NASA/TM—2007–214964

Living Together in Space: The International Space Station Internal Active Thermal Control System Issues and Solutions—Sustaining Engineering Activities at the Marshall Space Flight Center From 1998 to 2005

P.O. Wieland and M.C. Roman
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

L. Miller
JE Sverdrup, Huntsville, Alabama

June 2007

The NASA STI Program…in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>

- E-mail your question via the Internet to <help@sti.nasa.gov>

- Fax your question to the NASA STI Help Desk at 301–621–0134

- Phone the NASA STI Help Desk at 301–621–0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076–1320

NASA/TM—2007–214964

Living Together in Space: The International Space Station Internal Active Thermal Control System Issues and Solutions—Sustaining Engineering Activities at the Marshall Space Flight Center From 1998 to 2005

P.O. Wieland and M.C. Roman
Marshall Space Flight Center, Marshall Space Flight Center, Alabama

L. Miller
JE Sverdrup, Huntsville, Alabama

National Aeronautics and
Space Administration

Marshall Space Flight Center • MSFC, Alabama 35812

June 2007

Acknowledgments

The internal thermal control system sustaining engineering activities described in this Technical Memorandum require the efforts of many people. The design, development, preparation, assembly, operation, and documentation of the facility involved civil service and contractor personnel. The people involved in constructing the facilities, performing the testing, evaluating the results, and preparing this document and other documentation concerning the IATCS simulator facilities include: George William Barnett, Kenneth Frederick, Gene Hartsfield, and David Webb (EV52); Jay Perry (EV51); Mike Holt (ED25); James Fish, Thomas Williams, Paul Fisher, Russ Nagel, and Mark Etheridge (Sverdrup); Patrick Fulda and James Tatara (Qualis); Kurt Everhart (ERC); David Howard (Ion); Robert Carothers, Charles R. Cooper, Robert A. Jones, and Robert McCormick (Allied); Jamie Miernik, Thomas Ibarra, Samuel Woodward, Harold Cole, Steven Daugherty, John Golden, Natalee Weir, Alan Buitekant, and Dwight Link (Boeing); H. Danielle Hawk (SHARP student), and John Lowery and Amos Glenn (ASRI). Many documents and drawings of the flight IATCS components were provided by Gene Barton and Teresa Busby (Boeing).

TRADEMARKS

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076–1320
301–621–0390

This report is also available in electronic form at
<https://www2.sti.nasa.gov>

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF ACRONYMS AND SYMBOLS

AAA	avionics air assembly
ACOMC	assembly, checkout, operations, maintenance, and configuration procedures
Ag^+	silver ions, used as a antimicrobial in the HTF
Ag_3PO_4	silver phosphate (used in powder form)
ARIS	active rack isolation system
ATCS	active thermal control system (refers to Boeing Brassboard facility)
CCAA	common cabin air assembly
C&DH	command and data handling
CFST	cold plate/fluid stability test
CFU	colony forming unit (measure of bacterial populations)
CO_2	carbon dioxide
COTS	commercial off-the-shelf
CSCI	computer software configuration item
CTB	central thermal bus
DI	deionized
DO	dissolved oxygen
ECLS	environmental control and life support
ECLSS	environmental control and life support system
EDA	engineering development article
EDS	energy dispersion x-ray spectroscopy

LIST OF ACRONYMS AND SYMBOLS (Continued)

GNR	Gram-negative rod (bacteria)
H_2O_2	hydrogen peroxide (antimicrobial)
HLS	heat load simulation
HMS	habitat module simulator
HTF	heat transport fluid
HTL	high-temperature loop
HX	heat exchanger
INIK	internal active thermal control system NaOH injection kit
IPA	isopropyl alcohol (antimicrobial)
ISPR	International Standard Payload Rack
ISS	International Space Station
IATCS	internal active thermal control system
ITS	integrated truss segment
JSC	Johnson Space Center
KSC	Kennedy Space Center
LAC	rack location in the ceiling of the lab (now LAO)
LAD	rack location in the deck (or floor) of the lab (formerly LAF)
LAF	rack location in the floor of the lab (now LAD)
LAO	rack location overhead (in the ceiling) of the lab (formerly LAC)
LAP	rack location on the port side of the lab
LAS	rack location on the starboard side of the lab

LIST OF ACRONYMS AND SYMBOLS (Continued)

LCA	loop crossover assembly
LMS	lab module simulator
LTL	low-temperature loop
MDM	multiplexer-demultiplexer
MFCV	manual flow control valve
MOD	Mission Operations Directorate (at JSC)
MSFC	Marshall Space Flight Center
MSS	mobile system services
MTL	moderate-temperature loop
NaOH	sodium hydroxide
NH_3	ammonia
Ni	nickel
$Ni(OH)_2$	nickel hydroxide
NSB	nonsensitivity band
ORU	orbital replaceable unit
PACRATS	payloads and components real-time automated test system
PMC	pump motor controller
PPA	pump package assembly
PTFE	polytetrafluoroethylene
R2A	media for growing bacteria for viable microbial counts
RFCA	rack flow control assembly

LIST OF ACRONYMS AND SYMBOLS (Continued)

SEM	scanning electron microscopy
SFCA	system flow control assembly
SPCU	special performance checkout unit (heat exchanger for servicing spacesuits)
SPRT	system problem resolution team
ss	stainless steel
TCS	thermal control system
THCS	temperature and humidity control subsystem
TIC	total inorganic carbon
TOC	total organic carbon
TM	Technical Memorandum
TWMV	three-way mixing valve
UIP	utility interface panel
USL	United States Laboratory Module (Destiny)
ΔP	delta pressure

Microorganisms

Aa	*Acidovorax avenae*
Ad	*Acidovorax delafieldii*
Af	*Acidovorax facilis*
Ak	*Acidovorax konjaci*
Al	*Acinetobacter lwoffii/genospecies 9*

Microorganisms (Continued)

At	*Acidovorax temperans*
Bc	*Brevibacterium casei*
Bg	*Burkholderia glumae*
Bv	*Brevundimonas vesicularis*
Ca	*Comamonas acidovorans*
Da	*Delftia sp.*
Fr	*Flavobacterium resinovorum*
Jl	*Janthinobacterium lividum*
Ospecies	*Oligella* species
Re	*Ralstonia eutropha* (very similar genetically to *R. paucula*)
Rp	*Ralstonia pickettii*
Rpa	*Ralstonia paucula*
Sm	*Stenotrophomonas maltophilia*
Sp	*Sphingomonas paucimobilis*
Ss	*Sphingobacterium spiritovorum*
UNFGNR	unidentified nonfermenting Gram-negative rod
Vp	*Variovorax paradoxus*

TECHNICAL MEMORANDUM

LIVING TOGETHER IN SPACE: THE INTERNATIONAL SPACE STATION INTERNAL ACTIVE THERMAL CONTROL SYSTEM ISSUES AND SOLUTIONS—SUSTAINING ENGINEERING ACTIVITIES AT THE MARSHALL SPACE FLIGHT CENTER FROM 1998 TO 2005

1. INTRODUCTION

On board the International Space Station (ISS), heat is generated by the equipment and the crew. This heat contributes to the overall thermal load on the cabin environment and must be removed in order to maintain a comfortable working environment for the crew and to prevent equipment overheating. The thermal control system collects excess heat directly from equipment via conduction to cold plates and internal cooling, and indirectly by removing heat from the atmosphere through forced convection and an air-liquid heat exchanger (HX) of the temperature and humidity control subsystem (THCS) of the environmental control and life support system (ECLSS). The thermal control system consists of two distinct sections: (1) An internal section that uses an aqueous solution as the working fluid, or heat transport fluid (HTF), to acquire heat; and (2) an external section that uses ammonia (NH_3) as the working fluid to release heat to space via radiation. These two sections interact through liquid-liquid HXs that transfer heat while maintaining the physical separation of the different fluids. The internal section (with the aqueous HTF), called the internal active thermal control system (IATCS), consists of two loops that can be independently operated as a low-temperature loop (LTL), 3.3 to 5.5 ºC (38 to 42 ºF), and a moderate-temperature loop (MTL), 16.1 to 18.3 ºC (61 to 65 ºF). These loops can also be operated in single-loop mode using the loop-crossover assembly (LCA) while maintaining their respective temperature ranges. A schematic of the IATCS in the Lab Module, Destiny, (Fig. 1) shows the LTL, MTL, LCA, and other major components. The locations of the heat loads in the racks, endcones, and adjacent modules are also indicated. The coolant loop to node 1, branching from the MTL, is also shown. Not shown is a loop to the cupola that branches from the node 1 MTL and is referred to as the high temperature loop (HTL). The HTL operates over a temperature range of 17.2 to 32.2 ºC (63 to 90 ºF) and is primarily for preventing condensation on the cupola structure and windows. More detailed information on the IATCS design and operation is available in the "Architecture Control Document, Volume 6: U.S. Lab Thermal Control System" and the "Thermal Control Subsystem, Architecture Description Document, Volume 2."[1,2]

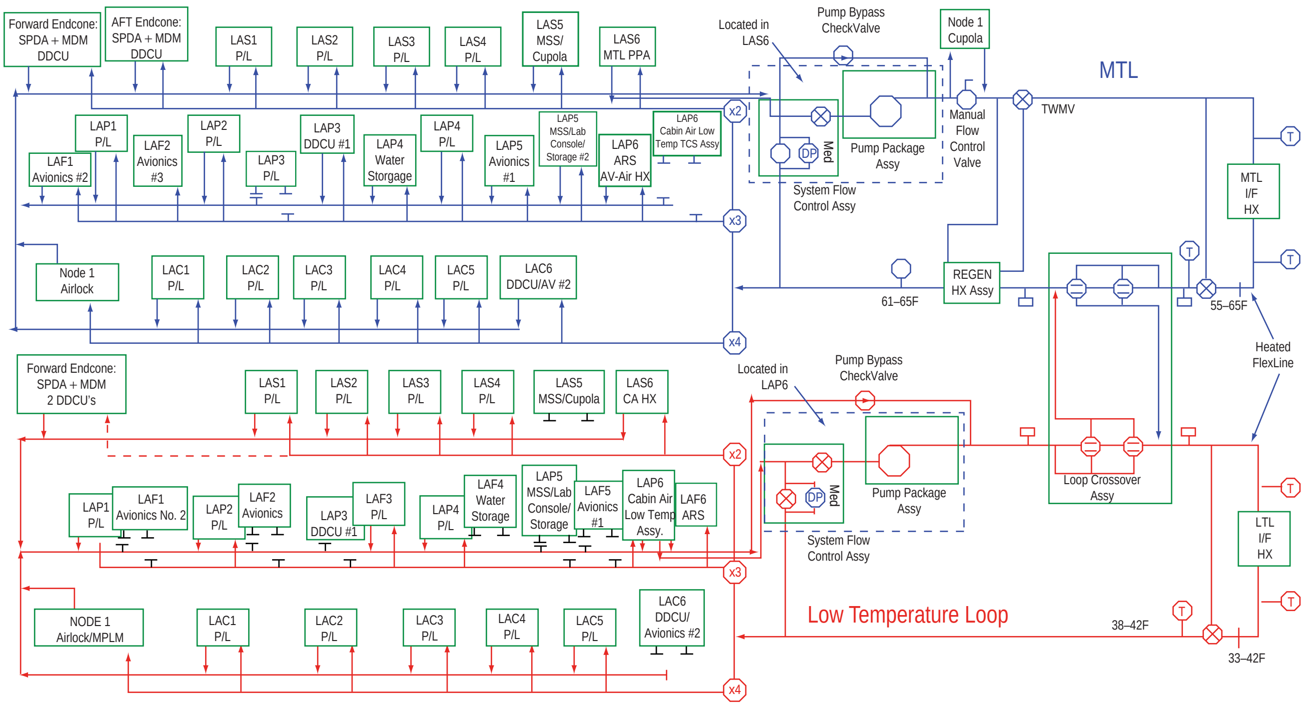


Figure 1. Schematic of the Destiny IATCS.

In 1998 at the direction of the ISS Program Office as part of the sustaining engineering effort, work was initiated to construct ground test facilities at the Marshall Space Flight Center (MSFC) to support the flight program by addressing issues and aiding in devising solutions.[3] This Technical Memorandum (TM) describes the development and use of the IATCS test facilities at the MSFC from 1998 to 2005. The design of the facilities, the similarities and differences with the flight IATCS, the testing capabilities, and results of testing that has been performed through 2004 to address flight issues are described, with references for further information.[4,5]

2. MARSHALL SPACE FLIGHT CENTER INTERNAL ACTIVE THERMAL CONTROL SYSTEM FACILITIES

MSFC supports the ISS program needs related to IATCS with two test beds that simulate specific aspects of the IATCS and additional capability to perform tests to address specific questions that arise. The facilities include a full-scale functional simulator of the Destiny module IATCS designed to have the same fluid flow, heat transport, and operational characteristics; a subscale IATCS Simulator, called the Cold Plate/Fluid Stability Test (CFST) facility, designed to predict the effects of material interactions; and other facilities suitable for specialized testing.

2.1 Full-Scale Destiny Module Functional Internal Active Thermal Control System Simulator

To support operations on board the ISS, beginning in 1998, a full-scale facility simulating the IATCS in the Destiny module was constructed at MSFC. In early 2001, the LTL was completed and validated prior to flight 5A when Destiny was launched, and in 2003, the MTL was completed and validated. This facility simulates the flow and thermal characteristics and has a control interface that simulates the control characteristics of the flight IATCS using the same algorithms as for the flight system software.[6–9] While not originally intended for testing related to fluid chemistry or for training astronauts, the facility was designed to be adaptable and has been used for both purposes. The facility operating procedure is presented in appendix A.1.

2.1.1 Technical Data

The full-scale IATCS Simulator is designed to match the following characteristics of the Destiny IATCS, which are defined in table 1.

The HTF formula used in the IATCS is intended to minimize corrosion and microbial growth, as well as to efficiently transport heat. The HTF is prepared by Boeing in their Huntsville lab and provided in 19 L (5 gal) cubitainers, collapsible plastic water containers delivered in cubic cardboard boxes. The formula is listed in SSP-30573 and summarized in table 2.[10]

To inhibit microbial growth, silver (Ag) was included in the formula. The amount of Ag dissolved in the HTF quickly decreases (within hours) due to deposition on metallic surfaces, so the “as-circulated-in-flight hardware” concentration is not specified. (Issues related to antimicrobial agents are discussed in sec. 3.7.) The HTF was formulated to have a pH of 9.5 ± 0.5 on orbit and chemical buffers are included to mitigate variations. However, during the first year of operation, the pH dropped to ≈8.4 as carbonic acid was formed because carbon dioxide (CO_2) levels in the ISS atmosphere were higher than in Earth’s atmosphere and also the resulting permeation of CO_2 through the Teflon® hoses (see also fig. 47 and sec. 4.5).

Table 1. IATCS Simulator heat-load capability and characteristics.

LTL heat loads	Payload racks (13), mobile system services (MSS) racks (2), and node 1 (airlock/MPLM)
MTL heat loads	Payload racks (13), MSS racks (2), endcones (2), and node 1 (including the cupola and airlock)
Total heat rejection load capability	28.7 kW
LTL heat load	6 kW of 13 kW allocation
LTL supply temperature	3.3–5.5 °C (38 to 42 °F) (insulated lines)
MTL heat load	12 kW of 13 kW allocation
MTL supply temperature	16.1–18.3 °C (61 to 65 °F)
HTL supply temperature	17.2–32.2 °C (63 to 90 °F) (not currently simulated)
PPA maximum flow rate	1,361 kg/hr (3,000 lb/hr) (MTL and LTL pumps, each)
Maximum operating pressure	793 kPa (115 psia)
Normal operating pressure	345–620 kPa (50–90 psia)*
Allowable differential pressure for components, and across a rack	76±7 kPa (11±1 psid)
Differential pressure between the supply and return headers	76±7 kPa (11±1 psid)
RFCA	Monitor and control HTF flow to each rack location

* The pressures in the LTL and MTL depend upon the configuration (single- or dual-loop) and the pressure drops across the filter, gas trap, and other components. In single-loop configuration with the MTL PPA operating, the pressure at the PPA outlet is ≈90 psia and the pressure of the LTL supply lines is ≈60 psia. The pressure at the PPA inlet is ≈24 psia and the pressure rise across the pump is ≈63 psia. During dual-loop operation, the PPA inlet pressure is also 24 psia, but the pressure rise across the MTL PPA is ≈43 psid for an outlet pressure of ≈65 psia, while the pressure rise across the LTL PPA is ≈43 psid for an outlet pressure of ≈65 psia, while the pressure rise across the LTL PPA is ≈25 psid for an outlet pressure of ≈50 psia. The difference in the LTL and MTL outlet pressures is due to the smaller size of the LTL (fewer payload- or system racks are connected to it) and differences in delta pressure (ΔP) of the filters and gas traps. These differences also allow the LTL PPA to run at slower speed (83% of full speed (18,900 rpm) compared with 90% of full speed for the MTL).

Table 2. Summary of HTF formula.

Compound	As delivered	As circulated in flight hardware
Chlorides	1 ppm (max)	1 ppm (max)
Dissolved Oxygen	6 ppm (max)	6 ppm (max)
TOC	5 ppm (max)	5 ppm (max)
Di or Tri Sodium Phosphate	200–250 ppm as PO_4	0–250 ppm as PO_4
Sodium Borate ($Na_2B_4O_7$)	800–1,200 ppm as B_4O_7	800–1,200 ppm as B_4O_7
Silver Sulfate	0.1–3 ppm	N/A

The total organic carbon (TOC) level is a primary monitoring factor, and the allowable maximum limit is 5 ppm, as stated in SSP 30573, although the actual level in the ISS HTF is higher (sec. 3.4.3). TOC is related to microbial growth, primarily as a food source. The goal is to minimize the TOC levels, and precautions are taken during cleaning the IATCS tubing, fittings, and valves to remove any organic cleaning agents prior to filling with HTF.[11]

2.1.2 Internal Active Thermal Control System Simulator Design

The IATCS Simulator is located in Building 4755 at MSFC. A Boeing-built engineering development article (EDA) mockup of Destiny (fig. 2) was used as the structure for constructing the IATCS

Simulator by replacing mockup components with functional items (fig. 3). Using the EDA provided a more flight-like layout of components than alternative structures that were considered.

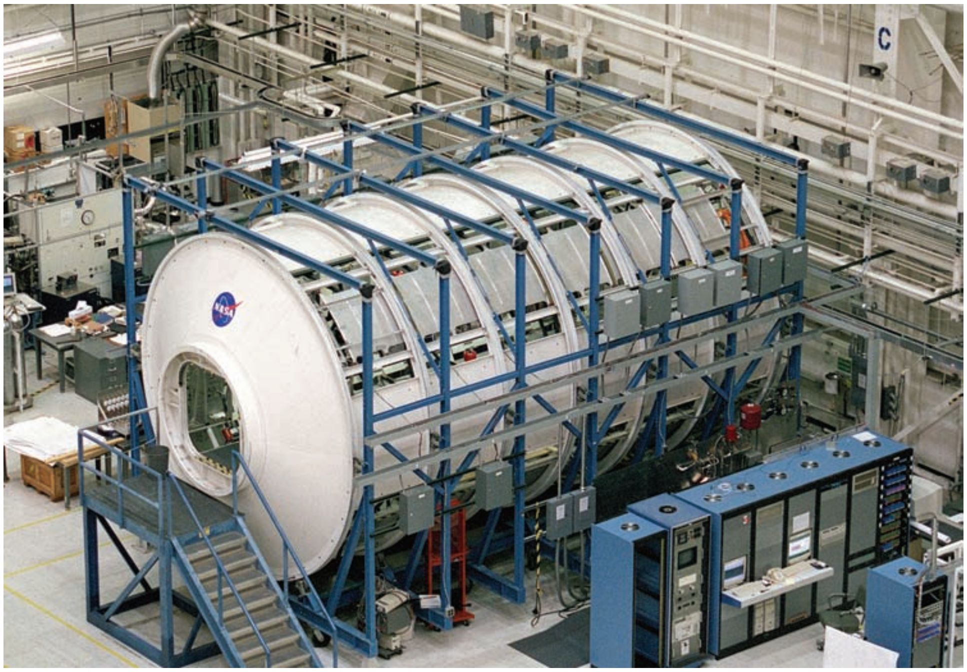


Figure 2. Exterior view of the IATCS Simulator at MSFC.

Figure 3. Interior view of the IATCS Simulator at MSFC showing the LTL PPA.

2.1.2.1 Requirements. The requirements for the IATCS Simulator were extracted from the Prime Item Development Specification for the United States Laboratory (USL) (S683–29523L).[12] Table 3 summarizes the requirements and how they were implemented in Destiny and in the IATCS Simulator.

Table 3. IATCS requirements and implementation in Destiny and in the IATCS Simulator.[12]

Paragraph	Requirement	Destiny Implementation	Simulator Implementation	Notes
3.1.1.s.	The USL will provide thermal conditioning of the USL by: (1) Collecting thermal energy from heat-producing hardware (2) Transporting the USL generated thermal energy to thermal radiators external to the USL	Cold plates for mounting heat-producing hardware Pumps, valves, liquid-coolant supply and return lines	Lab grade water heaters to simulate heat producing hardware Pumps, valves, liquid-coolant supply and return lines	
3.1.2.1.1	Interface with node 1	Supply and return lines to cold plate-mounted heat loads rack flow control assembly (RFCA)	Water heater to simulate heat loads, and an RFCA assembled from COTS components	
3.1.2.1.2	Interface with node 2	No connection	None	
3.1.2.1.3	Interface with integrated truss segment (ITS) S0	No connection	None	
3.1.2.1.5	Interface with ISPR and MSS	MTL and LTL supply and return to ISPR cold plates, MTL supply and return to MSS	MTL and LTL supply and return to ISPR locations, with water heaters to simulate cold plate heat loads	
3.1.2.1.20	Interface with oxygen-generating assembly	MTL supply and return	MTL supply and return	
3.1.2.1.21	Interface with communications outage recorder	MTL supply and return	MTL supply and return	
3.1.2.1.24	Interface with ARIS equipped payload rack	MTL and LTL supply and return to ISPR heat loads	LTL supply and return to water heaters at ISPR locations	
3.1.2.1.26	Interface with water processing, urine processing, and a commode/urinal	MTL supply and return	MTL supply and return	
3.1.2.2.42	Interface with ammonia/water HX assembly	The ammonia/water HX interfaces with inlet and outlet water coolant lines, and inlet and outlet ammonia lines	A water/water HX is used to transfer heat to a facility chiller	
3.1.2.2.44	Interface with pump package assembly (PPA)	The PPA interfaces with inlet and outlet water coolant lines.	A development unit PPA is used which is interfaced with the LTL supply and return lines. A COTS pump is used with the MTL.	

Table 3. IATCS requirements and implementation in Destiny and in the IATCS Simulator (Continued).

Paragraph	Requirement	Destiny Implementation	Simulator Implementation	Notes
3.1.2.2.45	Interface with system flow control assembly (SFCA)	The SFCA interfaces with inlet and outlet water coolant lines	The SFCA is constructed of COTS components and is interfaced with the supply and return lines	
3.1.2.2.46	Interface with RFCA	RFCAs interface with inlet and outlet water coolant lines	RFCAs are constructed of COTS components and interfaced with the supply and return lines	
3.1.2.2.47	Interface with three-way mixing valve (TWMV)	The TWMV interfaces with inlet and outlet water coolant lines	The TWMV is constructed of COTS components and is interfaced with the supply and return lines	
3.1.2.2.48	Interface with common cabin air assembly (CCAA)	The CCAA receives excess heat from the USL atmosphere, receives and returns water coolant for transport of excess thermal energy	The CCAA heat load is simulated using a COTS water heater, interfaced with the supply and return lines	
3.2.1.62	Accept user payload waste heat	The USL collects zero to 13 kW of thermal energy from payloads within the USL	Water heaters provide heat loads at the ISPR locations and are sized to permit the allocated heat load for each location	
3.2.1.94	Collect thermal energy	The USL collects excess heat from internal MSS components (max conductive heat load 244 W, max convective heat load of 250 W) and from the SIGL unit (up to 50 W)	Coolant supply and return lines are provided to each rack location containing heat loads	
3.2.1.95.1	Distribute LTL HTF with node 1	LTL supply and return	LTL supply and return to node 1 heat load simulator	
3.2.1.95.2	Distribute MTL HTF with node 1	MTL supply and return	MTL supply and return	
3.2.1.95.3	Distribute HTL HTF with node 1	HTL supply and return	None currently	Could be implemented by connecting jumper hoses from the MTL line that goes to the node 1 heat load to a heat sink
3.2.1.95.4	Distribute thermal energy rejection	Up to 28.7 kW of thermal energy can be delivered to the ITS S0; up to 14 kW to the ITS Z1—simultaneous distribution is not required	Heat is rejected via the water/water heat exchanger to the facility chiller	
3.7.28	Ammonia/water HX	A HX transfers excess USL thermal energy from the internal coolant loops to the external TCS	A water/water HX is used to transfer heat from the IATCS to a facility chiller	

Table 3. IATCS requirements and implementation in Destiny and in the IATCS Simulator (Continued).

Paragraph	Requirement	Destiny Implementation	Simulator Implementation	Notes
3.7.29	Cold plates	Cold plates provide cooling for equipment whose heat generation rates exceed the capability of the avionics air assembly (AAA) to dissipate	Controllable water heaters are used in place of cold plates with heat loads and are cooled by LTL or MTL coolant	Operating characteristics are the same: Coolant pressure is 124 to 634 kPa (18 to 121 psia), inlet temperature is 3.3 to 50 °C (38 to 122 °F)
3.7.30	Pump package	A PPA circulates IATCS coolant	A flight-like development unit PPA is used with the LTL, and a COTS pump is used with the MTL	Operating characteristics are identical: Supply coolant pressure not to exceed 689 kPa (100 psia) at variable flow rates up to 1,361 kg/hr (3,000 lbm/hr), and temperature up to 50 °C (122 °F)
3.7.35	Regenerative/payload HX	An ammonia/water HX provides for transfer of heat from the IATCS supply to the ISS thermal bus	A water/water HX is used to transfer heat from the IATCS to a facility chiller	The regenerative/payload HX is designed to operate at flow rates from zero to 1,361 kg/hr (3,000 lbm/hr), inlet pressures from 124 to 634 kPa (18 to 121 psia), inlet temperatures from 3.3 to 50 °C (38 to 122 °F), and to transfer heat loads up to 8 kW
3.7.36	Standalone temperature sensor	Temperature sensors provide an independent measurement of IATCS coolant temperature at selected locations	Temperature sensors are strategically located throughout the IATCS loops	The measurement range desired is –1.1 to 65.6 °C (30 to 150 °F) with an accuracy of ± 0.6 °C (1.5 °F) over the measurement range
3.7.37	SFCA	The SFCA regulates the IATCS coolant differential pressure in the USL	The SFCA is constructed of COTS components	Maintains the differential pressure of the supply and return headers within the range of 68.9 to 82.7 kPa (10 to 12 psid) Allows for manual operation of each powered valve (flow control valve and shutoff valve) Receives coolant from the supply header at flow rate of 0 to 1,361 kg/hr (3,000 lbm/hr), pressure 124 to 689 kPa (18 to 100 psia), temperature of 3.3 to 21.1 °C (38 to 70 °F) Receives coolant from the return header at flow rate of zero to 1,361 kg/hr (zero to 3,000 lbm/hr), pressure 124 to 689 kPa (18 to 100 psia), temperature of 3.3 to 50 °C (38 to 122 °F) Returns coolant to the coolant loop at flow rate of zero to 1,361 kg/hr (3,000 lbm/hr), pressure up to 689 kPa (100 psia), temperature of 3.3 to 35 °C (38 to 95 °F) SFCA is monitored and controlled through the C&DH MDM
3.7.38	RFCA	RFCAs regulate the flow of coolant through individual racks in response to changes in rack thermal loads	The RFCAs are constructed of COTS components	Modulate flow from 45.4 to 558 kg/hr (100 to 1,230 lbm/hr), can shut off flow, monitors temperature, measures flow rate, provides manual operation capability RFCA is monitored and controlled through the C&DH MDM

Table 3. IATCS requirements and implementation in Destiny and in the IATCS Simulator (Continued).

Paragraph	Requirement	Destiny Implementation	Simulator Implementation	Notes
3.7.79	Internal systems computer software configuration item	The CSCI coordinates overall operation of the IATCS, performs failure recovery in response to failure indications, and supports communications between higher tier and lower tier processors	Facility monitoring and control is performed using LabVIEW™ software running on PCs	(1) Coordinates startup of the IATCS in response to commands, (2) reports Class 2 warning alarm if heat transfer fluid leakage is detected, (3) determines configuration change needs to recover from a malfunction, reconfigure to maintain HTF within acceptable limits, or report that the system is no longer able to respond, (4) identify and report hazardous conditions and location to ORU or, for leaks, which loop (MTL or LTL)
3.7.80	Lab system 1 computer software configuration item	The LA–1 MDM provides a data interface between the internal MDM and sensors and effectors	Facility monitoring and control is performed using LabVIEW software running on PCs	CSCI provides closed loop control of the flow through the payload racks, the differential pressure across the racks, of the coolant pressure and the means to vent the pressure, isolation and combination of MTL and LTL loops, closed loop control of the water temperature in external water lines, and failure detection and isolation for ORUs, maintains the rack coolant output temperature to a steady state point of ± 2.8 °C (5 °F) within 10 min from command or maintain the output flow rate within ± 22.7 kg/hr (50 lbm/hr)
3.7.81	Lab system 2 computer software configuration item	The LA–2 MDM provides a data interface between the internal MDM and sensors and effectors	Facility monitoring and control is performed using LabVIEW software running on PCs	CSCI provides closed-loop control of the flow through the payload racks, the differential pressure across the racks, of the coolant pressure and the means to vent the pressure, isolation and combination of MTL and LTL loops, closed-loop control of the water temperature in external water lines, failure detection and isolation for ORUs, maintains the rack coolant output temperature to a steady state point of ± 2.8 °C (5 °F) within 10 min from command or maintain the output flow rate within ± 22.7 kg/hr (50 lbm/hr)
3.7.82	Lab system 3 computer software configuration item	The LA–3 MDM provides a data interface between the internal MDM and sensors and effectors		CSCI provides closed loop control of the flow through the payload racks, and failure detection and isolation for ORUs, maintains the rack coolant output temperature to a steady state point of ± 2.8 °C (5 °F) within 10 min from command or maintain the output flow rate within ± 22.7 kg/hr (50 lbm/hr)

2.1.2.2 Design Characteristics. The IATCS Simulator was designed to operate similarly to the Destiny IATCS and have comparable thermal and flow characteristics given limitations on the availability of flight-like hardware and the need to use commercial components and control software. Major components of the IATCS are the PPA (including the particulate filter and gas trap), a three-way mixing valve (TWMV), an LCA, a system flow control assembly (SFCA), and rack flow control assemblies (RFCAs). The RFCAs, tubing material, payload simulators, and the MTL pump are not flightlike, but key parameters such as thermal input, flow rate, and pressure drop can be adjusted to match flight conditions.

2.1.2.2.1 Similarities With the Destiny Internal Active Thermal Control System. Schematically, the IATCS Simulator is identical with the Destiny IATCS (fig. 1). By using the EDA and drawings of the flight system tubing when preparing the simulator tubing, the geometry of the tubing, including every bend, was replicated as faithfully as possible. The locations of components, fittings, connections, heat loads, etc. match the flight system as closely as possible. The LTL PPA (fig.4) is the development PPA (with some modifications—described in sec. 2.1.4.2) that operates the same as the flight PPA (fig. 5) with similar performance. A disassembled filter housing showing the filter cartridge is shown in figure 6, and the gas trap housing and membrane module are shown in figures 7 and 8. The LCA (fig. 9) that enables single-loop or dual-loop operation and the regenerative HX (fig. 10) that modulates the MTL temperature are also flight-like. The regenerative HX has BNi_3 nickel (Ni) brazing. Other similarities are listed in table 4. The components were cleaned according to the same cleaning specification required for the flight hardware (MIL spec.1246–300 (relaxed from 200A to conform with the Space Shuttle Orbiter cleaning specification)). The HTF used to fill the IATCS Simulator was prepared by Boeing according to the formulation used for Destiny (including silver, initially). The control software was prepared using the algorithms in the flight software requirements documents to develop the top-level controls.

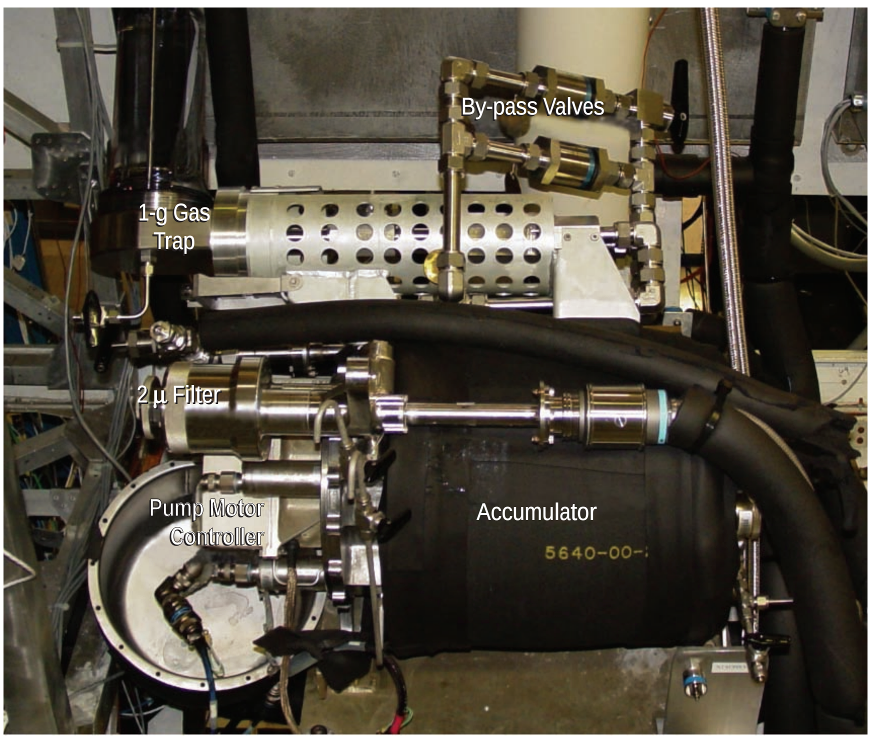


Figure 4. LTL PPA (modified for the IATCS Simulator).

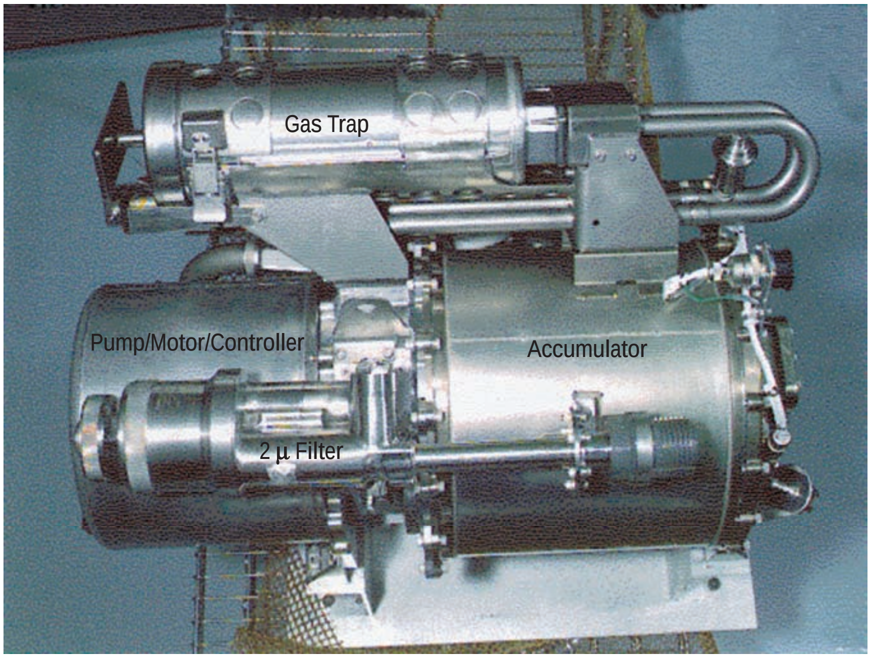


Figure 5. Flight PPA.

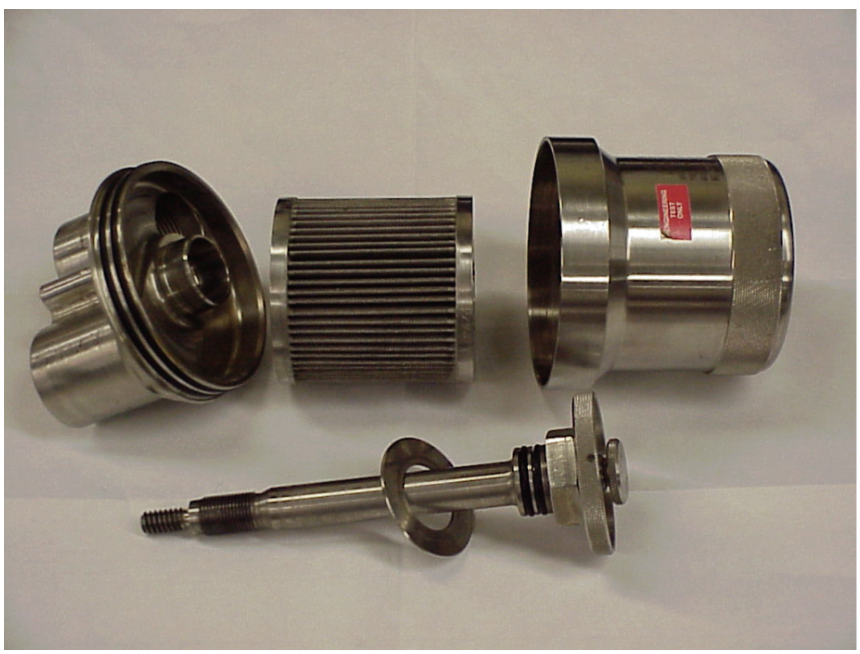


Figure 6. PPA flight-like filter housing with filter cartridge.

Figure 7. PPA flight-like gas trap housings (development unit on the left, flight unit on the right).

Figure 8. PPA flight-like gas trap membrane module.

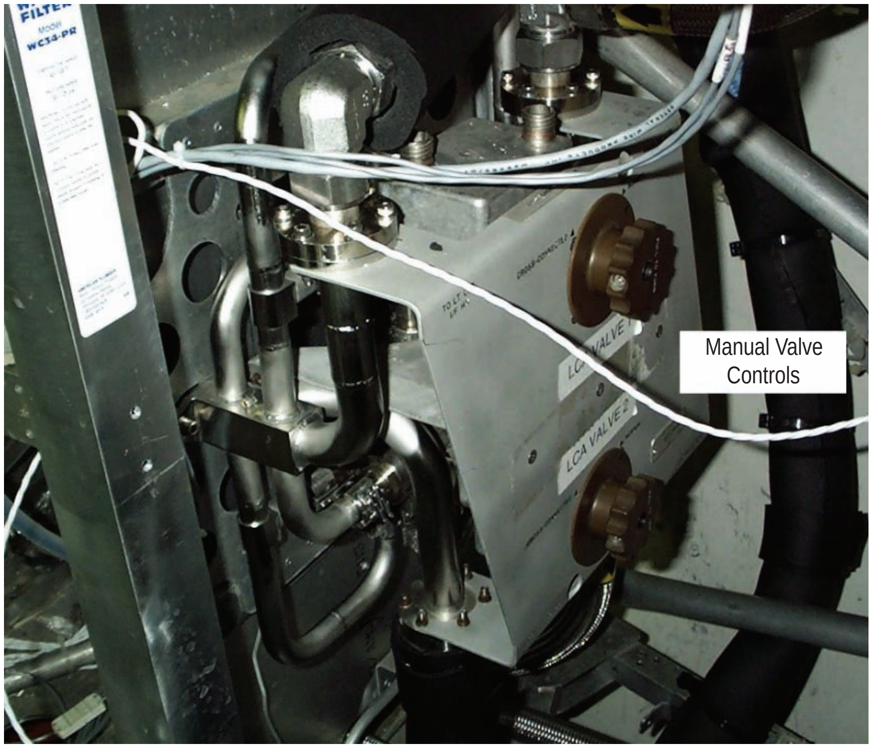


Figure 9. LCA.

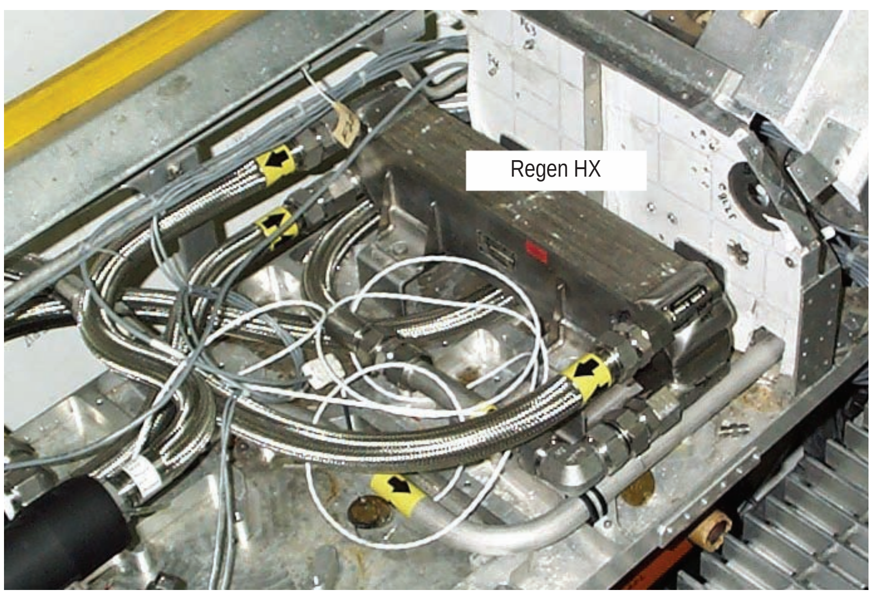


Figure 10. Regenerative HX.

Table 4. Comparison of the IATCS Simulator to the IATCS in Destiny.

Attribute	Destiny IATCS	IATCS Simulator	Notes
System architecture and facility layout	As shown in figure 15	Same as flight but with additional valves to assist in fluid replacement and removal of trapped air from high points in the system The three dimensional layout is identical due to use of the EDA	Additional valves ease fluid replacement as needed for coolant chemistry testing The effects of elevation differences are small
Tubing and hoses	Carbon-filled Teflon hoses, titanium tubing, other metal components of 316L stainless steel, LTL lines insulated	Same configuration, 316L stainless steel tubing, LTL lines insulated	Identical materials selection was not a requirement for the simulator
Flow resistance	The cold plates, with their small channels, can have a significant pressure drop, as well as the tubing and hoses, filters, gas trap, and other components	The water heaters restrict flow much less than cold plates, the flight quick disconnects (QDs) restrict flow less than the simulator QDs. The flow resistance for each payload location can be adjusted to match the flight condition	QDs, water heaters, and fittings have different CVs than flight components so hand valves are used to match the flight flow restrictions
Control software	Implemented primarily in the Ada programming language	Flight algorithms implemented using LabVIEW programming language with additional code implemented to map COTS hardware characteristics to flight hardware characteristics, to control rack thermal loads, and to perform data acquisition and storage	Software can easily be modified to evaluate potential flight algorithm modifications or to investigate flight system anomalies No MDMs are used in the simulator facility
Coolant fluid	Primarily water with additives including a silver based antimicrobial	Nominally same as flight but can be chemically modified for test purposes	The volume of HTF in the payload simulators and the total system volume can be adjusted to match the actual payload volume or the total system volume*
Pump	PPA—centrifugal pump	LTL uses the development PPA (with modifications) The MTL uses a commercial pump (regenerative turbine) with the capability of using flight-like gas trap and filter	A 1-g gas trap and commercial filters are also available for use when performing tests that have the potential for damaging the flight-like components The flight pump is more tolerant of particulates in the coolant—for the MTL, the qualification PPA (currently at the vendor) may be used in place of the commercial pump
Heat loads	Heat sources mounted on cold plates or direct cooling	Laboratory-grade water heaters with somewhat different volume and the materials are different; e.g., no nickel brazing	Thermal loads are controlled to match flight loads but can be adjusted to match configuration changes or to evaluate off-nominal scenarios
Rack flow and temperature control	ISS RFCA	Implemented with commercial valves and temperature and flow sensors	Software algorithms implemented to map commercial valve and sensor characteristics so that they match those of the flight system
System coolant pressure control	ISS SFCA	Implemented with commercial valves and pressure sensors	Software algorithm implemented to map commercial valve characteristics so that they match those of the flight system
Instrumentation	Limited by the availability of data channels	Additional instrumentation to aid in system characterization and anomaly investigations	Instrumentation is integrated with the facility data acquisition system to provide real time display as well as data archiving

Table 4. Comparison of the IATCS Simulator to the IATCS in Destiny (Continued).

Attribute	Destiny IATCS	IATCS Simulator	Notes
Regenerative HX	BNi_3 nickel brazed with stainless steel fins	Development unit for flight, same design and materials	This is the only nickel-brazed component in the IATCS simulator
LCA	Primary component that allows the LTLs and MTLs to operate with a single PPA	Uses a prototype flight-like LCA	Flight system failure recovery and maintenance algorithms and procedures can be verified
Science payloads	Payload racks are capable of being replaced to meet scientific objectives during the ISS mission	Implemented as shown in figure 13 (below)	Rack simulator approach allows matching any future payload's volume, heat load, and flow restriction characteristics as well as aiding anomaly investigations
System racks	Heat loads may vary somewhat as a function of ISS operations but coolant flow rate is determined by preset restrictions	Implemented as shown in figure 3 but note that RFCAs are not connected to system racks	Rack simulator approach allows modification of heat load and flow restriction characteristics to aid anomaly investigations
Interface to external TCS	IATCS coolant to external loop ammonia heat exchanger	Commercial HXs that have been modified to match flight flow characteristics The external loops are simulated with commercial recirculating chillers	Commercial chillers can be controlled to simulate scenarios that involve the IATCS interfaces with the external loops
Coolant temperature control	Maintains a constant coolant temperature with software-controlled TWMVs	Implemented with COTS valves and pressure sensors	Software algorithm implemented to map commercial valve characteristics so that they match those of the flight system

* When the HTF volume in specific payloads is more than the volume in the water heaters and hoses on the payload simulators, then additional lengths of hose can be added to the simulator to increase the volumes. If the volume of HTF in payloads is less than the volume in the payload simulators, then the discrepancy will have to be taken into account in the simulator performance.

2.1.2.3.2 Differences With the Flight IATCS. A fundamental difference between the IATCS Simulator and the IATCS in Destiny is the influence of gravity. One consequence of that difference is that any gas bubbles will tend to collect at the high dead-legs of the simulator rather than be swept through the system to the gas trap, so relief valves were installed to enable collected gas to be vented. Other differences relate to the use of commercial components, such as the flow control valves and actuators, that operate differently from the flight components. Mapping routines in the control software allow components such as the RFCAs to simulate the operation of flight RFCAs.

The MTL PPA (fig. 11) uses a commercial pump and filter with a flight-like gas trap, although a flight filter cartridge can be used and the flight-like gas trap can be replaced with a 1-g gas trap. The housing for the filter is acrylic. The IATCS Simulator RFCA, shown in figure 12, uses commercial components.

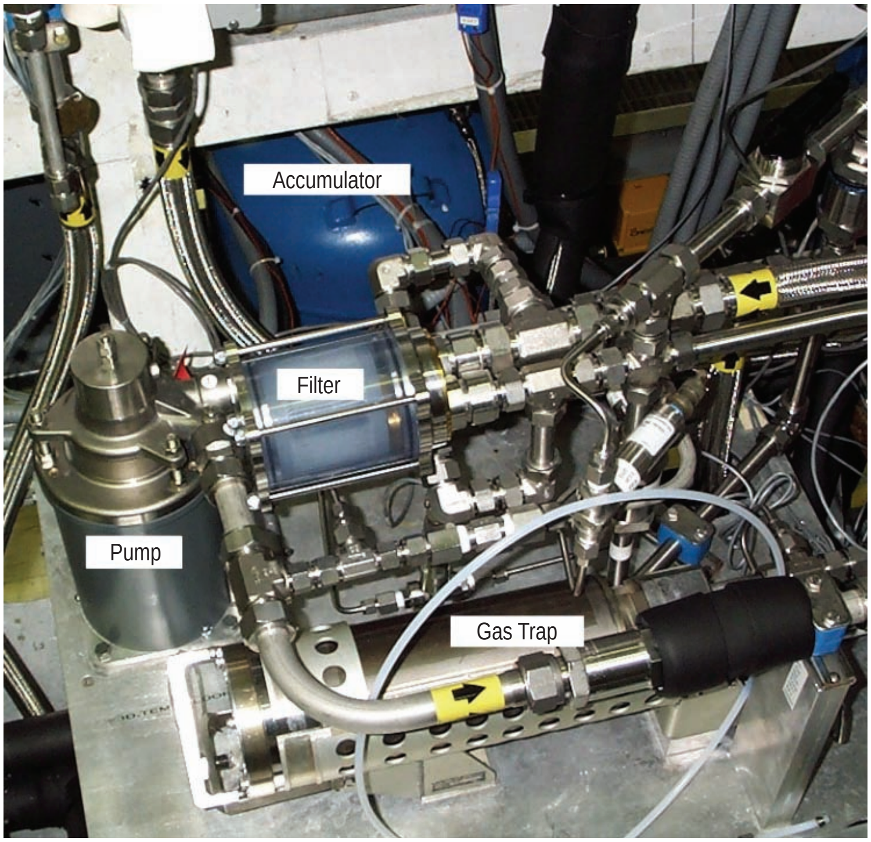


Figure 11. MTL PPA with commercial pump and filter.

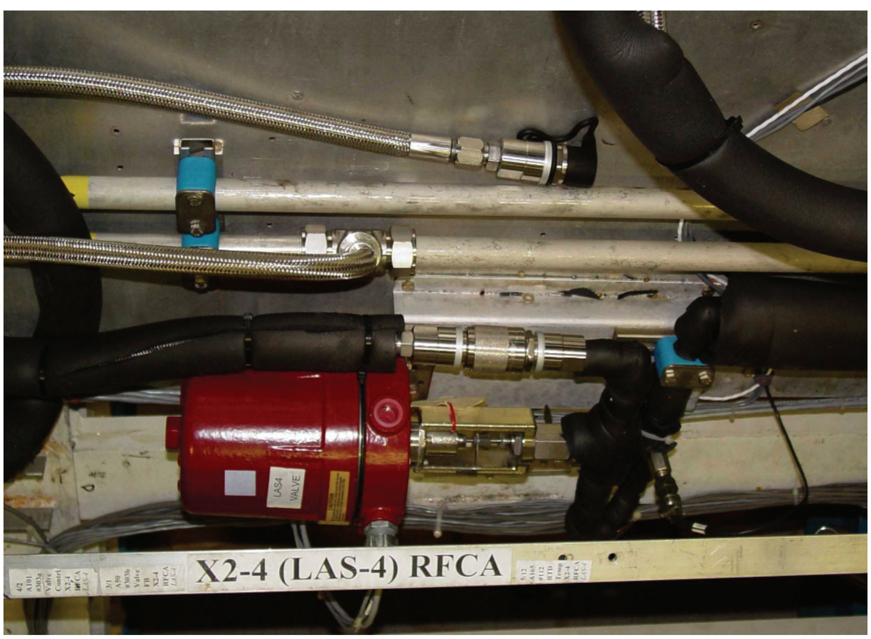


Figure 12. Simulator facility RFCA.

The LTL PPA is the development PPA, but it has been modified in several ways. The gas trap bypass valve was not operating properly and could not be removed for repair. A commercial valve was installed, but with new tubing that has a different form (fig. 4). In addition, because of the higher ΔP across the gas trap module that was available (due to fewer tube pairs (37) than are present in the flight gas trap module (84) (see also sec. 2.1.4.2)), a second bypass valve was added having a higher cracking pressure (10 psid) and full open pressure (13 psid) compared to 7 + 0.5 and 10 + 0.5 psid for the flight bypass valve. A hand valve was installed so that flow to the lower-pressure valve can be shut off. This provides flexibility for testing where gas trap response to test conditions is a primary concern.

Other differences are that the LTL PPA is rotated 90° from the flight orientation and is about 2 ft lower in the rack space. The MTL pump is mounted on a plate located at the base of a rack.

To prepare the control software, the top-level algorithms from the flight software requirements documents were programmed into LabVIEW. Lower level controls include mapping routines to operate the commercial components in a manner that, to the operator, appears to be identical with, or very close to, the flight system.

Coolant flow characteristics of the flight equipment are simulated by adjustable flow control devices at key locations that enable matching the flow and pressure drop characteristics of the flight equipment. The operational characteristics of the flight valves are matched by adjusting software factors to duplicate the performance of the flight hardware. For example, the flight IATCS RFCAs use ball valves with a tear-drop shape that goes from fully closed to fully open in less than 360°. The actuator commands the rate (speed) of valve movement. For the IATCS Simulator, commercial process control plug-type valves are used that enable precise control of flow. For these valves, the actuator commands the valve to specific positions; e.g., 50 percent. To simulate the operation of the flight valves, mapping routines were written for the control software to accommodate differences in C_v of the valves and to adjust from position control to speed control. The C_v plot for the flight valves is shown in the Thermal Control System Configuration Technical Description Document.[13]

Since the payload heat loads were largely undefined for Destiny and also will change as payloads are replaced, deactivated, or operated in different modes, the IATCS Simulator was designed to accommodate the allocated loads for each payload location. The sum of the allocated loads (88 kW) is much greater than the total allowable load (13 kW), so the facility, therefore, provides a flexibility of operation that allows simulation of a variety of heat load configurations.

The heat loads of payload- or system-rack equipment are simulated by controllable, laboratory-grade stainless steel water heaters rather than by the actual equipment transferring heat via nickel-brazed cold plates. At the interface of the internal and external thermal control systems, rather than nickel-brazed HXs as used for the flight system, the IATCS Simulator HXs use compression to hold the stainless steel parting sheets in place, with Viton rubber seals between the parting sheets.

2.1.3 Internal Active Thermal Control System Simulator Capabilities

As part of the ISS sustaining engineering program, the facility provides the capability to perform integrated ECLSS and IATCS testing to support ISS operations. The integrated ECLSS/IATCS test bed supports testing during launch processing, on-orbit assembly, and operation of the ISS. The IATCS Simulator provides a functionally flight-like ground test capability before and during the time the ISS becomes fully operational and:

- Serves as the primary means for investigating on-orbit contingency scenarios and in-flight anomalies.
- Enables troubleshooting operational and performance problems.
- Allows testing to optimize performance.
- Enables verification of system modifications and upgrades.
- Can be used to validate engineering analyses and models.

Destiny was the first ISS module simulated by the IATCS Simulator, though other modules can also be simulated with some modification of the facility. Material differences, such as the use of CRES 304 L tubing in node 3 instead of the titanium in Destiny, would not be feasible to address, but some configuration differences could be accommodated.

If desired, the payload and equipment simulators can be electronically linked with operating hardware to track changing heat loads. (If required, the capability of physically connecting the IATCS Simulator to ECLS equipment in the laboratory module simulator (LMS) in building 4755 can be provided; however, the fidelity of testing in that configuration will be reduced due to inherent limitations relating to increased fluid line lengths and other factors.) The ability to vary heat loads is provided, including the ability to vary heat loads according to a timeline and the ability to add or remove specific heat loads at specified times. Heat gain or loss through the coolant supply and return lines is simulated by using flight-like tubing having similar, or in some cases identical, material, diameter, and wall thickness of similar lengths and insulated as the flight IATCS.

Representative scenarios for operation of the IATCS Simulator include the following:

- Payload and ECLS equipment operation according to a timeline: The payload experiments and ECLS equipment in Destiny will be operated according to availability of power and other considerations, which will cause the heat loads on the IATCS to change as payloads and equipment are activated and deactivated. The IATCS Simulator will be used to evaluate the effects of equipment usage on the performance capabilities of the IATCS according to a timeline.

- Exchange of payload experiments and ECLS equipment: During the course of operation of ISS, experiments will be exchanged as research needs change, and improved ECLS or other system equipment may replace the initial equipment. The heat loads from the experiments and equipment will also change and the performance of the IATCS may be affected. The IATCS Simulator will be used to determine the effects of exchanging equipment and whether the IATCS performance is compromised by particular payload- and system-rack configurations.

- IATCS failure analysis: The IATCS includes two pumps and numerous valves, each of which has the potential to fail in an undesired configuration and lead to a reduced cooling flow at critical locations. Such failures could adversely affect the performance of the IATCS. The IATCS Simulator will be used to determine the effects on the IATCS performance of such failures, and to evaluate operational responses to such failures. The effects of failures of equipment that is cooled by the IATCS, including the effects on capabilities for cooling other equipment on the coolant loop, will also be evaluated.

- Software control algorithm verification: In the event of operational or control anomalies due to the controlling software algorithms, modifications will be necessary to maintain proper operation. Using the IATCS Simulator, proposed algorithm modifications will be rapidly evaluated for their effectiveness and to determine, prior to implementation on Destiny, whether undesired effects could occur. The test facility software allows stand-alone operation with specified heat loads, the use of virtual payloads to provide heat load data to the heaters, or the capability for integrated operation with real-time heat load data provided from ECLS equipment in the MSFC test facility.

- HTF chemistry evaluation: While evaluation of HTF chemistry changes and modifications was not one of the original planned capabilities, such evaluation has become an important capability. Due to the adaptability designed into the ITCS Simulator, testing related to HTF chemistry can be, and has been, performed.

- ISS crew training: Crew training was also not one of the original planned capabilities, but the facility can be, and has been, adapted for use in developing flight procedures related to the IATCS and for training the crew to perform procedures.

2.1.3.1 Heat Loads. Each payload- and system-rack location where heat-generating equipment may be used, as well as heat load locations in the endcones and node 1/airlock, is simulated with a water heater and flow control valve, as shown schematically in figure 13, and in the photo in figure 3. The allocated heat loads for each location are listed in tables 5 and 6. The heat load at each location can be independently adjusted to match a desired profile. The thermal, and flow, response can be estimated prior to operating the IATCS Simulator by using the spreadsheet, ITCSmodel.xls, on the CD–ROM accompanying this report.

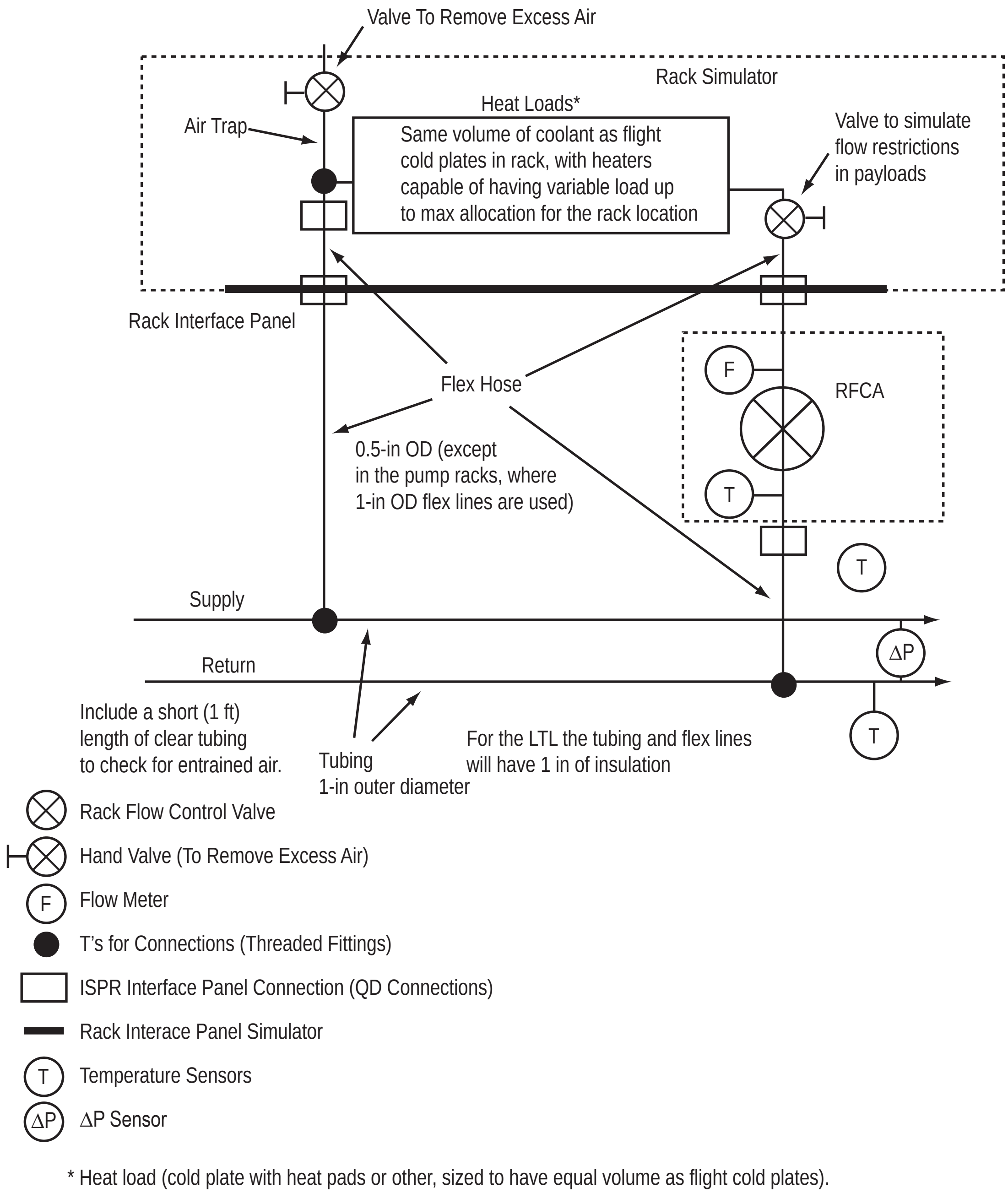


Figure 13. Schematic of rack heat load and flow control configuration.

Table 5. Heat load allocations in the LTL.

Rack Number	Heat Loads (W)	Inlet Temperature (°C (°F))	Outlet Temperature (°C (°F))	Minimum Flow Rate* (kg/h (lb/h))	Maximum Flow Rate* (kg/h (lb/h))	Notes
LAS1 (payload)	3,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAS2 (payload)	6,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAS3 (payload)	12,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAS4 (payload)	6,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAS5 (MSS/cupola)	–	–	–	–	–	no loads
LAS6 (Cabin air HX/ MTL TCS)	3,380	4.4 ± 1.1 (40 ± 2)	16.1 (61)	45.4 (100) to RPCM c/p	558 (1,230) to CA HX, 1361 (3,000) PPA cap	3.5 kW total, 1 kW latent, 5.5 °C (42 °F) supply
LAF1 (avionics no. 2)	–	4.4 ± 1.1 (40 ± 2)	16.1 (61)	–	–	–
LAF2 (avionics no. 3)	–	–	–	–	–	–
LAF3 (payload)	3,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAF4 (H_2O storage)	–	–	–	–	–	no loads
LAF5 (avionics no. 1)	–	–	–	–	–	–
LAF6 atmosphere revitalization system (AR)	118	4.4 ± 1.1 (40 ± 2)	16.1 (61)	59 (130)	59 (130)	CO_2 removal assembly
LAP1 (payload)	6,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAP2 (payload)	12,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAP3 (DDCU/Avionics #1)	–	–	–	–	–	–
LAP4 (payload)	6,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAP5 (MSS/Lab)	0	–	–		–	Cooled by MTL
LAP6 (CA HX/LT TCS)	3,387 total load, 3,380 + 7 (in parallel)	4.4 ± 1.1 (40 ± 2)	16.1 (61)	45.4 (100) to RPCM c/p	558 (1,230) to CA HX, 1,361 (3,000) PPA cap	low temperature IATCS pump, 5.5 °C (42 °F) supply, min flow to RPCM c/p: 45.4 kg/h @ 69 kPa ΔP (100 lb/h @ 10 psid), 50 kg/h @ 83 kPa ΔP (110 lb/h @ 12 psid)

Table 5. Heat load allocations in the LTL (Continued).

Rack Number	Heat Loads (W)	Inlet Temperature (°C (°F))	Outlet Temperature (°C (°F))	Minimum Flow Rate* (kg/h (lb/h))	Maximum Flow Rate* (kg/h (lb/h))	Notes
LAC1 (payload)	3,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAC2 (payload)	3,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAC3 (payload)	12,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAC4 (payload)	6,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAC5 (payload)	3,000	4.4 ± 1.1 (40 ± 2)	21 (70)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAC6 (DDCU/avionics no. 2)	–	–	–	–	–	no loads
Aft Endcone	–	–	–	–	–	no loads
Forward Endcone	Optional LTL	4.4 ± 1.1 (40 ± 2)	16.1 (61)	–	–	Optional MTL or LTL
Node1/AL	3,400	4.4 ± 1.1 (40 ± 2)	–	–	–	–

* Flow rates are approximate and should not be used for rack calibration.

Table 6. Heat load allocations in the MTL.

Rack Number	Heat Load (W)	Inlet Temperature (°C (°F))	Outlet Temperature (°C (°F))	Minimum Flow Rate* (kg/h (lb/h))	Maximum Flow Rate* (kg/h (lb/h))	Notes
LAS1 (payload)	3,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAS2 (payload)	6,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAS3 (payload)	12,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAS4 (payload)	6,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAS5 (MSS/cupola)	330	17 ± 1.1 (63 ± 2)	28 (83)	69 @ 69 kPa ΔP (152 @ 10 psid)	76 @ 83kPa ΔP (167 @ 12 psid)	max coolant set point = 28 °C (83 °F), series loop

Table 6. Heat load allocations in the MTL (Continued).

Rack Number	Heat Load (W)	Inlet Temperature (°C (°F))	Outlet Temperature (°C (°F))	Minimum Flow Rate* (kg/h (lb/h))	Maximum Flow Rate* (kg/h (lb/h))	Notes
LAS6 (CA HX/MTL TCS)	6.78	17 ± 1.1 (63 ± 2)	32 (90)	45.4 @ 69 kPa ΔP (100 @ 10 psid) and 49.9 @ 83 kPa ΔP (110 @ 12 psid) to RPCM c/p	1,361 kg/h (3,000 lb/h) PPA capacity	IATCS pump, 18.3 °C (65 °F) supply temp
LAF1 (avionics no. 2)	630	17 ± 1.1 (63 ± 2)	28 (83)	63.5 @ 69 kPa ΔP (140 @ 10 psid)	69.4 @ 83 kPa ΔP (153 @ 12 psid)	max coolant set point = 28 °C (83 °F), series loop
LAF2 (avionics no. 3)	740	17 ± 1.1 (63 ± 2)	28 (83)	65.3 @ 69 kPa ΔP (144 @ 10 psid)	71.7 @ 83 kPa ΔP (158 @ 12 psid)	max coolant set point = 28 °C (83 °F), series loop
LAF3 (payload)	3,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAF4 (H_2O storage)	5.6	17 ± 1.1 (63 ± 2)	28 (83)	45.4 @ 69 kPa ΔP (100 @ 10 psid)	45.4 @ 83 kPa ΔP (100 @ 12 psid)	max coolant set point = 28 °C (83 °F), series loop
LAF5 (avionics no. 1)	550	17 ± 1.1 (63 ± 2)	28 (83)	66.7 @ 69 kPa ΔP (147 @ 10 psid)	73.0 @ 83 kPa ΔP (161 @ 12 psid)	max coolant set point = 28 °C (83 °F), series loop
LAF6 (AR)	1,200	17 ± 1.1 (63 ± 2)	28 (83)	119 @ 69 kPa ΔP (262 @ 10 psid)	119 @ 83 kPa ΔP (262 @ 12 psid)	ARS AAA, max coolant setpoint = 28 °C (83 °F), series loop, min flow to RPCM coldplate: 45.4 @ 69 kPa ΔP (100 lb/h @ 10 psid), 50 @ 83 kPa ΔP (110 lb/h @ 12 psid)
LAP1 (payload)	6,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAP2 (payload)	12,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAP3 (DDCU/ Avionics no. 1)	570	17 ± 1.1 (63 ± 2)	28 (83)	69 @ 69 kPa ΔP (152 @ 10 psid)	76 @ 83 kPa ΔP (167 @ 12 psid)	max coolant set point = 28 °C (83 °F), series loop
LAP4 (payload)	6,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAP5 (MSS/Lab)	440	17 ± 1.1 (63 ± 2)	28 (83)	69 @ 69 kPa ΔP (152 @ 10 psid)	76 @ 83 kPa ΔP (167 @ 12 psid)	max coolant set point = 28 °C (83 °F), series loop
LAP6 (CA HX/LTL TCS)	–	–	–	–	–	no load
LAC1 (payload)	3,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–

Table 6. Heat load allocations in the MTL (Continued).

Rack Number	Heat Load (W)	Inlet Temperature (°C (°F))	Outlet Temperature (°C (°F))	Minimum Flow Rate* (kg/h (lb/h))	Maximum Flow Rate* (kg/h (lb/h))	Notes
LAC2 (payload)	3,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAC3 (payload)	12,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAC4 (payload)	6,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAC5 (payload)	3,000	17 ± 1.1 (63 ± 2)	49 (120)	45.4 (100)	131 – 143 (295 – 315) for 3 kW 171 – 209 (377 – 460) for 6 kW 338 (745) for 12 kW	–
LAC6 (DDCU/avionics no. 2)	480	17 ± 1.1 (63 ± 2)	28 (83)	69 @ 69 kPa ΔP (152 @ 10 psid)	76 @ 83 kPa ΔP (167 @ 12 psid)	max coolant set point = 28 °C (83 °F), series loop
Aft endcone	850	17 ± 1.1 (63 ± 2)	32 (90)	110 @ 69 kPa ΔP (243 @ 10 psid)	121 @ 83 kPa ΔP (266 @ 12 psid)	max coolant set point = 28 °C (83 °F), series loop
Fwd endcone	920	17 ± 1.1 (63 ± 2)	32 (90)	106 @ 69 kPa ΔP (234 @ 10 psid)	116 @ 83 kPa ΔP (256 @ 12 psid)	max coolant set point = 28 °C (83 °F), series loop
Node1/AL	2,600	17 ± 1.1 (63 ± 2)	–	–	–	–

* Flow rates are approximate and should not be used for rack calibration.

2.1.3.2 Fluid Volumes of Simulator Components. The volumes of the payload- or system-rack locations having heat loads in the IATCS Simulator are listed in table 7. These water heaters, tubing, and hoses are sized to be close to the flight volumes for each location. If needed, the volume can be increased by adding hoses to more closely match the flight coolant volumes at locations of interest. The spreadsheet, ITCS Volume.xls, on the CD–ROM accompanying this TM can be used to estimate the volume of HTF in the IATCS Simulator for configurations of interest.

2.1.3.3 Flow Rates. The flow rates through the rack locations and endcones can be adjusted to match the required scenario. The flow rates for one configuration in Destiny are listed in table 8. The flow, and thermal, response can be estimated prior to operating the IATCS Simulator by using the spreadsheet, ITCSmodel.xls, on the CD–ROM accompanying this TM.

2.1.4 Facility Validation

As the major sections of the IATCS Simulator were completed, validation testing was performed to determine how closely it compared with the operation of the IATCS of Destiny. The goal was to have the simulator response to conditions and input commands match the response of the flight system. The as-run test procedures, including settings for pumps and valves, performance results, problem reports, and problem resolutions, from testing of Destiny at KSC were acquired from Boeing and used to prepare the validation testing of the IATCS Simulator. Where the response differed from the response of Destiny, adjustments in software controls were made to match the responses. Sample pages from the as-run test procedure are given in appendix B.2.

Validation was performed in several stages:

(1) Prerequisite tests to characterize the components and to evaluate the operation of the system.

(a) RFCA control valve operation checkout.
(b) ITCS flow/temperature control checkout.
(c) System rack/endcone MFCV flow checkout.

(2) Validation of the IATCS Simulator performance.

Validation of the LTL was completed in 2001, prior to mission 5A when Destiny was launched. Validation of the MTL operation, single-loop operation (with the LTL and MTL connected through the LCA), and switching from dual- to single-loop configurations was performed after construction of the entire IATCS Simulator was completed in 2003. The results were compared with the results of acceptance testing of Destiny at KSC.

Table 7. Simulator coolant volumes of the heat-generating rack locations.

							Flight		
Panel	Component	O/D (in)	Wall Thickness (in)	Length (in)	Volume (gal)	Total (gal)	Total (gal) LTL	Total (gal) MTL	Payload
LAO1	S.S. tubing	0.5	0.049	100	0.0549	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	0.7600	–	–	–	–
	Heater/small	–	–	–	0.2705	1.0888	–	1.36	EXPRESS 2 rack
LAO2	S.S. tubing	0.5	0.049	129	0.0709	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	0.7600	–	–	–	–
	Heater/small	–	–	–	0.2705	1.1047	–	1.36	EXPRESS 1 rack
LAO3	S.S. tubing	0.5	0.049	129	0.0709	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	0.7600	–	–	–	–
	Heater/small	–	–	–	0.2705	1.1047	–	1.36	EXPRESS 3 rack
LAO4	S.S. tubing	0.5	0.049	129	0.0709	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	0.3700	–	–	–	–
	Heater/small	–	–	–	0.2705	0.7147	0.68	–	MELFI rack
LAO5	S.S. tubing	0.5	0.049	129	0.0709	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	0.0000	–	–	–	–
	Heater/small	–	–	–	0.2705	0.3447	–	0.09	Empty payload
LAO6	S.S tubing	0.5	0.049	96	0.0527	–	–	–	–
	S.S. flex hose	0.5	–	136	0.1297	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Added volume	–	–	–	0.7600	–	–	–	–
	Heater/small	–	–	–	0.2705	1.2196	–	1.17	DDCU no. 2

Table 7. Simulator coolant volumes of the heat-generating rack locations (Continued).

Panel	Component	O/D (in)	Wall Thickness (in)	Length (in)	Volume (gal)	Total (gal)	Flight: Total (gal) LTL	Flight: Total (gal) MTL	Flight: Payload
LAD1	S.S tubing	0.5	0.049	96	0.0527	–	–	–	–
	S.S. flex hose	0.5	–	96	0.0916	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Added volume	–	–	–	1.5200	–	–	–	–
	Heater/small	–	–	–	0.2705	1.9414		1.94	Avionics no. 2
LAD2	S.S tubing	0.5	0.049	96	0.0527	–	–	–	–
	S.S. flex hose	0.5	–	96	0.0916	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Added volume	–	–	–	1.9000	–	–	–	–
	Heater/small	–	–	–	0.2705	2.3214	–	2.38	Avionics no. 3
LAD3	S.S tubing	0.5	0.049	93.5	0.0514	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	1.1400	–	–	–	–
	Heater/small	–	–	–	0.2705	1.4652	–	1.68	WORF
LAD4 heatpad	S.S. tubing	1	0.049	15	0.0415	–	–	–	–
	S.S. tubing	0.5	0.049	73.5	0.0404	–	–	–	–
	S.S. flex hose	0.5	–	96	0.0916	–	–	–	–
	Added volume	–	–	–	0.3700	–	–	–	–
	Q.D.'s	2	–	–	0.0066	0.5501	–	0.52	CHeCS
LAD5	S.S. tubing	0.5	0.049	96	0.0527	–	–	–	–
	S.S. flex hose	0.5	–	96	0.0916	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Added volume	–	–	–	1.5200	–	–	–	–
	Heater/small	–	–	–	0.2705	1.9414	–	1.93	Avionics no. 1
LAD6	S.S. tubing	0.500	0.049	99	0.0544	–	–	–	–
	S.S. flex hose	0.500	–	144	0.1374	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Added volume	–	–	–	0.0000	–	–	–	–
	Heater/small	–	–	–	0.2705	0.4689	1.08	–	ARS (LTL)
LAD6	S.S. tubing	0.500	0.049	114	0.0626	–	–	–	–
	S.S. flex hose	0.500	–	96	0.0916	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Added volume	–	–	–	1.1400	–	–	–	–
	Heater/small	–	–	–	0.2705	1.5713	–	0.54	ARS (MTL)
LAS1	S.S. tubing	0.500	0.049	66	0.0363	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	0.0000	–	–	–	–
	Heater/small	–	–	–	0.2705	0.3101	–	0.15	TES
LAS2	S.S. tubing	0.500	0.049	67.5	0.0371	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	1.5200	–	–	–	–
	Heater/small	–	–	–	0.2705	1.8309	–	–	–
LAS3	S.S. tubing	0.500	0.049	89.5	0.0492	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	0.3700	1.3294	–	–	–
	Heater/large	–	–	–	0.9069		–	–	–

Table 7. Simulator coolant volumes of the heat-generating rack locations (Continued).

