	0	0.00	0.000	0.000	0.00	0
Food	23,593	105.79	0.960	0.960	0.00	31,417
Thermal	750	2.68	0.769	0.769	20.28	1,551
Waste	1,467	22.04	0.947	0.909	5,475.00	5,505
Water	1,483	2.07	2.143	2.143	0.00	3,335
Extravehicular Activity Support	0	0.00	0.000	0.000	0.00	0
Human Accommodations	12,727	20.00	0.633	0.633	0.00	14,567
Totals	**50,439**	**166.62**	**10.008**	**8.388**	**5,624.86**	

The total life support system ESM for the International Space Station Upgrade Mission using advanced technologies, rounded to the nearest 10 kg, is 70,910 kg. The computed crewtime-mass penalty for this assessment is 0.333 kg/CM-h.

Table 3.1.3 Near-Term Exploration Mission: Crew Exploration Vehicle using Baseline Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	681	1.29	0.317	0.317	0.00	966
Biomass	0	0.00	0.000	0.000	0.00	0
Food	97	0.37	0.960	0.960	0.00	492
Thermal	268	0.86	0.772	0.772	0.08	661
Waste	46	0.39	0.014	0.014	0.00	102
Water	1,168	0.90	0.042	0.026	0.00	1,301
Extravehicular Activity Support	0	0.00	0.000	0.000	0.00	0
Human Accommodations	59	0.21	0.000	0.000	0.00	86
Totals	**2,318**	**4.02**	**2.105**	**2.089**	**0.08**	

The total life support system ESM for the Crew Exploration Vehicle in the Near-Term Exploration Mission using baseline technologies, rounded to the nearest 10 kg, is 3,610 kg. The computed crewtime-mass penalty for this assessment is 7.42 kg/CM-h.

Table 3.1.4 Near-Term Exploration Mission: Crew Exploration Vehicle using Advanced Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	429	1.01	0.336	0.336	0.00	638
Biomass	0	0.00	0.000	0.000	0.00	0
Food	84	0.36	0.960	0.960	0.00	478
Thermal	271	0.87	0.774	0.774	0.08	666
Waste	46	0.39	0.014	0.014	0.00	102
Water	449	2.22	0.433	0.433	0.00	898
Extravehicular Activity Support	0	0.00	0.000	0.000	0.00	0
Human Accommodations	59	0.21	0.000	0.000	0.00	86
Totals	**1,337**	**5.06**	**2.517**	**2.517**	**0.08**	

The total life support system ESM for the Crew Exploration Vehicle in the Near-Term Exploration Mission using advanced technologies, rounded to the nearest 10 kg, is 2,910 kg. The computed crewtime-mass penalty for this assessment is 6.09 kg/CM-h.

Table 3.1.5 Near-Term Exploration Mission: Lunar Surface Access Module using Baseline Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	519	1.04	0.317	0.317	0.00	645
Biomass	0	0.00	0.000	0.000	0.00	0
Food	64	0.23	0.960	0.960	0.00	302
Thermal	268	0.86	0.771	0.771	0.03	493
Waste	41	0.25	0.014	0.014	0.00	56
Water	608	0.44	0.028	0.019	0.00	636
Extravehicular Activity Support	98	0.41	1.000	1.000	0.00	354
Human Accommodations	25	0.09	0.000	0.000	0.00	30
Totals	**1,623**	**3.32**	**3.090**	**3.081**	**0.03**	

The total life support system ESM for the Lunar Surface Access Module in the Near-Term Exploration Mission using baseline technologies, rounded to the nearest 10 kg, is 2,520 kg. The computed crewtime-mass penalty for this assessment is 10.66 kg/CM-h.

Table 3.1.6 Near-Term Exploration Mission: Lunar Surface Access Module using Advanced Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	346	0.84	0.345	0.345	0.00	469
Biomass	0	0.00	0.000	0.000	0.00	0
Food	58	0.21	0.960	0.960	0.00	294
Thermal	271	0.87	0.773	0.773	0.03	496
Waste	41	0.25	0.014	0.014	0.00	56
Water	408	2.23	0.437	0.437	0.00	621
Extravehicular Activity Support	98	0.41	1.000	1.000	0.00	354
Human Accommodations	25	0.09	0.000	0.000	0.00	30
Totals	**1,247**	**4.90**	**3.529**	**3.529**	**0.03**	

The total life support system ESM for the Lunar Surface Access Module in the Near-Term Exploration Mission using advanced technologies, rounded to the nearest 10 kg, is 2,320 kg. The computed crewtime-mass penalty for this assessment is 9.84 kg/CM-h.

Table 3.1.7 Near-Term Exploration Mission: Destination Surface System using Baseline Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	3,185	3.68	1.108	1.108	0.76	3,864
Biomass	0	0.00	0.000	0.000	0.00	0
Food	460	2.00	0.960	0.960	0.00	928
Thermal	279	0.88	0.783	0.783	0.54	586
Waste	115	2.31	0.014	0.014	0.00	350
Water	883	2.50	0.833	0.833	0.00	1,366
Extravehicular Activity Support	235	0.73	1.000	1.000	0.00	588
Human Accommodations	408	1.43	0.000	0.000	0.00	551
Totals	**5,564**	**13.53**	**4.698**	**4.698**	**1.30**	

The total life support system ESM for the Destination Surface System in the Near-Term Exploration Mission using baseline technologies, rounded to the nearest 10 kg, is 8,230 kg. The computed crewtime-mass penalty for this assessment is 2.14 kg/CM-h.

Table 3.1.8 Near-Term Exploration Mission: Destination Surface System using Advanced Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	1,258	1.53	1.129	1.129	0.76	1,728
Biomass	0	0.00	0.000	0.000	0.00	0
Food	367	1.88	0.960	0.960	0.00	823
Thermal	282	0.89	0.789	0.789	0.54	593
Waste	110	2.17	0.014	0.014	0.00	331
Water	649	1.30	1.428	1.428	0.00	1,178
Extravehicular Activity Support	235	0.73	1.000	1.000	0.00	588
Human Accommodations	408	1.43	0.000	0.000	0.00	551
Totals	**3,309**	**9.93**	**5.321**	**5.321**	**1.30**	

The total life support system ESM for the Destination Surface System in the Near-Term Exploration Mission using advanced technologies, rounded to the nearest 10 kg, is 5,790 kg. The computed crewtime-mass penalty for this assessment is 1.50 kg/CM-h.

Table 3.1.9 Independent Exploration Mission: Mars Transit Vehicle using Baseline Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	2,190	3.32	4.199	2.710	12.78	3,334
Biomass	761	17.03	6.099	6.099	0.00	2,607
Food	2,840	13.12	1.860	1.860	0.00	3,475
Thermal	329	1.00	0.888	0.888	2.00	586
Waste	382	9.73	0.014	0.014	0.00	475
Water	3,353	5.50	1.127	1.127	0.00	3,715
Extravehicular Activity Support	0	0.00	0.000	0.000	0.00	0
Human Accommodations	1,763	6.87	0.000	0.000	0.00	1,826
Totals	**11,617**	**56.57**	**14.187**	**12.698**	**14.78**	

The total life support system ESM for the Mars Transit Vehicle in the Independent Exploration Mission using baseline technologies, rounded to the nearest 10 kg, is 16,020 kg. The computed crewtime-mass penalty for this assessment is 0.728 kg/CM-h.

Table 3.1.10 Independent Exploration Mission: Mars Transit Vehicle using Advanced Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	1,367	2.94	4.350	2.863	12.78	2,518
Biomass	761	17.03	6.099	6.099	0.00	2,546
Food	2,343	10.45	0.960	0.960	0.00	2,695
Thermal	336	1.01	0.914	0.914	2.00	591
Waste	254	6.19	0.014	0.014	0.00	315
Water	1,011	2.92	3.048	3.048	180.00	1,953
Extravehicular Activity Support	0	0.00	0.000	0.000	0.00	0
Human Accommodations	863	1.35	0.633	0.633	0.00	1,044
Totals	**6,935**	**41.89**	**16.019**	**14.532**	**194.78**	

The total life support system ESM for the Mars Transit Vehicle in the Independent Exploration Mission using advanced technologies, rounded to the nearest 10 kg, is 11,660 kg. The computed crewtime-mass penalty for this assessment is 0.565 kg/CM-h.

Table 3.1.11 Independent Exploration Mission: Mars Descent / Ascent Lander using Baseline Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	1,071	2.16	4.251	2.742	1.07	2,586
Biomass	0	0.00	0.000	0.000	0.00	0
Food	620	3.37	2.128	2.128	0.00	1,638
Thermal	296	0.92	0.822	0.822	0.17	665
Waste	69	1.02	0.014	0.014	0.00	142
Water	737	2.88	0.896	0.896	0.00	1,263
Extravehicular Activity Support	22	0.25	0.000	0.000	0.00	38
Human Accommodations	188	0.65	0.000	0.000	0.00	231
Totals	**3,001**	**11.25**	**8.111**	**6.602**	**1.24**	

The total life support system ESM for the Mars Descent / Ascent Lander in the Independent Exploration Mission using baseline technologies, rounded to the nearest 10 kg, is 6,560 kg. The computed crewtime-mass penalty for this assessment is 3.71 kg/CM-h.

Table 3.1.12 Independent Exploration Mission: Mars Descent / Ascent Lander using Advanced Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	670	0.96	0.489	0.489	0.01	904
Biomass	0	0.00	0.000	0.000	0.00	0
Food	189	0.92	0.960	0.960	0.00	585
Thermal	280	0.89	0.784	0.784	0.17	613
Waste	67	0.99	0.014	0.014	0.00	138
Water	445	1.30	1.548	1.548	0.00	1,072
Extravehicular Activity Support	22	0.25	0.000	0.000	0.00	38
Human Accommodations	188	0.65	0.000	0.000	0.00	231
Totals	**1,860**	**5.96**	**3.795**	**3.795**	**0.18**	

The total life support system ESM for the Mars Descent / Ascent Lander in the Independent Exploration Mission using advanced technologies, rounded to the nearest 10 kg, is 3,580 kg. The computed crewtime-mass penalty for this assessment is 2.03 kg/CM-h.

Table 3.1.13 Independent Exploration Mission: Surface Habitat Lander using Baseline Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	4,195	5.52	5.847	3.732	21.30	5,315
Biomass	898	17.03	6.099	6.099	0.00	2,469
Food	7,580	38.39	4.272	4.272	0.00	8,923
Thermal	382	1.17	1.032	1.032	3.33	636
Waste	668	17.66	0.014	0.014	0.00	833
Water	10,380	9.82	1.285	1.285	0.00	10,768
Extravehicular Activity Support	1,292	2.91	2.500	2.500	0.00	1,899
Human Accommodations	2,938	11.45	0.000	0.000	0.00	3,043
Totals	**28,333**	**103.95**	**21.048**	**18.934**	**24.63**	

The total life support system ESM for the Surface Habitat Lander in the Independent Exploration Mission using baseline technologies, rounded to the nearest 10 kg, is 33,890 kg. The computed crewtime-mass penalty for this assessment is 0.957 kg/CM-h.

Table 3.1.14 Independent Exploration Mission: Surface Habitat Lander using Advanced Technologies

Subsystem / Interface	Mass [kg]	Volume [m^3]	Power [kW_e]	Cooling [kW_{th}]	Crewtime [CM-h]	ESM [kg]
Air	2,198	4.17	6.016	3.903	21.30	3,242
Biomass	898	17.03	6.099	6.099	0.00	2,323
Food	3,881	17.35	0.960	0.960	0.00	4,239
Thermal	376	1.16	0.999	0.999	3.33	596
Waste	392	6.69	0.353	0.353	360.00	694
Water	1,533	3.32	3.104	3.104	300.00	2,348
Extravehicular Activity Support	1,292	2.91	2.500	2.500	0.00	1,839
Human Accommodations	1,349	1.87	0.633	0.633	0.00	1,498
Totals	**11,919**	**54.50**	**20.664**	**18.552**	**684.63**	

The total life support system ESM for the Surface Habitat Lander in the Independent Exploration Mission using advanced technologies, rounded to the nearest 10 kg, is 16,780 kg. The computed crewtime-mass penalty for this assessment is 0.465 kg/CM-h.

3.2 ADVANCED LIFE SUPPORT RESEARCH AND TECHNOLOGY DEVELOPMENT METRIC

3.2.1 METRIC VALUES

Metric values were calculated for each of the mission vehicles described above. The ESM for each mission segment was estimated separately by applying the appropriate equivalencies or cost factors. The mission segment ESM values were summed to derive a total vehicle ESM. The vehicle ESM values were also summed to provide an overall mission ESM. Metrics were calculated for each vehicle and mission by dividing the ESM for the life support system using baseline technologies by the corresponding ESM for the life support system using advanced technologies. Different extravehicular activity models were used for the various vehicles, as applicable. The results are tabulated in Table 3.2.1.

