Requirements and Sizing Investigation for Constellation Space Suit Portable Life Support System Trace Contaminant Control

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Abstract

The Trace Contaminant Control System (TCCS), located within the ventilation loop of the Constellation Space Suit Portable Life Support System (PLSS), is responsible for removing hazardous trace contaminants from the space suit ventilation flow. This paper summarizes the results of a trade study that evaluated if trace contaminant control could be accomplished without a TCCS, relying on suit leakage, ullage loss from the carbon dioxide and humidity control system, and other factors. Trace contaminant generation rates were revisited to verify that values reflect the latest designs for Constellation Space Suit System (CSSS) pressure garment materials and PLSS hardware. Additionally, TCCS sizing calculations were performed and a literature survey was conducted to review the latest developments in trace contaminant technologies.

Introduction

The Constellation program operational concepts documents ([1] and [2]) require the ability to perform suited Extravehicular Activities (EVAs) on the lunar surface for lunar sorties, cargo unloading operations, extended stay operations, and continuous presence operations. Each EVA can last up to 8 hours. No nominal EVAs are currently planned for non-lunar-surface operations using Constellation assets. The second configuration of the CSSS, known as "Configuration 2," is being developed to provide a self-contained, pressurized, portable environment to accommodate the lunar EVA requirements. A crucial component of the Configuration 2 suit system is the PLSS, which provides oxygen (O_2) for breathing and pressurization, removes metabolically-produced carbon dioxide (CO_2), removes trace contaminants produced by material and crewmember off-gassing, and regulates the thermal environment of the crewmember.

A trace contaminant is a gaseous substance introduced into the space suit system via human, material, and hardware off-gassing. Depending on the substance, it can be hazardous to a crew member's health with side effects ranging from headaches to heart damage, as shown in Table 1, based on exposure level and duration. Therefore, it is critical that space suit trace contaminant levels be controlled, whether by a TCCS, or by relying on other means to vent contaminants overboard via ventilation subsystem hardware and space suit leakage.

Table 1: Summary of Expected Constellation Space Suit PLSS Ventilation Loop Trace Contaminants, with Generation Rates [3], Spacecraft Maximum Allowable Concentrations [4], and Adverse Effects [4]

		Generation Rate	**24-hr SMAC Limit**			
	Formula	*(mg/8-hr EVA)*	*(ppm)**	*(mg/m^3)*	**Affected Organ**	**Effect**
Acetaldehyde†	CH_3CHO	0.027	6	10	Mucosa	Irritation
Acetone	CH_3COCH_3	0.045	200	500	Central Nervous System	Fatigue
Ammonia	NH_3	83	20	14	Eye	Irritation
n-Butanol	BuOH	0.17	25	80	Eye	Irritation
Carbon Monoxide‡	CO	11	100	114	Central Nervous System	Depression
					Cardiovascular	Arrhythmia
Ethyl Alcohol	C_2H_5OH	1.3	5000	10000	Eye	Irritation
					Mucosa	Irritation
					Skin	Flushing
Formaldehyde†	H_2CO	0.13	0.5	0.6	Mucosa	Irritation
Furan	C_4H_4O	0.1	0.36	1	Liver	Hepatotoxicity
Hydrogen	H_2CO	17	4100	340	-	Explosion
Methane	CH_4	0.47	5300	3500	-	Explosion
Methyl Alcohol	CH_3OH	200	70	90	Eye	Visual Disturbance
Toluene	C_7H_8	0.2	16	60	Central Nervous System	Dizziness

* Evaluated at 25°C and 1 atm.
† Carcinogen
‡ Carboxyhemoglobin target

A trade study conducted in 2008 [5] investigated TCC technologies that were used in NASA space suits and vehicles, as well as commercial and academic applications, to identify the best technology options for the PLSS. The 2008 trade study also looked at the feasibility of regeneration of TCC technologies, specifically to determine the viability of vacuum regeneration for on-back, real-time extravehicular activity. Based on the knowledge that was gained in this study, activated charcoal was chosen as the baseline TCCS for the Constellation PLSS with further recommendations to impregnate the activated charcoal with zinc chloride for ammonia

(NH_3) adsorption, and to include a chemical-impregnated charcoal that specifically controls formaldehyde (H_2CO) levels. Furthermore, real-time regeneration of the TCCS during EVA was deemed unfeasible, therefore a replaceable activated charcoal bed that would support numerous EVAs was recommended. Follow-on work was proposed to identify proper sizing and implementation of the activated charcoal bed into the PLSS package.

This study was initiated to continue the efforts of the previous trade study. This paper presents the results of efforts to address the TCC functionality of the PLSS by revisiting and updating the removal requirements and generation rates of trace contaminant gasses, investigating the effects of anticipated O_2 leakage and ventilation rates on trace gas concentrations, and estimating the lifetime of a possible TCCS bed as a function of its size and mass to support ongoing TCCS design efforts.