Panel	Component	O/D (in)	Wall Thickness (in)	Length (in)	Volume (gal)	Total (gal)	Flight		
							Total (gal) LTL	Total (gal) MTL	Payload
LAS4	S.S. tubing	0.500	0.049	67.5	0.0371	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	1.1400	–	–	–	–
	Heater/small	–	–	–	0.2705	1.4509	–	–	–
LAS5	S.S. tubing	0.500	0.049	78	0.0429	–	–	–	–
	S.S. flex hose	0.500	–	96	0.0916	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Added volume	–	–	–	1.1400	–	–	–	–
	Heater/small	–	–	–	0.2705	1.5516	–	–	–
LAS6 LTL	S.S. tubing	0.500	0.049	65	0.0357	–	–	–	–
	S.S. flex hose	0.500	–	120	0.1145	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Heater/medium	–	–	–	0.5055	0.6623	–	–	–
LAS6 MTL	Added volume	–	–	–	4.5600	4.5600	–	–	–
LAP1	S.S. tubing	0.500	0.049	70	0.0385	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	0.0000	–	–	–	–
	Heater/small	–	–	–	0.2705	0.3123	–	–	–
LAP2	S.S. tubing	0.500	0.049	89	0.0489	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	0.7600	–	–	–	–
	Heater/large	–	–	–	0.9069	1.7191	–	–	–
LAP3	S.S. tubing	0.500	0.049	77.5	0.0426	–	–	–	–
	S.S. flex hose	0.500	–	144	0.1374	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Added volume	–	–	–	0.7600	–	–	–	–
	Heater/small	–	–	–	0.2705	1.2171	–	–	–
LAP4	S.S. tubing	0.500	0.049	70	0.0385	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	1.1400	–	–	–	–
	Heater/small	–	–	–	0.2705	1.4523	–	–	–
LAP5	S.S. tubing	0.500	0.049	77.5	0.0426	–	–	–	–
	S.S. flex hose	0.500	–	96	0.0916	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Added volume	–	–	–	1.1400	–	–	–	–
	Heater/small	–	–	–	0.2705	1.5513	–	–	–
Forward endcone	S.S. tubing	0.500	0.049	55	0.0302	–	–	–	–
	S.S. flex hose	0.500	–	114	0.1088	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Heater/small	–	–	–	0.2705	0.4161	–	–	–
AFT endcone (MTL)	S.S. tubing	0.500	0.049	62	0.0341	–	–	–	–
	S.S. flex hose	0.500	–	233	0.2223	–	–	–	–
	Q.D.'s	2	–	–	0.0066	–	–	–	–
	Heater/small	–	–	–	0.2705	0.5335	–	–	–
AFT endcone (LTL)	S.S. tubing	0.500	0.049	0	0.0000	–	–	–	–
	S.S. flex hose	0.500	–	0	0.0000	–	–	–	–
	Q.D.'s	2	–	–	0.0000	–	–	–	–
	Added volume	–	–	–	1.6800	–	–	–	–
	Heater/small	–	–	–	0.0000	1.6800	–	–	–

Table 7. Simulator coolant volumes of the heat-generating rack locations (Continued).

Panel	Component	O/D (in)	Wall Thickness (in)	Length (in)	Volume (gal)	Total (gal)	Flight		
							Total (gal) LTL	Total (gal) MTL	Payload
Node 1 (LTL)	S.S. tubing	0.500	0.049	70	0.0385	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	4.1800	–	–	–	–
	Heater/small	–	–	–	0.2705	4.4923	–	–	–
Node 1 (MTL)	S.S. tubing	0.500	0.049	83	0.0456	–	–	–	–
	Q.D.'s	1	–	–	0.0033	–	–	–	–
	Added volume	–	–	–	5.7000	–	–	–	–
	Heater/small	–	–	–	0.2705	6.0194	–	–	–

Note: Information provided by Mike McCormick, Allied

Table 8. Destiny IATCS flow rates.

Rack or Endcone	Loop	Location	Nominal Flowrate (pph)	Comment
Aft E/C	MTL	aft endcone	236	–
Forward E/C	MTL	forward endcone	278	–
DDCU no. 2 (LAO6)	MTL	LAO6	274	–
MSS no. 1 (LAS5)	MTL	LAS5	106	–
AV no. 1 (LAD5)	MTL	LAD5	123	–
MSS no. 2 (LAP5)	MTL	LAP5	103	–
CHeCS (LAD4)	MTL	LAD4	132	–
DDCU no. 1 (LAP3)	MTL	LAP3	271	–
AV no. 2 (LAD1)	MTL	LAD1	118	–
AV no. 3 (LAD2)	MTL	LAD2	127	–
ARS MTL	MTL	LAD6	132	ARS racks have both MTL and LTL flow. The MTL flow is used for the AAA hx
ARS LTL (LAD6)	LTL	LAD6	262	–
CCAA/MTL TCS – LTL (LAS6)	LTL	LAS6	1,230	Flow is alternated between P6 and S6 every few months. Both are not operated simultaneously
CCAA/LTL TCS – LTL (LAP6)	LTL	LAP6	1,230	Flow is alternated between P6 and S6 every few months. Both are not operated simultaneously

Note: Information provided by Tom Ibarra, Boeing

2.1.4.1 Preparation of the Procedure. As mentioned in section 2.1.4, the as-run test procedure for the acceptance test of Destiny was used as the basis for validation testing of the IATCS Simulator. Selected portions of the acceptance test procedure were extracted for specific stages of testing and a validation test procedure was prepared with input from Boeing thermal engineers regarding key characteristics that could be tested at each stage. For the acceptance test, the entire IATCS was assembled in Destiny, but for validation testing of the IATCS Simulator LTL in 2001, only those portions of the test relating specifically to the LTL could be tested and the acceptance test procedures were adapted to perform the LTL validation. After completion of the entire facility, other key portions of the acceptance test procedure, involving the combined loop system, were used for validating the combined system. Sample pages from the validation procedure are shown in appendix B with the comparable pages from the acceptance test procedure. Details of the procedures and the results are discussed in section 2.1.4.3.

2.1.4.2 Facility Issues. Depending on the type of testing performed and the parameters of interest, even with the efforts to match the physical characteristics of the flight IATCS, there are some differences that may be significant. Facility issues relate to the gas trap, the bypass valve around the gas trap, the pump speed, and the commercial pump on the MTL.

2.1.4.2.1 Gas Trap. Only one flight-like gas trap is available for the IATCS Simulator, and it has fewer membrane tube pairs (37 versus 84) and operates normally with a higher pressure drop (8.5 psid) than the flight gas trap (4.5 psid at 3,000 pph). This gas tap is installed on the MTL. A 1-g gas trap was fabricated and installed on the LTL. If necessary for a specific test, the gas traps can be exchanged.

During cleaning of the flight-like gas trap in November 2001, considerable contamination was found in the membrane module. This gas trap had been part of the Boeing brassboard test and had also been used in Italy. Specific information on its operational history are not known, so contamination could have come from several different sources. The cleaning procedure involved flushing with hydrogen peroxide (H_2O_2), isopropylalcohol (IPA), and deionized (DI) water, with agitation to loosen particles. A considerable amount of very fine reddish-brown particles was removed from the gas trap. The amount was not quantified, but the particles formed a sediment layer in the bottom of the flushwater container during several flushings. After vacuum drying to remove the residual IPA, the membrane module was again flushed with DI water and more particles were removed. Prior to cleaning, the pressure drop across this gas trap was about 12 psid. After cleaning, the pressure drop was ≈8 psid. Compared to the flight gas trap nominal delta pressure (ΔP) of 4.5 psid this is to be expected due to fewer membrane tube pairs. The membrane module, after cleaning, is shown in figure 14. The photo shows reddish-brown staining and numerous cracks in the module end pieces. During disassembly of the gas trap housing in preparation for cleaning, liquid was found on the gas vent side, which could severely affect gas removal capability, and it is possible that HTF penetrated through the cracks.

Figure 14. Gas trap membrane module after cleaning.

2.1.4.2.2 Gas Trap Bypass Valve. The flight gas trap bypass valves are set to begin cracking at 7±0.5 psid, and reach full open at 10±0.5 psid. So, roughly, the cracking pressure is ≈2.5 psid above the nominal operating ΔP (4.5 psid) and full open is 3 psid above cracking pressure. For the IATCS Simulator gas trap, with a higher normal ΔP (8–8.5 psid), a bypass check valve that cracks at 10 psid and reaches full open at 13 psid was installed. Since the gas trap was designed to allow venting to space vacuum, the additional ΔP should be acceptable. A second bypass check valve was also installed—in parallel, but capable of being valved off—that has the flight valve characteristics. When this bypass valve is in line, there will be little to no flow through the flight-like gas trap since the cracking pressure is less than the normal operating pressure of the gas trap; however, this valve can be used with the 1-g gas trap since the ΔP can be adjusted to match that of the flight gas trap.

2.1.4.2.3 Pump Speed. The pump motor controller (PMC) of the LTL PPA was not operating as intended—exhibiting erratic shutdowns—and was limiting operation to a flow rate of about 2,700 lb/hr, rather than the full 3,000 lb/hr required. This PMC was replaced in 2002 with a brassboard PMC that was not intended for flight: Part No. 70210–2354160–1–1, S/N 101–R3, marked "Research Non-Flight." With this PMC, the LTL PPA operated properly, though the indicated speed was slower than expected for a given flow rate. This discrepancy was investigated by checking the veracity of the Hall Effect sensors on the pump motor. It was found that while the indicated speed agreed with the set point, the actual motor speed was approximately 22 percent faster than indicated. The reason for the different speed was found to be an erroneous value for a variable in the firmware controller. The TH_0 *variable* had been set to a value of 241. Based on information found in older design documents, the value was changed to 238. With this change, the actual and indicated speeds matched within acceptable tolerances.

2.1.4.2.4 Commercial Pump. For the MTL, a commercial pump that operates at a different speed than the PPA for a given flow rate is used. To enable the pump to appear to be a flight pump to the operator, a conversion routine translates the actual speed to the expected flight pump speed based on the flow rate.

2.1.4.3 Validation Test Results. The LTL validation test included performing prerequisite tests of RFCAs and other components and comparing the performance of the LTL with a Boeing model of the IATCS LTL on Destiny. The model had already been shown to have good agreement with the Destiny IATCS performance. During the prerequisite tests, most RFCAs met specified response times, though for some RFCAs the specifications were not met. The prerequisite tests were later repeated for the completed system, at which time the RFCAs did meet the specifications (table 9).

Table 9. IATCS prerequisite test 1.

	RFCA Response Times											
	+5 VDC		–5 VDC		+1 VDC		–1 VDC		+0.5 VDC		–0.5 VDC	
RFCA	Spec (s)	Time (s)	Spec (s)	Time (s)	Spec (s)	Time (s)	Spec (s)	Time (s)	Spec (s)	Time (s)	Spec (s)	Time (s)
LAS1	17±3	18.9	17±3	17	90–100	95.19	90–100	94.27	180–200	190	180–200	188.7
LAS2	17±3	17	17±3	17	90–100	95.01	90–100	94.36	180–200	190.8	180–200	192
LAS3	17±3	18	17±3	17	90–100	94.61	90–100	94.29	180–200	190.6	180–200	188.6
LAS4	17±3	17	17±3	17	90–100	94.57	90–100	94.13	180–200	190.5	180–200	189.1
LAF3	17±3	17	17±3	17	90–100	95	90–100	95.07	180–200	190.7	180–200	188
LAP1	17±3	17	17±3	17	90–100	95.3	90–100	94.36	180–200	189.9	180–200	188.1
LAP2	17±3	17	17±3	17	90–100	95.37	90–100	94.29	180–200	190.3	180–200	188.2
LAP4	17±3	17	17±3	17	90–100	95.23	90–100	94.13	180–200	190	180–200	188.9
LAC1	17±3	17	17±3	17	90–100	94	90–100	94.27	180–200	190.2	180–200	188.1
LAC2	17±3	18	17±3	17	90–100	94.75	90–100	94.7	180–200	190.1	180–200	188
LAC3	17±3	17	17±3	17	90–100	95	90–100	94.32	180–200	190.9	180–200	188.5
LAC4	17±3	17	17±3	18	90–100	94	90–100	94.31	180–200	190	180–200	188.2
LAC5	17±3	17	17±3	17	90–100	94	90–100	95	180–200	190.3	180–200	188.6
Node MTL	17±3	17	17±3	17	90–100	94	90–100	94	180–200	190	180–200	187.6
Node LTL	17±3	17	17±3	17	90–100	94	90–100	94	180–200	190.7	180–200	188.2

The LTL performance test was run for the parameters listed in table 10 using the control gains for the TWMV and RFCAs listed in table 11. Results were compared with the Boeing computer model runs and showed that the IATCS Simulator performance matched the model.

Table 10. LTL verification parameters.

Test Parameter	Type	Expected Range	Requirement / Derived Requirement	Comment
Pump differential pressure	Performance characterization	–	–	Demonstrates system delta-p
Overall system compliance	Derived requirement	2 – 3%	Less than 14 Cu	Demonstrates system compliance
Three way mixing valve temperature control	Requirement	38 – 43 °F	38 – 43 °F	Demonstrates controller performance
System flow control assembly differential pressure control	Requirement	11 ± 1 psid	11 ± 1 psid	Demonstrates controller performance
ARS rack low temperature flow rate	Derived requirement	240 – 262 pph	240 – 262 pph	–
ARS rack low temperature outlet temp	Derived requirement	45 – 65 °F	< 53 °F	Verifies temperature sensor performance given heat load and flow rate
ARS rack moderate temperature flow rate	Derived requirement	130 – 143 pph	130 – 143 pph	–
ARS rack moderate temperature outlet temperature	Derived requirement	72 – 73 °F	< 85 °F	Verifies temperature sensor performance given heat load and flow rate
CCAA rack flow rate	Derived requirement	1,168 – 1,292 pph	1,168 – 1,292 pph	–
CCAA rack outlet temp	Derived requirement	51 – 52 °F	< 53 °F	Verifies temperature sensor performance given heat load and flow rate (max load)

Note: Information provided by Tom Ibarra, Boeing

Table 11. Control gains for Destiny's TWMVs and RFCAs.

	K_p	K_d	K_i	NSB (lb/hr)
Nominal TWMV gains				
MTL	0.5	3	0	1
LTL	0.5	3	0	1
Regen	0.2857	2	0	1.75
"Bullet proof" TWMV gains				
MTL	0.4	5.4	0	1.25
LTL	0.4	5.4	0	1.25
Regen	0.3	3.4	0	2
4 and 10 lb/hr RFCA gains	–0.125	0	0	4
(not to be used)	–0.05	0	0	10
5 and 10 lb/hr RFCA gains	–0.1	–0.27	0	5
(to be used)	–0.05	–0.05	0	10

Validation of the completed IATCS Simulator followed the progression of the acceptance test, including the prerequisite tests. For Prerequisite Test 1, RFCA control valve operation checkout, performed in February 2003, the response of each RFCA was individually checked to determine the time required to transition from closed to fully open positions and vice versa. The times for each of these operations are shown in table 9.

For prerequisite test 2, IATCS flow/temperature control checkout, performed in June 2003, the ability of the IATCS Simulator to maintain active control of flow rate or temperature at specific rack locations was evaluated. Three test cases were run with different groups of RFCAs activated and with two conditions for each case: (1) Flow control mode and (2) temperature control mode. For each condition, two runs were made. For this test, the LTL and MTL were both operated at 63 ºF.

For test case 1, condition 1, with RFCAs for LAC5, the airlock MTL, and the airlock LTL active, the responses were within specified limits for both runs in flow control mode (condition 1) as shown in table 12. For test case 1, condition 2 (table 13), operating in temperature control mode, however, the temperature setpoints could not be maintained, and the temperatures for some of the RFCAs were outside the expected ranges.

Table 12. IATCS prerequisite test 2, test case 1, condition 1.

Test Case 1—RFCA for LAC5, Airlock MTL, Airlock LTL Condition 1—Flow Control Mode			
RFCA		Setpoints (pph)	
LAC5 Airlock MTL Airlock LTL		100 350 100	
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.91/62.98	62.96/63.05
MTL temperature (°F)	63 ± 2	62.85/63.52	61.74/63.63
SFCA LTL ΔP	11 ± 1 psid	10.8/11.1	10.9/11
SFCA MTL ΔP	11 ± 1 psid	10.9/11	11
LAC5 RFCA flow	100 ± 10 pph	100.2/102.9	97.9/103.1
LAC5 RFCA temperature	baseline	63.0/63.1	63.3
Airlock MTL RFCA flow	350 ± 18 pph	349.1/355.8	351.9/356.1
Airlock MTL RFCA temperature	baseline	63.6/63.7	63.9/64
Airlock LTL RFCA flow	100 ± 10 pph	101.8/102.8	95.9/108.9
Airlock LTL RFCA temperature	baseline	62.1	64.2
RFCA		Setpoints (pph)	
LAC5 Airlock MTL Airlock LTL		350 100 350	
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.94/63.01	62.92/63.03
MTL temperature (°F)	63 ± 2	61.66/63.66	61.66/63.66
SFCA LTL ΔP	11 ± 1 psid	10.8/11.1	10.9/11.1
SFCA MTL ΔP	11 ± 1 psid	11.0/11.1	10.9/11
LAC5 RFCA flow	350 ± 18 pph	348.8/352.7	351.1/353.4
LAC5 RFCA temperature	baseline	62.4/62.5	62.5/62.6
Airlock MTL RFCA flow	100 ± 10 pph	104.9/107.2	105.2/108.2
Airlock MTL RFCA temperature	baseline	64.8/64.9	64.9
Airlock LTL RFCA flow	350 ± 18 pph	349.8/355.6	349.5/354.2
Airlock LTL RFCA temperature	baseline	63.4	63.4

Table 13. IATCS prerequisite test 2, test case 1, condition 2.

Temperature Control Mode (Flow set to 150 pph for LAC5, Airlock MT, and Airlock LT)			
RFCA	Setpoints (°F)	Heat Loads (kW)	
LAC5 Airlock MTL Airlock LTL	85 90 85	1.5 1.5 0.7	
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.98/63.03	62.92/63.01
MTL temperature (°F)	63 ± 2	62.80/62.89	62.89/62.98
SFCA LTL ΔP	11 ± 1 psid	10.9/11.1	10.8/11.1
SFCA MTL ΔP	11 ± 1 psid	10.9/11.1	10.9/11
LAC5 RFCA flow	baseline	193.9/230.9	194/231.5
LAC5 RFCA temperature (°F)	85 ± 2	84.3/85.6	84.2/85.7
Airlock MTL RFCA flow	baseline	69.9/301.9	70.8/328.6
Airlock MTL RFCA temperature (°F)	90 ± 2	78.9/100.3*	78/102.4*
Airlock LTL RFCA flow	baseline	88.1/173.9	86.7/165.4
Airlock LTL RFCA temperature (°F)	85 ± 2	80.5/87.6*	80.3/88*
RFCA	Setpoints (°F)		
LAC5 Airlock MTL Airlock LTL	90 85 90		
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.98/63.03	62.92/63.03
MTL temperature (°F)	63 ± 2	62.76/62.87	62.62/63.95
SFCA LTL ΔP	11 ± 1 psid	10.9/11.1	10.8/11.1
SFCA MTL ΔP	11 ± 1 psid	11/11.1	10.9/11.1
LAC5 RFCA flow	baseline	51.1/326.3	67.4/332.4
LAC5 RFCA temperature (°F)	90 ± 2	82.9/99.6*	82.9/99.8*
Airlock MTL RFCA flow	baseline	28.2/414.1	19.5/411.5
Airlock MTL RFCA temperature (°F)	85 ± 2	74.6/109.1*	74.1/115.3
Airlock LTL RFCA flow	baseline	97.2/102.9	150
Airlock LTL RFCA temperature (°F)	90 ± 2	86.1/87.2*	86.4/88.2

* Entry was outside the expected range.

For test cases 2 and 3, with more RFCAs operating, even in flow control mode (condition 1), for several RFCA locations, the flow exceeded the expected range (tables 14–17). While operating in temperature control mode, wide oscillations in flow occurred. These oscillations were similar to oscillations in the flight system that occurred under similar conditions—when more than two RFCAs were operating with the SFCA. For the flight system, the software algorithm was modified by adjusting the control gains for the TWMV and RFCAs which corrected the oscillations (table 11 and section 3.3). (Note: Operation in temperature-control mode was never performed satisfactorily with Destiny.)

For the IATCS Simulator, the oscillations were stopped initially by adjusting the response time to a once-per-second update rate. This fix was later replaced by implementing the updated algorithms with adjusted gain factors used for the flight system. (Note: The flight IATCS now operates in fixed mode, with neither temperature nor flow control, instead relying on payloads to adjust the flow they receive, where possible and if necessary.)

Table 14. IATCS prerequisite test 2, test case 2, condition 1.

Test Case 2—RFCA for LAS1, LAS2, LAP4, LAC2, LAC4, LAP1 Condition 1—Flow Control Mode			
RFCA		Setpoints (pph)	
LAS1 LAS2 LAP4 LAC2 LAC4 LAP1		100 350 100 350 100 350	
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.98/63.03	69.96/63.05
MTLtemperature (°F)	63 ± 2	63.0/63.01	62.98/63.01
SFCA LTL ∆P	11 ± 1 psid	10.9/11.1	10.9/11.1
SFCA MTL ∆P	11 ± 1 psid	10.9/11.1	10.9/11.1
LAS1 RFCA flow	100 ± 10 pph	92.1/103.5	102.0/104.1
LAS1 RFCA temperature	baseline	64.3	64.5
LAS2 RFCA flow	350 ± 18 pph	346.7/353.7	349.2/352.2
LAS2 RFCA temperature	baseline	66	65.9
LAP4 RFCA flow	100 ± 10 pph	93.6/104	96.8/107.1
LAP4 RFCA temperature	baseline	65.9	65.7
LAC2 RFCA flow	350 ± 18 pph	344.1/350.5	343.4/350.2
LAC2 RFCA temperature	baseline	63.6	63.4
LAC4 RFCA flow	100 ± 10 pph	88.4/109.5*	89.4/109.1*
LAC4 RFCA temperature	baseline	63.1	62.9
LAP1 RFCA flow	350 ± 18 pph	347.9/353.2	345.8/351.4
LAP1 RFCA temperature	baseline	63.2	63.2
RFCA		Setpoints (pph)	
LAS1 LAS2 LAP4 LAC2 LAC4 LAP1		350 100 350 100 350 100	
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.92/63.05	62.94/63.05
MTL temperature (°F)	63 ± 2	62.98/63.07	62.98/63.05
SFCA LTL ∆P	11 ± 1 psid	10.9/11.1	10.9/11.1
SFCA MTL ∆P	11 ± 1 psid	11.0/11.1	10.9/11
LAS1 RFCA flow	350 ± 18 pph	34.5/353.6	346.1/350.1
LAS1 RFCA temperature	baseline	63.5	63.4
LAS2 RFCA flow	100 ± 10 pph	96.4/97.9	102.2/110.1*
LAS2 RFCA temperature	baseline	66.5	66.3
LAP4 RFCA flow	350 ± 18 pph	348.2/352.1	349.5/353.9
LAP4 RFCA temperature	baseline	65.1	64.9
LAC2 RFCA flow	100 ± 10 pph	95.2/104.1	86.2/106.4*
LAC2 RFCA temperature	baseline	64.4	64
LAC4 RFCA flow	350 ± 18 pph	346.3/354.9	348.6/354.6
LAC4 RFCA temperature	baseline	62.7	62.6
LAP1 RFCA flow	100 ± 10 pph	95.1/109.7	88.1/103.4*
LAP1 RFCA temperature	baseline	63.9	63.7

* Entry was outside the expected range.

Table 15. IATCS prerequisite test 2, test case 2, condition 2.

Test Case 2—RFCA for LAS1, LAS2, LAP4, LAC2, LAC4, LAP1 Condition 2—Temperature Control Mode (flow set to 150 pph)			
RFCA		Setpoints (°F)	Heat Loads (kW)
LAS1		85	0.868
LAS2		90*	0.688
LAP4		85	1.5
LAC2		90	1.5
LAC4		85	1.5
LAP1		90*	1.5
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.78/62.8	62.76/63.39
MTL temperature (°F)	63 ± 2	64.54/64.76	62.79/63.84
SFCA LTL ΔP	11 ± 1 psid	10.9/11.1	10.9/11.2
SFCA MTL ΔP	11 ± 1 psid	11/11.1	10.9/11.1
LAS1 RFCA flow	baseline	93.8/112.2	94.19/108.85
LAS1 RFCA temperature (°F)	85 ± 2	84.6/85.2	83.69/84.43
LAS2 RFCA flow	baseline	94.6/109.9	94.57/109.41
LAS2 RFCA temperature (°F)	90 ± 2	88.1/88.8	87.52/88.2**
LAP4 RFCA flow	baseline	240.5/264.1	207.32/235.69
LAP4 RFCA temperature (°F)	85 ± 2	84.6/85.5	84.38/85.61
LAC2 RFCA flow	baseline	83.2/314.1	61.58/334.58
LAC2 RFCA temperature (°F)	90 ± 2	84.9/97.5**	83.09/99.73**
LAC4 RFCA flow	baseline	163.9/188.2	155.69/179.6
LAC4 RFCA temperature (°F)	85 ± 2	84.7/85.3	84.61/85.41
LAP1 RFCA flow	baseline	60.8/338.6	56.63/323.03
LAP1 RFCA temperature (°F)	90 ± 2	83.4/99.4**	81.94/102.83**
RFCA		Setpoints (°F)	Heat Loads (kW)
LAS1		90*	0.868
LAS2		85*	0.688
LAP4		90*	1.5
LAC2		85	1.5
LAC4		90*	1.5
LAP1		85*	1.5
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.94/63.05	62.92/63.05
MTL temperature (°F)	63 ± 2	64.58/64.72	63.72/63.79
SFCA LTL ΔP	11 ± 1 psid	10.9/11.1	10.8/11.1
SFCA MTL ΔP	11 ± 1 psid	10.9/11	10.9/11.1
LAS1 RFCA flow	baseline	87/112.4	92.21/109.54
LAS1 RFCA temperature (°F)	90 ± 2	84.8/85.7**	83.45/84.03**
LAS2 RFCA flow	baseline	90.2/184.5	90.5/164.57
LAS2 RFCA temperature (°F)	85 ± 2	82.6/87.8**	82.77/87.2**
LAP4 RFCA flow	baseline	166/219.7	115.32/230.34
LAP4 RFCA temperature (°F)	90 ± 2	88.8/91.3	87.33/93.15**
LAC2 RFCA flow	baseline	204.6/247	205.09/244.64
LAC2 RFCA temperature (°F)	85 ± 2	84.4/85.7	84.1/85.91
LAC4 RFCA flow	baseline	94.8/159.7	87.65/166.18
LAC4 RFCA temperature (°F)	90 ± 2	88.4/91.8	87.83/92.28**
LAP1 RFCA flow	baseline	176.4/261.7	188.96/252.25
LAP1 RFCA temperature (°F)	85 ± 2	83/87.2**	83.63/86.41

* Unable to maintain setpoints for one or both runs.
** Entry was outside the expected range.

Table 16. IATCS prerequisite test 2, test case 3, condition 1.

Test Case 3—RFCA for LAP2, LAS3, LAC1, LAS4, LAC3, LAF3 Condition 1—Flow Control Mode			
RFCA		Setpoints (pph)	
LAP2		100	
LAS3		350	
LAC1*		100	
LAS4		350	
LAC3		100	
LAF3		350	
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.96/63.05	62.96/63.05
MTL temperature (°F)	63 ± 2	62.98/63.07	62.98/63.03
SFCA LTL ΔP	11 ± 1 psid	10.8/11.1	10.9/11.1
SFCA MTL ΔP	11 ± 1 psid	10.9/11.1	11/11.1
LAP2 RFCA flow	100 ± 10 pph	91.86/103.66	96.1/103.5
LAP2 RFCA temperature	baseline	64.6/64.7	64.5
LAS3 RFCA flow	350 ± 18 pph	344.97/353.75	344.2/354.1
LAS3 RFCA temperature	baseline	63.8	63.8
LAC1 RFCA flow	100 ± 10 pph	95.76/107.99	91.6/115**
LAC1 RFCA temperature	baseline	64.5	64.5
LAS4 RFCA flow	350 ± 18 pph	346.1/353.67	345.3/352
LAS4 RFCA temperature	baseline	63.2	63.2
LAC3 RFCA flow	100 ± 10 pph	92.56/111.33**	94.6/99.6
LAC3 RFCA temperature	baseline	62.7	94.6/99.6
LAF3 RFCA flow	350 ± 18 pph	338.51/355.01	345/349.2
LAF3 RFCA temperature	baseline	63.2	63.2
RFCA		Setpoints (pph)	
LAP2		350	
LAS3		100	
LAC1*		350	
LAS4		100	
LAC3		350	
LAF3		100	
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.94/63.05	62.94/63.05
MTL temperature (°F)	63 ± 2	62.98/63.01	62.96/63.01
SFCA LTL ΔP	11 ± 1 psid	10.9/11.1	10.9/11.2
SFCA MTL ΔP	11 ± 1 psid	11/11.1	10.9/11
LAP2 RFCA flow	350 ± 18 pph	346.6/350.9	343/355.1
LAP2 RFCA temperature	baseline	63.4	63.2
LAS3 RFCA flow	100 ± 10 pph	94.73/107.9	97.6/104.2
LAS3 RFCA temp	baseline	64.2	64.2
LAC1 RFCA flow	350 ± 18 pph	348.6/352.9	346.9/356
LAC1 RFCA temperature	baseline	63.5	63.3
LAS4 RFCA flow	100 ± 10 pph	100.7/102.7	95/108.1
LAS4 RFCA temperature	baseline	63.8	63.7
LAC3 RFCA flow	350 ± 18 pph	349.8/353.8	344.8/352.5
LAC3 RFCA temperature	baseline	61.7	61.5
LAF3 RFCA flow	100 ± 10 pph	94.8/110	95.4/102.4
LAF3 RFCA temperature	baseline	63.7	63.5

* Unable to maintain setpoints for one or both runs.
** Entry was outside the expected range.

Table 17. IATCS prerequisite test 2, test case 3, condition 2.

Test Case 3—RFCA for LAP2, LAS3, LAC1, LAS4, LAC3, LAF3 Condition 2—Temperature Control Mode (flow set to 150 pph)			
RFCA		Setpoints (°F)	Heat Loads (kW)
LAP2		85	1.5
LAS3		90*	1.5
LAC1*		85	1.5
LAS4		90*	1.5
LAC3		85	1.5
LAF3		90*	1.5
Parameter	Expected	Run No. 1	Run No. 2
LTL temperature (°F)	63 ± 2	62.98/63.12	62.85/62.92
MTL temperature (°F)	63 ± 2	64.92/65.1**	64.65/64.76
SFCA LTL ΔP	11 ± 1 psid	10.9/11.2	10.9/11.1
SFCA MTL ΔP	11 ± 1 psid	10.9/11.1	10.9/11.1
LAP2 RFCA flow	baseline	250.73/265.73	243.69/264.26
LAP2 RFCA temperature (°F)	85 ± 2	84.66/85.16	84.64/85.1
LAS3 RFCA flow	baseline	173.7/206.72	172.24/201.47
LAS3 RFCA temperature (°F)	90 ± 2	89.34/90.5	89.35/90.36
LAC1 RFCA flow	baseline	211.17/261.37	220.95/258.85
LAC1 RFCA temperature (°F)	85 ± 2	83.93/86.07	84.18/85.75
LAS4 RFCA flow	baseline	68.06/351.09	65.05/349.79
LAS4 RFCA temperature (°F)	90 ± 2	83.21/100.61**	83.45/100.22**
LAC3 RFCA flow	baseline	173.79/245.35	181.98/238.28
LAC3 RFCA temperature (°F)	85 ± 2	83.66/86.43	83.54/86.39
LAF3 RFCA flow	baseline	139.61/225.06	148.42/210.13
LAF3 RFCA temperature (°F)	90 ± 2	88.21/91.6	88.52/91.47
RFCA		Setpoints (°F)	Heat Loads (kW)
LAP2		90*	1.5
LAS3		85*	1.5
LAC1*		90*	1.5
LAS4		85	1.5
LAC3		90	1.5
LAF3		85*	1.5
Parameter	Expected	Run #1	Run #2
LTL temperature (°F)	63 ± 2	63.09/63.12	62.79/63.18
MTL temperature (°F)	63 ± 2	64.83/64.89	63.82/64.37
SFCA LTL ΔP	11 ± 1 psid	11/11.1	10.9/11.2
SFCA MTL ΔP	11 ± 1 psid	10.8/11.1	10.9/11.1
LAP2 RFCA flow	baseline	180.97/229.56	149.16/264.17
LAP2 RFCA temperature (°F)	90 ± 2	89.05/90.94	87.28/93**
LAS3 RFCA flow	baseline	236.56/242.9	225.83/238.2
LAS3 RFCA temperature (°F)	85 ± 2	84.91/85.15	84.74/85.12
LAC1 RFCA flow	baseline	53.05/364.23	65.07/389.07
LAC1 RFCA temperature (°F)	90 ± 2	83.62/99.46**	83.06/100.86**
LAS4 RFCA flow	baseline	197.97/229.42	198.63/224.59
LAS4 RFCA temperature (°F)	85 ± 2	84.54/85.57	84.28/85.4
LAC3 RFCA flow	baseline	77.77/283.35	79.90/286.43
LAC3 RFCA temperature (°F)	90 ± 2	84.54/97.25**	84.18/97.23**
LAF3 RFCA flow	baseline	205.83/237.29	204.67/233.31
LAF3 RFCA temperature (°F)	85 ± 2	84.38/85.49	84.32/85.37

* Unable to maintain setpoints for one or both runs.
** Entry was outside the expected range.

When comparing the results of the IATCS Simulator performance qualification test with the Destiny acceptance test results, as shown in appendix B, there is good correlation, but some differences are apparent, as follows:

- For the Destiny acceptance test, most of the measurements were within the expected ranges, but for some the expected ranges were changed, such as the LTL CTB HX TWMV temperature, for which the actual measurement was above the original expected range. Some other measurements were off-scale high.

- Most of the measurements for the IATCS Simulator—as with the acceptance test—were within the expected ranges, but some were outside of the expected range—such as the LAF1 and LAS6 temperatures, which were slightly above the maximum expected temperatures, and the LTL pump speed, which was almost 4,000 rpm slower than expected (sec. 2.1.4.2).

- The expected range for the LAC4 RFCA flow meter for the Destiny acceptance test is 805 + 60 pph, whereas, for the validation test for the LAC4 RFCA flowmeter, the expected range is 200 + 15 pph. This difference is due to a change in location of specific flows based on which flow meters were installed in specific locations in the IATCS Simulator.

Overall, the IATCS Simulator performance matched very well with the performance of Destiny during IATCS Acceptance Testing, including exhibiting out-of-spec behavior in a similar manner.

2.2 Cold Plate/Fluid Stability Test Subscale Internal Active Thermal Control System Facility

A subscale IATCS facility, CFST, was also constructed at MSFC beginning in 1999. For the CFST facility, special attention was placed on materials and proportions of wetted surfaces in order to provide information on fluid chemistry changes, material corrosion, and microbial activity over extended periods of operation. The initial purpose was to evaluate the effects of repeated thermal cycling on the cold plates to determine whether this would promote debonding of the cold-plate brazing. The scope was broadened to also provide advance indication of potential problems related to chemical processes in the HTF, including corrosion and fluid composition changes and microbial growth and interaction with the fluid and materials. This facility is located near the Destiny IATCS Simulator in Building 4755. The CFST facility was assembled in 2000 and the initial 3-yr test period for this facility began on September 5, 2000. The test and checkout procedure for this facility is in appendix A.2.

2.2.1 Facility Design

The CFST facility (figs. 15–20) was designed to enable the long-term monitoring of cold-plate debonding, fluid chemistry composition changes, corrosion, and microbial growth in planktonic and biofilm forms. The facility consists of two cold plates (-6 and -9 sizes), three biofilm test panels, three Robbins devices with nickel 201 and CRES 347 ss coupons, Teflon hoses, a flight-like gas trap and filter, commercial pumps, and an accumulator sized to allow monthly coolant samples to be collected for the 3-yr duration of the test. During assembly of the facility, care was taken to clean and fill the hardware according to the ACOMC procedures (app. C.1) used for the ISS flight hardware. Since the Teflon is exposed to the cabin environment and will introduce oxygen into the system, the hoses were simulated very closely and a representative length Teflon hose (1 in diameter and 12 ft length) was included. Simulation of the other material line lengths was not considered as important, and proportional lengths or wetted areas for the other materials of the flight IATCS were not attempted (these are not fixed parameters for ISS). The CFST facility is designed as follows:

- To be materially similar to the flight IATCS having flight-like cold plates, HX, filter, gas trap, Teflon hoses, and stainless steel tubing, and using the flight coolant formula (with silver initially). Differences relate to gravity and ambient atmosphere composition (especially CO_2 concentration).

- To allow for monitoring of:

  – Chemical composition and microbial population of the HTF (via monthly samples). Table 18 shows the schedule for sampling the coolant, and table 19 shows the schedule for microbial sampling.

  – Corrosion and microbial attachment to surfaces (via removable tubing and Robbins devices with removable coupons).

  – Cold-plate debonding (via annual ultrasound scans).

- To run continuously for 3 yr in order to obtain advance information on any significant divergences of the flight IATCS from the desired operating conditions (sec. 2.2.2).

Figure 15. CFST facility, general view.

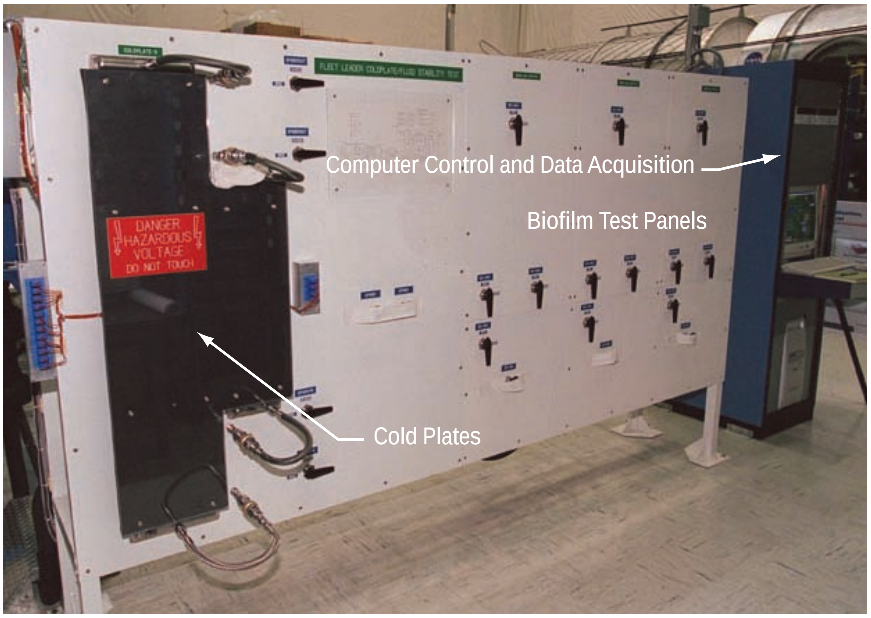


Figure 16. View of front of CFST main panel.

Figure 17. View of rear of the CFST main panel.

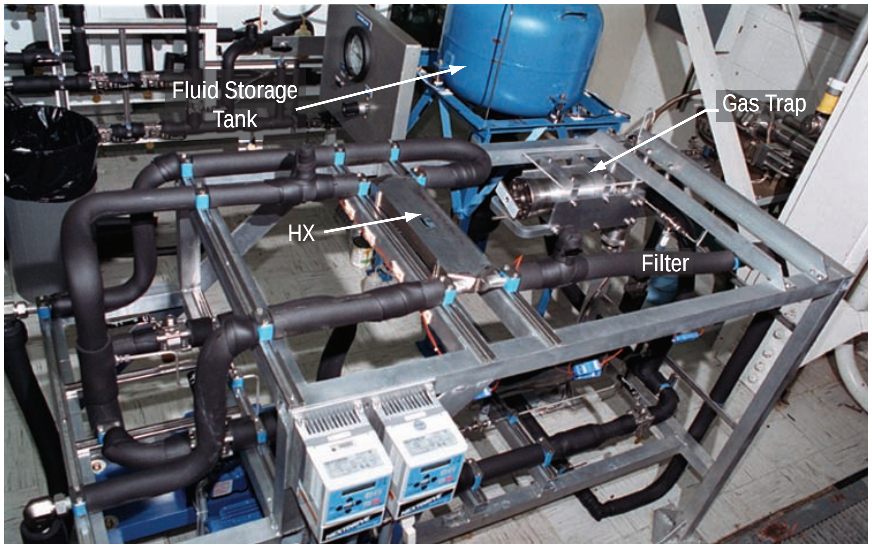


Figure 18. CFST fluid storage tank and flight-like HX, gas trap, and filter.

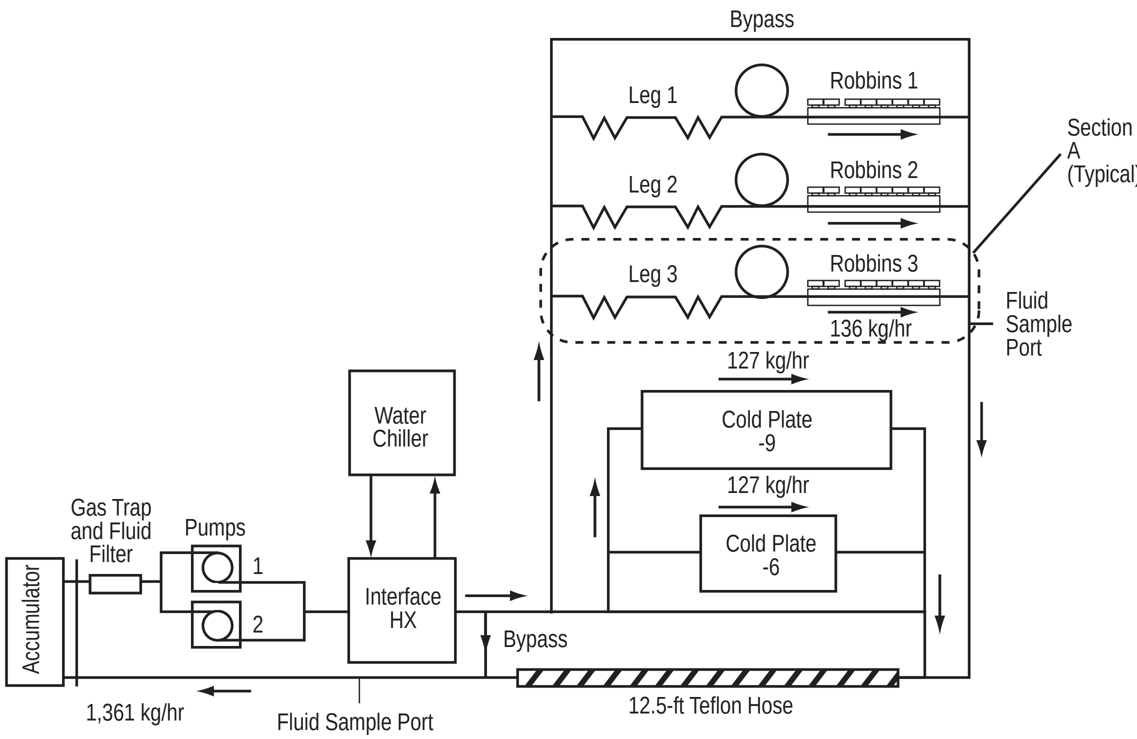


Figure 19. Schematic of the CFST thermal loop.

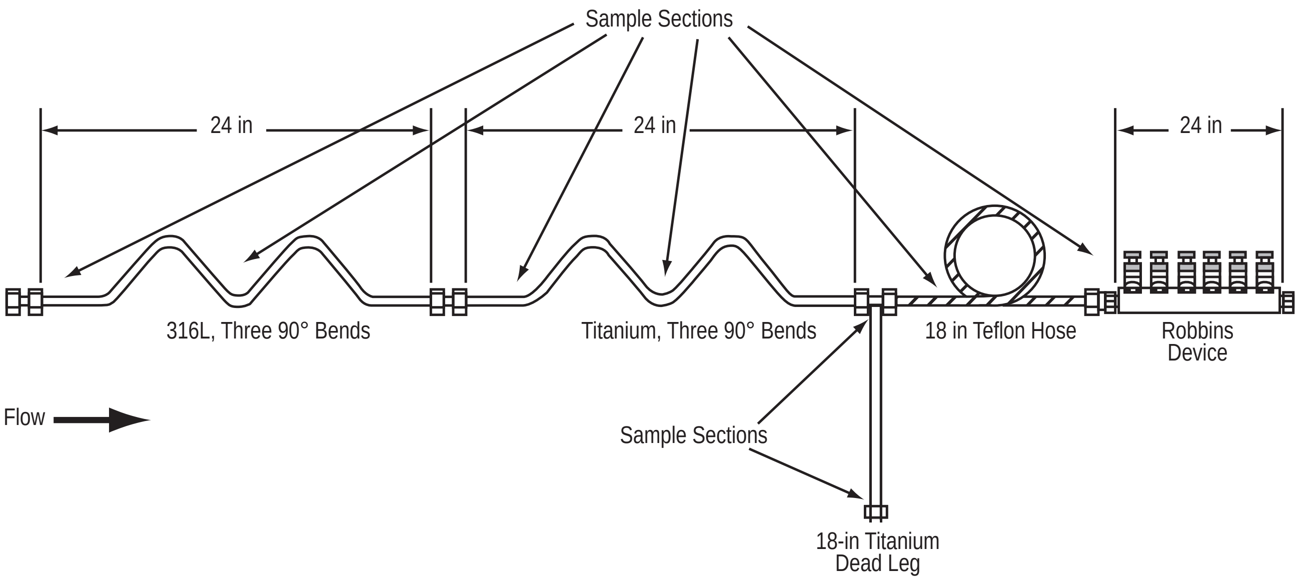


Figure 20. Detail of the removable tubing and Robbins device showing sample sections (sec. A of fig. 19).

Table 18. Original coolant sampling schedule.

Time	Analysis
Pretest	Microbial Swabs
24 hr	Microbial Particulates Metals – Chromium – Iron – Copper – Nickel – Silver Chlorides TOC DO Di- or Tri-Sodium Phosphate Sodium Borate pH
48, 168, 360, and 720 hr	Same as for 24 hr
Monthly after 720 hr for 3 yr*	Same as for 24 hr

* Note: Samples are to be taken before and after cold plate removal or other major hardware removal event.

Table 19. Original microbial sampling schedule.

Description	Analysis	Test Month					
		0	3	6	12	24	36
Nickel 201 coupons	R2A	–	1	1	1	1	1*
	SEM	1	1	1	1	1	1
	EDS	1	1	1	1	1	1
	MEP	1	–	–	–	–	–
CRES 347 coupons	R2A	–	1	1	1	1	1*
	SEM	1	1	1	1	1	1
	EDS	1	1	1	1	1	1
	MEP	1	–	–	–	–	–
SS tube	R2A & SEM	–	–	–	–	–	–
TT tube	R2A & SEM	–	–	–	1	1	1
TT dead leg	R2A & SEM	–	–	–	–	–	–
Teflon tube	R2A & SEM	–	–	–	–	–	–
Cold plate #9	R2A & SEM	–	–	–	–	–	1
Gas trap membrane	R2A	–	–	–	–	–	–
	SEM	–	–	–	–	–	1
	DAPI	–	–	–	–	–	–

* At 36 mo the R2A and MEP analyses were performed using the same coupon for each nickel and CRES sample.

2.2.2 Comparison With the Flight Internal Active Thermal Control System

This facility is also referred to as the IATCS "Fleetleader," and the intention was that this facility would "lead the fleet" with regard to any anomalies that occur with the flight IATCS. After 2 yr of operation, the conditions of the HTF and components were remarkably stable. During this same period of time, however, the conditions of the IATCS on board the ISS significantly diverged from the specified state. Due to this divergence, the test-bed stability was not reflected in the flight IATCS condition. The CFST facility provided information that helped to understand that the chemical/microbial changes occurring with the flight IATCS were not due to the natural decomposition of the fluid or materials. The facility was modified slightly (sec. 4.5.3) to more closely match the flight conditions; i.e., CO_2 in the atmosphere, and to gain insight into the reasons for the divergence. Carbon dioxide permeation of the Teflon hoses was determined to be a significant factor in the flight IATCS changes.

2.2.3 Microbial Considerations

A major purpose of this test facility is to evaluate the growth and effects of microorganisms in the coolant and on internal surfaces of the IATCS components. Microbial analyses included monthly monitoring of planktonic microorganisms in the HTF and periodic analyses of surfaces to monitor microbial attachment or biofilm growth (table 19). Microbiological analyses of the fluid consisted of heterotrophic plate counts on R2A medium for determination of viable heterotrophic bacterial population. Analysis of the surfaces consisted of heterotrophic plate counts on R2A medium for microbial analyses, scanning electron microscopy (SEM) for determination of the presence of biofilm, and energy dispersive x-ray spectroscopy (EDS) for determination of the presence of inorganic contamination. Analyses of test surfaces were performed by Altran Corporation.[14,15]

To obtain the required samples, the facility was designed with removable components and the capability to collect coolant samples for microbial and chemical analysis. The sample port design for microbial analyses is shown in figure 21. Removable sample sections included three biofilm test panels consisting of 316L ss and titanium tubing with deadlegs and bends to represent similar bends in flight tubing, Teflon hoses, and three Robbins devices with 10 coupons in each (figs. 17, 19, and 20), half made of nickel 201 and half of CRES 347 stainless steel. Following the sample schedule (table 19), Robbins device coupons were removed for analysis and replaced with sterile "blanks" of stainless steel, and biofilm test panels were removed for destructive analysis, to analyze the inner surfaces of the tubing and hoses.

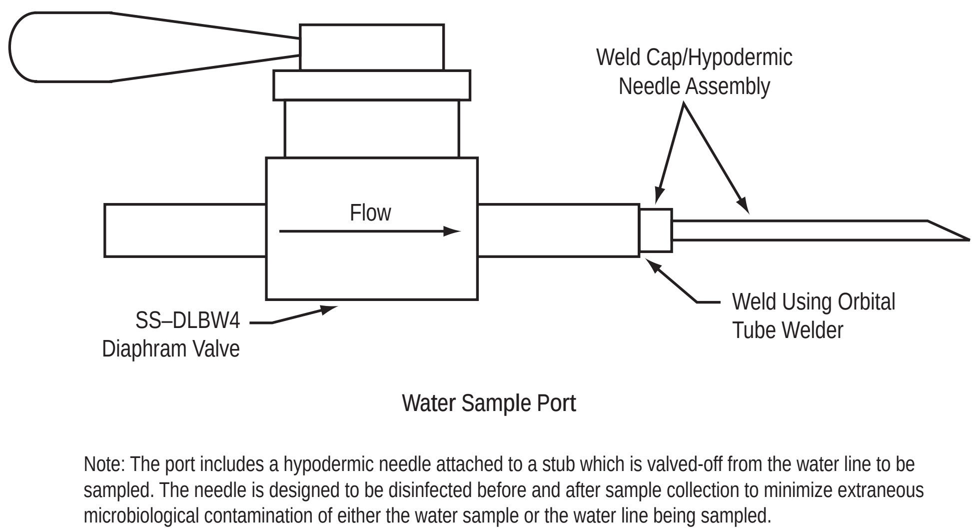


Figure 21. Drawing of port for HTF samples for microbial analyses.

2.3 Other Internal Active Thermal Control System Test Capabilities

Other facilities are also available to perform IATCS-related testing at MSFC. For example, environmental chambers in Building 4619 were used for testing a coolant-filled IATCS jumper hose to determine whether it can tolerate the temperature extremes during transportation without being damaged. This hose expansion test is summarized in section 4.1 and described in NASA/TM—2001–211330.[16]

3. DESTINY INTERNAL ACTIVE THERMAL CONTROL SYSTEM FLIGHT OPERATION ISSUES

Several IATCS design and flight issues arose before and after Destiny was launched and attached to ISS. These issues relate to hardware capability, HTF chemistry, and system operation. The issues are summarized in this section and use of the IATCS Simulator and facilities at MSFC to address these issues is described in section 4.

3.1 Cold Plate Debonding

Prior to the launch of Destiny, it was found that some of the cold plates did not meet the specifications for flatness and braze bonding. Debonding of the brazing was evident in a number of cold plates during ultrasound scanning, and there were concerns about growth of debonded areas over time, especially in locations with cycling of heat loads. This issue was addressed by constructing the CFST facility. Results of this test are discussed in section 4.5.

3.2 Jumper Hose Transport

IATCS jumper hoses, also referred to as integrated hose assemblies (IHA), must be transported to the ISS when new modules are added so that the IATCS systems can be connected. It is desirable to launch the IHAs already filled with HTF, but there was a concern that excessive temperatures during transportation could result in overpressurization that would damage the IHAs. This issue was addressed by testing an IHA in an environmental chamber. Results of this test are discussed in section 4.1.

3.3 Internal Active Thermal Control System Pulsing

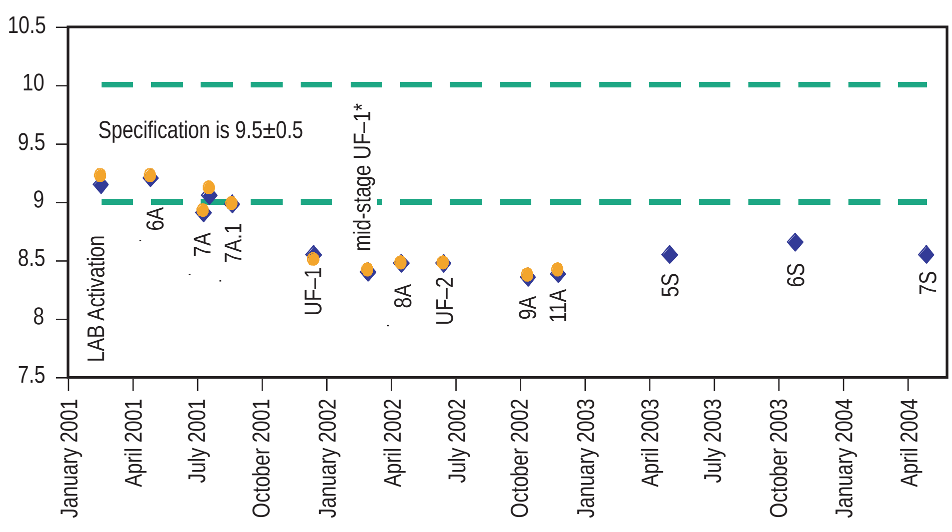
When Destiny was added to ISS and activated, the IATCS experienced pulsing or oscillations of the RFCAs as payload racks were added and activated while in closed-loop flow-control mode. These oscillations occurred when more than two RFCAs were operating in addition to the SFCA and were due to a sensor time lag. The original ±4 pph control gain for the RFCAs had been determined based on an analytical model of the IATCS. The model, however, did not include a 0.9-s lag in the feedback loop that was present in the actual IATCS. When this lag was included in the model, it was evident that the control gain was too narrow and it was adjusted to ±5 pph (table 11). Testing indicated that the new gain was effective, and it was uploaded to the ISS software. In practice, though, the IATCS operates in fixed mode rather than temperature- or flow-controlled, and the payloads provide any needed regulation. When the IATCS Simulator was activated, a similar pulsing occurred when two or more RFCAs were operating in addition to the SFCA, discussed in section 2.1.4.3.

3.4 Heat Transport Fluid Chemistry

The chemical composition of the HTF in Destiny was expected to remain fairly constant. Instead, there were significant changes during the first year on orbit, especially a significant decrease in pH and an increase in NH_3. Changes in other parameters such as TOC also were evident.

3.4.1 Heat Transport Fluid pH

During the first year of operation on orbit, the pH decreased from the specified 9.5±0.5 to ≈8.4, as shown in figure 22. This led to a number of undesirable consequences, including corrosion of Ni and growth of microorganisms (secs. 3.5 and 3.6). The IATCS System Problem Resolution Team (SPRT) discussed this issue and considered a number of possible causes, as shown in figure 23. Solid and dashed lines indicate that these potential causes were ruled out, or conditionally ruled out, respectively. The primary cause of the pH decrease was determined by performing a slight modification to the CFST facility (discussed in section 4.5.3), that confirmed that CO_2 can permeate the Teflon hose, resulting in lower pH. (This cause had been ruled out prematurely, as shown in fig. 23, when analysis indicated that permeation would take several hundred years to achieve the observed pH decrease (sec. 3.8)). A plan was developed to raise the pH by injecting concentrated sodium hydroxide (NaOH) (8% N solution) into the IATCS loop using Shuttle-provided syringes and the ISS fluid system servicing kit. The initial concept was presented to a safety review panel on February 14, 2002, but was rejected due to insufficient containment of the concentrated NaOH, which is a very caustic fluid, to prevent leakage. The approach was modified to use a glove box to provide another level of containment. The modified approach was approved and evaluated using the IATCS Simulator, but was not implemented based on the results of that test (sec. 4.3).



* Note: Samples from UF–1 Stage were taken approximately 55 days prior to ground analysis, which allowed limited permeation of CO_2 into the sample and lowering pH; so data point is likely slightly below actual value in loop at that time.

Figure 22. pH of flight samples through flight 7S.

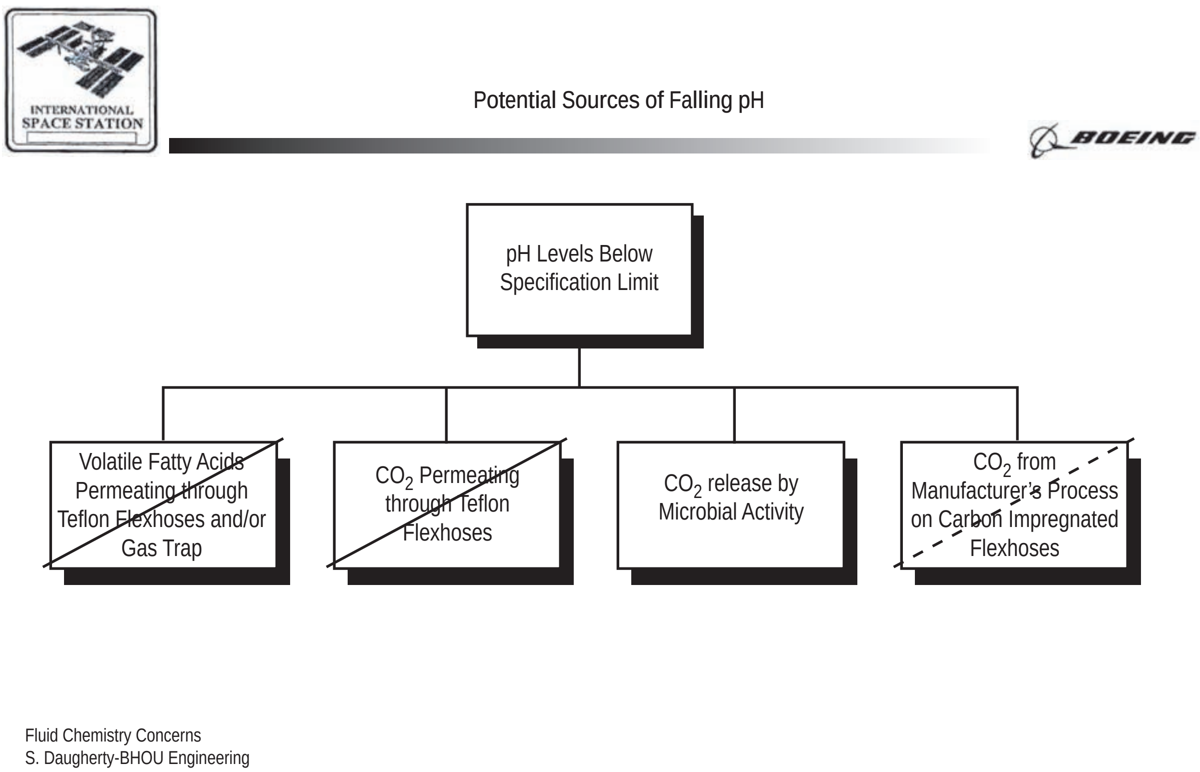
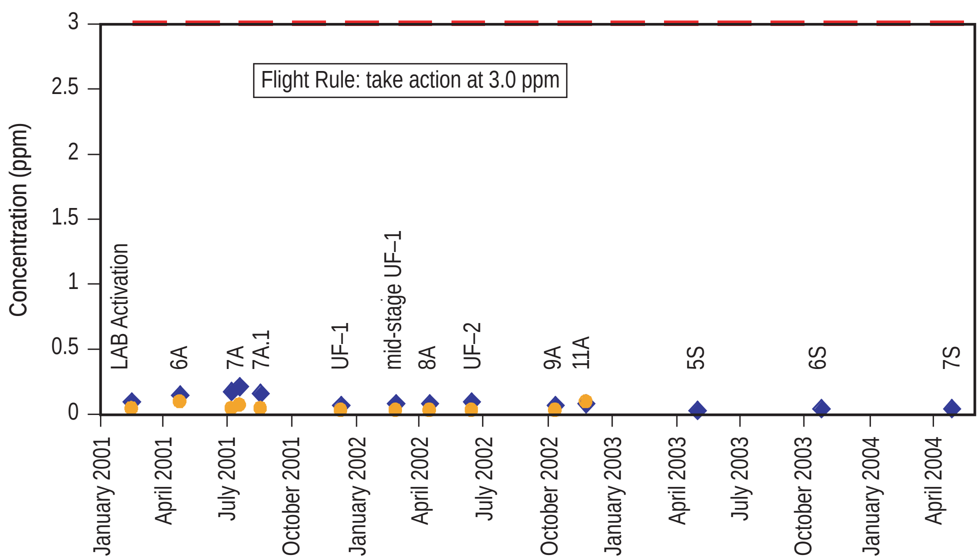


Figure 23. Fault tree for pH decrease in HTF.

The pH appears to have stabilized at 8.4, but the below-specification pH is an ongoing issue and as of this writing, January 2005, other methods of raising the pH are being considered, particularly by adding borate. Borate is present in the HTF formula to serve as a buffer and prevent deviations from the specified pH. The amount was based on ambient Earth-atmosphere concentrations of CO_2 and was insufficient to counter the effects of the higher CO_2 concentrations on ISS. Use of borate to raise the pH of the HTF is discussed in section 5.1.2.

3.4.2 Ammonia in Heat Transport Fluid

The detection of increasing, though low, levels of NH_3 in the HTF from February 15, 2001–July 19, 2001, caused alarm. The main concern was the possibility of a leak in the liquid-liquid HX with the external TCS (ETCS) NH_3 loop. (Note: At that time, the ETCS was referred to as the early external TCS (EETCS), which is used until the external active TCS (EATCS) is assembled as the ISS is completed.) Since the ETCS operates at a higher pressure (normally 350 psia, with a maximum of 500 psia) than the IATCS (normally 50 to 90 psia, with a maximum of 115 psia) even a small leak could result in significant amounts of NH_3 entering the IATCS. But, the concentration of NH_3, though initially increasing to 0.211 ppm, later decreased to the initial 0.09 ppm and lower (fig. 24), a scenario not likely to occur due to a leak, so leakage was ruled out.[17] SPRT discussions considered possibilities such as NH_3 generation by microorganisms, ground processing contamination, and permeation of NH_3 from the atmosphere (fig. 25) though ground processing and permeation from the cabin atmosphere are crossed off the list. Also, a backup jumper hose that had not been connected to the IATCS loop was returned from ISS, and it was found to also contain NH_3. This indicates that contamination occurred during processing or permeation through the Teflon. Ammonia is removed by the trace contaminant control system (TCCS) and by the humidity control system since NH_3 is found in the condensed humidity, but a background level is always present in the atmosphere because it is a metabolic byproduct. Calculations indicated that it would take ≈350 yr for sufficient NH_3 to permeate the Teflon hoses to reach the concentrations found in the HTF.[17] Later calculations (app. E.1) showed that it would take only 75 yr to reach the concentrations found. The discrepancy is related to the uncertainties associated with several of the variables, especially the permeability factor for NH_3 through Teflon, the total surface area of the Teflon hoses, and the partial pressure of NH_3 in the atmosphere. The permeability factor is also highly dependent on the temperature. There may be as much as 50 percent uncertainty in each of these values, so it is not surprising that calculations could achieve such different answers. This indicates the importance of determining the permeability for the system under the conditions of interest. To address the permeation of NH_3, the CFST facility was modified to enable a mixed-gas representative of ISS atmosphere conditions, including elevated NH_3 concentrations, to bathe the large Teflon hose and test the permeability of NH_3 through Teflon under operating IATCS conditions. More permanent modifications are being made, as of January 2005, as discussed in section 5.2.



Note: The concentration of NH_3 in the ISS atmosphere is not determined directly but is derived from the measured concentration of NH_3 in the humidity condensate, assuming equilibrium with the atmosphere. The concentration of NH_3 in the atmosphere was calculated by Jay Perry (app. E.1) and then used in the Teflon permeability calculations.

Figure 24. Ammonia concentration in the HTF through Flight 7S.

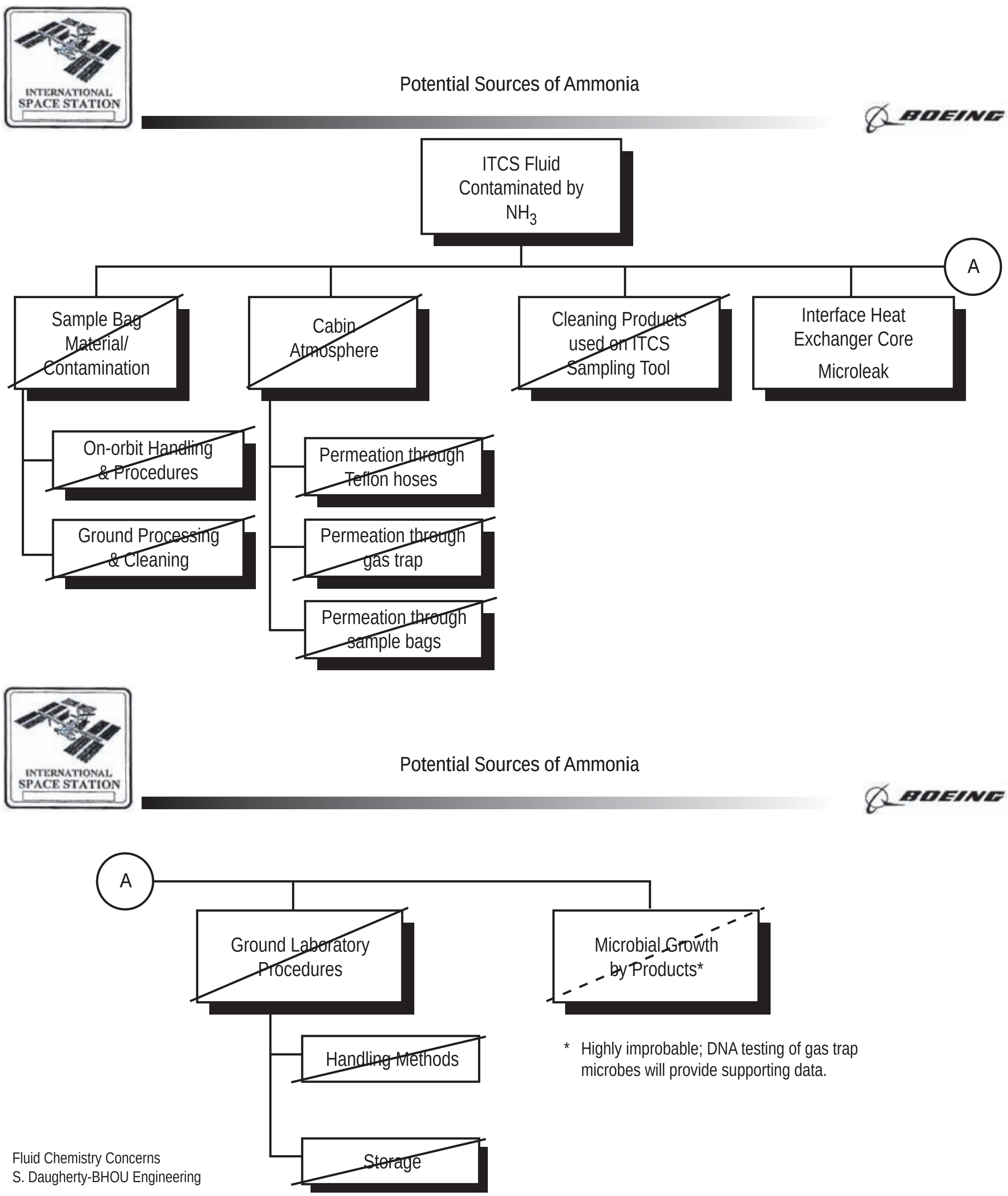
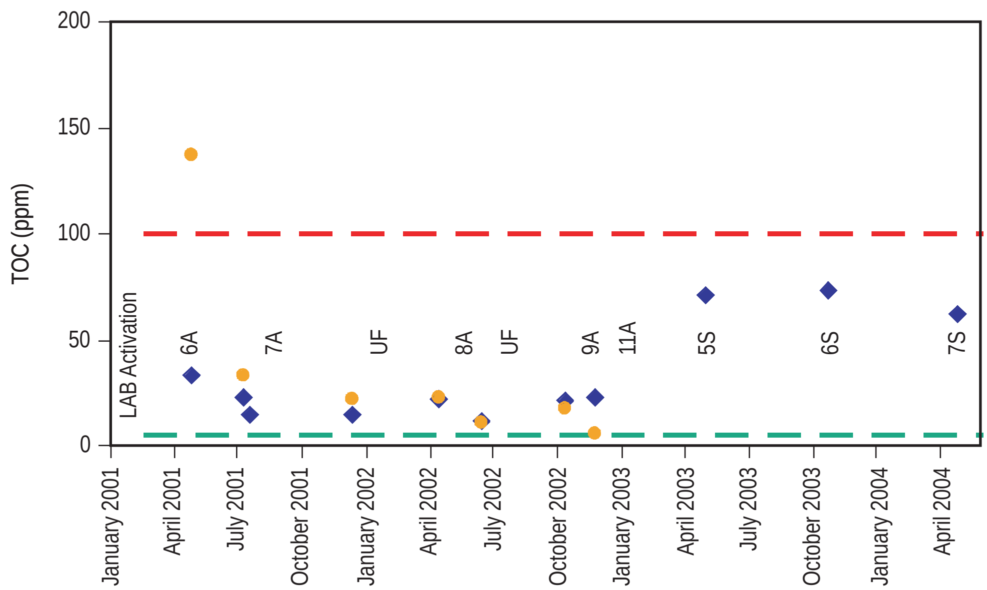


Figure 25. Fault tree for NH_3 source of HTF contamination.

3.4.3 Total Organic Carbon in Heat Transfer Fluid

The TOC level in the HTF has exceeded the specified limit of 5 ppm (fig. 26). The initial increase was traced to IPA, used to clean the hardware prior to launch, that was not flushed from a sampling adapter prior to delivery to the ISS. This problem was believed to be solved in subsequent missions, and HTF samples collected from the MTL during mission 11A contained a TOC concentration of 6 ppm. However, the concentration in the sample collected during the next mission, 5S, increased to 71 ppm, and the concentration stayed around those levels for subsequent missions—6S: 73 ppm, 7S: 62 mppm, and 8S: 80 ppm. The source of the TOC is unknown at this time, January 2005, but it was found to be composed of acetone, 20 ppm, and ethanol, 70 to 80 ppm. Ethanol is one of the highest concentrations of organics in the ISS atmosphere. The increase in the microbial load could account for some of the increase in TOC but not all of it. Several other factors, such as leaching and the installation of contaminated hardware, could also contribute to the increase.



Note: While still above the specified limit of 5 ppm, the TOC had stabilized below 25 ppm, until the last three samples which had an unexplained high level of ethyl alcohol not traceable to system processing. TOC levels below 100 ppm are currently considered acceptable.

Figure 26. TOC in HTF in Destiny.

3.5 Corrosion of Nickel From Cold Plates and Heat Exchangers

The concentration of dissolved Ni in the HTF has increased substantially, from near zero (below detection limits) to over 16 ppm (fig. 27). Since Ni solubility is highly pH dependent (fig. 28), it follows that the Ni concentration correlates with the decrease in pH (fig. 29) for the first year of operation on orbit. Increased growth of microorganisms also coincided with these changes, and for a time, it was thought that microbial growth may be significantly contributing to corrosion. An uncontrolled beaker test performed by Hamilton Sundstrand had indicated that silver may be a factor in corrosion, too, and

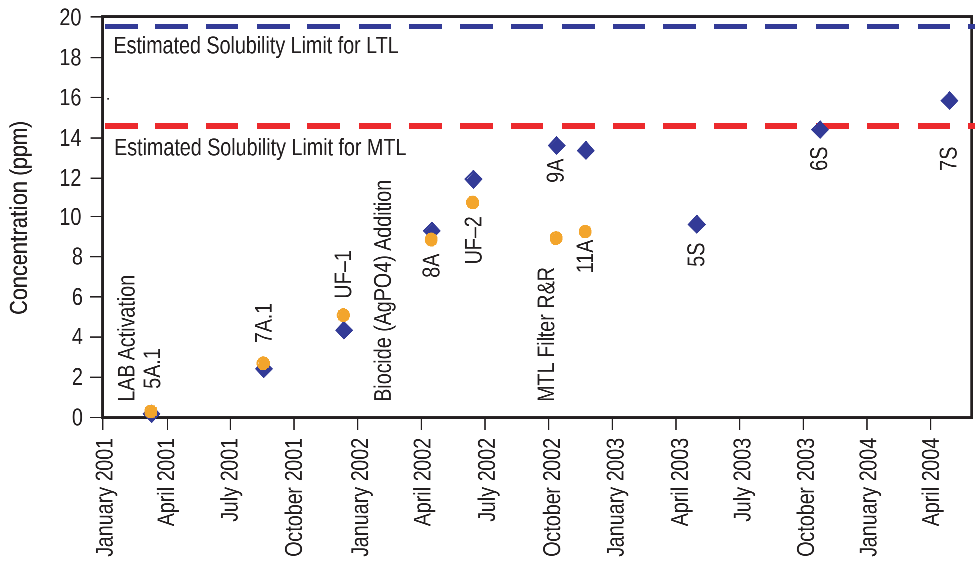


Figure 27. Nickel concentration in the HTF through Flight 7S.

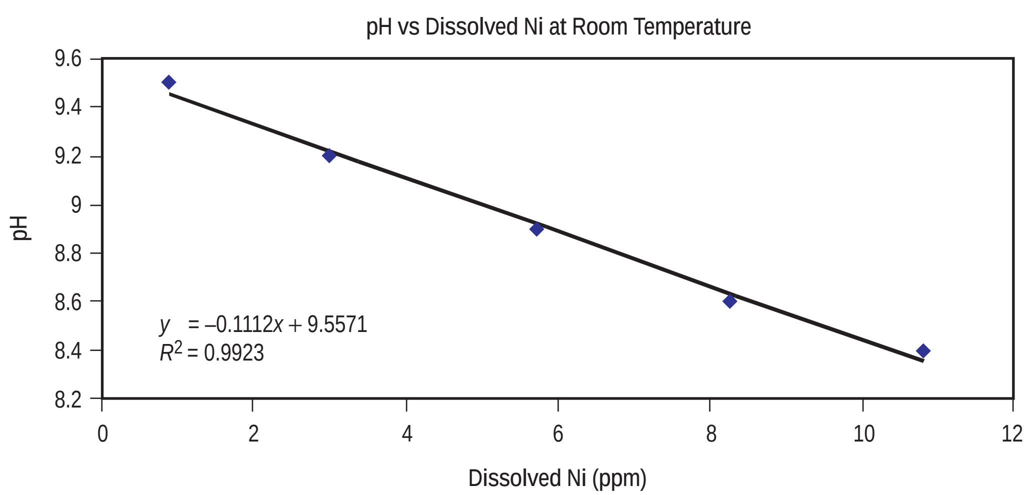


Figure 28. Relation between pH and Ni solubility (from Harold Cole, Boeing).

there were some tantalizing flight data that seemed to support this correlation: An increase in Ni concentration was measured following the addition of silver phosphate (Ag_3PO_4) in January 2002 that turned out to be unrelated. The primary factor that is known to affect corrosion is pH. The CFST facility was used to verify the ability of CO_2 to permeate Teflon and also showed increasing Ni concentration indicative of corrosion as the pH decreased, which is discussed in section 4.5.3.2.

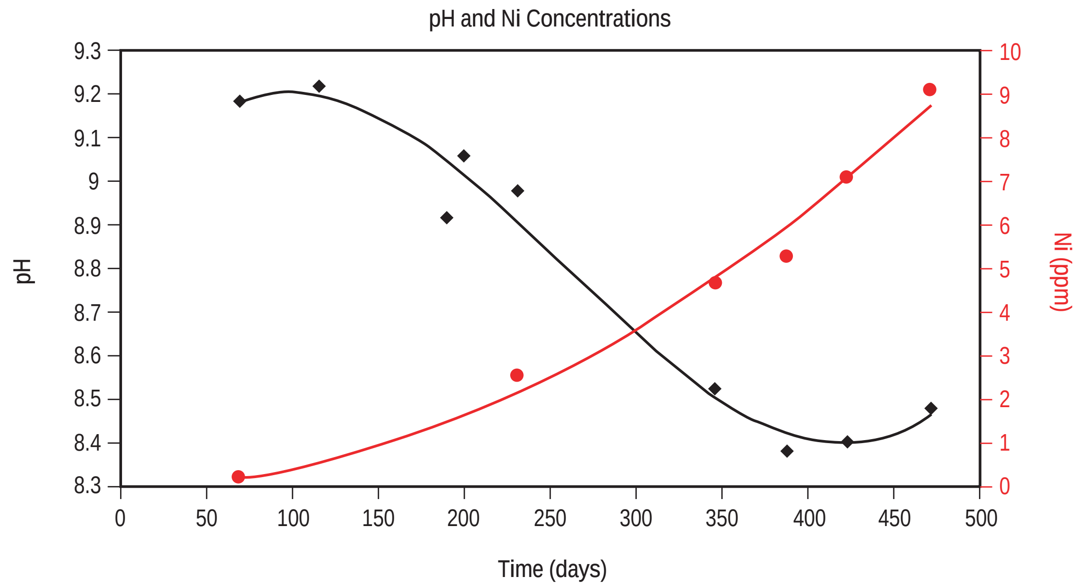


Figure 29. pH and Ni concentration in the Destiny HTF during the first year.

However, later testing showed that silver was not a significant factor in the observed corrosion nor was there any evidence that microbial growth contributed to corrosion. Follow-on testing of the effects of silver on corrosion, in a controlled experiment, indicated that any contribution to corrosion by silver was small if even present, though repeated dosings may have some long-term effects—over several years. The pH of the fluid was found to have a much greater effect on the corrosion of Ni, such that, at a pH of 9.5 corrosion is negligible, but at a pH of 8.4, it is significant. Even at pH 8.4, the rate of corrosion is sufficiently low that, except for the special performance checkout unit (SPCU) HX (fig. 30) for servicing space suits in the Airlock, the life of the hardware will still exceed the design life, 10 yr. Though concerns about Ag were based on a fallacious assumption related to an uncontrolled test since it had been decided to pursue alternative antimicrobials, silver was dropped from further consideration except for emergency use.

