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Trace Contaminant Control During the International Space Station's On-Orbit Assembly and Outfitting

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LIST OF DESIGNATORS, ACRONYMS, AND SYMBOLS

AC	trade designator for acid-impregnated activated carbon
AFOT	Russian acronym for the thermal decomposition products removal filter
APM	attached pressurized module
ARL	acceptable risk level
ARS	Atmosphere Revitalization Subsystem
ASU	air supply unit
ATV	automated transfer vehicle
BMP	Russian acronym for the microimpurity adsorption device on board Zvezda
CACEA	cabin air catalyst element assembly
CBA	charcoal bed assembly
CO	carbon monoxide
COA	catalytic oxidizer assembly
CP	computer program
ECLS	Environmental Control and Life Support
ECLSS	Environmental Control and Life Support System
ELM	experiment logistics module
ESTEC	European Space Research and Technology Centre
FGB	Russian acronym for the functional cargo block
FM	flight module
FVP	ФВП (Russian)

LIST OF DESIGNATORS, ACRONYMS, AND SYMBOLS (Continued)

GA	Russian acronym for Zarya’s transfer compartment
GAC	granular activated charcoal
GMT	Greenwich mean time
GSC	grab sampling containers
GSE	ground support equipment
HCF	harmful contaminants filter
HTV	H-I/H-II transfer vehicle
ICD	Interface Control Document
IMBP	Russian acronym for the State Institute of Medico-Biological Problems
IMV	intermodule ventilation
ISS	International Space Station
JAXA	Japanese Aerospace Exploration Agency
JSC	Johnson Space Center
JEM	Japanese Experiment Module
LiOH	lithium hydroxide
LPC	limiting permissible concentration
MET	mission elapsed time
MORD	Medical Operations Requirements Document
MPLM	multipurpose logistics module
MRM	mini research module
MSFC	Marshall Space Flight Center

LIST OF DESIGNATORS, ACRONYMS, AND SYMBOLS (Continued)

NMVOC	nonmethane volatile organic compound
ORU	on-orbit replaceable unit
PGO	Russian acronym for Zarya's working compartment
PIDS	Prime Item Development Specification
PLC	permissible limiting concentration
PM	pressurized module
PMA	pressurized mating adapter
PMM	permanent multipurpose module
PS	pressurized section
Pt	platinum
PVOC	polar volatile organic compound
PxO	Russian acronym for Zvezda's transfer compartment
ROS	Russian on-orbit segment
SBA	sorbent bed assembly
SM	service module
SMAC	spacecraft maximum allowable concentration
SSP	System Specification
SSPF	Space Station Processing Facility
STS	Space Transportation System
TCC	trace contaminant control
TCCS	trace contaminant control subassembly
TCCS-CP	Trace Contaminant Control Simulation-Computer Program

LIST OF DESIGNATORS, ACRONYMS, AND SYMBOLS (Continued)

ULF	utilization and logistics flight
U.S.	United States
USOS	U.S. on-orbit segment
ZRL	zero risk level

NOMENCLATURE

C	contaminant concentration
C_i	individual contaminant concentration
$C_{i,o}$	initial concentration
C_j	average concentration at sampling event
m	contaminant mass at time equal to t; mass of contaminant
m_i	contaminant mass in the cabin atmosphere (mg)
m_o	contaminant mass at time equal to zero
n	number of sampling events
r	correlation coefficient; generation rate
r_i	contaminant generation rate
T	final T-value
T_0	beginning T-value
T-value	toxic hazard index
t	time (hr)
V	module/cabin free volume (m^3)
$\dot{v}$	intermodule ventilation flow
v	intermodule ventilation flow rate (m^3/hr)
$\Sigma \eta v$	total active removal capacity for all known contamination control equipment

TECHNICAL PUBLICATION

TRACE CONTAMINANT CONTROL DURING THE INTERNATIONAL SPACE STATION'S ON-ORBIT ASSEMBLY AND OUTFITTING

1. INTRODUCTION

Achieving acceptable cabin air quality must balance competing elements during spacecraft design, assembly, ground processing, and flight operations. Among the elements that contribute to the trace chemical contaminant load and, therefore, the cabin air quality aboard crewed spacecraft are the vehicle configuration, crew size and activities, mission duration and objectives, materials selection, and vehicle manufacturing and preflight ground processing methods.[1] Trace chemical contaminants produced from pervasive sources such as equipment offgassing, human metabolism, and cleaning fluids during preflight ground processing present challenges to maintaining acceptable cabin air quality.

To address these challenges, both passive and active contamination control techniques are used during a spacecraft's design, manufacturing, preflight preparation, and operational phases. Passive contamination control methods seek to minimize the equipment offgassing load by selecting materials, manufacturing processes, preflight preparation processes, and in-flight operations that have low chemical offgassing characteristics. Passive methods can be employed across the spacecraft's entire life cycle from conceptual design through flight operations. However, because the passive contamination control techniques cannot fully eliminate the contaminant load, active contamination control equipment must be deployed aboard the spacecraft to purify and revitalize the cabin atmosphere during in-flight operations. Verifying that the passive contamination control techniques have successfully maintained the total trace contaminant load within the active contamination control equipment's capabilities occurs late in the preflight preparation stages. This verification consists of subjecting the spacecraft to an offgassing test to determine the trace contaminant load. This load is then assessed versus the active contamination control equipment's capabilities via trace contaminant control (TCC) engineering analysis.

During the International Space Station's (ISS's) on-orbit assembly and outfitting, a series of engineering analyses were conducted to evaluate how effective the passive TCC methods were relative to providing adequate operational margin for the active TCC equipment's capabilities aboard the ISS. These analyses were based on habitable module and cargo vehicle offgassing test results. The offgassing test for a fully assembled module or cargo vehicle is an important preflight spacecraft evaluation method that has been used successfully during all crewed spacecraft programs to provide insight into how effectively the passive contamination control methods limit the equipment offgassing component of the overall trace contaminant generation load. The progression of TCC assessments beginning in 1998 with the ISS's first habitable element launch and continuing through the final pressurized element's arrival in 2010 are presented. Early cargo vehicle flight assessments between 2008 and 2011 are also presented as well as a discussion on predictive methods for assessing cargo via a purely analytical technique.

The technical approach for TCC employed during this 13-year period successfully maintained the cabin atmospheric quality within specified parameters during the technically challenging ISS assembly and outfitting stages. The following narrative provides details on the important role of spacecraft offgassing testing, trace contaminant performance requirements, and flight rules for achieving the ultimate result—a cabin environment that enables people to live and work safely in space.

1.1 The Role of Spacecraft Offgassing Tests for Ensuring Cabin Air Quality

Conducting offgassing tests on crewed spacecraft provides the data to verify that the various passive contamination control methods for minimizing the trace chemical offgassing load during the design and manufacturing have been successful. The offgassing test is an important tool within an operational framework that continually ensures that the cabin atmosphere is maintained within acceptable standards. The framework involves three primary elements—collecting data during prelaunch spacecraft offgassing tests, employing predictive techniques to evaluate cabin atmospheric quality at key mission stages, and monitoring cabin atmospheric quality via various techniques.

The first element, conducting a preflight spacecraft offgassing test, is used primarily for new spacecraft and habitable modules. These tests characterize the trace chemical concentration buildup in a habitable element volume over time. It should be noted that methane is rarely found above trace concentrations in equipment offgassing test samples because human metabolism is the dominant source. However, methane and other chemical compounds generated from human metabolism are added to the equipment offgassing rate to form the basis for the overall trace chemical generation rate which is used to verify the active TCC equipment design.

During the ISS program, offgassing tests ranging in duration from 6 days to more than 15 days were conducted for each habitable module and cargo vehicle by NASA and the ISS progam's international partners. Ideally, the offgassing test duration was at least one-fifth the elapsed time interval between the module's final prelaunch closeout and subsequent breathing air purge on the ground and first entry after berthing to the ISS. Samples were usually collected at the beginning, middle, and end of the test. In some instances, more than three sampling events occurred. The data collected from these tests were analyzed to determine offgassing rates. Combined with human metabolic loads from reference 2, the total chemical generation load is evaluated to ensure that it does not exceed the active contamination control system's capabilities.

The second element uses offgassing rate data to predict cabin atmospheric quality changes over time.[3] These changes may occur during quiescent periods when a module is isolated from active contamination control equipment or when new habitable volumes and equipment are added to an existing spacecraft. Either vehicle offgassing test data or a generalized equipment offgassing rate model may serve as the equipment offgassing rate basis. The generalized equipment offgassing rate model, combined with the human metabolic load reported in the literature, served as the basis for the ISS trace contaminant control subassembly (TCCS) design. The offgassing rate model documented by reference 2 is based on the statistical treatment of numerous individual equipment offgassing tests conducted during the Spacelab program. Comparison of the equipment offgassing component of the load model to results obtained from ISS element offgassing tests has demonstrated that this model is representative of the general offgassing characteristics of U.S. spacecraft hardware. For a cargo transfer mission, the net cargo mass transferred to the spacecraft is considered to provide the most realistic estimate of the net growth in the total spacecraft equipment offgassing load. The total predicted trace contaminant generation rate at any particular time is the sum of the offgassing rate derived from preflight testing, the human metabolic rate, and the predicted rate for net cargo transferred.

The third element involves monitoring trace chemical contaminant concentrations in the cabin atmosphere by various methods. Monitoring methods may employ archival sample collection with subsequent analysis in a ground-based laboratory, near real-time instrumentation aboard the spacecraft, or a combination of these approaches.[4] Monitoring results are assessed to evaluate trends and to provide a direct, continuing verification of not only the active contamination control methods but also for the passive methods employed during engineering design and spacecraft assembly and ground processing.

In the case of first module entry operations, the methods employed by the first element, conducting a preflight offgassing test, are preferred for new and heavily refurbished habitable modules and crewed vehicles. The following narrative presents details on TCC for the major characterizing the trace contaminant load for ISS habitable modules and cargo vehicles during the Station's assembly and outfitting.

2. GENERAL REQUIREMENTS AND GUIDELINES

General requirements and guidelines have been established for TCC during habitable module and cargo vehicle first entry operations. Module-specific requirements cover both air quality and hardware performance. In general, individual trace contaminant concentrations must be controlled to levels below their respective spacecraft maximum allowable concentration (SMAC).[5] For the first entry situation, the 7-day SMACs apply rather than 180-day SMACs. This is consistent with flight rules pertaining to first entry operations. The progression of the first entry flight rule's development over the course of the ISS's early assembly is provided in appendix A.

Requirements pertaining to the trace contaminant load model to be used for TCC engineering design, however, are tailored for first entry cases where data are available from module offgassing tests. Offgassing test data better reflect the actual offgassing load and supersede the TCC design load found in module design specifications. In such instances the offgassing test data are used to derive an actual load model to take the place of that documented by the module's design specifications. Metabolic contaminant generation from reference 2 is included in the overall trace contaminant load as appropriate.

In addition to the TCC requirements in the module design specifications, toxicological guidelines for ingress operations have been developed by the NASA medical toxicology experts. These guidelines center upon the toxic hazard index (*T*-value) which is defined by equation (1):

$$T = \sum C_i / C_{\mathrm{SMAC}} \, . \tag{1}$$

The *T*-value is the dimensionless ratio of the individual contaminant concentration, C_i, and its respective SMAC, C_{SMAC}. The *T*-value guidelines for module first entry operations are provided in table 1. The first column of table 1 lists the initial *T*-value in the module of interest while the second column lists the corresponding time allowed to reduce the initial *T*-value to 1.

Table 1. Ingress contamination control guidelines.

Initial Node *T*-Value	Allowable Scrub Time (hr)
10	1
7	2
6	8
5	24
4	36

Further guidelines for safe first entry and prelaunch monitoring of trace contaminants are specified not only by flight rules pertaining to first ingress criteria but also by the ISS Medical Operations Requirements Document (MORD) (SSP 50260, sec. 7.3).[6] The flight rules provided in appendix A require that specific actions be taken at different initial *T*-value levels. In general, the flight rule criteria specify that if the predicted *T*-value is ≤3, then first ingress without first scrubbing the module cabin atmosphere is acceptable. All other cases require some form of active contamination removal before first ingress. The ISS MORD requires that a pressurized module's atmosphere be sampled during prelaunch processing according to the Qualification and Acceptance Environmental Test Requirements document (SSP 41172, sec. 5.2.4) to allow for accurate prediction of trace contaminant concentrations during in-flight ingress operations. As noted previously, data collected during this module sampling effort supersede the TCC load model used for engineering design. Specific TCC requirements for each major ISS module are provided by the following summary.

2.1 Requirements for Node 1

Requirements specific to the Destiny Node 1's TCC capability are documented in the Prime Item Development Specification (PIDS) for Node 1 (S684-10102F, paragraphs 3.2.1.63 and 4.3.2.1.63 and tables XI and XII). Also, cabin air catalyst element assembly (CACEA) filter qualification test data were used as the basis for assessing the active TCC performance capability during early Node 1 entry operations. The flight rule version that guided Node 1 first entry is provided in appendix A.

2.2 Requirements for Russian Modules—Assembly Mission 2R

Requirements specific to assessing the ISS's TCC capability for assembly mission 2R are documented in the ISS System Specification (SSP 41000R, paragraphs 4.3.7.1.3.14.2, .3.7.5.3.13.2, and 3.7.5.3.13.2) and the Russian Segment Specification (SSP 41163C, paragraph 4.3.2.1.1.1.13.2a.) These requirements addressed both cabin atmospheric quality and hardware performance. Flight rule 3A_3B-1 applied to assembly mission 2R is provided in appendix A.

2.3 Requirements for the Lab Module—Assembly Mission 5A

Requirements specific to assessing the ISS's TCC capability for mission STS-98/5A cover first ingress operations of the Destiny laboratory module and the long-term TCC capability provided by the TCCS on board Destiny and the Russian microimpurity adsorption device (BMP) on board the Zvezda service module after the Shuttle undocks. Overall ISS program requirements relating to TCC are documented in the ISS System Specification (SSP 41000R, paragraphs 3.7.1.3.14.2 and 3.7.5.3.13.2). These requirements state that the U.S. on-orbit segment (USOS) and Russian on-orbit segment (ROS) must control individual trace chemical contaminants in the cabin atmosphere below their respective SMACs. These requirements were verified by analysis methods according to the ISS System Specification (paragraphs 4.3.7.1.3.14.2 and 4.3.7.5.3.13.2). The requirements relating to both air quality and hardware performance are repeated in the USOS Specification (SSP 41162R, paragraphs 3.2.1.1.1.59 and 3.7.1.3.97) and the ROS Specification (SSP 41163C, paragraph 4.3.2.1.1.1.13.2a). As well, the USOS Specification (paragraph 3.7.1.3.97f) places specific requirements on the initial ingress of Destiny. The USOS Specification (paragraph 3.2.1.1.1.59) also requires an assessment of the effects that intermodule ventilation (IMV) may have on trace contaminant concentrations and the service life of TCCS expendables.

According to the ISS System Specification, the integrated analysis used qualification data from the various modules comprising the ISS for the assembly mission 5A configuration. Accordingly, offgassing test data from Destiny, Unity, Zarya, and Zvezda were used as the trace contaminant load basis. Effectively, this replaced the ISS program load model requirements contained in the ISS System Specification and the U.S. and Russian segment specifications with a load model derived from actual ISS element offgassing tests and in-flight air quality sample analysis results. Because these data were collected during the ground-based offgassing tests and from in-flight atmospheric quality data collected between STS-88/2A and STS-106/2A.2b, they better reflect the true offgassing load. Their use as input to the analysis provides a more realistic result. Where data gaps exist, such as for stowage hardware, the specific load for a unit mass of hardware listed by the ISS System Specification (table LXXIII) is used to predict rates from the hardware that has been stowed on board the ISS through assembly mission STS-106/2A.2b.

2.4 Requirements for the Columbus Laboratory Module

The specific requirement for TCC for the Columbus attached pressurized module (APM) is found in the ISS System Specification (paragraph 3.7.1.3.14.2). This requirement states that the USOS must control individual trace chemical contaminants in the cabin atmosphere below their respective SMACs. The ISS program requirements pertaining to trace chemical contamination control functional performance were flowed to the Columbus Systems Requirements Document (COL-ESA-RQ-001). Specifically, controlling to the individual compound SMACs is imposed on the Columbus APM because the Columbus APM relies completely on ventilation flow with the Station's core modules to maintain cabin air quality as it does not possess active contamination control equipment. The Interface Requirements Document Space Station Manned Base to Columbus Attached Pressurized Module (SSP 41150K, paragraph 3.1.7.1.1) specifies the ventilation rate with Harmony Node 2 must be 229 m^3/hr. Flight rule X13.2.2-2 listed in appendix A applied to the Columbus APM first entry operations.

2.5 Requirements for the Kibo Japanese Experiment Module

The ISS program requirements pertaining to trace chemical contamination control functional performance are flowed to the Segment Specification for the Japanese Experiment Module (JEM) (SSP 41165) which implements the ISS program TCC requirements from the ISS System Specification for the Kibo habitable elements. Exchange of information pertaining to the Kibo experiment logistics module (ELM) pressurized section (PS) offgassing testing and the resulting data analysis is governed by the NASA/NASDA Bilateral Data Exchange Agreements (SSP 50126).

2.6 Requirements for Harmony Node 2

Once attached to the ISS the Harmony Node 2 relies completely on ventilation flow with the Station's core modules to maintain cabin air quality because it does not possess active contamination control equipment. The Space Station program Node Element 2 to U.S. Laboratory Element Interface Control Document (SSP 41143, paragraph 3.2.1.2.3.1.4) specifies the ventilation rate with Harmony Node 2 must be between 229 and 246 m^3/hr. Before attachment to the ISS and activation, contamination control is accomplished via passive means such as materials selection and atmospheric renewal with clean breathing air. Flight rule X13.2.2-2 applied to the Harmony Node 2 first entry operations.

2.7 Requirements for Tranquility Node 3

When initially attached to the ISS, the Tranquility Node 3 will rely completely on ventilation flow with the Station's core modules to maintain cabin air quality. The Node Element 1 to U.S. Habitation Element Interface Control Document (ICD) (SSP 41140E, paragraph 3.2.1.5.1.4) specifies the ventilation rate between the Unity Node 1 and Tranquility Node 3 modules must be ~204 m^3/hr. Before attachment to the ISS and activation, contamination control is accomplished via passive means such as materials selection and atmospheric renewal with clean breathing air. Active contamination control will reside in Node 3 after the atmosphere revitalization subsystem rack is installed. Flight rule X13.2.2-2 applied to the Tranquility Node 3 first entry operations.

2.8 Requirements for the Leonardo Permanent Multipurpose Module

When attached to the ISS, the Leonardo permanent multipurpose module (PMM) will rely completely on ventilation flow with the Station's core modules to maintain cabin air quality. The Joint Environmental Control and Life Support Functionality Strategy Document (SSP 50623) specifies the minimum ventilation rate with the Multipurpose Logistics Module to be ~229 m^3/hr. This minimum flow is used for assessing dynamic atmospheric quality during Leonardo PMM first entry operations. Before attachment to the ISS and activation, contamination control for the Leonardo PMM is accomplished via passive means such as materials selection and atmospheric renewal with clean breathing air via a dry air purge. Flight rule X13.2.2-2 applied to the Leonardo PMM first entry operations.

2.9 Requirements for Cargo Vehicles—Multipurpose Logistics Module

The specific ISS program requirement for TCC pertaining to cargo mission STS-100/6A is documented in the ISS System Specification (paragraph 3.7.1.3.14.2). Specifically, this requirement states that the USOS must control individual trace chemical contaminants in the cabin atmosphere below their respective SMACs. This includes on-orbit first ingress of logistics modules.

2.10 Module Offgassing Rate Calculation

During ISS on-orbit assembly beginning in 1998 and continuing through 2010, testing was conducted to characterize the offgassing rates from habitable modules, cargo modules, and cargo vehicles. The data, reported by the NASA and the ISS international partners, were assessed to characterize each ISS element's trace contaminant generation load with respect to rate and the contribution of chemical functional groups. Trace contaminant concentration, C_i, changes over time, t, as denoted by equation (2):

$$\frac{dC_i}{dt} = \frac{r_i}{V} \ . \tag{2}$$

Generation rate, r_i, may change with time. The rate of change is typically slow compared to typical offgassing test duration and is treated as a time-averaged constant. The module free volume, V, is constant and accounts for the volume occupied by internal equipment.

Individual contaminant generation rates are derived using equation (3) which is equation (2) in differential form solved for the generation rate. In equation (2), r_i is the individual contaminant generation rate in mg/hr, V is the cabin free volume in m^3, n is the number of sampling events during the test, C_j is the average concentration at sampling event j and time, t_j, during the offgassing test in mg/m^3, and C_{j-1} is the average concentration for the previous sampling event $j-1$ at time, t_{j-1}, during the test:

$$r_i = \left(\frac{V}{n-1} \right) \sum_{j=1}^{n} \left(\frac{C_j - C_{j-1}}{t_j - t_{j-1}} \right) . \tag{3}$$

Results from each element offgassing test were evaluated using equation (3) to determine time-averaged generation rates. The rates derived from this evaluation are used as the basis for general cabin material balance calculations.

Each contaminant concentration at ingress is calculated directly using the solved form of equation (2) as shown in equation (4):

$$C_i - C_{i,o} + \frac{r_i}{V} \left(t_2 - t_1 \right) . \tag{4}$$

The initial concentration, $C_{i,o}$, is assumed zero as is t_1. Once the concentration has been calculated, the overall T-value is calculated using equation (1).

The time to reduce the T-value from a beginning level to the flight rule ingress criterion of 3 is calculated directly by using the solved mass balance equations between the ISS cabin and the airlock. The solved form is shown in equation (5):

$$T = T_o - \left(\frac{1}{V_{\text{module}}} + \frac{1}{V_{\text{ISS}}} \right) vt \ , \tag{5}$$

where

T = final T-value
T_o = beginning T-value
v = IMV flow rate (m^3/hr)
t = time (hours).

The equation is then solved for time.

2.11 Cabin Material Balance

Assuming that a spacecraft cabin is a single, well-mixed volume, equation (6) provides the material balance for any chemical contaminant:

$$\frac{dm_i}{dt} = r_i - \frac{\Sigma \eta v}{V} m_i \ , \tag{6}$$

where

m_i = contaminant mass in the cabin atmosphere (mg)
r_i = contaminant generation rate (mg/hr)
V = cabin free volume (m^3)
$\Sigma \eta v$ = total active removal capacity for all known contamination control equipment removal routes (m^3/hr).

The solved form of this mass balance equation yields equation (7):

$$m_i = m_{o,i} e^{-\left(\Sigma \eta v / V\right) t} + \left(r_i V / \Sigma \eta v \right) \left[1 - e^{-\left(\Sigma \eta v / V\right) t} \right], \tag{7}$$

where

m = contaminant mass at time, t (mg)
m_o = contaminant mass at time equal to zero (mg)
V = cabin free volume (m^3)
$\Sigma \eta v$ = effective contaminant removal flow for all removal routes (m^3/hr)
r_i = contaminant generation rate (mg/hr)
t = time (hr).

The rate of change for most contaminant concentrations is very slow. Therefore, equation (8), the steady state form of equation (7), can be used for most TCC calculations:

$$m_i = r_i V / \Sigma \eta v \ . \tag{8}$$

Simplifying equation (7) by assuming the contaminant mass removal rate is much greater than the generation rate and solving the resulting equation for time yields equation (9):

$$t = -\left(\Sigma \eta \dot{v} / V \right) \ln \left(m_{t,i} / m_{o,i} \right) . \tag{9}$$

This equation is useful for calculating the active scrubbing duration after a transient contamination event. The active scrubbing device volumetric flow and efficiency are assumed to be constant.

2.12 Adjacent Well-Mixed Cabin Volumes

First entry of a module or a cargo vehicle requires assessing the time-dependent effect that buildup of contamination has on the general ISS cabin environment. In this case, the material balance between two adjacent, well-mixed volumes consists of a simultaneous mass balance on each individual volume. The material balance equations for two well-mixed cabin volumes A and B are provided in equations (10) and (11), respectively. These equations define the change in contaminant mass as a function of time:

$$\frac{dm_A}{dt} = \frac{\dot{v}_B}{V_B} m_B - \frac{\dot{v}_A}{V_A} m_A - \frac{\sum \eta v}{V_A} m_A + r_A \tag{10}$$

and

$$\frac{dm_B}{dt} = \frac{\dot{v}_A}{V_A} m_A - \frac{\dot{v}_B}{V_B} m_B - \frac{\sum \eta v}{V_B} m_B + r_B \ , \tag{11}$$

where

m_A = total mass of contaminant in cabin A
m_B = total mass of contaminant in the cabin B
V_A = cabin A free volume
V_B = cabin B free volume
$\dot{v}_A$ = intermodule ventilation flow from cabin A to cabin B
$\dot{v}_B$ = intermodule ventilation flow from cabin B to cabin A
$\sum \eta v$ = removal capacity in the respective cabin volume
r_A = generation rate in cabin A
r_B = generation rate in cabin B.

Simultaneous solution of equations (10) and (11) provide an equation for each cabin volume in the form of equation (12):

$$m = \alpha + \beta e^{x_2 t} + \gamma e^{x_3 t} \ , \tag{12}$$

where

m = total mass of contaminant in the reference cabin volume
α, β, γ = constants calculated from the cabin free volume, ventilation flow, removal capacity, and contaminant generation rate
x_2, x_3 = integration constants. The integration constants are calculated from the cabin free volume, ventilation flow, and removal capacity parameters. Concentration is calculated by simply dividing the contaminant mass by the cabin free volume.

3. CABIN AIR QUALITY CONTROL FOR NODE 1 ASSEMBLY MISSION 2A

This assessment was originally released as NASA Memorandum ED62(134-98) dated November 2, 1998.

3.1 Background

In preparation for the Unity Node 1 flight operations, a 5-day trace contaminant offgassing test was conducted October 1–6, 1998. During this test, sets of three grab samples were collected at the beginning, middle, and end of the test. Subsequent analysis of these samples established trace contaminant concentrations as a function of time. From these concentrations, generation rates were determined.

The generation rates derived from the offgassing test results serve as input data for an engineering analysis of the Unity Node 1's TCC capabilities. Results, conclusions, and recommendations of the engineering analysis are presented in the following discussion.

3.2 Purpose

The engineering analysis summarized by the following discussion serves to verify that the Unity Node 1's TCC capability, at a minimum, can maintain trace contaminants below their respective SMACs and comply with related medical operations guidelines for safe ingress.

3.3 Objectives

The adequacy of the Unity Node 1's trace contaminant removal capability was assessed by engineering analysis. Specific objectives of the analysis that allowed for appropriate verification of this capability were the following:

- Determine the trace contaminant concentrations during Unity Node 1 ingress operations for assembly missions 2A and 2A.1.

- Determine the adequacy of the Node 1 CACEA for meeting the relevant Node 1 PIDS requirements and medical operations guidelines.

3.4 Assumptions

To conduct the Node 1 TCC capability assessment, assumptions were made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, CACEA configuration, and mission timeline.

3.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for all phases of the verification analysis were the following:

- Offgassing rates are derived from Node 1 offgassing test results.

- Unity Node 1 atmospheric leakage is zero. This is considered to be true for a newly launched element.

- Unity Node 1 atmospheric conditions are on average 10 °C, 30% relative humidity (–6.7 °C dew-point), and 1 atm. These conditions approximate the on-orbit atmospheric conditions of Unity Node 1.

- Offgassing rates are constant with time, and effects of temperature and pressure fluctuations are negligible. Offgassing has been shown to be very sensitive to temperature fluctuations. Because the offgassing test temperature was higher, the rates derived from it are considered to be conservative.

- Seven-day SMACs apply for the analysis.

3.4.2 Node 1 Configuration

On orbit, Unity Node 1 was attached to a pressurized mating adapter 1 (PMA-1), which is in turn attached to the Shuttle during each assembly flight. The Unity Node 1 was provided with a contamination control capability consisting of a cabin fan and four CACEAs located in the cabin air return duct in place of the cabin air bacteria filter elements. The configuration provided at least a 340 m^3/hr total air flow rate through the CACEAs. Assumptions pertaining to the Unity Node 1 configuration and its contamination control capability were the following:

- Cabin free volumes of Unity Node 1, PMA-1, and Shuttle are 51.3, 6.1, and 65.8 m^3, respectively.

- The total Node 1 scrubbing rate is 340 m^3/hr with the flow split evenly between four individual CACEAs.

- Each CACEA has a minimum type AC granular activated charcoal (AC/GAC) packing depth of 3.3 cm and a platinum on charcoal (2% Pt/GAC) packing depth of 1.27 cm.

3.4.3 Mission Timeline

Unity Node 1 was launched during assembly flight 2A. Approximately 70 days before launch, a final purge was conducted to provide a dry atmosphere. This purge had the added benefit of removing trace contaminants and establishing a clean atmosphere baseline. The elapsed 70 days included a 6-day launch delay based upon a September 30, 1998, dry air purge and planned December 3 launch. During mission 2A, pressure was equalized between the Orbiter and Unity Node 1 on flight day 3. Because no air flows into Unity Node 1, this operation did not reduce contamination in the Unity Node 1 cabin. However, it did introduce some contamination into the Orbiter. On flight day 6, the Unity Node 1 cabin fan ran for 2 hours to scrub the cabin air. Ingress activities were conducted on flight day 8. The ingress operation did not include an additional preingress scrub. However, the cabin fan ran during the entire ingress period and IMV between Unity Node 1 and the Shuttle Orbiter cabin, which was initiated after the hatch was opened, was provided during the entire ingress operation. During the first 2 hours of the ingress, the IMV provided an additional dilution of the remaining trace contaminants in Unity Node 1's atmosphere. Ingress operations lasted approximately 8 hours. At the completion of flight 2A, a period of untended operations of approximately 161 days began. After that time, the next planned ingress activities occured during assembly flight 2A.1. Multiple ingress events occur during flight 2A.1. A similar ingress approach employing a 2-hour scrub followed by opening the hatch and activating IMV was followed. At the conclusion of flight 2A.1, the expended CACEAs were replaced with fresh ones. The engineering analysis does not include flights beyond 2A.1 due to schedule uncertainty. The timeline used for the engineering analysis is summarized in table 2.

Table 2. Mission timeline for flights 2A and 2A.1.

Time (hr)	Event
0	Node 1 purge at launch minus 70 days
1,680	Launch
1,752	Pressure equalization on flight day 3
1,824–1,826	Run cabin fan for 2 hours on 2A flight day 6
1,872–1,880	Ingress on 2A flight day 8
1,968	Flight 2A complete
5,832	161 days elapse between flights 2A and 2A.1
5,928	Ingress on 2A.1 flight day 4
5,928–5,930	Run cabin fan for 2 hours
5,930–5,938	Ingress for 8 hours with cabin fan running
5,952	Ingress on 2A.1 flight day 5
5,952–5,960	Ingress for 8 hours with cabin fan running
5,976	Ingress on 2A.1 flight day 6
5,976–5,984	Ingress for 8 hours with cabin fan running
6,000	Ingress on 2A.1 flight day 7
6,000–6,008	Ingress for 8 hours with cabin fan running
6,024	Ingress on 2A.1 flight day 8
6,024–6,032	Ingress for 8 hours with cabin fan running
6,048	Replace CACEAs
6,072	Flight 2A.1 complete

3.5 Approach

The following discussion summarizes the Unity Node 1 TCC capability assessment approach. The discussion includes a summary on trace contaminant generation rate derivation, the analytical tool, and cases considered for the assessment.

3.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of Unity Node 1 offgassing test grab samples. The procedure used to derive the rates follows:

- Determine the average concentration for each contaminant for each sampling event.

- Determine the generation rate between the first and second sampling events for each contaminant.

- Determine the generation rate between the second and third sampling events for each contaminant.

- Determine the time-averaged generation rate for each contaminant over the entire offgassing test duration.

3.5.2 Simulation Computer Program

The Trace Contaminant Control Simulation-Computer Program (TCCS-CP), version 8.1, was used to conduct the analysis.[7,8] This analytical tool calculates the cabin concentration of individual trace chemical contaminants when generated at a specified rate and controlled by any combination of removal devices. It contains subroutines for simulating the performance of AC/GAC and 2% Pt/GAC.

The TCCS-CP, version 8.1, was previously assessed for its applicability for use in spacecraft TCC verification analyses and was found to be acceptable, and the subroutine for the 2% Pt/GAC was found to provide a conservative performance assessment.[9]

3.5.3 Analysis Cases Considered

Three analysis cases were considered. The first uses the generation rates derived from Unity Node 1 offgassing testing to predict Unity Node 1 cabin concentrations during ingress operations. Results from the first case allowed the expected individual contaminant concentrations and the resulting *T*-value to be determined. These results provide insight into the risk presented during missions 2A and 2A.1 by trace contamination produced by materials offgassing. The second case is a subset of the first case. Results from the second case allowed for a prediction of contamination of the Orbiter habitable volume which may result during the pressure equalization planned on flight day 3 of mission 2A. The final case considers the rate of contamination buildup to determine the duration of a launch delay which would require Unity Node 1's atmosphere to be purged or scrubbed again.

3.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the three analysis cases.

3.6.1 Derived Generation Rates

Generation rates were derived from the Unity Node 1 offgassing test air sample analysis results listed in appendix B using equation (3). Table 3 provides a summary of the average concentration for each contaminant for the baseline ($t=0$), 32.8-hour, and 118.6-hour sampling events. Overall, the time-averaged generation rates agreed well with those based upon the predicted offgassing from 2,359 kg of internal hardware. Out of the total of 125 compounds used for Unity Node 1 TCC design, only 6 were found to have higher derived generation rates. Thus, 95.2% of the generation rates used for design were higher than those derived from the Unity Node 1 offgassing test data. This is consistent with the approach for the design rates which represent a 96% confidence interval. This demonstrates that the Unity Node 1 CACEA design is conservative and, therefore, should be capable of handling the observed load. Detailed engineering analysis of missions 2A and 2A.1 provide the necessary Unity Node 1 CACEA design verification.

Table 3. Unity Node 1 trace contaminant generation rates.

	Average Concentration (mg/m^3)			Generation Rate (mg/hr)			
Compound	**$t=0$ hr**	**$t=32.8$ hr**	**$t=118.6$ hr**	**$t=0/32$**	**$t=32/118$**	**Time Averaged**	**Predicted**
Acetaldehyde	0.025	0.025	0.025	–	–	–	0.0107
Methanol	0.08	0.43	0.73	0.544	0.18	0.28	0.1251
Ethanol	0.20	0.76	1.65	0.876	0.532	0.627	0.772
Acetone	0.025	0.15	0.38	0.196	0.138	0.154	0.3558
Propanal	0.025	0.025	0.025	–	–	–	0.0314
Isopropanol	0.15	0.80	1.5	1.02	0.419	0.585	0.392
2-methyl-2-propanol	–	–	0.025	–	0.0149	0.0149	0.0073
Dichloromethane	–	0.055	0.19	0.086	0.0807	0.0822	0.211
Trichlorotrifluoroethane (R-113)	0.0105	0.075	0.125	0.101	0.0299	0.0496	1.862
Propanol	–	0.085	0.225	0.133	0.0.0837	0.0973	0.0237
Butanal	0.0125	0.025	0.025	0.0196	–	0.0196	0.0844
2-butanone	–	0.075	0.18	0.117	0.0628	0.0778	0.59
Butanol	–	–	0.13	–	0.0777	0.0777	0.463
Pentanal	0.025	0.025	0.025	–	–	–	0.0076
Trichloroethene	0.025	0.025	0.025	–	–	–	0.0085
Trichlorofluoromethane	–	–	0.025	–	0.0149	0.0149	0.1383
Methylbenzene (toluene)	0.025	0.08	0.125	0.086	0.0269	0.0432	0.195
Hexanal	0.025	0.025	0.025	–	–	–	0.0052
Butyl acetate	0.025	0.025	0.025	–	–	–	0.0733
Tetrachloroethene	0.025	0.025	0.025	–	–	–	0.0716
Ethylbenzene	–	–	0.025	–	0.0149	0.0149	0.0147
M-/p-xylenes	–	0.025	0.025	0.0391	–	0.0391	0.254
Cyclohexanone	0.025	0.042	0.085	0.0266	0.0257	0.0259	0.0652
Heptanal	0.025	0.025	0.025	–	–	–	0.0017
O-xylene	–	–	0.025	–	0.0149	0.0149	0.106
Carbon disulfide	0.025	0.025	0.025	–	–	–	0.0031
2-methyl-2-propenal	–	–	0.025	–	0.0149	0.0149	0.0002
Octamethylcyclotetrasiloxane	0.075	0.16	0.32	0.133	0.0957	0.106	0.0266
Hexamethylcyclotrisiloxane	–	–	0.025	–	0.0149	0.0149	0.0159

3.6.2 Relative Contamination for Missions 2A and 2A.1

The first case considered used the time-averaged generation rates for all of the contaminants observed during the Unity Node 1 offgassing test. Concentrations calculated for each contaminant at the beginning of each ingress operation are listed in table 4. As can be seen, all the contaminants are well below their respective 7-day SMACs.

Table 4. Predicted concentrations during missions 2A and 2A.1 ingress operations.

Compound	7-Day SMAC (mg/m^3)	Concentration (mg/m^3)						
		2A 1,752 hr	2A 1,872 hr	2A.1 No. 1 5,932 hr	2A.1 No. 2 5,952 hr	2A.1 No. 3 5,976 hr	2A.1 No. 4 6,000 hr	2A.1 No. 5 6,024 hr
Methanol	9	8.55E+00	1.82E+00	3.62E+00	3.72E+00	1.85E+00	9.76E-01	5.69E-01
Ethanol	2,000	1.91E+01	7.86E-01	4.13E-01	6.32E-01	5.50E-01	5.12E-01	4.94E-01
2-propanol	150	1.79E+01	5.43E-01	2.06E-02	1.67E-01	1.88E-01	1.88E-01	1.88E-01
n-propanol	98	2.97E+00	9.22E-02	1.14E-03	2.49E-02	2.83E-02	2.83E-02	2.83E-02
2-methyl-2-propanol	120	4.55E-01	1.39E-02	1.19E-04	3.76E-03	4.28E-03	4.28E-03	4.28E-03
n-butanol	80	2.37E+00	6.63E-02	5.05E-04	1.95E-02	2.22E-02	2.22E-02	2.22E-02
2-methyl-2-propenal	1.7	4.55E-01	1.69E-02	2.62E-04	3.83E-03	4.35E-03	4.35E-03	4.35E-03
Butanal	120	5.98E-01	1.76E-02	1.38E-04	4.93E-03	5.61E-03	5.61E-03	5.61E-03
Methylbenzene	60	1.32E+00	3.72E-02	2.76E-04	1.08E-02	1.24E-02	1.24E-02	1.24E-02
1,2- & 1,3-dimethylbenzenes	220	1.19E+00	3.24E-02	2.09E-04	9.77E-03	1.11E-02	1.11E-02	1.11E-02
1,4-dimethylbenzene	220	4.55E-01	1.24E-02	8.19E-05	3.73E-03	4.25E-03	4.25E-03	4.25E-03
Ethylbenzene	130	4.55E-01	1.25E-02	8.26E-05	3.73E-03	4.25E-03	4.25E-03	4.25E-03
Dichloromethane	10	2.51E+00	1.45E-01	7.17E-02	1.00E-01	8.03E-02	7.09E-02	6.66E-02
Trichlorofluoromethane	560	4.55E-01	1.87E-02	3.52E-04	3.84E-03	4.36E-03	4.36E-03	4.36E-03
Trichlorotrifluoroethane	400	1.51E+00	4.55E-02	3.73E-04	1.25E-02	1.42E-02	1.42E-02	1.42E-02
2-propanone	50	4.70E+00	1.73E-01	1.20E-02	5.08E-02	5.63E-02	5.63E-02	5.64E-02
2-butanone	30	2.38E+00	7.29E-02	7.36E-04	1.97E-02	2.24E-02	2.24E-02	2.24E-02
Cyclohexanone	60	7.91E-01	2.15E-02	1.43E-04	6.48E-03	7.38E-03	7.38E-03	7.38E-03
Hexamethylcyclotrisiloxane	230	4.55E-01	1.22E-02	6.87E-05	3.71E-03	4.23E-03	4.23E-03	4.23E-03
Octamethylcyclotetrasiloxane	281	3.24E+00	8.54E-02	3.52E-04	2.62E-02	2.99E-02	2.99E-02	2.99E-02

1,752 hr = flight day 3, mission 2A, Node 1 concentrations during pressure equalization
1,872 hr = flight day 8, mission 2A, ingress with no additional scrub
5,932 hr = flight day 4, mission 2A.1, post scrub
5,952 hr = flight day 5, mission 2A.1, ingress with no scrub
5,976 hr = flight day 6, mission 2A.1, ingress with no scrub
6,000 hr = flight day 7, mission 2A.1, ingress with no scrub
6,024 hr = flight day 8, mission 2A.1, ingress with no scrub

As can be seen by figures 1 and 2, the *T*-value rises to approximately 1.98 by flight day 6 of mission 2A. At that time, the Unity Node 1 cabin fan is run for 2 hours. This reduces the *T*-value to 0.19. On flight day 8, Node 1 ingress operations are conducted. By that time, the *T*-value has climbed to 0.24. It should be noted that methanol accounts for 0.2 *T*-value units or 83% of the contamination load at ingress. After opening the hatch, starting the Node 1 cabin fan, and initiating ventilation flow between the Unity Node 1 and Orbiter cabins, the *T*-value is reduced to 0.1 within 2 hours. Methanol's concentration is reduced to 0.85 mg/m^3 and accounts for 0.095 *T*-value units. This is 95% of the relative contamination load. The Unity Node 1 cabin fan operates continuously throughout the ingress operation and is turned off at its conclusion. It should be noted that this result does not include any scrubbing by Orbiter-provided contamination control devices. Contamination is maintained at a steady level throughout the ingress by using the Unity Node 1 CACEAs alone. By the end of the mission, the *T*-value climbs to approximately 0.2 because there is no active scrubbing in Unity Node 1 after the 8-hour ingress operation has concluded. The methanol concentration climbs to 1.3 mg/m^3 which accounts for 0.15 *T*-value units or 75% of the contamination load in Unity Node 1.

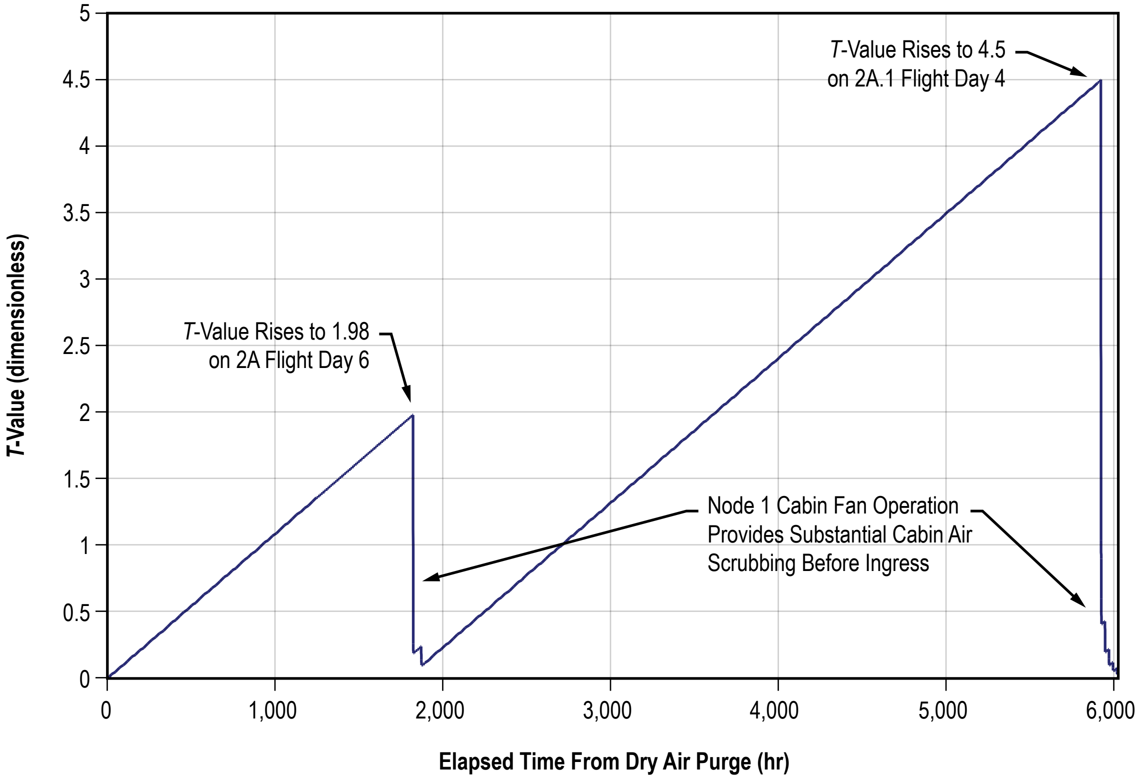

Figure 1. Unity Node 1 relative contamination during flights 2A and 2A.1.

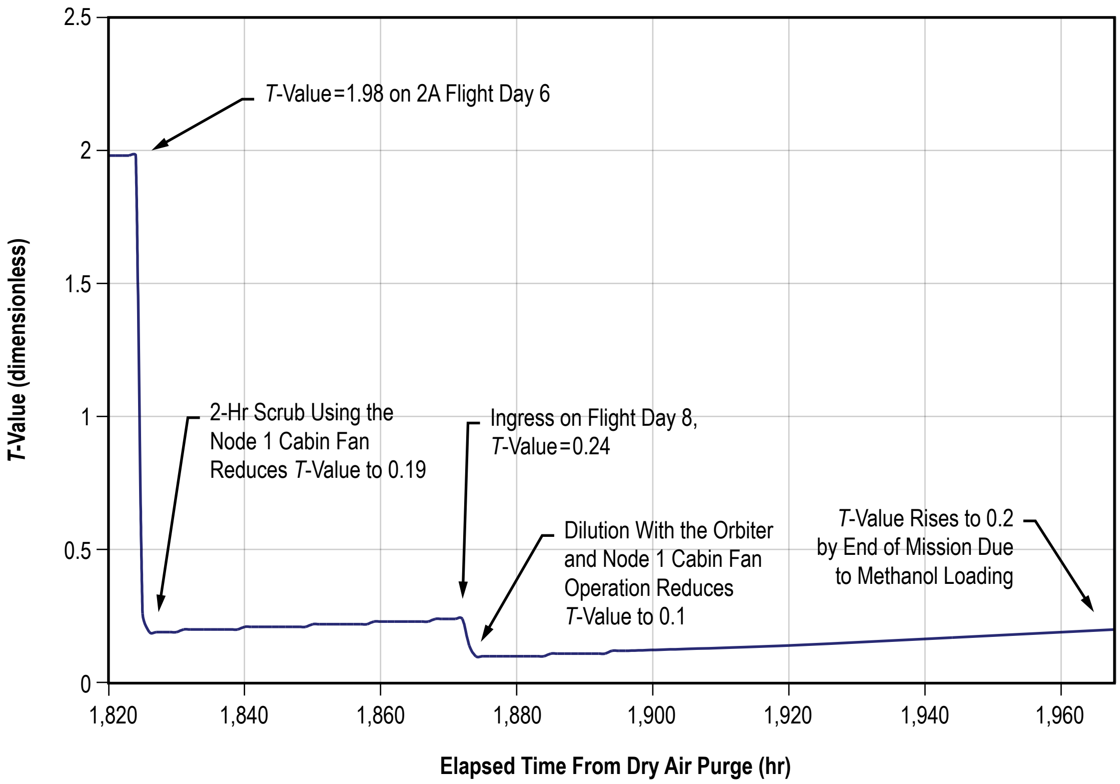

Figure 2. Relative contamination during 2A ingress.

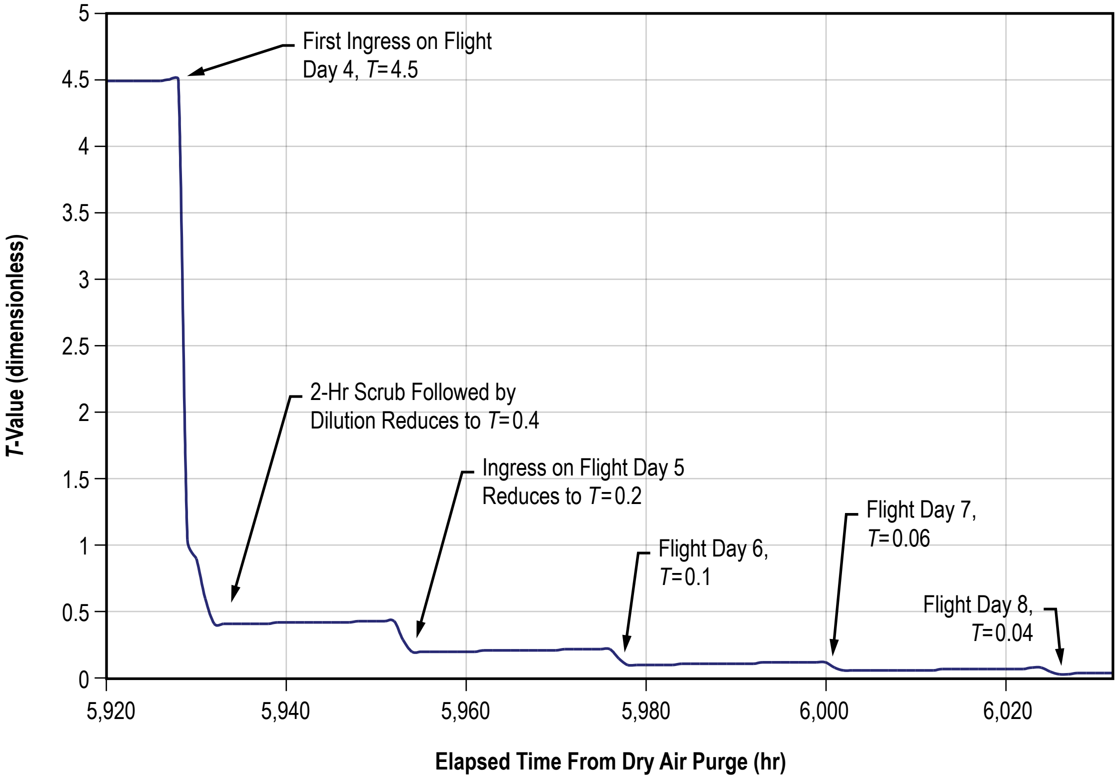

Figure 3. Relative contamination of Unity Node 1 during mission 2A.1.

Figures 1 and 3 show that the *T*-value increases to 4.5 by the first 2A.1 ingress which is scheduled for flight day 4. A single 8-hour ingress of Unity Node 1 is conducted on each day through flight day 8. During each ingress, the *T*-value is reduced further based upon the Unity Node 1 CACEA capacity and the Orbiter's TCC capability. After scrubbing the Unity Node 1 atmosphere on flight day 4 and diluting into the Orbiter habitable volume, the *T*-value drops to 0.4. For subsequent ingress operations, the *T*-value after dilution is 0.2, 0.1, 0.6, and 0.04. This continued reduction in relative contamination indicates that the CACEA's capacity to remove contamination from Unity Node 1 offgassing is sufficient.

3.6.3 Pressure Equalization During Mission 2A

Table 4 shows the concentrations for each individual contaminant in Unity Node 1 at the time of pressure equalization. During this operation, the pressure between the Orbiter (70.3 kPa) and Node 1 (101.3 kPa) is equalized. Assuming ideality, the Orbiter cabin contains 1,886 moles of air and Unity Node 1 contains 2,371 moles of air. These quantities of air produce a pressure of 84.8 kPa in the combined cabin volumes. During the equalization, approximately 387 moles will flow from Unity Node 1 into the Orbiter. This is approximately 11.2 m^3 of air at 84.8 kPa and 22 °C.

The air transferred from Unity Node 1 will contain contaminants at concentrations listed in table 4 under the column for 1,752 hours. At that concentration, the air from Unity Node 1 will contribute 0.32 *T*-value units to the Orbiter cabin. Typically, the Orbiter cabin averages approximately

0.5 *T*-value units. Therefore, the combined contamination load may be approximately 0.8 *T*-value units. This is within the acceptable range of 1 *T*-value unit.

3.6.4 Launch Delay Window

According to the offgassing test data, the relative contamination in the Unity Node 1 cabin builds up at a rate of 0.023 *T*-value units/day. The limiting capability for ingress is the contingency capability provided by the Orbiter. Previous analysis has shown that the Orbiter-provided capability cannot handle the Unity Node 1 contamination if the *T*-value at ingress exceeds 6. At the rate of 0.023 *T*-value units/day, it takes approximately 260 days to reach a *T*-value magnitude of 6 in Unity Node 1. This would indicate that a launch slip of up to 190 days may occur before another cabin air purge or scrubbing operation is needed. The present engineering analysis includes a 6-day, built-in launch slip with no additional ground-based scrub or purge. The 190-day slip includes the 6-day, built-in slip.

3.7 Discussion

As can be seen by the analysis results, sufficient air quality can be maintained during all phases of assembly for missions 2A and 2A.1. Medical operations experts determined that the *T*-value in Unity Node 1 must be at or below 3 for safe ingress. Otherwise, some additional means of contamination control must be used. Figure 2 shows that this condition is met for mission 2A; however, the *T*-value magnitude may exceed 3 at the time of the first ingress during mission 2A.1. The more specific instructions provided by the ingress flight rule provided in appendix A indicates that the Orbiter-provided contingency ingress hardware is necessary for both missions because the *T*-value may be in the range of 1.5 to 3 when it is time to open the hatch.

As noted previously, the Orbiter-provided contingency capabilities, when combined with dilution between the two volumes, cannot handle a Unity Node 1 *T*-value greater than a magnitude of 6 and still meet medical operations guidelines presented in table 1. As seen in figures 1 through 3, this limit for contingency ingress is not exceeded. Therefore, the crew could enter Unity Node 1 safely even if the Unity Node 1 cabin fan does not or cannot operate. However, because the *T*-value magnitude may be in the range of 1.5 to 3, Orbiter-provided contingency ingress hardware must be provided during both missions 2A and 2A.1 to ensure safe ingress operations.

3.8 Ability to Meet Russian Air Quality Standards

According to recent agreements between the U.S. and Russian sides documented in the Protocol of a Bilateral Splinter Meeting of the Air Quality Subgroup of the Environments Group of the Multilateral Medical Operations Panel held July 17–23, 1998, in Moscow, Russia, the Unity Node 1 atmosphere must be assessed relative to Russian air quality standards when the hatch between it and the Russian functional cargo block (FGB) is opened during deep ingress operations. Table 5 lists some of the Russian limiting permissible concentrations (LPCs) that must be met according to this agreement. Comparison of the predicted concentrations listed in table 4 with the LPCs in table 5 show that each individual contaminant within Unity Node 1 will be less than its respective Russian PLC except methanol. The joint agreement had already identified methanol as a potential problem and the Russian side accepted it without impact.

Table 5. Selected Russian air quality standards.

Compound	LPC (mg/m^3)
Methanol	0.2
Ethanol	10
2-propanol	1.5
n-butanol	0.8
Ethanal	1
Methylbenzene	8
Xylenes	5
Dichloromethane	5
2-propanone	2
2-butanone	0.25
Carbon monoxide	5
Polymethylcyclosiloxanes	0.2

3.9 Conclusions

Conclusions based on the Unity Node 1 TCC capability assessment results were the following:

- The Unity Node 1 contamination removal capability provided by the CACEAs meets the requirements of the Node 1 PIDS for all compounds.

- The observed contamination load is within allowable limits for contingency ingress operations.

- Pressure equalization between the Orbiter and Unity Node 1 during mission 2A does not adversely affect the Orbiter's cabin air quality. The resulting relative contamination level of approximately 0.8 *T*-value units is within the normal operating limit of 1.

- A slip of up to 190 days beyond the scheduled December 3, 1998, launch may occur before another ground-based cabin air scrub or purge is needed for Unity Node 1.

- The Unity Node 1 TCC capability can provide air quality that meets individual Russian PLCs with the exception of methanol.

3.10 Recommendations

Recommendations for addressing Unity Node 1 TCC issues during ingress operations were the following:

- Orbiter-provided contingency ingress hardware should be provided for both missions 2A and 2A.1. This hardware is the odor control cartridge (part No. SVHS783970). At least one cartridge is necessary to ensure safe ingress in the event that the Unity Node 1 cabin fan fails to operate.

- In-flight samples of Unity Node 1 during mission 2A are recommended to provide data for further assessing the ability to accomplish a contingency ingress during mission 2A.1.

4. POSTFLIGHT EVALUATION OF MISSION 2A AND PREFLIGHT PREDICTIONS FOR MISSION 2A.1

This assessment was originally released as NASA Memorandum ED62(29-99) dated April 21, 1999.

4.1 Background

In preparation for Unity Node 1 flight operations, a 5-day trace contaminant offgassing test was conducted October 1–6, 1998. During this test, sets of three grab samples were collected at the beginning, middle, and end of the test. Subsequent analysis of these samples established trace contaminant concentrations as a function of time. From these concentrations, generation rates were determined.

The generation rates derived from the offgassing test results were used as input data for an engineering analysis to predict the in-flight concentrations and relative contamination (*T*-value) of the Node 1 atmosphere upon ingress during ISS assembly mission 2A. This analysis served as a basis for establishing in-flight operations for both nominal and contingency ingress scenarios.

During assembly mission 2A, grab samples of the Unity Node 1 and Shuttle atmospheres were collected and analyzed postflight. Results from the sample analyses have been evaluated and served as a secondary basis for the Unity Node 1 trace contaminant load. Using an updated load model based on both the preflight offgassing test and in-flight grab sample analysis results, an updated TCC capability assessment was conducted to support in-flight operations for ISS logistics flight 2A.1. Results, conclusions, and recommendations of the engineering analysis are presented by the following discussion.

4.2 Purpose

The engineering analysis summarized by the following discussion served as verification of the Unity Node 1 TCC capability for logistics flight 2A.1.

4.3 Objectives

The adequacy of the Unity Node 1 trace contaminant removal capability was assessed by engineering analysis. Specific objectives of the analysis that allowed for appropriate verification of this capability were the following:

- Determine the Unity Node 1 trace contaminant load based upon both preflight offgassing test and in-flight air quality data.
- Determine the trace contaminant concentrations during Unity Node 1 ingress operations for logistics mission 2A.1.

- Determine the adequacy of the Unity Node 1 CACEAs for meeting the relevant Node 1 PIDS requirements and medical operations guidelines.

- Determine logistics requirements for the Unity Node 1 CACEAs and Shuttle-provided odor control cartridges.

4.4 Assumptions

To conduct the Node 1 TCC capability assessment, assumptions were made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, CACEA configuration, and mission timeline.

4.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for all phases of the verification analysis were the following:

- Offgassing rates are derived from Node 1 offgassing test results and revised according to results of in-flight air quality data.

- Unity Node 1 atmospheric leakage is zero. This is considered to be true for a newly launched element.

- Unity Node 1 atmospheric conditions are on average 10 °C, 30% relative humidity (–6.7 °C dew-point), and 1 atm. These conditions approximate the on-orbit atmospheric conditions of Unity Node 1.

- Offgassing rates are constant with time and effects of temperature and pressure fluctuations are negligible. Offgassing has been shown to be very sensitive to temperature fluctuations. Because the offgassing test temperature was higher, the rates derived from it are considered to be conservative.

- Seven-day SMACs apply for the analysis.

4.4.2 Node 1 Configuration

On orbit, Unity Node 1 was attached to the PMA 1 which was in turn attached to the Shuttle Orbiter during each assembly flight. The Unity Node 1 was provided with a contamination control capability consisting of a cabin fan and four CACEAs located in the cabin air return duct in place of the cabin air bacteria filter elements. The configuration provides at least a 340 m^3/hr total air flow rate through the CACEAs. Assumptions pertaining to the Unity Node 1 configuration and its contamination control capability were the following:

- Cabin free volumes of Unity Node 1, PMA 1, and Shuttle are 51.3, 6.1, and 65.8 m^3, respectively.

- The total Unity Node 1 scrubbing rate is 340 m^3/hr with the flow split evenly between four individual CACEAs.

- Each CACEA has a minimum type AC/GAC packing depth of 3.3 cm (1.3 in) and a platinum on charcoal (2% Pt/GAC) packing depth of 1.27 cm (0.5 in).

- Contamination generation and removal contributions from the FGB are assumed negligible until more data on Russian equipment offgassing and the design of the harmful contaminants filter (HCF) are available.

4.4.3 Mission Timeline

The timeline used for the engineering analysis is shown in table 6. The relative timing of in-flight Environmental Control and Life Support (ECLS) operations and sampling events for assembly flight 2A are summarized in table 7 along with projected dates and approximate times—Greenwich mean time (GMT) and mission elapsed time (MET)—for major ECLS events for flights 2A.1 and 2A.2. In-flight operations for logistics flights 2A.1 and 2A.2 were modeled similarly to what was actually experienced during 2A. The engineering analysis did not include flights beyond 2A.2 due to schedule uncertainty.

Table 6. Engineering analysis timeline for flights 2A through 2A.2.

Time (hr)	Event
0	Node 1 purge at launch minus 65 days
960	Cabin fan operated on pad
1,560	Launch
1,670.5	Cabin fan started
1,715	Hatch open and IMV started
1,715.5	Node 1 ingress sample collected
1,717	FGB ingress sample collected
1,741	FGB egress sample collected
1,743	Node 1 egress sample collected
1,841	Cabin fan shut down
5,201	2A.1 launch
5,297	Cabin fan started approximately flight day 4
5,417	Cabin fan shut down
8,729	2A.2 launch
8,825	Cabin fan started approximately flight day 4
8,849	Cabin fan shut down

Unity Node 1 was launched as the payload for mission STS-88, which was designated as ISS assembly flight 2A. Approximately 65 days before launch, a final purge was conducted on approximately September 30, 1998, to provide a dry atmosphere. This purge had the added benefit of removing trace contaminants and establishing a clean atmospheric baseline. After approximately 40 days elapsed, the cabin fan was operated for 30 minutes to provide additional prelaunch atmospheric conditioning. Launch occurred on December 4 after a 1-day slip from the original December 3 date.

Table 7. Relative timing of events during mission 2A and projected for 2A.1 and 2A.2.

Event	Date	Time	
		GMT	MET
Node 1 purge at launch minus 65 days	09/30/98	00:00*	NA
Cabin fan operated on pad for 30 minutes	11/09/98	00:00*	NA
Launch	12/04/98	09:00	0/00:00
Cabin fan started	12/09/98	01:54	4/14:32
Hatch open	12/10/98	20:02	6/11:00
IMV activation	12/10/98	20:09	6/11:07
Node 1 ingress sample collected	12/10/98	20:22	6/11:22
FGB ingress sample collected	12/10/98	21:45	6/12:45
FGB egress sample collected	12/11/98	22:23	7/13:23
Node 1 egress sample collected	12/12/98	00:24	7/15:12
Cabin fan shut down	12/12/98	07:57	8/23:09
2A.1 launch	05/20/99	NA	0/00:00
Cabin fan started approximately flight day 4	05/24/99*	NA	4/00:00*
Cabin fan shut down	05/28/99*	NA	8/00:00*
2A.2 launch	10/14/99	NA	0/00:00
Cabin fan started approximately flight day 4	10/19/99*	NA	4/00:00*
Cabin fan shut down	10/20/99*	NA	5/00:00*

* Assumed for analysis purposes.

In flight, the cabin fan was started on December 9 and operated continuously up to and throughout the entire ISS ingress operation. It should be noted that the hatch between the Shuttle and Unity Node 1 was not opened until December 10, approximately 45 hours after the Unity Node 1 cabin was started. The fan was shut down on December 12 upon egress. In all, the fan operated for approximately 170 hours.

As a part of assembly mission 2A ingress operations, atmospheric samples were collected via evacuated grab sampling containers (GSCs) in Unity Node 1 and the FGB. All of the samples were collected on December 10. The first sample was collected approximately 30 minutes after the hatch was opened and the IMV was initiated. The second sample was collected from the FGB upon ingress approximately 2 hours after the Unity Node 1 hatch was opened, and the third sample upon FGB egress 24 hours later. The fourth sample was collected from Unity Node 1 just before egress approximately 2 hours after FGB egress.

After egress during assembly flight 2A, a period of untended operations of approximately 144 days began. After that time, the next planned ingress activities occured during logistics flight 2A.1. Launch for flight 2A.1 (STS-96) was scheduled for May 20, 1999, and ISS ingress was to be on flight day 4. It was anticipated that, like during flight 2A, the cabin fan will be activated and operate continuously throughout the planned ingress. It was assumed that, for purposes of this analysis, egress will occur on flight day 8 during 2A.1.

Beyond logistics flight 2A.1, the next flight, designated 2A.2, to the ISS is planned for October 4. The elapsed time between 2A.1 egress and 2A.2 ingress is approximately 142 days. A secondary case was investigated in which the launch for flight 2A.2 slips to mid-January 2000. This slip effectively adds 93 days (2,232 hours) to the timing for the 2A.2 events documented in table 6. Regardless of when logistics flight 2A.2 occurs, it was anticipated that the CACEAs would have to be replaced at its conclusion to support operations through assembly flights 3A and 4A.

4.5 Approach

The following discussion summarizes the Unity Node 1 TCC capability assessment approach. The discussion includes a summary on trace contaminant generation rate derivation, the analytical tool, and cases considered for the assessment.

4.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of Unity Node 1 offgassing test grab samples. This load model was supplemented by the addition of several contaminants that were observed during the first offgassing test conducted from August 26 through September 4, 1998. In addition, correlation of the relative timing of major in-flight ECLS events and ingress grab sample collection indicates that the Shuttle's contribution to the overall contamination load must be considered during the early stages of ingress. The load model used for the engineering analysis was modified to account for this.

4.5.2 Trace Contaminant Control Simulation Computer Program

The TCCS-CP, version 8.1, was used to conduct the analysis.[7,8] This analytical tool calculates the cabin concentration of individual trace chemical contaminants when generated at a specified rate and controlled by any combination of removal devices. It contains subroutines for simulating the performance of AC/GAC and 2% Pt/GAC.

The TCCS-CP, version 8.1, has previously been assessed for its applicability for use in spacecraft TCC verification analyses and was found to be acceptable, and the subroutine for the 2% Pt/GAC has been found to provide a conservative performance assessment.[9]

4.5.3 Analysis Cases Considered

Cases considered by the engineering analysis encompassed normal and contingency ingress scenarios for logistics flights 2A.1 and 2A.2. These cases reflect the order of events and are summarized in tables 6 and 7. In addition, a case was considered in which flight 2A.2 launch slips to mid-January 2000.

Assessment of contingency ingress operations was conducted by considering the capability to remove built-up trace contaminants from Unity Node 1 via atmospheric dilution and scrubbing by Shuttle-provided resources. The contingency scenarios used assembly flight 2A as a basis and then considered ingress operations ranging from 70 days through 9 months after egress.

4.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the three analysis cases.

4.6.1 Derived Generation Rates

The trace contaminant generation rates used for all analysis cases are documented in table 8. They were derived from the Unity Node 1 offgassing test air sample analysis results documented in appendix B using equation (3). The load model used previously for the preflight 2A analysis was supplemented by adding ethanal, 2-propenal, pentenal, hexanal, heptanal, and butyl acetate to the load. These compounds were observed in the in-flight grab samples and contributed significantly to the overall *T*-value. Many of these compounds were observed during the first preflight element offgassing test conducted in late August through early September 1998. Generation rates for these supplementary compounds were derived from the results of that first test result.

Table 8. Unity Node 1 trace contaminant generation rates.

	Concentration (mg/m^3)		Generation Rate (mg/hr)			
Compound	**STS-88***	**Archive****	**Node 1**	**Shuttle**	**Combined**	**IMV**
Methanol	0.09	0.039	0.028	0.18	0.208	7.64
Ethanol	1	2.96	0.627	2	2.627	84.95
2-propanol	1.6	2.15	0.585	3.2	3.785	135.92
n-propanol	–	–	0.0973	–	0.0973	–
2-methyl-2-propanol	0.025	0.037	0.0149	0.00367	0.0186	2.12
n-butanol	0.025	0.032	0.0777	0.05	0.1277	2.12
Ethanal	0.08	0.16	0.0258	0.16	0.1858	13.59
2-propenal	0.025	0.0005	0.0049	0.05	0.0549	2.12
Propanal	0.025	–	0.0197	0.05	0.0697	2.12
2-methyl-2-propenal	–	–	0.0149	–	0.0149	–
Butanal	0.025	0.014	0.0196	0.045	0.0646	2.12
Pentanal	0.025	0.01	0.0062	0.045	0.0512	2.12
Hexanal	0.025	0.0042	0.0062	0.045	0.0512	2.12
Heptanal	0.025	0.0031	0.0062	0.045	0.0512	2.12
Methylbenzene	0.025	1.08	0.0432	0.042	0.0852	2.12
1,2- & 1,3-dimethylbenzenes	0.025	0.11	0.0391	0.042	0.0811	2.12
1,4-dimethylbenzene	0.025	0.011	0.0149	0.042	0.0569	2.12
Ethylbenzene	0.025	0.072	0.0149	0.042	0.0569	2.12
Butyl acetate	0.025	0.0048	0.0062	0.045	0.0512	2.12
Dichloromethane	0.07	0.35	0.0822	0.119	0.2012	5.95
Trichlorofluoromethane	–	–	0.0149	–	0.0149	–
Trichlorotrifluoroethane	0.025	1.78	0.0496	0.042	0.0916	2.12
2-propanone	0.14	0.796	0.1540	0.294	0.448	11.89
2-butanone	0.025	0.051	0.0778	0.0925	0.1703	2.12
Cyclohexanone	–	–	0.0259	–	0.0259	–
Hexamethylcyclotrisiloxane	0.94	0.17	0.0149	1.598	1.6129	79.85
Octamethylcyclotetrasiloxane	0.4	0.3	0.106	0.68	0.786	33.98

* Reported concentration from the Shuttle mid-deck at MET 11/10:56.

** Average concentration observed from in-flight Shuttle air quality samples collected since STS-1.

It has been noted that the generation rate for methanol continued to decrease when compared to the earlier offgassing test results. Review of the analytical results from the in-flight grab samples indicates that the methanol generation rate from Unity Node 1 has decreased by approximately 90% since the second offgassing test was conducted. The rate in table 8 reflects this decrease.

Correlation of preflight predictions with the analytical results from the in-flight grab samples indicated that contamination carryover from the Shuttle via the IMV contributes significantly to the Unity Node 1 contamination control situation. Based upon the observed concentrations from the Shuttle atmosphere determined from analysis of an in-flight sample collected at MET 11/10:56, contaminant generation rates were established for the Shuttle and for the IMV. As can be seen in table 8, the Shuttle atmosphere during STS-88 was typical of in-flight, mid-deck air quality when compared to the average of all archival samples collected during the Shuttle program since STS-1.

4.6.2 Relative Contamination for Flights 2A Through 2A.2

The first case is a validation of the flight 2A prediction. During flight 2A, the *T*-value at ingress, excluding carbon dioxide, was reported to be 0.47. This is well within the medical operations criteria for safe ingress. However, the original analysis predicted a much lower *T*-value of 0.19. Review of the in-flight operations timeline indicated that the ingress sample was collected more than 20 minutes after the IMV flow was initiated. Therefore, it was necessary to incorporate contaminant generation via the IMV into the engineering model. Figure 4 shows the results after incorporating contaminant carryover from the Shuttle to Node 1 via IMV. As can be seen, the initial air scrubbing reduces the *T*-value to approximately 0.05. Once IMV is established, a contamination spike is experienced which increases the *T*-value to as high as 0.63. Therefore, when the timing of the ingress sample is considered, the generation rates predicted for Node 1 hardware and the performance of the CACEAs is as expected.

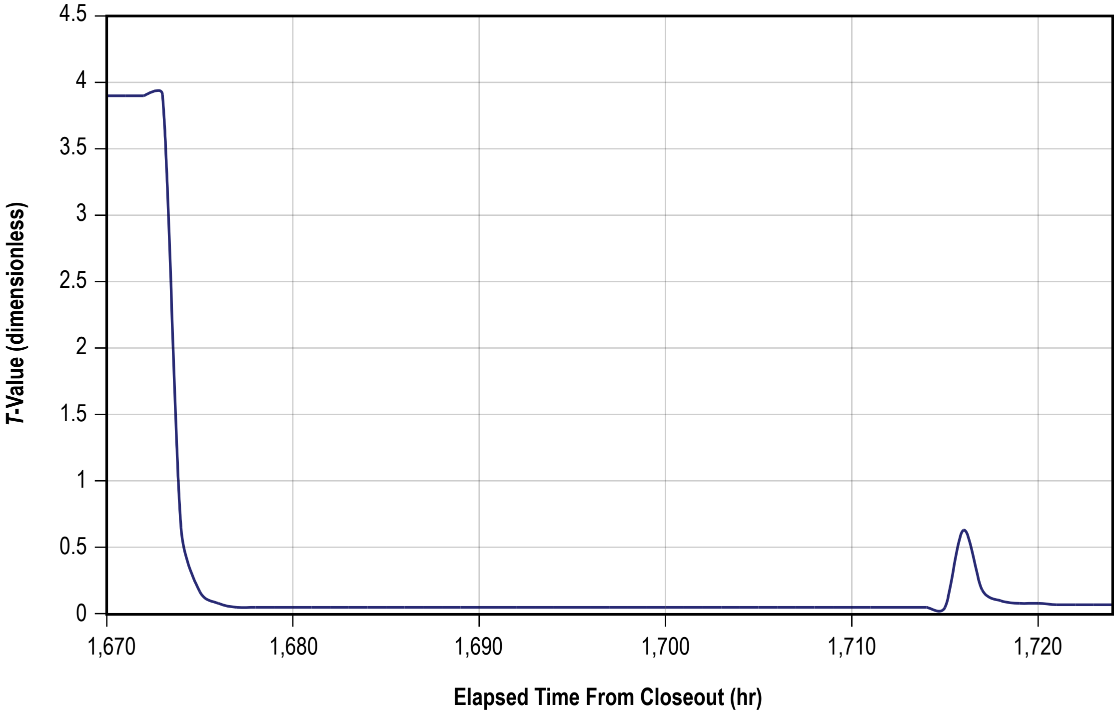

Figure 4. Unity Node 1 relative contamination during flight 2A ingress.

One parameter that has not been thoroughly investigated is the effects of contaminant carry-over from the FGB via IMV. Samples collected from both the FGB and Node 1 upon egress indicate that the FGB is a significant contributor to overall air quality. The predicted *T*-value with no FGB load accountability is approximately 0.07, while in-flight sample analysis indicated a *T*-value for both the FGB and Node 1 of approximately 0.6. Major contributions to this *T*-value were provided by ethanal and 2-propenal. Further study of the FGB's contribution to overall ISS cabin air quality is recommended. Until that time, it is recommended that predicted steady state *T*-values be increased by 0.5 for added safety.

Continuing the analysis from the conclusion of flight 2A up to cabin fan activation during flight 2A.1 shows that, assuming the contaminant generation rates remain constant, the *T*-value could be expected to rise to approximately 12.5. As shown in figure 5, the CACEAs still provided adequate capability. A normal scrub reduces the *T*-value to approximately 0.5. Upon IMV activation, the *T*-value spikes to 0.8 before being scrubbed to approximately 0.2. Accounting for the 0.5 *T*-value unit factor of safety, the steady state *T*-value is 0.7 which is well below acceptable medical operations requirements.

