

Development Requirements for the Exploration PLSS (xPLSS) Carbon Dioxide and Humidity Control Unit (CDHCU)

Functional Requirements for the CDHCU:

- 1) The CDHCU is a component of the Exploration Portable Life Support System (xPLSS) to provide carbon dioxide (CO₂) and humidity control within the spacesuit for a crewmember to perform extravehicular activities (EVA) in vacuum (micro-g), lunar, and Mars* environments for up to 8 hours continuous, and during EVA preparation in airlocks or support vehicles for an additional 2 hours (TBR) continuous.

* For development design purposes, focus shall be on the lunar design and microgravity with protection for key design features for the Mars capability. Full Mars functional capability is to be demonstrated in future developments.

Preliminary Performance Requirements for the CDHCU:

- 1) Temperature for the CDHCU
60°F to 90°F (15.6°C to 32.2°C)

Rationale: Results are based on thermal analysis for PLSS 2.5 performed by the xPLSS team for the worst-case hot and cold environments assumed for future missions.

- 2) Pressure for the CDHCU
3.1 psia to 25.0 psia (21.4 kPa to 172.4 kPa)

Rationale:

- a. *The lower limit provides a 0.4 psi guard-band to the lowest secondary regulator supply pressure of 3.5 psia, which is only experienced during regulator droop conditions present at higher flowrates, making this a conservative number.*

The upper limit is based on a 15.5 psia cabin pressure and 8 psid operating suit (decompression sickness treatment or zero pre-breathe) with guard band for suit or cabin pressure fluctuations in reality or design requirements.

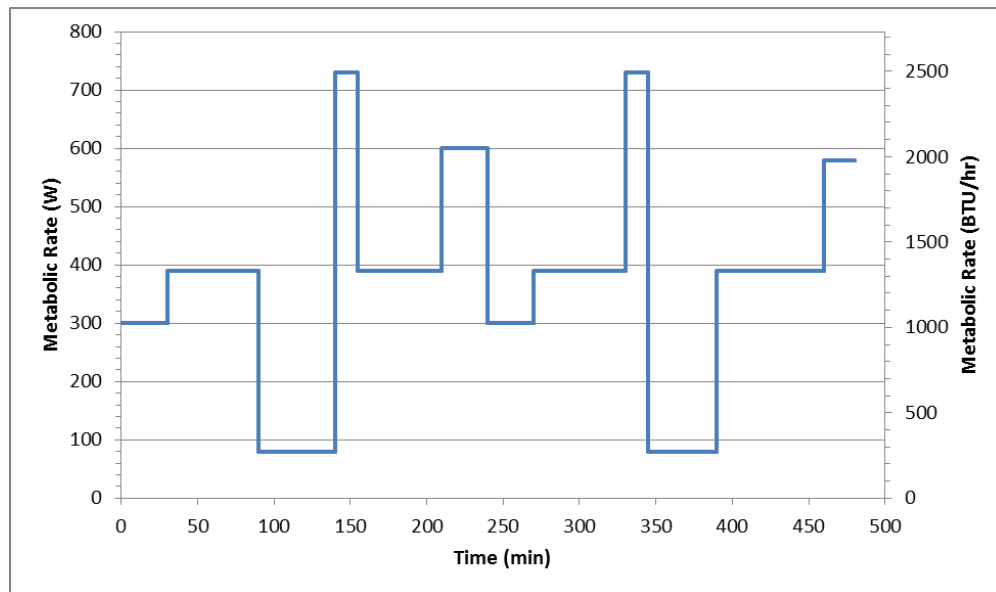
- 3) Carbon Dioxide and Water Removal Rate

The CDHCU shall maintain outlet CO₂ levels at an average of 3.8 mmHg for an 8-hour EVA as described in the table and metabolic profile as shown below with an average metabolic rate of 1024 Btu/hr over the eight-hour simulated extravehicular activity.

Rationale: Medical research (Ref. 1) on health effects experienced on ISS has indicated that CO₂ levels of 3.8 mmHg or less on average would be recommended for future life support systems.

Nominal Suited Conditions

Average Metabolic Rate	1230 Btu/hr (300 W)
CO ₂ Production Rate	0.25 lb _m /hr (1.87 g/min.)
H ₂ O Production Rate	0.20 lb _m /hr (1.48 g/min.)
Flow Rate	6.0 ACFM (1.7 m ³ /hr)
Pressure	4.3 psia (29.6 kPa)
System Free Volume	2 ft ³ (56.6 liters)



- 4) Inlet Humidity, Water vapor concentrations
0% to 100% relative humidity at 70°F (21.1°C), which equates to partial pressures of 0 mm Hg to 17.9 mm Hg of water vapor (0 Pa to 2390 Pa)

Rationale: Range based on possible humidity of the ventilation loop.