Relevant Requirements and System Configuration

Results from the 2008 trade study [5] were used as the basis for requirement CSSE3038 of the CSSE EVA Requirements Document (ERD), CxP 72208 Draft Rev. C.3 [3], which specifies that the trace contaminant concentrations are not to exceed the 24-hr Spacecraft Maximum Allowable Concentrations (SMAC) [4] concentrations listed in Table 1. Implementing a strategy to satisfy this requirement requires knowledge of the trace contaminant generation rates and the rates at which these contaminants are removed from the suit as entrainments in exhausted and/or leaked ventilation gases. These rates are dependent upon the hardware components and materials used in both the pressure garment and the PLSS.

The current design of the CSSS PLSS [6] is shown schematically in Figure 1. The ventilation loop is conditioned through the use of a Rapid Cycling Amine (RCA) (GX-311a) system to remove CO_2 and humidity and a Trace Contaminant Control System (TCCS) (TC-311d) to remove trace contaminants. Oxygen is nominally provided by the primary O_2 tank (TK-100), with a secondary O_2 tank (TK-200) as a backup. Thermal control and re-humidification of the ventilation loop are accomplished via heat and mass transfer with the cooling water loop by a humidifying heat exchanger (HX-526). The cooling water loop is cooled by a Suit Water Membrane Evaporator (SWME) (HX-501a).

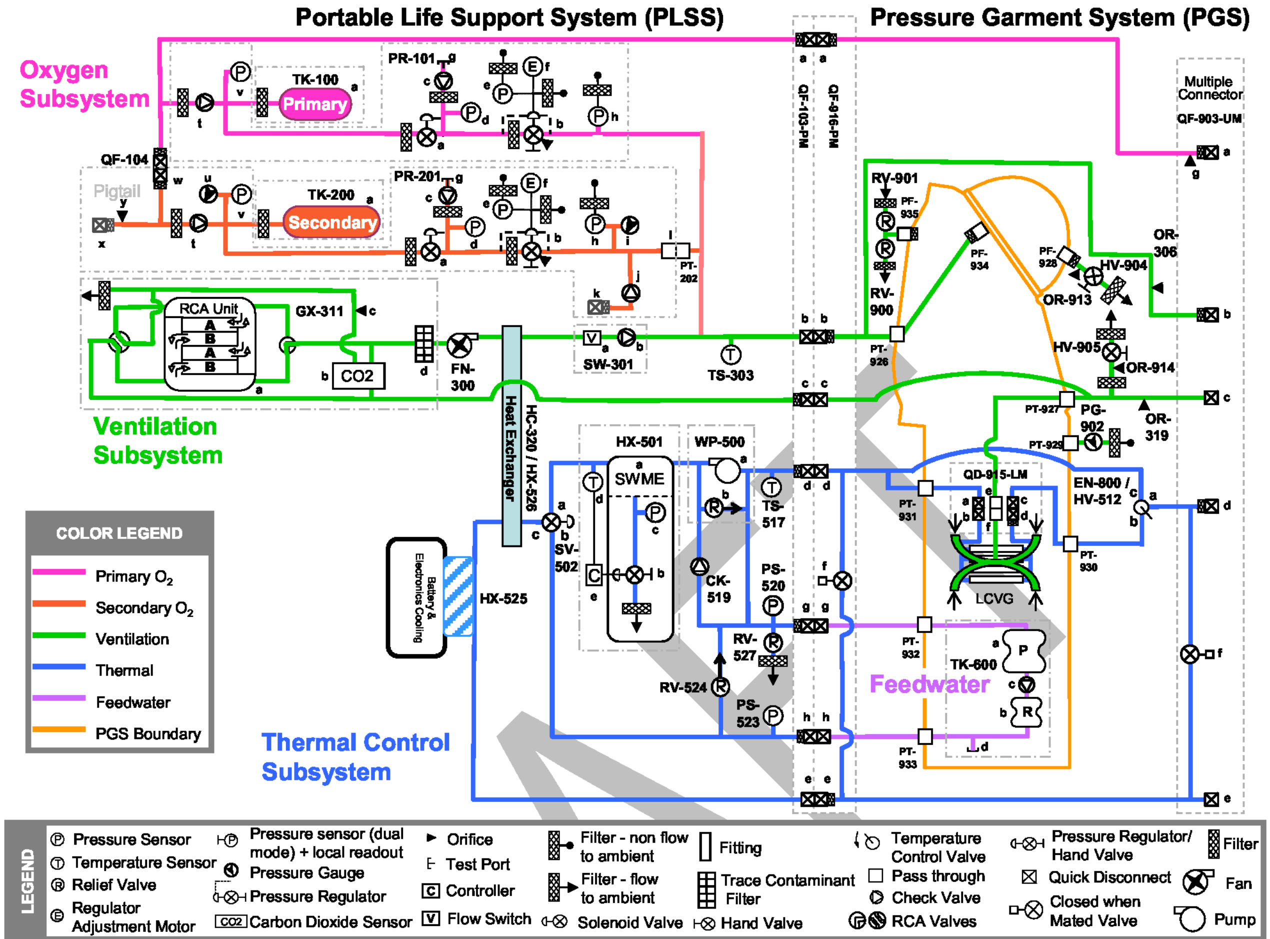

Figure 1: CSSE PLSS Schematic [6]