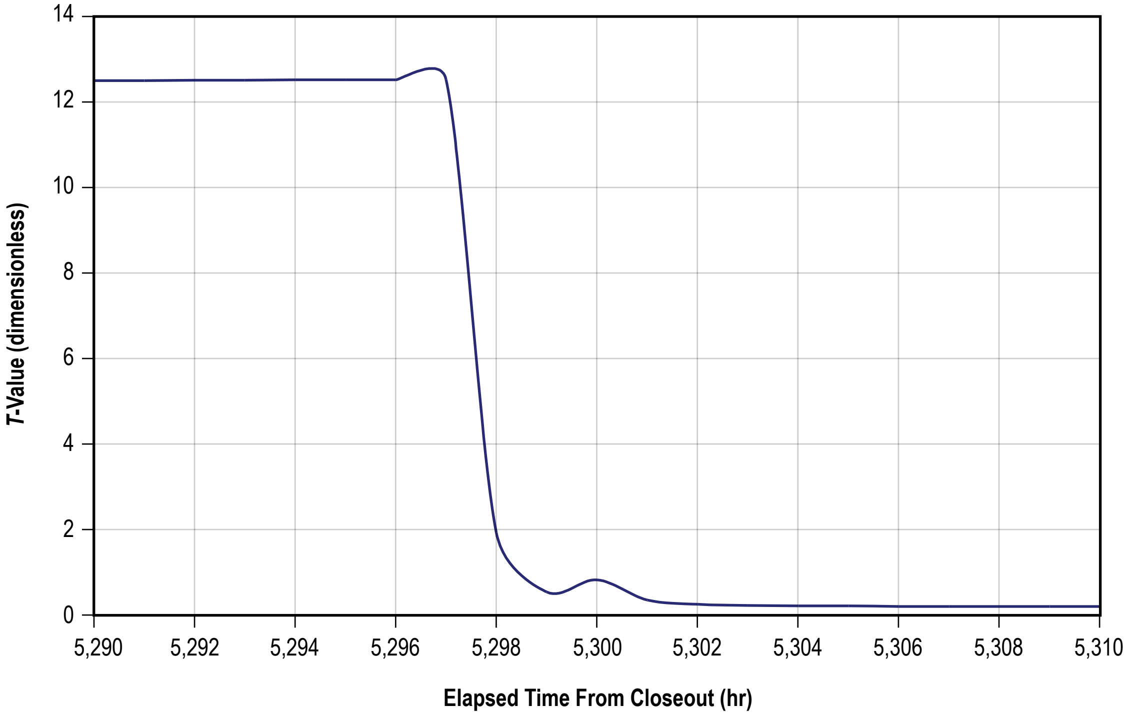

Figure 5. Relative contamination of Unity during flight 2A.1 ingress.

For flight 2A.2, shown in figure 6, the *T*-value again builds up to approximately 12.5. After starting the cabin fan, scrubbing provided by the CACEAs reduces the *T*-value to approximately a magnitude of 2. At that time, the IMV flow is initiated and a break in the shoulder in the relative contamination curve is observed. Once the Shuttle and Unity Node 1 volumes become well mixed, the *T*-value slowly approaches a final level of 0.33. Even with the 0.5 *T*-value unit factor of safety to account for the FGB load, the final steady state *T*-value was projected to be 0.83.

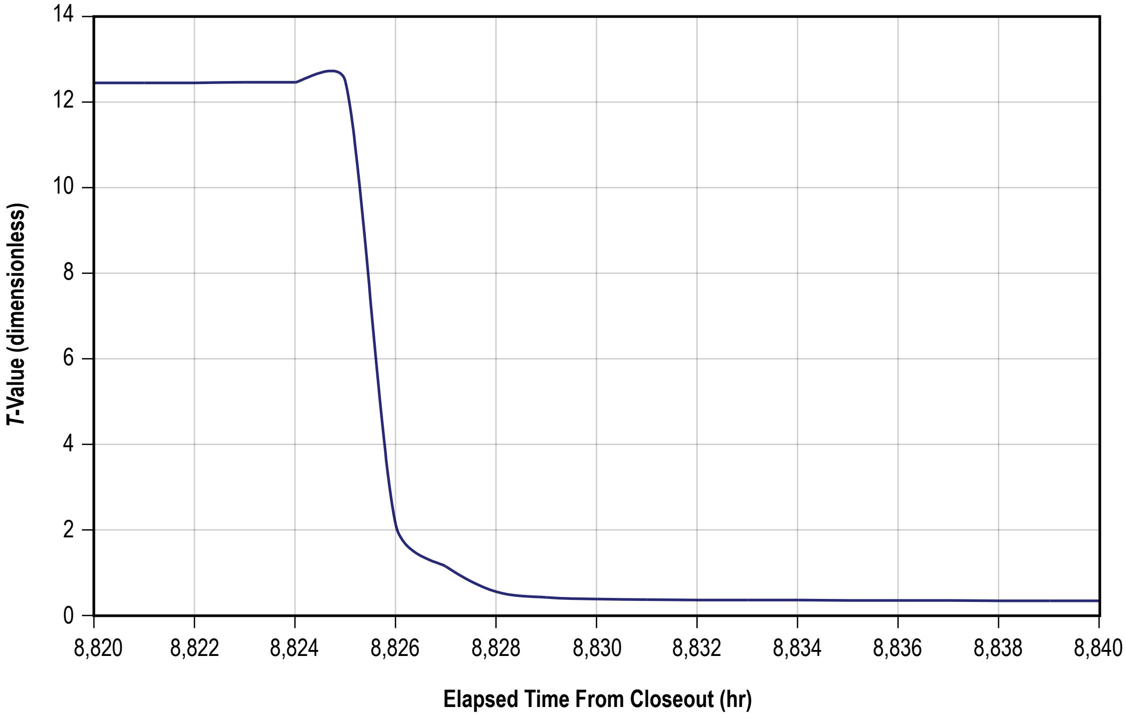

Figure 6. Relative contamination of Unity Node 1 during flight 2A.2 ingress.

In the event that flight 2A.2 slipped to mid-January 2000, the *T*-value could rise to as high as 20.5 before the next ingress. As shown in figure 7, the preingress scrub would reduce the *T*-value to approximately 1 followed by an IMV-induced spike to 1.1. After the volumes become well mixed, the *T*-value is reduced to approximately 0.4. Including the 0.5 *T*-value unit factor of safety would indicate that a final projected *T*-value of 0.9 is quite possible. While this is still within the criteria set forth by medical operations personnel, further projection of the upward trend in steady state *T*-value indicates that the CACEAs should be replaced at the conclusion of ingress operations for flight 2A.2. Replacing the CACEAs is also necessary at this time because of the uncertainty in the launch schedule for flights 3A and 4A.

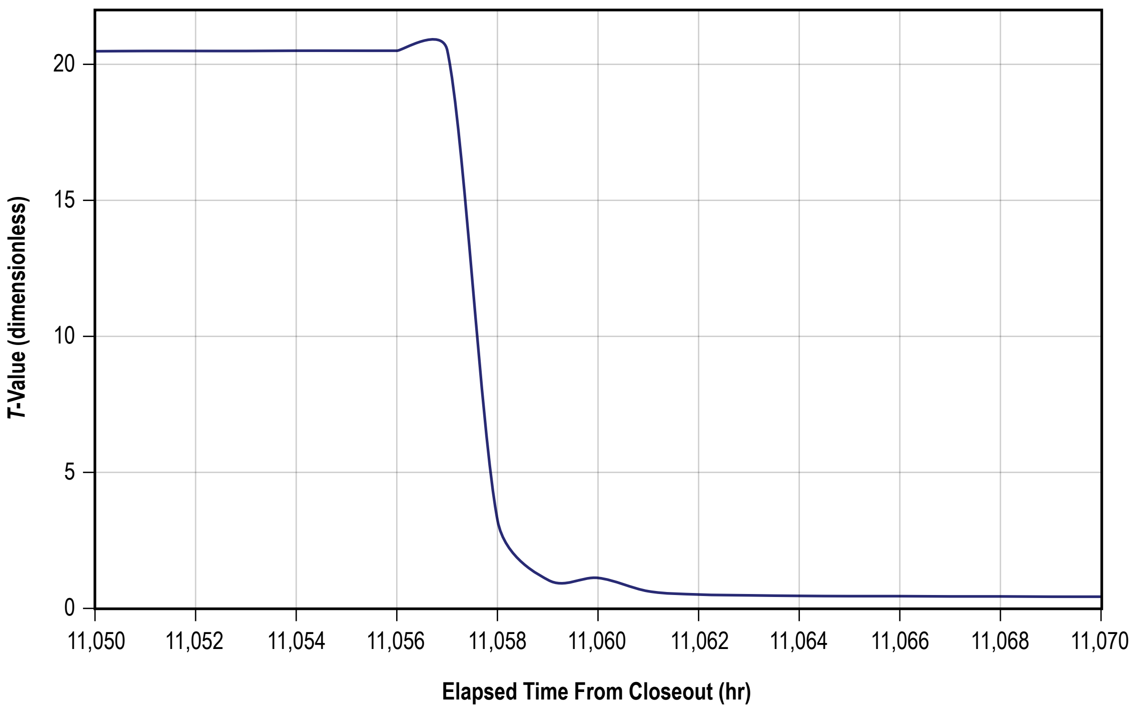

Figure 7. Relative contamination of Unity Node 1 during flight 2A.2 after slipping mission to January 2000.

As can be observed by the preceding discussion and from figures 4 through 7, the *T*-value during normal Unity Node 1 ingress operations is maintained below 1 for all assembly and logistics flights through 2A.2, even with a potential slip in launch schedule, which could place flight 2A.2 in mid-January 2000. By definition, all contaminants contributing to the *T*-value must be well below their respective SMACs to result in an overall *T*-value less than 1. Therefore, the requirement to maintain individual trace contaminants below their respective SMACs is met during all ingress operations.

4.6.3 Contingency Operations

Several analysis cases were conducted to investigate the necessary Shuttle-provided resources to support contingency ingress operations. Contingency ingress is necessary in the event that the Unity Node 1 cabin fan fails to operate for any reason. Flight 2A was used as the basis for the analysis and the elapsed time to the next ingress was varied from 70 days to 9 months. The results of the analysis are summarized in table 9.

Table 9. Relative contamination of Unity Node 1 during various contingency ingress scenarios.

Time (mo)	Projected *T*-Value	*T*-Value During Contingency Ingress				Hours to *T*-Value = 1
		+1 Hr	+2 Hr	+3 Hr	+4 Hr	
70 days	6.1	5.3	3.9	3	2.3	~7+
3	8.6	7	5.2	3.9	2.9	~8+
4	10.6	8.4	6.2	4.6	3.5	~9
5	13	10	7.4	5.4	4.1	~10
6	15.6	11.8	8.6	6.4	4.8	~11
9	23.7	17.3	12.6	9.2	6.9	~12+

The medical operations criteria to ensure safe ingress was summarized in table 1. As can be seen by the contingency ingress analysis results, the only case that satisfies the medical operations criteria is that for the 70-day elapsed time to the next ingress. This is consistent with past analyses of Unity Node 1 ingress operations which established a magnitude of 6 as the maximum threshold *T*-value to accommodate contingency ingress operations. The case for the 5-month elapsed time corresponds to logistics flights 2A.1 and 2A.2. The 9-month elapsed time corresponds to flight 2A.2 in the event its launch slips to mid-January 2000.

Because the scrubbing rate is flow limited, using more than one charcoal canister in series does not provide relief from this situation. It cannot be accelerated unless both of the Shuttle lithium hydroxide (LiOH) canisters are replaced with charcoal canisters. Such an approach is not considered viable, however, because it raises the added safety issue of carbon dioxide buildup.

Review of the analysis results in table 9 indicates that an operational workaround could be possible. The flight rule for ingress, included as appendix A, allows for the crew to open the hatch, establish IMV, and wait for at least 1 hour in the Shuttle before actually entering Node 1. During this time, one of the Shuttle LiOH canisters is replaced with a charcoal canister to provide added protection to the crew. For flights 2A.1 and 2A.2, a modification to this approach in which the crew waits until the *T*-value is reduced to at least a magnitude of 4. That would require a waiting period of at least 4 hours before full ingress. More time would be necessary if the 2A.2 launch slips significantly. This approach must be reviewed and approved by the responsible medical operations personnel.

4.7 Discussion

As can be seen by the analysis results, sufficient air quality can be maintained during all phases of missions 2A.1 and 2A.2 as long as normal cabin fan operations can be provided. Medical operations experts have determined that the *T*-value in Unity Node 1 must be at or below a magnitude of 3 for safe ingress. Otherwise, some additional means of contamination control or operational constraints must be used.

As noted previously, the Shuttle-provided contingency capabilities, when combined with dilution between the two volumes, cannot handle a Unity Node 1 *T*-value greater than a magnitude of 6 and still meet medical operations guidelines presented in table 1. As seen in table 9, this limit for contingency ingress is exceeded for all flights except 2A. Therefore, it is necessary for the crew to wait for at least 4 hours before entering Unity Node 1 in the event of a contingency ingress. At least one Shuttle-provided charcoal canister must be provided to support contingency ingress operations. If the manifest can accommodate two charcoal canisters, it would be wise to include it for flight 2A.2 if it slips to January 2000.

4.8 Conclusions

Conclusions based upon the Unity Node 1 TCC capability assessment results were the following:

- The Unity Node 1 contamination removal capability provided by the CACEAs meets the requirements of the Node 1 PIDS for all compounds through flight 2A.2.

- The CACEAs have sufficient capacity to be used through 2A.2 even if the mission slips to January 2000.

- Contamination introduced from the Shuttle via IMV during the early stages of ingress is significant and must be accounted for in all future engineering analyses.

- Initial Unity Node 1 air quality exceeds the criteria for safe contingency ingress for all flights.

4.9 Recommendations

Recommendations for addressing Node 1 TCC issues during ingress operations were the following:

- Replace the CACEAs at the conclusion of flight 2A.2 ingress operations.

- Conduct additional analysis to better define the contribution of the FGB contamination load to overall ISS air quality and its effects upon TCC logistics.

- Continue in-flight samples of Node 1 through flight 4A to allow for continual TCC verification.

- Provide one Shuttle-provided charcoal canister for flights 2A.1 and 2A.2 to support contingency ingress operations.

- Provide two Shuttle-provided charcoal canisters for flight 2A.2 if the launch date slips to January 2000.

- Reevaluate the contingency ingress operations to extend the waiting period from 1 to 4 hours.

5. MANAGEMENT OF TRACE CONTAMINANT CONTROL RESOURCES ON BOARD ZARYA

This assessment was originally released as NASA Memorandum FD21(00-67) dated April 20, 2000.

5.1 Background

TCC on board Zarya is provided by a Harmful Impurities Filter, known by its Russian acronym ФВП (FVP), which removes volatile organic compounds, ammonia, and carbon monoxide from the cabin atmosphere. The FVP normally operates for 48 hours with 24 hours minimum operation before the crew enters Zarya, according to flight rule X17.4.1-4, FGB Trace Contaminant Removal Control, to ensure that the cabin air quality meets toxicological standards for safe ingress. Specifically, these criteria are documented in flight rule X13.1.2-2, Node Ingress Criteria. While the flight rule on ingress criteria specifically addresses Unity, the same criteria can be applied to any flight element that has been closed for an extended time. Both flight rules are included in appendix A for reference purposes.

The FVP is comprised of a fan, a fixed ambient temperature carbon monoxide oxidation catalyst cartridge, and an expendable bed containing SKT-2 activated carbon and KHPA-63 ammonia adsorbent. According to data provided by Russian experts, the FVP packing characteristics are summarized in table 10. From these data it is understood that process air flow is axial through the bed materials at 20 m^3/hr. The catalyst cartridge is rated for a 2,000 man-day service life while the 8-kg expendable adsorbent bed is rated for 280 man-days.[10]

Table 10. FVP packing characteristics.

Packing	Diameter (mm)	Length (mm)	Mass (kg)
KHPA-63 adsorbent	385	25	2.5
SKT-2 charcoal	385	75	3.9
CO oxidation catalyst	385	50	2.9

The ISS program is presently challenged by the fact that there are only two remaining FVP expendable beds but up to as many as six missions for which Zarya's atmosphere must be scrubbed prior to ingress. The missions that must be served by these two filters are STS-101/2A.2a, STS-106/2A.2b, STS-92/3A, 2R, and at least two contingency flights. One of these two beds is presently installed in the FVP on board Zarya.

The present recommendation from Russian experts is to operate the FVP for 48 hours before ingress during STS-101/2A.2a according to original plans, continue its operation during the ingress period, and replace the expendable bed at the conclusion of ingress operations. The used bed is to be bagged and stowed on board the ISS for potential reuse. To better understand the necessity to replace the FVP's expendable bed at the conclusion of STS-101/2A.2a ingress operations and more efficiently use the available resources, an engineering analysis has been conducted. The following discussion summarizes key elements of that analysis and its results.

5.2 Offgassing Characteristics of Zarya

Based upon equipment offgassing rates derived from in-flight air quality data and ground-based flight element offgassing tests, trace chemical contaminants are expected to be produced at the rates listed in table 11. Basic rates for Zarya are derived by multiplying flight element offgassing rate data for Unity by the observed concentration ratio between Zarya and Unity at ingress. Using this technique to derive generation rates for Zarya is much more conservative than using its ground-based offgassing test data. The rates derived in this manner result in predicted air quality that more accurately reflects the in-flight conditions observed during the STS-88/2A and STS-96/2A.1 missions.

Table 11. Basic trace contaminant generation rates.

	Generation Rate (mg/hr)	
Compound	Zarya*	Stowage**
Methanol	0.084	0.002
Ethanol	4.96	0.1
2-propanol	0.645	0.06
n-butanol	1.27	0.07
Ethanal	0.026	0.0002
Methylbenzene	0.073	0.03
1,2- & 1,3-dimethylbenzenes	1.13	0.04
1,4-dimethylbenzene	0.455	0.02
Ethylbenzene	0.091	0.002
Butyl acetate	0.006	–
Dichloromethane	0.112	0.03
2-propanone	0.546	0.05
2-butanone	0.158	0.08
Cyclohexanone	0.035	0.009
Hexamethylcyclotrisiloxane	0.017	0.002
Octamethylcyclotetrasiloxane	0.106	–

* Based upon in-flight ratio of FGB to Node ingress concentration.

** Based upon 462 kg offgassing at Node 1 PIDS rates.

The ratio for volatile alcohols should provide an accurate rate because the activated charcoal will saturate rapidly and result in a concentration ratio at ingress that is a strong function of generation rate differences between the Zarya FGB and Unity Node 1. Other less volatile compounds, such as n-butanol and dimethylbenzenes, are well removed at all times during the ingress scrub; therefore, their concentration ratio is also a function of the difference in flow rate through the contamination control devices as well as differences in generation rate. Unity effectively provides 17 times more air flow through its CACEAs than Zarya provides through its FVP. Even so, for conservatism, the full ratio was used to estimate their generation rate. Offgassing rates for stowage hardware for each flight are based upon the generic load model from the Node 1 PIDS. For conservatism, it is assumed that a similar amount of hardware will be delivered to Zarya during each mission.

5.3 Analytical Approach

The generation rates listed in table 11 were used as the primary trace contaminant load for the calculation. In addition, transient rates from previous analysis conducted for Unity Node 1 were included to account for contaminant carryover from Unity Node 1 and the Shuttle during the first hour of ingress. After the first hour, a combined steady state generation rate is used. This rate combines the basic Zarya load from table 10 with the human metabolic load used for the analysis documented by reference 2. The TCC Simulation computer program (CP) was used to calculate the resulting contamination levels that result from the onboard atmospheric scrubbing devices' action upon the contaminant load during the various ingress periods.[7] It has been demonstrated to provide concentration predictions within the range of analytical chemistry methods used for analyzing in-flight air quality samples.[9] The TCCS-CP essentially solves the cabin mass balance, summarized by equation (7), using a backwards differencing technique.

Once the TCCS-CP calculates a cabin concentration based upon an incremental removal efficiency and cabin generation rate, that concentration is compared to the individual contaminant's SMAC. The T-value is calculated for comparison to the safe ingress criteria for Zarya documented in flight rule X13.1.2-2 listed in appendix A.

A timeline for the missions beginning with STS-101/2A.2a and extending to five flights afterward was used. Included in the timeline are 328 days of contaminant buildup without removal before STS-101/2A.2a. The quiescent period between each remaining flight was set at 120 days. During each ingress, the FVP is operated for 48 hours before opening the hatch and beginning the mixing between Zarya and Unity. For all cases, the FVP operates continuously during the ingress period.

According to preflight planning for STS-101/2A.2a., the FVP's expendable bed containing the ammonia adsorbent and activated charcoal is replaced at the conclusion of the ingress. The new bed is used for STS-106/2A.2b and subsequent flights. The two contingency flights are assumed to occur after 2R as a worst case.

5.4 Results

Analysis results are summarized in table 12. As can be seen, the T-value in Zarya is predicted to be highest for STS-101/2A.2a based upon approximately 328 days of buildup. Subsequent flights will have a T-value at FVP startup ranging from 3.82 to 3.87. The contingency cases are considered as a worst case to occur after 2R; however, it is more likely that a contingency flight would occur sometime between STS-106/2A.2b and STS-92/3A. The scrubbing duration required to reach a T-value magnitude of 3 for which the crew can safely enter Zarya with no additional remedial action is just under 1 hour. Scrubbing for an additional 4 to 4.5 hours provides for a T-value magnitude of 1.

Table 12. Minimum atmospheric scrubbing duration for Zarya by flight.

Flight	*T*-Value at Scrub Start	Time to *T*-Value = 3 (hr)	Time to *T*-Value = 1 (hr)
STS-101/2A.2a	9.6	4	8
STS-106/2A.2b	3.82	0.82	4.5
STS-92/3A	3.84	0.85	4.7
2R	3.87	0.87	4.8
Contingency 1	3.89	0.9	5
Contingency 2	3.91	0.92	5.4

Figure 8 shows the predicted relative contamination level during STS-101/2A.2a ingress. As can be seen, a steady state is achieved after approximately 25 hours of scrubbing. Beyond that time, very little change in relative contamination level occurs. As a comparison, Russian experts predict that steady state will be achieved in Zarya after approximately 27.5 hours of scrubbing. Essentially, this shows good agreement between NASA and Russian assessments of the FVP's performance. The primary compounds that contribute to the total *T*-value of 9.65 at the beginning of the scrub are methanol (11%), n-butanol (20%), dichloromethane (14%), and 2-propanone (13%). Upon achieving steady state, methanol accounts for 75% of the *T*-value of 0.16. This is because activated charcoal removes methanol less efficiently than other less volatile compounds. Ethanal also contributes approximately 12% of the total steady state *T*-value.

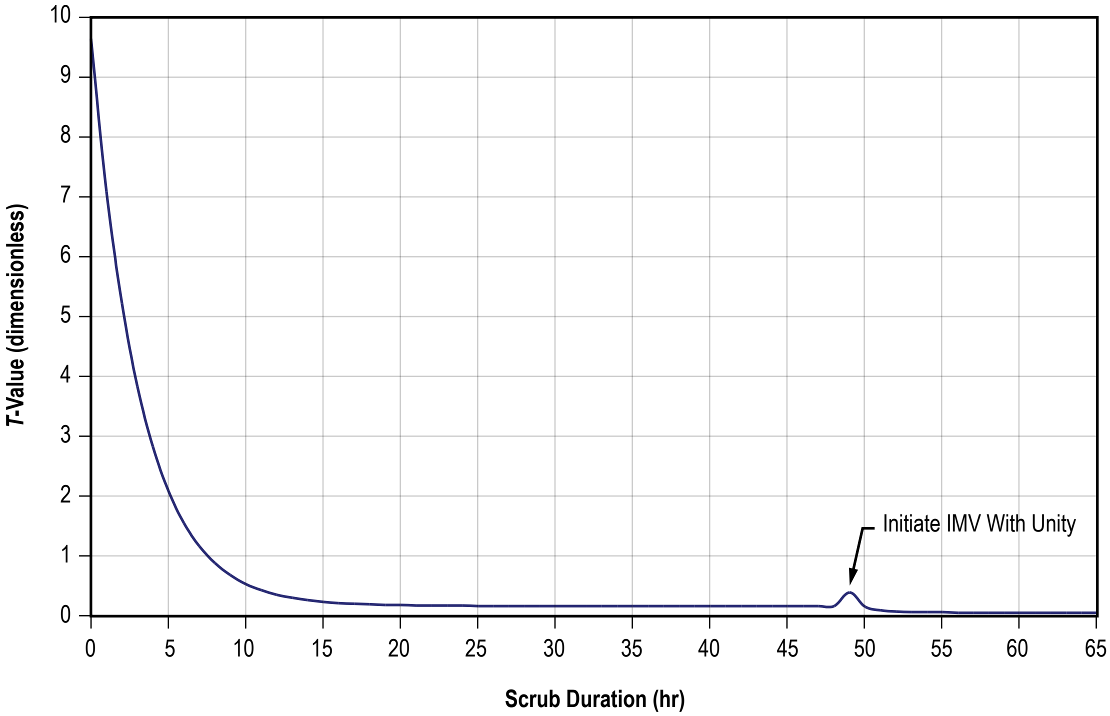

Figure 8. Relative contamination during Zarya ingress for STS-101/2A.2a.

Figure 9 shows a plot of predicted relative contamination level for flights beyond STS-101/2A.2a. Since all the starting contamination levels are similar, this figure is typical for all flights. Because the starting contamination level is lower, a steady state is achieved approximately 19 hours after starting the atmospheric scrub. Methanol (10%), n-butanol (18%), dichloromethane (15%), and 2-propanone (13%) continue to account for the major portion of the overall cabin *T*-value at the beginning of the scrub. Like the prediction for STS-101/2A.2a, methanol (51%) and ethanal (15%) are the primary contributors to the steady state cabin *T*-value.

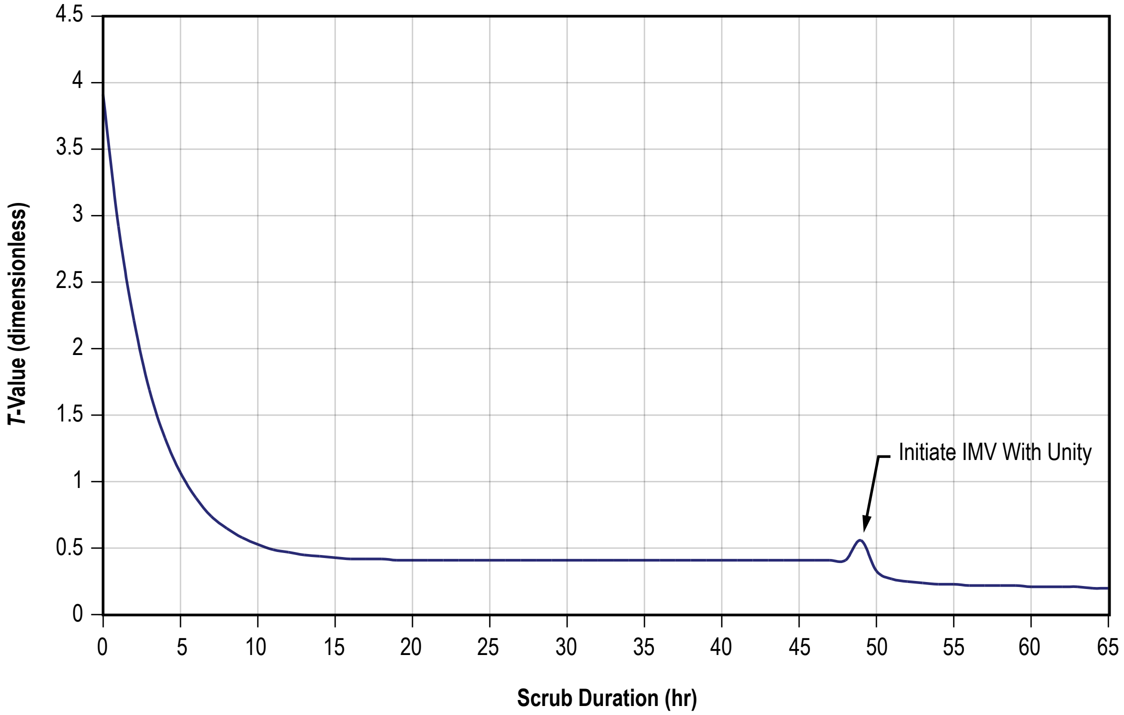

Figure 9. Typical relative contamination during Zarya ingress for STS-106/2A.2b and subsequent flights.

5.5 Conclusion

As presented in table 12 and figures 8 and 9, the two remaining expendable beds should allow the FVP to adequately reduce built-up contamination levels in Zarya to within the criteria defined for safe ingress conditions. These conditions can be achieved by operating the FVP for a minimum of 4 hours before ingress during STS-101/2A.2a and a minimum of 1 hour for all subsequent flights. Operating the FVP for approximately 8 hours for STS-101/2A.2a should provide the best possible ingress condition relative to the trace contaminant environment. Operating the FVP for 5.5 hours should achieve similar results for mission STS-106/2A.2b and beyond.

In the event that insufficient FVP resources are available or that it malfunctions, the combined TCC capability of Unity and the Shuttle are capable of providing a safe ingress condition according compliant with part B of flight rule X17.4.1-4.

5.6 Recommendations

Engineering analysis of Zarya's predicted trace contaminant load and the capacity of the FVP expendable filter to control that load demonstrates that the available resources can accommodate ingress operations during STS-101/2A.2a and subsequent flights through 2R. Detailed recommendations are the following:

- Operate the FVP for at least 8 hours before crew ingress during STS-101/2A.2a.

- Operate the FVP for at least 5.5 hours before crew ingress during STS-106/2A.2b and subsequent flights through 2R.

- Replace the expendable FVP bed at the conclusion of the STS-101/2A.2a ingress. Bag the used bed and stow it on board Zarya for future contingency use.

- Consider shutting the FVP off during the ingress period for all flights. Based upon in-flight air quality data from STS-88/2A, it is apparent that the TCC capacity on board Unity and the Shuttle is capable of maintaining an acceptably clean cabin environment throughout the combined ISS-Orbiter cabin.

6. POSTFLIGHT EVALUATION OF MISSIONS 2A AND 2A.1 WITH PREFLIGHT PREDICTIONS FOR MISSION 2A.2

This assessment was originally released as NASA Memorandum FD21(99-112) dated September 17, 1999.

After a mission STS-101 launch slip of approximately 130 days from the original December 1999 date, a follow-up review documented by NASA Memoranda FD21(00-35) dated February 29, 2000, and FD21(00-53) dated March 31, 2000, concluded that the Node 1's TCC capability was sufficient to accommodate the new launch date.

6.1 Background

In preparation for Unity Node 1 flight operations, a 5-day trace contaminant offgassing test was conducted October 1–6, 1998. During this test, sets of three grab samples were collected at the beginning, middle, and end of the test as specified by the ISS Qualification and Acceptance Environmental Test Requirements (SSP 41172). Subsequent analysis of these samples established trace contaminant concentrations as a function of time. Generation rates were determined from these concentrations, the vehicle free volume, and sample timing. The generation rates derived from the offgassing test results were used as input data for an engineering analysis to predict the in-flight concentrations and relative contamination (*T*-value) of the Unity Node 1 cabin atmosphere upon ingress during ISS assembly mission STS-88/2A. This analysis served as a basis for establishing in-flight operations for both nominal and contingency ingress scenarios.

During mission STS-88/2A, grab samples of the Unity Node 1 and Shuttle cabin atmospheres were collected and analyzed postflight. Results from the sample analyses were evaluated and served as a secondary basis for the Unity Node 1 trace contaminant load. Using an updated load model based on both the preflight offgassing test and in-flight grab sample analysis results, an updated TCC capability assessment was conducted to support in-flight operations for ISS logistics flight STS-96/2A.1.

As with STS-88/2A, atmospheric grab samples were collected during STS-96/2A.1. Results from the sample analyses have been evaluated and used to update the original offgassing test basis. Using this new information to refine the offgassing rate basis, an engineering analysis has been conducted for the ISS logistics flight STS-101/ 2A.2. Results and conclusions of the engineering analysis are presented by the following discussion. Based upon the results, recommendations are presented for consideration.

6.2 Purpose

The engineering analysis summarized by the following discussion served as verification of the Unity Node 1's TCC capability for logistics flight STS-101/2A.2. Further, the analysis serves to validate assumptions used during previous TCC capability assessments conducted for STS-88/2A and STS-96/2A.1. Continually validating these assumptions is important because each analysis builds upon its predecessors.

6.3 Objectives

The adequacy of the Unity Node 1's trace contaminant removal capability was assessed by engineering analysis. Specific objectives of the analysis which will allow for appropriate verification of this capability are the following:

- Determine the Unity Node 1 trace contaminant load based upon both preflight offgassing test, stowage hardware mass, and in-flight air quality data.

- Determine the trace contaminant concentrations during Unity Node 1 ingress operations for logistics mission STS-101/2A.2.

- Determine the adequacy of the Unity Node 1 CACEAs for meeting the relevant Node 1 PIDS requirements and medical operations guidelines during STS-101/2A.2.

- Determine logistics requirements for the Unity Node 1 CACEAs and Shuttle-provided odor control cartridges.

6.4 Assumptions

To conduct the Unity Node 1 TCC capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, CACEA configuration, and mission timeline.

6.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for all phases of the verification analysis are the following:

- Offgassing rates are derived from the Unity Node 1 offgassing test results and revised according to results of in-flight air quality data.

- Additional offgassing from stowage hardware are estimated using the Unity Node 1 offgassing test results for U.S. hardware and Node 1 PIDS rates for Russian hardware.

- Unity Node 1 cabin atmospheric leakage is zero. This is considered to be true for a newly launched element.

- Unity Node 1 cabin atmospheric conditions are on average 10 ºC, 30% relative humidity (–6.7 ºC dewpoint), and 1 atm. These conditions approximate the on-orbit atmospheric conditions of Unity Node 1.

- Offgassing rates are constant with time and effects of temperature and pressure fluctuations are negligible. Offgassing has been shown to be sensitive to temperature fluctuations. Because the offgassing test temperature was higher, the rates derived from it are considered to be conservative.

- Seven-day SMACs apply for the analysis according to flight rule X13.1.2-2 found in appendix A.

6.4.2 Node 1 Configuration

On orbit, Unity Node 1 is attached to PMA 1 which is in turn attached to the Shuttle Orbiter during each assembly flight. The Unity Node 1 is provided with a contamination control capability consisting of a cabin fan and four CACEAs located in the cabin air return duct in place of the cabin air bacteria filter elements. The configuration provides at least a 340 m^3/hr total air flow rate through the CACEAs. Assumptions pertaining to the Unity Node 1 configuration and its contamination control capability are the following:

- Cabin free volumes of Unity Node 1, PMA 1, and Shuttle are 51.3, 6.1, and 65.8 m^3, respectively.

- The Unity Node 1's total scrubbing rate is 340 m^3/hr with the flow split evenly between four individual CACEAs.

- Each CACEA has a minimum type AC/GAC packing depth of 3.3 cm and a platinum on charcoal (2% Pt/GAC) packing depth of 1.27 cm.

- Contamination generation and removal contributions from the FGB are estimated based upon egress concentration gradients observed during STS-96/2A.1 until more data on Russian equipment offgassing and the design of the HCF are made available.

- Contribution to overall contamination generation and removal by the Service Module is unknown and conservatively considered to be negligible because of its TCC system capabilities.

6.4.3 Mission Timeline

The timeline used for the engineering analysis is shown in table 13 which provides the relative timing of in-flight ECLS operations and sampling events for assembly flights 2A through 2A.2. These events are further summarized in table 14 along with projected dates and approximate times for major ECLS events for flight STS-101/2A.2. In-flight operations for logistics flight STS-101/2A.2 has been modeled similarly to what was actually experienced during 2A.1. The engineering analysis does not include flights beyond 2A.2 due to schedule uncertainty.

Table 13. Engineering analysis timeline for flights 2A through 2A.2.

Time (hr)	Event
0	Node 1 purge at launch minus 65 days
960	Cabin fan operated on pad
1,560	STS-88/2A launch
1,670.5	Cabin fan started
1,715	Hatch open and IMV started
1,715.5	Node 1 ingress sample collected
1,717	FGB ingress sample collected
1,741	FGB egress sample collected
1,743	Node 1 egress sample collected
1,841	Cabin fan shut down
5,369	STS-96/2A.1 launch
5,412	Cabin fan started
5,453	Node 1 ingress and sample collected
5,455	FGB ingress and sample collected
5,532	FGB egress and sample collected
5,534	Node 1 egress and sample collected
5,538	Cabin fan shut down
9,900	STS-101/2A.2 launch
9,943	Cabin fan started
9,985	Node 1 ingress
9,986	FGB ingress
10,063	FGB egress
10,064	Node 1 egress
10,066	Cabin fan shut down

Table 14. Relative timing of events during mission 2A and projected for 2A.1 and 2A.2.

Event	Date	Time GMT	Time MET
Node 1 purge at launch minus 65 days	09/30/98	00:00*	NA
Cabin fan operated on pad for 30 minutes	11/09/98	00:00*	NA
Launch	12/04/98	09:00	0/00:00
Cabin fan started	12/09/98	01:54	4/14:32
Hatch open	12/10/98	20:02	6/11:00
IMV activation	12/10/98	20:09	6/11:07
Node 1 ingress sample collected	12/10/98	20:22	6/11:22
FGB ingress sample collected	12/10/98	21:45	6/12:45
FGB egress sample collected	12/11/98	22:23	7/13:23
Node 1 egress sample collected	12/12/98	00:24	7/15:12
Cabin fan shut down	12/12/98	07:57	8/23:09
2A.1 launch	05/27/99	11:49	0/00:00
Cabin fan started approximately flight day 4	05/29/99	06:45	1/19:57
Node 1 ingress and sample collected	05/30/99	23:50	3/14:28
FGB ingress and sample collected	05/31/99	01:16	3/16:05
FGB egress and sample collected	06/03/99	05:56	6/19:08
Node 1 egress and sample collected	06/03/99	08:12	6/21:24
Cabin fan shut down	06/03/99	11:37	7/00:49
2A.2 launch	12/02/99	NA	0/00:00
Cabin fan started	12/04/99*	NA	1/19:00*
Node 1 ingress	12/06/99*	NA	3/13:00*
FGB ingress	12/06/99*	NA	3/14:00*
FGB egress	12/09/99*	NA	6/20:00*
Node 1 egress	12/09/99*	NA	6/21:00*
Cabin fan shut down	10/20/99*	NA	7/23:00*

* Assumed for analysis purposes.

Unity Node 1 was launched as the payload for mission STS-88, which was designated as ISS assembly flight 2A. Approximately 65 days before launch, a final purge was conducted on approximately September 30, 1998, to provide a dry atmosphere. This purge had the added benefit of removing trace contaminants and establishing a clean atmospheric baseline. After approximately 40 days elapsed, the cabin fan was operated for 30 minutes to provide additional prelaunch atmospheric conditioning. Launch occurred on December 4, after a 1-day slip from the original December 3 date.

In flight, the cabin fan was started on December 9 and operated continuously up to and throughout the entire ISS ingress operation according to analysis conducted for assembly missions 2A and 2A.1. It should be noted that the hatch between the Shuttle and Node 1 was not opened until December 10, approximately 45 hours after the Unity Node 1 cabin fan was started. The fan was shut down on December 12 upon egress. In all, the fan operated for approximately 170 hours.

As a part of mission 2A ingress operations, atmospheric samples were collected via evacuated GSCs in Unity Node 1 and the Zarya FGB. All of the samples were collected on December 10. The first sample was collected approximately 30 minutes after the hatch was opened and the IMV was initiated. The second sample was collected from the FGB upon ingress approximately 2 hours after the Unity Node 1 hatch was opened, and the third sample upon FGB egress 24 hours later. The fourth sample was collected from Unity Node 1 just before egress approximately 2 hours after the FGB.

After assembly flight STS-88/2A egress, a period of untended operations of approximately 147 days elapsed before STS-96/2A.1 was launched on May 27, 1999. The cabin fan was activated during STS-96/2A.1 on May 29 approximately 43 hours after launch. Like STS-88/2A, the cabin fan operated continuously throughout the planned ingress. Approximately 41 hours after activating the Unity Node 1 cabin fan, ingress activities began. A grab sample was collected immediately upon ingress. Nearly 2 hours later, a second sample was collected upon FGB ingress. For this mission, the initial ingress activities took longer than originally expected. After approximately 76 hours after completing the initial ingress activities, egress began. A third grab sample was collected from the FGB and a fourth sample was collected from Unity Node 1 about 2 hours later. Another 4 hours elapse before the Unity Node 1 cabin fan is shut off.

Approximately 182 days elapse between STS-96/2A.1 egress and STS-101/2A.2 launch. During STS-101/2A.2, it is planned to activate the Unity Node 1 cabin fan approximately at MET 1/19:00 followed by Unity Node 1 ingress at MET 3/13:00 and FGB egress at MET 3/14:00. FGB egress is planned for MET 6/20:00 followed approximately 1 hour later by Unity Node 1 egress. The cabin fan will be shut off at approximately MET 7/23:00.

Additional analysis runs were conducted to account for potential launch slips for STS-101/2A.2 of 40, 60, and 80 days. These cases merely added additional time to the planned 182 days between STS-96/2A.1 egress and the planned STS-101/2A.2 launch. The planned STS-101/2A.2 timeline still applies to these cases. Presently, STS-101/2A.2 launch may slip to January 22, 2000. This constitutes a 51-day slip which is within the range considered by the analysis cases.

Beyond STS-101/2A.2 are ISS assembly flights 3A and 4A. Due to Shuttle launch schedule uncertainty, these flights were not considered by this analysis.

6.5 Approach

The following discussion summarizes the Node 1 TCC capability assessment approach. The discussion includes a summary on trace contaminant generation rate derivation, the analytical tool, and cases considered for the assessment.

6.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of Node 1 offgassing test grab samples. This model has been supplemented by the addition of several contaminants that were observed during the first offgassing test conducted from August 26 through September 4, 1998. In addition, correlation of the relative timing of major in-flight ECLS events and ingress grab sample collection indicates that the FGB's and Shuttle's contribution to the overall contamination load must be considered during the early stages of ingress. Also, major metabolic contaminants produced by the crew during ingress have been incorporated. As additional hardware has been left on board the ISS, the offgassing contribution of that hardware has been estimated based upon Unity Node 1 offgassing test data and Node 1 PIDS generation rate data. The load model used for the engineering analysis was modified to account for all contaminant generation sources beyond those quantified during the basic Unity Node 1 launch configuration test.

6.5.2 Simulation Computer Program

The TCCS-CP, version 8.1, was used to conduct the analysis.[7,8] This analytical tool calculates the cabin concentration of individual trace chemical contaminants when generated at a specified rate and controlled by any combination of removal devices. It contains subroutines for simulating the performance of AC/GAC and 2% Pt/GAC.

The TCCS-CP, version 8.1, has previously been assessed for it applicability for use in spacecraft TCC verification analyses and was found to be acceptable and the subroutine for the 2% Pt/GAC has been found to provide a conservative performance assessment.[9]

6.5.3 Analysis Cases Considered

Cases considered by the engineering analysis encompass normal and contingency ingress scenarios for flight STS-101/2A.2. These cases reflect the order of events summarized in tables 13 and 14. In addition, cases were considered in which the flight STS-101/2A.2 launch slips from 40 to 80 days.

Assessment of contingency ingress operations was conducted by considering the capability to remove built-up trace contaminants from Unity Node 1 via atmospheric dilution and scrubbing by Shuttle-provided resources. The contingency scenarios used logistics flight STS-96/2A.1 as a basis. As with normal operations summaries, contingency operations cases were considered for the potential launch slip window of 40 to 80 days.

6.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the three analysis cases.

6.6.1 Derived Generation Rates

The basic Unity Node 1 and human metabolic trace contaminant generation rates used for all analysis cases are documented in table 15. Basic Unity Node 1 offgassing rates were derived from the offgassing test air sample analysis results using equation (3). Based upon review of postflight toxicology reports for STS-88/2A, the basic Unity Node 1 load model used for the preflight STS-88/2A analysis was supplemented by adding ethanal, 2-propenal, pentenal, hexanal, heptanal, and butyl acetate to the load. These compounds were observed in the in-flight grab samples and contributed significantly to the overall *T*-value. Many of these compounds were observed during the first preflight element offgassing test conducted in late August through early September 1998. Generation rates for these supplementary compounds were derived from the results of that first test. The basic model was also expanded to account for the metabolic production of carbon monoxide, hydrogen, and methane. It has been assumed that an average 2.5 crewmembers are continually in the ISS during ingress operations.

Review of the STS-88/2A postflight toxicology reports indicated that the generation rate for methanol continued to decrease when compared to the earlier offgassing test results. Comparison of the analytical results from the in-flight grab samples with concentrations predicted using the original vehicle offgassing data indicates that the methanol generation rate from Unity Node 1 decreased by approximately 90% since the second offgassing test was completed. The basic rate in table 15 reflects this decrease. Additional in-flight sample analysis results from STS-96/2A.1 indicate that the methanol generation rate remained fairly steady between flights STS-88/2A and STS-96/2A.1.

Table 15. Basic trace contaminant generation rates.

Compound	Generation Rate (mg/hr)	
	Node 1*	Metabolic
Methanol	0.028	0.09
Ethanol	0.627	0.44
2-propanol	0.585	0.18
n-propanol	0.0973	0.06
2-methyl-2-propanol	0.0149	–
n-butanol	0.0777	0.05
Ethanal	0.0258	0.06
2-propenal	0.0049	–
Propanal	0.0197	0.04
2-methyl-2-propenal	0.0149	–
Butanal	0.0196	–
Pentanal	0.0062	0.002
Hexanal	0.0062	0.002
Heptanal	0.0062	0.002
Methylbenzene	0.0432	0.07
1,2- & 1,3-dimethylbenzenes	0.0391	0.012
1,4-dimethylbenzene	0.0149	0.006
Ethylbenzene	0.0149	0.06
Butyl acetate	0.0062	0.019
Dichloromethane	0.0822	–
Trichlorofluoromethane	0.0149	–
Trichlorotrifluoroethane	0.0496	–
2-propanone	0.154	1.95
2-butanone	0.0778	0.94
Cyclohexanone	0.0259	–
Hexamethylcyclotrisiloxane	0.0149	–
Octamethylcyclotetrasiloxane	0.106	–
Carbon monoxide	–	1.83
Hydrogen	–	4.4
Methane	–	9.75**

* Based upon preflight vehicle offgassing test results.

** Based upon 2.5 crewmembers. Methane rate assumes one-half crew are producers.

Correlation of preflight predictions with the analytical results from the in-flight grab samples after STS-88/2A indicated that contamination carryover from the Shuttle and FGB via the IMV contributes significantly to the Node 1 air quality. The IMV contribution to the contamination load is summarized in table 16. Based upon the observed concentrations from the Shuttle atmosphere determined from analysis of an in-flight sample collected during STS-88/2A, contaminant generation rates were established for the Shuttle/Node 1 IMV. According to the in-flight cabin grab sample analyses, the Shuttle air quality during STS-88 was typical of in-flight mid-deck air quality when compared to the average of all archival samples collected during the Shuttle program since STS-1. Similarly, assuming that a steady state had been established between Node 1 and the FGB upon egress, the samples collected during STS-96/2A.1 were used to determine the basic generation rates for the FGB's contribution to the Node 1 contamination load via IMV.

Table 16. IMV and stowage hardware contributions to offgassing rate.

	Shuttle IMV (mg/hr)		FGB IMV (mg/hr)		Stowage (mg/hr)	
Compound	**Initial***	**Steady State****	**Initial*****	**Steady State†**	**2A**	**2A.1**
Methanol	15.1	–	210.9	–	0.0008	0.003
Ethanol	168.2	–	1,094	75.6	0.0184	0.0678
2-propanol	269.1	213.6	18.9	22.2	0.0172	0.0632
n-propanol	–	–	–	–	0.0029	0.0105
2-methyl-2-propanol	4.2	–	–	–	0.0004	0.0016
n-butanol	4.2	–	51.4	14.8	0.0023	0.0084
Ethanal	13.5	–	18.1	–	0.0008	0.0028
2-propenal	1.7	–	0.8	–	0.0001	0.0005
Propanal	4.2	–	–	–	0.0006	0.0021
2-methyl-2-propenal	–	–	–	–	0.0004	0.0016
Butanal	4.2	–	–	–	0.0006	0.0021
Pentanal	4.2	–	–	–	0.0002	0.0007
Hexanal	4.2	–	6.4	–	0.0002	0.0007
Heptanal	4.2	–	–	–	0.0002	0.0007
Methylbenzene	4.2	–	30.2	–	0.0013	0.0047
1,2- & 1,3-dimethylbenzenes	4.2	–	107.4	13	0.0012	0.0042
1,4-dimethylbenzene	4.2	–	103.6	14.8	0.0004	0.0016
Ethylbenzene	4.2	–	23.4	4.6	0.0004	0.0016
Butyl acetate	4.2	–	18.1	–	0.0002	0.0007
Dichloromethane	11.8	3.4	5.7	9.3	0.0024	0.0089
Trichlorofluoromethane	4.2	–	–	–	0.0004	0.0016
Trichlorotrifluoroethane	4.2	–	–	–	0.0014	0.0054
2-propanone	23.5	–	41.6	18.5	0.0045	0.0166
2-butanone	4.2	–	–	–	0.0023	0.0084
Cyclohexanone	–	–	33.3	–	0.0008	0.0028
Hexamethylcyclotrisiloxane	158.1	143	310	–	0.0004	0.0016
Octamethylcyclotetrasiloxane	67.3	47.1	499	–	0.0031	0.0114
Carbon Monoxide	92.5	–	–	–	–	–
Hydrogen	319.6	–	–	–	–	–
Methane	773.7	–	–	–	–	–

* Based on STS-88 post-ingress Shuttle mid-deck sample and IMV = 168.2 m^3/hr.
** Based upon gradient between Shuttle and Node with IMV = 168.2 m^3/hr.
*** Average FGB ingress sample and IMV = 151.2 m^3/hr.
† Based upon 2A.1 egress gradient and IMV = 151.2 m^3/hr.

Offgassing from stowage equipment must also be accounted for. During STS-88/2A, approximately 84 kg of equipment was left aboard Unity Node 1 while an additional 308.5 kg was left on board at the conclusion of STS-96/2A.1. The offgassing from this equipment was derived from the Unity Node 1 vehicle offgassing test data divided by the mass of internal hardware present during the test. During the Unity Node 1 offgassing test, there were 2,854.39 kg of hardware present. It is assumed that the stowage hardware left on board the ISS would offgas at similar rates per unit mass. The additional offgassing rates contributed by stowage hardware are summarized in table 16.

Because the offgassing rates are influenced by the stowage hardware, each mission to the ISS results in changes in the basic Node 1 generation rates. Similarly, various activities during ingress operations also contribute to variations in contaminant generation rates. Variations in generation rates derived from combinations of rates listed in tables 15 and 16 are summarized in appendix C.

6.6.2 Relative Contamination for Flights 2A Through 2A.2 for Normal Operations

After accounting for all of the known trace contaminant sources, the analysis was conducted by considering Unity Node 1 as the reference volume. Results from the analysis of in-flight air quality samples were compared to the engineering analysis predictions to provide a continuing validation of the engineering methodology. During STS-88/2A, the *T*-value at ingress, excluding carbon dioxide, was reported to be 0.47. By comparison, the engineering analysis predicted a *T*-value of 0.65. This is well within the medical operations criteria for safe ingress.

The timing of the sample relative to IMV flow initiation can have an effect on the air quality. As seen in figure 10, the effect of contaminant carryover from the Shuttle and the FGB during the first hour after initiating IMV flow results in contamination spikes in Unity Node 1. The CACEAs rapidly reduce the contamination level; however, the air quality measured from a sample collected during this transient can be affected. For example, the first analysis of Unity Node 1 ingress operations predicted a much lower *T*-value of 0.19. Review of the in-flight operations timeline for STS-88/2A indicated that the ingress sample was collected more than 20 minutes after the IMV flow was initiated. The results from this sample demonstrated without doubt that the contamination spike induced upon initiating IMV flow must be accounted for in the Unity Node 1 TCC analysis. Figure 11 shows the results after incorporating contaminant carryover from the Shuttle and FGB to Unity Node 1 via IMV. As can be seen, the initial air scrubbing reduces the *T*-value to approximately 0.05. Once IMV is established, a contamination spike is experienced which increases the *T*-value to as high as 0.65. A similar magnitude spike is experienced during FGB IMV initiation. Therefore, when the timing of the ingress sample is considered, the generation rates predicted for Unity Node 1 hardware and the performance of the CACEAs are as expected.

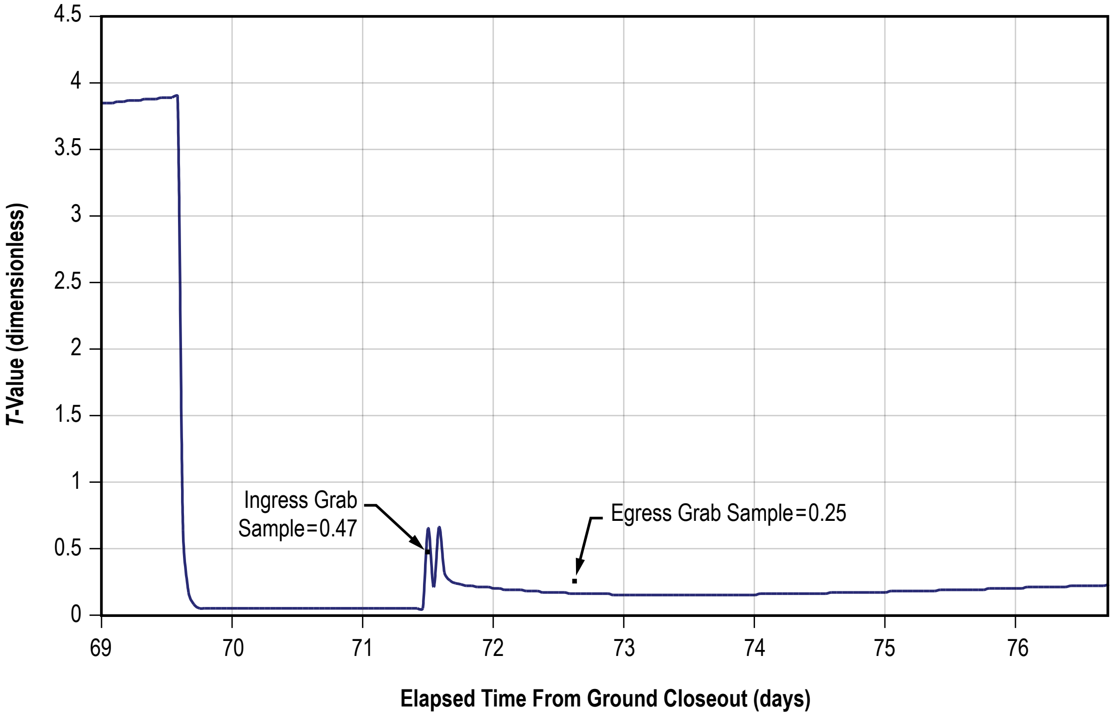

Figure 10. Node 1 relative contamination during flight 2A ingress, STS-101/2A.2.

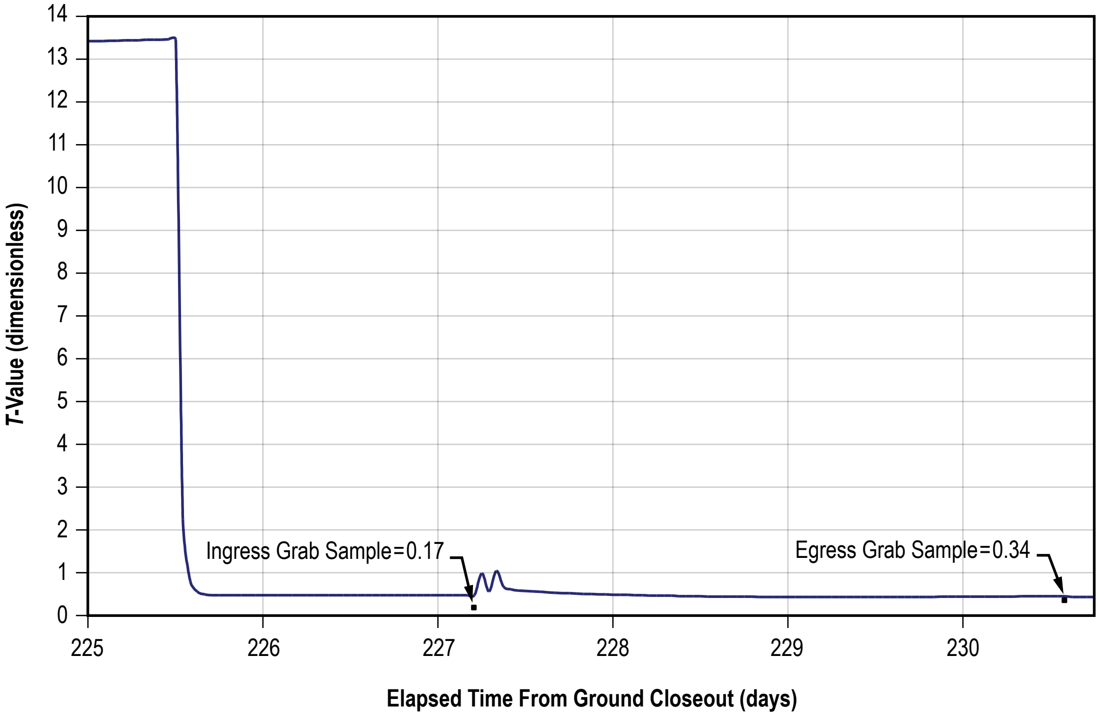

Figure 11. Relative contamination of Node 1 during flight 2A.1 ingress, STS-96/2A.1.

Continuing the analysis from the conclusion of flight STS-88/2A up to cabin fan activation during flight STS-96/2A.1 shows that, assuming the contaminant generation rates remain constant, the *T*-value can be expected to rise to approximately 13.5. As shown in figure 11, the CACEAs still provided adequate capability. A normal scrub reduces the predicted *T*-value to approximately 0.47. By comparison, the in-flight grab sample analysis found a *T*-value of 0.17. Upon Shuttle IMV activation, the *T*-value spikes to 0.98 and then to 1.04 during FGB IMV activation. After all IMV is established, the *T*-value was predicted to approach 0.45 by the end of ingress operations. This compares favorably to the in-flight egress air quality samples which indicated a *T*-value of 0.34.

For flight STS-101/2A.2, shown in figure 12, the *T*-value builds up to approximately 19.7. This higher relative contamination is caused by the additional offgassing from stowage hardware combined with the longer duration between missions. After starting the cabin fan, the scrubbing provided by the CACEAs reduces the *T*-value to approximately 0.95. When IMV flow is initiated, a spike to a *T*-value of 1.58 occurs. This spike is less distinct because it is assumed for this analysis that the ingress operations will not take as long as during STS-88 or STS-96. Once the Shuttle, Unity Node 1, and FGB volumes become well mixed, the *T*-value slowly approaches a final level of 0.8. All normal ingress operations are well below the medical operations guidelines of table 1.

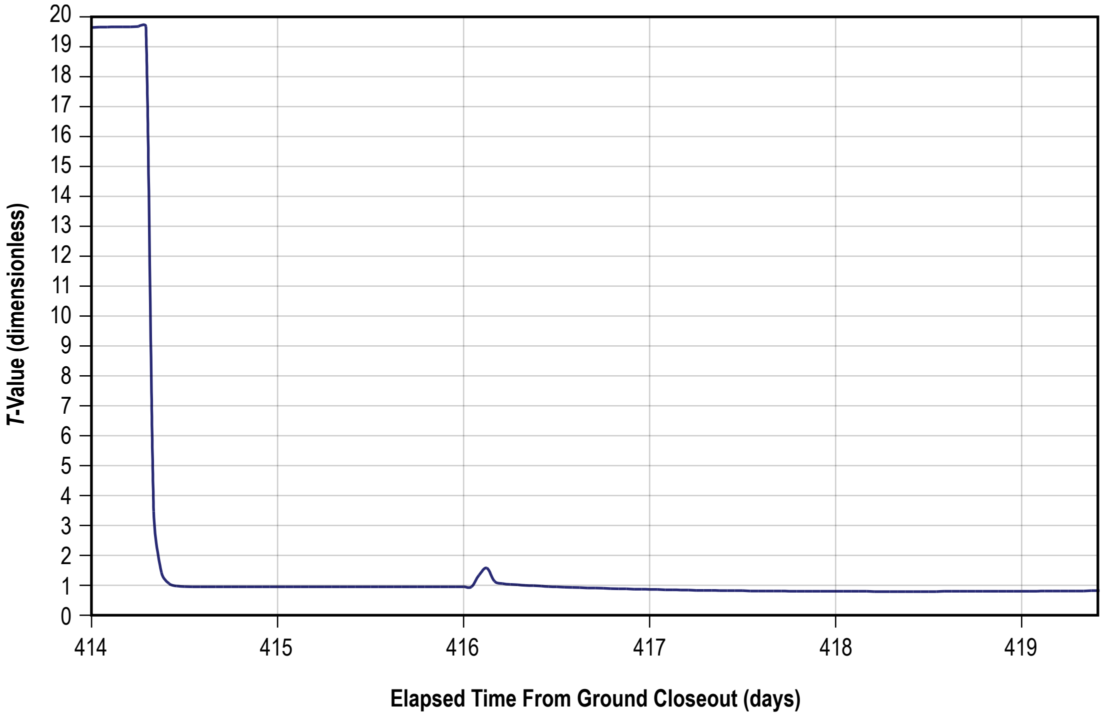

Figure 12. Relative contamination of Node 1 during flight 2A.2 ingress, STS-101/2A.2.

6.6.3 Impact of Launch Slip on 2A.2 Relative Contamination

In the event that flight STS-101/2A.2 slips significantly, the *T*-value could rise to as high as 28. This magnitude is for an 80-day launch slip beyond the planned December 2, 1999, date. In this extreme case, the *T*-value could be reduced to 1.12 by the CACEAs in Unity Node 1 and ultimately to 0.89 by the end of the ingress activities. Again, this is well within the medical operations guidelines. For a 40-day launch slip, the *T*-value at Unity Node 1 fan activation may be as high as 24. This would be reduced to 1.06 at ingress and slowly reduced to 0.85 during the course of ingress operations. Similarly, a 60-day launch slip would produce predicted initial, ingress, and egress *T*-values of 26, 1.09, and 0.87, respectively. While these predicted *T*-values are still within the medical operations guidelines, the fact that the ingress *T*-value is slightly greater than 1 indicates that the CACEAs should be replaced at the conclusion of ingress operations for flight STS-101/2A.2. Replacing the CACEAs is also necessary at this time because of the uncertainty in the launch schedule for flights 3A and 4A.

6.6.4 Accuracy of Contamination Predictions

The ability to accurately predict trace contaminant concentrations, and therefore *T*-values, over a long period of time is a significant challenge. Typically, as time passes, one would expect the predictions to become increasingly conservative because of the assumption used in the analysis that generation rate is constant with time. Significant studies have demonstrated that offgassing rates do not remain constant with time. In fact, offgassing rates from more than 60% of materials used on board spacecraft tend to decay over time. The comparison of the predicted and actual measured *T*-values for STS-88/2A and STS-96/2A.1 show that the engineering analysis had a positive deviation of 0.045 *T*-value units 72.6 days after Unity Node 1 closeout and 0.205 *T*-value units 228.9 days after Node 1 closeout. This indicates that the magnitude by which the engineering analysis may overpredict *T*-value is 0.00102 *T*-value units/day. At the time of STS-101/2A.2, it is likely that the engineering analysis may have a positive deviation of up to 0.39 *T*-value units. This is an important observation as it demonstrates that the engineering analysis technique's conservatism will increase over time.

6.6.5 Capability to Maintain Concentrations Below Spacecraft Maximum Allowable Concentrations

As can be observed by the preceding discussion and from figures 10 through 12, the *T*-value during normal Node 1 ingress operations is maintained below 1 for all assembly and logistics flights through STS-101/2A.2, even with a potential slip in launch schedule which could place flight STS-101/2A.2 in late-January 2000. By definition, all contaminants contributing to the *T*-value must be well below their respective SMACs to result in an overall *T*-value magnitude less than 1. Therefore, the requirement to maintain individual trace contaminants below their respective SMACs is met during all ingress operations. Further evidence of this is provided by the concentration summary in appendix D.

6.6.6 Flight 2A.2 Contingency Operations

Several analysis cases were conducted to investigate the capability of Shuttle-provided resources to support contingency ingress operations. Contingency ingress is necessary in the event that the Unity Node 1 cabin fan fails to operate for any reason. Flight STS-96/2A.1 was used as the basis for the analysis and the elapsed time to the next ingress was set to the planned early December 1999 STS-101/2A.2 launch date. In addition, cases were considered in which the elapsed time was extended by 40, 60, and 80 days beyond the early December 1999 launch date. The results of the analysis are summarized in table 17.

Table 17. Effect of launch slip on contingency ingress scrub duration.

Time (days)	Projected *T*-Value	Elapsed Time (hr)		Final *T*-Value
		T = 3	*T* = 1	
0	19.87	8.5	19	0.71
40	24.06	9.5	21	0.75
60	26.16	10	22	0.78
80	28.26	10.5	23	0.81

As can be seen by the contingency ingress analysis results, none of the contingency cases satisfy the medical operations criteria because the ingress *T*-value magnitude is greater than 6. Review of the analysis results in table 17 indicate that the crew surgeon must evaluate the health risk or any operational workaround. Flight rule X13.1.2-2 for ingress, included as appendix A, allows for the crew to open the hatch, establish IMV, and wait for at least 1 hour in the Shuttle before actually entering Unity Node 1 if the *T*-value magnitude is less than 6. During this time, one of the Shuttle LiOH canisters is replaced with a charcoal canister to provide added protection for the crew. For STS-101/2A.2, a modification to this approach in which the crew waits until the *T*-value magnitude is reduced to at least 3 may be used. That would require a waiting period of at least 8 hours before full ingress. More time would be necessary if the STS-101/2A.2 launch slips significantly. This approach must be reviewed and approved by the responsible medical operations personnel.

An interesting observation from table 17 is that the contingency capability can reduce the *T*-value below what is predicted for the Node 1 CACEAs. This is not very surprising when it is considered that the CACEAs have been subjected to 1 year or more of offgassing and have very little remaining capacity for highly volatile compounds such as methanol and dichloromethane which both have low SMACs. By virtue of being fresh, the Shuttle-provided charcoal beds, although flow limited, can ultimately reduce the overall *T*-value much lower than the CACEAs because they can handle more methanol and dichloromethane.

6.7 Predicted Offgassing Load Versus Russian BMP Capability

Of particular concern and interest to the Russian side is the combined trace contaminant load which may be present upon Zvezda service module (SM) ingress. This concern exists because the Russian Segment TCCS, known as the BMP, has been designed to remove compounds representative of various functional classes at specified rates. During STS-101/2A.2, the crew will enter the SM and contaminants from Unity Node 1 and the FGB will be introduced into it via the IMV flow. To address this concern, the total estimated offgassing rate from Unity Node 1 and the FGB have been compared to the ‘as designed’ BMP contaminant removal capability.[11] Table 18 summarizes this comparison.

Table 18. BMP contaminant removal capability versus estimated generation rates.

Compound	Russian BMP Rate (mg/day)	Node 1 with* Stowage (mg/day)	Estimated** FGB Stowage (mg/day)	Estimated*** Basic FGB (mg/day)
Methanol	3	0.8	1.3	–
Ethanol	250	17	8.1	75.6
2-propanol	–	16	4.1	22.2
n-butanol	80	2.1	4.9	14.8
Ethylene glycol	50	–	–	–
Methanal	10	–	–	–
Ethanal	24	0.7	0.1	–
2-propenal	–	0.14	–	–
Benzene	0.45	–	–	–
Methylbenzene	66	1.2	2	–
Dimethylbenzenes	–	1.5	3.8	27.8
Isopropyl benzene	50	–	–	–
Ethyl acetate	250	–	–	–
Dichloromethane	–	2.2	2.2	9.3
2-propanone	27	4.2	3.7	18.5
2-butanone	–	2.1	6.2	–
Carbon monoxide	390	–	–	–
Ammonia	20	–	–	–
Polymethylcyclosiloxanes	–	3.3	0.4	–

* Additional 84 kg of stowage hardware at STS-88/2A and 308.5 kg at STS-96/2A.1.

** 1,031.5 kg FGB stowage hardware (690.4 kg Russian, 341.1 kg U.S.)

*** Greatest rate derived from egress concentration gradient between Node 1 and FGB for 2A/2A.1 and assumed IMV of 151.2 m^3/hr.

The second column in table 18 summarizes the BMP capability while the remaining columns provide corresponding estimated offgassing rates for Unity Node 1, the FGB and stowage hardware. As can be seen, the total sum of columns three through five show the BMP capability will not be exceeded. If it is assumed that the Zvezda SM equipment offgassing is similar in magnitude to that of the FGB, then the only compound that may be a challenge for the BMP is 2-propanone. Although the BMP has no specific design requirement for 2-propanol, 2-propenal, dimethylbenzenes, dichloromethane, 2-butanone, and polymethylcyclosiloxanes, it is anticipated that its rated capacity for similar compounds is indicative of how well it can remove them from the air. For instance, the BMP has the capability to remove 250 mg/day of ethanol and 80 mg/day of n-butanol. Based upon the similarity of its physical properties to ethanol and n-butanol, it would follow that its capacity for 2-propanol would fall between 80 mg/day and 250 mg/day. The estimated generation rate for 2-propanol is well below this range. By applying a similar analysis for the other compounds, it can be concluded that the BMP's capacity will not be exceeded at any time during the STS-101/2A.2 ingress or at any time subsequent to the ingress operation.

6.8 Discussion

As can be seen by the analysis results, sufficient air quality can be maintained during all phases of missions STS-101/2A.2 as long as normal cabin fan operation can be provided. Medical operations experts have determined that the *T*-value magnitude in Unity Node 1 must be at or below 3 for safe ingress. Otherwise, some additional means of contamination control or operational constraints must be used.

As indicated by the analysis, the Shuttle-provided contingency capabilities, when combined with dilution between the ISS and Shuttle volumes, cannot meet the medical operations guidelines presented in table 1. As seen in table 17, this limit for contingency ingress is exceeded for all possible STS-101/2A.2 launch dates. Therefore, it is necessary for the crew to wait for at least 8 hours before entering Unity Node 1 in the event of a contingency ingress. At least one Shuttle-provided charcoal canister must be provided to support contingency ingress operations.

6.9 Conclusions

Based upon the Unity Node 1 TCC capability assessment results, conclusions that can be made are the following:

- The Unity Node 1 contamination removal capability provided by the CACEAs will meet the requirements of the Node 1 PIDS for all compounds for flight STS-101/2A.2.

- The CACEAs have sufficient capacity to be used through the ingress period of STS-101/2A.2 even if the mission slips to January 2000 or beyond.

- Initial Unity Node 1 air quality may exceed the criteria for safe contingency ingress for STS-101/2A.2.

The combined Unity Node 1, FGB, and stowage hardware offgassing rates do not exceed the BMP capability.

6.10 Recommendations

Recommendations for addressing Unity Node 1 TCC issues during ingress operations are the following:

- Replace the CACEAs at the conclusion of flight STS-101/2A.2 ingress operations.

- Continue in-flight samples of Unity Node 1 through flight 3A to allow for continual TCC verification.

- Provide one Shuttle-provided charcoal canister for STS-101/2A.2 to support contingency ingress operations.

- Evaluate the health risk presented by contingency ingress operations in which the waiting period is extended from 1 to 8 hours.

7. POSTFLIGHT EVALUATION THROUGH MISSION 2A.2a WITH PREFLIGHT PREDICTIONS FOR MISSIONS 2A.2b AND 3A

This assessment was originally released under NASA Memorandum FD21(00-146) dated August 23, 2000.

7.1 Background

In preparation for ISS flight operations, ground-based trace contaminant offgassing tests have been conducted on the Unity Node 1, Zarya FGB, and Zvezda SM modules. For Unity, a 5-day test was conducted October 1–6, 1998. During this test, sets of three grab samples were collected at the beginning, middle, and end of the test as specified by the ISS Qualification and Acceptance Environmental Test Requirements (SSP 41172). Subsequent analysis of these samples established trace contaminant concentrations as a function of time. Generation rates were determined from these concentrations, the vehicle free volume, and sample timing. Both Zarya and Zvezda have been subjected to 48-hour trace contaminant offgassing tests according to Russian procedures and standards.

The generation rates derived from the offgassing test results for each element were used as input data for an engineering analysis to predict the in-flight concentrations and relative contamination (*T*-value) of the atmosphere upon ingress during ISS missions STS-88/2A, STS-96/2A.1, and STS-101/2A.2a. Each analysis built upon the in-flight experience gained from each preceding mission.

The analysis for STS-88/2A served as a basis for establishing in-flight operations for both nominal and contingency ingress scenarios. Grab samples collected during STS-88/2A, STS-96/2A.1, and STS-101/2A.2a of the Unity, Zarya, and Shuttle atmospheres were collected and analyzed postflight. Results from the sample analyses were evaluated and served as a secondary basis for the trace contaminant load for each module. As well, predicted offgassing from additional hardware stowed on board the ISS during each mission has been accounted for. Using an updated load model based on both the preflight offgassing test and in-flight grab sample analysis results, an updated TCC capability assessment was conducted to support in-flight operations for ISS flight STS-101/2A.2a .

As with STS-88/2A and STS-96/2A.1, atmospheric grab samples were collected during STS-101/2A.2a. Results from the sample analyses have been evaluated and used to update the original offgassing test basis. Using this new information to refine the offgassing rate basis, an engineering analysis has been conducted for ISS flights STS-106/2A.2b and STS-92/3A. Results and conclusions of the engineering analysis are presented by the following discussion. Based upon the results, recommendations are presented for consideration.

7.2 Purpose

The engineering analysis summarized by the following discussion serves as verification of the ISS's TCC capability for missions STS-106/2A.2b and STS-92/3A. Further, the analysis serves to validate assumptions used during previous TCC capability assessments conducted for STS-88/2A, STS-96/2A.1, and STS-101/2A.2a. Continually validating these assumptions is important because each analysis builds upon its predecessors.

7.3 Objectives

The adequacy of the trace contaminant removal capability presently on board the ISS was assessed by engineering analysis. Specific objectives of the analysis which will allow for appropriate verification of this capability are the following:

- Determine the trace contaminant load for each on-orbit ISS element based upon both preflight offgassing test, stowage hardware mass, and in-flight air quality data.

- Determine the trace contaminant concentrations during ingress operations for missions STS-106/2A.2b and STS-92/3A using previous missions to the ISS as a basis.

- Determine the adequacy of the onboard TCC resources for meeting the relevant ISS program requirements, flight rules, and medical operations guidelines during STS-106/2A.2b and STS-92/3A.

- Evaluate predicted trace contaminant concentrations relative to documented odor thresholds. A 'glue-like' odor has been reported after previous missions and specific trace contaminants produced by offgassing may contribute to the odor.

7.4 Assumptions

To conduct the ISS trace contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

7.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for all phases of the verification analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results and revised according to results of in-flight air quality data.