As noted earlier, the International Space Station mission employs a single vehicle here, thus the mission and the vehicle are equivalent. The Lunar Reference Mission and the Mars Independent Exploration mission each use three different vehicles to place a single crew on Luna or Mars and return that crew safely to Earth. The overall mission ESM and Metric are listed on the first line for these latter two missions, and the individual vehicle ESM and Metric values are listed on the lines below.

Table 3.2.1 Equivalent System Mass and Metric Values for a Range of Missions and Technologies

Mission / Vehicle	Baseline Technology ESM [kg]	Advanced Technology ESM [kg]	ALS R&TD Metric
Orbiting Research Facility: International Space Station Upgrade Mission	**150,360**	**70,910**	**2.12**
Near-Term Exploration Mission:	**14,360**	**11,020**	**1.30**
Crew Exploration Vehicle	3,610	2,910	1.24
Lunar Surface Access Module	2,520	2,320	1.08
Destination Surface System	8,230	5,790	1.42
Independent Exploration Mission:	**56,470**	**32,020**	**1.76**
Mars Transit Vehicle	16,020	11,660	1.37
Mars Descent / Ascent Lander	6,560	3,580	1.83
Surface Habitat Lander	33,890	16,780	2.02

Table 3.2.1 with Figure 3.3.1, Figure 3.3.2, and Figure 3.3.3 summarize calculations supporting the Fiscal Year 2005 Advanced Life Support Research and Technology Development Metric. Figure 3.3.1 presents the overall equivalent masses for both reference missions used for the Fiscal Year 2005 Metric. Figure 3.3.2 presents the individual equivalent system masses for the vehicles of the Near-Term Exploration Mission to Luna. Finally, Figure 3.3.3 provides equivalent masses for each of the vehicles within the Independent Exploration Mission to Mars.

3.2.2 DISCUSSION

Examination of Figure 3.3.1, which provides a graphical breakdown of equivalent system mass by subsystem, reveals that food, air, and water are the most massive systems associated with supporting a human crew. The human accommodations external interface, which represents clothing primarily, can be significant for long-duration missions such as the Orbiting Research Facility. The advanced configurations reduce most crew-support system masses.

Most trends noted below are likely a strong function of mission duration more than any other variable. Thus, in order from shortest to longest in terms of mission duration, the vehicles assessed for the Fiscal Year 2005 Metric computation are the Lunar Surface Access Module, the Crew Exploration Vehicle, the Mars Descent / Ascent Lander, the Destination Surface System, the Mars Transit Vehicle, the Surface Habitat Lander, and the International Space Station.

The current evaluation, which considered several alternate technology suites available within ALSSAT, selected several technologies over the range of vehicles and mission durations. For the air system, oxygen generation via electrolysis and carbon dioxide reduction, via Sabatier, were more economical for long-duration vehicles such as the International Space Station, the Mars Transit Vehicle, and the Surface Habitat Lander. Shorter duration vehicles, such as all elements of the Near-Term Exploration Mission and the Mars Descent / Ascent Lander, were more economical with using stored, cryogenic gases in place of generating oxygen by any means. Cryogenic gas storage was also more economical for long-duration elements.

A frozen food diet was heavier in all cases than a shelf-stable, ambient storage food system. More surprisingly, a low-moisture Shuttle Training Menu diet was more economical only for the short-duration vehicles including all within the Near-Term Exploration Mission and the Mars Descent / Ascent Lander. Assessments for the longer-duration vehicles universally selected the “standard moisture” Shuttle Training Menu diet probably to offset water losses. Additionally, though not evident in the values here, a salad machine is only reasonable if required by mission protocols, because current assessments and hardware are not frugal enough to reduce the life support system costs simply based on other benefits of a small biomass production chamber.

For the waste system, long-duration missions benefit from water recovery, usually via lyophilization. The short-duration vehicles, including the Destination Surface System, appear to require nothing more than storage when considering the available options within ALSSAT. However, ALSSAT did not provide a “compaction only with storage” option which may be more economical than storage alone, especially for vehicles with a mission duration greater than something on the order of 10 days.

Within the water system assessments, vapor phase catalytic ammonia removal was significantly more economical for longer-duration mission segments such as the International Space Station, the Surface Habitat Lander, the Mars Transit Vehicle, the Destination Surface System, and the Mars Descent / Ascent Lander. Assessments of the Crew Exploration Vehicle and the Lunar Surface Access Module selected versions of the International Space Station Water Recovery System without urine treatment.

3.3 METRIC REPORTING RECOMMENDATIONS

3.3.1 METRIC RECOMMENDATION FOR FISCAL YEAR 2005

It is recommended that the following values of the Advanced Life Support Research and Technology Development Metric be reported to the Office of Biological and Physical Research and the Advanced Human Support Technology Program for Government Fiscal Year 2005:

Orbiting Research Facility:	2.12
Near-Term Exploration Mission:	1.30
Independent Exploration Mission:	1.76

3.3.2 COMPARISON WITH PAST ASSESSMENTS

Table 3.3.1 provides recent values of the Advanced Life Support Research and Technology Development Metric with associated sources. These values are plotted in Figure 3.3.4. Please note that each annual assessment to date, though similar in overall approach, has really been unique in one or more ways when compared to the other assessments, so the progressions of values are not directly comparable.

Table 3.3.1 Previous Advanced Life Support Research and Technology Development Metric Values

	Government Fiscal Year				
Mission	**2001**	**2002**	**2003**	**2004**	**2005**
Orbiting Research Facility	1.32 (1)	1.53 (2)	1.47 (3)	2.03 (4)	2.12 (5)
Near-Term Exploration Mission					1.30 (5)
Independent Exploration Mission	1.28 (1)	1.37 (2)	1.36 (3)	1.62 (4)	1.76 (5)

References

(1) Drysdale and Hanford (2002)
(2) Hanford (2003a)
(3) Hanford (2003b)
(4) Hanford (2004c)
(5) This document

The values in Table 3.3.1 generally increase as a function of time for the first and third reference missions.

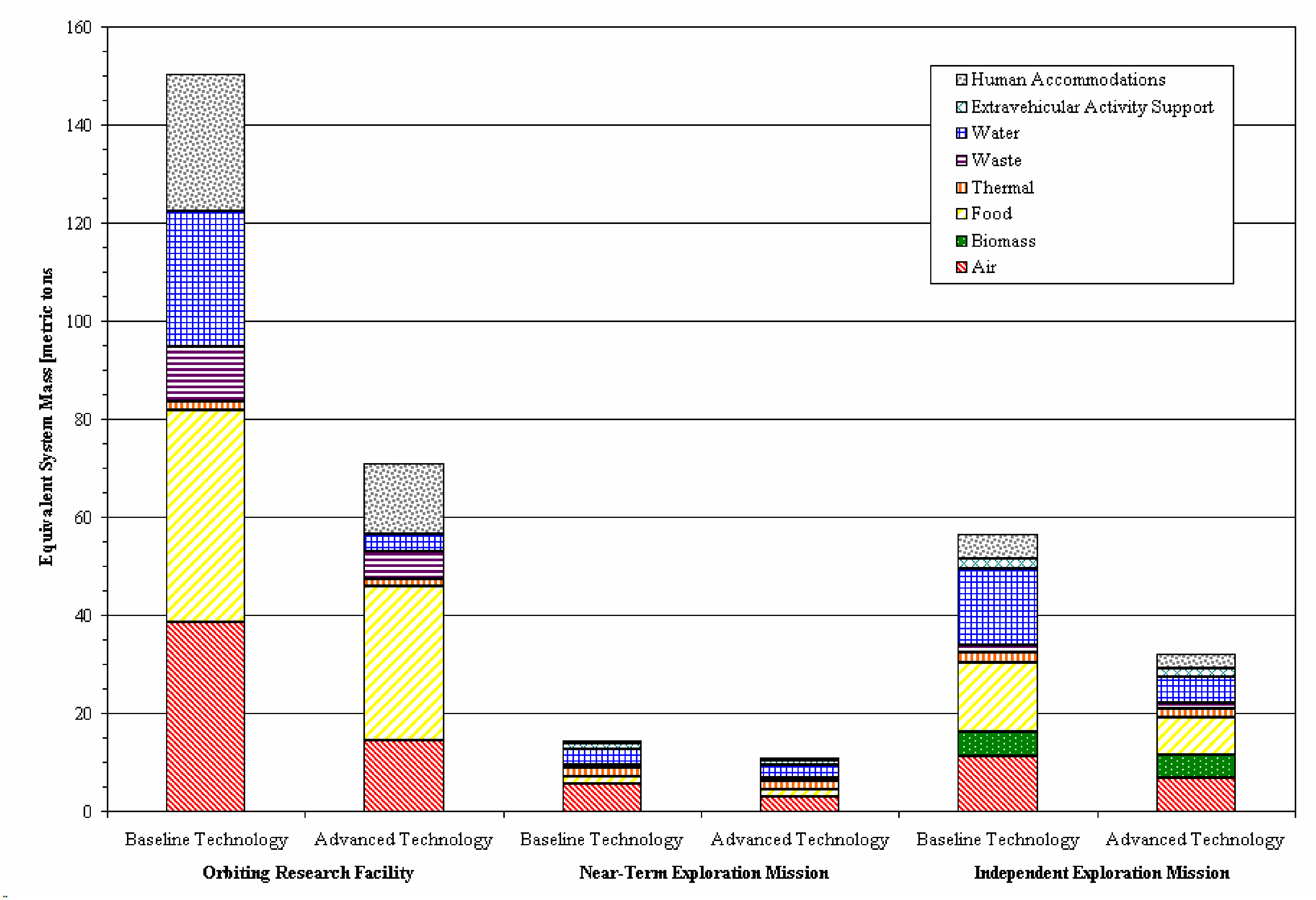

Figure 3.3.1 Equivalent system mass summary for the Fiscal Year 2005 ALS Research and Technology Development Metric missions and technology suites.

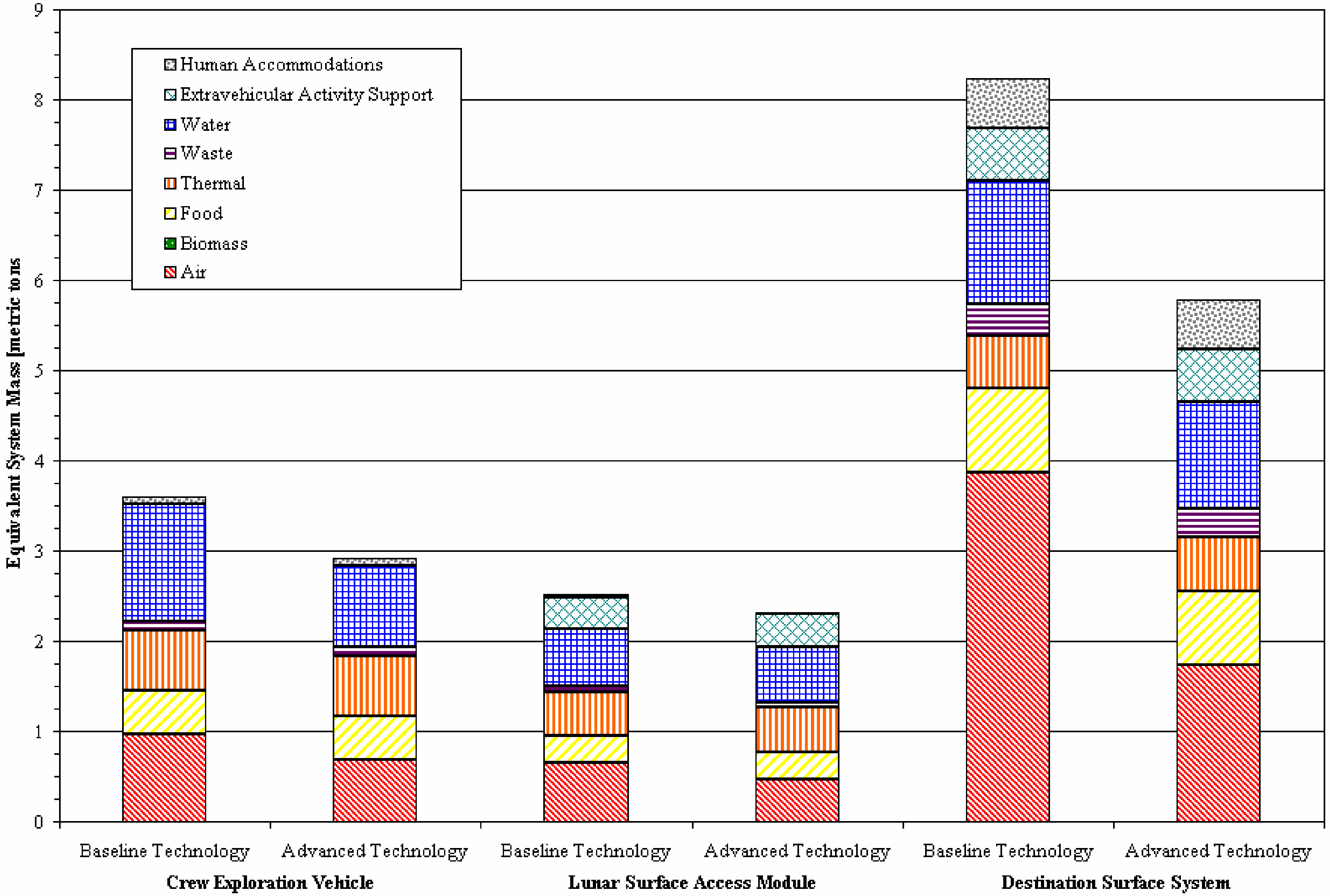

Figure 3.3.2 Equivalent system mass summary for the components of the Near-Term Exploration Mission.