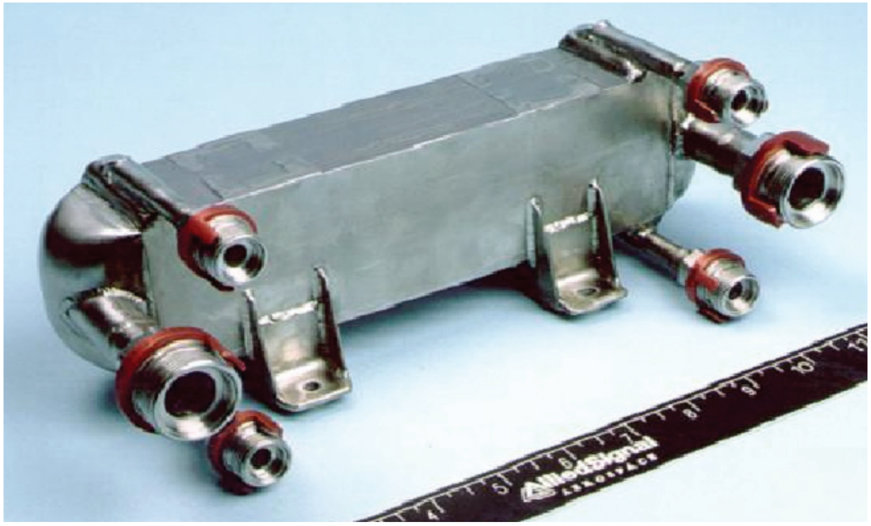


Figure 30. SPCU HX.

During testing by the suppliers of the cold plates and HXs, it was also found that the type of Ni brazing and method of brazing was a significant factor in corrosion. The BNi_2 brazing, which contains some chromium, used by Hamilton Sundstrand on the interface HXs (and CCAA, AAA, and PPA internal HXs) was found to be more resistant than the BNi_3 brazing used by Honeywell on the cold plates and SPCU HX. One difference between them is that BNi_2 uses thin sheets of Ni brazing, whereas the BNi_3 involves spraying a thin coating of braze particles on the item being brazed. Interestingly, when BNi_3 items were rebrazed, by running them through the heating cycle a second time, they showed similar resistance to corrosion as the BNi_2-brazed material.

As the Ni corrodes from brazing, it also forms precipitates which have been found on various parts of the PPA. Phosphate was included in the HTF primarily to serve as a corrosion inhibitor; however, it combines with dissolved Ni and precipitates out of solution as nickel phosphate ($NiPO_4$). Gas traps have been found coated with a green $NiPO_4$ precipitate, and filter elements have been found partially clogged with $NiPO_4$ and nickel hydroxide (NiOH). As shown in figure 31, the amount of phosphate in the HTF decreased considerably during the first year of operation on orbit. A flight filter element from the MTL returned on flight 9A was analyzed by Boeing (Huntsville Laboratory), and $NiPO_4$ and NiOH were found to be the primary constituents clogging the filter.[18] (Note: The analytical techniques used were able to identify the presence of Ni and oxygen on the filter surface, so the presence of NiOH was inferred but could not be specifically determined.) When the filter from the CFST facility was analyzed, the same compounds were found, though the proportion of $NiPO_4$ was less. The reason for the difference in proportions was surmised to be due to the difference in duration at specific pH conditions; i.e., additional time at a lower pH results in a higher proportion of $NiPO_4$. The amount of precipitate on the outlet of the filter was similar to the amount on the inlet, which indicated that the precipitates were formed in place rather than formed upstream and simply trapped on the filter. This same situation was found with the flight 9A filter. The amount of $NiPO_4$ on the CFST filter was determined to be 0.89 gm—compared to 5.5 gm found on the Flight 9A filter. Again, this is related to the duration of exposure to the low pH/high Ni fluid. Analytical modeling shows that, at these conditions, the hydroxide exchanges with

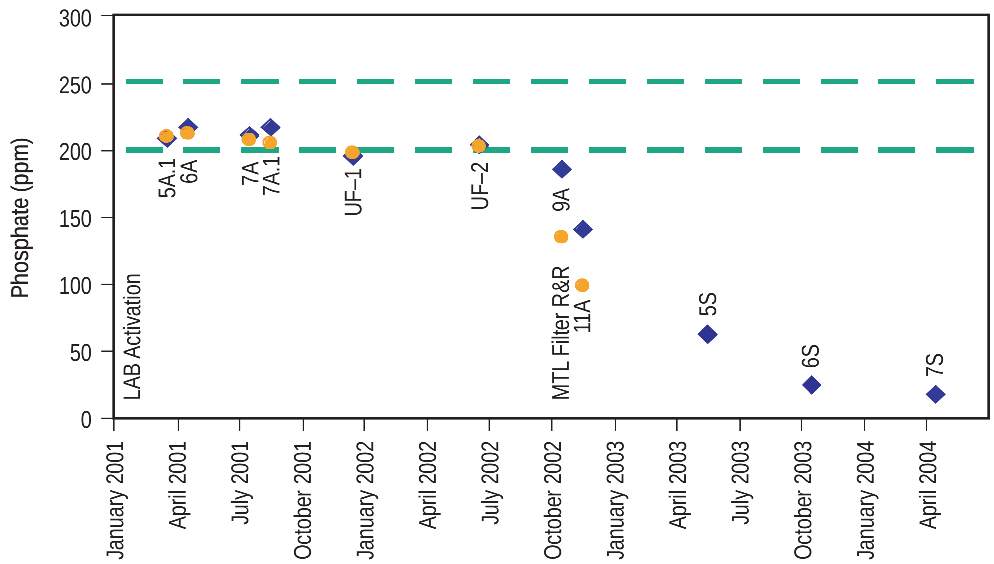


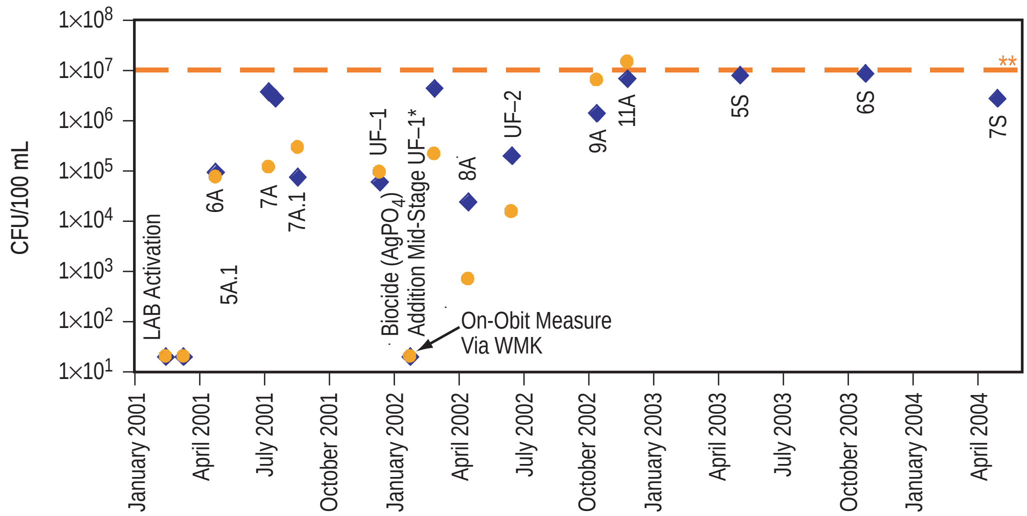
Figure 31. Phosphate concentration in HTF through Flight 7S.

phosphate in the HTF, and this exchange is shown by the actual results. These results indicate that the CFST did reproduce the processes that occurred in the flight IATCS.

The amount of missing phosphate implies that $NiPO_4$ particulates exist throughout the system. It is expected $NiPO_4$ will continue to form until most of the phosphate is consumed.

3.6 Microbial Growth

Also during the first year of operation, the microbial population increased several orders of magnitude, from 1×10^1 to 1×10^6 CFU/100 mL (fig. 32). Again, this could correlate with the decrease in pH from the original 9.5 to 8.4 since more species of microorganisms prefer the lower pH conditions (table 20). Several possible causes were considered (fig. 33), but lowered pH and contamination from hardware are the strongest factors though not initially considered. A test was performed using the CFST facility to determine the ability of CO_2 to permeate Teflon which also showed increasing microbial population as the pH decreased (secs. 4.5 and 5.2.). Payload racks and other IATCS fluid-containing hardware may have had a microbial population as high as 1×10^7 CFU/100 mL. When these racks were installed in ISS, they provided an immediate increase of the microbial population in the ISS HTF. Measures are being taken now to prevent the launch of hardware with high microbial counts in the HTF, methods to ensure the hardware is clean are being implemented (app. C), and additional methods are being considered for implementation if needed. Microbial loads in the HTF of flight hardware are monitored while being prepared for launch, and if necessary, the hardware will be disinfected prior to launch. In addition, use of an antimicrobial agent will control the microbial population in the hardware while on the ground (sec. 3.7). Adding a solution of H_2O_2 and silver (Ag+) (low levels, such as were used to control the microbial population in node 2), for example, could be used since the concerns with Ag related corrosion pertain to the Ni braze in the HX and not the materials in the ground hardware.



* Samples from UF–1 Stage allowed microbes to grow for approximately 55 days (without refrigeration or other precautions) prior to ground analysis; so data is likely not representative of the loop microbial count at that time.

** 1×10^7 is the not to exceed number established by Mike Holt, ITCS Lead

Figure 32. Microbial population in HTF samples (R2A analyses).

Table 20. Range of pH for microbial growth.[19]

Bacteria	Fungi	Algae
pH 1 to 4 Few species (e.g., sulfur-oxidizing Bacteria)	pH 1 to 5 Many species (e.g., molds)	pH 1 to 5 Very few species
pH 4 to 8 Majority of species	pH 4 to 7 Majority of species (e.g., molds and yeasts)	pH 5 to 9 Majority of species
pH 8 to 11 Few species (spore-formers)	pH 7 to 8 Few species, (e.g., molds)	pH 9 to 11 Few species

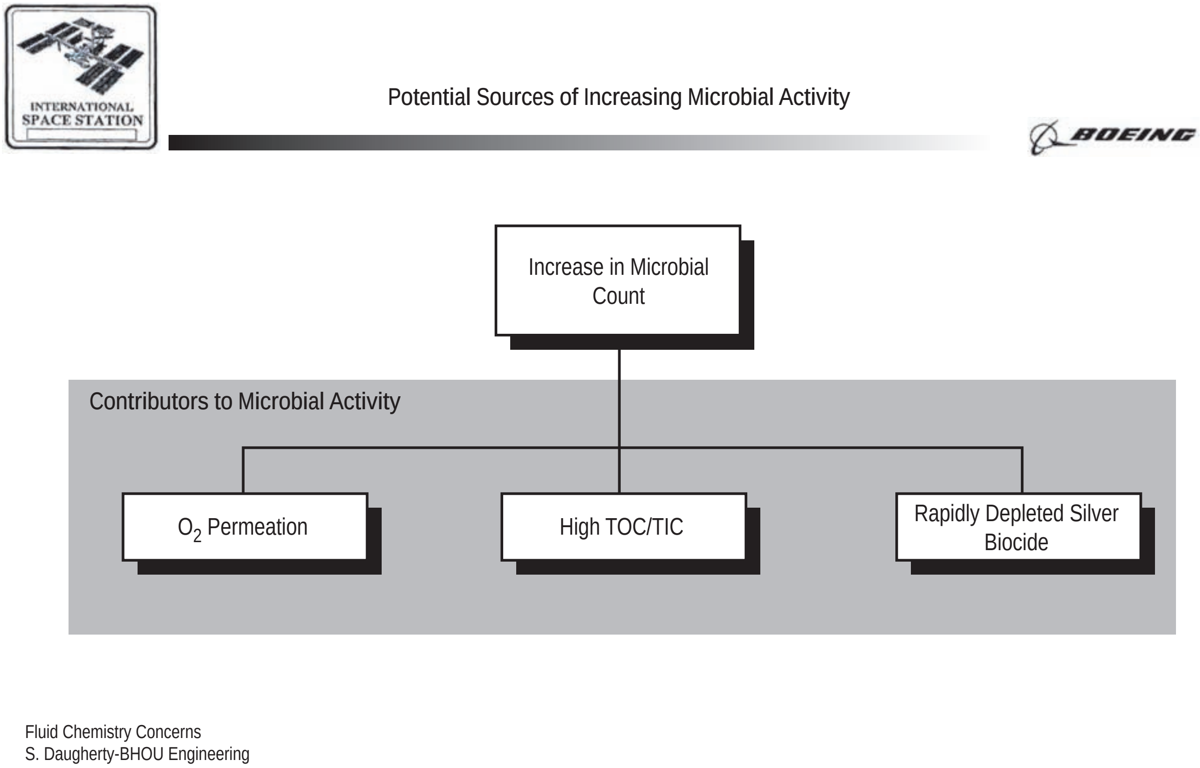


Figure 33. Possible causes of increased microbial growth considered by the SPRT.

3.7 Antimicrobial

The increased microbial growth was an ongoing concern because, even though the cause of the lower pH had been identified, the CO_2 level in the ISS atmosphere could not reasonably be lowered. To reduce the microbial population, silver was added in January 2002, after testing in the IATCS Simulator to verify the procedure and ensure that no unexpected problems would occur, such as due to the air bubble introduced by the method of adding Ag_3PO_4 powder in a filter (sec. 4.2). The procedure was found to be acceptable and was implemented on ISS with no problems, resulting in successfully decreasing the planktonic microorganism population.

Due to concerns that silver contributed to corrosion of Ni from the Ni brazing of the cold plates and HXs, the IATCS SPRT chose to remove Ag from the HTF formula. Even though follow-on testing of this phenomenon showed that silver was not significantly contributing to corrosion (sec. 3.5), efforts to develop a new antimicrobial had already begun so silver was not reinstated in the formula because of remaining concerns that repeatedly adding silver to the system might increase the chances of galvanic pitting corrosion on the Ni brazed surfaces since the Ag deposits on metallic surfaces. An effort to identify alternative antimicrobial agents that could be used in the IATCS fluid was initiated in the spring of 2002.

Through literature reviews and vendor inquiries, an initial list of antimicrobials, which follows, was developed:

- Aldehydes (AQUACAR), a series of Dow microbiocides that contain varying concentrations of the active ingredient glutaraldehyde, and pure glutaraldehyde.
- Bismuth thiols, including bismuth-2,3-dimercaptopropanol (BisBAL) and bismuth-3,4-dimercaptotoluene (BisTOL).
- Nonhalogenated oxidizers (H_2O_2, potassium monopersulfate, ozone, Bellacide® 375, and Sterilex Ultra).
- DOWACIDE 1 (99 percent o-phenylphenol).
- Quaternary ammonium detergents.
- Polyhexylmethylene biguanidine (Bacquacil Ultra).
- Isothiazolone (Kathon); 8) 2,5-dimercapto-1,3,4-thiazole; and 9) sodium azide.

A rating scale was used to score each antimicrobial agent on the initial list against 10 weighted assessment criteria. The criteria (and weighting factor) used to prioritize the list were as follows:

- Material compatibility (4×).
- Chemical compatibility (3×).
- Safety/toxicity (3×).
- Disinfection effectiveness (2×).
- Stability (2×).
- By-product acceptability (2×).
- On-orbit implementation (1×).
- Cost (1×).
- In-flight monitoring (1×).
- Technology readiness (1×).

The highest ranked biocides, having weighted average scores ranging between 70 and 80 out of a possible 100 total points, included the following in descending order:

- Hydrogen peroxide (80).
- Bismuth thiols (77).
- Bellacide® 375 (73).
- Enzymes (73).
- Glutaraldehyde (71).
- Quaternary ammoniums (70).

Other compounds with weighted scores between 60 and 70 were also selected for initial tests, including benzotriazole, Baquacil Ultra, and sodium azide. Detailed information on the testing rational and procedure that was used can be found in references 20–22.

Results of the initial testing and additional information narrowed the list of antimicrobials to only four: (1) H_2O_2, (2) glutaraldehyde, (3) bismuth thiols, and (4) Baquacil (backup). These four were further tested for material compatibility, stability, and long-duration effectiveness. In December 2003, the selection of glutaraldehyde was recommended as the best antimicrobial agent for use in the ITCS HTF. While effective at sufficient concentrations for controlling microbial growth, some problems with the use of glutaraldehyde were also identified. One of the problems was that the current test methodologies used to measure NH_3 levels in the ITCS HTF on orbit would be invalidated by the implementation of glutaraldehyde; therefore, a leak from the external loop would not be detected in its early stages. Another problem with the use of glutaraldehyde in the ITCS fluid is that, at the currently accepted HTF leak rates, glutaraldehyde concentrations in cabin air will quickly reach and surpass the allowable concentration (as defined in the NASA Spacecraft Maximum Allowable Concentrations/SMAC document) (app. E.2). Due to the potential health hazard and the risk of exposing the crew to harmful levels of glutaraldehyde, a chemical that presently cannot be monitored in ISS, it was considered imprudent to proceed with implementation.

In June 2004, NASA initiated a contract for an independent assessment of antimicrobial agents. The work was performed by a group at Montana State University, headed by Barry Pyle and a company in Boston, MA (Mittelman and Associates) headed by Marc Mittelman and Ralph Mitchell. Results of the study provided NASA with additional antimicrobial candidates to consider.[23,24]

As of January 2005, no decision regarding an alternative antimicrobial agent has been made, though silver, in the form of a H_2O_2 solution, $H_2O_2/Ag+$ (0.5 ppm/10 to 10 ppb), is being considered again, along with glutaraldehyde, isothiazolone, orthophthaldehyde (OPA), and tetrakishydroxymethyl phosphonium sulfate (THPS) modified to replace the sulfate with another anion (acetate is being considered). These five candidates were selected for further evaluation in December 2004.

3.8 Flight Issues and Assumptions

During the design of the IATCS early in the Space Station program, several assumptions were made that turned out to be fallacious. Initially it was thought that the HTF would not have any oxygen dissolved in it since oxygen was thought to not permeate the Teflon hoses. It was further assumed that without oxygen the growth of microorganisms would be prevented; therefore, there would be no need for microbial control. These assumptions ignore anaerobic microorganisms that do not need oxygen and ignore the ability of oxygen to permeate through the many Teflon hoses of the IATCS, even in the case of a considerable total pressure differential (47.3 to 90 psia inside the hoses versus 14.7 psia in the ISS atmosphere). The errors of these assumptions were discovered prior to launch of the first modules, and silver was added to the HTF formula to serve as an antimicrobial agent. The basis for these assumptions was experience on the ground with relatively short-duration or open-loop systems. The significant difference with ISS was not the effect of gravity, but the difference in atmosphere composition and that the system would operate for long periods (years) in that atmosphere without having the HTF replaced.

It was further assumed that CO_2 does not permeate through the Teflon hoses. This assumption was found to be incorrect only after operation in orbit had begun. While CO_2 permeation is slow, over time significant amounts do permeate, even against a higher total pressure. Although low, the concentration of CO_2 in the ISS atmosphere is significantly greater than typically found in Earth's atmosphere (≈0.7 percent in the ISS atmosphere, compared with 0.03 percent in Earth's atmosphere), which means that testing in ambient conditions on the ground does not represent typical conditions on board ISS. As the CO_2 permeated the Teflon hoses, it was converted to carbonic acid in the HTF, thereby, lowering the pH (fig. 34). Over the course of the first year of operation in orbit, the pH of the HTF in Destiny's IATCS dropped from the specified 9.5 + 0.5 to 8.4 as mentioned in section 3.4.1. The specified pH provided benefits including inhibiting microbial growth and inhibiting dissolution of Ni (fig. 34). As the pH decreased, other parameters were also affected, including increases in the microbial population, Ni corrosion from cold plates and HXs, and particles due to the formation of precipitates. There was much discussion among the IATCS SPRT as to whether the decreasing pH was due to something in the IATCS loop, such as microbial activity, affecting the pH or whether CO_2 permeation was the cause and microbial growth simply an effect. A page from a presentation about this issue is shown in figure 23, which indicates that CO_2 permeation was ruled out as a cause and microbial activity was considered the most likely source. As mentioned in section 3.4.1, calculations of permeation by NASA Johnson Space Center (JSC) determined that permeation could account for only 10 percent of the observed pH change, based on testing of CO_2 permeation through Teflon by the Boeing Huntsville lab. The CFST facility, which was operating in ambient conditions (low CO_2) so the pH was stable at 9.5, was modified to bathe the large Teflon hose in CO_2 (as discussed in sec. 4.5.3). The results, evident within the first couple of weeks, showed that CO_2 could permeate into a pressurized, flowing IATCS loop as the pH steadily decreased.

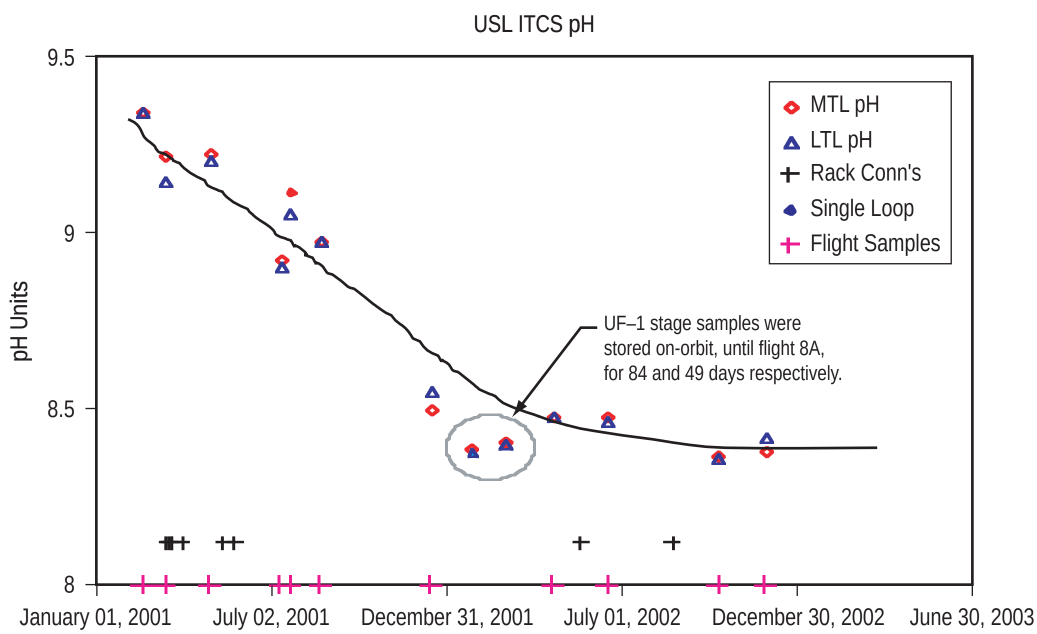


Figure 34. pH of the Destiny module IATCS coolant over the first year.

Concerning the presence of NH_3 in the HTF, a number of possible sources were considered, as indicated in figure 25. Early assessments by the SPRT seemed to indicate that a microleak in the interface HX was the most likely cause, and permeation from the ISS atmosphere was ruled out. This is discussed in section 4.4.2, and rather than a leak, permeation and ground processing are the most likely causes.

Concerning increasing microbial growth in the HTF, several possible causes were also considered (fig. 33). None of the listed causes had yet been ruled out, but decreasing pH was not identified as a possible cause because, at the time, microbial growth was thought to be a significant cause of decreasing pH. It was later determined that the lower pH contributed to increasing microbial growth in the absence of Ag+ ions in the HTF due to deposition on the metal surfaces.

The following lessons to be learned here are important for any project:

- Do not rule out possible explanations for phenomena prematurely.
- Clearly identify and state any assumptions that are made.
- Test assumptions when possible to be sure that they are valid for the conditions of interest.
- Tests must be performed under relevant conditions.

Also, when chemical changes can be simulated on the ground—under correct atmospheric conditions—they should be ruled out as causes of a change in fluid chemistry before microbial sources are considered as the cause for anomalies. Changes caused by microbial metabolism are hard to verify when the complete picture of the microbial population within a flight system is not known, especially when there are constraints on returning sufficient samples to the ground for analysis. Even samples, though, may not accurately portray the flight conditions if not collected, transported, and processed properly.

The initial disregarding of permeation of NH_3 from the atmosphere through the Teflon hoses was due to the early calculations that indicated exceedingly slow permeation times, which lead to an assumption that NH_3 would not significantly permeate through Teflon. This should lead one to consider other possibilities; however, it should also lead one to perform a test to verify the assumptions in the calculations or to perform independent calculations as a cross check. Later calculations (app. E.1) indicated that permeation of NH_3 occurred much faster, pointing out the uncertainty associated with those calculations. The source of NH_3 was either permeation or, possibly, contamination from the processing facility at Kennedy Space Center (KSC) since NH_3 is used in that facility. For the assumption that CO_2 could not permeate the Teflon hose and affect the pH, a very simple test was performed, but only after considerable time and effort had been spent evaluating other possibilities. Performing the test earlier, prior to ruling out permeation, would have allowed more effort to focus on the real cause and development of effective solutions.

4. TEST ACTIVITIES

Tests relating to the IATCS have ranged from tests on individual parts, such as an IATCS jumper hose to HTF chemistry response to IATCS performance to astronaut training. For some tests, the facilities were used even before assembly was completed, producing valuable results that reduced risk to the ISS. These tests are summarized below, including the hose expansion test, tests using the IATCS Simulator, and the CFST facility.

4.1 Hose Expansion Test—2000

During assembly of ISS, jumper hoses are used by the astronauts on board to connect the IATCS loops in adjacent modules. A jumper hose with quick disconnects (QDs) and end caps attached is referred to as an IHA. As mentioned in section 3.2, it would be preferable to launch the IHAs already filled with HTF, but there was a concern that in the event of high temperature during storage or transportation the IHAs may leak or become damaged due to excessive pressure. To address this concern, a test was performed to evaluate the ability of an IHA to be launched wet and safely accommodate the increased pressure of the HTF if the temperature increased to the worst-case condition of 60 °C (140 °F). The test was performed using a flight-like hose with a flight end cap to evaluate the maximum pressure that would occur under the worst-case condition. Four cases were run with test conditions subjecting the test article to up to 71 °C (160 °F). Results show that the pressure at this temperature reached ≈228 kPa (33 psia), well below the design maximum of 689 kPa (100 psia). The test conditions and results are described in report NASA/TM—2001–211330 and are summarized in sections 4.1.1–4.1.3.[16]

4.1.1 Test Description

The test article (fig. 35) consisted of an IHA, an aluminum adapter block fabricated to attach a pressure transducer and a 3-way valve for connecting a vacuum source, and a pressurized tank containing HTF. The IHA was a flight IHA rejected due to a change in materials. The hose was made of convoluted Teflon (polytetrafluoroethylene (PTFE)) with a nominal diameter of 12.7 mm (0.5 in) and a length of 914 mm (36 in), including fittings.

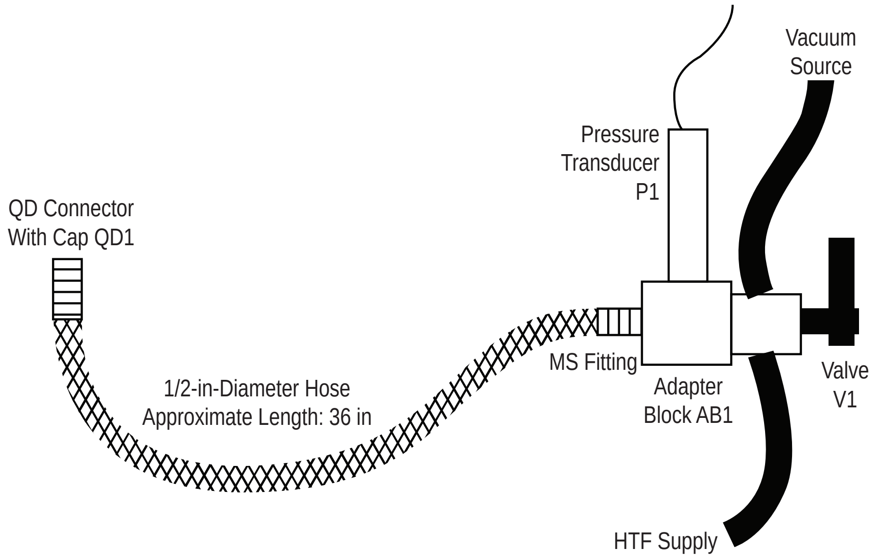


Figure 35. IHA test article schematic.

An Ecosphere thermal/humidity chamber by Despatch (model 16664) located in Building 4619 at MSFC was used for this test. The chamber can be maintained at any temperature between –70 and 180 ºC (–94 and 356 ºF) and is large enough to accommodate the IHA with the adapter. Temperature and pressure data were recorded every 20 s by the Payloads and Components Real-time Automated Test System (PACRATS). The IHA was filled with HTF to a pressure of 179 kPa (26 psia).

4.1.2 Schedule

Preparations for the test were initiated on February 3, 2000. The test was performed from June 27–30, 2000, and consisted of four temperature swing cases. This test was conceived, planned, performed, and concluded within 5 mo.

4.1.3 Results and Conclusions

As shown in figure 36, the data show that, for all cases, the pressure increases as the temperature rises. However, as shown in figure 37, for case 1, the pressure profile is noticeably different from the following cases, having a much shallower slope that is almost linear. The pressure increase is significantly less than for the following cases, including case 2, which followed the same temperature profile. This is thought to be related to expansion of the hose, which would result in decreasing pressure, mitigating the pressure increase due to increasing temperature. However, as the temperature nears 60 °C (140 °F), the slope changes to match the slope of case 2 above 57.2 °C (135 °F). This indicates that expansion of the hose had essentially ceased, so the final part of the curve parallels the later cases where it is assumed that additional expansion of the hose is minimal. At 60 °C (140 °F), the pressure reached just over 200 kPa (29 psia). When the temperature was reduced to ambient, the pressure decreased to 134 kPa (19.5 psia).

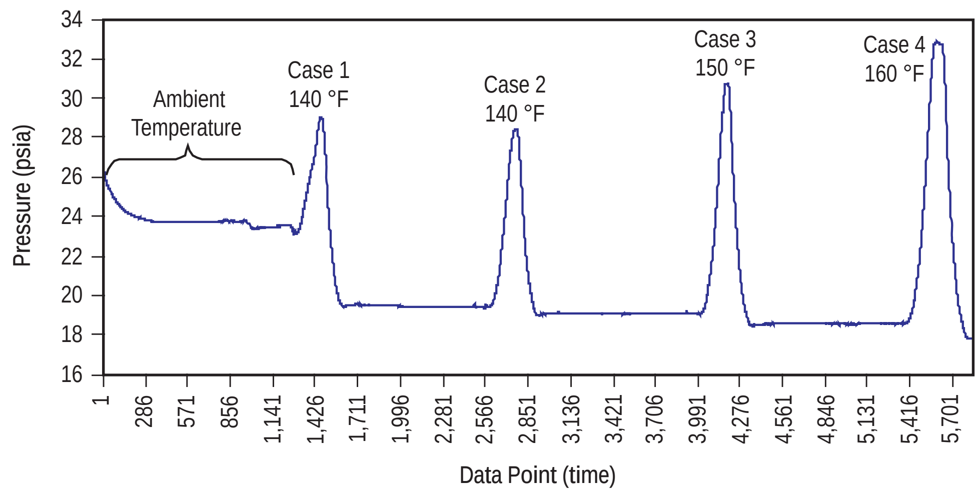


Figure 36. Test article pressure profile.

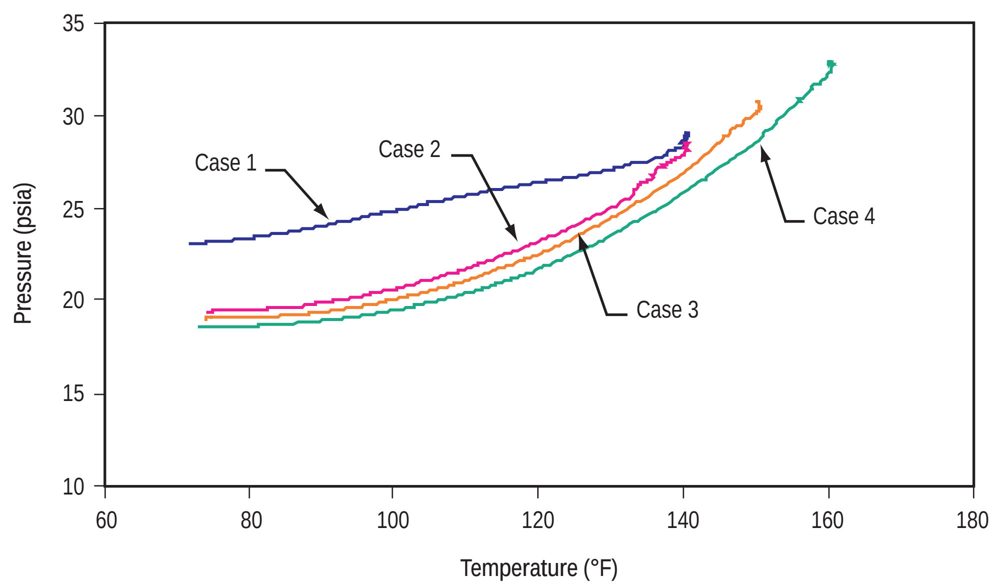


Figure 37. IHA test article pressure versus temperature profiles.

Cases 2, 3, and 4 show closely parallel pressure profiles, successively peaking at somewhat higher pressures due to the higher successive temperatures. With each successive case there is also a slight (3.4 to 9.0 kPa (0.5 to 1.3 psia)) decrease in pressure at a given temperature. This decrease is partly or wholly related to effusion of the HTF through the PTFE hose material. The reported effusion rates, provided by Ahmad Sleiman of Boeing, are: 1.74×10^{-7} g/min/in^2 at 18.3 °C (65 °F), and 7.68×10^{-7} g/min/in^2 at 48.9 °C (120 °F).

This test showed that the IHAs could be safely filled with HTF prior to delivery to the ISS, thereby saving the crew time that would otherwise have been needed to fill the IHAs while on orbit.

4.2 Silver Addition Test—2001

In 2001, within a year of activation of Destiny on orbit, several changes were noted in the coolant chemistry that raised concerns. The changes of greatest concern were, the pH decrease from the specified 9.5 to 8.5 (fig. 34), the population of microorganisms increase from $1{\times}10^1$ to $1{\times}10^6$ CFU/100 mL (fig. 34), a noticeable increase in the concentration of dissolved Ni in the HTF. These deviations from the specified conditions prompted concerns about undesired effects such as the growth of biofilm and corrosion of the Ni brazing of the HXs and cold plates. (See sec. 3 for more detail of the flight issues.)

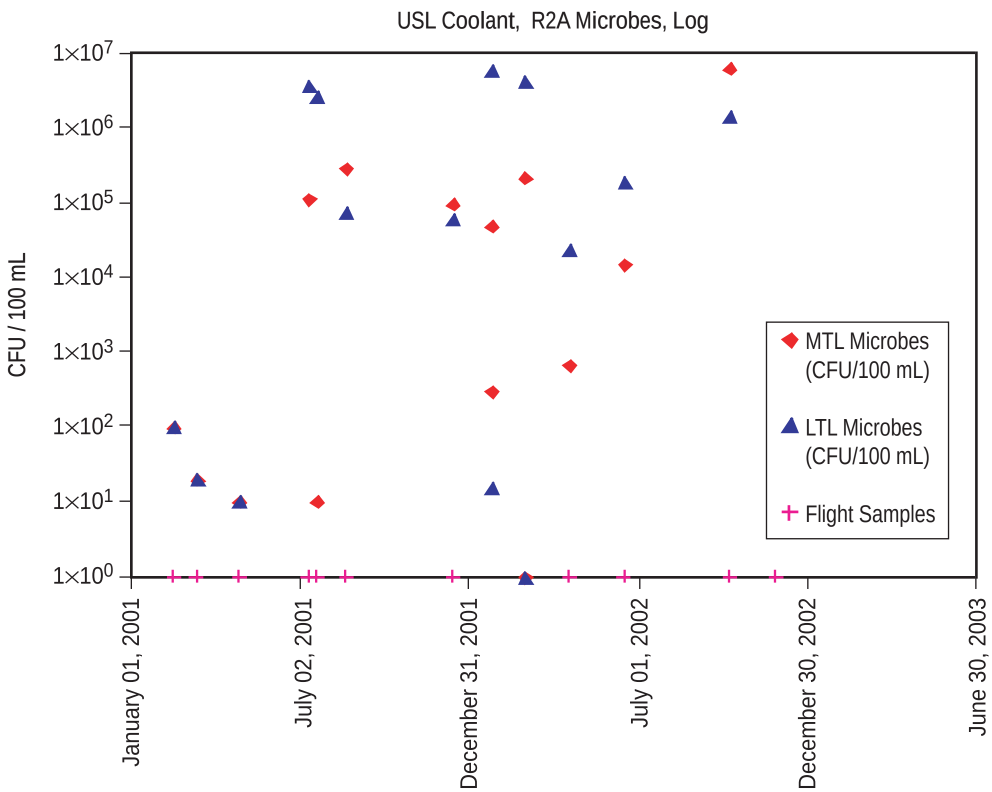


Figure 38. Microbial population of the Lab module.

The initial concentration of silver antimicrobial in the HTF rapidly depletes, within days as it deposits on metal surfaces, thereby losing effectiveness to minimize the growth of microorganisms in the HTF. Adding silver will reduce the microorganisms to acceptable levels, and the IATCS SPRT decided in late 2000 to implement a method to do so. A test was performed from October 25–29, 2001, in the IATCS Simulator to determine whether this method itself would cause undesired consequences since it involves adding powdered Ag_3PO_4 and an air bubble upstream of the pump.

4.2.1 Test Description

To address concerns about possible clogging of the filter with Ag_3PO_4 powder (provided by Boeing), 840 mg (twice the amount required to achieve the specified concentration for the volume of HTF in the system) was placed in the housing of the filter of the PPA by removing the inlet QD and pouring the powder into the housing (fig. 39). To implement this method, the astronauts would simply replace the operating filter orbital replaceable unit (ORU) with a filter that had been precharged with Ag_3PO_4 before launch. In addition to potential clogging of the filter, other issues of concern were the possibility that the air bubble in the filter (launched dry) might cause unacceptable gas trap performance, the rate of Ag_3PO_4 dissolution and resulting Ag concentration increase in the HTF, and the effectiveness of the method for reducing the microbial population. The test was performed to address all of these issues. Due to the concern of clogging the filter, the flow rate was decreased to reduce the ΔP. After a slight increase ($\approx$0.5 psia), the ΔP showed no change for several minutes after the filter was installed, and the flow rate was raised back to 3,000 pph. This increased the ΔP to 2 psid, still well below the bypass valve cracking pressure of 4.5 psid.

Figure 39. Filter housing with QDs removed and Ag_3PO_4 powder (in vial) to be added.

4.2.2 Results

As shown in figure 40, the Ag_3PO_4 dissolved rapidly at first before slowing and leveling as the concentration increased. The pressure drop across the filter showed no significant increase and the effects of the air bubble were within allowable limits. The rate of Ag_3PO_4 dissolution was acceptable, raising the Ag^+ concentration rapidly to the specification range: 0.1 to 3 ppm (or mg/L). The Ag^+ concentration continued increasing over the 90 hr of the test, and as figure 41 shows, granules of Ag_3PO_4 were still present in the filter at the end of the test. This indicates that this method of Ag^+ addition will provide effective microbial control for a much longer period of time than when added as premixed HTF, even with a relatively small amount, 840 mg, of Ag_3PO_4 and, therefore, might provide extended control of planktonic microbial growth. (Additional testing is needed to determine how long the antimicrobial benefit would last and identify any unexpected effects.) Microbial samples were collected and analysis showed a 4 log reduction in microbial concentration. Based on the results of this testing, the ISS

Program office approved this method for adding silver to the IATCS of Destiny, and two filter ORUs were launched on flight UF–1 in November 2001 and installed on the PPAs in Destiny by the astronauts in January 2002. Samples collected after the new filters were installed show that the microbial population was reduced to the desired level.

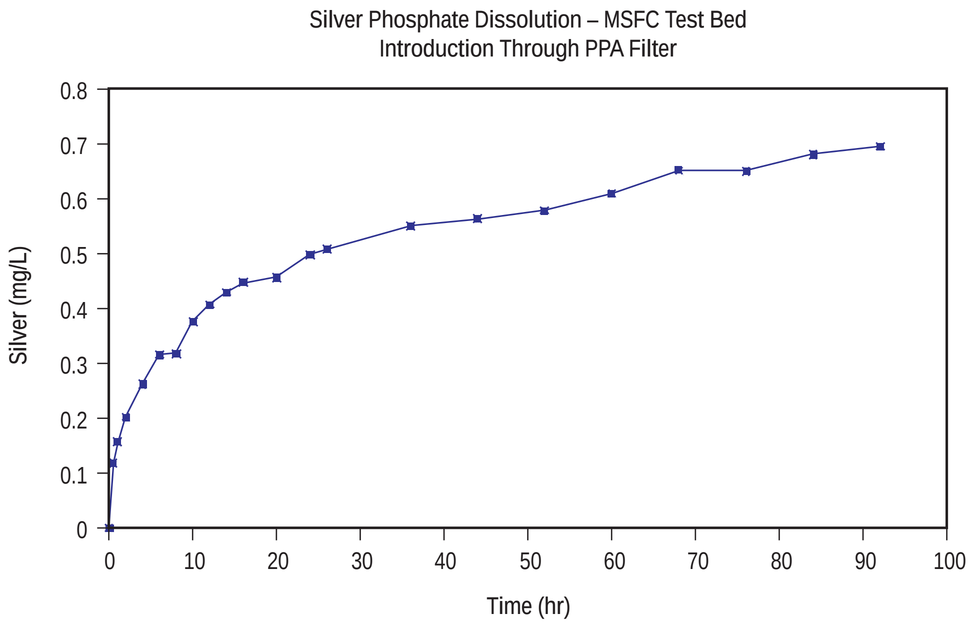


Figure 40. Silver addition dissolution concentration.

Figure 41. Filter cartridge with residual Ag_3PO_4 granules after 90 hr.

4.3 Sodium Hydroxide Injection Procedure Verification and Training Activity—2002

In addition to adding Ag_3PO_4 to reduce microbial populations, methods of raising the pH directly, which would also inhibit microbial growth, were considered by the IATCS SPRT, as described in section 3.4.1. A procedure was developed and approved, but because it was a new procedure that the astronauts had not practiced, it was necessary to videotape the procedure as it was being performed to prepare a training video to send to the crew along with the IATCS NaOH injection kits (INIK).

4.3.1 Test Description

The IATCS Simulator was modified to increase the fidelity of key interface connections with the Destiny IATCS interfaces in order to enable verifying the procedure and preparing the video. For this training activity, the injection syringes were filled with HTF solution rather than the NaOH solution. The procedure was prepared by the Missions Operations Directorate (MOD) office at JSC and followed step by step to verify that it was correct and could be performed as intended. A schematic of the connections to be made is shown in figure 42.

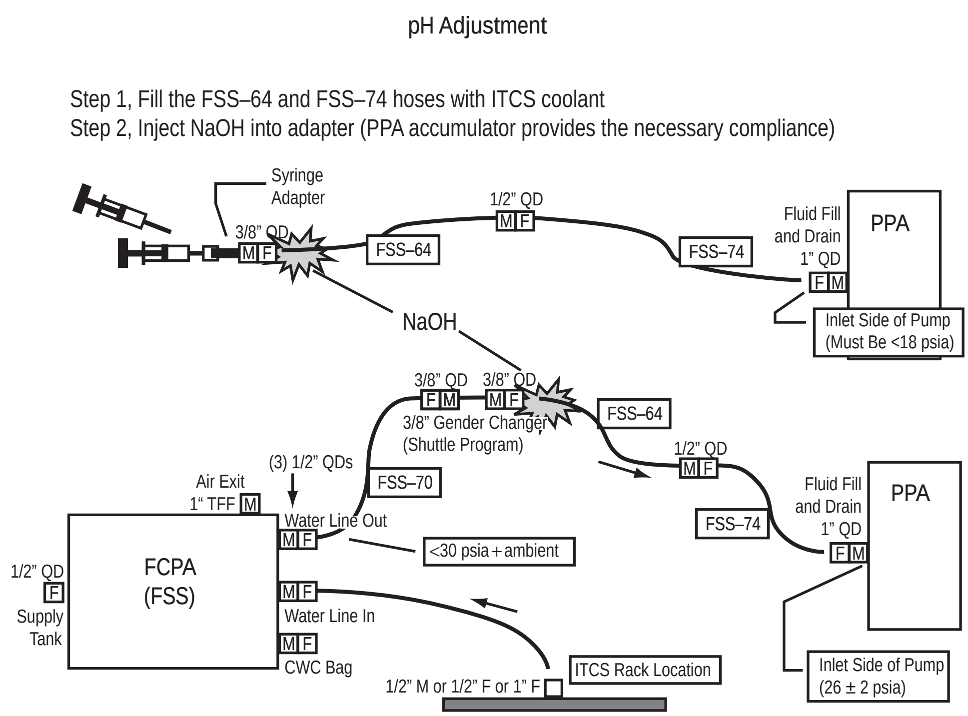


Figure 42. Sodium hydroxide injection procedure schematic.

4.3.2 Facility Preparations

Facility modifications included adding rack face frames to two locations, LAS6 and LAP6, to attach a portable glove box and QD fittings for the required hose connections to the LTL PPA. A simulated utility interface panel was added to the LAO5 rack location. Personnel from MOD at JSC came to MSFC with a prepared procedure and equipment to videotape the procedure as it was performed (figs. 43–46) in order to prepare the training video for the astronauts on board the ISS.

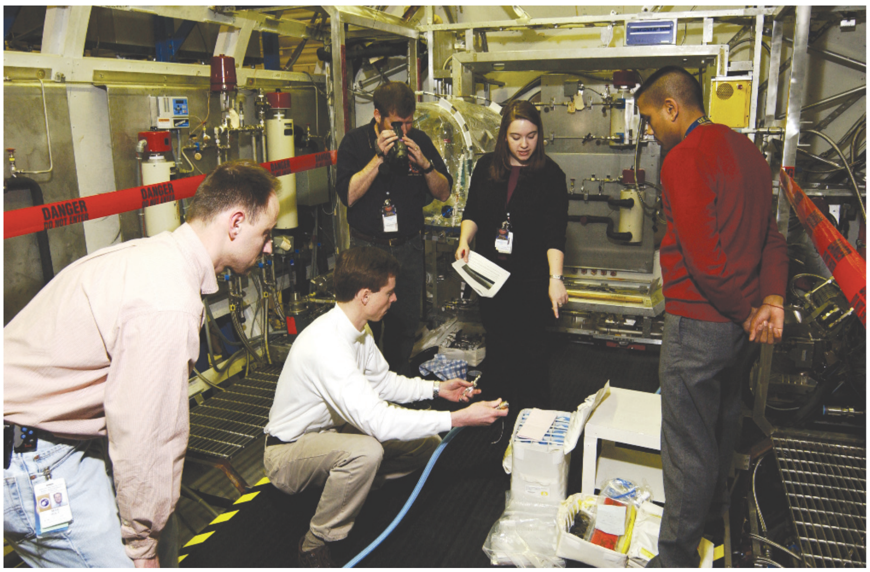


Figure 43. Sodium hydroxide injection procedure verification.

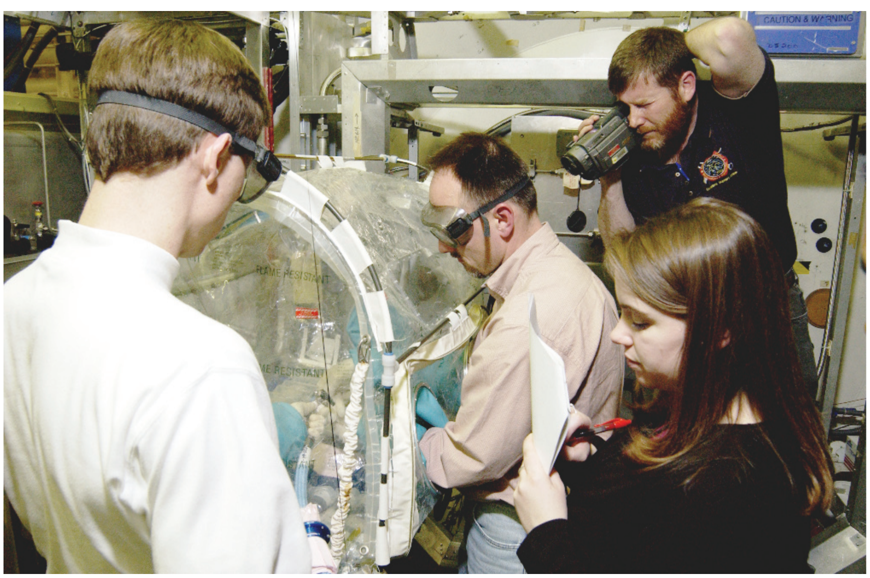


Figure 44. Using the portable Glovebox during NaOH injection procedure training.

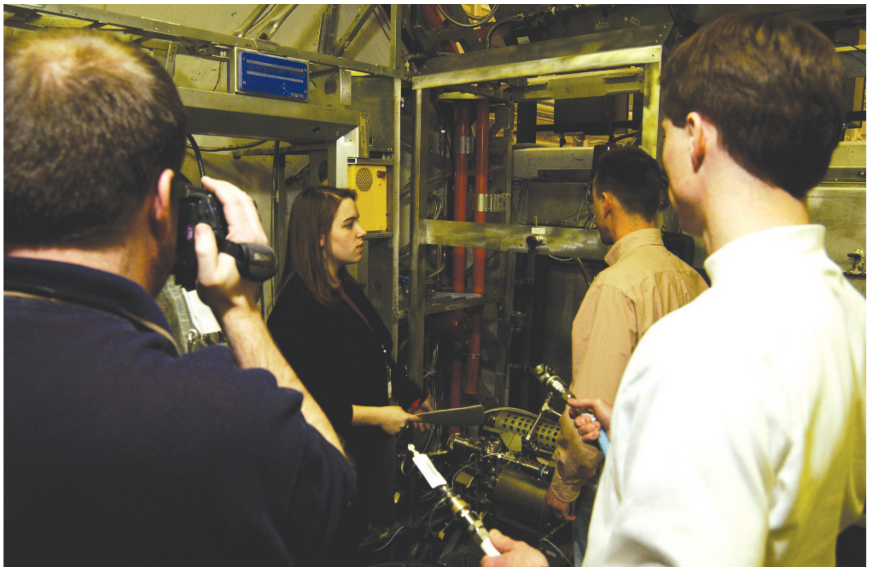


Figure 45. Preparing to connect the IATCS hoses to the PPA interface.

Figure 46. Connecting a hose to a rack utility interface panel.

4.3.3 Schedule

Test planning and preparations occurred from January to February 2002. The training session using the IATCS Simulator at MSFC was held on March 1, 2002.

4.3.4 Results and Lessons Learned

As the procedure was performed, it was necessary to modify some details, and it was found that a specific hose connection sequence is important. For example, the hose with the orifice fitting must be properly installed to ensure acceptable flow rates.

Two kits of NaOH-filled syringes were prepared and launched to the ISS on flight 8A in April 2002. Prior to performing the procedure onorbit it was found, while performing the test described in section 4.4, that implementing the injection procedure may lead to undesired consequences, so the procedure was not implemented and the kits were returned to Earth.

4.4 Sodium Hydroxide Injection Test—2002

Following the training exercise on March 1 in the IATCS Simulator in Building 4755, further laboratory studies by Boeing indicated that raising the pH in a solution with dissolved Ni would lead to precipitation of NiOH. (Nickel leaches from the HX and cold plate brazing material at pH levels below 9 so raising the pH back to 9 or above leads to precipitation of NiOH.) The concern is that Ni precipitates may adversely affect IATCS performance. To identify and evaluate possible effects, a test was performed using the IATCS Simulator in order to determine the extent of effects and the validity of the concerns.

4.4.1 Test Description

The primary test objective was to determine if adding 8%N NaOH solution to HTF, in order to raise the pH from 7.8 to 9.5, that is contaminated with dissolved Ni would have a deleterious effect on the 2-µm filter or other components. Of special concern were pressure drop characteristics of the filter and gas trap. A secondary objective was to collect data for risk mitigation. The test requirements sheet for this test (prepared by Sam Woodward, Boeing) is in appendix D.2.

A special mixture of HTF with elevated concentrations of Ni (≈8.5 ppm) and lower pH (≈7.8) was prepared by Boeing and flushed through the IATCS Simulator during the week of April 9, 2002.[25] The LTL and MTL were connected in single-loop configuration and operated at 51 °F and 63 °F, respectively, with representative heat loads. The total volume of circulating HTF was ≈67 gal, including additional volume provided by tanks. A peristaltic pump setup was used to inject the concentrated NaOH solution into the IATCS loop, as discussed in section 4.4.4, with up to 22 injections to reach a pH of 9.5. Samples were collected after each injection to measure the pH.

4.4.2 Schedule

Planning for this test began after the training procedure on March 1, 2002. Facility preparations were complete by April 9, 2002, when HTF changeout was initiated. On April 11, 2002, the system was started. On April 12, 2002, the filter was replaced with a new filter, and the research gas trap (provided by Honeywell) was installed. The test concluded on April 17, 2002.

4.4.3 Facility Preparation

To avoid any adverse affects to the only flight-like gas trap available for the IATCS Simulator, a research gas trap was obtained from Honeywell for this test. It was found that the housing was sufficiently different that it would not fit on the LTL development PPA. The gas trap module was removed and inserted into the development gas trap housing. The module had a ruptured membrane tube that had been sealed to isolate it from the flow (as discussed in sec. 4.4.4—after the test it was found that the tube had only been sealed at one end). An associated test was performed to evaluate the gas removal capability of the gas trap. The setup for this associated test used a hose connected to a fitting over the vent of the gas trap to direct gas to an inverted graduated cylinder in a beaker of water. The idea was to collect any vented gas in the graduated cylinder in order to quantify the rate of gas venting.

During the week of April 9, the HTF in the IATCS Simulator was replaced with the high Ni/low pH HTF. When the system was reactivated, the 2-µm filter became clogged within 15 min. A sample of the HTF was analyzed and found to have a Ni concentration of 5.4 ppm, down from the initial 8.5 ppm. This filter and the gas trap membrane module were replaced prior to initiating the NaOH injection. No additional Ni was added.

4.4.4 Results and Lessons Learned

As indicated on the data plot in figure 47, prior to the start of the test, the filter was replaced and baseline testing was performed to characterize the filter ΔP with flow rate and determine the effects of installing a dry filter; i.e., with an air bubble, on the gas trap and the ability of the gas trap to contain and remove the bubble. Also as indicated on the data plot, there were times when the PPA would stop and need to be restarted. This was due to problems with the motor controller, which were not corrected until after this test when a research motor controller was received from Honeywell, the manufacturer of the PPA, and installed. The other “hiccups” due to the PPA shutdowns have been removed from the data plot. Starting from test-time zero, when injections of NaOH were initiated, the accumulator percent full shows increases due to the injections, followed by decreases due to sample collections. Injections were made every 5 min. Samples were collected every 5 min for the first 30 min, then every 10 min for the second 30 min, and then less frequently. The ΔP across the filter remained at 2 psid until ≈45 min into the test, when a rapid rise began. About 110 min into the test, the pressure had increased to the point that the bypass valve opened, at somewhat under 8 psid. As the ΔP increased, the flow rate showed a decrease, which was expected and resulted in a slight dip in the ΔP across the gas trap due to the reduced flow rate. After the filter bypass valve opened, unfiltered HTF with $Ni(OH)_2$ precipitates reached the gas trap, which then showed an increase in ΔP as the $Ni(OH)_2$ partially clogged the membranes. This is most noticeable on the plot after the data dropout period. During the data dropout, the ΔP across the filter decreased, presumably as the $Ni(OH)_2$, which is a slimy gelatinous material, gradually penetrated the filter. This eventually allowed flow to resume through the filter, reducing the ΔP below the bypass valve cracking pressure so that filtered HTF was again reaching the gas trap, though likely containing $Ni(OH)_2$. The ΔP across the gas trap then decreased, presumably as the $Ni(OH)_2$ worked its way through the gas trap. Due to the $Ni(OH)_2$ in the system, the ΔP across the filter reached a new equilibrium of about 7 psid, although over several days additional partial recovery of the filter was observed. The interactions of pH and Ni during NaOH injection are shown in figure 48. As shown, the amount of dissolved Ni rapidly decreases as the amount of “Ni Lost From Circulation;” i.e., precipitated or deposited, rapidly increases until leveling off when the dissolved Ni concentration drops below 2 ppm.

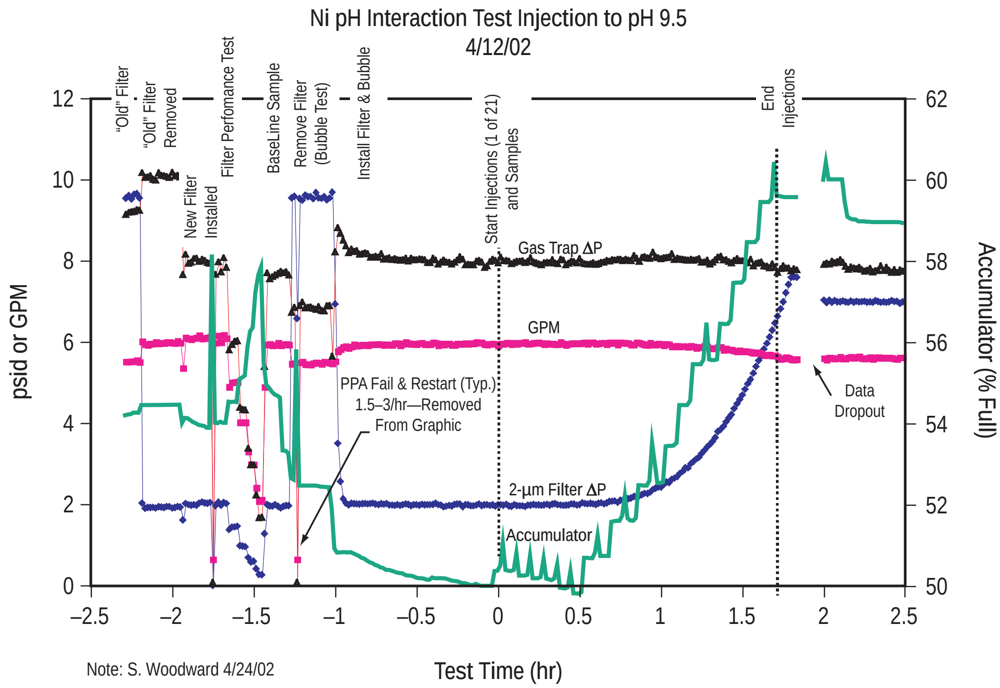


Figure 47. Data plot of INIK test.

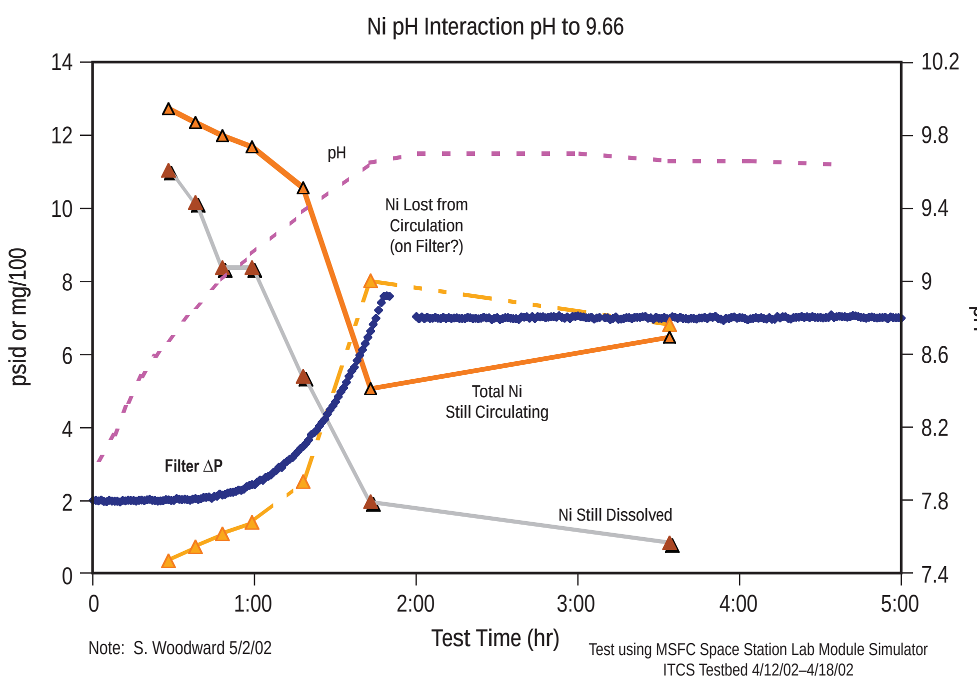


Figure 48. pH and Ni response to NaOH injection.

The results of the bubble test were inconclusive concerning the ability of the gas trap to remove such a large bubble. An inverted graduated cylinder in a water bath with a hose connected to the vent of the gas trap was intended to collect the removed gas; however, no gas was collected in the cylinder. In addition, a gurgling sound was heard from the pump, which indicated air bubbles flowing through the pump. Initially it was thought that the gas collection method had not been properly configured, but following the test when the gas trap was returned to Honeywell for analysis and performance testing, it was found that the tube that had previously ruptured was only sealed at one end and was allowing HTF to reach the air side and, thus, preventing gas from venting through the liquid-filled endspace. The secondary membrane was also found to be in very poor condition. The housing was cleaned and the secondary membrane replaced prior to return of the housing to MSFC.

The results of this test show that the filter is effective at removing the Ni compounds. Since the Ni reaction occurs over a period of time, the test was continued for a few more days to obtain data on longer-term results of the injection procedure. Performing this test in the IATCS Simulator facility revealed concerns that were not previously known, and follow-on lab tests were performed to more thoroughly quantify the rate and magnitude of precipitate formation. Because the Ni concentration was lower than expected at the beginning of the test and due to other unanswered questions, the decision was made to not implement the INIK procedure on orbit.

The primary conclusions follow:

- Adding 8%N NaOH solution to raise the IATCS circulating fluid pH back to 9.5±.5 results in a dramatic increase in pressure drop across the 2-µm filter, sufficient to activate bypass flow, due to the formation of $Ni(OH)_2$. The effect on the gas trap is less pronounced but must also be considered.

- Dissolved Ni will have to be removed before the pH can be raised in order to avoid formation of precipitates leading to clogging of the filter.

- The rebound effect of the filter suggests that a filter clogged with precipitated Ni compounds could be cleaned for reuse.

4.5 Cold Plate/Fluid Stability Test Facility Test Results

As described in section 2, the CFST facility was constructed to “lead the fleet” in three areas of concern: (1) Cold-plate debonding, (2) stability of the HTF, and (3) microbial growth and effects. Results for these three areas are described in section 4.5.2. A slight modification was made in the facility after two years of operation to increase similarity with the flight conditions. The modification and the results before and after it was made are described in section 4.5.3. Comparisons with the flight conditions over the same time period show the similarities and divergences. Results after the modification provide insight into the development of the conditions on orbit.

4.5.1 Flight Conditions

On board ISS, the IATCS has experienced some conditions that cannot easily be simulated on the ground, namely, new modules have been connected and payload racks have been installed. The effects of these activities include addition of Ag^+ antimicrobial to the coolant, and potential contamination with chemical compounds and microorganisms. There were also fluctuations in atmospheric CO_2 levels from <2 to >5 mmHg, and times when the IATCS operated in single-loop mode as well as dual-loop mode. In addition, on January 21, 2002, in response to concerns about increased microbial growth, Ag_3PO_4 was added to both operating IATCS loops in powder form via replacement fine-filter assemblies. This procedure was tested in the IATCS Lab simulator ground facility prior to implementation, as described in section 4.2 and in ICES paper 2003–01–2519.[26] And of course, special environmental factors, such as microgravity, cannot be duplicated, which potentially has significant effects on biofilm development.

Over the course of the first year of operation, the Destiny IATCS exhibited decreasing pH (fig. 34, also showing rack connection, single-loop operation, and sample collection events), increasing total inorganic carbon (TIC) and TOC, generally increasing microbial growth (fig. 38), increasing Ni concentrations, and increasing NH_3 concentrations.

These unexpected changes resulted in the coolant no longer meeting specifications and raised concerns about corrosion of the Ni brazing in HXs and cold plates, possible microleakage of NH_3 from the external thermal control loop through the water/NH_3 HXs, and excess microbial growth potentially clogging filters as well as the cold plate and HX channels. Due to the microbial activity, there is also the potential for biofilm formation and microbially influenced corrosion (MIC).

4.5.2 Test Facility Performance During the First 2 Years

Samples of the HTF were collected on test days 1, 2, 7, and 15 and monthly thereafter. The samples were analyzed for specific ions and metals of interest, pH, TOC, DO, and particulates. The results of these analyses are in the file dataplots.xls on the CD–ROM that accompanies this TM and are discussed in ICES papers.[27,28] Microbial analyses were performed to quantify and identify bacterial populations in the fluid and on surfaces. The cold plates were also removed periodically to check for changes in debonding.

4.5.2.1 Cold Plate Ultrasound Scans. In 1998, the following issues were identified with the cold plates:

- Variation in braze joint gap.
- Debonding of the top plate and fins.
- Overall flatness of the cold plates.

To address these issues and determine long-term effects, two cold plates, a -6 and a -9, were installed in the CFST facility after being scanned with ultrasound in 1998 and 2000. These were flight cold plates that did not meet the flatness specification. The -6 cold plate is 6.5 in wide, 28.4 in long, and 0.2 in thick (16.5 by 72.1 by 0.508 cm) with 160 W of heater pads bonded to the surface in 4 heat zones, and the -9 cold plate is 10.5 in wide, 51.4 in long, and 0.2 in thick (26.7 by 130.6 by 0.508 cm) with 320 W of heater pads attached in 12 heat zones (fig. 49). After 1 yr of operation with cyclic heat loads, they were removed and scanned again. Areas with good bonding are shown as red or orange whereas areas with poorer bonding show as blue or green. As shown in figures 50–57, there is little difference between the 1998 and 2000 scans whereas there appears to be more debonded area shown in the 2001 scan for both cold plates. The scans in May 2003 appear more like the earlier scans, indicating that the apparent changes are due to variations in the scanning process and do not show increased debonding. A software upgrade, recalibration, replacement of components, and other changes occurred to the equipment during this time period.

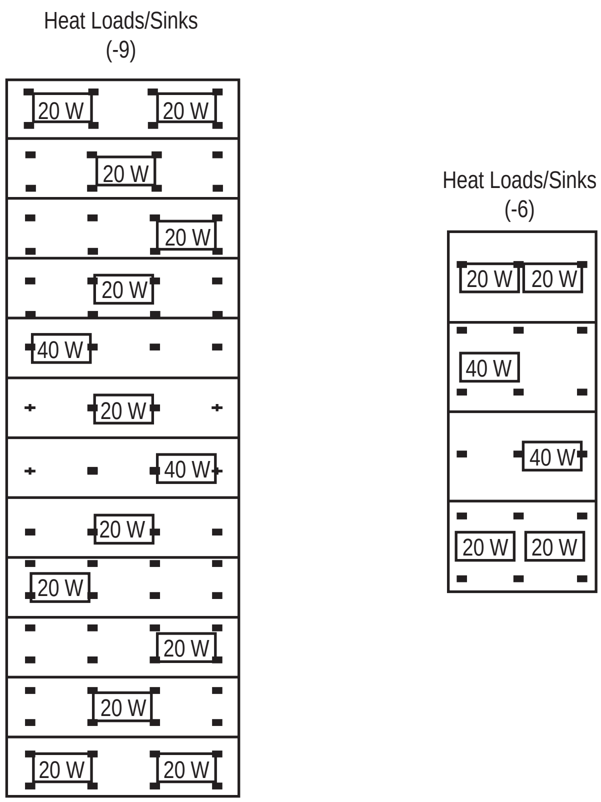


Figure 49. Heater pad mounting patterns.

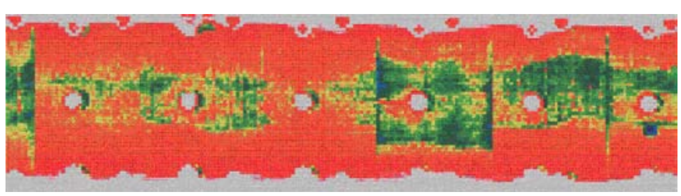


Figure 50. -6 Cold plate scanned on October 20, 1998.

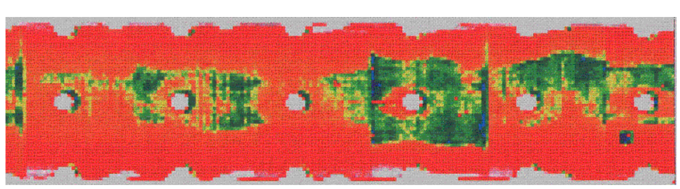


Figure 51. -6 Cold plate scanned on June 16, 2000.

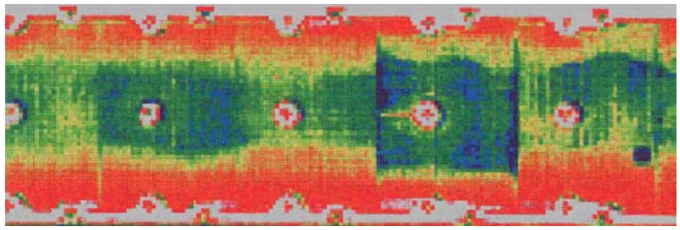


Figure 52. -6 Cold plate scanned on September 14, 2001.

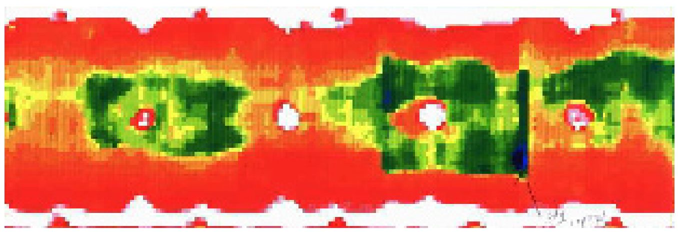


Figure 53. -6 Cold plate scanned on June 12, 2003.

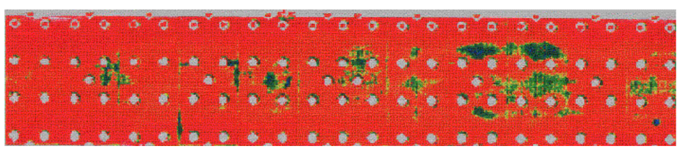


Figure 54. -9 Cold plate scanned on October 23, 1998.

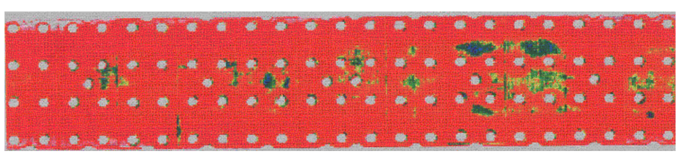


Figure 55. -9 Cold plate scanned on June 16, 2000.

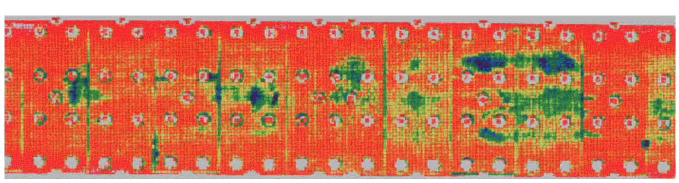


Figure 56. -9 Cold plate scanned on September 14, 2001.

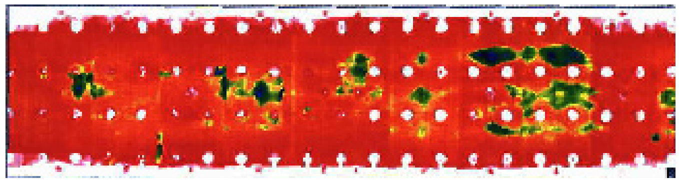


Figure 57. -9 Cold plate scanned on June 11, 2003.

Removal of the cold plates requires shutting off the system and draining coolant from the cold plates, which must be performed carefully by following aseptic procedures to minimize contamination. Though a slight dip in microbial population is indicated after the cold plates were removed and replaced, the microbial population returned to preremoval levels and there is no indication that microbial populations were significantly affected due to this procedure (fig. 58).

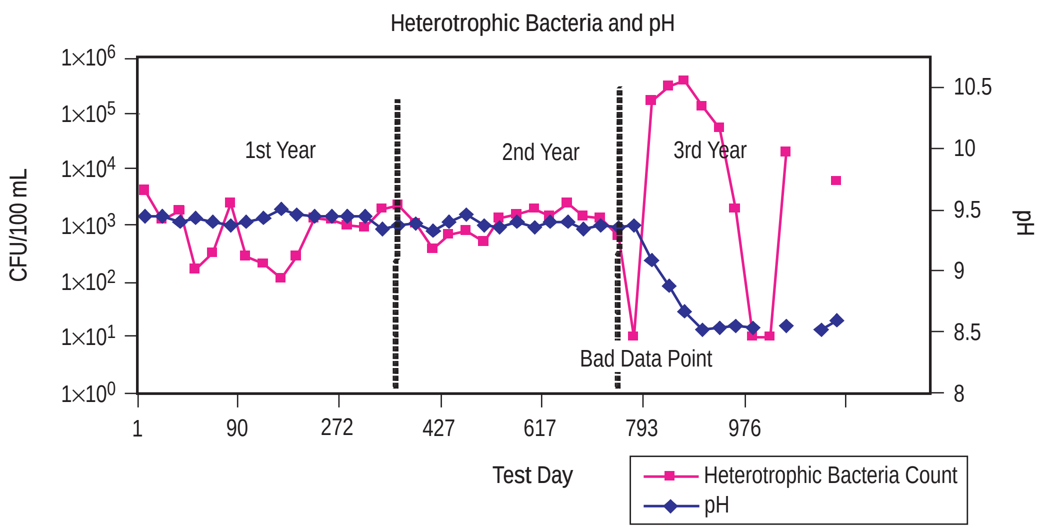


Figure 58. Bacteria population and pH of the HTF.

4.5.2.2 Heat Transfer Fluid Chemistry and Microbial Response. Most of the fluid chemistry parameters of interest and the microbial population remained remarkably stable after some initial variability. When the cold plates and tubing sections were removed after 1 yr there were perturbations; e.g., barium and calcium concentrations decreased, that soon settled back to the previous levels. The pH remained about 9.4, DO remained at 9.5±1 mg/L, Ni remained below 0.03 mg/L (except when the cold plates and tubing were removed on test day 378 when it spiked to 0.215 mg/L), and other metals remained at low concentrations.

Plots of key parameters are shown in figures 58–61. (After the second year, modifications were made (sec. 4.5.3) that relate to the changes in concentrations after that time.) To evaluate the extent and effect of biofilm growth, Robbins devices having coupon "pins" of stainless steel (CRES 347) and Ni (201), and tubing (steel, titanium, and Teflon) with bends and deadlegs representing conditions in the

IATCS loop, were mounted on removable panels in the test facility. Sets of coupons and tubing were removed for microbiological analyses, which are discussed in section 4.5.3.3 for before and after the modification.

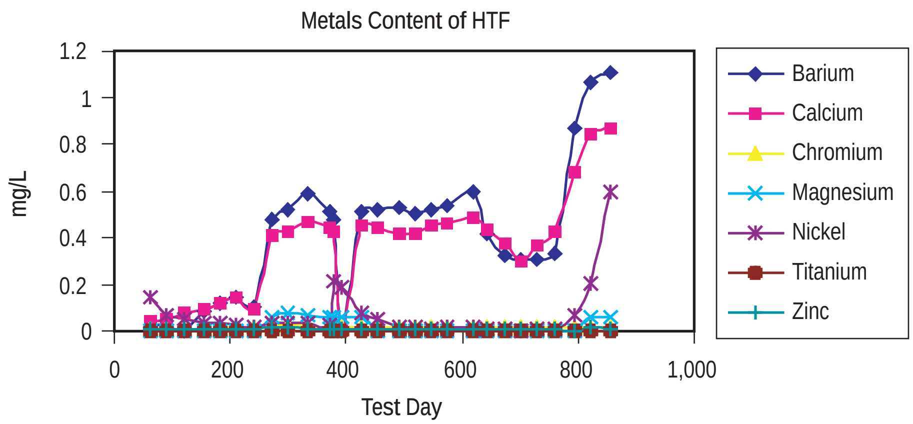


Figure 59. Metal content of the HTF.

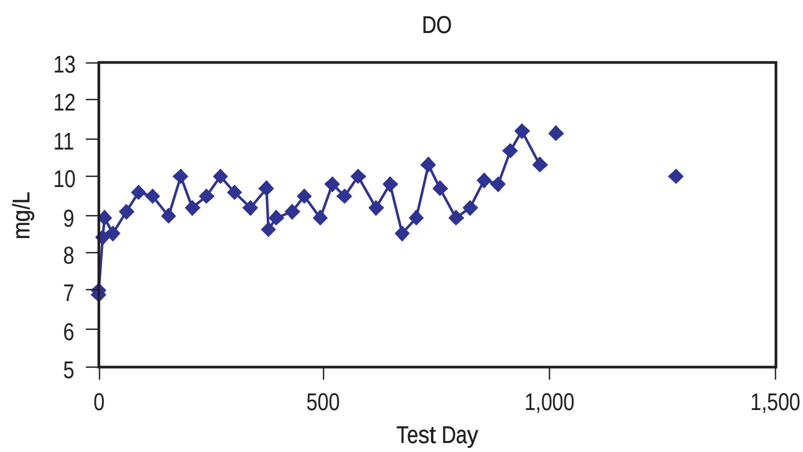


Figure 60. DO content of the HTF.