- Additional offgassing from stowage hardware is estimated using Unity's offgassing test results for U.S. hardware and Node 1 PIDS rates for Russian hardware.

- ISS atmospheric leakage is zero. This is considered to be true for a newly launched element.

- Cabin atmospheric conditions are on average 10 °C, 30% relative humidity (–6.7 °C dewpoint), and 1 atm.

- Offgassing rates are constant with time with negligible effects of temperature and pressure fluctuations. Offgassing has been shown to be sensitive to temperature fluctuations. Because the offgassing test temperature was higher, the rates derived from it are considered to be conservative.

- Seven-day SMACs apply for the analysis according to flight rule X13.1.2-2 provided in appendix A.

7.4.2 On-Orbit Configuration

As configured on orbit, the forward end of Unity is attached to a PMA-2 which is in turn attached to the Shuttle during each assembly flight. Zarya is attached to the aft end of Unity via PMA-1. Unity is provided with a contamination control capability consisting of a cabin fan and four CACEAs located in the cabin air return duct in place of the cabin air bacteria filter elements. Zvezda is attached to the aft end of Zarya. Both Zvezda and Zarya have onboard contamination control systems. The ventilation configuration normally provides 340 m^3/hr total air flow rate through Unity's CACEAs. Assumptions pertaining to Unity's configuration and its contamination control capability are the following:

- Cabin free volumes of Unity, PMA-1, PMA-2, Zarya, Zvezda, and Shuttle are 55.2, 5.7, 5.2, 61, 87, and 70 m^3, respectively.

- Unity's normal scrubbing rate is 340 m^3/hr for a 4,000 rpm fan speed with the flow split evenly between four individual CACEAs.

- Each CACEA has a minimum type AC/GAC packing depth of 3.3 cm and a platinum on charcoal (2% Pt/GAC) packing depth of 1.27 cm.

- Contamination generation and removal contributions from Zarya are estimated based upon egress concentration gradients observed during STS-96/2A.1 until more data on Russian equipment offgassing and the design of the Harmful Contaminants Filter (Russian acronym FVP) are made available.

- Contribution to overall contamination generation and removal on board Unity by the BMP system on board Zvezda is conservatively considered to be negligible.

7.4.3 Mission Timeline

The timeline used for the engineering analysis is shown in table 19 which provides the relative timing of in-flight ECLS operations and sampling events for missions STS-88/2A through STS-92/3A. These events are summarized in table 20 along with projected dates and approximate times for major ECLS events for flight STS-106/2A.2b. In-flight operations for flight STS-92/3A have been modeled similarly to what was experienced during STS-101/2A.2a.

Table 19. Engineering analysis timeline for flights STS-88/2A through STS-92/3A.

Time (hr)	Event
0	Node 1 purge at launch minus 65 days
960	Cabin fan operated on pad
1,560	STS-88/2A launch
1,670.5	Cabin fan started
1,715	Hatch open and IMV started
1,715.5	Node 1 ingress sample collected
1,717	FGB ingress sample collected
1,741	FGB egress sample collected
1,743	Node 1 egress sample collected
1,841	Cabin fan shut down
5,369	STS-96/2A.1 launch
5,412	Cabin fan started
5,453	Node 1 ingress and sample collected
5,455	FGB ingress and sample collected
5,532	FGB egress and sample collected
5,534	Node 1 egress and sample collected
5,538	Cabin fan shut down
13,968	STS-101/2A.2a launch
14,026	Cabin fan started
14,066	Node 1 ingress and sample collected
14,067	FGB ingress and sample collected
14,138–14,140	Cabin fan and CACEA R&R
14,143	FGB egress and sample collected
14,145	Node 1 egress and sample collected
14,147	Cabin fan shut down
16,667	STS-106/2A.2b launch
16,712	Cabin fan started
16,755	Node 1 ingress and sample collection
16,756	FGB/SM ingress and sample collection
16,858	FGB/SM egress and sample collection
16,860	Node 1 egress and sample collection
16,860	Cabin fan shut down
17,316	STS-92/3A launch
17,374	Cabin fan started
17,414	Node 1 ingress and sample collection
17,415	FGB/SM ingress and sample collection
17,491	FGB/SM egress and sample collection
17,492	Node 1 egress and sample collection
17,494	Cabin fan shut down

Table 20. Relative timing of events from mission STS-88/2A through STS-92/3A.

Event	Date	Time	
		GMT	MET
Node 1 purge at launch minus 65 days	09/30/98	00:00*	NA
Cabin fan operated on pad for 30 minutes	11/09/98	00:00*	NA
STS-88/2A Launch	12/04/98	09:00	0/00:00
Cabin fan started	12/09/98	01:54	4/14:32
Hatch open	12/10/98	20:02	6/11:00
IMV activation	12/10/98	20:09	6/11:07
Node 1 ingress sample collected	12/10/98	20:22	6/11:22
FGB ingress sample collected	12/10/98	21:45	6/12:45
FGB egress sample collected	12/11/98	22:23	7/13:23
Node 1 egress sample collected	12/12/98	00:24	7/15:12
Cabin fan shut down	12/12/98	07:57	8/23:09
STS-96/2A.1 launch	05/27/99	11:49	0/00:00
Cabin fan started approximately flight day 4	05/29/99	06:45	1/19:57
Node 1 ingress and sample collected	05/30/99	23:50	3/14:28
FGB ingress and sample collected	05/31/99	01:16	3/16:05
FGB egress and sample collected	06/03/99	05:56	6/19:08
Node 1 egress and sample collected	06/03/99	08:12	6/21:24
Cabin fan shut down	06/03/99	11:37	7/00:49
STS-101/2A.2a launch	05/19/00	10:12	0/00:00
Cabin fan started	05/21/00	08:38	1/22:26
Node 1 ingress and sample collected	05/22/00	00:33	3/14:00
FGB ingress and sample collected	05/22/00	01:00	3/14:30
Cabin fan and CACEA repair and replacement	05/26/00	00:38 – 02:10	6/14:04 – 15:46
FGB egress and sample collected	05/26/00	05:30	6/19:06
Node 1 egress and sample collected	05/26/00	07:33	6/21:09
Cabin fan shut down	06/26/00	10:00	6/23:36
STS-106/2A.2b launch	09/08/00	12:00	0/00:00
Cabin fan started	09/10/00	09:00	1/20:30
Node 1 ingress and sample collection	09/12/00	03:30	3/15:00
FGB/SM ingress and sample collection	09/12/00	05:00	3/16:30
FGB/SM egress and sample collection	09/16/00	09:30	7/21:00
Node 1 egress and sample collection	09/16/00	11:30	7/23:00
Cabin fan shut down	09/16/00	14:00	8/01:30
STS-92/3A launch	10/05/00*	00:00*	0/00:00*
Cabin fan start	10/07/00*	10:00*	1/10:00*
Node 1 ingress and sample collection	10/08/00*	00:00*	3/00:00*
FGB/SM ingress and sample collection	10/08/00*	01:00*	3/01:00*
FGB/SM egress and sample collection	10/11/00*	05:00*	6/05:00*
Node 1 egress and sample collection	10/11/00*	06:00*	6/06:00*
Cabin fan shut down	10/11/00*	08:00*	6/08:00*

*Assumed for analysis purposes.

Unity was launched as the payload for mission STS-88/2A. Approximately 65 days before launch, a final purge was conducted on approximately September 30, 1998, to provide a dry atmosphere. This purge had the added benefit of removing trace contaminants and establishing a clean atmospheric baseline. After approximately 40 days elapsed, the cabin fan was operated for 30 minutes to provide additional prelaunch atmospheric conditioning. Launch occurred on December 4, after a 1-day slip from the original December 3 date.

In flight, the cabin fan was started on December 9 and operated continuously up to and throughout the entire ISS ingress operation. It should be noted that the hatch between the Shuttle and Unity was not opened until December 10, approximately 45 hours after Unity's cabin fan was started. The fan was shut down on December 12 upon egress. In all, the fan operated for approximately 170 hours.

As a part of mission STS-88/2A ingress operations, atmospheric samples were collected via evacuated GSCs in Unity and Zarya. All of the samples were collected on December 10. The first sample was collected approximately 30 minutes after the hatch was opened and the IMV was initiated. The second sample was collected from Zarya upon ingress approximately 2 hours after the Unity's hatch was opened, and the third sample was collected upon exiting Zarya 24 hours later. The fourth sample was collected from Unity just before egress approximately 2 hours later.

After mission STS-88/2A egress, a period of untended operations of approximately 147 days elapsed before STS-96/2A.1 was launched on May 27, 1999. Unity's cabin fan was activated during STS-96/2A.1 on May 29 approximately 43 hours after launch. Like STS-88/2A, the cabin fan operated continuously throughout the planned ingress. Approximately 41 hours after activating the cabin fan, ingress activities began. A grab sample was collected in Unity immediately upon ingress. Nearly 2 hours later, a second sample was collected upon entering Zarya. For this mission, the initial ingress activities took longer than originally expected. Approximately 76 hours after completing the initial ingress activities, egress began. A third grab sample was collected from Zarya and a fourth sample was collected from Unity about 2 hours later. Another 4 hours elapsed before Unity's cabin fan was shut off.

Approximately 350 days elapsed between STS-96/2A.1 egress and STS-101/2A.2a launch on May 19, 2000. Unity's cabin fan was started on May 21 with ingress beginning approximately 40 hours later on May 22. Ingress samples were collected from both Unity and Zarya. Before egress on May 26, the original CACEAs which had been launched on board Unity were replaced along with the cabin fan. Following replacement, the cabin fan was restarted and ran for approximately 7 hours.

The planned launch date for STS-106/2A.2b is September 8, 2000. Approximately 105 days elapse between cabin fan shutdown during STS-101/2A.2a and STS-106/2A.2b launch. The mission timeline is quite similar to those of STS-96/2A.1 and STS-101/2A.2a. The only exception is that the crew will enter Zvezda for the first time. Mission STS-92/3A launch is planned for October 5, 2000. A timeline similar to that planned for STS-106/2A.2b is used for analysis purposes.

Additional analysis runs have been conducted to predict the trace contaminant loading in Zvezda during STS-106/2A.2b. The TCC system on board Zvezda, known by the Russian acronym BMP, employs expendable and regenerable activated carbon beds to scrub the atmosphere. The BMP's performance has been evaluated and verified during independent testing by Boeing under contract to NASA Marshall Space Flight Center (MSFC).[12] The BMP will be started 48 hours before ingress. At that time, Zvezda will have been sealed for approximately 107 days.

7.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach. The discussion includes a summary on trace contaminant generation rate derivation, the analytical tool, and cases considered for the assessment.

7.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of offgassing test grab samples collected from Unity, Zarya, and Zvezda as well as considering in-flight sample analysis results. The original load derived from offgassing test data collected from Unity has been supplemented by the addition of several contaminants that were observed during the first offgassing test conducted from August 26 through September 4, 1998. In addition, evaluation of in-flight sample analysis data indicate that Zarya's and the Shuttle's contribution to the overall contamination load on Unity must be considered in addition to major metabolic contaminants produced by the crew during ingress. As additional hardware has been left on board the ISS, the offgassing contribution of that hardware has been estimated based upon ground-based offgassing test data and Node 1 PIDS generation rate data.

7.5.2 Trace Contaminant Control Simulation Computer Program

The TCCS-CP, version 8.1, was used to conduct the analysis.[7,8] This analytical tool calculates the cabin concentration of individual trace chemical contaminants when generated at a specified rate and controlled by any combination of removal devices. It contains subroutines for simulating the performance of AC/GAC and 2% Pt/GAC.

The TCCS-CP, version 8.1, has previously been assessed for its applicability for use in spacecraft TCC verification analyses and was found to be acceptable, and the subroutine for the 2% Pt/GAC has been found to provide a conservative performance assessment.[9]

7.5.3 Analysis Cases Considered

Cases considered by the engineering analysis encompass normal ingress scenarios for missions STS-106/2A.2a and STS-92/3A. Ingress into Unity as well as into Zarya and Zvezda is considered. These cases build upon engineering analysis and in-flight sample analysis results for STS-88/2A through STS-106/2A.2a. As well, the in-flight sample analysis results serve to validate the engineering analysis and TCC design methodology used for the ISS. As such, analysis results through STS-101/2A.2a compared to in-flight sample analysis results are discussed as a precursor to the evaluation of the STS-106/2A.2b and STS-92/3A missions.

Assessment of contingency ingress operations was conducted by considering past missions in which similar predicted contamination levels were present. As such, the STS-106/2A.2b and STS-92/3A contingency ingress cases were evaluated by bounding them within flight experience to date.

7.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the three analysis cases.

7.6.1 Derived Generation Rates

The basic ISS and human metabolic trace contaminant generation rates used for all analysis cases are documented in table 21. Basic offgassing rates for Unity were derived from the offgassing test grab sample analysis results using equation (3). Review of the postflight toxicology reports for STS-88/2A required Unity's basic load model originally used for the preflight STS-88/2A analysis to be supplemented by adding ethanal, 2-propenal, pentenal, hexanal, heptanal, and butyl acetate to the load. These compounds were observed in the in-flight grab samples and contributed significantly to the overall *T*-value. Many of the supplemental compounds were observed during the first preflight element offgassing test conducted in late August through early September 1998. Generation rates for these supplementary compounds were derived from the results of that first test. The basic model was also expanded to account for the metabolic production of carbon monoxide, hydrogen, and methane. It has been assumed that, on average, 2.5 crewmembers are continually in the ISS during ingress operations.

Table 21. Basic trace contaminant generation rates.

Compound	Generation Rate (mg/hr)	
	Unity*	Metabolic
Methanol	0.0280	0.09
Ethanol	0.6270	0.44
2-propanol	0.5850	0.18
n-propanol	0.0973	0.06
2-methyl-2-propanol	0.0149	–
n-butanol	0.0777	0.05
Ethanal	0.0258	0.06
2-propenal	0.0049	–
Propanal	0.0197	0.04
2-methyl-2-propenal	0.0149	–
Butanal	0.0196	–
Pentanal	0.0062	0.002
Hexanal	0.0062	0.002
Heptanal	0.0062	0.002
Methylbenzene	0.0432	0.07
1,2- & 1,3-dimethylbenzenes	0.0391	0.012
1,4-dimethylbenzene	0.0149	0.006
Ethylbenzene	0.0149	0.06
Butyl acetate	0.0062	0.019
Dichloromethane	0.0822	–
Trichlorofluoromethane	0.0149	–
Trichlorotrifluoroethane	0.0496	–
2-propanone	0.1540	1.95
2-butanone	0.0778	0.94
Cyclohexanone	0.0259	–
Hexamethylcyclotrisiloxane	0.0149	–
Octamethylcyclotetrasiloxane	0.1060	–
Carbon monoxide	–	1.83
Hydrogen	–	4.4
Methane	–	9.75**

* Based upon preflight vehicle offgassing test results.
** Based upon 2.5 crewmembers. Methane rate assumes one-half crew are producers.

Further review of the STS-88/2A postflight toxicology reports indicated that the generation rate for methanol continued to decrease compared to the earlier offgassing test results. Comparison of the analytical results from the in-flight grab samples with concentrations predicted using the original vehicle offgassing data indicates that the methanol generation rate on board Unity decreased by approximately 90% from the end of the second offgassing test until STS-88/2A ingress. The basic rate in table 21 reflects this decrease. Additional in-flight sample analysis results from STS-96/2A.1 indicate that the methanol generation rate remained fairly steady between flights STS-88/2A and STS-96/2A.1. Based upon that observation, the basic methanol generation rate has been held steady throughout the analysis.

Additional evaluation of in-flight data also indicates that the basic rate for 2-propenal also has decayed significantly. This compound has a very low SMAC. Although more recent data indicate that it is below detectable limits, a residual generation rate of 0.0001 mg/hr is used in the analysis beyond STS-88/2A. Review of the postflight toxicology report for STS-101/2A.2a indicates that 2-propenal may be present at trace levels as a residual in the grab sample containers. Until this can be confirmed, it will be retained in the basic load.

Correlation of preflight predictions with the analytical results from the in-flight grab samples after STS-88/2A indicated that contamination carryover from the Shuttle and Zarya via the IMV contributes significantly to Unity's air quality. The IMV contribution to the contamination load is summarized in table 22. Based upon the observed concentrations from the Shuttle atmosphere determined from analysis of an in-flight sample collected during STS-88/2A, contaminant generation rates were established for the Shuttle/Unity IMV. According to the assessment of STS-88/2A, the Shuttle air quality during STS-88 was typical of in-flight mid-deck air quality when compared to the average of all archival samples collected during the Shuttle Program since STS-1. Similarly, assuming that a steady state had been established between Unity and Zarya upon egress, the samples collected during STS-96/2A.1 were used to determine the basic generation rates for Zarya's contribution to the contamination load introduced into Unity via IMV.

Table 22. IMV contributions to offgassing rate.

	Shuttle IMV (mg/hr)		FGB IMV (mg/hr)	
Compound	**Initial***	**Steady State****	**Initial*****	**Steady State†**
Methanol	15.1	–	210.9	–
Ethanol	168.2	–	1,094	75.6
2-propanol	269.1	213.6	18.9	22.2
n-propanol	–	–	–	–
2-methyl-2-propanol	4.2	–	–	–
n-butanol	4.2	–	51.4	14.8
Ethanal	13.5	–	18.1	–
2-propenal	1.7	–	0.8	–
Propanal	4.2	–	–	–
2-methyl-2-propenal	–	–	–	–
Butanal	4.2	–	–	–
Pentanal	4.2	–	–	–
Hexanal	4.2	–	6.4	–
Heptanal	4.2	–	–	–
Methylbenzene	4.2	–	30.2	–
1,2- & 1,3-dimethylbenzenes	4.2	–	107.4	13
1,4-dimethylbenzene	4.2	–	103.6	14.8
Ethylbenzene	4.2	–	23.4	4.6
Butyl acetate	4.2	–	18.1	–
Dichloromethane	11.8	3.4	5.7	9.3
Trichlorofluoromethane	4.2	–	–	–
Trichlorotrifluoroethane	4.2	–	–	–
2-propanone	23.5	–	41.6	18.5
2-butanone	4.2	–	–	–
Cyclohexanone	–	–	33.3	–
Hexamethylcyclotrisiloxane	158.1	143	310	–
Octamethylcyclotetrasiloxane	67.3	47.1	499	–
Carbon monoxide	92.5	–	–	–
Hydrogen	319.6	–	–	–
Methane	773.7	–	–	–

* Based on STS-88 post-ingress Shuttle mid-deck sample and IMV = 168.2 m^3/hr.

** Based upon gradient between Shuttle and Node with IMV = 168.2 m^3/hr.

*** Average FGB ingress sample and IMV = 151.2 m^3/hr.

† Based upon 2A.1 egress gradient and IMV = 151.2 m^3/hr.

Offgassing from stowage equipment must also be accounted for. During STS-88/2A, approximately 84 kg of equipment was left on board Unity while an additional 308.5 kg and 527 kg was left on board at the conclusion of STS-96/2A.1 and STS-101/2A.2a, respectively. Approximately 265.4 kg will be left on board Unity during STS-106/2A.2b. The offgassing rates for this equipment are summarized in table 23. They were obtained by multiplying Unity's basic generation rate derived from the ground-based offgassing test data divided by the ratio of stowage mass divided by the mass of internal hardware present during the offgassing test. During Unity's offgassing test, there were 2,854.39 kg of hardware present. It is assumed that the U.S.-provided stowage hardware left on board the ISS would offgas at similar rates per unit mass.

Table 23. Stowage hardware contributions to Unity's offgassing rate.

	Offgassing Rate From Stowage (mg/hr)			
Compound	2A	2A.1	2A.2a	2A.2b
Methanol	0.0008	0.003	0.0052	0.0026
Ethanol	0.0184	0.0678	0.1158	0.0583
2-propanol	0.0172	0.0632	0.108	0.0544
n-propanol	0.0029	0.0105	0.018	0.009
2-methyl-2-propanol	0.0004	0.0016	0.0028	0.0014
n-butanol	0.0023	0.0084	0.0143	0.0072
Ethanal	0.0008	0.0028	0.0048	0.0024
2-propenal	–	–	–	–
Propanal	0.0006	0.0021	0.0036	0.0018
2-methyl-2-propenal	0.0004	0.0016	0.0028	0.0014
Butanal	0.0006	0.0021	0.0036	0.0018
Pentanal	0.0002	0.0007	0.0011	0.0006
Hexanal	0.0002	0.0007	0.0011	0.0006
Heptanal	0.0002	0.0007	0.0011	0.0006
Methylbenzene	0.0013	0.0047	0.008	0.004
1,2- & 1,3-dimethylbenzenes	0.0012	0.0042	0.0072	0.0036
1,4-dimethylbenzene	0.0004	0.0016	0.0028	0.0014
Ethylbenzene	0.0004	0.0016	0.0028	0.0014
Butyl acetate	0.0002	0.0007	0.0011	0.0006
Dichloromethane	0.0024	0.0089	0.0152	0.0076
Trichlorofluoromethane	0.0004	0.0016	0.0028	0.0014
Trichlorotrifluoroethane	0.0014	0.0054	0.0092	0.0046
2-propanone	0.0045	0.0166	0.0284	0.0143
2-butanone	0.0023	0.0084	0.0144	0.0072
Cyclohexanone	0.0008	0.0028	0.0048	0.0024
Hexamethylcyclotrisiloxane	0.0004	0.0016	0.0028	0.0014
Octamethylcyclotetrasiloxane	0.0031	0.0114	0.0196	0.0099
Carbon monoxide	–	–	–	–
Hydrogen	–	–	–	–
Methane	–	–	–	–

Stowage mass increase = 84 kg at 2A, 308.5 kg at 2A.1, 527 kg at 2A.2a, and 265.4 kg at 2A.2b.

Because the offgassing rates are influenced by the stowage hardware, Unity's basic generation rates change with each mission. Similarly, various activities during ingress operations also contribute to variations in contaminant generation rates. Variations in generation rates as a function of time derived from combinations of rates listed in tables 21–23 are summarized in appendix C.

7.6.2 Relative Contamination of Unity Through Mission STS-101/2A.2a

After accounting for all of the known trace contaminant sources, the *T*-value for Unity is calculated as a function of time. The analysis considers Unity as the reference volume. A continuing validation of the TCC engineering and preflight prediction methodology is provided by comparing the results from the analysis of in-flight air quality samples to the engineering analysis predictions. During STS-88/2A, the *T*-value at ingress, excluding carbon dioxide, was reported to be 0.47. By comparison, the engineering analysis predicted a *T*-value of 0.65. This is well within the medical operations criteria for safe ingress. Similarly, the predicted *T*-values at ingress for STS-96/2A.1 and

STS-101-2A.2a were higher than reported from in-flight sample analysis results. The ingress *T*-value for STS-96/2A.1 was predicted to be 0.45 while that predicted for STS-101/2A.2a was 0.98. These predicted ingress *T*-values are substantially higher than the 0.17 reported from in-flight samples.

The timing of the in-flight samples relative to IMV flow initiation can have an effect on the air quality. This effect was first observed during STS-88/2A. As seen in figure 13, the effect of contaminant carryover from the Shuttle and Zarya during the first hour after initiating IMV flow results in contamination spikes in Unity. The CACEAs rapidly reduce the contamination level; however, the air quality measured from a sample collected during this transient can be affected. For example, the original analysis of Unity Node 1 predicted a much lower *T*-value of 0.19. Review of the in-flight operations timeline for STS-88/2A indicated that the ingress sample was collected more than 20 minutes after the IMV flow was initiated. The results from this sample demonstrated without doubt that the contamination spike induced upon initiating IMV flow must be accounted for in the Node 1 TCC analysis. Figure 13 shows the results after incorporating contaminant carryover from the Shuttle and Zarya into Unity via IMV. As can be seen, the initial air scrubbing reduces the *T*-value to approximately 0.05. Once IMV is established, a contamination spike is experienced, which increases the *T*-value to as high as 0.65. A similar magnitude spike is experienced when ventilation is initiated between Unity and Zarya. Once these effects were considered, the in-flight data from STS-88/2A showed that the trace contaminant generation rates predicted for Unity hardware and the performance of the CACEAs were as expected.

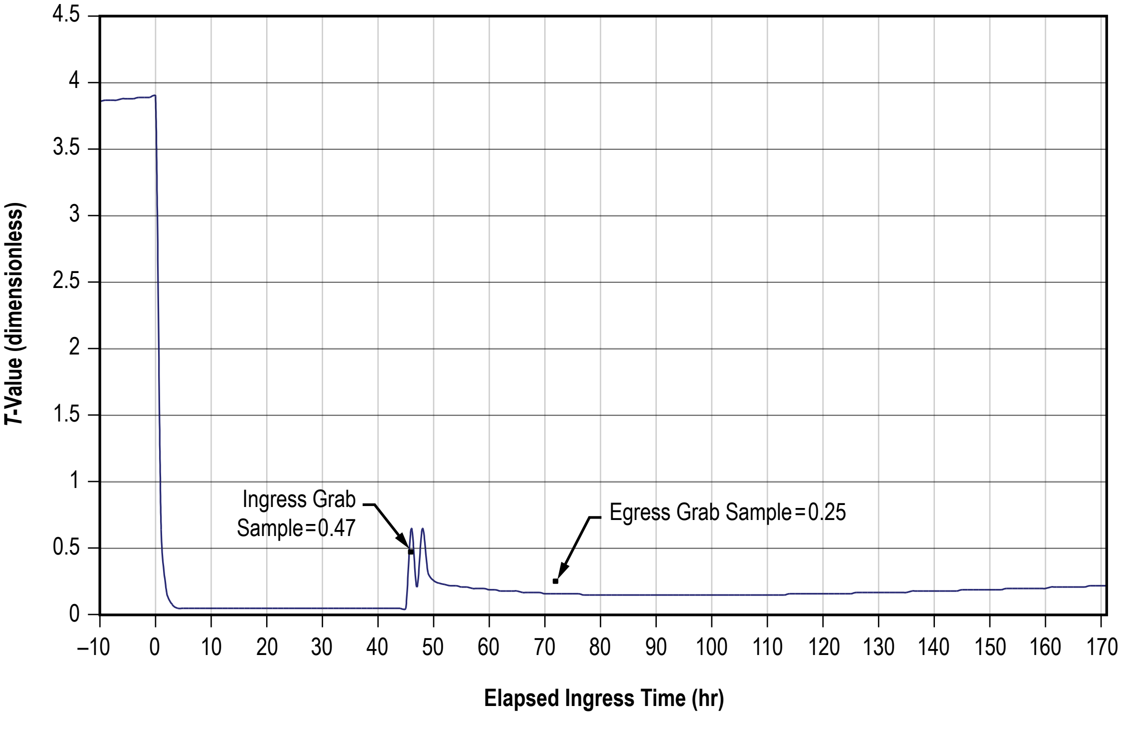

Figure 13. Relative contamination of Unity during mission STS-88/2A ingress.

Continuing the analysis from the conclusion of flight STS-88/2A up to cabin fan activation during flight STS-96/2A.1 shows that, assuming the contaminant generation rates remain constant, the *T*-value was expected to rise to approximately 3.3. As shown in figure 14, the CACEAs still provided adequate capability to reduce the *T*-value to a level within the range specified by flight rule X13.1.2-2 for safe ingress conditions. A normal scrub reduces the predicted *T*-value to approximately 0.45. By comparison, the in-flight grab sample analysis found a *T*-value of 0.17. Upon Shuttle IMV activation, the predicted *T*-value dips slightly and then spikes to 0.98 during IMV activation with Zarya. This dip followed by a spike results because the Shuttle cabin is cleaner than Unity's while contaminant levels in Zarya are higher than those in Unity. The net effect is a slight dilution followed by a generation rate spike. After the transient induced by the ingress, the predicted *T*-value slowly approaches 0.45 by the end of ingress operations. This compares favorably to the in-flight egress air quality samples which indicated a *T*-value of 0.34.

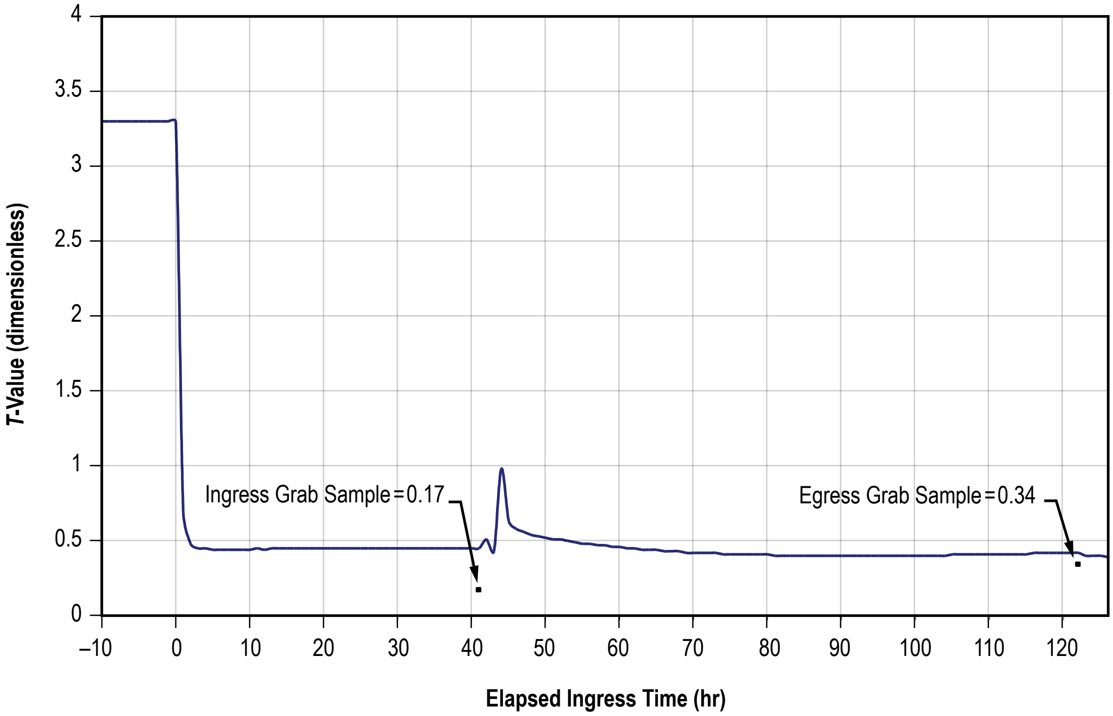

Figure 14. Relative contamination of Unity during mission STS-96/2A.1 ingress.

For flight STS-101/2A.2a, shown in figure 15, the *T*-value builds to approximately 8.4. This higher relative contamination is caused by the additional offgassing from stowage hardware combined with the more than 353 days between missions. After starting the cabin fan, the scrubbing provided by the CACEAs reduces the *T*-value to just over 1.1. A brief spike to a *T*-value of 1.4 accompanies IMV initiation with Zarya. This spike is preceded by a decrease to 0.98 as Unity's atmosphere is diluted by cleaner air from the Shuttle. As the Shuttle, Unity, and Zarya become well-mixed, the *T*-value slowly approaches a final level of 0.86 which is higher than the 0.61 observed from the in-flight grab sample collected at egress.

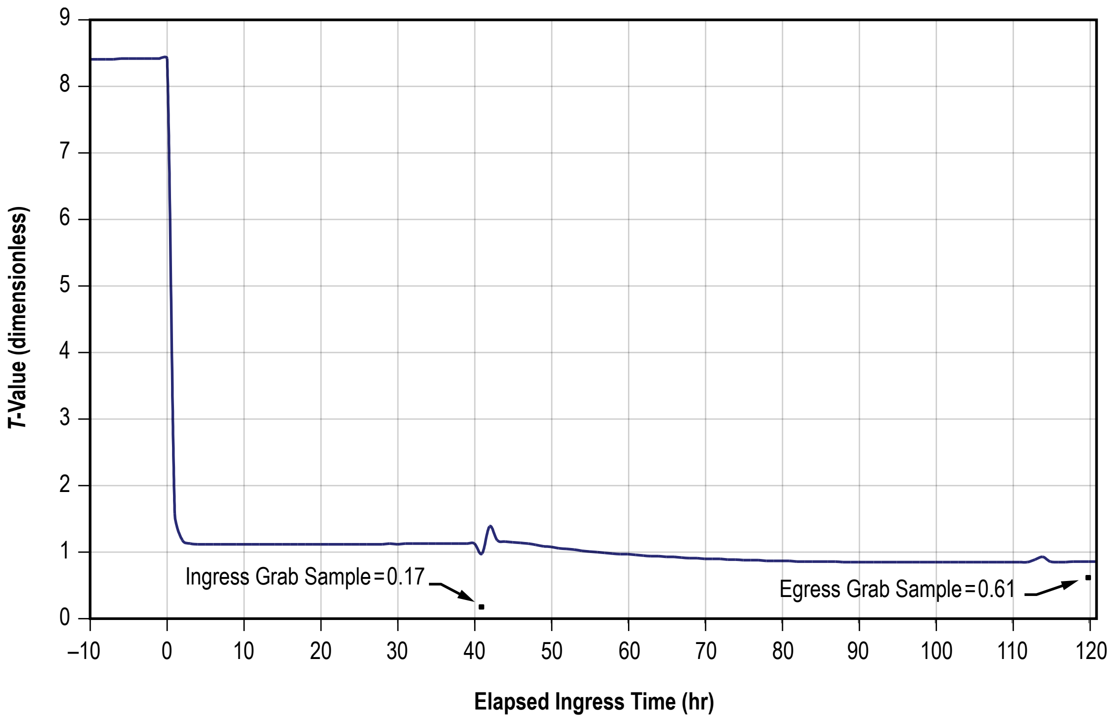

Figure 15. Relative contamination of Node 1 during flight 2A.2a ingress.

7.6.3 Predicted Relative Contamination During Missions STS-106/2A.2b and STS-92/3A

Predicted contamination levels within Unity for STS-106/2A.2b and STS-92/3A are shown graphically in figures 16 and 17. For STS-106/2A.2b, the *T*-value is predicted to rise to approximately 3.7 at which time Unity's cabin fan is started to provide the preingress scrub. The *T*-value is reduced to 0.44 within the first hour of scrubbing and ultimately stabilizes at 0.14. Ingress begins approximately 43 hours after the scrub begins. During ingress, contaminant carryover from the Shuttle into Unity is predicted to cause a transient contamination spike to a *T*-value of 0.52. Considering the contaminant carryover from the Shuttle and Zarya at steady state derived from previous flight experience to the ISS indicates that the *T*-value should stabilize at a magnitude of approximately 0.2 during the ingress period.

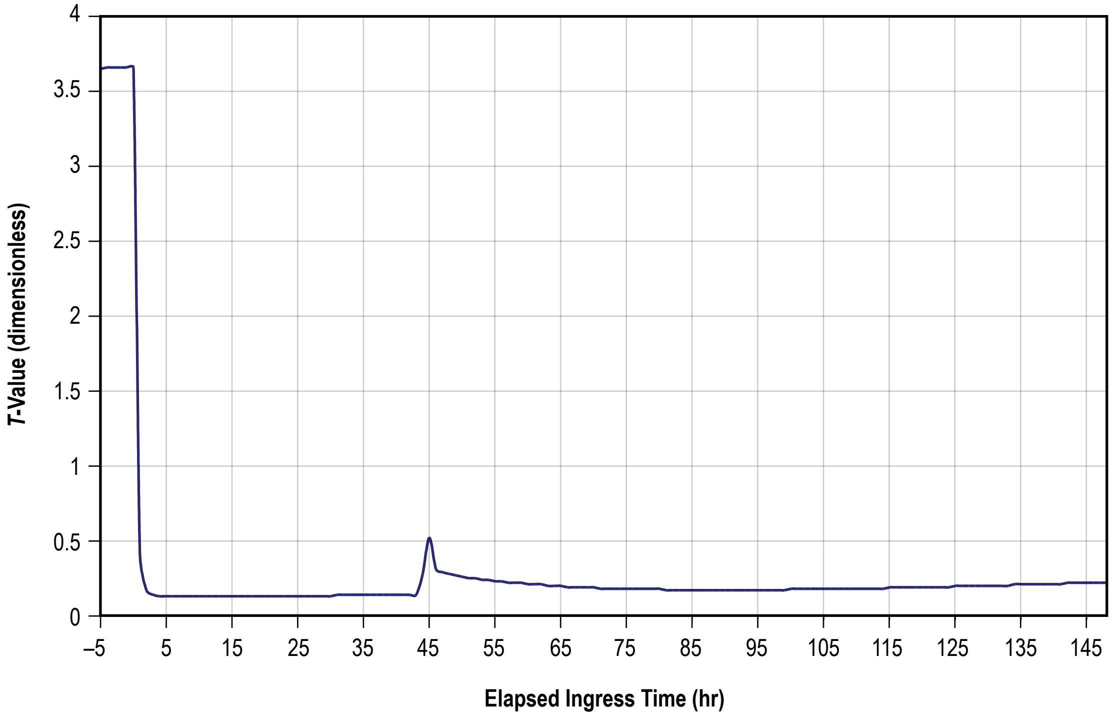

Figure 16. Predicted relative contamination of Unity during STS-106/2A.2b ingress.

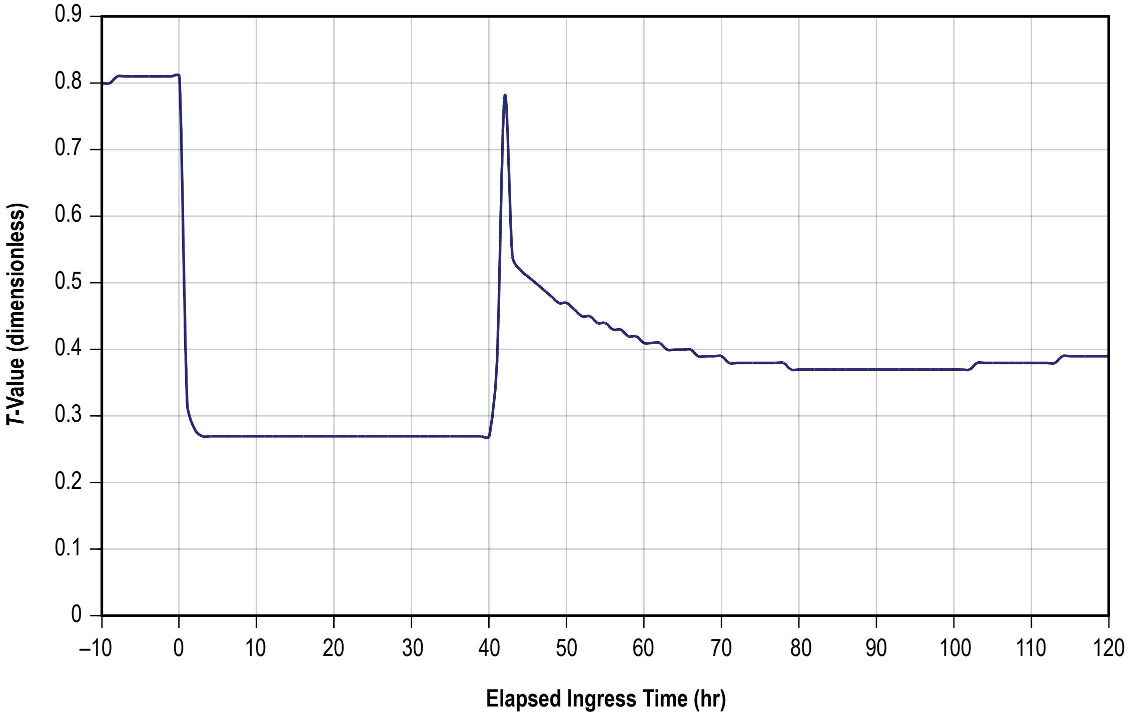

Figure 17. Predicted relative contamination of Unity during STS-92/3A ingress.

According to the predicted concentrations, the major contributors to the *T*-value at the time of scrub start during STS-106/2A.2b are expected to be methanol (0.24 *T*-value units), 2-propanol (0.3 *T*-value units), 2-methyl-2-propanol (0.71 *T*-value units), ethanal (0.5 *T*-value units), dichloromethane (0.64 *T*-value units), 2-propanone (0.23 *T*-value units), and 2-butanone (0.2 *T*-value units). These compounds comprise nearly 77% of the total predicted *T*-value. After scrubbing and dilution via mixing, methanol and ethanal account for nearly 86% of the total *T*-value by contributing 0.07 and 0.05 *T*-value units, respectively. No SMACs are expected to be exceeded during the course of STS-106/2A.2b.

A very short period of time elapses between the STS-106/2A.2b egress and STS-92/3A ingress. As seen in figure 17, this short time between missions keeps the *T*-value at the beginning of the scrub much lower than has been the case. Since the predicted starting *T*-value magnitude of 0.81 is much lower than 1, even if the scrub fails, the crew may enter Unity with no special actions according to flight rule X13-1.2-2 provided in appendix A. For a normal ingress, it is prudent to conduct the scrub, however. In this case, the predicted *T*-value is reduced to 0.27 before the crew enters Unity. During the early stages of ingress, contaminant carryover from the Shuttle and Zarya results in a contamination spike to a *T*-value of 0.78. After the ingress spike, the onboard scrubbing capacity reduces the *T*-value to approximately 0.38.

The compounds predicted to contribute most heavily to the *T*-value at STS-92/3A ingress scrub start are methanol (0.05 *T*-value units), 2-propanol (0.05 *T*-value units), 2-methyl-2-propanol (0.11 *T*-value units), ethanal (0.14 *T*-value units), dichloromethane (0.2 *T*-value units, acetone (0.04 *T*-value units), 2-butanone (0.03 *T*-value units), and hydrogen (0.09 *T*-value units. Together they contribute nearly 77% of the predicted *T*-value. Hydrogen is also predicted to contribute significantly to the *T*-value. However, it is well below its lower explosive limit. After mixing between the Shuttle and ISS volumes combined with continuous scrubbing, methanol (0.02 *T*-value units), ethanal (0.09 *T*-value units), and dichloromethane (0.19 *T*-value units) account for nearly 79% of the predicted egress *T*-value. As with STS-106/2A.2b, there are no predicted instances of any compound exceeding its SMAC.

7.6.4 Effects of Inlet On-Orbit Replaceable Unit Fan Speed on Scrub Duration

To conserve power resources, it is likely that the cabin fan on board Unity may be operated at a reduced speed of 3,900 rpm. For past missions, the fan speed has been 4,000 rpm and higher. Flows through the CACEAs observed for various fan speeds during missions through STS-101/2A.2a were obtained from the flight cabin fan performance curve. As can be seen in figure 18, operating the cabin fan over the range of 3,900 to 5,100 rpm causes very little change in scrubbing duration. Therefore, the cabin fan can be operated at reduced speed without adversely impacting the ingress timeline.

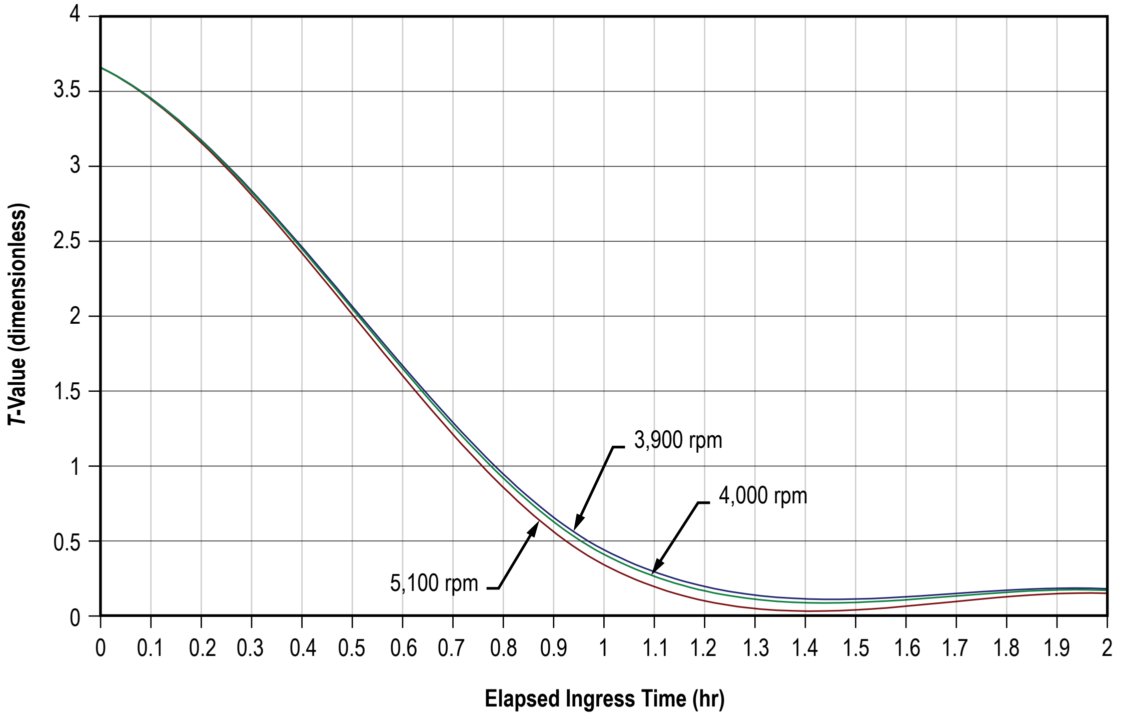

Figure 18. Scrub duration for varying inlet ORU fan speeds.

7.6.5 Accuracy of Contamination Predictions

The ability to accurately predict trace contaminant concentrations, and therefore *T*-values, over a long period of time is a significant challenge. Typically, as time passes, one would expect the predictions to become increasingly conservative because of the assumption used in the analysis that generation rate is constant with time. Studies have demonstrated that offgassing rates do not remain constant with time. In fact, offgassing rates from more than 60% of materials used on board spacecraft tend to decay over time. The comparison of the predicted and actual measured *T*-values for STS-88/2A, STS-96/2A.1, and STS-101/ 2A.2a shows that the engineering analysis had a positive deviation of 0.045, 0.205, and 0.53 *T*-value units 72.6, 228.9, and 588 days, respectively, after Unity closeout on the ground. This indicates that the magnitude by which the engineering analysis may overpredict *T*-value is 0.000934 *T*-value units/day. The rate of increase in positive deviation of the predicted *T*-value compared to that measured from in-flight grab samples indicates a strong linear correlation (correlation coefficient, *r*, of 0.9996). At the time of STS-106/2A.2b, it is likely that the engineering analysis may have a positive deviation of up to 0.45 *T*-value units. This is an important observation as it demonstrates that the engineering analysis technique's conservatism continues to increase over time. This is an indicator that onboard generation rates are decaying significantly as a function of time.

7.6.6 Relative Contamination During Zarya Ingress

Previous analysis of the relative contamination in Zarya during STS-106/2A.2b still applies because the onboard FVP unit has a fresh adsorbent canister and the elapsed time between STS-101/ 2A.2a and STS-106/2A.2b is less than the previously assumed 4 months. As such, the ingress scenario depicted in figure 19 is conservative and can also be applied to STS0-92/3A. With the short elapsed time between STS-106/2A.2b and STS-92/3A, it would be anticipated that the *T*-value within Zarya would be 1 or lower.

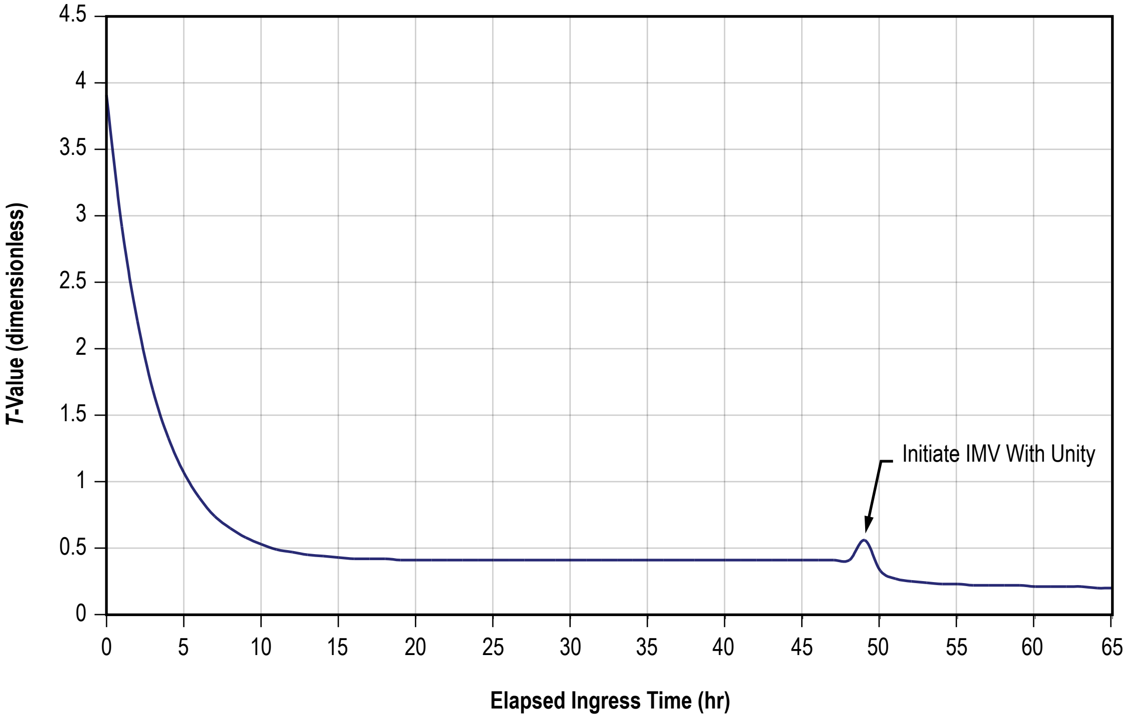

Figure 19. Typical relative contamination of Zarya during STS-106/2A.2b ingress.

Recent reports of a strong glue-like odor in the vicinity of Zarya's transfer compartment or hermetic compartment, known as the GA, prompted a review of the vehicle configuration between flights. This review shows that in practice, the GA and PMA-1 are not scrubbed before ingress. Assuming that the *T*-value may climb at a similar rate (0.0286 *T*-value units/day) in the GA and PMA-1 as in Zarya's instrument cargo compartment, known as the PGO, it is quite possible that a *T*-value of approximately 3.6 is possible in the GA at the time the crew enters it during STS-106/2A.2b. This is clearly a case where flight rule X13.1.2-2 is not strictly followed because the crew briefly enters an unscrubbed volume.

Zarya's GA is approximately 6.5 m^3 while the PMA-1 is approximately 5.7 m^3. Compared to the combined Shuttle, Unity, and Zarya volume of 208 m^3, the GA and PMA-1 make up only 6% of the total stack volume. Once the crew passes through this volume into Zarya's PGO and sets up ventilation, the *T*-value in the GA and PMA-1 will be reduced to as low as 0.83 within 1 hour.

7.6.7 Relative Contamination During Zvezda Ingress

Evaluation of offgassing data obtained from Zvezda by the Russian State Institute of Medico-Biological Problems (IMBP) shows that relative contamination increases by 0.002083 *T*-value units/day (fig. 20). Individual contaminants are generated at the rates listed in table 24. After approximately 90 days, the *T*-value magnitude is predicted to rise to just over 4. With an added 20 days, the predicted *T*-value may be as high as 4.4. This prediction includes an adjustment which adds methanol generation at a magnitude similar to that originally observed for Unity. This adjustment has been made to account for known analytical limitations for the IMBP analytical method for polar organic compounds and methanol in particular.[12] Approximately 48 hours before the crew enters Zvezda, the onboard TCC system, known by its Russian acronym BMP, will be started. Modeling the BMP based upon known performance documented by reference 13, it is predicted that the *T*-value magnitude will be reduced to less than 1 within 6 hours after starting the scrub and less than 0.1 within 15 hours.

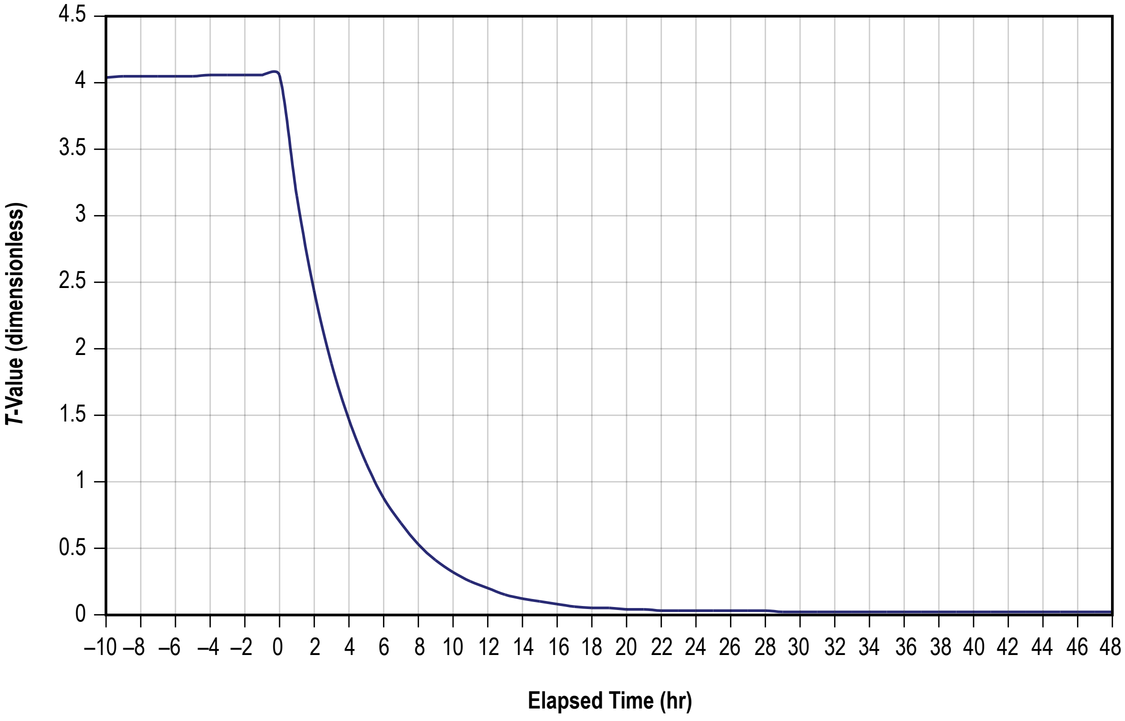

Figure 20. Relative contamination during preingress scrub of Zvezda.

Table 24. Offgassing rates derived from Zvezda's ground test.

Compound	Rate (mg/hr)
Methanol	0.208*
Ethanol	3.1
2-propanol	0.0039
Ethanal	0.15
Benzene	0.0009
Methylbenzene	0.16
Styrene	0.0059
1,3,5-trimethylbenzene	0.0113
Ethyl acetate	4.7
Butyl acetate	0.083
Dichloromethane	0.0054
Chloroethane	0.0047
Trichloromethane	0.005
1,2-dichloroethane	0.0072
Chlorobenzene	0.0016
Heptane	0.112
Octane	0.0034
Nonane	0.0155
2-propanone	0.506
2-butanone	0.908

* Estimated for analysis purposes.

Zvezda presents a situation similar to that of Zarya in that its spherically-shaped transfer compartment, the PxO, is not scrubbed before ingress. Like Zarya's GA, the PxO is approximately 6.5 m^3. By establishing ventilation, a T-value of magnitude 4 to 4.5 can be reduced to under 1 by dilution alone. The onboard scrubbing further enhances the rate at which the PxO is scrubbed. Further evaluation of Zvezda's offgassing data indicate that no contaminant would exceed its individual SMAC. It is likely, however, that ethanal, 2-butanone, and ethyl acetate will be above the low end of their individual odor threshold ranges. Therefore, the crew should expect a composite, solvent-like odor in Zvezda's PxO.

7.6.8 Capability to Maintain Concentrations Below Spacecraft Maximum Allowable Concentrations

As can be observed by the preceding discussion, the T-value magnitude during normal ingress operations is maintained below 1 for all assembly and logistics flights through STS-92/3A. As well, the predicted individual contaminant concentrations for STS-106/2A.2b and STS-92/3A are below individual SMACs. Further evidence of this is provided by the concentration summary in appendix D. The only threat to the accuracy of these predictions is the fact that PMA-1, Zarya's GA, and Zvezda's PxO are not scrubbed before crew ingress and the T-value magnitude is predicted to be above 3 in these volumes. Individual contaminant concentrations for compounds such as ethanal, 2-butanone, dimethylbenzenes, and butyl and ethyl acetates are anticipated to contribute to a solvent or glue-like odor in these volumes during the initial stages of ingress. Fortunately, the volumes involved are small compared to the total vehicle volume and adequate scrubbing capacity exists to rapidly reduce concentrations to levels to well below their individual SMACs and odor thresholds.

7.6.9 Contingency Ingress During STS-106/2A.2b and STS-92/3A

Previous analysis for assembly missions 2A and 2A.1 has established that Shuttle-provided resources are sufficient to reduce a *T*-value of 6 within Unity to less than 1 within the allowable time recommended by toxicology experts. The predicted *T*-values at scrub start are well below 6; therefore, the Shuttle-provided scrubbing resources are more than adequate to allow for a contingency ingress during both STS-106/2A.2b and STS-92/3A.

7.7 Predicted Offgassing Load Versus Russian BMP Capability

A continuing concern and interest to the Russian side is the combined trace contaminant load which may be present at the time the crew enters Zvezda during STS-106/2A.2b and beyond. This concern exists because the BMP has been designed to remove compounds representative of various functional classes at specified rates. During STS-106/2A.2b, the crew will enter Zvezda and contaminants from Unity, Zarya, and the Shuttle will be introduced into it via the IMV flow. To address this concern, the total estimated offgassing rate from Unity and Zarya have been compared to the 'as designed' BMP contaminant removal capability.[11] Table 25 summarizes this comparison.

Table 25. BMP contaminant removal capability versus estimated generation rates.

Compound	Russian BMP Rate (mg/day)	Unity With* Stowage (mg/day)	Zarya With** Stowage (mg/day)	Estimated*** Zvezda (mg/day)
Methanol	3	0.95	2.2	0.78
Ethanol	250	21	89.3	80.3
2-propanol	–	20	29.2	2.5
n-butanol	80	2.6	23	2.9
Ethylene glycol	50	–	–	–
Methanal	10	–	–	–
Ethanal	24	0.88	0.19	3.8
2-propenal	–	0.002	0.006	0.02
Benzene	0.45	–	0.044	0.035
Methylbenzene	66	1.5	3.4	5.1
Dimethylbenzenes	–	1.8	33	2.2
Isopropyl benzene	50	–	0.02	0.009
Ethyl acetate	250	–	0.42	112.5
Dichloromethane	–	2.8	12.3	1.4
2-propanone	27	5.2	23.6	14.3
2-butanone	–	2.6	8.5	25.5
Carbon monoxide	390	–	3.5	1.2
Ammonia	20	–	–	–
Polymethylcyclosiloxanes	–	4.1	0.58	0.23

* Includes stowage through STS-106/2A.2b.

** Basic FGB rates derived from observed in-flight concentration gradients plus estimated stowage offgassing rates.

*** Derived from ground offgassing test data plus estimated stowage offgassing rates.

The second column in table 25 summarizes the BMP's capability while the remaining columns provide corresponding estimated offgassing rates for Unity, Zarya, and Zvezda, including stowage hardware. It should be noted that hardware to be transferred from the recently launched Progress vehicle is not included in this estimate.

As can be seen, the total sum of columns three through five show the BMP capability will not be exceeded except for 2-propanone. Although the BMP has no specific design requirement for 2-propanol, 2-propenal, dimethylbenzenes, dichloromethane, 2-butanone, and polymethylcyclosiloxanes, it is anticipated that its rated capacity for similar compounds is indicative of how well it can remove them from the air. For instance, the BMP has the capability to remove 250 mg/day of ethanol and 80 mg/day of n-butanol. Based upon the similarity of its physical properties to ethanol and n-butanol, it would follow that its capacity for 2-propanol would fall between 80 and 250 mg/day. The estimated generation rate for 2-propanol is well below this range. By applying similar logic to the other compounds, it can be concluded that the BMP's capacity will not be exceeded at any time during the STS-106/2A.2a and STS-92/3A ingress. Continued in-flight monitoring will be necessary to ensure that 2-propanone and other similar contaminant generation rates do not become excessive. As well, it will be necessary to continue efforts to characterize offgassing from each ISS element before launch.

7.8 Summary

According to results of analyses of in-flight air quality grab samples combined with knowledge gained from ground-based element offgassing tests, the overall trace contaminant load during STS-106/2A.2b and STS-92/3A is expected to be within the capabilities of the onboard contamination control systems. These onboard systems are predicted to maintain individual contaminant concentrations below their respective SMAC as well as maintaining the *T*-value within medical operations guidelines with margin. Performance for the systems on board Unity will not be affected significantly by operating its cabin fan in the range of 3,900 to 5,100 rpm.

Further assessment of the on-orbit vehicle configuration shows that transfer compartments for both Zarya and Zvezda as well as PMA-1 will not be scrubbed before the crew enters. Analysis of this situation indicates that a *T*-value magnitude greater than 3 can be expected in these volumes. While greater than 3 at the beginning, the *T*-value can be reduced to less than 1 within 6 hours, thus meeting medical operations guidelines for allowable scrubbing duration. Because these volumes will not be scrubbed before ingress, it is anticipated that solvent- or glue-like odors may be present initially. The intensity of these odors should decrease as the ingress progresses and the concentrations of the individual compounds contributing to the odors become diluted.

7.9 Conclusions

Based upon the ISS TCC capability assessment results, conclusions that can be made are the following:

- The CACEAs installed in Unity will meet the requirements of the Node 1 PIDS for all compounds for missions STS-106/2A.2b and STS-92/3A.

- The CACEAs have sufficient capacity to be used through the ingress period of STS-101/ 2A.2 even if the mission slips to January 2000 or beyond.

- Operating Unity's cabin fan in the range of 3,900 to 5,100 rpm has little effect on preingress scrub duration and effectiveness.

- The FVP and BMP installed on board Zarya and Zvezda, respectively, have sufficient capability to maintain trace chemical contaminants to within acceptable levels.

- Solvent- or glue-like odors are expected in the transfer compartments of both Zarya and Zvezda.

- The total ISS on-orbit hardware offgassing rates do not exceed the BMP capability with the exception of 2-propanone.

7.10 Recommendations

Recommendations for addressing continuing ISS TCC issues during ingress operations are the following:

- Continue collecting in-flight samples on board ISS using both U.S. and Russian air sampling devices to allow for continual TCC verification.

- Operate Unity's cabin fan at the appropriate speed between 3,900 and 5,100 rpm to obtain necessary energy savings.

- Provide one Shuttle-provided charcoal canister for STS-106/2A.2b and STS-92/3A to support contingency ingress operations.

- Continue to conduct ground-based element offgassing tests to ensure that the on-orbit contamination control capacity is not exceeded.

8. MISSION 2R TRACE CONTAINMENT CONTROL CAPABILITY ASSESSMENT

This assessment was originally released under NASA Memorandum FD21(01-006) dated October 20, 2000.

8.1 Background

Under the continuing effort to track the ISS TCC capability and assess its effectiveness at each successive assembly stage, an engineering analysis has been conducted for ingress and steady state scenarios for mission 2R. This analysis builds upon that conducted for missions STS-106/2A.2b and STS-92/3A. In addition, the analysis takes into account preliminary results from the ground-based analysis of air quality samples collected during STS-106/2A.2b to better understand its inherent conservatism.

8.2 Purpose

The engineering analysis summarized by the following discussion serves to verify the ISS's TCC capability for mission 2R. The Zvezda SM's generation rates, which were derived from ground-based offgassing test data, are compared to preliminary air quality sample analysis results from mission STS-106/2A.2b to evaluate conservatism.

8.3 Objectives

The adequacy of the trace contaminant removal capability presently on board the ISS during mission 2R is assessed by engineering analysis. Specific objectives of the analysis which serve to verify this capability are the following:

- Determine the trace contaminant load for each on-orbit ISS element based upon both preflight offgassing test, stowage hardware mass, and in-flight air quality data.

- Determine the trace contaminant concentrations during ingress operations as well as the predicted steady state concentrations.

- Determine the adequacy of the onboard TCC resources for meeting the relevant ISS program requirements, flight rules, and medical operations guidelines.

8.4 Assumptions

To conduct the mission 2R TCC capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

8.4 1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the mission 2R engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results and revised according to results reported from ground-based analyses of in-flight air quality samples.

- Additional offgassing from stowage hardware is estimated using design specification rates.

- ISS atmospheric leakage is zero. This is considered to be true for the early stages of the ISS's on-orbit life.

- Cabin atmospheric conditions are on average 20 °C, 50% relative humidity, and 101.3 kPa.

- Offgassing rates are constant with time. This has been shown by analyses conducted to date to be conservative as rates tend to decay with time.

- Seven-day SMACs apply for the ingress analysis scenario according to flight rule 3A_13B-1 while 180-day SMACs apply to the steady state analysis.

8.4.2 On-Orbit Configuration

During 2R, the ISS's on-orbit configuration consists of PMA-1, PMA-2, PMA-3, Unity (Node 1), Zarya, Zvezda, a Soyuz spacecraft, and a Progress vehicle. Effectively, the crew will inhabit only the volume represented by Zarya, Zvezda, Soyuz, and Progress. During normal operations, the other pressurized elements will remain isolated unless special circumstances require the crew to enter them. Assumptions pertaining to the ISS's configuration and its contamination control capability are the following:

- Cabin free volumes of Unity, PMA-1, PMA-2, PMA-3, Zarya, Zvezda, Soyuz, and Progress are 55.2, 5.7, 5.2, 5.2, 61, 87, 10.5, and 7.4 m^3, respectively.

- Contamination control is provided by the hazardous contaminant filter (FVP) on board Zarya and the BMP on board Zvezda. Each contamination control device provides 20 m^3/hr of air flow. They are described in detail by references 10 and 12.

8.4.3 Mission Timeline

The mission timeline used for the ingress analysis builds upon that used for the STS-106/2A.2b. Approximately 46 days elapse between Zvezda egress at the end of STS-106/2A.2b and ingress during 2R. The 2R crew should arrive at the ISS on approximately November 2, 2000, with an on-time launch on October 30. The steady state analysis uses a total elapsed time of 20 days which is a normal BMP regeneration cycle.

8.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for mission 2R. The discussion includes a summary on trace contaminant generation rate derivation, the analytical tool, and cases considered for the assessment.

8.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of offgassing test grab samples collected from Unity, Zarya, and Zvezda as well as considering in-flight sample analysis results. As additional hardware has been left on board the ISS, the offgassing contribution of that hardware has been estimated based upon ground-based offgassing test data and design generation rate data contained in ISS program documentation.

8.5.2 Trace Contaminant Control Simulation Computer Program

The TCCS-CP, version 8.1, was used to conduct the analysis.[7,8] This analytical tool calculates the cabin concentration of individual trace chemical contaminants when generated at a specified rate and controlled by any combination of removal devices. The TCCS-CP, version 8.1, has previously been assessed for its applicability for use in spacecraft TCC system verification analyses and was found to be acceptable.[9]

8.5.3 Analysis Cases Considered

Two analysis cases have been considered. The first is the 2R crew ingress of Zvezda while the second is a steady state trace contaminant concentration prediction with Zvezda's BMP controlling the offgassing load and the metabolic load from the three crewmembers.

8.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the three analysis cases.

8.6.1 Derived Generation Rates

Generation rates for the crew, ISS elements, and the total estimated 2R load are summarized in table 26. The metabolic rates for three crewmembers are obtained from reference 2 rather than from specification load listings. The reference 2 metabolic load is considered more complete and represents a greater challenge to the onboard contamination control systems. Rates for equipment offgassing for Unity, Zarya, and Zvezda were derived from test data listed in appendix B using equation (3). Although the normal on-orbit configuration has Unity isolated from the rest of the ISS, the total load at 2R includes the contribution from all elements for conservatism. It is possible that the entire cabin may be accessible to the crew once they arrive and it is necessary to demonstrate by analysis that the BMP can handle the entire load.

Table 26. Trace contaminant generation rates at 2R.

	Generation Rate (mg/hr)					
Compound	**Crew**	**Unity + PMA-1**	**Zarya**	**Zvezda**	**Progress + Soyuz**	**Total**
Methanol	0.05	0.0396	0.084	0.208	0.0416	0.4232
Ethanol	0.27	0.8873	4.96	3.1	0.62	9.8373
2-propanol	0.13	0.8276	0.645	0.0039	0.00078	1.6073
n-propanol	0.05	0.1377	–	–	–	0.1877
2-methyl-2-propanol	–	0.0211	–	–	–	0.0211
n-butanol	0.05	0.1099	1.27	–	–	1.4299
Ethanal	0.04	0.0366	0.026	0.15	0.03	0.2826
2-propenal	–	0.0001	–	–	–	0.0001
Propanal	0.02	0.0278	–	–	–	0.0478
2-methyl-2-propenal	–	0.0211	–	–	–	0.0211
Butanal	–	0.2095	–	–	–	0.2095
Pentanal	0.002	0.0079	–	–	–	0.0099
Hexanal	0.002	0.0079	–	–	–	0.0099
Heptanal	0.002	0.0079	–	–	–	0.0099
Methylbenzene	0.06	0.0612	0.073	0.16	0.032	0.3862
1,2- & 1,3-dimethylbenzenes	0.008	0.0553	1.13	–	–	1.1933
1,4-dimethylbenzene	0.004	0.0211	0.455	–	–	0.4801
Ethylbenzene	0.05	0.0211	0.091	–	–	0.1621
Butyl acetate	0.02	0.0079	0.006	0.083	0.0166	0.1335
Dichloromethane	–	0.1163	0.112	0.0054	0.0011	0.2348
Trichlorofluoromethane	–	0.0211	–	–	–	0.0211
Trichlorotrifluoroethane	–	0.0702	–	–	–	0.0702
2-propanone	1.2	0.2178	0.546	0.506	0.1012	2.571
2-butanone	1.1	0.1101	0.158	0.908	0.1816	2.4577
Cyclohexanone	–	0.0367	0.035	–	–	0.0717
Hexamethylcyclotrisiloxane	–	0.0211	0.017	–	–	0.0381
Octamethylcyclotetrasiloxane	–	0.15	0.106	–	–	0.256
Carbon monoxide	2.2	–	–	–	–	2.2
Hydrogen	3.9	–	–	–	–	3.9
Methane	15	–	–	–	–	15
Benzene	0.15	–	–	0.0009	0.0002	0.1511
Styrene	–	–	–	0.0059	0.0012	0.0071
1,3,5-trimethylbenzene	–	–	–	0.0113	0.0023	0.136
Ethyl acetate	0.05	–	–	4.7	0.94	5.69
Choroethane	–	–	–	0.0047	0.0009	0.0056
Trichloromethane	–	–	–	0.005	0.001	0.006
1,2-dichloroethane	–	–	–	0.0072	0.0014	0.0086
Chlorobenzene	–	–	–	0.0016	0.00032	0.0048
Heptane	0.01	–	–	0.112	0.0224	0.1444
Octane	0.01	–	–	0.0034	0.00068	0.01408
Nonane	0.0065	–	–	0.0155	0.0031	0.0251

8.6.2 Normal 2R Ingress

According to figure 21, from the time of STS-106/2A.2b egress until the BMP is started for a normal preingress scrub at 2R, the *T*-value rises to approximately 2.1. This is below the 3 limit specified by flight rule 3A_13B-1 provided in appendix A and, in the case of a contingency, the crew may enter without the scrub. All predicted concentrations are below individual SMACs; a detailed listing of predicted concentrations for 2R are provided in table 27. As seen in figure 21, a normal scrub by the BMP reduces the *T*-value to less than 1 within 4 hours and to less than 0.1 within 18 hours. Due to the short elapsed time between STS-92/3A and 2R, the FGB ingress situation remains within the bounds of the analysis of Zarya first entry.

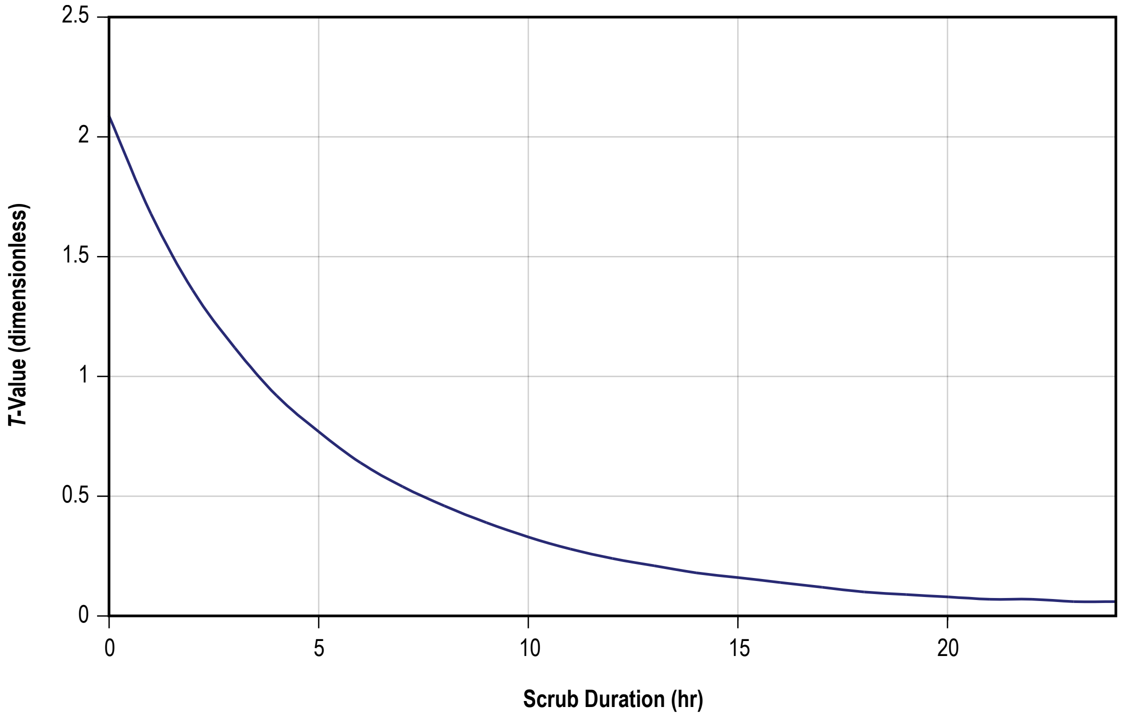

Figure 21. Predicted relative contamination on board Zvezda during 2R ingress.

Table 27. Predicted steady state concentrations compared to air quality standards.