Trace Contaminant Generation

The trace contaminant generation rates were estimated in the 2008 trade study [5] and are presented in Table 1. These generation rates were derived from data used during the development of the Extravehicular Mobility Unit and data from a White Sands Test Facility amine bed off-gassing test [7]. As an objective of the current study, inquiries were made regarding any updated information that may affect the accuracy of the generation rate estimates. Representatives from the PLSS and PGS teams were contacted to generate the latest list of all components and materials that are planned for the space suit system, specifically those that would interact with the ventilation flow. At this point in development, the Oxygen Subsystem does not expect to use any new materials that would potentially add contaminants to the ventilation loop [8]. The Thermal Subsystem is evaluating the use of

Ethylene Vinyl Acetate, which is currently used in the Space Shuttle Extravehicular Mobility Unit (EMU) Liquid Cooling and Ventilation Garment (LCVG) [9]. The Ventilation Subsystem has determined that 2% Pennzane 2001 solution and Braycote 815Z, 25-35% Volume Fill will be used as lubricants for the fan assembly bearings. Both of these lubricants are certified and or used in the EMU [10]. The PGS subsystem did not have any further input on new materials for the Constellation space suit, as the materials being considered are similar to those currently used in the EMU [11]. Based on this information, the revised generation rate estimates remain unchanged from those of the 2008 trade study [5].

<u>Expulsion of Ventilation Gases</u>

The trace contaminants generated within the space suit system are entrained within the ventilation loop gases. A portion of these contaminants are thus expelled from the suit at any point where the ventilation gases are lost to the vacuum environment, such as through RCA ullage, CO_2 sensor losses, and PGS leakage.

Rapid Cycling Amine (RCA) System

The Rapid Cycling Amine (RCA) system removes CO_2 and water vapor from the ventilation stream through adsorption within one of two solid amine sorbent beds. Once the active bed reaches capacity, the RCA system simultaneously redirects the ventilation stream through the second sorbent bed while regenerating the first bed via exposure to vacuum. The ventilation gases trapped within the first bed are vented to vacuum during the switchover and the CO_2 is desorbed from the same bed. The duration of exposure of each bed to the ventilation gases is called the half-cycle time. As the crewmember's metabolic rate increases, the CO_2 input rate into the RCA also increases. Figure 2, as reproduced from ICES paper 2007-01-3272 [12], shows that shorter half-cycle times are required as CO_2 input rate increases if the CO_2 partial pressure at the RCA outlet is to be kept below a targeted 6 mm Hg, leading to increased ullage loss rates. According to the results of ICES paper 2007-01-3272 [12], accommodating a peak metabolic rate of 600 W (EVA ERD requirement CSSE0008 [3]) would require an RCA that treats a CO_2 input rate of 3 g/min, corresponding to a 1 to 2 minute half-cycle time and O_2 ullage losses ranging from 7 to 11 g/hr.