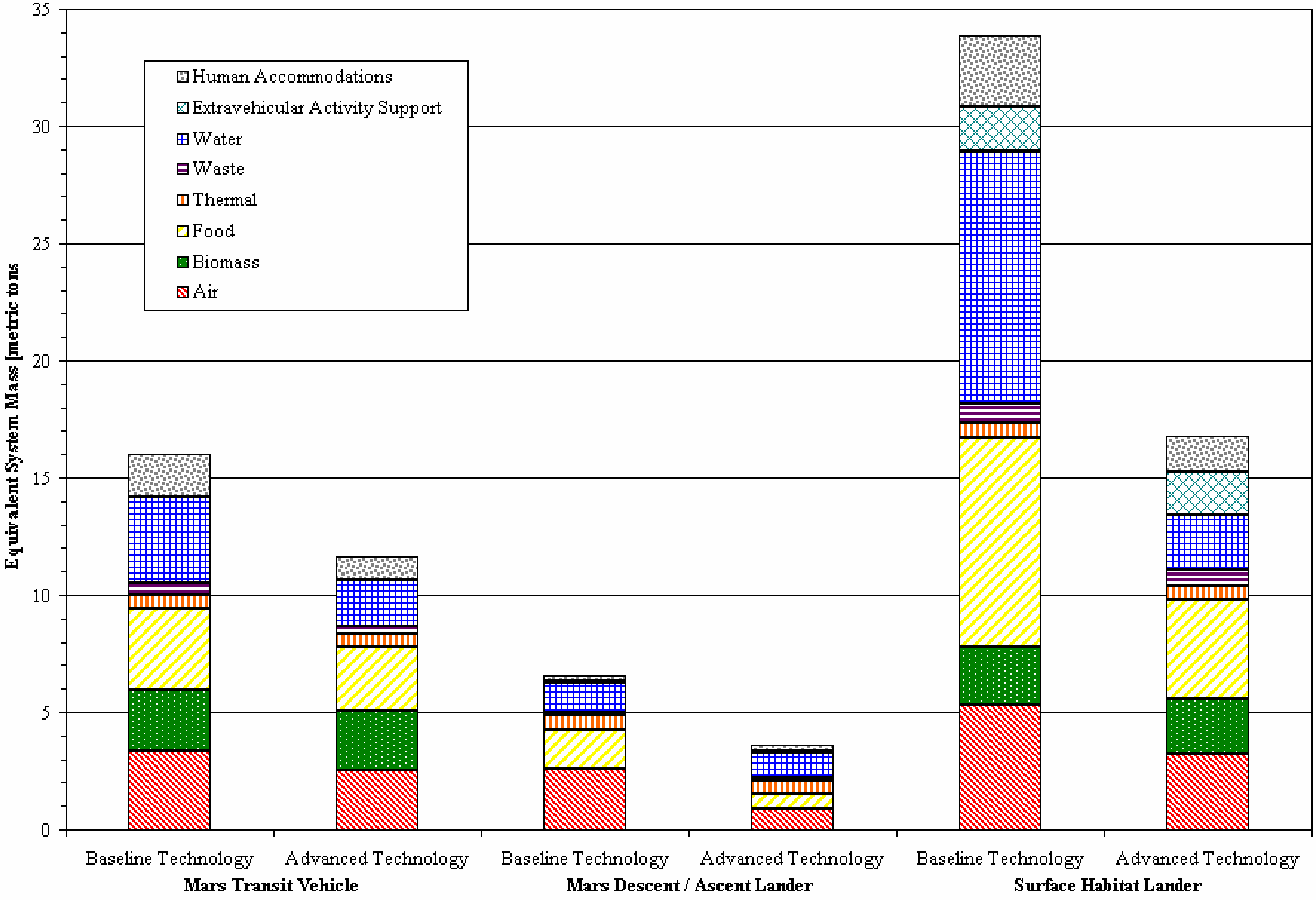

Figure 3.3.3 Equivalent system mass summary for the components of the Independent Exploration Mission.

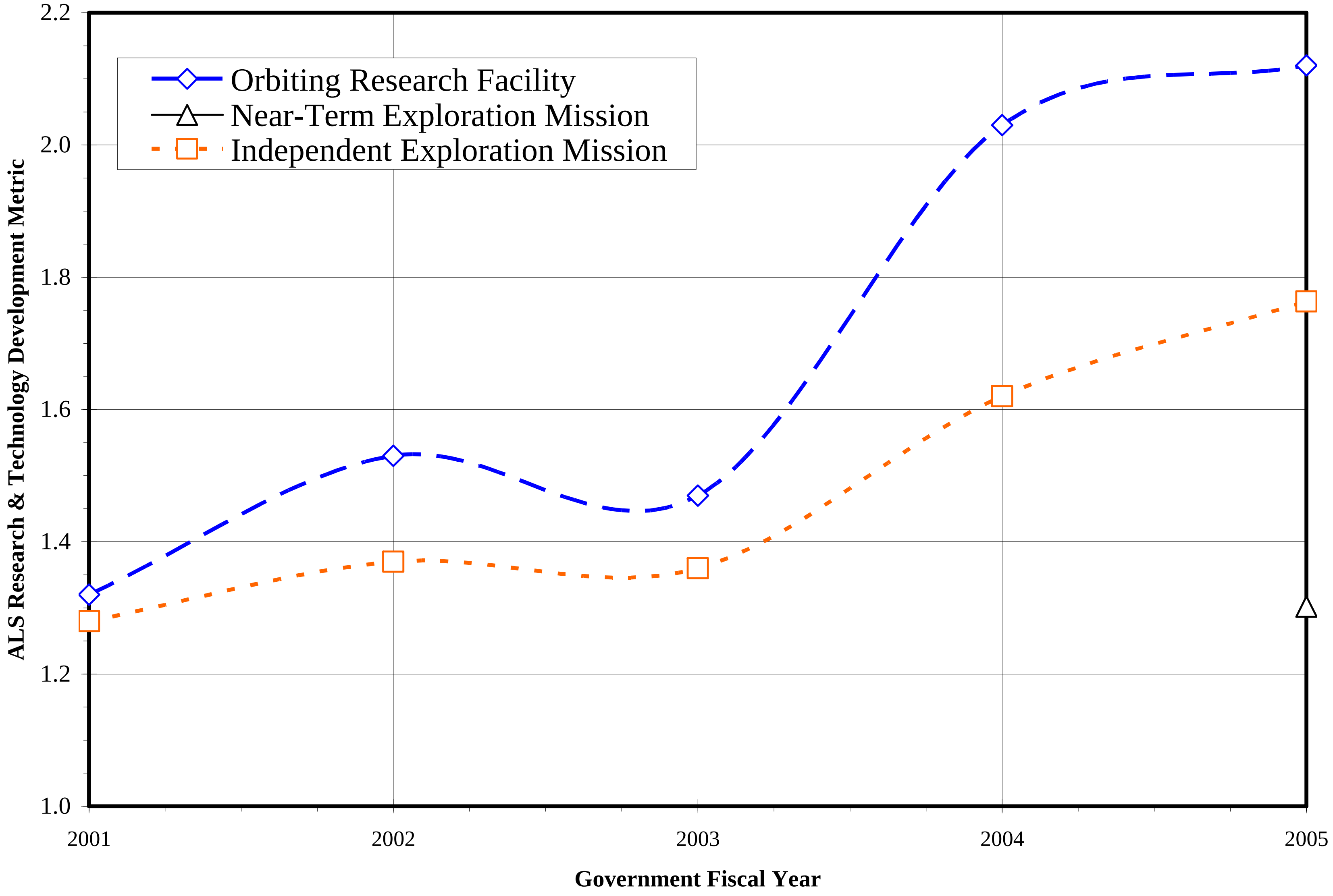

Figure 3.3.4 Historical progression of Advanced Life Support Research and Technology Development Metric values as a function of fiscal year.

4 CAUTIONS AND DISCLAIMERS

This type of analysis includes several inescapable sources of variation from actual flight systems. The first is that these estimations fail to consider contingency or redundancy in any detail. Further, inclusion of contingency or redundancy invariably increases the overall equivalent system mass of all configurations, although this may have little significant impact on the overall conclusions and, therefore, the implied direction, above. The second source of uncertainty, which is related to the first, is that all calculations above use only single-string life support system architecture. Multi-string systems, where each life support processor is sized to handle a larger load should one processor fail, are essential to meeting actual flight requirements for safety. Because processor physical attributes do not, in general, scale linearly with capacity, two processors in place of one will be more massive, even excluding the extra capability to insure redundancy. Again, this impact would apply to all configurations; therefore, it may not affect the direction implied above. The third source of uncertainty resides in the preliminary nature of the data employed for the advanced equipment. While it is desirable that flight equipment will be more economical than the values assumed here, it is possible that real systems may actually be less economical due to unforeseen difficulties during development or added components to assure safe operation in the flight environment. Fourthly, as ALS research and technology development continues, new technologies and architectural ideas may drastically change current doctrine about providing life support, producing profound savings for future human spaceflight. Thus, these estimates should be considered preliminary and not definitive, although they provide one measure of where NASA and the ALS Project are today.

5 SPECIAL RECOGNITION OF WORK

The author would like to thank many people, both within and outside of NASA, for their thoughts and input into both what is presented above and what has come before. Many metric formulations were considered by a group of life support analysts and researchers, and it is due to their excellent input that the Metric now exists in its current form. In particular, Dr. A. E. Drysdale of The Boeing Company deserves recognition for developing equivalent system mass in its current form for the ALS Project and guiding the Metric in previous years.

For compiling an archival source detailing the current definition of equivalent system mass, special recognition is due J. A. Levri of Ames Research Center.

For the current work, the author especially recognizes J. Yeh and C. Brown of Hamilton Sundstrand within the Engineering and Science Contract Group, Houston, Texas, for their continuing support of the Advanced Life Support Sizing Analysis Tool during the computation of the Metric.

This document is available electronically from the Advanced Life Support Project of the National Aeronautics and Space Administration at Lyndon B. Johnson Space Center at:

http://advlifesupport.jsc.nasa.gov/

6 SUBSYSTEM COMPONENTS IN FISCAL YEAR 2005 ALS R&TD METRIC

This section describes the assembly level for the subsystem summations presented in Section 3.1. The values in the tables below, Table 6.1 through Table 6.14, list the assemblies, using the organization and names within the Advanced Life Support Sizing Analysis Tool (ALSSAT) for each ALS element. These tables specifically detail mass, volume, power, cooling, and crewtime.

The overall subsystem values are listed on the line following each subsystem entry. These values are consistent with those reported in Section 3.1 for each vehicle. Any deviations between these values and those in above arise from differences in when individual numerical values were rounded to prepare each table, and therefore the resulting minor differences should not concern even a careful reader. Section 3.1 uses the units kW_e and kW_{th} for power and cooling, respectively, while the nomenclature below uses W_e and W_{th}, which is consistent with the native units within ALSSAT.

The assemblies, as specified within ALSSAT, are listed in bold below their respective subsystems. When recognizable assembly components are not listed within ALSSAT, a summary of the assembly is provided on the same line as the entry for the assembly. Assemblies with one or more recognizable components are further described by the indented entries below them. See Yeh, *et al.* (2002), Yeh, *et al.* (2003), Yeh, *et al.* (2004a), Yeh, *et al.* (2004b), Yeh, *et al.* (2005a), and Yeh, *et al.* (2005b) for details about ALSSAT organization. Except for the dry food mass listed within the Food Processing, Packaging, and Storage within the Food Subsystem, total values for assemblies would be the sum of their components. The Dry Food Mass, however, is that portion of the food system that was excluded during the computation of the Fiscal Year 2005 ALS R&TD Metric. It is listed here to provide a reference, but it is otherwise ignored in the overall totals. When applicable, the technology label from ALSSAT is listed in the second column, and the associated abbreviations are listed in Section 8. For more details of the technologies assumed for each mission, please see Section 2.4 for descriptions of each subsystem and overall life support system schematics.