	Standard (mg/m^3)		Concentration (mg/m^3)		
Compound	NASA	Russia	Prescrub	Postscrub	Steady State
Methanol	9	0.2	3.2	0.21	0.072
Ethanol	2,000	10	44.6	1.3	0.49
2-propanol	150	1.5	0.06	0.0005	0.08
n-propanol	98	0.6	–	–	0.009
2-methyl-2-propanol	120	0.1	–	–	0.001
n-butanol	40	0.8	–	–	0.072
Ethanal	4	1	2.2	0.096	0.015
2-propenal	0.03	–	–	–	0.000005
Propanal	95	–	–	–	0.002
2-methyl-2-propenal	1.7	–	–	–	0.001
Butanal	120	–	–	–	0.01
Pentanal	110	–	–	–	0.0005
Hexanal	4.9	–	–	–	0.0005
Heptanal	5.6	–	–	–	0.0005
Methylbenzene	60	8	2.3	0.014	0.019
1,2- & 1,3-dimethylbenzenes	220	5	–	–	0.06
1,4-dimethylbenzene	220	5	–	–	0.024
Ethylbenzene	130	–	–	–	0.008
Butyl acetate	190	2	1.2	0.007	0.007
Dichloromethane	10	–	0.08	0.001	0.012
Trichlorofluoromethane	560	–	–	–	0.001
Trichlorotrifluoroethane	400	–	–	–	0.0035
2-propanone	50	2	7.3	0.084	0.13
2-butanone	30	0.25	13.1	0.095	0.12
Cyclohexanone	60	1.3	–	–	0.0036
Hexamethylcyclotrisiloxane	230	–	–	–	0.0019
Octamethylcyclotetrasiloxane	281	–	–	–	0.013
Carbon Monoxide	10	5	–	–	0.12
Hydrogen	340	3,342	–	–	11.3
Methane	3,800	0.2	–	–	43.4
Benzene	0.2	–	0.013	0.0001	0.0076
Styrene	43	–	–	–	0.0004
1,3,5-trimethylbenzene	15	4	0.16	0.0009	0.007
Ethyl acetate	180	–	67.3	0.52	0.28
Choroethane	260	–	0.07	0.0008	0.0003
Trichloromethane	4.9	0.5	0.07	0.0006	0.0003
1,2-dichloroethane	1	1.5	0.1	0.0008	0.0004
Chlorobenzene	46	10	0.023	0.0002	0.0002
Heptane	200	10	1.6	0.0094	0.0072
Octane	350	–	0.05	0.0003	0.0007
Nonane	320		0.22	0.0001	0.0013

8.6.3 Contingency 2R Ingress

Because the predicted *T*-value for Zvezda at the beginning of the preingress scrub for 2R is less than 3, the crew will be able to enter the Station even in the event that the BMP fails to operate. Zarya will have been scrubbed during STS-92/3A and a fresh FVP filter installed. Since only about 21 days elapse between STS-92/3A egress and 2R ingress, the *T*-value in Zarya is predicted to be approximately 0.8. By establishing ventilation flow between Zvezda and Zarya, the crew can effectively reduce the combined cabin *T*-value to approximately 1.6 via dilution. The FVP will have sufficient capability to accommodate the initial offgassing load and the metabolic load for 280 man-days. The metabolic load is understood to be based upon ammonia generation. This would provide approximately 90 days of active control in the event the BMP fails to operate properly.

8.6.4 Steady State Capability

A steady state analysis of the BMP's capability shows that all chemical contaminants comprising the combined offgassing and crew metabolic loads can be maintained below their individual NASA 180-day SMAC. Table 27 compares the predicted steady state concentrations to the NASA 180-day SMAC and the Russian 360-day LPC. As can be seen, the only compound that may present difficulty in controlling its concentration to less than the Russian LPC is methanol. It is anticipated that this situation will improve as the Station hardware ages. For example, the methanol generation rate observed during Unity's ground-based offgassing test decayed by approximately 90% by the time the first crew entered it on orbit during STS-88/2A. A similar trend for Zvezda and other Station hardware is expected.

8.6.5 Analysis Conservatism

The ability to accurately predict trace contaminant concentrations, and therefore *T*-values, over a long period of time is a significant challenge. Typically, as time passes, one would expect the predictions to become increasingly conservative because of the assumption used in the analysis that generation rate is constant with time. Based upon previous analyses, a positive deviation in the magnitude of the predicted *T*-value with respect to that reported from analyses of in-flight grab samples indicated an increase in the size of the deviation at a rate of 0.000934 *T*-value units/day. Upon Zvezda ingress during STS-106/2A.2b, as shown in figure 22, the predicted *T*-value of 0.37 exceeds the predicted *T*-value of 0.295 by 0.075 units. This ingress was approximately 93 days after Zvezda's ground-based offgassing test was conducted. Applying the rate of deviation increase, the predicted *T*-value should be approximately 0.087 higher than the measured *T*-value. This would yield a prediction of 0.38 which is very close to the predicted 0.37 and indicates that the deviation growth rate observed for ISS hardware offgassing continues to hold. Extending the analysis to 2R, it is anticipated that the predicted *T*-value may be conservative by approximately 0.14 *T*-value units. Therefore, by using the rates directly from the ground-based offgassing tests for all elements, a conservative estimate for the Station's atmospheric quality is provided.

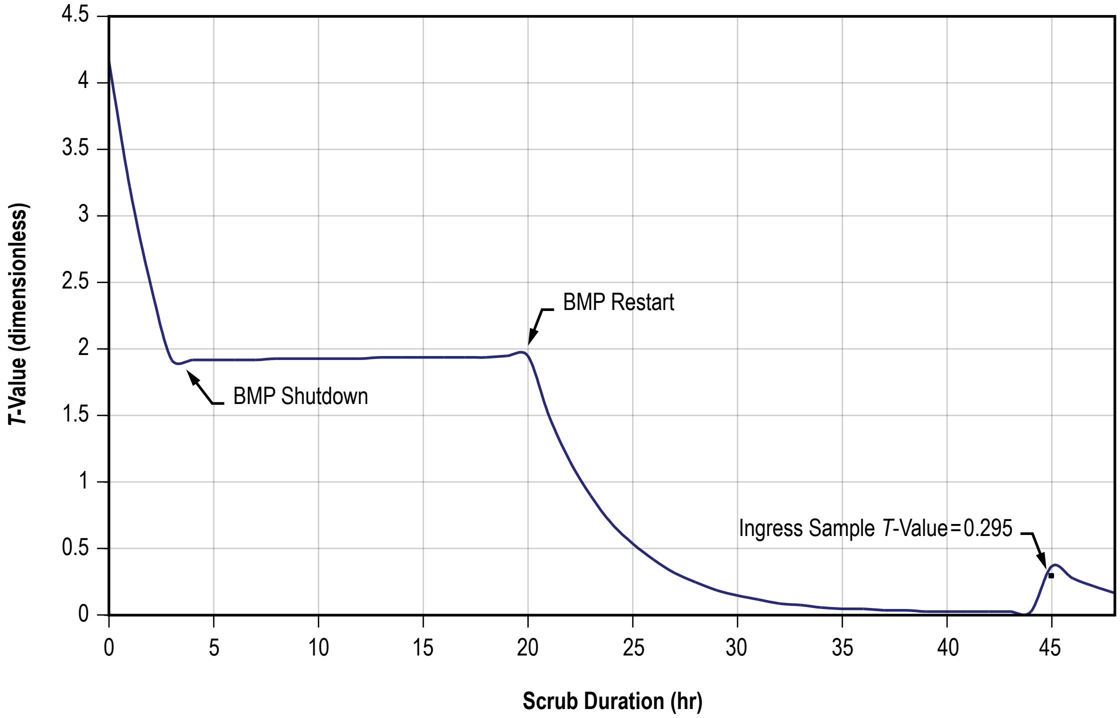

Figure 22. Relative contamination during STS-106/2A.2b ingress of Zvezda.

8.7 Summary

Analysis of the ingress and steady state scenarios has been conducted to determine the ISS's capability for meeting relevant TCC requirement and ingress flight rule criteria during mission 2R. According to the analysis, the onboard contamination control systems can provide adequate preingress atmospheric scrubbing and maintain individual trace contaminant concentrations below their respective SMACs with margin.

8.8 Conclusions

Based upon the ISS TCC capability assessment results, conclusions that can be made are the following:

- The BMP and FVP will provide adequate preingress atmospheric scrubbing for mission 2R.

- The BMP can maintain individual trace contaminant concentrations below their respective SMACs.

- The BMP can maintain individual trace contaminant concentrations below their respective Russian LPCs with the exception of methanol. However, the methanol concentration is anticipated to continue to decrease as the on-orbit hardware ages.

8.9 Recommendations

Recommendations for addressing continuing ISS TCC issues during ingress operations are the following:

- The minimum scrubbing duration for Zvezda should be 4 hours to ensure a *T*-value magitude less than 1 at ingress.

- A spare FVP filter should be provided as a contingency in the event the BMP fails.

9. MISSION 4A TRACE CONTAINMENT CONTROL CAPABILITY ASSESSMENT

This assessment was originally released under NASA Memorandum FD21(01-017) dated November 28, 2000.

9.1 Background

In order to satisfy the ISS program's Node 1 (Unity) TCC requirements, the analysis previously conducted for STS-92/3A has been extended through STS-97/4A. The STS-97/4A analysis is part of the continuing effort to evaluate the TCC capability at each successive assembly stage. It takes into account preliminary results from the ground-based analysis of air quality samples collected during STS-106/2A.2b to better understand its inherent conservatism.

9.2 Purpose

The engineering analysis summarized by the following discussion serves to verify the ISS's TCC capability for mission 4A. Specifically, the capability for Unity's TCC equipment to provide acceptable cabin atmospheric quality during ingress operations are addressed. While the trace contaminant environment in the ROS will influence the initial loading in Unity, a steady state is rapidly achieved throughout the Station's volume.

9.3 Objectives

The adequacy of the trace contaminant removal equipment presently on board Unity during mission 4A is assessed by engineering analysis. Specific objectives of the analysis which serve to verify this capability are the following:

- Determine the trace contaminant concentrations during ingress operations as well as the predicted steady state concentrations.

- Determine the adequacy of the onboard TCC resources for meeting the relevant ISS program requirements, flight rules, and medical operations guidelines.

9.4 Assumptions

To conduct the mission 4A TCC capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

9.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the mission 4A engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results and revised according to results reported from ground-based analyses of in-flight air quality samples.

- Additional offgassing from stowage hardware are estimated using design specification rates.

- ISS atmospheric leakage is zero. This is considered to be true for the early stages of the ISS's on-orbit life.

- Cabin atmospheric conditions are on average 20 ºC, 50% relative humidity, and 101.3 kPa.

- Offgassing rates are constant with time. This has been shown by analyses conducted to date to be conservative as rates tend to decay with time.

- Seven-day SMACs apply for the ingress analysis scenario according to flight rule 3A_13B-1 in appendix A.

9.4.2 On-Orbit Configuration

During 4A, the ISS's on-orbit configuration consists of PMA-1, PMA-2, PMA-3, Unity (Node 1), Zarya, Zvezda, a Soyuz spacecraft, and the Shuttle. Until the Shuttle docks with the ISS, the crew will inhabit only the Zarya, Zvezda, and the Soyuz volumes. Unity will remain isolated until adequate power can be supplied to provide adequate shell heating. Therefore, Unity is effectively isolated from the Expedition 1 crew and contaminants slowly build up between the STS-92/3A egress and STS-97/4A ingress. Assumptions pertaining to the ISS's configuration and its contamination control capability are the following:

- Cabin free volumes of Unity, PMA-1, PMA-2, PMA-3, Zarya, Zvezda, Soyuz, and Shuttle are 55.2, 5.7, 5.2, 5.2, 61, 87, 10.5, and 70 m^3, respectively.

- Contamination control in Unity is provided by four CACEAs. Total air flow through the CACEAs is 339.8 m^3/hr.

9.4.3 Mission Timeline

The mission timeline used for the ingress analysis builds upon that used for the STS-92/3A mission. Approximately 45 days elapse between Unity egress at the end of STS-92/3A and ingress during STS-97/4A. A typical ingress timeline similar to that of STS-101/ 2A.2b is used.

9.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for mission STS-97/4A. The discussion includes a summary on trace contaminant generation rate derivation, the analytical tool, and cases considered for the assessment.

9.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of offgassing test grab samples collected from Unity, Zarya, and Zvezda as well as considering in-flight sample analysis results. As additional hardware has been left on board the ISS, the offgassing contribution of that hardware has been estimated based upon ground-based offgassing test data and design generation rate data contained in ISS program documentation.

9.5.2 Trace Contaminant Control Simulation Computer Program

The TCCS-CP, version 8.1, was used to conduct the analysis.[7,8] This analytical tool calculates the cabin concentration of individual trace chemical contaminants when generated at a specified rate and controlled by any combination of removal devices. The TCCS-CP, version 8.1, has previously been assessed for its applicability for use in spacecraft TCC system verification analyses and was found to be acceptable and the subroutine for the 2% Pt/GAC has been found to provide a conservative performance assessment.[9]

9.5.3 Analysis Cases Considered

The primary case considered is for normal ingress of Unity. Contingency ingress is considered relative to analyses conducted for previous missions.

9.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the three analysis cases.

9.6.1 Derived Generation Rates

Generation rates for the crew and Unity were taken from the previous analysis for mission STS-92/3A. As with all previous analyses, the metabolic rates for three crewmembers are obtained from reference 2 rather than from specification load listings. The reference 2 metabolic load is considered more complete and represents a greater challenge to the onboard contamination control systems. Rates for equipment offgassing for Unity, Zarya, and Zvezda are from the analysis conducted for the 2A.2b and 3A missions.

9.6.2 Normal 4A Ingress

According to figure 1, from the time of STS-92/3A egress until Unity's cabin fan is started for a normal preingress scrub just before STS-92/3A, the *T*-value rises to approximately 1.7. This is below the 3 limit specified by flight rule 3A_13B-1 and, in the case of a contingency, the crew may enter without the scrub. As well, simultaneous ingress and atmospheric scrubbing may be permitted to ease timeline pressures. For the remainder of the ingress period, the predicted *T*-value magnitude remains below 1 except for a brief peak when ventilation is initiated between Unity and the Shuttle. While not shown by figure 23, a similar peak occurs when ventilation between Zarya and Unity is established.

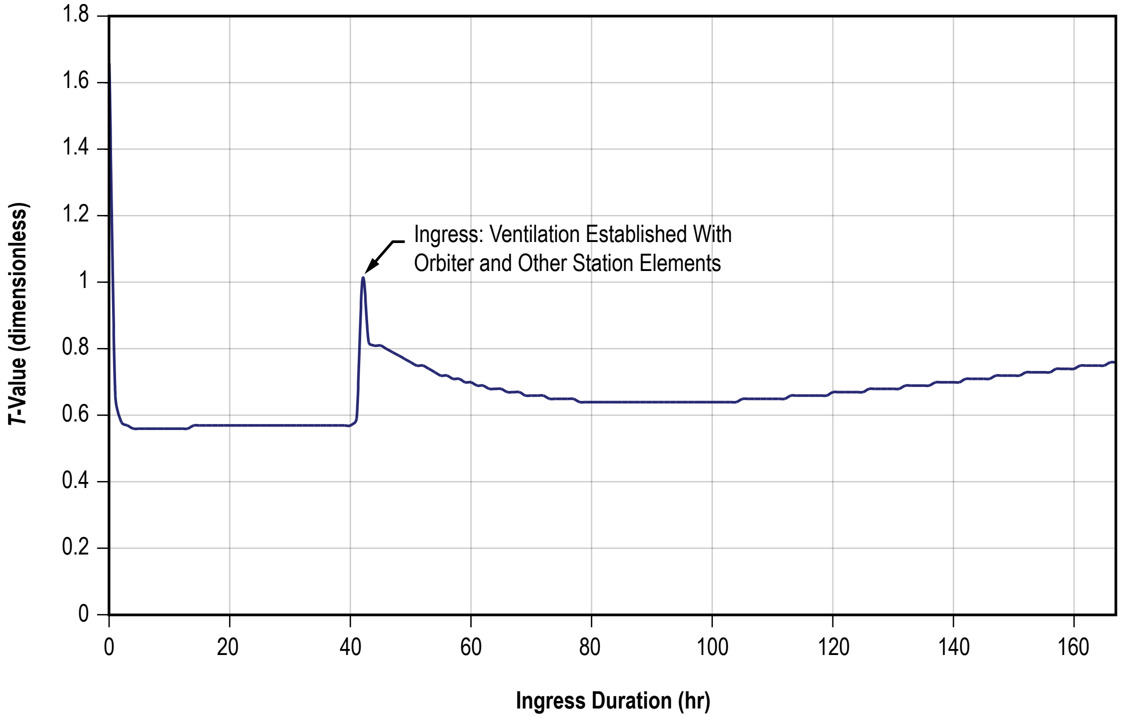

Figure 23. Predicted relative contamination on board Unity during ingress.

All predicted concentrations are below individual SMACs. A detailed listing of predicted concentrations for STS-97/4A are provided in table 28. Further, figure 24 shows that a normal scrub reduces the *T*-value magnitude to less than 1 within 1 hour. Therefore, the normal 2-hour scrub prescribed by flight rule 4A_17B-1 should be more than sufficient. The first hour of scrubbing reduces the *T*-value to just under 0.6. Beyond 1 hour, the *T*-value continues to decrease very slightly. According to table 28, dichloromethane is the major contributor to the overall *T*-value followed by ethanal.

Table 28. Predicted concentrations in Unity during STS-97/4A ingress.

	Standard (mg/m^3)		Concentration (mg/m^3)		
Compound	NASA	Russia	Prescrub	End 2-Hr Scrub	Ingress Complete
Methanol	9	0.2	0.8	0.8	0.08
Ethanol	2,000	10	26.4	10	16.8
2-propanol	150	1.5	15.2	0.1	0.03
n-propanol	98	0.6	2.5	0.01	0.002
2-methyl-2-propanol	120	0.1	0.4	0.002	0.0002
n-butanol	40	0.8	2.1	0.006	0.09
Ethanal	4	1	1	0.5	0.5
2-propenal	0.03	–	0.002	0.0005	0.00007
Propanal	95	–	0.5	0.01	0.002
2-methyl-2-propenal	1.7	–	0.4	0.005	0.0003
Butanal	120	–	3.8	0.008	0.001
Pentanal	110	–	0.1	0.0005	0.00007
Hexanal	4.9	–	0.1	0.0003	0.00006
Heptanal	5.6	–	0.1	0.0001	0.00005
Methylbenzene	60	8	1.1	0.002	0.0009
1,2- & 1,3-dimethylbenzenes	220	5	1.1	0.001	0.06
1,4-dimethylbenzene	220	5	0.5	0.0006	0.07
Ethylbenzene	130	–	0.4	0.0005	0.02
Butyl acetate	190	2	0.1	0.0002	0.0002
Dichloromethane	10	–	4.6	2.5	4.8
Trichlorofluoromethane	560	–	0.4	0.006	0.0003
Trichlorotrifluoroethane	400	–	1.3	0.005	0.0005
2-propanone	50	2	4.6	0.5	1.1
2-butanone	30	0.25	2	0.01	0.008
Cyclohexanone	60	1.3	0.7	0.0007	0.0002
Hexamethylcyclotrisiloxane	230	–	0.4	0.0002	0.0001
Octamethylcyclotetrasiloxane	281	–	2.8	0.0006	0.0005
Carbon monoxide	10	5	0.03	0.004	0.03
Hydrogen	340	–	23	23	30
Methane	3,800	3,342	52	52	68

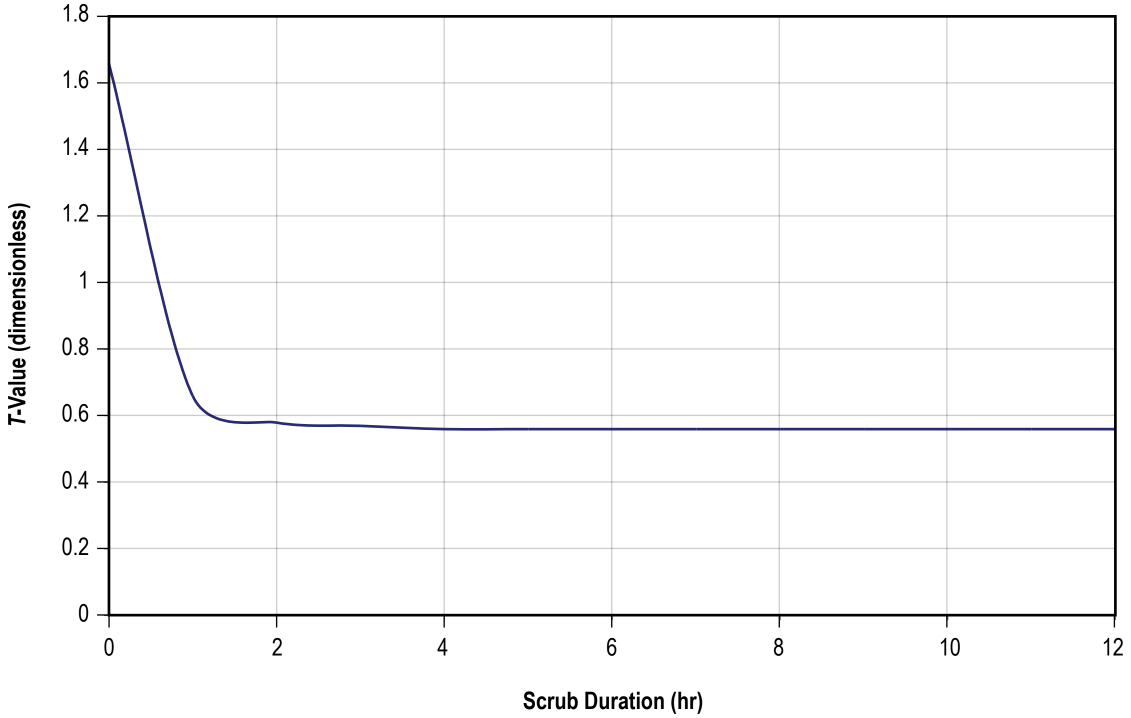

Figure 24. Relative contamination level during a normal scrub.

9.6.3 Contingency 2R Ingress

Because the predicted *T*-value magnitude for Unity at the beginning of the preingress scrub is much less than 3, the crew will be able to enter even in the event that the cabin fan fails to operate. Other onboard resources housed in Zarya and Zvezda have been shown by previous analysis to be capable of handling the entire ISS load according to the analysis conducted for mission 2R. Therefore, by establishing ventilation between Unity and the ROS elements of the ISS, the necessary contamination control capability can be provided.

9.6.4 Analysis Conservatism

Previous analyses have indicated an increasing degree of conservatism over time ranging from 0.045 *T*-value units for STS-88/2A up to 0.53 *T*-value units for STS-101/ 2A.2a. The trend increased over time. A similar comparison for STS-106/2A.2b, however, shows little difference between the predicted and measured *T*-values. This would indicate that the present trace contaminant generation rate predictions are very close to the actual rates. Therefore, the predictions should be quite close to the actual measured *T*-values for STS-92/3A and STS-97/4A.

9.7 Summary

An engineering analysis of the relevant ingress scenarios for Unity has been conducted to determine the ISS's capability for meeting relevant TCC requirement and ingress flight rule criteria during STS-97/4A. According to the analysis, the onboard contamination control systems can provide adequate preingress atmospheric scrubbing and maintain individual trace contaminant concentrations below their respective SMACs with margin.

9.8 Conclusions

Based upon the STS-97/4A TCC capability assessment results, conclusions that can be made are the following:

- The CACEAs will provide adequate preingress atmospheric scrubbing.

- The crew may enter Unity without scrubbing if necessary because the predicted *T*-value magnitude is less than 3.

- Total onboard TCC resources are capable of maintaining acceptable air quality for Unity in the event that its cabin fan fails.

9.9 Recommendations

Recommendations for addressing continuing ISS TCC issues during ingress operations are the following:

- The minimum scrubbing duration for Unity should be 1 hour to ensure a *T*-value magnitude less than 1 at ingress.

- Consider simultaneous scrubbing and ingress operations to ease mission timeline pressures.

10. ASSEMBLY MISSION 5A TRACE CONTAMINANT CONTROL CAPABILITY ASSESSMENT

This assessment was originally released under NASA Memorandum FD21(01-021) dated December 1, 2000.

10.1 Background

An engineering analysis of the ISS's TCC capability has been conducted for U.S. Laboratory (Destiny) ingress and steady state scenarios for mission STS-98/5A and beyond. This analysis is part of the continuing effort to track TCC capability and assess its effectiveness at each successive assembly stage. The analysis builds upon those conducted for STS-88/2A through the Increment 1 crew's arrival on flight 2R presented in previous sections. This continuing effort evaluates the TCC capabilities on board Destiny and Zvezda relative to the appropriate ISS program requirements to ensure an acceptably clean atmosphere is maintained during all Station assembly stages.

10.2 Purpose

The engineering analysis summarized by the following discussion serves to verify the ISS's TCC capability for mission STS-98/5A and beyond. Specifically, the capability for Destiny's TCC equipment to provide acceptable cabin atmospheric quality during ingress and normal on-orbit operations is addressed. As well, the capability of the BMP located in Zvezda in combination with the TCCS in Destiny to provide overall contamination control during normal operations is evaluated.

10.3 Objectives

The adequacy of the trace contaminant removal equipment on board the ISS during mission 5A is assessed by engineering analysis. Specific objectives of the analysis which serve to verify this capability are the following:

- Determine the trace contaminant concentrations during ingress operations of Destiny.

- Determine the adequacy of the onboard TCC resources for meeting the relevant ISS program requirements, flight rules, and medical operations guidelines.

- Determine the steady state performance of the TCCS and BMP to control the on-orbit trace contaminant load.

- Determine the TCCS expendable bed service life.

10.4 Assumptions

To conduct the mission STS-98/5A TCC capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and Destiny's preflight processing timeline.

10.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the mission STS-98/5A engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results and revised according to results reported from ground-based analyses of in-flight air quality samples.
- Additional offgassing from stowage hardware is estimated using design specification rates.
- Metabolic loading is based upon a crew of three.
- ISS atmospheric leakage is zero. This is considered to be true for the early stages of the ISS's on-orbit life.
- Cabin atmospheric conditions are on average 20 °C, 55% relative humidity, and 101.3 kPa.
- No contaminant removal assist is provided by absorption in humidity condensate. This is a conservative assumption since ground testing and flight data indicate that this assist is significant for water soluble compounds.
- Offgassing rates are constant with time. This has been shown by analyses conducted to date to be conservative as rates tend to decay with time.
- Seven-day SMACs apply for the ingress analysis scenario according to flight rule X13.2.2-2 found in appendix A, while 180-day SMACs apply to all steady state analysis cases.

10.4.2 On-Orbit Configuration

Once flight STS-98/5A is completed, the ISS's habitable on-orbit configuration consists of Destiny, PMA-1, Unity (Node 1), Zarya, Zvezda, and a Soyuz spacecraft. Periodically a Progress spacecraft and the Shuttle will join the ISS; however, their contribution to the habitable volume is considered transient so they are not considered for the analysis. The Increment 1 crew typically will inhabit the volume provided by Destiny, Unity, Zarya, Zvezda, and PMA-1. While PMA-2 and PMA-3 are also part of the on-orbit configuration, they are not normally part of the habitable volume unless the Shuttle is docked to the Station. Based upon the post STS-98/5A configuration, assumptions pertaining to the ISS's configuration and its contamination control capability are the following:

- Cabin free volumes of Destiny, Unity, PMA-1, PMA-2, PMA-3, Zarya, Zvezda, Soyuz, and Shuttle are 98, 55.2, 5.7, 5.2, 5.2, 61, 87.9, 10.5, and 70 m^3, respectively.

- Total post-5A habitable volume, comprised of Destiny, Unity, Zarya, Zvezda, and PMA-1, is 307.8 m^3.

- Contamination control in Destiny is provided by six CACEAs during ingress. Air flow through each CACEA is 84.95 m^3/hr.

- Contamination control after Destiny is provided by the USOS TCCS located in Destiny and the ROS BMP located in Zvezda. The flow through the TCCS is 15.29 m^3/hr through the charcoal bed and 4.59 m^3/hr through its catalytic oxidizer and LiOH post sorbent bed. Flow through the BMP is 20 m^3/hr.

10.4.3 Mission Timeline

The mission timeline used for the ingress analysis scenario for Destiny assumes up to 120 days elapse between final ground closeout and on-orbit ingress. The steady state scenario timelines consider a 90-day period. More than 1 year is considered for the TCCS expendable bed service life assessment.

10.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for STS-98/5A. The discussion includes a summary on trace contaminant generation rate derivation, the analytical tool, and cases considered for the assessment.

10.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates are derived from the analytical results of offgassing test grab samples collected from Destiny, Unity, Zarya, and Zvezda as well as considering in-flight sample analysis results. As additional hardware has been left on board the ISS, the offgassing contribution of that hardware has been estimated based upon ground-based offgassing test data and design generation rate data contained in ISS program documentation.

10.5.2 Trace Contaminant Control Simulation Computer Program

The TCCS-CP, version 8.1, was used to conduct the analysis.[7,8] This analytical tool calculates the cabin concentration of individual trace chemical contaminants when generated at a specified rate and controlled by any combination of removal devices. The TCCS-CP, version 8.1, has previously been assessed for its applicability for use in spacecraft TCC system verification analyses and was found to be acceptable, and the subroutine for the 2% Pt/GAC has been found to provide a conservative performance assessment.[9]

10.5.3 Analysis Cases Considered

Cases considered are the normal ingress of Destiny and the steady state capability of the TCCS and BMP to control the Station's offgassing and crew metabolic loads. TCC by the TCCS and BMP operating simultaneously and alone are considered. Contingency ingress of Destiny is considered as dilution followed by control via the BMP. TCCS expendables service life evaluation are based upon the ISS program specification load model for assembly completion.

10.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases for Destiny first ingress and the subsequent contamination control capability provided by the TCCS and BMP for the ISS configuration after STS-98/5A undocking.

10.6.1 Derived Generation Rates

Generation rates for the crew and the various ISS modules were taken from the previous analysis for flight 2R and the ground offgassing test data for Destiny listed in appendix B. As with all previous analyses, the metabolic rates for three crewmembers are obtained from reference 2 rather than from specification load listings. The reference 2 metabolic load is considered more complete and represents a greater challenge to the onboard contamination control systems. The rates used to conduct the various analysis cases are listed in table 29.

Table 29. ISS trace contaminant generation rates.

	Generation Rate (mg/hr)						
Compound	Crew	Destiny	Unity + PMA-1	Zarya	Zvezda	Progress + Soyuz	Total
Methanol	0.05	1.07	0.0396	0.084	0.208	0.0416	1.4914
Ethanol	0.27	1.06	0.8873	4.96	3.1	0.62	10.8957
2-propanol	0.13	1.08	0.8276	0.645	0.0039	0.00078	2.6912
n-propanol	0.05	0.15	0.1377	–	–	–	0.3367
2-methyl-2-propanol	–	–	0.0211	–	–	–	0.0211
n-butanol	0.05	0.097	0.1099	1.27	–	–	1.5269
Ethanal	0.04	0.04	0.0366	0.026	0.15	0.03	0.3228
2-propenal	–	–	0.0001	–	–	–	0.0001
Propanal	0.02	–	0.0278	–	–	–	0.0478
2-methyl-2-propenal	–	–	0.0211	–	–	–	0.0211
Butanal	–	–	0.2095	–	–	–	0.2095
Pentanal	0.002	–	0.0079	–	–	–	0.0099
Hexanal	0.002	–	0.0079	–	–	–	0.0099
Heptanal	0.002	–	0.0079	–	–	–	0.0099
Methylbenzene	0.06	0.076	0.0612	0.073	0.16	0.032	0.4623
1,2- & 1,3-dimethylbenzenes	0.008	–	0.0553	1.13	–	–	1.1933
1,4-dimethylbenzene	0.004	–	0.0211	0.455	–	–	0.4801
Ethylbenzene	0.05	–	0.0211	0.091	–	–	0.1621
Butyl acetate	0.02	–	0.0079	0.006	0.083	0.0166	0.1335
Dichloromethane	–	0.035	0.1163	0.112	0.0054	0.0011	0.2701
Tetrachloroethene	–	0.038	–	–	–	–	0.0375
Trichlorofluoromethane	–	–	0.0211	–	–	–	0.0211
Trichlorotrifluoroethane	–	0.5	0.0702	–	–	–	0.568
2-propanone	1.2	0.42	0.2178	0.546	0.506	0.1012	2.9924
2-butanone	1.1	0.14	0.1101	0.158	0.908	0.1816	2.5978
Cyclohexanone	–	0.03	0.0367	0.035	–	–	0.0978
Hexamethylcyclotrisiloxane	–	0.69	0.0211	0.017	–	–	0.729
Octamethylcyclotetrasiloxane	–	0.22	0.15	0.106	–	–	0.4736
Decamethylcyclopentasiloxane	–	0.07	–	–	–	–	0.0678
Trimethylsilanol	–	0.93	–	–	–	–	0.9261
Carbon monoxide	2.2	0.39	–	–	–	–	2.5949
Hydrogen	3.9	–	–	–	–	–	3.9
Methane	15	–	–	–	–	–	15
Benzene	0.15	–	–	–	0.0009	0.0002	0.1511
Styrene	–	–	–	–	0.0059	0.0012	0.0071
1,3,5-trimethylbenzene	–	–	–	–	0.0113	0.0023	0.136
Ethyl acetate	0.05	–	–	–	4.7	0.94	5.69
Choroethane	–	–	–	–	0.0047	0.0009	0.0056
Trichloromethane	–	–	–	–	0.0050	0.0010	0.006
1,2-dichloroethane	–	0.01	–	–	0.0072	0.0014	0.0189
Chlorobenzene	–	–	–	–	0.0016	0.00032	0.0048
Heptane	0.01	–	–	–	0.112	0.0224	0.1444
Octane	0.01	–	–	–	0.0034	0.00068	0.0141
Nonane	0.0065	–	–	–	0.0155	0.0031	0.0251

10.6.2 Scrubbing Resources Required for Destiny Ingress

Before launch, the appropriate scrubbing equipment must be installed in Destiny to allow for a normal preingress atmospheric scrub. The Atmosphere Revitalization Subsystem (ARS) rack is not launched fully configured. For this reason, the TCCS cannot be used for the preingress scrub. Like

Unity, the bacteria filter elements in the ventilation ducts are replaced with CACEAs. Destiny has six filter element locations available. In order to have the appropriate number of CACEAs installed, the offgassing data from Destiny were used to evaluate ingress cases in which two, four, and six CACEAs are installed. Figure 25 shows that a 2-hour scrub with as few as three CACEAs can reduce the *T*-value magnitude at ingress from just over 6.9 to less than 3.

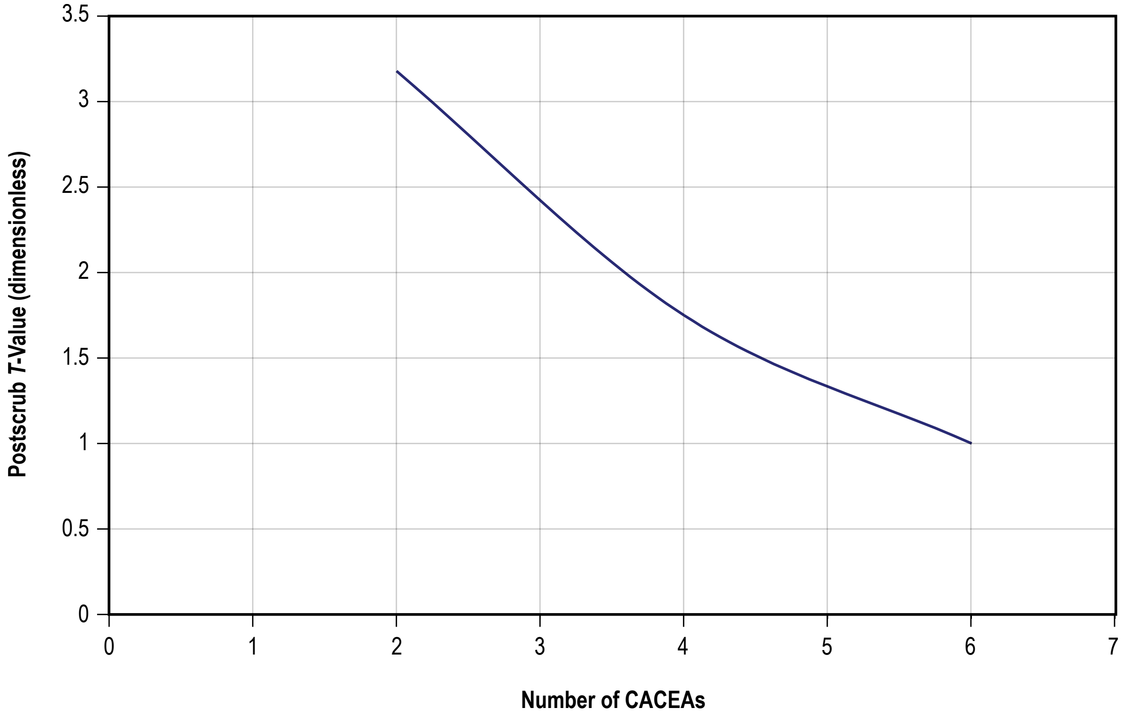

Figure 25. Number of CACEAs required for Destiny preingress scrub.

While this meets the intent of flight rule X13.2.2-2, a second factor—the requirement that all contaminants must be less than their individual SMACs—must be considered. Evaluation of predicted concentrations shows that methanol is the key compound that drives the number of CACEAs required. As shown in figure 26, more than five CACEAs are required to ensure that the methanol concentration at ingress does not exceed its SMAC. By using six CACEAs, the methanol concentration can be reduced from its predicted 31.5 mg/m^3 to just over 7 mg/m^3 within the 2-hour scrub duration specified by the ingress criteria flight rule. It should be noted that the USOS Specification (SSP 41162R, paragraph 3.7.1.3.97f) allows methanol to be 25 mg/m^3 for 24 hours after ingress. This is actually greater than the official 24-hour SMAC of 13 mg/m^3. While the condition allowed by the USOS specification is achieved using only two CACEAs, it is prudent to provide the crew with the best possible environment upon their first ingress that meets both the required SMAC and *T*-value levels. This is achieved by installing six CACEAs in Destiny. The final launch configuration has six CACEAs installed and the normal ingress analysis is based upon this configuration.

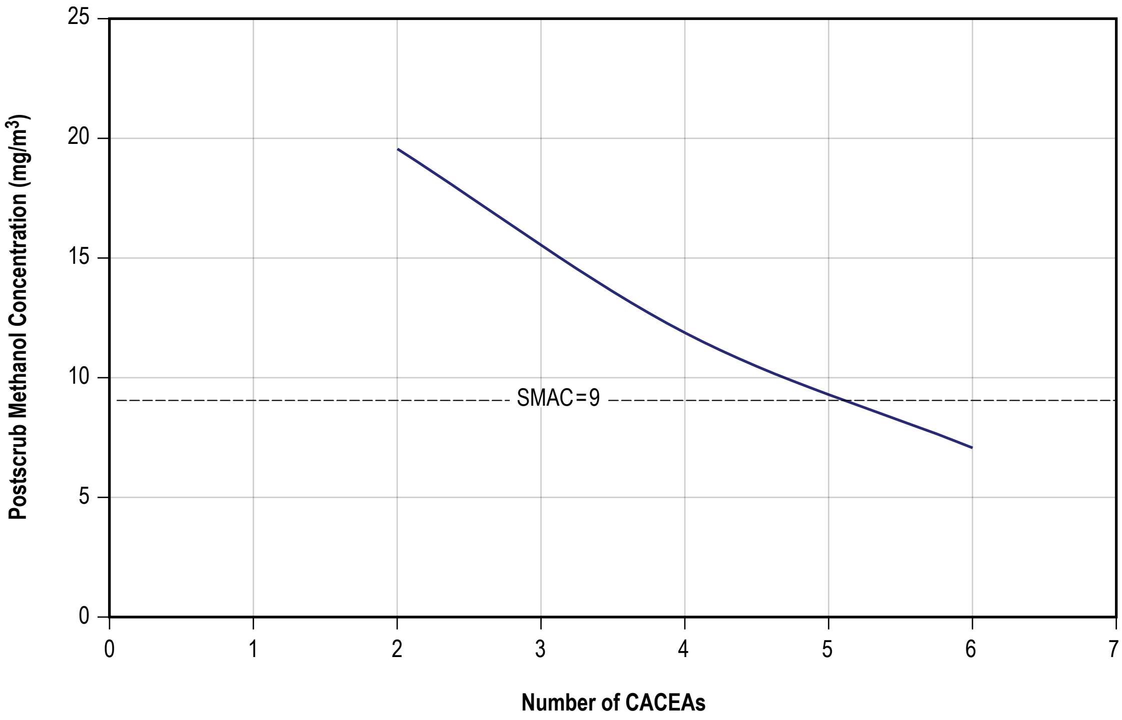

Figure 26. Number of CACEAs necessary to reduce methanol below SMAC.

10.6.3 Normal Destiny Ingress

According to figure 27, from the time of ground closeout until ingress during STS-98/5A the *T*-value rises to just over 6.9. This is above the limit of 3 specified by flight rule X13.2.2-2 and, in the case of a contingency, the crew may enter only with crew surgeon approval because the predicted starting *T*-value is greater than 6. Once the cabin fan is activated, the *T*-value is reduced to 1.4 within 1 hour and to 1 within 2 hours. This is within the 2-hour scrub duration prescribed by the module ingress flight rule. Beyond 2 hours, the *T*-value slowly decreased to 0.83. Methanol is the dominant contributor to the *T*-value. Before scrubbing, it accounts for 3.5 *T*-value units or nearly 51% of the total *T*-value. After scrubbing, methanol accounts for approximately 0.79 *T*-value units which is more than 94% of the total *T*-value. Other major contributors to the starting *T*-value are 2-propanol (3%), ethanal (4%), trichlorotrifluoroethane (4%), 2-propanone (6%), trimethylsilanol (11%), hexamethylcyclotrisiloxane (3%), and carbon monoxide (15%). These compounds are reduced to trace levels after a successful scrub. All predicted concentrations at ingress are below individual SMACs provided the 2-hour scrub is completed. A detailed listing of predicted concentrations for Destiny first ingress during STS-98/5A are provided in table 30.

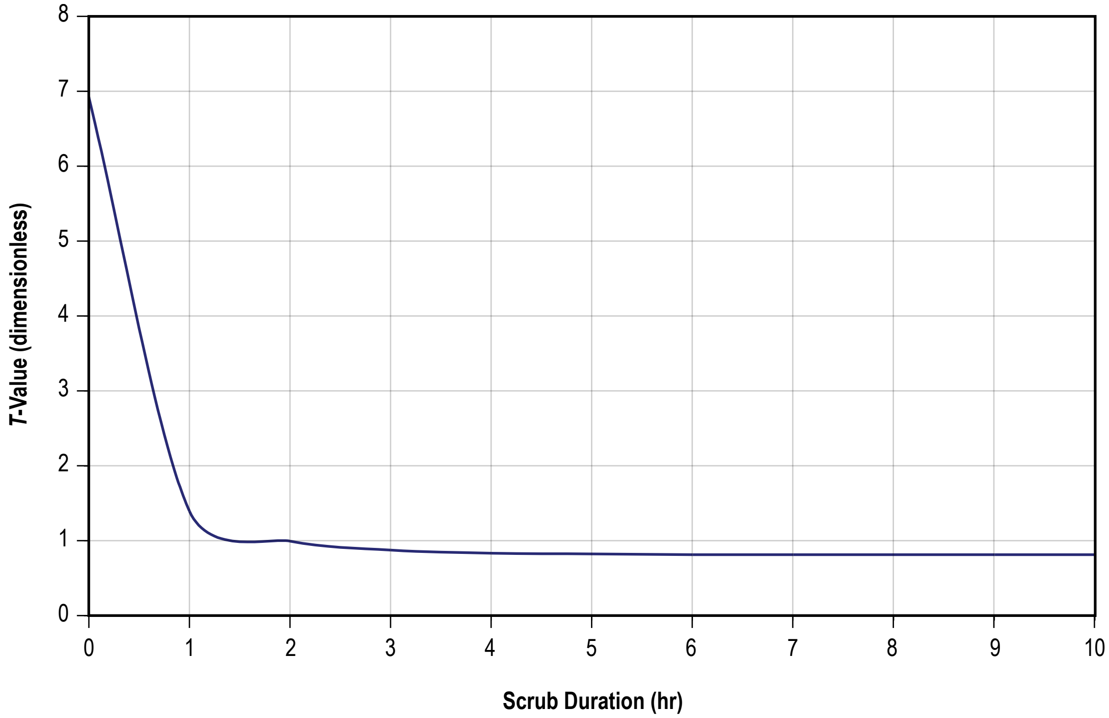

Figure 27. Predicted relative contamination during Destiny ingress.

Table 30. Predicted concentrations during Destiny ingress.

Compound	Standard (mg/m^3)		Concentration (mg/m^3)	
	NASA*	Russia	Prescrub	Postscrub
Methanol	9	0.2	31.5	7.1
Ethanol	2,000	10	31.2	0.62
2-propanol	150	1.5	32	0.2
n-propanol	98	0.6	4.4	0.03
2-methyl-2-propanol	120	0.1	–	–
n-butanol	80	0.8	2.8	0.008
Ethanal	4	1	1.2	0.14
2-propenal	0.03	–	–	–
Propanal	95	–	–	–
2-methyl-2-propenal	1.7	–	–	–
Butanal	120	–	–	–
Pentanal	110	–	–	–
Hexanal	4.9	–	–	–
Heptanal	5.6	–	–	–
Methylbenzene	60	8	2.2	0.007
1,2- & 1,3-dimethylbenzenes	220	5	–	–
1,4-dimethylbenzene	220	5	–	–
Ethylbenzene	130	–	–	–
Butyl acetate	190	2	–	–
Dichloromethane	50	–	1	0.046
Tetrachloroethene	34	–	0.3	0.0047
Trichlorofluoromethane	790	–	1.1	0.0047
Trichlorotrifluoroethane	400	–	14.7	0.062
2-propanone	50	2	12.4	0.18
2-butanone	30	0.25	4.1	0.028
Cyclohexanone	60	1.3	0.77	0.0013
Hexamethylcyclotrisiloxane	230	–	20.4	0.0077
Octamethylcyclotetrasiloxane	280	–	6.4	0.00093
Decamethylcylopentasiloxane	100	–	2	0.00025
Trimethylsilanol	37	–	27.3	0.056
Carbon monoxide	11	5	11.6	1.8
Hydrogen	340	–	–	–
Methane	3,800	3,342	–	–
Benzene	0.2	0.2	–	–
Styrene	43	–	–	–
1,3,5-trimethylbenzene	15	–	–	–
Ethyl acetate	180	4	–	–
Choroethane	260	–	–	–
Trichloromethane	4.9	–	–	–
1,2-dichloroethane	1	0.5	0.3	0.0046
Chlorobenzene	46	1.5	–	–
Heptane	200	10	–	–
Octane	350	10	–	–
Nonane	320	–	–	–

*7-day SMACs for ingress according to flight rule X13.2.2-2 and JSC 20584.

10.6.4 Contingency Ingress of Destiny

Because the starting *T*-value magnitude in Destiny is predicted to be greater than 6, the crew cannot enter without taking special precautions as defined by flight rule X13.2.2-2 if the preingress scrub is not conducted successfully. In this case, ventilating the module becomes the means for reducing the trace contaminant load in the cabin to acceptable levels. At the conclusion of STS-106/2A.2b, the average *T*-value in the ISS cabin, which consisted of Unity, Zarya, Zvezda, and PMA-1, was 0.25. Assuming that a similar *T*-value exists in the ISS before the crew enters Destiny, is it possible to disperse the accumulated contaminants throughout the ISS cabin to achieve a *T*-value of 2.4. Previous analysis conducted for Node 1 first entry has indicated that this dilution would take approximately 2 hours to complete. The CACEAs installed in Unity and the BMP in Zvezda would then reduce this *T*-value to 1 within another 2 hours. Therefore, in the event of a preingress scrub failure, the crew should wait 2 hours before entering Destiny for any extended period without respiratory protection.

10.6.5 Steady State Contamination Control

According to flight rule 5A_17B-2, which is provided in appendix A for reference purposes, the TCCS in Destiny will operate in parallel with the BMP in Zvezda for the 5A Station assembly stage. As shown in table 31, the combined operation of the TCCS and BMP is predicted to maintain individual trace contaminant concentrations not only below the NASA 180-day SMACs but also below Russian 360-day limiting permissible concentrations.

Table 31. Predicted steady state trace contaminant concentrations.

	Standard (mg/m^3)		Concentration (mg/m^3)		
Compound	**NASA***	**Russia**	**TCCS**	**BMP**	**TCCS/BMP**
Methanol	9	0.2	0.32	0.21	0.12
Ethanol	2,000	10	1.1	0.54	0.33
2-propanol	150	1.5	0.18	0.13	0.076
n-propanol	98	0.6	0.022	0.017	0.0095
2-methyl-2-propanol	120	0.1	0.0014	0.0011	0.0006
n-butanol	40	0.8	0.1	0.077	0.043
Ethanal	4	1	0.07	0.016	0.013
2-propenal	0.03	–	0.000006	0.000005	0.000003
Propanal	95	–	0.0031	0.0024	0.0014
2-methyl-2-propenal	1.7	–	0.0014	0.0011	0.0006
Butanal	120	–	0.014	0.01	0.006
Pentanal	110	–	0.00065	0.0005	0.00028
Hexanal	4.9	–	0.00065	0.0005	0.00028
Heptanal	5.6	–	0.00065	0.0005	0.00028
Methylbenzene	60	8	0.03	0.023	0.013
1,2- & 1,3-dimethylbenzenes	220	5	0.078	0.06	0.034
1,4-dimethylbenzene	220	5	0.031	0.024	0.014
Ethylbenzene	50	–	0.011	0.0081	0.0046
Butyl acetate	190	2	0.0087	0.0067	0.0038
Dichloromethane	10	–	0.026	0.014	0.0079
Tetrachloroethene	34	–	0.0024	0.0019	0.0011
Trichlorofluoromethane	790	–	0.0014	0.0011	0.0006
Trichlorotrifluoroethane	400	–	0.037	0.028	0.016
2-propanone	50	2	0.2	0.15	0.085
2-butanone	30	0.25	0.17	0.13	0.074
Cyclohexanone	60	1.3	0.0064	0.0049	0.0028
Hexamethylcyclotrisiloxane	9	–	0.048	0.036	0.021
Octamethylcyclotetrasiloxane	12	–	0.031	0.024	0.013
Decamethylcylopentasiloxane	15	–	0.0044	0.0034	0.0019
Trimethylsilanol	37	–	0.061	0.046	0.026
Carbon monoxide	11	5	0.57	0.14	0.12
Hydrogen	340	–	0.85	27.4	0.85
Methane	3,800	3,342	3.7	105	3.7
Benzene	0.2	0.2	0.0099	0.0076	0.0043
Styrene	43	–	0.00046	0.00036	0.0002
1,3,5-trimethylbenzene	15	–	0.0089	0.0068	0.0038
Ethyl acetate	180	4	0.37	0.28	0.16
Choroethane	260	–	0.00037	0.00028	0.00016
Trichloromethane	4.9	–	0.00039	0.0003	0.00017
1,2-dichloroethane	1	0.5	0.0012	0.00094	0.00054
Chlorobenzene	46	1.5	0.00031	0.00024	0.00014
Heptane	200	10	0.0094	0.0072	0.0041
Octane	350	10	0.00092	0.00071	0.0004
Nonane	320	–	0.0016	0.0013	0.00071

*180-day SMAC according to SSP 41000R and JSC 20584.

Figure 28 shows the predicted *T*-value for normal TCC system operation for the 5A assembly stage. As can be seen, the *T*-value fluctuates between 0.06 and 0.08. The initial rise in *T*-value after approximately 2 days is due to methanol and ethanal (acetaldehyde) breakthrough of the TCCS charcoal bed assembly (CBA) and the BMP's expandable charcoal bed. These compounds continue to be removed at 100% efficiency through the TCCS catalytic oxidizer assembly (COA); however, the lower flow rate results in a slightly higher cabin concentration. After approximately 10 days, these same compounds begin to break through the BMP's regenerable charcoal beds. This corresponds to the rise in *T*-value from 0.06 to 0.07. After regeneration, the BMP's capacity for methanol and ethanal removal is temporarily restored. The spikes to a *T*-value of 0.08 correspond to BMP regeneration. The first regeneration did not experience a peak because the predicted methanol and ethanal breakthrough is incomplete. Methanol is still being removed at 18% efficiency through the BMP beds while ethanal is removed at 98% efficiency. During later regeneration cycles, the methanol removal efficiency is under 10% and the ethanal removal efficiency drops to 92%. This allows the concentration for both compounds to contribute an additional 0.01 *T*-value unit during the regeneration.

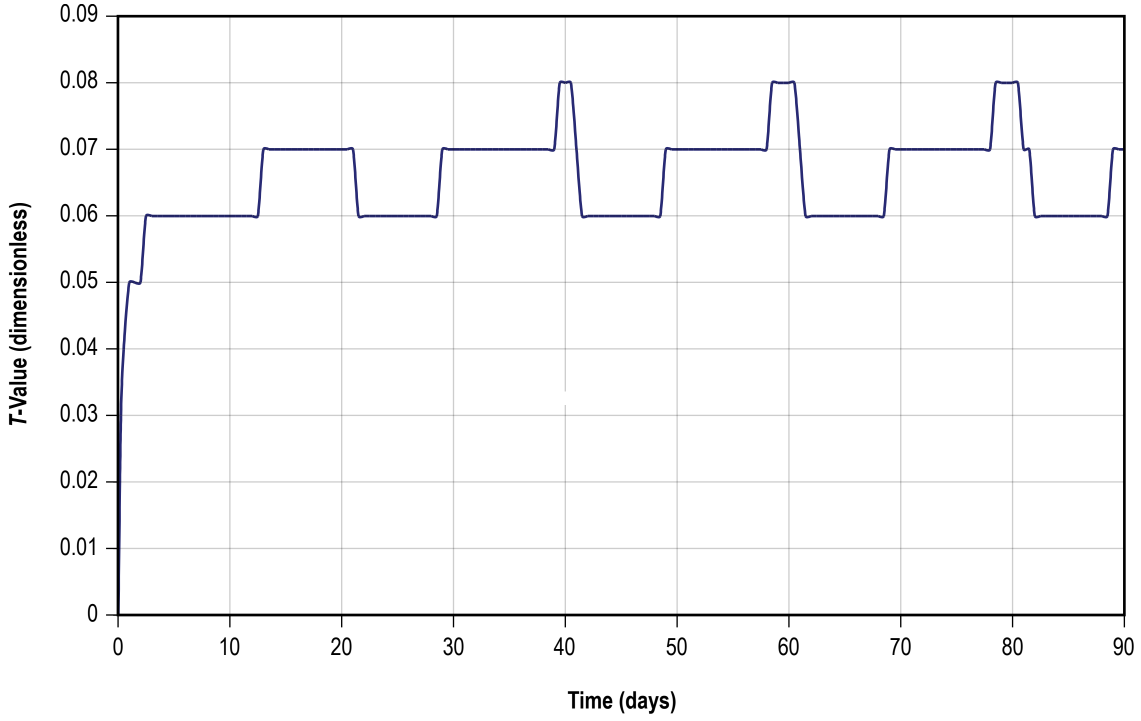

Figure 28. Relative contamination level during normal contamination control.

10.6.6 Contingency Contamination Control

In the event that either the TCCS or the BMP fail, table 4 shows that all contaminants identified during ground offgassing tests will be controlled to less than their respective 180-day SMAC. As well, all but methanol will be controlled to less than the Russian 360-day LPCs. This is consistent with previous analyses conducted in 1994.[14]

The predicted effects on the *T*-value in the event of either a TCCS or BMP failure are shown in figures 29 and 30, respectively. With the TCCS operating alone, the predicted *T*-value converges on 0.19 and remains steady. Operating the BMP alone, however, results in a steady rise in the *T*-value due to methane and hydrogen accumulation. The BMP, as shown by ground testing, does not remove hydrogen and methane, therefore, they continuously build up leading to a rise in the *T*-value.[12]

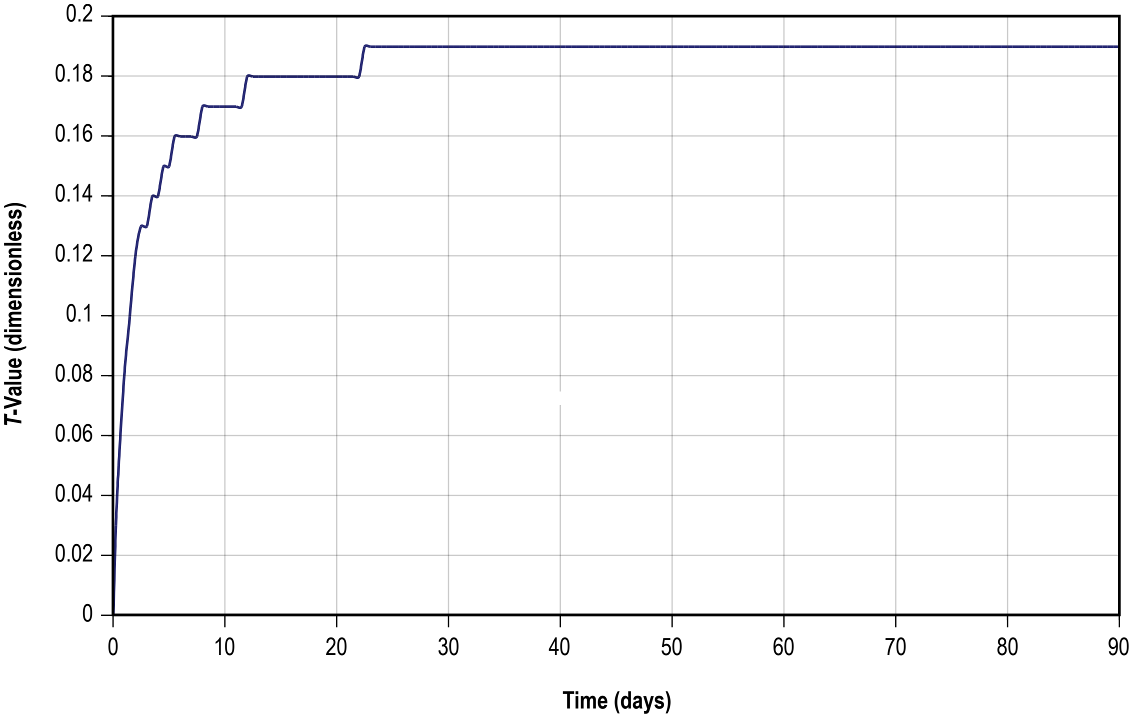

Figure 29. Relative contamination level with TCCS operating alone.

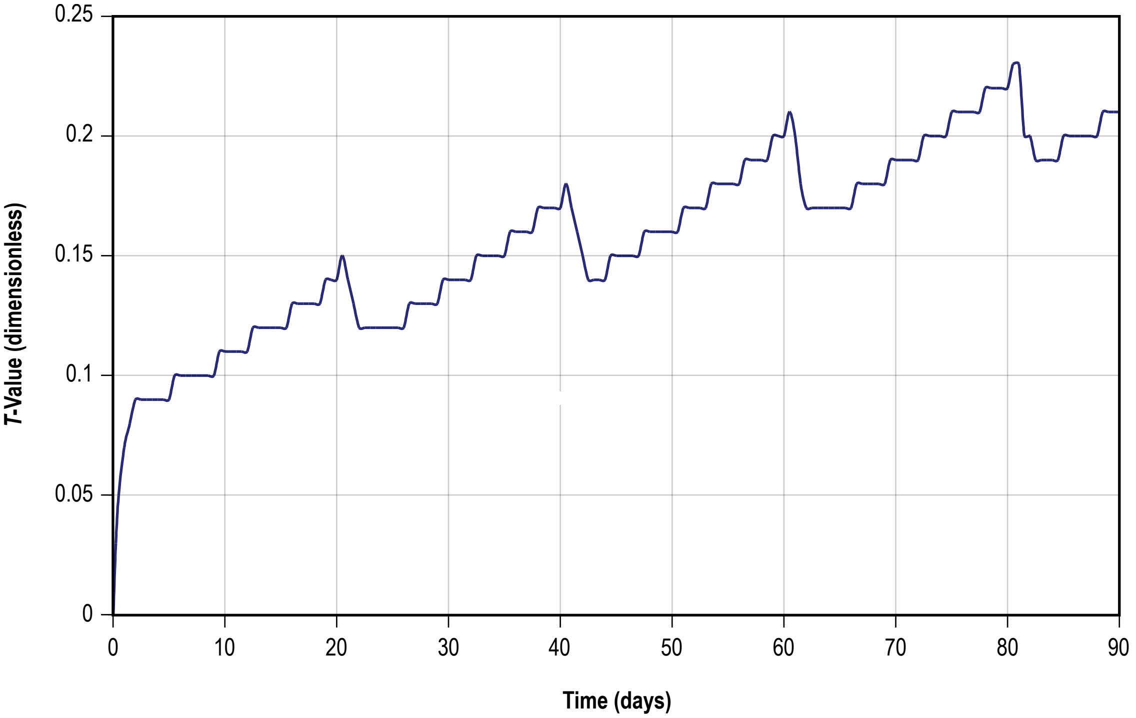

Figure 30. Relative contamination with the BMP operating alone.

10.6.7 Trace Contaminant Control Subassembly Component Service Life

Previous analyses and tests serve as the basis for the recommended service life for the TCCS CBA, COA, and sorbent bed assembly (SBA). Analysis was conducted by Lockheed Martin in 1995 which considered the TCCS's ability to maintain contaminants below individual SMACs as required by the USOS Specification (SSP 41162R). In this analysis, the full offgassing load from 75,000 kg of hardware and metabolic load from 5.25 crewmembers served as the challenge to the TCCS. No assist from the ROS BMP was considered; however, an assist from absorption into humidity condensate was considered. This analysis found that the TCCS could operate for 100 years without bed replacement while still satisfying the TCC requirements of the USOS specification. In such a situation, water soluble compound absorption in humidity condensate becomes the dominant removal route.

Careful evaluation of this result shows that the charcoal bed would become fully saturated for all compounds, including ammonia, if such a maintenance approach was used. Clearly, this is not an acceptable approach because ammonia breakthrough can lead to the production of oxides of nitrogen in the COA. Under cabin conditions of 21 °C and 50% relative humidity with no consideration given to absorption by humidity condensate, the Lockheed Martin analysis predicted that ammonia would completely saturate the CBA in 82 days. This is fairly consistent with a recent follow-up analysis conducted by MSFC's Environmental Control and Life Support System (ECLSS) Group that shows ammonia breakthrough beginning after 62 days with complete saturation after 79 days.

Assuming that there is no assist from absorption by humidity condensate, however, is not realistic. Ground-based testing has demonstrated that a significant percentage of the water soluble contaminants are removed by absorption into humidity condensate. In particular, more than 50% of the ammonia load was removed via this route during testing.[15] By including the assist provided by absorption into the condensate, ammonia breakthrough does not begin until 694 days elapse. The onset of ammonia breakthrough is a primary driver for CBA replacement because doing so before breakthrough prevents the production of oxides of nitrogen in the COA. According to the available test data and analyses based upon it, it is reasonable to conclude that the ammonia breakthrough may begin any time between 62 and 694 days. The median between these times is 316 days. Given that under the most challenging conditions, breakthrough is not predicted for 62 days; it is reasonable to conclude that 62 days can be added to the median for a recommended CBA service life of 378 days. Therefore, a 1-year service life should prevent ammonia breakthrough with significant margin. This estimate is consistent and conservative to Lockheed Martin's recommendation of 467 days (1.28 years).

Other considerations to the CBA service life pertain to potential catalyst poisons. According to the recent NASA analysis, dichloromethane, a secondary CBA design driver, begins to break through after 20 days and completely saturates the bed after 164 days when the TCCS is challenged with the USOS Specification (SSP 41162R) load. Ground testing of TCCS proto-flight unit No. 2 in early 1998 confirmed this result.[16] Dichloromethane, when introduced into the COA, reversibly poisons the high temperature catalyst leading to reduced methane oxidation efficiency. Detailed evaluation of the TCCS high temperature catalyst has demonstrated this effect to be reversible and a function of the inlet concentration. The predicted dichoromethane concentration at the COA inlet is approximately 1.2 mg/m^3. At this concentration, the methane oxidation efficiency would be expected to decay from greater than 95% to 80%. It should be noted that in order for the TCCS to maintain methane below its 180-day SMAC when challenged with the USOS specification load, the COA must provide a single-pass efficiency of 0.21%. Even with dichloromethane and other halocarbon breakthrough of the CBA, the COA should maintain more than sufficient capacity to keep methane below its 180-day SMAC. Up to 2 years of accelerated life testing has been conducted on the high temperature catalyst as well as 762 days (2.09 years) of continuous operation during which time the CBA was not serviced while processing facility high bay air.[17] Therefore, a service life of 2 years is recommended for the COA.

In addition to reversible poisons, attention must be given to other trace contaminants which could irreversibly poison the catalyst bed. Organosilicone compounds are the primary concern. Analysis of past mission experience indicates that at the concentrations typically observed and generation rates documented in the USOS Specification (SSP 41162R), it will take approximately 31 years before these compounds saturate the charcoal.[18] Clearly, ammonia remains the greatest concern and should be the primary driver for CBA service life.

With respect to the LiOH SBA, a worst case assessment of acid gas production in the COA indicates that if the entire halocarbon load of the USOS specification load is processed in the oxidizer, that is, the charcoal bed is completely saturated with halocarbons, the overall acid gas production rate is 9.68×10^{-4} mole acid gas as HF and HCl/hour. The TCCS LiOH postsorbent bed contains 1.4 kg of granular LiOH of which only about one-third is available for reaction with acid gases as noted by reference 18. Thus, 18.94 moles of LiOH can react with the acid gases produced in a catalytic oxidizer. By dividing the number of moles of LiOH available by the acid gas production rate, it is found that 815 days (2.2 years) elapse before the LiOH is exhausted. Therefore, a conservative 2-year service life for the LiOH postsorbent bed can be projected. To ensure the best performance, it is recommended that the SBA replacement occur at the same time as the CBA replacement.

The recommended service lives for the CBA, COA, and SBA compare favorably with previous Lockheed Martin estimates. In 1995, the replacement intervals recommended by Lockheed Martin were 1.28 years for the CBA and SBA and 2.56 years for the COA. The independent evaluation conducted by MSFC arrived at replacement intervals of 1 year for the CBA and SBA which compares well with Lockheed Martin's recommendation. The recommended 1-year replacement interval provides a 28% margin compared to the earlier 1.28-year interval. Similarly, the recommended 2-year replacement interval for the COA also provides a 28% margin compared to Lockheed Martin's 2.56-year interval. These recommended service intervals are based upon a trace contaminant load representative of the ISS after assembly is completed. Therefore, the margin is expected to be much greater than 28% during the early Station assembly period. (Note: TCCS flight operations allowed later CBA, COA, and SBA performance evaluation that extended the component service lives. See reference 18 for details on the TCCS process economics.)

10.7 Summary

An engineering analysis of the relevant ingress scenarios for Destiny has been conducted to determine the ISS's capability for meeting relevant TCC requirement and ingress flight rule criteria during STS-98/5A. As well, the ability of the TCCS and BMP located in Destiny and Zvezda, respectively, to control the entire ISS trace contaminant load during the 5A increment under normal and contingency conditions has been evaluated. The evaluation of the service intervals for the major TCCS expendable beds against the USOS Specification (SSP 41162R) trace contaminant load was conducted and yielded recommendations consistent with and conservative with respect to those prescribed by Lockheed Martin. Based upon the overall analysis results, the onboard contamination control systems available during STS-98/5A can provide adequate preingress atmospheric scrubbing for Destiny and maintain individual trace contaminant concentrations below their respective SMACs with margin for the entire ISS during increment 5A and beyond.

10.8 Conclusions

Based upon the STS-98/5A TCC capability assessment results, conclusions that can be made are the following:

- Six CACEAs must be installed in Destiny to provide preingress scrubbing capacity that will allow ISS program requirements and atmospheric quality parameters documented by flight rules to be met.
- The crew must take special precautions to enter Destiny safely in the event that the preingress scrub is not successfully completed.
  (Note: TCCS flight operations allowed later CBA, COA, and SBA performance evaluation that extended the component service lives. See reference 19 for details on the TCCS process economics.)

- The TCCS and BMP are capable of handling the entire ISS trace contaminant load while operating simultaneously or alone.

10.9 Recommendations

Recommendations for addressing continuing ISS TCC issues during ingress operations are the following:

- The minimum preingress scrubbing duration for Destiny should be 2 hours to ensure a *T*-value magnitude of at least 1 at ingress.

- In the event that Destiny's preingress scrub is not completed successfully, the crew should establish ventilation with the other ISS modules and wait 2 hours before entering for an extended period without respiratory protection.

- Operate the TCCS in parallel with the BMP to adequately control methane and hydrogen concentrations.

- Replace the TCCS CBA and SBA at 1-year intervals and the COA at 2-year intervals.

11. MISSION 7A TRACE CONTAMINANT CONTROL CAPABILITY ASSESSMENT

This assessment was originally released under NASA Memorandum FD21(01-085) dated April 9, 2001.

11.1 Background

The airlock is the primary cargo for the STS-104/7A mission to the ISS. In order to satisfy the ISS program's TCC requirements, as well as to ensure crew health and safety, the expected air quality during initial ingress of the airlock has been predicted by analysis. Offgassing test data collected from the airlock between November 16 and December 1, 2000, serve as the basis for trace gaseous contaminant generation. These data are provided in appendix B.

11.2 Purpose

The engineering analysis summarized by the following discussion serves to verify the ISS's TCC capability for mission 7A. Specifically, it addresses the air quality during the first ingress of the airlock.

11.3 Objectives

The approach to maintaining acceptable cabin air quality in the airlock during mission 7A is assessed by engineering analysis. Specific objectives of the analysis which serve to verify the approach are the following:

- Predict individual trace contaminant concentrations during ingress operations.

- Determine the minimum on-orbit purge duration in the event ingress flight rule criteria are exceeded.

11.4 Assumptions

To conduct the mission 7A trace contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

11.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the mission 7A engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results and adjusted by a factor of 1.33 to account for hardware not yet installed in the airlock.

- ISS atmospheric leakage is zero. This is considered to be true for the early stages of the ISS's on-orbit life.

- Cabin atmospheric conditions are on average 20 °C, 50% relative humidity, and 101.3 kPa.

- Offgassing rates are constant with time. This has been shown by analyses conducted to date to be conservative as rates tend to decay with time.

- Seven-day SMACs apply for the ingress analysis scenario according to flight rule X13.2.2-2 provided in appendix A.

11.4.2 On-Orbit Configuration

During mission 7A, the ISS's on-orbit configuration consists of PMA-1, PMA-2, PMA-3, Unity (Node 1), Destiny (U.S. Laboratory), Zarya, Zvezda, a Soyuz spacecraft, the airlock, and the Shuttle. The airlock remains isolated until it is attached to the ISS. Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Previous analysis conducted for missions 5A and 5A.1 has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] In the airlock's case, IMV forces contaminant-laden air out where it is mixed with conditioned air in the main ISS cabin. The TCCS and BMP remove the added contaminants from the airlock and the revitalized air flows back into the airlock via the IMV system. Assumptions pertaining to the ISS's configuration and its contamination control capability are the following:

- Airlock free volume is 29.7 m^3.

- ISS free volume is approximately 300.4 m^3.

- Contamination control in the airlock is provided parasitically via IMV with the ISS.

- IMV flow is 203.9 m^3/hr for the airlock open hatch configuration and 106.2 m^3/hr for the housekeeping mode.[5]

11.4.3 Mission Timeline

The mission timeline used to evaluate ingress of the airlock assumes approximately 81 days elapse between ground closeout on approximately March 30, 2001, and on-orbit ingress on approximately June 19. The time to reach a *T*-value magnitude of 3 is also evaluated to understand the allowable launch slip before a ground purge would be necessary.

11.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for STS-104/7A. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

11.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of grab samples collected from airlock between November 6 and December 1, 2000. Test results are provided in appendix B. Sample sets were collected at the beginning of the test, at 187 hours, and at 354 hours. Approximately 75% of the internal hardware mass was accounted for at the time of this test. Accordingly, the derived rates are adjusted by a factor of 1.33 to account for the missing mass. Individual contaminant generation rates for each time increment are derived using equation (3) which is the differential form of equation (2).

11.5.2 Analysis Cases Considered

The primary case considered is the normal ingress of the airlock. Projections of the elapsed time to *T*-value magnitudes of 1 and 3 are also considered as well as a calculation of the appropriate amount of time to reduce the *T*-value from an arbitrary value of 5 to the flight rule ingress criterion of 3.

11.5.3 Calculation Approach

Each contaminant concentration at ingress is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1. Once the concentration has been calculated, the overall *T*-value is calculated using equation (1).

The time to reduce the *T*-value magnitude from a beginning level to the flight rule ingress criterion of 3 is calculated directly by using equation (5) solved for time.

11.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

11.6.1 Derived Generation Rates

Analysis of samples collected during the element offgassing test identified 14 chemical compounds with measurable generation rates (summarized in table 2). The average concentrations at each sampling event during the test are provided. These concentrations were used in equation (3) to derive the generation rate.

11.6.2 Normal Airlock Ingress During Mission 7A

As shown in table 32, none of the 15 chemical compounds identified by the offgassing test will exceed their individual SMACs after the approximately 81 days that elapse between closeout on the ground and on-orbit ingress. Based on the assumption that closeout occurs on March 30, 2001, with STS-104/7A launch on June 14 and airlock ingress on approximately June 19. Based upon these concentrations, the predicted *T*-value is 1.35. This is well below the 3 allowed by flight rule X13.2.2- 2.

Therefore, no special ventilation setup or scrubbing equipment are necessary to support a normal airlock ingress and activation. Methanol is the major contributor to the predicted *T*-value. Trimethylsilanol, hexamethylcylclotrisiloxane, 2-propanol, and 2-propanone also contribute significantly. Overall, the *T*-value rises at 0.000698 units/hour or 0.0167 units/day. The airlock's offgassing load represents a 2% increase in the total Station load.

Table 32. Generation rates and predicted ingress concentrations for mission 7A.

Compound	SMAC (mg/m^3)	C_1 (mg/m^3)	C_2 (mg/m^3)	C_3 (mg/m^3)	Rate (mg/hr)	$C_{Ingress}$ (mg/m^3)
Methanol	9	0.025	0.365	0.7	0.0757	4.96
Ethanol	2,000	0.66	2.05	3.05	0.266	17.4
2-propanol	150	89.5	77.5	78.5	0.237	15.5
n-propanol	98	0.025	0.45	0.635	0.0669	4.38
n-butanol	80	0.025	0.2	0.295	0.0298	1.95
Ethanal	4	0.0425	0.065	0.07	0.00298	0.195
Propanal	95	–	0.065	0.11	0.0122	0.8
Methylbenzene	60	0.025	0.16	0.24	0.0238	1.56
Trichlorotrifluoroethane (Freon 113)	400	0.025	0.175	0.165	0.0147	0.962
2-propanone	52	0.225	0.54	0.68	0.0499	3.27
2-butanone	30	0.025	0.12	0.17	0.016	1.05
Cyclohexanone	60	0.025	0.12	0.195	0.0189	1.24
Octamethylcyclotetrasiloxane	280	0.055	0.36	0.305	0.0258	1.69
Hexamethylcyclotrisiloxane	90	–	0.92	1.85	0.208	13.6
Trimethylsilanol	37	–	0.87	1.35	0.149	9.75

11.6.3 Contingency Ingress Scenario

Contingency operations are required only in the event the predicted *T*-value exceeds 3. A *T*-value magnitude of 3 is reached after the airlock has been sealed for 179 days. This condition would not be reached unless the STS-104/7A launch slips 98 days. Therefore, based upon the offgassing test data, the crew will be able to enter the airlock during STS-104/7A without taking special actions unless a major problem results in a substantial launch delay or there has been some indication of a fire in the airlock.