- 5) Pressure/Flow Characteristics
Pressure drop across the CDHCU shall not exceed 2.5 inches H₂O (622 Pa) at 4.3 psia (29.6 kPa) and 6 acfm flow (10.2 m³/hr, actual flow)

Rationale: CDHCU Pressure drop allocation is driven by the amount of pressure head that can be provided by the PLSS fan.

- 6) Operating Voltage
22-34 VDC

Rationale: The current power distribution architecture provides filtered battery/vehicle supply voltage directly to the PLSS controllers for local regulation as needed. The implementation of the distributed battery approach on PLSS 2.5 removed the possibility of being able to use the existing Ag-Zn battery from the Shuttle/ISS EMU Program as a back-up to mitigate risk in new battery development. However, the larger voltage range limited component selections on the controllers and the caution and warning system and made it difficult to have both motors and brushless direct current motor drivers that could successfully meet performance requirements over such a wide input voltage range. To this end, limiting the lower end to the lower end output voltage permitted from an 8S Li-Ion cell stack-up mitigates these issues. Actual lower end of the Li-Ion battery voltage is anticipated to be >24 VDC.

- 7) Power
3 W average and 10 W peak

*Rationale:
This is the expected power allotment that the xPLSS battery can provide to the CDHCU.*

- 8) Operational Life
4000 hours

Rationale: The goal is to make the hardware and its associated certification “robust-enough” such that detailed tracking of operating cycles and the resultant operational overhead is not required.

- a. This is based on 100 EVAs at 8 hours per EVA and 2 hours pre/post-EVA functional time for prebreathe and other activities with a scatter factor of 4.*

- 9) Useful/Service Life
15 years

Rationale: The useful life is the total chronological time that an assembly, component, or detail part may be used. It is the total of shelf life and operational life. Useful life begins at the item’s birth date which can be initial acceptance, date of manufacture, date of cure, etc. The component may sit on the shelf in controlled storage for 15 years until it expires, it may be placed into service for 15 years (but within the operational life) until it expires, or some combination with the total tracked time of 15 years and total operating hours as defined in the operational life.

- 10) Servicing and Maintenance: As a minimum, replacement of the CDHCU within the PLSS shall be carried out at the lunar lander, the lunar habitat, and in zero and micro-g while in the lunar transport vehicle.

11) Packaging Geometry, Volume, and Mass

The CDHCU shall have a volume that is compatible with the integrated PLSS package with a mass of no more than 22 lb_m (10 kg) and a volume of less than 0.40 ft³ (11.3 liters). The contractor shall work iteratively with NASA to determine acceptable dimensional trade-offs and placement of critical features (e.g., motor, inlet and outlet connectors, vacuum duct) within the integrated package.

Rationale: These requirements are targeted for microgravity and lunar environment. For Mars application, the mass and volume should be minimized.

12) Standby and Startup Capability

During unpowered modes, the CDHCU shall be capable of startup when the initial air inlet is between 0-100% relative humidity and carbon dioxide is 0-20 mm Hg.

Rationale: The CDHCU must be able to maintain safe breathing conditions following unpowered modes so that it is capable of startup after being unpowered. The PLSS systems must maintain these required startup temperatures that dictate humidity conditions. The upper limit for CO₂ is based upon testing performed for current CDHCU prototypes.

13) External Operating Atmospheres

Deep Space Vacuum, 10⁻¹⁷ torr¹

Lunar Polar and Equatorial, 10⁻¹¹ torr^{2,3,4}

Mars, 4.8 torr, 95.3% CO₂

Rationale: External atmospheres are relevant for technologies relying upon either vacuum of an external environment or concentration differentials as a means of regenerating sorbent.

References:

¹Thirsk, R, A Kuipers, C Mukai, D Williams, "The space-flight environment: the International Space Station and beyond." *Canadian Medical Association Journal* 180.12 (2009): 1216-1220.

²<https://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html>

³Johnson, FS "Lunar Atmosphere." *Rev. Geophys. & Space Phys.*, 9(3), 1917.

⁴<https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html>

Design Considerations:

- 1) Replacement of the CDHCU shall be considered on-orbit during lunar transit.
- 2) Packaging Shape: TBD.

- 3) The ventilation loop temperature control is to be achieved using the gas/water heat exchanger (HX-340), which thermally links the ventilation and thermal control loops where thermal control is to be achieved with a back-pressure control valve of the spacesuit water membrane evaporator (SWME).
- 4) Contamination issues are to be addressed. Chemical adsorption/absorption should not be susceptible to trace interfering compounds such as oxygen, ammonia, formaldehyde, or other trace metabolic byproducts.
- 5) Materials shall be compatible with a 100% oxygen environments.
- 6) Different packaging schemes are to be evaluated to minimize packaging volume of the carbon dioxide and humidity control technology.

References:

- 1) Law, J., Watkins, S., and Alexander, D., "In-flight Carbon Dioxide Exposures and Related Symptoms: Association, Susceptibility, and Operational Implications," NASA/TP-2010-216126, 2010.