

Status of the International Space Station (ISS) Trace Contaminant Control System

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ABSTRACT

A habitable atmosphere is a fundamental requirement for human spaceflight. To meet this requirement, the cabin atmosphere must be constantly scrubbed to maintain human life and system functionality. The primary system for atmospheric scrubbing of the US on-orbit segment (USOS) of the *International Space Station* (ISS) is the Trace Contaminant Control System (TCCS). As part of the Environmental Control and Life Support Systems' (ECLSS) atmosphere revitalization rack in the US Lab, the TCCS operates continuously, scrubbing trace contaminants generated primarily by two sources: the metabolic off-gassing of crew members and the off-gassing of equipment in the ISS. It has been online for approximately 95% of the time since activated in February 2001. The TCCS is comprised of a charcoal bed, a catalytic oxidizer, and a lithium hydroxide post-sorbent bed, all of which are designed to be replaced on-orbit when necessary. In 2006, all three beds were replaced following an observed increase in the system resistance that occurred over a period several months. The beds were returned to ground and subjected to a test, teardown and evaluation (TT&E) to investigate the root cause(s) of the decrease in flow rate through the system. In addition, various chemical and physical analyses of the bed materials were performed to determine contaminant loading and any changes in

performance. This paper will mainly focus on the results of these analyses and how this correlates with what has been observed from archival sampling and on-orbit events. This has provided insight into the future performance of the TCCS and rate of change for orbital replacement units in the TCCS.

INTRODUCTION

The design of an ISS cabin trace contaminant control system must be designed within the confines of the air quality standard. In this case, that standard is the Spacecraft Maximum Allowable Concentration (SMAC) which is set for each contaminant by NASA Toxicology in conjunction with the National Research Council of the National Academy of Sciences. Other elements affecting cabin air quality, such as, materials selection and control, hardware design, manufacturing processes, chemical process design, mission characteristics as well as crew size and activities must conform within the constraints of the air quality standards as well. Any of these can negatively impact cabin atmospheric quality, the Environmental and Life Support (ECLS) system equipment, or both. Selecting chemicals for use on board a spacecraft were subjected to a complete assessment by ECLS engineering to ensure any

potential impacts to the cabin environment, as well as the ECLS system equipment, are negligible.

Standard design practice requires a conservative approach. The active contamination control system must perform its function unassisted by any other systems or processes in the cabin since the data necessary to fully validate its design is preceded by its specification. Systems and processes such as overboard atmospheric leakage, CO₂ removal and humidity control were not considered during the design and validation of the active trace contaminant control equipment. To maintain consistency and to ensure system health, all new contamination loads are assessed in the same manner.

For the *ISS*, the key design requirements pertaining to trace contaminant control design and performance are found in the *ISS* System Specification (SSP-41000Y), the USOS Specification (SSP-41162AN), and the U.S. Laboratory Prime-Item Development Specification or PIDS (S683-29523P). These requirements state that trace contaminants shall be controlled to less than their respective SMAC for normal equipment off gassing and crew metabolic load. More specifically, the U.S. Laboratory PIDS requires that the trace contaminant control subassembly (TCCS) maintain trace atmospheric component concentration from normal equipment off gassing and crew metabolic processes to less than 90% of individual contaminant SMACs. These design specifications are for the active contamination control systems operating without assistance from other ECLS processes or overboard leakage. It is also important to note that they do not specify that the active contamination control systems on board the *ISS* must be designed to accommodate chronic, fugitive leaks from other systems, payloads, or docked vehicles nor do they specify that these systems' performance must be verified for such an additional contamination loading. Further, these requirements do not authorize using the active contamination control systems as hazard controls for other onboard systems, payloads, or docked vehicles. Table 1 lists the average concentration of typical contaminants found in the *ISS* atmosphere and their respective SMACs. Also listed are their respective Russian Limiting Permissible Concentrations (LPCs) for comparison. The concentrations listed are the result of analyses of grab sample containers used to sample the *ISS* atmosphere at certain points in time. It is important to note that these concentrations are attributed to not only to the scrubbing of the USOS TCCS but also of the USOS Carbon Dioxide Removal Assembly (CDRA), humidity condensate, Russian micro-purification system CBMP, and overboard leakage.