For the hypothetical case where the starting *T*-value magnitude is equal to 6, the upper operational bound specified by flight rule X13.2.2-2 provided in appendix A, the airlock must be ventilated for 24 minutes minimum using the IMV setup in the open hatch configuration before the crew may enter. Using a 10% margin, a ventilation period of 26 minutes is recommended. This will reduce the *T*-value below the flight rule criterion of 3, thus minimizing the effects on crew health and mission timeline. In the event that the airlock's cabin fan does not operate properly, the IMV may be set up in the housekeeping mode. In this case, the elapsed time before crew ingress would be a minimum of 46 minutes. Including a 10% margin, the recommended time before initiating IMV and crew ingress is 51 minutes.

11.7 Summary

The air quality in the airlock has been evaluated based upon data acquired from the element offgassing test. The analysis projects an ingress *T*-value of 1.35 and a contaminant buildup rate of 0.0167 *T*-value units/day. The contamination load from airlock represents a 2% increase in the total Station load. This increase is easily accommodated by the TCCS and BMP. As well, a substantial launch slip must occur before the predicted contamination level would exceed the ingress criteria of flight rule X13.2.2-2.

In the event of a substantial delay or the known introduction of highly volatile materials, it is recommended that airlock be purged for 26 minutes via the IMV setup in the open hatch configuration before the crew enters. If both a substantial launch delay and the cabin fan fails to operate, the airlock must be purged for 51 minutes via the IMV setup in the housekeeping configuration before the crew enters.

11.8 Conclusions

Based upon the evaluation of offgassing data collected from the airlock, conclusions which can be made are the following:

- Equipment offgassing rates observed for the airlock are low.

- The crew may enter airlock without special precaution because the predicted *T*-value is less than 3.

- Total onboard TCC resources are capable of maintaining acceptable air quality in airlock as well as the overall ISS cabin.

11.9 Recommendations

Recommendations pertaining to the in-flight activation and operation of the airlock are the following:

- In the event of a substantial launch delay, the recommended ventilation duration using the IMV setup in the open hatch configuration is 26 minutes to ensure a *T*-value less than 3 at ingress. In the case of the airlock, a substantial delay is defined as greater than 98 days.

- In the event of both a substantial launch delay and an airlock cabin fan failure, the recommended ventilation duration using the IMV setup in the housekeeping mode is 51 minutes to ensure a *T*-value less than 3.

12. ASSEMBLY MISSION 10A—HARMONY NODE 2 TRACE CONTAMINANT CONTROL ASSESSMENT

The original assessment was released under NASA Memorandum EI12(07-015) dated August 31, 2007.

12.1 Background

The Harmony Node 2, a habitable element of the USOS, will be attached to the forward hatch of the ISS's Destiny laboratory module. Because the Harmony Node 2 module is sealed from the time it is closed out in the Space Station Processing Facility (SSPF) until it is mated to the ISS on orbit, buildup of trace chemical contaminants becomes a concern. Adding new modules to the ISS can be a source of trace chemical contamination generation that may cause cabin air quality transients during module first entry and activation. The available Harmony Node 2 offgassing testing data are assessed before flight to satisfy the ISS program's TCC requirements as well as to ensure crew health and safety during first entry and activation. The assessment predicts the expected air quality during initial entry of the Harmony Node 2 using NASA-acquired, module-level offgassing test data.

12.2 Purpose

The engineering analysis summarized by the following discussion serves to predict the trace chemical contaminant concentration condition within the Harmony Node 2 cabin at the time the hatch is opened to the ISS.

12.3 Objective

The approach to maintaining acceptable cabin air quality in the Harmony Node 2 during first entry on orbit is assessed by engineering analysis. The primary objective of the assessment is to predict individual trace chemical contaminant concentrations at the time the hatch opens on orbit and to recommend appropriate actions, if any, necessary to ensure crew and ISS cabin environmental health and safety.

12.4 Assumptions

To conduct the Harmony Node 2 trace chemical contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

12.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the Harmony Node 2 TCC engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results reported by NASA.
- Atmospheric leakage from the Harmony Node 2 is zero. This is considered to be true for all new ISS elements.
- The Harmony Node 2 free volume is approximately 62 m^3.
- The Harmony Node 2 was completely outfitted for flight at the time of the offgassing test.
- Cabin atmospheric conditions are on average 20 °C, 50% relative humidity, and 101.3 kPa.
- Offgassing rates are constant with time. This is conservative because experience has shown rates decay with time.
- Acceptable risk and zero risk air quality concentrations as defined by the ISS MORD (SSP 50260) apply.[6]
- Ventilation flow between the Harmony Node 2 and Destiny laboratory module are maintained between 229 and 246 m^3/hr after successful on-orbit module activation.

12.4.2 On-Orbit Configuration

During the ISS assembly mission STS-120/10A that will deliver the Harmony Node 2 module, the ISS's on-orbit configuration consists of PMA-1, PMA-2, Unity (Node 1), Destiny (U.S. Laboratory), Quest (U.S. airlock), Zarya (FGB), Zvezda (service module), a Soyuz spacecraft, and a Progress cargo vehicle. The ISS's total habitable volume is approximately 452 m^3, including the Harmony Node 2 module. The Harmony Node 2 remains isolated until it is attached to the ISS and the hatch opens. Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] Once the Harmony Node 2 hatch is opened, accumulated trace chemical contamination will mix within the main ISS cabin where the TCCS and BMP remove the added contaminants.

12.4.3 Mission Timeline

The total elapsed time between final closeout and on-orbit first entry is ~65 days assuming the module is sealed on approximately August 13, 2007, for STS-120/10A launch scheduled for October 16, 2007, with subsequent on-orbit entry on flight day 5 on approximately October 21, 2007, any launch delay will increase the elapsed closeout time on a day-to-day basis.

12.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for evaluating the scenario for the first entry of the Harmony Node 2. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

12.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of offgassing test grab samples collected from the Harmony Node 2 by NASA between June 11 and July 5, 2007. Sample sets were collected at approximately 165 hours, 332 hours, and 567 hours after closing the hatch. A sample set was also collected immediately at hatch closure. The Harmony Node 2 was configured for flight at the time of the test. Therefore, no adjustment is necessary to account for missing internal equipment. Individual contaminant generation rates for each time increment are derived using equation (3) which is the differential form of equation (2).

12.5.2 Analysis Cases Considered

The primary case considered is the normal first entry of the Harmony Node 2. Comparison of the individual contaminant concentrations to zero risk and acceptable risk concentrations defined by the ISS MORD is conducted for the normal first entry case to satisfy basic ISS program contamination control requirements. A prediction of the T-value magnitude at first entry is made to address guidelines contained in flight rules pertaining to first module ingress. Margin for launch delays or other delays to on-orbit first entry is also evaluated.

12.5.3 Calculation Approach

Each contaminant concentration at ingress is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1. Once the concentration has been calculated, the overall T-value is calculated using equation (1).

12.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

12.6.1 Derived Generation Rates

The element offgassing test conducted by NASA found the Harmony Node 2 to be very clean. Twenty-four chemical compounds with measurable generation rates were noted in the test samples and are summarized in table 33. The average concentrations at each sampling event, listed in appendix B, were used in equation (3) to derive the generation rate.

Table 33. Generation rates and predicted ingress concentrations for mission 10A.

	Limits in Air			
Compound	ZRL (mg/m^3)	ARL (mg/m^3)	Rate (mg/hr)	$C_{Ingress}$ (mg/m^3)
Methanol	0.2	9	0.011	0.27
Ethanol	10	2,000	0.049	1.23
2-propanol	1.5	150	0.023	0.58
Propanol	0.6	98	0.009	0.22
2-methyl-2-propanol	0.1	100	0.002	0.06
Butanol	0.8	40	0.018	0.45
Ethanal	1	4	0.014	0.36
Propanal	N/A	95	0.003	0.09
2-methyl-2-propenal	N/A	3.4	0.003	0.08
Butanal	N/A	118	0.002	0.04
Methylbenzene	8	60	0.003	0.06
1,3-dimethylbenzene	5	220	0.002	0.04
1,4-dimethylbenzene	5	220	0.002	0.04
Dichloromethane	5	10	0.003	0.08
1,2-dichloroethane	0.5	1	0.003	0.06
Trichlorofluoromethane	N/A	790	0.003	0.08
1,2-dichloro-1,1,2,2-tetrafluoroethane	100	700	0.005	0.13
2-propanone	2	50	0.018	0.45
2-butanone	0.25	30	0.026	0.65
Cyclohexanone	1.3	60	0.003	0.09
Carbon monoxide	5	11	0.035	0.89
Carbonyl sulfide	N/A	12	0.009	0.22
Carbon disulfide	1	16	0.0001	0.003
Trimethylsilanol	0.2	37	0.05	1.26
Hexamethylcyclotrisiloxane	0.2	9	0.035	0.86

12.6.2 Normal Entry of the Harmony Node 2

As shown in table 33, none of the 25 chemical compounds identified by the offgassing tests will exceed the acceptable risk concentrations after the elapsed 65 days between final Harmony Node 2 closeout and on-orbit first entry. Methanol, 2-butanone, trimethylsilanol, and hexamethylcyclotrisiloxane may be expected to exceed their respective zero risk concentrations. These results indicate that the risk to the crew for developing sick building syndrome symptoms upon entering the Harmony Node 2 is quite low.

12.6.3 Total Contamination Contribution to the International Space Station

Overall, the *T*-value rises at 0.00032 units/hour or 0.0077 units/day when using the acceptable risk concentrations as a basis. The total *T*-value is expected to be 0.5 units for a normal flight itinerary. The total estimated 0.33 mg/hr offgassing load from the Harmony Node 2 represents a 0.6% increase in the total Station load compared to 56.6 mg/hr at flight 5A. The maximum magnitude of the concentration transient that may occur during the Harmony Node 2 first entry operations is ~1 mg/m^3 over a 2-hour period. Previous analysis of Unity Node 1 first entry operations has established that mixing between the ISS volume and a new cargo carrier or module is complete within approximately 2 hours of establishing ventilation flow. If the predicted offgassing from the Harmony

Node 2 is sustained over time, the total Station trace chemical contaminant concentration is predicted to rise by ~0.01 mg/m^3.

The total trace chemical contaminant concentration predicted at first entry, 8 mg/m^3, is more than four times lower than the 25 mg/m^3 guideline used by NASA toxicology personnel for preventing sick building syndrome symptoms. This total nonmethane volatile organic compound (NMVOC) concentration guideline is not documented in any ISS specification or operations documentation. However, it is prudent to consider it for overall completeness. The ISS cabin total NMVOC concentration is maintained between 10 and 15 mg/m^3. The predicted *T*-value magnitude below 1 indicates the risk for short-lived sick building syndrome symptoms is expected to be quite low. Based on these observations, it is expected that the ISS crew may enter the Harmony Node 2 immediately during the first entry flight operations.

12.6.4 Margin for Launch and Docking Delay

The present analysis indicates that the maximum *T*-value magnitude of 3, referenced to the acceptable risk concentrations, is not reached for 390 days after the final prelaunch closeout. This allows for substantial operational margin that should accommodate any launch delays when using the *T*-value as a basis for safe entry. After 670 days of isolation, hexamethylcyclotrisiloxane is the first compound to reach its individual acceptable risk concentration. These predicted results indicate that the need to purge the module again after a launch delay is unlikely. However, to address uncertainties associated with the module's configuration and sample analysis methods, it is recommended that, as a precaution, the module be purged for launch slips in excess of 6 months.

12.7 Summary

The predicted air quality in the Harmony Node 2 has been evaluated based upon data acquired from the element offgassing test. The analysis projects an ingress *T*-value of 0.5 using the acceptable risk concentrations defined by the ISS MORD as the reference basis. No single chemical compound is predicted to exceed its acceptable risk concentration; however, methanol, 2-butanone, trimethylsilanol, and hexamethylcyclotrisiloxane are predicted to exceed their respective zero risk concentrations. The contribution to the total ISS trace contaminant load may result in a ~0.01 mg/m^3 increase in total NMVOC concentration. The total trace contaminant concentration inside the Harmony Node 2 is predicted to be ~8 mg/m^3—32% of the 25 mg/m^3 guideline for minimizing the risk for developing sick building syndrome symptoms. This low total concentration, which is below the normal total NMVOC concentration range maintained within the main ISS cabin, will allow the flight crew to enter the module without taking precautions beyond those already prescribed by flight rules governing module first entry. The offgassing test results indicate that the Harmony Node 2 is exceptionally clean and substantial operational margin exists to accommodate launch delays up to 6 months.

12.8 Conclusions

Conclusions from the predicted trace contaminant environment in the Harmony Node 2 at first entry using offgassing data collected from the module are the following:

- No single contaminant will exceed its individual acceptable risk concentration (NASA SMAC).
- Methanol, 2-butanone, trimethylsilanol, and hexamethylcyclotrisiloxane may temporarily exceed their individual zero risk concentrations during first entry operations.
- The predicted maximum transient in the ISS cabin total NMVOC concentration during Harmony Node 2 first entry operation is ~1 mg/m^3.
- The predicted maximum sustained increase in cabin total NMVOC concentration that may result from adding the Harmony Node 2 to the ISS is ~0.01 mg/m^3.

12.9 Recommendation

The module offgassing test results from the Harmony Node 2 find that the module is very clean and that substantial margin exists to accommodate long-term launch delays. For conservatism, it is recommended that a module purge be conducted for a launch delay exceeding 6 months.

13. ASSEMBLY MISSION 1E—COLUMBUS ATTACHED PRESSURIZED MODULE TRACE CONTAMINANT CONTROL ASSESSMENT

This assessment was originally released under NASA Memorandum EI12(07-013) dated August 3, 2007.

13.1 Background

The Columbus APM is a major contribution from the ISS program's international partner that will be attached to the Node 2 starboard radial port. Because the Columbus APM is sealed from the time it is closed out in the SSPF until it is mated to the ISS on orbit, buildup of trace chemical contaminants becomes a concern. Adding new modules to the ISS can be a source of trace chemical contamination generation that may cause cabin air quality transients during module first entry and activation. The available Columbus APM offgassing testing data were assessed before flight to satisfy the ISS program's TCC requirements as well as to ensure crew health and safety during first entry and activation. The assessment predicts the expected air quality during initial entry of the Columbus APM using NASA-acquired, module-level offgassing test data.

13.2 Purpose

The engineering analysis summarized by the following discussion serves to predict the trace chemical contaminant concentration condition within the Columbus APM cabin at the time the hatch is opened to the ISS.

13.3 Objective

The approach to maintaining acceptable cabin air quality in the Columbus APM during first entry on orbit is assessed by engineering analysis. The primary objective of the assessment is to predict individual trace chemical contaminant concentrations at the time the hatch opens on orbit and to recommend appropriate actions, if any, necessary to ensure crew and ISS cabin environmental health and safety.

13.4 Assumptions

To conduct the Columbus APM trace chemical contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, trace contaminant control hardware configuration, and mission timeline.

13.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the Columbus APM trace contaminant control engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results reported by NASA.
- Atmospheric leakage from the Columbus APM is zero. This is considered to be true for all new ISS elements.
- The Columbus APM free volume is approximately 64 m^3.
- The Columbus APM was completely outfitted for flight at the time of the offgassing test.
- Atmospheric conditions are on average 20 °C, 50% relative humidity, and 1 atm.
- Offgassing rates are constant with time. This has been shown to be conservative because experience has shown rates decay with time.
- Acceptable risk and zero risk air quality limits as defined by SSP 50260 apply.
- Ventilation flow between the Columbus APM and Node 2 are maintained at ~229 m^3/hr after successful on-orbit module activation.

13.4.2 On-Orbit Configuration

During the ISS assembly mission STS-122/1E that will deliver and activate the Columbus APM, the ISS's on-orbit configuration consists of PMA-1, PMA-2, Unity (Node 1), Destiny (U.S. Laboratory), Quest (U.S. airlock), Harmony (Node 2), Zarya (FGB), Zvezda (service module), a Soyuz spacecraft, and a Progress cargo vehicle. The ISS's total habitable volume is approximately 478 m^3, including the Columbus APM. The Columbus APM remains isolated until it is attached to the ISS and the hatch opens. The total elapsed time between the last breathing air renewal on the ground and docking with the ISS is approximately 54 days, assuming the module is sealed on approximately October 17, 2007, and on-orbit entry occurs on approximately December 10, 2007. The STS-122/1E mission launch is scheduled for December 6, 2007. Any launch delay will increase the elapsed closeout time on a day-to-day basis. Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] Once the Columbus APM hatch is opened, accumulated trace chemical contamination will mix within the main ISS cabin where the TCCS and BMP remove the added contaminants.

13.4.3 Mission Timeline

The mission timeline used to evaluate the air quality conditions during the first entry of the Columbus APM assumes approximately 54 days elapse between the last breathing air renewal during final prelaunch processing and on-orbit ingress. The time to reach a *T*-value of 1 and 3 are also evaluated to understand the allowable launch slip before a new breathing air renewal would be necessary.

13.5 Approach

The following discussion summarizes the ISS trace contaminant control capability assessment approach for evaluating the scenario for the first entry of the Columbus APM. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

13.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of offgassing test grab samples collected from the Columbus APM by NASA between November 2 and November 21, 2006. Sample sets were collected at 288 hours and 456 hours after closing the hatch. A sample set was also collected immediately at hatch closure. The Columbus APM was empty at the time of the test but fully configured for flight. Therefore, no adjustment is necessary to account for missing internal equipment. Individual contaminant generation rates are derived using equation (3).

13.5.2 Analysis Cases Considered

The primary case considered is the normal first entry of the Columbus APM. Comparison of the individual contaminant concentrations to zero risk and acceptable risk concentrations defined by the MORD is conducted for the normal first entry case to satisfy basic ISS program contamination control requirements. A prediction of the T-value magnitude at first entry is made to address guidelines contained in flight rules pertaining to first module ingress. Margin for launch delays and docking delays is also evaluated.

13.5.3 Calculation Approach

Each contaminant concentration at ingress is calculated directly using the solved form of equation (2) as shown by equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1. Once the concentration has been calculated, the overall T-value is calculated using equation (1).

13.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

13.6.1 Derived Generation Rates

The element offgassing test conducted by NASA found the Columbus APM to be exceptionally clean. Only nine chemical compounds with measurable generation rates were noted in the test samples. They are summarized in table 34. The average concentrations for the Columbus APM offgassing test listed in appendix A were used in equation (3) to derive the generation rate.

Table 34. Generation rates and predicted ingress concentrations.

Compound	Limits in Air		Rate (mg/hr)	$C_{Ingress}$ (mg/m^3)
	ZRL (mg/m^3)	ARL (mg/m^3)		
Methanol	0.2	9	0.4	0.34
Ethanol	10	2,000	0.21	0.17
n-propanol	1.5	150	0.26	0.22
n-butanol	0.8	40	0.16	0.13
Ethanal	1	4	0.16	0.13
Methylbenzene	8	60	0.21	0.17
2-propanone	2	50	0.16	0.13
2-butanone	0.25	30	0.71	0.6
Trimethylsilanol	0.2	37	2.5	2.1

13.6.2 Normal Entry of the Columbus Attached Pressurized Module

As shown in table 34, none of the nine chemical compounds identified by the offgassing tests will exceed the acceptable risk concentrations after the elapsed 54 days between final Columbus APM closeout and on-orbit ingress. Methanol, 2-butanone, and trimethylsilanol may be expected to exceed their respective zero risk concentrations. These results indicate that the risk to the crew for developing sick building syndrome symptoms upon entering the Columbus APM is exceptionally low.

13.6.3 Total Contamination Contribution to the International Space Station

Overall, the T-value rises at 0.000125 units/hour or 0.003 units/day when using the acceptable risk concentrations as a basis. The total T-value is expected to be 0.16 units for a normal flight itinerary. The total estimated 4.8 mg/hr offgassing load from the Columbus APM represents an 8.5% increase in the total Station load compared to 56.6 mg/hr at flight 5A. The maximum magnitude of the concentration transient that may occur during the Columbus APM first entry operations is ~0.5 mg/m^3 over a 2-hour period. Previous analysis for Node 1 first entry operations has established that mixing between the ISS volume and a new cargo carrier or module is complete within approximately 2 hours of establishing ventilation flow. If the predicted offgassing from the Columbus APM is sustained over time, the total Station trace chemical contaminant concentration is predicted to rise by ~0.1 mg/m^3.

The total trace chemical contaminant concentration predicted at first entry, 4 mg/m^3, is more than 6 times lower than the 25 mg/m^3 guideline used by NASA toxicology personnel for preventing sick building syndrome symptoms. This total NMVOC concentration guideline is not documented in any ISS specification or operations documentation. However, it is prudent to consider it for overall completeness. The ISS cabin total NMVOC concentration is maintained between 10 and 15 mg/m^3. The predicted T-value far below 1, indicating the risk for short-lived sick building syndrome symptoms, is expected to be quite low. Based on these observations, it is expected that the ISS crew may enter the Columbus APM immediately during the first entry flight operations.

13.6.4 Margin for Launch and Docking Delay

The present analysis indicates that the maximum *T*-value of 3, referenced to the acceptable risk concentrations, is not reached for 1,000 days after the final prelaunch closeout. This allows for substantial operational margin that should accommodate any launch delays when using the *T*-value as a basis for safe entry. After 143 days of isolation, methanol is the first compound to reach its individual acceptable risk concentration. These predicted results indicate that the need to purge the module again after a launch slip is unlikely. However, to address uncertainties associated with the module's configuration and sample analysis methods, it is recommended that, as a precaution, the module be purged for launch slips in excess of 2 months.

13.6.5 Analysis Conservatism

The analysis assumes that all equipment planned to be in the Columbus APM at launch was actually in the module at the time of the offgassing test. If it is assumed that 25% of the internal equipment was missing, then the contaminant rates must be adjusted upward by a factor of 1.33. Including this factor, a substantial operational margin remains for maintaining acceptable cabin air quality during first entry operations.

13.7 Summary

The predicted air quality in the Columbus APM has been evaluated based upon data acquired from the element offgassing test. The analysis projects an ingress *T*-value of 0.16 using the acceptable risk concentrations defined by SSP 50260 as the reference basis. No single chemical compound is predicted to exceed its acceptable risk concentration; however, methanol, 2-butanone, and trimethylsilanol are predicted to exceed their respective zero risk concentrations. The contribution to the total ISS trace contaminant load may result in a ~0.1 mg/m^3 increase in total NMVOC concentration. The total trace contaminant concentration inside the Columbus APM is predicted to be ~4 mg/m^3—less than 20% of the 25 mg/m^3 guideline for minimizing the risk for developing sick building syndrome symptoms. This low total concentration will allow the flight crew to enter the module without taking precautions beyond those already prescribed by flight rules governing module first entry. The offgassing test results indicate that the Columbus APM is exceptionally clean and substantial operational margin exists to accommodate launch delays up to 2 months.

13.8 Conclusions

Conclusions from the predicted trace contaminant environment in the Columbus APM at first ingress using offgassing data collected from the module are the following:

- No single contaminant will exceed its individual acceptable risk concentration (NASA SMAC).
- Methanol, 2-butanone, and trimethylsilanol may temporarily exceed their individual zero risk concentrations during first entry operations.
- The predicted maximum transient in the ISS cabin total NMVOC concentration during Columbus APM first entry operation is ~0.5 mg/m^3.

- The predicted maximum sustained increase in cabin total NMVOC concentration that may result from adding the Columbus APM to the ISS is ~0.1 mg/m^3.

13.9 Recommendation

The module offgassing test results from the Columbus APM find that the module is exceptionally clean and that substantial margin exists to accommodate long-term launch delays. For conservatism, it is recommended that a module purge be conducted for a launch delay exceeding 2 months.

14. ASSEMBLY MISSION 1J/A—KIBO EXPERIMENT LOGISTICS MODULE PRESSURIZED SECTION TRACE CONTAMINANT CONTROL ASSESSMENT

This assessment was originally released under NASA Memorandum ES22(08-001) dated January 7, 2008.

14.1 Background

The Kibo experiment logistics module (ELM) PS is a major contribution from the ISS program's international partner, the Japanese Aerospace Exploration Agency (JAXA), which attaches to the larger Kibo pressurized laboratory module. Because the Kibo ELM PS is sealed from the time it is closed out in the SSPF until it is mated to the ISS on orbit, buildup of trace chemical contaminants becomes a concern. Adding new modules to the ISS is a source of trace chemical contamination generation that causes cabin air quality transients during module first entry and activation. The available Kibo ELM PS offgassing testing data are assessed by NASA toxicologists and ECLSS engineers before flight to ensure crew health and safety as well as to satisfy the ISS program's TCC requirements for module first entry and activation. The assessment predicts the expected air quality during initial entry of the Kibo ELM PS using NASA-acquired, module-level offgassing test data.

14.2 Purpose

The engineering analysis summarized by the following discussion serves to predict the trace chemical contaminant concentration condition within the Kibo ELM PS cabin at the time the hatch is opened to the ISS.

14.3 Objective

The approach to maintaining acceptable cabin air quality in the Kibo ELM PS during first entry on orbit is assessed by engineering analysis. The assessment's primary objective is to predict individual trace chemical contaminant concentrations at the time the hatch opens on orbit and to recommend appropriate actions, if any, necessary to ensure crew and ISS cabin environmental health and safety.

14.4 Assumptions

To conduct the Kibo ELM PS trace chemical contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

14.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the Kibo ELM PS TCC engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results reported by NASA.
- Atmospheric leakage from the Kibo ELM PS is zero. This is considered to be true for all new ISS elements.
- The Kibo ELM PS free volume is approximately 39 m^3.
- The Kibo ELM PS was 77% outfitted by mass for flight at the time of the offgassing test.
- Cabin atmospheric conditions are on average 20 °C, 50% relative humidity, and 101.3 kPa.
- Offgassing rates are constant with time. This has been shown to be conservative because experience has shown rates decay with time.
- Acceptable risk and zero risk air quality limits as defined by the ISS MORD apply.
- Ventilation flow between the Kibo ELM PS and Node 2 are maintained at ~229 m^3/hr after successful on-orbit module activation.

14.4.2 On-Orbit Configuration

During the ISS assembly mission STS-123/ISS 1J/A that will deliver and activate the Kibo ELM PS, the ISS's on-orbit configuration consists of PMA-1, PMA-2, Unity (Node 1), Destiny (U.S. Laboratory), Quest (U.S. airlock), Harmony (Node 2), Columbus APM, Zarya (FGB), Zvezda (service module), a Soyuz spacecraft, and a Progress cargo vehicle. The ISS's total habitable volume is approximately 497 m^3, including the Kibo ELM PS. The Kibo ELM PS remains isolated until it is attached to the ISS and the hatch opens.

Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] Once the Kibo ELM PS hatch is opened, accumulated trace chemical contamination will mix within the main ISS cabin where the TCCS and BMP remove the added contaminants.

14.4.3 Mission Timeline

The total elapsed time between the last breathing air renewal on the ground and docking with the ISS is approximately 72 days assuming the module is sealed on approximately November 7, 2007, in preparation for STS-123/ISS 1J/A mission launch on February 14, 2008. On-orbit entry is scheduled to occur on February 18, 2008. Any launch delay will increase the elapsed closeout time on a day-to-day basis. The elapsed time necessary to reach the acceptable risk concentration for any single chemical contaminant as well as the time to reach T-value magnitude of 3 are also evaluated to understand the allowable launch slip before a new breathing air renewal is necessary.

14.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for evaluating the scenario for the first entry of the Kibo ELM PS. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

14.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation results in a steady increase in concentration, C_i, over time, t, as denoted by equation (2). Trace contaminant generation rates are derived from the analytical results of offgassing test grab samples collected from the Kibo ELM PS by NASA between August 29 and September 21, 2007. Sample sets were collected at 144 hours and 552 hours after closing the hatch. A sample set was also collected immediately at hatch closure. This first sample set serves as the starting basis at time zero. The Kibo ELM PS was 77% outfitted by mass for flight at the time of the test. Individual contaminant generation rates are derived using equation (3) which is equation (2) in differential form solved for the generation rate. The resulting rate is divided by 0.77 to account for equipment that was not installed in the Kibo ELM PS at the time of the offgassing test. For the test conducted on the Kibo ELM PS, time increment values of 144 and 552 hours apply.

14.5.2 Analysis Cases Considered

The primary case considered is the normal first entry of the Kibo ELM PS. Comparison of the individual contaminant concentrations to zero risk and acceptable risk concentrations defined by the ISS MORD (SSP 50260) is conducted for the normal first entry case to satisfy basic ISS program contamination control requirements.[6] A prediction of the T-value magnitude at first entry is made to address guidelines contained in flight rules pertaining to first module ingress. Margin for launch delays and docking delays are also evaluated.

14.5.3 Calculation Approach

Each contaminant concentration at ingress is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1. Once the concentration has been calculated, the overall T-value is calculated using equation (1).

14.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

14.6.1 Derived Generation Rates

The element offgassing test conducted by NASA found the Kibo ELM PS to be quite clean. Twenty-one chemical compounds with measurable concentrations were found in the test samples. Five compounds—methanol, ethanol, 2-propanol, ethyl acetate, and 4-methyl-2-pentanone—exhibited decreasing concentration trends during the test which do not allow for a generation rate to be determined. Due to the significant concentrations observed for these five compounds, it is likely that they will be present in the Kibo ELM PS atmosphere at first module entry on orbit. Experience from first ingress operations for seven multipurpose logistics module (MPLM) missions has found average concentrations for methanol, ethanol, 2-propanol, ethyl acetate, and 4-methyl-2-pentanone to average 0.3 mg/m^3, 1.5 mg/m^3, 2.3 mg/m^3, 0.1 mg/m^3, and trace, respectively. The individual compound generation rates derived from the offgassing test data are summarized in table 35. Average concentrations at each sampling event, provided in appendix B, were used in equation (3) to derive the generation rate. The result was divided by 0.77 to account for equipment not installed in the Kibo ELM PS at the time of the test.

14.6.2 Normal Entry of the Kibo Experiment Logistics Module Pressurized Section

As shown in table 35, none of the 16 chemical compounds identified by the offgassing tests will exceed the acceptable risk concentrations after the elapsed 72 days between final Kibo ELM PS closeout and on-orbit ingress. Trimethylsilanol and 2-butanone may be expected to exceed their respective zero risk concentrations. These results indicate low risk to the crew for developing sick building syndrome symptoms upon entering the Kibo ELM PS.

Table 35. Generation rates and predicted ingress concentrations for mission 1J/A.

Compound	Limits in Air		Rate (mg/hr)	$C_{Ingress}$ (mg/m^3)
	ZRL (mg/m^3)	ARL (mg/m^3)		
2-methyl-2-propanol	0.1	100	0.05	0.1
Butanol	0.8	40	0.1	0.2
Ethanal	1	4	0.2	0.4
Propanal	N/A	95	0.1	0.02
Butanal	N/A	118	0.02	0.03
Pentanal	N/A	21	0.02	0.03
Hexanal	N/A	24	0.02	0.03
Heptanal	N/A	28	0.02	0.03
Methylbenzene	8	60	0.04	0.07
1,3-/1,4-dimethylbenzene	5	220	0.02	0.03
Ethylbenzene	N/A	130	0.01	0.02
Dichloromethane	5	10	0.04	0.06
Pentane	10	625	0.02	0.04
2-propanone	2	50	0.2	0.3
2-butanone	0.25	30	0.2	0.3
Trimethylsilanol	0.2	37	3.6	6.5

14.6.3 Total Contamination Contribution to the International Space Station

Overall, the *T*-value rises at 0.00018 units/hour or 0.0042 units/day when using the acceptable risk concentrations as a basis. The total *T*-value is expected to be 0.3 units for a normal flight itinerary. The *T*-value rate of rise over all sample events is approximately 1.7 times greater than the rate determined for the 'terminal' case that uses offgassing sample analysis results for the second and final sample sets. For the purposes of engineering estimation, the more conservative case based on all three sample sets is preferred to account for uncertainties in the offgassing testing process.

The total estimated 0.2 mg/hr offgassing load from the Kibo ELM PS represents a 0.4% increase in the total Station load compared to 56.6 mg/hr at flight 5A. The maximum magnitude of the concentration transient that may occur during the Kibo ELM PS first entry operations is ~0.6 mg/m^3 over a 2-hour period. Previous analysis conducted for Node 1 first entry operations has established that mixing between the ISS volume and a new cargo carrier or module is complete within approximately 2 hours of establishing ventilation flow. If the predicted offgassing from the Kibo ELM PS is sustained over time, the total Station trace chemical contaminant concentration is predicted to rise by ~0.005 mg/m^3 which is below air quality method detection sensitivity.

The total trace chemical contaminant concentration predicted at first entry, 8 mg/m^3, is approximately three times lower than the 25 mg/m^3 guideline used by NASA toxicology personnel for preventing sick building syndrome symptoms. This total NMVOC concentration guideline is not documented in any ISS specification or operations documentation. However, it is prudent to consider it for overall completeness. The ISS cabin total NMVOC concentration is maintained between 10 mg/m^3 and 15 mg/m^3. The predicted *T*-value magnitude $\ll 1$ indicates the risk for short-lived sick building syndrome symptoms is expected to be quite low. Based on these observations, it is expected that the ISS crew may enter the Kibo ELM PS immediately during the first entry flight operations without taking special precautions. While methanol, ethanol, 2-propanol, ethyl acetate, and 4-methyl-2-pentanone will likely be present, their concentrations can be expected to be below their respective acceptable risk levels and their contribution to the total NMVOC concentration may be ~4 mg/m^3 according to experience gained from MPLM first ingress operations.

14.6.4 Margin for Launch and Docking Delay

The present analysis indicates that the maximum *T*-value of 3, referenced to the acceptable risk concentrations, is not reached for 714 days after the final prelaunch closeout. This allows for substantial operational margin that should accommodate any launch delays when using the *T*-value as a basis for safe entry. After 407 days of isolation, trimethylsilanol is the first compound to reach its individual acceptable risk concentration. Two compounds, 2-butanone and trimethylsilanol, are predicted to exceed their respective zero risk concentrations.

Overall, the predicted cabin air quality with the Kibo ELM PS indicates that the need to purge the module again after a launch delay is unlikely. However, to address uncertainties associated with sample analysis methods and the generation of methanol, ethanol, and 2-propanol, it is recommended that, as a precaution, the module be purged for launch delays exceeding 6 months duration.

14.7 Summary

The predicted air quality in the Kibo ELM PS has been evaluated based upon data acquired from the element offgassing test. The analysis projects an ingress *T*-value of 0.3 using the acceptable risk concentrations defined by the ISS MORD as the reference basis. No single chemical compound is predicted to exceed its acceptable risk concentration; however, 2-butanone and trimethylsilanol are predicted to exceed their respective zero risk concentrations. The contribution to the total ISS trace contaminant load may result in a ~0.005 mg/m^3 increase in total NMVOC concentration. The total trace contaminant concentration inside the Kibo ELM PS is predicted to be ~8 mg/m^3—or ~32% of the 25 mg/m^3 guideline for minimizing the risk for developing sick building syndrome symptoms. These predicted conditions allow the flight crew to enter the module without taking precautions beyond those already prescribed by flight rules governing module first entry. The offgassing test results indicate that the Kibo ELM PS is acceptably clean and substantial operational margin exists to accommodate launch delays up to 6 months or longer.

14.8 Conclusions

Conclusions from the predicted trace contaminant environment in the Kibo ELM PS at first ingress using offgassing data collected from the module are the following:

- No single contaminant will exceed its individual acceptable risk concentration (NASA SMAC).

- 2-butanone and trimethylsilanol may temporarily exceed their individual zero risk concentrations during first entry operations.

- The predicted maximum transient in the ISS cabin total NMVOC concentration during Kibo ELM PS first entry operation is <1 mg/m^3.

- The predicted maximum sustained increase in cabin total NMVOC concentration that may result from adding the Kibo ELM PS to the ISS is <0.01 mg/m^3.

14.9 Recommendation

The module offgassing test results from the Kibo ELM PS find that the module is acceptably clean and that substantial margin exists to accommodate long-term launch delays. For conservatism, it is recommended that a module purge be conducted for launch delays exceeding 6 months to address uncertainties surrounding the generation rates of methanol, ethanol, and 2-propanol.

15. ASSEMBLY MISSION 1J—KIBO PRESSURIZED MODULE TRACE CONTAMINANT CONTROL ASSESSMENT

This assessment was originally released under NASA Memorandum ES21-08-003 dated February 6, 2008.

15.1 Background

The Kibo pressurized module (PM) laboratory is a major contribution from the ISS program's international partner, JAXA, which attaches to the Harmony Node 2 element. Because the Kibo PM is sealed from the time it is closed out in the SSPF until it is mated to the ISS on orbit, buildup of trace chemical contaminants becomes a concern. Adding new modules to the ISS is a source of trace chemical contamination generation that causes cabin air quality transients during module first entry and activation. The available Kibo PM offgassing testing data are assessed by NASA toxicologists and ECLSS engineers before flight to ensure crew health and safety as well as to satisfy the ISS program's TCC requirements for module first entry and activation. The assessment predicts the expected air quality during initial entry of the Kibo PM using NASA-acquired, module-level offgassing test data.

15.2 Purpose

The engineering analysis summarized by the following discussion serves to predict the trace chemical contaminant concentration condition within the Kibo PM cabin at the time the hatch is opened to the ISS.

15.3 Objective

The approach to maintaining acceptable cabin air quality in the Kibo PM during first entry on orbit is assessed by engineering analysis. The assessment's primary objective is to predict individual trace chemical contaminant concentrations at the time the hatch opens on orbit and to recommend appropriate actions, if any, necessary to ensure crew and ISS cabin environmental health and safety.

15.4 Assumptions

To conduct the Kibo PM trace chemical contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

15.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the Kibo PM TCC engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results reported by NASA.
- Atmospheric leakage from the Kibo PM is zero. This is considered to be true for all new ISS elements.
- The Kibo PM free volume is approximately 125 m^3.
- The Kibo PM was 93.4% outfitted by mass for flight at the time of the offgassing test.
- Cabin atmospheric conditions are on average 20 °C, 50% relative humidity, and 101.3 kPa.
- Offgassing rates are constant with time. This has been shown to be conservative because experience has shown rates decay with time.
- Acceptable risk and zero risk air quality limits as defined by the ISS MORD apply.
- Ventilation flow between the Kibo PM and Harmony Node 2 are maintained at ~229 m^3/hr after successful on-orbit module activation.

15.4.2 On-Orbit Configuration

During the ISS assembly mission STS-124/ISS 1J that will deliver and activate the Kibo PM, the ISS's on-orbit configuration consists of PMA-1, PMA-2, Unity (Node 1), Destiny (U.S. Laboratory), Quest (U.S. airlock), Harmony (Node 2), Columbus APM, Kibo ELM PS, Jules Verne (ATV-1), Zarya (FGB), Zvezda (service module), a Soyuz spacecraft, and a Progress cargo vehicle. The ISS's total habitable volume is approximately 732 m^3, including the Kibo PM. The Kibo PM remains isolated until it is attached to the ISS and the hatch opened.

Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] Once the Kibo PM hatch is opened, accumulated trace chemical contamination will mix within the main ISS cabin where the TCCS and BMP remove the added contaminants.

15.4.3 Mission Timeline

The total elapsed time between the last breathing air renewal on the ground and docking with the ISS is approximately 107 days, assuming the module is sealed on approximately January 8, 2008. On-orbit entry is scheduled to occur on approximately April 28, 2008, in preparation for STS-124/ ISS 1J mission launch on April 24, 2008. Any launch delay will increase the elapsed closeout time on a day-to-day basis. The elapsed time necessary to reach the acceptable risk concentration for any single chemical contaminant as well as the time to reach *T*-value magnitude of 3 are also evaluated to understand the allowable launch slip before a new breathing air renewal is necessary.

15.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for evaluating the scenario for the first entry of the Kibo PM. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

15.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation results in a steady increase in concentration, C_i, over time, t, as denoted by equation (2). Trace contaminant generation rates are derived from the analytical results of offgassing test grab samples collected from the Kibo PM by NASA between November 8 and 20, 2007. Sample sets were collected at ~119 and ~289 hours after closing the hatch. A sample set was also collected immediately at hatch closure. This first sample set serves as the starting basis at time zero. The Kibo PM was 93.4% outfitted by mass for flight at the time of the test. Individual contaminant generation rates are derived using equation (3) which is equation (2) in differential form solved for the generation rate. The resulting rate is divided by 0.934 to account for equipment that was not installed in the Kibo PM at the time of the offgassing test. For the test conducted on the Kibo PM, time increment values of 119 and 170 hours apply.

15.5.2 Analysis Cases Considered

The primary case considered is the normal first entry of the Kibo PM. Comparison of the individual contaminant concentrations to zero risk and acceptable risk concentrations defined by the ISS MORD is conducted for the normal first entry case to satisfy basic ISS program contamination control requirements. A prediction of the *T*-value magnitude at first entry is made to address guidelines contained in flight rules pertaining to first module ingress. Margin for launch delays and docking delays is also evaluated.

15.5.3 Calculation Approach

Each contaminant concentration at ingress is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1. Once the concentration has been calculated, the overall *T*-value is calculated using equation (1).

15.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

15.6.1 Derived Generation Rates

The element offgassing test conducted by NASA found the Kibo PM to be quite clean. Twenty chemical compounds with measurable concentrations were found in the test samples. Four of these compounds—acetonitrile, propenal, n-propanol, and 1,2-dichloroethane—were reported at trace concentrations throughout the offgassing test. Therefore, their estimated offgassing rate is zero. Seven compounds—ethanol, 2-propanol, propanal, hexanal, heptanal, ethyl acetate, and 4-methyl-2-pentanone—exhibited decreasing concentration trends during the test which do not allow for a generation rate to be determined. Because significant concentrations were observed for these five compounds during the offgassing test, it is likely that they will be present in the Kibo PM atmosphere at first module entry on orbit. Experience from first ingress operations for seven MPLM missions has found average concentrations for ethanol, 2-propanol, propanal, ethyl acetate, and 4-methyl-2-pentanone to average 1.5 mg/m^3, 2.3 mg/m^3, 0.07 mg/m^3, 0.1 mg/m^3, and trace, respectively. For the same seven MPLM missions the average concentrations for 4-methyl-2-pentanone, hexanal, and heptanal reported from first entry grab samples were 0.025 mg/m^3 or trace for all three compounds.

The individual compound generation rates derived from the offgassing test data are summarized in table 36. Average concentrations at each sampling event, provided in appendix B, were used in equation (3) to derive the generation rate. The result was divided by 0.934 to account for equipment not installed in the Kibo PM at the time of the test.

Table 36. Generation rates and predicted ingress concentrations for mission 1J.

Compound	Limits in Air		Rate (mg/hr)	C_{Ingress} (mg/m^3)
	ZRL (mg/m^3)	ARL (mg/m^3)		
Methanol	0.2	9	0.3	0.3
2-methyl-2-propanol	0.1	100	0.2	0.2
Butanol	0.8	40	0.03	0.03
Ethanal	1	4	0.1	0.1
Butanal	N/A	118	0.0004	0.0003
Pentanal	N/A	21	0.05	0.04
2-propanone	2	50	0.4	0.4
2-butanone	0.25	30	0.1	0.1
Trimethylsilanol	0.2	37	8.8	7.6

15.6.2 Normal Entry of the Kibo Pressurized Module

As shown in table 36, none of the nine chemical compounds for which generation rates could be determined from the offgassing test data will exceed the acceptable risk concentrations after the elapsed 107 days between final Kibo PM closeout and on-orbit ingress. Methanol, 2-methyl-2-propanol, and trimethylsilanol may be expected to exceed their respective zero risk concentrations. These results indicate low risk to the crew for developing sick building syndrome symptoms upon entering the Kibo PM.

15.6.3 Total Contamination Contribution to the International Space Station

Overall, the *T*-value rises at 0.00011 units/hour or 0.0026 units/day when using the acceptable risk concentrations as a basis. The total *T*-value is expected to be ~0.3 units for a normal flight itinerary. The total estimated 0.14 mg/hr offgassing load from the Kibo PM represents a ~0.2% increase in the total Station load compared to 56.6 mg/hr at flight 5A. The maximum magnitude of the concentration transient that may occur during the Kibo PM first entry operations is ~1.5 mg/m^3 over a 2-hour period. Previous analysis for Node 1 first entry operations has established that mixing between the ISS volume and a new cargo carrier or module is complete within approximately 2 hours of establishing ventilation flow. If the predicted offgassing from the Kibo PM is sustained over time, the total Station trace chemical contaminant concentration is predicted to rise by ~0.08 mg/m^3 which is below air quality method detection sensitivity.

The total trace chemical contaminant concentration predicted at first entry, 8.6 mg/m^3, is approximately three times lower than the 25 mg/m^3 guideline used by NASA toxicology personnel for preventing sick building syndrome symptoms. This total NMVOC concentration guideline is not documented in any ISS specification or operations documentation. However, it is prudent to consider it for overall completeness. The ISS cabin total NMVOC concentration is maintained between 10 and 15 mg/m^3. The predicted *T*-value magnitude $\ll 1$ indicates the risk for short-lived sick building syndrome symptoms is expected to be quite low. Based on these observations, it is expected that the ISS crew may enter the Kibo PM immediately during the first entry flight operations without taking special precautions. While ethanol, 2-propanol, propanal, hexanal, heptanal, ethyl acetate, and 4-methyl-2-pentanone will likely be present, their concentrations can be expected to be below their respective acceptable risk levels and their contribution to the total NMVOC concentration may be ~4 mg/m^3 according to experience gained from MPLM first ingress operations.

15.6.4 Margin for Launch and Docking Delay

The present analysis indicates that the maximum *T*-value magnitude of 3, referenced to the acceptable risk concentrations, is not reached for 1,154 days after the final prelaunch closeout. This allows for substantial operational margin that should accommodate any launch delays when using the *T*-value as a basis for safe entry. After 522 days of isolation, trimethylsilanol is the first compound to reach its individual acceptable risk concentration. Three compounds—methanol, 2-methyl-2-propanol, and trimethylsilanol—are predicted to exceed their respective zero risk concentrations.

Overall, the predicted cabin air quality with the Kibo PM indicates that the need to purge the module again after a launch delay is unlikely. However, to address uncertainties associated with sample analysis methods and the generation of the seven compounds for which generation rates could not be determined, it is recommended that, as a precaution, the module be purged for launch delays exceeding 6 months duration.

15.7 Summary

The predicted air quality in the Kibo PM has been evaluated based upon data acquired from the element offgassing test. The analysis projects an ingress *T*-value of ~0.3 using the acceptable risk concentrations defined by the ISS MORD as the reference basis. No single chemical compound is predicted to exceed its acceptable risk concentration; however, methanol, 2-methyl-2-propanol, and trimethylsilanol are predicted to exceed their respective zero risk concentrations. The contribution to the total ISS trace contaminant load may result in a ~0.08 mg/m^3 increase in total NMVOC concentration. The total trace contaminant concentration inside the Kibo PM is predicted to be ~8.6 mg/m^3, or ~34% of the 25 mg/m^3 guideline for minimizing the risk for developing sick building syndrome symptoms. During first entry operations the prevailing concentration in the Kibo PM may contribute to a concentration transient of ~1.5 mg/m^3 over the normal prevailing concentration. The predicted conditions allow the flight crew to enter the module without taking precautions beyond those already prescribed by flight rules governing module first entry. The offgassing test results indicate that the Kibo PM is acceptably clean and that a substantial operational margin exists to accommodate launch delays up to 6 months or longer.

15.8 Conclusions

Conclusions from the predicted trace contaminant environment in the Kibo PM at first ingress using offgassing data collected from the module are the following:

- No single contaminant will exceed its individual acceptable risk concentration (NASA SMAC).
- Methanol, 2-methyl-2-propanol, and trimethylsilanol may temporarily exceed their individual zero risk concentrations during first entry operations.
- The predicted maximum transient in the ISS cabin total NMVOC concentration during Kibo PM first entry operation is <1 mg/m^3.
- The predicted maximum sustained increase in cabin total NMVOC concentration that may result from adding the Kibo PM to the ISS is <0.08 mg/m^3.

15.9 Recommendation

The module offgassing test results from the Kibo PM find that the module is acceptably clean and that a substantial margin exists to accommodate long-term launch delays. For conservatism, it is recommended that a module purge be conducted for launch delays exceeding 6 months to address uncertainties associated with the generation rates of ethanol, 2-propanol, propanal, hexanal, heptanal, ethyl acetate, and 4-methyl-2-pentanone.

16. ASSEMBLY MISSION 20A—TRANQUILITY NODE 3 TRACE CONTAMINANT CONTROL ASSESSMENT

This assessment was originally released under NASA Memorandum ES62(09-013) dated December 14, 2009.

16.1 Background

The Tranquility Node 3, a habitable element of the USOS, will be attached to the nadir radial port of the Unity Node 1 module. Because the Tranquility Node 3 module is sealed from the time it is closed out in the SSPF until it is mated to the ISS on orbit, buildup of trace chemical contaminants becomes a concern. Adding new modules to the ISS can be a source of trace chemical contamination generation that may cause cabin air quality transients during module first entry and activation. The available Tranquility Node 3 offgassing testing data are assessed before flight to satisfy the ISS program's TCC requirements as well as to ensure crew health and safety during first entry and activation. The assessment predicts the expected air quality during initial entry of the Tranquility Node 3 based on NASA-acquired, module-level offgassing test data. The offgassing test data were acquired during a test conducted between December 19, 2008, and January 21, 2009, at the Thales Alenia Space facilities in Torino, Italy.

16.2 Purpose

The engineering analysis summarized by the following discussion serves to predict the trace chemical contaminant concentration condition within the Tranquility Node 3 cabin at the time the hatch is opened to the ISS. Individual concentrations are compared to concentration limits prescribed by ISS specification documents.

16.3 Objective

The approach to maintaining acceptable cabin air quality in the Tranquility Node 3 during first entry on orbit is assessed by engineering analysis. The assessment's primary objective is to predict individual trace chemical contaminant concentrations at the time the hatch opens on orbit and to recommend appropriate actions, if any, necessary to ensure compliance with the ISS system specification and relevant U.S. segment specification documents.

16.4 Assumptions

To conduct the Tranquility Node 3 trace chemical contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

16.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the Tranquility Node 3 TCC engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results reported by NASA.
- Atmospheric leakage from the Tranquility Node 3 module is zero. This is considered to be true for all new ISS elements.
- The Tranquility Node 3 free volume in its launch configuration is approximately 62 m^3.
- The Tranquility Node 3 was 100% outfitted by mass for flight at the time of the offgassing test.
- Cabin atmospheric conditions are on average 20 °C, 50% relative humidity, and 101.3 kPa.
- Offgassing rates are constant with time. This has been shown to be conservative because experience shows rates decay with time.
- Acceptable risk and zero risk air quality limits as defined by the ISS MORD apply.
- Ventilation flow between the Tranquility Node 3 and Unity Node 1 is maintained at ~204 m^3/hr minimum after successful on-orbit docking and activation.

16.4.2 On-Orbit Configuration

During the ISS assembly mission STS-130/20A, the ISS's on-orbit configuration consists of PMA-1, PMA-2, Unity (Node 1), Destiny (U.S. Laboratory), Quest (U.S. airlock), Harmony (Node 2), the Columbus APM, the Kibo ELM PS and PM modules, Jules Verne (ATV-1) cargo vehicle, HTV-1 cargo vehicle, Zarya (FGB), Zvezda (service module), Pirs docking compartment, Poisk mini research module (MRM-1), two Soyuz spacecraft, and a Progress cargo vehicle. The ISS's total habitable volume is approximately 787 m^3, including the cargo and crew transport vehicles. The Tranquility Node 3 module remains isolated until it is attached to the ISS and the hatch opens. The ISS cabin volume increases by nearly 8% to 849 m^3 after Tranquility Node 3 activation.

Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] After the Tranquility Node 3 module hatch opens, accumulated trace chemical contamination will mix within the main ISS cabin where the TCCS and BMP remove the added contaminants. When fully activated, the second USOS TCCS unit located in the Tranquility Node 3 module will contribute to the active contamination control.

16.4.3 Mission Timeline

The total elapsed time between the last prelaunch purge on the ground and hatch opening at the ISS is approximately 67 days. The module closeout is scheduled for December 4, 2009. Launch is scheduled for February 4, 2010, with hatch opening scheduled for approximately February 9, 2010. Any launch delay will increase the elapsed closeout time on a day-to-day basis unless the late access operations are also delayed.

16.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for evaluating the scenario for the first entry of the Tranquility Node 3 module. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

16.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation results in a steady increase in concentration, C_i, over time, t, as denoted by equation (2). Trace contaminant generation rates are derived from the analytical results of offgassing test grab samples collected from the Tranquility Node 3 module by NASA between December 19, 2008, and January 21, 2009. The analysis results are provided in appendix B. Sample sets were collected at hatch closure and at 453 hours and 790 hours after hatch closure. The first sample set serves as the starting basis at time zero. The Tranquility Node 3 module was 100% outfitted by mass for flight at the time of the test. Individual contaminant generation rates are derived using equation (3) which is equation (2) in differential form solved for the generation rate. No adjustment was necessary to account for equipment that was not installed in the Tranquility Node 3 module at the time of the offgassing test. For the test conducted on the Tranquility Node 3 module, time increment values of 453 hours and 337 hours apply.

16.5.2 Analysis Cases Considered

The primary case considered is the normal first entry of the Tranquility Node 3 module. Comparison of the individual contaminant concentrations to zero risk and acceptable risk concentrations defined by ISS specification documents is conducted for the normal first entry case to satisfy basic ISS program contamination control requirements.

16.5.3 Calculation Approach

Each contaminant concentration at ingress is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1. The effect of the contaminant buildup in the Tranquility Node 3 module on the ISS cabin environment is assessed using equations (10) and (11).

16.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

16.6.1 Derived Generation Rates

The element offgassing test results indicate that the Tranquility Node 3 module was relatively clean at time zero with 26 compounds reported by the first sample set analysis. The sample set analysis at 453 hours reported 28 compounds. Thirty compounds were reported in the sample set collected at 790 hours. Overall, 31 chemical compounds with measurable concentrations were reported in the test samples. Three compounds—propanal, 3-methyl-2-propenal, and cyclohexane—exhibited decreasing concentration trends during the test which does not allow for a generation rate to be determined. Due to the very low concentration observed for these compounds, it is likely that they may not be present in the Tranquility Node 3 cabin atmosphere above detectable limits at first module entry on orbit. The individual compound generation rates derived from the offgassing test data are summarized in table 37. Average concentrations at each sampling event, provided in appendix B, were used in equation (3) to derive the generation rate. No adjustment was necessary to account for equipment not installed in the Tranquility Node 3 module at the time of the test.

Table 37. Generation rates and predicted ingress concentrations for mission 20A.

	Limits in Air			
Compound	**ZRL (mg/m^3)**	**ARL (mg/m^3)**	**Rate (mg/hr)**	**C_{Ingress} (mg/m^3)**
Methanol	0.2	9	0.013	0.35
Ethanol	10	2,000	0.004	0.1
2-propanol	1.5	150	0.155	4.03
2-methyl-2-propanol	0.1	100	0.001	0.01
Butanol	0.8	40	0.038	0.99
2-ethylhexanol	3.3	0.1	0.003	0.09
Ethanal	1	4	0.006	0.16
Propanal	1	14	N/A	N/A
2-methyl-2-propenal	1	1.7	N/A	N/A
Butanal	1	118	0.0002	0.01
Hexanal	1	24	0.0003	0.01
Benzene	0.2	0.2	0.0006	0.01
Methylbenzene	8	60	0.0075	0.19
1,3-/1,4-dimethylbenzene	5	220	0.0019	0.05
1,2-dimethylbenzene	5	220	0.0008	0.02
Ethylbenzene	2	130	0.0004	0.01
Ethanoic acid butyl ester	2	190	0.0018	0.05
Dichloromethane	5	10	0.004	0.1
1,2-dichloroethane	0.5	1	0.0148	0.38
n-pentane	10	625	0.0005	0.01
Cyclohexane	3	210	N/A	N/A
2-propanone	2	50	0.014	0.36
3-buten-2-one	N/A	0.43	0.0004	0.01
2-butanone	0.25	30	0.0235	0.61
2-pentanone	N/A	70	0.0003	0.01
Cyclohexanone	1.3	60	0.0006	0.01
Carbon monoxide	5	11	0.0699	1.81
Carbonyl sulfide	N/A	12	0.0205	0.53
Carbon disulfide	1	16	0.004	0.1
Trimethylsilanol	0.2	37	0.0561	1.45
Fluorotrimethylsilane	N/A	0.5	0.0055	0.14

16.6.2 First Entry of the Tranquility Node 3 Module

As shown in table 37, based on the NASA-acquired offgassing test results, no compound is predicted to exceed its acceptable risk concentration after the elapsed 67 days between the Tranquility Node 3 module final prelaunch closeout and on-orbit ingress. Five compounds—methanol, 2-propanol, n-butanol, 2-butanone, and trimethylsilanol—may be expected to exceed their respective zero risk concentrations. This result indicates that, for a brief time, these compounds may exceed their zero risk concentrations and contribute to a slight increase in the ISS cabin as the two volumes mix after establishing ventilation. Figure 31 shows that the total trace chemical contaminant concentration in the Tranquility Node 3 module cabin can be expected to decrease less than 1 hour after establishing active ventilation with the ISS cabin.

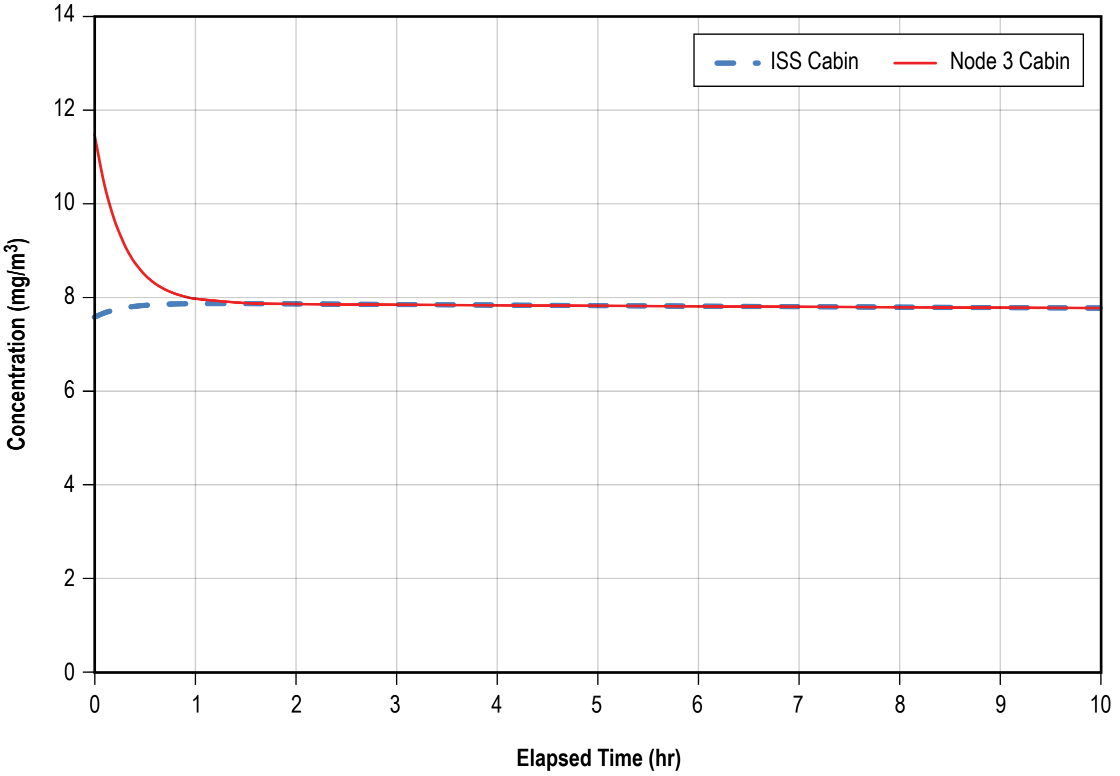

Figure 31. Trace contaminant concentration transient during tranquility node 3 first entry.

16.6.3 Total Contamination Contribution to the International Space Station

The total estimated 0.44 mg/hr offgassing load from the Tranquility Node 3 module represents a 0.8% increase in the total Station load compared to 56.6 mg/hr at flight 5A. The maximum magnitude of the concentration transient that may occur during the Tranquility Node 3 first entry operations is ~0.4 mg/m^3 reached ~1.5 hours after the hatch opens. Previous analysis of Node 1 first entry operations has established that mixing between the ISS volume and a new cargo carrier or module is complete within approximately 2 hours of establishing ventilation flow. If the predicted offgassing from the Tranquility Node 3 module equipment is sustained over time, the total Station trace chemical contaminant concentration is predicted to return to its initial docking magnitude within 96 hours and rise by no more than ~0.01 mg/m^3. Overall, individual trace contaminant concentrations in the ISS cabin are expected to remain within their acceptable range during Tranquility Node 3 first entry and activation operations.

16.7 Summary

The predicted cabin atmospheric quality in the Tranquility Node 3 module has been evaluated based on data acquired from the element offgassing test. None of the compounds reported in the offgassing test samples are predicted to exceed their individual acceptable risk concentrations. Five compounds—methanol, 2-propanol, n-butanol, 2-butanone, and trimethylsilanol—are predicted to exceed their respective zero risk concentrations. The contribution to the total ISS trace contaminant load may result in a ~0.01 mg/m^3 long-term increase in total trace chemical contaminant concentration. The magnitude of the short duration ISS trace contaminant concentration transient is expected to not exceed 0.4 mg/m^3. The active contamination control equipment on board the ISS is expected to accommodate the additional load from the Tranquility Node 3 module and its equipment.

16.8 Conclusions

Conclusions from the predicted trace contaminant environment in the Tranquility Node 3 module at first entry using offgassing data collected from the module are the following:

- No compound is predicted to exceed its acceptable risk concentration (NASA SMAC) in the Tranquility Node 3 cabin during first entry operations.

- Methanol, 2-propanol, n-butanol, 2-butanone, and trimethylsilanol may temporarily exceed their individual zero risk concentrations in the Tranquility Node 3 module cabin during first entry operations.

- The predicted maximum transient in the ISS cabin total trace chemical contaminant concentration during Tranquility Node 3 first entry operations is ~0.4 mg/m^3.

- No individual trace contaminant concentration in the ISS cabin is expected to exceed either its zero or acceptable risk concentration.

- The predicted maximum sustained increase in cabin total trace chemical contaminant concentration that may result from adding the Tranquility Node 3 module and equipment to the ISS is ~0.01 mg/m^3.

16.9 Recommendation

The module offgassing test results from the Tranquility Node 3 module find that the module is reasonably clean and that the active contamination control equipment on board the ISS possesses the necessary capability and capacity to accommodate the additional trace contaminant generation load. No special precautions beyond standard first module entry procedures are anticipated during Tranquility Node 3 module first entry and activation operations.

17. ASSEMBLY MISSION ULF-5—LEONARDO PERMANENT MULTIPURPOSE MODULE AND INTERNATIONAL SPACE STATION STAGE ULF-5 TRACE CONTAMINANT CONTROL ASSESSMENT

This assessment was originally released in August 2010.

17.1 Background

The Leonardo PMM, a habitable element of the ISS USOS, will be attached to the nadir radial port of the Unity Node 1 module. Because the PMM is sealed from the time it is closed out in the SSPF until it is mated to the ISS on orbit, buildup of trace chemical contaminants becomes a concern. Adding new modules to the ISS is a source of trace chemical contamination generation that causes cabin air quality transients during module first entry and activation. The predicted PMM offgassing load and its contribution to the total ISS trace contaminant load during the ULF-5 stage is assessed before flight to satisfy the ISS program's TCC requirements as well as to ensure crew health and safety during first entry and activation. The assessment predicts the expected air quality during initial entry of the PMM based on NASA-acquired historical USOS module-level offgassing test data. The ability of ISS TCC assets to maintain the cabin atmospheric quality within specified limits is assessed.

17.2 Purpose

The engineering analysis summarized by the following discussion serves to predict the trace chemical contaminant concentration condition within the Leonardo PMM cabin at the time the hatch is opened to the ISS. Individual concentrations are compared to concentration limits prescribed by ISS specification documents. Also, the ISS ULF-5 stage TCC capability is assessed versus the predicted load to evaluate compliance with performance specifications.

17.3 Objective

The approach to maintaining acceptable cabin air quality in the PMM during first entry on orbit is assessed by engineering analysis. The assessment's primary objective is to predict individual trace chemical contaminant concentrations at the time the hatch opens on orbit and to recommend appropriate actions, if any, necessary to ensure compliance with ISS system and USOS specification documents. The basic ISS trace contaminant generation load combined with the predicted PMM equipment offgassing load are also assessed for specification compliance.

17.4 Assumptions

To conduct the PMM and ISS ULF-5 stage trace chemical contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

17.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the PMM and ISS ULF-5 stage TCC engineering analysis are the following:

- PMM offgassing rates are derived from a generalized equipment offgassing load model adjusted according to ground-based USOS element offgassing test results reported by NASA.

- PMM cargo mass contributing to the offgassing load is 2,572.4 kg.

- Atmospheric leakage from the PMM is zero. This is considered to be true for all new ISS elements.

- The PMM free volume in its launch configuration is approximately 45 m^3.

- Cabin atmospheric conditions are on average 20 ºC, 50% relative humidity, and 101.3 kPa.

- Offgassing rates are constant with time. This has been shown to be conservative because experience shows rates decay with time.

- Acceptable risk and zero risk air quality limits defined by the ISS MORD apply.

- Ventilation flow between the PMM and ISS cabin is maintained at ~229 m^3/hr minimum after successful on-orbit docking and activation.

17.4.2 On-Orbit Configuration

During the ISS mission STS-133/ULF-5, the ISS's on-orbit configuration consists of PMA-1, PMA-2, Unity (Node 1), Destiny (U.S. Laboratory), Quest (U.S. airlock), Harmony (Node 2), the Columbus APM, the Kibo ELM PS and PM modules, Zarya (FGB), Zvezda (service module), Pirs docking compartment, Rassvet MRM-1, Poisk MRM-2, two Soyuz spacecraft, and a Progress cargo vehicle. The ISS's total habitable volume is approximately 763 m^3 according to habitable element free volumes documented by the Joint Environmental Control and Life Support Functionality Strategy Document (SSP 50623, section 4.2). The PMM remains isolated until it is attached to the ISS and the hatch opens. The ISS cabin volume increases by nearly 6% to ~808 m^3 after the PMM addition.

Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] Once the PMM hatch opens, accumulated trace chemical contamination mixes with the main ISS cabin where the TCCS and BMP remove the added contaminants.

17.4.3 Mission Timeline

The total elapsed time between the last prelaunch dry air purge on the ground and hatch opening at the ISS is approximately 43 days. The module dry air purge is scheduled for September 24, 2010. Launch is scheduled for November 1, 2010, with hatch opening scheduled for approximately November 6, 2010. Any launch delay will increase the elapsed closeout time on a day-to-day basis unless the late access operations are also delayed.

17.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for evaluating the scenario for the first entry of the PMM and the expected ISS cabin atmospheric quality during the ULF-5 stage. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

17.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation results in a steady increase in concentration, C_i, over time, t, as denoted by equation (2). In order to prepare for ISS mission STS-133/ULF-5, an understanding of the offgassing characteristics of candidate equipment to be delivered to the ISS on board the vehicle is necessary. Because past studies by NASA have demonstrated that using raw, unadjusted equipment and bulk materials offgassing test data results in excessive conservatism, a generalized equipment load model has been developed to facilitate spacecraft design and onboard air quality control system design and performance assessment. This generalized load model was developed in 1995.[2]

Studies conducted on materials offgassing characteristics for the Spacelab program have established that no more than 126 chemical compounds account for 99% of the total equipment offgassing load per unit mass. This list of 126 compounds has been established as the design basis for ISS hardware offgassing and is included in the USOS Specification (SSP 41162, table LIII). It is considered technically acceptable and appropriate to use this generalized load model for ISS design because the materials selection and control process for both the ISS USOS and Spacelab programs are virtually identical. By virtue of materials selection program similarity, similar offgassing characteristics for the hardware should result. Preflight and in-flight characterization of the Unity Node 1 and Destiny laboratory module has verified this assumption and demonstrated that using the generalized load model is a sound, conservative approach for designing spacecraft air quality control systems as well as predicting hardware offgassing characteristics. Further, continued ISS element offgassing rate characterization efforts have demonstrated that approximately 44 chemical compounds routinely contribute to ISS element offgassing loads.[20] Therefore, this assessment considers these 44 compounds rather than the entire list of 126 documented by the USOS Specification. Generation rates derived from the generalized load model documented by reference 2 are adjusted to best approximate generation rate magnitudes reported from USOS element offgassing tests reported by reference 20.

17.5.2 Analysis Cases Considered

The first case considered is the normal first entry of the PMM. Comparison of the individual contaminant concentrations to zero risk and acceptable risk concentrations defined by ISS program specification documents is conducted for the normal first entry case to satisfy basic ISS program contamination control requirements. A cursory prediction of the *T*-value magnitude at first entry is conducted but final assessment of compliance with first entry flight rules is left to the responsible NASA toxicology and ISS program medical operations personnel.

The second case considered is the steady state TCC equipment performance on the ULF-5 trace contaminant generation load. The human metabolic generation contribution for a crew of six is included in the steady state analysis.

17.5.3 Calculation Approach

17.5.3.1 Trace Contaminant Buildup. Each contaminant concentration at PMM first entry is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1.

17.5.3.2 Assessing Dynamic Conditions. Once the PMM hatch opens, a dynamic atmospheric quality condition exists as the contaminants that have built up in the PMM are diluted by ventilation with the ISS cabin. Assessing this condition requires conducting a more rigorous mass balance on both the ISS and PMM cabin volumes. This more rigorous mass balance requires the simultaneous solution of the mass balance equations for each individual segment. This mass balance uses equations (10) and (11).

17.5.3.3 Assessing Steady State Conditions. Assessing the capability of the atmospheric quality control systems on board the ISS to effectively control the ULF-5 stage trace contaminant load under steady state conditions is less complex. First, the entire ISS cabin is assumed to be a well-mixed volume and the effective removal term, $\sum\eta v$, remains constant with time. This simplifies the cabin mass balance equation to the form shown by equation (6). The solved form of the basic cabin mass balance equation is shown by equation (7) and the steady state condition is represented by equation (8). Reference 21 documents the derivation of equations (7) and (8).

17.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

17.6.1 Derived Generation Rates

The PMM will contain approximately 2,572 kg of cargo. Applying the equipment offgassing rate in appendix B expressed in units of mg/day/kg to the total 2,572 kg of cargo provides the estimated offgassing rate summarized in table 38. The cargo offgassing rate is added to the basic ISS offgassing rate to obtain a ULF-5 stage total offgassing rate to assess steady state TCC functional performance.

Table 38. Predicted PMM generation rates and first entry concentrations.

	Limits in Air			
Compound	**ZRL (mg/m^3)**	**ARL (mg/m^3)**	**Rate (mg/hr)**	**$C_{Ingress}$ (mg/m^3)**
Methanol	0.2	9	0.07	1.6
Ethanol	10	2,000	0.4	9.6
2-propanol	1.5	150	0.2	4.9
1-propanol	0.6	98	0.01	0.3
2-methyl-1-propanol	0.1	120	0.04	1
2-methyl-2-propanol	3.3	120	0.004	0.09
n-butanol	0.8	40	0.05	1.2
Ethanal	1	4	0.01	0.3
Propanal	1	14	0.02	0.4
2-methylpropenal	1	1.7	0.0002	0.005
Butanal	1	4	0.005	0.1
Pentanal	1	4	0.006	0.1
Hexanal	1	4	0.004	0.09
Benzenecarbonal	1	4	0.002	0.03
Heptanal	1	4	0.001	0.03
Octanal	1	4	0.0003	0.01
Nonanal	1	4	0.01	0.3
Benzene	0.2	0.2	0.002	0.04
Methylbenzene	8	60	0.05	1.1
Ethenylbenzene	0.25	43	0.002	0.05
Ethylbenzene	2	50	0.01	0.3
1,3-/1,4-dimethylbenzenes	5	220	0.007	0.2
1,2-dimethylbenzene	5	220	0.007	0.2
Ethanoic acid ethyl ester	4	180	0.008	0.2
Ethanoic acid butyl ester	2	190	0.02	0.5
1,3-dioxolane	16.6	N/A	–	–
Dichloromethane	5	10	0.03	0.8
1,2-dichloroethane	0.5	1	0.006	0.1
Pentane	10	590	0.007	0.2
Cyclohexane	3	210	0.03	0.7
Hexane	5	180	0.005	0.1
Heptane	10	200	0.004	0.1
3-methylhexane	20	29	–	–
2-methylheptane	20	29	–	–
Nonane	10	320	0.0006	0.01
2-propanone	1	50	0.13	3
2-butanone	0.25	30	0.09	2
Cyclohexanone	1.3	60	0.012	0.3
Acetophenone	0.2	250	–	–
Carbon monoxide	5	10	0.22	5
Carbon disulfide	1	16	0.0025	0.06
Trimethylsilanol	0.2	37	0.013	0.3
Hexamethylcyclotrisiloxane	0.2	9	0.016	0.4
Octamethylcyclotetrasiloxane	0.2	12	0.02	0.5

Table 38 summarizes the predicted generation rates for the PMM for the 44 chemical compounds most often reported by ISS habitable element offgassing test results. The total trace contaminant generation rate is 1.56 mg/hr. Converted to a toxic hazard index rate, the predicted relative contamination buildup rate is approximately 0.04 *T*-value units/day.

The background ISS generation rate, including the contribution from six crewmembers, is 230 mg/hr. The listing for the PMM in appendix B contains a more detailed listing of the rate derivation basis. This predicted generation rate is consistent with rates derived from ISS cabin atmosphere quality measurements. Concentrations reported from samples collected between May 27, 2009, and October 28, 2010, indicate a total NMVOC concentration of ~4 mg/m^3. Samples collected between November 13, 2009, and February 13, 2010, indicate ~1.8 mg/m^3 carbon monoxide. The combined NMVOC and carbon monoxide concentrations yield 5.8 mg/m^3. These results serve as a comparative basis to assess the influence that the PMM and its cargo may have on trace chemical concentrations in the ISS cabin. From the samples collected from the ISS, the estimated total offgassing rate on board the ISS is approximately 161 mg NMVOC/hour and 53 mg CO/hour or 214 mg/hour total. By comparison, the predicted background ISS generation rate of 207 mg NVMOC/hour and 33.7 mg CO/hour is quite close, averaging within 10% of rates derived from flight atmospheric quality data. The PMM and its cargo represent a 0.7% increase in the total generation rate.

17.6.2 First Entry of the Leonardo Permanent Multipurpose Module

The PMM will be sealed for approximately 43 days between the final dry air purge before launch and hatch opening at the ISS. Table 38 summarizes the predicted first entry concentrations for the 44 compounds most commonly observed during ISS element offgassing tests. Accumulated volatile organic compound contamination in the sealed PMM cabin may result in a total predicted NMVOC concentration of approximately 31 mg/m^3. This is higher than the guideline 25 mg/m^3 recommended by NASA toxicology experts. Carbon monoxide is predicted to reach approximately 5 mg/m^3. Together, the predicted NMVOC and carbon monoxide concentration is approximately 36 mg/m^3.

Compared to individual SMACs—the acceptable risk limits—the predicted toxic hazard index at first entry is approximately 1.7. Therefore, it is likely that the conditions at PMM first entry will comply with first entry flight rules. However, the final determination is left to NASA toxicology experts.