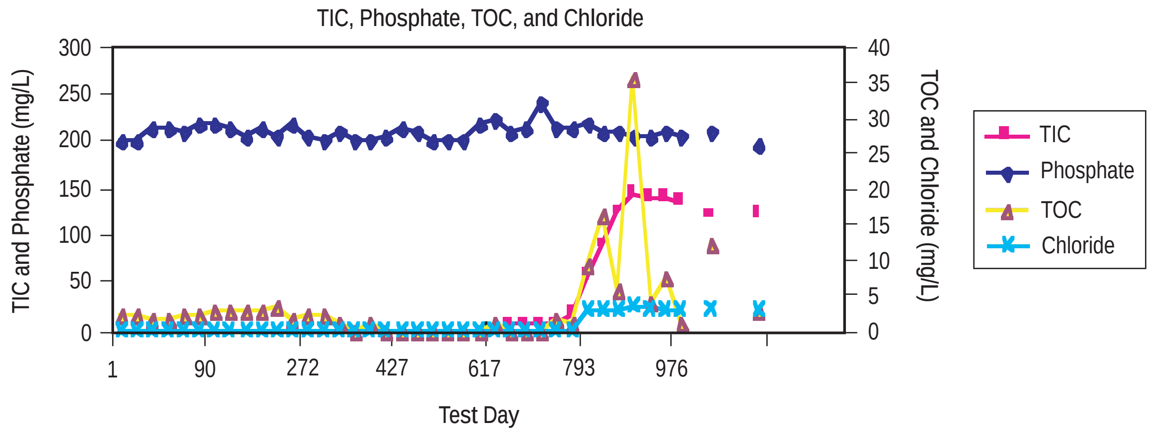


Figure 61. TOC, TIC, chloride, and phosphate content of the HTF.

4.5.3 Modification and Effects

When the performance of similar systems shows significant divergence it is important to closely consider the aspects that are not similar. A key difference between the flight IATCS and the CFST facility is that the test facility is in an ambient ground-level environment with a CO_2 concentration of ≈0.036 percent (0.036 kPa (0.27 mmHg)), whereas onorbit the atmosphere has a higher CO_2 concentration (0.705 to 1.011 kPa (5.3 to 7.6 mmHg)). This difference had been considered insignificant since the IATCS loop is closed. However, the Teflon hoses are slightly permeable to atmospheric gases. As such, the effects of CO_2 permeation would only become evident over extended periods of operation, and for a long-duration system such as ISS, the cumulative effects are quite significant.

To address the divergence from the flight coolant composition, the facility was modified to more closely represent the flight condition. The modification was to provide a higher concentration of CO_2 around the large Teflon hose. This resulted in a lowering of the pH and led to development, in the CFST facility, of several other characteristics of the flight IATCS HTF.

4.5.3.1 Description of the Cold Plate/Fluid Stability Test Facility Modification. The modification was intended to mimic the processes occurring on ISS that lowered the pH from the specified 9.4 to the flight condition of ≈8.4. On September 23, 2002, the large Teflon hose, 12.5 ft (3.8 m), was sealed in a plastic bag and pure CO_2 injection into the bag initiated. Later the smaller Teflon hoses were sealed using Armaflex insulation, and the vent holes of the gas trap were bagged to limit permeation. This served to accelerate the effects of the elevated CO_2 concentration in the ISS atmosphere.

The following aspects were addressed with this modification:

- CO_2 permeation through Teflon hoses.
- CO_2 permeation through the gas trap.
- Effects of ISS-composition mixed gas atmosphere on the HTF pH.

After the pH dropped to 8.4, the injection of pure CO_2 was replaced with a mixed gas more representative of the ISS atmosphere. The mixed gas also contained NH_3, so another aspect addressed was permeation of NH_3 through the Teflon hoses. Since the concentration was very low, the time of exposure required is long and there was insufficient time before the injection was stopped to draw any conclusions regarding NH_3 permeation; although, the last HTF sample analyzed by the Boeing Huntsville Laboratory tantalizingly showed the presence of NH_3 right at the detection limit of the analysis technique. The refurbishment of the CFST facility, described in section 5.2, also addresses NH_3 addition.

When the facility was modified to enclose the large Teflon hose in a CO_2 bath, the effects of CO_2 permeation of the hose were monitored by collecting samples of the HTF to check the pH. In an effort to reduce the amount of coolant removed for sampling, an in-line pH probe was installed on October 9, 2002, so that continuous pH measurements could be made without requiring removing HTF. However, due to the type of pH probe used, chloride was released into the HTF to a concentration of 3.65 mg/L—compared to ISS HTF chloride concentrations of 0.1 to 0.4 mg/L. The effects of this on the overall chemistry were thought to be small but unknown, so the in-line pH probe was removed on December 9, 2002. A residual level of chloride remained in the HTF. There was no apparent change in microbialpopulation related to installing the pH probe. (The same cleaning procedures used when constructing the facility were used when installing the pH probe.) There was also some concern that microbial contamination may have occurred during installation of the in-line pH probe. Prior to installation, the metallic parts; e.g., tubing, etc., were autoclaved; i.e., sterilized, and the pH probe was new, in the package, and disinfected with H_2O_2 before installation. A point of comparison is the removal and reinstallation of the cold plates after 1 yr of operation when there was a slight decrease in microbial population rather than an increase, which suggests that such opening of the system would not result in contamination when proper procedures are followed to sterilize and disinfect components.

4.5.3.2 Chemistry Effects of the Modification. As expected, one effect of the modification was a decrease in HTF pH (fig. 62). As the CO_2 surrounding the Teflon hose permeated into the HTF, carbonic acid formed, lowering the pH. After ≈3 mo, the pH dropped to 8.4 and the injection of pure CO_2 into the bag around the large Teflon hose was stopped. The pH remained steady for a few days, then slowly began increasing, likely due to release of CO_2 out of the coolant. Injection of pure CO_2 was restarted and, when the pH dropped to the on-orbit range, as mentioned in section 4.5.3.1, injection of a mixed gas (air, CO_2, and NH_3 at ISS atmospheric concentrations (0.845 percent CO_2 and 0.027 percent NH_3, with the balance air)) into the bag around the large Teflon hose was initiated, which as expected, maintained the pH at ISS IATCS conditions (≈8.4). After several weeks of mixed-gas injection with a fairly constant pH, the gas injection was stopped and the Teflon hoses unsealed to determine whether the reaction was readily reversible. The pH gradually increased, likely due to the slow release of CO_2 from the HTF.

As shown in figures 59–61, there were associated chemical changes including increases in Ni, barium, and calcium concentrations. TIC also increased, as expected due to CO_2 permeating into the HTF, and TOC showed a sharp increase, then declined. An increase in chloride level is also evident in figure 61, however, this is related to installation of an in-line pH probe, as discussed in section 4.5.3.1.

The Ni concentration increased from 0.012 to 1.16 mg/L, and there was some concern that chloride may contribute to corrosion of Ni. Tests performed previously by Boeing showed that, while a concentration of 100 ppm of chloride has a definite effect on corrosion, 1 ppm has no effect and 10 ppm may have a slight effect. (The Boeing tests were performed at a pH of 9.4, so the effects of pH in combination with chloride were not determined.) Therefore, for the conditions of this facility, 3.65 mg/L of chloride would have negligible effect on the corrosion of Ni, especially when compared to the corrosive effect of lower pH. As an acid-soluble metal, the corrosion rate of Ni is higher at lower pH values.

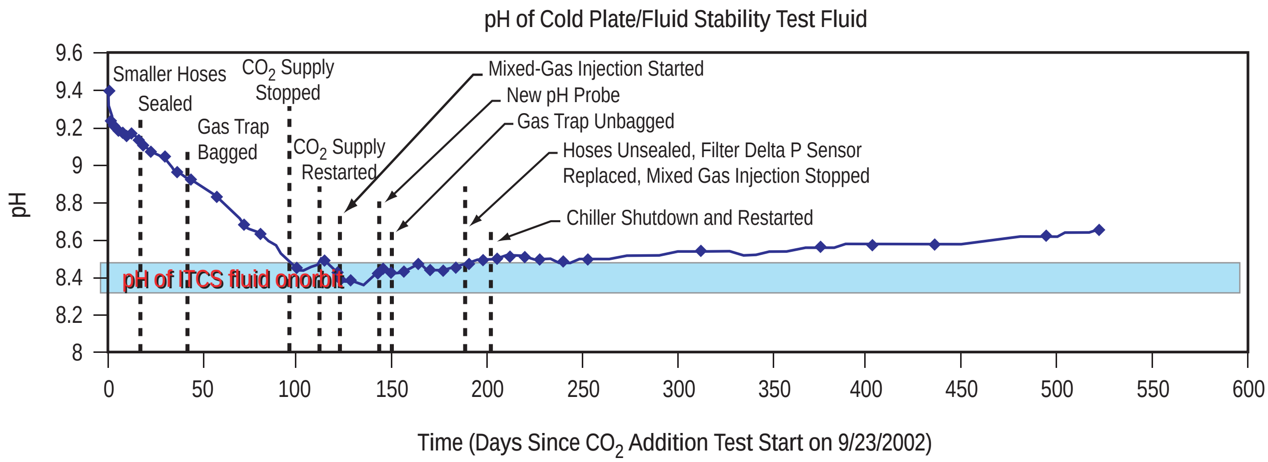


Figure 62. Effect on pH of injecting CO_2 around large Teflon hose.

4.5.3.3 Microbial Effects. The microbial population in the HTF was stable (within 1-log) for the first 2 yr of the test with no significant increase or decrease recorded during that time (figs. 63 and 64). The population in the HTF at the start of the test was 4.3×10^3 CFU/100 mL. Within the first 6 mo, the bacteria concentration dropped to the lowest concentrations recorded in the test (110 CFU/100 mL), although it eventually increased to 1,000 CFU/100 mL and stayed at that level. Predominant bacterial species in the fluid changed over time. The rate of microbial growth depends on the concentration of nutrients in the fluid, among other things. It is possible that, as the initial concentration of substrates in the fluid changed, so did the bacterial population.

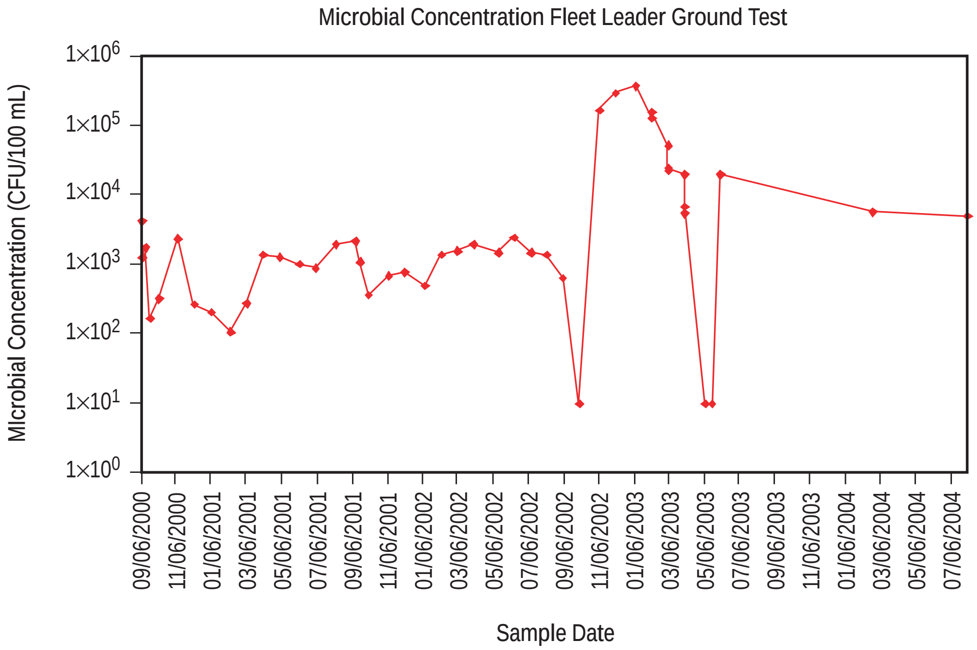


Figure 63. CFST microbial concentration.

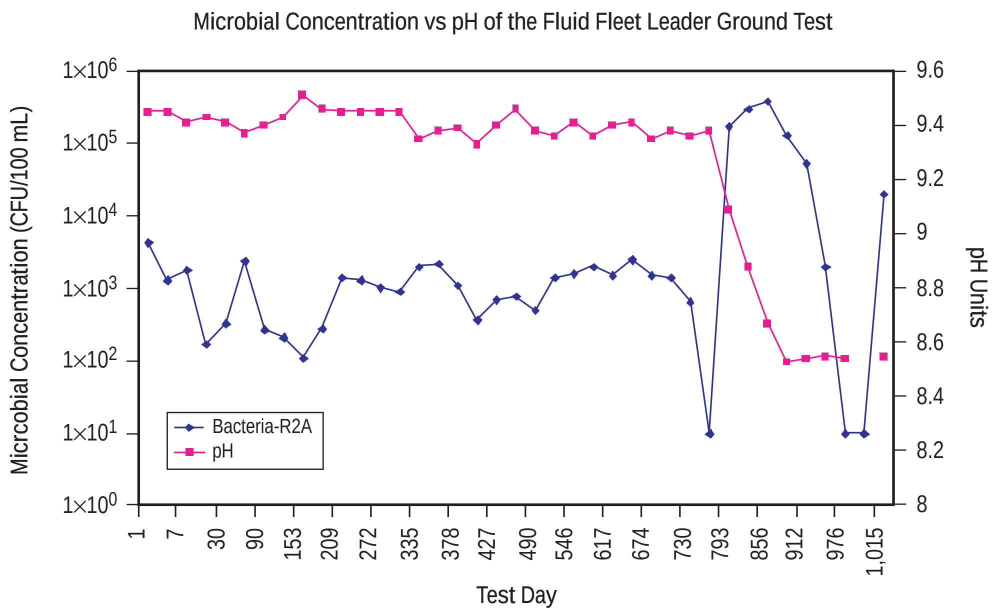


Figure 64. CFST microbial concentration and pH.

After the modification, there was a change in the bacterial population likely due to the change in pH of the fluid. Immediately after the system fluid was exposed to CO_2 (September 2002) the overall concentration of bacteria decreased. It was originally believed that the microbial population might have been exposed to lower oxygen levels, and as a result, the mostly aerobic population would have decreased, but data show that oxygen levels in the fluid remained stable or even increased throughout the test (fig. 60). It is unknown if this microbial decrease was a result of a sampling irregularity or if it was a result of the environmental change (exposure to the CO_2). As shown in figure 63, the microbial population in the next sample (November 2002) increased more than 4-logs—2-logs more than the population during the previous 2 yr—and remained at those levels for several months until the temperature was inadvertently increased to >130 ºF for 46 hr (with >135 ºF for 42 hr) in the system (April 2003), due to shutdown of the chiller during a power outage that did not restart when the power was restored. This resulted in a decrease of more than 3-logs in microbial population to <1 CFU/100 mL. (These results demonstrate a possible method that could be used in the future to disinfect the fluid, in flight or on the ground, by increasing the temperature to at least 135 ºF for a number of hours.)

It is interesting to note that the TOC concentration in the fluid spiked a few weeks after the test set-up was exposed to CO_2 (fig. 65). It was initially thought that the increase in the microbial population was in response to that spike. However, after further analysis, it was observed that the largest TOC spike was detected after the microbial population increased to its highest level (>100,000 CFU/100 mL). This indicates that the population probably did not increase as a result of the TOC increase but that the increase in the microbial population contributed in part to the increase in TOC concentration. The temporary increase in the TOC concentration to 35 ppm, however, was likely due to dissolution into the HTF of the organic material that had naturally deposited on the surface of the Teflon hoses throughout the previous 2 yr of testing. The Teflon hoses are corrugated, which facilitates the deposition of particles and debris in the valleys of the pleats.

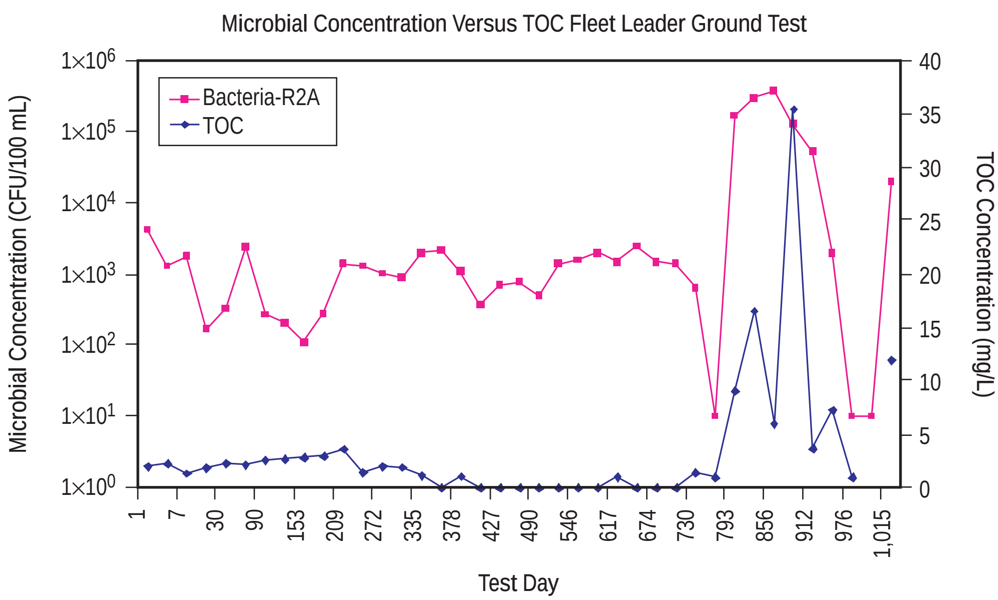


Figure 65. CFST microbial concentration and TOC.

4.5.3.3.1 Microbial Population. Table 21 lists the microorganisms isolated from the CFST HTF, along with the microorganisms identified in the ISS LTL and MTL fluid (flight) samples. Seven of the

10 microbial species identified in the CFST were also identified in samples returned from the ISS IATCS loop fluid. Because the microbial population of the CFST was not intentionally added to the fluid, the similarities in the species identified on the ground and the species identified in flight suggest that many of the microorganisms currently in the flight system were present when the ISS segments were launched. The organisms that were not identified in the CFST fluid samples but were found in the flight fluid most likely were added when racks were connected to the IATCS loop. The microbial concentration in the thermal fluid of the flight racks was not closely monitored or controlled before launch in the past. Measures to minimize contamination of this fluid have been implemented at KSC (using Operations and Maintenance Requirements and Specifications (OMRS) JA16583R2, which replaces the previously used ACOMC (app. C.)).[29]

Table 21. Microorganisms isolated from the CFST, ISS LTL and ISS MTL HTF.

Microorganism	Fleet Leader (Ground Test)	ISS LTL (Flight Fluid)	ISS MTL (Flight Fluid)
Acidovorax avenae	–	X	–
Acidovorax delafieldii	X	X	X
Acidovorax facilis	X	–	X
Acidovorax konjaci	X	–	X
Acidovorax temperans	–	X	–
Acinetobacter lwoffii/genospecies 9	–	–	X
Brevibacterium casei	–	–	X
Brevundimonas vesicularis	–	–	X
Burkholderia glumae	X	–	–
Comamonas acidovorans	X	X	–
Flavobacterium resinovorum	–	–	X
Janthinobacterium lividum	X	–	–
Oligella species	–	–	X
Ralstonia eutropha (very similar genetically to *R. paucula*)	–	–	X
Ralstonia paucula	–	X	X
Ralstonia pickettii	X	–	X
Sphingobacterium spiritovorum	–	X	–
Sphingomonas paucimobilis	–	–	X
Stenotrophomonas maltophilia	X	–	–
Unidentified nonfermenting Gram-negative rod (GNR)	X	X	X
Variovorax paradoxus	X	–	X

Ralstonia picketii was isolated in fluid for only the first three ground samples (test days 1, 7, and 15). During the first weeks of testing, the concentration of this bacterium steadily declined—probably because it could not adapt to the environmental conditions or was out-competed by the other bacteria populations. It was not isolated from the samples even when the pH of the fluid dropped, suggesting the population in the test fluid was highly compromised—in a viable but not culturable state—or eliminated. *Ralstonia picketii* has also been identified in samples from the ISS MTL.

Acidovorax sp. were the dominant bacterial species identified after the first month of testing, until samples from test day 270. For the next 456 test days, *Stenotrophomonas maltophilia* (formerly *Pseudomonas*/*Xanthomonas*) was the dominant organism. *Stenotrophmonas maltophilia* and *Acidovorax spp*. were the only bacteria consistently identified in the CFST fluid after the first month of testing. The concentration of *S. maltophilia* varied from test day 14 to test day 240—from test day 240 until the test was exposed to the CO_2, the concentration of this bacteria in the fluid was stable. The drop in the fluid pH and subsequent increase in the concentration of other bacteria species resulted in a temporary reduction of *S. maltophilia* concentration (fig. 66). As a result, the percentage of *S. maltophilia* in the fluid also dropped significantly after the test exposure to CO_2 as can be seen in figure 67. *Stenotrophomonas maltophilia* was not isolated in any of the fluid samples returned from flight. *Stenotrophomonas maltophilia* is an aerobic Gram-negative bacillus that is frequently found in a variety of aquatic environments. It is an organism of low virulence that must bypass normal host defenses to cause human infection.

Variovorax paradoxus (*Vp*) was identified at low levels (8 percent of the overall microbial population) in the fluid throughout the test prior to the pH decrease. A sharp increase in the concentration of *V. paradoxus* was recorded after the pH decrease (30 percent of the overall microbial population) and the bacteria became the predominant specie. Analysis of the data shows that the overall concentration of two of the species that were predominant while the pH was maintained above 9, *Acidovorax spp*. and *Strenotrophomonas spp.*, dropped at the same time that *V. paradoxus* increased as the result of the pH drop. In addition, other species, like *Comamonas sp*., *Delftia sp*. and *Janthinobacterium sp*. were identified for the first time. *Variovorax paradoxus* is a mesophilic, hydrogen-oxidizing bacteria that has the capability to be a facultative autotroph growing either on organic substrate or on hydrogen with CO_2, that is commonly found in habitats in which hydrogen, CO_2, and oxygen are simultaneously available. Other capabilities of strains of *V. paradoxus* include degradation of bioplastics.

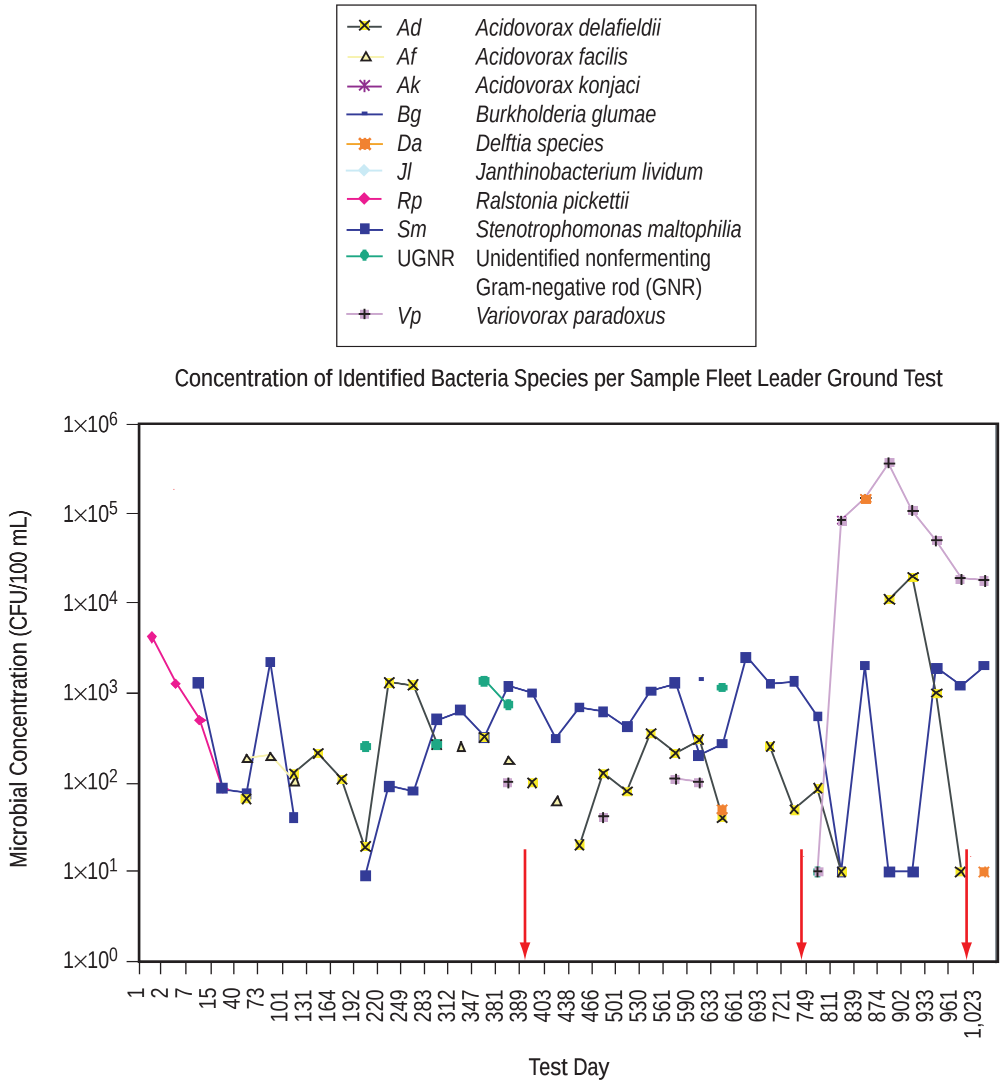


Figure 66. Concentration of identified bacteria species per sample

The other two organisms that were identified in the CFST HTF but not in the flight HTF were *Burkholderia glumae* and *Janthinobacterium lividum*. Twice, *J. lividum* was identified in very low numbers (<1 percent and 4 percent of the sample/June 2003 and August 2004) after the CFST was exposed to mixed gas with NH_3 and CO_2. *Janthinobacterium lividum* is a purple-pigmented bacterium, common in soil and water in temperate regions. This organism is known to assimilate for the assimilation of NH_3. *Burkholderia glumae* was also identified only twice in the fluid (April 2002 and February 2003), but the concentrations in those samples were significant, 70 percent and 85 percent. It is possible that one or both of these bacteria species are contaminants because they have not been found in any other fluid sample or in any of the surface analyses.

The overall percentage of bacteria isolated and identified in the samples collected from the CFST fluid are presented in figure 68. Thirty-five percent of all the bacteria identified in the test were *Acidovorax* species. *Stenotrophomonas maltophilia* was the second most identified (34 percent), followed by

V. paradoxus (15 percent). If the percentage of bacteria identified is calculated using only the species that were identified before the exposure to CO_2—while the pH of the fluid was higher—as can be seen in figure 69, *Acidovorax* species are predominant in the samples (40 percent of the organisms identified). *Stenotrophomonas maltophilia* is a close second, 37 percent of the organisms identified. Only 8 percent of the bacteria species identified was *V. paradoxus*. After the exposure to CO_2 (fig. 70), the predominant organisms identified were *V. paradoxus* (30 percent) and *S. maltophilia* (30 percent). *Acidovorax* species was found in 28 percent of the samples. The increase in the concentration of *V. paradoxus* as a result of the exposure to CO_2 is significant (more than 3-logs).

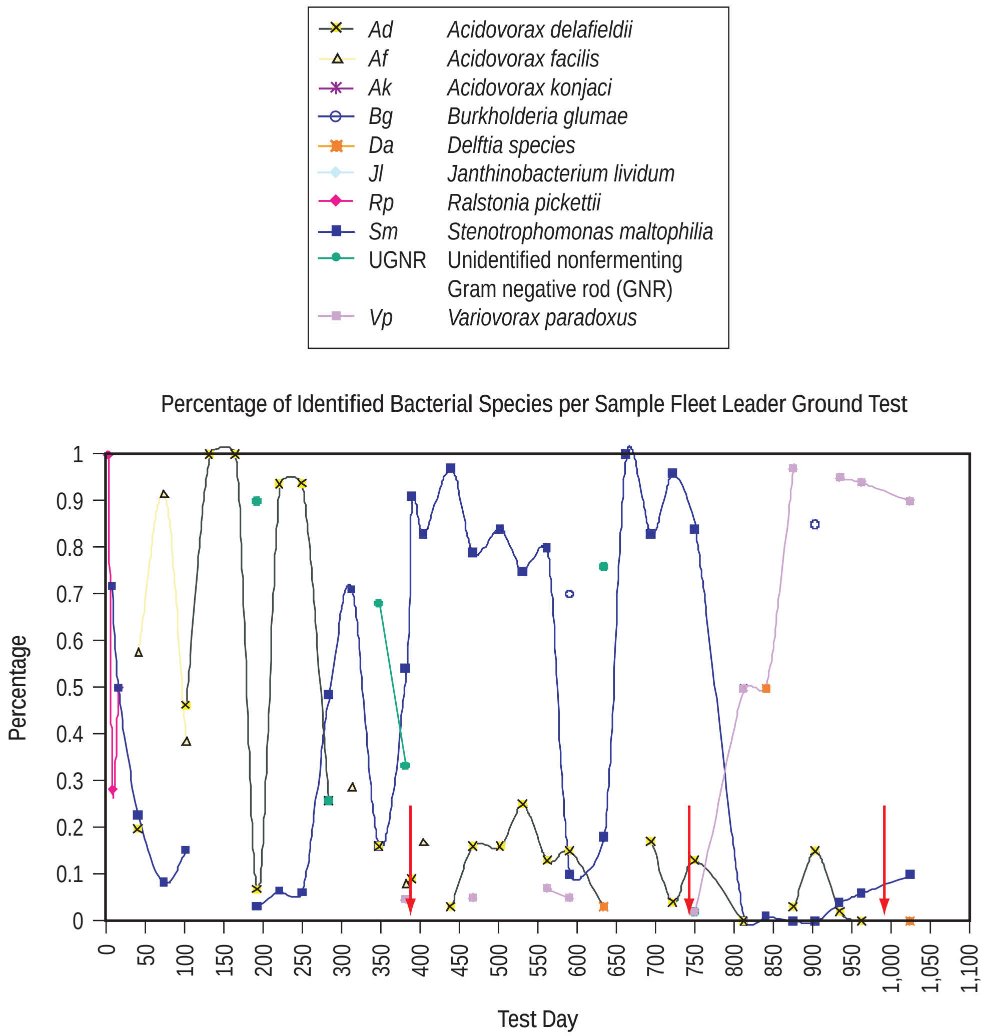


Figure 67. Percentage of identified bacterial species per sample.

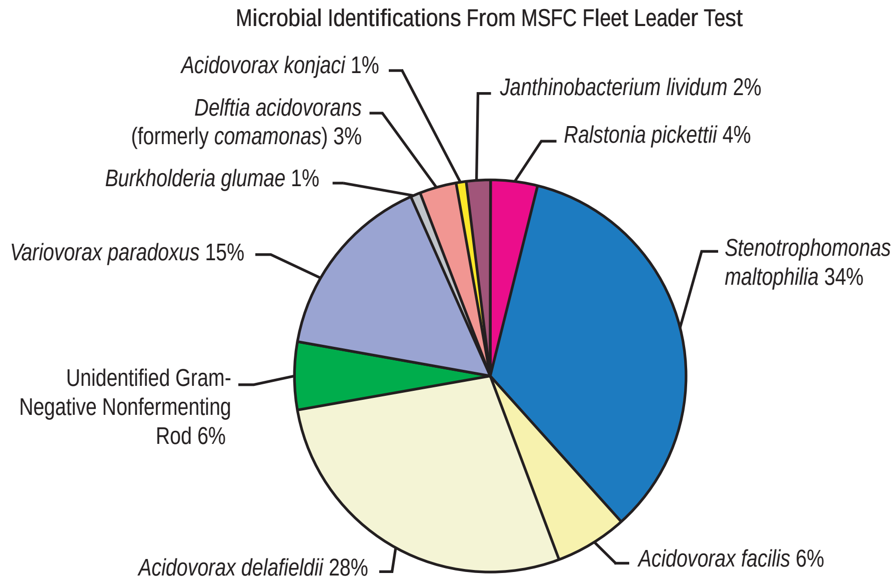


Figure 68. Overall percentage of bacteria species identified from the CFST test fluid.

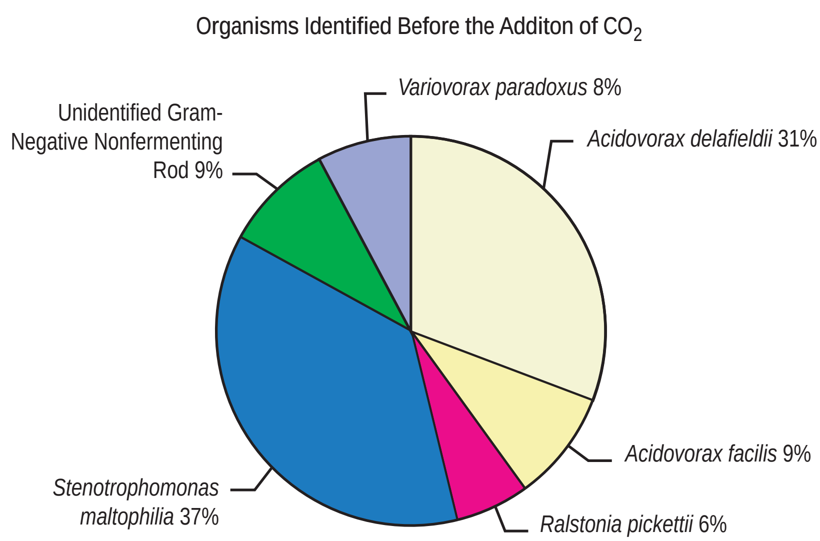


Figure 69. Percentage of bacterial species identified in the CFST test fluid before the CO_2 exposure.

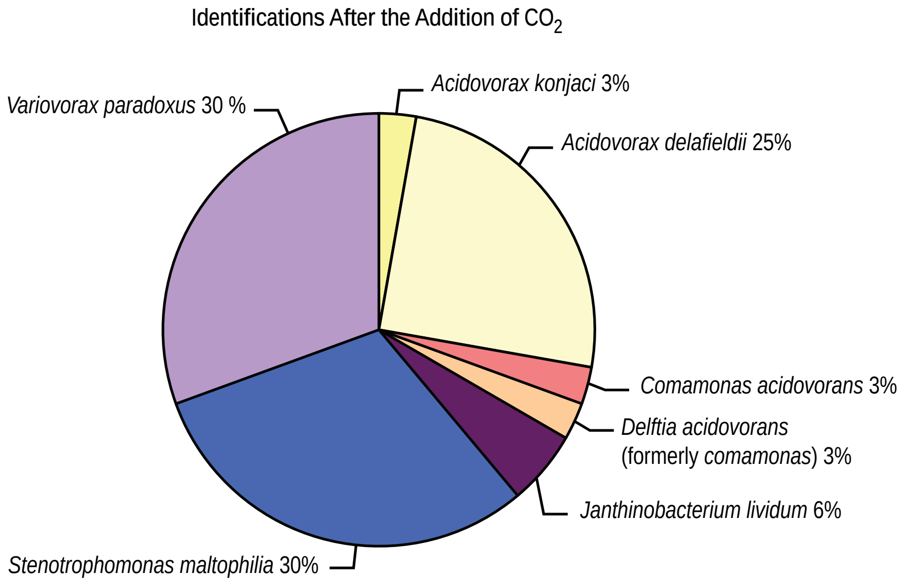


Figure 70. Percentage of bacterial species identified in the CFST test fluid after the CO_2 exposure (and resulting pH decrease).

5.5.3.3.2 Biofilm Analyses. Biofilm samples were collected in two ways, as described in section 2.2.2, by Robbins device coupons, or pins, and biofilm test panels, and analyzed as indicated in table 22.

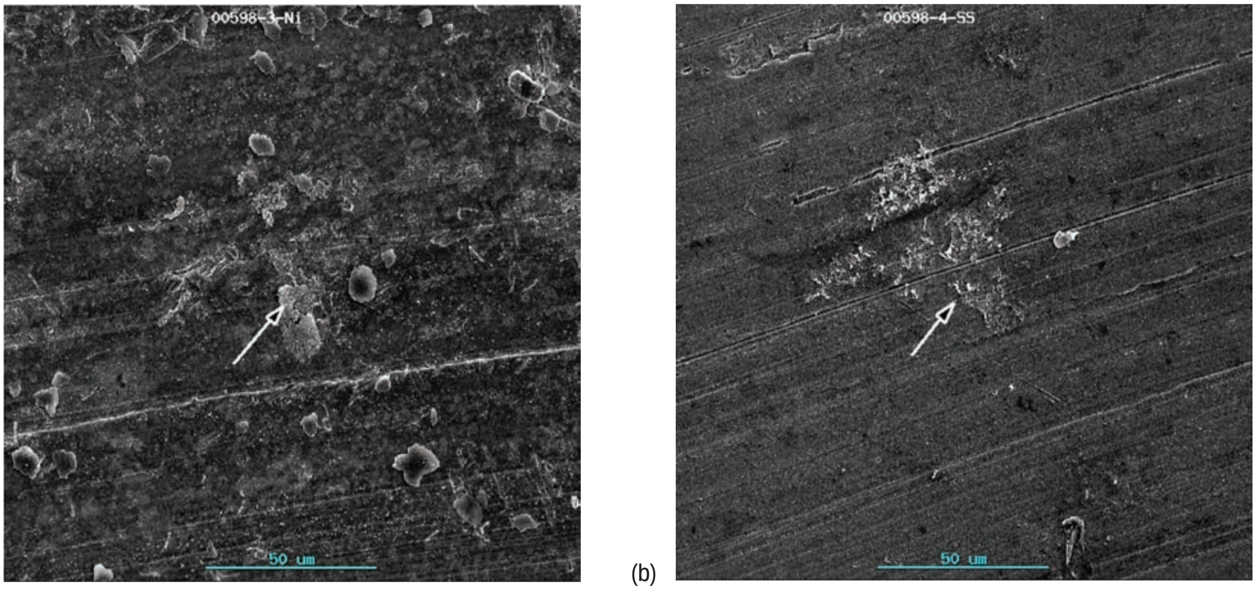
Table 22. Laboratory identification number, sample description, and type of analyses performed by Altran Corporation.[15]

Sample ID	Test Day (mo)	Description	Analysis
00598-1-Ni	3	Robbins device pin	R2A
00598-2-SS	3	Robbins device pin	R2A
00598-Ni-003	3	Robbins device pin	SEM
00598-SS-004	3	Robbins device pin	SEM
00598-5-Ni	3	Robbins device pin	EDS
00598-6-SS	3	Robbins device pin	EDS
01543-Ni-001	6	Robbins device pin	R2A
01543-SS-001	6	Robbins device pin	R2A
01543-Ni-002	6	Robbins device pin	SEM
01543-SS-002	6	Robbins device pin	SEM
01543-Ni-003	6	Robbins device pin	EDS
01543-SS-003	6	Robbins device pin	EDS
01543-Ni-1	12	Robbins device pin	R2A
01543-SS-1	12	Robbins device pin	R2A
01543-Ni-2	12	Robbins device pin	SEM
01543-SS-2	12	Robbins device pin	SEM
01543-Ni-3	12	Robbins device pin	EDS
01543-SS-3	12	Robbins device pin	EDS
01543-Ti-1A-S	12	Titanium tube straight section	R2A
01543-Ti-1B-S	12	Titanium tube straight section	SEM
01543-Ti-2A-B	12	Titanium tube bent section	R2A
01543-Ti-2B-B	12	Titanium tube bent section	SEM

Table 22. Laboratory identification number, sample description, and type of analyses performed by Altran Corporation (Continued).

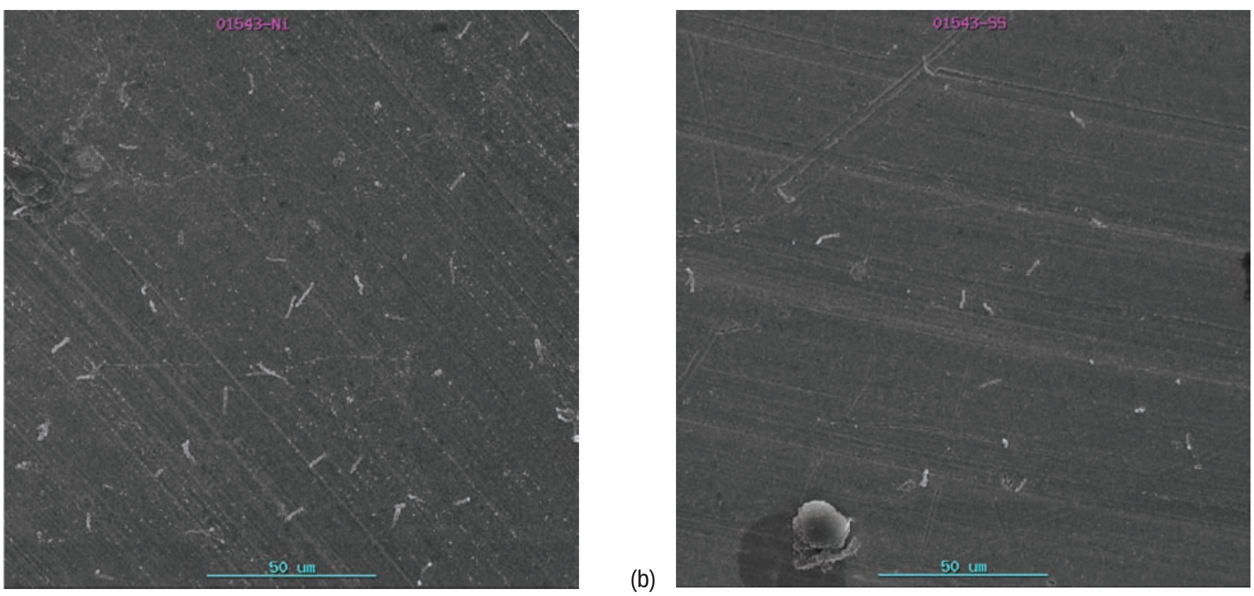
Sample ID	Test Day (mo)	Description	Analysis
01543-Ti-3A-D	12	Titanium tube dead leg upstream section	R2A
01543-Ti-3B-D	12	Titanium tube dead leg upstream section	SEM
01543-Ti-4A-D	12	Titanium tube dead leg downstream section	R2A
01543-Ti-4B-D	12	Titanium tube dead leg downstream section	SEM
01543-SS-5A-S	12	Stainless steel tube straight section	R2A
01543-SS-5B-S	12	Stainless steel tube straight section	SEM
01543-SS-6A-B	12	Stainless steel tube bent section	R2A
01543-SS-6B-B	12	Stainless steel tube bent section	SEM
01543-TF-7A	12	Teflon tube upstream section	R2A
01543-TF-7B	12	Teflon tube upstream section	SEM
01543-TF-8A	12	Teflon tube downstream section	R2A
01543-TF-8B	12	Teflon tube downstream section	SEM
03563-Ni-1	36	Robbins device pin	R2A
03563-SS-1	36	Robbins device pin	R2A
03563-Ni-2	36	Robbins device pin	SEM
03563-SS-2	36	Robbins device pin	SEM
03563-Ni-3	36	Robbins device pin	EDS
03563-SS-3	36	Robbins device pin	EDS
03563-Ti-1A-S	36	Titanium tube straight section	R2A
03563-Ti-1B-S	36	Titanium tube straight section	SEM
03563-Ti-2A-B	36	Titanium tube bent section	R2A
03563-Ti-2B-B	36	Titanium tube bent section	SEM
03563-Ti-3A-D	36	Titanium tube dead leg upstream section	R2A
03563-Ti-3B-D	36	Titanium tube dead leg upstream section	SEM
03563-Ti-4A-D	36	Titanium tube dead leg downstream section	R2A
03563-Ti-4B-D	36	Titanium tube dead leg downstream section	SEM
03563-SS-5A-S	36	Stainless steel tube straight section	R2A
03563-SS-5B-S	36	Stainless steel tube straight section	SEM
03563-SS-6A-B	36	Stainless steel tube bent section	R2A
03563-SS-6B-B	36	Stainless steel tube bent section	SEM
03563-TF-7A	36	Teflon™ tube upstream section	R2A
03563-TF-7B	36	Teflon™ tube upstream section	SEM
03563-TF-8A	36	Teflon™ tube downstream section	R2A
03563-TF-8B	36	Teflon™ tube downstream section	SEM

Robbins device pin analysis was performed and monitored the viable heterotrophic bacterial population at 3, 6, 12, and 36 mo. Figures 71–74 contain representative SEM pictures of the Ni and stainless steel pins. No significant change in the amount of bacteria attached to the Ni pins was detected after 36 mo (table 23). A decrease of bacteria attached to the stainless steel pins was detected after 36 mo. The decrease might not be significant, since it was within 1-log of the amount reported after 12 mo of exposure.



(a) (b)

Figure 71. SEM representative view of (a) Robbins device pin 00598-3-Ni and (b) Robbins device pin 00598-4-SS after 3 mo of exposure. Arrows show debris accumulation on the surface.



(a) (b)

Figure 72. SEM representative view of (a) Robbins device pin 01543-Ni-002 and (b) Robbins device pin 01543-SS-002 after 6 mo of exposure.

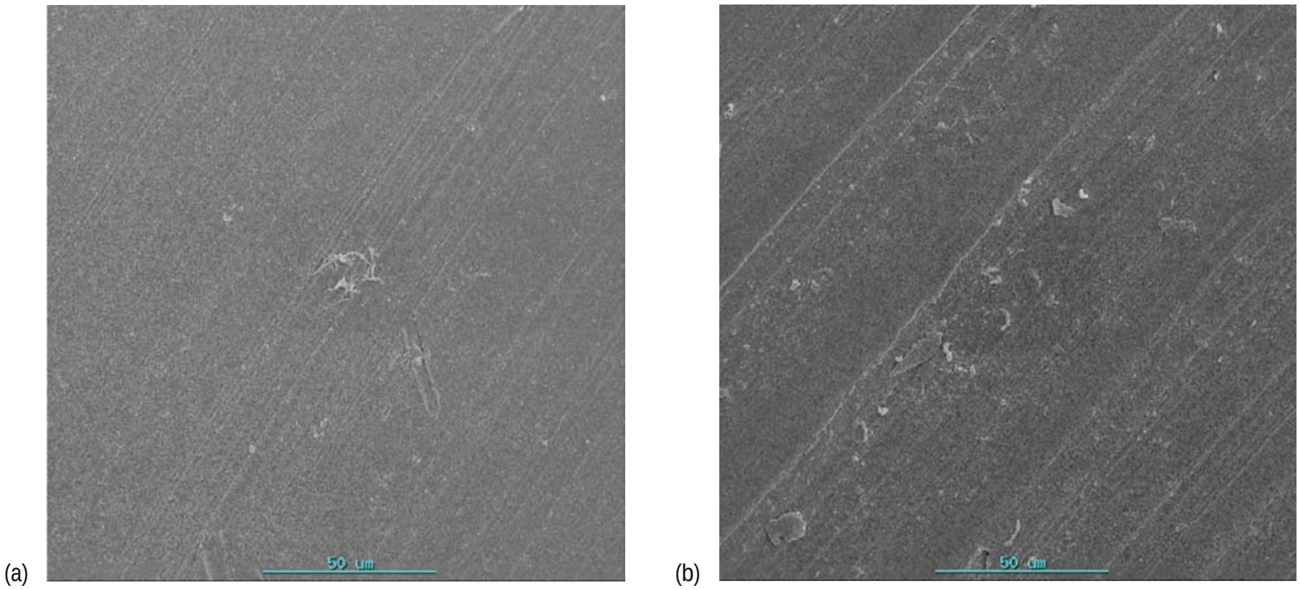


Figure 73. SEM representative view of (a) Robbins device pin 01543-Ni-2 and (b) Robbins device pin 01543-SS-2 after 12 mo of exposure.

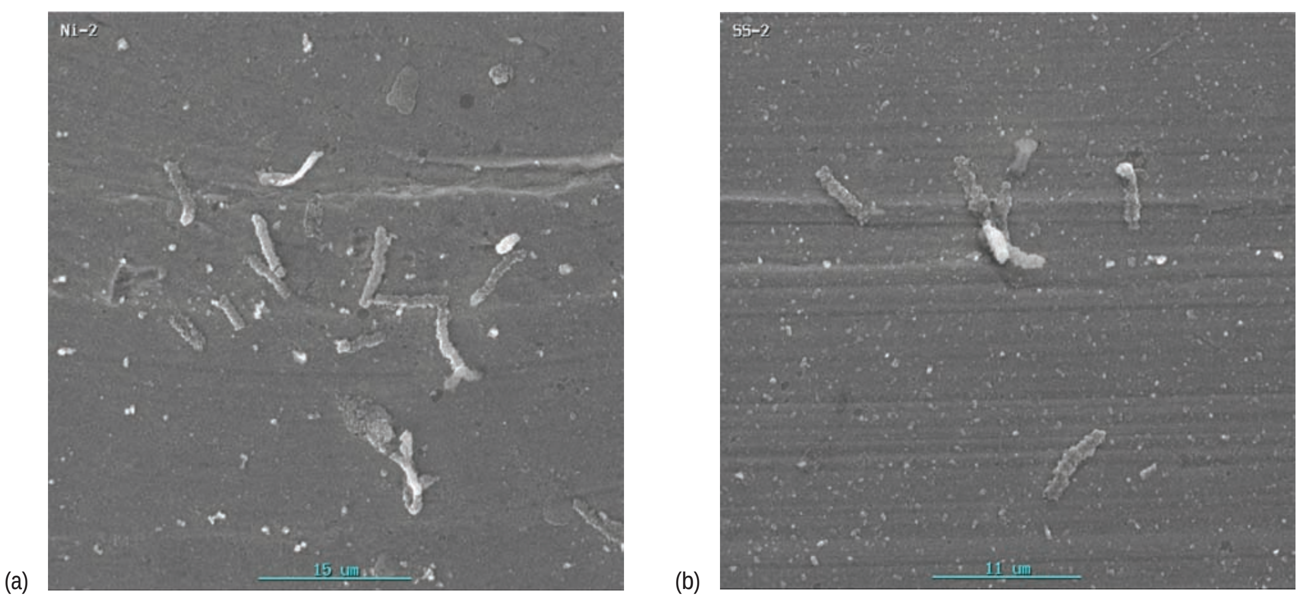


Figure 74. SEM representative view of (a) Robbins device pin 03563-Ni-2 and (b) Robbins device pin 03563-SS-2 after 36 mo of exposure.

Table 23. Heterotrophic viable counts (on R2A media) on the surface of Robbins device pins.

Sample Material	Months			
	3	6	12	36
Nickel 201	1.2×10^3 CFU/0.968 *cm^2	2×10^2 CFU/0.968 cm^2	$>1\times10^3$ CFU/0.968 cm^2	1.3×10^2 CFU/0.968 cm^2
CRES 347 stainless steel	1.2×10^3 CFU/0.968 cm^2	6×10^2 CFU/0.968 cm^2	7×10^2 CFU/0.968 cm^2	1.2×10^1 CFU/0.968 cm^2

* Effective surface area of the coupon.

Results of the 3-, 6-, 12-, and 36-mo SEM analyses of Robbins device pins showed some surface debris visible at both low power (500×) and high power (5,000×). Sparse biofilm formation was evident—bacterial cells mostly appeared singly (rod shaped) or together as small microcolonies. No significant increase in biofilm over the course of the test was observed.

What looked like fungal spores was observed on the 36-mo samples. It is unclear if the structures observed at this time were from fungal contamination during sampling, the fungi were indeed part of the CFST HTF, or the observed structures were part of the Teflon. Samples from clean/control Teflon hoses analyzed at a later time, showed very similar structures.

Robbins device pins were also analyzed using EDS. Results showed typical spectra for CRES 347 stainless steel and 201 nickel materials. No other elements were detected.

Biofilm test panels, with stainless steel and titanium tubes (including dead legs) and Teflon hoses, were removed and analyzed at 12 and 36 mo. Samples from the tubes and hoses were aseptically removed at the Altran Corporation microbiology laboratory. The locations of the samples removed are shown in figure 20. Titanium and stainless steel samples from the flowing system harbored few viable heterotrophic bacterial cells. A titanium dead leg sample contained the highest viable microbial levels after 36 mo of exposure. The Teflon tube sample showed moderate levels of viable bacteria and the presence of mold (supported by SEM analysis). The Teflon tube viable counts, indicated in table 24, are possibly lower than actual levels as it was not possible to sample the troughs of that corrugated material.

Table 24. Heterotrophic viable counts on the surface of the CFST test tube and hose samples.

Sample Identification	Months	
	12	36
Titanium tube	<1 CFU/cm^2	<1 CFU/cm^2
Titanium tube	<1 CFU/cm^2	<1 CFU/cm^2
Titanium dead leg	1 CFU/cm^2	>1×10^3 CFU/cm^2
Titanium dead leg	<1 CFU/cm^2	>1×10^3 CFU/cm^2
Stainless steel tube	<1 CFU/cm^2	1.2×10^1 CFU/cm^2
Stainless steel tube	<1 CFU/cm^2	4.6×10^1 CFU/cm^2
Teflon hose	2×10^2 CFU/cm^2	5.4×10^1 CFU/cm^2
Teflon hose	7×10^2 CFU/cm^2	3.4×10^2 CFU/cm^2

SEM analyses of bent titanium and stainless steel tube samples showed little evidence of biofilm formation at 12 and 36 mo. Representative photomicrographs (figs. 75–78) demonstrate the presence of mostly individual rod-shaped cells or detritus present. In the 36-mo samples of the titanium dead leg tube, the section close to the flowing system showed biofilm formation with stalked bacteria, rod-shaped cells, and spores within crevices in the material (fig. 79). In comparison, the sample section away from the flowing system showed only individual bacterial cells. This was not observed in the 12-mo samples (fig. 80).

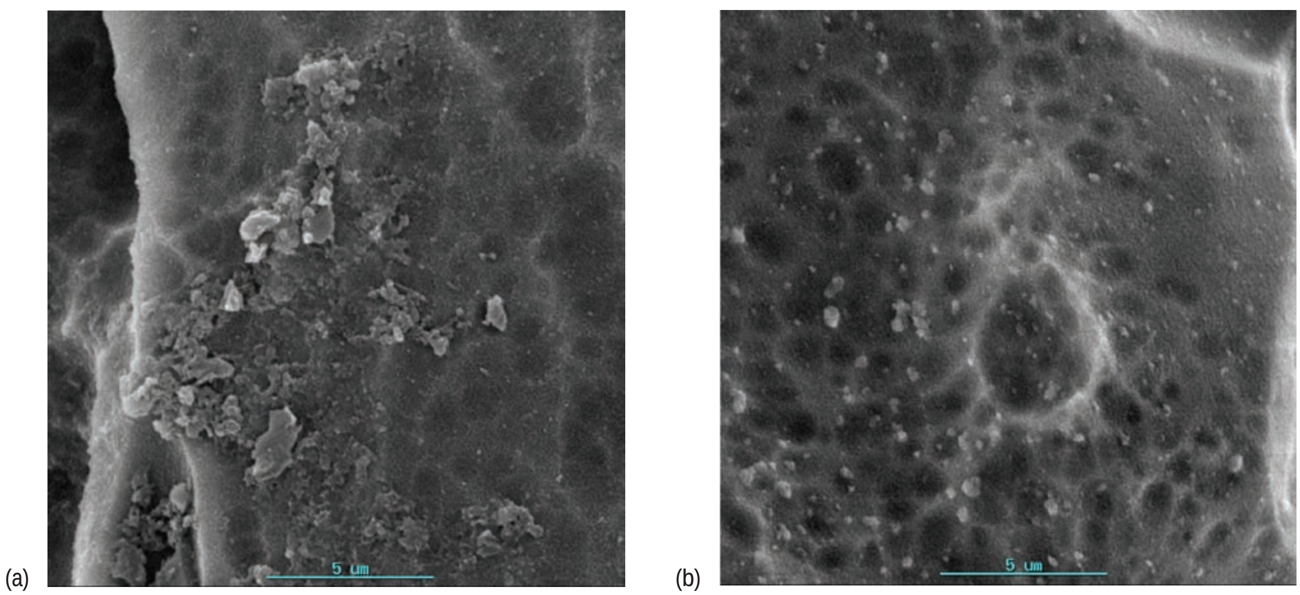


Figure 75. SEM representative view of (a) straight section from titanium tube coupon 01543-Ti-1B-S and (b) bent section from titanium tube coupon 01543-Ti-2B-B after 12 mo of exposure.

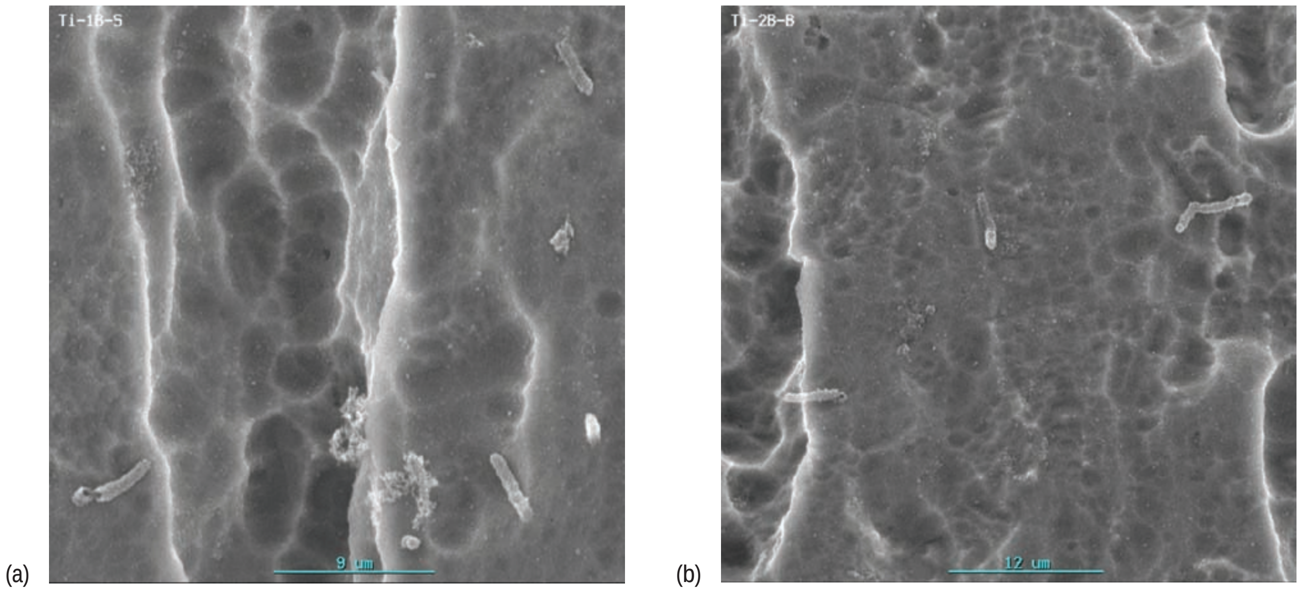


Figure 76. SEM of (a) straight section from titanium tube 03563-Ti-1B-S and (b) bent section from titanium tube 03563-Ti-2B-B after 36 mo of exposure.

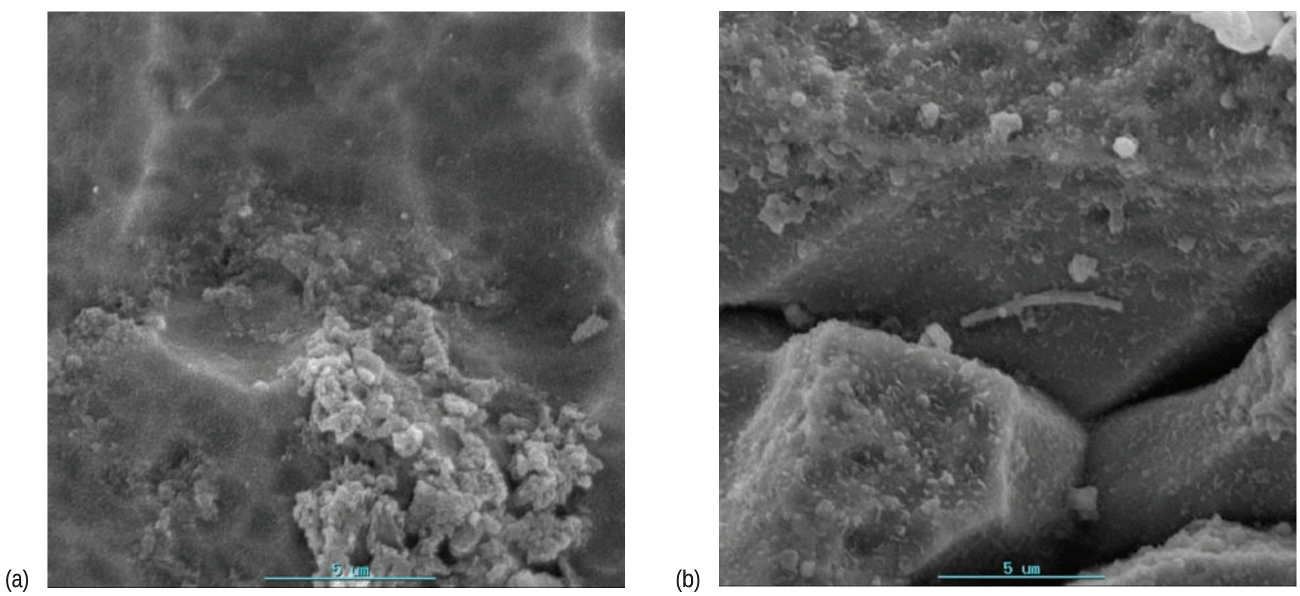


Figure 77. SEM representative view of (a) straight section from stainless steel tube coupon 01543-SS-5B-S and (b) bent section from stainless steel tube coupon 01543-SS-6B-B after 12 mo of exposure.

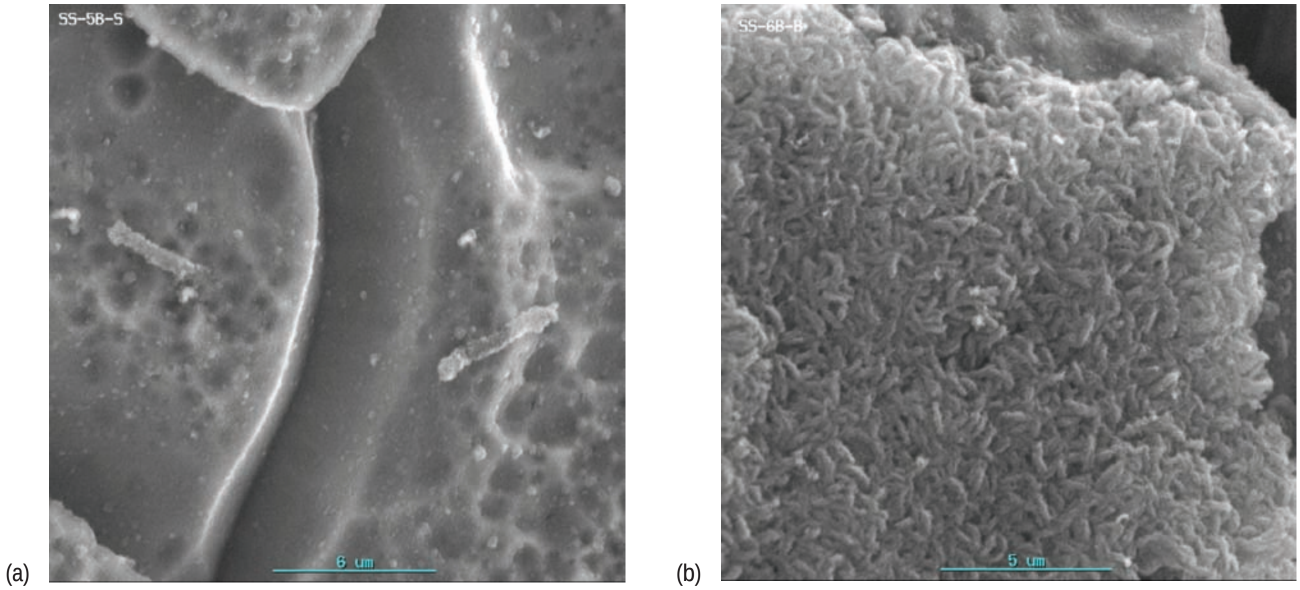


Figure 78. SEM view of straight section from (a) stainless steel tube 03563-SS-5B-S and (b) stainless steel tube 03563-SS-6B-B, showing the Crystal-like deposits after 36 mo of exposure.

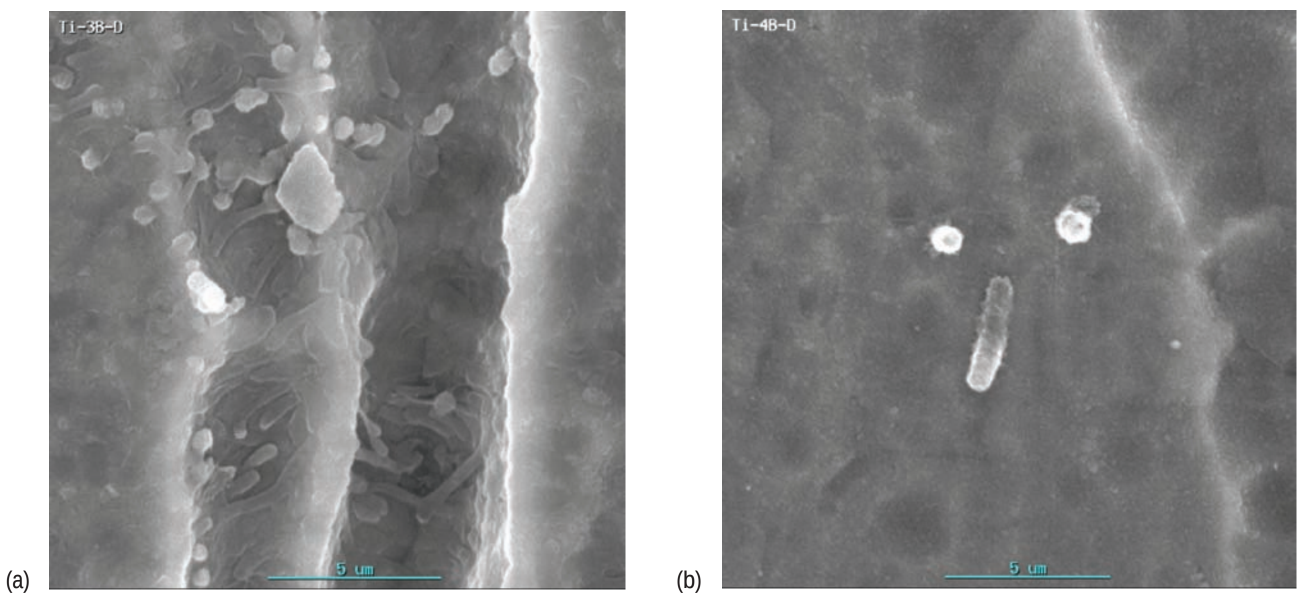
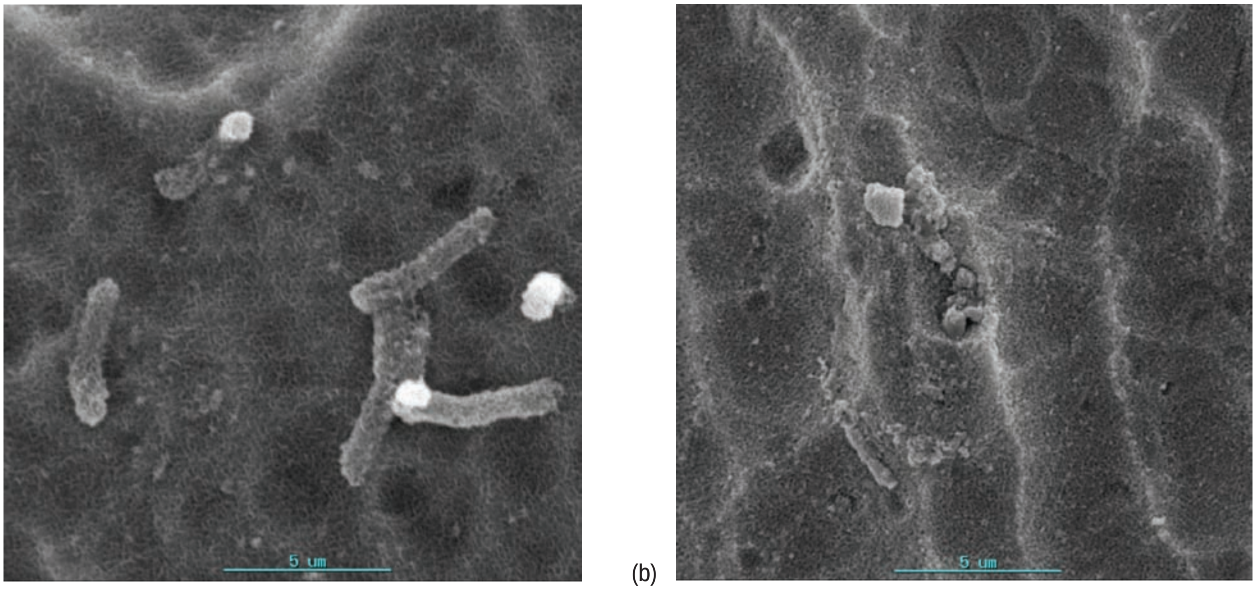


Figure 79. SEM representative views (a) and (b) of upstream section from Teflon tube coupon 01543-TF-7B after 12 mo of exposure.



(a) (b)

Figure 80. SEM view of (a) upstream section from Teflon tube 03563-TF-7B and (b) downstream section from Teflon tube 03563-TF-8B after 36 mo of exposure.

Teflon hose samples, after 36 mo of exposure, showed the presence of what was thought to be fungal hyphae and spores (figs. 81 and 82). There was visible fungal growth on the surface of the hoses (outside) and it was possible that during cutting of the hoses, although precautions were taken to prevent cross contamination, some of the fungi might have contaminated the inside of the hose. After further investigation, it was found that the Teflon hose structure, under the SEM microscope, resembles fungal hyphae, which is true even for virgin material that has never been exposed to aqueous conditions. There is no way at this time to verify if the structures that resembled spores are debris or spores from the outside of the hose.

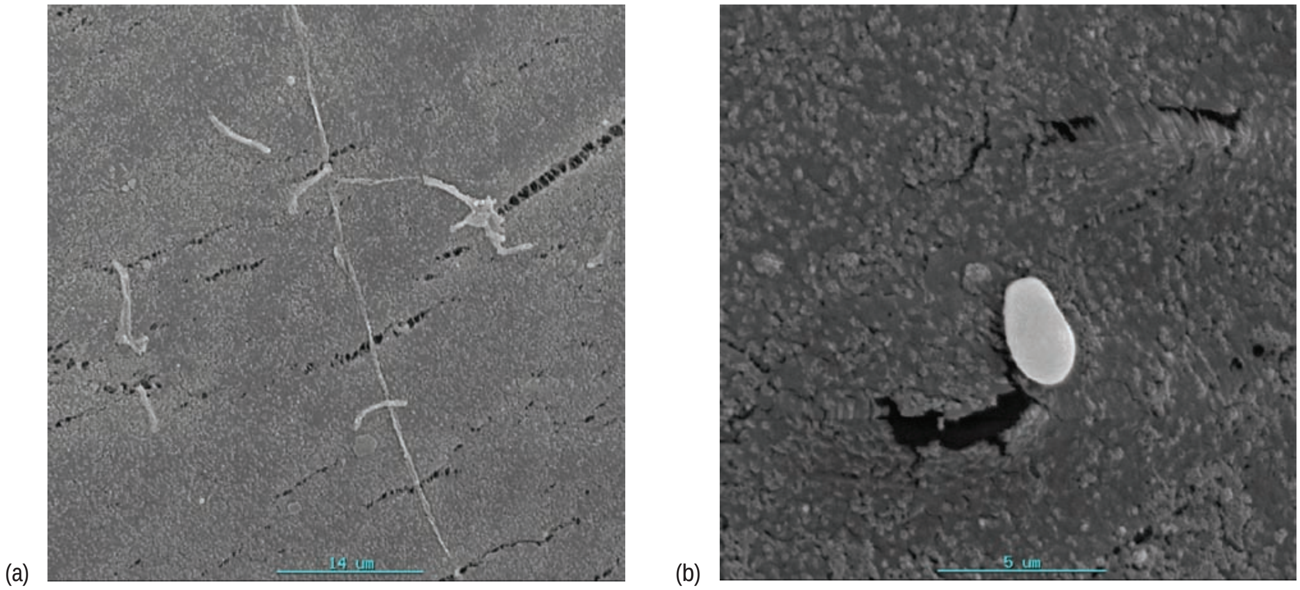


Figure 81. SEM representative view of (a) upstream section from titanium tube dead leg coupon 01543-Ti-3B-D and (b) downstream section from titanium tube dead leg coupon 01543-Ti-4B-D after 12 mo of exposure.

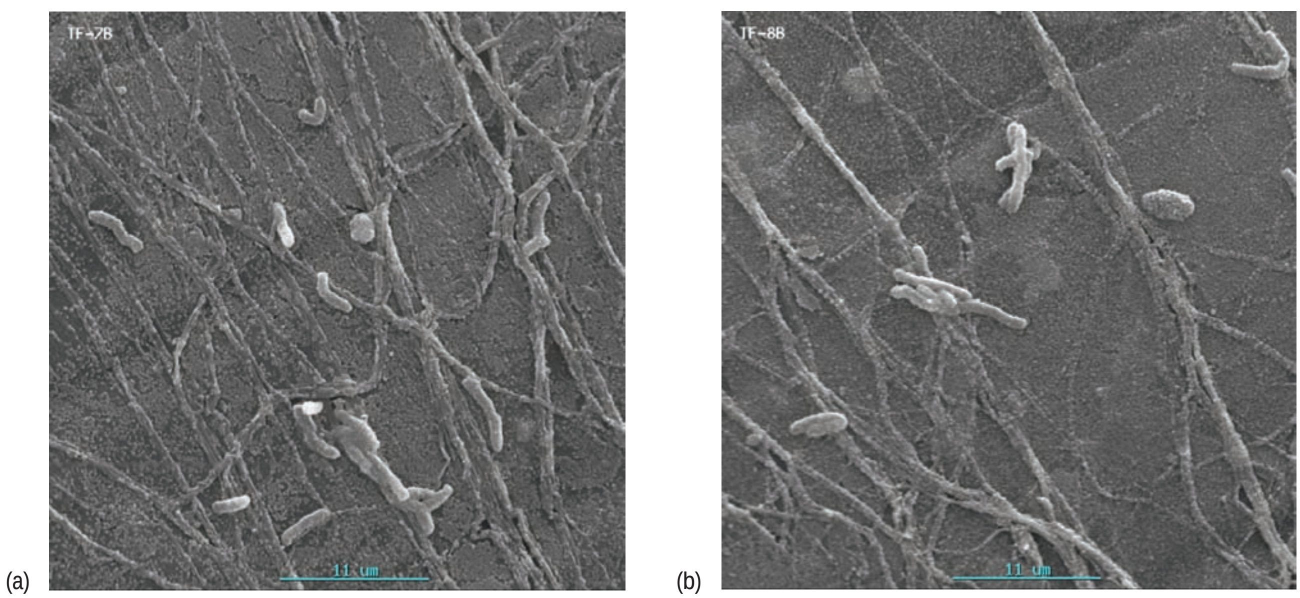


Figure 82. SEM view of (a) upstream section from titanium tube dead leg 03563-Ti-3B-D and (b) downstream section from titanium tube dead leg 03563-Ti-4B-D after 36 mo of exposure.

SEM analysis of the 12-mo stainless steel tube coupon, sample 01543–SS–6B (table 22), showed evidence of regular crystal-like formations that were high in copper content compared to the base metal by EDS analysis. SEM analysis of the 36-mo stainless steel tube coupon sample 03563–SS–6B (table 22) showed evidence of rod-shaped structures that were high in copper and zinc content. A peak for sulfur was also present in this sample spectrum. The samples were coated with gold for SEM biofilm analysis; therefore, the laboratory could not analyze it quantitatively by EDS. The presence of copper and zinc suggest that a source for these contaminants is present in the system, and may be actively corroding (dezincification). There also appears to be preferential corrosion of the grain boundaries of the base material; however, this is currently inconclusive. Metallographic analysis of the samples is needed to further investigate the apparent corrosion.

4.5.4 Conclusions

The CFST facility is a high-fidelity simulator of the materials and components of the IATCS, with the capability of performing specific tests related to the fluid chemistry, microbiology, and materials performance in support of the ISS program. Previous ground testing at ambient conditions showed stable pH, leading to false expectations of performance of the system on board ISS. The assumption was that CO_2 permeation of the Teflon hoses would be negligible, which is not the case for the special conditions of this system (closed-loop, long-term operation in a CO_2-enriched atmosphere). Conclusions that can be drawn from the results to date include the following:

- Maintaining the specified pH effectively controls the microorganism growth and corrosion.
- CO_2 does significantly permeate Teflon hoses.
- A higher atmospheric CO_2 concentration leads to lower pH, due to permeation.
- The lower pH leads to chemistry changes in the coolant.
- Increased Ni concentration in the coolant correlates with decrease in pH.
- Increased microbial populations in the coolant correlate with a decrease in pH.

The results of this test show the importance of testing in a relevant environment for a representative duration. For the IATCS this includes having a flight-like atmosphere around key components of the test facility and testing for an extended period of time.

In the absence of an antimicrobial agent, the conditions in the IATCS HTF can support microbial growth. In addition to the CFST, samples of flight HTF from node 1/Destiny have confirmed this. The chemical changes in the flight HTF, combined with the uncontrolled microbial population in the hardware that was connected, over time have created an environment that contains an established and stable microbial population. The extent of biofilm formation and the damage that it might have created on the surfaces of the flight system are currently unknown, but there is little doubt that biofilm is present on the surfaces. Based on currently available data, the effect of biofilm on the surfaces cannot be determined, and return of flight IATCS hardware is needed. (A report on analysis of flight hardware returned in 2005 is being prepared.) Removal of the biofilm in node 1/Destiny would require active scrubbing of the surfaces or the use of hazardous chemicals not permitted in ISS, so it is likely that the bioaccumulation on the surfaces of the flight hardware will never be completely removed. Therefore, hardware currently in flight, unless replaced, will always be at risk, even after the addition of an antimicrobial agent.

From the CFST, it is evident that if the pH in Destiny's HTF had been maintained at the specification levels, the microbial population would have stayed at a low, stable concentration and the biofilm accumulation would not have been a problem for at least 2 yr, despite the disappearance of the Ag antimicrobial from the solution within hours of the hardware being charged with the HTF. This lesson should be kept in mind when the chemistry of the HTF in node 2 (and other modules) is considered. If the system is initially clean, the microbial concentration of the ground support equipment is controlled, and the pH of the fluid is maintained at 9.5 (±0.5), other chemical parameters (except for Ag^+) will be maintained within the baseline specifications and the microbial load can reasonably be expected to remain acceptable for at least 2 yr. If, prior to launch, the microbial load did exceed acceptable levels, methods are available to remove it.

