# JSC/EC5 U.S. Spacesuit Knowledge Capture (KC) Series Synopsis

**All KC events will be approved for public using NASA Form 1676.**

*This synopsis provides information about the Knowledge Capture event below.*

**Topic** Constellation Spacesuit PLSS Trace Contaminant Control

**Date:** September 8, 2010 **Time:** unknown **Location:** JSC/B5S/R3204

**DAA 1676 Form #: 29692**

A PDF of the presentation is also attached to the DAA 1676 and this is a link to all lecture material and video: \\js-ea-fs-01\pd01\EC\Knowledge-Capture\FY10 Knowledge Capture\20100928_M. Jennings TCC\For 1676 Review & Public Release

*A copy of the video will be provided to NASA Center for AeroSpace Information (CASI) via the Agency's Large File Transfer (LFT), or by DVD using the USPS when the DAA 1676 review is complete.

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*For 1676 review use_Synopsis_Jennings & Waguespack_Constellation Spacesuit PLSS _9-8-2010.pdf*

**Presenters:** Mallory Jennings and Glenn Waguespack

**Synopsis**: This presentation summarized the results of a trade study that evaluated whether trace contaminant control within the Constellation Spacesuit PLSS could be achieved without a Trace Contaminant Control System (TCCS) by relying on suit leakage, ullage loss from the carbon dioxide and humidity control system, and other factors. Mallory Jennings and Dr. Glenn Waguespack studied trace contaminant generation rates to verify that values reflected the latest designs for Constellation spacesuit system pressure garment materials and PLSS hardware. They also calculated TCCS sizing and conducted a literature survey to review the latest developments in trace contaminant technologies.

**Biographies:** Mallory Jennings was graduated from Wichita State University in 2010 with a bachelor of science in mechanical engineering. She joined NASA as a cooperative education student with the Mission Operations Directorate (MOD) at JSC in 2007. She transitioned to EC5 in 2008 and spent four semesters working various projects with the ventilation subsystem of the PLSS. Jennings later served as a technology development engineer, working with various PLSS subsystems at JSC.

Dr. Glenn Waguespack was graduated from Louisiana State University in 1997 with a Ph.D. in mechanical engineering and a minor in physics. Subsequently, he spent six years working for Sempra Energy

Solutions developing energy performance projects for commercial, government, and educational building environmental systems. He joined the NASA team in 2005 as an employee of GeoControl Systems, Inc., working on the Jacobs Technology ESC. In this position, he supported spacecraft and spacesuit thermal and environmental analysis and development efforts at JSC.