Previous analysis of Unity Node 1 first entry operations has established that mixing between the ISS volume and a new cargo carrier or module is complete within approximately 2 hours of establishing ventilation flow. The predicted dilution transient with the ISS lasts approximately 40 hours. Figure 32 shows the peak concentration increase in the ISS cabin is approximately 1.6 mg/m^3 over the prevailing background concentration. The local concentration peak adjacent to the PMM may be higher, possibly approaching 10 mg/m^3 over the prevailing ISS trace contaminant background. Mixing between the PMM and ISS cabins is approximately complete within approximately 1 hour of hatch opening. Active atmospheric scrubbing continues to reduce the combined concentration.

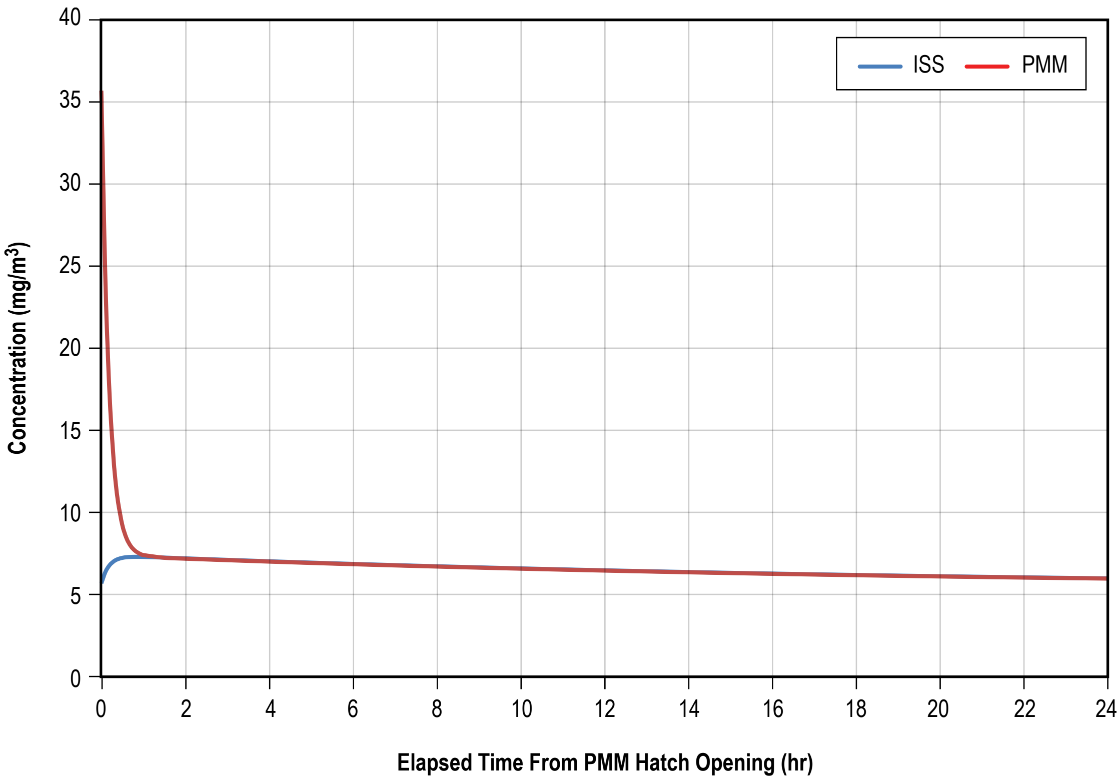

Figure 32. Trace contaminant concentration transient during PMM first entry.

With no active scrubbing before hatch opening, ethanol, 2-propanol, 2-methyl-1-butanol, n-butanol, 2-propanone, 2-butanone, trimethylsilanol, hexamethyltrisiloxane, and octamethylcyclotetrasiloxane are predicted to exceed their respective ISS MORD zero risk concentrations when the hatch is first opened. The zero risk concentrations are the Russian LPCs. Likewise, with no active scrubbing before hatch opening, all predicted concentrations in the PMM at the time the hatch is opened are expected to comply with their respective ISS MORD acceptable risk level concentrations. The acceptable risk concentrations are the NASA SMACs.

17.6.3 Trace Contaminant Control During the International Space Station ULF-5 Stage

The total estimated 1.6 mg/hr offgassing load from the PMM represents a 0.7% increase in the total ISS trace contaminant load compared to the ULF-4 stage. The maximum magnitude of the concentration transient that may occur during the Tranquility Node 3 first entry operations is ~0.4 mg/m^3 reached ~1.5 hours after the hatch opens. If the predicted offgassing from the PMM equipment is sustained over time, the total Station trace chemical contaminant concentration is predicted to return to its initial docking magnitude within 40 hours and rise by no more than ~0.04 mg/m^3. Overall, individual trace contaminant concentrations in the ISS cabin, summarized in table 39, are expected to remain within their acceptable range during ISS ULF-5 stage operations.

Table 39. Predicted ISS ULF-5 stage generation rates and concentrations.

	Limits in Air			
Compound	ZRL (mg/m^3)	ARL (mg/m^3)	Rate (mg/hr)	$C_{Ingress}$ (mg/m^3)
Methanol	0.2	9	7.2	0.2
Ethanol	10	2,000	44	1
2-propanol	1.5	150	22	0.5
1-propanol	0.6	98	1.5	0.03
2-methyl-1-propanol	0.1	120	4.7	0.1
2-methyl-2-propanol	3.3	120	0.4	0.01
n-butanol	0.8	40	26	0.6
Ethanal	1	4	0.7	0.02
Propanal	1	14	1.6	0.04
2-methylpropenal	1	1.7	0.01	0.0002
Butanal	1	4	4	0.1
Pentanal	1	4	0.4	0.01
Hexanal	1	4	0.3	0.006
Benzenecarbonal	1	4	0.1	0.002
Heptanal	1	4	0.09	0.002
Octanal	1	4	0.03	0.0007
Nonanal	1	4	–	–
Benzene	0.2	0.2	0.7	0.02
Methylbenzene	8	60	9.7	0.2
Ethenylbenzene	0.25	43	0.2	0.004
Ethylbenzene	2	50	0.9	0.02
1,3-/1,4-dimethylbenzenes	5	220	9.8	0.2
1,2-dimethylbenzene	5	220	2.7	0.07
Ethanoic acid ethyl ester	4	180	1.6	0.04
Ethanoic acid butyl ester	2	190	3.6	0.09
1,3-dioxolane	16.6	N/A	0.1	0.003
Dichloromethane	5	10	10	0.3
1,2-dichloroethane	0.5	1	0.4	0.01
Pentane	10	590	0.8	0.02
Cyclohexane	3	210	1.9	0.05
Hexane	5	180	0.5	0.01
Heptane	10	200	0.3	0.01
3-methylhexane	20	29	–	–
2-methylheptane	20	29	–	–
Nonane	10	320	0.05	0.001
2-propanone	1	50	22	0.5
2-butanone	0.25	30	31	0.8
Cyclohexanone	1.3	60	3.2	0.08
Acetophenone	0.2	250	0.003	0.0001
Carbon monoxide	5	10	14	0.5
Carbon disulfide	1	16	0.2	0.004
Trimethylsilanol	0.2	37	0.8	0.02
Hexamethylcyclotrisiloxane	0.2	9	1	0.03
Octamethylcyclotetrasiloxane	0.2	12	1.3	0.03

17.7 Summary

The predicted cabin atmospheric quality in the PMM has been evaluated based on a generalized load model and taking into consideration observed offgassing rate magnitudes from USOS habitable element tests. None of the 44 compounds commonly reported in USOS element offgassing test samples are predicted to exceed their individual SMAC, also known as the ISS acceptable risk concentrations. Nine compounds—ethanol, 2-propanol, 2-methyl-1-butanol, n-butanol, 2-propanone, 2-butanone, trimethylsilanol, hexamethyltrisiloxane, and octamethylcyclotetrasiloxane—are predicted to exceed their respective ISS MORD zero risk concentrations when the hatch is first opened. The contribution to the total ISS trace contaminant load may result in a ~0.04 mg/m^3 long-term increase in total trace chemical contaminant concentration. The magnitude of the short duration ISS trace contaminant concentration transient is expected to not exceed 1.6 mg/m^3 at the Station level during PMM first entry; however, concentration increases in the adjacent module may approach 10 mg/m^3. Overall, the active contamination control equipment on board the ISS is expected to accommodate the additional load from the PMM and its equipment as well as maintain individual trace contaminant concentrations below the SMAC during the ISS ULF-5 stage.

17.8 Conclusions

Conclusions from the predicted trace contaminant environment in the PMM at first entry using predicted offgassing rates are the following:

- No compound is predicted to exceed its acceptable risk concentration (NASA SMAC) in the PMM cabin during first entry operations.
- Ethanol, 2-propanol, 2-methyl-1-butanol, n-butanol, 2-propanone, 2-butanone, trimethylsilanol, hexamethyltrisiloxane, and octamethylcyclotetrasiloxane may temporarily exceed their individual zero risk concentrations in the PMM cabin during first entry operations.
- The predicted maximum transient in the ISS cabin total trace chemical contaminant concentration during PMM first entry operations is ~1.6 mg/m^3.
- The predicted maximum transient may approach ~10 mg/m^3 in the module adjacent to the PMM during first entry operations.
- No individual trace contaminant concentration in the ISS cabin is expected to exceed either its zero or acceptable risk concentration during ULF-5 stage operations after adding the PMM equipment offgassing contribution.
- The predicted maximum sustained increase in cabin total trace chemical contaminant concentration that may result from adding the PMM and its cargo equipment to the ISS is ~0.04 mg/m^3.

17.9 Recommendation

The assessment of predicted offgassing from the PMM finds that the module is expected to be reasonably clean as long as acceptable, standard materials selection and contamination control protocols are followed. Further, the assessment finds that the active contamination control equipment on board the ISS possesses the necessary capability and capacity to accommodate the additional trace contaminant generation load. No special precautions beyond standard first module entry procedures are anticipated during PMM first entry and activation operations. Compliance with ISS habitable module first entry flight rules must be determined by the responsible NASA toxicology organization.

18. CARGO MISSION 5A.1—MISSION 5A.1 TRACE CONTAMINANT CONTROL CAPABILITY ASSESSMENT

This assessment was originally released under NASA Memorandum FD21(01-051) dated February 7, 2001.

18.1 Background

The MPLM flight module number 1 (FM-1), known also as Leonardo, is the primary cargo for the STS-102/5A.1 mission to the ISS. In order to satisfy the ISS program's TCC requirements as well as to ensure crew health and safety, the expected air quality during initial ingress of the Leonardo MPLM has been predicted by analysis. Offgassing test data, provided in appendix B, collected from the Leonardo MPLM between December 26, 2000, and January 4, 2001, serve as the basis for trace gaseous contaminant generation.

18.2 Purpose

The engineering analysis summarized by the following discussion serves to verify the ISS's TCC capability for mission 5A.1. Specifically, it addresses the air quality during the first ingress of Leonardo.

18.3 Objectives

The approach to maintaining acceptable cabin air quality in Leonardo during mission 5A.1 is assessed by engineering analysis. Specific objectives of the analysis that serve to verify the approach are the following:

- Predict individual trace contaminant concentrations during ingress operations.

- Determine the minimum on-orbit purge duration in the event ingress flight rule criteria are exceeded.

18.4 Assumptions

To conduct the mission 5A.1 trace contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

18.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the mission 5A.1 engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results and adjusted by a factor of 1.27 to account for hardware not yet installed in the Leonardo MPLM.

- ISS atmospheric leakage is zero. This is considered to be true for the early stages of the ISS's on-orbit life.

- Cabin atmospheric conditions are on average 20 °C, 50% relative humidity, and 101.3 kPa.

- Offgassing rates are constant with time. This has been shown by analyses conducted to date to be conservative as rates tend to decay with time.

- Seven-day SMACs apply for the ingress analysis scenario according to flight rule X13.2.2-2 provided in appendix A.

18.4.2 On-Orbit Configuration

During mission 5A.1, the ISS's on-orbit configuration consists of PMA-1, PMA-2, PMA-3, Unity (Node 1), Destiny (U.S. Laboratory), Zarya, Zvezda, a Soyuz spacecraft, Leonardo MPLM, and the Shuttle. The Leonardo MPLM remains isolated until it is attached to the ISS. Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] In the Leonardo MPLM's case, IMV forces contaminant-laden air out where it is mixed with potentially cleaner air in the main ISS cabin. The TCCS and BMP remove the added contaminants from the Leonardo MPLM and the revitalized air flows back into the Leonardo MPLM via the IMV system. Assumptions pertaining to the ISS's configuration and its contamination control capability are the following:

- Leonardo's free volume is 45.02 m^3 which is 58.46% of the empty shell volume as reported at the MPLM critical design review held in November 1996.

- Contamination control in the Leonardo MPLM is provided parasitically via IMV with the ISS.

- IMV flow is 101.94 m^3/hr (60 ft^3/min).

18.4.3 Mission Timeline

The mission timeline used to evaluate ingress of the Leonardo MPLM assumes approximately 30 days elapse between ground closeout and on-orbit ingress. The time to reach a *T*-value magnitude of 1 and 3 are also evaluated to understand the allowable launch slip before a ground purge would be necessary.

18.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for STS-102/5A.1. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

18.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of offgassing test grab samples collected from the Leonardo MPLM between December 26, 2000, and January 4, 2001. Sample sets were collected at the beginning of the test, at 89 hours, at 73 hours, and at 209.83 hours. Approximately 78.76% of the cargo mass was installed at the time this test was conducted. Accordingly, the derived rates are adjusted by a factor of 1.27 to account for the remaining cargo mass. Individual contaminant generation rates for each time increment are derived using equation (3) which is the differential form of equation (2). For the time variables, t_i, values of 89.73 hours and 120.1 hours (209.83 minus 89.73) are used.

18.5.2 Analysis Cases Considered

The primary case considered is the normal ingress of the Leonardo MPLM. Projections of the elapsed time to a *T*-value magnitudes of 1 and 3 are also considered as well as a calculation of the appropriate amount of time to reduce the *T*-value magnitude from an arbitrary value of 5 to the flight rule ingress criterion of 3.

18.5.3 Calculation Approach

Each contaminant concentration at ingress is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1. Once the concentration has been calculated, the overall *T*-value is calculated using equation (1).

The time to reduce the *T*-value from a beginning level to the flight rule ingress criterion of 3 is calculated directly by using the solved mass balance equations between the ISS cabin and the Leonardo MPLM expressed by equation (5).

18.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

18.6.1 Derived Generation Rates

The element offgassing test identified 14 chemical compounds with measurable generation rates (summarized in table 40). The average concentrations at each sampling event during the test are provided. These concentrations were used in equation (3) to derive the generation rate.

Table 40. Generation rates and predicted ingress concentrations for mission 5A.1.

Compound	SMAC (mg/m^3)	C_1 (mg/m^3)	C_2 (mg/m^3)	C_3 (mg/m^3)	Rate (mg/hr)	$C_{Ingress}$ (mg/m^3)
Methanol	9	0.025	0.11	0.11	0.0271	0.433
2-propanol	150	0.19	1	1.8	0.448	7.17
Ethanal	4	0.0375	0.085	0.095	0.0175	0.280
Propanal	95	0.025	0.055	0.08	0.0155	0.248
Methylbenzene	60	0.025	0.12	0.15	0.0374	0.598
Dichloromethane	50	0.025	0.05	0.105	0.0211	0.337
Trichlorotrifluoroethane (Freon 113)	400	0.025	0.18	0.505	0.127	2.03
2-propanone	50	0.99	1.25	1.4	0.119	1.90
2-butanone	30	0.085	0.39	0.64	0.157	2.51
Carbon disulfide	16	–	–	0.025	0.00595	0.0952
Fluorinated hydrocarbon	325	0.64	1.9	2.1	0.449	7.18
Octamethylcyclotetrasiloxane	280	0.06	0.07	0.11	0.0127	0.203
Hexamethylcyclotrisiloxane	230	0.155	0.495	0.703	0.158	2.52
Trimethylsilanol	37	0.02	0.165	0.17	0.0474	0.758

18.6.2 Normal 5A.1 Ingress of Leonardo

As shown in table 40, none of the 14 chemical compounds identified by the offgassing test will exceed the SMACs after the planned 30 days between closeout on the ground and on-orbit ingress. Based upon these concentrations, the predicted *T*-value magnitude is 0.37 which is well below the 3 allowed by flight rule X13.2.2-2. Methanol, 2-propanol, ethanal, 2-propanone, and 2-butanone are the major contributors to the predicted *T*-value. Overall, the *T*-value rises at 0.000515 units/hour or 0.0124 units/day. The Leonardo MPLM's offgassing load represents a 2.9% increase in the total Station load.

18.6.3 Contingency Ingress Scenario

Contingency operations would be required only in the event the predicted *T*-value exceeds 3. For the Leonardo MPLM, such a situation would not present itself unless the launch slips 242.7 days. Before the *T*-value magnitude reaches 1, 80.9 days elapse. Therefore, based upon the offgassing test data, the crew will be able to enter the Leonardo MPLM during STS-102/5A.1 without taking special actions unless a major problem results in a substantial launch delay.

For the hypothetical case for a starting *T*-value equal to 5, the Leonardo MPLM would have to be ventilated for 41 minutes minimum before the crew may enter. Using a 10% margin, a ventilation period of 50 minutes is recommended. This will reduce the *T*-value magnitude below the flight rule criterion of 3, thus minimizing the effects on crew health and mission timeline.

18.7 Summary

The air quality in the Leonardo MPLM has been evaluated based upon data acquired from the element offgassing test. The analysis projects an ingress *T*-value of 0.37 and a contaminant buildup rate of 0.0124 *T*-value units/day. The contamination load from Leonardo represents a 2.9% increase in the total Station load. This increase is easily accommodated by the TCCS and BMP. As well, a substantial launch slip must occur before the predicted contamination level would exceed the ingress criteria of flight rule X13.2.2-2. In the event of a substantial delay or the known introduction of highly volatile materials, it is recommended that the Leonardo MPLM be purged for 50 minutes via the IMV before the crew enters.

18.8 Conclusions

Based upon the evaluation of offgassing data collected from the Leonardo MPLM, conclusions that can be made are the following:

- Equipment offgassing rates observed for the Leonardo MPLM are very low.

- The crew may enter the Leonardo MPLM without special precaution because the predicted *T*-value magnitude is much less than 3.

- Total onboard TCC resources are capable of maintaining acceptable air quality in the Leonardo MPLM as well as the overall ISS cabin.

18.9 Recommendation

In the event of a substantial launch delay, the minimum scrubbing duration for the Leonardo MPLM is 50 minutes to ensure a *T*-value magnitude less than 3 at ingress. In the case of the Leonardo MPLM, a substantial delay is defined as greater than 200 days.

19. CARGO MISSION 6A—TRACE CONTAMINANT CONTROL CAPABILITY ASSESSMENT

This assessment was originally released under NASA Memorandum FD21(01-074) dated March 20, 2001.

19.1 Background

The MPLM flight module number 2 (FM-2), known also as Raffaello, is the primary cargo for the STS-100/6A mission to the ISS. In order to satisfy the ISS program's TCC requirements as well as to ensure crew health and safety, the expected air quality during initial ingress of the Raffaello MPLM has been predicted by analysis. Offgassing test data collected from the Raffaello MPLM between February 2 and 12, 2001, serve as the basis for trace gaseous contaminant generation.[1]

19.2 Purpose

The engineering analysis summarized by the following discussion serves to verify the ISS's TCC capability for mission 6A. Specifically, it addresses the air quality during the first ingress of the Raffaello MPLM.

19.3 Objectives

The approach to maintaining acceptable cabin air quality in the Raffaello MPLM during mission 6A is assessed by engineering analysis. Specific objectives of the analysis that serve to verify the approach are the following:

- Predict individual trace contaminant concentrations during ingress operations.

- Determine the minimum on-orbit purge duration in the event ingress flight rule criteria are exceeded.

19.4 Assumptions

To conduct the mission 6A trace contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

19.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the mission 6A engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results and adjusted by a factor of 1.42 to account for hardware not yet installed in the Raffaello MPLM.

- ISS atmospheric leakage is zero. This is considered to be true for the early stages of the ISS's on-orbit life.

- Cabin atmospheric conditions are on average 20 ºC, 50% relative humidity, and 101.3 kPa.

- Offgassing rates are constant with time. This has been shown by analyses conducted to date to be conservative as rates tend to decay with time.

- Seven-day SMACs apply for the ingress analysis scenario according to flight rule X13.2.2-2 provided in appendix A.

19.4.2 On-Orbit Configuration

During mission 6A, the ISS's on-orbit configuration consists of PMA-1, PMA-2, PMA-3, Unity (Node 1), Destiny (U.S. Laboratory), Zarya, Zvezda, a Soyuz spacecraft, the Raffaello MPLM, and the Shuttle. The Raffaello MPLM remains isolated until it is attached to the ISS. Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Previous analysis for missions 5A and 5A.1 has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load. In the Raffaello MPLM's case, IMV forces contaminant-laden air out where it is mixed with potentially cleaner air in the main ISS cabin. The TCCS and BMP remove the added contaminants from the Raffaello MPLM and the revitalized air flows back into the Raffaello MPLM via the IMV system. Assumptions pertaining to the ISS's configuration and its contamination control capability are the following:

- The Raffaello MPLM's free volume is 45.02 m^3 which is 58.46% of the empty shell volume as reported at the MPLM critical design review held in November 1996.

- Contamination control in the Raffaello MPLM is provided parasitically via IMV with the ISS.

- IMV flow is 101.94 m^3/hr (60 ft^3/min).

19.4.3 Mission Timeline

The mission timeline used to evaluate ingress of the Raffaello MPLM assumes approximately 30 days elapse between ground closeout and on-orbit ingress. The time to reach a *T*-value magnitude of 1 and 3 are also evaluated to understand the allowable launch slip before a ground purge would be necessary.

19.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for STS-100/6A. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

19.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of grab samples collected from the Raffaello MPLM between February 2 and 12, 2001. Test results and mass accountability are provided in appendix B. Sample sets were collected at the beginning of the test, at 113.1 hours, and at 233 hours. Approximately 70.54% of the cargo mass was installed at the time of this test. Accordingly, the derived rates are adjusted by a factor of 1.42 to account for the missing mass. Individual contaminant generation rates for each time increment are derived using equation (3) which is the differential form of equation (2). For the time variables, t_i, values of 113.1 hours and 119.9 hours (233 minus 113.1) are used.

19.5.2 Analysis Cases Considered

The primary case considered is the normal ingress of the Raffaello MPLM. Projections of the elapsed time to T-value magnitudes of 1 and 3 are also considered as well as a calculation of the appropriate amount of time to reduce the T-value magnitude from an arbitrary value of 5 to the flight rule ingress criterion of 3.

19.5.3 Calculation Approach

Each contaminant concentration at ingress is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1. Once the concentration has been calculated, the overall T-value is calculated using equation (1).

The time to reduce the T-value magnitude from a beginning level to the flight rule ingress criterion of 3 is calculated directly by using the solved mass balance equations between the ISS cabin and the Raffaello MPLM as described by equation (5) and solving for time.

19.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

19.6.1 Derived Generation Rates

Analysis of samples collected during the element offgassing test identified 14 chemical compounds with measurable generation rates (summarized in table 41). The average concentrations at each sampling event during the test are provided. These concentrations were used in equation (3) to derive the generation rate.

Table 41. Generation rates and predicted ingress concentrations for mission 6A.

Compound	SMAC (mg/m^3)	C_1 (mg/m^3)	C_2 (mg/m^3)	C_3 (mg/m^3)	Rate (mg/hr)	$C_{Ingress}$ (mg/m^3)
Methanol	9	0.025	0.235	0.325	0.0832	1.33
2-propanol	150	0.17	0.695	0.99	0.227	3.62
n-propanol	98	–	0.025	0.085	0.023	0.368
n-butanol	80	0.0125	0.06	0.1	0.024	0.385
Ethanal	4	0.0575	0.13	0.17	0.0311	0.497
Propanal	95	–	0.065	0.11	0.0303	0.485
Methylbenzene	60	0.025	0.26	0.305	0.0783	1.25
Trichlorotrifluoroethane (Freon 113)	400	0.025	0.175	0.165	0.0397	0.634
2-propanone	52	0.0525	0.13	0.18	0.0352	0.563
2-butanone	30	0.025	0.39	0.725	0.192	3.07
4-methyl-2-pentanone	140	–	0.025	0.06	0.0164	0.262
Octamethylcyclotetrasiloxane	280	0.075	0.61	0.92	0.233	3.73
Hexamethylcyclotrisiloxane	90	0.055	1.04	1.35	0.36	5.76
Trimethylsilanol	37	–	0.1	0.31	0.0841	1.34

19.6.2 Normal 6A Ingress of Raffaello

As shown in table 41, none of the 14 chemical compounds identified by the offgassing test will exceed the SMACs after the planned 30 days between closeout on the ground and on-orbit ingress. Based upon these concentrations, the predicted *T*-value magnitude is 0.56 which is well below the 3 allowed by flight rule X13.2.2-2. Methanol and ethanal are the major contributors to the predicted *T*-value. Overall, the *T*-value rises at 0.000767 units/hour or 0.0184 units/day. The Raffaello MPLM's offgassing load represents a 2.5% increase in the total Station load.

19.6.3 Contingency Ingress Scenario

Contingency operations would be required only in the event the predicted *T*-value exceeds 3. For the Raffaello MPLM, such a situation would not present itself unless the launch slips 132.6 days. Before the *T*-value magnitude reaches 1, 54.3 days elapse. Therefore, based upon the offgassing test data, the crew will be able to enter the Raffaello MPLM during STS-100/6A without taking special actions unless a major problem results in a substantial launch delay or there has been some indication of a fire in the Raffaello MPLM.

For the hypothetical case, for a starting *T*-value magnitude equal to 5, the Raffaello MPLM would have to be ventilated for 41 minutes minimum before the crew may enter. Using a 10% margin, a ventilation period of 50 minutes is recommended. This will reduce the *T*-value magnitude below the flight rule criterion of 3, thus minimizing the effects on crew health and mission timeline.

19.6.4 Other Considerations

Examination of the offgassing test results provided in appendix B shows very high concentrations for ethanol. The first pair of samples average 120.5 mg/m^3 while the second and third pairs average 66.5 and 53.5 mg/m^3, respectively. The concentration trend is downward indicating no new ethanol generation. Ethanol and other organic solvents are used for maintaining surface cleanliness during ground processing. In addition, ethanol is used as needed for disinfecting surfaces; therefore, ethanol is used liberally during ground processing.

The concentrations observed during the Raffaello MPLM's offgassing test are a factor of 2.1 to 4.8 times higher than the greatest in-flight concentration observed through STS-92/3A. That was 25 mg/m^3 upon SM PxO ingress. During the same mission, the initial concentration in the Progress vehicle was 20 mg/m^3. Both the SM PxO and Progress volumes were not scrubbed before ingress.

Effectively, the Raffaello MPLM is similar to the SM PxO and Progress. The situation at ingress is further complicated because present procedures allow the ventilation diffusers to be blocked by stowed equipment. This extends the amount of time required to dilute the trace contaminant concentrations upon ingress.

A long-term issue relating to high concentrations of ethanol and other organic solvents are their effect on the performance and process economics of the water processing systems on board the SM and the future Node 3. Engineering analysis has shown that the U.S. water processor's design load for ethanol is exceeded above an air concentration of 0.82 mg/m^3.[22] This is more than 2,400 times lower than ethanol's SMAC. All of the concentrations reported during the Raffaello MPLM's offgassing test exceeded this threshold. In-flight cabin air quality samples collected through STS-92/3A also indicate consistent ethanol concentrations exceeding this threshold. The combined concentration threshold for ethanol, 2-propanol, and acetone according to engineering analysis documented by reference 20 is 11.72 mg/m^3. Therefore, to avoid water processor performance impacts, the combined concentration of these compounds should not exceed this threshold. Fortunately, the combined in-flight concentrations for these compounds have typically been below the 11.72 mg/m^3 threshold.

Overall, if unrestricted volatile organic solvent use continues during ground processing, each MPLM will be a significant contamination source. Steps to restrict volatile organic solvent use within a reasonable time period before hatch closure and a clean air purge just after hatch closure should minimize the long-term impact that repeated MPLM missions will have on the Station's cabin air quality and water processing system performance.

19.7 Summary

The air quality in the Raffaello MPLM has been evaluated based upon data acquired from the element offgassing test. The analysis projects an ingress *T*-value magnitude of 0.56 and a contaminant buildup rate of 0.0184 *T*-value units/day. The contamination load from the Raffaello MPLM represents a 2.5% increase in the total Station load. This increase is easily accommodated by the TCCS and BMP. As well, a substantial launch slip must occur before the predicted contamination level would exceed the ingress criteria of flight rule X13.2.2-2. In the event of a substantial delay or the known introduction of highly volatile materials, it is recommended that the Raffaello MPLM be purged for 50 minutes via the IMV before the crew enters.

19.8 Conclusions

Based upon the evaluation of offgassing data collected from the Raffaello MPLM, conclusions that can be made are the following:.

- Equipment offgassing rates observed for the Raffaello MPLM are very low.
- Ethanol use during ground processing contributes to very high concentrations during the offgassing test. Since no additional ethanol is introduced into the MPLM during the test, the concentration decays for a net ethanol loss.
- The crew may enter the Raffaello MPLM without special precaution because the predicted *T*-value magnitude is much less than 3.
- Total onboard TCC resources are capable of maintaining acceptable air quality in the Raffaello MPLM as well as the overall ISS cabin.

19.9 Recommendations

Recommendations pertaining to the ground processing and in-flight operations of the Raffaello MPLM are the following:

- Restrictions should be established with respect to using ethanol and other volatile organic solvents for cleaning. To reduce the amount of these contaminants transported to the ISS on board each MPLM, volatile organic solvents should not be used on any internal surfaces within 5 days of ground closeout.
- The MPLM should be purged after hatch closure to remove excessive amounts of volatile organic solvents.
- In the event of a substantial launch delay, the minimum scrubbing duration for the Raffaello MPLM is 50 minutes to ensure a *T*-value magnitude less than 3 at ingress. In the case of the Raffaello MPLM, a substantial delay is defined as greater than 130 days.

20. CARGO MISSION ATV-1—JULES VERNE AUTOMATED TRANSFER VEHICLE CARGO CARRIER TRACE CONTAMINANT CONTROL ENGINEERING ASSESSMENT

This assessment was originally released under NASA Memorandum ES22-08-021 dated March 25, 2008.

20.1 Background

The automated transfer vehicle (ATV) cargo carrier is designed to transport equipment and supplies to the ISS. Offgassing test data acquired during ground processing after cargo installation are evaluated to ensure acceptable cabin air quality on opening the hatch. Contaminant buildup is a concern because the ATV cargo carrier from vehicle and cargo offgassing is sealed for more than 30 days before docking with the ISS. Offgassing from new equipment adds to the trace chemical contamination generation load on board the ISS and may cause cabin air quality transients during the time of hatch opening on orbit. Assessing the offgassing test data before flight satisfies the ISS program's TCC requirements during ATV first entry operations. The assessment predicts the expected air quality during initial entry of the first ATV cargo carrier, Jules Verne, using offgassing test data acquired by NASA, European Space Research and Technology Centre (ESTEC), and IMBP during the vehicle's ground processing at the launch facility in Kourou, French Guiana, and updates the June 2007 NASA engineering assessment of the empty ATV.

20.2 Purpose

The engineering analysis summarized by the following discussion predicts the trace chemical contaminant concentration condition within the Jules Verne ATV-1 cargo carrier cabin at the time the hatch is opened to the ISS and transient conditions during first entry operations.

20.3 Objective

The approach to maintaining acceptable cabin air quality in the Jules Verne ATV-1 cargo carrier during first entry on orbit is assessed by engineering analysis. The primary objective of the assessment is to predict individual trace chemical contaminant concentrations at the time the hatch opens on orbit and to recommend appropriate actions, if any, necessary to ensure ISS cabin environmental conditions comply with relevant specifications and guidelines.

20.4 Assumptions

To conduct the Jules Verne ATV-1 trace chemical contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

20.4.1 Offgassing and Cabin Conditions

The assumptions for the offgassing rates and cabin atmospheric conditions relevant to evaluating TCC for the Jules Verne ATV-1 cargo carrier mission engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results reported from samples collected and analyzed by NASA, ESTEC, and IMBP.
- Last purge approximately February 2, 2008; launch approximately March 9, 2008; docking approximately April 3, 2008 for 43 days elapsed time.
- Atmospheric leakage from the Jules Verne ATV-1 cargo carrier is zero.
- The Jules Verne ATV cargo carrier free gas volume is 39 m^3.
- The Jules Verne ATV cargo carrier is 100% configured for launch.
- Atmospheric conditions are on average 20 °C, 50% relative humidity, and 101.3 kPa.
- Offgassing rates are constant with time.
- Acceptable risk and zero risk air quality concentrations as defined by the ISS MORD apply.

20.4.2 On-Orbit Configuration

During the flight of the Jules Verne ATV-1 cargo carrier, the ISS's habitable on-orbit configuration consists of PMA-1, Unity (Node 1), Destiny (U.S. Laboratory), Quest (U.S. airlock), Harmony (Node 2), Columbus APM, Zarya (FGB), Zvezda (service module), a Soyuz spacecraft, and a Progress cargo vehicle. The ISS's total habitable volume is approximately 584 m^3. The Jules Verne ATV-1 cargo carrier remains isolated until it docks with the ISS and the hatch opens. Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Portable scrubbing is provided using the Russian AFOT unit. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] Once the ATV cargo carrier's hatch is opened, accumulated trace chemical contamination will mix within the main ISS cabin where the TCCS and BMP remove the added contaminants.

20.4.3 Mission Timeline

The mission timeline used to evaluate the air quality conditions during the first entry of the Jules Verne ATV-1 cargo carrier consists of approximately 43 days elapsed time between the last breathing air renewal on February 20, 2008, during final prelaunch processing and on-orbit ingress, and docking is scheduled on April 3, 2008. Mission launch is scheduled for March 9, 2008.

20.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for evaluating the scenario for the first entry of the Jules Verne ATV-1 cargo carrier. The discussion includes a summary on trace contaminant generation rate derivation, mass balance equation development, and cases considered for the assessment.

20.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of offgassing test grab samples collected from the Jules Verne ATV-1 cargo carrier by NASA, ESTEC, and IMBP between December 14 and 22, 2007. The elapsed time for the basic offgassing test was 205 hours. Additional samples were collected by ESTEC 470 hours after the initial sample set on January 2, 2008. The Jules Verne ATV-1 cargo carrier was fully outfitted at the time of the test, including cargo.

Individual contaminant generation rates are derived for each time increment between sampling events using equation (3) which is the differential form of equation (2).

Offgassing rates were derived for each set of sample results reported by NASA, ESTEC, and IMBP. These results were compared and a composite offgassing generation rate load compiled from the three sample sets.

20.5.2 Analysis Cases Considered

The primary case considered is the normal first entry of the Jules Verne ATV-1 cargo carrier. Comparison of the individual contaminant concentrations to zero risk and acceptable risk concentrations defined by the ISS MORD is conducted for the normal first entry case to satisfy basic ISS program contamination control requirements. Entry conditions for cases with and without active scrubbing are considered. Predicted active scrubbing duration to comply with total NMVOC and polar volatile organic compound (PVOC) concentration guidelines using the Russian AFOT equipment is determined. Margin for launch delays and docking delays is also evaluated.

20.5.3 Contamination Buildup Calculation

The magnitude of individual and total trace chemical contaminant buildup is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero at t_1 equal to zero.

20.5.4 Contamination Transient Calculation

Assessing the effects of accumulated contaminant buildup during the Jules Verne ATV-1 cargo carrier's transit to the ISS on the ISS's cabin environment employs simultaneous mass balance techniques on the two attached volumes. The mass balance for the ISS and Jules Verne ATV-1 cargo carrier volumes are provided by equations (10) and (11).

20.5.5 Active Scrubbing Duration Calculation

Assuming that the contaminant mass removal rate is much greater than the generation rate simplifies the cabin mass balance equation and allows equation (9) to be used to calculate the active scrubbing duration. This equation serves as the basis for calculating the active scrubbing duration. The active scrubbing device volumetric flow and efficiency are assumed to be constants.

20.6 Results

The following discussion summarizes offgassing rate derivation and first entry trace contaminant concentration predictions.

20.6.1 Derived Generation Rates

The samples collected and analyzed by NASA, ESTEC, and IMBP during the element offgassing test conducted in December 2007 identified 73 chemical compounds with measurable generation rates. The composite offgassing load is summarized in table 42. The average concentrations at each sampling event, listed in appendix B, were evaluated using equation (3) to derive the generation rate for each set of data. The composite offgassing generation rate load in table 42 represents the average generation rate for each compound obtained from evaluating the three sample analysis data sets.

Table 42. Generation rates and predicted prescrub ingress concentrations for mission ATV-1.

	Limits in Air			
Compound	**ZRL (mg/m^3)**	**ARL (mg/m^3)**	**Rate (mg/hr)**	**$C_{Ingress}$ (mg/m^3)**
Methanol	0.2	9	0.0005	0.01
Ethanol	10	2,000	0.32	8.5
2-propanol	1.5	150	0.31	8.1
1-propanol	0.6	98	0.0013	0.03
2-methyl-2-propanol	3.3	120	0.018	0.5
n-butanol	0.8	40	0.031	0.8
Phenol	0.1	7.7	0.018	0.5
Ethanal	1	4	0.032	0.9
Propanal	1	14	0.0019	0.05
2-methylpropenal	1	1.7	0.0014	0.04
Butanal	1	4	0.0048	0.1
Pentanal	1	4	0.0003	0.01
Hexanal	1	4	0.0064	0.2
Benzenecarbonal	1	4	0.0055	0.2
Heptanal	1	4	0.0003	0.01
Octanal	1	4	0.0016	0.04
Nonanal	1	4	0.0027	0.07
Decanal	1	4	0.0056	0.2
Benzene	0.2	0.2	0.0013	0.03
Methylbenzene	8	60	0.038	1
Ethenylbenzene	0.25	43	0.0016	0.04
1,3-/1,4-dimethylbenzenes	5	220	0.0121	0.3
1,2-dimethylbenzene	5	220	0.038	1
Ethanoic acid methyl ester	–	125	0.0006	0.02
Ethanoic acid ethyl ester	4	180	0.02	0.5
Ethanoic acid butyl ester	2	190	0.0052	0.1
Ethanoic acid 1-methoxy-2-propyl ester	–	55	0.0053	0.1
Butanoic acid ethyl ester	–	80	0.0048	0.1
Ethanoic acid 2-ethoxyethyl ester	–	160	0.033	0.9

Table 42. Generation rates and predicted prescrub ingress concentrations for mission ATV-1 (Continued).

	Limits in Air			
Compound	ZRL (mg/m^3)	ARL (mg/m^3)	Rate (mg/hr)	$C_{Ingress}$ (mg/m^3)
1,3-dioxolane	16.6	–	0.011	0.29
Chloromethane	0.5	42	0.0007	0.02
Dichloromethane	5	10	0.0094	0.25
Trichloromethane	0.03	5	0.0007	0.02
Trichloroethene	1.5	10	0.0004	0.01
Tetrachloroethene	–	34	0.0086	0.2
C4-alkane as n-butane	10	104	0.0037	0.1
2-methyl-1,3-butadiene	3	3	0.0008	0.02
Pentane	10	590	0.0005	0.01
1-hexene	–	180	0.02	0.5
Methylcyclopentane	3	52	0.0003	0.01
Cyclohexane	3	210	0.0007	0.02
Hexane	5	180	0.003	0.08
3-methylpentane	20	1,800	0.0008	0.02
2-methylpentane	20	1,800	0.0024	0.06
3-ethylpentane	–	1,800	0.0009	0.02
Heptane	10	200	0.001	0.03
2,2-dimethylpentane	20	208	0.0003	0.01
2-methylhexane	20	29	0.003	0.08
2,3-dimethylpentane	20	208	0.0007	0.02
2,2,4-trimethylpentane	–	180	0.01	0.3
2,3,3-trimethylpentane	–	180	0.003	0.07
2,4-dimethylhexane	–	180	0.0005	0.01
2,5-dimethylhexane	–	180	0.0002	0.01
Nonane	10	320	0.003	0.08
4-isopropenyl-1-methylcyclohexene	3	560	0.002	0.06
Decane	10	230	0.002	0.05
2-propanone	1	50	0.1	3
3-buten-2-one	–	0.43	0.0007	0.02
2-butanone	0.25	30	0.009	0.24
2-pentanone	–	70	0.0007	0.02
Cyclohexanone	1.3	60	0.26	6.8
4-methyl-2-pentanone	–	140	0.0087	0.2
5-methyl-3-hexanone	–	60	0.012	0.3
Acetophenone	0.2	250	0.0005	0.01
Carbon monoxide	5	10	0.11	2.9
Methyl cyanide	–	7	0.0006	0.01
Carbon disulfide	1	16	0.0007	0.02
Trimethylsilanol	0.2	37	0.08	2.1
Hexamethyldisiloxane	0.2	9	0.004	0.1
Hexamethylcyclotrisiloxane	0.2	9	0.027	0.7
Octamethylcyclotetrasiloxane	0.2	12	0.017	0.4
Decamethylcyclopentasiloxane	0.2	15	0.014	0.4

20.6.2 Individual Contaminant Concentration and Total Contaminant Load Contribution

None of the 73 chemical compounds identified by the three offgassing test data sets are predicted to exceed their respective acceptable risk concentrations after the planned 43 days between final Jules Verne ATV-1 cargo carrier breathing air renewal and on-orbit first entry. Compounds in the alcohol, ketone, and organosilicone classes may exceed their zero risk concentrations. These compounds are 2-propanol, n-butanol, phenol, 2-propanone, cyclohexanone, trimethylsilanol, hexamethylcyclotrisiloxane, octamethylcyclotetrasiloxane, and decamethylcyclopentasiloxane. The total estimated 1.7 mg/hr offgassing load from the Jules Verne ATV-1 cargo carrier and its cargo represents a 2.9% increase in the total Station load compared to 56.6 mg/hr at flight 5A. Six compounds contribute ~72% of this load.

20.6.3 Total Nonmethane Volitile Organic Compound Concentration Transient

The predicted total NMVOC concentration in the Jules Verne ATV-1 cargo carrier cabin at first entry, 43.8 mg/m^3, is ~4.4 times higher than the ~10 mg/m^3 on average that normally exists in the ISS cabin. This total NMVOC load induces a ~2.2 mg/m^3 concentration increase over the prevailing ISS cabin condition. The peak concentration is reached approximately 48 minutes after opening the hatch and establishing ventilation between the Jules Verne ATV-1 cargo carrier and the ISS cabins shown in figure 33. Normal trace contaminant concentration conditions are expected to be restored within 72 hours by normal ISS TCC equipment operation. Previous analysis of the Unity Node 1 first entry operations has established that mixing between the ISS volume and a new cargo carrier or module is complete within approximately 2 hours of establishing ventilation flow. The present assessment agrees with this earlier observation. If the predicted offgassing from the Jules Verne ATV-1 cargo carrier and its cargo is sustained over time, the total Station trace chemical contaminant concentration is predicted to be below detectable levels.

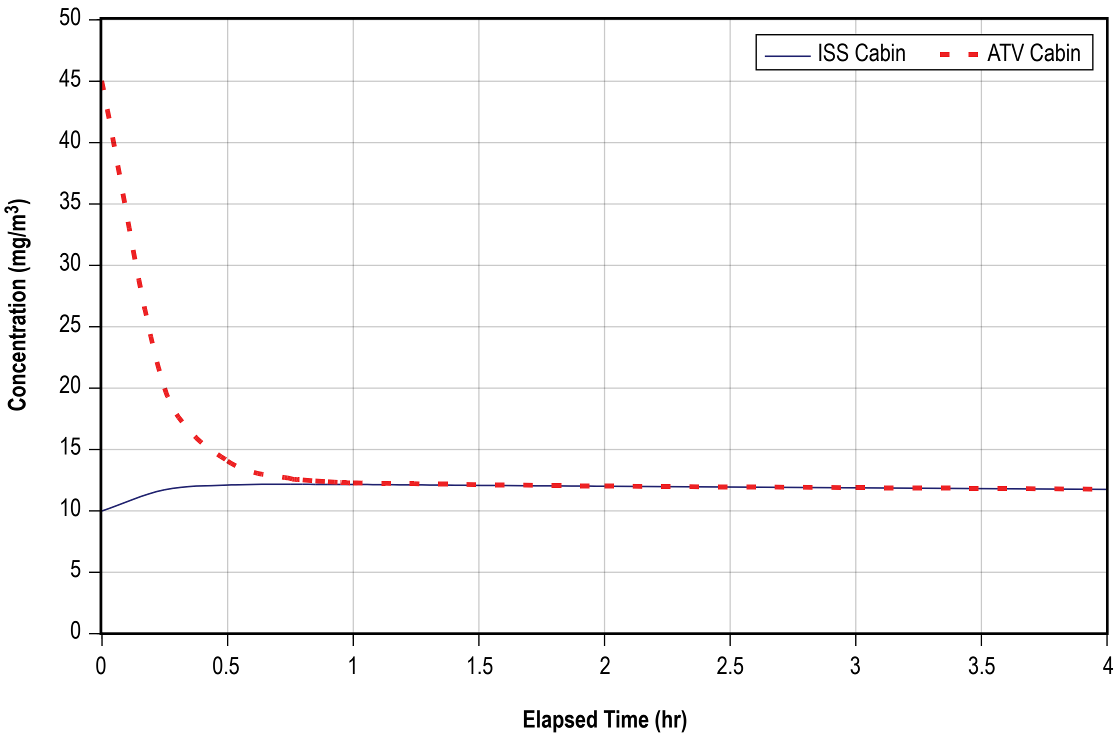

Figure 33. Total NMVOC concentration transient—no active scrubbing.

20.6.4 Total Polar Volitile Organic Ccompound Concentration Transient

The total PVOC concentration at first entry is predicted to be 29 mg/m^3, approximately 5.8 times higher than the ~5 mg/m^3 normally observed in the ISS cabin. This loading induces a 1.5 mg/m^3 transient increase in the ISS total PVOC concentration as shown in figure 34 and temporarily increases the volatile loading into humidity condensate by ~30%. The ISS total PVOC concentration returns to its prevailing condition ~96 hours after the first entry operation begins if no active scrubbing is employed.

To reduce the impact that the total PVOC concentration load at first entry will have on the ISS ECLS equipment performance, particularly for water purification equipment, actively scrubbing the Jules Verne ATV-1 cabin for 4 hours before opening the hatch using the Russian AFOT equipment should be considered. Actively scrubbing the Jules Verne ATV-1 cargo carrier's cabin ensures its cabin PVOC concentration condition is equal to or better than the prevailing condition in the ISS cabin.

Scrubbing before first entry reduces the magnitude of the initial transient contamination load introduced into the ISS cabin during first entry operations and is deemed a prudent action to take when entering any sealed habitable volume.

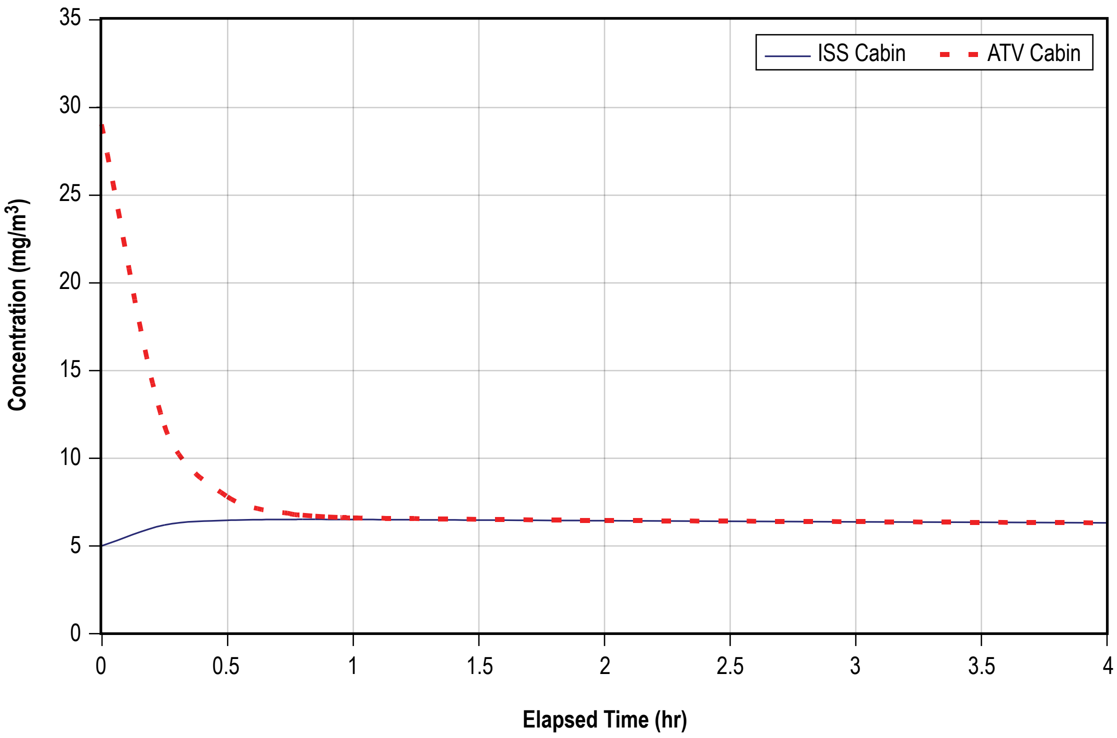

Figure 34. Total PVOC concentration transient—no active scrubbing.

20.6.5 Margin for Launch and Docking Delay

The present analysis indicates that carbon monoxide is the first chemical contaminant to reach its individual acceptable risk concentration. This condition is predicted for the sealed Jules Verne ATV-1 cargo carrier 151 days after the final air renewal. For the normal 43-day transit to the ISS, an approximately 108-day margin exists relative to the individual acceptable risk concentration. Actively scrubbing the Jules Verne ATV-1 cargo carrier cabin for 4 hours before first entry increases this margin by 48 days to 156 days total.

20.6.6 Analysis Conservatism

The analysis assumes that chemical contaminant generation rates remain constant with time. The degree of conservatism associated with this assumption increases over time. Evaluation of chemical contaminant generation rate decay has found ~64% decrease over 20 days.[23] The earlier prediction for the empty Jules Verne ATV-1 and cargo indicates that the degree of conservatism is probably ~40%. Therefore, it is reasonable that generation rates, and likewise, concentrations may be lower than predicted depending on the age of the cargo at the time of the offgassing test.

The engineering assessment assumes that the gas volume for the Jules Verne ATV-1 cargo carrier is ~39 m^3. This volume accounts for ~5% conservatism compared to the recommended 41 m^3 to be used for rapid depressurization calculations. The smaller volume was chosen to accommodate uncertainty associated with the empty volume reported for the cargo carrier and the degree for which cabin air permeates the cargo. When these parameters are considered, the Jules Verne ATV-1 cargo carrier's gas volume may range from 36.4 m^3 to 41.5 m^3. Using the average 39 m^3 volume provides a reasonable middle ground to address this variation without adding excessive conservatism to the overall concentration calculation.

The Russian AFOT equipment will provide a range of removal performance for the individual chemical contaminants. The efficiency range specified by Russian experts is 30% to 50%. The lower end of the efficiency range is used although high molecular weight compounds will likely be removed at efficiencies approaching 100%. Using the lower efficiency of the recommended range contributes to conservatism approaching 70% for the recommended scrubbing duration.

The total analysis general conservatism may be up to ~80%. This magnitude depends mostly on the effect that elapsed time between the offgassing test and the scheduled launch date may have on individual chemical contaminant offgassing rates and the AFOT equipment's actual efficiency. If offgassing rate decay was complete at the time the offgassing test was conducted, the general conservatism is estimated to be up to 70% depending on the AFOT equipment's actual performance. If the AFOT equipment's actual efficiency is indeed close to 30%, then contaminant generation rates drive conservatism to between 40% and 64%. Overall, an expected range for the assessment's conservatism is likely between 40% and 80%.

20.7 Summary

The predicted air quality in the Jules Verne ATV-1 cargo carrier has been evaluated based on data acquired by NASA, ESTEC, and IMBP during the element offgassing test conducted in December 2007. No single chemical compound is predicted to exceed its acceptable risk concentration; however, compounds in the alcohol, ketone, and organosilicone classes are predicted to exceed their respective zero risk concentrations. The contribution to the total ISS trace contaminant load may result in a maximum 2.2 mg/m^3 transient increase in total NMVOC concentration and 1.5 mg/m^3 transient increase in total PVOC concentration. Because the total PVOC concentration inside the Jules Verne ATV-1 cargo carrier is predicted to be ~5.8 times greater than the concentration normally observed in the ISS cabin, consideration should be given to actively scrubbing the cargo carrier's cabin for 4 hours before permanent ventilation flow is established between the ISS and Jules Verne ATV-1 cargo carrier cabins.

20.8 Conclusions

Conclusions from the predicted trace contaminant environment in the Jules Verne ATV-1 cargo carrier at first ingress using offgassing data collected from the fully loaded vehicle are the following:

- No single contaminant will exceed its individual acceptable risk concentration (NASA SMAC).

- Nine contaminants representing the alcohol, ketone, and organosilicone classes may exceed their individual zero risk concentrations during first entry operations.

- The maximum total NMVOC concentration transient expected during Jules Verne ATV-1 cargo carrier first entry operations is ~2.2 mg/m^3 if no active scrubbing is employed.

- The maximum total PVOC concentration transient expected during Jules Verne ATV-1 cargo carrier first entry operations is ~1.5 mg/m^3 if no active scrubbing is employed.

- The maximum total PVOC concentration transient expected during Jules Verne ATV-1 cargo carrier first entry operations may increase humidity condensate loading by ~30% and impact ECLS equipment performance.

- The trace contaminant load presented by the Jules Verne ATV-1 cargo carrier and its cargo is expected to be accommodated long term by the active contamination control equipment on board the ISS.

- A 4-hour active scrub before first entry using the Russian AFOT equipment reduces the total NMVOC and total PVOC concentrations to levels comparable to those normally observed in the ISS cabin.

- A 4-hour active scrub before first entry using the Russian AFOT equipment extends the margin for Jules Verne ATV-1 cargo carrier docking delay by 48 days to 156 days total.

20.9 Recommendation

A 4-hour duration active atmospheric scrub using the Russian AFOT equipment should be considered before establishing active ventilation between the ISS and Jules Verne ATV-1 cargo carrier cabins. This scrubbing duration ensures that the total PVOC concentration load presented by the Jules Verne ATV-1 cargo carrier will not adversely affect the ISS's long term ECLS water processing equipment performance.

21. CARGO MISSION ATV-2—JOHANNES KEPLER AUTOMATED TRANSFER VEHICLE CARGO CARRIER TRACE CONTAMINANT CONTROL ENGINEERING ASSESSMENT

This evaluation was originally released in December 2010.

21.1 Background

The ATV cargo carrier is designed to transport equipment and supplies to the ISS. Offgassing test data acquired during ground processing after cargo installation are evaluated to ensure acceptable cabin air quality on opening the hatch. Contaminant buildup from vehicle and cargo offgasing is a concern because the ATV cargo carrier is sealed for approximately 17 days before docking with the ISS and opening the hatch. Offgassing from new equipment adds to the trace chemical contamination generation load on board the ISS and may cause cabin air quality transients during the time of hatch opening on orbit. Assessing the offgassing test data before flight satisfies the ISS program's TCC requirements during ATV first entry operations. The assessment predicts the expected air quality during initial entry of the second ATV cargo carrier, Johannes Kepler (ATV-2), using offgassing test data acquired by ESTEC during the vehicle's ground processing at the launch facility in Kourou, French Guiana.

21.2 Purpose

The engineering analysis summarized by the following discussion predicts the trace chemical contaminant concentration condition within the Johannes Kepler ATV-2 cargo carrier cabin at the time the hatch is opened to the ISS and transient conditions during first entry operations.

21.3 Objective

The approach to maintaining acceptable cabin air quality in the Johannes Kepler ATV-2 cargo carrier during first entry on orbit is assessed by engineering analysis. The primary objective of the assessment is to predict individual trace chemical contaminant concentrations at the time the hatch opens on orbit and to recommend appropriate actions, if any, necessary to ensure that ISS cabin environmental conditions comply with relevant specifications and guidelines.

21.4 Assumptions

To conduct the Johannes Kepler ATV-2 trace chemical contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

21.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the Johannes Kepler ATV-2 cargo carrier mission engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results reported from samples collected and analyzed by ESTEC.
- Last purge is approximately launch minus 1 week; launch ~2/15/11; docking ~2/25/11 for ~17 days elapsed.
- Atmospheric leakage from the Johannes Kepler ATV-2 cargo carrier during the closed out phase is zero.
- The Johannes Kepler ATV-2 cargo carrier free gas volume is ~39 m^3.
- The Johannes Kepler ATV-2 cargo carrier is 77.8% configured for launch.
- Cabin atmospheric conditions are on average 20 ºC, 50% relative humidity, and 101.3 kPa.
- Offgassing rates are constant with time.
- Acceptable risk and zero risk air quality concentrations as defined by the ISS MORD apply.

21.4.2 On-Orbit Configuration

During the flight of the Johannes Kepler ATV-2 cargo carrier, the ISS's habitable on-orbit configuration consists of PMA-1, PMA-2, Unity (Node 1), Destiny (U.S. Laboratory), Quest (U.S. airlock), Harmony (Node 2), Tranquility (Node 3 and cupola), Columbus APM, Kibo ELM PS and PM modules, the Leonardo PMM, Zarya (FGB), Zvezda (service module), MRM-1, MRM-2, two Soyuz spacecraft, and a Progress cargo vehicle. The ISS's total habitable volume is ~804 m^3. The Johannes Kepler ATV-2 cargo carrier remains isolated until it docks with the ISS and the hatch opens. Active TCC is provided for the ISS by the USOS TCCS located in Destiny and/or Tranquility and the BMP located in Zvezda. Portable scrubbing is provided using the Russian AFOT unit as determined by Russian life support system experts. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] Once the Johannes Kepler ATV-2 cargo carrier's hatch is opened, accumulated trace chemical contamination will mix within the main ISS cabin where the TCCS and BMP remove the added contaminants.

21.4.3 Mission Timeline

The mission timeline used to evaluate the air quality conditions during the first entry of the Johannes Kepler ATV-2 cargo carrier assumes ~17 days elapse between the last breathing air renewal at launch minus 1 week during final prelaunch processing and on-orbit ingress. Launch is planned for February 15, 2011. Docking is scheduled for February 25, 2011.

21.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for evaluating the scenario for the first entry of the Johannes Kepler ATV-2 cargo carrier. The discussion includes a summary on trace contaminant generation rate derivation, mass balance equation development, and cases considered for the assessment.

21.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation rates were derived from the analytical results of offgassing test grab samples collected from the Johannes Kepler ATV-2 cargo carrier by ESTEC between September 21 and 27, 2010. The elapsed time for the basic offgassing test was 147 hours. The Johannes Kepler ATV-2 cargo carrier was outfitted with ~1,400 kg of cargo and ~400 kg of cargo is scheduled for late stowage. Based on the cargo loading, the Johannes Kepler ATV-2 was ~77.8% outfitted for launch at the time of the test.

Individual contaminant generation rates are derived for each time increment between sampling events using equation (3) which is the differential form of equation (2). Offgassing rates were derived for the sample results reported by ESTEC.

21.5.2 Analysis Cases Considered

The primary case considered is the normal first entry of the Johannes Kepler ATV-2 cargo carrier. Comparison of the individual contaminant concentrations to zero risk and acceptable risk concentrations defined by the ISS MORD is conducted for the normal first entry case to satisfy basic ISS program contamination control requirements. Entry conditions for cases with and without active scrubbing are considered. Predicted active scrubbing duration to comply with total NMVOC concentration guidelines assuming no active scrubbing before hatch opening is determined.

21.5.3 Contamination Buildup Calculation

The magnitude of individual and total trace chemical contaminant buildup is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero at t_1 equal to zero.

21.5.4 Contamination Transient Calculation

Assessing the transient effects of accumulated contaminant buildup during the Johannes Kepler ATV-2 cargo carrier's transit to the ISS employs mass balance techniques that employ equations (10) and (11).

21.6 Results

The following discussion summarizes offgassing rate derivation and first entry trace contaminant concentration predictions.

21.6.1 Derived Generation Rates

The samples collected and analyzed by ESTEC during the element offgassing test conducted in September 2010 identified 31 chemical compounds with measurable generation rates. The derived Johannes Kepler ATV-2 offgassing load is summarized in table 43. The reported concentrations at each sampling event beginning with event number 7 (48.25 hours after time zero), listed in appendix B, were evaluated using equation (3) to derive the generation rate for each set of data. The test data, beginning with sampling event 7, indicated greater stability, allowing for better generation rate estimation.

Table 43. Generation rates and predicted prescrub ingress concentrations for mission ATV-2.

	Limits in Air			
Compound	ZRL (mg/m^3)	ARL (mg/m^3)	Rate (mg/hr)	$C_{Ingress}$ (mg/m^3)
2-propanol	1.5	150	0.09	1
n-butanol	0.8	40	0.005	0.05
2-ethylhexanol	3.3	N/A	0.005	0.05
Benzenecarbonal	1	4	0.02	0.2
Nonanal	1	4	0.009	0.1
Methylbenzene	8	60	0.02	0.2
1,3-/1,4-dimethylbenzenes	5	220	0.0006	0.01
1,2-dimethylbenzene	5	220	0.01	0.1
Tetrachloroethene	N/A	34	0.01	0.1
Propene	N/A	860	0.08	0.8
2-methylpropene	N/A	240	0.05	0.5
3-methylpropane	N/A	240	1	10.4
Methycyclohexane	3	60	0.007	0.08
3-ethylpentane	N/A	1800	0.006	0.06
Heptane	10	200	0.006	0.06
3-methylhexane	20	29	0.03	0.3
2-methylhexane	20	29	0.02	0.2
3,3-dimethylpentane	20	208	0.009	0.09
2,3-dimethylpentane	20	208	0.02	0.2
α-pinene	3	N/A	0.03	0.3
C11 compounds as undecane	N/A	320	0.05	0.6
C13 compounds as dodecane	N/A	280	0.3	2.8
C15 compounds	N/A	N/A	0.02	0.2
2-propanone	1	50	0.1	1.1
Trimethylfluorosilane	N/A	N/A	0.04	0.4
Hexamethyldisiloxane	0.2	9	0.04	0.4
Hexamethylcyclotrisiloxane	0.2	9	0.06	0.6
Octamethyltrisiloxane	N/A	40	0.001	0.02
Octamethylcyclotetrasiloxane	0.2	12	0.06	0.6
Unidentified compounds	N/A	N/A	0.08	0.8

Fourteen compounds exhibited a decreasing concentration trend during the Johannes Kepler ATV-2 offgassing test. These compounds are ethanol; 1,2-propanediol (propylene glycol); ethanal (acetaldehyde); 2-propenal (acrolein); 3,3,4,4-tetrafluorohexane; 4-isopropenyl-1-methylcycolhexene (limonene); heptamethylheptene, 3-buten-2-one (methyl vinyl ketone); cyclohexanone; ethanoic acid (acetic acid); trimethylsilanol; decametylcylopentasiloxane; dodecamethylcyclohexasiloxane; and tetradecamethylcylcoheptasiloxane. These compounds may be present in trace concentrations at the time of hatch opening. It is noted that 1,2-propanediol and 2-propenal were observed to originate from the air supply unit (ASU) used as ground support equipment (GSE) for the Johannes Kepler ATV-2 for the offgassing test. The source of these compounds was determined to be a filter element used in the ASU. This source has been removed for subsequent air renewal operations; therefore, no additional generation of 1,2-propanediol or 2-propenal is anticipated.

21.6.2 Individual Contaminant Concentration and Total Contaminant Load Contribution

None of the 31 chemical compounds identified by the ESTEC offgassing test data set are predicted to exceed their respective acceptable risk concentrations after the planned 17 days between final Johannes Kepler ATV-2 cargo carrier breathing air renewal and on-orbit first entry. Compounds in the ketone and organosilicone classes may exceed their zero risk concentrations. These compounds are 2-propanone, trimethylfluorosilane, hexamethyldisiloxane, hexamethylcyclotrisiloxane, and octamethylcyclotetrasiloxane. The total estimated 2.2 mg/hr offgassing load from the ATV-2 cargo carrier and its cargo represents a 1% increase in the 210 mg/hr estimated ULF-5 stage total Station load. The ISS active contamination control equipment is expected to easily handle this added offgassing load.

21.6.3 Total Nonmethane Volitile Organic Compound Concentration Transient

The predicted total NMVOC concentration in the Johannes Kepler ATV-2 cargo carrier cabin at first entry, 22.3 mg/m^3, is ~4 times higher than the ~5.6 mg/m^3 on average that normally exists in the ISS cabin. This total NMVOC load induces a ~0.74 mg/m^3 transient concentration increase over the prevailing ISS cabin condition. The peak concentration is reached approximately 60 minutes after opening the hatch and establishing ventilation between the Johannes Kepler ATV-2 cargo carrier and the ISS cabins as shown in figure 35. Previous analysis of Node 1 first entry operations has established that mixing between the ISS volume and a new cargo carrier or module is complete within approximately 2 hours of establishing ventilation flow. The ISS cabin concentration is predicted to approach the prehatch opening concentration level over 96 hours. The offgassing load from the Johannes Kepler ATV-2 and its cargo increases the ISS total NMVOC steady state concentration by approximately 0.05 mg/m^3. This result indicates that the active contamination control equipment on board the ISS is expected to be capable of handling the added offgassing load from the Johannes Kepler ATV-2 and its cargo.

21.7 Summary

The predicted air quality in the Johannes Kepler ATV-2 cargo carrier at hatch opening and the effect on ISS NMVOC concentration has been evaluated based on data acquired by ESTEC during the element offgassing test conducted in September 2010. Before Johannes Kepler ATV-2 hatch opening, no single chemical compound is predicted to exceed its acceptable risk concentration in the Johannes Kepler ATV-2 cabin; however, compounds in the ketone and organosilicone classes are predicted to exceed their respective zero risk concentrations. The contribution to the total ISS trace contaminant load may result in a maximum 0.7 mg/m^3 transient increase in total NMVOC concentration. The continued offgassing load contribution presented by the Johannes Kepler ATV-2 and its cargo is predicted to increase the ISS total NMVOC concentration by approximately 0.05 mg/m^3.

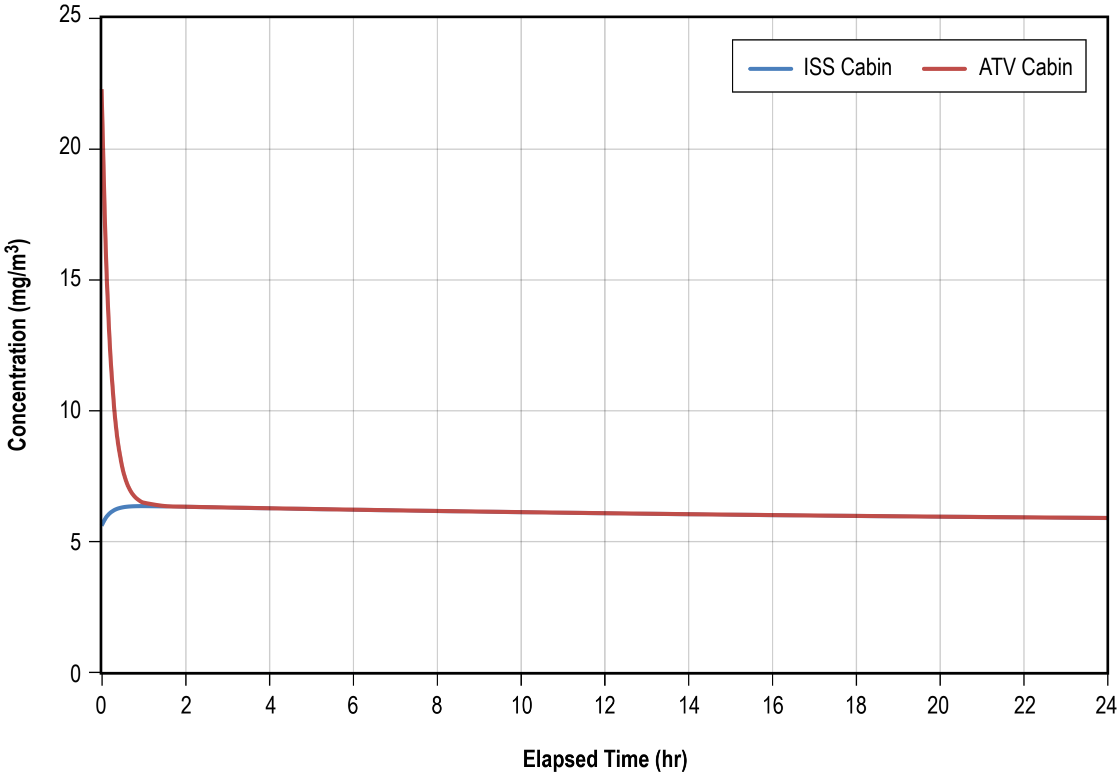

Figure 35. Total NMVOC concentration transient—no active scrubbing before hatch opening.

21.8 Conclusions

Conclusions from the predicted trace contaminant environment in the Johannes Kepler ATV-2 cargo carrier at hatch opening using offgassing data collected from the vehicle in September 2010 are the following:

- No single contaminant will exceed its individual acceptable risk concentration (NASA SMAC).

- Five contaminants representing the ketone and organosilicone classes may exceed their individual zero risk concentrations during first entry operations.

- The maximum total NMVOC concentration transient expected during Johannes Kepler ATV-2 cargo carrier first entry operations is ~0.7 mg/m^3 if no active scrubbing is employed.

- The offgassing load from the Johannes Kepler ATV-2 and its cargo is expected to increase the long-term ISS total NMVOC concentration by approximately 0.05 mg/m^3.

- The trace contaminant load presented by the Johannes Kepler ATV cargo carrier and its cargo is expected to be accommodated long term by the active contamination control equipment on board the ISS.

21.9 Recommendation

The Johannes Kepler ATV-2 vehicle and its cargo are found to be quite clean relative to equipment offgassing. Standard first entry procedures are recommended. Compliance with the first entry flight rule *T*-value criterion is left to the responsible NASA toxicology and ISS program medical operations personnel.

22. CARGO MISSION HTV-1—H-II TRANSFER VEHICLE TRACE CONTAMINANT CONTROL ASSESSMENT

This assessment was originally released under NASA Memorandum ES62(09-12) dated December 14, 2009.

22.1 Background

The H-II transfer vehicle (HTV) is a major contribution from the ISS program's international partner, JAXA, to provide cargo transport. Because the HTV is sealed from the time it is closed out and purged 7 days before launch from the Tanegashima Space Center by an augmented H-II launch vehicle until it is mated to the ISS on orbit approximately 14 days later, buildup of trace chemical contaminants becomes a concern. Adding new modules and equipment to the ISS is a source of trace chemical contamination generation that causes cabin air quality transients during module first entry and activation. The available HTV offgassing testing data are assessed by NASA toxicologists and ECLSS engineers before flight to ensure crew health and safety as well as to satisfy the ISS program's TCC requirements for module first entry and activation. The assessment predicts the expected air quality during initial entry of the HTV using JAXA-acquired, vehicle-level offgassing test data.

22.2 Purpose

The engineering analysis summarized by the following discussion serves to predict the trace chemical contaminant concentration condition within the HTV cabin at the time the hatch is opened to the ISS. Individual concentrations are compared to concentration limits prescribed by SSP specification documents.

22.3 Objective

The approach to maintaining acceptable cabin air quality in the HTV during first entry on orbit is assessed by engineering analysis. The assessment's primary objective is to predict individual trace chemical contaminant concentrations at the time the hatch opens on orbit and to recommend appropriate actions, if any, necessary to ensure compliance with the ISS system specification and relevant U.S. segment specification documents.

22.4 Assumptions

To conduct the HTV trace chemical contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

22.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the HTV TCC engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results reported by JAXA.
- Atmospheric leakage from the HTV is zero. This is considered to be true for all new ISS elements.
- The HTV free volume, with cargo, is approximately 28.4 m^3.
- The HTV was 98.3% outfitted by mass for flight at the time of the offgassing test.
- Cabin atmospheric conditions are on average 20 °C, 50% relative humidity, and 101.3 kPa.
- Offgassing rates are constant with time. This has been shown to be conservative because experience has shown rates decay with time.
- Acceptable risk and zero risk air quality limits as defined by the ISS MORD apply.
- Ventilation flow between the HTV and Node 2 is maintained at ~180 m^3/hr minimum after successful on-orbit docking.

22.4.2 On-Orbit Configuration

During the ISS HTV-1 cargo mission, the ISS's on-orbit configuration consists of PMA-1, PMA-2, Unity (Node 1), Destiny (U.S. Laboratory), Quest (U.S. airlock), Harmony (Node 2), Columbus APM, Kibo ELM PS and PM modules, Jules Verne (ATV-1) cargo vehicle, Zarya (FGB), Zvezda (service module), a Soyuz spacecraft, and a Progress cargo vehicle. The ISS's total habitable volume is approximately 682 m^3, including the HTV cargo vehicle. The HTV remains isolated until it is attached to the ISS and the hatch opens.

Active TCC is provided for the ISS by the USOS TCCS located in Destiny and the BMP located in Zvezda. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] After the HTV hatch is opened, accumulated trace chemical contamination will mix within the main ISS cabin where the TCCS and BMP remove the added contaminants.

22.4.3 Mission Timeline

The total elapsed time between the last prelaunch purge on the ground and docking with the ISS is approximately 14 days, assuming the module is sealed after late access at launch minus 7 days and an on-time launch occurs. Launch is scheduled for September 11, 2009. Any launch delay will increase the elapsed closeout time on a day-to-day basis unless the late access operations are also delayed.

22.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for evaluating the scenario for the first entry of the HTV. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

22.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation results in a steady increase in concentration, C_i, over time, t, as denoted by equation (2). Trace contaminant generation rates are derived from the analytical results of offgassing test grab samples collected from the HTV by JAXA between May 28 and June 13, 2009. Sample sets were collected at hatch closure and 366 hours later. The first sample set serves as the starting basis at time zero. The HTV was 98% outfitted by mass for flight at the time of the test. Individual contaminant generation rates are derived using equation (3) which is equation (2) in differential form solved for the generation rate. The resulting rate is divided by 0.98 to account for equipment that was not installed in the HTV at the time of the offgassing test. For the test conducted on the HTV, a time increment value of 366 hours applies.

22.5.2 Analysis Cases Considered

The primary case considered is the normal first entry of the HTV. Comparison of the individual contaminant concentrations to zero risk and acceptable risk concentrations defined by the ISS MORD is conducted for the normal first entry case to satisfy basic ISS program contamination control requirements. A prediction of the T-value magnitude at first entry to assess compliance with first entry flight rules is left to the responsible NASA toxicology and ISS program medical operations personnel.

22.5.3 Calculation Approach

Each contaminant concentration at ingress is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1. The transient mass balance described by equations (10) and (11) are used to assess the contamination impact on the ISS cabin environment.