TRACE CONTAMINANT CONTROL SYSTEM IN US LAB

The TCCS in the US Lab of *ISS* was first commissioned in 13-February-2001. The 3-bed system was designed to control trace contaminants in the *ISS* habitable

volume containing approximately 75,000kg of equipment and up to six crew members. The TCCS employs a three-pronged approach to the maintenance of the *ISS* atmosphere: physical adsorption, thermal catalytic oxidation, and chemical adsorption. Most of the various types of contaminants found in the *ISS* atmosphere are physically adsorbed in the charcoal bed assembly (CBA) which contains granular activated charcoal treated with approximately 10% phosphoric acid for ammonia removal. Contaminants such as highly volatile, low-molecular weight compounds are typically poorly adsorbed onto the activated charcoal surface. These compounds will eventually pass through the CBA as other larger, less volatile contaminants are adsorbed from the flow stream. Contaminants not easily removed by the CBA undergo thermal catalytic oxidation in the catalytic oxidizer assembly (COA). Using a bed of palladium-supported catalyst pellets and operating at a temperature of 400°C, the COA catalytically oxidizes contaminants to carbon dioxide and water. Halogen-containing compounds have the potential to form acid gases such as hydrochloric acid, hydrofluoric acid, and hydrobromic acid, during the course of catalytic oxidation. These acids are highly corrosive and are irritants to soft tissue, e.g. eyes and mucosal membranes of the respiratory system, even at very low concentrations. As these oxidation products leave the COA, a bed of granular, anhydrous lithium hydroxide in the sorbet bed assembly (SBA) chemical adsorb the carbon dioxide, water, and acid gases prior to releasing the flow stream back into the cabin atmosphere. Each bed is an orbital-replacement unit (ORU).

The initial service interval for the CBA and SBA were set to 90 days, and 1 year for the COA. Based on further analysis and testing of poisoning-effects on catalyst activity the service interval of the COA was extended to a little more than 2.5 years. Ensuing analyses of the levels of halogenated compounds in the *ISS* atmosphere and their effects on the catalytic activity of the COA further extended the service interval of the SBA to just over 3.5 years. Engineering analysis as well as system-level testing accounting for the assist provided in *ISS* atmosphere scrubbing by humidity condensate, extended the service interval for the CBA to just over 1 year.

The CBA installed in the TCCS when first activated in the US Lab in February 2001, was returned to ground after approximately 14 months of service. During this time, the TCCS was operational 74% of the time, with the other 26% of the time devoted to in-service hours. It was returned to NASA Kennedy Space Center on STS-111/ULF-2 in June 2002. Samples for analysis were obtained in four, different quadrants per level, plus a center sample. A total of five different layers were sampled, each layer at a specified depth. Based on the analyzed ammonia loading and volatile organic compound loading, and the prevailing archival sampling data of the *ISS* atmosphere, the service interval was further increased

Halocarbons	mg/m³ (ppm)	US 180- day SMAC (mg/m³)	Russian 360-day LPC (mg/m³)
Dichlorodifluoromethane (Freon 12)	0.04 (0.008)	470	150
Dichloromethane (Methylene Chloride)	0.134 (0.039)	10	5.0
1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113)	0.034 (0.004)	400	
Octafluoropropane (Perfluoropropane, (Freon 218)	43.3 (5.64)	85,000	150
Bromotrifluoromethane (Halon 1301)	0.050 (0.008)	11,000	
Aldehydes			
Acetaldehyde	0.342 (0.190)	4	1.0
Propanal	0.047 (0.020)	4 - 8	1.0
Propenal (Acrolein)	0.018 (0.008)	0.03	0.02
Butanal (Butyraldehyde)	0.042 (0.014)	4 - 8	1.0
Pentanal	0.031 (0.009)	4 - 8	1.0
Alcohols			
Methanol	0.809 (0.617)	9	0.2
Ethanol	4.25 (2.26)	2000	10.0
Isopropanol	0.271 (0.110)	150	1.5
n-Butanol	0.173 (0.057)	40	0.8
Ketones			
Acetone	0.324 (0.136)	50	2.0
2-Butanone (Methyl Ethyl Ketone)	0.065 (0.022)	30	0.25
Cyclohexanone	0.047 (0.012)		1.3
Esters			
Ethyl acetate	0.051 (0.014)		4.0
Butyl acetate	0.034 (0.007)		2.0
Aromatic			
Benzene	0.027 (0.009)	0.2	0.2 (180-d)
Toluene	0.070 (0.018)	60	8.0
m-Xylene and p-Xylene	0.040 (0.009)	220	5.0
o-Xylene	0.090 (0.021)	220	5.0
Siloxanes			
Octamethylcyclotetrasiloxane	1.167 (0.096)	12	0.2
Decamethylcyclopentasiloxane	0.827 (0.055)	15	0.2
Hexamethylcyclotrisiloxane	1.732 (0.190)	9	0.2
Methane	15.7 (23.9)	3800	3300
Hydrogen	1.28 (15.5)	340	1600
Carbon Monoxide	0.302 (0.264)	10	5.0

Table 1. Contaminants nominally found in the ISS atmosphere and the average concentration in mg/m³ and ppm. Concentration data for these compounds were collected from December 1998 to June 2008 by grab sampling containers. Average concentration for octafluoropropane excludes off-nominal concentrations from 2001-2002, but does include off-nominal concentrations experienced in May 2008. US 180-day Spacecraft Maximum Allowable Concentrations (SMAC) were obtained from JSC 20584. Russian 360-day Limiting Permissible Concentrations (LPC) were obtained from Russian State Standard GOST P50804-95.