Table 6.1 Subsystem Breakdown for Orbiting Research Facility: International Space Station Upgrade Mission using Baseline Technologies

Subsystem or Component	Technology	Mass [kg]	Volume $[m^3]$	Power $[W_e]$	Cooling $[W_{th}]$	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**33,084.77**	**34.97**	**4,398.74**	**2,814.93**	**129.58**	**38,516.64**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	193.13
Atmosphere Revitalization System							
Carbon Dioxide Removal	4BMS/ISS	182.17	0.43	546.29	546.29	27.58	667.80
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	SPE/ISS	1,549.80	1.03	3,482.62	1,898.81	101.39	3,964.66
Gaseous Trace Contaminant Control	ISS	327.22	3.94	194.35	194.35	0.00	745.48
Atmosphere Composition Monitoring Assembly	ISS	149.99	0.25	103.50	103.50	0.00	249.45
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	37.78
Airlock Carbon Dioxide Removal	n/a	0.00	0.00	0.00	0.00	0.00	0.00
Gas Storage							
Nitrogen Storage	High Pressure	27,390.53	27.16	0.00	0.00	0.00	29,202.10
Oxygen Storage	High Pressure	3,322.25	1.82	0.00	0.00	0.00	3,443.64
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.61	3.13
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	9.47
Biomass Subsystem		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Crop Storage	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Plant Growth Chamber / Salad Machine	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Food Subsystem		**31,303.68**	**129.74**	**4,272.00**	**4,272.00**	**0.00**	**43,374.51**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM + Frozen	46,236.03	129.74	4,272.00	4,272.00	0.00	58,306.86
Dry Food Mass (neglected)		*-14,932.35*	*0.00*	*0.00*	*0.00*	*0.00*	*-14,932.35*
Thermal Subsystem		**762.82**	**2.70**	**769.15**	**769.15**	**20.28**	**1,572.84**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	119.72	0.51	530.52	530.52	0.00	578.10
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	154.38
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	59.93
Atmospheric Microbial Control	ISS	529.53	2.00	0.00	0.00	20.28	677.61
Internal Thermal Control System		**91.37**	**0.14**	**2.63**	**2.63**	**0.00**	**102.81**

Table 6.1 Subsystem Breakdown for Orbiting Research Facility: International Space Station Upgrade Mission using Baseline Technologies (cont.)

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W$_e$]	Cooling [W$_{th}$]	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**3,917.04**	**107.93**	**14.00**	**14.00**	**0.00**	**11,127.17**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**56.23**
Solid Waste Processing System							
Solid Waste Treatment	Storage	3,880.68	107.80	0.00	0.00	0.00	11,070.94
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**25,677.42**	**13.82**	**1,322.21**	**1,322.21**	**0.00**	**27,656.85**
Urine / Waste Water Collection System	**ISS**	**41.11**	**0.02**	**4.00**	**4.00**	**0.00**	**45.64**
Water Recovery System							
Water Treatment Process	ISS WRS	10,785.18	2.35	712.61	712.61	0.00	11,511.94
Urine, Hygiene & Potable Water, & Brine Storage Tankage		242.39	0.26	10.73	10.73	0.00	268.31
Microbial Check Valve		20.37	0.01	0.00	0.00	0.00	21.04
Process Controller		51.57	0.08	156.18	156.18	0.00	181.83
Water Quality Monitoring		49.74	0.04	4.72	4.72	0.00	56.18
Product Water Delivery System		46.23	0.07	2.08	2.08	0.00	52.56
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		14,440.83	10.99	431.89	431.89	0.00	15,519.33
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Maximum Absorbency Garments		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Carbon Dioxide Removal (LiOH)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Airlock Recycle Pump for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**22,798.79**	**79.59**	**0.00**	**0.00**	**0.00**	**28,107.44**
Clothing		**10,643.40**	**62.42**	**0.00**	**0.00**	**0.00**	**14,806.81**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**7,227.66**	**7.23**	**0.00**	**0.00**	**0.00**	**7,709.90**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		4,927.73	9.94	0.00	0.00	0.00	5,590.73
Totals		**117,545**	**368.75**	**10,776**	**9,192**	**149.86**	**150,355**

Table 6.2 Subsystem Breakdown for Orbiting Research Facility: International Space Station Upgrade Mission using Advanced Technologies

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W$_e$]	Cooling [W$_{th}$]	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**10,419.62**	**14.04**	**4,555.66**	**2,973.85**	**129.58**	**14,530.96**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	193.13
Atmosphere Revitalization System							
Carbon Dioxide Removal	4BMS/ISS	182.19	0.43	546.37	546.37	27.58	657.10
Carbon Dioxide Reduction	Sabatier	146.09	0.20	151.05	151.05	0.00	280.25
Oxygen Generation	SPE/ISS	1,548.03	1.03	3,478.62	1,896.81	101.39	3,920.69
Gaseous Trace Contaminant Control	ISS	327.22	3.94	194.35	194.35	0.00	745.48
Atmosphere Composition Monitoring Assembly	ISS	149.99	0.25	103.50	103.50	0.00	249.45
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	37.78
Airlock Carbon Dioxide Removal	n/a	0.00	0.00	0.00	0.00	0.00	0.00
Gas Storage							
Nitrogen Storage	Cryogenic	7,196.60	5.48	6.85	6.85	0.00	7,591.61
Oxygen Storage	Cryogenic	706.69	2.01	2.94	2.94	0.00	843.11
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.61	2.89
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	9.47
Biomass Subsystem		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Crop Storage	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Plant Growth Chamber / Salad Machine	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Food Subsystem		**23,593.30**	**105.79**	**960.00**	**960.00**	**0.00**	**31,417.40**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM	38,500.08	105.79	960.00	960.00	0.00	46,324.18
Dry Food Mass (neglected)		*-14,906.78*	*0.00*	*0.00*	*0.00*	*0.00*	*-14,906.78*
Thermal Subsystem		**750.13**	**2.68**	**768.73**	**768.73**	**20.28**	**1,550.55**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	119.72	0.51	530.52	530.52	0.00	578.10
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	154.38
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	59.93
Atmospheric Microbial Control	ISS	529.53	2.00	0.00	0.00	20.28	669.68
Internal Thermal Control System		**78.68**	**0.12**	**2.21**	**2.21**	**0.00**	**88.45**

Table 6.2 Subsystem Breakdown for Orbiting Research Facility: International Space Station Upgrade Mission using Advanced Technologies (cont.)

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W_e]	Cooling [W_{th}]	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**1,466.71**	**22.04**	**947.08**	**908.87**	**5,475.00**	**5,505.15**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**56.23**
Solid Waste Processing System							
Solid Waste Treatment	Lyophilization + PMWC + Storage	1,430.35	21.91	933.08	894.87	5,475.00	5,448.92
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**1,482.78**	**2.07**	**2,142.98**	**2,142.98**	**0.00**	**3,335.02**
Urine / Waste Water Collection System	**ISS**	**41.11**	**0.02**	**4.00**	**4.00**	**0.00**	**45.64**
Water Recovery System							
Water Treatment Process	VPCAR; no AES	473.44	1.45	1,934.15	1,934.15	0.00	2,117.28
Urine, Hygiene & Potable Water, & Brine Storage Tankage		574.46	0.44	16.86	16.86	0.00	617.29
Microbial Check Valve		52.56	0.01	0.00	0.00	0.00	53.23
Process Controller		212.04	0.00	180.00	180.00	0.00	356.02
Water Quality Monitoring		49.74	0.04	4.72	4.72	0.00	56.18
Product Water Delivery System		79.43	0.11	3.25	3.25	0.00	89.37
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Maximum Absorbency Garments		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Carbon Dioxide Removal (LiOH)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Airlock Recycle Pump for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**12,726.66**	**20.00**	**633.33**	**633.33**	**0.00**	**14,567.26**
Clothing		**438.00**	**2.57**	**0.00**	**0.00**	**0.00**	**609.42**
Laundry Equipment							
Washer / Dryer		80.00	0.26	633.33	633.33	0.00	603.94
Detergent		53.27	0.00	0.00	0.00	0.00	53.27
Miscellaneous Items		**7,227.66**	**7.23**	**0.00**	**0.00**	**0.00**	**7,709.90**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		4,927.73	9.94	0.00	0.00	0.00	5,590.73
Totals		**50,439**	**166.62**	**10,008**	**8,388**	**5,624.86**	**70,906**

Table 6.3 Subsystem Breakdown for Near-Term Exploration Mission: Crew Exploration Vehicle using Baseline Technologies

Subsystem or Component	Technology	Mass [kg]	Volume $[m^3]$	Power $[W_e]$	Cooling $[W_{th}]$	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**681.04**	**1.29**	**317.16**	**317.16**	**0.00**	**965.63**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	179.13
Atmosphere Revitalization System							
Carbon Dioxide Removal	LiOH	108.66	0.49	0.00	0.00	0.00	173.29
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	Storage	0.00	0.00	0.00	0.00	0.00	0.00
Gaseous Trace Contaminant Control	ISS	13.29	0.02	141.68	141.68	0.00	67.05
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	103.52
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	40.39
Airlock Carbon Dioxide Removal	n/a	0.00	0.00	0.00	0.00	0.00	0.00
Gas Storage							
Nitrogen Storage	High Pressure	87.41	0.09	0.00	0.00	0.00	99.28
Oxygen Storage	High Pressure	254.57	0.26	0.00	0.00	0.00	288.86
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.00	2.03
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	12.08
Biomass Subsystem		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Crop Storage	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Plant Growth Chamber / Salad Machine	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Food Subsystem		**96.95**	**0.37**	**960.00**	**960.00**	**0.00**	**492.15**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM	135.07	0.37	960.00	960.00	0.00	530.27
Dry Food Mass (neglected)		*-38.12*	*0.00*	*0.00*	*0.00*	*0.00*	*-38.12*
Thermal Subsystem		**268.41**	**0.86**	**771.61**	**771.61**	**0.08**	**660.86**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	375.46
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	79.50
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	34.45
Atmospheric Microbial Control	ISS	100.00	0.27	0.00	0.00	0.08	136.21
Internal Thermal Control System		**28.13**	**0.04**	**5.09**	**5.09**	**0.00**	**35.24**

Table 6.3 Subsystem Breakdown for Near-Term Exploration Mission: Crew Exploration Vehicle using Baseline Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W_e]	Cooling [W_{th}]	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**45.70**	**0.39**	**14.00**	**14.00**	**0.00**	**102.19**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**58.56**
Solid Waste Processing System							
Solid Waste Treatment	Storage	9.34	0.26	0.00	0.00	0.00	43.63
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**1,167.58**	**0.90**	**41.81**	**26.15**	**0.00**	**1,301.07**
Urine / Waste Water Collection System	**ISS**	**4.55**	**0.02**	**4.00**	**4.00**	**0.00**	**8.63**
Water Recovery System							
Water Treatment Process	Storage	0.00	0.00	0.00	0.00	0.00	0.00
Urine, Hygiene & Potable Water, & Brine Storage Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Water Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Product Water Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Storage							
Hygiene Water Storage		251.36	0.14	8.14	8.14	0.00	272.76
Potable Water Storage		368.82	0.27	14.01	14.01	0.00	409.49
Urine Storage		332.32	0.15	1.29	0.00	0.00	352.55
Waste Water Storage		210.53	0.32	14.37	0.00	0.00	257.64
Extravehicular Activity		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Maximum Absorbency Garments		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Carbon Dioxide Removal (LiOH)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Airlock Recycle Pump for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**58.53**	**0.21**	**0.00**	**0.00**	**0.00**	**86.23**
Clothing		**27.22**	**0.16**	**0.00**	**0.00**	**0.00**	**48.32**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**18.48**	**0.02**	**0.00**	**0.00**	**0.00**	**21.12**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		12.83	0.03	0.00	0.00	0.00	16.79
Totals		**2,318**	**4.02**	**2,105**	**2,089**	**0.08**	**3,608**

Table 6.4 Subsystem Breakdown for Near-Term Exploration Mission: Crew Exploration Vehicle using Advanced Technologies