22.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

22.6.1 Derived Generation Rates

The element offgassing test conducted by JAXA found the HTV to be quite clean at time zero with only five compounds reported by the first sample set analysis. The sample set analysis had elapsed after 366 hours and reported 20 compounds. Twenty-one chemical compounds with measurable concentrations were found in the test samples. Two compounds—ethanal and 1,2-difluoroethane—exhibited decreasing concentration trends during the test which do not allow for a generation rate to be determined. Due to the very low concentrations observed for these two compounds, it is likely that they may not be present in the HTV cabin atmosphere above detectable limits at first module entry on orbit. The individual compound generation rates derived from the offgassing test data are summarized in table 44. Average concentrations at each sampling event, provided in appendix B, were used in equation (3) to derive the generation rate. The result was divided by 0.98 to account for equipment not installed in the HTV at the time of the test.

Table 44. Generation rates and predicted ingress concentrations for mission HTV-1.

Compound	Limits in Air		Rate (mg/hr)	$C_{Ingress}$ (mg/m^3)
	ZRL (mg/m^3)	ARL (mg/m^3)		
2-propanol	1.5	150	0.268	3.17
Butanol	0.8	40	0.005	0.06
Methylbenzene	8	60	0.007	0.08
Methane	3,342	3,800	0.053	0.62
C4 alkene as butene	15	230	0.003	0.04
2-methylpropane	N/A	240	0.137	1.62
Cyclohexane	3	210	0.003	0.03
Methylcyclohexane	N/A	60	0.003	0.04
n-heptane	10	200	0.003	0.03
2,2,4-trimethylpentane	N/A	0.5	0.005	0.06
C11 alkane as n-undecane	N/A	320	0.018	0.21
2-propanone	2	50	0.044	0.52
2-butanone	0.25	30	0.011	0.13
Cyclohexanone	1.3	60	0.05	0.59
Phenyl methyl ketone	0.8	250	0.003	0.03
Carbon monoxide	5	11	5.167	61.13
Dimethyl carbonate	N/A	0.5	0.065	0.76
Trimethylsilanol	0.2	37	0.253	2.99
Fluorotrimethylsilane	N/A	0.5	0.009	0.11

22.6.2 First Entry of the H-II Transfer Vehicle

As shown in table 44, based on the JAXA-acquired offgassing test results, carbon monoxide is predicted to exceed its acceptable risk concentration after the elapsed 14 days between the HTV prelaunch purge and on-orbit ingress. Trimethylsilanol and 2-propanol may be expected to exceed their respective zero risk concentrations. This result indicates that, for a brief time, the carbon monoxide concentration in the HTV cabin may be above its acceptable risk concentration and contribute to a slight increase in the ISS cabin as the two volumes mix after establishing ventilation. Figure 36 shows that the carbon monoxide concentration in the HTV cabin can be expected to decrease below its acceptable risk concentration in less than 1 hour after establishing ventilation between the HTV and ISS cabins.

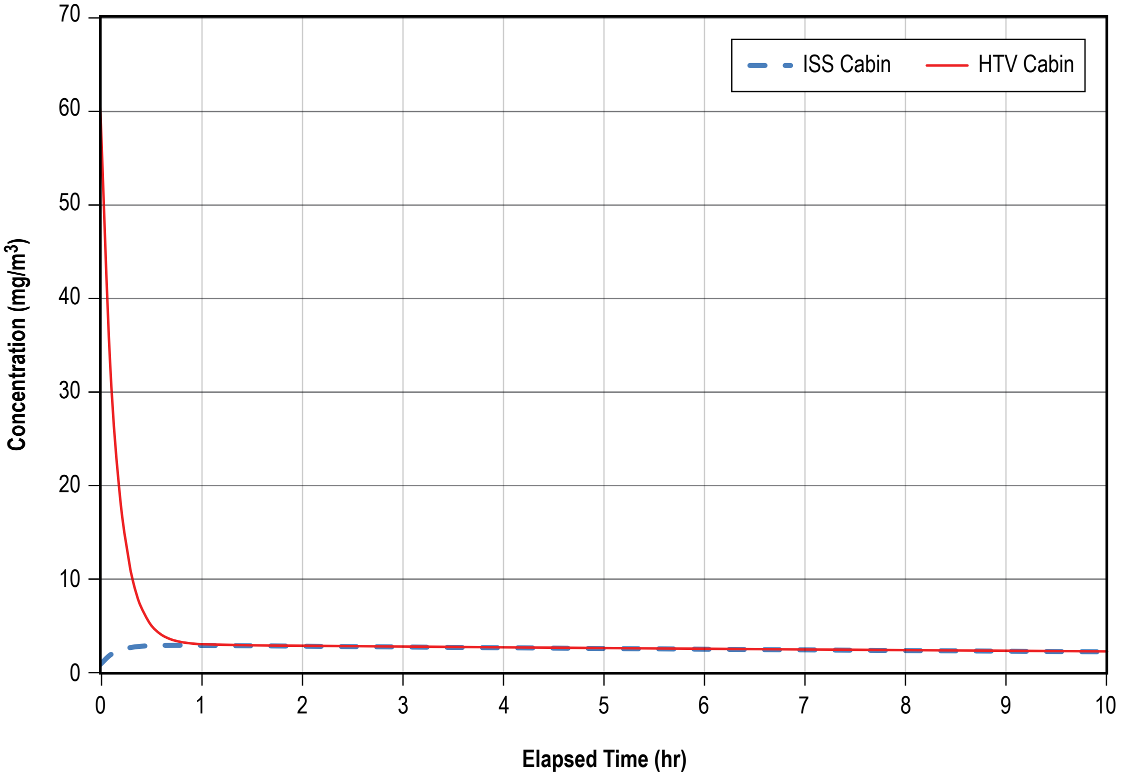

Figure 36. Carbon monoxide concentration transient.

22.6.3 Total Contamination Contribution to the International Space Station

The total estimated 6.1 mg/hr offgassing load from the HTV and its cargo represents a 10.8% increase in the total Station load compared to 56.6 mg/hr at flight 5A. The maximum magnitude of the concentration transient that may occur during the HTV first entry operations is ~3 mg/m^3, reached 1 hour after the hatch opens. Previous analysis of Unity Node 1 first entry operations has established that mixing between the ISS volume and a new cargo carrier or module is complete within approximately 2 hours of establishing ventilation flow. If the predicted offgassing from the HTV and its cargo is sustained over time, the total Station trace chemical contaminant concentration is predicted to return to its pre-HTV docking magnitudes within 48 hours and rise by no more ~0.21 mg/m^3. Of this increase, 90% (0.19 mg/m^3) is predicted to result from carbon monoxide. Overall, individual trace contaminant concentrations in the ISS cabin are expected to remain within their acceptable range after the HTV cabin mixes uniformly with the ISS cabin.

22.7 Summary

The predicted air quality in the HTV has been evaluated based on data acquired from the element offgassing test. Carbon monoxide is predicted to exceed both its zero risk and acceptable risk concentrations while 2-propanol and trimethylsilanol are predicted to exceed their respective zero risk concentrations. The contribution to the total ISS trace contaminant load may result in a ~0.2 mg/m^3 increase in total trace chemical contaminant concentration. The active contamination control equipment on board the ISS is expected to accommodate the additional load from the HTV and its cargo.

22.8 Conclusions

Conclusions from the predicted trace contaminant environment in the HTV at first ingress using offgassing data collected from the module are the following:

- Carbon monoxide is predicted to temporarily exceed its individual zero risk and acceptable risk concentration (NASA SMAC) in the HTV cabin during first entry operations.

- 2-propanol and trimethylsilanol may temporarily exceed their individual zero risk concentrations in the HTV cabin during first entry operations.

- The predicted maximum transient in the ISS cabin total trace chemical contaminant concentration during HTV first entry operations is ~3 mg/m^3.

- No individual trace contaminant concentration in the ISS cabin is expected to exceed either its zero or acceptable risk concentration.

- The predicted maximum sustained increase in cabin total trace chemical contaminant concentration that may result from adding the HTV and its cargo to the ISS is ~0.2 mg/m^3.

22.9 Recommendation

The module offgassing test results from the HTV find that the vehicle and its cargo is reasonably clean and that the active contamination control equipment on board the ISS possess the necessary capability and capacity to accommodate the additional trace contaminant generation load. Responsible NASA toxicology and ISS program medical operations personnel may wish to evaluate first entry conditions with a focus on carbon monoxide.

23. CARGO MISSION HTV-2—H-II TRANSFER VEHICLE SECOND FLIGHT TRACE CONTAMINANT CONTROL ASSESSMENT

This evaluation was originally released in December 2010.

23.1 Background

The HTV is a major contribution from the ISS program's international partner, JAXA, to provide cargo transport. During the second flight of the HTV, referred to as HTV-2, the vehicle is sealed and purged for 8 days before launch from the Tanegashima Space Center by an augmented H-II booster. The HTV-2 cargo vehicle is scheduled to dock with the ISS approximately 15 days after launch. Buildup of trace chemical contaminants becomes a concern due to the 15-day elapsed time between the final vehicle cabin purge and docking with the ISS. Adding new modules and equipment to the ISS is a source of trace chemical contamination generation that causes cabin air quality transients during module first entry and activation. The available HTV-2 offgassing test data are assessed by NASA toxicologists and ECLSS engineers before flight to ensure crew health and safety as well as to satisfy the ISS program's TCC requirements for module first entry and activation. The assessment predicts the expected air quality during initial entry of the HTV-2 based on JAXA-acquired, vehicle-level offgassing test data.

23.2 Purpose

The engineering analysis summarized by the following discussion serves to predict the trace chemical contaminant concentration condition within the HTV-2 cabin at the time the hatch is opened to the ISS. Individual concentrations are compared to concentration limits prescribed by SSP specification documents.

23.3 Objective

The approach to maintaining acceptable cabin air quality in the HTV-2 during first entry on orbit is assessed by engineering analysis. The assessment's primary objective is to predict individual trace chemical contaminant concentrations at the time the hatch opens on orbit and to recommend appropriate actions, if any, necessary to ensure compliance with ISS System Specification (SSP 41000) and relevant USOS specification documents.

23.4 Assumptions

To conduct the HTV-2 trace chemical contamination control capability assessment, assumptions must be made concerning the offgassing rates, cabin atmospheric conditions, hardware configuration, TCC hardware configuration, and mission timeline.

23.4.1 Offgassing and Cabin Conditions

Basic assumptions pertaining to offgassing rates and cabin atmospheric conditions for the HTV-2 TCC engineering analysis are the following:

- Offgassing rates are derived from ground-based offgassing test results reported by JAXA.
- Atmospheric leakage from the HTV-2 is zero. This is considered to be true for all new ISS elements.
- The HTV-2 free volume, with cargo, is approximately 25.9 m^3.
- The HTV-2 was 93.3% outfitted by mass for flight at the time of the offgassing test.
- Cabin atmospheric conditions are on average 20 °C, 50% relative humidity, and 101.3 kPa.
- Offgassing rates are constant with time. This has been shown to be conservative because experience has shown rates decay with time.
- Acceptable risk and zero risk air quality limits as defined by the ISS MORD apply.
- Ventilation flow between the HTV-2 and Node 2 is maintained at ~180 m^3/hr minimum after successful on-orbit docking.

23.4.2 On-Orbit Configuration

During the ISS HTV-2 cargo mission, the ISS's on-orbit configuration consists of PMA-1, PMA-2, Unity (Node 1), Destiny (U.S. Laboratory), Quest (U.S. airlock), Harmony (Node 2), Tranquility (Node 3 and cupola), Columbus APM, Kibo ELM PS and PM modules, Zarya (FGB), Zvezda (service module), MRM-1, MRM-2, two Soyuz spacecraft, and a Progress cargo vehicle. The ISS's total habitable volume is approximately 763 m^3, excluding the HTV-2 cargo vehicle. The HTV-2 remains isolated until it docks with the ISS and the hatch opens. For conservatism, the Leonardo PMM volume is not included because the STS-133/ULF-5 mission may occur after HTV-2 docking.

Active TCC is provided for the ISS by the USOS TCCS located in Destiny or Tranquility and the BMP located in Zvezda. At least one TCCS is assumed to operate in tandem with the BMP. Previous analysis has shown that both the TCCS and BMP have sufficient capacity to control the Station's trace contaminant load.[14] After the HTV hatch is opened, accumulated trace chemical contamination will mix within the main ISS cabin where the TCCS and BMP remove the added contaminants.

23.4.3 Mission Timeline

The total elapsed time between the last prelaunch purge on the ground and docking with the ISS is approximately 15 days, assuming the module is sealed after late access at launch minus 8 (L–8) days and an on-time launch occurs. Launch is scheduled for January 20, 2011. Any launch delay will increase the elapsed closeout time on a day-to-day basis unless the late access operations are also delayed.

23.5 Approach

The following discussion summarizes the ISS TCC capability assessment approach for evaluating the scenario for the first entry of the HTV-2. The discussion includes a summary on trace contaminant generation rate derivation and cases considered for the assessment.

23.5.1 Trace Contaminant Generation Rate Derivation

Trace contaminant generation results in a steady increase in concentration, C_i, over time, t, as denoted by equation (2). Trace contaminant generation rates are derived from the analytical results of offgassing test grab samples collected from the HTV-2 by JAXA between September 29 and October 18, 2010. Sample sets were collected at hatch closure and ~450 hours later. The first sample set serves as the starting basis at time zero. The HTV-2 was 93.3% outfitted by mass for flight at the time of the test. Individual contaminant generation rates are derived using equation (3) which is equation (2) in differential form solved for the generation rate. The resulting rate is divided by 0.933 to account for equipment that was not installed in the HTV-2 at the time of the offgassing test. For the test conducted on the HTV-2, a time increment value of 450 hours applies.

23.5.2 Analysis Cases Considered

The primary case considered is the normal first entry of the HTV-2. Comparison of the individual contaminant concentrations to zero risk and acceptable risk concentrations defined by ISS program specification documents is conducted for the normal first entry case to satisfy basic ISS program contamination control requirements. A prediction of the *T*-value magnitude at first entry to assess compliance with first entry flight rules is left to the responsible NASA toxicology and ISS program medical operations personnel.

23.5.3 Calculation Approach

Each contaminant concentration at ingress is calculated directly using equation (4). The initial concentration, $C_{i,o}$, is assumed zero as is t_1. The transient mass balance described by equations (10) and (11) are used to assess the contamination impact on the ISS cabin environment.

23.6 Results

The following discussion provides a summary of the contaminant generation rate derivation and results from the analysis cases.

23.6.1 Derived Generation Rates

The element offgassing test conducted by JAXA found the HTV-2 to be quite clean at time zero with only five compounds reported by the first sample set analysis. After ~450 hours had elapsed, the sample set analysis reported 16 compounds. Fourteen chemical compounds with measurable concentrations were found in the test samples. Two compounds—methanol and 1,1,1,2-tetrafluoroethane—exhibited decreasing concentration trends during the test which do not allow for a generation rate to be determined. Concentration decay for both of these compounds indicates no internal source and likely adsorption onto vehicle and cargo surfaces. Assuming a classical exponential decay, both compounds are expected to be <0.5 mg/m^3 at the time the HTV-2 hatch opens to the ISS cabin. The individual compound generation rates derived from the offgassing test data are summarized in table 45. Reported concentrations at each sampling event, provided in appendix B, were used in equation (3) to derive the generation rate. The result was divided by 0.933 to account for equipment not installed in the HTV-2 at the time of the test.

Table 45. Generation rates and predicted ingress concentrations for mission HTV-2.

Compound	Limits in Air		Rate (mg/hr)	C_{Ingress} (mg/m^3)
	ZRL (mg/m^3)	ARL (mg/m^3)		
Methanol	0.2	9	N/A	<0.5
Ethanol	10	2,000	0.009	0.12
2-propanol	1.5	150	0.13	1.8
Butanol	0.8	40	0.006	0.08
Methylbenzene	8	60	0.005	0.07
1,1,1,2-tetrafluoroethane	N/A	N/A	N/A	<0.5
Methane	3,342	3,800	0.0002	0.003
C4 alkene as butene	15	230	0.006	0.08
2-methylpropane	N/A	240	0.02	0.24
n-heptane	10	200	0.002	0.03
3-methylhexane	20	29	0.005	0.07
2,3-dimethylpentane	20	208	0.002	0.03
2-propanone	2	50	0.01	0.2
Carbon monoxide	5	11	0.04	0.6
Trimethylsilanol	0.2	37	0.11	1.6
Fluorotrimethylsilane	N/A	0.5	0.002	0.03

23.6.2 First Entry of the H-II Transfer Vehicle

As shown in table 45, based on the JAXA-acquired offgassing test results, 2-propanol and trimethylsilanol may be expected to exceed their respective zero risk concentrations at the time the HTV-2 hatch opens to the ISS cabin. All compounds reported by the offgassing test results are expected to comply with ISS acceptable risk concentrations. Figure 37 shows the total NMVOC concentration transient between the HTV-2 and ISS cabins. Because the HTV-2 total trace contaminant concentration at the time of hatch opening to the ISS is predicted to be less than the prevailing concentration in the ISS cabin, a very slight dilution effect is expected in the ISS cabin. The combined cabins are expected to return to prehatch opening trace contaminant concentration levels within approximately 48 hours. Most of the mixing between the two cabin volumes is predicted to occur within approximately 1 hour after establishing forced ventilation flow.

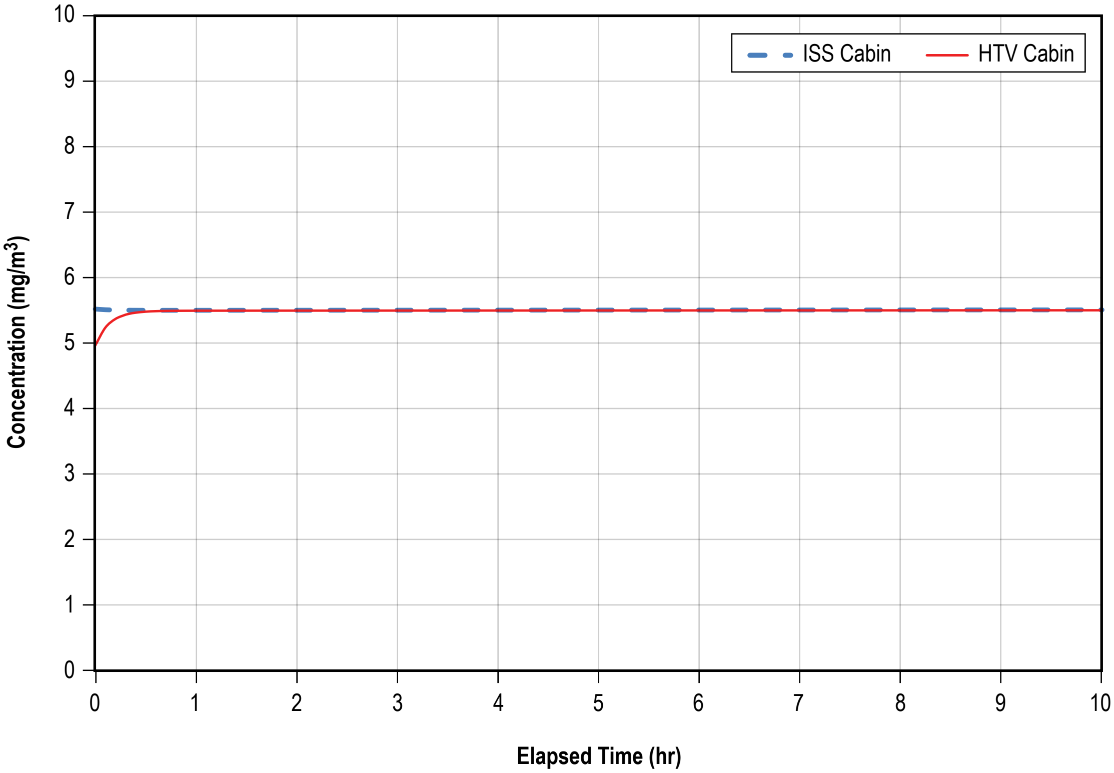

Figure 37. Predicted total NMVOC concentration transient.

23.6.3 Total Contamination Contribution to the International Space Station

The ISS cabin air quality measurements reported from samples collected between May 27, 2009, and February 13, 2010, indicate a total trace contaminant generation rate of 216 mg/hr. The total estimated 0.36 mg/hr offgassing load from the HTV-2 and its cargo represents a ~0.2% increase in the total Station load compared for the entire ISS. Opening the HTV-2 hatch to the ISS cabin is predicted to have a temporary dilution effect on the ISS cabin. Previous analysis of Unity Node 1 first entry operations has established that mixing between the ISS volume and a new cargo carrier or module is complete within approximately 2 hours of establishing ventilation flow. If the predicted offgassing from the HTV-2 and its cargo is sustained over time, the total Station trace chemical contaminant concentration is predicted to return to its pre-HTV-2 docking magnitudes within 48 hours and rise by a negligible amount. Individual trace contaminant concentrations in the ISS cabin are expected to remain within their acceptable range after the HTV-2 cabin mixes uniformly with the ISS cabin.

23.7 Summary

The predicted air quality in the HTV-2 has been evaluated based on data acquired from the element offgassing test. All compounds reported from the offgassing test results are predicted to remain below their individual acceptable risk concentrations at the time the HTV-2 hatch is opened to the ISS cabin. Two compounds, 2-propanol and trimethylsilanol, are predicted to exceed their respective zero risk concentrations. The HTV-2 trace contaminant load contribution to the total ISS trace contaminant load may result in a negligible increase in total trace chemical contaminant concentration. The active contamination control equipment on board the ISS is expected to fully accommodate the additional load from the HTV-2 and its cargo.

23.8 Conclusions

Conclusions from the predicted trace contaminant environment in the HTV-2 at first ingress using offgassing data collected from the module are the following:

- All chemical compounds reported by the offgassing test results are predicted to comply with the ISS acceptable risk criteria during all HTV-2 operational phases.

- 2-propanol and trimethylsilanol may temporarily exceed their individual zero risk concentrations in the HTV-2 cabin during first entry operations.

- Methanol and 1,1,1,2-tetrafluoroethane exhibited concentration decay during the offgassing test and their concentrations at HTV-2 hatch opening to the ISS cabin are expected to be <0.5 mg/m^3.

- No individual trace contaminant concentration in the ISS cabin is expected to exceed either its zero or acceptable risk concentration during HTV-2 docked operations.

- The predicted maximum sustained increase in cabin total trace chemical contaminant concentration that may result from adding the HTV and its cargo to the ISS is negligible and expected to be below detection.

23.9 Recommendation

The module offgassing test results from the HTV-2 find that the vehicle with its cargo is very clean relative to volatile chemical contaminants and that the active contamination control equipment on board the ISS possesses the necessary capability and capacity to accommodate the additional trace contaminant generation load.

24. PREDICTING OFFGASSING RATES FROM HARDWARE DELIVERED TO THE INTERNATIONAL SPACE STATION ABOARD CARGO VEHICLES

In order to prepare for ISS logistics flights, an understanding of the offgassing characteristics of candidate equipment to be delivered to the ISS on board the Shuttle vehicle is necessary. Because past studies by NASA have demonstrated that using raw, unadjusted equipment and bulk materials offgassing test data results in excessive conservatism, a generalized equipment load model has been developed to facilitate spacecraft design and onboard air quality control system design and performance assessment. This generalized load model was developed in 1995. Reference 2 documents the approach to the model's development.

Studies conducted on materials offgassing characteristics for the Spacelab program have established that no more than 126 chemical compounds account for 99% of the total equipment offgassing load per unit mass. This list of 126 compounds has been established as the design basis for ISS hardware offgassing and is included in the USOS Specification (SSP 41162R, table LIII). It is considered technically acceptable and appropriate to use this generalized load model for ISS design because the materials selection and control process for both the ISS U.S. Segment and Spacelab programs are virtually identical. By virtue of materials selection program similarity, similar offgassing characteristics for the hardware should result. Preflight and in-flight characterization of the Unity node and Destiny laboratory module has verified this assumption and demonstrated that using the generalized load model is a sound, conservative approach for designing spacecraft air quality control systems as well as predicting hardware offgassing characteristics. Further, evaluation of 16 ISS module offgassing test results has reported that 44 chemical compounds contribute routinely to ISS equipment offgassing loads.[19] Therefore, predictive assessments for cargo vehicles consider these 44 compounds rather than the entire list of 126.

The offgassing rates per unit kilogram for the 44 compounds are obtained from reference 2. The equipment rate listed for each of the 44 compounds is the mean plus 1 standard deviation, σ. That is approximately the 96% confidence interval upper bound when using a student-t distribution and provides a reasonable confidence without resulting in excessive conservatism.

The total cargo mass to be transported to the ISS by the vehicle and the mass of cargo to be removed from the ISS and returned via the vehicle are determined. The net equipment transfer mass is calculated from these mass numbers. Applying the equipment offgassing rate expressed in units of mg/day/kg to the net equipment mass to be transferred provides the estimated net offgassing rate increase expressed in units of mg/day.

Using the ISS cabin air quality measurements reported from the most recently reported cabin sample analysis results, the total NMVOC concentration is determined using a steady state cabin material balance. Using this concentration as a comparative basis, the influence that the new equipment to be transferred to the ISS during the cargo mission may have on the trace chemical contaminant load and the concentrations in the cabin atmosphere is estimated and the percentage increase in the total ISS trace contaminant load is determined. The net equipment transferred to the ISS aboard cargo vehicles has been shown to increase the total ISS trace contaminant load by between 0.5% and 4% for each transfer which is within the ISS's active TCC capability.[22] The cabin trace contaminant concentration change is typically <1 mg/m^3.

25. SYNOPSIS

The approach to ensure that the cabin atmosphere aboard the ISS is maintained within acceptable standards has been presented over the period or Station assembly and outfitting between 1998 and 2010. The approach involves the following three primary elements:

(1) Collecting data during prelaunch element offgassing tests to determine trace contaminant generation rates.

(2) Using predictive techniques using the offgassing testing results as the assessment basis to evaluate module first ingress scenarios and the net contribution to the offgassing load of each new module and new equipment transfer relative to the active TCC capability.

(3) Evaluating analysis results of in-flight grab samples versus predictions to determine the conservatism of the predictive technique and to understand the functional margin that is maintained for the active contamination control equipment aboard the ISS.

The first element was used for new ISS modules and cargo vehicles. Offgassing tests ranged in duration from 6 days to more than 16 days. The data collected from these tests were analyzed to determine the basic offgassing rates. Combined with human metabolic loads, the offgassing rates for the major ISS elements were assessed against the basic onboard TCC capabilities provided by the TCCS in the U.S. segment and the BMP in the Russian segment. The assessments presented concluded that the combined basic offgassing and metabolic load typically falls within the active trace contamination control equipment's capabilities. This is true even for the TCCS or BMP operating alone although the normal vehicle configuration requires both the TCCS and BMP to operate simultaneously.

All three of the MPLM flight modules were subjected to offgassing tests by Alenia before shipment to NASA and were shown to be quite clean. However, for flight operations purposes, the TCC capability evaluation must also include the cargo offgassing load in addition to the basic module offgassing load. To this end, element offgassing tests that included the cargo were conducted for MPLM FM-1 and FM-2. No additional tests were conducted for the reflight of these elements. This was because the results from the first two MPLM missions showed no significant difference in offgassing load for the two elements that contained different cargo. Essentially the first tests validated NASA's material selection and control process as well as the vehicle ground processing methods by demonstrating uniformity between the different cargo contributions. Therefore, subsequent MPLM offgassing was evaluated using predictive techniques.

The second element uses a conservative offgassing load per unit mass of cargo as its basis to predict the additional contribution that each net cargo mass transfer to the ISS represents. The offgassing load served as the basis for the TCCS design and is based upon a statistical treatment of numerous individual equipment offgassing tests conducted during the Spacelab program and evaluation of multiple ISS module offgassing tests. Comparison of this load model to results obtained from ISS element offgassing tests indicates that this model is representative and conservative of the general offgassing characteristics of U.S. hardware. For each cargo flight, the net cargo mass transferred to the ISS is considered. This net cargo mass is the cargo launch mass minus the return cargo mass. This is a more realistic measure of the net contribution to the total ISS offgassing load. Typical cargo delivery missions to the ISS increased the general trace contaminant generation load aboard the ISS by approximately 0.5% to approximately 5%.

The third element involves receiving results from ground-based analyses conducted on in-flight grab samples of the cabin atmosphere collected by the crew. The NASA toxicology laboratory conducted the analyses and reported the results as part of the ISS cabin air quality maintenance program. These results are tracked according to mission timeline to evaluate trends, known upset conditions, and serve as a basis for comparison for the TCC assessments. The reported cabin air quality based on the grab sample analysis results serves as the final verification that the passive and active TCC methods are indeed doing their job. This is the most cost effective, direct method available to determine the long-term acceptability of engineering design and ground processing methods for providing acceptable air quality.

APPENDIX A—FLIGHT RULES FOR TRACE CONTAMINANT CONTROL DURING MODULE FIRST ENTRY OPERATIONS

The flight rules regarding trace contaminant control during module first entry evolved over the course of the ISS's assembly. Each stage in the flight rule development is presented as it applied to successive ISS assembly missions. The flight rule for each assembly mission guided the trace contaminant control analysis success criteria in combination with ISS Program trace contaminant control performance requirements.

Assembly Missions 2A and 2A.1

DRAFT DATED SEPTEMBER 18, 1998

GROUND-BASED OFFGAS TEST DATA WILL PROVIDE THE BASIS FOR PREDICTING THE TOXICITY INDEX (T VALUE) REACHED INSIDE THE SEALED NODE FROM THE TIME OF LAST GROUND-BASED PURGE UNTIL THE CREW BEGINS FIRST ENTRY. THE T VALUE SHALL BE ESTIMATED FROM THE RATE OF CONTAMINANT ACCUMULATION (T UNITS/DAY) TIMES THE NUMBER OF DAYS THE NODE IS SEALED BEFORE ENTRY. CREW ACTIONS WILL DEPEND ON THE ESTIMATED T VALUE AS FOLLOWS:

1) IF T<1.5, THE CREW CAN ENTER WITHOUT PRECAUTIONS
2) IF 1.5<T<3.0, THE FOLLOWING ACTIONS ARE TAKEN:
    A) INSTALL ONE SHUTTLE CHARCOAL CONTINGENCY CANISTER
    B) CHANGEOUT SHUTTLE CHARCOAL CANISTER HOURLY UNTIL THE T VALUE IS PREDICTED BY ANALYSIS TO BE BELOW 1.0.
3) IF 3.0<T<6.0, THE FOLLOWING ACTIONS ARE TO BE TAKEN:
    A) PERFORM ACTIONS 2A AND 2B ABOVE.
    B) THE CREW MEMBERS ENTERING THE PMA2 AND NODE MUST DON THE QUICK DON MASKS TO INSTALL THE DUCTING. THEY RETURN TO THE SHUTTLE MIDDECK AND DOFF THE QDMS.
    C) OTHER CREW MEMBERS STAY IN THE MIDDECK WITHOUT MASKS.
    D) ALL CREW MEMBERS REMAIN IN THE MIDDECK FOR 1 HOUR AFTER FLOW IS BROUGHT TO THE DUCTS PLACED IN THE NODE.
4) IF T>6.0, CONTACT THE MCC FOR INSTRUCTIONS

The estimates of T at the time of crew first entry will be calculated from the rate of contaminant accumulation during the ground-based test and the time over which the Node is sealed. T values are calculated from the analytical concentrations (C_n) as follows:

$$T = C_1/SMAC_1 + C_2/SMAC_2 + \ldots + C_n/SMAC_n$$

Seven-day spacecraft maximum allowable concentrations (SMACs) are to be used in the calculation. Even though the crew will be briefly exposed to air with a T value >1, they will be fully protected by this approach because the calculation is very conservative (based on 7-day SMACs and assuming all effects are additive), the air will be rapidly diluted into the entire interior volume, and the air will be rapidly scrubbed of trace contaminants.

X17.4.1-4 FGB TRACE CONTAMINANT REMOVAL CONTROL (HC)

A. THE FGB TRACE CONTAMINANT REMOVAL SYSTEM WILL NOMINALLY BE OPERATED FOR APPROXIMATELY 48 HOURS (MINIMUM 24 HOURS) PRIOR TO PLANNED INGRESS BY SHUTTLE CREWMEMBERS.

Forty-eight hours is the approximate amount of time required by internal FGB Trace Contaminant Filter to provide for safe entry into the FGB Pressurized Adapter GA (ГА). Most off-gassing material is located in the Instrumentation Cargo Compartment PGO (ПГО); as a result, the GA (ГА) compartment is not as contaminated as the PGO (ПГО). A minimum of 24 hours represents an exchange of seven times the volume of the FGB PGO (ПГО) and provides sufficient removal of trace contaminants.

Reference: April 1997, OPS TIM 8 in Houston.

B. OFF-NOMINAL CASE: IF THE FGB TRACE CONTAMINANT REMOVAL SYSTEM HAS FAILED, ONE SHUTTLE CREWMEMBER WEARING A QDM WILL INGRESS INTO THE FGB AND SET UP THE AIR DUCT TO EXCHANGE AIR WITH THE NODE/SHUTTLE. CRITERIA FOR INGRESS WITHOUT QDM'S WILL BE BASED ON PREFLIGHT PROJECTION OF TOXICITY LEVEL PRIOR TO INGRESS AND SCRUB DURATION USING COMBINED SHUTTLE AND NODE 1 TRACE CONTAMINANT CONTROL RESOURCES.

For failure of the FGB to remove trace contaminants from the atmosphere, a shuttle crewmember will don an orbiter supplied QDM with station supplied 70 ft O_2 *hose in order to ingress into FGB GA (ГА) and PGO (ПГО). Once in the FGB, the shuttle crewmember will install ductwork that will enhance forced air flow exchange between FGB and Node 1. Once ducting has been assembled and scrub is initiated, crewmember will return to shuttle and close Node 1 Fwd Hatch.*

Scrub duration using shuttle and Node 1 trace contaminant control system resources will be based on the expected toxicity level upon ingress into the FGB. Preflight analysis will be performed to determine the required scrub time to allow safe ingress into the FGB without use of breathing devices.

DOCUMENTATION: (1) April 1997, OPS TIM 8 in Houston, (2) Rule {B13.2.2-1}, MODULE FIRST INGRESS.

X13.1.2-2 NODE 1 INGRESS CRITERIA

GROUND-BASED OFF-GAS TEST DATA, IN CONJUNCTION WITH DATA FROM SAMPLES ACQUIRED DURING FLIGHT 2A, WILL PROVIDE THE BASIS FOR PREDICTING THE TOXICITY INDEX (T-VALUE) REACHED INSIDE THE SEALED NODE AT 2A.1 FIRST ENTRY. THE PRESCRUB T-VALUE SHALL BE ESTIMATED FROM THE 2A NODE EGRESS T-VALUE, ADDED TO THE RATE OF CONTAMINANT ACCUMULATION (T UNITS/DAY), TIMES THE NUMBER OF DAYS THE NODE HAS BEEN SEALED SINCE CLOSEOUT ON 2A. A SCRUB MODEL SHALL BE USED TO PREDICT THE AMOUNT OF REDUCTION IN THE T-VALUE FACILITATED BY OPERATION OF THE NODE FILTERS IMMEDIATELY BEFORE CREW INGRESS. CREW ACTIONS WILL DEPEND ON THE ESTIMATED T-VALUE AS FOLLOWS:

A. FOR NODE 1 BASED SCRUB USING NODE 1 CHARCOAL FILTERS:

   1. IF $T \leq 3.0$, NO PRE-INGRESS SCRUB REQUIRED.
   2. IF $3.0 < T \leq 6.0$, PERFORM 2-HOUR PRE-INGRESS SCRUB.
   3. IF $T > 6.0$, RISK TO CREW HEALTH MUST BE EVALUATED BY THE CREW SURGEON, AND ECLS MUST DETERMINE THE TIME REQUIRED TO SCRUB TO NOMINAL CONDITIONS.

B. FOR SHUTTLE BASED SCRUB USING SHUTTLE CHARCOAL CANISTER(S):

   1. IF $T \leq 3.0$, CREWMEMBERS CAN ENTER NODE 1 WITHOUT PRECAUTIONS.
   2. IF $3.0 < T \leq 6.0$, THE FOLLOWING ACTIONS ARE TAKEN:
      A. SHUTTLE CREW WILL INSTALL ONE SHUTTLE CHARCOAL CANISTER PRIOR TO INGRESS OPERATIONS.
      B. CREWMEMBERS ENTERING NODE 1 WILL DON QDM’S FOR INSTALLATION OF DUCTING. REMOVAL OF QDM’S WILL BE SURGEON CALL.
      C. CREWMEMBERS NOT INGRESSING NODE 1 WILL REMAIN IN THE SHUTTLE MIDDECK OR FLIGHT DECK WITHOUT QDM’S.
      D. ONCE DUCTING IS INSTALLED, CREWMEMBERS WILL RETURN TO THE SHUTTLE, DOFF QDM’S, AND INITIATE AIR EXCHANGE BETWEEN THE ISS AND SHUTTLE. CREWMEMBERS WILL REMAIN IN THE SHUTTLE FOR 1 HOUR.
      E. PROVIDED THE 1 HOUR WAIT PERIOD IS OBSERVED, AND THE CHARCOAL CANISTER HAS BEEN INSTALLED, THE CREWMEMBERS MAY PROCEED WITH ISS INGRESS AND PERFORM IVA ACTIVITIES WITHOUT THE NEED OF QDM’S.
   3. IF $T > 6.0$, RISK TO CREW HEALTH MUST BE EVALUATED BY THE CREW SURGEON, AND ECLS MUST DETERMINE THE TIME REQUIRED TO SCRUB TO NOMINAL CONDITIONS.

The estimate of T at the time of crew first entry will be calculated from the rate of contaminant accumulation during the ground-based test and the time over which Node 1 is sealed. T-values are calculated from the analytical concentrations (C_n) as follows:

$$T=C_1/SMAC_1 + C_2/SMAC_2 + C_n/SMAC_n$$

Seven-day spacecraft maximum allowable concentrations (SMAC's) are to be used in the calculation. Even though the crew will be briefly exposed to air with a T-value > 1, they will be fully protected by this approach because the calculation is very conservative (based on 7-day SMAC's and assuming all effects are additive), the air will be rapidly diluted into the entire interior volume, and the air will be rapidly scrubbed of trace contaminants.

Nominally, Node 1 cabin fan with inline charcoal filters will be used to scrub the Node 1 atmosphere prior to ingress operations. In the event of inability to operate the Node 1 cabin fan, shuttle charcoal canisters will be used to implement a backup method of scrubbing the Node 1 atmosphere.

X17.4.1-2 FGB TRACE CONTAMINANT REMOVAL CONTROL (HC)

A. THE FGB TRACE CONTAMINANT REMOVAL SYSTEM WILL NOMINALLY BE OPERATED FOR APPROXIMATELY 48 HOURS (MINIMUM 24 HOURS) PRIOR TO PLANNED INGRESS BY SHUTTLE CREWMEMBERS. ®[CR 3262A]

Forty-eight hours is the approximate amount of time required by internal FGB Trace Contaminant Filter to provide for safe entry into the FGB Pressurized Adapter GA (ГА). Most off-gassing material is located in the Instrumentation Cargo Compartment PGO (ПГО); as a result, the GA (ГА) compartment is not as contaminated as the PGO (ПГО). A minimum of 24 hours represents an exchange of seven times the volume of the FGB PGO (ПГО) and provides sufficient removal of trace contaminants.

Reference: April 1997, OPS TIM 7 in Houston.

B. OFF-NOMINAL CASE: IF THE FGB TRACE CONTAMINANT REMOVAL SYSTEM HAS FAILED, ONE SHUTTLE CREWMEMBER WEARING A QDM WILL INGRESS INTO THE FGB AND SET UP THE AIR DUCT TO EXCHANGE AIR WITH THE NODE/SHUTTLE. CRITERIA FOR INGRESS WITHOUT QDM'S WILL BE BASED ON PREFLIGHT PROJECTION OF TOXICITY LEVEL PRIOR TO INGRESS AND SCRUB DURATION USING COMBINED SHUTTLE AND NODE 1 TRACE CONTAMINANT CONTROL RESOURCES.

For failure of the FGB to remove trace contaminants from the atmosphere, a shuttle crewmember will don an orbiter supplied QDM with station supplied 70 ft O_2 *hose in order to ingress into FGB GA (ГА) and PGO (ПГО). Once in the FGB, the shuttle crewmember will install ductwork that will enhance forced air flow exchange between FGB and Node 1. Once ducting has been assembled and scrub is initiated, crewmember will return to shuttle and close Node 1 Fwd Hatch.*

Scrub duration using shuttle and Node 1 trace contaminant control system resources will be based on the expected toxicity level upon ingress into the FGB. Preflight analysis will be performed to determine the required scrub time to allow safe ingress into the FGB without use of breathing devices.

Nominally, the harmful impurities filter will be changed out during STS101/ISS 2A.2b. Pending results of testing on the filter returned on STS 101, it may be possible to use the currently installed filter for additional scrubbing of the environment.

DOCUMENTATION: (1) April 1997, OPS TIM 7 in Houston, (2) Rule {B13.2.2-1}, MODULE FIRST INGRESS, (3) Trace Contaminant Control During Unity and Zarya Ingress Operations For STS-101/2A.2a by MSFC/Jay Perry, March 29, 2000. ®[CR 3262A]

Assembly Mission 4A

B13.2.2-1 MODULE FIRST INGRESS (HC)

A. THE ATMOSPHERE OF A SEALED ISS MODULE WILL BE CONTROLLED IN SUCH A MANNER THAT MODULE ATMOSPHERE TOXICITY WILL REPRESENT AN ACCEPTABLE RISK PRIOR TO CREW INGRESS. THE ACCEPTABLE RISK LEVEL WILL BE DETERMINED BY THE MEDICAL SCIENCES DIVISION AND WILL BE BASED ON SMAC LEVELS FOR TOXICOLOGICAL CONSTITUENTS.

Prior to crew first ingress into a previously sealed module, the atmosphere may contain various toxicological constituents that represent an increased risk to crew safety. These constituents may include toxic offgassing products, leakage from service systems, pyrolysis products, microbial metabolites, and possible propellant contamination. When such levels exist for specific contaminants, crew safety will be determined on the basis of Spacecraft Maximum Allowable Concentration (SMAC) levels for the mixture of contaminants present. A total “T” value will be calculated for these contaminants by summing the ratios of each measured concentration to corresponding 7-day SMACs.

B. CREWMEMBERS CANNOT ENTER A SEALED MODULE UNLESS ONE OR MORE OF THE FOLLOWING PRECAUTIONS HAS BEEN TAKEN TO ENSURE CREW SAFETY:

1. *PRELAUNCH SAMPLING HAS BEEN PERFORMED AND HAS SHOWN THAT PASSIVE SAFETY MEASURES (GROUND PREPARATIONS) HAVE PREVENTED CONTAMINANTS FROM ACCUMULATING TO UNSAFE LEVELS BY FIRST ENTRY.*
2. *THE ATMOSPHERE HAS BEEN SAMPLED ON-ORBIT AND TARGETED CONTAMINANT LEVELS HAVE BEEN DETERMINED TO BE AT SAFE LEVELS.*
3. *THE ATMOSPHERE HAS BEEN ACTIVELY SCRUBBED, FOLLOWING A SCHEDULE THAT ANALYSIS DETERMINES WILL RESULT IN TARGETED CONTAMINANT CONCENTRATIONS AT ACCEPTABLE LEVELS.*
4. *THE MODULE IS DEPRESSURIZED AND REPRESSURIZED WITH AIR OF KNOWN ACCEPTABLE QUALITY.*
5. *THE CREW IS EQUIPPED WITH AN ALTERNATE AIR SOURCE.*

Prelaunch sampling will ensure insight into the offgassing behavior of new ISS modules prior to launch. After the last person exits the module during ground based operations, the module must be purged with clean air. The final sample should be obtained and analyzed close to launch, but should allow time for remedial action should a toxicological problem occur. Ground sampling during the sealed prelaunch phase represents cheap insurance; a stable profile after sealing and shortly before launch should mitigate the need for sampling for offgassing products on-orbit prior to crew ingress. Similar requirements for microbiological sampling of a module may be identified.

As experience is gained during the assembly phase, these requirements (and sampling operation in general) should be fine tuned. Medical Sciences Division toxicology specialists will continue working with their Russian counterparts in developing a plan to characterize the atmospheric toxicological environment during the early ISS assembly phase.

Real-time sampling for targeted constituents represents the safest approach, but also a greater overhead in hardware and timeline requirements. If scrubbers are employed, it must be verified that this system was operated for a sufficient duration and in close enough proximity to crew entry such that resulting contaminant levels are safely below identified SMAC values. Ground analysis and in-flight atmosphere sampling to characterize module offgassing profiles prior to crew entry may mitigate the need for real-time sampling if a favorable offgassing profile is observed. In all cases, an alternate source of safe breathing air should be available for contingency operations.

If real-time module atmosphere testing for combustion products is required prior to arrival of the Crew Health Care System (CHeCS) Environmental Health System (EHS) monitoring equipment, the orbiter Combustion Products Analyzer (CPA) will be used.

C. IF A MODULE HAS NO ACTIVE FIRE DETECTION/SUPPRESSION SYSTEM (FDS) CAPABILITIES, OR IF THERE IS NO GROUND OR CREW INSIGHT INTO FDS ACTIVITY, CREWMEMBERS SHALL NOT INGRESS THE MODULE UNLESS AT LEAST ONE OF THE FOLLOWING PROCEDURES IS PERFORMED:

1. *THE ATMOSPHERE HAS BEEN ACTIVELY SCRUBBED WITHIN 24 HOURS OF INGRESS.*
2. *THE MODULE HAS BEEN SAMPLED FOR PYROLYSIS PRODUCTS AND DETERMINED SAFE.*
3. *THE MODULE'S ATMOSPHERE HAS BEEN DUMPED AND REPLACED WITH AIR OF KNOWN QUALITY.*
4. *COMBUSTION INCIDENTS CAN BE RULED OUT BY PRESSURE, TEMPERATURE, AND ELECTRICAL INDICATORS.*
5. *THE CREW IS EQUIPPED WITH AN ALTERNATE SAFE BREATHING SOURCE.*

This requirement ensures that an undue time interval between atmospheric scrubbing and crew ingress does not pass without insight into possible combustion events.

DOCUMENTATION: MEMORANDUM SD2 95 576.

Reference JSC 20584, SPACECRAFT MAXIMUM ALLOWABLE CONCENTRATIONS FOR AIRBORNE CONTAMINANTS.

FLIGHT/INCREMENT APPLICABILITY: *ALL FLIGHTS*

Assembly Mission 2R

3A_13B-1 MODULE INGRESS CRITERIA

GROUND-BASED OFF-GASSING TEST DATA, IN CONJUNCTION WITH DATA FROM SAMPLES ACQUIRED DURING PREVIOUS FLIGHTS, WILL PROVIDE THE BASIS FOR PREDICTING THE TOXICITY INDEX (T-VALUE) REACHED INSIDE A SEALED MODULE DURING ANY FIRST ENTRY AFTER ITS INITIAL CLOSEOUT AND LAUNCH OR ON-ORBIT QUIESCENT PERIOD. FOR INITIAL CLOSEOUT, LAUNCH, AND SUBSEQUENT INGRESS, THE PRESCRUB T-VALUE SHALL BE ESTIMATED FROM AN ASSUMED ZERO BASIS AT MODULE CLOSEOUT PLUS THE PRODUCT OF THE MEASURED RATE OF CONTAMINANT ACCUMULATION (T UNITS/DAY MEASURED FROM GROUND-BASEDC OFF-GASSING TESTS) AND TOTAL NUMBER OF DAYS ELAPSED BETWEEN CLOSEOUT AND ON-ORBIT INGRESS. FOR INGRESS FOLLOWING ON-ORBIT QUIESCENT PERIODS, THE PRESCRUB T-VALUE SHALL BE ESTIMATED FROM THE MODULE EGRESS T-VALUE MEASURED FROM THE PREVIOUS FLIGHT PLUS THE PRODUCT OF THE RATE OF CONTAMINANT ACCUMULATION (T UNITS/DAY) AND THE NUMBER OF DAYS THE MODULE HAS BEEN SEALED SINCE THE LAST ON-ORBIT EGRESS. A SCRUB MODEL SHALL BE USED TO PREDICT THE AMOUNT OF REDUCTION IN THE T-VALUE PROVIDED BY OPERATING THE MODULE’S CONTAMINATION CONTROL SYSTEMS IMMEDIATELY BEFORE CREW INGRESS. CREW ACTIONS WILL DEPEND ON THE ESTIMATED T-VALUE AS FOLLOWS:

A. FOR MODULE INGRESS WITH A MODULE BASED SCRUB USING CHARCOAL FILTERS:

   1. IF $T \leq 3.0$, NO PRE-INGRESS SCRUB REQUIRED, BUT SCRUB IS RECOMMENDED.
   2. IF $3.0 < T \leq 6.0$, PERFORM NOMINAL PRE-INGRESS SCRUB.
   3. IF $T > 6.0$, RISK TO CREW HEALTH MUST BE EVALUATED BY THE CREW SURGEON, AND ECLS MUST DETERMINE THE TIME REQUIRED TO SCRUB TO NOMINAL CONDITIONS.

MODULE	NOMINAL SCRUB TIME (HRS)
NODE	2
FGB	48
SM	48
U.S. LAB	TBD

B. FOR ANY MODULE INGRESS WITH A SHUTTLE BASED SCRUB USING CHARCOAL CANISTER(S):

   1. IF $T \leq 3.0$, CREWMEMBERS CAN ENTER MODULE WITHOUT PRECAUTIONS.
   2. IF $3.0 < T \leq 6.0$, THE FOLLOWING ACTIONS ARE TAKEN:
      A. SHUTTLE CREW WILL INSTALL ONE SHUTTLE CHARCOAL CANISTER IN PLACE OF LIOH CANISTER PRIOR TO INGRESS OPERATIONS.
      B. CREWMEMBERS ENTERING MODULE WILL DON QDM’S FOR INSTALLATION OF DUCTING. REMOVAL OF QDM’S WILL BE SURGEON CALL.
      C. CREWMEMBERS NOT INGRESSING MODULE WILL REMAIN IN THE SHUTTLE MIDDECK OR FLIGHT DECK WITHOUT QDM’S.

D. ONCE DUCTING IS INSTALLED, CREWMEMBERS WILL RETURN TO THE SHUTTLE, DOFF QDM'S, AND INITIATE AIR EXCHANGE BETWEEN THE ISS AND SHUTTLE. CREWMEMBERS WILL REMAIN IN THE SHUTTLE FOR 1 HOUR, OR UNTIL NOMINAL SCRUB IS COMPLETE.

E. PROVIDED THE 1 HOUR WAIT PERIOD IS OBSERVED, AND THE CHARCOAL CANISTER HAS BEEN INSTALLED, THE CREWMEMBERS MAY PROCEED WITH ISS INGRESS AND PERFORM IVA ACTIVITIES WITHOUT THE NEED OF QDM'S.

3. IF T > 6.0, RISK TO CREW HEALTH MUST BE EVALUATED BY THE CREW SURGEON, AND ECLS MUST DETERMINE THE TIME REQUIRED TO SCRUB TO NOMINAL CONDITIONS.

The estimate of T at the time of crew first entry will be calculated from the rate of contaminant accumulation during the ground-based test and the time over which the module is sealed. T-values are calculated from the analytical concentrations (C_n) as follows:

$$T=C_1/SMAC_1 + C_2/SMAC_2 + C_n/SMAC_n$$

Seven-day spacecraft maximum allowable concentrations (SMAC's) are to be used in the calculation. Even though the crew will be briefly exposed to air with a T-value > 1, they will be fully protected by this approach because the calculation is very conservative (based on 7-day SMAC's and assuming all effects are additive), the air will be rapidly diluted into the entire interior volume, and the air will be rapidly scrubbed of trace contaminants.

X13.2.2-2 MODULE INGRESS CRITERIA

GROUND-BASED OFF-GASSING TEST DATA, IN CONJUNCTION WITH DATA FROM SAMPLES ACQUIRED DURING PREVIOUS FLIGHTS, WILL PROVIDE THE BASIS FOR PREDICTING THE TOXICITY INDEX (T-VALUE) REACHED INSIDE A SEALED MODULE DURING ANY FIRST ENTRY AFTER ITS INITIAL CLOSEOUT AND LAUNCH OR ON-ORBIT QUIESCENT PERIOD. FOR INITIAL CLOSEOUT, LAUNCH, AND SUBSEQUENT INGRESS, THE PRESCRUB T-VALUE SHALL BE ESTIMATED FROM AN ASSUMED ZERO BASIS AT MODULE CLOSEOUT PLUS THE PRODUCT OF THE MEASURED RATE OF CONTAMINANT ACCUMULATION (T UNITS/DAY MEASURED FROM GROUND-BASED OFF-GASSING TESTS) AND TOTAL NUMBER OF DAYS ELAPSED BETWEEN CLOSEOUT AND ON-ORBIT INGRESS. FOR INGRESS FOLLOWING ON-ORBIT QUIESCENT PERIODS, THE PRESCRUB T-VALUE SHALL BE ESTIMATED FROM THE MODULE EGRESS T-VALUE MEASURED FROM THE PREVIOUS FLIGHT PLUS THE PRODUCT OF THE RATE OF CONTAMINANT ACCUMULATION (T UNITS/DAY) AND THE NUMBER OF DAYS THE MODULE HAS BEEN SEALED SINCE THE LAST ON-ORBIT EGRESS. A SCRUB MODEL SHALL BE USED TO PREDICT THE AMOUNT OF REDUCTION IN THE T-VALUE PROVIDED BY OPERATING THE MODULE'S CONTAMINATION CONTROL SYSTEMS IMMEDIATELY BEFORE CREW INGRESS. CREW ACTIONS WILL DEPEND ON THE ESTIMATED T-VALUE AS FOLLOWS:

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   3. IF $T > 6.0$, RISK TO CREW HEALTH MUST BE EVALUATED BY THE CREW SURGEON, AND ECLS MUST DETERMINE THE TIME REQUIRED TO SCRUB TO NOMINAL CONDITIONS.

MODULE	NOMINAL SCRUB TIME (HRS)
NODE	2
FGB	48
SM	48
U.S. LAB	2

NOMINAL MODULE INGRESS SCRUB TIMES

B. FOR ANY MODULE INGRESS WITH A SHUTTLE BASED SCRUB USING CHARCOAL CANISTER(S):

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      b. CREWMEMBERS ENTERING MODULE WILL DON QDM'S FOR INSTALLATION OF DUCTING. REMOVAL OF QDM'S WILL BE SURGEON CALL.

      c. CREWMEMBERS NOT INGRESSING MODULE WILL REMAIN IN THE SHUTTLE MIDDECK OR FLIGHT DECK WITHOUT QDM'S.

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Logistics Missions 5A.1 and 6A, Assembly Mission 7A, and
all subsequent logistics and assembly missions

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If real-time module atmosphere testing for combustion products is required prior to arrival of the Crew Health Care System (CHeCS) Environmental Health System (EHS) monitoring equipment, the orbiter Combustion Products Analyzer (CPA) will be used.

C. IF A MODULE HAS NO ACTIVE FIRE DETECTION/SUPPRESSION SYSTEM (FDS) CAPABILITIES, OR IF THERE IS NO GROUND OR CREW INSIGHT INTO FDS ACTIVITY, CREWMEMBERS SHALL NOT INGRESS THE MODULE UNLESS AT LEAST ONE OF THE FOLLOWING PROCEDURES IS PERFORMED:

1. *THE ATMOSPHERE HAS BEEN ACTIVELY SCRUBBED WITHIN 24 HOURS OF INGRESS.*
2. *THE MODULE HAS BEEN SAMPLED FOR PYROLYSIS PRODUCTS AND DETERMINED SAFE.*
3. *THE MODULE’S ATMOSPHERE HAS BEEN DUMPED AND REPLACED WITH AIR OF KNOWN QUALITY.*
4. *COMBUSTION INCIDENTS CAN BE RULED OUT BY PRESSURE, TEMPERATURE, AND ELECTRICAL INDICATORS.*
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This requirement ensures that an undue time interval between atmospheric scrubbing and crew ingress does not pass without insight into possible combustion events.

DOCUMENTATION: MEMORANDUM SD2 95 576.

Reference JSC 20584, SPACECRAFT MAXIMUM ALLOWABLE CONCENTRATIONS FOR AIRBORNE CONTAMINANTS.

FLIGHT/INCREMENT APPLICABILITY: *ALL FLIGHTS*

APPENDIX B—MODULE OFFGASSING TEST DATA

Node 1

	COMMON NAME	IUPAC NAME	MOLECULAR	LIMITS IN AIR*		EQUIPMENT	NODE 1	NASA NODE 1 OFFGASSING TEST DATA (mg/m^3)			NODE 1	NODE 1
			WEIGHT	ZRL	ARL	RATE$^\#$	CARGO	Sample Zero	Sample 1	Sample 2	TERMINAL RATE	RATE
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	32.8	118.6	mg/day	mg/h
	ALCOHOLS											
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00	8.00E-02	4.30E-01	5.44E-01	7.34E-02	3.10E-01
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	2.00E-01	7.60E-01	1.65E+00	1.38E+01	7.08E-01
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	1.50E-01	8.00E-01	1.50E+00	1.08E+01	7.22E-01
		Propanol						0.00E+00	8.50E-02	2.25E-01		1.09E-01
4	t-butyl alcohol	2-methyl-2-propanol	74.12	0.10	100.00	7.38E-05	0.00E+00	0.00E+00	0.00E+00	2.50E-02	3.86E-01	7.52E-03
5	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	0.00E+00	0.00E+00	1.30E-01	2.01E+00	3.91E-02
	ALDEHYDES											
6	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	2.50E-02	2.50E-02	2.50E-02	0.00E+00	0.00E+00
7	Propionaldehyde	Propanal	58.08	N/A	95.00	3.19E-04	0.00E+00	2.50E-02	2.50E-02	2.50E-02	0.00E+00	0.00E+00
8	n-butylaldehyde	Butanal	72.10	N/A	118.00	8.59E-04	0.00E+00	1.25E-02	2.50E-02	2.50E-02	0.00E+00	9.83E-03
9	Valeraldehyde	Pentanal	86.13	N/A	21.00	7.84E-07	0.00E+00	2.50E-02	2.50E-02	2.50E-02	0.00E+00	0.00E+00
10	Caproaldehyde	Hexanal	100.16	N/A	24.00	5.34E-05	0.00E+00	2.50E-02	2.50E-02	2.50E-02	0.00E+00	0.00E+00
		2-methyl-2-propenal						0.00E+00	0.00E+00	2.50E-02	3.86E-01	7.52E-03
11	Enanthaldehyde	Heptanal	114.19	N/A	28.00	1.77E-05	0.00E+00	2.50E-02	2.50E-02	2.50E-02	0.00E+00	0.00E+00
	AROMATIC HYDROCARBONS											
12	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	2.50E-02	8.00E-02	1.25E-01	6.95E-01	5.68E-02
13	m-/p-xylene	1,3-/1,4-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00	0.00E+00	2.50E-02	2.50E-02	0.00E+00	1.97E-02
		1,2-dimethylbenzene						0.00E+00	0.00E+00	2.50E-02	3.86E-01	7.52E-03
14	Ethylbenzene	Ethylbenzene	106.16	N/A	130.00	1.50E-04	0.00E+00	0.00E+00	0.00E+00	2.50E-02	3.86E-01	7.52E-03
	ESTERS											
15	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Ethyl acetate	Ethanoic acid butyl ester					0.00E+00	2.50E-02	2.50E-02	2.50E-02	0.00E+00	0.00E+00
	HALOCARBONS											
16	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	0.00E+00	0.00E+00	5.50E-02	1.90E-01	2.09E+00	8.39E-02
		Trichloroethene						2.50E-02	2.50E-02	2.50E-02	0.00E+00	0.00E+00
		Trichlorofluoromethane						0.00E+00	0.00E+00	2.50E-02	3.86E-01	7.52E-03
		Tetrachloroethene						2.50E-02	2.50E-02	2.50E-02	0.00E+00	0.00E+00
16	Methylene chloride	Trichlorotrifluoromethane					0.00E+00	1.05E-02	7.50E-02	1.25E-01	7.73E-01	6.58E-02
	ALIPHATIC HYDROCARBONS											
17	n-pentane	Pentane	72.15	10.00	625.00	9.54E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	KETONES											
18	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	2.50E-02	1.50E-01	3.80E-01	3.55E+00	1.67E-01
19	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	0.00E+00	7.50E-02	1.80E-01	1.62E+00	9.06E-02
		Cyclohexanone						2.50E-02	4.20E-02	8.50E-02		
20	Methyl isobutyl ketone	4-methyl-2-pentanone	100.16	N/A	140.00	7.60E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	MISCELLANEOUS											
21	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Hexamethylcyclotrisilixane						0.00E+00	0.00E+00	2.50E-02	3.86E-01	7.52E-03
21		Octamethylcycltrisiloxane					0.00E+00	7.50E-02	1.60E-01	3.20E-01	2.47E+00	1.15E-01
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	(Free	5.16E+01		2.54
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)	Volume)	5.16E+01		
	$^\#$ 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0					

Node 2

	COMMON NAME	IUPAC NAME	MOLECULAR	LIMITS IN AIR*		EQUIPMENT	NODE 2	NASA NODE 2 OFFGASSING TEST DATA (mg/m^3)				NASA
			WEIGHT	ZRL	ARL	RATE$^\#$	CARGO	Sample Zero	Sample 1	Sample 2	Sample 3	NODE 2 RATE
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	165.4	331.9	567.1	mg/day
	ALCOHOLS											
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00	3.50E-02	7.35E-02	7.80E-02	1.40E-01	2.60E-01
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	5.85E-01	8.45E-01	9.30E-01	1.00E+00	1.18E+00
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	7.15E-01	7.35E-01	9.05E-01	9.00E-01	5.56E-01
4	n-propyl alcohol	Propanol	60.09	0.60	98.00	2.41E-04	0.00E+00	2.50E-02	4.60E-02	6.85E-02	1.05E-01	2.07E-01
5	t-butyl alcohol	2-methyl-2-propanol	74.12	0.10	100.00	7.38E-05	0.00E+00	0.00E+00	1.25E-02	0.00E+00	2.50E-02	5.30E-02
6	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	2.75E-02	8.30E-02	1.25E-01	1.90E-01	4.29E-01
	ALDEHYDES											
7	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	3.55E-02	9.30E-02	5.55E-02	1.90E-01	3.44E-01
8	Propionaldehyde	Propanal	58.08	N/A	95.00	3.19E-04	0.00E+00	2.50E-02	3.70E-02	3.10E-02	6.15E-02	8.24E-02
9	Methacrolein	2-methyl-2-propenal	70.09	N/A	3.40	2.01E-06	0.00E+00	0.00E+00	2.50E-02	2.50E-02	2.50E-02	7.50E-02
10	n-butylaldehyde	Butanal	72.10	N/A	118.00	8.59E-04	0.00E+00	1.25E-02	2.50E-02	2.50E-02	2.50E-02	3.75E-02
	AROMATIC HYDROCARBONS											
11	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	2.50E-02	2.60E-02	4.05E-02	4.80E-02	6.20E-02
12	m-xylene	1,3-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00	0.00E+00	6.25E-03	1.25E-02	1.28E-02	3.79E-02
13	p-xylene	1,4-dimethylbenzene	106.16	5.00	220.00	1.08E-03	0.00E+00	0.00E+00	6.25E-03	1.25E-02	1.28E-02	3.79E-02
	HALOCARBONS											
14	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	0.00E+00	0.00E+00	0.00E+00	2.50E-02	2.50E-02	7.45E-02
15	Ethylene dichloride	1,2-dichloroethane	98.97	0.50	1.00	7.74E-05	0.00E+00	2.50E-02	2.50E-02	3.95E-02	4.75E-02	6.01E-02
16	Freon 11	Trichlorofluoromethane	136.48	N/A	790.00	1.41E-03	0.00E+00	0.00E+00	2.50E-02	2.50E-02	2.50E-02	7.50E-02
17	Freon 114	1,2-dichloro-1,1,2,2-tetrafluoroethan	170.92	100.00	700.00	2.62E-05	0.00E+00	0.00E+00	2.50E-02	2.95E-02	4.50E-02	1.21E-01
	KETONES											
18	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	6.30E-02	1.45E-01	1.50E-01	2.30E-01	4.30E-01
19	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	5.35E-02	1.55E-01	2.05E-01	2.85E-01	6.22E-01
20	cyclohexanone (pimelic ketone)	Cyclohexanone	98.14	1.30	60.20	6.62E-04	0.00E+00	2.50E-02	2.50E-02	3.25E-02	6.10E-02	8.25E-02
	MISCELLANEOUS											
		Carbon monoxide	28.01	5.00	11.00	2.03E-03	0.00E+00	0.00E+00	0.00E+00	2.85E-01	2.85E-01	8.49E-01
21	Carbon oxisulfide	Carbonyl sulfide	60.07	N/A	12.00	6.05E-06	0.00E+00	2.50E-02	4.80E-02	7.50E-02	1.05E-01	2.13E-01
22	Carbon disulfide	Carbon disulfide	76.14	1.00	16.00	3.23E-05	0.00E+00	2.50E-02	2.50E-02	2.50E-02	2.65E-02	3.16E-03
23	trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	1.20E-01	2.55E-01	3.60E-01	5.90E-01	1.20E+00
24	Hexamethylcyclotrisiloxane	Hexamethylcyclotrisiloxane	222.40	0.20	9.00	1.62E-04	0.00E+00	1.45E+00	1.09E+00	3.35E+00	1.06E+00	8.28E-01
25	Octamethylcyclotetrasiloxane	Octamethylcyclotetrasiloxane	296.62	0.20	12.00	2.70E-04	0.00E+00	5.25E+00	9.60E-01	1.39E+00	3.25E+00	-7.67E+00
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	Empty Node 2	6.20E+01		7.9232
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)	Node 2 with cargo	6.20E+01		
	$^\#$ 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0					

Node 3

	COMMON NAME	IUPAC NAME	MOLECULAR WEIGHT	LIMITS IN AIR*		EQUIPMENT RATE#	NODE 3 CARGO	NASA NODE 3 TEST DATA (mg/m^3)			NODE 3 TERMINAL RATE	NODE 3 RATE
				ZRL	ARL			Sample Zero	Sample 1	Sample 2		
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	453.2	790.1	mg/day	mg/day
	ALCOHOLS											
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00	4.10E-02	1.93E-01	3.00E-01	4.73E-01	3.24E-01
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	3.50E-02	8.57E-02	1.10E-01	1.07E-01	9.13E-02
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	9.93E+00	9.30E+00	1.23E+01	1.33E+01	3.73E+00
4	t-butyl alcohol	2-methyl-2-propanol	74.12	0.10	100.00	7.38E-05	0.00E+00	0.00E+00	1.25E-02	1.25E-02	0.00E+00	1.37E-02
5	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	1.85E-02	3.20E-01	7.17E-01	1.75E+00	9.15E-01
6	2-ethyl hexyl alcohol	2-ethylhexanol	130.23	3.30	0.10	9.85E-06	0.00E+00	8.33E-03	1.25E-02	6.47E-02	2.31E-01	8.14E-02
	ALDEHYDES											
7	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	1.04E-01	1.33E-01	2.10E-01	3.40E-01	1.45E-01
8	Proprionaldehyde	Propanal	58.08	1.00	14.00	3.19E-04	0.00E+00	3.07E-02	1.25E-02	2.48E-02	5.43E-02	-1.81E-03
9	Methacrolein	2-methyl-2-propenal	70.09	1.00	1.70	2.01E-06	0.00E+00	8.33E-03	4.17E-03	4.17E-03	0.00E+00	-4.55E-03
10	n-butylaldehyde	Butanal	72.10	1.00	118.00	8.59E-04	0.00E+00	1.97E-02	2.45E-02	2.48E-02	1.33E-03	5.70E-03
11	Caproaldehyde	Hexanal	100.16	1.00	24.00	5.34E-05	0.00E+00	8.33E-03	4.17E-03	1.25E-02	3.68E-02	7.71E-03
	AROMATIC HYDROCARBONS											
12	Benzene	Benzene	78.11	0.20	0.20	2.51E-05	0.00E+00	0.00E+00	1.25E-02	1.25E-02	0.00E+00	1.37E-02
13	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	8.33E-03	1.67E-02	1.32E-01	5.09E-01	1.79E-01
14	m-/p-xylene	1,3-/1,4-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00	1.25E-02	1.25E-02	4.37E-02	1.38E-01	4.59E-02
15	o-xylene	1,2-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00	0.00E+00	0.00E+00	1.25E-02	5.52E-02	1.84E-02
16	Ethylbenzene	Ethylbenzene	106.16	2.00	130.00	1.50E-04	0.00E+00	4.17E-03	1.25E-02	1.25E-02	0.00E+00	9.12E-03
	ESTERS											
17	Butyl acetate	Ethanoic acid butyl ester	116.16	2.00	190.00	7.46E-04	0.00E+00	0.00E+00	1.25E-02	3.20E-02	8.61E-02	4.24E-02
	HALOCARBONS											
18	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	0.00E+00	1.25E-02	5.03E-02	8.73E-02	1.63E-01	9.59E-02
19	Ethylene dichloride	1,2-dichloroethane	98.97	0.50	1.00	7.74E-05	0.00E+00	1.25E-02	1.43E-01	2.87E-01	6.36E-01	3.55E-01
	ALIPHATIC HYDROCARBONS											
20	Pentane	n-pentane	72.15	10.00	625.00	9.54E-05	0.00E+00	4.17E-03	4.17E-03	1.25E-02	3.68E-02	1.23E-02
21	Hexamethylene	Cyclohexane	84.16	3.00	210.00	3.79E-04	0.00E+00	8.67E-02	0.00E+00	0.00E+00	0.00E+00	-9.49E-02
	KETONES											
22	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	1.50E-01	2.37E-01	4.00E-01	7.20E-01	3.36E-01
23	Methyl vinyl ketone	3-buten-2-one	70.00	N/A	0.43	1.60E-07	0.00E+00	4.17E-03	1.25E-02	1.25E-02	0.00E+00	9.12E-03
24	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	2.97E-02	2.23E-01	4.63E-01	1.06E+00	5.65E-01
25	Methyl propyl ketone	2-pentanone	86.13	N/A	70.00	4.03E-06	0.00E+00	4.17E-03	0.00E+00	8.33E-03	3.68E-02	7.70E-03
26	Pimelic ketone	Cyclohexanone	98.14	1.30	60.00	6.62E-04	0.00E+00	0.00E+00	1.25E-02	1.25E-02	0.00E+00	1.37E-02
	MISCELLANEOUS											
27	Carbon monoxide	Carbon monoxide	28.01	5.00	11.00	2.03E-03	0.00E+00	1.43E-01	1.50E+00	1.63E+00	5.74E-01	1.68E+00
28	Carbon oxysulfide	Carbonyl sulfide	60.07	N/A	12.00	6.05E-06	0.00E+00	1.25E-02	2.10E-01	3.97E-01	8.26E-01	4.92E-01
29	Carbon disulfide	Carbon disulfide	76.14	1.00	16.00	3.23E-05	0.00E+00	8.33E-03	4.70E-02	8.27E-02	1.58E-01	9.49E-02
30	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	4.32E-02	6.00E-01	1.10E+00	2.21E+00	1.35E+00
31	Trimethylfluorosilane	Fluorotrimethylsilane	92.19	N/A	0.50	0.00E+00	0.00E+00	8.33E-03	5.83E-02	1.10E-01	2.28E-01	1.31E-01
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	Empty Node 3	6.20E+01		10.75
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)	Node 3 with cargo	6.20E+01		
	# 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0					

U.S. Lab

	COMMON NAME	IUPAC NAME	MOLECULAR WEIGHT	LIMITS IN AIR*		EQUIPMENT RATE#	USL CARGO	NASA USL OFFGASSING TEST DATA (mg/m^3)			USL TERMINAL RATE	USL RATE
				ZRL	ARL			Sample Zero	Sample 1	Sample 2		
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	287.7	443.7	mg/h	mg/h
	ALCOHOLS											
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00	2.25E+00	3.80E+00	5.25E+00	1.14E+00	8.96E-01
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	4.65E+00	5.45E+00	8.20E+00	2.30E+00	1.33E+00
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	2.75E+00	4.60E+00	6.55E+00	1.63E+00	2.37E-01
		Propanol						5.20E-01	1.05E+00	1.20E+00	1.29E-01	1.84E-01
4	t-butyl alcohol	2-methyl-2-propanol	74.12	0.10	100.00	7.38E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	2.50E-01	4.35E-01	5.85E-01	1.25E-01	1.05E-01
	ALDEHYDES											
6	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	1.10E-01	1.60E-01	1.45E-01	-1.25E-02	5.06E-03
7	Propionaldehyde	Propanal	58.08	N/A	95.00	3.19E-04	0.00E+00	2.50E-02	2.50E-02	4.25E-02	1.46E-02	7.31E-03
8	n-butylaldehyde	Butanal	72.10	N/A	118.00	8.59E-04	0.00E+00				0.00E+00	0.00E+00
9	Valeraldehyde	Pentanal	86.13	N/A	21.00	7.84E-07	0.00E+00				0.00E+00	0.00E+00
10	Caproaldehyde	Hexanal	100.16	N/A	24.00	5.34E-05	0.00E+00				0.00E+00	0.00E+00
		2-methyl-2-propenal									0.00E+00	0.00E+00
11	Enanthaldehyde	Heptanal	114.19	N/A	28.00	1.77E-05	0.00E+00				0.00E+00	0.00E+00
	AROMATIC HYDROCARBONS											
12	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	2.35E-01	4.20E-01	4.35E-01	1.25E-02	4.81E-02
13	m-/p-xylene	1,3-/1,4-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00	2.50E-02	2.50E-02	2.50E-02	0.00E+00	0.00E+00
		1,2-dimethylbenzene						0.00E+00	2.50E-02	2.50E-02	0.00E+00	5.66E-03
14	Ethylbenzene	Ethylbenzene	106.16	N/A	130.00	1.50E-04	0.00E+00	0.00E+00	1.25E-02	2.50E-02	1.04E-02	8.05E-03
	ESTERS											
15	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	0.00E+00				0.00E+00	0.00E+00
15	Ethyl acetate	Ethanoic acid butyl ester					0.00E+00				0.00E+00	0.00E+00
	HALOCARBONS											
16	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	0.00E+00	9.50E-02	2.00E-01	2.40E-01	3.34E-02	4.05E-02
		Trichloroethene						2.50E-02	2.50E-02	2.50E-02	0.00E+00	0.00E+00
		Tetrachloroethene						1.25E-01	2.25E-01	2.60E-01	2.92E-02	3.72E-02
		1,2-dichloroethane						2.50E-02	5.50E-02	6.50E-02	8.35E-03	1.10E-02
16	Methylene chloride	Trichlorotrifluoromethane					0.00E+00	8.55E-01	3.25E+00	2.35E+00	-7.51E-01	0.00E+00
	ALIPHATIC HYDROCARBONS											
17	n-pentane	Pentane	72.15	10.00	625.00	9.54E-05	0.00E+00				0.00E+00	0.00E+00
	KETONES											
18	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	1.50E+00	2.50E+00	3.10E+00	5.01E-01	4.77E-01
19	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	3.55E-01	6.25E-01	7.60E-01	1.13E-01	1.17E-01
		Cyclohexanone						7.00E-02	1.20E-01	1.60E-01	3.34E-02	2.80E-02
20	Methyl isobutyl ketone	4-methyl-2-pentanone	100.16	N/A	140.00	7.60E-02	0.00E+00				0.00E+00	0.00E+00
	MISCELLANEOUS											
		Carbon disulfide									0.00E+00	0.00E+00
		Carbon monoxide						0.00E+00	1.30E+00	1.90E+00	5.01E-01	5.45E-01
21	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	2.30E+00	3.87E+00	4.90E+00	8.60E-01	7.85E-01
		Dodecamethylpentasiloxane						8.00E-02	1.95E-01	2.35E-01	3.34E-02	4.27E-02
21		Octamethylcycltrisiloxane					0.00E+00				0.00E+00	0.00E+00
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	(Free	9.77E+01		4.909
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)	Volume)	9.77E+01		
	# 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0					