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

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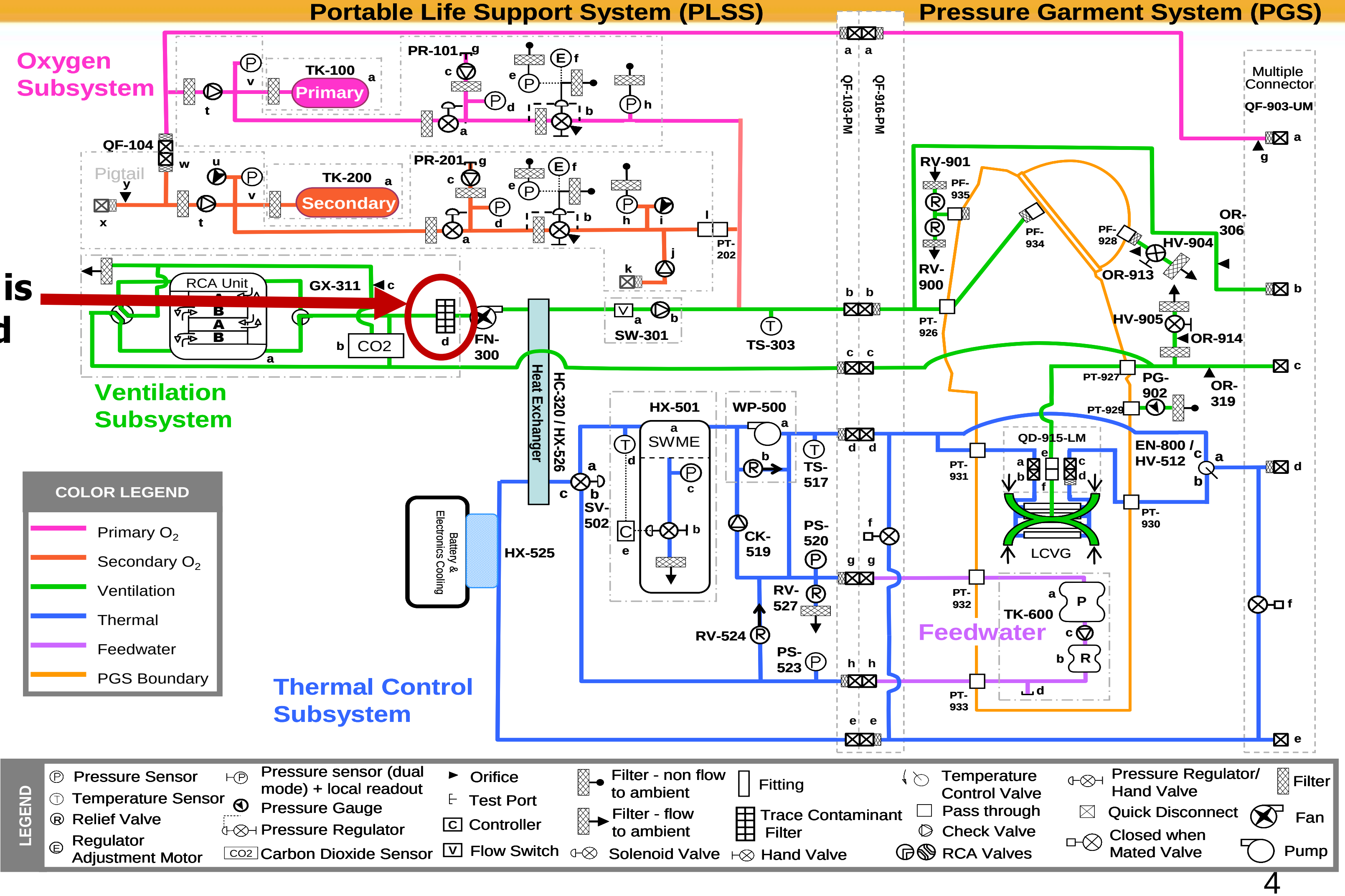
# Overview

- This paper is proceeded by the *Trace Contaminant Control (TCC) Trade Study Results (2009-01-2370)*
  - Set up TCC requirements, researched past and possible future technologies, and determined the feasibility of regeneration of TCCS
- The purpose of this study
  - Revisiting generation rates
  - Feasibility of Eliminating the TCC System (TCCS) from the Space Suit
    - Sources of Ventilation Gas Loss
    - Advantages of Removal of TCCS
    - Feasibility Analysis Assumptions
  - TCCS Sizing Calculation
  - Update on Prospective Technologies

# Introduction

- Portable Life Support System (PLSS) provides:
  - Ventilation loop which removes metabolically produced carbon dioxide, water, and trace contaminants as well providing makeup $O_2$ and thermal control
- Trace contaminants are produced by both crew metabolism and material/equipment off-gassing
  - Defined as a gaseous substance introduced into the Space Suit system
  - Can be hazardous to a crewmember's health with side effects ranging from headaches to heart damage depending on the exposure level and duration



**TCC System is located here**

Barnes, B., Conger, B., Leavitt, G., Autrey, D., and Wells, J., *Constellation Space Suit Element PLSS Baseline Schematics and Internal Interfaces*, Rev. B, JSC-65563, NASA, September 2009.

# Introduction

- A trade study conducted in 2008 evaluated the expected Space Suit PLSS ventilation loop trace contaminants with generation rates, Spacecraft Maximum Allowable Concentrations (SMAC), and adverse effects
- CSSE EVA Requirements Document (ERD) specified that the trace contaminant concentrations are not to exceed the 24-hr SMAC
- The generation rates were derived from data used during the development of the Extravehicular Mobility Unit (EMU) and data from a NASA White Sands Test Facility amine bed off-gassing test

# Contaminant Generation Rates

| | | **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**[†] | $CH_2O$ | 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