Subsystem or Component	Technology	Mass [kg]	Volume $[m^3]$	Power $[W_e]$	Cooling $[W_{th}]$	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**426.58**	**1.01**	**336.42**	**336.42**	**0.00**	**683.19**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	179.13
Atmosphere Revitalization System							
Carbon Dioxide Removal	LiOH	108.87	0.49	0.00	0.00	0.00	173.50
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	Storage	0.00	0.00	0.00	0.00	0.00	0.00
Gaseous Trace Contaminant Control	ISS	13.29	0.02	141.68	141.68	0.00	67.05
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	103.52
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	40.39
Airlock Carbon Dioxide Removal	n/a	0.00	0.00	0.00	0.00	0.00	0.00
Gas Storage							
Nitrogen Storage	Cryogenic	23.02	0.02	6.10	6.10	0.00	27.86
Oxygen Storage	Cryogenic	66.29	0.05	13.16	13.16	0.00	77.63
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.00	2.03
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	12.08
Biomass Subsystem		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Crop Storage	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Plant Growth Chamber / Salad Machine	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Food Subsystem		**84.04**	**0.36**	**960.00**	**960.00**	**0.00**	**477.92**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM with LMC	121.58	0.36	960.00	960.00	0.00	515.46
Dry Food Mass (neglected)		*-37.54*	*0.00*	*0.00*	*0.00*	*0.00*	*-37.54*
Thermal Subsystem		**271.19**	**0.87**	**773.71**	**773.71**	**0.08**	**665.61**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	375.46
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	79.50
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	34.45
Atmospheric Microbial Control	ISS	100.00	0.27	0.00	0.00	0.08	136.10
Internal Thermal Control System		**30.91**	**0.05**	**7.19**	**7.19**	**0.00**	**40.10**

Table 6.4 Subsystem Breakdown for Near-Term Exploration Mission: Crew Exploration Vehicle using Advanced Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume $[m^3]$	Power $[W_e]$	Cooling $[W_{th}]$	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**45.61**	**0.39**	**14.00**	**14.00**	**0.00**	**102.10**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**58.56**
Solid Waste Processing System							
Solid Waste Treatment	Storage	9.25	0.26	0.00	0.00	0.00	43.54
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**449.24**	**2.22**	**433.21**	**433.21**	**0.00**	**898.37**
Urine / Waste Water Collection System	**ISS**	**4.55**	**0.02**	**4.00**	**4.00**	**0.00**	**8.63**
Water Recovery System							
Water Treatment Process	ISS WRS Opt 3	111.00	1.74	250.52	250.52	0.00	430.90
Urine, Hygiene & Potable Water, & Brine Storage Tankage		116.07	0.19	8.75	8.75	0.00	144.29
Microbial Check Valve		0.86	0.00	0.00	0.00	0.00	0.86
Process Controller		36.11	0.08	156.18	156.18	0.00	103.02
Water Quality Monitoring		14.07	0.04	4.72	4.72	0.00	21.05
Product Water Delivery System		20.84	0.05	1.65	1.65	0.00	28.03
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		145.74	0.10	7.39	7.39	0.00	161.60
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Maximum Absorbency Garments		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Carbon Dioxide Removal (LiOH)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Airlock Recycle Pump for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**58.53**	**0.21**	**0.00**	**0.00**	**0.00**	**86.23**
Clothing		**27.22**	**0.16**	**0.00**	**0.00**	**0.00**	**48.32**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**18.48**	**0.02**	**0.00**	**0.00**	**0.00**	**21.12**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		12.83	0.03	0.00	0.00	0.00	16.79
Totals		**1,337**	**5.06**	**2,517**	**2,517**	**0.08**	**2,913**

Table 6.5 Subsystem Breakdown for Near-Term Exploration Mission: Lunar Surface Access Module using Baseline Technologies

Subsystem or Component	**Technology**	**Mass [kg]**	**Volume [m³]**	**Power [W_e]**	**Cooling [W_{th}]**	**Crewtime [CM-h]**	**Equivalent System Mass [kg]**
Air Subsystem		**519.03**	**1.04**	**317.16**	**317.16**	**0.00**	**645.33**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	148.91
Atmosphere Revitalization System							
Carbon Dioxide Removal	LiOH	58.18	0.36	0.00	0.00	0.00	76.04
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	Storage	0.00	0.00	0.00	0.00	0.00	0.00
Gaseous Trace Contaminant Control	ISS	10.31	0.01	141.68	141.68	0.00	44.18
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	83.15
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	37.09
Airlock Carbon Dioxide Removal	n/a	0.00	0.00	0.00	0.00	0.00	0.00
Gas Storage							
Nitrogen Storage	High Pressure	69.70	0.07	0.00	0.00	0.00	73.17
Oxygen Storage	High Pressure	163.73	0.17	0.00	0.00	0.00	172.16
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.00	1.85
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	8.78
Biomass Subsystem		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Crop Storage	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Plant Growth Chamber / Salad Machine	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Food Subsystem		**64.05**	**0.23**	**960.00**	**960.00**	**0.00**	**301.62**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM	81.11	0.23	960.00	960.00	0.00	318.68
Dry Food Mass (neglected)		*-17.06*	*0.00*	*0.00*	*0.00*	*0.00*	*-17.06*
Thermal Subsystem		**267.94**	**0.86**	**770.81**	**770.81**	**0.03**	**492.51**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	267.87
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	55.12
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	25.16
Atmospheric Microbial Control	ISS	100.00	0.27	0.00	0.00	0.03	113.71
Internal Thermal Control System		**27.66**	**0.04**	**4.29**	**4.29**	**0.00**	**30.65**

Table 6.5 Subsystem Breakdown for Near-Term Exploration Mission: Lunar Surface Access Module using Baseline Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume $[m^3]$	Power $[W_e]$	Cooling $[W_{th}]$	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**40.77**	**0.25**	**14.00**	**14.00**	**0.00**	**56.47**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**46.11**
Solid Waste Processing System							
Solid Waste Treatment	Storage	4.41	0.12	0.00	0.00	0.00	10.36
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**607.73**	**0.44**	**27.77**	**18.67**	**0.00**	**635.59**
Urine / Waste Water Collection System	**ISS**	**4.55**	**0.02**	**4.00**	**4.00**	**0.00**	**6.48**
Water Recovery System							
Water Treatment Process	Storage	0.00	0.00	0.00	0.00	0.00	0.00
Urine, Hygiene & Potable Water, & Brine Storage Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Water Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Product Water Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Storage							
Hygiene Water Storage		127.43	0.06	5.35	5.35	0.00	131.67
Potable Water Storage		210.71	0.15	9.32	9.32	0.00	220.35
Urine Storage		147.41	0.06	0.59	0.00	0.00	150.49
Waste Water Storage		117.63	0.15	8.51	0.00	0.00	126.60
Extravehicular Activity		**98.09**	**0.41**	**1,000.00**	**1,000.00**	**0.00**	**354.02**
Maximum Absorbency Garments		**1.38**	**0.00**	**0.00**	**0.00**	**0.00**	**1.38**
Carbon Dioxide Removal (LiOH)		**26.41**	**0.27**	**0.00**	**0.00**	**0.00**	**39.80**
Airlock Recycle Pump for EVA		**70.30**	**0.14**	**1,000.00**	**1,000.00**	**0.00**	**312.83**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**25.21**	**0.09**	**0.00**	**0.00**	**0.00**	**29.67**
Clothing		**11.66**	**0.07**	**0.00**	**0.00**	**0.00**	**15.13**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**7.92**	**0.01**	**0.00**	**0.00**	**0.00**	**8.42**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		5.63	0.01	0.00	0.00	0.00	6.13
Totals		**1,623**	**3.32**	**3,090**	**3,081**	**0.03**	**2,515**

Table 6.6 Subsystem Breakdown for Near-Term Exploration Mission: Lunar Surface Access Module using Advanced Technologies

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W_e]	Cooling [W_{th}]	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**346.49**	**0.84**	**345.00**	**345.00**	**0.00**	**469.43**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	148.91
Atmosphere Revitalization System							
Carbon Dioxide Removal	LiOH	58.27	0.36	0.00	0.00	0.00	76.13
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	Storage	0.00	0.00	0.00	0.00	0.00	0.00
Gaseous Trace Contaminant Control	ISS	10.31	0.01	141.68	141.68	0.00	44.18
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	83.15
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	37.09
Airlock Carbon Dioxide Removal	n/a	0.00	0.00	0.00	0.00	0.00	0.00
Gas Storage							
Nitrogen Storage	Cryogenic	18.23	0.01	9.28	9.28	0.00	20.91
Oxygen Storage	Cryogenic	42.57	0.03	18.56	18.56	0.00	48.43
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.00	1.85
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	8.78
Biomass Subsystem		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Crop Storage	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Plant Growth Chamber / Salad Machine	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Food Subsystem		**57.80**	**0.21**	**960.00**	**960.00**	**0.00**	**294.38**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM with LMC	74.60	0.21	960.00	960.00	0.00	311.18
Dry Food Mass (neglected)		*-16.80*	*0.00*	*0.00*	*0.00*	*0.00*	*-16.80*
Thermal Subsystem		**270.82**	**0.87**	**772.67**	**772.67**	**0.03**	**496.30**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	267.87
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	55.12
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	25.16
Atmospheric Microbial Control	ISS	100.00	0.27	0.00	0.00	0.03	113.69
Internal Thermal Control System		**30.54**	**0.05**	**6.15**	**6.15**	**0.00**	**34.47**

Table 6.6 Subsystem Breakdown for Near-Term Exploration Mission: Lunar Surface Access Module using Advanced Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W_e]	Cooling [W_{th}]	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**40.73**	**0.25**	**14.00**	**14.00**	**0.00**	**56.43**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**46.11**
Solid Waste Processing System							
Solid Waste Treatment	Storage	4.37	0.12	0.00	0.00	0.00	10.32
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**407.78**	**2.23**	**436.89**	**436.89**	**0.00**	**621.31**
Urine / Waste Water Collection System	**ISS**	**4.55**	**0.02**	**4.00**	**4.00**	**0.00**	**6.48**
Water Recovery System							
Water Treatment Process	ISS WRS Opt 3	116.77	1.78	255.45	255.45	0.00	265.24
Urine, Hygiene & Potable Water, & Brine Storage Tankage		116.83	0.20	8.91	8.91	0.00	128.85
Microbial Check Valve		0.95	0.00	0.00	0.00	0.00	0.95
Process Controller		36.11	0.08	156.18	156.18	0.00	76.87
Water Quality Monitoring		14.07	0.04	4.72	4.72	0.00	17.17
Product Water Delivery System		21.40	0.05	1.69	1.69	0.00	24.28
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		97.10	0.06	5.94	5.94	0.00	101.48
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**98.09**	**0.41**	**1,000.00**	**1,000.00**	**0.00**	**354.02**
Maximum Absorbency Garments		**1.38**	**0.00**	**0.00**	**0.00**	**0.00**	**1.38**
Carbon Dioxide Removal (LiOH)		**26.41**	**0.27**	**0.00**	**0.00**	**0.00**	**39.80**
Airlock Recycle Pump for EVA		**70.30**	**0.14**	**1,000.00**	**1,000.00**	**0.00**	**312.83**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**25.21**	**0.09**	**0.00**	**0.00**	**0.00**	**29.67**
Clothing		**11.66**	**0.07**	**0.00**	**0.00**	**0.00**	**15.13**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**7.92**	**0.01**	**0.00**	**0.00**	**0.00**	**8.42**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		5.63	0.01	0.00	0.00	0.00	6.13
Totals		**1,247**	**4.90**	**3,529**	**3,529**	**0.03**	**2,322**

Table 6.7 Subsystem Breakdown for Near-Term Exploration Mission: Destination Surface System using Baseline Technologies

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W_e]	Cooling [W_{th}]	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**3,184.90**	**3.68**	**1,108.24**	**1,108.24**	**0.76**	**3,864.39**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	165.11
Atmosphere Revitalization System							
Carbon Dioxide Removal	4BMS/ISS	137.31	0.29	394.08	394.08	0.74	278.08
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	Storage	0.00	0.00	0.00	0.00	0.00	0.00
Gaseous Trace Contaminant Control	ISS	42.05	0.08	141.68	141.68	0.00	89.66
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	92.24
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	39.11
Airlock Carbon Dioxide Removal	ISS	181.30	0.23	397.00	397.00	0.00	315.30
Gas Storage							
Nitrogen Storage	High Pressure	434.29	0.41	0.00	0.00	0.00	475.29
Oxygen Storage	High Pressure	2,172.84	2.24	0.00	0.00	0.00	2,396.84
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.02	1.96
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	10.80
Biomass Subsystem		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Crop Storage	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Plant Growth Chamber / Salad Machine	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Food Subsystem		**459.89**	**2.00**	**960.00**	**960.00**	**0.00**	**928.31**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM	727.44	2.00	960.00	960.00	0.00	1,195.86
Dry Food Mass (neglected)		*-267.55*	*0.00*	*0.00*	*0.00*	*0.00*	*-267.55*
Thermal Subsystem		**278.50**	**0.88**	**782.52**	**782.52**	**0.54**	**586.45**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	316.41
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	64.33
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	28.86
Atmospheric Microbial Control	ISS	100.00	0.27	0.00	0.00	0.54	128.16
Internal Thermal Control System		**38.22**	**0.06**	**16.00**	**16.00**	**0.00**	**48.69**