4.6 System Flow Control Assembly Setpoint Change Test

During assembly of ISS, changes in the assembly sequence were made (or considered), including installing the regenerative environmental control and life support racks (water recovery and oxygen generation) in Destiny rather than node 3. Adjustments in the IATCS operation would be needed for this configuration to ensure sufficient HTF flow to the payloads. This would involve reducing the pressure drop across the SFCA to increase the flow rate. A simple test was devised that would provide data for comparison with a computer model. The test was performed on September 14, 2004, during a monthly exercise of the IATCS Simulator, and did not require any physical modification of the facility or extended run times. The entire test was concluded within 2 hr.

4.6.1 Test Description

The purposes of the test were to demonstrate SFCA stability during a step change, quantify the increase in system flow as the SFCA ΔP is reduced in each loop, and show how the subsystem flows are reduced. This test was a simplified version of the planned on-orbit test so that it could be incorporated as part of the monthly system checkout for the IATCS Simulator. This test did not incorporate heat loads. (The test procedure and data analysis and figures were prepared by Tom Ibarra (Boeing).)

4.6.2 Test Procedure

The procedure follows:

(1) Start up in single-loop mode.
(2) Command the MTL SFCA setpoint from 11 psid to 8 psid.
(3) Command the LTL SFCA setpoint from 11 psid to 8 psid.
(4) Return the LTL SFCA setpoint back to the nominal 11 psid setpoint.
(5) Return the MTL SFCA setpoint back to the nominal 11 psid setpoint.
(6) Proceed to normal shutdown.

4.6.3 Test Results and Conclusions

The test data are plotted in figure 83 and a comparison with the model prediction is shown in table 25. The SFCA ΔP control was excellent with control from 11 to 8 psid within 20–30 s with no oscillations. The system flow rates follow:

- –2,550 pph with both SFCAs at 11 psid.
- –2,645 pph after the MTL SFCA was reduced to 8 psid (a 95 pph increase).
- –2,758 pph after the LTL SFCA was reduced to 8 psid (a 113 pph increase).

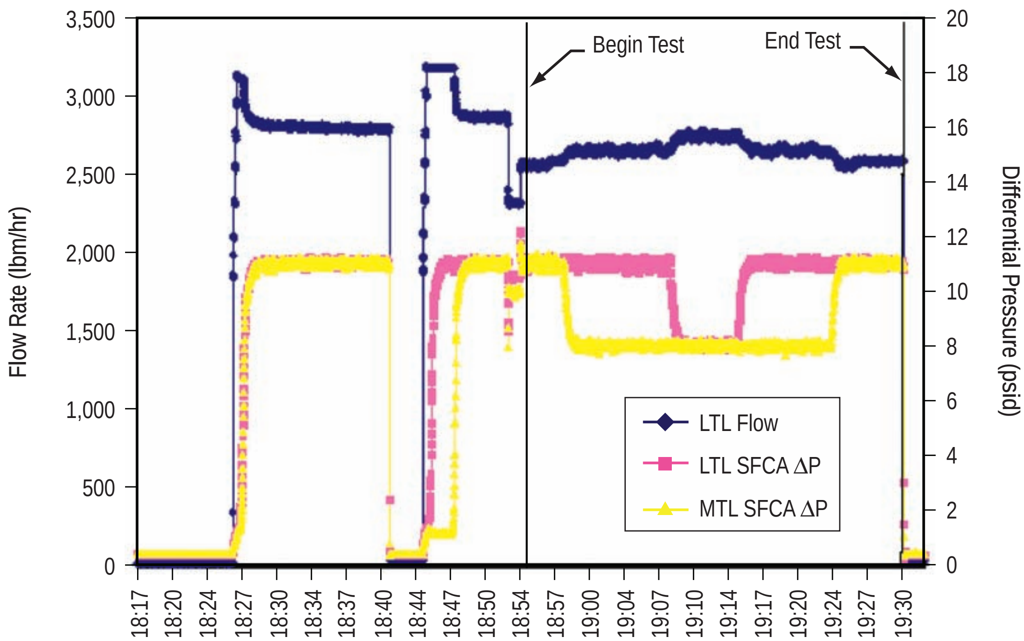


Figure 83. SFCA setpoint change test data.

This results in a total of 208 pph increase from the PPA with both the MTL and LTL SFCAs at 8 psid, The subsystem flows were reduced as predicted (within ≈ 5 percent of the predicted values) as shown in table 25, indicating that the regenerable ECLS racks could be safely accommodated in Destiny while maintaining operation of the experiment payloads.

Table 25. SFCA setpoint change data comparison with prediction.

Location	MSFC Lab Simulator Flow Rate (lbm/hr)		Model Protection Flow Rate (lbm/hr)
	11 psid	8 psid	8 psid
FWD E/C	248	205.8	211.5
AFT E/C	230	192.6	196.1
AV No. 2	94	76.1	80.2
AV No. 3	116	95	98.9
CHeCs	131	109.2	111.7
AV No. 1	117	96.3	99.8
ARS–MT	129	107.3	110
DDCU No. 2	0	0	0
DDCU No. 1	261.8	213.3	223.3
MSS2	145.6	120.2	124.2
MSS1	154.6	126.6	131.8

5. FUTURE TESTING

The IATCS facilities at MSFC have demonstrated their value in addressing flight IATCS issues by verifying procedures or methods, identifying mechanisms related to on-orbit behavior of the IATCS, identifying procedures that may be detrimental to the flight IATCS, and providing a facility for training astronauts to implement procedures. The facilities are available for future testing of similar natures, as well as thermal and flow analyses and other testing as initially conceived. Some specific tests have been proposed for the near future, to address current issues with the flight IATCS and are described in this section. The process for using the MSFC IATCS test facilities is described in flow-chart form in figure 84.

5.1 Internal Active Thermal Control System Simulator System Test

Though designed and intended to support testing and evaluation related to heat loads and HTF flow, as mentioned previously, the IATCS Simulator was designed with sufficient fidelity and adaptability to perform a variety of other tests, including evaluation of chemistry changes.

Due to on-orbit chemistry changes that have occurred with the HTF, the IATCS SPRT is considering methods to adjust the HTF chemistry. Proposed tests include evaluation of techniques to remove dissolved Ni and phosphate from HTF, and add a buffer and an antimicrobial agent to the HTF. These actions are proposed to be performed together, either simultaneously or in close sequence, and testing them collectively, using the IATCS Simulator, is referred to as the system test. Individually the components are referred to as the Ni removal assembly (NiRA), the phosphate removal assembly (PhosRA), etc. Performing this test would require some modifications to the IATCS Simulator, including increasing the total volume to match the current on-orbit HTF volume of Destiny.

Note: Following completion of this TM the systems test requirements was finalized with some differences from the version presented here. The final test requirements document is included as appendix A3.

5.1.1 System Test Plan

Implementation of any procedures to modify the HTF chemistry onorbit needs to be validated in a suitably similar test facility. Key aspects are chemistry, microbial population, fluid volume, flow rates, temperatures, thermal distribution, surface area, materials, hardware fidelity, and ambient environment (especially CO_2 concentration). Ion-exchange resins packaged in 2-L canisters (fig. 85) are planned to remove Ni and phosphate and add a buffer; e.g., trisodium borate. The exact method of adding the antimicrobial agent has not yet been determined and depends on the antimicrobial agent selected and the prototype method of adding it to the HTF. Validating the methods and procedures by ground test would reduce the risk for implementation in ISS and would validate the implementation sequence and timing, as well as enable evaluation of any secondary effects. Potential risks include the sudden release or removal of a compound that may lead to precipitation and clogging of the filter or gas trap or may result in a mechanical failure of the PPA or valves, enhanced corrosion when the dissolved Ni is removed, and reprecipitation of compounds such as phosphates. The duration of the test may be several months, including facility preparation and conditioning of the system, though the primary activity is expected to take only a few weeks.

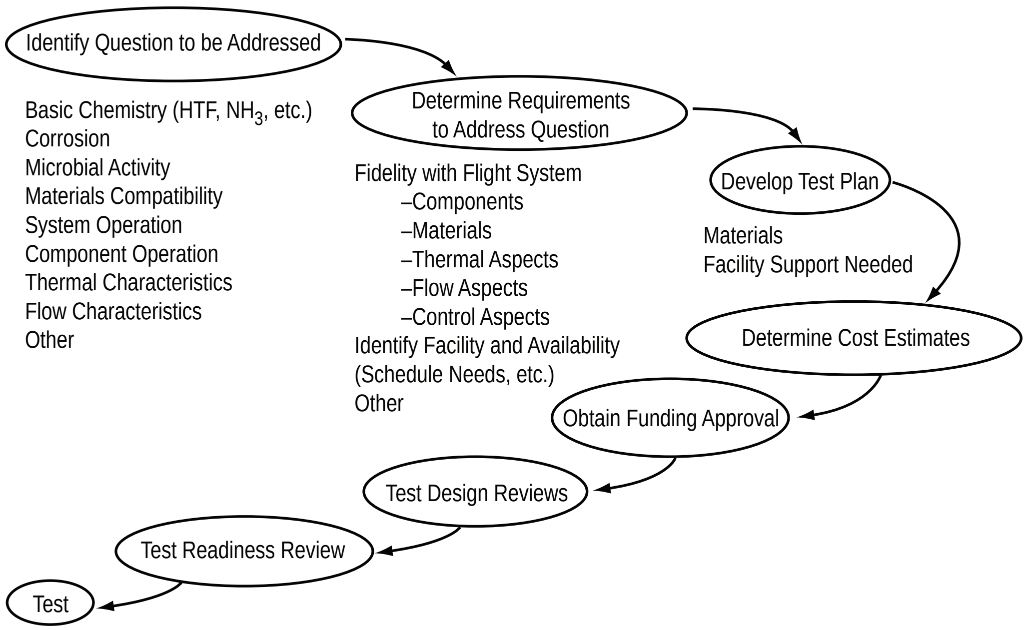


Figure 84. Flowchart of procedure to use the IATCS test facility.

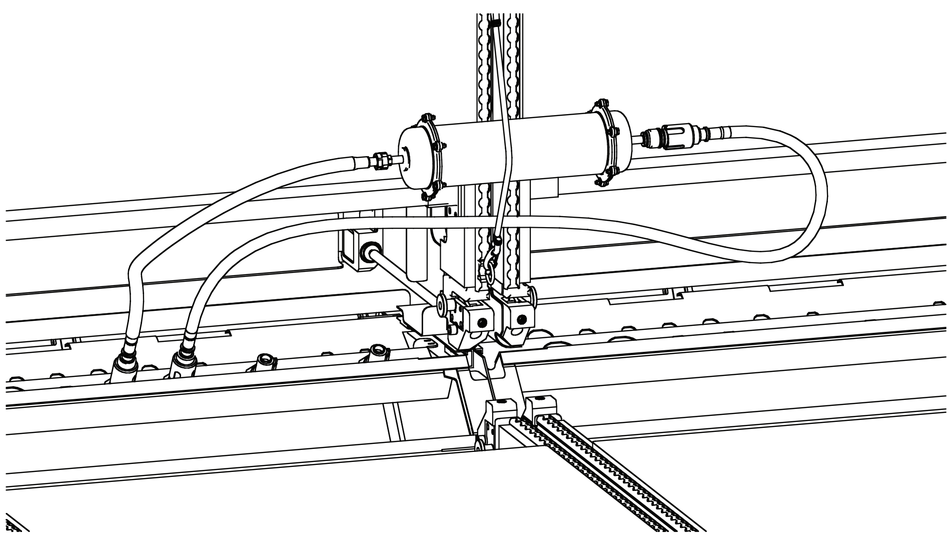


Figure 85. Concept for the NiRA (similar for the PhosRA, and buffer and antimicrobial addition).

Issues that may be important and need to be addressed include the higher CO_2 concentration, which may affect pH and $NiCO_3$ precipitation; the large tubing surface area with long runs and components that can interact chemically with the HTF; the presence of dead-leg tubing that may have different concentrations of key chemicals or a different pH; variations in temperature when operating in single-loop mode; the presence of Ni-braze that is available to corrode; and a robust microbial population.

5.1.2 System Test Objectives

The objectives of the system test follow:

- Demonstrate and quantify the removal of dissolved and precipitated Ni.
- Demonstrate and quantify the removal of re-dissolved phosphate.
- Demonstrate the implementation concept.
  - NiRA1, NiRA2, PhosRA1, PhosRA2, PhosRA3, buffer, antimicrobial.
- Validate that the system complexity and operation do not adversely affect remediation or the system performance.
  - Quantify effects on gas trap and filter pressure drop for each remediation step.
  - Demonstrate that microbes do not interfere with chemical remediation.
  - Demonstrate that chemical changes in microbial environment will not cause microbial upset.
  - Validate chemistry change resulting from NiRA, PhosRA, Borate use within safe and expected range (compare and analyze against Bench Data).
- Demonstrate that jumpering procedures are effective to treat the whole volume without causing a system upset (due to mixing of deadlegs with circulating system).
- Show that corrosion is not significantly increased by remediation.
- Understand antimicrobial degradation and possible microbial recovery effects.

5.1.3 Facility Modifications and Test Hardware Needed

Some modifications to the ITCS Simulator will be needed, as well as some additional test hardware. The MTL volume needs to be about 79 gallons, which may require adding tanks. Since the ITCS Simulator currently does not contain any flightlike cold plates, installation of rejected flight cold plates may be needed, to provide additional surface area and flight materials. Flight filter cartridges will be needed in both loops. The 1-g gas trap in the LTL will need to be replaced with a flight-like gas trap. Suitable support structure (fig. 85) will need to be fabricated and installed in the appropriate location to support the test canisters. A means of injecting a buffer and antimicrobial agent will need to be accommodated. (Details of the methods have not yet been determined as of January 2005.) The capability of immersing the ITCS Simulator Teflon hoses in a CO_2 (or CO_2-enriched air) bath will also be needed.

5.1.4 System Test Procedure

The test procedure will consist of the following (or similar) steps (see app. A.3 for detailed test procedure):

(1) In single-loop mode with the LTL operating, acquire baseline ΔPs, microbial population, performance characteristics, and thermal loads.

(2) Adjust the fluid chemistry (1,000 ppm Borate, 25 ppm PO_3, ≈8 ppm Ni(t), 20 ppm Acetone, 50 ppm Ethanol, and 8.4 pH) via concentrate addition and CO_2 hose permeation, and final sparging to the flowing system with temporary jumpers and in situ equilibration. (Characterization of hose permeation can be performed during this step.)

(3) Redo the baseline, step 1.

(4) Switch to single-loop mode with the MTL operating (and the LTL deactivated), with a flight filter and research gas trap (GTR).

(5) Perform Precipitate procedure (load precipitate on walls—not COTS filters) by adding $NiNO_3$ in 100-ml steps, adjust pH via CO_2 sparge and NaOH between steps. After loading, equilibrate for 2 days. During loading, remove the filter and GTR after the ΔP increases by 50 percent of the sensor range. Install the filter on the deactivated LTL.

(6) Install a COTS filter in the MTL and circulate for 1 day. Remove the filter and desorb Ni to determine the mass of Ni collected. Repeat loading step (5) as required until 100-gm Ni precipitate has loaded on surfaces.

(7) Refresh the fluid chemistry with fluid loaded to end (6) conditions less any NO_3 and excess Na.

(8) Re-install the LTL filter and GTR, and switch to single LTL and redo the baseline.

(9) Add 1 gal of 1×10^7 CFU/100 mL inoculum to achieve 1×10^6 CFU/100 ml in the 79-gal loop.

(10) Mix and equilibrate (with jumpering) until the ΔPs are ±10 percent baseline. This step may take about 3 wk.

(11) Add a 2-L NiRAH+ (NiRA1) at the LTL LAO5 location and provide 400-pph flow. Sample per table 26.

(12) Jumper per expected flight procedure over 9 days.

(13) Remove the NiRAH+ and analyze the resin. Sample for rebound effects.

(14) Adjust the pH via sparging equivalent to orbital rebound (may be none).

(15) Redo baseline.

(16) Install second NiRAH+ (sample per app. A.3—30-day duration).

(17) Install PhosRA1 at LTL LAC5 (sample per app. A.3—after 24 hr remove and analyze resin).

(18) Install PhosRA2 at LTL LAC5 (sample per app. A.3—after 48 hr remove and analyze resin).

(19) Install PhosRA3 at LTL LAC5 (sample per app. A.3—after 48 hr remove and analyze resin).

(20) Sample for rebound effects.

(21) Inject concentrated buffer solution to increase (after jumpering) the total volume concentration.

(22) Equilibrate with CO_2 challenge for 10 days.

(23) Inject antimicrobial agent and sample per appendix A.3.

(24) Monitor conditions with biocide injections based on on-orbit sampling intervals and continual CO_2 permeation challenge.

5.2 Cold Plate/Fluid Stability Test Facility

Refurbishment of the CFST facility, with modifications, is in progress (as of January 2005) to more closely replicate the condition on ISS (especially the CO_2 and NH_3 levels in the atmosphere) to address permeation through the Teflon hoses and better monitor the condition of the materials. These additional modifications include the following:

- Installing a permanent enclosure for the large Teflon hose (fig. 86).
- Replacing the Robbins device coupons that were removed with Ni-brazed coupons for easier evaluation of the condition of the cold plates and HXs.
- Injecting a sample of coolant containing microorganisms from the flight IATCS coolant, if available.

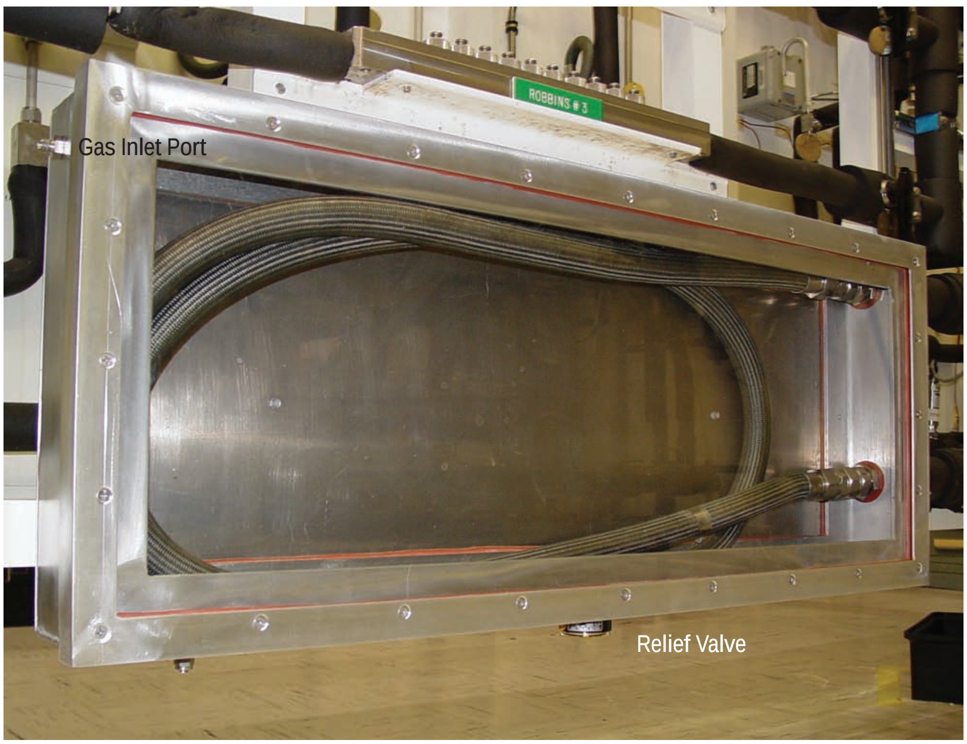


Figure 86. Enclosure around the large Teflon hose.

As part of these modifications, the Robbins devices and removable biofilm test panels will be rebuilt and the coolant will be replenished so that samples can continue to be collected for analysis. Additional uses of the test bed currently under consideration include evaluating alternative antimicrobials (sec. 3.7).

The refurbished facility will be capable of operation for at least 3 yr with occasional maintenance for sensor repair or replacement, pump replacement (if needed, the pumps will be replaced as part of the refurbishment), or other facility needs. As an improved simulation of the flight IATCS, the facility will be better able to assist in troubleshooting IATCS-related issues and will be suitable for the qualification of material or fluid changes prior to implementation on ISS.

5.2.1 Modification Goals

The goals of the modifications follow:

- Establish conditions similar to those of the flight IATCS.
- Gain insight into the causes of the conditions in the flight IATCS.
- Evaluate methods to counteract detrimental effects.

Parameters and aspects to be addressed are the pH, the amount of Ag that has been added, corrosion of Ni brazing in the HXs and cold plates, microbial growth, TOC level, and possible sources of nitrogen.

5.2.2 Modification Approach

The approach is basically to return the test bed to its original condition, but with the following modifications:

- Refurbish the biofilm test panels with new tubing and hoses.
- Braze Robbins device coupons with BNi_2 (Hamilton Sundstrand) and BNi_3 (Honeywell) and install in the existing Robbins devices.
- Flush fresh Ag-containing HTF through the system several times to deposit a similar amount of silver as in the flight IATCS.
- Add coolant with microbial populations (from flight or from the current coolant in the test-bed) to better match the microbial populations in the flight IATCS.
- Install a permanent enclosure around the large Teflon hose for mixed gas injection (fig. 86).

Sample collection and monitoring includes collecting coolant samples for chemistry analyses (table 26), removing coupons of nickel braze materials for microbial and corrosion analyses (table 27), and monitoring of conditions such as pressure drop across the filter and gas trap.

Thirty-three coupons each of BNi_2, BNi_3 single-braze, BNi_3 double-braze (with Ni 201 strip, to simulate fillet area) will be fabricated as shown in figure 87. This provides some extra coupons for comparative analyses or as replacements.

Table 26. Schedule of coolant chemistry analyses.

Sample Collection	Analyses
Pretest	Microbial Swabs
After 24 hr, 48 hr, 168 hr, 360 hr, 720 hr Monthly or bimonthly after 720 hr	Microbial Particulates (may be less frequent) Metals – Chromium – Iron – Copper – Nickel – Silver – Barium – Magnesium – Titanium – Zinc Calcium Chlorides Total organic carbon Total inorganic carbon Dissolved oxygen Di- or tri-sodium phosphate Sodium borate pH Ammonia Nitrates Nitrites

Table 27. Schedule of microbial and corrosion analyses.

Analysis	Description	Test Month				
		0	0.25*	12+	24+	36 or end of test
Microbial count and ID (R2A)	BNi_2 braze	–	–	1	1	1
Microscopic assessment of biofilm (SEM, AFM, ...)		–	–	1	1	1
Surface condition and pitting (SEM, MEP, ...)		1	1	1	1	1
Microbial count and ID (R2A)	BNi_3 single Braze	–	–	1	1	1
Microscopic assessment of biofilm (SEM, AFM, ...)		–	–	1	1	1
Surface condition and pitting (SEM, MEP, ...)		1	1	1	1	1
Microbial count and ID (R2A)	BNi_3 double Braze	–	–	1	1	1
Microscopic assessment of biofilm (SEM, AFM, ...)		–	–	1	1	1
Surface condition and pitting (SEM, MEP, ...)		1	1	1	1	1
Microscopic assessment of biofilm (SEM, AFM, ...)	SS tube	–	–	1	1	1
	TT tube	–	–	1	1	1
Surface condition and pitting (SEM, MEP, ...)	TT dead leg	–	–	1	1	1
	Teflon hose	–	–	1	1	1
	Cold plate No. 9	–	–	–	–	1
Microbial Assessment (R2A, SEM, ...)	Gas trap membrane	–	–	–	–	1

* After the Ag concentration in the fluid is depleted, coupons are to be removed for evaluation of Ag deposition (by EDS and/or MEP).
Note: SEM = scanning electron microscopy, EDS = energy dispersive spectroscopy, AFM = atomic force microscope, MEP = metallurgical evaluation for pitting, R2A = technique for microbial identification.

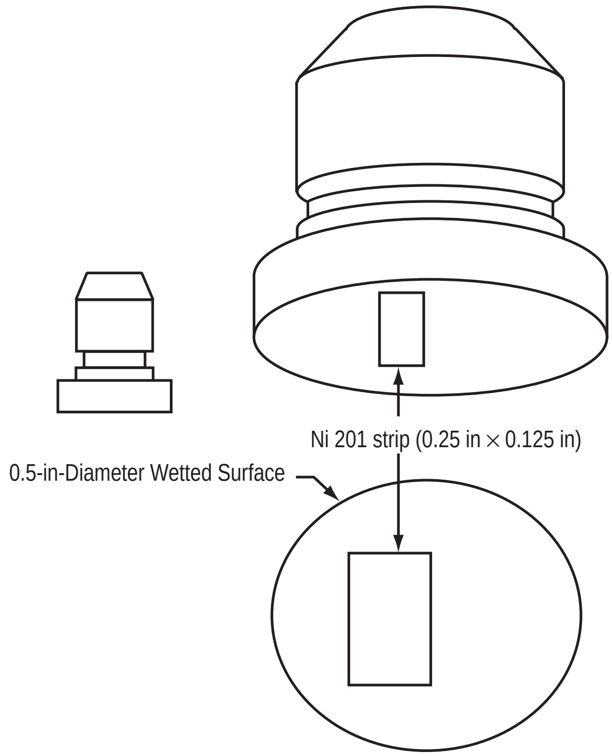
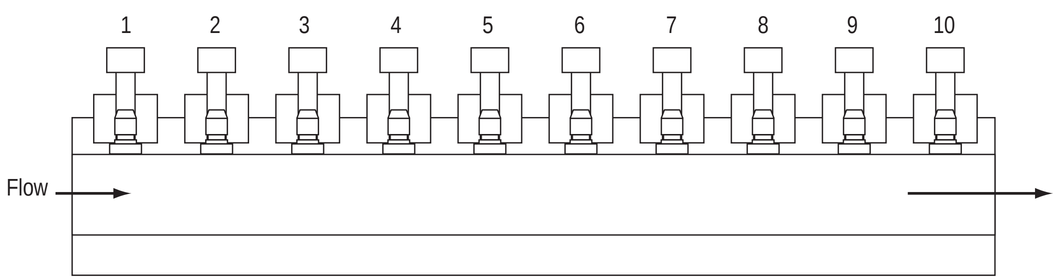


Figure 87. Robbins device coupon (pin).

Each Robbins device will hold 10 coupons, as shown in figure 88. Coupons must be inserted so that the Ni 201 strip is parallel with the flow direction.



Coupon 1: After the Ag concentration in the fluid has dropped to non-detectable levels, remove this coupon for silver deposition analysis and replace it with a fresh coupon brazed the same way. After 3 yr of operation this second coupon will be removed for analysis.

Coupons 2 – 4: After one year of operation, remove these coupons for analysis, and replace them with blank coupons (plain CRES 347 or brazed Ni).

Coupons 5 – 7: After two yr of operation, remove these coupons for analysis, and replace them with blank coupons (plain CRES 347 or brazed Ni).

Coupons 8 – 10: After three yr of operation, remove these coupons for analysis, and replace them with blank coupons (plain CRES 347 or brazed Ni).

Figure 88. Robbins device with coupon pins and replacement sequence.

APPENDIX A—FACILITY DOCUMENTATION

A.1 Facilities Operating Procedure for the IATCS Simulator

A.2 Test and Checkout Procedure for the Fleet Leader Cold Plate and Fluid Stability Test

A.3 ISS Coolant Remediation System Test Requirements No. ITCS006RevD

MARSHALL WORK INSTRUCTION

FD21A

Facilities Operating Procedure for the Internal Thermal Control System (IATCS) Simulator

DRAFT

DOCUMENT HISTORY LOG

Status (Baseline/ Revision/ Canceled)	Document Revision	Effective Date	Description
Baseline			

1. PURPOSE

To list the sequence of events required to bring the Internal Thermal Control System (ITCS) testbed to a ready status. Support to the following subsystem functions will be required during testing: Low Temperature Loop (LTL) Pump Package Assembly (PPA), Moderate Temperature Loop (MTL) PPA, Rack Flow Control Assemblies (RFCAs), System Flow Control Assemblies (SFCAs), Rack Heat Load Simulators (RHLSs), and LTL & MTL Common Temperature Bus (CTB) chillers. Facilities including nitrogen (N_2) and various types of power (detailed in Section 6.1) will be furnished to the subsystems.

2. APPLICABILITY

This Facilities Operating Procedure (FOP) applies to the support hardware, both mechanical and electrical, required for the ITCS Testbed to remove heat from a variety of loading conditions.

3. APPLICABLE DOCUMENTS

4. REFERENCES

5. DEFINITIONS

6 Instructions

6.1 Startup

During the Startup phase of a test, each subsystem will be powered up independently.

6.1.1 Verify the required ITCS facilities, and subsystems are configured per the latest ITCS Schematics To Be Determined (TBD). Furthermore, confirm all facility valves are in the "fail safe" configuration (unless otherwise noted: inlet valves-closed, vent valves open, subsystem interconnect valves closed, sample line valves – closed).

6.1.2 On Uninterruptible Power Supply (UPS) Status Board (located between columns G & H of the NHB), confirm the status indicates “System Normal”.

6.1.3 On Power Panel (PP) UP (located in the UPS room on the NE side of the North High Bay (NHB)), confirm Circuit Breaker (CB) 3 is on.

6.1.4 On PP UP1 (located between columns C & D on the north wall of the NHB), confirm CB 4 is on.

6.1.5 On PP TTUP (located on the ITCS port side exterior), confirm all connected CBs (as appropriately labeled) are on. Do not energize CBs labeled as “spare”.

6.1.6 On Switchboard BK02 (located in the North Power Room), confirm feed to PP1 is on.

6.1.7 On PP PP1 (located in the North Power Room), confirm CB to PP2 is on.

6.1.8 On PP PP2 (located at column G of the NHB) confirm CB 3 is on.

6.1.9 On box CB-1 (located between columns G & H of the NHB), confirm lever is in “on” position.

6.1.10 On PP DPEM (located between columns E & F of the NHB), confirm CB 4 is on.

6.1.11 On PP ITEM (located at column C of the NHB), confirm all connected CBs (as appropriately labeled) are on. Do not energize CBs labeled as “spare”.

6.1.12 On PP TTUP (located on the ITCS port side exterior), confirm all connected CBs (as appropriately labeled) are on. Do not energize CBs labeled as “spare”.

6.1.13 On PP ITEMA (located on the ITCS port side exterior), confirm heaters LAP1, LAP2, LAP3, LAP4, LAP5, LAP6, AFT, FWD, MID, NODE 1 MTL, NODE 1 LTL are off. Confirm all CBs labeled as “receptacle” are on. Do not energize CBs labeled as “spare”.

6.1.14 On PP ITEMB (located on the ITCS starboard side exterior), confirm heaters LAC1, LAC2, LAC3, LAC4, NODE, LTL FWD END, LAS1, LAS2, LAS3, LAS4, LAS6, LAF3, & LAS6 (LTL) are off. Confirm all CBs labeled as “receptacle” are on. Do not energize CBs labeled as “spare”.

6.1.15 On PP ITEMB (located on the ITCS starboard side exterior), confirm heaters LAS5, LAF1, LAF2, LAF5, LAF6 (MTL), LAC6, & AFT END MTL are off. Confirm all CBs labeled as “receptacle” are on. Do not energize CBs labeled as “spare”.

6.1.16 Open the N_2 supply valve located between columns C and D of the NHB.

6.1.17 Open the N_2 supply valve located on the aft port side exterior of the ITCS Testbed just above the LTL Accumulator Pressure Panel (APP).

6.1.18 Open the N_2 supply valve located on the LTL Accumulator APP.

6.1.19 Adjust the LTL Accumulator Pressure Regulator located on the LTL APP to read 10 – 15 psi.

6.1.20 Open the MTL APP N_2 supply valve located on the aft starboard exterior side of the ITCS Testbed.

6.1.21 Adjust the MTL Accumulator Pressure Regulator located on the MTL APP to read 10 – 15 psi.

6.1.22 Turn Payloads and Components Real-Time Automated Test System monitoring (ITCS-PACRATS)computer/monitor ON.

6.1.22.1 Login at the prompt.

Id: ECLSS
Password: See Test Conductor
Network: MSFC-ECLSS domain

6.1.22.2 Double click the shortcut on desktop to run PACRATS.

6.1.22.3 Type “Login”, and enter the following.

Id: ECLSS
Password: *See Test Conductor*

6.1.22.4 Type “START TEST ITCS”.

6.1.22.5 Type “SET RECORD ON”.

6.1.22.6 Double click the shortcut on desktop to run Netscan.vi.

6.1.22.7 Click the white Run arrow at top, left hand corner of screen.

6.1.22.8 Push button labeled “Load Driver List?” on the Netscan VI.

6.1.23. Turn System Control for ITCS (ITCS-SYS-CTRL) computer/monitor ON.

6.1.23.1 Login at the prompt.

Id: ECLSS
Password: *See Test Conductor*
Network: MSFC-ECLSS domain

6.1.23.2 Double click the shortcut on desktop to run SCITCS Main.vi

6.1.23.3 Click the white Run arrow at top, left hand corner of screen.

6.1.23.4 Verify that the SCITCS Heartbeat LED is blinking, and the Error counter is not incrementing.

6.1.24 Turn Rack Flow Control Assembly Control (ITCS-RFCA-CTRL)computer/monitor ON.

6.1.24.1 Login at the prompt.

Id: ECLSS
Password: *See Test Conductor*
Network: MSFC-ECLSS domain

6.1.24.2 Double click the shortcut on desktop to run ITCS RFCA.vi.

6.1.24.3 Click the white Run arrow at top, left hand corner of screen.

6.1.24.4 Verify that the Program Heartbeat LED is blinking, and the Error counter is not incrementing.

6.1.25 Turn Moderate Temperature Loop Control (ITCS-MTL-CTRL)computer/monitor ON.

6.1.25.1 Login at the prompt.

Id: ECLSS
Password: *See Test Conductor*
Network: MSFC-ECLSS domain

6.1.25.2 Double click the shortcut on desktop to run MTL PPA.vi.

6.1.25.3 Click the white Run arrow at top, left hand corner of screen.

6.1.25.4 Verify that the Program Heartbeat LED is blinking, and the Error counter is not incrementing.

6.1.25.5 Turn Low Temperature Loop Control (ITCS-LTL-CTRL)computer/monitor ON.

6.1.25.6 Login at the prompt.

Id: ECLSS

Password: *See Test Conductor*
Network: MSFC-ECLSS domain

6.1.25.7 Double click the shortcut on desktop to run LTL PPA.vi.

6.1.25.8 Click the white Run arrow at top, left hand corner of screen.

6.1.25.9 Verify that the Program Heartbeat LED is blinking, and the Error counter is not incrementing.

6.1.26 Turn Heat Load Simulator Control (ITCS-HLS)computer/monitor ON.

6.1.26.1 Login at the prompt.

Id: ECLSS
Password: *See Test Conductor*
Network: MSFC-ECLSS domain

6.1.26.2 Double click the shortcut on desktop to run ITCS Heat Load Simulator.vi.

6.1.26.3 Click the white Run arrow at top, left hand corner of screen.

6.1.26.4 Verify that the Heartbeat LED is blinking, and the Error counter is not incrementing.

6.1.27 Turn 1553B Bus Monitor (ITCS-1553_BM)computer/ monitor ON.

6.1.27.1 Login at the prompt.

Id: ECLSS
Password: *See Test Conductor*
Network: MSFC-ECLSS domain

6.1.27.2 Double click the shortcut on desktop to run BusTools-1553-S.

6.1.27.3 Click “No” in response to the “Will BusTools simulate the Bus Controller?” pop-up.

6.1.27.4 Double click the “BM” icon.

6.1.27.5 Click “Run” after accepting, or modifying the listed default values.

6.1.28 Push the “start” button on the LTL chiller located between columns B and C of the NHB.

6.1.29 Push the “start” button on the MTL chiller located between columns B and C of the NHB.

6.1.30 Activate the 120 VDC power supply located below the ITCS-HLS computer monitor.

6.1.31 Activate the 28 VDC power supply located below the ITCS-HLS computer monitor.

6.2 Normal Shutdown

Under conditions of normal shutdown the control of the system is passed back to this document when the system has reached parallel status to the completed section 6.1. The electrical system, and Facility N_2 remain on at all times unless repairs are being made.

6.2.1 On PP ITEMA, confirm heaters LAP1, LAP2, LAP3, LAP4, LAP5, LAP6, AFT, FWD, MID, NODE 1 MTL, NODE 1 LTL are off.

6.2.2 On PP ITEMB, confirm heaters LAC1, LAC2, LAC3, LAC4, NODE, LTL FWD END, LAS1, LAS2, LAS3, LAS4, LAS6, LAF3, & LAS6 (LTL) are off.

6.2.3 On PP ITEMB, confirm heaters LAS5, LAF1, LAF2, LAF5, LAF6 (MTL), LAC6, & AFT END MTL are off.

6.2.4 Verify LTL PPA flowrate is less than 30 pounds per hour at workstation ITCS-LTL-CTRL.

6.2.5 Verify MTL PPA flowrate is less than 30 pounds per hour at workstation ITCS-MTL-CTRL.

6.2.6 Push the “stop” button on the LTL chiller.

6.2.7 Push the “stop” button on the MTL chiller.

6.2.8 Type “SET RECORD OFF” at the ITCS-PACRATS workstation.

6.3 Emergency Shutdown

The conditions for emergency shutdown are to be decided upon by the individual responsible for the system activities (usually the Test Director).

7. NOTES

8. SAFETY PRECAUTIONS AND WARNING NOTES

9. RECORDS

10. PERSONNEL TRAINING AND CERTIFICATION

11. FLOW DIAGRAM

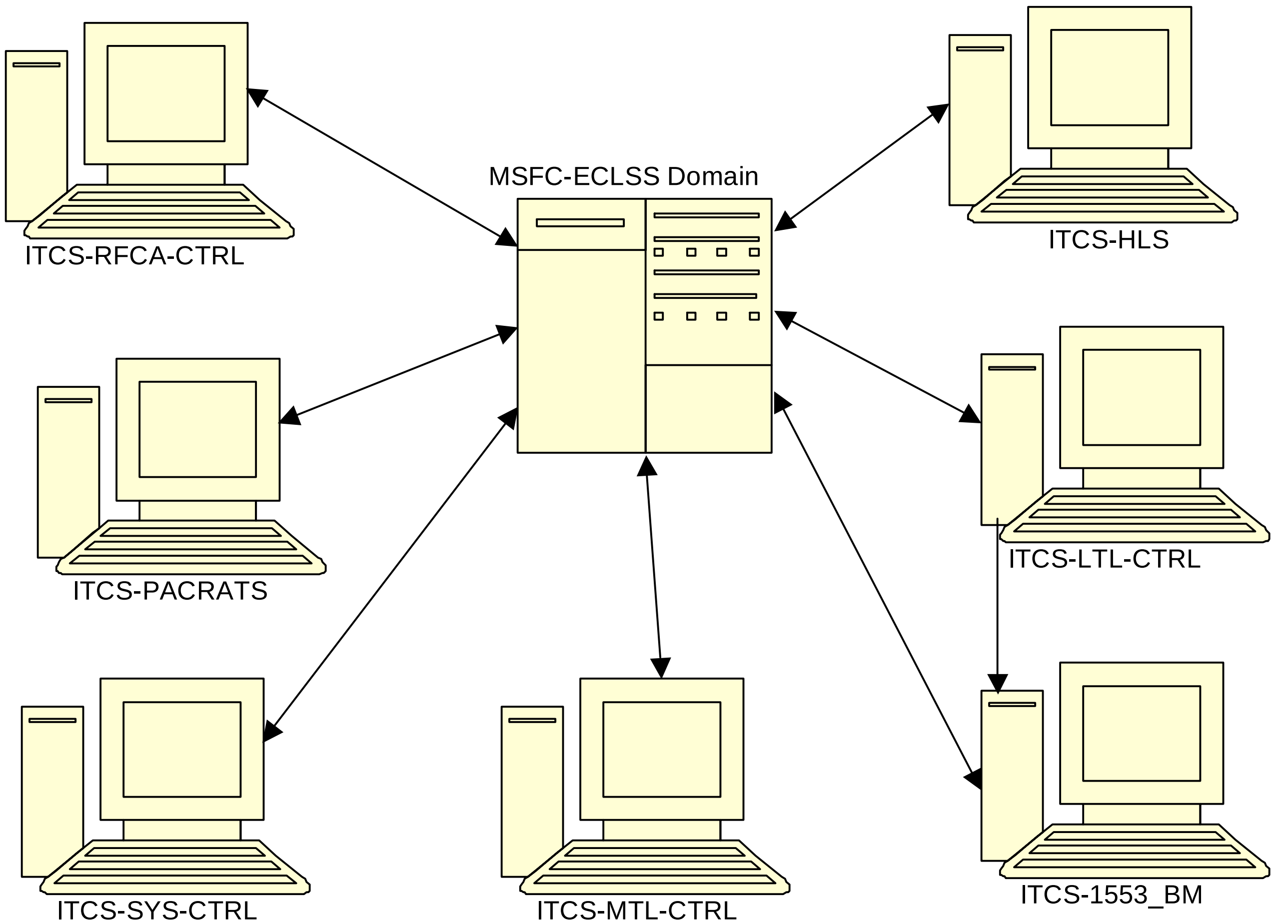


Figure 1 ITCS PC Connectivity

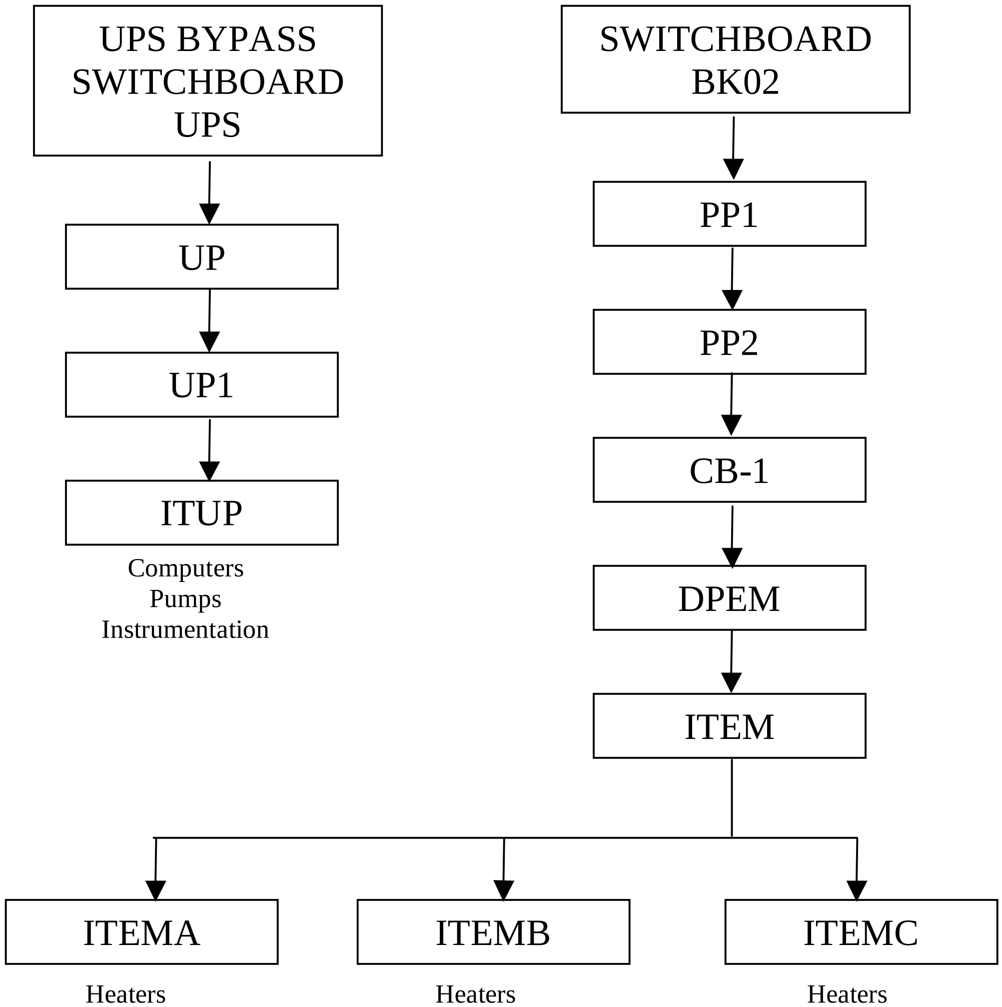


Figure 2 ITCS Power Panel Hierarchy

12. CANCELLATION

FD21TST-TCP-ITC-00-001
REVISION B
September 20, 2000

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

TEST AND CHECKOUT PROCEDURE FOR THE FLEET LEADER COLD PLATE & FLUID STABILITY TEST

TEST TEAM
ECLSS GROUP
FLIGHT SYSTEMS DEPARTMENT

TEST AND CHECKOUT PROCEDURE
FOR THE
FLEET LEADER COLD PLATE & FLUID STABILITY TEST
FD21TST-TCP-ITC-00-001

Prepared by:
Patrick Fulda, Mark E. Etheridge,
Dave Callahan & James Fish
ECLSS Group Test Team, FD21

Approved by:____________________________
Bill Barnett
Systems Test Engineer, ECLSS Group, FD21

Approved by:____________________________
Gene A. Hartsfield
Team Lead, ECLSS Group, Test Team, FD21

Approved by:____________________________
Charles D. Ray
Design Engineer, ECLSS Group, FD21

Document History Log

Status Baseline/ Revision/ Canceled	Document Revision	Effective Date	Description
Baseline		July 7, 2000	
Revision	A	August 15, 2000	Adds the steps to install and "wet" the gas trap Clarifies the operation of the DACS
Revision	B	September 18, 2000	Revised ITCS fluid sample collection procedures in accordance with Boeing procedures.

TABLE OF CONTENTS

1.0 INTRODUCTION

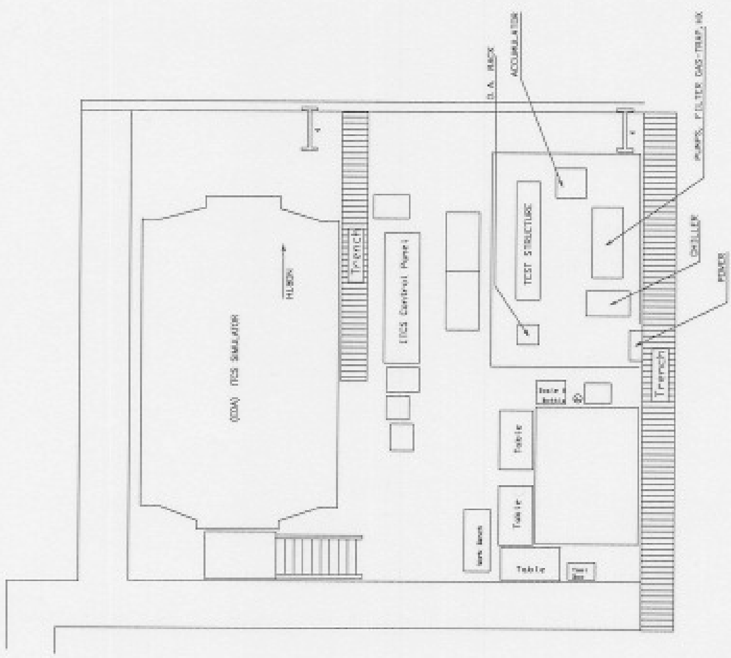
1.1 Purpose

The purpose of this Test and Checkout Procedure is to detail the proper sequence of events for the Fleet Leader Cold Plate and Fluid Stability (FLCP&FS) pre-test and test operations. All operations described in this procedure will be under the control of the ECLSS Group/Test Team.

1.2 System Description

The Fleet Leader Cold Plate and Fluid Stability Test will explore the life cycle of the current chemical make-up of the Internal Thermal Control System (ITCS) coolant along with the effects of varying heat loads on two ITCS cold plates. This test will generate data for review of the ITCS coolant stability and the cold plates for the International Space Station (ISS).

A diagram of the test facility is provided as Figure 1.



FLEETLEADER COLDPLATE/FLUID STABILITY TEST
BLD. 4755 NORTH HIGH BAY
FIGURE 1.

1.3 List of Abbreviations

APHA	-----	American Public Health Association
ASTM	-----	American Society for Testing and Materials
CFU	-----	Colony Forming Units
DAPI	-----	Epifluorescence dye
degC	-----	Degrees Celcius
ECLSS	-----	Environmental Control & Life Support System
EDA	-----	Engineering Development Assembly
EDS	-----	Energy Dispersive Spectroscopy
EPA	-----	Environmental Protection Agency
FEDS	-----	Functional ECLSS Database System
FLCP&FS	-----	Fleet Leader Cold Plate & Fluid Stability
GFI	-----	Ground Fault Interrupt
IHX	-----	Interface Heat Exchanger
ISS	-----	International Space Station
ITCS	-----	Internal Thermal Control System
lb/hr	-----	Pounds per Hour
MEP	-----	Metallurgical Evaluation for Pitting
Ml	-----	Milliliter
MSFC	-----	Marshall Space Flight Center
N_2	-----	Nitrogen
N/A	-----	Not Applicable
Ni	-----	Nickel
ORU	-----	Orbital Replacement Units
OWI	-----	Organizational Work Instruction
PACRATS	-----	Payloads and Components Real-Time Automated Test System
PP	-----	Poly Propylene
PPA	-----	Pump Package Assembly
PPE	-----	Personnel Protective Equipment
PPM	-----	Parts Per Million
psia	-----	Pounds per square inch absolute
psig	-----	Pounds per square inch gauge
R2A	-----	Heterotrophic growth media
rpm	-----	Revolutions per minute
SEM	-----	Scanning Electron Microscopy
SS	-----	Stainless Steel
TOC	-----	Total Organic Carbon
TT	-----	Titanium
UPS	-----	Uninterruptable Power Supply
UT	-----	Ultrasonic Test
VFD	-----	Variable Frequency Drive
VOC	-----	Volatile Organic Compound

1.4 Applicable Documents

The following referenced documents' current issue is the only valid issue for use during the FLCP&FS test.

1.4.1 Management Instructions

FPD-OI-FD21-003	Organizational Instruction for the Environmental Control and Life Support System (ECLSS) Facility
FPD-OI-FD21-005	Quality Record Maintenance for the Environmental Control and Life Support System Group
MPG 1700.1	Industrial Safety Procedures and Guidelines
MPG 8730.3A	Control of Inspection, Measuring, and Test Equipment
SSP 30573B	Space Station Program Fluid Procurement and Use Control Specification
D683-10450	Precision cleaning and In-Process Packaging for Space Station Freedom
A-0ITCS-TCS-001	Internal Thermal Control System (ITCS) Hardware and Fluid Contamination Control

1.4.2 Standards

NFPA 70 National Electrical Code

2.0 SCOPE

This Test and Checkout Procedure applies to the FLCP&FS test article, basic facility equipment, Payloads And Components Real-time Automated Test System (PACRATS), the local data acquisition system (including software), and any special test equipment required for the FLCP&FS test.

3.0 SAFETY

3.1 General Safety

The operational hazards of the FLCP&FS test article are minimal. There are mechanical (pressures/fluids) and electrical (120VAC) hazards that will be discussed in the following sections. Safeguards such as controlled access to the test area will not be required since the High Bay of Building 4755 is a controlled access area.

The criteria set forth in FPD-OI-FD21-003, Organizational Instruction for the Environmental Control and Life Support System (ECLSS) Facility, shall be adhered to during all test operations.

No repairs (including tightening of leaking joints) are to be made on the test article or facility support hardware without first shutting down the test article and making the system safe. Systems Test Engineer will log all activities associated with repairs to the test article in the FLCP&FS Activity LogBook located at the test article.

3.2 Safety Critical / Hazardous Operations

There are no safety critical/hazardous operations associated with this test procedure.

3.3 Personnel Protective Equipment

Personnel Protective Equipment (PPE) – neoprene gloves, safety glasses, face shields, and lab coats – will be provided and used for the sampling activities included in this procedure.

3.4 Grounding Requirements

Grounding is per NFPA 70 National Electrical Code.

3.5 Electrical Systems

3.5.1 Heater Pads

Each heater pad is fused at 3 amps to protect the data system and other hardware from excessive current.

The 120VAC power to the heater pads is routed through a Ground Fault Interrupt (GFI) circuit breaker for personnel safety.

3.6 Mechanical Systems

3.6.1 Pressures

The test system will be operated at a maximum pressure of 100 psia. This is the maximum design pressure for the ITCS Low and Moderate Temperature Loops. The test system has a maximum operating pressure of 200 psia. The 200 psia maximum is the limit of the pumping system, flex hoses, heat exchanger and accumulator. The remaining tubing and fittings are rated for operational pressure greater than 1000 psia. A safety relief valve at the accumulator gas side is set at 100 psia.

Note that the heat exchanger has been modified for this test. The coolant side has been proof tested to 200 psia and the ammonia side (now water side) has been clearly marked that the unit is Class III, water use only, 100 psi max.

3.7 Fluids

De-ionized water used in flushing the test system will conform to SSP 30573B, Table 4.1-2.8. GN_2 used in purging procedures will contain less than 5 ppm of gaseous hydrocarbon. The ITCS fluid to be used in the test will be provided by Boeing under SSCN 002960.

3.8 Emergency Telephone Numbers

If serious injury to personnel occurs, call an ambulance immediately. Do not move the injured personnel unless required to prevent further serious injury.

Emergency Telephone Numbers

Ambulance	911
Fire	911
Chemical Spill	911
Medical Center	544-2390
Blood Cleanup	544-4000
Safety Hotline	544-0046
Security	544-4357
Utilities	544-3919
Communication Repair	544-1771

3.9 Test Revision

Only the Test Director may make revisions to this document. All revisions to this document shall be according to the procedures set forth in FPD-OI-FD21-003. Only the FD21 Test Team Lead's approval is necessary.

4.0 PRE-TEST PREPARATION

The following procedure subsections outline the activities necessary to prepare the FLCP&FS test article for test operations. All of these activities will be under the control of the MSFC ECLSS Group.

4.1 Establish Data System/PACRATS Communications

4.2 Verify ALL sensors installed and operational

4.3 System Software Verification

4.4 Verify Uninterruptable Power Supply (UPS) integrity

4.5 GN2 meets specifications

4.6 De-ionized water meets specifications

4.7 Mechanical hardware installed per Figure 2.

4.8 Verify Heat Load Injection System

4.9 Three nickel 201 and three CRES 347 coupons shall be submitted for analyses.

4.9.1 One of the nickel 201 and one of the CRES 347 coupons shall undergo Scanning Electron Microscopy (SEM).

4.9.2 One of the nickel 201 and one of the CRES 347 coupons shall undergo Energy Dispersive Spectroscopy (EDS).

4.9.3 One of the nickel 201 and one of the CRES 347 coupons shall undergo Metallurgical Evaluation for Pitting (MEP). These analyses will constitute the baseline or control samples used to compare against the other coupons.

4.10 Test Readiness Review

A test readiness review will be held prior to performing this test. All test equipment used in this test will be inspected for damage and, where appropriate, will be verified to be operational and currently calibrated.

The following is a list of personnel, by job title, for all of the positions referenced in this Test and Checkout Procedure.

Responsibility	Name	Work Phone
Test Engineer	Pat Fulda	544-2057
Systems Test Engineer	Bill Barnett	544-8546
Team Leader	Gene Hartsfield	544-6965
Design Engineer	Charlie Ray	544-7227
MSFC Lead Representative	Mike Holt	544-3253
Test Facility Manager	Jim Reuter	544-5763

4.11 Facility Configuration

This test will be performed in the North high bay of the Environmental Control and Life Support System (ECLSS) facility, Building 4755.

4.12 Test Equipment

The following is a list of the test equipment and hardware required to construct the test panels. Also included is some general test information and assumptions.

- No sensors will be removed for calibration during over the duration of the test
- Two pumps rated 3000 lb/hr @ 64.7 psid head rise.
- All wetted materials are consistent with flight like materials.
- ORU gas-trap, filter and heat exchanger.
- Metal tubing used; Stainless steel 316L, Titanium grade 2 (commercially pure).
- All flex hoses are either 510 series Titeflex (PTFE) conductive inner-liner or Stainless steel 316L bellows type with stainless over braid.
- Accumulator volume is 20 liters for fluid sample removal.
- Three Biofilm loops are employed with Titanium and Stainless steel tubing. Each loop has one eighteen inch (PTFE) hose. The three loops can be valved off and removed for testing.
- Each Biofilm loop contains a Robbin device for coupon sampling.
- One 12.5' X 1" diameter (PTFE) hose is installed as a representative length.
- The system operates at 100 psia max pressure.
- The temperature range of the system is controlled within the ITCS moderate loop range (16-18) degrees C.
- Two cold plates are installed on the test structure with On/Off zone heating. The (-9) cold plate has twelve heat zones at a total of 220 watts. The (-6) cold plate has four heat zones with a total of 20 watts. Each cold plate is configured for easy removal utilizing quick-disconnect interfaces.
- The test system incorporates two connections for the Fluid Sampling Tool.
- A By-pass loop controls the flow to the test subjects while maintaining the 3000 lb/hr flow rate required by the filter and gas-trap.
- Flow rate sensors at each biofilm loop and cold plate.
- Differential pressure sensors are installed at the pumps, cold plates, filter, gas-trap, and By-pass loop.
- Flow rates will be set at 300 lb/hr at each biofilm loop. The flow rates for the two cold plates will be set at 280 lb/hr. Over all system flow will be set at 3000 lb/hr.

4.13 SAMPLE COLLECTION

Analytical performance begins prior to the actual collection of samples. All procedures for sample tracking including sample collection, preservation, analysis, storage, and disposal shall be in compliance with approved U.S. Environmental Protection Agency (EPA), American Society for Testing and Materials (ASTM), American Public Health Association (APHA) and/or NASA reviewed and approved procedures. All deviations or unusual sample collection techniques require the approval of the Design Engineer prior to use.

Containers for the collection of various samples will meet or exceed all APHA, ASTM, and/or EPA requirements.

Sample collection should be accomplished by procedures described by the APHA, and/or EPA unless specified elsewhere. Analysts trained in aseptic technique will collect samples. A minimum number of people should be involved in the actual sampling process. Prior to collection, fifty milliliters of fluid will be voided through the collection port. If both chemical and microbiological samples are collected from a given sample location the chemical sample is collected first immediately following initial flushing. Once all the samples are collected for the chemical parameters the microbial sample shall be collected. Sample collection labels should be affixed to each sample container and should minimally contain the following information:

- NASA Sample collection number
- Date collected
- Time collected
- Collection location/description
- Initials of personnel collecting the sample
- Parameters for analysis
- How preserved
- Any anomalies encountered during sampling
- Laboratory to which the sample is to be sent

After collection, samples will be delivered to the Data Custodian for weighing and recording into the Data Log (which resides on the FEDS database). Samples should be handled as little as possible after collection.

Sample tracking procedures will be maintained for the life cycle of the sample. The sample life cycle will begin when the sample is collected and will continue until final sample disposal. Initial sample tracking will be accomplished using sample labels and chain of custody forms generated by the FEDS. When it is not practical or possible to generate forms and labels by computer, either the Data Custodian or sampling personnel will fill out these items by hand just prior to sample collection. Samples will be assigned a Sample Number and logged into the Data Log by the Data Custodian.

Custody of samples within the laboratory is defined as:

- In actual physical possession of laboratory personnel
- In view, after being in physical possession
- In physical possession and in secured storage to prevent tampering
- In a secured area, restricted to authorized personnel.

If a sample does not meet one of the above categories then it is not in custody. If a sample must leave the primary laboratory, for any reason, the chain of custody form must accompany it.

Sample degradation can begin immediately following collection. Preservation is necessary to retard the degradation of chemicals and/or the alteration of microbial populations in samples prior to analysis. Samples shall be processed and relinquished by the Data Custodian within a maximum of six hours after collection. Samples should be analyzed in a timely manner as received by the laboratory.

All sample preservation will be accomplished at the time of collection. Sample containers will be prepared with the appropriate preservative, sterilized if required, and labeled prior to use.

Samples requiring transport should be shipped on "blue ice" by an overnight delivery service. Blue ice is used so that leakage will not occur and result in courier rejection. Samples will be stored by the laboratory under proper conditions in a controlled access facility.

Following review and analysis of the sample results, the laboratory is authorized to dispose of their samples. The Principal Investigator, or designee, will contact participating laboratories by way of written notification if samples should be retained.

4.14 Fluid Sampling

Two fluid sample ports are available in the Fleet Leader Cold Plate and Fluid Stability Test system as indicated in Figure 2. These ports provide the capability to monitor physical, chemical, and microbiological fluid quality parameters. The high flow port will be utilized on a regular basis for ITCS fluid sample collection.

The fluid sample port is valved-off from the fluid line to be sampled. The volume of water in the sample port shall be flushed prior to sampling to insure the sample provides an adequate representation of the port's location. Chemical samples shall always be collected before microbial samples to reduce the possibility of microbial contamination. Prior to the removal of a component, such as a coldplate, a sample will be collected in conjunction with a scheduled sample event. An additional sample will be collected after a component is reinstalled in the test, such as after a coldplate is removed for UV scan and returned to the test bed. Samples will also be collected from one of the prime/fill lines (PF1 or PF2) at 12, 24, and 36 test months. Sample collection from the prime/fill ports will be alternated. Samples will be collected at specified intervals as described by the schedule in Figure 5.1-2.

A flush of 50 ml shall be collected prior to the collection of the chemical samples. Due to volume constraints, the collection of a fluid samples shall not exceed 270 ml, excluding the 50 ml flush. Table 5.1-1 identifies chemical sample sequence and volumes required for each sample bottle. Table 2 identifies chemical sample sequence and volumes required for each sample bottle.

Table 1. Fluid Sample Schedule

Collection Time	Collection Time
24 hr	Month 17
48 hr	Month 18
168 hr	Month 19
360 hr	Month 20
720 hr	Month 21
Month 2	Month 22
Month 3	Month 23
Month 4	Month 24
Month 5	Month 25
Month 6	Month 26
Month 7	Month 27
Month 8	Month 28
Month 9	Month 29
Month 10	Month 30
Month 11	Month 31
Month 12	Month 32
Month 13	Month 33
Month 14	Month 34
Month 15	Month 35
Month 16	Month 36

Table 1. Chemical Sample Sequence and Volumes

ITCS FLEETLEADER COLDPLATE/FLUID STABILITY TEST

Revised September 12, 2000

Bottle/Parameter	Sample Volume (ml)	Detection Limit
BOTTLE 1 (120 ml PE BOTTLE)	60	
1.1 Metals		
Cr, Fe, Cu, Ni, Ag, As, Ba, Cd, Ca, Pb, Mg, Mn, Mo, Se, Zn, Al, Ti, Co		
o Cr		0.005 ppm
o Fe		0.005 ppm
o Cu		0.005 ppm
o Ag		0.002 ppm
o As		0.050 ppm
o Ba		0.001 ppm
o Cd		0.001 ppm
o Ca		0.005 ppm
o Pb		0.010 ppm
o Mg		0.050 ppm
o Mn		0.001 ppm
o Zn		0.001 ppm
o Al		0.020 ppm
o Ti		0.005 ppm
o Co		0.005 ppm
1.2 Chloride		0.030 ppm
1.3 Phosphate		0.100 ppm
1.4 Borate		1.000 ppm
1.5 pH		N/A
BOTTLE 2 (60 ML GLASS w/H20 SEAL)	60	
3.1 Dissolved Oxygen		1.000 ppm
BOTTLE 3 (40 ml GLASS W/TEFLON LINER)	20	
4.1 TOC		1.000 ppm
BOTTLE 4 (200 ml GLASS, PRE-CLEANED)	100	
5.1 Particles		1 particle/100 ml
BOTTLE 5 (60 ml PP, STERILE)	30	
o R2A		10 CFU/100 ml
o ID All Colony Types		N/A
plus 50 ml of sample line purge, total volume	320	ml

5.0 TEST OPERATIONS

****NOTE Refer to Figure 2, when performing SECTIONS 5.1.X through 5.10.X**

5.1 GN_2 Leak Check Procedure

5.1.1 Install ½" caps at fluid sampling tool ports and ¼" caps at fluid sampling ports and bleed valves.

5.1.2 Verify all ball valves and metering valves are open.

5.1.3 Open (PF-BV1) and close (PF-BV2).

5.1.4 Purge facility GN_2 at 5 psig as the connection to the prime fill line at (PF-BV1) is made. The hose used will be a stainless steel Teflon lined type pre-cleaned to specification SS 30573B, Table 4.1-2.8.

5.1.5 Increase the regulated pressure at the Engineering Development Assembly (EDA) GN_2 high side supply to 100 psig slowly to avoid over spinning the turbine flow meters in the test system.

5.1.6 Close (PF-BV1).

5.1.7 Observe the pressure readings from (PPANEL) and check for leaks.

5.1.8 Identify leaks.

5.1.9 Depressurize system by slowly opening (PF-BV2).

5.1.10 Fix leaks identified in step (5.1.8).

5.1.11 Repeat steps (5.1.3 - 5.3.10) until obvious leaks are stopped.

5.1.12 Pressurize system to 100 psig then close (PF-BV2).

5.1.13 Observe (PPANEL) over a three hour period to insure all leaks have been fixed.

5.1.14 Depressurize system by slowly opening (PF-BV2).

5.1.15 Close (PF-BV2), remove GN2 supply line.

5.1.16 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.2 Accumulator Level Calibration

5.2.1 Close (FSTBVR), (AC-BVOUT), (PF-BV3), and (PF-BV1).

5.2.2 Connect ½" 3-way valve (pre-cleaned to specification D683-10450, Precision Cleaning and In-Process Packaging for Space Station Freedom) to (PF-BV1).

5.2.3 Connect the 3-way valve to a facility supplied Teflon diaphragm vacuum pump with a ½" Teflon hose.

5.2.4 Evacuate the accumulator by opening the 3-way valve and (PF-BV1). Open the valve slowly so not to surge the 1" flow meter in-line. Evacuation of the accumulator is complete when the absolute pressure reaches approximately 1 torr.

5.2.5 Close the 3-way valve.

5.2.6 Verify that tank has been cleaned to specification SS 3057B, Table 4.1-2.8 prior to filling.

5.2.7 Fill 30 gallon stainless steel feed tank with facility de-ionized water per SSP 30573B, table 4.1-2.8.

5.2.8 Fill four 40 ml Volatile Organic Compound (VOC) vials and one 250 ml ultra clean borsilicate glass jar with polypropolyn lid and Teflon liner. The sample containers should be filled to a zero headspace.

5.2.9 Connect facility GN_2 to the tank with a stainless steel braided Teflon lined hose pre-cleaned to specification D683-10450, Precision Cleaning and In-Process Packaging for Space Station Freedom.

5.2.10 Connect feed tank to the remaining port on the 3-way valve with ¼" Teflon tubing pre-cleaned to specification D683-10450, Precision Cleaning and In-Process Packaging for Space Station Freedom.

5.2.11 Place feed tank on weight scale.

5.2.12 Pressurize the feed tank to 5psig.

5.2.13 Bleed the air trapped in the ¼" line by cracking the connection at the 3-way valve.

5.2.14 Open the 3-way valve so that fluid flows into the system. Open the valve slowly so not to surge the 1" flow meter (FTOTAL).

5.2.15 Slowly increase the pressure on the feed tank to 40 psig.

5.2.16 Note the weight of the tank as the accumulator fills. The accumulator is full when the weight of the feed tank stops decreasing.

5.2.17 Close the 3-way valve.

5.2.18 Note the four load cell outputs in the FLCP&FS Activity LogBook.

5.2.19 Close (MVAC).

5.2.20 Open (BVAC).

5.2.21 Open and adjust (MVAC) to 15 psig.

5.2.22 Remove the ¼" feed line from the tank and place it in a collection tank located at the same height as the accumulator (approximately 12 inches down from the top).

5.2.23 Open the 3-way valve so that the accumulator drains into the collection tank.

5.2.24 When flow stops, close the 3-way valve.

5.2.25 Note the load readings on all four load cells in the FLCP&FS Activity LogBook.

5.2.26 Note the weight of the collection tank and drained fluid.

5.2.27 Empty the collection tank and note the weight. Calculate the weight of the collected fluid and compare to the difference in load cell readings.

5.2.28 Repeat steps (5.2.10) through (5.2.27) two times.

5.2.29 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.3 De-ionized Water Flush

This procedure should begin at the completion of the accumulator calibration, therefore the accumulator should be full between ball valves (AC-BVOUT) and (PF-BV3).

5.3.1 Wet the gas trap with de-ionized water.

5.3.1.1 Remove dry unit from packaging.

5.3.1.2 Attach interface fixture to gas trap at quick disconnects (QD's). The fixture should have QD's on one end and threaded fittings at opposite end that allow view of water level in outlet of fixture.

5.3.1.3 Orient unit vertically, with QD's up and cover down.

5.3.1.4 Attach source of DI water to inlet of interface fixture, and vent outlet of interface fixture to ambient.

5.3.1.5 Fill gas trap with DI water, feeding into inlet at a slow rate, until water is observed exiting the interface fixture outlet port.

5.3.1.6 Cap off outlet port of interface fixture, and rotate and shake unit by hand for approximately 30 seconds.

5.3.1.7 Orient gas trap vertically, remove cap from interface fixture outlet port and observe water level. If water level has decreased from that observed in step 5.3.1.5, repeat fill and shake operations of steps 5.3.1.5 and 5.3.1.6 until water level does not decrease.

5.3.1.8 Disconnect interface fixture from gas trap at the QD's while still vertical and then orient the gas trap horizontally.

5.3.1.9 Let the gas trap soak for at least two hours (preferably more).

5.3.1.10 Gas trap is now ready for installation. DO NOT INSTALL GAS TRAP AT THIS POINT!

5.3.2 Connect the ¼" Teflon hose to (PF-BV1) and the feed tank.

5.3.3 Bleed the air in the ¼" hose by loosening the fitting at (PF-BV1) after a 5 psig head is applied to the feed tank.

5.3.4 Open (PF-BV2).

5.3.5 Open (PF-BV1).

5.3.6 Open (AC-BVOUT).

5.3.7 Increase the pressure in the feed tank to 30 psig.

5.3.8 Place a collection tank under the outlet of (PF-BV2).

5.3.9 Close (PF-BV2) after a steady stream of fluid flows into the collection tank.

5.3.10 Bleed air from system. Air bleed valves are located on the filter/gas-trap manifold, between the biofilm loop and the cold plates, and on either side of the heat exchanger.

5.3.11 Bleed air from sample ports and the fluid sampling tool ports.

5.3.12 Loosen the fittings on either side of all the differential pressure transducers and bleed the air from these lines.

5.3.13 Perform Instrumentation Verification.

5.3.14 Install the Gas Trap.

5.3.15 Close (MVAC) and adjust to zero psig.

5.3.16 Open (BVAC).

5.3.17 Open (MVAC) and adjust pressure to 30 psig.

5.3.18 Close (PUMP2-BVIN) and (PUMP2-BVOUT).

5.3.19 Verify that (BPL-MV) is fully open.

5.3.20 Verify (PUMP1-BVIN) and (PUMP1-BVOUT) are fully open.

5.3.21 From the FLCP&FS Control System computer, set pump #1 flow rate to 3000 lb/hr. with respect to (FTOTAL).

5.3.22 Close metering valves (BF1-MV), (BF2-MV), (BF3-MV), (CP9MV), and (CP6MV).

5.3.23 Set the flow rates of each Biofilm loop to 300 lb/hr. by opening (BF1-MV), (BF2-MV), and (BF3-MV). Refer to (FBIOFILM1), (FBIOFILM2), and (FBIOFILM3) respectfully during this process. Adjustment of the loop by-pass-metering valve (BPL-MV) will be required to develop the necessary differential pressure.

5.3.24 Set the two cold plate flow rates to 280 lb/hr by opening (CP9MV) and (CP6MV). Refer to (FCP9) and (FCP6) during this process. Adjustment of the by-pass loop-metering valve (BPL-MV) will be required to develop the necessary differential pressure.

5.3.25 Verify that (FBIOFILM1), (FBIOFILM2), (FBIOFILM3), (FCP6), and (FCP9) read 300 lb/hr. Adjust as necessary.

5.3.26 Verify (FTOTAL) reads 3000 lb/hr.

5.3.27 Run the pump for 10 minutes. This will turn the test fluid volume over approximately three times.

5.3.28 During step (5.3.25) verify and note all sensor output.

5.3.29 Stop Pump #1.

5.3.30 Open (PUMP2-BVIN) and (PUMP2-BVOUT).

5.3.31 Close (PUMP1-BVIN) and (PUMP1-BVOUT).

5.3.32 Start Pump #2.

5.3.33 Run Pump #2 for 10 minutes.

5.3.34 Stop Pump #2.

5.3.35 Perform Section 5.19, Fluid Collection Procedure at both Fluid Sampling Port locations and deliver samples to facility lab for immediate evaluation of Total Organic Content (TOC).

5.3.36 Review TOC report. If TOC is less than 5-ppm De-ionized water flush is complete and the Drain/Purge Procedure 5.4, Draining/GN2 Purge Procedure, can begin. If TOC is greater than 5 ppm proceed with remainder of section 5.3.

5.3.37 Open (PUMP1-BVIN) and (PUMP1-BVOUT).

5.3.38 Close (PF-BV3).

5.3.39 Verify that the De-ionized water tank is full (30 gallons).

5.3.40 Adjust feed tank pressure to 40 psig.

5.3.41 Open (PF-BV2) and collect 20 gallons of water.

5.3.42 Close (PF-BV2).

5.3.43 Open (PF-BV3).

5.3.44 Reduce feed tank pressure to 30 psig.

5.3.45 Close (PUMP2-BVIN) and (PUMP2-BVOUT).

5.3.46 From the FLCP&FS Control System computer, set pump #1 flow rate to 3000 lb/hr. with respect to (FTOTAL).

5.3.47 Operate the pump for 10 minutes.

5.3.48 Repeat steps (5.3.26 through 5.3.33).

5.3.49 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.4 Draining /GN_2 Purge Procedure

5.4.1 Remove the gas trap from the system.

5.4.2 Re-install the filling fixture to the gas trap.

5.4.3 Invert the gas trap to allow the De-ionized water to run out of the gas trap.

5.4.4 If the De-ionized water feed tank is connected to (PF-BV1), disconnect it and cover the end of the hose with foil.

5.4.5 Connect the facility GN_2 line to (PF-BV1).

5.4.6 Adjust the facility GN_2 pressure to 10 psig.

5.4.7 Open (PF-BV2) and collect the fluid in a container for disposal.

5.4.8 System pressure will force fluid to flow out of (PF-BV2). As the system pressure drops between (10-5) psig, open (PF-BV1) forcing GN_2 into the system.

5.4.9 Drain the fluid in the dead legs of the biofilm loops by loosening the cap fittings.

5.4.10 When fluid ceases to flow, close (PF-BV1) and (PF-BV2).

5.4.11 Disconnect facility GN_2 from (PF-BV1).

5.4.12 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.5 ITCS Fluid Filling

5.5.1 Repeat Sections 5.2.1 through 5.2.27, of the Accumulator Level Calibration procedure with ITCS fluid (fill one time).

5.5.2 Verify all load cell outputs with respect to those values measured during the initial calibration with De-ionized water.

5.5.3 Repeat Section 5.3, De-ionized Water Flush procedure with ITCS fluid.

5.5.4 At step (5.3.35) of De-ionized Water Flush Procedure review the TOC results. If the TOC level is between (0-5) ppm, the system is within spec. and verification of the fluid stability can begin (proceed to step 5.5.5). If the TOC level is between (6-20) ppm, continue at step (5.3.36). If the TOC is greater than or equal to 20 ppm, repeat section 5.4, Draining /GN_2 Purge Procedure followed by section 5.3, De-ionized Water Flush with De-ionized Water.

5.5.5 At ten-minute intervals, obtain TOC samples by performing step 5.3.35 and 5.3.36. After two consecutive readings (ten minutes apart) have been obtained with TOC levels within 1 ppm of each other, the fluid is considered stable. Enter all data into the FLCP&FS Activity LogBook.

5.5.6 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.6 Setting Flow Rates

5.6.1 Close (BF1-BV1), (BF2-BV1), (BF3-BV1), (CP9BVIN), and (CP6BVIN).

5.6.2 Open the By-pass Loop Metering Valve (BPL-MV) fully.

5.6.3 Set the pump speed with respect to (FTOTAL) equal to 3000 lb/hr.

5.6.4 Set the flow rates in the biofilm loops by adjusting the metering valves (BF1-MV), (BF2-MV) and (BF3-MV) with respect to (FBIOFILM1), (FBIOFILM2), and (FBIOFILM3) outputs. The flow rate at each loop should be adjusted to (300 lb/hr). The Loop By-pass Metering Valve (BPL-MV) will have to be adjusted to produce the necessary flow rates.

5.6.5 Set the flow rates of the two cold plates by adjusting the metering valves (CP9MV) and (CP6MV) with respect to (FCP9) and (FCP6) outputs. The flow rate at each cold plate should be adjusted to (280 lb/hr). The Loop By-pass Metering Valve (BPL-MV) will have to be adjusted to produce the necessary flow rates.

5.6.6 As the By-pass Metering Valve (BPL-MV) is adjusted in the above steps, it may be required to repeat steps (5.6.4) and (5.6.5) several times.

5.6.7 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.7 Robbin Samples

Prior to performing the actual Robbin sampling, flow through the device must be stopped and pressure relieved. The text below outlines the steps required to accomplish this.

5.7.1 Robbin #1: Close (BF1-BV4) and (BF1-BV5). Remove cap and open (BF1-BLDV1) to relieve pressure and close.

5.7.2 Perform Section 5.21, Robbin Sampling procedure. Open (BF1-BV4) and (BF1-BV5).

5.7.3 Robbin #2: Close (BF2-BV4) and (BF2-BV5). Remove cap and open (BF2-BLDV1) to relieve pressure and close.

5.7.4 Perform Section 5.21, Robbin Sampling procedure. Open (BF2-BV4) and (BF2-BV5).

5.7.5 Robbin #3: Close (BF3-BV4) and (BF3-BV5). Remove cap and open (BF3-BLDV1) to relieve pressure and close.

5.7.6 Perform Section 5.21, Robbin Sampling procedure. Open (BF3-BV4) and (BF3-BV5).

5.7.7 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.8 Biofilm Loop Removal

NOTE: Section 5.21 must be completed BEFORE removal of a Biofilm Loop.