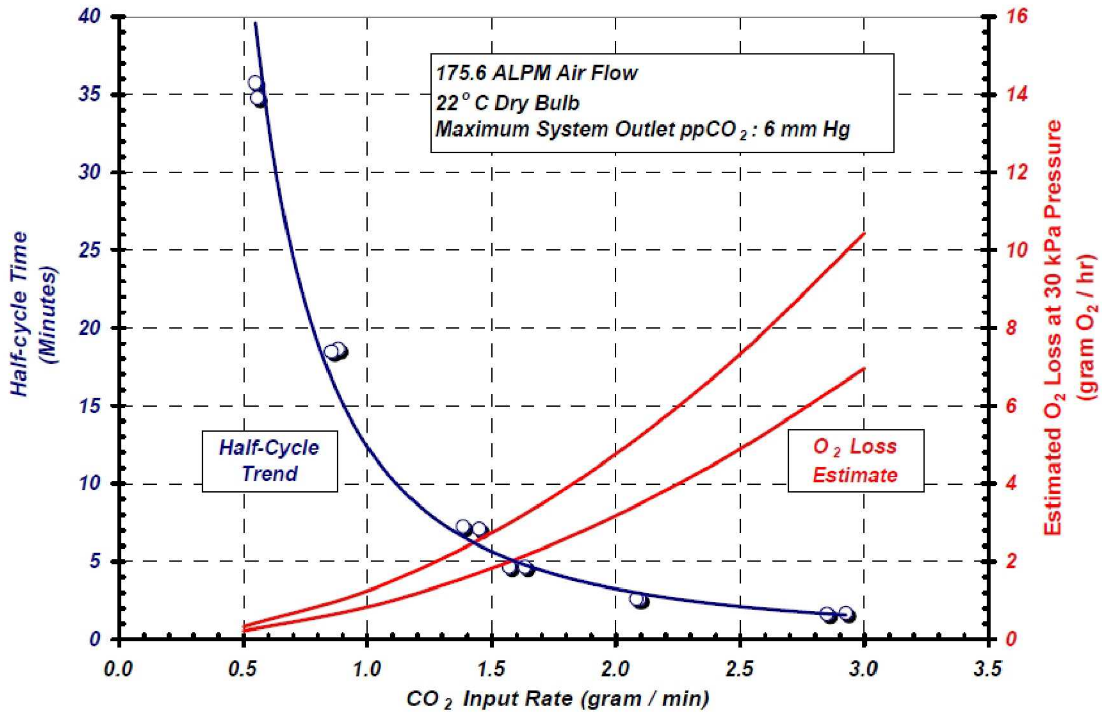

Figure 2: Required half-cycle time and corresponding ullage loss as a function of CO_2 input rate [12].

Carbon Dioxide (CO_2) Sensor Losses

The CO2 sensor (GS-311b) senses CO_2 levels entering the helmet and leaving the pressure garment via the Liquid Cooling and Ventilation Garment (LCVG) to indicate RCA scrubbing performance and determine crew metabolic rate [6]. Two small streams of ventilation flow are extracted from the ventilation loop, flow through the CO_2 sensor, and are then expelled to vacuum. Currently, the only estimate available for the O_2 losses through the CO_2 sensor is an order-of-magnitude approximation of 0.01 kg O_2 per 8-hr EVA [13].

Suit Leakage

Historically, even the best space suit designs leak since they are pressurized systems operating in a vacuum environment. When researching suit leakage throughout the history of the space suit, it was found that requirements exist for the *maximum* leakage for the space suit system but no requirements exist for a *minimum* leakage.

Table 2 shows data collected for suit leakage during the Apollo Program [14]. This information was used as a baseline for the suit leakage calculations in this study.

Table 2: Apollo Pre Flight Suit Leakage

Apollo PGA	Crewmember	Mission	Suit Pressure *(psia)*	Ambient Pressure *(psia)*	PreFlt Leakage *(sccm)*	Spec *(sccm)*
A7L-033	Collins	Apollo 11	18.47	14.72	60	180
A7L-077	Aldrin	Apollo 11	18.47	14.72	95	180
A7L-056	Armstrong	Apollo 11	18.47	14.72	50	180
A7L-066	Gordon	Apollo 12	18.47	14.72	55	180
A7L-067	Bean	Apollo 12	18.47	14.72	51	180
A7L-065	Conrad	Apollo 12	18.47	14.72	105	180
A7L-078	CDR	Apollo 13	18.47	14.72	80	180
A7L-061	LMP	Apollo 13	18.47	14.72	60	180
A7L-088	CMP	Apollo 13	18.47	14.72	130	180
A7L-090	CDR	Apollo 14	18.47	14.72	93	180
A7L-073	LMP	Apollo 14	18.47	14.72	90	180
A7L-085	CMP	Apollo 14	18.47	14.72	125	180

Mean Preflight leakage (sccm)	82.8333	
Max Preflight leakage (sccm)	130	
Min Preflight leakage (sccm)	50	
Mean-2sigma Leakage (sccm)	26.543	95% confidence
Mean-3sigma Leakage (sccm)	-1.60226	99% confidence

The current maximum allowable leak rate for the CSSS when pressurized to 4.8 psid (33 kPa-d) during lunar surface EVA is established by the CSSE ERD (requirement CSSE1000) [3] as 300 sccm.

Feasibility of Satisfying Trace Contaminant Requirements without a TCCS

A primary objective of this trade study is to examine the feasibility of removing the TCCS and relying on the semi-open nature of the PLSS ventilation loop. The ventilation loop is considered "semi-open" due to the deliberate expulsion of a portion of the ventilation gases from the system by the RCA and the CO_2 sensor. Suit leakage also contributes to the "opening" of the ventilation loop. The advantages of removing the TCCS from the PLSS include:

- Direct mass reduction – Approximately 0.45 kg (1 lbm) could be saved, assuming that the CxP PLSS TCCS mass is similar to the Shuttle EMU TCCS mass, as specified in the NASA EMU LSS/SSA Data Book [15].
- Secondary mass reduction – Removal of the TCCS from the ventilation flow path removes a source of pressure drop, which leads to a reduction of ventilation fan power and therefore the required battery mass. Depending on the magnitude of

the pressure drop reduction relative to the total ventilation system pressure drop, it may also be possible (though unlikely) to downsize the ventilation fan.

- Direct volume reduction – The TCCS is expected to occupy a currently-unknown volume within the PLSS that is anticipated to be small relative to other PLSS components.
- Secondary volume reduction – Battery and (possibly) fan volume reductions corresponding to the secondary mass reductions listed above will result from TCCS removal.
- Reduction in maintenance overhead – Removal of the TCCS eliminates the need to periodically replace the filter beds and maintain the associated connectors and plumbing.
- Increase in system reliability – Removal of the TCCS from the PLSS decreases the number of parts that can fail.
- Decrease in PLSS development and fabrication costs – The costs associated with designing, fabricating, and testing the TCCS would be eliminated if no TCCS is required.