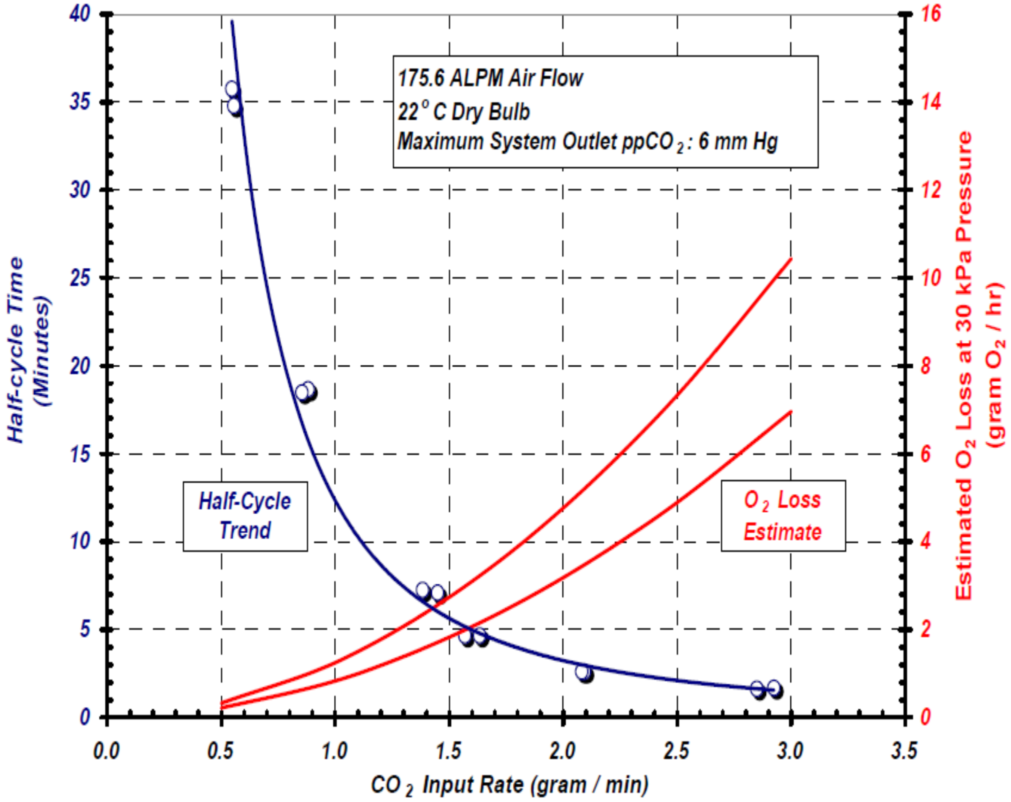
‡ Carboxyhemoglobin target

*Constellation Program Extravehicular (EVA) Systems Project Office (ESPO) Space Suit Element Requirements Document,* Rev.C.3, CxP 72208, NASA, September 22, 2009.

*Spacecraft Maximum Allowable Concentrations for Airborne Contaminants*, JSC-20584, NASA, November 2008.

# Sources of Ventilation Gas Loss

- Where we lose ventilation loop gas and trace contaminants. . .
  - Carbon Dioxide Sensor Losses
    - Approximated at 0.01 kg $O_2$ per 8-hr EVA
  - Suit Leakage
    - Approximated at 82.8 sccm from the Apollo data
  - RCA ullage



175.6 ALPM Air Flow
22° C Dry Bulb
Maximum System Outlet $ppCO_2$: 6 mm Hg

Papale, W., and Paul, H. L., "Development Status of an EVA-sized Cycling Amine Bed System for Space Suit Carbon Dioxide and Humidity Removal," 37th International Conference on Environmental Systems, 2007.

# Advantages of Removal of TCCS

- Direct Mass Reduction
  - Approximately 0.24 kg (0.53 lbm)
- Secondary Mass Reduction
  - Eliminates a source of pressure drop
  - Reduction of ventilation fan power
  - Reduction of the required battery mass
- Direct Volume Reduction
- Secondary Volume Reduction
- Reduction in maintenance overhead
- Increase in system reliability
- Decrease in PLSS development and fabrication costs

# Feasibility Analysis Assumptions

- The assumptions made during the trace contaminant post-EVA concentration analysis:
  - RCA cycle time is held constant
  - Oxygen loss from RCA venting ≈ 6 g/h
  - $O_2$ venting through the $CO_2$ sensor ≈ 0.01 kg per 8 hours
  - Pressure Garment System (PGS) leak rate = 82.8 sccm (Apollo pre-flight average)
  - The initial trace contaminant mass and the initial concentration = 0
  - The suit free volume is 2 $ft^3$
  - The ratio of contaminant mass to $O_2$ mass is identical at all leakage and ventilation locations
  - Each contaminant mass generation rate is constant throughout the EVA duration
  - TCCS removal efficiency of each contaminant is constant