Prior to performing the annual Biofilm loop removal, the loop must be isolated from the test system and the dead leg will need to be closed off.

5.8.1 Loop #1: Close (BF1-BV1), (BF1-BV2), (BF1-BV3), (BF1-BV4), and (BF1-BV5).

5.8.2 Disconnect and remove the tube fittings between (BF1-BV1) and (BF1-BV2).

5.8.3 Disconnect and remove the tube fittings between (BF1-BV4) and the flow meter (FBIOFILM1).

5.8.4 Remove the counter sink screws from the panel and lift the panel vertically while pulling out.

5.8.5 Loop #2: Close (BF2-BV1), (BF2-BV2), (BF2-BV3), (BF2-BV4), and (BF2-BV5).

5.8.6 Disconnect and remove the tube fittings between (BF2-BV1) and (BF2-BV2).

5.8.7 Disconnect and remove the tube fittings between (BF2-BV4) and the flow meter (FBIOFILM2).

5.8.8 Remove the counter sink screws from the panel and lift the panel vertically while pulling out.

5.8.9 Loop #3: Close (BF3-BV1), (BF3-BV2), (BF3-BV3), (BF3-BV4), and (BF3-BV5).

5.8.10 Disconnect and remove the tube fittings between (BF3-BV1) and (BF3-BV2).

5.8.11 Disconnect and remove the tube fittings between (BF3-BV4) and the flow meter (FBIOFILM3).

5.8.12 Remove the counter sink screws from the panel and lift the panel vertically while pulling out.

5.8.13 Perform Section 5.6, Setting Flow Rates.

5.8.14 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.9 Cold Plate Removal

5.9.1 Disconnect power source for the heater pads from both cold plates by setting the heater pad circuit breaker (panel BIOFILM, slot 29) to the OFF position.

5.9.2 Remove the plexi-glass cover from the two cold plates.

5.9.3 Disconnect the heater pads from the terminal strip.

5.9.4 Disconnect the thermocouples.

5.9.5 Remove the heat load plates from the cold plate.

5.9.6 Close (CP9BVIN) and (CP9BVOUT) or (CP6BVIN) and (CP6BVOUT).

5.9.7 Disconnect the quick disconnects from the Test panel.

5.9.8 Remove the screws that secure the cold plates to the cold plate mounting structure.

5.9.9 Remove cold plates.

5.9.10 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.10 Cycling Pumps

Pump cycling is required to reduce water stagnation in the fluid lines of the idle pump. Two pumps were incorporated in the test for redundancy due to the three-year duration of the test.

Pump cycling will occur on the first Monday of each month for the duration of the test program.

5.10.1 From the FLCP&FS computer, STOP the operating pump by selecting the appropriate icon.

5.10.2 Close inlet and outlet valves of stopped pump by closing (PUMPX-BVIN) and (PUMPX-BVOUT).

5.10.3 Open inlet and outlet valves of other pump by opening (PUMPX-BVIN) and (PUMPX-BVOUT)

5.10.4 From the FLC&FS computer, START the other pump by selecting the appropriate icon.

5.10.5 Verify (FTOTAL) reads 3000 lb/hr and each biofilm loop has a flow rate of 300 lb/hr and that each cold plate has a flow rate of 280 lb/hr.

5.10.6 If flow settings are not correct, follow the section 5.4, Setting Flow Rates.

5.10.7 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.11 Electrical Systems Initial Start-up

This section should only need to be performed ONCE unless there is a major unplanned event that requires the removal of ALL power from the data system.

5.11.1 Verify that the chiller 3-pole circuit breaker in panel LPCT1 slots 2, 4, and 6 is switched ON.

5.11.2 Verify that the chiller circuit breaker located on the right side of the chiller is switched ON and the chiller is powered.

5.11.3 Verify that the chiller temperature set point is 17 degC.

5.11.4 Place the chiller in remote mode by pressing the REMOTE button on the chiller control panel. A light in the button will appear indicating the chiller is in the REMOTE mode.

5.11.5 Verify that the heater pad circuit breaker in panel BIOFILM, slot 29 is switched ON.

5.11.6 Verify that the *Pump 1,* 3-pole circuit breaker in panel BIOFILM, slots 19, 21, and 23 is switched ON and the *Pump 1* Variable Frequency Drive (VFD) is powered.

5.11.7 Verify that the *Pump 1,* speed setpoint is *XXX* rpm on the VFD liquid crystal display.

5.11.8 Verify that the *Pump 2,* 3-pole circuit breaker in panel BIOFILM, slots 20, 22, and 24 is switched ON and the *Pump 2* VFD is powered.

5.11.9 Verify that the *Pump 2* speed setpoint is *XXX* rpm on the VFD liquid crystal display.

5.11.10 Verify that the control cabinet circuit breaker in panel BIOFILM slot 27 is switched ON and the control cabinet is powered.

5.11.11 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

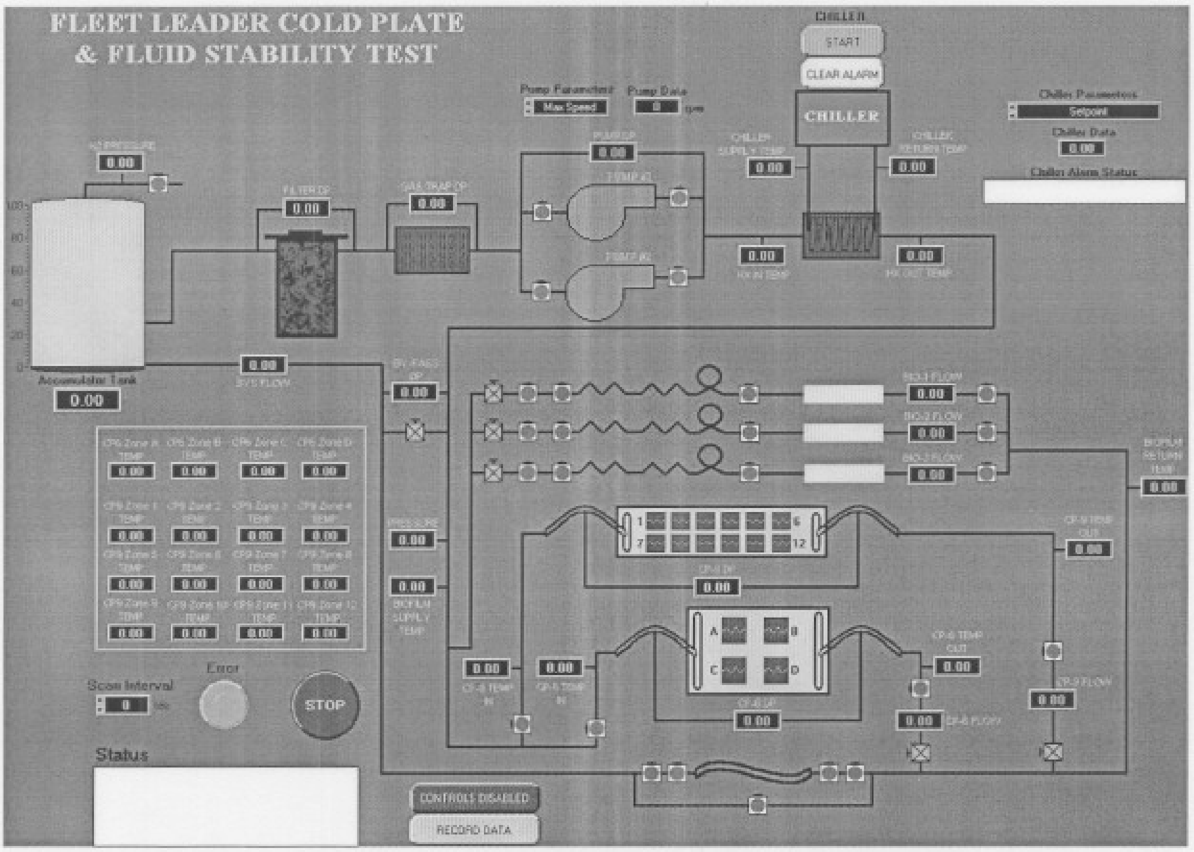


Figure 4. FLCP&FS Control/Data Panel

****NOTE Refer to Figure 4. when performing SECTIONS 5.12.X through 5.18.X**

5.12 Data Acquisition System Normal Start-Up

This section is performed any time that the data acquisition system software must be restarted.

5.12.1 Verify that Section 5.11, Electrical Systems Initial Start-up has been completed.

5.12.2 Verify the FLCP&FS control computer is **ON**.

5.12.3 Open and run the *Netscan.vi* program. Verify that the following programs are **OPEN** and running (the arrow in the upper left-hand corner of the monitor is black):

Data Transmit.vi
Host.vi
Transmit.vi
Netpage.vi

5.12.4 Start the Scanner software routine by double clicking on the *SCAN DATA.vi* icon.

5.12.5 Press the green start button. The button will change to a red stop button. Set the Scan Interval by double clicking on the "Scan Interval" control and entering the required scan interval

5.12.6 Run the *SCAN DATA.vi* by clicking on the run arrow in the upper left-hand area of the program front panel.

5.12.7 After *SCAN DATA.vi* is running, the scanner configuration program will appear on the monitor. The configuration of each channel that is in use on the scanners must be entered.

5.12.8 For the voltage measurements: Verify that the "DC/AC" switch is set to DC, the "Autorange" switch is set to OFF and, the "Voltage Range" control is set to MAXIMUM.

5.12.9 Press the "OK" button once for each voltage measurement in use on the FLCPFS test article (a total of 18 measurements).

5.12.10 Once all voltage measurements have been configured, the screen will automatically change to the thermocouple configuration screen. For thermocouple measurements, verify the "Units" control is set to FARENHEIGHT.

5.12.11 Press the "OK" button once for each voltage measurement in use on the FLCPFS test article (a total of 26 measurements).

5.12.12 After the thermocouple channels have been configured, the scanner configuration screen will disappear. Minimize the *SCAN DATA.vi* program.

5.12.13 Start the main software routine by double clicking on the *FLEET LEADER TEST.vi* icon.

5.12.14 Start the PACRATS program by performing Section 5.13, PACRATS Start-Up.

5.12.15 Set the Scan Interval by performing Section 5.15, System Scan Interval Set.

5.12.16 Run the *FLEET LEADER TEST.vi* program by clicking on the run arrow in the upper left-hand area of the monitor.

5.12.17 Click on the RECORD DATA button to begin sending data to PACRATS.

5.12.18 Start the chiller by clicking on the green start button over the CHILLER icon. The button will change to a red stop button.

5.12.19 Start one of the pumps by clicking on the appropriate pump icon.

5.12.20 Apply required heat loads by clicking on ALL heater pad zone.

5.12.21 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.13 PACRATS Start-Up

This section is performed any time there is need for data to be recorded and transmitted to PACRATS.

5.13.1 Verify the FLCP&FS control computer is ON.

5.13.2 Start PACRATS by double clicking on the *PACRATS.exe* icon.

5.13.3 Once the application window is displayed, type "LOGON" and press the ENTER key. A dialog box will appear requesting a username and password. Enter the correct information and click the OK button.

5.13.4 Start the test by typing "START TEST FLCPFS".

5.13.5 Begin recording data by typing "SET RECORD ON".

5.13.6 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.14 Normal Shutdown

This section is performed any time that the data acquisition system software must be restarted.

5.14.1 Remove any heat loads that are currently on by clicking on the appropriate heater pad zone.

5.14.2 Turn off the pump that is currently running by clicking on the appropriate pump icon.

5.14.3 Turn off the chiller by clicking on the red stop button under "CHILLER". The button will change to a green start button.

5.14.4 Stop PACRATS data recording by typing "STOP TEST FLCPFS" in the PACRATS window.

5.14.5 Stop the *FLEET LEADER TEST.vi* program by pressing the red stop button near the lower left-hand corner of the monitor.

5.14.6 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.15 Emergency Shutdown

5.15.1 Switch the pump 3-pole circuit breakers (panel BIOFILM, slots 19-24) OFF.

5.15.2 Switch the heater pad circuit breaker (panel BIOFILM, slot 29) OFF.

5.15.3 Press the Emergency Stop button on the chiller control panel.

5.15.4 If required, switch the control cabinet circuit breaker (panel BIOFILM, slot 27) OFF.

5.15.5 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.16 Monitoring

The system will be monitored to keep controllable parameters within acceptable limits and to start and stop operations of the pumps and heater pads. All instrumentation should be checked periodically to ensure proper operation of the test article and control by the system computer. All actions occurring during Full-up System Monitoring will be recorded in the FLCP&FS Activity LogBook.

If anomalous behavior occurs that affects normal test operation, record all information available on that condition in the FLCP&FS Activity LogBook and notify the Systems Test Engineer before any corrective action is taken. The FLCP&FS software contains fault detection and isolation capabilities that will assist in problem diagnosis.

5.17 Security

The *FLEET LEADER TEST.vi* program has password protection on some controls to prevent tampering with the FLCPFS test article during test activities. This includes the pumps, the heater pads, and the chiller start/stop button. Any control on the monitor that is "grayed out" is currently inactive and will not respond to user input.

To activate the controls, click on the "Enable Controls" button in the lower left corner of the monitor. The button will change to "Disable Controls." A dialog box will appear prompting the user for a password. Enter the correct password and click on "OK" and the controls will become active.

When finished with the controls, click on the "Disable Controls" button and the controls will be "grayed out" and become inactive.

5.18 Fluid Collection Procedures

NOTE: The Design Engineer will designate which sample port should be used. The high flow sample port shall be the default sample port location.

5.18.1 To flush the port, open the sample port and collect 50 ml of fluid in a volumetric flask and close valve. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.18.2 Remove lid from bottle #1 (metals, anions, borate, pH), open valve and collect 60 ml then close valve. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.18.3 Remove lid from bottle #2 (dissolved oxygen), open valve and collect 60 ml then close valve. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.18.4 Remove lid from bottle #3 (TOC), open valve and collect 20 ml then close valve. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.18.5 Remove lid from bottle #4 (particulates), open valve and collect 100 ml then close valve. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.18.6 Remove lid from bottle #5 (microbes) open valve and collect 30 ml then close valve. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.18.7 Initial and date the FLCP&FS Activity LogBook indicating when this section was performed.

5.19 Biofilm Sampling

Stainless, titanium, and Teflon tubing, a gas trap, a cold plate, and Robbin devices will be utilized for biofilm analysis. Robbin devices, which hold removable coupons in the fluid, will suspend nickel 201 and CRES 347 coupons. Samples will be collected at predetermined intervals for microbial and corrosion assessments.

5.20 Robbin Samples

A variety of analyses shall be performed on 30 coupon samples taken from Robbin devices installed in the closed loop coolant system. The Robbin device allows for the exposure and removal of sample coupons to and from the fluid. The typical coupon surface exposed to the fluid stream is 50 mm^2. Figure 5. A total of eighteen nickel (Ni) 201, eighteen CRES 347, and thirty 316L stainless steel (Figure 5 and 6) coupons are utilized in the test. Fifteen Ni 201 and fifteen CRES 347 coupons will be installed in the Robbin devices. Ni 201 coupons will occupy the odd numbered Robbin ports and CRES coupons will occupy the even numbered ports as shown in Figure 7.

During test buildup the Robbin devices and coupons were cleaned per *Precision cleaning and In-Process Packaging for Space Station Freedom*, D683-10450-1, level 300A. Prior to installation, the coupons were assembled into the Robbin devices and sterilized by autoclave.

5.20.1 During the test, the coupons will be removed at specified intervals (see Table 3) for analysis. When a coupon is removed for analysis, the sample port will not be left unoccupied. A sterile 316L stainless steel coupon will replace the coupon removed for analysis. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

* * NOTE: Two people are required for sampling Robbin devices.

5.20.2 One sampler will wear sterile gloves and maintain a sterile field. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

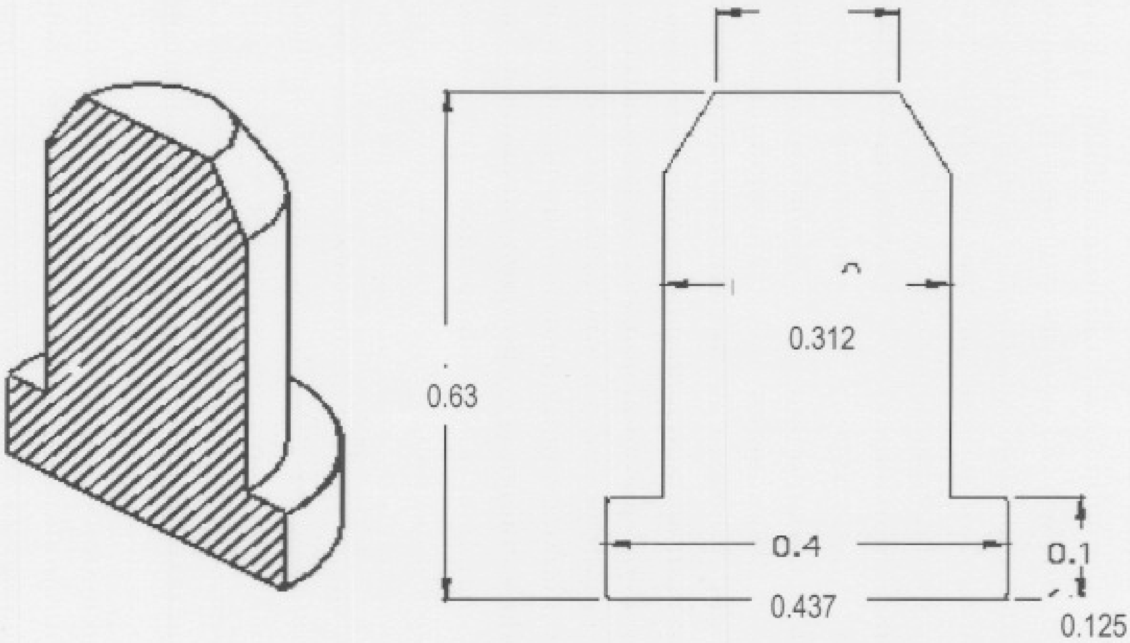
5.20.3 The second sampler shall remove the port from the Robbin device and present the coupon to the first sampler by forcing the coupon from the port by way of rotating the screw clockwise. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.4 The first sampler will remove the coupon using his or her thumb and forefinger taking care not to touch the flat sample surface. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.5 Once the coupon is removed, it shall be placed in a presterilized transportation container. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

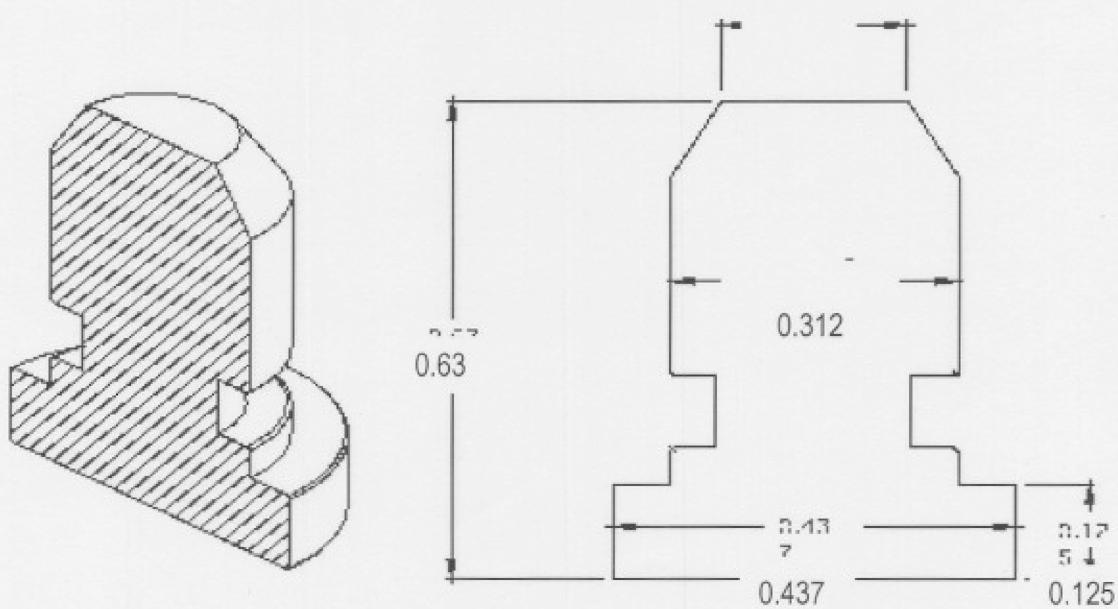
5.20.6 The first sampler shall then obtain a 316L stainless steel coupon, exposed prior to sampling, and insert the coupon into the port. It may be necessary to cover the port with a sterile covering to allow the application of additional force to insert the coupon. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.7 During the test, the coupons will be removed at specified intervals (see Table 3) for analysis. When a coupon is removed for analysis, the sample port will not be left unoccupied. A sterile 316L stainless steel coupon will replace the coupon removed for analysis. Initial and date the FLCP&FS Activity LogBook that this step has been completed.



(Inches not to scale)

Figure 5. Ni 201 and CRES 347 Coupon Drawing



(Inches not to scale)

Figure 6. 316L Stainless Steel Coupon Drawing

* * NOTE: Two people are required for sampling Robbin devices.

5.20.8 One sampler will wear sterile gloves and maintain a sterile field. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.9 The second sampler shall remove the port from the Robbin device and present the coupon to the first sampler by forcing the coupon from the port by way of rotating the screw clockwise. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.10 The first sampler will remove the coupon using his or her thumb and forefinger taking care not to touch the flat sample surface. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.11 Once the coupon is removed, it shall be placed in a presterilized transportation container. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.12 The first sampler shall then obtain a 316L stainless steel coupon, exposed prior to sampling, and insert the coupon into the port. It may be necessary to cover the port with a sterile covering to allow the application of additional force to insert the coupon. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.13 After ninety days of testing, three nickel 201 (Robbin #1 port numbers 1, 3, and 5) and three CRES 347 coupons (Robbin #1 port numbers 2, 4, and 6) shall be submitted for analyses. Perform steps 5.21.2 through 5.21.6. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.14 On test day one hundred and eighty (180), three nickel 201 (Robbin #1 port numbers 7, 9, and Robbin #2 port number 1) and three CRES 347 coupons (Robbin #1 port numbers 8, 10, and Robbin #2 port number 2) shall be submitted for analyses. Perform steps 5.21.2 through 5.21.6. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.15 After one year of testing, three nickel 201 (Robbin #2 port numbers 3, 5, and 7) and three CRES 347 coupons (Robbin #2 port numbers 4, 6, and 8) shall be submitted for analyses. Perform steps 5.21.2 through 5.21.6. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.16 After two years of testing, three nickel 201 (Robbin #2 port numbers 9 and Robbin # 3 port numbers 1 and 3) and three CRES 347 coupons (Robbin #2 port number 10 and Robbin #3 port numbers 2 and 4) shall be submitted for analyses. Perform steps 5.21.2 through 5.21.6. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.17 After three years of testing, three nickel 201 (Robbin #3 port numbers 5, 7, and 9) and three CRES 347 coupons (Robbin #3 port numbers 6, 8, and 10) shall be submitted for analyses. Perform steps 5.21.2 through 5.21.6. Initial and date the FLCP&FS Activity LogBook that this step has been completed.

5.20.18 Initial and date the FLCP&FS Activity Log Book indicating when this section was performed.

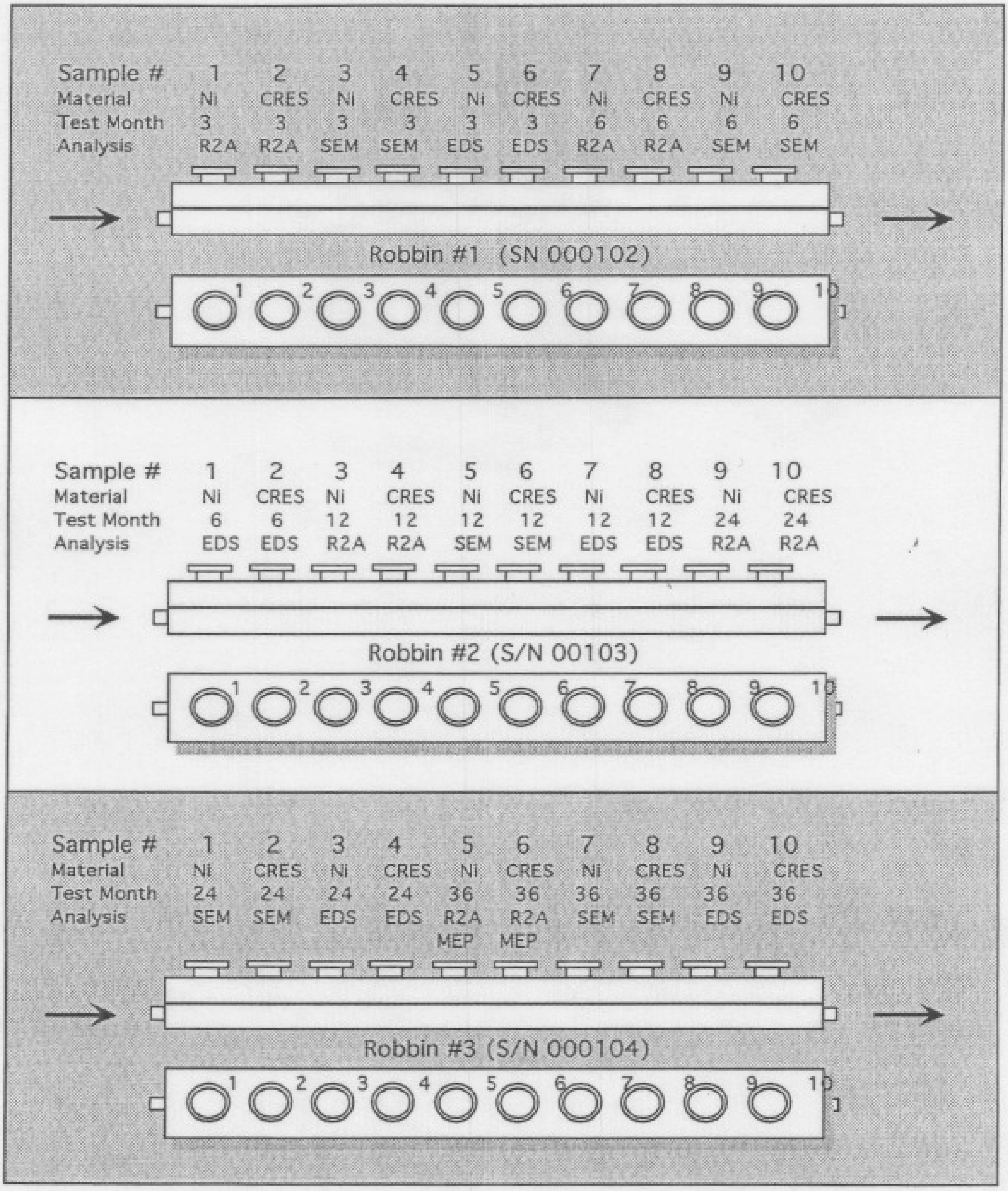


Figure 7. Coupon Identification

5.21 Schedule

The simplified sample schedule shown in Table 3 depicts the schedule for the removal of Robbin coupons, tubes, cold plate, and gas trap membrane.

			Test Month					
Analysis	**Description**	**Special Instructions**	**0**	**3**	**6**	**12**	**24**	**36**
R2A	Nickel 201	1 COUPON REQUIRED		1	1	1	1	1*
SEM		1 COUPON REQUIRED	1	1	1	1	1	1
EDS		1 COUPON REQUIRED	1	1	1	1	1	1
MEP		1 COUPON REQUIRED	1					
R2A	CRES 347	1 COUPON REQUIRED		1	1	1	1	1
SEM		1 COUPON REQUIRED	1	1	1	1	1	1
EDS		1 COUPON REQUIRED	1	1	1	1	1	1
MEP		1 COUPON REQUIRED	1					
R2A & SEM	SS Tube	One "leg"						
R2A & SEM	TT Tube							
R2A & SEM	TT Dead Leg					1	1	1
R2A & SEM	Teflon Tube							
R2A & SEM	Cold Plate #9	-						1
R2A	Gas Trap Membrane	-						
SEM								1
DAPI								

* At 36 Months, the R2A and MEP analyses will be performed using the same coupon for each Nickel and CRES sample.

Table 3. Biofilm Sample Schedule

ISS Coolant Remediation System Test Requirements

Date: 5/31/2006

Purpose: To assess the effects of providing ITCS coolant remediation (Nickel removal, Phosphate removal, buffer addition and antimicrobial application/removal) to simulated on-orbit ITCS fluid on the ITCS filters, Gas Trap, and Pump Package Assembly. This will be accomplished through the measurement and recording of the ITCS system parameters and fluid, chemical, and microbiological characteristics prior to, during, and after remediation.

Special Purpose Test Equipment: **NASA will provide:**

1. Operational ITCS System Simulator (ITCSSS) test bed in MSFC Building 4755 with heat input available to rack and end cone locations, heat rejection available to both loops, capable of flow and heat loads per Tables A and B, and with fully operating system control and data acquisition system (SCADA) with fail-safe operation to prevent overheat in case of facility power loss. Sensor calibrations will be up to date and any maintenance on ITCSS hardware or SCADA will be complete. Data rates will be adjustable from ≥ 1Hz to ≤ 0.003Hz and data retrievable without SCADA shutdown. Variations to data rate will be documented in the Test Log and collection rates will be about every 5 minutes during equilibrations and faster for dynamic system events . Data retrieval and transmittal will be by request of the PI or other test personnel for selected parameters and approximately every month for all parameters. Transmittal may be by file transfer or by CD or DVD in **ASCII or CSV** format
2. Chemical supplies and clean, sterile containers to collect samples, perform routine pH and other measurements as may be requested.
3. A DI water supply, TOC<1, and nominal 1 Mohm quality, of sufficient capacity to fill the system up to 3 times in any 48 hour period. (will be used to make ITCS fluids as needed.)
4. Stainless Steel Tanks, cylinders, or piping to increase, in the noted sections, the Moderate Temperature Loop (MTL) and Low Temperature loop (LTL) to the following gallonages: MTL to 66.9±2 gallons (including ±3% gallon targets of 6.25-Fwd Endcone, 7.28-Aft Endcone, 8.91-Node 1/Airlock loop) and; LTL to 21.5±0.6(including ±3% gallon targets of 5.24-Node 1/Airlock loop and 6.69-LTL/CCAA loop at LAS6). . Plug flow design for volume additions is required. "ITCS Volume Calculation Ver. 6.02.xls" contains details to match volumes to on-orbit values down to the rack and branch level.
5. Hoses, equipped where necessary with QDs and valving to facilitate plug flow draining or flushing with minimal or without ITCS Pump operation. A teflon lined, ½" dia., 60" length with female Staubli QDs on each end will be needed to install remediation canisters as noted elsewhere in this document.
6. 1 and 2 gallon containers with quantity divisions indicated to 0.5 liter, and graduated cylinders, to catch and measure fluid from deadlegs during drain and fill operations.
7. A size 200 cylinder of 99.999% pure research grade CO2 gas ported to diffusion location on SK683-99102 Corrosion Panel SN002 on the MTL at LAS1.When in use, flow will be 300-1000 sccm
8. A supply of ~0.45% CO_2 (≈ 12mL/min scc) in dry air, gas supply ported to diffusion location on SK683-99102 Corrosion Panel SN002 on the MTL at LAS1. Flow will be controlled via a NASA supplied pressure regulator and shutoff valve, connecting to ¼" PFA tubing as part of a Boeing SK683-99102 CO2 Contractor utilizing a gas filter, needle valve, Liqui-Cel® Membrane Contactor and other valving to maintain the research grade CO_2 flow or CO_2 enriched air headspace on the ITCS fluid as part of the -99102 panel.
9. 2 each Flight filter cartridges, Pall P/N AD-B916F-1602, will beused as denoted elsewhere in this document for installation in each ITCS loop.
10. An inverted cylinder type of gas trap will be used on the MTL pump.
11. The LTL pump will use a 35 tube developmental gas trap, similar to the flight design concept.
12. 120VAC power supply for a power/data converter associated with 6 each SmartCet® corrosion sensors
13. A Windows based computer that will accomodate a SmartCet® provided control/visibility software program to accept and store raw sensor data for the 6 SmartCet® sensors via a single RS-232 data stream, (6 sensors with time stamps and 13 parameters per sensor at approximately every 7 minutes), with capability for data storage locally and on the PACRATS and retrieval on demand. The SmartCet® software will have displays to view Corrosion Rate and Pitting Factor parameters for each Sensor. A special data retrieval from PACRATS in ASCII or CSV format of all Corrosion data will be made monthly or at Robbins plug removal events and transmitted via file or CD or DVD to PI designated individuals. .
14. A metering pump capable of 1.3 - 80 mL/min injection of fluids for fluid chemistry adjustment as connected to the inlet port of either the MTL or LTL pump inlets via a valved Tee and short injection lines**.**
15. Accommodation of Boeing supplied 1" PVC piping parallel to or in each of the 3 Standoff areas as a low flow, low pressure 0.45%CO_2 in air gas supply headers with ¼" flexible supply lines to sleeves installed over LTL hoses at rack locations LAS1, 2, 3, 4, 6; LAP1, 2; LAD3, 6; and LAO1,2,3
16. Facility spill clean up materials, including pads and glycine neutralizer (embedded in pads is best)

17. Any support structure or fastening needed for application of coolant remediation devices at Rack Location LAO5 and Corrosion Sensor panels mounted on external module support structure located below LAP4 and LAS1
18. Accommodation (via appropriate connection hardware and 1 each isolation valve) of Boeing supplied Price Model 3MS50-SS-100 3 stage Stainless Steel centrifugal pump in a bypass across the MTL pump for 6 GPM fluid circulation during precipitation and conditioning steps below.
19. 2 ea 500 ml bottles of un-preserved SupraPure 30% H_2O_2 solution.

Boeing will supply the following items to be inserted at various times and locations in the ITCSSS:

1. 10 each rejected flight cold-plates, identified and modified per Boeing Drawing SK683-99007, for placement around the system per the drawing.
2. 3 each low flow (~50pph) jumpers per Boeing Drawing SK683-99006 for use between Supply and Return as needed at LTL rack locations LAO1, LAP1, and LAS1 to emulate flight jumpers for flow circulation through system "deadlegs".
3. 2 structure attachable panels, per Boeing drawing SK683-99102, with valves, bleeds, hoses, and terminated with ½" Staubli QDs, one for the MTL and one for the LTL, each populated with
   a. an inline real-time SmartCET® corrosion sensor (3 probes and 3 transmitters) with a shared power/data box on one panel and with a single RS232 output
   b. a "Robbins" style in-line corrosion/biofilm coupon unit with valves
   c. SN002 panel will also be populated with an 2.5x8, X50, LiquiCel® device to facilitate CO_2 gas diffusion into the circulating fluid with capability to be bypassed. This will be documented on drawing SK683-99102.
4. 4 each developmental 2 liter Resin Bed containers per Boeing Drawing SK683-99005 with ITCSSS compatible QDs and caps (comes with hose on inlet side), containing, when needed per the appropriate Test Instruction, a) Nickel Removing Resin per 683-62430-1 FN33, b) Phosphate Removal Resin per 683-63436-1 FN30, c) Buffer Compound per 683-62430-2 FN 37, 38, 39, d) Antimicrobial Application Resin per 683-63436-2 FN39 or e) Antimicrobial Removal Resin per 683-63436-3 FN40.
5. A developmental Gas Trap, with housing, previously borrowed from MSFC, will be have been checked out, repaired if possible, flow characterized, disinfected, rinsed, and aseptically packaged and ready for installation on the LTL PPA.
6. Various resins or buffer compound to pack containers with Nickel, phosphate, antimicrobial removal or antimicrobial or buffer addition compounds for the test duration (per above #4 a, b, c, d, e).
7. Per Boeing drawing SK2006-00395-01, a 100 gallon clean PP lidded tank, mixing/transfer pump, sterilizable filter and filter housing, cart or stand, and fittings and appropriate hoses assembled on site to serve as a mix/fill station for the ITCS system.
8. PVC piping, fittings, ¼" flex lines, hose sleeves, etc. to create a 0.45%CO2 in air blanket over the unused LTL rack attachment hoses, from a supply point on the MTL SK683-99102 panel.
9. Chemicals, chemical solutions, sample bottles, and microbial nutrient and inoculums to convert available DI fluid to test fluids not otherwisw supplied by NASA.
10. Prototype antimicrobial detection kit(s) [Boeing/JSC provided] if available.
11. A circulation pump (CP) capable of 6 GPM for temporary use during preparation, precipitation and microbial conditioning steps and 1 each isolation valves.
12. LTL pump will be capable of being bypassed during use of external circulation Pump.

Test Support Services:

Boeing will provide:

Boeing HSV prepares System Test Requirements and preliminary and final Test Plans which identify desired facility modifications and test conduct steps. Boeing will build or provide Special Purpose Test Equipment (SPTE) as already noted. A Boeing engineer will perform as Test Director, conduct Test Reviews, and participate in test conduct.. They will request test design or conduct modifications. They provide sampling services and complex chemical and microbial analyses as needed. They evaluate test data and provide conclusions, recommendations and final report per informal Boeing Document Format.

NASA will provide:

MSFC Test Labs performs as System Test Conductor and develops any unique MSFC Test Facility Requirements or procedures. They build or purchase SPTE to make ITCSSS modifications for increased surface area, volume and sensor accommodation, train test personnel on MSFC systems, hold Test Readiness Review, configure ITCSSS, write detailed test instructions (DTIs) on MSFC Form 248 Test Preparation Sheet [Type B] (TPS) to implement test preparation and conduct steps as needed, conduct test, provide routine chemical sampling and analysis as needed, and compile data reports with test logs and all time stamped data recorded, and ensure personnel safety and facility integrity. Standard MSFC informal test report format is acceptable.

Test Prerequisites (TPs):

1. All open items from test reviews will have been closed and approved by Test Conductor and Director, Test Facility Manager, Institutional Safety, ISS ITCS project office representatives, et al. Test Requirements and available TPS sheets will be signed per MSFC form 248 [Type B] instructions.
2. Logs: All events, including changes to configurations and parameters, samples, and hardware or fluid additions/subtractions will be logged in a 3 ring binder with numbered log sheets. Right hand column of the log sheets will be used to record volume additions or subtractions and resultant system fluid volume.
3. Test Changes and Clarifications: Detail procedures, special, or daily instructions associated with any step of this test plan may be needed and, if so, a TPS will be written and copies kept in the log for daily use, archival, logging, etc. [It is anticipated that each step may require a TPS.].
4. Filter and GasTrap Readiness: The filters cartridges and housings per NASA SPTE item 9, above, and LTL gas trap per NASA SPTE item 11, above, will be ready for installation as needed by the Test Instructions..
5. SPTE Installation: All SPTE mentioned previously will have been built, provided, or on schedule to support a test instruction when needed . Volume modifications, fluid introduction, cold-plates, corrosion sensors, attachment hoses, will have been installed or available when needed. Corrosion Sensors and Robbins samplers will have been mounted and connected for power and data but not wetted, and be checked out for data transmission and functionality from their intended install locations below Rack stations LTL LAP4 and MTL LAS1 respectively. ~0.45% in air CO_2 Size 200 cylinder tank and gas blanket method using a LiquiCel® gas contactor will have been validated hydraulically and installed on the SN001 Corrosion Panel. Similarly, the 0.45% CO2 distribution system for stubends will have been installed and checked out Low Temperature Loop (LTL) and Moderate Temperature Loop (MTL) will be configurable into a combined "Single Loop" operating mode with a combined volume of ***88.4*** ± 3% gallons[@~70% accumulator level], including planned intermittent operational rack locations . The LTL maximum fluid volume at 70% accumulator level will be 21.5±3% gallons. "ITCS Volume Calculation Ver 6 02.xls" will be used as the guide for volume allocations. Attach external circulation pump (CP) with bypass valves across the MTL pump location and bleed air from connections in readiness for use. A ¼" swagelock connection (with ¼" Swagelock valve, will be installed near the MTL pump inlet (outside of bypass zone) to accommodate metering pump usage.
6. DI Water Fill: The control and data system will be activated with data recording rates available from 1Hz to > 1/300 Hz per PI direction. The combined loop, without filters and gas trap installed, but with all its branches including dead legs, will be initially filled, now or previously, with DI water, circulated and mixed, sampled and verified that fluid can be made into test fluid. The goal for TOC is <1±0.5 ppm. Low flow or other SPTE jumpers between inlet and outlet at rack locations should be available to properly mix fluid and insure homogeneity per TPS. Mixing will be facilitated by switching back and forth between dual and single loop mode with MT and LT pumps both being operated. If the circulating fluid is acceptable, Corrosion Sensors data recording will be initiated and panels hydraulically connected and flow set to 135±7pph. Add special microbial inoculum using equivalent amounts of each of 8 organisms found in returned on-orbit hardware per Table C to achieve a calculated >1.0E+06 CFU/100ml initial concentration in each loop. Install Low Flow jumpers. [2 Day]
7. Set Loads and Flows: Either before or after TP6, the LTL and MTL shall be set and validated to operate with the ability to add thermal energy at various points in the system, to remove thermal energy, to adjust loop mix temperatures, and to record system temperatures, flows, pressure, and pressure drops. In dual loop mode and each loop pump set to 3174+400-100pph, each payload/system rack location will be set to provide a flow and heat load through that location to ensure mixing and best similarity to the flight article during this test per ***Tables A*** and ***B*** attached and for all Test Configurations except where otherwise noted. RFCAs will initially be used to adjust flow at the ISPR rack locations and then inhibited to maintain flow at a steady condition. Similarly, any heat load parameters reductions needed to accommodate an undersized external circulation pump will be determined. [1 Day]
8. Install Filters and Gas Trap: aseptically remove filters and gas trap from their packaging and install into the system. [1 filter on the MTL pump and 1 Filter and housing and 35 Tube developmental gas trap on the LTL PPA. Sample per Table 1 concurrent with following TPs until filters are taken offline. [2 Day]
9. Characterize Filters and Gas Trap: With a nominally pressurized system in dual loop mode, and at 40±1°F LTL set point and a 63±1°F MTL set point, record the LTL filter and gas trap pressure drops as LTL flow is varied from 700 to 3200 pph in 500 pph steps. Repeat for the MTL filter. [1 Day]
10. Pump Operation: Set to single MTL loop mode. If an external Circulation Pump (CP) is used, turn off MTL pump and bypass MTL pump with previously installed CP. Start CP and set valving to achieve a nominal 6 GPM (Less flow is acceptable but heat loads may need reduction to maintain local temperatures in the racks and return loops.) Sample as needed [1 Day]
11. Fill with "No TOC" nominal test fluid: Details will be covered under a separate TPS. Turn pump off. Aseptically introduce, using plug flow techniques, a premixed ITCS Baseline solution into both loops and crossovers of the system, including accumulators, dead legs and stubends. [Baseline solution is achieved by mixing, in the 100 gallon tank, 1±0.5 Mohm DI water, with sodium tetraborate and Trisodium Phosphate , and adding 50% NaOH solution to [5 Day]

achieve a 9.5 pH, [Borate to 1000±100 ppm B_4O_7 (dissolved), Phosphate to 212±20ppm PO_4 (dissolved)]. Repeat mixing activities per previous steps, re-sampling and re-adjustment to be made as necessary. Repeat mixing activities per previous steps, re-sampling and re-adjustment to be made as necessary. Add, as determined by previous sampling, microbial concentrate directly into MTL pump inlet side via metering pump per Table C to achieve 1E6 CFU/100mL. Turn pump (CP if utilized) on and circulate and mix to equilibrate entire system including deadlegs and stubends. Add fluid as necessary to fill accumulators. Sample as a cross check to system volume.

12. <u>CO_2 Diffusion Response</u>. Under separate TPS, start a pure CO2 gas blanket at the gas diffusion site and utilizing Boeing provided calibrations as a guide, contact CO2 gas with flowing stream to cause a theoretical 0.1 pH change and determine actual time to effect this change in the mixed fluid. (note, the basic flow and pressure conditions will have been checked out on a similar volume at Boeing) After diffusion rate has been determined for a set of liquid/gas flows by repetition of 0.1 pH unit changes, adjust pH via additional time with CO_2 blanket to achieve a 8.35±0.05pH. Repeat good mixing activities per previous steps, re-sampling and re-adjustment to be made as necessary. . Use of NaOH in final pH adjustment is permitted. [2 Day]
13. <u>0.45% CO2 Gas Blanket</u>. Apply 0.45% CO2 in air at the Gas Diffuser with minimal flow and head pressure as a gas blanket to stub end locations identified on Boeing drawing SK683-99102, sh 6. Determine consumption rate of gas cylinder with minimal, but detectable flows to any of the gas blanket locations [1 Day]
14. <u>Initial Equilibration</u>. Take samples at start and end of shifts for 2 days. Switch between Single LT, Single MT, and Dual Loop modes and back as needed to ensure fluid homogeneity. Use mix jumpers at unused rack locations to ensure baseline fluid is everywhere in the system. Adjust chemistry as necessary. [2 Day]
15. <u>Re-Characterize filter and Gas Trap:</u> Near end of 2^{nd} day of TP14, return to Dual Loop mode and repeat TP9. [½ Day]
16. <u>Initial In Situ precipitation.</u> Remove jumpers and place system in dual loop mode. Add, in 30 mL steps (1.5mL/min), with 40 minute equilibration “wait” after last portion of 30 ml have been added, 1.67% Ni as $Ni(NO_3)_2$ solution to the LTL loop. Sample the affected loop before each step. NaOH addition may be needed between steps to maintain pH. When ΔP for the LTL Fine Filter and Gas Trap have reached about ¼ of their usable range as based on TP9, stop addition to the LTL. Repeat process for the MTL loop, removing the MTL FFA when it has reached about ¼ of its usable range. [2 Day]
17. <u>Final In Situ Precipitation:</u> Configure to Single MT loop (with CP valved in and operating), remove Fine Filter assemblies from both loops and Gas Trap from the LTL., Continue to add 1.67% Ni as $Ni(NO_3)_2$ solution in 30 mL (@1.5mL/min) steps with 40 minute equilibration “wait” after last portion of 30 ml have been added, to the combined circulating fluid via MTL connected metering pump until PO_4(dissolved) concentration has reached 12[+0/-5] ppm. Overnight and weekend equilibrations are acceptable between 30mL steps Sample per schedule. Cycle crossovers lines to ensure treatment of deadleg line portions. Pure CO_2 diffusion or NaOH addition may be needed between steps to maintain pH. [4 Day]
18. <u>Equilibration:</u> Equilibrate for 5 days, sampling at start and end of shifts. Cycle crossovers lines to ensure treatment of deadleg line portions. Pure CO_2 diffusion or NaOH addition may be needed between steps to maintain pH. [5 Day]
19. <u>Flush Removal of NO_3:</u> Stop pump(s) and heat loads. Using the values of pH, Ni, PO4 and Borate from the last fluid sample, and per PI direction, prepare 100 gallons of “ersatz” ITCS fluid to match the last sample of the previously circulating fluid, with only the amount of NO_3 as $Ni(NO_3)_2$ needed to match Ni (or as otherwise specified) and Na matched and replacement fluid volume reduced for possible addition of nutrient, and slowly plug flow drain and refill each line in which precipitation has occurred with ~ 1 volume of this ersatz. Retain fluid that was forced out for mass balance analysis. Repeat up to 2 times, as indicated by sample to reduce NO_3 load to <2.2 times the circulating Ni ppm. [4 Day]
20. <u>Adjust Nickel precipitate:</u> Restart Pumps in Single MT loop mode. Depending on results of previous steps, more $Ni(NO_3)_2$ solution may be added to ensure adequate nickel precipitate load, per PI direction. Adjust other chemicals as needed to bring to post precipitate levels. Equilibrate for 2 day and sample. Note: This step may take longer depending ability to accomodateon logistics of following steps. [2 Day]
21. <u>Add TOC Components:</u> When inorganic chemistry levels have been measured and adjusted to reach specified values, separately add Acetone to 10±2 ppm TOC, IPA to 10±2ppm TOC and Ethanol to 45±5 ppm TOC. Sample after each addition. [2 Day]
22. <u>Add Microbes</u>. Repeat addition of special microbial inoculum using equivalent amounts of each of 8 organisms found in returned on-orbit hardware per Table C to achieve a calculated >1.0E+06 CFU/100ml initial concentration in each loop volume. Take sample per table. Adjust chemistry, micro-organisms, or nutrient per PI direction. Operate system in following manner:
    - **a.** Run for 14 days, sample at days 1, 3, 7 and 14. [14 Day]
    - **b.** Take fluid sample and perform total and viable enumerations of planktonic microorganisms.
    - **c.** Add additional microbiological inoculum to > 1.0 E+06 CFU/100 mL if required.

23. Chembio sample immediately before next step and adjust chemistry to ensure it is consistent to that achieved at the end of TP22.

1 Day

24. LTL FFA Microbial Exposure: In AM and in dual loop mode, install FFA in circulating LTL loop. Sample per Table 1. If FFA pressure drop increases to 50% of cracking pressure, remove and convene incident board. Re-innoculation may occur at PI direction if microbial population drops below 1E4 CFU/100mL per Petroff-Hauser method on samples before and 4 hours after exposure. After 6 hours, Repeat TP9 and take Chembio Sample immediately before next step.

1 Day

25. MTL FFA Microbial Exposure: In AM, in dual loop mode, install FFA in circulating MTL loop. Sample per Table 1. If FFA pressure drop increases to 50% of cracking pressure, remove and convene incident board. Re-innoculation may occur at PI direction if microbial population drops below 1E4 CFU/100mL per Petroff-Hauser method on samples before and 4 hours after exposure. After 6 hours, Repeat TP9 and take Chembio Sample immediately before next step.

1 Day

26. LTL Gas Trap Microbial Exposure: In AM, take Chem Bio Sample then install LTL gas trap. Sample per Table 1. If Gas Trap pressure drop increases to 50% of cracking pressure, remove and convene incident board. Re-innoculation may occur at PI direction if microbial population drops below 1E4 CFU/100mL per Petroff-Hauser method on samples before and 4 hours after exposure. After 6 hours, Repeat TP9 and take Chembio Sample immediately before next step.

14 Day

27. 2 week Microbial Equilibration. Convert to Single MT and run for 14 days until microbial population has stabilized through out system (at >1.0E+06 CFU/100ml). Sample at start of AM shifts and alternating between single MT and dual loop modes (1 day Single MT, 1 day Dual, …) If below specification system flow rates have been used as part of FFA and Gas Trap exposure incident recovery, they may be gradually increased to 3174+400-100pph as long as pressure relief valves around Fine Filter Assemblies do not exceed 60% of usable pressure range. Re-inoculate if microbial population drops below specification. At end repeat TP9.
28. Final Test fluid Correction. If needed, per PI direction and in Single MT, correct test fluid [Nominal is 1000±100ppm Borate, ***TBD*** PO4(d), ***TBD*** Ni(d), 10±1ppm IPA, 10±1 ppm Acetone, 50±5 ppm Ethanol and 8.37±0.05pH. Sample

3 Day

29. If corrections are made for TP28, run system at full flow (3174+400-100pph) for 3 days, alternating between single MT and dual loop modes (1 day Single MT, 1 day Dual, …) taking 1 chembio sample at each day work shift start before mode change.

1 Day

30. Robbins Device Baseline: Remove 2 of each type Robbins samples from each loop, and perform inspection and photographic record. Use new Robbins plugs of identical type to replace those removed. Appropriately pack and send 3 samples for detailed analysis to HSSSI and Boeing Huntsville Labs each. Prepare a data file for SmartCet® probes and send to Honeywell Houston subcontractor for analysis.
31. Ready to Install NiRA: Place the 2 liter NiRA (SPTE Boeing item 4a), loaded with Nickel removing resin identical to Boeing Drawing 683-62430-1 FN33, in the support structure for it on the LTL between the supply and return of the connection at rack location LAO5.

Data Required: Event Log, available system flows, pressure, Δp across filters and gas traps, and temperatures or calculated heat loads, at 5 minute data collection or faster rate per PI direction, and ITCS fluid samples per the attached Table 1.

Test Configurations:

Configuration 1: - The LTL and MTL shall be in dual loop mode with the respective PPAs supplying fluid at a 3174+400-100pph rate for the each system. LTL temperature will be set to 40±1°F. MTL loop temperature after the regen HX mix temperature will be set to 63±1°F. LTL system thermal load will be ***2933 ± 100W*** of system (excluding ~300 W due to PPA operation) with Payload heat provided as heat load to the LTL loop per the attached ***Table A***. Similarly, ***8783±100*** W of system and payload heat load to the MTL loop will be provided per the attached ***Table B***. Test Prerequisites through TP34 will have been completed. A 2 Liter NiRA is ready to be installed at LAO5 per TP34.

Configuration 2: - Same as Configuration 1, except with partial Nickel removal afforded by application of the 1st NiRA, but the 2nd 2 liter NiRA (SPTE item 4a) ready to be installed in place of the 1st 2 liter NiRA.

Configuration 3: - Same as Configuration 2, except with full Nickel removal afforded by application of the 2nd NiRA, but the 1st 2 liter PhosRA (SPTE item 4b, packed with 2 liters of pH adjusted, Phosphate removing resin similar to Boeing Drawing 683-63436) ready to be installed in place of the 2nd 2 liter NiRA.

Configuration 4: - Same as Configuration 3, except with partial Phosphate removal afforded by application of the 1st PhosRA, but the 2nd 2 liter PhosRA (SPTE item 4b) ready to be installed in place of the 1st PhosRA.

Configuration 5: - Same as Configuration 4, except with partial Phosphate removal afforded by application of the 2nd 2 liter PhosRA, but the 3rd 2 liter PhosRA (SPTE item 4a repacked with PhosRA resin) ready to be installed in place of the 2nd 2 liter PhosRA.

Configuration 6: - Same as Configuration 5, except with full Phosphate afforded by application of the 3rd PhosRA, but the 2 liter Buffer Delivery Applicator (BuDA) – (SPTE item 4a, repacked with buffer compound per Boeing Drawing SK683-99005) ready to be installed in place of the 3rd 2 liter PhosRA.

Configuration 7: - Same as Configuration 6, except with buffer enhancement afforded by application of the Buffer Addition Assembly, but the Antimicrobial Applicator (AmiA) (SPTE item 4d and per Boeing Drawing SK683-99005) ready to be installed in place of the BuDA.

Configuration 8: - Same as Configuration 7, except with antimicrobial treatment afforded by application of the AmiA, but the Antimicrobial Removal Applicator (AmiRA) (SPTE item 4e, as repacked with antimicrobial removing compound TBD) ready to be installed.

Configuration 9: - Same as Configuration 8, except with antimicrobial removal afforded by application of the AmiRA, but the AmiA (SPTE item 4d per Boeing Drawing SK683-99005) ready to be installed.

Configuration A: - At any time during test conduct, per PI direction, an AmIA (SPTE item 4d) may be applied at LAO5 or other Rack location, possibly eliminating Configuration 7.

Configuration B: - If Configuration A is invoked, Configuration 9 Antimicrobial Removal Assembly may be applied at a later time per PI direction (pre-installation conditions adjusted accordingly).

Test Instructions:

1. NiRA:
   a. After taking a Baseline sample, and in Dual loop at Test Configuration 1, plug in the 1st NiRA at the LAO5 position and set flow to achieve 360±40pph through the fluid lines of the NiRA. Take Chembio samples per Table 2. After 48 hours, configure to Single LTL mode. After 120 hours, switch to Single MTL operation. After 240±16 hours remove 1st NiRA. NiRA will be returned to Boeing Huntsville Labs for sectioning, analysis for mass balance, and repacking into a PhosRA needed for Configuration 5. Continue to take ChemBio Sample per **Table 2** for 3[-0+2]days

   10 Day Test

   3 Day Rebound

   b. Switch to Dual loop, at Test Configuration 2, and plug in the 2nd NiRA at the LAO5 position and set flow to achieve 360±40pph through the fluid lines of the NiRA#2. Take Chembio samples per Table 2. After 48 hours, configure to Single LTL mode. After 360 hours, switch to Single MTL operation. After ***720*** [-0+48] hours, remove 2nd NiRA. NiRA will be returned to Boeing Huntsville Labs for sectioning, analysis for mass balance, and repacking into a Buffer Delivery Applicator (BuDA) needed for Configuration 6. Continue to take ChemBio Sample per Table 2 for 5 [-0+2] days

   30 Day Test

   5 Day Rebound

2. PhosRA:
   a. Switch to Dual Loop, at Test Configuration 3, attach deadleg mix Low Flow Jumpers to LTL locations LAS1, LAP1, LAO1. Plug in the 1st PhosRA at the LAO5 position and set flow to achieve 360±40pph through the fluid lines of the PhosRA#1. Take Chembio samples per **Table 3**. After 4 hours, configure to Single LTL mode. After 24 hours, switch to Single MTL operation. After 48 hours, remove 1st PhosRA. PhosRA will be returned to Boeing Huntsville Labs for sectioning, analysis for mass balance, and repacking into a Antimicrobial Applicator (AmiA) needed for Configuration 7. Continue to take ChemBio Sample per **Table 3** for 1 [-0+0.5] days

   2 Day Test

   1 Day Rebound

   b. Switch to Dual Loop, at Test Configuration 4, plug in the 2nd PhosRA at the LAO5 position and set flow to achieve 360±40pph through the fluid lines of the PhosRA#2. Take Chembio samples per Table 3. After 4 hours, configure to Single LTL mode. After 24 hours, switch to Single MTL operation. After 48 hours, remove 2nd PhosRA. PhosRA will be returned to Boeing Huntsville Labs for sectioning, analysis for mass balance, and repacking into a Antimicrobial Removal Assembly (AmiRA) needed for Configuration 8. Continue to take ChemBio Sample per **Table 3** for 5 [-0+2] days

   2 Day Test

   5 +Day Rebound

   c. Switch to Dual Loop, at Test Configuration 5, plug in the 3rd PhosRA at the LAO5 position and set flow to achieve 360±40pph through the fluid lines of the PhosRA#3 Take Chembio samples per Table 3. After 4 hours, configure to Single LTL mode. After 24 hours, switch to Single MTL operation. Disconnect a Low Flow Jumper and reconnect for 10 minutes each at the 9 LTL ISPR unused rack stubs [LAS2,3,4,6; LAD3,6; LAP2; LAO2,3]. After 48 hours, remove 3rd PhosRA and return to Boeing Huntsville Labs for sectioning, analysis for mass balance, and possible repacking. Continue to take ChemBio Sample per **Table 3**.

   2 Day Test

   ½ Day Rebound

3. Buffer Application: Within ½ day of completion of TI-2.c., switch to Dual Loop, at Test Configuration 6, plug in the BuDA at the LAO5 position and set flow to achieve 360±40pph through the fluid lines of the BuDA. Take Chembio samples per **Table 4**. After 2 hours, configure to Single LTL mode. After 12[-0/+12] hours, switch to Single MTL operation. Disconnect a Low Flow Jumper and reconnect for 10 minutes each at the 9 LTL and 2 MTL ISPR unused rack stubs [LAS2,3,4,6; LAD3,6; LAP2; LAO2,3]. Remove BuDA. BuDA will be returned to Boeing Huntsville Labs for possible repacking. Continue to take ChemBio Sample per Table 4 for 3 [-0+2] days

   1 Day Test

   3 Day Equil

4. Antimicrobial Application: Switch to Dual Loop at Test Configuration 7. Remove 2 sets of Robbins sample plugs from each loop for further analysis by Boeing and HSSSI. Attach the Antimicrobial Applicator (AmiA) to the LAO5

1 Day Applic location and set flow to achieve 360±40pph through the fluid lines of the AmiA. After 2 hours, configure to Single LTL mode and equilibrate. After 12 [-0+12] hours, switch to Single MTL operation. Disconnect a Low Flow Jumper and reconnect for 10 minutes each at the 9 LTL ISPR unused rack stubs [LAS2,3,4,6; LAD3,6; LAP2; LAO2,3]. After 2 hours equilibration, switch back to Single LTL mode, remove AmiA and Low Flow Jumpers, and operate for 30 [-
30 Day Ops 0/+2] days. AmiA will be returned to Boeing Labs for mass balance analysis. Take samples per **Table 5**.

5. Antimicrobial Removal: Switch to Dual Loop at Test Configuration 8. Remove 2 sets of Robbins sample plugs from each loop for further analysis by Boeing and HSSSI. Install Mix Jumpers. Plug in the Antimicrobial Removal
2 Day Applic Applicator (AmiRA) at the LAO5 position and set flow to achieve 360±40pph through the fluid lines of the AmiRA. Take Chembio samples per **Table 6**. After 4 hours, configure to Single LTL mode. After 24 hours, switch to Single MTL operation. Disconnect a Low Flow Jumper and reconnect for 10 minutes each at the 9 LTL ISPR unused rack stubs [LAS2,3,4,6; LAD3,6; LAP2; LAO2,3]. After 48 hours, remove AmiRA. AmiRA will be returned to Boeing Huntsville Labs for mass balance analysis. Remove Mix Jumpers. Continue to take ChemBio Sample per **Table 6**
30 Day Ops for at least 30 [-0+2] days.

6. Re-Application of Antimicrobial: Switch to Dual loop at Test Configuration 9. Install Mix Jumpers. Attach the
1 Day Applic Antimicrobial Applicator (AmiA) to the LAO5 location and set flow to achieve 360±40pph through the fluid lines of the AmiA. After 2 hours, configure to Single LTL mode. After 12 [-0+12]hours, switch to Single MTL operation. Disconnect a Low Flow Jumper and reconnect for 10 minutes each at the 9 LTL ISPR unused rack stubs [LAS2,3,4,6; LAD3,6; LAP2; LAO2,3]. After 2 hours equilibration, switch back to Single LTL mode, remove AmiA and the Low
120 Day Ops Flow Jumpers, and operate for 120 [-0+2] days. Take samples per **Table 7**. .Re-characterize filter and Gas Trap by repeating TP9.

7. Post Test Analyses: At the conclusion of TI 6, remove heat load, stop both pumps and de-pressurize the system. Remove LiquiCel assembly from Corrosion Panel SN001 and plumb LiquiCel assembly into an otherwise unused rack location. Re-operate system as needed [24 hours every 2 weeks?] or as directed by NASA Sustaining authority to maintain system chemistry and 0.45%CO_2 in air blanket effect. Ship corrosion sensor panels wet to Boeing for further disassembly and analysis by Boeing, HSSSI, and Honeywell. The Gas trap and flight filters will be retained in the loops if performance is within specification.

Table A Lab Racks - **LTL**
Heat [W] & Flow [pph] Loads

#	Port	Overh	Stbd	Deck
1	**Jumper 0W [50p]**	**Jumper 0W [50p]**	**Jumper 0W [50p]**	MT AV2
2	MT ER4	MT ER1	MT HRF	MT AV3
3	MT DDCU1	MT ER3	MT MSG	MT CHeCS
4	**0W 135pph CSens**	**950 W 204 pph MELFI**	MT ER5	MT WORF
5	MT MSS2	**NiRA 0W - 400p Return**	MT MSS1	MT AV1
6	**LT PPA CCAA 973w 1230p**	MT DDCU2	CCAA PPA 0W 0p	**ARS 250W 262p**
N1,A/L	**760 W 484pph**			
Fwd E/C				

Table B Lab Racks - **MTL** **[MTL SFCA @ 9.5±.1psid]** Heat [W] & Flow [pph] Loads				
#	Port	Overhead	Stbd	Deck
1	**2320 W** **483 pph** OGS	0W 0-50pph Express 2	**0W** **135pph** **CSens**	**478 W** **119 pph** AV#2
2	**690 W** **110 pph** Express 4	**430 W** **95 pph** Express 1	**205 W** **137 pph** HRF	**480 W** **130 pph** AV#3
3	**327 W** **277 pph** DDCU1	0W 0-50pph Express 3	0W 0-50pph MSG	**155 W** **137 pph** CheCS
4	**205W** **132pph** HRF2	(LT Payload MELFI)	0W 0-50pph Express 5	**0 W** **0-50 pph** WORF
5	**250W** **106 pph** MSS#2	NiRA on LT	**250 W** **105 pph** MSS#1	**486 W** **126 pph** AV#1
6	(LT PPA CCAA)	**336 W** **284 pph** DDCU#2	MT PPA CCAA	**300W** **132 pph** ARS
N1,A/L	**420 W 125 pph**			
Fwd E/C	**753 W 278 pph**			
Aft E/C	**698 W 236 pph**			

	Table C – On-Orbit Microbial Isolates used for Inoculum			
	Sample	FlexHose or HX sample #	Identification	Type
1	2005-08-19-1434-4A	HX027	Lampropedia hyalina (UnidFame Genus 4)	Nit -
2	2005-08-19-1397-2	HX021	Sphingomonas parapaucimobilis	
3	2005-08-19-1391-3	HX009	Methylobacterium extorquens	
4	2005-08-19-1429-2	FH036	Unid GNR Fame Genus 1	Nit -
5	2005-08-19-1422-1A	FH040	Acidovora species	Nit +
6	2005-08-19-1301-1B	FH002	Ralstonia eutropha/paucula	Nit +
7	2002-xx-xx-0807-2		Variovorax paradoxus	
8	2002-xx-xx-0816-2		Stenotrophomonas maltophilia	

Ref	Table 1 – Test Prerequisite Sampling						
	t ▬ "total" measurement d ▬ "dissolved" measurement	Sampling Parameters					Sp = Include Speciation; AR = As Required
		PO4	pH	µ	TIC TOC	NI	other
TP6	Baseline DI water		X	Sp	X	t	**F=Full ICP metals analysis**
TP10	Baseline as Circulated		X	Sp	X		
TP11	Make test fluid - add Borate & Phosphate – in Mix Tank	X	X				**B**=Borate. Repeat as necessary
TP11	As added test Fluid	X	X				**B**=Borate. Repeat as necessary to ensure chemistry in system is well mixed and at correct levels.
TP12	CO2 Diffusion Response and pH drop		X		TIC		Ad Hoc pH to determine response time ~20 samples
TP14	Initial Equilibration	X	X	X	X	t	**At start & end of shift for ~48hrs**
TP14	After adjustments	?	?	?	?	?	**As needed**
TP16	Initial In-Situ Precipitation	X	X		X	t&d	**Before each step**
TP17	Final In-Situ Precipitation	X	X		X	t&d	**Before each step**
TP18	Equilibration	X	X		X	t&d	**At start & end of shift for ~5 day, Borate, NO3 on last**
TP19	1st Volume Flush Water	X	X		X	t&d	**Include Borate, NO3**
TP19	2nd Volume Flush Water	X	X		X	t&d	**Include Borate, NO3**
TP19	3rd Volume Flush Water	X	X		X	t&d	**Include Borate, NO3**
TP20	Adjust Precipitate	X	X		X	t&d	**Before each step and at end**
TP21	Make test fluid – add Ethanol & Acetone & IPA		X		TOC	t&d	**O**=ETA & Ace & IPA. Do TOC after each constit. Addition.
TP22	Add Microbes	X	X	X	X	t&d	**@1,3,7,14 days SP @7 & 14 day**
TP23	Recheck after adjustments	X	X		X	t	**As directed**
TP24	LTL FFA Conditioning			X			**@15',30',60', 2hr, 4hr, 8hr in LTL only**
TP24	LTL FFA Conditioning	X	X	X	X	X	**After 24 hours in LTL**
TP25	MTL FFA Conditioning			X			**@ 15',30',60', 2hr, 4hr, 8hr in MTL only**
TP25	MTL FFA Conditioning	X	X	X	X	X	**After 24 hours in MTL**
TP26	LTL GT Conditioning			X			**@15',30',60', 2hr, 4hr, 8hr in LTL only**
TP26	LTL GT Conditioning	X	X	X	X	X	**After 24 hours in LTL**
TP 27	2 Week Microbial equilibration	X	X	X	X	X	**@ shift start on days 1, 4, 8, 12, 14 days [Note: samples in Single MT]**
TP28	Test Fluid Correction	X	X	X	X	X	**6 hours after adjustment**
TP29	3 Day equilibtation	X	AR		d	X	**Daily and after any adjustment**
TP31	Prior to NiRA Introduction	X	X	Sp	d	t&d	

Ref	Table 2 – Test Instruction 1 - NiRA Sampling						
	t ▬ "total" measurement d ▬ "dissolved" measurement	Sampling Parameters					Sp = Include Speciation
		PO4	pH	µ	TICTOC	NI*	other
TI1.a.1	Baseline Coolant water	t	X	X	d	t&d	**F=Full ICP metals analysis, Both Loops. Include Borate, NO3**
TI1.a.2	Dual Loop, LTL Only, NiRA1	t	X	@48 hr	d	t&d	**LTL only** At hours = 0.5, 1, 1.5, 2, 3, 4, 8, 24, 32, 48 hours
TI1.a.3	Dual Loop, MTL before xtion to single LTL	t	X	X	d	t&d	**Include Borate**
TI1.a.4	Single MTL Loop, NiRA1	t	X	Day 4,7	d	t&d	At hours = 0.5, 1, 1.5, 2, 3, 4, 8, 24, 48, then daily through day 10.
TI1.a.5	Single MTL Loop, No NiRA (Rebound)	t	X	Last	d	t&d	Every 4 Hours for 24 hrs, then every 12 hours to 3 days until Mode switch to dual., Borate check at last
TI1.b.1	Dual Loop, LTL Only, NiRA2	t	X	@48 hr	d	t&d	**LTL only** At hours = 0.5, 1, 1.5, 2, 3, 4, 8, 24, 32, 48 hours
TI1.b.2	Dual Loop, MTL before xtion to single LTL	t	X	X	d	t&d	**Include Borate**
TI1.b.3	Single LTL Loop, NiRA2	t	X	1/week	d	t&d	At hours = 0.5, 1, 1.5, 2, 3, 4, 8, 24, 48, start of shift every 2 days for ~28 days.
TI1.b.4	Single LTL Loop, No NiRA2 (Rebound)	t	X	Lastw/ Sp	d	t&d	Every 4 Hours for 24 hrs, then every 12 hours to 3 days then 1/day through day 5 or until next configuration.
							*** after difference between t&d is <5%, analyze for t only**

Ref	Table 3 – Test Instruction 2 - PhosRA Sampling						
	t ▬ "total" measurement d ▬ "dissolved" measurement	Sampling Parameters					Sp = Include Speciation
		PO4	pH	µ	TICTOC	NI	other
TI2.a.1	Baseline Coolant water	t	X	X	t&d	t&d	**F=Full ICP metals analysis, Include Borate, NO3 [May be same as TI1.b.4]**
TI2.a.2	Dual Loop, LTL Only, PhosRA1 in	t	X	@4 hr	t&d	t&d	**LTL only** Every 15 min for 2 hours then every 30 min to 4 hours
TI2.a.3	Dual Loop, **MTL** before xtion to single LTL	t	X	X	t&d	t&d	**Include Borate**
TI2.a.4	Single LTL, PhosRA1	t	X		t&d	t&d	Every 15 min for 2 hours then every 30 min to 4 hrs, then every hr to 8 hr then every 2 hrs to 16 hours then every 4 hours to 24 hrs
TI2.a.5	Single MTL, PhosRA1	t	X		t&d	t&d	15 min after mode switch, just before stubend procedure and 15 min after, at shift end and 48 hrs
TI2.a.6	Single MTL, No PhosRA	t	X		t&d	t&d	At shift end and at just before next step., Borate check at last
TI2.b.1	Dual Loop, LTL Only, PhosRA2	t	X	@4 hr	t&d	t&d	**LTL only** Every 15 min for 2 hours then every 30 min to 4 hours
TI2.b.2	Dual Loop, **MTL** before xtion to single LTL	t	X	X	t&d	t&d	**Include Borate**
TI2.b.3	Single LTL, PhosRA2	t	X		t&d	t&d	Every 15 min for 2 hours then every 30 min to 4 hrs, then every hr to 8 hr then every 2 hrs to 16 hours then every 4 hours to 24 hrs
TI2.b.4	Single MTL, PhosRA2	t	X		t&d	t&d	15 min after mode switch, just before stubend procedure and 15 min after, at shift

Ref	Table 3 – Test Instruction 2 - PhosRA Sampling						
	t ▬ "total" measurement **d ▬ "dissolved" measurement**	**Sampling Parameters**					**Sp = Include Speciation**
		PO4	**pH**	**µ**	**TICTOC**	**NI**	**other**
							end and 48 hrs
TI2.b.5	Single MTL, No PhosRA	**t**	**X**		**t&d**	**t&d**	At shift end and at just before next step., Borate check at last
TI2.c.1	Baseline Coolant water before Mix jumpers installed	**t**	**X**	**X**	**t&d**	**t&d**	**F=Full ICP metals analysis, Include Borate, NO3 [May be same as TI1.b.4]**
TI2.c.2	Baseline Coolant water after Mix jumpers installed	**t**	**X**	**X**	**t&d**	**t&d**	**F=Full ICP metals analysis, Include Borate, NO3 [May be same as TI1.b.4]**
TI2.c.3	Dual Loop, LTL Only, PhosRA3	**t**	**X**	**@4 hr**	**t&d**	**t&d**	**LTL only** Every 15 min for 2 hours then every 30 min to 4 hrs
TI2.c.4	Dual Loop, **MTL** before xtion to single LTL	**t**	**X**	**X**	**t&d**	**t&d**	**Include Borate**
TI2.c.5	Single LTL, PhosRA3	**t**	**X**		**t&d**	**t&d**	Every 15 min for 2 hours then every 30 min to 4 hrs, then every hr to 8 hr then every 2 hrs to 16 hours then every 4 hours to 24 hrs
TI2.c.6	Single MTL, PhosRA3	**t**	**X**		**t&d**	**t&d**	15 min after mode switch, just before stubend procedure and 15 min after, at shift end and 48 hrs
TI2.c.7	Single MTL, No PhosRA		**X**	**Last w/Sp**	**t&d**	**t&d**	sample just before next step

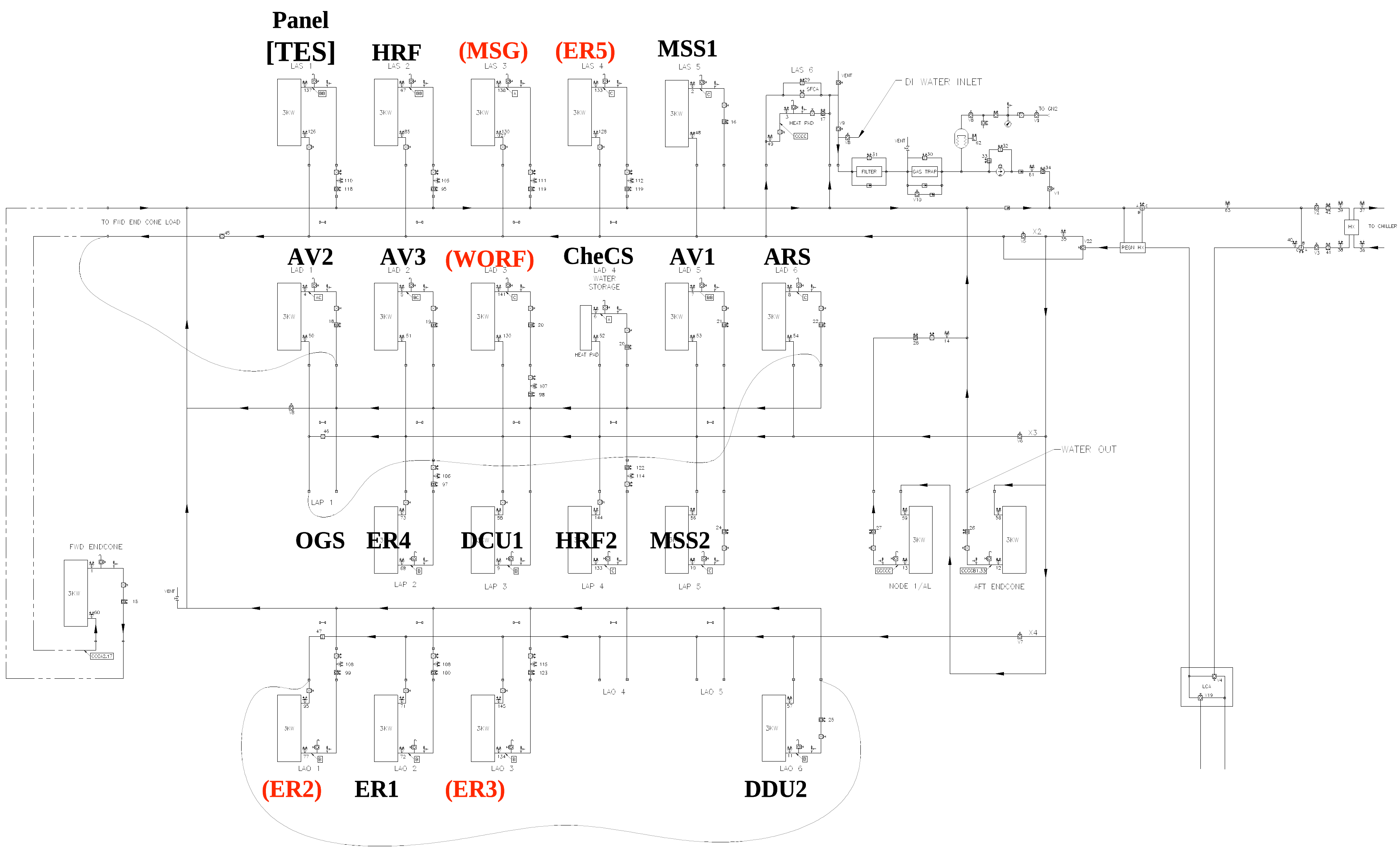
Ref	Table 4 – Test Instruction 3 – Buffer Application Sampling						
	t ▬ "total" measurement **d ▬ "dissolved" measurement**	**Sampling Parameters**					**Sp = Include Speciation**
	BuDA= Buffer Applicator	**PO4**	**pH**	**µ**	**TICTOC**	**NI**	**other**
TI3.1	Baseline Coolant water	**t**	**X**	**X**	**t&d**	**t&d**	**F=Full ICP metals analysis, Both Loops. Include Borate, NO3**
TI3.2	Dual Loop, LTL Only, BuDA in		**X**	**@2 hr**	**t&d**	**t&d**	**LTL only** Every 15 min for 2 hours. Include Borate
TI3.3	Dual Loop, **MTL** before xtion to single LTL		**X**	**X**	**t&d**	**t&d**	Include Borate
TI3.4	Single LTL Loop, BuDA in		**X**		**t&d**	**t&d**	Every 15 min for 2 hours then every hour to 4 hrs, then every 4 hr to 8 hr then at shift end 24hours. Include Borate
TI3.5	Single MTL Loop, BuDA in		**X**		**t&d**	**t&d**	15 min after mode switch, just before stubend procedure and 15 min after, at shift end and 48 hrs Include Borate
TI3.6	Single MTL Loop, No BuDA		**X**	**Last w/ Sp**	**t&d**	**t&d**	AM sample for 3 days and just before next step Include Borate

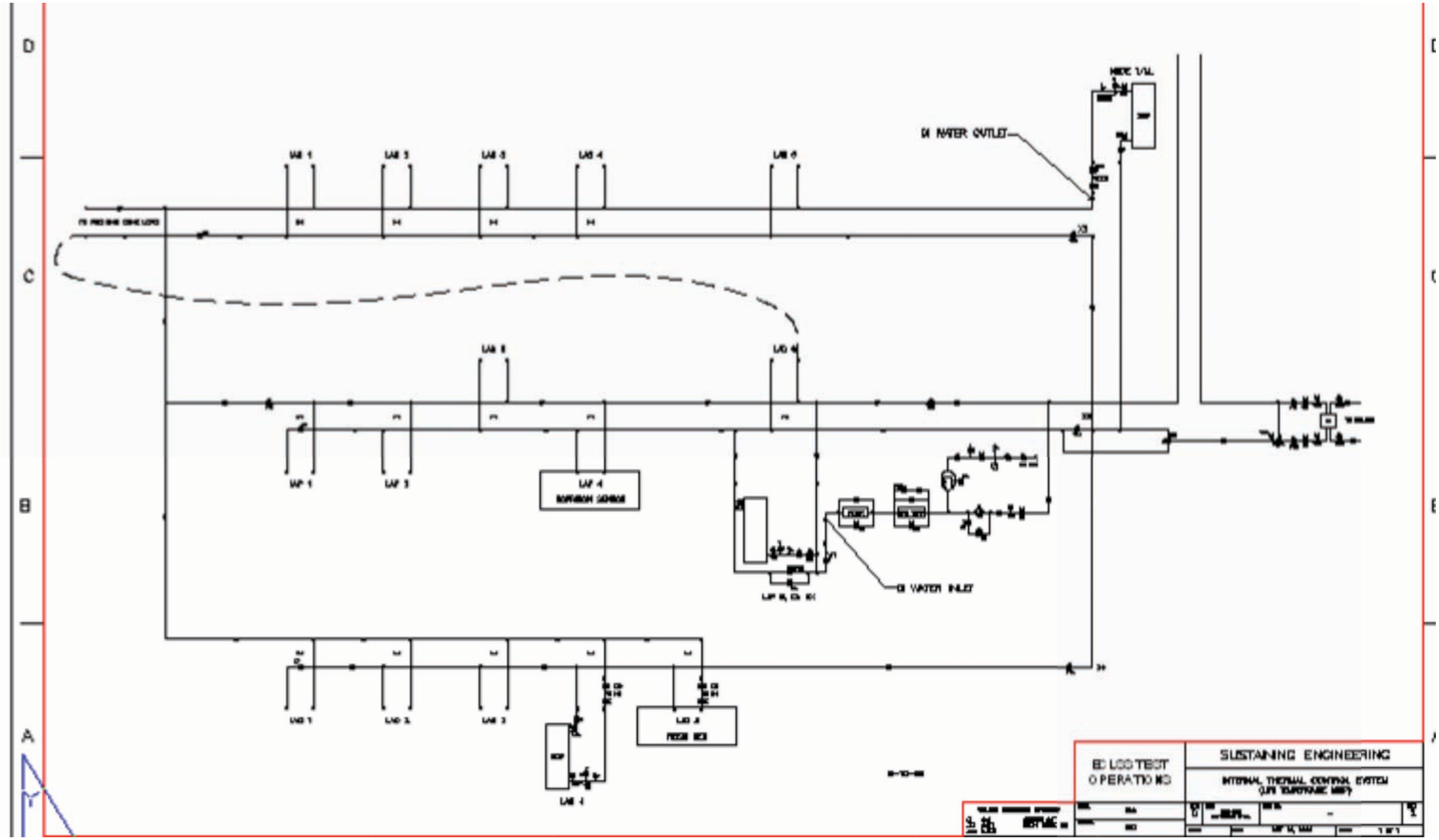
Ref	Table 5 – Test Instruction 4 – Antimicrobial Application Sampling						
	t ▬ "total" measurement **d ▬ "dissolved" measurement**	**Sampling Parameters**					**Sp = Include Speciation** **AC=TOC accountability**
	AmiA=Antimicrobial Applicator	**PO4**	**pH**	**µ**	**TICTOC**	**NI**	**other**
TI4.1	Baseline Coolant water	**t**	**X**	**Sp**	**t&d**	**t&d**	**F=Full ICP metals analysis, Both Loops. Include Borate,**
TI4.2	Dual Loop, LTL Only, After exposure		**1hr, 2hr**	**¼, ½, ¾, 1, 2 hrs**	**d, AC@2hr**	**last**	**LTL only** Every 15 min for 2 hours , Include AM(antimicrobial). Stabilize Microbial Samples immediately. Include Borate
TI4.3	Single LTL Loop, during application		**¼hr, AR**	**1/hr to 8hr, 16hr 24hr**	**1/hr to 8hr, 16hr AC Last**	**Last**	OPA coincides with Micro sample. Stabilize Microbial Samples immediately
TI4.4	Single MTL Loop, AmiA in then out		**X**	**X, Sp AR**	**d**	**1/wk**	1 hr after Mode switch, just before stubend procedure and 1 hr after, at shift end and 48 hrs. Then every 4 days to 30days OPA coincides with Micro sample. Stabilize Microbial Samples immediately, Include Borate

Ref	Table 6 – Test Instruction 5 – Antimicrobial Removal Sampling						
	t ▬ "total" measurement **d ▬ "dissolved" measurement**	**Sampling Parameters**					**Sp = Include Speciation**
	AmiRA=Antimicrobial Removal Applicator	**PO4**	**pH**	**µ**	**TICTOC**	**NI**	**other**
TI5.1	Baseline Coolant water	**t**	**X**	**X**	**t&d**	**t&d**	**F=Full ICP metals analysis, Both Loops. Include Borate,**
TI5.2	Dual Loop, LTL Only, AmiRA in		**X**	**2 hr**	**¼, ½, ¾, 1, 2 hrs**		**LTL only** Every 15 min for 2 hours , Then every 30 min to 4 hours. OPA coincides with TOC measurement. Stabilize Microbial Samples immediately. Include Borate
TI5.3	Single LTL Loop, AmiRA in		**X**	**24 hr**	**¼, ½, ¾, 1, 2, 3, 4, 8, 12, 24 hrs**		Every 15 min for 2 hours after Single loop mode. then every hour to 4 hrs, then every 4 hr to 8 hr then at shift end 24hours. Include Borate OPA coincides with TOC measurement. Stabilize Microbial Samples immediately
TI5.4	Single MTL Loop, AmiRA in, out		**X**	**X, Sp AR**	**d**		1 hr after Mode switch, just before stubend procedure and 1 hr after, at shift end and 48 hrs. Then every 4 days to 30 days OPA coincides with Micro sample. Stabilize Microbial Samples immediately, Include Borate

Ref	Table 7 – Test Instruction 6 – Re-Application of Antimicrobial Sampling						
	t ▬ "total" measurement **d ▬ "dissolved" measurement**	**Sampling Parameters**					**Sp = Include Speciation** **AC=TOC accounability**
	AmiA=Antimicrobial Applicator	**PO4**	**pH**	**µ**	**TICTOC**	**NI**	**other**
TI6.1	Baseline Coolant water	**t&d**	**X**	**Sp**	**t&d**	**t&d**	**F=Full ICP metals analysis, Both Loops. Include Borate,**
TI6.2	Dual Loop, LTL Only, After exposure		**1hr, 2hr**	**¼, ½, ¾, 1, 2 hrs**	**d, AC@2hr**		**LTL only** Every 15 min for 2 hours , Include AM(antimicrobial). Stabilize Microbial Samples immediately. Include Borate
TI6.3	Single LTL Loop, during application		**¼hr, AR**	**1/hr to 8hr, 16hr 24hr**	**1/hr to 8hr, 16hr AC Last**		OPA coincides with Micro sample. Stabilize Microbial Samples immediately
TI6.4	Single MTL Loop, AmiA in then out	**1/mo**	**X, AR**	**X, Sp AR**	**d**	**1/wk**	1 hr after Mode switch, just before stubend procedure and 1 hr after, at shift end and 48 hrs. Then every 7 days to 120 days OPA coincides with Micro sample. Stabilize Microbial Samples immediately, Include Borate

post - TRR


Panel
[TES]
HRF
(MSG)
(ER5)
MSS1
LAS 1
LAS 2
LAS 3
LAS 4
LAS 5
LAS 6
DI WATER INLET
FILTER
GAS TRAP
HEAT PAD
TO GN2
TO FWD END CONE LOAD
AV2
AV3
(WORF)
CheCS
AV1
ARS
LAD 1
LAD 2
LAD 3
LAD 4
WATER
STORAGE
LAD 5
LAD 6
REGN HX
TO CHILLER
X2
X3
X4
WATER OUT
LAP 1
OGS
ER4
DCU1
HRF2
MSS2
LAP 2
LAP 3
LAP 4
LAP 5
NODE 1/AL
AFT ENDCONE
FWD ENDCONE
VENT
LAO 1
LAO 2
LAO 3
LAO 4
LAO 5
LAO 6
(ER2)
ER1
(ER3)
DDU2


D
C
B
A
DI WATER OUTLET
DI WATER INLET
SUSTAINING ENGINEERING
ED LSS TEST OPERATIONS
INTERNAL THERMAL CONTROL SYSTEM

APPENDIX B—ACCEPTANCE/QUALIFICATION TEST EXAMPLES

Sample pages from Destiny Acceptance Test and IATCS Simulator Validation Test. The following pages are for the test of the LTL in single-loop operation.