For this investigation, an analysis was performed to determine the trace contaminant concentrations within the suit environment at the end of an 8 hour EVA using the as-designed ventilation gas losses (RCA ullage and CO_2 sensor losses) with and without an estimated average suit leak rate. Since the suit leakage is not a design feature, however, the selection criteria for whether or not to incorporate a TCCS should be based on a suit leak rate of 0 sccm, unless a specific exhaust port or orifice is added to the system to provide the required dilution (along with the added O_2 storage to accommodate the extra loss).

<u>Assumptions</u>

The trace contaminant post-EVA concentration analysis relies on the following assumptions.

- Oxygen loss via RCA venting is estimated to be 6 g/h. This is conservative compared to the 7 to 11 g/h range determined from Figure 2 for a 3 g/min CO_2 input rate.

Since the O_2 loss rate is very sensitive to half-cycle time, this conservative approach allows for the possibility that the half-cycle time is closer to 2 minutes.

- The rate of O_2 venting through the CO_2 sensor is approximately 0.01 kg O_2 per 8-hr EVA [13].
- The CSSS Configuration 2 leak rate is assumed equal to the average measured mean Apollo pre-flight value of 82.8 sccm.
- The suit environment contains no trace contaminants at the beginning of each EVA, so both the initial trace contaminant mass m_{ci} and concentration C_{ci} are equal to zero.
- The free volume V within the suit is equal to 2 ft^3 [13].
- The ratio f of contaminant mass m_c to O_2 mass m_o is identical at all O_2 venting locations (RCA, CO_2 sensor, and suit leak points).
- The mass generation (off-gasing) rate $\dot{m}_{cgen}$ of each trace contaminant is constant throughout the EVA duration.
- For cases in which a TCCS is present, the TCCS removal efficiency η_c of each contaminant species is a constant.

<u>Analysis</u>

According to mass conservation, the rate of change of each contaminant species mass m_c within the suit environment is equal to its generation rate $\dot{m}_{cgen}$ minus all losses. Thus,

$$\frac{dm_c}{dt} = \dot{m}_{cgen} - f\sum_i \dot{m}_{Li} \, , \qquad (1)$$

where

$$f \equiv \frac{m_c}{m_o}$$

and $\dot{m}_{Li}$ is the mass flow rate of O_2 exiting the ventilation system at due to the *i*th loss mechanism. The losses considered in this study include the RCA ullage $\dot{m}_{RCAo}$; the O_2 loss through the CO_2 sensor $\dot{m}_{CO_2}$; PGS leakage $\dot{m}_{PGSo}$; and TCCS adsorption $\eta_c \dot{m}_o$, where η_c is the TCCS contaminant removal efficiency and $\dot{m}_o$ is the O_2 mass flow rate into the TCCS. For the case where no TCCS is present, the contaminant removal efficiency η_c equals zero. Also, the PGS leakage rate $\dot{m}_{PGSo}$ can be set equal to zero whenever suit leakage effects are not to be considered. In the general case, the summation in equation (1) expands to

$$\sum_i \dot{m}_{Li} = \dot{m}_{PGSo} + \dot{m}_{RCAo} + \dot{m}_{CO2} + \eta_c \dot{m}_o . \tag{2}$$

Integration of equation (1) to find the total in-suit contaminant mass m_c at the end of an EVA of duration t yields

$$m_c = \dot{m}_{cgen}\tau - \left(\dot{m}_{cgen}\tau - m_{ci}\right)e^{-\frac{t}{\tau}}, \tag{3a}$$

where

$$\tau = \frac{m_o}{\sum_i \dot{m}_{Li}} . \tag{3b}$$

The contaminant concentration C_c, which is defined as the contaminant mass per unit volume V, is determined from the above result as follows:

$$C_c \equiv \frac{m_c}{V} = \frac{\dot{m}_{cgen}\tau}{V}\left(1 - e^{-\frac{t}{\tau}}\right) + \frac{m_{ci}}{V}e^{-\frac{t}{\tau}} \tag{4}$$

or

$$C_c = C_{cs}\left(1 - e^{-\frac{t}{\tau}}\right) + C_{ci}e^{-\frac{t}{\tau}}, \tag{5a}$$

where

$$C_{cs} \equiv \lim_{t\to\infty} C_c = \frac{\dot{m}_{cgen}\tau}{V} . \tag{5b}$$

The quantity C_{cs} is the steady-state concentration of the trace contaminant.

The calculation results for the trace contaminant concentrations at the end of an 8 hour EVA are shown in Table 3. The 24-hr SMAC limits are greatly exceeded by ammonia and slightly exceeded by formaldehyde. If an average suit leakage rate of 82.8 sccm is considered, the 8-hr formaldehyde concentration will not exceed the SMAC limit. However, the values obtained with zero suit leakage should be used for design purposes since the PGS design goal is to minimize suit leakage as much as possible.