# Trace Contaminant (TC) Concentration Analysis

## Mass Conservation

$$\frac{dm_c}{dt} = \dot{m}_{cgen} - \frac{m_c}{m_o}\sum_i \dot{m}_{Li}$$

where

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

$$\Downarrow$$

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

where

$$\tau = \frac{m_o}{\sum_i \dot{m}_{Li}}$$

| | |
|---|---|
| $C_c$ | TC concentration |
| $C_{ci}$ | Initial TC concentration (= 0) |
| $m_c$ | Total TC mass in suit |
| $m_o$ | Total $O_2$ mass in suit |
| $\dot{m}_{CO2}$ | $O_2$ leakage rate through $CO_2$ sensor |
| $\dot{m}_{cgen}$ | TC mass generation rate |
| $\dot{m}_o$ | $O_2$ mass flowrate through TCCS |
| $\dot{m}_{PGSo}$ | $O_2$ suit leakage |
| $\dot{m}_{RCAo}$ | RCA $O_2$ ullage |
| $\eta_c$ | TCCS capture efficiency (= 0) |
| $t$ | Time |
| $V$ | Suit internal gas volume |

# Feasibility Analysis Results

- Results at end of 8 hr EVA, no contaminants at the beginning

| | | | **8-hr Concentration*** *(mg/m$^3$)* | |
|---|---|---|---|---|
| **Chemical Name** | **Total Generation Rate** *(mg/8-hr EVA)* | **SMAC** *(mg/m$^3$)* | w/o Suit Leak | 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.

# TCCS Sizing Calculations

- The extra $O_2$ required to meet the $NH_3$ concentration requirements without a TCCS is 2.2 kg (5.14 lbm) over the $O_2$ normally lost due to ullage and leakage
- Initial TCCS size estimate was calculated for the bed mass of a TCCS design for Constellation EVA conditions & requirements

# TCCS Sizing Assumptions

- 10%-phosphoric-acid-impregnated Granular Activated Carbon (GAC) bed
- Sized for ammonia only
- Used ISS TCCS adsorption capacity

  (4.4 milligram ammonia/gram carbon)
- Ammonia capture efficiency equals 100% when residence time ≥ 0.25 s and varies linearly with residence time otherwise
- Residence time is determined by the unused bed volume and breathing gas volume flow rate

# TCCS Sizing Analysis

TC Capture Efficiency: $\eta_c \approx \begin{cases} \dfrac{t_R}{t_{Ro}} & \text{if} \quad t_R < t_{Ro} \\ 1 & \text{if} \quad t_R \geq t_{Ro} \end{cases}$

Residence Time: $t_R = \dfrac{V_{B,eff}}{\dot{V}_o}$

Unused Bed Volume: $V_{B,eff} = \dfrac{1}{\rho_B}\left(m_B - \dfrac{m_{cads}}{\zeta}\right)$

**If** $t >> \tau = \dfrac{m_o}{\dot{m}_{PGSo} + \dot{m}_{RCAo} + \dot{m}_{CO2} + \eta_c \dot{m}_o} = \dfrac{m_o}{\sum\limits_{j-1} \dot{m}_{Lj} + \eta_c \dot{m}_o}$ **then:**