B.1 Destiny Acceptance Test

B.2 IATCS Simulator Validation Test

C. Condition 3, Single LT Loop Mode

NOTE: STEPS (1) – (2) TRANSITION ITCS FROM SINGLE MT MODE TO SINGLE LT LOOP MODE.

(1) COMMAND the "ITCS Set Operating Mode" command arm and command confirmation to "Single LT" by utilizing the MATE-3 TCL command interface. Record IRIG-B time in the table below:

W. BAHR 8806
TC
NOV 13 '99
Date

Test Script	Test Word #1	Test Word #2	IRIG-B Time Executed
18	1	3	318 / 03:13:39 -

PC

(2) VERIFY the following expected test response parameters:

W. BAHR 8806
TC
NOV 13 '99
Date

DISPLAY FILE #: LT_MT_DUAL_MODE_CB

Test Response Parameters	PUI #	Expected	Actual	1553 Data Bus
ITCS LAB Operating Mode	LADP08MD2439J	Single LT	SINGLE LT	CB INT
ITCS LAB System Status	LADP08MD2446J	Operating	OPERATING	CB INT
ITCS LCA Lab Valve 1 Position	LADS19MD0185J	Single	SINGLE	CB INT
ITCS LCA Lab Valve 2 Position	LADS20MD0156J	Single	SINGLE	CB INT

CONTROL COPY

W. BAHR 8806

70250

Pg. Complete: TC: ________ QA: ________ DATE: NOV 13 '99

NOV 13 '99

70250

NOTE: STEP (3) ESTABLISHES THE STEADY–STATE CONDITION.

(3) RECORD the following system rack, endcone, and pump outlet temperatures on the next three tables at a frequency per TCS Engineering direction. After these outlet temperatures change by no more than 0.5 °F/hour then proceed to the next step.

DISPLAY FILE #: lt_mt_rsts.v

IRIG–B Time	**LAF1 (Avionics #2)** ***LATT04SR0001T***	**LAF5 (Avionics #1)** ***LATT09SR0001T***	**LAFE (Fwd Endcone)** ***LATT01SR0001T***	**LAAE (Aft Endcone)** ***LATT02SR0001T***

DISPLAY FILE #: lt_mt_rsts.v

IRIG–B Time	**LAC6 (DDCU #2)** ***LATT03SR0001T***	**LAS5 (MSS #1)** ***LATT05SR0001T***	**LAP5 (MSS #2)** ***LATT10SR0001T***	**LAF4 (CHeCS)** ***LATT11SR0001T***

Pg. Complete: TC: ____________ QA: ____________ DATE: ____________

DISPLAY FILE #: lt_mt_rsts.v

IRIG–B Time	**LAF2 (Avionics #3)** *LATT12SR0001T*	**LAP3 (DDCU #1)** *LATT13SR0001T*	**MT Pump Outlet Temp** *LATI02SR0001T*	**LT Pump Outlet Temp** *LATI01SR0001T*

Pg. Complete: TC:____________ QA:____________ DATE:____________

NOTE: STEP (4) VERIFIES ITCS HYDRAULIC AND HEAT REMOVAL PERFORMANCE WHILE IN SINGLE LT MODE.

(4) Verify the following flight and non–flight test response parameters:

W. BAHR 8806
TC

NOV 13 '99
Date

DISPLAY FILE #: lt_mt_rsts.v

Test Response Parameters	PUI #	Expected	Actual	1553 Data Bus
RSTS LA1 LAF1 Temperature Sensor	LATT04SR0001T	61 – 85 °F	66.3	CB INT
RSTS LA2 LAS6 Temperature Sensor	LATT08SR0001T	38 – 70 °F	58.2	CB INT
RSTS LA3 LAF5 Temperature Sensor	LATT09SR0001T	61 – 85 °F	68.1	CB INT
RSTS LA1 LAFE Temperature Sensor	LATT01SR0001T	61 – 85 °F	67.2	CB INT
RSTS LA3 LAAE Temperature Sensor	LATT02SR0001T	61 – 85 °F	65.4	CB INT
RSTS LA2 LAC6 Temperature Sensor	LATT03SR0001T	61 – 85 °F	63.5	CB INT
RSTS LA3 LAS5 Temperature Sensor	LATT05SR0001T	61 – 85 °F	N/A	CB INT
RSTS LA1 LAP5 Temperature Sensor	LATT10SR0001T	61 – 85 °F	N/A	CB INT
RSTS LA3 LAF4 Temperature Sensor	LATT11SR0001T	61 – 85 °F	61.8	CB INT
RSTS LA3 LAF2 Temperature Sensor	LATT12SR0001T	61 – 85 °F	65.9	CB INT
RSTS LA1 LAP3 Temperature Sensor	LATT13SR0001T	61 – 85 °F	63.6	CB INT

CONTROL COPY

Pg. Complete: TC: W. BAHR 8806 QA: 70250 DATE: NOV 13 '99

NOV 13 '99
70250

DISPLAY FILE #: mt_rack_cb.v

Test Response Parameters	PUI #	Expected	Actual	1553 Data Bus
MT Pump Speed: LSB MB MSB	 LATI21FC0007U LATI21FC0006U LATI21FC0002U	0 rpm	0 * ~~18~~	CB INT
MT SFCA Differential Pressure	LATL02SR0001P	11 ± 1 psid	10.7	CB INT
MT Pump Filter Differential Pressure	LATI02SR0301P	0 psid	0	CB INT
MT Gas Trap Differential Pressure	LATI02SR0201P	0 psid	0	CB INT
MT Pump Differential Pressure	LATI02SR0401P	0 psid	0	CB INT
MT Pump Inlet Pressure	LATI02SR0101P	18 – 50 psia	26.4	CB INT
MT Average Accumulator Quantity	LADS20MD0001Q	20 – 90 %	78.6	CB INT
MT Pump Flow – Low Range	LATI02FM0001R	0 pph	19.5	CB INT
MT Pump Flow – High Range	LATI02FM0002R	baseline	6.6	CB INT
MT Pump Outlet Temperature	LATI02SR0001T	61 – 90 °F	64.0	CB INT
MT CTB HX TWMV Temperature	LATM02SR0001T	55 – 65 °F	54.9	CB INT
MT Reg HX TWMV Temperature	LATM03SR0001T	61 – 65 °F	60.75	CB INT

KI001782
NOV 13 '99
70250

* ENTERED WRONG VALUE 70250 NOV 13 '99

CONTROL COPY

Pg. Complete: TC: ______ QA: ______ DATE: ______

DISPLAY FILE #: lt_rack_cb.v

Test Response Parameters	PUI #	Expected	Actual	1553 Data Bus
LT Pump Speed: LSB MB MSB	 LATI20FC0007U LATI20FC0006U LATI20FC0002U	18,900 ± 600 rpm	18980	CB INT
LT SFCA Differential Pressure	LATL01SR0001P	11 ± 1 psid	10.9	CB INT
LT Pump Filter Differential Pressure	LATI01SR0301P	1 – 8 psid	1.5	CB INT
LT Gas Trap Differential Pressure	LATI01SR0201P	2 – 8 psid	3.4	CB INT
LT Pump Differential Pressure	LATI01SR0401P	18 – 80 psid	69.7	CB INT
LT Pump Inlet Pressure	LATI01SR0101P	18 – 50 psia	20.3	CB INT
LT Average Accumulator Quantity	LADS19MD0001Q	20 – 90 %	56.9	CB INT
LT Pump Flow – Low Range	LATI01FM0001R	baseline	HIGH	CB INT
LT Pump Flow – High Range	LATI01FM0002R	1245 – 3255 pph	2798.2	CB INT
LT Pump Outlet Temperature	LATI01SR0001T 11/17/99 C. SANDERS 9741 H-116	38–~~70~~ 90 °F	58.8	CB INT
LT CTB HX TWMV Temperature	LATM01SR0001T	~~38–43~~ °F 55–65	58.9 * ~~67.4~~	CB INT

H-114 C. SANDERS 9741 Q-92268
11-13-99

* ENTERED WRONG VALUE 70250 NOV 13 '99

CONTROL COPY

W. BAHR 8805

70250 NOV 13 '99

Pg. Complete: TC: ______ QA: ______ DATE: ______

NOV 13 '99
70250

H-27 SANDERS 9741 11-7-99

A
Q-90730

DISPLAY FILE #:

LAP4	~~LAP2~~ RFCA LR Flow Meter	LATR~~07~~FM0001R 08	230 ± 17 pph		CB–INT
LAP4	~~LAP2~~ RFCA HR Flow Meter	LATR~~07~~FM0002R 08	baseline		CB–INT
LAP4	~~LAP2~~ RFCA Temperature Sensor	LATR~~07~~SR0001T 08	61 – 120 °F		CB–INT

H-74 SANDERS 9741 11-11-99

DISPLAY FILE #: FE 1247–1 DAS H-74 SANDERS 9741 11-11-99 Q-90730

Test Response Parameters	MID# LAP4	Expected H-74 SANDERS 9741 Q-90730 11-11-99	Actual
Cart 2 / Middle Assembly (ISPR ~~LAP2~~ RFCA)			
Temperature In	PS–TS–1455	61 – 65 °F	
Temperature Out	PS–TS–1454	61 – 120 °F	
Differential Pressure	PS–PT–1453	9.0 +0/–0.25 psid	
Flowrate	PS–FM–1451	230 ± 17 pph	

3-649.1
Q-90607

Pg. Complete: QA DATE

Q-90730
C. SANDERS 9741 11-11-99

DISPLAY FILE #: H-74

Test Response Parameters	PUI # H-74	Expected	Actual	1553 Data Bus
~~LAC3~~ LAC4 RFCA LR Flow Meter	LATR~~11~~12FM0001R	baseline	OFF SCALE HIGH	CB–INT
~~LAC3~~ LAC4 RFCA HR Flow Meter	LATR~~11~~12FM0002R	805 ± 60 pph	790	CB–INT
~~LAC3~~ LAC4 RFCA Temperature Sensor	LATR~~11~~12SR0001T	61 – 120 °F	61.5	CB–INT
LAS4 RFCA LR Flow Meter	LATR04FM0001R	baseline	OFF SCALE HIGH	CB–INT
LAS4 RFCA HR Flow Meter	LATR04FM0002R Q-92268 C. SANDERS 9741 11/19/99 H-113	~~960 ± 70~~ 890±50 pph	890	CB–INT
LAS4 RFCA Temperature Sensor	LATR04SR0001T 11/17/99 C. SANDERS 9741 H-116	38 – ~~70~~ 120 °F	58	CB–INT
LAF3 RFCA LR Flow Meter	LATR06FM0001R	baseline	265	CB–INT
LAF3 RFCA HR Flow Meter	LATR06FM0002R	baseline	174	CB–INT
LAF3 RFCA Temperature Sensor	LATR06SR0001T 11/17/99 C. SANDERS 9741 H-116	38 – ~~70~~ 120 °F	58.9	CB–INT

CONTROL COPY

W. BAHR 8806

Pg. Complete: TC: ________ QA: 70250 ________ DATE: NOV 13 '99 ________

NOV 13 '99
70250

KI 001782 70250 NOV 13 '99

DISPLAY FILE #: FE 1247–1 DAS

Test Response Parameters	MID#	Expected	Actual
Cart 3 / Top Assembly (ISPR LAS4 RFCA)		890 ± 50 H-115	SANDERS 9741 92268 11-13-99
Temperature In	PS–TS–1475	38 – ~~43~~ °F ~~55~~ ~~65~~	57.34
Temperature Out	PS–TS–1474	38 – ~~70~~ °F 65 120	57.66
Differential Pressure	PS–PT–1473	7.0 +0/–0.25 psid H-116 SANDERS 9741 11-17-99	8.86
Flowrate	PS–FM–1471	~~960 ± 70~~ pph	850
Cart 3 / Middle Assembly (ISPR ~~LAC3 RFCA~~)		LAC4 H-74	SANDERS 9741 90736 11-11-99
Temperature In	PS–TS–1485	61 – 65 °F	60.82
Temperature Out	PS–TS–1484	61 – 120 °F	63.02
Differential Pressure	PS–PT–1483	7.5 +0/–0.25 psid	7.8
Flowrate	PS–FM–1481	805 ± 60 pph	785
Cart 3 / Bottom Assembly (ISPR LAF3 RFCA)		H-116 SANDERS 9741	11/17/99
Temperature In	PS–TS–1495	38 – ~~43~~ °F 65	57.51
Temperature Out	PS–TS–1494	38 – ~~70~~ °F 120	58.48
Differential Pressure	PS–PT–1493	baseline	8.24
Flowrate	PS–FM–1491	baseline	220

NOV 13 '99 70250 KI001782

DISPLAY FILE #: FE 1053 DAS

Test Response Parameters	MID#	Expected	Actual
LTL ΔT	CALC–dT–LTL	baseline	
MTL ΔT	CALC–dT–LTL	baseline	
LTL Heat Rejection	CALC–dT–LTL	13.4 kW maximum	
MTL Heat Rejection	CALC–dT–LTL	20.6 kW maximum	

NOTE: AFTER SUCCESSFUL COMPLETION OF THE ABOVE STEP: VO USL.TCS.44 ITEM 2 IS FULLY ACCOMPLISHED, AND VO USL.TCS.46 ITEM 2 IS PARTIALLY ACCOMPLISHED.

CONTROL COPY

* ENTERED IN ERROR NOV 13 '99 70250

Pg. Complete: TC: ______ QA: ______ DATE: ______

NOTE: **STEPS (5) – (6) TRANSITION ITCS FROM SINGLE LT MODE TO DUAL LOOP MODE.**

CAUTION

IN CASE OF LCA FAILURE DURING TRANSITION FROM SINGLE LOOP MODE TO DUAL LOOP MODE, REPOSITION THE LCA VALVES TO THE DUAL LOOP POSITION WITHIN A MAXIMUM OF TWO MINUTES.

(5) COMMAND the "ITCS Set Operating Mode" command arm and command confirmation to "Dual" by utilizing the MATE–3 TCL command interface. Record IRIG–B time in the table below:

W. BAHR 8806
TC
NOV 13 '99
Date

Test Script	Test Word #1	Test Word #2	IRIG–B Time Executed
18	1	2	03:51:38

PCS

(6) VERIFY the following expected test response parameters:

W. BAHR 8806
TC
NOV 13 '99
Date

DISPLAY FILE #: LT_MT_DUAL_MODE_CB

Test Response Parameters	PUI #	Expected	Actual	1553 Data Bus
ITCS LAB Operating Mode	LADP08MD2439J	Dual	DUAL	CB INT
ITCS LAB System Status	LADP08MD2446J	Operating	OPERATING	CB INT
ITCS LCA Lab Valve 1 Position	LADS19MD0185J	Dual	DUAL	CB INT
ITCS LCA Lab Valve 2 Position	LADS20MD0156J	Dual	DUAL	CB INT
PUMP LAB MT Started	LADP08MD2754J	True	TRUE	CB INT
PUMP LAB LT Started	LADP08MD2730J	True	TRUE	CB INT

11-7-99
Q -92268

11/6/99
SANDERS
9741
H-3

CONTROL COPY

W. BAHR 8806

Pg. Complete: TC: ______ QA: 70250 DATE: NOV 13 '99

NOV 13 '99
70250

D. Condition 3, Single LT loop Mode

NOTE: STEPS (1) – (2) TRANSITION ITCS FROM SINGLE MT MODE TO SINGLE LT LOOP MODE.

CAUTION

IN CASE OF LCA FAILURE DURING TRANSITION FROM DUAL LOOP MODE TO SINGLE LOOP MODE, REPOSITION THE LCA VALVES TO THE SINGLE LOOP POSITION WITHIN A MAXIMUM OF TWO MINUTES.

1 COMMAND the "ITCS Set Operating Mode" command arm and command confirmation to "Single LT" by utilizing the SCITCS Control interface. Record time below.

Time: 10:01

2 VERIFY the following expected test response parameters::

Test Response Parameters	Expected	Actual
ITCS LAB Operating Mode	Single LT	SINGLE LT
ITCS LAB System Status	Operating	OPERATING
ITCS LCA Lab Valve 1 Position	Single	CROSS-CONNECTED
ITCS LCA Lab Valve 2 Position	Single	CROSS-CONNECTED

* 10:05 CHANGED LT SINGLE SPEED TO 15500 RPM *

Page Complete:	TC:	Date: 12/10/03

3 RECORD the following system rack, endcone, and pump outlet temperatures on the next table at a frequency per TCS Engineering direction. After these outlet temperatures change by no more than 0.5 °F/hour then proceed to the next step.

TIME	LAF1	LAF5	LAFE	LAAE	LAC6	LAS5	LAP5	LAF4	LAF2	LAP3	MT Pump Outlet	LT Pump Outlet
10:33	85.34	67.28	73.11	70.91	65.48	68.49	66.69	71.79	79.17	71.65	75.11	55.53
10:53	85.74	67.27	73.59	71.13	67.71	70.09	68.54	72.07	79.40	71.10	74.84	55.47
11:26	85.25	67.25	73.30	70.82	65.81	68.86	66.92	71.89	79.36	71.76	74.50	55.58

Page Complete:	TC:	Date: 12/16/03

4 Verify the following flight and non–flight test response parameters:

Test Response Parameters	Expected	Actual	
LAF1 Temperature Sensor	61 – 85 °F	85.54	*
LAS6 Temperature Sensor	38 – 70 °F	72.74	*
LAF5 Temperature Sensor	61 – 85 °F	66.38	
LAFE Temperature Sensor	61 – 85 °F	72.24	
LAAE Temperature Sensor	61 – 85 °F	73.26	
LAC6 Temperature Sensor	61 – 85 °F	68.57	
LAS5 Temperature Sensor	61 – 85 °F	70.74	
LAP5 Temperature Sensor	61 – 85 °F	68.03	
LAF4 Temperature Sensor	61 – 85 °F	72.00	
LAF2 Temperature Sensor	61 – 85 °F	79.40	
LAP3 Temperature Sensor	61 – 85 °F	72.94	

Test Response Parameters	Expected	Actual	
LT Pump Speed:	18,900 +/- 1500 rpm	15288 / 15444	*
LT SFCA Differential Pressure	11 ± 1 psid	11.0	
LT Pump Filter Differential Pressure	1 – 8 psid	4.6	
LT Gas Trap Differential Pressure	2 – 8 psid	6.8	
LT Pump Differential Pressure	18 – 80 psid	54.7	

Page Complete:	TC:	Date: 12/11/03

LT Pump Inlet Pressure	18 – 50 psia	24.8	
LT Average Accumulator Quantity	20 – 90 %	87.5	
LT Pump Flow – Low Range	baseline		
LT Pump Flow – High Range	1245 – 3255 pph	FLOW METER IS MAXED 3281.	*
LT Pump Outlet Temperature	38 – 70 °F	55.5	
LT CTB HX TWMV Temperature	38 – 43 °F	45.73 / 47.30	*

Test Response Parameters	Expected	Actual	
MT Pump Speed:	0 rpm	0	
MT SFCA Differential Pressure	11 ± 1 psid	11.0 / 11.3	
MT Pump Filter Differential Pressure	0 psid	-0.0	
MT Gas Trap Differential Pressure	0 psid	-0.4	
MT Pump Differential Pressure	0 psid	0.1	
MT Pump Inlet Pressure	18 – 50 psia	27.7	
MT Average Accumulator Quantity	20 – 90 %	90.3	
MT Pump Flow –	0 pph	2	
MT Pump Outlet Temperature	61 – 90 °F	74.4	
MT CTB HX TWMV Temperature	55 – 65 °F	56.8 / 60.08	
MT Reg HX TWMV Temperature	61 – 65 °F	58.15 / 67.77	*

Page Complete:	TC:	Date: 12/10/03

Test Response Parameters	Expected	Actual
LAC4 RFCA Flowmeter	200 ± 15 pph	196.19 / 203.81
LAC4 RFCA Temperature Sensor	61 – 120 °F	94.45 / 95.29
LAS3 RFCA Flowmeter	260 ± 18 pph	255.23 / 262.53
LAS3 RFCA Temperature Sensor	61 – 120 °F	78.92 / 79.61
LAP4 RFCA LR Flowmeter	325 ± 20 pph	316.03 / 332.62
LAP4 RFCA Temperature Sensor	61 – 120 °F	85.33 / 87.60
LAS4 RFCA LR Flowmeter	480 ± 50 pph	472.61 / 482.18
LAS4 RFCA Temperature Sensor	38 - 70 °F	54.46 / 54.72
LAC1 RFCA LR Flowmeter	480 ± 50 pph	473.88 / 483.14
LAC1 RFCA Temperature Sensor	38 - 70 °F	55.10 / 55.26
LAF3 RFCA Flowmeter	265 ± 20 pph	259.36 / 270.79
LAF3 RFCA Temperature Sensor	38 – 70 °F	60.52 / 60.62
Airlock MT RFCA Flowmeter	385 ± 20 pph	378.28 / 396.54
Airlock MT RFCA Temperature Sensor	61 – 90 °F	81.58 / 84.24
Airlock LT RFCA Flowmeter	550 ± 50 pph	541.41 / 553.99
Airlock LT RFCA Temperature Sensor	38 – 70 °F	56.49 / 57.08

NOTE: AFTER SUCCESSFUL COMPLETION OF THE ABOVE STEP, VOUSL.TCS.52 ITEM 4 IS FULLY ACCOMPLISHED.

Page Complete:	TC:	Date: 12/10/03

APPENDIX C—FLIGHT HARDWARE PROCESSING PROCEDURES

C.1 ACOMC for Filling ITCS With HTF

C.2 Operations and Maintenance Requirements and Specifications

REQUIREMENT NUMBER: A-OITCS-TCS-001

REQUIREMENT TITLE: Internal Thermal Control Sys (ITCS) Hardware and Fluid Contamination Ctrl

REQUIREMENT REVISION LEVEL: C

REQUIREMENT TEXT: Verify that ITCS flight hardware (flight hardware containing ITCS fluid) is adequately flushed and is filled with ITCS fluid compliant with SSP 30573B, Table 4.1-2.8, Heat Transport Fluid.

REFERENCE: SSP 30573B

MEASUREMENT - STIMULI:

STAGE EFFECTIVITY: 7A.1 | UF1 | 8A | UF2 | 10A | UF3 | 20A | ULF-1

PASS - FAIL CRITERIA: 1) Verify that ITCS flight hardware has been pretreated/serviced using one the following commodities to ensure removal of cleaning residue:
a) Flush with high purity deionized water per SSP 30573B, Table 4.1-2.17, and purged with gaseous Nitrogen per SSP 30573B, Table 4.1-2.13, Grade B. Maximum TOC in flush water is 5 ppm.
b) Flushed with ITCS fluid. Maximum TOC in flush fluid is 5ppm.

2) Verify that gases used in contact with ITCS fluid meet a maximum gaseous hydrocarbon concentration of 5 ppm.

3) Verify that ITCS fluid circulated or drained through ITCS flight hardware has a stabilized, maximum TOC of 5ppm, as verified by two, consecutive readings within 0.5ppm. Flushing can be continued until TOC measurement is stable.

4) Verify microbial count (R2A Heterotrophic Plate Count), pH, and silver concentration is measured on ITCS flight hardware with stabilized TOC measurement and is in accordance with SSP 30573B, as applicable. Data to be provided to Boeing Houston Thermal System.

5) Verify that flight hardware containing ITCS fluid for over 30 days are sampled monthly and analyzed for pH, TOC, silver concentration, and microbial count (R2A Heterotrophic Plate Count). ITCS hardware requiring power-up for circulation and sampling shall not be required to have monthly sampling during non-powered time periods. Sampling of such hardware shall occur as soon as possible after next power-up.

6) Verify that a final sample is taken and analyzed in accordance with SSP 30573B, Table 4.1-2.8, with the addition of silver concentration and microbial count (R2A Heterotrophic Plate Count), prior to close-out of ITCS flight hardware. Data shall be recorded as with item 4) above.

7) Verify upon return of hardware from orbit, appropriate sampling of the contained ITCS fluid is conducted with full chemical analysis against the requirements of SSP 30573B, Table 4.1-2.8 "As Circulated in Flight Hardware", plus a microbial count (R2A Heterotrophic Plate Count) (for baseline data) and ammonia concentration. In the event of limited fluid volume for analysis, priority will be given to determination of ammonia concentration, microbial count, and pH. Data to be provided as with item 4) above.

RESOURCES:

CONSTRAINTS: Hardware closed for flight will not be further sampled per the Pass/Fail criteria.

CAUTION:

WARNING:

REMARKS: All MPLMs are exempt from this requirement. The intent of this requirement is satisfied in the MPLM generic OMRS file.

ARCN KEY: 1855

DVO/DTO NUMBER:

IMPLEMENTING ORGANIZATION: NASA-KSC

RCN NO: JA16583R2 A STATUS: P	REQUIREMENTS CHANGE NOTICE TITLE: A2000 - CCAA ITCS FLUID FILL		INTERNAL PROJ. CONT. NO.
OMRS FILE NO: X OMRS VOLUME : 3	OMRS DOCGROUP: A2000	CAT: M STS: 121	RELATED PCIN/ECP/RCN/EO NUMBER

NUMBER	DESCRIPTION	MEAS/STIMU	SPECIFICATION	INTERVALS/CONSTRAINTS/REMARKS
PRESENT				

```
|----------------------------------------------------------------------------------------------------------------------------|
|NUMBER        | DESCRIPTION                              |MEAS/STIMU|  SPECIFICATION      |      INTERVALS/CONSTRAINTS/REMARKS      |
|----------------------------------------------------------------------------------------------------------------------------|
|NEW REVISION                                                                                                                |

A2000MT.010**           -0  CCAA ITCS FLUID FILL                      SSPF                 -0 A:PACCAA
         CRIT: NONE                                                                           B:
A2000MT.010-A           -0  ITCS FLUID PRE-TREATMENT CHARACTERISTICS                       -0 C:C-2: CCAA ITCS LINES SHALL BE
                                                                                           -0   FILLED WITH FLIGHT ITCS COOLANT
        1  -1  VERIFY ITCS FLUID PRIOR TO CHEMICAL                                         -0   USING GSE WITH A STERILE 0.2 MICRON
           -1  TREATMENT (C-4)                                                             -0   FILTER.
           -1  CONDUCTIVITY, 1/OHM-CM                     1.0X10E-6 (MAX.)
           -1  CHLORIDES, PPM                             1.0 (MAX.)                       -0   C-3: TOC CONTENT SHALL BE VERIFIED
           -1  DISSOLVED OXYGEN, PPM                      6.0 (MIN.)                       -0   BY TWO SAMPLE READINGS WITHIN 0.5
           -1  TOTAL ORGANIC CARBON, PPM                  1 (MAX.)                         -0   PPM.

                                                                                           -0   C-4: THE MIXING/STORAGE CONTAINER
A2000MT.010-B           -0  ITCS INITIAL FILL                                              -0   FOR THE ITCS FLUID SHALL BE FILLED
                                                                                           -0   USING GSE WITH A STERILE 0.2 MICRON
        1  -1  VERIFY ITCS FLUID AS DELIVERED TO FLIGHT                                    -0   FILTER.
           -1  INTERFACE (C-2, R-2)
           -1  CHLORIDES, PPM                             1.0 (MAX.)                       -0   R-1: DATA WILL BE FORWARDED TO NASA
           -1  DISSOLVED OXYGEN, PPM                      6.0 (MIN.)                       -0   IATCS AND ECLS SPRT CHAIRMEN AND
           -1  TOTAL ORGANIC CARBON, PPM                  5 (MAX.)                         -0   BOEING HOUSTON IATCS AND ECLS
           -1  SODIUM BORATE, PPM AS B407                 800-1250                         -0   SYSTEMS.
           -1  PH                                         8.5 +/- 0.3
           -1  SAMPLE FOR PRESENCE OF SULFATE-REDUCING    SAMPLE TAKEN                     -0   R-2: FLUSH OF GSE AND SAMPLING FOR
           -1  BACTERIA (SRB). (R-1)                                                       -0   SILVER IS NOT REQUIRED.
           -2  DRAW ITCS FLUID SAMPLE FOR ANALYSIS        SAMPLE SENT
           -2  (R-5)                                                                       -0   R-3: THE BUBBLE SIZE CAN BE
                                                                                           -0   VALIDATED BY ANALYSIS BASED ON
                                                                                           -0   TOTAL WATER THAT ORU HOLDS MINUS A
A2000MT.010-C           -0  FINAL ITCS FLUID SAMPLE                                        -0   REMOVAL OF EQUIVALENT AMOUNT OF
                                                                                           -0   WATER.
        1  -1  VERIFY FINAL ITCS FLUID SAMPLES ARE
           -1  TAKEN FROM THE FLIGHT UNIT (C-3, R-1)                                       -1   R-4: MEASUREMENT WILL BE ACCURATE
           -1  CHLORIDES, PPM                             1.0 (MAX.)                       -1   TO WITHIN 0.1 LB (45 G) OR
           -1  DISSOLVED OXYGEN, PPM                      6.0 (MIN.)                       -1   EQUIVALENT VOLUME.
           -1  TOTAL ORGANIC CARBON, PPM                  5 (MAX.)
           -1  SODIUM BORATE, PPM AS B4O7                 800-1250                         -1   R-5: A SAMPLE WILL BE SENT TO
           -1  PH                                         8.5 +/- 0.3                      -1   BOEING HUNTSVILLE FOR TOTAL AND
           -1  SAMPLE FOR PRESENCE OF SULFATE-REDUCING    SAMPLE TAKEN                     -1   DISSOLVED NICKEL, MICROBIOLOGICAL
           -1  BACTERIA (SRB). (R-1)                                                       -1   ENUMERATION, AND NH3 ANALYSIS.
           -2  DRAW ITCS FLUID SAMPLE FOR ANALYSIS        SAMPLE SENT
           -2  (R-5)                                                                          D:


A2000MT.010-D           -1  DELETED
```

```
A2000MT.010-E           -0  QTY OF H2O ADDED TO HX

       1  -1  DETERMINE THE FINAL QTY OF H2O ADDED TO             MEASUREMENT TAKEN
          -1  THE ORU. (R-1, R-4)

A2000MT.010-F           -0  VOLUME OF BUBBLE ADDED TO CCAA HX

       1  -2  ADD BUBBLE TO THE ORU. (R-1, R-3)                   13 +/- 3 CU IN
          -2                                                      (213 +/- 49 ML)
```

NAME	DATE	RESPONSE	JUSTIFICATION:
			TO CONFIRM COMMON CABIN AIR ASSEMBLY (CCAA) ITCS FLUID FILL IS COMPLETED
INITIATOR & SPONSORS NAME / MAIL CODE / PHONE NO. SCOTT YOUNG/JSC-EC/281-483-7298			RCN IMPACT: INVALIDATES CIL RETENTION RATIONALE _____ YES __X__ NO INVALIDATES HAZARD CONTROLS _____ YES __X__ NO VIOLATES MVP _____ YES __X__ NO RATIONALE FOR INVALIDATION OF CIL RETENTION RATIONALE, HAZARD CONTROLS OR MVP VIOLATIONS...

APPENDIX D—NaOH INJECTION TEST

D.1 Training Procedure Requirements

D.2 Test Requirements Sheet

TEST REQUIREMENTS

IATCS Sodium Hydroxide Injection Kit (INIK) Training

MSFC, Building 4755

March 1, 2002

1.0 Purpose

The development of the Internal Active Thermal Control System (IATCS) Sodium Hydroxide (NaOH) Injection Kit (INIK) has progressed as a means to adjust falling pH levels in the ISS IATCS coolant loops. This test plan describes the specific procedures to execute training for the INIK. The goal of this training is to assess system interfaces and verify the procedure for syringe injection into the IATCS coolant loop. A video recording will be produced as a training tool for on-orbit crew.

1.2 Test Objectives

- ✓ Execute IATCS pH restoration procedures
- ✓ Verify feasibility of methods and interfaces
- ✓ Video record for on-orbit training

1.2 Operating Conditions

Loop Mode	Single during hose fill Single during injection
Flow Rate	3,000 lb/hr
Temperature	61 (±2) °F
Accumulator Pressure	18 psia during fill Atmospheric during injection
Accumulator Level	Must accommodate 140 in^3 of coolant during injection

2.0 Hardware Requirements

Hardware	Provider	Date
IATCS Coolant	Boeing (Huntsville)	2/26/02

Quick Disconnects 3/8" (2 each)	JSC/EC3	TBD
Adapters Syringe Gender Changer 3/8" Orifice FSS-65	 JSC/EC3 JSC/EC3 MSFC/FD21 MSFC/FD21	 TBD TBD 2/27/02 2/27/02
Flex Hoses FSS-64 FSS-70 FSS-74	 MSFC/FD21 MSFC/FD21 MSFC/FD21	 2/27/02 2/27/02 2/27/02
MWA (Glove Box)	JSC/EC3	2/27/02
Syringes	JSC/EC3	TBD
Safety Equipment and Supplies	JSC/EC3	3/1/02

3.0 Test Conduct

- Pre-fill syringes (12 injection + 6 flush)
- Pre-fill the following hardware
  - Orifice Adapter
  - 3/8" Gender Changer
  - FSS-65 Adapter
  - FSS-70 Flex Hose
- Refer to IATCS pH Restore procedure (Attached)

5.0 Safety Considerations

- Safety Equipment provided by JSC/EC3
- NOTE: No Sodium Hydroxide will be used in any portion of this test. All solutions will consist of IATCS coolant.
- CAUTION: This is a working test area. Personnel should remain within designated areas. Some areas will be constricted and will require extra attention to walkways and overhead clearances.

Appendix D.2 ITCS Nickel–pH Effects No. ITCS002RevC
4/11/2002
Ni pH T1.doc
Sam Woodward (Boeing)

Test Requirements Sheet

Date: 4/11/02

Purpose: To generate data by which to assess effects of pH increase in ITCS fluid contaminated with dissolved nickel on ITCS filter and GasTrap.

Special Purpose Test Equipment: ITCS Low Temperature Loop Test bed in MSFC Building 4755. Pre-labled Sample bottles.

Test Prerequisites:

1. A research gas trap P/N PA169479-1-1, shipped 4/2/02 from Honeywell, will have been filled with test fluid, and installed on the Low Temperature Loop (LTL) Pump Package Assy (PPA)
2. Low Temperature Loop (LTL) and Moderate Temperature Loop (MTL) will be configured into a combined "Single Loop" operating mode with a combined volume of 67.5 ± 1 Gallons by calculation. The combined loop will be filled with a representative ITCS water, circulated, and tested to ensure that any original silver content has been depleted and pH is equal to or greater than 7.8±0.2 and Ni content of 8.5 ±1ppm.
3. LTL and MTL shall be operational with the ability to add thermal energy at various points in the system, to remove thermal energy, to adjust loop mix temperatures, and to record system temperatures, flows, pressure, and pressure drops. Each payload/system rack location will be adjusted to provide a flow and heat load through that location to ensure mixing and best similarity to the flight article during this test per Tables II and III attached.
4. A method to introduce approx. 1 gal of 8% NaOH into the system over the course of 2 hours using the PPA fill port (while operating) will be provided for. System will be capable of accepting the additional fluid.
5. Baseline <u>ΔP's across the PPA filter and gas trap</u> will be recorded electronically and logged.
6. Just prior to test, a 100 ml sample of the loop, after circulation, will be taken to establish baseline microbial activity and chemical properties. The PPA Filter will be removed, and drained into a measured beaker. The Gas Trap air outlet flow will be diverted to a tank with an inverted, filled water column. The drained PPA filter will then be slowly reinstalled (¼ turn increments) and the air volume expelled by the gas trap measuered via the inverted column.

Data Required: Event Log, available system flows, pressure, Δp across filter and gas trap, and temperatures, and ITCS fluid samples at the Node 1/Airlock thermal simulator location per the attached ***Table I***.

Test Configurations: Low Temperature Loop (LTL) and Moderate Temperature Loop (MTL) shall be combined with the LTL PPA supplying fluid at a 2700+400-100pph rate for the combined system. LTL mix temperature will be set to 51°F. MTL mix temperature will be set to 63°F. LTL system thermal load will be 1733 ± 10Wof system (excluding ~300 W due to PPA operation) with Payload heat provided as heat load to the LTL loop per the attached Table II. Similarly, 4966 W of system and payload heat load to the MTL loop will be provided per the attached Table III. Where it is not feasible to provide heat or fluid flow in the quantities specified, other rack locations may be used, after consultation and documentation.

Special Instructions:

1. With the LTL PPA providing fluid motion to both MTL and LTL loops, the ITCS will be started, in increments until full test flow is reached to characterize the system and ΔPs, and operated at full flow and pressure until temperatures stabilize.
2. Reduce system pressure to ambient. Attach the NaOH injection assy to LTL PPA fill port and begin injection at 120cc/min for 1 minute and then stop injection for 4 minutes. Repeat this cycle until a total of 22 injections (based on a 67.5 Gallon combined system) is reached. Samples will be taken during and after injections per the schedule of Table I. Injection line should be primed with NaOH prior to first injection.
3. After fluid measurements at 5 hours, the X4 LTL dead run will be jumpered in (jumper with orifice at LAC1) to add its residual volume into the system. At 6 hours and 7 hrs, the X3 LTL (at LAP1) and X2 LTL (at LAS1) will be jumpered in respectively for 1 hour each.
4. Test will operate a minimum of 32 Hours at the ~9.5pH set point. Test apparatus may run over the weekend at reduced flow before proceding to the next step. Following that, fluid measurements and air side gas trap performance will be taken (per prerequisite instruction 7, above).
5. For the second phase, pressure will again be reduced, injection of NaOH (same cycle as before) made to bring system pH to 10.0±0.1 pH. Restore system pressure and operate at the 10 pH set point for 8-24 hours. Samples will be according to Table I. Gas trap performance will be measured at end of test per previous method.
6. Subsequent to test, the LTL PPA filter assy and gas trap assy will be removed and delivered to Boeing Analytical Labs for inspection/analysis. Drained filter will be returned after 1 week for re-integration into Test Bed PPA.

	NaOH ADDITION SAMPLING PLAN				
I	Phase 1 Goal - Add NaOH to pH 7.8 fluid to achieve pH of 9.5				
	Volume of ITCS fluid in Test = ~ 67 gal (single) or 69.8 (dual)				
	Approximate pH = 7.8				
	Amount of 2N NaOH required = 38 mL/gal to achieve a pH of 9.5 from pH of 7.8 for 67 gal				
	total 2N NaOH =		2613	mls total to be injected	
	or a total of	21.775	1 minute pulses		
	Estimated time to inject NaOH = 2 hrs				
	Therefore 2613 mL/2hr =			1306.5	mL/hr
	Or			120.0	mL/min pulsed every 5 minutes
II	Phase 2 Goal - Add NaOH to pH 9.5 fluid to achieve pH of 10				
	After achieving a pH of 9.5, then a second injection (Phase 2) will be made to achieve a				
	pH of 10				
	Additional volume required =		1072	mL estimated as required to achieve pH 10	
	or syringe (pulses) =		8.93	~ 9 syringes	
	Total NaOH Required for Test =		3685	mLs or	0.974868 gallons
III	Target Parameters				
	Fluid Baseline at beginning & end-of-test Parameters = PO4, Cl, borate, Ni, pH, TOC, and TIC				
	During Test Parameters = pH, Total Ni, Dissolved Ni, and Turbidity				
	NOTE: pH, and Turbidity will be monitored on site as time permits to provide feedback on test				
	Sampling locations = Post PPA at Endcone Rack position, and pre-PPA just prior to PPA				

IV	Sampling For PPA Inlet and outlet Ports - Phase 1						
IV	i ■ inlet Sample Port o ■ outlet sample port			Sampling Parameters			
		Syringe	Time (Hr)	pH	Turbidity	T/D NI	All Parameters
	Phase 1						
	Sample after	Syringe #					i
	injection with a	1		i&o	i&o		
	delay time to detn.	2		i&o	i&o		
	pH of fluid from	3		i&o	i&o	i&o	
	addition - TBD Sam	4		i&o	i&o		
		5		i&o	i&o		
		6		i&o	i&o	i&o	
		8		i&o	i&o		
		10		i&o	i&o		
		12		i&o	i&o		
		18		i&o	i&o		
		22	2 hr	i&o	i&o	i&o	
			3 hr	i	i		
			4hr	i	i		
			5 hr	i	i	i	
			6 hr	i	i		
			7 hr	i	i		
	end of shift Test Day1		8 hr	i	i	i	
	Every hr 2nd Day		24 hr	i	i	i	
	8 hr shift		25 hr	i	i		
			26 hr	i	i		
			27 hr	i	i	i	
			28 hr	i	i		
			29 hr	i	i		
			30 hr	i	i	i	
			31 hr	i	i		
			32 hr	i	i	i	
	End of Test (phase 1)						i

V	Sampling For PPA Inlet and outlet Ports - Phase 2						
				Sampling Parameters			
		Syringe	Time (Hr)	pH	Turbidity	T/D NI	All Parameters
	Phase 2						
	Carry to pH 10	1		i&o	i&o	i&o	
		2		i&o	i&o		
		3		i&o	i&o	i&o	
	(Add additional 9	4		i&o	i&o		
	Syringes worth of NaOH)	5		i&o	i&o	i&o	
		7		i&o	i&o		
		9		i&o	i&o	i&o	
			1 hr	i	i		
			2 hr				
			3 hr	i	i	i	
			4 hr	i	i		
			5 hr	i	i		
			6 hr	i	i	i	
			7 hr	i	i		
	End of Test		8 hr	i	i	i	i

Sample Count

pH =	58	58each 50mL sample bottles
Turbidity =	58	
T/D Nickel =	23	
Tot ITCS parameters=	3	3 each 100mL sample bottles
Total Volume Used =	3200	mL or 0.847gal

Table II Lab Rack LTL Heat [W] & Flow [pph] Loads				
#	Port	Overh	Stbd	Deck
1	Empty pl loc	MT PL	Empty Pl Loc	MT Rack
2	MT PL	MT PL	MT PL	MT Rack
3	MT Rack	Empty Pl Loc	Empty PL Loc	Empty pl loc
4	Empty pl loc	Empty Pl Loc	MT PL	MT Rack
5	MT Rack	Empty Pl Loc	MT Rack	MT Rack
6	973W 1230p	MT Rack	0W 0p	ARS inactive
N1,A/L	760 W 484 pph			
Fwd E/C				

Table III Lab Rack MTL Heat [W] & Flow [pph] Loads				
#	Port	Overhead	Stbd	Deck
1	Empty pl loc	538 W 176 pph Express 2	Empty Pl Loc	397 W 117 pph AV#2
2	690 W 197 pph Express 4	430 W 95 pph Express 1	205 W 100 pph HRF	203 W 127 pph AV#3
3	140 W 271 pph DDCU1	Empty Pl Loc	Empty Pl Loc	Empty pl loc
4	Empty PL loc	Empty Pl Loc	Inactive Express 5	115 W 132 pph CheCS
5	100W 103 pph MSS#2	Empty Pl Loc	113 W 106 pph MSS#1	240 W 123 pph AV#1
6	LT PPA CCAA	217 W 273 pph DDCU#2	MT PPA CCAA	0W 132 pph ARS
N1,A/L	420 W 200 pph			
Fwd E/C	685 W 278 pph			
Aft E/C	473 W 236 pph			

APPENDIX E—CALCULATIONS

E.1 Ammonia Permeation Through Teflon Hoses

E.2 Glutaraldehyde Antimicrobial Engineering Analysis

E.1 Ammonia Permeation Through Teflon Hoses—Jay Perry (2004)

Where

$$P = 1.75 \times 10^{-7} \frac{\text{cm}^3 \cdot \text{mm}}{\text{cm}^2 \cdot \text{atm} \cdot \text{s}} \text{ at } 29.3\ ^\circ\text{C}$$

$$N = P \frac{(p_1 - p_2)}{\ell}$$

$$N = \text{permeation flux } \left(\frac{\text{cm}^3}{\text{s} \cdot \text{cm}^2}\right)$$

$$P = \text{permeability } \left(\frac{\text{cm}^3 \cdot \text{cm}}{\text{cm}^2 \cdot \text{s} \cdot \text{cmHg}}\right)$$

p = pressure (cmHg)

ℓ = thickness (cm)

Convert P:

$$P = \left(1.75 \times 10^{-7}\right) \frac{\text{cm}^3 \cdot \text{mm}}{\text{cm}^2 \cdot \text{atm} \cdot \text{s}} \frac{\text{atm}}{76 \text{ cmHg}} = 2.303 \times 10^{-9} \left(\frac{\text{cm}^3 \cdot \text{mm}}{\text{cm}^2 \cdot \text{s} \cdot \text{cmHg}}\right)$$

½-in hose:

$$\ell = 0.119 \text{ in } \left(\frac{2.54 \text{ cm}}{\text{in}}\right) = 0.301 \text{ cm}$$

$$p_1 = 0.59 \text{ ppm } \left(\frac{0.41 \text{ mg}}{\text{m}^3}\right) \frac{1\,\%}{10{,}000 \text{ ppm}} = 5.9 \times 10^{-5} \left(\frac{\%}{100}\right) 76 \text{ cmHg} = 4.48 \times 10^{-5} \left(\text{cmHg}\right)$$

$$p_2 = 0$$

$$N_{\frac{1}{2}} = 2.303 \times 10^{-9} \left(\frac{4.48 \times 10^{-5} - 0}{0.301}\right) = 3.43 \times 10^{-13} \left(\frac{\text{cm}^3}{\text{s} \cdot \text{cm}^2}\right)$$

1-in hose:

$$\ell = 0.1525 \text{ in} \left(\frac{2.54 \text{ cm}}{\text{in}}\right) = 0.387 \text{ cm}$$

$$N_1 = 2.303 \times 10^{-9} \left(\frac{4.48 \times 10^{-5} - 0}{0.387}\right) = 2.67 \times 10^{-13} \left(\frac{\text{cm}^3}{\text{s} \cdot \text{cm}^2}\right)$$

LTL:

$$L_1 = 1{,}224 \text{ in} = 3{,}108.98 \text{ cm}$$

$$OD_1 = 1.290 \text{ in} = 3.2766 \text{ cm}$$

$$A_1 = \pi \cdot OD \cdot L_1 = 10{,}186.82 \text{ cm}^2$$

$$L_{\frac{1}{2}} = 760 \text{ in} = 1{,}930.4 \text{ cm}$$

$$OD_{\frac{1}{2}} = .755 \text{ in} = 1.9177 \text{ cm}$$

$$A_{\frac{1}{2}} = 3{,}701.93 \text{ cm}^2$$

References:

1. Perry, Robert H., and Don Green, *Perry's Chemical Engineers' Handbook*, 6th ed., McGraw-Hill, Inc., New York, p. 17-15, 1984.

2. Treybal, Robert E., *Mass-Transfer Operations*, 3rd ed., McGraw-Hill, Inc., New York, pp. 93–94, 1980.

Note: All volumes are at standard temperature and pressure; i.e., 273 K and 1 atm.

$$V = \left(3.43 \times 10^{-13}\right)\left(3{,}701.93\right) + \left(2.67 \times 10^{-13}\right)\left(10{,}186.82\right) = 3.99 \times 10^{-9} \ \frac{\text{cm}^3}{\text{s}}$$

$$p = \frac{MP}{RT} = \frac{(17)(1 \text{ atm})}{(82.06)(273 \text{ K})} = 0.000759 \frac{\text{g}}{\text{cm}^3}$$

$$V = \left[\left(3.99 \times 10^{-9}\right)\frac{\text{cm}^3}{\text{s}}\right]\left[0.000759\left(\frac{\text{g}}{\text{cm}^3}\right)\left(1{,}000 \frac{\text{mg}}{\text{g}}\right)\left(3{,}600 \frac{\text{s}}{\text{h}}\right)\left(24 \frac{\text{hr}}{\text{day}}\right)\right]$$

$$V = 0.000262 \frac{\text{mg}}{\text{day}}$$

$$V = \left(0.07 \frac{\text{mg}}{\text{L}}\right) 27 \text{ gal}\left[\frac{1{,}000 \text{ L}}{264.17 \text{ gal}}\right] = 7.15 \text{ mg}$$

$$t = 27{,}343 \text{ days} = 74.9 \text{ yr}$$

National Aeronautics and
Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

June 9, 2004

Reply to Attn of: FD21(04-086)

TO: ED25/J. M. Holt

FROM: FD21/J. L. Perry

SUBJECT: Compatibility of a Candidate Internal Thermal Control System Biocide with the *International Space Station's* Environmental Control and Life Support System

At the request of the Internal Active Thermal Control System (IATCS) problem resolution team, an engineering assessment has been conducted to fully understand the Environmental Control and Life Support (ECLS) system-related impacts associated with changing the IATCS biocidal additive from silver to glutaraldehyde. A narrative report documenting this assessment is attached. The assessment was conducted according to standard practice for assessing the environmental impacts of payloads and within the bounds set by *International Space Station* (*ISS*) Program specifications for trace contaminant control.

Because the specification of the active trace contaminant control equipment for any spacecraft precedes those data necessary to fully validate its design, standard design practice dictates an approach whereby the active contamination control system performs its function unassisted by any other systems or processes in the cabin. This means that overboard atmospheric leakage and assists provided by other air processing systems such as CO_2 removal and humidity control equipment are not considered during the design and validation of the active trace contaminant control equipment. To maintain consistency, all new contamination loads are assessed in the same manner.

Within the context of *ISS* Program requirements, an additional loading of a chemical compound not contained in the design listing provided in SSP-41000Y, SSP-41162AN, or S683-29523P constitutes a new, specific verification case. Therefore, this verification is constrained to consider only the active contamination control systems on board the *ISS*, unassisted by other serendipitous removal, for maintaining the added contamination load below individual compound spacecraft maximum allowable concentrations (SMACs). This maintains consistency with the active contamination control equipment's certification.

Specific findings from the detailed evaluation of glutaraldehyde as a candidate biocidal additive to the IATCS working fluid relating directly to contamination control equipment certification are the following:

1. Evaporation rates from concentrated aqueous solutions of glutaraldehyde are such that appropriate containment and personal protective equipment must be used when injecting the solution into the IATCS.

2. Basic, unassisted trace contaminant control capability as defined by *ISS* Program specification cannot accommodate the range of IATCS leakage rates for any glutaraldehyde concentration in the IATCS fluid. Therefore, the *ISS* active contamination control systems cannot be certified to control glutaraldehyde emissions into the cabin within the range of IATCS leakage specification.

Additional effort was undertaken by expanding the assessment's scope to address the fate of glutaraldehyde within the *ISS* cabin environment to address and understand the impact upon all ECLS system processes—both atmospheric and water processing. This expansion considers an assist to the basic contamination control equipment provided via absorption by humidity condensate and the operation of contamination control equipment in the Russian On-orbit Segment (ROS). Contamination control system failure scenarios are also considered. Findings from the expanded evaluation are the following:

1. The combined ECLS trace contaminant control and water processing systems cannot be certified for IATCS fluid concentrations >25 mg/liter glutaraldehyde. If no other suitable additive can be found, however, glutaraldehyde concentrations <25 mg/liter may be used, based upon the IATCS fluid leakage specification, to ensure long-term hazards to human health and ECLS system air quality control and water processing equipment are acceptable.

2. Any decision by the *ISS* Program to use glutaraldehyde as a biocidal additive to the IATCS fluid in the USOS must be reviewed by the International Partners within the Common Environments Team forum. This is necessary because fugitive emissions from the IATCS effect the common cabin environment and require removal by contamination control equipment on board the ROS to ensure acceptable cabin air quality is maintained.

Overall, measures must be taken to minimize the risk to human health and maintaining the *ISS's* cabin air quality as well as protecting the water processing systems. Although the active contamination control systems have proven themselves reliable, they are designed specifically to control the contamination loading from equipment offgassing and human metabolic processes alone. They are not designed to serve as a hazard control for chronic or acute chemical releases into the cabin. It should be noted that cabin air quality monitoring techniques employed by the *ISS* Program are not sensitive enough to monitor glutaraldehyde's concentration at or below the 180-day SMAC. Therefore, it is not possible to verify cabin air quality maintenance via existing monitoring techniques.

Based upon *ISS* ECLS engineering evaluation, it is found that the overall challenges and risks associated with using glutaraldehyde as a biocidal additive are significant and present long-term operational issues to the *ISS* Program if implemented. Therefore, it is recommended that other candidate biocidal additives be evaluated and a suitable alternative to glutaraldehyde selected. If no suitable alternative can be found, it is recommended that the existing silver additive or glutaraldehyde at concentrations <25 mg/liter be used on a periodic basis. Further, if glutaraldehyde is ultimately selected, its use must be reviewed and approved by the International Partners within the Common Environments forum.

Please contact me at 544-2730 concerning details of this assessment.

/original signed/
Jay L. Perry
Senior Engineer
ISS Air Quality Control Systems
Environmental Control and Life Support Group

Attachment

cc:

FD01/A. Lavoie/R. Goss
FD20/S. Croomes
FD21/R. Bagdigian/R. Carrasquillo/D. Holder/D. Carter
FD21/J. Perry/M. Roman/P. Wieland
ED25/L. Turner

NASA JSC:

EC6/D. Williams/J. Lewis/K. Prokhorov/B. Shkedi/G. Rankin
OB2/A. Sang
SF2/N. Packham/J. James/H. Garcia/P. Mudgett
ES4/M. Pedley

NASA Engineering Analysis Report

Compatibility of a Candidate Internal Thermal Control System Biocide with the *International Space Station's* Environmental Control and Life Support System

J. L. Perry

George C. Marshall Space Flight Center
Flight Projects Directorate

June 2004

NASA ENGINEERING ANALYSIS

COMPATIBILITY OF A CANDIDATE INTERNAL THERMAL CONTROL SYSTEM BIOCIDE WITH THE *INTERNATIONAL SPACE STATION'S* ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM

BACKGROUND

The *International Space Station's* (*ISS*) active thermal control system (ATCS) presently uses silver as a biocidal additive in the internal water working fluid. The silver concentration in the fluid declines within a few days as silver deposits upon metal surfaces, but microbial control is maintained by the specified 9.5 pH. Samples returned from flight have indicated that the internal ATCS fluid chemistry is affected by the on-orbit environment. Decreased pH and other changes have been traced to CO_2 permeation through the Teflon® flex hoses. Due to the combination of lower pH and lower biocidal additive concentration in the fluid concerns exist that microbially-induced corrosion (MIC) rates for internal ATCS wetted components may have increased, particularly for heat exchangers and cold plates.

The concern about MIC has led to a search for an alternative biocidal additive. Beyond periodically injecting more silver biocidal additive, hydrogen peroxide and glutaraldehyde are being considered as candidates.[1, 2] Material compatibility testing for glutaraldehyde has been completed while more work is pending for hydrogen peroxide. Since work to evaluate glutaraldehyde's suitability has reached a more advanced stage, a change request, SSCN 008447, was prepared that sought to implement glutaraldehyde on board the *ISS* U.S. On-orbit Segment (USOS).

One supporting basis for proceeding with the change request was an assessment of glutaraldehyde's toxicity hazard rating that stated that environmental control and life support (ECLS) system "charcoal filters should efficiently remove" glutaraldehyde vapors.[3] While a correct statement, it was not quantified and does not address the overall capability to control glutaraldehyde's concentration to below its 180-day spacecraft maximum allowable concentration (SMAC) of 0.002 mg/m^3. This SMAC is the lowest documented in JSC 20584. Chemical compounds with a very low SMAC are typically difficult for the ECLS system to control if persistent generation sources exist because the total effective flow rate through the contamination control equipment is limited. That is, active contamination control equipment on board the *ISS* is accomplished using fixed flow devices. The primary means for maintaining cabin concentration below the SMAC in such cases then becomes source control. With this in mind, an engineering assessment has been conducted to address the ECLS system's capability to accommodate routes by which glutaraldehyde can enter the cabin environment if it is employed as a biocidal additive to the internal ATCS working fluid.

Spacecraft Trace Contaminant Control Design Practice

Designing for spacecraft cabin trace contaminant control requires substantial design activity within the confines of the air quality standard. In the case of crewed spacecraft, that standard is the SMAC. Materials selection and control, hardware design, manufacturing processes, chemical process design, mission characteristics as well as crew size and activities are only a few of elements that must occur within the constraints of the air quality standards. A change to any of these, as is the case of a change in a thermal control system working fluid from a nonvolatile, inorganic silver ion biocidal additive to a semi-volatile, organic additive, can have an impact upon cabin atmospheric quality, to the ECLS system equipment, or both. A complete assessment by ECLS engineering is required when such changes are proposed to ensure any potential impacts to the cabin environment, as well as the ECLS system equipment, are negligible.

Because the specification of the active trace contaminant control equipment for a spacecraft precedes those data necessary to fully validate its design, standard design practice dictates a conservative approach whereby the active contamination control system performs its function unassisted by any other systems or processes in the cabin.[4] This means that overboard atmospheric leakage and assists provided by other air processing systems such as CO_2 removal and humidity control equipment are not considered during the design and validation of the active trace contaminant control equipment. To maintain consistency, 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). In summary, these requirements state that trace contaminants shall be controlled to less than their respective SMAC for a normal equipment offgassing 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 offgassing and crew metabolic processes to less than 90% of individual contaminant SMACs.[5, 6, 7] 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 or payloads 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 or payloads.

Within the context of requirements, an additional loading of a chemical compound not contained in the design listing provided in SSP-41000Y, SSP-41162AN, or S683-29523P constitutes a new, specific verification case. As such, this verification must assume that only the active contamination control systems on board the *ISS* remove the added contamination load. This maintains consistency with the equipment's certification. It is informative to expand the assessment, however, to address the fate of the contamination to ensure that the impact upon all ECLS system processes—both atmospheric and water processing—are addressed.

APPROACH

Two basic assessments comprise the evaluation of glutaraldehyde's compatibility with the *ISS's* ECLS system. Concentrated aqueous solutions will be injected into the internal ATCS if glutaraldehyde's use as an alternative biocidal additive is implemented. Therefore, the first is an assessment of a bulk release of candidate stock solutions containing either 5% or 50% glutaraldehyde by mass. An additional subset of the first assessment is a case that considers a bulk release of 0.025% aqueous solution is considered as a gross leak from an internal ATCS failure. Second, is an assessment of the *ISS* ECLS system's capability to handle chronic, fugitive leaks from the internal ATCS for various concentrations of glutaraldehyde. This second assessment considers the ability of the ECLS atmospheric quality control equipment to accommodate chronic emissions from a range of internal ATCS leakage rates and glutaraldehyde concentrations. Appropriate equations and calculation techniques are developed to address these assessment cases.

Evaporation Rate

Estimating evaporation rate from a gross leak of stock solution or internal ATCS working fluid is accomplished using calculation techniques documented in the literature and employed by the U.S. Environmental Protection Agency (EPA) for assessing environmental impacts of chemical spills. Two equations are employed for calculating evaporation rate and the average result used for the purposes of this assessment. These equations require information on air velocity, vapor pressure, molecular weight, and leaked surface area. Equation 1 calculates the evaporation rate, q, in kg/s.[8]

$$q \cong (5.23\times10^{-9})U_S^{0.78} P_V M_W^{0.67} A_P^{0.94} \tag{1}$$

In Equation 1, U_S is air velocity in m/s, P_V is vapor pressure in N/m^2, M_W is molecular weight in g/mole, and A_P is leaked pool surface area in m^2. Similarly, Equation 2 estimates evaporation rate, *QR*, in lb/minute.[9] In Equation 2, *M* is molecular weight in g/mole, *A* is the leaked pool surface area in ft^2, T is absolute temperature in Kelvin, P_V is vapor pressure in mm Hg, and *u* is air velocity in m/s.

$$QR = \frac{0.284u^{0.78} M^{2/3} AP_V}{82.05T} \tag{2}$$

Both Equations 1 and 2 are used to estimate the evaporation rate from a leaked volume of a fluid with the average result from the two equations serving as the final estimate.

Cabin Mass Balance

Assessing the capability of the atmospheric quality control systems on board the *ISS* to effectively control glutaraldehyde concentration in the cabin as a result of fugitive emissions to below specified limits requires two stages. The first assumes the entire *ISS* cabin is a well-mixed volume and that the effective removal term, $\Sigma\eta v$, remains constant with time. This makes the solution of the basic mass balance equation, shown by Equation 3, fairly simple. The solved form of the equation is shown by Equation 4. Reference 10 documents the derivation of Equation 4. In Equations 3 and 4, *m* is the contaminant mass at time, *t*; m_o is the contaminant mass at time equal to zero; *V* is cabin volume; $\Sigma\eta v$ is the contaminant removal capacity; g is the contaminant generation rate; and t is time.

$$\frac{dm}{dt} = g - \left(\frac{\sum \eta v}{V}\right)m \tag{3}$$

$$m = m_o e^{-\left(\sum \eta v / V\right)t} + \left(gV / \sum \eta v\right)\left[1 - e^{-\left(\sum \eta v / V\right)t}\right] \tag{4}$$

The second stage assumes that in the case of a fugitive emission, conditions approach those of a steady state. At steady state conditions, Equation 4 reduces to a very simple form involving only the generation rate, cabin volume, and effective removal terms as shown by Equation 5.

$$m = gV / \sum \eta v \tag{5}$$

The second stage requires conducting a more rigorous mass balance on both the USOS and ROS to examine the effects of either the loss of ventilation flow between the USOS and ROS or the failure of active contamination control systems in either segment. As well, this assessment will provide a more detailed insight of the effects upon humidity condensate loading. This more rigorous mass balance requires the simultaneous solution of the mass balance equations for each individual segment. The mass balance equations for the USOS and ROS are provided by Equations 6 and 7, respectively. These equations define the change in contaminant mass as a function of time.

$$\frac{dm_U}{dt} = \frac{\dot{v}_R}{V_R} m_R - \frac{\dot{v}_U}{V_U} m_U - \frac{\sum \eta v}{V_U} m_U + g_U \tag{6}$$

$$\frac{dm_R}{dt} = \frac{\dot{v}_U}{V_U} m_U - \frac{\dot{v}_R}{V_R} m_R - \frac{\sum \eta v}{V_R} m_R + g_R \tag{7}$$

In Equations 6 and 7, m_U is the total mass of contaminant in the USOS, m_R is the total mass of the contaminant in the ROS, V_U is the USOS free volume, V_R is the ROS free volume, $\dot{v}_U$ is the intermodule ventilation flow from the USOS to ROS, $\dot{v}_R$ is the intermodule ventilation flow from the ROS to USOS, $\Sigma\eta v$ is the removal capacity in the respective segment, g_U is the generation rate in the USOS, and g_R is the generation rate in the ROS.

Simultaneous solution of Equations 6 and 7 provide an equation for each segment in the form of Equation 8. Details concerning the solution are provided in Appendix A. In Equation 8, *m* is the total mass of contaminant in the reference cabin volume; α, β, and γ are constants calculated from the segment cabin free volume, ventilation flow, removal capacity, and contaminant generation rate; and x_2 and x_3 are constants. The integration constants are calculated from the segment free volume, ventilation flow, and removal capacity parameters. Concentration is calculated by simply dividing the contaminant mass by the segment free volume.

$$m = \alpha + \beta e^{x_x t} + \gamma e^{x_3 t} \tag{8}$$

If the entire cabin volume is assumed to be well mixed, or each segment is isolated, the total cabin mass balance equation can be defined more simply as Equation 4.

Cases Considered

Cases considered include several scenarios involving substantial leaks of stock solution as well as a range of fugitive emissions encompassing the range of leakage from the internal ATCS by specification. Effects upon the ability to maintain cabin air quality for the specified range of internal ATCS fluid leakage presented by normal operation of the trace contaminant control equipment on board the *ISS* and failure scenarios of this equipment are also considered.

<u>Evaporation Rate</u>

Evaporation rates were evaluated from a 1-liter spill of 5% aqueous glutaraldehyde, 100 ml of 50% aqueous glutaraldehyde, and 3.8 liters of 0.025% glutaraldehyde. All cases were evaluated at 20º C. The last case was also evaluated at 4.4º C because that case represents leakage from the internal ATCS while operating and the fluid would initially be at a lower temperature before warming to the cabin temperature. In all cases, it is assumed that the spill takes the form of a sphere as the minimum energy shape.

<u>Control of Fugitive Emissions</u>

Initial screening was conducted using Equation 5 to understand the effects of not only internal ATCS fluid leakage rate but also the glutaraldehyde concentration and available active contamination control capacity upon cabin atmospheric quality. The assessment bounds the capability dictated by specification documents and also assists in evaluating the potential impacts upon water processing systems. The leakage rates and concentrations listed in Table 1 were investigated. In addition, leakage rates of 0.2 mg/h and 2.7 mg/h were investigated because actual fluid leaks of these magnitudes have been experienced. Additional details on internal ATCS fluid leakage specifications defined by the internal ATCS System Problem Resolution Team (SPRT) are provided by Appendix B.

The initial concept involved using 250 mg glutaraldehyde/liter; however, subsequent review focused upon either 100 mg glutaraldehyde/liter or 50 mg glutaraldehyde/liter in the internal ATCS fluid. These latter concentrations are the focus for cases that consider a more rigorous cabin mass balance based upon Equations 6 and 7. Using the appropriate numerical values for the system variables in the solved form of Equation 8 for the USOS and ROS, the effects of various leakage rates of internal ATCS fluid containing either 100 mg/liter or 50 mg/liter glutaraldehyde on cabin atmospheric quality and humidity condensate loading were assessed.

Table 1. Internal ATCS Leakage Rates and Candidate Biocide Concentrations Investigated

PARAMETER	MAGNITUDE					
Leakage Rate (ml/h)	0.16	1.6	3.9	4.8	5.3	14.7
Biocide Concentration (mg/liter)	25	50	100	150	200	250

Vehicle Configuration

Two vehicle configurations are considered—the configuration as of Flight 4R and the *ISS* assembly complete 6-person crew capability. Estimated total cabin free volume for the 4R configuration is 371 m^3 comprised of the USOS free volume of 190.4 m^3 and the ROS free volume of 180.6 m^3. The U.S. assembly compete configuration expands the USOS volume to include the Japanese Experiment Module, Columbus Module, Centrifuge Accommodation Module, Node 2, and Node 3. It is assumed that the ROS volume will not change appreciably to accommodate the 6-crew capability; therefore, the total *ISS* free volume will increase to approximately 928 m^3 as a result of the USOS free volume increasing to approximately 747.4 m^3. The Flight 4R configuration cases consider the present crew size of 2 people while the *ISS* assembly complete 6-crew capability cases consider only a crew of 3. Using only a crew of 3 for the assembly complete case is considered a greater challenge to overall trace contaminant control because the crew latent load is smaller than for the 6-person crew size. It is anticipated that a checkout period during assembly complete will have a 3-person crew.

In both the Flight 4R and assembly complete configurations, the TCCS and BMP provide the active contamination control on board the *ISS*. During both *ISS* assembly stages, the TCCS and BMP operate in parallel with each other to maintain the cabin atmospheric quality. The TCCS removes glutaraldehyde at 100% efficiency in its charcoal bed assembly. If the charcoal bed assembly becomes saturated, then the TCCS will remove the glutaraldehyde via its catalytic oxidizer assembly. The flows through the charcoal bed assembly and catalytic oxidizer assembly are 15.3 m^3/h and 4.6 m^3/h, respectively. The BMP removes glutaraldehyde at 100% efficiency at 27 m^3/h flow. This performance is estimated based upon activated charcoal's capacity for glutaraldehyde. Net intermodule ventilation (IMV) flow between the ROS to the USOS is typically 180 m^3/h. No attempt is made to account for the effects of IMV flow short circuiting. The challenges presented by failures of the TCCS and BMP, either individually or at the same time, are considered.

Absorption by Humidity Condensate as a Removal Device

In addition to removal by the active contamination control equipment, water soluble contaminants are also removed by absorption in humidity condensate. As noted earlier, the assist provided to the active contamination control equipment on board the *ISS* is considered only to address potential impacts to water processing systems. Absorption via humidity condensate is not considered when evaluating the capability for the active control systems to accommodate a new contaminant loading.

The primary condensate removal for the Flight 4R configuration is provided by the SKV in the ROS. Typical flow rate through the heat exchanger core is 144 m^3/h. The condensate loading normally ranges between a 3-person and 2-person latent load depending upon the crew size. Removal efficiency via absorption by humidity condensate is 86% for a 2-person latent load and 91% for a 3-person latent load. The calculation technique for estimating condensate absorption efficiency is documented by References 11 through 13. An average latent load is defined as 1.4 liters/day/person.