Table 3: Calculated 8-hr Trace Contaminant Concentrations Obtained with No TCCS in Ventilation Loop

Chemical Name	Total Generation Rate (mg/8-hr EVA)	SMAC (mg/m^3)	8-hr Concentration* (mg/m^3) w/o Suit Leak	8-hr Concentration* (mg/m^3) w/ Suit Leak
Acetaldehyde	0.0267	10	0.181	0.104
Acetone	0.0445	500	0.301	0.173
Ammonia	83.3	14	564	324
n-Butanol	0.167	80	1.13	0.649
Carbon Monoxide	11.0	114	74.4	42.8
Ethyl alcohol	1.34	10,000	9.03	5.20
Formaldehyde	0.133	0.6	0.902	0.519
Furan	0.100	1	0.676	0.389
Hydrogen	16.7	340	113	64.9
Methyl alcohol	0.467	90	3.16	1.82
Methane	200	3,500	1,352	778
Toluene	0.201	60	1.36	0.781

* Highlighted values exceed SMAC concentrations.

Setting C_c equal to the SMAC ammonia requirement and numerically solving equations (2) through (5) for the PGS O_2 leakage rate $\dot{m}_{PGSo}$ reveals that 4,013 sccm of O_2 venting would be required, in addition to the RCA ullage and CO2 sensor losses, to reduce the 8-hour ammonia concentration to its 24-hr SMAC requirement. For an 8-hour EVA, this would require 2.22 kg (5.14 lbm) of O_2 storage beyond that which would otherwise be required to accommodate metabolic consumption, maximum allowable suit leakage, RCA ullage, and CO_2 sensor losses. The mass associated with expanding the O_2 tank capacity would also add to this increase. Since the extra O_2 needed to satisfy ammonia concentration requirements without a TCCS is significantly more massive than a 0.45 kg (1 lbm) TCCS, removal of the TCCS from the PLSS design is not recommended.

TCCS Sizing Calculations

Given that the comparison between the Shuttle EMU TCCS mass and the mass of extra O_2 needed to satisfy ammonia concentration requirements greatly favors the use of a TCCS, an initial estimate was calculated for the bed mass of a TCCS designed for Constellation EVA conditions and requirements. Since a TCCS bed material has not yet been selected for the CSSS PLSS and the available data for most of the candidates is limited, a 10%-phosphoric-acid-impregnated granular activated carbon (GAC) bed is assumed for initial sizing purposes. For this study, the TCCS bed is sized for the adsorption of ammonia (NH_3), which exceeds requirements more than any other trace contaminant, as shown in Table 3.

The sizing capacity ζ for the assumed bed material is 4.4 mg NH_3/g carbon, based on International Space Station (ISS) experience [16]. Additionally, sizing calculations performed for a Crew Exploration Vehicle (CEV) study [16] make use of a minimum residence time requirement t_{Ro} of 0.25 s, suggesting that this residence time is the minimum required to obtain a high or near-optimal capture efficiency. With the full PLSS ventilation flow passing through the TCCS, the residence time requirement would be the main driver in the sizing process and lead to a very large bed. To avoid an excessively large TCCS bed, the residence time requirement was relaxed, requiring the use of an assumed ammonia capture efficiency η_c degradation strategy to account for the low residence time effects. For purposes of this investigation, the ammonia capture efficiency η_c is assumed equal to 100% when this residence time t_R is greater than or equal to t_{Ro} = 0.25 s and decrease linearly to 0% as the residence time decreases to 0 s.

$$\eta_c = \frac{t_R}{t_{Ro}} \tag{6}$$

The residence time t_R is estimated from unused bed mass $m_{B,eff}$, GAC density ρ_B, and O_2 volume flow rate $\dot{V}_o$ as follows:

$$t_R = \frac{m_{B,eff}}{\rho_B \dot{V}}. \tag{7}$$

The unused bed mass is the total bed mass m_B minus the mass of bed material saturated with ammonia m_{cads}/ζ :

$$m_{B,eff} = m_B - \frac{m_{cads}}{\zeta}, \tag{8}$$

where m_{cads} is the total mass of contaminant (ammonia) adsorbed into the bed. Thus, the ammonia capture efficiency η_c is expressed as

$$\eta_c = \frac{m_B - \dfrac{m_{cads}}{\zeta}}{\rho_B \dot{V} t_{Ro}}. \tag{9}$$

For times t much larger than the time constant τ, the contaminant concentration C_c is approximately equal to the steady state contaminant concentration C_{cs}.

$$C_c \approx C_{cs} = \frac{\dot{m}_{cgen}\tau}{V} = \frac{\dot{m}_{cgen} m_o}{V\left(\sum_{i-1} \dot{m}_{Li} + \eta_c \dot{m}_o\right)} \tag{10}$$

The efficiency term is explicitly broken out of the summation term defined in equation (2). Similarly, the adsorbed contaminant mass m_{cads} is approximated as

$$m_{cads} \approx \eta_c \dot{V}_o C_{cs} t. \tag{11}$$

The adsorbent bed mass m_B required to provide trace contaminant control such that the in-suit ammonia concentration C_c is less than or equal to the SMAC ammonia concentration C_{SMAC} for duration t is found by combining equations (9), (10), and (11), yielding

$$m_B \approx \frac{1}{\zeta}\left[\dot{m}_{cgen} - C_{SMAC} V \left(\frac{\sum_{i-1} \dot{m}_{Li}}{m_o}\right)\right]\left(t + \frac{\zeta \rho_B t_{Ro}}{C_{SMAC}}\right). \tag{12}$$

The resulting bed mass estimates are plotted, without safety margins, in Figure 3. The bed mass ranges from 43.6 g for a single 8-hr EVA to 117.6 g for five 8-hr EVAs.