TC Concentration: $C_c \approx \dfrac{\dot{m}_{cgen}\tau}{V}$

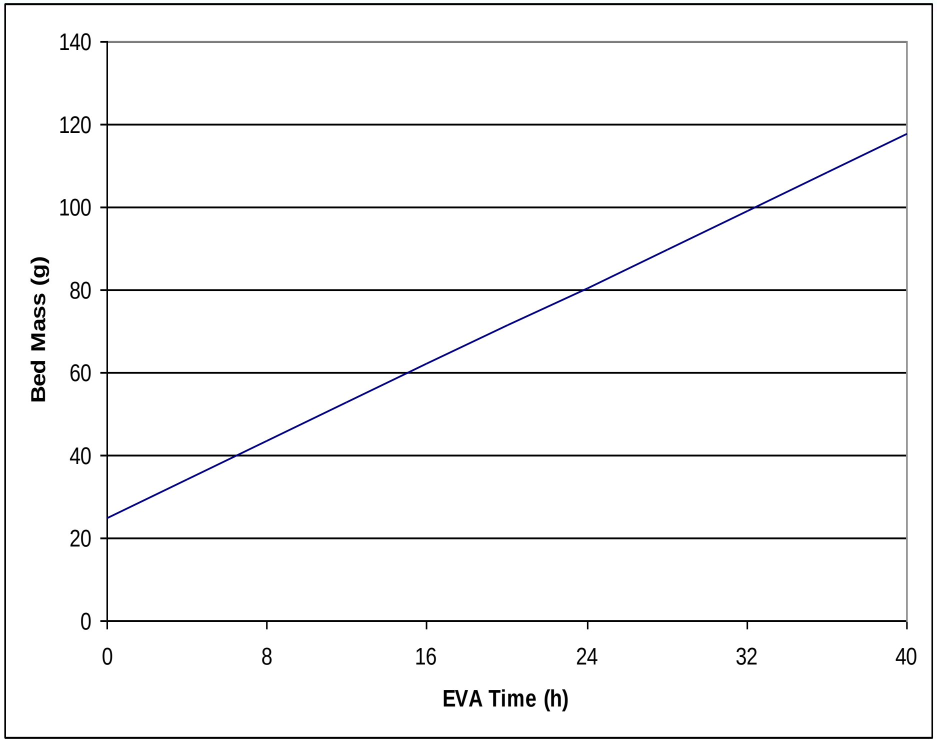
Total Adsorbed TC: $m_{cads} \approx \eta_c \dot{V}_o C_c t$

**Setting** $C_{cs} = C_{SMAC}$ **and solving for** $m_B$ **yields:**

$$m_B \approx \frac{1}{\zeta}\left[\dot{m}_{cgen} - C_{SMAC} V \left(\frac{\sum\limits_{j-1} \dot{m}_{Lj}}{m_o}\right)\right]\left(t + \frac{\zeta \rho_B t_{Ro}}{C_{SMAC}}\right)$$

| | |
|---|---|
| $C_c$ | TC concentration |
| $C_{SMAC}$ | TC maximum concentration limit |
| $m_B$ | TCC bed mass |
| $m_{cads}$ | Total adsorbed TC mass |
| $\dot{m}_{cgen}$ | TC mass generation rate |
| $\rho_B$ | TCC bed density |
| $\zeta$ | TC bed adsorption capacity (TC mass/bed mass) |
| $t$ | Time |
| $t_{Ro}$ | Minimum residence time for 100% capture |
| $V$ | Suit internal volume |
| $\dot{V}_o$ | $O_2$ volume flow rate through TCCS |

# TCCS Sizing Analysis Results



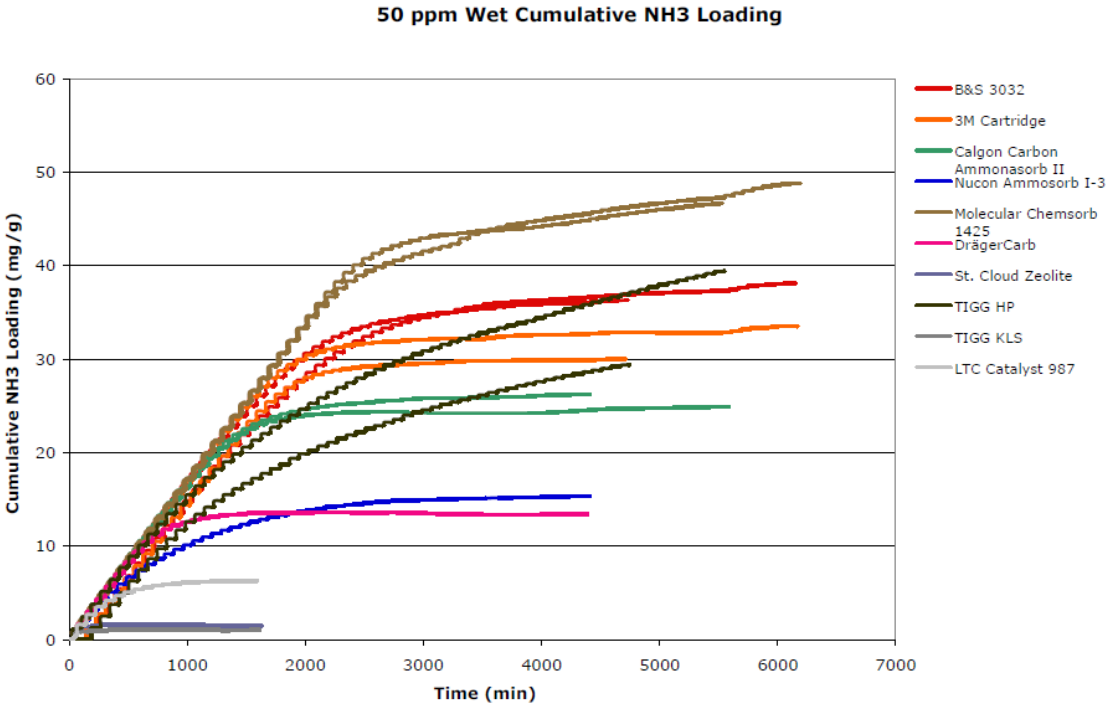
- Resulting bed mass estimates
  - 43.6 g for a single 8-hr EVA
  - 117.6 g for five 8-hr EVAs