For the *ISS* assembly complete 6-person crew capability, the most challenging case exists during the time when the crew is limited to 3 people. The combination of added internal ATCS fluid loops and limited trace contaminant control scrubbing capacity are most severe during this time. It is assumed for these cases that a 2-person latent load is removed by the SKV and a 1-person latent load is removed by a CCAA in the USOS. At this rate of humidity condensate collection, the single pass removal efficiency is approximately 55% for the CCAA. Removal efficiency for the SKV is 86% as noted previously.

It must be noted that deviations from ideal Henry's Law behavior, as reported by References 12 and 13 are not accounted for in this assessment because specific data on glutaraldehyde are not available. For this reason, this aspect of the assessment is not conservative.

RESULTS AND DISCUSSION

The following discussion presents and discusses results for estimated evaporation rates from stock solutions, basic control of cabin atmospheric quality under varying internal ATCS fluid leakage conditions, and effects upon humidity condensate loading. Guidelines are presented for maintaining 2-failure tolerance with respect to ECLS atmospheric quality and water quality control functions.

Evaporation from Bulk Leakage

Evaporation rates from 1-liter of 5% aqueous solution, 100-ml of 50% aqueous solution, and 3.8-liters of 0.025% aqueous solution were calculated using Equations 1 and 2. The elapsed time to reach the 180-day SMAC is also calculated assuming no removal during the period of release. This is a standard, conservative approach to evaluating the time to reach the 180-day SMAC.

For the first case, the calculated evaporation rate is 3.5 mg/h. At this rate, the time to reach the 180-day SMAC in the USOS is 6.6 minutes. If allowed to disperse throughout the entire *ISS* cabin, the 180-day SMAC is reached in 13 minutes. As expected, the second case shows that the more concentrated solution gives the crew less time to react. The calculated evaporation rate from the 100-ml release of 50% aqueous solution is 9.9 mg/h. At this rate, the 180-day SMAC can be reached in the USOS within 2.3 minutes and for the entire *ISS* cabin within 4.5 minutes. Evaporation from the dilute solution containing 0.025% glutaraldehyde is 0.054 mg/h. At this rate, the 180-SMAC is reached within 7 hours in the USOS and 14 hours for the entire *ISS*.

Based upon the evaluation of evaporation rate, appropriate containment is required for any operation that involves handling aqueous glutaraldehyde solutions in the cabin. Also, depending upon the prevailing glutaraldehyde concentration in the internal ATCS fluid, evaporation from fugitive emissions is considered to be a concern making the rapid detection and remediation of any leak highly important to maintaining the *ISS's* cabin air quality. Evaporation from a 3.8-liter release of fluid (0.01 mg/h) is equivalent to the amount of glutaraldehyde introduced into the *ISS* cabin by a continuous 0.2 ml/h leak. Leaks of approximately 0.2 ml/h and 2.7 ml/h have been experienced on board the *ISS*.

Control of Fugitive Emissions

The ability to maintain cabin air quality in the presence of fugitive emissions must first consider the available equipment for actively removing the contamination. Figures 1 and 2 illustrate the overall scrubbing flow required to accommodate a range of internal ATCS fluid leakage containing 50 mg/liter and 100 mg/liter glutaraldehyde. These glutaraldehyde concentrations are considered to be the most likely implemented if approved by the *ISS* Program. Leakage rates of 3.9 ml/h and 5.3 ml/h most likely can be sustained for about 1 month while deliberating the need to shut down an internal ATCS fluid loop. For these leakage rates, Figures 1 and 2 show that effective removal flow rate ranges of 95 – 130 m^3/h and 195 – 265 m^3/h are necessary to maintain the concentration in the cabin below the 180-day SMAC for 50 mg/liter and 100 mg/liter glutaraldehyde in the fluid. This is far greater than the 15.3 m^3/h provide by the TCCS alone. The BMP provides an additional 27 m^3/h and removal via absorption by humidity condensate can vary.

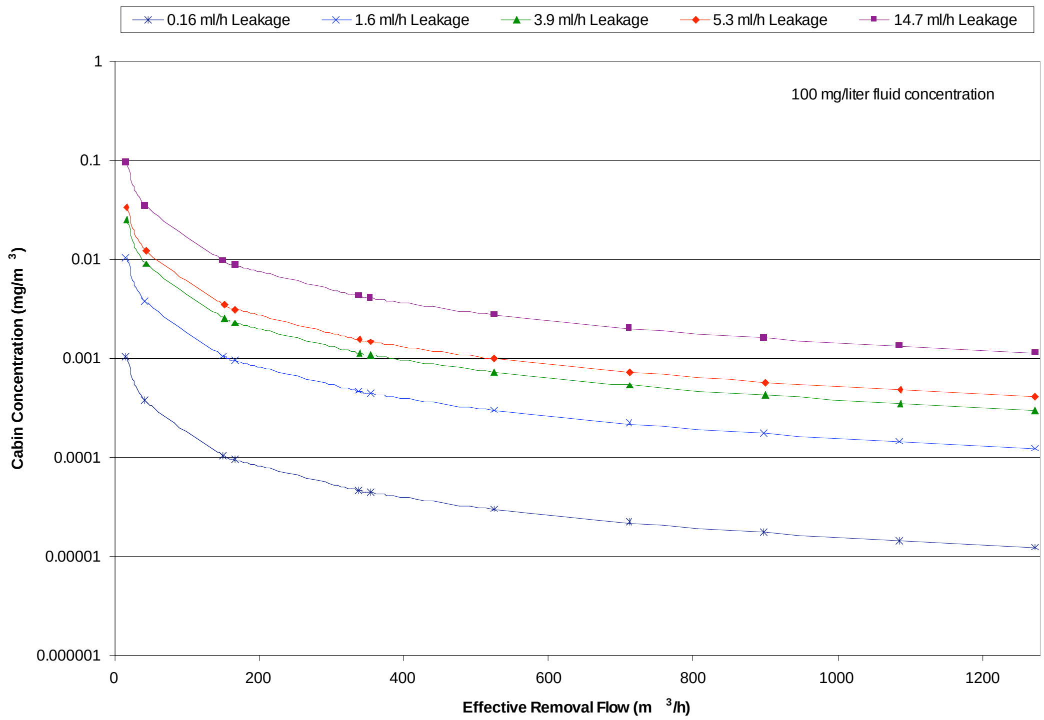


Figure 1. Effective Removal Flow to Maintain SMAC for 100 mg/liter Glutaraldehyde

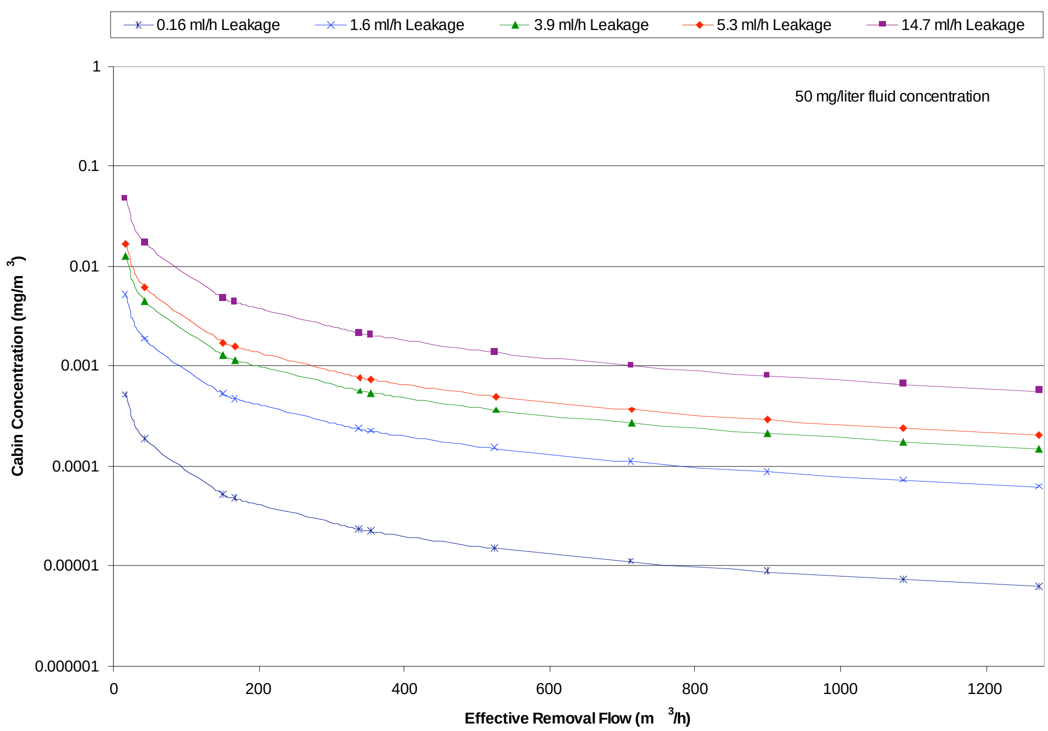


Figure 2. Effective Removal Flow to Maintain SMAC for 50 mg/liter Glutaraldehyde

Trace contaminant control for the *ISS* USOS was certified by engineering analysis using the constraint that the TCCS, with no assist from the Russian BMP or removal via absorption in humidity condensate, provides active control. Because any new contamination source represents an extension of the specified trace contaminant control design load, each new source is evaluated using the same criterion. This ensures that the same levels of safety apply for any known increase in the trace contaminant load. For information the assist provided to the TCCS by both the BMP and removal via absorption in humidity condensate are included. The additional cases allow the potential impact upon ECLS system water processing systems to be estimated; however, they do not serve as the primary basis for assessing trace contaminant control capacity for normal operations.

USOS TCCS Capability

A range of internal ATCS working fluid leakage rates and glutaraldehyde concentrations were evaluated. Figure 3 shows the steady state concentration that results when the TCCS provides the sole active removal. The TCCS, when operating alone, can provide effectively control for a glutaraldehyde source of no greater than 0.03 mg/h and still maintain the cabin concentration below the 180-day SMAC. This capability is equivalent to a sustained leakage from the internal ATCS up to 1.1 ml/h for 25mg/liter glutaraldehyde in the fluid. As the fluid's glutaraldehyde concentration increases, the magnitude of the sustained leak accommodated by the TCCS decreases to as low as 0.11 ml/h for 250 mg/liter glutaraldehyde in the fluid. These rates are much lower than those allowed for the internal ATCS by specification. Also, these rates are lower than the nearly 0.2 ml/h and 2.7 ml/h leakage rates that have been experienced on board the *ISS.*

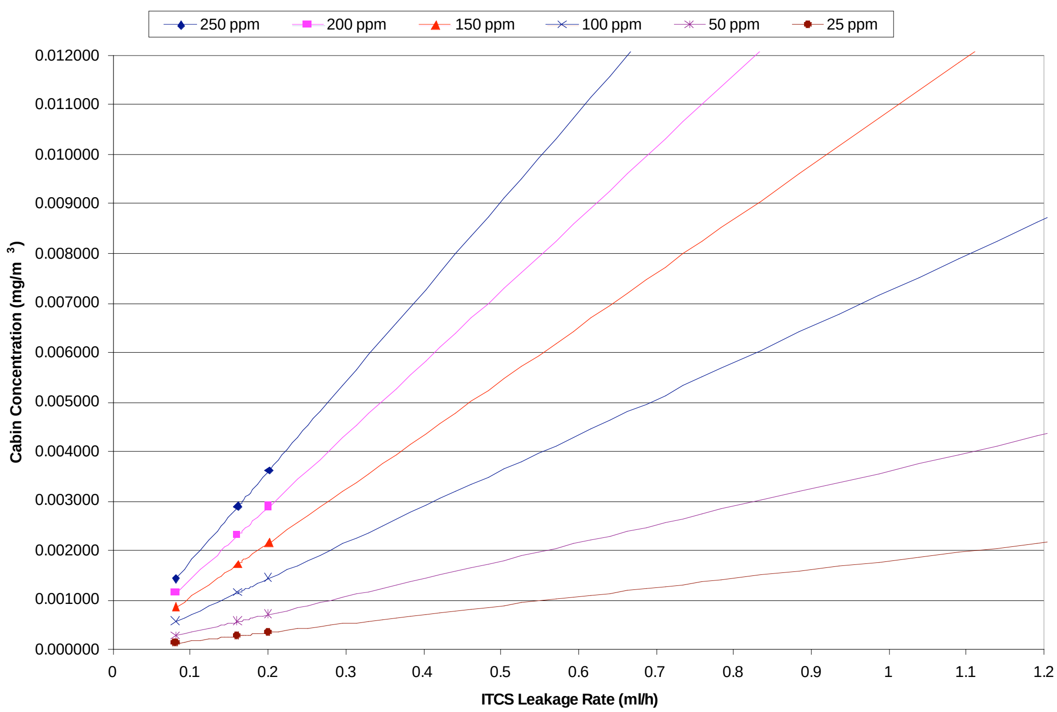


Figure 3. Leakage Accommodated by the USOS TCCS

TCCS and BMP Dual Capability

For the TCCS operating with an assist from the ROS's BMP, the range of leakage accommodated increases by nearly a factor of 3. Figure 4 shows that up to 3 ml/h and 0.3 ml/h fluid leakage can be accommodated for 25 mg/liter and 250 mg/liter glutaraldehyde in the fluid, respectively. This range of leakage rates is comparable to that observed on board the *ISS*.

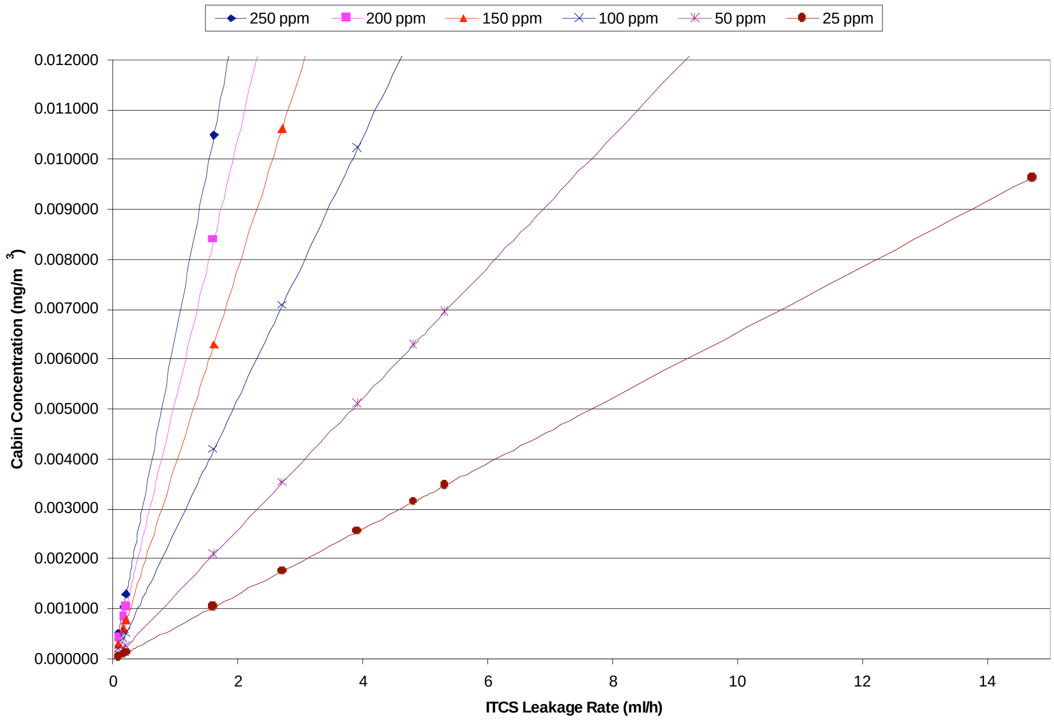


Figure 4. Leakage Accommodated by the USOS TCCS and ROS BMP

Absorption via Humidity Condensate and Impacts to Water Processing Equipment

Figure 5 shows the additional capability that absorption via humidity condensate provides. A single common cabin air assembly (CCAA) heat exchanger removing condensate at a 1-person equivalent latent load can remove glutaraldehyde via absorption at 55% efficiency. Similarly, the SKV heat exchanger on board the ROS can remove glutaraldehyde at 75% efficiency while removing condensate at a 1-person equivalent latent load. This increases to 86% for a 2-person latent load. Leakage ranging from 2.5 ml/h to nearly 13 ml/h leakage can be accommodated for 250 mg/liter and 50 mg/liter glutaldehyde in the fluid, respectively. The 25 mg/liter glutaraldehyde concentration is accommodated across the full range of specified and observed leakage.

It is evident that removal via absorption by humidity condensate provides an effective assist to the active contamination control equipment. This is vividly illustrated by Figure 6 where the capabilities for the TCCS and BMP operating alone and when assisted by varying removal via absorption in humidity condensate are compared. The removal via absorption provided by a 2-person latent load can increase the capacity by more than a factor of 5 and a latent load equivalent to 3 people more than doubles that. While obviously effective, the impacts to water processing equipment must be accounted for. Water processing equipment engineers from both NASA and RSC Energia have indicated glutaraldehyde in humidity condensate must not exceed 5 mg/liter. Figures 4 and 5 show the effect that varying cabin concentration and crew latent load can have upon humidity condensate loading for the CCAA and SKV units.

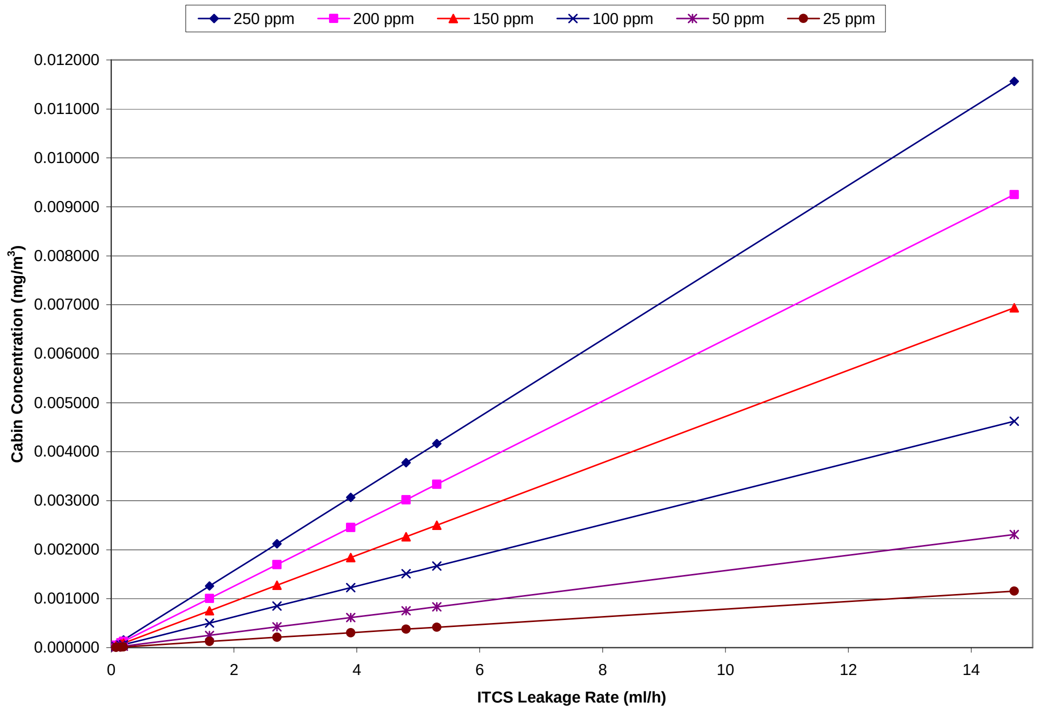


Figure 5. Leakage Accommodated by the USOS TCCS and ROS BMP Assisted by Humidity Condensate Absorption at Assembly Complete for a Crew of Three

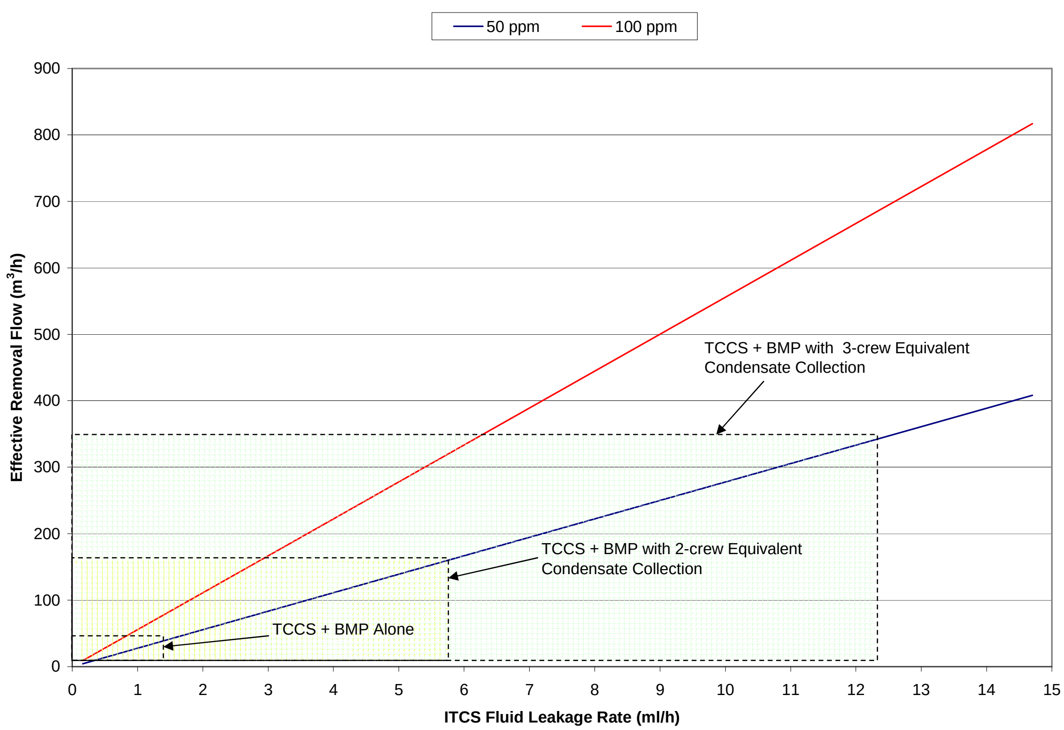


Figure 6. Comparison of Assisted and Unassisted Contamination Control Capacity

While removal via absorption by humidity condensate is a potentially effective removal route, the potential impact to the water processing systems can be significant and must be considered. Figures 7 and 8 show how the condensate loading varies when the latent load and the cabin concentration change. For the CCAA, Figure 7 shows the cabin concentration that can contribute to 5 mg/liter glutaraldehyde in the condensate ranges from 0.0015 mg/m^3 to 0.0032 mg/m^3 for latent loading up to 3 people. Similarly, Figure 8 shows that a cabin concentration ranging from 0.0027 mg/m^3 to 0.0066 mg/m^3 contribute to 5 mg/liter glutaraldehyde in the condensate collected by the SKV for latent loads up to 3 people.

To understand the potential impact upon humidity condensate loading for the Flight 4R and assembly complete configurations, the rigorous mass balance based upon the simultaneous solution of Equations 6 and 7 is used. Appendix C contains tabular results.

Figure 5 indicates that, with respect to maintaining cabin air quality, fluid containing up to 100 mg/liter glutaraldehyde can be used for nearly half the specified range of fluid leakage when all removal routes are considered. However, fluid containing <50 mg/liter glutaraldehyde has the least potential impact upon the cabin's atmosphere. Based upon the rigorous mass balance, the cabin concentration for the Flight 4R configuration can exceed the lower range for condensate loading acceptability for a CCAA when leakage is >1.8 ml/h for fluid containing 100 mg/liter glutaraldehyde. This increases to >3.6 ml/h for fluid containing 50 mg/liter glutaraldehyde. These leakage rates are within that allowed by specification for the Flight 4R configuration. Humidity condensate collected by the SKV will not be overloaded for the Flight 4R configuration unless total leakage exceeds 7.7 ml/h and 15.4 ml/h for fluid containing 100 mg/liter and 50 mg/liter glutaraldehyde, respectively.

For the assembly complete configuration, leakage >4.7 ml/h can overload the condensate collected by the CCAA for fluid containing 100 mg/liter glutaraldehyde. Similarly, leakage >9.4 ml/h containing 50 mg/liter glutaraldehyde can overload the condensate collected by the CCAA. Leakage much greater than allowed by specification is required to overload condensate collected by the SKV. For fluid containing 100 mg/liter glutaraldehyde, leakage >22 ml/h results in >5 mg/liter glutaraldehyde in the condensate. Sustained leakage >44 ml/h is necessary for fluid containing 50 mg/liter glutaraldehyde.

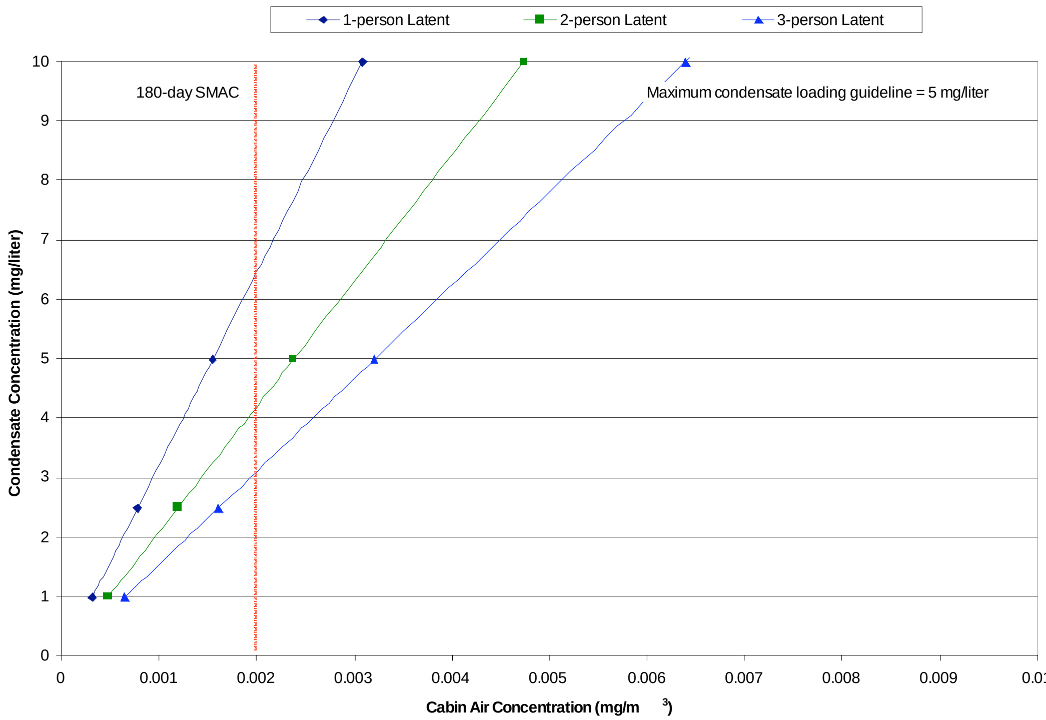


Figure 7. Effect of Cabin Glutaraldehyde Concentration upon Condensate Collected by the CCAA

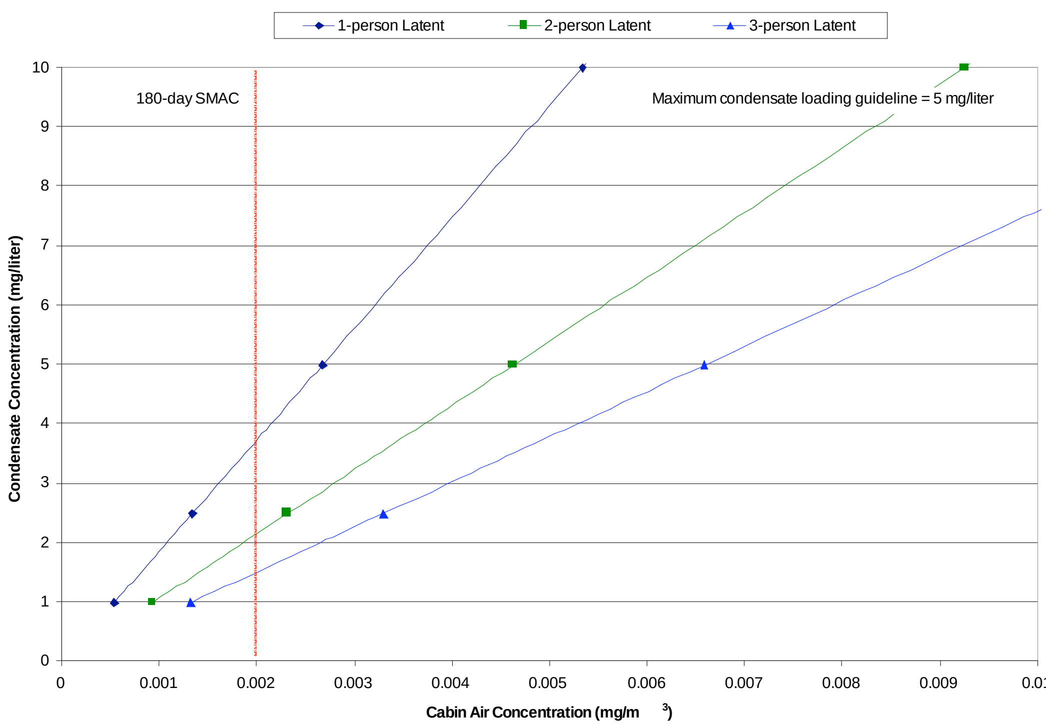


Figure 8. Effect of Cabin Glutaraldehyde Concentration upon Condensate Collected by the CCAA

Consideration for Air Quality Control System Failures

Given glutaraldehyde's very low 180-day SMAC and the fact that fluid leakage from the internal ATCS is expected, it is necessary to understand the potential effects that a failure of the TCCS and BMP either individually or simultaneously may have upon the *ISS's* overall trace contaminant control capability. The rigorous mass balance provided by simultaneous solution of Equations 6 and 7 was used to evaluate the effects. Internal ATCS fluid containing 100 mg/liter and 50 mg/liter glutaraldehyde was considered for both the Flight 4R and assembly complete configurations. Results are tabulated in Appendix C.

The worst case situation occurs when both the TCCS and BMP fail simultaneously. For such a situation, internal ATCS fluid leakage >1.9 ml/h for fluid containing 100 mg/liter glutaldehyde and >3.8 ml/h for fluid containing 50 mg/liter glutaraldehyde result in cabin concentration exceeding the 180-day SMAC. These leakage rates are within the range allowed by specification. For assembly complete, leakage >5.6 ml/h and >11.2 ml/h result in cabin concentration greater than the 180-day SMAC. Again, these leakage rates are within the range allowed by specification.

For individual failures of the TCCS and BMP for the *ISS* Flight 4R configuration, leakage rates >2.1 ml/h and >4.2 ml/h for fluid containing 100 mg/liter and 50 mg/liter glutaraldehyde, respectively, can result in cabin concentration greater than the 180-day SMAC. At assembly complete, the leakage rates increase to >5.9 ml/h for fluid containing 100 mg/liter glutaraldehyde and >11.8 ml/h for fluid containing 50 mg/liter glutaraldehyde.

If internal ATCS fluid leakage can be adequately controlled and monitored, leakage no greater than 1.8 ml/h for the Flight 4R configuration and 4.7 ml/h for the assembly complete configuration for internal ATCS fluid containing 100 mg/liter glutaraldehyde can achieve acceptable results. Likewise, for ATCS fluid containing 50 mg/liter glutaraldehyde, rates no greater than 3.6 ml/h for the Flight 4R configuration and 9.4 ml/h for the assembly complete configuration achieve acceptable results.

When considering the concentration threshold of 0.0015 mg/m^3 for avoiding adverse impacts upon humidity condensate loading in the USOS combined with a single trace contaminant control failure, leakage rates for the 4R configuration >1.6 ml/h and >3.2 ml/h for fluid containing 100 mg/liter and 50 mg/liter glutaraldehyde, respectively, exceed the threshold. Similarly, at assembly complete, leakage of fluid containing 100 mg/liter and 50 mg/liter glutaraldehyde exceeds the threshold at >4.4 ml/h and >8.8 ml/h, respectively. The range of leakage in both cases is within the range of internal ATCS leakage allowed by specification.

Summary

Overall, measures must be taken to minimize the risk to human health and maintaining the *ISS's* cabin air quality as well as protecting the water processing systems. Although the TCCS and BMP have proven themselves reliable, they are designed specifically to control the contamination loading from equipment offgassing and human metabolic processes alone. Further, cabin air quality monitoring techniques are not sensitive enough to monitor glutaraldehyde's concentration at or below the 180-day SMAC. Therefore, it is not possible to verify cabin air quality maintenance via existing monitoring techniques. Therefore, as shown by Figures 5 and 7 and presented earlier, to ensure that the risk to human health presented by potentially overwhelming the active air quality control systems and overloading humidity condensate, the internal ATCS fluid should contain <25 mg/liter glutaldehyde. For the entire range of specified internal ATCS fluid leakage, this concentration protects against all human health and ECLS equipment performance impacts as well as accommodates for the potential for air quality control equipment failures.

CONCLUSIONS

Based upon evaluation of glutaraldehyde as a candidate biocidal additive to the internal ATCS working fluid, conclusions are the following:

1. Evaporation rates from concentrated aqueous solutions of glutaraldehyde are such that appropriate containment and personal protective equipment must be used when injecting the solution into the internal ATCS.

2. Basic, unassisted trace contaminant control capability as defined by *ISS* Program specification cannot accommodate the range of internal ATCS leakage rates for any glutaraldehyde concentration in the fluid.

3. If no suitable alternative can be found, internal ATCS fluid must contain <25 mg/liter glutaraldehyde to ensure that long-term hazards to human health and operability of ECLS air quality control and water processing systems are acceptable.

RECOMMENDATIONS

Based upon *ISS* ECLS engineering evaluation, it is recommended that other candidate biocidal additives be evaluated. The overall challenges and risks associated with using glutaraldehyde as a biocidal additive are significant and present long-term operational issues to the *ISS* Program if implemented.

The USOS ECLS systems cannot be certified for glutaraldehyde concentration >25 mg/liter in the internal ATCS fluid. If no other suitable additive can be found, however, glutaraldehyde concentrations <25 mg/liter may be used within the range of internal ATCS fluid leakage specification to ensure long-term hazards to human health and ECLS system air quality control and water processing equipment are acceptable.

Further, any decision by the *ISS* Program to use glutaraldehyde as a biocidal additive to the internal ATCS fluid in the USOS must be reviewed by the International Partners within the Common Environments Team forum. This is necessary because fugitive emissions from the internal ATCS effect the common cabin environment.

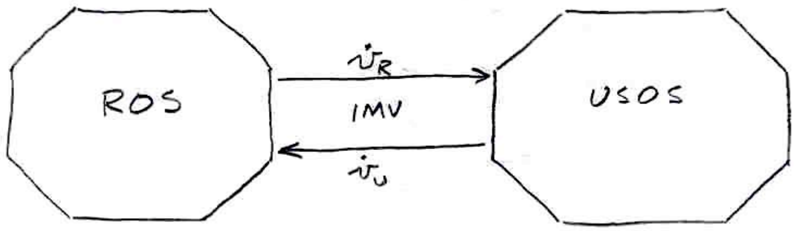
REFERENCES

1. Wilson, M.; Cole, H.; Weir, N.; Roman, M.; Steele, J.; and Lukens, C.: Selection of an Alternate Biocide for the *ISS* ITCS Coolant Loops. SAE 2003-01-2568. Society of Automotive Engineers: Warrendale, PA; 2003.
2. Wilson, M.; Cole, H.; Weir, N.; Oehler, B.; Steele, J.; Varsik, J.; and Lukens, C.: Selection of an Alternate Biocide for *ISS* Internal Thermal Control Coolant—Phase II. SAE 2004-01-2472. Society of Automotive Engineers: Warrendale, PA; 2004.
3. Garcia, H.: Toxicity Hazard Rating of Glutaraldehyde Solutions. Memorandum JSCTox-HDG-03-06-03. NASA Johnson Space Center: Houston, TX; June 25, 2003.
4. Perry, J.L.: Elements of Spacecraft Cabin Air Quality Control Design. NASA/TP-1998-207978. NASA: MSFC, AL; May 1998, p. 19.
5. System Specification for the International Space Station. SSP-41000Y. February 15, 2001.
6. Segment Specification for the United States On-orbit. SSP-41162AN. December 12, 2003.
7. Prime Item Development Specification for United States Laboratory. S683-29523P. August 30, 2002.
8. Kumar, A.; Vatcha, N.S.; and Schmelzle, J.: Estimate Emissions from Atmospheric Releases of Hazardous Substances. *Environmental Engineering World*. November-December, 1996.
9. Peress, J.: Estimate Evaporative Losses from Spills. *Chemical Engineering Progress.* April 2003.
10. Perry, J.L.: Elements of Spacecraft Cabin Air Quality Control Design. NASA/TP-1998-207978. NASA: MSFC, AL; May 1998, pp. 137-139.
11. Ibid, pp. 145-148.
12. Tatara, J.; Franks, G.; and Perry, J.: *International Space Station* System-Level Trace Contaminant Injection Test. NASA/TM-1999-209010. NASA: MSFC, AL; March 1999, pp. 25-26.
13. Perry, J.L.: The Interaction of Spacecraft Cabin Atmospheric Quality and Water Processing System Performance. SAE 2002-01-2300. Society of Automotive Engineers: Warrendale, PA; July 2002, pp. 2-3.

APPENDIX A—MASS BALANCE EQUATION DERIVATION AND EVAPORATIVE LOSS CALCULATIONS

CABIN MASS BALANCE – GENERALIZED

V. L. PERRY
MSFC/FD21
4-7-04



$V_R = 180.6\ m^3$	CABIN VOLUME	$V_U = 190.4\ m^3$
$C_R = 0.02\ mg/m^3$	CONCENTRATION @ $t = \infty$	$C_U = 0.04\ mg/m^3$
$\dot{v}_R = 252.7\ m^3/h$	IMV FLOW	$\dot{v}_U = 118.6\ m^3/h$
$g_R = ?$	GENERATION RATE	$g_U = ?$
	REMOVAL DEVICES	
	TCCS $\longrightarrow$	$\eta\dot{v} = (1.0)(4.6) = 4.6\ m^3/h$
$\eta\dot{v} = (0.9)(27)$	$\longleftarrow$ BMP	
$\eta\dot{v} = (0.073)(144)$	$\longleftarrow$ SKV	
$\Sigma\eta\dot{v}_R = 34.8\ m^3/h$	TOTAL REMOVAL	$\Sigma\eta\dot{v}_U = 4.6\ m^3/h$

USOS MASS BALANCE

$$\frac{dm_U}{dt} = \dot{v}_R C_R - \dot{v}_U C_U - \left(\Sigma\eta\dot{v}_U\right) C_U + g_U$$

$$= \left(\frac{\dot{v}_R}{V_R}\right) M_R - \left(\frac{\dot{v}_U}{V_U}\right) M_U - \left(\frac{\Sigma\eta\dot{v}_U}{V_U}\right) M_U + g_U \qquad (1)$$

RDS MASS BALANCE

$$\frac{dM_R}{dt} = \dot{v}_U C_U - \dot{v}_R C_R - \left(\Sigma\eta\dot{v}_R\right) C_R + g_R$$

$$= \left(\frac{\dot{v}_U}{V_U}\right) M_U - \left(\frac{\dot{v}_R}{V_R}\right) M_R - \left(\frac{\Sigma\eta\dot{v}_R}{V_R}\right) M_R + g_R \qquad (2)$$

(1)

DEFINE IN OPERATOR FORM

USOS

$$\frac{dM_U}{dt} = \frac{\dot{v}_R}{V_R} M_R - \frac{\dot{v}_U}{V_U} M_U - \left(\frac{r_U}{V_U}\right) M_U + g_U$$

$$\frac{dM_U}{dt} = \frac{\dot{v}_R}{V_R} M_R - \left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right) M_U + g_U$$

so $$\left[D + \left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right)\right] M_U - \left(\frac{\dot{v}_R}{V_R}\right) M_R = g_U \qquad (3)$$

RDS

$$\frac{dM_R}{dt} = \frac{\dot{v}_U}{V_U} M_U - \frac{\dot{v}_R}{V_R} M_R - \left(\frac{r_R}{V_R}\right) M_R + g_R$$

$$\frac{dM_R}{dt} = \frac{\dot{v}_U}{V_U} M_U - \left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R}\right) M_R + g_R$$

so $$\left[D + \left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R}\right)\right] M_R - \frac{\dot{v}_U}{V_U} M_U = g_R \qquad (4)$$

USING THE ANNIHILATOR METHOD
- TAKE DERIVATIVE OF BOTH SIDES OF (3) AND (4)

$$D\left[D + \left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right)\right] M_U - D\left(\frac{\dot{v}_R}{V_R}\right) M_R = 0 \qquad (3a)$$

$$D\left[D + \left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R}\right)\right] M_R - D\left(\frac{\dot{v}_U}{V_U}\right) M_U = 0 \qquad (4a)$$

- ELIMINATE M_R

$$\left[D + \left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R}\right)\right] D\left[D + \left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right)\right] M_U - \cancel{\left[D + \left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R}\right)\right] D\left(\frac{\dot{v}_R}{V_R}\right) M_R} = 0$$

$$+ \cancel{\left(\frac{\dot{v}_R}{V_R}\right) D\left[D + \left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R}\right)\right] M_R} - \left(\frac{\dot{v}_R}{V_R}\right) D\left(\frac{\dot{v}_U}{V_U}\right) M_U = 0$$

$$\left[D + \left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R}\right)\right] D\left[D + \left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right)\right] M_U - \frac{\dot{v}_R \dot{v}_U}{V_R V_U} D M_U = 0$$

$$\cancel{D}\left[D + \left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R}\right)\right]\left[D + \left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right)\right] M_U - \cancel{D} \frac{\dot{v}_R \dot{v}_U}{V_R V_U} M_U = 0$$

$$\left[D^2 + D\left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U} + \frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R}\right) + \cancel{\frac{\dot{v}_R \dot{v}_U}{V_R V_U}} + \frac{\dot{v}_R r_U}{V_R V_U} + \frac{r_R \dot{v}_U}{V_R V_U} + \frac{r_R r_U}{V_R V_U} - \cancel{\frac{\dot{v}_R \dot{v}_U}{V_R V_U}}\right] M_U = 0$$

$$\left[D^2 + D\left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U} + \frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R}\right) + \frac{\dot{v}_R r_U}{V_R V_U} + \frac{r_R \dot{v}_U}{V_R V_U} + \frac{r_R r_U}{V_R V_U}\right] M_U = 0$$

(2)

$D = 0$

$a = 1$

$b = \frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R} + \frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}$

$c = \frac{\dot{v}_R r_U + r_R \dot{v}_U + r_R r_U}{V_R V_U}$

$\therefore x_1 = 0 \; ; \; x_2 = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \; ; \; x_3 = \frac{-b - \sqrt{b^2 - 4ac}}{2a}$

and

$$x_2 = \frac{-\left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R} + \frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right) + \sqrt{\left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R} + \frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right)^2 - 4(1)(c)}}{2(1)}$$

$$x_3 = \frac{-\left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R} + \frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right) - \sqrt{\left(\frac{\dot{v}_R}{V_R} + \frac{r_R}{V_R} + \frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right)^2 - 4(1)(c)}}{2(1)}$$

so

$$m_U = a + b e^{x_2 t} + c e^{x_3 t}$$

$$D_{m_U} = b\, x_2 e^{x_2 t} + c\, x_3 e^{x_3 t}$$

SUBSTITUTE D_{MU} INTO (3)

$$b e^{x_2 t} + c e^{x_3 t} + \left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right)\left(a + b e^{x_2 t} + c e^{x_3 t}\right) - \frac{\dot{v}_R}{V_R} m_R = g_U$$

$$\left(\frac{\dot{v}_R}{V_R}\right) m_R = \left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right) a + \left(x_2 + \frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right) b e^{x_2 t} + \left(x_3 + \frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right) c e^{x_3 t} - g_U$$

$$* \quad \boxed{m_R = \left(\frac{V_R}{\dot{v}_R}\right)\left[\left(\frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right) a + \left(x_2 + \frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right) b e^{x_2 t} + \left(x_3 + \frac{\dot{v}_U}{V_U} + \frac{r_U}{V_U}\right) c e^{x_3 t} - g_U\right]}$$

(3)

DETERMINE CONSTANTS – a, b, c

FOR TOTAL MASS BALANCE, $M_T = M_U + M_R$

AT $t \to \infty$, $C_i = \frac{g_i}{\Sigma \eta \dot{v}}$ OR $\frac{M_T}{V_U + V_R} = \frac{(g_U + g_R)}{(r_U + r_R)}$

SO $M_T = \frac{(g_U + g_R)(V_U + V_R)}{r_U + r_R}$

SUBSTITUTE M_U AND M_R INTO EQUATION FOR M_T

$$\frac{(g_U + g_R)(V_U + V_R)}{r_U + r_R} = a + b e^{x_2 t} + c e^{x_3 t} + \left(\frac{V_R}{\dot{v}_R}\right)\left(\frac{\dot{v}_U + r_U}{V_U}\right) a + \left(\frac{V_R}{\dot{v}_R}\right)\left(x_2 + \frac{\dot{v}_U + r_U}{V_U}\right) b e^{x_2 t} + \left(\frac{V_R}{\dot{v}_R}\right)\left(x_3 + \frac{\dot{v}_U + r_U}{V_U}\right) c e^{x_3 t} - \frac{V_R g_U}{\dot{v}_R}$$

$$\frac{(g_U + g_R)(V_U + V_R)}{r_U + r_R} = \left[\left(\frac{V_R}{\dot{v}_R}\right)\left(\frac{\dot{v}_U + r_U}{V_U}\right) + 1\right] a + \left[\left(\frac{V_R}{\dot{v}_R}\right)\left(x_2 + \frac{\dot{v}_U + r_U}{V_U}\right) + 1\right] b e^{x_2 t} + \left[\left(\frac{V_R}{\dot{v}_R}\right)\left(x_3 + \frac{\dot{v}_U + r_U}{V_U}\right) + 1\right] c e^{x_3 t} - \frac{V_R g_U}{\dot{v}_R}$$

FOR x_2 AND $x_3 < 0$

$$\frac{(g_U + g_R)(V_U + V_R)}{r_U + r_R} = \left[\left(\frac{V_R}{\dot{v}_R}\right)\left(\frac{\dot{v}_U + r_U}{V_U}\right) + 1\right] a - \frac{V_R g_U}{\dot{v}_R}$$

$$\frac{(g_U + g_R)(V_U + V_R)}{r_U + r_R} = \left(\frac{V_R}{\dot{v}_R}\right)\left[\left(\frac{\dot{v}_U + r_U}{V_U} + \frac{\dot{v}_R}{V_R}\right) a - g_U\right]$$

$$\frac{(g_U + g_R)(V_U + V_R)\dot{v}_R}{(r_U + r_R) V_R} = \left(\frac{\dot{v}_U + r_U}{V_U} + \frac{\dot{v}_R}{V_R}\right) a - g_U$$

$$* \quad a = \left[\frac{(g_U + g_R)(V_U + V_R)\dot{v}_R}{(r_U + r_R) V_R} + g_U\right] \Big/ \left(\frac{\dot{v}_U + r_U}{V_U} + \frac{\dot{v}_R}{V_R}\right)$$

(4)

DETERMINE CONSTANTS b AND C:

AT $t=0$, $M_U = M_{U0}$, $M_R = M_{R0}$

SO, $M_{U0} = a + b + c$

$$M_{R0} = \left(\frac{V_R}{\dot{v}_R}\right)\left[\left(\frac{\dot{v}_U + r_U}{V_U}\right)a + \left(\chi_2 + \frac{\dot{v}_U + r_U}{V_U}\right)b + \left(\chi_3 + \frac{\dot{v}_U + r_U}{V_U}\right)c - g_U\right]$$

ELIMINATE b:

$$-\left[\left(\frac{V_R}{\dot{v}_R}\right)\left(\chi_2 + \frac{\dot{v}_U + r_U}{V_U}\right)\right]M_{0U} = -\left[\left(\frac{V_R}{\dot{v}_R}\right)\left(\chi_2 + \frac{\dot{v}_U + r_U}{V_U}\right)\right](a + \cancel{b} + c)$$

$$+ \quad M_{R0} = \left(\frac{V_R}{\dot{v}_R}\right)\left[\left(\frac{\dot{v}_U + r_U}{V_U}\right)a + \cancel{\left(\chi_2 + \frac{\dot{v}_U + r_U}{V_U}\right)b} + \left(\chi_3 + \frac{\dot{v}_U + r_U}{V_U}\right)c - g_U\right]$$

$$M_{R0} - \left[\left(\frac{V_R}{\dot{v}_R}\right)\left(\chi_2 + \frac{\dot{v}_U + r_U}{V_U}\right)\right]M_{0U} = -\left[\left(\frac{V_R}{\dot{v}_R}\right)\left(\chi_2 + \frac{\dot{v}_U + r_U}{V_U}\right)\right]a$$

$$+ \left(\frac{V_R}{\dot{v}_R}\right)\left(\frac{\dot{v}_U + r_U}{V_U}\right)a - \left[\left(\frac{V_R}{\dot{v}_R}\right)\left(\chi_2 + \frac{\dot{v}_U + r_U}{V_U}\right)\right]c$$

$$+ \left[\left(\frac{V_R}{\dot{v}_R}\right)\left(\chi_3 + \frac{\dot{v}_U + r_U}{V_U}\right)\right]c - \frac{V_R g_U}{\dot{v}_R}$$

$$\frac{\dot{v}_R M_{R0}}{V_R} - \left(\chi_2 + \frac{\dot{v}_U + r_U}{V_U}\right)M_{0U} = -\left(\chi_2 + \cancel{\frac{\dot{v}_U + r_U}{V_U}}\right)a + \cancel{\left(\frac{\dot{v}_U + r_U}{V_U}\right)}a$$

$$-\left(\chi_2 + \cancel{\frac{\dot{v}_U + r_U}{V_U}}\right)c + \left(\chi_3 + \cancel{\frac{\dot{v}_U + r_U}{V_U}}\right)c - g_U$$

$$\frac{\dot{v}_R M_{R0}}{V_R} - \left(\chi_2 + \frac{\dot{v}_U + r_U}{V_U}\right)M_{0U} = (\chi_3 - \chi_2)c - \chi_2 a - g_U$$

SOLVE FOR C:

$$* \quad c = \left(\frac{1}{\chi_3 - \chi_2}\right)\left[\frac{\dot{v}_R M_{R0}}{V_R} - \left(\chi_2 + \frac{\dot{v}_U + r_U}{V_U}\right)M_{0U} + \chi_2 a + g_U\right]$$

$$* \quad b = M_{0U} - a - c$$

(5)

GLUTARALDEHYDE EVALUATION - REVISED

J.L. PERRY
1-20-03
MSFC/FD21

PHYSICAL PROPERTIES

$M = 100.13$ g/mole
Sp. Gr. = 0.72 (PURE LIQUID @ 20°C) Sp. Gr. (aqueous) = 1.06-1.12
P_v (20°C) = 17 mm Hg

AQUEOUS GLUTARALDEHYDE VAPOR PRESSURE

AT 20°C AS A FUNCTION OF COMPOSITION*

$$ppmv = 0.0122(\%\,mass)^2 + 1.9496(\%\,mass) + 0.0172$$

AT VARYING TEMPERATURE*

0.1% MASS AQUEOUS SOLUTION

$$\log_{10} P_v = (-12.853)\ln\left(\frac{1}{T}\right) - 73.739$$

0.01% MASS AQUEOUS SOLUTION

$$\log_{10} P_v = (-12.853)\ln\left(\frac{1}{T}\right) - 74.739$$

* BASIS: J.D. OLSON: THE VAPOR PRESSURE OF PURE AND AQUEOUS GLUTARALDEHYDE. UNION CARBIDE, UNDATED.

HENRY'S LAW CONSTANT

$$\ln H = 29.1352 - 9187.99/T$$

REF: J.D. OLSON: THE VAPOR PRESSURE OF PURE AND AQUEOUS GLUTARALDEHYDE. UNION CARBIDE, UNDATED.

SPACECRAFT MAXIMUM ALLOWABLE CONCENTRATIONS

180-DAY	0.002 mg/m³	REF. JSC 20584 JUNE 1999.
30-DAY	0.012 mg/m³	
7-DAY	0.025 mg/m³	
24-HOUR	0.08 mg/m³	
1-HOUR	0.5 mg/m³	

REMOVAL MECHANISMS AND ISS CONFIGURATION

BMP — $\dot{v} = 27\ m^3/h$; $\eta = 1.0$
TCCS — $\dot{v} = 15.3\ m^3/h$; $\eta = 1.0$
SKV — $\dot{v} = 144\ m^3/h$; $\eta = 0.88$ 76% BYPASS
CCAA — $\dot{v} = 68\ m^3/h$; $\eta = 0$ 90% BYPASS - NO CONDENSATE
$V_{CABIN} = 371\ m^3$ $V_{USOS} = 190.6\ m^3$
CABIN AIR VELOCITY = 15 ft/minute (0.0762 m/s)
$T_{CABIN} = 20°C$

1

EVALUATION CASES

- SPILLED 1 LITER 5% SOLUTION AT 20°C.
- SPILLED 100 ml 50% SOLUTION AT 20°C
- SPILLED 3.8 LITER (1 GALLON) 0.025% SOLUTION AT 4.4°C AND AT 20°C
- EVALUATE TIME TO EFFECT FROM ½ 180-DAY SMAC TO 24-HOUR AND 1-HOUR SMACS
- EVALUATE DECAY TIME FROM 1-HOUR SMAC TO 180-DAY SMAC
  - TOTAL ISS VOLUME AND RESOURCES
  - USOS ISOLATED WITH TCCS ONLY
- EVALUATE ALLOWABLE MAGNITUDE OF FUGITIVE EMISSION
  - GLUTARALDEHYDE ALONE
  - GLUTARALDEHYDE IN CONTEXT WITH T-VALUE

ASSUMPTIONS

- SPILLED LIQUID FORMS MINIMUM ENERGY CONFIGURATION
  - SPHERICAL BLOB

$$V = \frac{\pi}{6} D^3 \qquad S = \pi D^2$$

- FOR $V = 1000\ cm^3$, $D = 12.4\ cm$ $\quad S = 483.05\ cm^2$, $0.0483\ m^2$ or $0.52\ ft^2$

  $V = 100\ cm^3$, $D = 5.76\ cm$ $\quad S = 104.23\ cm^2$, $0.0104\ m^2$ or $0.11\ ft^2$

  $V = 3800\ cm^3$, $D = 19.4\ cm$ $\quad S = 1182.37\ cm^2$, $0.118\ m^2$ or $1.27\ ft^2$

- CABIN AIR VELOCITY = 15 ft/minute or 0.0762 m/s

2

EVAPORATION RATE EQUATIONS

- $q \cong (5.23 \times 10^{-9}) U_s^{0.78} P_v M_w^{0.67} A_p^{0.94}$ REF. KUMAR, VATCHA, & SCHMELZLE. ENV. ENG. WORLD, NOV/DEC 1996

$q [=] kg/s$; $U_s [=] m/s$; $P_v [=] N/m^2$; $M_w [=] g/mole$; $A_p [=] m^2$

- $QR = \dfrac{0.284 u^{0.78} M^{2/3} A P_v}{82.05\ T}$ REF. J. PETERSS, CEP, APRIL 2003.

$QR [=] lb/min$; $u [=] m/s$; $P_v [=] mmHg$; $M [=] g/mole$
$T [=] K$; $A [=] ft^2$

CASE 1 - EVAPORATION RATE FROM 1 LITER, 5% AT 20°C

$P_v = 10.07\ ppm_v \times \dfrac{100.13}{24.044} = 41.94\ mg/m^3$

$\rho = \dfrac{MP}{RT}$

$P = \dfrac{\rho RT}{M} \times \dfrac{g}{1000\ mg} \times \dfrac{m^3}{10^6\ cm^3}$

$P = \dfrac{(41.94)(82.06)(293)}{(100.13)(1000)(10^6)} = 1.007 \times 10^{-5}\ atm$
or
$0.00765\ mm\,Hg$
or
$1.02\ Pa$

$q \cong (5.23 \times 10^{-9})(0.0762)^{0.78}(1.02)(100.13)^{0.67}(0.0483)^{0.94}$

$q \cong 9.085 \times 10^{-10}\ kg/s$ or $3.27\ mg/h$

$QR = \dfrac{(0.284)(0.0762)^{0.78}(100.13)^{2/3}(0.52)(0.00765)}{(82.05)(293)}$

$QR = 1.36 \times 10^{-7}\ lb/min$ or $3.70\ mg/h$

AVERAGE = 3.485 mg/h

TIME TO 24-HOUR SMAC:

$t = (371)(0.08 - 0.00)/3.485$

$t = 8.5$ HOURS

TIME TO 180-DAY SMAC

$t = (371)(0.002 - 0.00)/3.485 = 0.213$ HOURS (12.8 MINUTES)

3

CASE 2 - EVAPORATION RATE FROM 100 ml, 50% AT 20°C

$$P_v = 128 \text{ ppm}_v \times \frac{100.13}{24.044} = 533.04 \text{ mg/m}^3$$

$$P_v = \frac{(533.04)(82.06)(293)}{(100.13)(1000)(10^6)} = 1.28 \times 10^{-4} \text{ atm}$$

or

0.0973 mm Hg

or

12.97 Pa

$$q \cong (5.23 \times 10^{-9})(0.0762)^{0.78}(12.97)(100.13)^{0.67}(0.0104)^{0.94}$$

$$q \cong 2.727 \times 10^{-9} \text{ kg/s or } 9.82 \text{ mg/h}$$

$$QR = \frac{(0.284)(0.0762)^{0.78}(100.13)^{2/3}(0.11)(0.0973)}{(82.05)(293)}$$

$$QR = 3.66 \times 10^{-7} \text{ lb/min or } 9.96 \text{ mg/h}$$

AVERAGE = 9.89 mg/h

TIME TO 180-DAY SMAC

$$t = (371)(0.002)/9.89 = 0.075 \text{ h or } 4.5 \text{ minutes}$$

TIME TO 24-HOUR SMAC

$$t = (371)(0.08)/9.89 = 3.0 \text{ h}$$

CASE 3 - EVAPORATION RATE FROM 3.8 LITERS, 0.025% AT 4.4°C AND 20°C

$P_v(4.4°C) = \log_{10}(P_v) = -2.435$ FOR 0.01% SOLUTION

$$P_v = 10^{-2.435} \times 2.5 = 0.00918 \text{ ppm}_v$$

$$P_v = 0.00918 \times \frac{100.13}{24.044} \times \frac{(82.06)(277.4)}{(100.13)(1000)(10^6)}$$

$$P_v = 8.694 \times 10^{-9} \text{ atm}$$

or

6.607×10^{-6} mm Hg

or

8.809×10^{-4} Pa

$$q \cong (5.23 \times 10^{-9})(0.0762)^{0.78}(8.809 \times 10^{-4})(100.13)^{0.67}(0.118)^{0.94}$$

$$q \cong 1.82 \times 10^{-12} \text{ kg/s or } 0.00654 \text{ mg/h}$$

$$QR = \frac{(0.284)(0.0762)^{0.78}(100.13)^{2/3}(1.27)(6.607 \times 10^{-6})}{(82.05)(277.4)}$$

$$QR = 3.03 \times 10^{-10} \text{ lb/minute or } 0.00825 \text{ mg/h}$$

AVERAGE = 0.0074 mg/h

4

TIME TO 180-DAY SMAC

$$t = (371)(0.002)/0.0074 = 100.3\ h$$

$P_v(20°C) = 0.0659$ ppmv

$$P_v(20°C) = \frac{(0.0659)(82.06)(293)}{(24.044)(1000)(10^6)} = 6.595 \times 10^{-8}\ atm$$

or

5.012×10^{-5} mm Hg

or

6.682×10^{-3} Pa

$$q \cong (5.23\times10^{-9})(0.0762)^{0.78}(6.682\times10^{-3})(100.13)^{0.67}(0.118)^{0.94}$$

$2.756 \times 10^{-?}$ kg/s

$q \cong 1.378 \times 10^{-11}$ kg/s or 0.0496 mg/h

$$QR = \frac{(0.284)(0.0762)^{0.78}(100.13)^{2/3}(1.27)(5.012\times10^{-5})}{(82.05)(293)}$$

$QR = 2.177 \times 10^{-9}$ lb/minute or 0.0592 mg/h

AVERAGE = 0.0544 mg/h

TIME TO 180-DAY SMAC

$$t = (371)(0.002)/0.0544 = 13.6\ h$$

DECAY RATE FROM 1-HOUR SMAC TO 180-DAY SMAC

$$t = \frac{-V}{\sum \eta \dot{v}} \ln(C/C_0)$$

$C_0 = 0.5\ mg/m^3$ $\quad \ln(H) = -3.9866 \quad H = 0.01856$ kPa/mol frac.

or

$H = 1.832 \times 10^{-4}$ atm/mol frac.

$\sum \eta \dot{v} = 27 + 15.3 + 123.8 = 166.1$ (ISS)

$\sum \eta \dot{v} = 15.3$ (USOS)

C/C_0	ISS t	USOS t
0.95	0.11	0.64
0.75	0.64	3.6
0.5	1.5	8.6
0.25	3.1	17.3
0.1	5.1	28.7
0.05	6.7	37.3
0.004	12.3	68.8

5

MAXIMUM CABIN GENERATION

$$C = \frac{g}{\sum_i \eta \dot{v}}$$

USL PIDS = $0.9\, C_{SMAC}$ or $0.0018\, mg/m^3$

$$g = \left(\sum_i \eta \dot{v}\right) C$$

$$g = (169)(0.0018) = 0.304\, mg/h$$

AT 250 mg/LITER, MAX LEAK = $\frac{0.304}{250} \times \frac{1000\, ml}{LITER}$

$= 1.22\, ml/h$

or

$29.2\, ml/day$

∴ COULD LEAK FOR 130 DAYS BEFORE REACH 1 GALLON LOSS

WITHOUT HUMIDITY CONDENSATE,

$$g = (27 + 15.3)(0.0018) = 0.0761\, mg/h \quad \text{or } 0.305\, ml/h \quad \text{or } 7.3\, ml/day$$

IN CONTEXT WITH T-VALUE - PRIMARY AIR QUALITY CONTRIBUTORS

	C (mg/m³)	SMAC
METHANOL	1.7	9
ETHANOL	5.9	2100
2-PROPANOL	0.34	150
n-BUTANOL	0.53	40
ACETALDEHYDE	0.25	4
ETHYL ACETATE	0.08	180
BUTYL ACETATE	0.025	190
DICHLOROMETHANE	0.4	10
TOLUENE	0.06	60
m-/p- XYLENES	0.05	220
O- XYLENE	0.1	220
ACETONE	0.38	52
2-BUTANONE	0.06	30
OMTS	3.75	12
DMPS	0.63	15
HMTS	4.4	9
METHANE	215	3800
HYDROGEN	22	340
CARBON MONOXIDE	1.6	11
FORMALDEHYDE	0.031	0.05
AMMONIA	0.3	7

OVERALL

T-VALUE = 2.09

IRRITANTS

T-VALUE = 0.73

∴ 0.27 FOR GLUTARALDEHYDE

AND $0.00055\, mg/m^3$

$$g = (169)(0.00055) = 0.0929\, mg/h$$

or $0.37\, ml/h$

or $8.9\, ml/d$

6

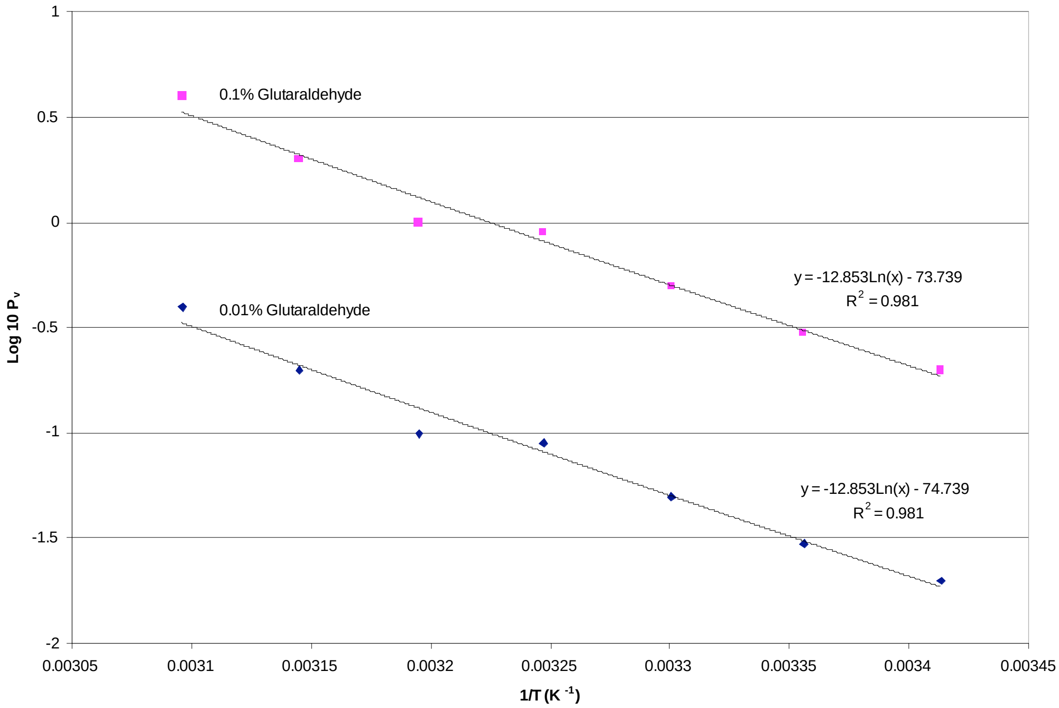


Figure A-1. Aqueous Glutaraldehyde Vapor Pressure

APPENDIX B—INTERNAL ATCS LEAKAGE SPECIFICATIONS

(Provided by Internal ATCS SPRT)

Spec. Leakage Rates (cc/hr)

	LTL	MTL
USL	0.80	0.80
Airlock	0.80	0.80
Node 1	0.80	0.80
Node 2	1.09	0.86
Node 3	1.50	2.00
CAM	0.48	0.48
MPLM	0.275	NA
Cupola	NA	0.026
APM	0.800	0.800
JEM	0.800	0.800

Combined spec. lkg = 14.71 cc/hr

Combined Spec. Leakage for current on-orbit IATCS in Single Loop Mode =	4.80	cc/hr
Threshold On-orbit leakage to initiate IFI (<1%/mo.) =	0.161624	cc/hr
Threshold On-orbit leakage at which a loop would be shut down (<1%/day) =	3.878967	cc/hr
Normal Leakage @ assembly complete (10 x's current IFI threshold) =	1.616236	cc/hr
Combined normal leakage & leakage at which a loop would be shut down =	5.333579	cc/hr

APPENDIX C—TABULAR RESULTS FROM USOS AND ROS MATERIAL BALANCE CALCULATIONS

100 ppm Loading/4R Configuration												
Leak Rate (ml/h)	CONCENTRATION											
	All Operating			TCCS Off			BMP Off			TCCS & BMP Off		
	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)
0.16	0.000134	5.66E-05	9.63E-05	0.000149	6.05E-05	0.000106	0.000152	7.6E-05	0.000115	0.000173	8.36E-05	0.000129
0.2	0.000168	7.07E-05	0.00012	0.000187	7.56E-05	0.000133	0.00019	9.5E-05	0.000144	0.000216	0.000105	0.000162
1.6	0.001341	0.000566	0.000963	0.001494	0.000605	0.001061	0.00152	0.00076	0.00115	0.001725	0.000836	0.001292
2.7	0.002262	0.000954	0.001626	0.002521	0.001021	0.00179	0.002565	0.001283	0.001941	0.002911	0.001411	0.002181
3.9	0.003267	0.001379	0.002348	0.003641	0.001474	0.002586	0.003705	0.001853	0.002804	0.004205	0.002038	0.00315
5.3	0.00444	0.001873	0.003191	0.004948	0.002003	0.003515	0.005035	0.002519	0.00381	0.005714	0.00277	0.004281

50 ppm Loading/4R Configuration												
Leak Rate (ml/h)	CONCENTRATION											
	All Operating			TCCS Off			BMP Off			TCCS & BMP Off		
	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)
0.16	6.7E-05	2.83E-05	4.82E-05	7.47E-05	3.02E-05	5.31E-05	7.6E-05	3.8E-05	5.75E-05	8.63E-05	4.18E-05	6.46E-05
0.2	8.38E-05	3.53E-05	6.02E-05	9.34E-05	3.78E-05	6.63E-05	9.5E-05	4.75E-05	7.19E-05	0.000108	5.23E-05	8.08E-05
1.6	0.00067	0.000283	0.000482	0.000747	0.000302	0.000531	0.00076	0.00038	0.000575	0.000863	0.000418	0.000646
2.7	0.001131	0.000477	0.000813	0.00126	0.00051	0.000895	0.001283	0.000642	0.000971	0.001456	0.000706	0.00109
3.9	0.001634	0.000689	0.001174	0.00182	0.000737	0.001293	0.001853	0.000927	0.001402	0.002102	0.001019	0.001575
5.3	0.00222	0.000937	0.001595	0.002474	0.001002	0.001757	0.002518	0.001259	0.001905	0.002857	0.001385	0.002141

100 ppm Loading/Assembly Complete												
Leak Rate (ml/h)	CONCENTRATION											
	All Operating			TCCS Off			BMP Off			TCCS & BMP Off		
	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)
1.6	0.000513	0.000201	0.000453	0.000537	0.000206	0.000474	0.000544	0.000266	0.000491	0.000572	0.000276	0.000515
2.7	0.000866	0.000339	0.000765	0.000907	0.000348	0.000799	0.000918	0.00045	0.000828	0.000964	0.000466	0.000869
5.3	0.0017	0.000666	0.001501	0.001779	0.000684	0.001569	0.001802	0.000883	0.001625	0.001893	0.000915	0.001705
14.7	0.004714	0.001846	0.004163	0.004936	0.001896	0.004352	0.004998	0.002448	0.004508	0.005251	0.002539	0.00473

50 ppm Loading/Assembly Complete												
Leak Rate (ml/h)	CONCENTRATION											
	All Operating			TCCS Off			BMP Off			TCCS & BMP Off		
	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)	USOS (mg/m^3)	ROS (mg/m^3)	Total Cabin (mg/m^3)
1.6	0.000257	0.0001	0.000227	0.000269	0.000103	0.000237	0.000272	0.000133	0.000245	0.000286	0.000138	0.000257
2.7	0.000433	0.00017	0.000382	0.000453	0.000174	0.0004	0.000459	0.000225	0.000414	0.000482	0.000233	0.000434
5.3	0.00085	0.000333	0.00075	0.00089	0.000342	0.000784	0.000901	0.000441	0.000813	0.000947	0.000458	0.000853
14.7	0.002357	0.000923	0.002082	0.002468	0.000948	0.002176	0.002499	0.001224	0.002254	0.002625	0.001269	0.002365

APPENDIX F—CD–ROM CONTENTS

F.1 Spreadsheet of IATCS Simulator Volume Calculations

F.2 Spreadsheet of CFST Sample Analysis Data

F.3 ITCS Computer Simulation

- **Memo and Report by David Howard on Flow Model**
- **Spreadsheet of System Performance (Thermal and Flow)**

REFERENCES

1. Architecture Control Document, Volume 6: US Lab Thermal Control System, D683-14719-1-6, Revision New, Boeing, November 27, 1996.

2. Thermal Control System Architecture Description Document, Volume 2, D-684-10511-02, Revision G, Boeing, January 4, 2000.

3. Perry, J.L.: "International Space Station Sustaining Engineering Environmental Control and Life Support System and Internal Thermal Control System Integrated Test Facility," NASA Test Facility Documentation, Marshall Space Flight Center, July 2000.

4. Ray, C.D.; Perry, J.L.; and Callahan, D.M.: "International Space Station Sustaining Engineering: A Ground-Based Test Bed for Evaluating Integrated Environmental Control and Life Support System and Internal Thermal Control System Flight Performance," SAE paper 2000-01-2249, 30th International Conference on Environmental Systems, Toulouse, France, July 10–13, 2000.

5. Phase V Hardware/Software Integration Brassboard Test Report, Boeing, PG-3, Huntsville, AL, December 13, 1996.

6. Lab System 1 CSCI Software Requirements Specification, S683-70726, Boeing, December 1997.

7. Lab System 2 CSCI Software Requirements Specification, S683-70727, Boeing, December 1997.

8. Lab System 3 CSCI Software Requirements Specification, S683-70728, Boeing, December 1997.

9. Internal Systems CSCI 683G92A Software Requirements Specification Revision E, S683-70731, Boeing, December 1, 1998.

10. "Space Station Fluid Procurement and Use Control Specification," SSP- 30573, Rev. E, March 1, 1998.

11. "Space Station and Shuttle Payloads: OGS Rack ITCS Servicing Test Preparation Sheet," WONUM: 108257 WAD Number: SS-CARGO-T798, Revision: Basic, NASA Kennedy Space Center, January 9, 2006.

12. Prime Item Development Specification for the United States Laboratory, S683–29523L, Boeing Company, Huntsville, AL, November 30, 1998.

13. "Thermal Control System Configuration Technical Description Document," D683-14719-1-6, Revision New, Boeing, November 27, 1996.

14. "Microbial Influenced Corrosion of International Space Station Heat Exchanger Materials: Simulation Test of Worst Case Conditions," Technical Report 02660-TR-001, Rev. 0, Altran Corporation, October 2003.

15. "Analysis of Samples from NASA's International Space Station Internal Thermal Control System Simulation Test," Technical Report 03563-TR-001, Rev. 0, Altran Corporation, July 2003.

16. Wieland, P.; and Hawk, H.D.: "Internal Thermal Control System Hose Heat Transfer Fluid Thermal Expansion Evaluation Test Report," NASA/TM—2001–211330, NASA Marshall Space Flight Center, October 2001.

17. "PRACA 2784 Ammonia Contamination of Lab ITCS Fluid, White-Paper Analysis Summary and Closure Rationale," Muniz Engineering, November 1, 2004.

18. Manual, S.: "Chemical FTIR/SEM Analysis of Filter and Filter Fluid," Boeing Huntsville Laboratories, Report 2004-10-25-01742, October 25, 2004.

19. URL:http://www.gc3.com/techdb/manual/mbiotext.htm. Accessed January 2005.

20. Wilson, M.; Cole, H.; Weir, N.; Roman, M.; Steele, J.; and Lukens, C.: Selection of an Alternate Biocide for the International Space Station Internal Active Thermal Control System Coolant Loops. SAE Technical Paper 2003–01–2568, 2003.

21. Wilson, M.; Cole, H.; Weir, N.; Oehler, B.; Steele, J.; Varsik, J.; and Luke, C.: "Selection of an Alternate Biocide for the ISS Internal Active Thermal Control System Coolant—Phase II," SAE Paper Number 2004-1-2472, International Conference on Environmental Systems, Vancouver, BC, Canada, July 2004.

22. Wilson, M.: "Selection of an Alternate Biocide for the International Space Station Internal Active Thermal Control System," Presentation WPRR W-000078, Boeing, December 2, 2003.

23. Pyle, B.; Broadaway, S.C.; del Pulcini, E.; et al., "Assessment of ISS IATCS Loop Microbial Control Options," Final Report, Department of Microbiology and Center for Biofilm Engineering, Montana State University, Bozeman, MT, October 2004.

24. Mittelman, M.; Mitchell, R.; and Ridgway, H.: "Assessment of ISS IATCS Loop Microbial Control Options," Project Report, NASA RFP PS410-06/09/04, Mittleman and Associates, Braintree, MA, September 15, 2004.

25. Thurman, R.; Holt, M.; and Daugherty, S.; "NaOH Injection Test," presentation, Boeing, April 16, 2002.

26. Wieland, P.; Miller, L.; and Ibarra, T.: "International Space Station Internal Thermal Control System Lab Module Simulator Build-Up and Validation," SAE Paper Number 2003–01–2519, International Conference on Environmental Systems, Vancouver, BC, Canada, July 2003.

27. Wieland, P.; Holt, M.; Roman, M.; Cole, H.; and Daugherty, S.: "International Space Station Internal Thermal Control System Cold Plate/Fluid-Stability Test Two-Year Update," SAE Paper Number 2003–01–2518, International Conference on Environmental Systems, Vancouver, BC, Canada, July 2003.

28. Ray, C.D.; and Daugherty, R.S.: "International Space Station Internal Thermal Control System Cold Plate/Fluid Stability Test Set-up and Preliminary Test Results," SAE paper 2001-01-2334, 31st International Conference on Environmental Systems, Orlando, FL, July 9-12, 2001.

29. Operations and Maintenance Requirements Specification, OMRS JA16583 R2, accessed 2005.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 2007	Technical Memorandum

4. TITLE AND SUBTITLE
Living Together in Space: The International Space Station Internal Active Thermal Control System Issues and Solutions—Sustaining Engineering Activities at the Marshall Space Flight Center From 1998 to 2005

5. FUNDING NUMBERS

6. AUTHORS
P.O. Wieland, M.C. Roman, and L. Miller*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

8. PERFORMING ORGANIZATION REPORT NUMBER
M–1193

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/TM—2007–214964

11. SUPPLEMENTARY NOTES
Prepared by the Spacecraft and Vehicle Systems Department, Engineering Directorate
* JE Sverdrup, Huntsville, AL

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 54
Availability: NASA CASI 301–621–0390

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
On board the International Space Station, heat generated by the crew and equipment is removed by the internal active thermal control system to maintain a comfortable working environment and prevent equipment overheating. Test facilities simulating the internal active thermal control system (IATCS) were constructed at the Marshall Space Flight Center as part of the sustaining engineering activities to address concerns related to operational issues, equipment capability, and reliability. A full-scale functional simulator of the Destiny lab module IATCS was constructed and activated prior to launch of Destiny in 2001. This facility simulates the flow and thermal characteristics of the flight system and has a similar control interface. A subscale simulator was built, and activated in 2000, with special attention to materials and proportions of wetted surfaces to address issues related to changes in fluid chemistry, material corrosion, and microbial activity. The flight issues that have arisen and the tests performed using the simulator facilities are discussed in detail. In addition, other test facilities at the MSFC have been used to perform specific tests related to IATCS issues. Future testing is discussed as well as potential modifications to the simulators to enhance their utility.

14. SUBJECT TERMS
International Space Station, thermal control, test facilities, MSFC, flight issues

15. NUMBER OF PAGES
274

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

National Aeronautics and
Space Administration
IS20
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama
35812