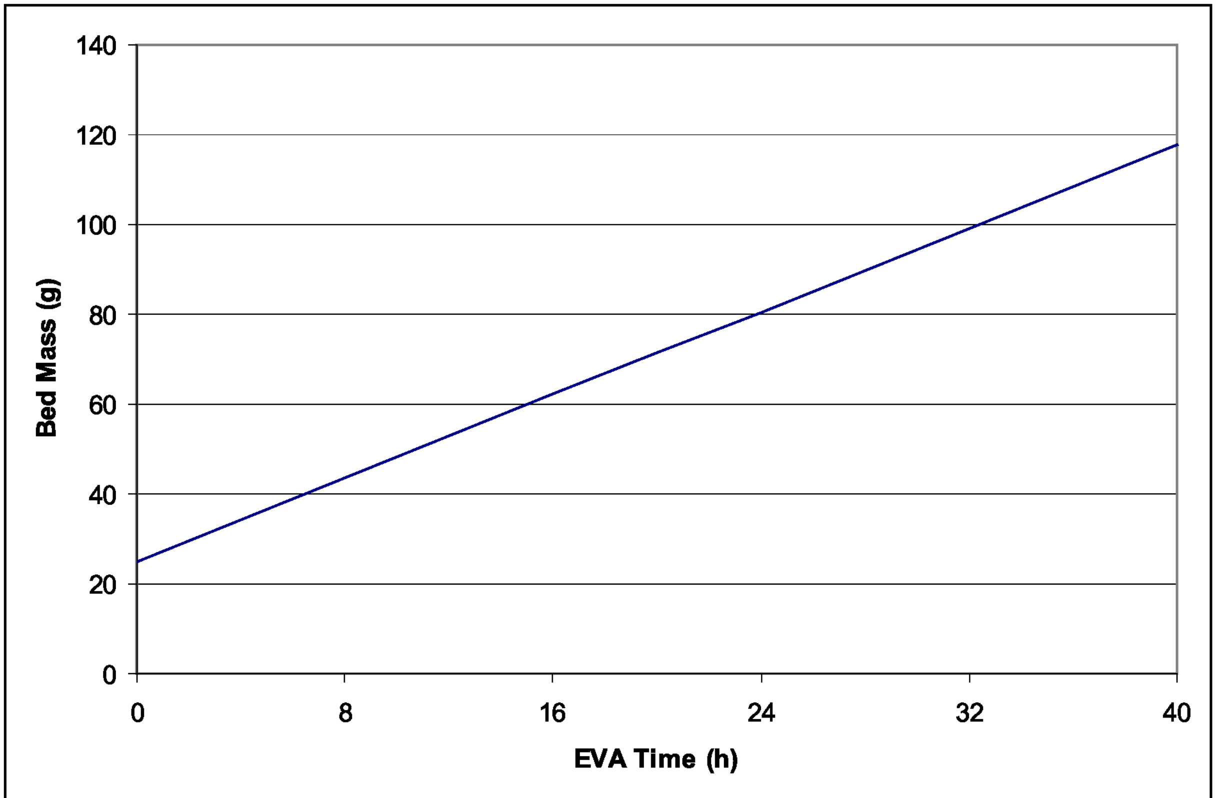

Figure 3: Estimated H_3PO_4 Impregnated GAC Bed Mass Required for Ammonia Treatment as a Function of EVA Time

Technology Development and Ongoing Research

Technology development for trace contaminant control technologies continues at several NASA centers and in industry and academia. Marshall Space Flight Center is working on a TCC sorbent that utilizes microlith-based absorbers for the Crew Exploration Vehicle (CEV). Testing was planned for the end of 2009, but due to delays in acquiring process monitoring instruments the testing began late. Therefore, results were not available prior to the completion of this study. The revised test completion date is May 2010. It is recommended that the PLSS ventilation subsystem team follow-up with the engineers at Marshall Space Flight Center to obtain the results.