- Refer to Perry, J. L., *Elements of Spacecraft Cabin Air Quality Control Design*, Marshall Space Flight Center, AL, NASA/TP-19980207978, 1998 for an alternate, well-tested approach to TCCS bed sizing that includes accommodations for multiple contaminant species.

# Tech Development and Continued Research

- NASA Marshall Space Flight Center
  - Microlith-based absorbers
- NASA Ames Research Center
  - Carbon or Zeolite to remove ammonia
  - Research is specific for vehicle applications

**Ames Research Center Ammonia Scrubbing Test Results**



# Conclusions and Recommendations

- Generation rates for trace contaminants revealed no change from previously published data
- Ammonia found to greatly exceed the 24-hr SMAC limits
- TCCS is required for the suit
- The bed mass is 43.6 grams for 8 hr EVA
- The sizing evaluation will need to be expanded and updated for the RCA cycle time
- Research continues at several NASA centers and should be followed as it progresses

# Questions?

# Backup Slides

The World's Forum for Aerospace Leadership

# TC Concentration Analysis Derivation 1

Mass Continuity

$$\frac{dm_c}{dt} = \dot{m}_{cgen} - \frac{m_c}{m_o} \sum_j \dot{m}_{Lj}$$

where

$$\sum_j \dot{m}_{Lj} = \dot{m}_{PGSo} + \dot{m}_{RCAo} + \dot{m}_{CO_2} + \eta_c \dot{m}_o$$

All variables are assumed constant except $m_c$

Separating variables and formulating integral:

$$\int_{m_{ci}}^{m_c} \frac{dm_c}{\dot{m}_{cgen} - \frac{m_c}{m_o} \sum_j \dot{m}_{Lj}} = \int_0^t dt$$

# TC Concentration Analysis Derivation 2

Substituting variables: $u = \dot{m}_{cgen} - \frac{m_c}{m_o}\sum_j \dot{m}_{Lj}$ ⇒ $du = -\frac{dm_c}{m_o}\sum_j \dot{m}_{Lj}$

⇓

$$-\frac{m_o}{\sum_j \dot{m}_{Lj}} \int_{\dot{m}_{cgen}-\frac{m_{ci}}{m_o}\sum_j \dot{m}_{Lj}}^{\dot{m}_{cgen}-\frac{m_c}{m_o}\sum_j \dot{m}_{Lj}} \frac{du}{u} = \int_0^t dt$$

Integration yields:

$$-\frac{m_o}{\sum_j \dot{m}_{Lj}} \ln\left(\frac{\dot{m}_{cgen} - \frac{m_c}{m_o}\sum_j \dot{m}_{Lj}}{\dot{m}_{cgen} - \frac{m_{ci}}{m_o}\sum_j \dot{m}_{Lj}}\right) = t$$

# TC Concentration Analysis Derivation 3

Simplifying the solution yields:

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

where

$$\tau = \frac{m_o}{\sum_j \dot{m}_{Lj}}$$

or, in terms of concentrations:

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

where

$$C_{ci} = \frac{m_{ci}}{V}$$