Table 6.7 Subsystem Breakdown for Near-Term Exploration Mission: Destination Surface System using Baseline Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W$_e$]	Cooling [W$_{th}$]	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**114.69**	**2.31**	**14.00**	**14.00**	**0.00**	**349.60**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**53.27**
Solid Waste Processing System							
Solid Waste Treatment	Storage	78.33	2.18	0.00	0.00	0.00	296.33
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**882.85**	**2.50**	**833.31**	**833.31**	**0.00**	**1,365.84**
Urine / Waste Water Collection System	**ISS**	**4.55**	**0.02**	**4.00**	**4.00**	**0.00**	**7.67**
Water Recovery System							
Water Treatment Process	ISS WRS	481.78	1.93	647.17	647.17	0.00	855.73
Urine, Hygiene & Potable Water, & Brine Storage Tankage		81.28	0.21	9.24	9.24	0.00	104.86
Microbial Check Valve		1.23	0.00	0.00	0.00	0.00	1.23
Process Controller		36.11	0.08	156.18	156.18	0.00	87.78
Water Quality Monitoring		14.07	0.04	4.72	4.72	0.00	19.39
Product Water Delivery System		23.16	0.05	1.79	1.79	0.00	28.66
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		240.67	0.17	10.21	10.21	0.00	260.52
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**234.94**	**0.73**	**1,000.00**	**1,000.00**	**0.00**	**587.54**
Maximum Absorbency Garments		**19.38**	**0.00**	**0.00**	**0.00**	**0.00**	**19.38**
Carbon Dioxide Removal (LiOH)		**145.26**	**0.59**	**0.00**	**0.00**	**0.00**	**204.26**
Airlock Recycle Pump for EVA		**70.30**	**0.14**	**1,000.00**	**1,000.00**	**0.00**	**363.90**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**408.31**	**1.43**	**0.00**	**0.00**	**0.00**	**551.31**
Clothing		**190.51**	**1.12**	**0.00**	**0.00**	**0.00**	**302.51**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**129.37**	**0.13**	**0.00**	**0.00**	**0.00**	**142.37**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		88.43	0.18	0.00	0.00	0.00	106.43
Totals		**5,564**	**13.53**	**4,698**	**4,698**	**1.30**	**8,233**

Table 6.8 Subsystem Breakdown for Near-Term Exploration Mission: Destination Surface System using Advanced Technologies

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W_e]	Cooling [W_{th}]	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**1,258.28**	**1.53**	**1,129.46**	**1,129.46**	**0.76**	**1,728.22**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	165.11
Atmosphere Revitalization System							
Carbon Dioxide Removal	4BMS/ISS	137.31	0.29	394.75	394.75	0.74	277.79
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	Storage	0.00	0.00	0.00	0.00	0.00	0.00
Gaseous Trace Contaminant Control	ISS	42.05	0.08	141.68	141.68	0.00	89.66
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	92.24
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	39.11
Airlock Carbon Dioxide Removal	ISS	181.30	0.23	397.00	397.00	0.00	315.30
Gas Storage							
Nitrogen Storage	Cryogenic	115.12	0.11	5.02	5.02	0.00	127.52
Oxygen Storage	Cryogenic	565.39	0.39	15.53	15.53	0.00	608.73
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.02	1.94
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	10.80
Biomass Subsystem		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Crop Storage	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Plant Growth Chamber / Salad Machine	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Food Subsystem		**366.71**	**1.88**	**960.00**	**960.00**	**0.00**	**823.13**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM with LMC	630.19	1.88	960.00	960.00	0.00	1,086.61
Dry Food Mass (neglected)		*-263.48*	*0.00*	*0.00*	*0.00*	*0.00*	*-263.48*
Thermal Subsystem		**282.18**	**0.89**	**788.85**	**788.85**	**0.54**	**592.55**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	316.41
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	64.33
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	28.86
Atmospheric Microbial Control	ISS	100.00	0.27	0.00	0.00	0.54	127.81
Internal Thermal Control System		**41.90**	**0.07**	**22.33**	**22.33**	**0.00**	**55.14**

Table 6.8 Subsystem Breakdown for Near-Term Exploration Mission: Destination Surface System using Advanced Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume [m³]	Power [W_e]	Cooling [W_{th}]	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**109.65**	**2.17**	**14.00**	**14.00**	**0.00**	**330.56**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**53.27**
Solid Waste Processing System							
Solid Waste Treatment	Storage	73.29	2.04	0.00	0.00	0.00	277.29
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**648.95**	**1.30**	**1,428.45**	**1,428.45**	**0.00**	**1,178.34**
Urine / Waste Water Collection System	**ISS**	**4.55**	**0.02**	**4.00**	**4.00**	**0.00**	**7.67**
Water Recovery System							
Water Treatment Process	VPCAR; no AES	199.39	0.80	1,218.06	1,218.06	0.00	619.96
Urine, Hygiene & Potable Water, & Brine Storage Tankage		89.10	0.21	9.26	9.26	0.00	112.69
Microbial Check Valve		1.23	0.00	0.00	0.00	0.00	1.23
Process Controller		63.00	0.00	180.00	180.00	0.00	113.33
Water Quality Monitoring		14.07	0.04	4.72	4.72	0.00	19.39
Product Water Delivery System		23.16	0.05	1.79	1.79	0.00	28.66
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		254.45	0.18	10.62	10.62	0.00	275.42
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**234.94**	**0.73**	**1,000.00**	**1,000.00**	**0.00**	**587.54**
Maximum Absorbency Garments		**19.38**	**0.00**	**0.00**	**0.00**	**0.00**	**19.38**
Carbon Dioxide Removal (LiOH)		**145.26**	**0.59**	**0.00**	**0.00**	**0.00**	**204.26**
Airlock Recycle Pump for EVA		**70.30**	**0.14**	**1,000.00**	**1,000.00**	**0.00**	**363.90**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**408.31**	**1.43**	**0.00**	**0.00**	**0.00**	**551.31**
Clothing		**190.51**	**1.12**	**0.00**	**0.00**	**0.00**	**302.51**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**129.37**	**0.13**	**0.00**	**0.00**	**0.00**	**142.37**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		88.43	0.18	0.00	0.00	0.00	106.43
Totals		**3,309**	**9.93**	**5,321**	**5,321**	**1.30**	**5,792**

Table 6.9 Subsystem Breakdown for Independent Exploration Mission: Mars Transit Vehicle using Baseline Technologies

Subsystem or Component	**Technology**	**Mass [kg]**	**Volume $[\mathrm{m}^3]$**	**Power $[W_e]$**	**Cooling $[W_{th}]$**	**Crewtime [CM-h]**	**Equivalent System Mass [kg]**
Air Subsystem		**2,190.10**	**3.32**	**4,198.66**	**2,709.73**	**12.78**	**3,333.98**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	141.31
Atmosphere Revitalization System							
Carbon Dioxide Removal	4BMS/ISS	179.12	0.42	535.98	535.98	2.72	333.56
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	SPE/ISS	379.16	1.00	3,292.85	1,803.92	10.00	1,248.70
Gaseous Trace Contaminant Control	ISS	85.81	0.40	194.35	194.35	0.00	143.31
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	83.79
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	35.48
Airlock Carbon Dioxide Removal	n/a	0.00	0.00	0.00	0.00	0.00	0.00
Gas Storage							
Nitrogen Storage	High Pressure	1,028.73	0.92	0.00	0.00	0.00	1,037.16
Oxygen Storage	High Pressure	300.17	0.15	0.00	0.00	0.00	301.54
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.06	1.96
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	7.17
Biomass Subsystem		**761.03**	**17.03**	**6,099.43**	**6,099.43**	**0.00**	**2,606.57**
Crop Storage		**205.88**	**0.00**	**0.00**	**0.00**	**0.00**	**205.88**
Plant Growth Chamber / Salad Machine		**555.15**	**17.03**	**6,099.43**	**6,099.43**	**0.00**	**2,339.69**
Food Subsystem		**2,839.53**	**13.12**	**1,860.00**	**1,860.00**	**0.00**	**3,474.93**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM + Frozen + Salad	4,301.15	13.12	1,860.00	1,860.00	0.00	4,936.55
Dry Food Mass (neglected)		*-1,461.62*	*0.00*	*0.00*	*0.00*	*0.00*	*-1,461.62*
Thermal Subsystem		**329.08**	**1.00**	**887.95**	**887.95**	**2.00**	**585.77**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	269.61
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	61.15
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	26.88
Atmospheric Microbial Control	ISS	100.00	0.27	0.00	0.00	2.00	104.04
Internal Thermal Control System		**88.80**	**0.18**	**121.43**	**121.43**	**0.00**	**124.08**

Table 6.9 Subsystem Breakdown for Independent Exploration Mission: Mars Transit Vehicle using Baseline Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W$_e$]	Cooling [W$_{th}$]	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**381.96**	**9.73**	**14.00**	**14.00**	**0.00**	**474.96**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**41.43**
Solid Waste Processing System							
Solid Waste Treatment	Storage	345.60	9.60	0.00	0.00	0.00	433.54
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**3,353.03**	**5.50**	**1,126.62**	**1,126.62**	**0.00**	**3,715.48**
Urine / Waste Water Collection System	**ISS**	**4.55**	**0.02**	**4.00**	**4.00**	**0.00**	**5.84**
Water Recovery System							
Water Treatment Process	ISS WRS	2,463.74	4.31	919.74	919.74	0.00	2,757.99
Urine, Hygiene & Potable Water, & Brine Storage Tankage		181.57	0.47	17.80	17.80	0.00	190.81
Microbial Check Valve		5.72	0.02	0.00	0.00	0.00	5.90
Process Controller		36.11	0.08	156.18	156.18	0.00	80.10
Water Quality Monitoring		14.07	0.04	4.72	4.72	0.00	15.74
Product Water Delivery System		51.73	0.12	3.44	3.44	0.00	53.78
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		595.54	0.44	20.74	20.74	0.00	605.32
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Maximum Absorbency Garments		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Carbon Dioxide Removal (LiOH)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Airlock Recycle Pump for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**1,762.62**	**6.87**	**0.00**	**0.00**	**0.00**	**1,825.55**
Clothing		**1,049.76**	**6.16**	**0.00**	**0.00**	**0.00**	**1,106.19**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**712.86**	**0.71**	**0.00**	**0.00**	**0.00**	**719.36**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Totals		**11,617**	**56.57**	**14,187**	**12,698**	**14.78**	**16,017**

Table 6.10 Subsystem Breakdown for Independent Exploration Mission: Mars Transit Vehicle using Advanced Technologies

Subsystem or Component	Technology	Mass [kg]	Volume $[m^3]$	Power $[W_e]$	Cooling $[W_{th}]$	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**1,367.03**	**2.94**	**4,350.34**	**2,863.40**	**12.78**	**2,518.11**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	140.61
Atmosphere Revitalization System							
Carbon Dioxide Removal	4BMS/ISS	179.12	0.42	536.06	536.06	2.72	327.65
Carbon Dioxide Reduction	Sabatier	143.53	0.19	148.59	148.59	0.00	184.94
Oxygen Generation	SPE/ISS	378.86	1.00	3,288.88	1,801.94	10.00	1,227.19
Gaseous Trace Contaminant Control	ISS	85.81	0.40	194.35	194.35	0.00	141.37
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	82.76
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	35.48
Airlock Carbon Dioxide Removal	n/a	0.00	0.00	0.00	0.00	0.00	0.00
Gas Storage							
Nitrogen Storage	Cryogenic	275.81	0.31	4.09	4.09	0.00	279.74
Oxygen Storage	Cryogenic	86.77	0.19	2.89	2.89	0.00	89.28
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.06	1.93
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	7.17
Biomass Subsystem		**761.03**	**17.03**	**6,099.43**	**6,099.43**	**0.00**	**2,545.57**
Crop Storage		**205.88**	**0.00**	**0.00**	**0.00**	**0.00**	**205.88**
Plant Growth Chamber / Salad Machine		**555.15**	**17.03**	**6,099.43**	**6,099.43**	**0.00**	**2,339.69**
Food Subsystem		**2,342.86**	**10.45**	**960.00**	**960.00**	**0.00**	**2,694.90**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM + Salad	3,801.98	10.45	960.00	960.00	0.00	4,154.02
Dry Food Mass (neglected)		*-1,459.12*	*0.00*	*0.00*	*0.00*	*0.00*	*-1,459.12*
Thermal Subsystem		**336.20**	**1.01**	**913.74**	**913.74**	**2.00**	**590.55**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	264.31
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	59.40
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	26.27
Atmospheric Microbial Control	ISS	100.00	0.27	0.00	0.00	2.00	103.60
Internal Thermal Control System		**95.92**	**0.19**	**147.22**	**147.22**	**0.00**	**136.97**