Ames Research Center continues to evaluate carbon technologies. The primary focus of the evaluation is to find a carbon or zeolite that can be used for ammonia removal. This research is specific for vehicle applications, however the results could influence decisions on space suit TCCS design, particularly since ammonia is a contaminant anticipated to exceed allowable concentrations in the space suit system. The test involved both dry and humid flows, as well as a higher (50 ppm) and lower (25 ppm) ammonia feed load as the trace contaminant. The carbons were treated with either phosphoric acid, chloride, or nitrate. Overall the performance was highest when water vapor was in the ventilation flow, the ammonia levels were higher, and the carbon beds had larger mesh size. The number indicates the number of wires per inch of screen. Preliminary results show that the phosphoric acid carbons work the best. Figure 4 shows the initial data from the ammonia test with humidity [17].

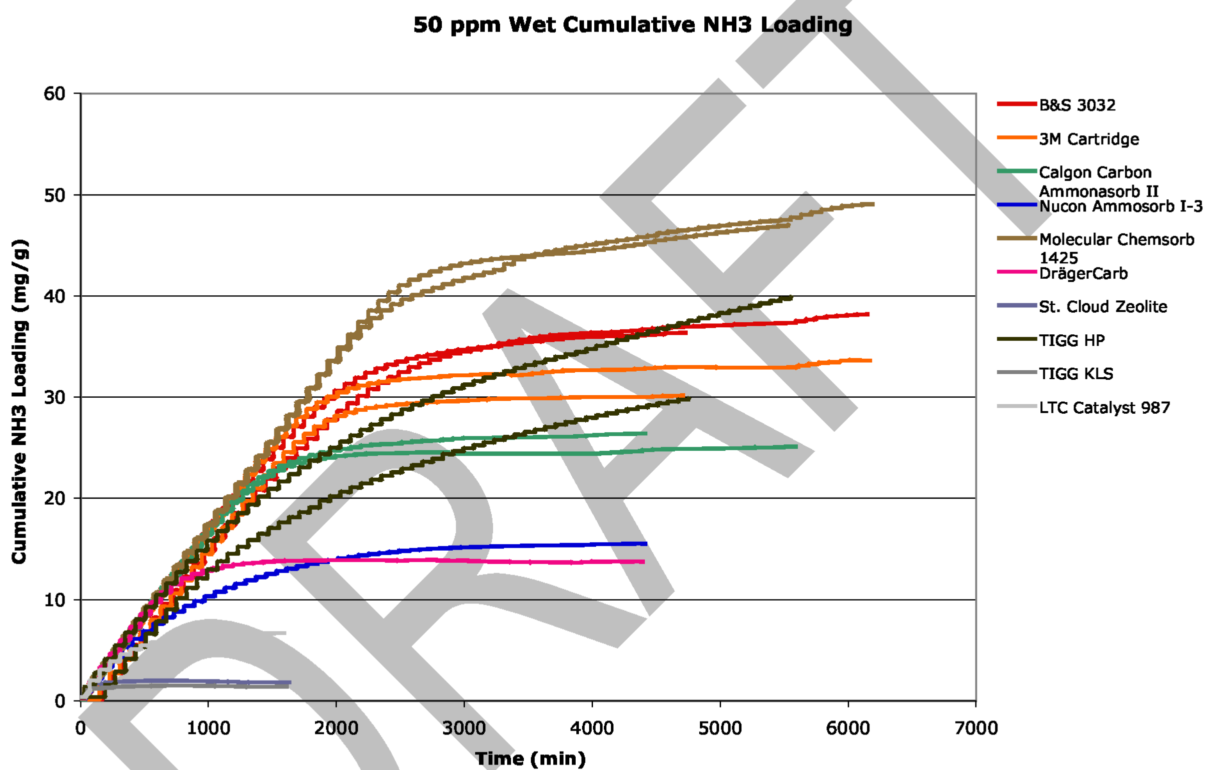

Figure 4: Ames Research Center Ammonia Scrubbing Test Results [16]

Conclusions and Recommendations

A review of the requirements and generation rates for trace contaminants in Configuration 2 of the Constellation Space Suit System has revealed no change from previously published data. The 0% scrubbing concentrations in section CSSE3038 of the CSSE EVA Requirements Document (ERD) CxP 72208 [3], however, should be updated to the values in

Table 3. As previously found, ammonia is the most prevalent trace contaminant, relative to maximum concentration requirements, followed by formaldehyde. The other contaminants generated in the suit system do not build up to toxic levels because of the ventilation effect of RCA ullage and CO_2 sensor losses.

An investigation of the effects of removing the TCCS from the PLSS schematic has shown that advantages do exist, but the extra O_2 mass required provides a significant enough mass penalty to recommend keeping the TCCS.

A preliminary sizing analysis based on ammonia removal using phosphoric acid impregnated granulated carbon shows that the required bed mass is a linear function of EVA time. Calculated bed mass results range from 43.6 g for a single 8-hr EVA to 117.6 g for five 8-hr EVAs.

Research continues for additional or alternative methods of trace contaminant removal within the Constellation Space Suit Portable Life Support System. The investigation at Ames Research Center for new TCCS materials seems promising, however further testing and evaluation is warranted before incorporating these materials into this TCCS.

It is recommended that all the research and continued technology development work be monitored for possible TCC use in the future. A considerable amount of work remains in selecting the best adsorbent material and studying its properties and performance.

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