Table 6.10 Subsystem Breakdown for Independent Exploration Mission: Mars Transit Vehicle using Advanced Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W$_e$]	Cooling [W$_{th}$]	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**254.37**	**6.19**	**14.00**	**14.00**	**0.00**	**314.81**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**41.29**
Solid Waste Processing System							
Solid Waste Treatment	Storage	218.01	6.06	0.00	0.00	0.00	273.52
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**1,010.77**	**2.92**	**3,048.42**	**3,048.42**	**180.00**	**1,953.15**
Urine / Waste Water Collection System	**ISS**	**4.55**	**0.02**	**4.00**	**4.00**	**0.00**	**5.80**
Water Recovery System							
Water Treatment Process	VPCAR + Lyophilization	582.42	2.02	2,831.45	2,831.45	180.00	1,458.62
Urine, Hygiene & Potable Water, & Brine Storage Tankage		266.78	0.65	23.67	23.67	0.00	279.05
Microbial Check Valve		8.67	0.02	0.00	0.00	0.00	8.85
Process Controller		63.00	0.00	180.00	180.00	0.00	111.06
Water Quality Monitoring		14.07	0.04	4.72	4.72	0.00	15.70
Product Water Delivery System		71.28	0.17	4.58	4.58	0.00	74.06
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Maximum Absorbency Garments		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Carbon Dioxide Removal (LiOH)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Airlock Recycle Pump for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**862.93**	**1.35**	**633.33**	**633.33**	**0.00**	**1,044.40**
Clothing		**64.80**	**0.38**	**0.00**	**0.00**	**0.00**	**68.28**
Laundry Equipment							
Washer / Dryer		80.00	0.26	633.33	633.33	0.00	251.48
Detergent		5.27	0.00	0.00	0.00	0.00	5.27
Miscellaneous Items		**712.86**	**0.71**	**0.00**	**0.00**	**0.00**	**719.36**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Totals		**6,935**	**41.89**	**16,019**	**14,532**	**194.78**	**11,661**

Table 6.11 Subsystem Breakdown for Independent Exploration Mission: Mars Descent / Ascent Lander using Baseline Technologies

Subsystem or Component	**Technology**	**Mass [kg]**	**Volume [m^3]**	**Power [W_e]**	**Cooling [W_{th}]**	**Crewtime [CM-h]**	**Equivalent System Mass [kg]**
Air Subsystem		**1,070.64**	**2.16**	**4,250.98**	**2,742.06**	**1.07**	**2,585.50**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	163.04
Atmosphere Revitalization System							
Carbon Dioxide Removal	4BMS/ISS	182.77	0.43	548.32	548.32	0.23	416.83
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	SPE/ISS	382.21	1.00	3,332.83	1,823.91	0.83	1,476.34
Gaseous Trace Contaminant Control	ISS	25.46	0.05	194.35	194.35	0.00	101.29
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	98.91
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	37.78
Airlock Carbon Dioxide Removal	n/a	0.00	0.00	0.00	0.00	0.00	0.00
Gas Storage							
Nitrogen Storage	High Pressure	173.01	0.17	0.00	0.00	0.00	184.35
Oxygen Storage	High Pressure	90.08	0.08	0.00	0.00	0.00	95.42
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.01	2.09
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	9.47
Biomass Subsystem		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Crop Storage	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Plant Growth Chamber / Salad Machine	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Food Subsystem		**619.72**	**3.37**	**2,128.00**	**2,128.00**	**0.00**	**1,638.24**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM with Frozen	743.00	3.37	2,128.00	2,128.00	0.00	1,761.52
Dry Food Mass (neglected)		*-123.28*	*0.00*	*0.00*	*0.00*	*0.00*	*-123.28*
Thermal Subsystem		**296.40**	**0.92**	**822.24**	**822.24**	**0.17**	**665.09**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	349.31
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	79.68
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	33.89
Atmospheric Microbial Control	ISS	100.00	0.27	0.00	0.00	0.17	118.64
Internal Thermal Control System		**56.12**	**0.10**	**55.72**	**55.72**	**0.00**	**83.57**

Table 6.11 Subsystem Breakdown for Independent Exploration Mission: Mars Descent / Ascent Lander using Baseline Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W$_e$]	Cooling [W$_{th}$]	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**68.56**	**1.02**	**14.00**	**14.00**	**0.00**	**141.82**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**50.25**
Solid Waste Processing System							
Solid Waste Treatment	Storage	32.20	0.89	0.00	0.00	0.00	91.56
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**736.68**	**2.88**	**895.54**	**895.54**	**0.00**	**1,262.81**
Urine / Waste Water Collection System	**ISS**	**4.55**	**0.02**	**4.00**	**4.00**	**0.00**	**7.38**
Water Recovery System							
Water Treatment Process	ISS WRS	462.20	2.35	712.07	712.07	0.00	884.55
Urine, Hygiene & Potable Water, & Brine Storage Tankage		98.86	0.26	10.74	10.74	0.00	120.21
Microbial Check Valve		2.01	0.01	0.00	0.00	0.00	2.68
Process Controller		36.11	0.08	156.18	156.18	0.00	99.70
Water Quality Monitoring		14.07	0.04	4.72	4.72	0.00	18.50
Product Water Delivery System		28.17	0.07	2.08	2.08	0.00	33.61
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		90.71	0.05	5.75	5.75	0.00	96.19
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**21.74**	**0.25**	**0.00**	**0.00**	**0.00**	**38.42**
Maximum Absorbency Garments		**1.04**	**0.00**	**0.00**	**0.00**	**0.00**	**1.04**
Carbon Dioxide Removal (LiOH)		**20.70**	**0.25**	**0.00**	**0.00**	**0.00**	**37.38**
Airlock Recycle Pump for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**187.62**	**0.65**	**0.00**	**0.00**	**0.00**	**230.98**
Clothing		**87.48**	**0.51**	**0.00**	**0.00**	**0.00**	**121.50**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**59.41**	**0.06**	**0.00**	**0.00**	**0.00**	**63.41**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		40.73	0.08	0.00	0.00	0.00	46.07
Totals		**3,001**	**11.25**	**8,111**	**6,602**	**1.24**	**6,563**

Table 6.12 Subsystem Breakdown for Independent Exploration Mission: Mars Descent / Ascent Lander using Advanced Technologies

Subsystem or Component	Technology	Mass [kg]	Volume $[\mathrm{m}^3]$	Power $[\mathrm{W_e}]$	Cooling $[\mathrm{W_{th}}]$	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**669.74**	**0.96**	**488.92**	**488.92**	**0.01**	**904.43**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	161.35
Atmosphere Revitalization System							
Carbon Dioxide Removal	SAVD	134.30	0.28	92.10	92.10	0.00	185.12
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	Storage	0.00	0.00	0.00	0.00	0.00	0.00
Gaseous Trace Contaminant Control	ISS	25.46	0.05	194.35	194.35	0.00	96.62
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	96.42
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	37.78
Airlock Carbon Dioxide Removal	n/a	0.00	0.00	0.00	0.00	0.00	0.00
Gas Storage							
Nitrogen Storage	Cryogenic	78.11	0.06	8.29	8.29	0.00	85.01
Oxygen Storage	Cryogenic	214.76	0.14	18.70	18.70	0.00	230.62
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.01	2.04
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	9.47
Biomass Subsystem		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Crop Storage	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Plant Growth Chamber / Salad Machine	**n/a**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Food Subsystem		**188.68**	**0.92**	**960.00**	**960.00**	**0.00**	**585.08**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM with LMC	309.87	0.92	960.00	960.00	0.00	706.27
Dry Food Mass (neglected)		*-121.19*	*0.00*	*0.00*	*0.00*	*0.00*	*-121.19*
Thermal Subsystem		**280.23**	**0.89**	**783.55**	**783.55**	**0.17**	**613.40**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	336.58
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	75.48
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	32.42
Atmospheric Microbial Control	ISS	100.00	0.27	0.00	0.00	0.17	118.35
Internal Thermal Control System		**39.95**	**0.07**	**17.03**	**17.03**	**0.00**	**50.56**

Table 6.12 Subsystem Breakdown for Independent Exploration Mission: Mars Descent / Ascent Lander using Advanced Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume [m³]	Power [W_e]	Cooling [W_{th}]	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**67.42**	**0.99**	**14.00**	**14.00**	**0.00**	**138.34**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**49.92**
Solid Waste Processing System							
Solid Waste Treatment	Storage	31.06	0.86	0.00	0.00	0.00	88.42
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**444.88**	**1.30**	**1,548.42**	**1,548.42**	**0.00**	**1,071.99**
Urine / Waste Water Collection System	**ISS**	**4.55**	**0.02**	**4.00**	**4.00**	**0.00**	**7.28**
Water Recovery System							
Water Treatment Process	VPCAR; no AES	228.40	0.92	1,347.02	1,347.02	180.00	759.87
Urine, Hygiene & Potable Water, & Brine Storage Tankage		105.24	0.25	10.63	10.63	0.00	125.62
Microbial Check Valve		1.94	0.01	0.00	0.00	0.00	2.61
Process Controller		63.00	0.00	180.00	180.00	0.00	125.82
Water Quality Monitoring		14.07	0.04	4.72	4.72	0.00	18.39
Product Water Delivery System		27.68	0.06	2.05	2.05	0.00	32.40
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**21.74**	**0.25**	**0.00**	**0.00**	**0.00**	**38.42**
Maximum Absorbency Garments		**1.04**	**0.00**	**0.00**	**0.00**	**0.00**	**1.04**
Carbon Dioxide Removal (LiOH)		**20.70**	**0.25**	**0.00**	**0.00**	**0.00**	**37.38**
Airlock Recycle Pump for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Oxygen Recharge Compressor Assembly for EVA		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Human Accommodations		**187.62**	**0.65**	**0.00**	**0.00**	**0.00**	**230.98**
Clothing		**87.48**	**0.51**	**0.00**	**0.00**	**0.00**	**121.50**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**59.41**	**0.06**	**0.00**	**0.00**	**0.00**	**63.41**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		40.73	0.08	0.00	0.00	0.00	46.07
Totals		**1,860**	**5.96**	**3,795**	**3,795**	**0.18**	**3,583**

Table 6.13 Subsystem Breakdown for Independent Exploration Mission: Surface Habitat Lander using Baseline Technologies

Subsystem or Component	Technology	Mass [kg]	Volume [m^3]	Power [W_e]	Cooling [W_{th}]	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**4,194.56**	**5.52**	**5,846.50**	**3,732.19**	**21.30**	**5,315.32**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	138.14
Atmosphere Revitalization System							
Carbon Dioxide Removal	4BMS/ISS	179.12	0.42	536.05	536.05	4.53	311.69
Carbon Dioxide Reduction	None	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen Generation	SPE/ISS	586.98	1.25	4,543.62	2,429.31	16.67	1,361.93
Gaseous Trace Contaminant Control	ISS	103.41	0.66	194.35	194.35	0.00	154.54
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	79.14
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	35.48
Airlock Carbon Dioxide Removal	ISS	181.30	0.23	397.00	397.00	0.00	275.51
Gas Storage							
Nitrogen Storage	High Pressure	2,183.84	2.02	0.00	0.00	0.00	2,202.34
Oxygen Storage	High Pressure	742.78	0.51	0.00	0.00	0.00	747.45
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.10	1.94
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	7.17
Biomass Subsystem		**898.28**	**17.03**	**6,099.43**	**6,099.43**	**0.00**	**2,469.34**
Crop Storage		**343.13**	**0.00**	**0.00**	**0.00**	**0.00**	**343.13**
Plant Growth Chamber / Salad Machine		**555.15**	**17.03**	**6,099.43**	**6,099.43**	**0.00**	**2,126.21**
Food Subsystem		**7,579.74**	**38.39**	**4,272.00**	**4,272.00**	**0.00**	**8,922.50**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM + Frozen + Salad	10,016.14	38.39	4,272.00	4,272.00	0.00	11,358.90
Dry Food Mass (neglected)		*-2,436.40*	*0.00*	*0.00*	*0.00*	*0.00*	*-2,436.40*
Thermal Subsystem		**382.25**	**1.17**	**1,032.03**	**1,032.03**	**3.33**	**635.58**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	245.74
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	53.27
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	24.14
Atmospheric Microbial Control	ISS	131.33	0.40	0.00	0.00	3.33	138.18
Internal Thermal Control System		**110.64**	**0.22**	**265.51**	**265.51**	**0.00**	**174.25**

Table 6.13 Subsystem Breakdown for Independent Exploration Mission: Surface Habitat Lander using Baseline Technologies (concluded)

Subsystem or Component	Technology	Mass [kg]	Volume $[m^3]$	Power $[W_e]$	Cooling $[W_{th}]$	Crewtime [CM-h]	Equivalent System Mass [kg]
Waste Subsystem		**667.58**	**17.66**	**14.00**	**14.00**	**0.00**	**832.59**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**40.80**
Solid Waste Processing System							
Solid Waste Treatment	Storage	631.22	17.53	0.00	0.00	0.00	791.79
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**10,380.48**	**9.82**	**1,284.51**	**1,284.51**	**0.00**	**10,768.44**
Urine / Waste Water Collection System	**ISS**	**7.22**	**0.02**	**4.00**	**4.00**	**0.00**	**8.33**
Water Recovery System							
Water Treatment Process	ISS WRS	3,836.35	4.33	909.85	909.85	0.00	4,087.10
Urine, Hygiene & Potable Water, & Brine Storage Tankage		182.13	0.47	17.85	17.85	0.00	190.58
Microbial Check Valve		9.50	0.02	0.00	0.00	0.00	9.68
Process Controller		36.11	0.08	156.18	156.18	0.00	73.08
Water Quality Monitoring		14.07	0.04	4.72	4.72	0.00	15.53
Product Water Delivery System		51.89	0.12	3.45	3.45	0.00	53.79
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		6,243.21	4.74	188.46	188.46	0.00	6,330.35
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**1,292.18**	**2.91**	**2,500.00**	**2,500.00**	**0.00**	**1,898.84**
Maximum Absorbency Garments		**242.20**	**0.00**	**0.00**	**0.00**	**0.00**	**242.20**
Carbon Dioxide Removal (LiOH)		**817.20**	**2.43**	**0.00**	**0.00**	**0.00**	**839.46**
Airlock Recycle Pump for EVA		**70.30**	**0.14**	**1,000.00**	**1,000.00**	**0.00**	**303.58**
Oxygen Recharge Compressor Assembly for EVA		**162.48**	**0.34**	**1,500.00**	**1,500.00**	**0.00**	**513.59**
Human Accommodations		**2,937.71**	**11.45**	**0.00**	**0.00**	**0.00**	**3,042.59**
Clothing		**1,749.60**	**10.26**	**0.00**	**0.00**	**0.00**	**1,843.58**
Laundry Equipment							
Washer / Dryer		0.00	0.00	0.00	0.00	0.00	0.00
Detergent		0.00	0.00	0.00	0.00	0.00	0.00
Miscellaneous Items		**1,188.11**	**1.19**	**0.00**	**0.00**	**0.00**	**1,199.01**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Totals		**28,333**	**103.95**	**21,048**	**18,934**	**24.63**	**33,885**

Table 6.14 Subsystem Breakdown for Independent Exploration Mission: Surface Habitat Lander using Advanced Technologies

Subsystem or Component	Technology	Mass [kg]	Volume $[m^3]$	Power $[W_e]$	Cooling $[W_{th}]$	Crewtime [CM-h]	Equivalent System Mass [kg]
Air Subsystem		**2,198.26**	**4.17**	**6,015.56**	**3,903.01**	**21.30**	**3,241.98**
Atmospheric Control System							
Atmospheric Pressure Control	ISS	119.40	0.26	70.50	70.50	0.00	136.45
Atmosphere Revitalization System							
Carbon Dioxide Removal	4BMS/ISS	179.16	0.42	536.13	536.13	4.53	296.63
Carbon Dioxide Reduction	Sabatier	160.43	0.23	164.83	164.83	0.00	196.82
Oxygen Generation	SPE/ISS	586.62	1.25	4,540.09	2,427.54	16.67	1,294.54
Gaseous Trace Contaminant Control	ISS	103.41	0.66	194.35	194.35	0.00	149.88
Atmosphere Composition Monitoring Assembly	ISS	54.30	0.09	103.50	103.50	0.00	76.65
Sample Delivery System	ISS	35.11	0.04	0.00	0.00	0.00	35.48
Airlock Carbon Dioxide Removal	ISS	181.30	0.23	397.00	397.00	0.00	265.98
Gas Storage							
Nitrogen Storage	Cryogenic	581.44	0.59	4.55	4.55	0.00	587.79
Oxygen Storage	Cryogenic	188.79	0.36	3.13	3.13	0.00	192.74
Fire Detection and Suppression							
Fire Detection System	ISS	1.50	0.00	1.48	1.48	0.10	1.85
Fire Suppression System	ISS	6.80	0.04	0.00	0.00	0.00	7.17
Biomass Subsystem		**898.28**	**17.03**	**6,099.43**	**6,099.43**	**0.00**	**2,322.96**
Crop Storage		**343.13**	**0.00**	**0.00**	**0.00**	**0.00**	**343.13**
Plant Growth Chamber / Salad Machine		**555.15**	**17.03**	**6,099.43**	**6,099.43**	**0.00**	**1,979.83**
Food Subsystem		**3,880.67**	**17.35**	**960.00**	**960.00**	**0.00**	**4,239.28**
Food Processing, Packaging, and Storage							
Food Processing		0.00	0.00	0.00	0.00	0.00	0.00
Food Packaging		0.00	0.00	0.00	0.00	0.00	0.00
Food Storage	STM + Salad	6,312.90	17.35	960.00	960.00	0.00	6,671.51
Dry Food Mass (neglected)		*-2,432.23*	*0.00*	*0.00*	*0.00*	*0.00*	*-2,432.23*
Thermal Subsystem		**375.93**	**1.16**	**999.36**	**999.36**	**3.33**	**595.97**
Temperature and Humidity Control							
Common Cabin Air Assembly	ISS	118.08	0.50	530.52	530.52	0.00	233.01
Avionics Air Assembly	ISS	12.40	0.03	175.00	175.00	0.00	49.07
Atmosphere Circulation	ISS	9.80	0.02	61.00	61.00	0.00	22.67
Atmospheric Microbial Control	ISS	131.33	0.40	0.00	0.00	3.33	136.54
Internal Thermal Control System		**104.32**	**0.21**	**232.84**	**232.84**	**0.00**	**154.67**

Table 6.14 Subsystem Breakdown for Independent Exploration Mission: Surface Habitat Lander using Advanced Technologies (concluded)

Subsystem or Component	**Technology**	**Mass [kg]**	**Volume [m^3]**	**Power [W$_e$]**	**Cooling [W$_{th}$]**	**Crewtime [CM-h]**	**Equivalent System Mass [kg]**
Waste Subsystem		**391.83**	**6.69**	**352.68**	**352.68**	**360.00**	**693.87**
Solid Waste Collection	**ESDM**	**36.36**	**0.13**	**14.00**	**14.00**	**0.00**	**40.46**
Solid Waste Processing System							
Solid Waste Treatment	Lyophilization	355.47	6.56	338.68	338.68	360.00	653.41
Solid Waste Processing System Tankage		0.00	0.00	0.00	0.00	0.00	0.00
Microbial Check Valve		0.00	0.00	0.00	0.00	0.00	0.00
Process Controller		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Quality Monitoring		0.00	0.00	0.00	0.00	0.00	0.00
Solid Product Delivery System		0.00	0.00	0.00	0.00	0.00	0.00
Water Subsystem		**1,532.67**	**3.32**	**3,103.92**	**3,103.92**	**300.00**	**2,348.20**
Urine / Waste Water Collection System	**ISS**	**7.22**	**0.02**	**4.00**	**4.00**	**0.00**	**8.24**
Water Recovery System							
Water Treatment Process	VPCAR + Lyophilization	591.23	2.05	2,868.96	2,868.96	300.00	1,346.25
Urine, Hygiene & Potable Water, & Brine Storage Tankage		282.16	0.66	24.04	24.04	0.00	293.21
Microbial Check Valve		14.65	0.02	0.00	0.00	0.00	14.83
Process Controller		63.00	0.00	180.00	180.00	0.00	100.44
Water Quality Monitoring		14.07	0.04	4.72	4.72	0.00	15.42
Product Water Delivery System		72.53	0.17	4.65	4.65	0.00	75.05
Water Storage							
Hygiene Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Potable Water Storage		487.81	0.36	17.55	17.55	0.00	494.76
Urine Storage		0.00	0.00	0.00	0.00	0.00	0.00
Waste Water Storage		0.00	0.00	0.00	0.00	0.00	0.00
Extravehicular Activity		**1,292.18**	**2.91**	**2,500.00**	**2,500.00**	**0.00**	**1,838.84**
Maximum Absorbency Garments		**242.20**	**0.00**	**0.00**	**0.00**	**0.00**	**242.20**
Carbon Dioxide Removal (LiOH)		**817.20**	**2.43**	**0.00**	**0.00**	**0.00**	**839.46**
Airlock Recycle Pump for EVA		**70.30**	**0.14**	**1,000.00**	**1,000.00**	**0.00**	**279.58**
Oxygen Recharge Compressor Assembly for EVA		**162.48**	**0.34**	**1,500.00**	**1,500.00**	**0.00**	**477.59**
Human Accommodations		**1,348.88**	**1.87**	**633.33**	**633.33**	**0.00**	**1,497.74**
Clothing		**72.00**	**0.42**	**0.00**	**0.00**	**0.00**	**75.85**
Laundry Equipment							
Washer / Dryer		80.00	0.26	633.33	633.33	0.00	214.11
Detergent		8.77	0.00	0.00	0.00	0.00	8.77
Miscellaneous Items		**1,188.11**	**1.19**	**0.00**	**0.00**	**0.00**	**1,199.01**
Wipes							
Hand/Face Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Shower Wet Wipes		0.00	0.00	0.00	0.00	0.00	0.00
Totals		**11,919**	**54.50**	**20,664**	**18,552**	**684.63**	**16,779**

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8 ABBREVIATIONS AND ACRONYMS

4BMS	four-bed molecular sieve
AAA	avionic air assembly
AES	air evaporation subsystem
A/L	airlock
ALS	Advanced Life Support
ALSSAT	Advanced Life Support Sizing Analysis Tool
AS	ambient storage
ATCO	ambient temperature catalytic oxidizer (for carbon monoxide removal)
CCAA	common cabin air assembly
CH_4	methane
CM	crewmember (*i.e.*, units for enumerating people)
CM-d	crewmember-day (*i.e.*, the time from one crewmember for one day.)
CM-h	crewmember-hour (*i.e.*, the time from one crewmember for one hour.)
CO_2	carbon dioxide
Cond. HX	anti-microbial condensing heat exchanger
Cond. Tank	condensate tank
d	day (*i.e.*, units of time.)
ECLSS	environmental control and life support system
EMU	extravehicular mobility unit
ESDM	Environmental Control and Life Support System Design Model
ESM	equivalent system mass
EVA	extravehicular activity
FDS	fire detection and suppression
G/L	gas/liquid (separator)
h	hour (*i.e.*, units of time)
H_2	hydrogen
H_2O	water
H_2SO_4	sulfuric acid
HEPA	high efficiency particulate air
HP	high-pressure (gas)
HX	heat exchanger
ITCS	internal thermal control system
ISS	International Space Station
IX	ion exchange
kg	kilogram (*i.e.*, units of mass.)
kPa	kilo Pascal (*i.e.*, units of pressure.)
kW_e	kilo Watt, electric (*i.e.*, units of electric power.)
kW_{th}	kilo Watt, thermal (*i.e.*, units of heat transfer rate.)
LiOH	lithium hydroxide
LMC	low-moisture content (food)
m	meter (*i.e.*, units of length)
m^3	cubic meters (*i.e.*, units of volume.)
MCA	major constituent analyzer
MCV	microbial check valve
MF	multifiltration
MJ	mega Joule (*i.e.*, units of energy.)
MLS	mostly liquid separator
mod	modules (*i.e.*, units for enumerating modules)
n/a	not applicable
N_2	nitrogen
NASA	National Aeronautics and Space Administration
O_2	oxygen
OGA	oxygen generation assembly
ORCA	oxygen recharge compressor assembly
pH	potential of hydrogen
PMA	pressurized mating adaptor
PMWC	plastic melt waste compaction
RFR	refrigerator freezer rack
SAVD	solid amine vacuum desorption
SIMA	Systems Integration, Modeling, and Analysis Project Element
SPE	solid polymer [water] electrolysis
STM	Shuttle Training Menu
TCCS	trace contaminant control subsystem
TCS	thermal control subsystem
TRL	technology readiness level (See Table 1.2.1)
USOS	United States On-Orbit Segment (of the International Space Station)
VCD	vapor compression distillation
VPCAR	vapor phase catalytic ammonia removal
VRA	volatile removal assembly
WRS	water recovery subsystem
WRS Opt 3	[ISS] water recovery subsystem without urine recovery [VCD]; urine dumped overboard. See text.
WW	wastewater (tank)