Airlock

	COMMON NAME	IUPAC NAME	MOLECULAR WEIGHT g/mole	LIMITS IN AIR*		EQUIPMENT RATE$^{\#}$ mg/day/kg	AIRLOCK CARGO mg/day	NASA AIRLOCK OFFGASSING TEST DATA (mg/m^3)			AIRLOCK TERMINAL RATE mg/day	AIRLOCK RATE mg/h
				ZRL mg/m^3	ARL mg/m^3			Sample Zero 0.0	Sample 1 187.0	Sample 2 354.0		
	ALCOHOLS											
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00	2.50E-02	3.65E-01	7.00E-01	7.94E-02	7.57E-02
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	6.60E-01	2.05E+00	3.05E+00	2.37E-01	2.66E-01
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	8.95E+01	7.75E+01	7.85E+01	2.37E-01	2.37E-01
		Propanol						2.50E-02	4.50E-01	6.35E-01	4.39E-02	6.69E-02
4	t-butyl alcohol	2-methyl-2-propanol	74.12	0.10	100.00	7.38E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	2.50E-02	2.00E-01	2.95E-01	2.25E-02	2.98E-02
	ALDEHYDES											
6	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	4.25E-02	6.50E-02	7.00E-02	1.19E-03	2.98E-03
7	Propionaldehyde	Propanal	58.08	N/A	95.00	3.19E-04	0.00E+00	0.00E+00	6.50E-02	1.10E-01	1.07E-02	1.22E-02
8	n-butylaldehyde	Butanal	72.10	N/A	118.00	8.59E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Valeraldehyde	Pentanal	86.13	N/A	21.00	7.84E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Caproaldehyde	Hexanal	100.16	N/A	24.00	5.34E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		2-methyl-2-propenal						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Enanthaldehyde	Heptanal	114.19	N/A	28.00	1.77E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	AROMATIC HYDROCARBONS											
12	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	2.50E-02	1.60E-01	2.40E-01	1.90E-02	2.38E-02
13	m-/p-xylene	1,3-/1,4-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		1,2-dimethylbenzene						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Ethylbenzene	Ethylbenzene	106.16	N/A	130.00	1.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ESTERS											
15	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Ethyl acetate	Ethanoic acid butyl ester					0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	HALOCARBONS											
16	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Trichloroethene						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Trichlorofluoromethane						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Fluorinated hydrocarbon						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Methylene chloride	Trichlorotrifluoromethane					0.00E+00	2.50E-02	1.75E-01	1.65E-01	-2.37E-03	1.47E-02
	ALIPHATIC HYDROCARBONS											
17	n-pentane	Pentane	72.15	10.00	625.00	9.54E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	KETONES											
18	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	2.25E-01	5.40E-01	6.80E-01	3.32E-02	5.00E-02
19	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	2.50E-02	1.20E-01	1.70E-01	1.19E-02	1.60E-02
		Cyclohexanone						2.50E-02	1.20E-01	1.95E-01	1.78E-02	1.90E-02
20	Methyl isobutyl ketone	4-methyl-2-pentanone	100.16	N/A	140.00	7.60E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	MISCELLANEOUS											
		Carbon disulfide						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	0.00E+00	8.70E-01	1.35E+00	1.14E-01	1.49E-01
		Hexamethylcyclotrisilixane						0.00E+00	9.20E-01	1.85E+00	2.21E-01	2.08E-01
21		Octamethylcycltrisiloxane					0.00E+00	5.50E-02	3.60E-01	3.05E-01	-1.30E-02	2.58E-02
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	(Free	2.97E+01		1.20
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)	Volume)	2.97E+01		
	$^{\#}$ 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0					

JEM ELM PS

	COMMON NAME	IUPAC NAME	MOLECULAR WEIGHT g/mole	LIMITS IN AIR*		EQUIPMENT RATE$^{\#}$ mg/day/kg	ELM CARGO mg/day	NASA ELM OFFGASSING TEST DATA (mg/m^3)			ELM PS TERMINAL RATE mg/day	ELM PS RATE mg/day
				ZRL mg/m^3	ARL mg/m^3			Sample Zero 0.0	Sample 1 143.9	Sample 2 551.9		
	ALCOHOLS											
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	2.40E-01	2.90E+00	2.40E+00	4.30E-01	-5.92E+00	-5.09E+00
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	1.20E+00	2.30E+00	2.40E+00	1.95E+00	-1.35E+00	-2.50E-01
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	5.00E-01	2.60E+01	1.70E+01	1.25E+01	-1.35E+01	-4.51E+01
4	t-butyl alcohol	2-methyl-2-propanol	74.12	0.10	100.00	7.38E-05	0.00E+00	0.00E+00	1.25E-02	3.20E-02	5.86E-02	8.26E-02
5	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	1.25E-02	3.40E-02	7.55E-02	1.25E-01	1.54E-01
	ALDEHYDES											
6	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	3.15E-02	1.12E-01	8.30E-02	-8.72E-02	3.00E-01
7	Propionaldehyde	Propanal	58.08	N/A	95.00	3.19E-04	0.00E+00	1.25E-02	1.88E-02	1.25E-02	-1.88E-02	1.72E-02
8	n-butylaldehyde	Butanal	72.10	N/A	118.00	8.59E-04	0.00E+00	6.25E-03	1.25E-02	1.25E-02	0.00E+00	2.66E-02
9	Valeraldehyde	Pentanal	86.13	N/A	21.00	7.84E-07	0.00E+00	6.25E-03	1.25E-02	1.25E-02	0.00E+00	2.66E-02
10	Caproaldehyde	Hexanal	100.16	N/A	24.00	5.34E-05	0.00E+00	6.25E-03	1.25E-02	1.25E-02	0.00E+00	2.66E-02
11	Enanthaldehyde	Heptanal	114.19	N/A	28.00	1.77E-05	0.00E+00	6.25E-03	1.25E-02	1.25E-02	0.00E+00	2.66E-02
	AROMATIC HYDROCARBONS											
12	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	6.25E-03	1.25E-02	3.05E-02	5.41E-02	5.37E-02
13	m-/p-xylene	1,3-/1,4-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00	6.25E-03	1.25E-02	1.25E-02	0.00E+00	2.66E-02
14	Ethylbenzene	Ethylbenzene	106.16	N/A	130.00	1.50E-04	0.00E+00	0.00E+00	0.00E+00	1.25E-02	3.76E-02	1.88E-02
	ESTERS											
15	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	0.00E+00	3.65E-02	2.62E-02	0.00E+00	-7.88E-02	-8.33E-02
	HALOCARBONS											
16	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	0.00E+00	0.00E+00	1.25E-02	1.25E-02	0.00E+00	5.33E-02
	ALIPHATIC HYDROCARBONS											
17	n-pentane	Pentane	72.15	10.00	625.00	9.54E-05	0.00E+00	0.00E+00	6.25E-03	1.25E-02	1.88E-02	3.60E-02
	KETONES											
18	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	8.10E-02	1.30E-01	1.70E-01	1.20E-01	2.69E-01
19	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	1.25E-02	4.95E-02	1.10E-01	1.82E-01	2.49E-01
20	Methyl isobutyl ketone	4-methyl-2-pentanone	100.16	N/A	140.00	7.60E-02	5.00E-01	1.04E-01	2.50E-02	3.25E-02	2.25E-02	-3.25E-01
	MISCELLANEOUS											
21	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	5.50E-02	9.65E-01	1.95E+00	2.96E+00	5.36E+00
	NOTES:				TOTAL	(mg/day)	2.44E+00	VOLUME	Empty ELM	3.94E+01		6.73
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	1.02E-01	(m^3)	ELM with cargo	3.94E+01		
	$^{\#}$ 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0					

JEM PM

	COMMON NAME	IUPAC NAME	MOLECULAR WEIGHT g/mole	LIMITS IN AIR*		EQUIPMENT RATE# mg/day/kg	ELM CARGO mg/day	NASA ELM OFFGASSING TEST DATA (mg/m^3)			PM TERMINAL RATE mg/day	PM RATE mg/day
				ZRL mg/m^3	ARL mg/m^3			Sample Zero 0.0	Sample 1 118.7	Sample 2 288.9		
	ALCOHOLS											
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00	3.60E-01	6.50E-01	2.85E-01	-6.86E+00	4.78E-01
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	5.95E-01	1.14E+00	1.15E-01	-1.92E+01	-2.31E+00
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	2.35E+00	1.85E+00	1.90E+01	3.22E+02	1.54E+02
4	t-butyl alcohol	2-methyl-2-propanol	74.12	0.10	100.00	7.38E-05	0.00E+00	6.25E-03	1.25E-02	3.45E-02	4.14E-01	2.91E-01
5	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	1.25E-02	2.33E-02	1.25E-02	-2.02E-01	4.38E-02
	ALDEHYDES											
6	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	7.63E-02	1.61E-01	5.85E-02	-1.92E+00	1.77E-01
7	Propionaldehyde	Propanal	58.08	N/A	95.00	3.19E-04	0.00E+00	2.58E-02	5.38E-02	1.25E-02	-7.75E-01	-1.04E-02
8	n-butylaldehyde	Butanal	72.10	N/A	118.00	8.59E-04	0.00E+00	2.03E-02	3.83E-02	1.25E-02	-4.84E-01	5.60E-04
9	Valeraldehyde	Pentanal	86.13	N/A	21.00	7.84E-07	0.00E+00	6.25E-03	2.48E-02	6.25E-03	-3.48E-01	7.54E-02
10	Caproaldehyde	Hexanal	100.16	N/A	24.00	5.34E-05	0.00E+00	1.25E-02	1.25E-02	0.00E+00	-2.35E-01	-1.17E-01
11	Enanthaldehyde	Heptanal	114.19	N/A	28.00	1.77E-05	0.00E+00	6.25E-03	6.25E-03	0.00E+00	-1.17E-01	-5.87E-02
	AROMATIC HYDROCARBONS											
12	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	1.25E-02	1.25E-02	1.25E-02	0.00E+00	0.00E+00
13	m-/p-xylene	1,3-/1,4-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Ethylbenzene	Ethylbenzene	106.16	N/A	130.00	1.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ESTERS											
15	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	0.00E+00	6.25E-03	1.25E-02	0.00E+00	-2.35E-01	-3.33E-02
	HALOCARBONS											
16	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ALIPHATIC HYDROCARBONS											
17	n-pentane	Pentane	72.15	10.00	625.00	9.54E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	KETONES											
18	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	8.15E-02	1.57E-01	1.14E-01	-8.08E-01	6.13E-01
19	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	2.48E-02	6.35E-02	2.75E-02	-6.77E-01	1.84E-01
20	Methyl isobutyl ketone	4-methyl-2-pentanone	100.16	N/A	140.00	7.60E-02	0.00E+00	1.25E-02	2.08E-02	0.00E+00	-3.90E-01	-8.38E-02
	MISCELLANEOUS											
21	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	2.25E-01	9.95E-01	1.30E+00	5.73E+00	1.32E+01
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	Empty PM	1.25E+02		169.55
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)	PM with cargo	1.25E+02		
	# 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0					

Columbus

	COMMON NAME	IUPAC NAME	MOLECULAR WEIGHT g/mole	LIMITS IN AIR*		EQUIPMENT RATE# mg/day/kg	APM CARGO mg/day	NASA COLUMBUS OFFGASSING TEST DATA			NASA APM RATE mg/day
				ZRL mg/m^3	ARL mg/m^3			t=0 mg/m^3	t=288 h mg/m^3	t=456 h mg/m^3	
	ALCOHOLS										
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00	2.50E-02	9.00E-02	1.40E-01	4.02E-01
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	2.50E-02	2.50E-02	7.00E-02	2.06E-01
3	Propyl alcohol	n-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	2.50E-02	7.00E-02	1.00E-01	2.57E-01
4	Isobutyl alcohol	2-methyl-1-propanol	74.12	0.10	100.00	7.38E-05	0.00E+00				0.00E+00
5	Butyl alcohol	n-butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	2.50E-02	5.00E-02	7.00E-02	1.58E-01
	ALDEHYDES										
6	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	2.50E-02	5.00E-02	7.00E-02	1.58E-01
7	Propionaldehyde	Propanal	58.08	N/A	95.00	3.19E-04	0.00E+00				0.00E+00
8	n-butylaldehyde	Butanal	72.10	N/A	118.00	8.59E-04	0.00E+00				0.00E+00
9	valeraldehyde	Pentanal	86.13	N/A	106.00	7.84E-05	0.00E+00				0.00E+00
	AROMATIC HYDROCARBONS										
10	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	2.50E-02	2.50E-02	7.00E-02	2.06E-01
11	o-xylene	1,2-dimethylbenzene	106.16	5.00	220.00	5.56E-04	0.00E+00				0.00E+00
12	m-xylene	1,3-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00				0.00E+00
13	p-xylene	1,4-dimethylbenzene	106.16	5.00	220.00	1.08E-03	0.00E+00				0.00E+00
	ESTERS										
14	butyl acetate	Butyl acetate	116.16	2.00	190.00	7.46E-04	0.00E+00				0.00E+00
	CHLOROCARBONS										
15	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	0.00E+00				0.00E+00
16	Trichloroethylene	Trichloroethene	131.39	N/A	10.00						
17	Tetrachloroethylene	Tetrachloroethene	165.83	N/A	34.00	7.28E-04	0.00E+00				0.00E+00
	KETONES										
18	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	1.10E-01	1.00E-01	1.40E-01	1.56E-01
19	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	2.50E-02	1.70E-01	2.40E-01	7.07E-01
20	cyclohexanone (pimelic ketone)	Cyclohexanone	98.14	1.30	60.20	6.62E-04	0.00E+00				0.00E+00
	MISCELLANEOUS										
21	trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	4.00E-02	6.40E-01	8.40E-01	2.51E+00
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	BASIC APM	6.40E+01	4.76E+00
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)		6.40E+01	
	# 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0				

FGB

			MOLECULAR	LIMITS IN AIR*		EQUIPMENT	FGB	IMBP FGB OFFGASSING TEST DATA (mg/m^3)			IMBP
	COMMON NAME	IUPAC NAME	WEIGHT	ZRL	ARL	RATE$^{\#}$	CARGO	Event 0	Event 1	Event 2	FGB RATE
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	24.0	48.0	mg/h
	ALCOHOLS										
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	1.52E+00				0.00E+00
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	9.42E+00	3.50E-02	4.00E-02	5.00E-02	1.91E-02
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	4.78E+00				0.00E+00
4	Propyl alcohol	1-propanol	60.09	0.60	98.00	2.41E-04	2.89E-01				0.00E+00
5	Cyclobutanol	Cyclobutanol	72.11	6.60	0.10	0.00E+00	0.00E+00				0.00E+00
6	Isobutyl alcohol	2-methyl-1-propanol	74.12	0.10	120.00	8.47E-04	1.02E+00	0.00E+00	0.00E+00	3.00E-02	3.81E-02
7	tert-butyl alcohol	2-methyl-2-propanol	74.12	3.30	120.00	7.38E-05	8.86E-02				0.00E+00
8	Butyl alcohol	n-butanol	74.12	0.80	40.00	4.71E-03	5.65E+00	0.00E+00	0.00E+00	2.00E-02	2.54E-02
9	2-ethyl hexyl alcohol	2-ethylhexanol	130.23	3.30	0.10	9.85E-06	1.18E-02				0.00E+00
10	Hydroxynaphthalene	Naphthol	144.19	0.50	0.10	0.00E+00	0.00E+00				0.00E+00
	ALDEHYDES										
11	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	1.30E-01	3.00E-02	3.00E-02	3.50E-02	6.35E-03
12	Acrolein	2-propenal	56.06	0.02	0.03	3.46E-06	4.15E-03	6.00E-03	8.00E-03	1.80E-02	1.53E-02
13	Methacrolein	2-methylpropenal	70.09	1.00	1.70	2.01E-06	2.41E-03				0.00E+00
14	Butylaldehyde	Butanal	72.10	1.00	4.00	8.59E-04	1.03E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Valeraldehyde	Pentanal	86.13	1.00	4.00	7.84E-05	9.41E-02				0.00E+00
16	Furaldehyde	Furfural	96.09	0.60	7.90	0.00E+00	0.00E+00				0.00E+00
17	Caproaldehyde	Hexanal	100.16	1.00	4.00	5.34E-05	6.41E-02	1.00E-02	1.50E-02	8.00E-02	8.90E-02
18	Benzaldehyde	Benzenecarbonal	106.12	1.00	4.00	1.99E-05	2.39E-02	2.00E-02	1.50E-02	4.00E-02	2.54E-02
19	Enanthaldehyde	Heptanal	114.19	1.00	4.00	1.77E-05	2.12E-02	3.00E-03	3.00E-03	2.50E-02	2.80E-02
20	Caprylaldehyde	Octanal	128.22	1.00	4.00	4.32E-06	5.18E-03				0.00E+00
21	Pelargonaldehyde	Nonanal	142.24	1.00	4.00	0.00E+00	0.00E+00				0.00E+00
22	Capraldehyde	Decanal	156.27	1.00	4.00	0.00E+00	0.00E+00				0.00E+00
	AROMATIC HYDROCARBONS										
23	Benzene	Benzene	78.11	0.20	0.20	2.51E-05	3.01E-02	4.00E-02	4.00E-02	5.00E-02	1.27E-02
24	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	2.38E+00	1.55E-01	1.55E-01	2.80E-01	1.59E-01
25	Styrene	Ethenylbenzene	104.14	0.25	43.00	3.13E-05	3.76E-02	3.00E-03	2.00E-03	1.00E-02	8.90E-03
26	Ethylbenzene	Ethylbenzene	106.16	2.00	50.00	1.50E-04	1.80E-01	2.00E-02	2.00E-02	7.00E-02	6.35E-02
27	m-/p-xylenes	1,3-/1,4-dimethylbenzenes	106.16	5.00	220.00	2.03E-03	2.43E+00	6.50E-02	6.00E-02	2.40E-01	2.22E-01
28	o-xylene	1,2-dimethylbenzene	106.16	5.00	220.00	5.56E-04	6.67E-01	6.00E-02	5.50E-02	1.50E-01	1.14E-01
		Isopropylbenzene						5.00E-03	4.00E-03	1.00E-02	6.35E-03
29	Propylbenzene	Propylbenzene	120.20	2.00	49.00	2.15E-04	2.58E-01	5.00E-03	5.00E-03	2.00E-02	1.91E-02
	ESTERS										
30	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	3.55E-01				0.00E+00
31	Methyl methacrylate	2-methyl propenoic acid methyl ester	100.12	0.30	100.00	1.30E-04	1.56E-01				0.00E+00
32	Butyl acetate	Ethanoic acid butyl ester	116.16	2.00	190.00	7.46E-04	8.95E-01				0.00E+00
	ETHERS										
33	Tetrahydrofuran	1,4-epoxybutane	72.11	3.00	120.00	6.93E-05	8.32E-02				0.00E+00
34	Glycol methylene ether	1,3-dioxolane	74.08	16.60	0.10	0.00E+00	0.00E+00				0.00E+00
35	Propylcellosolve	Ethylene glycol monopropyl ether	104.15	0.20	0.10	0.00E+00	0.00E+00				0.00E+00
	CHLOROCARBONS										
36	Methylene chloride	Dichloromethane	84.93	16.60	10.00	2.15E-03	2.58E+00				0.00E+00
		Choroform						0.00E+00	3.00E-03	1.50E-02	1.91E-02
37	Chloroform	Trichloromethane	119.38	0.03	5.00	1.76E-05	2.11E-02				0.00E+00
	HYDROCARBONS										
38	Isoprene	2-methyl-1,3-butadiene	68.12	3.00	3.00	0.00E+00	0.00E+00				0.00E+00
39	Amyl hydride	Pentane	72.15	10.00	590.00	9.54E-05	1.14E-01	3.00E-02	3.50E-02	1.00E-01	8.90E-02
40	Methylpentamethylene	Methylcyclopentane	84.16	3.00	52.00	2.97E-05	3.56E-02	1.00E-02	1.50E-02	1.50E-02	6.35E-03
41	Hexamethylene	Cyclohexane	84.16	3.00	210.00	3.79E-04	4.55E-01				0.00E+00
42	Hexane	Hexane	86.18	5.00	180.00	6.95E-05	8.34E-02	4.00E-02	4.00E-02	7.00E-02	3.81E-02
43	Diethylmethylmethane	3-methylpentane	86.18	20.00	1800.00	5.97E-06	7.16E-03	1.00E-02	2.00E-02	2.50E-02	1.91E-02
44	Isohexane	2-methylpentane	86.18	20.00	1800.00	0.00E+00	0.00E+00	2.00E-02	3.00E-02	4.00E-02	2.54E-02
45	Hexahydrotoluene	Methylcyclohexane	98.18	3.00	60.00	6.09E-05	7.31E-02	1.00E-02	1.00E-02	1.50E-02	6.35E-03
46	Dimethylpentamethylene	Dimethylcyclopentane	98.19	3.00	170.00	0.00E+00	0.00E+00				0.00E+00
47	Dipropylmethane	Heptane	100.21	10.00	200.00	5.60E-05	6.72E-02				0.00E+00
48	Dimethylpentane	2,2-dimethylpentane	100.21	20.00	208.00	2.59E-05	3.11E-02				0.00E+00
49	Methylhexane	3-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00				0.00E+00
50	Isoheptane	2-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00				0.00E+00
51	Dimethylpentane	2,4-dimethylpentane	100.21	20.00	208.00	2.67E-07	3.20E-04				0.00E+00
52	Diethylpropane	3,3-dimethylpentane	100.21	20.00	208.00	0.00E+00	0.00E+00				0.00E+00
53	Dimethylpentane	2,3-dimethylpentane	100.21	20.00	208.00	0.00E+00	0.00E+00				0.00E+00
54	Trimethylpentamethylene	Trimethylcyclopentane	112.22	3.00	170.00	0.00E+00	0.00E+00				0.00E+00
55	Octane	Octane	114.23	10.00	350.00	1.61E-05	1.93E-02				0.00E+00
56	Isooctane	2-methylheptane	114.23	20.00	200.00	0.00E+00	0.00E+00	1.50E-02	1.50E-02	2.00E-02	6.35E-03
57	Methylheptane	3-methylheptane	114.23	20.00	200.00	0.00E+00	0.00E+00	1.50E-02	1.70E-02	2.50E-02	1.27E-02
58	Nonyl hydride	Nonane	128.26	10.00	320.00	7.34E-06	8.81E-03	8.00E-02	9.00E-02	3.20E-01	3.05E-01
59	Limonene	4-isopropenyl-1-methylcyclohexene	136.23	3.00	560.00	3.58E-06	4.30E-03				0.00E+00
60	Pinene	a-pinene	136.24	3.00		0.00E+00	0.00E+00				0.00E+00
61	Decyl hydride	Decane	142.28	10.00	230.00	2.78E-05	3.34E-02				0.00E+00
	KETONES										
62	Acetone	2-propanone	58.08	1.00	50.00	3.62E-03	4.35E+00	2.00E-02	1.10E-01	1.00E-01	1.02E-01
63	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	7.21E+00	0.00E+00	0.00E+00	3.00E-03	3.81E-03
64	Acetol	1-hydroxy-2-propanone	74.08	3.30	0.10	0.00E+00	0.00E+00				0.00E+00
65	Methylfuranone	3-methylfuranone	98.10	0.80	0.10	0.00E+00	0.00E+00				0.00E+00
66	Pimelic ketone	Cyclohexanone	98.14	1.30	60.00	6.62E-04	7.95E-01				0.00E+00
67	Phenyl methyl ketone	Acetophenone	120.14	0.20	250.00	5.66E-07	6.79E-04				0.00E+00
	MISCELLANEOUS										
68	Acetic acid	Ethanoic acid	60.05	0.50	7.40	1.42E-06	1.71E-03	0.00E+00	3.60E-01	0.00E+00	0.00E+00
69	Propanolamine	3-aminopropanol	75.11	0.30	0.10	0.00E+00	0.00E+00	0.00E+00	1.10E-01	0.00E+00	0.00E+00
70	Methyl diethylenediamine	Methylpiperazine	100.17	0.30	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Diisopropylamine	Amino-2,3-dimethylbutane	101.19	0.30	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Octylamine	2-aminooctane	129.25	0.30	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Methyl sulfide	Dimethyl sulfide	62.14	4.00	2.50	1.88E-07	2.26E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Carbon bisulfide	Carbon disulfide	76.14	1.00	16.00	3.23E-05	3.88E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Dimethyldisulfide	Dimethyldisulfide	94.20	4.00	0.10	0.00E+00	0.00E+00	0.00E+00	1.30E-01	0.00E+00	0.00E+00
76	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	2.02E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Triethylsilanol	Triethylsilanol	132.28	0.20	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Trimethyl methaneorthosiliconate	Methyltriethoxysilane	178.31	0.20	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
79	Octamethylcyclotetraoxosilane	Octamethylcyclotetrasiloxane	296.62	0.20	12.00	2.70E-04	3.24E-01	0.00E+00	1.10E-01	0.00E+00	0.00E+00
80	Decamethylcyclopentaoxosilane	Decamethylcyclopentasiloxane	370.64	0.20	15.00	4.96E-05	5.95E-02	0.00E+00	9.00E-02	0.00E+00	0.00E+00
	NOTES:				TOTAL	(mg/day)	4.66E+01	VOLUME	(Free	6.10E+01	1.49E+00
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	1.94E+00	(m^3)	Volume)	6.10E+01	
	$^{\#}$ 1.23E-02 represents the scientific notation 1.23 x 10^{-2}				Equipment Mass (kg)		1200				

Service Module

			MOLECULAR	LIMITS IN AIR*		EQUIPMENT	SM	IMBP SM OFFGASSING TEST DATA (mg/m^3)						IMBP
	COMMON NAME	IUPAC NAME	WEIGHT	ZRL	ARL	RATE[#]	CARGO	Event 0	Event 1	Event 2	Event 3	Event 4	Event 5	SM RATE
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	10.0	16.0	24.0	36.0	48.0	mg/day
	ALCOHOLS													
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00							0.00E+00
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	9.20E-01	1.10E+00	1.00E+00	2.60E+00	2.10E+00	2.70E+00	7.75E+01
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	3.00E-02	2.00E-02	4.00E-02	3.00E-02	5.00E-02	2.00E-02	9.24E-02
4	Propyl alcohol	1-propanol	60.09	0.60	98.00	2.41E-04	0.00E+00							0.00E+00
5	Cyclobutanol	Cyclobutanol	72.11	6.60	0.10	0.00E+00	0.00E+00							0.00E+00
6	Isobutyl alcohol	2-methyl-1-propanol	74.12	0.10	120.00	8.47E-04	0.00E+00							0.00E+00
7	tert-butyl alcohol	2-methyl-2-propanol	74.12	3.30	120.00	7.38E-05	0.00E+00							0.00E+00
8	Butyl alcohol	n-butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	0.00E+00	1.00E-03	1.10E-01	2.10E-01	2.40E-01	9.00E-02	7.68E+00
9	2-ethyl hexyl alcohol	2-ethylhexanol	130.23	3.30	0.10	9.85E-06	0.00E+00							0.00E+00
10	Hydroxynaphthalene	Naphthol	144.19	0.50	0.10	0.00E+00	0.00E+00							0.00E+00
	ALDEHYDES													
11	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	9.40E-01	1.00E-03	1.00E-03	1.18E+00	1.20E+00	9.80E-01	1.36E+01
12	Acrolein	2-propenal	56.06	0.02	0.03	3.46E-06	0.00E+00							0.00E+00
13	Methacrolein	2-methylpropenal	70.09	1.00	1.70	2.01E-06	0.00E+00							0.00E+00
14	Butylaldehyde	Butanal	72.10	1.00	4.00	8.59E-04	0.00E+00							0.00E+00
15	Valeraldehyde	Pentanal	86.13	1.00	4.00	7.84E-05	0.00E+00							0.00E+00
16	Furaldehyde	Furfural	96.09	0.60	7.90	0.00E+00	0.00E+00							0.00E+00
17	Caproaldehyde	Hexanal	100.16	1.00	4.00	5.34E-05	0.00E+00							0.00E+00
18	Benzaldehyde	Benzenecarbonal	106.12	1.00	4.00	1.99E-05	0.00E+00							0.00E+00
19	Enanthaldehyde	Heptanal	114.19	1.00	4.00	1.77E-05	0.00E+00							0.00E+00
20	Caprylaldehyde	Octanal	128.22	1.00	4.00	4.32E-06	0.00E+00							0.00E+00
21	Pelargonaldehyde	Nonanal	142.24	1.00	4.00	0.00E+00	0.00E+00							0.00E+00
22	Capraldehyde	Decanal	156.27	1.00	4.00	0.00E+00	0.00E+00							0.00E+00
	AROMATIC HYDROCARBONS													
23	Benzene	Benzene	78.11	0.20	0.20	2.51E-05	0.00E+00	3.00E-03	1.30E-02	3.00E-03	2.00E-03	6.00E-03	7.00E-03	0.00E+00
24	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	1.19E-01	1.74E-01	1.02E-01	1.03E-01	1.92E-01	2.29E-01	1.52E+00
25	Styrene	Ethenylbenzene	104.14	0.25	43.00	3.13E-05	0.00E+00	1.00E-02	6.00E-03	1.00E-02	4.00E-03	1.00E-02	1.30E-02	9.86E-02
26	Ethylbenzene	Ethylbenzene	106.16	2.00	50.00	1.50E-04	0.00E+00	4.20E-02	3.00E-03	2.99E-02	4.00E-03	4.60E-02	1.30E-02	0.00E+00
27	m-/p-xylenes	1,3-/1,4-dimethylbenzenes	106.16	5.00	220.00	2.03E-03	0.00E+00	4.50E-01	4.63E-01	1.85E-01	1.90E-01	2.10E-01	3.50E-01	0.00E+00
28	o-xylene	1,2-dimethylbenzene	106.16	5.00	220.00	5.56E-04	0.00E+00	1.68E-01	2.90E-01	1.35E-01	5.40E-02	1.78E-01	1.90E-01	0.00E+00
29	Propylbenzene	Propylbenzene	120.20	2.00	49.00	2.15E-04	0.00E+00							0.00E+00
	ESTERS													
30	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	0.00E+00	5.80E-01	4.90E-01	9.80E-01	9.80E-01	1.92E+00	3.48E+00	1.04E+02
31	Methyl methacrylate	2-methyl propenoic acid methyl este	100.12	0.30	100.00	1.30E-04	0.00E+00							0.00E+00
32	Butyl acetate	Ethanoic acid butyl ester	116.16	2.00	190.00	7.46E-04	0.00E+00	2.30E-02	1.40E-02	1.40E-02	5.00E-03	1.00E-03	7.20E-02	1.32E+00
	ETHERS													
33	Tetrahydrofuran	1,4-epoxybutane	72.11	3.00	120.00	6.93E-05	0.00E+00							0.00E+00
34	Glycol methylene ether	1,3-dioxolane	74.08	16.60	0.10	0.00E+00	0.00E+00							0.00E+00
35	Propylcellosolve	Ethylene glycol monopropyl ether	104.15	0.20	0.10	0.00E+00	0.00E+00							0.00E+00
	CHLOROCARBONS													
36	Methylene chloride	Dichloromethane	84.93	16.60	10.00	2.15E-03	0.00E+00	3.00E-03	5.00E-03	3.00E-03	4.00E-03	5.00E-03	7.00E-03	8.93E-02
		Chloroethane						3.00E-03	0.00E+00	2.00E-03	2.00E-03	3.00E-03	5.00E-03	1.05E-01
		Trichlorofluoromethane						2.04E-01	4.60E-01	1.49E-01	3.42E-01	3.76E-01	1.17E-01	0.00E+00
		Trichlorotrifluoroethane						1.00E-03	3.00E-03	5.00E-04	2.00E-03	2.00E-03	1.00E-03	0.00E+00
		cis-1,2-dichloroethylene						2.00E-03	1.14E-01	1.00E-03	2.00E-03	3.00E-03	2.00E-03	0.00E+00
		Chloroform						3.00E-03	5.00E-03	4.00E-03	2.00E-03	7.00E-03	6.00E-03	4.31E-02
		1,2-dichloroethane						5.00E-03	4.00E-03	5.00E-03	4.00E-03	7.00E-03	9.00E-03	1.32E-01
		Carbon tetrachloride						1.20E-02	7.00E-03	3.00E-03	2.00E-03	5.00E-03	5.00E-03	0.00E+00
		Chlorobenzene						2.00E-03	2.00E-03	1.00E-03	2.00E-03	2.00E-03	3.00E-03	1.54E-02
		Ethylbenzene						4.20E-02	3.00E-03	2.99E-02	4.00E-03	4.60E-02	1.30E-02	0.00E+00
		1,3,5-trimethylbenzene						3.80E-02	3.30E-02	2.60E-02	3.45E-02	3.90E-02	4.10E-02	0.00E+00
		1,2,4-trimethylbenzene						7.00E-03	3.50E-02	6.00E-03	6.00E-03	9.00E-03	9.00E-03	0.00E+00
37	Chloroform	Trichloromethane	119.38	0.03	5.00	1.76E-05	0.00E+00							0.00E+00
	HYDROCARBONS													
38	Isoprene	2-methyl-1,3-butadiene	68.12	3.00	3.00	0.00E+00	0.00E+00							0.00E+00
39	Amyl hydride	Pentane	72.15	10.00	590.00	9.54E-05	0.00E+00	2.20E-02	0.00E+00	0.00E+00	3.00E-03	8.00E-03	9.00E-03	0.00E+00
40	Methylpentamethylene	Methylcyclopentane	84.16	3.00	52.00	2.97E-05	0.00E+00							0.00E+00
41	Hexamethylene	Cyclohexane	84.16	3.00	210.00	3.79E-04	0.00E+00							0.00E+00
42	Hexane	Hexane	86.18	5.00	180.00	6.95E-05	0.00E+00	7.00E-02	4.00E-02	2.00E-02	7.00E-02	6.00E-02	2.50E-02	0.00E+00
43	Diethylmethylmethane	3-methylpentane	86.18	20.00	1800.00	5.97E-06	0.00E+00							0.00E+00
44	Isohexane	2-methylpentane	86.18	20.00	1800.00	0.00E+00	0.00E+00							0.00E+00
45	Hexahydrotoluene	Methylcyclohexane	98.18	3.00	60.00	6.09E-05	0.00E+00							0.00E+00
46	Dimethylpentamethylene	Dimethylcyclopentane	98.19	3.00	170.00	0.00E+00	0.00E+00							0.00E+00
47	Dipropylmethane	Heptane	100.21	10.00	200.00	5.60E-05	0.00E+00	1.30E-01	9.00E-02	1.90E-02	2.80E-02	2.80E-02	2.30E-01	7.85E-01
48	Dimethylpentane	2,2-dimethylpentane	100.21	20.00	208.00	2.59E-05	0.00E+00							0.00E+00
49	Methylhexane	3-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00							0.00E+00
50	Isoheptane	2-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00							0.00E+00
51	Dimethylpentane	2,4-dimethylpentane	100.21	20.00	208.00	2.67E-07	0.00E+00							0.00E+00
52	Diethylpropane	3,3-dimethylpentane	100.21	20.00	208.00	0.00E+00	0.00E+00							0.00E+00
53	Dimethylpentane	2,3-dimethylpentane	100.21	20.00	208.00	0.00E+00	0.00E+00							0.00E+00
54	Trimethylpentamethylene	Trimethylcyclopentane	112.22	3.00	170.00	0.00E+00	0.00E+00							0.00E+00
55	Octane	Octane	114.23	10.00	350.00	1.61E-05	0.00E+00	6.00E-03	6.00E-03	3.00E-03	4.00E-03	6.00E-03	8.00E-03	0.00E+00
56	Isooctane	2-methylheptane	114.23	20.00	200.00	0.00E+00	0.00E+00							0.00E+00
57	Methylheptane	3-methylheptane	114.23	20.00	200.00	0.00E+00	0.00E+00							0.00E+00
58	Nonyl hydride	Nonane	128.26	10.00	320.00	7.34E-06	0.00E+00	0.00E+00	1.50E-02	8.00E-03	9.00E-03	1.60E-02	1.90E-02	4.77E-01
59	Limonene	4-isopropenyl-1-methylcyclohexene	136.23	3.00	560.00	3.58E-06	0.00E+00							0.00E+00
60	Pinene	a-pinene	136.24	3.00		0.00E+00	0.00E+00							0.00E+00
61	Decyl hydride	Decane	142.28	10.00	230.00	2.78E-05	0.00E+00	1.00E-03	1.50E-02	0.00E+00	0.00E+00	3.00E-03	0.00E+00	0.00E+00
	KETONES													
62	Acetone	2-propanone	58.08	1.00	50.00	3.62E-03	0.00E+00	5.10E-01	5.00E-01	3.00E-01	4.00E-01	6.00E-01	8.00E-01	4.25E+00
63	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	0.00E+00	1.00E-02	3.00E-02	4.00E-01	3.80E-01	4.80E-01	2.12E+01
64	Acetol	1-hydroxy-2-propanone	74.08	3.30	0.10	0.00E+00	0.00E+00							0.00E+00
65	Methylfuranone	3-methylfuranone	98.10	0.80	0.10	0.00E+00	0.00E+00							0.00E+00
66	Pimelic ketone	Cyclohexanone	98.14	1.30	60.00	6.62E-04	0.00E+00							0.00E+00
67	Phenyl methyl ketone	Acetophenone	120.14	0.20	250.00	5.66E-07	0.00E+00							0.00E+00
	MISCELLANEOUS													
68	Acetic acid	Ethanoic acid	60.05	0.50	7.40	1.42E-06	0.00E+00							0.00E+00
69	Propanolamine	3-aminopropanol	75.11	0.30	0.10	0.00E+00	0.00E+00							0.00E+00
70	Methyl diethylenediamine	Methylpiperazine	100.17	0.30	0.10	0.00E+00	0.00E+00							0.00E+00
71	Diisopropylamine	Amino-2,3-dimethylbutane	101.19	0.30	0.10	0.00E+00	0.00E+00							0.00E+00
72	Octylamine	2-aminooctane	129.25	0.30	0.10	0.00E+00	0.00E+00							0.00E+00
73	Methyl sulfide	Dimethyl sulfide	62.14	4.00	2.50	1.88E-07	0.00E+00							0.00E+00
74	Carbon bisulfide	Carbon disulfide	76.14	1.00	16.00	3.23E-05	0.00E+00							0.00E+00
75	Dimethyldisulfide	Dimethyldisulfide	94.20	4.00	0.10	0.00E+00	0.00E+00							0.00E+00
76	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00							0.00E+00
77	Triethylsilanol	Triethylsilanol	132.28	0.20	0.10	0.00E+00	0.00E+00							0.00E+00
78	Trimethyl methaneorthosiliconate	Methyltriethoxysilane	178.31	0.20	0.10	0.00E+00	0.00E+00							0.00E+00
79	Octamethylcyclotetraoxosilane	Octamethylcyclotetrasiloxane	296.62	0.20	12.00	2.70E-04	0.00E+00							0.00E+00
80	Decamethylcyclopentaoxosilane	Decamethylcyclopentasiloxane	370.64	0.20	15.00	4.96E-05	0.00E+00							0.00E+00
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME				SM PO	7.70E+01	2.33E+02
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)				Volume (m^3)	7.70E+01	
	[#] 1.23E-02 represents the scientific notation 1.23 x 10^{-2}				Equipment Mass (kg)		0							

MPLM 1

	COMMON NAME	IUPAC NAME	OLECULAR WEIGHT g/mole	LIMITS IN AIR*		EQUIPMENT RATE# mg/day/kg	MPLM FM-1 CARGO mg/day	ASA MPLM FM-1 OFFGASSING TEST DATA (mg/m^3			MPLM FM-1 ERMINAL RATE mg/day	MPLM FM-1 RATE mg/h
				ZRL mg/m^3	ARL mg/m^3			Sample Zero 0.0	Sample 1 89.7	Sample 2 209.8		
	ALCOHOLS											
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00	2.50E-02	1.10E-01	1.10E-01	0.00E+00	2.71E-02
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	1.90E-01	1.00E+00	1.80E+00	3.81E-01	4.48E-01
		Propanol						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	t-butyl alcohol	2-methyl-2-propanol	74.12	0.10	100.00	7.38E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ALDEHYDES											
6	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	3.75E-02	8.50E-02	9.50E-02	4.76E-03	1.75E-02
7	Propionaldehyde	Propanal	58.08	N/A	95.00	3.19E-04	0.00E+00	2.50E-02	5.50E-02	8.00E-02	1.19E-02	1.55E-02
8	n-butylaldehyde	Butanal	72.10	N/A	118.00	8.59E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Valeraldehyde	Pentanal	86.13	N/A	21.00	7.84E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Caproaldehyde	Hexanal	100.16	N/A	24.00	5.34E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		2-methyl-2-propenal						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Enanthaldehyde	Heptanal	114.19	N/A	28.00	1.77E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	AROMATIC HYDROCARBONS											
12	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	2.50E-02	5.00E-02	1.05E-01	2.62E-02	2.11E-02
13	m-/p-xylene	1,3-/1,4-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		1,2-dimethylbenzene						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Ethylbenzene	Ethylbenzene	106.16	N/A	130.00	1.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ESTERS											
15	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Ethyl acetate	Ethanoic acid butyl ester					0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	HALOCARBONS											
16	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Trichloroethene						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Trichlorofluoromethane						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Fluorinated hydrocarbon						6.40E-01	1.90E+00	2.10E+00	9.52E-02	4.49E-01
16	Methylene chloride	Trichlorotrifluoromethane					0.00E+00	2.50E-02	1.80E-01	5.05E-01	1.55E-01	1.27E-01
	ALIPHATIC HYDROCARBONS											
17	n-pentane	Pentane	72.15	10.00	625.00	9.54E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	KETONES											
18	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	9.90E-01	1.25E+00	1.40E+00	7.14E-02	1.19E-01
19	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	8.50E-02	3.90E-01	6.40E-01	1.19E-01	1.57E-01
		Cyclohexanone						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Methyl isobutyl ketone	4-methyl-2-pentanone	100.16	N/A	140.00	7.60E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	MISCELLANEOUS											
		Carbon disulfide						0.00E+00	0.00E+00	2.50E-02	1.19E-02	5.95E-03
21	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	2.00E-02	1.65E-01	1.70E-01	2.38E-03	4.74E-02
		Hexamethylcyclotrisilixane						1.55E-01	4.95E-01	7.03E-01	9.90E-02	1.58E-01
21		Octamethylcycltrisiloxane					0.00E+00	6.00E-02	7.00E-02	1.10E-01	1.90E-02	1.27E-02
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	(Free	4.50E+01		1.60
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)	Volume)	4.50E+01		
	# 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0					

MPLM 2

	COMMON NAME	IUPAC NAME	MOLECULAR WEIGHT	LIMITS IN AIR*		EQUIPMENT RATE$^{\#}$	MPLM FM-2 CARGO	ASA MPLM FM-2 OFFGASSING TEST DATA (mg/m^3			MPLM FM-2 TERMINAL RATE	MPLM FM-2 RATE
				ZRL	ARL			Sample Zero	Sample 1	Sample 2		
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	113.1	233.0	mg/day	mg/h
	ALCOHOLS											
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00	2.50E-02	2.35E-01	3.25E-01	4.79E-02	8.32E-02
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	1.70E-01	6.95E-01	9.90E-01	1.57E-01	2.27E-01
		Propanol						0.00E+00	2.50E-02	8.50E-02	3.19E-02	2.30E-02
4	t-butyl alcohol	2-methyl-2-propanol	74.12	0.10	100.00	7.38E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	1.25E-02	6.00E-02	1.00E-01	2.13E-02	2.40E-02
	ALDEHYDES											
6	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	5.75E-02	1.30E-01	1.70E-01	2.13E-02	3.11E-02
7	Propionaldehyde	Propanal	58.08	N/A	95.00	3.19E-04	0.00E+00	0.00E+00	6.50E-02	1.10E-01	2.40E-02	3.03E-02
8	n-butylaldehyde	Butanal	72.10	N/A	118.00	8.59E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Valeraldehyde	Pentanal	86.13	N/A	21.00	7.84E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Caproaldehyde	Hexanal	100.16	N/A	24.00	5.34E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		2-methyl-2-propenal						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Enanthaldehyde	Heptanal	114.19	N/A	28.00	1.77E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	AROMATIC HYDROCARBONS											
12	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	2.50E-02	2.60E-01	3.05E-01	2.40E-02	7.83E-02
13	m-/p-xylene	1,3-/1,4-dimethylbenzene	106.16	5.00	220.00	2.03E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		1,2-dimethylbenzene						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Ethylbenzene	Ethylbenzene	106.16	N/A	130.00	1.50E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	ESTERS											
15	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Ethyl acetate	Ethanoic acid butyl ester					0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	HALOCARBONS											
16	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Trichloroethene						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Trichlorofluoromethane						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
		Fluorinated hydrocarbon						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Methylene chloride	Trichlorotrifluoromethane					0.00E+00	2.50E-02	1.75E-01	1.65E-01	-5.32E-03	3.97E-02
	ALIPHATIC HYDROCARBONS											
17	n-pentane	Pentane	72.15	10.00	625.00	9.54E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	KETONES											
18	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	5.25E-02	1.30E-01	1.80E-01	2.66E-02	3.52E-02
19	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	2.50E-02	3.90E-01	7.25E-01	1.78E-01	1.92E-01
		Cyclohexanone						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Methyl isobutyl ketone	4-methyl-2-pentanone	100.16	N/A	140.00	7.60E-02	0.00E+00	0.00E+00	2.50E-02	6.00E-02	1.86E-02	1.64E-02
	MISCELLANEOUS											
		Carbon disulfide						0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	0.00E+00	1.00E-01	3.10E-01	1.12E-01	8.41E-02
		Hexamethylcyclotrisilixane						5.50E-02	1.04E+00	1.35E+00	1.65E-01	3.60E-01
21		Octamethylcycltrisiloxane					0.00E+00	7.50E-02	6.10E-01	9.20E-01	1.65E-01	2.33E-01
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	(Free	4.50E+01		1.46
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)	Volume)	4.50E+01		
	$^{\#}$ 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0					

HTV-1

	COMMON NAME	IUPAC NAME	MOLECULAR WEIGHT	LIMITS IN AIR*		EQUIPMENT RATE$^{\#}$	HTV 1 CARGO	JAXA TEST DATA (mg/m^3)		HTV 1 TERMINAL RATE	HTV 1 RATE
				ZRL	ARL			Sample Zero	Sample 2		
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	366.4	mg/day	mg/day
	ALCOHOLS										
1	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	0.00E+00	3.40E+00	6.43E+00	6.43E+00
2	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	0.00E+00	6.48E-02	1.23E-01	1.23E-01
	ALDEHYDES										
3	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	0.00E+00	8.90E-02	0.00E+00	-1.68E-01	-1.68E-01
	AROMATIC HYDROCARBONS										
4	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	0.00E+00	8.42E-02	1.59E-01	1.59E-01
	HALOCARBONS										
5	Ethylidene fluoride	1,1-difluoroethane	66.05	5.00	10.00	0.00E+00	0.00E+00	1.00E-01	9.65E-02	-6.62E-03	-6.62E-03
	ALIPHATIC HYDROCARBONS										
6	Methane	Methane	16.04	3342.00	3800.00	6.39E-04	0.00E+00	1.22E+00	1.88E+00	1.26E+00	1.26E+00
7	Butylene	C4 alkene as butene	56.10	15.00	230.00	8.03E-05	0.00E+00	0.00E+00	3.87E-02	7.32E-02	7.32E-02
8	Isobutane	2-methylpropane	58.12	N/A	240.00	1.10E-05	0.00E+00	0.00E+00	1.73E+00	3.28E+00	3.28E+00
9	Hexamethylene	Cyclohexane	84.16	3.00	210.00	3.79E-04	0.00E+00	0.00E+00	3.19E-02	6.04E-02	6.04E-02
10	Hexahydrotoluene	Methylcyclohexane	98.18	N/A	60.00	6.09E-05	0.00E+00	0.00E+00	3.87E-02	7.32E-02	7.32E-02
11	Heptane	n-heptane	100.21	10.00	200.00	5.60E-05	0.00E+00	0.00E+00	3.70E-02	7.00E-02	7.00E-02
12	Trimethylpentane	2,2,4-trimethylpentane	114.23	N/A	0.50	3.40E-07	0.00E+00	0.00E+00	6.16E-02	1.17E-01	1.17E-01
13	Hendecane	C11 alkane as n-undecane	156.13	N/A	320.00	2.51E-05	0.00E+00	0.00E+00	2.24E-01	4.24E-01	4.24E-01
	KETONES										
14	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	7.22E-02	6.34E-01	1.06E+00	1.06E+00
15	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	0.00E+00	0.00E+00	1.36E-01	2.57E-01	2.57E-01
16	Pimelic ketone	Cyclohexanone	98.14	1.30	60.00	6.62E-04	0.00E+00	0.00E+00	6.30E-01	1.19E+00	1.19E+00
17	Acetophenone (acetylbenzene)	Phenyl methyl ketone	120.14	0.80	250.00	3.45E-07	0.00E+00	0.00E+00	3.73E-02	7.06E-02	7.06E-02
	MISCELLANEOUS										
18	Carbon monoxide	Carbon monoxide	28.01	5.00	11.00	2.03E-03	0.00E+00	3.12E-01	6.58E+01	1.24E+02	1.24E+02
19	Methyl carbonate	Dimethyl carbonate	90.08	N/A	0.50	0.00E+00	0.00E+00	0.00E+00	8.20E-01	1.55E+00	1.55E+00
20	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	0.00E+00	3.21E+00	6.07E+00	6.07E+00
21	Trimethylfluorosilane	Fluorotrimethylsilane	92.19	N/A	0.50	0.00E+00	0.00E+00	0.00E+00	1.15E-01	2.18E-01	2.18E-01
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	2.84E+01		146.51
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)	2.84E+01		
	$^{\#}$ 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0				

HTV-2

	COMMON NAME	IUPAC NAME	OLECULAR WEIGHT	LIMITS IN AIR*		EQUIPMENT RATE$^{\#}$	HTV 1 CARGO	JAXA TEST DATA (mg/m^3)		HTV 2 ERMINAL RATE	HTV 2 RATE
				ZRL	ARL			Sample Zero	Sample 2		
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	450.0	mg/day	mg/day
	ALCOHOLS										
		Methanol	32.04	0.20	9.00	1.27E-03	0.00E+00	4.40E-01	3.68E-01	-1.07E-01	-1.07E-01
		Ethanol	46.07	10.00	2000.00	7.85E-03	0.00E+00	1.77E-01	3.19E-01	2.10E-01	2.10E-01
1	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	0.00E+00	0.00E+00	2.15E+00	3.19E+00	3.19E+00
2	n-butyl alcohol	Butanol	74.12	0.80	40.00	4.71E-03	0.00E+00	0.00E+00	9.50E-02	1.41E-01	1.41E-01
	AROMATIC HYDROCARBONS										
4	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	0.00E+00	0.00E+00	8.30E-02	1.23E-01	1.23E-01
	HALOCARBONS										
5	HFC-134a	1,1,1,2-tetrafluoroethane	102.30	N/A	N/A	0.00E+00	0.00E+00	1.18E+01	7.37E+00	-6.52E+00	-6.52E+00
	ALIPHATIC HYDROCARBONS										
6	Methane	Methane	16.04	3342.00	3800.00	6.39E-04	0.00E+00	1.23E+00	1.24E+00	5.63E-03	5.63E-03
7	Butylene	C4 alkene as butene	56.10	15.00	230.00	8.03E-05	0.00E+00	0.00E+00	9.88E-02	1.46E-01	1.46E-01
8	Isobutane	2-methylpropane	58.12	N/A	240.00	1.10E-05	0.00E+00	0.00E+00	2.83E-01	4.20E-01	4.20E-01
11	Heptane	n-heptane	100.21	10.00	200.00	5.60E-05	0.00E+00	0.00E+00	3.50E-02	5.18E-02	5.18E-02
	Methylhexane	3-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00	0.00E+00	8.73E-02	1.29E-01	1.29E-01
13	Dimethylpentane	2,3-dimethylpentane	100.21	20.00	208.00	0.00E+00	0.00E+00	0.00E+00	3.98E-02	5.89E-02	5.89E-02
	KETONES										
14	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	0.00E+00	0.00E+00	1.78E-01	2.64E-01	2.64E-01
	MISCELLANEOUS										
18	Carbon monoxide	Carbon monoxide	28.01	5.00	11.00	2.03E-03	0.00E+00	2.80E-01	9.88E-01	1.05E+00	1.05E+00
20	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	0.00E+00	0.00E+00	1.84E+00	2.73E+00	2.73E+00
21	Trimethylfluorosilane	Fluorotrimethylsilane	92.19	N/A	0.50	0.00E+00	0.00E+00	0.00E+00	3.98E-02	5.89E-02	5.89E-02
	NOTES:				TOTAL	(mg/day)	0.00E+00	VOLUME	2.59E+01		8.57
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	0.00E+00	(m^3)	2.59E+01		0.357
	$^{\#}$ 1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		0				

ATV-1: ESA Data

			MOLECULAR	LIMITS IN AIR*		EQUIPMENT	ATV	ESA ATV OFFGASSING TEST DATA (mg/m^3)							ESA
	COMMON NAME	IUPAC NAME	WEIGHT	ZRL	ARL	RATE^{2}	CARGO	S5C16	S5C17	S5C18	S5C19	S5C20	S5C21	S5C23	ATV RATE
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	86.0	103.5	111.5	133.0	205.0	205.7	470.0	mg/day
	ALCOHOLS														
1	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	9.42E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-02	1.03E-01	8.61E-02	1.01E+00	1.07E+00
2	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	4.78E+00	0.00E+00	0.00E+00	0.00E+00	4.14E-01	1.18E+00	1.55E+00	7.40E+00	9.90E+00
3	tert-butyl alcohol	2-methyl-2-propanol	74.12	3.30	100.00	7.38E-05	8.86E-02	0.00E+00	3.47E-02	0.00E+00	0.00E+00	3.89E-02	2.76E-02	0.00E+00	7.51E-01
4	Butyl alcohol	n-butanol	74.12	0.80	40.00	4.71E-03	5.65E+00	0.00E+00	6.41E-02	6.96E-02	1.05E-01	1.44E-01	4.61E-02	0.00E+00	1.46E+00
5	Carbolic acid	Phenol	94.11	0.10	7.70	4.83E-04	5.80E-01	3.14E-02	0.00E+00	2.68E-02	0.00E+00	1.57E-01	1.16E-01	1.55E-01	1.32E+00
	ALDEHYDES														
6	Benzaldehyde	Benzenecarbonal	106.12	1.00	4.00	1.09E-04	1.30E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-02	1.62E-02	2.06E-02	4.26E-02
	AROMATIC HYDROCARBONS														
7	Benzene	Benzene	78.11	0.20	0.20	2.51E-05	3.01E-02	8.50E-03	4.79E-03	0.00E+00	9.10E-03	1.77E-02	1.11E-02	2.05E-02	7.68E-02
8	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	2.38E+00	8.15E-02	1.13E-01	1.36E-01	8.09E-02	1.89E-01	1.52E-01	2.45E-01	5.40E-01
9	o-xylene	1,2-dimethylbenzene	106.16	5.00	220.00	5.56E-04	6.67E-01	7.72E-02	0.00E+00	1.88E-01	0.00E+00	0.00E+00	0.00E+00	6.67E-01	2.39E+00
10	m-xylene	1,3-dimethylbenzene	106.16	5.00	220.00	2.03E-03	2.43E+00	2.14E-02	0.00E+00	2.18E-02	0.00E+00	2.00E-02	3.14E-02	4.00E-02	1.56E-01
	ESTERS														
11	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	3.55E-01	4.87E-02	1.23E-01	1.02E-01	8.57E-02	1.59E-01	1.78E-01	5.40E-01	6.22E-01
12	Butyl acetate	Ethanoic acid butyl ester	116.16	2.00	190.00	7.46E-04	8.95E-01	4.39E-02	0.00E+00	0.00E+00	4.47E-02	9.05E-02	0.00E+00	4.90E-02	1.38E-01
13	Cellosolve acetate	Ethanoic acid 2-ethoxyethyl ester	132.16	N/A	160.00	7.46E-04	8.95E-01	0.00E+00	0.00E+00	1.38E-01	0.00E+00	0.00E+00	0.00E+00	4.88E-01	2.35E+00
14	Ethyl butanoate	Butanoic acid ethyl ester	116.16	N/A	80.00	0.00E+00	0.00E+00	9.29E-02	6.63E-02	6.54E-02	4.15E-02	8.63E-02	8.98E-02	1.70E-01	3.48E-01
	CHLOROCARBONS														
15	Trichloroethylene	Trichloroethene	131.39	1.50	10.00	8.62E-05	1.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.74E-02	2.62E-02
16	Tetrachloroethylene	Tetrachloroethene	165.83	N/A	34.00	7.28E-04	8.74E-01	1.20E-01	1.07E-01	1.23E-01	1.23E-01	9.90E-02	1.02E-01	3.10E-01	3.19E-01
	HYDROCARBONS														
17	Hexylene	1-hexene	84.16	N/A	180.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.94E+00	1.36E+00
18	Dipropylmethane	Heptane	100.21	10.00	12.00	5.60E-05	6.72E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.52E-02	2.47E-02
19	Triethylmethane	3-ethylpentane	100.21	N/A	1800.00	2.88E-07	3.46E-04	1.67E-02	2.16E-02	2.64E-02	0.00E+00	3.44E-02	3.26E-02	4.79E-02	3.36E-02
20	Isoheptane	2-methylhexane	100.21	20.00	180.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.15E-02	0.00E+00	0.00E+00	0.00E+00	2.44E-02	1.85E-01
21	Isooctane	2,2,4-trimethylpentane	114.23	N/A	180.00	0.00E+00	0.00E+00	7.22E-02	7.12E-02	0.00E+00	3.60E-02	7.00E-02	8.75E-02	1.81E-01	7.14E-01
22	Trimethylpentane	2,3,3-trimethylpentane	114.23	N/A	180.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-02	3.81E-02	0.00E+00	4.89E-02	1.86E-01
23	Dimethylhexane	2,4-dimethylhexane	114.23	N/A	180.00	0.00E+00	0.00E+00	3.20E-03	0.00E+00	0.00E+00	0.00E+00	2.62E-02	2.03E-02	2.98E-02	3.61E-02
24	Dimethylhexane	2,5-dimethylhexane	114.23	N/A	180.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.45E-02	1.72E-02
	KETONES														
25	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	4.35E+00	0.00E+00	0.00E+00	0.00E+00	2.89E-01	6.83E-01	5.98E-01	1.92E+00	4.38E+00
26	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	7.21E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E-01	1.08E-01	2.99E-01	4.22E-01
27	Cyclohexanone (pimelic ketone)	Cyclohexanone	98.14	1.30	60.00	6.62E-04	7.95E-01	1.61E-01	1.92E+00	1.36E+00	2.47E+00	1.77E+00	1.64E+00	7.01E-01	1.27E+01
28	Methyl isobutyl ketone	4-methyl-2-pentanone	100.16	N/A	140.00	1.41E-03	1.69E+00	1.67E-02	0.00E+00	2.78E-02	4.04E-02	5.18E-02	4.47E-02	4.23E-02	5.99E-01
29	Ethyl isobutyl ketone	5-methyl-3-hexanone	114.18	N/A	60.00	2.15E-06	2.58E-03	0.00E+00	0.00E+00	4.08E-02	0.00E+00	1.17E-01	1.05E-01	9.27E-02	8.79E-01
	MISCELLANEOUS														
30	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	2.02E-01	0.00E+00	3.32E-01	2.51E-01	2.20E-01	5.72E-01	4.22E-01	7.60E-01	2.41E+00
31	Hexamethyldioxosilane	Hexamethyldisiloxane	162.48	0.20	9.00	8.52E-06	1.02E-02	6.28E-02	0.00E+00	0.00E+00	8.18E-02	1.37E-01	1.63E-01	2.76E-01	2.80E-01
32	Hexamethylcyclotrioxosilane	Hexamethylcyclotrisiloxane	222.40	0.20	9.00	2.11E-04	2.53E-01	5.34E-01	6.89E-01	6.52E-01	6.18E-01	1.07E+00	7.02E-01	1.48E+00	1.94E+00
33	Octamethylcyclotetraoxosilane	Octamethylcyclotetrasiloxane	296.62	0.20	12.00	2.70E-04	3.24E-01	3.29E-01	2.80E-01	3.15E-01	3.43E-01	4.82E-01	4.39E-01	9.24E-01	1.20E+00
34	Decamethylcyclopentaoxosilane	Decamethylcyclopentasiloxane	370.64	0.20	15.00	4.96E-05	5.95E-02	1.99E-01	0.00E+00	9.13E-02	1.70E-01	2.37E-01	2.82E-01	4.00E-01	9.74E-01
	NOTES:				TOTAL	(mg/day)	4.42E+01	VOLUME	Empty ATV	4.64E+01					4.99E+01
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	1.84E+00	(m^3)	ATV with Cargo	3.90E+01					

ATV-1: IMBP Data

			MOLECULAR	LIMITS IN AIR*		EQUIPMENT	ATV	IMBP ATV OFFGASSING TEST DATA (mg/m^3)												IMBP
	COMMON NAME	IUPAC NAME	WEIGHT	ZRL	ARL	RATE*	CARGO	Event 0	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Event 8	Event 9	Event 10	Event 11	ATV RATE
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	2.0	6.0	17.5	23.0	40.0	43.5	55.5	67.5	79.5	133.0	205.0	mg/day
	ALCOHOLS																			
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	1.52E+00	1.00E-01	1.00E-01	0.00E+00	5.00E-02	5.00E-02	1.00E-01	9.00E-02	5.00E-02	1.00E-01	1.10E-01	1.00E-01	1.20E-01	3.78E-02
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	9.42E+00	2.50E-01	4.00E-01	1.10E+00	1.00E+00	8.30E-01	2.70E+00	3.30E-01	1.90E+00	2.40E+00	3.10E+00	2.70E+00	3.10E+00	1.99E+01
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	4.78E+00	4.00E-01	7.00E-01	1.00E+00	1.00E+00	1.20E+00	1.10E+00	3.10E+00	1.80E+00	1.90E+00	1.90E+00	2.80E+00	2.60E+00	8.30E+00
4	Propyl alcohol	1-propanol	60.09	0.60	98.00	2.41E-04	2.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Cyclobutanol	Cyclobutanol	72.11	6.60	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-02	0.00E+00	0.00E+00	2.30E-01	0.00E+00	0.00E+00	0.00E+00
6	Isobutyl alcohol	2-methyl-1-propanol	74.12	0.10	120.00	8.47E-04	1.02E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	0.00E+00	2.00E-02	0.00E+00	1.00E-02	0.00E+00	5.00E-02	0.00E+00	0.00E+00
7	tert-butyl alcohol	2-methyl-2-propanol	74.12	3.30	120.00	7.38E-05	8.86E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Butyl alcohol	n-butanol	74.12	0.80	40.00	4.71E-03	5.65E+00	5.00E-02	3.50E-01	5.00E-02	9.00E-02	8.00E-02	1.20E-01	8.00E-02	1.10E-01	9.00E-02	1.20E-01	1.40E-01	1.80E-01	6.59E-01
9	2-ethyl hexyl alcohol	2-ethylhexanol	130.23	3.30	0.10	9.85E-06	1.18E-02	8.00E-02	1.00E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-02	4.30E-01	0.00E+00	5.00E-02	6.00E-02	0.00E+00	-6.24E-01
10	Hydroxynaphthalene	Naphthol	144.19	0.50	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-01	0.00E+00	0.00E+00	0.00E+00
	ALDEHYDES																			
11	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	1.30E-01	3.00E-01	3.00E-01	1.00E-01	4.00E-01	3.00E-01	6.00E-01	1.50E-01	2.00E-01	4.00E-01	2.00E-01	1.50E-01	3.00E-01	1.77E+00
12	Acrolein	2-propenal	56.06	0.02	0.03	3.46E-06	4.15E-03	1.00E-02	0.00E+00	0.00E+00	4.00E-02	0.00E+00	5.00E-02	0.00E+00	0.00E+00	0.00E+00	3.00E-02	0.00E+00	0.00E+00	-2.36E+00
13	Methacrolein	2-methylpropenal	70.09	1.00	1.70	2.01E-06	2.41E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Butylaldehyde	Butanal	72.10	1.00	4.00	8.59E-04	1.03E+00	0.00E+00	4.00E-02	0.00E+00	1.00E-02	1.00E-02	3.00E-02	0.00E+00	1.00E-02	0.00E+00	3.00E-02	3.00E-02	0.00E+00	1.77E-01
15	Valeraldehyde	Pentanal	86.13	1.00	4.00	7.84E-05	9.41E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-01	0.00E+00	0.00E+00	5.00E-02	0.00E+00	0.00E+00	0.00E+00
16	Furaldehyde	Furfural	96.09	0.60	7.90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-01	0.00E+00	0.00E+00	0.00E+00
17	Caproaldehyde	Hexanal	100.16	1.00	4.00	5.34E-05	6.41E-02	1.10E-01	1.50E-01	5.00E-02	7.00E-02	6.00E-02	2.00E-01	9.00E-02	1.20E-01	1.20E-01	1.60E-01	1.60E-01	6.00E-02	4.37E-01
18	Benzaldehyde	Benzenecarbonal	106.12	1.00	4.00	1.99E-05	2.39E-02	0.00E+00	0.00E+00	4.00E-02	1.20E-01	0.00E+00	6.00E-02	0.00E+00	0.00E+00	0.00E+00	8.00E-02	0.00E+00	0.00E+00	3.55E-01
19	Enanthaldehyde	Heptanal	114.19	1.00	4.00	1.77E-05	2.12E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Caprylaldehyde	Octanal	128.22	1.00	4.00	4.32E-06	5.18E-03	0.00E+00	0.00E+00	0.00E+00	2.00E-02	0.00E+00	2.00E-02	0.00E+00	0.00E+00	0.00E+00	8.00E-02	1.00E-02	0.00E+00	1.18E-01
21	Pelargonaldehyde	Nonanal	142.24	1.00	4.00	0.00E+00	0.00E+00	2.00E-02	4.00E-02	2.00E-02	5.00E-02	0.00E+00	5.00E-02	5.00E-02	2.00E-02	2.00E-02	3.00E-01	6.00E-02	3.00E-02	1.96E-01
22	Capraldehyde	Decanal	156.27	1.00	4.00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	2.00E-02	4.00E-02	0.00E+00	3.00E-02	4.00E-02	2.00E-02	2.00E-02	3.50E-01	1.00E-01	1.20E-01	4.04E-01
	AROMATIC HYDROCARBONS																			
23	Benzene	Benzene	78.11	0.20	0.20	2.51E-05	3.01E-02	8.00E-02	8.00E-02	6.00E-02	8.00E-02	8.00E-02	2.00E-01	1.50E-01	9.00E-02	7.00E-02	7.00E-02	9.00E-02	8.00E-02	-1.28E+00
24	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	2.38E+00	2.00E-02	1.10E-01	1.20E-01	2.00E-01	2.80E-01	2.10E-01	2.50E-01	2.60E-01	3.30E-01	3.60E-01	3.40E-01	4.40E-01	1.92E+00
25	Styrene	Ethenylbenzene	104.14	0.25	43.00	3.13E-05	3.76E-02	0.00E+00	2.00E-02	0.00E+00	1.00E-02	0.00E+00	2.00E-02	2.00E-02	0.00E+00	0.00E+00	6.00E-02	4.00E-02	0.00E+00	1.18E-01
26	Ethylbenzene	Ethylbenzene	106.16	2.00	50.00	1.50E-04	1.80E-01	3.00E-02	5.00E-02	2.00E-02	2.00E-02	3.00E-02	2.00E-02	6.00E-02	2.00E-02	3.00E-02	4.00E-02	1.00E-01	4.00E-02	-4.02E-02
27	m-/p-xylenes	1,3-/1,4-dimethylbenzenes	106.16	5.00	220.00	2.03E-03	2.43E+00	1.30E-01	1.60E-01	5.00E-02	9.00E-02	9.00E-02	1.00E-01	1.70E-01	1.20E-01	2.40E-01	4.00E-01	4.00E-01	4.40E-01	4.09E-01
28	o-xylene	1,2-dimethylbenzene	106.16	5.00	220.00	5.56E-04	6.67E-01	5.00E-02	6.00E-02	2.00E-02	1.00E-01	5.00E-02	8.00E-02	1.00E-01	4.00E-02	4.00E-02	1.00E-01	1.50E-01	8.00E-02	2.34E-01
29	Propylbenzene	Propylbenzene	120.20	2.00	49.00	2.15E-04	2.58E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-02	0.00E+00	0.00E+00	3.00E-02	0.00E+00	0.00E+00	0.00E+00
	ESTERS																			
30	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	3.55E-01	9.00E-02	1.00E-01	9.00E-02	1.30E-01	1.50E-01	1.60E-01	2.00E-01	2.00E-01	1.20E-01	1.50E-01	1.70E-01	1.60E-01	5.46E-01
31	Methyl methacrylate	2-methyl propenoic acid methyl este	100.12	0.30	100.00	1.30E-04	1.56E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Butyl acetate	Ethanoic acid butyl ester	116.16	2.00	190.00	7.46E-04	8.95E-01	2.00E-02	6.00E-02	1.00E-02	2.00E-02	1.00E-02	2.00E-02	5.00E-02	2.00E-02	3.00E-02	4.00E-02	5.00E-02	1.30E-01	2.08E-01
	ETHERS																			
33	Tetrahydrofuran	1,4-epoxybutane	72.11	3.00	120.00	6.93E-05	8.32E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Glycol methylene ether	1,3-dioxolane	74.08	16.60	0.10	0.00E+00	0.00E+00	5.00E-02	5.00E-02	3.00E-02	4.00E-02	1.60E-01	7.00E-02	1.30E-01	1.40E-01	4.00E-02	1.20E+00	6.00E-01	4.00E-01	7.80E-01
35	Propylcellosolve	Ethylene glycol monopropyl ether	104.15	0.20	0.10	0.00E+00	0.00E+00	0.00E+00	1.40E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-01	0.00E+00	0.00E+00	0.00E+00
	CHLOROCARBONS																			
36	Methylene chloride	Dichloromethane	84.93	16.60	10.00	2.15E-03	2.58E+00	0.00E+00	4.00E-02	2.00E-02	5.00E-02	6.00E-02	5.00E-02	6.00E-02	9.00E-02	7.00E-02	1.00E-01	1.30E-01	1.50E-01	5.79E-01
37	Chloroform	Trichloromethane	119.38	0.03	5.00	1.76E-05	2.11E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E-02	0.00E+00	0.00E+00	7.00E-02	0.00E+00	0.00E+00	0.00E+00
	HYDROCARBONS																			
38	Isoprene	2-methyl-1,3-butadiene	68.12	3.00	3.00	0.00E+00	0.00E+00	0.00E+00	2.00E-02	1.00E-02	1.00E-02	4.00E-02	1.00E-02	2.00E-02	0.00E+00	0.00E+00	2.00E-02	0.00E+00	0.00E+00	5.91E-02
39	Amyl hydride	Pentane	72.15	10.00	590.00	9.54E-05	1.14E-01	2.00E-02	1.00E-01	2.00E-02	4.00E-02	0.00E+00	1.00E-02	9.00E-02	4.00E-02	4.00E-02	4.00E-02	6.00E-02	3.00E-02	-4.02E-02
40	Methylpentamethylene	Methylcyclopentane	84.16	3.00	52.00	2.97E-05	3.56E-02	3.00E-02	3.00E-02	2.00E-02	0.00E+00	3.00E-02	3.00E-02	5.00E-02	5.00E-02	2.00E-02	3.00E-02	1.20E-01	1.30E-01	1.89E-01
41	Hexamethylene	Cyclohexane	84.16	3.00	210.00	3.79E-04	4.55E-01	3.00E-02	2.00E-02	0.00E+00	2.00E-02	6.00E-02	2.00E-02	7.00E-02	5.00E-02	2.00E-02	4.00E-02	7.00E-02	3.00E-02	-5.91E-02
42	Hexane	Hexane	86.18	5.00	180.00	6.95E-05	8.34E-02	2.00E-02	1.00E-01	2.00E-02	2.00E-02	4.00E-02	5.00E-02	1.20E-01	4.00E-02	4.00E-02	4.00E-02	5.00E-02	4.00E-02	2.15E-01
43	Diethylmethylmethane	3-methylpentane	86.18	20.00	1800.00	5.97E-06	7.16E-03	0.00E+00	3.00E-02	0.00E+00	1.00E-02	1.00E-02	1.00E-02	3.00E-02	0.00E+00	0.00E+00	2.00E-02	4.00E-02	0.00E+00	5.91E-02
44	Isohexane	2-methylpentane	86.18	20.00	1800.00	0.00E+00	0.00E+00	0.00E+00	4.00E-02	0.00E+00	2.00E-02	0.00E+00	2.00E-02	4.00E-02	1.00E-02	3.00E-02	3.00E-02	4.00E-02	3.00E-02	1.75E-01
45	Hexahydrotoluene	Methylcyclohexane	98.18	3.00	60.00	6.09E-05	7.31E-02	2.00E-02	5.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.10E-01	0.00E+00	1.00E-02	3.00E-02	2.50E-01	2.00E-02	-1.18E-01
46	Dimethylpentamethylene	Dimethylcyclopentane	98.19	3.00	170.00	0.00E+00	0.00E+00	3.00E-02	2.00E-02	0.00E+00	0.00E+00	0.00E+00	2.00E-02	6.00E-02	3.00E-02	3.00E-02	7.00E-02	9.00E-02	3.00E-02	-5.91E-02
47	Dipropylmethane	Heptane	100.21	10.00	200.00	5.60E-05	6.72E-02	4.00E-02	4.00E-02	3.00E-02	6.00E-02	7.00E-02	4.00E-02	4.00E-02	4.00E-02	3.00E-02	5.00E-02	6.00E-02	5.00E-02	1.89E-02
48	Dimethylpentane	2,2-dimethylpentane	100.21	20.00	208.00	2.59E-05	3.11E-02	0.00E+00	7.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-02	1.00E-02	0.00E+00	0.00E+00	0.00E+00	1.00E-02	1.89E-02
49	Methylhexane	3-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00	7.00E-02	4.00E-02	4.00E-02	5.00E-02	1.00E-01	6.00E-02	9.00E-02	8.00E-02	4.00E-02	4.00E-02	9.00E-02	6.00E-02	-7.80E-02
50	Isoheptane	2-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00	4.00E-02	4.00E-02	3.00E-02	4.00E-02	8.00E-02	4.00E-02	4.00E-02	7.00E-02	3.00E-02	3.00E-02	3.00E-02	4.00E-02	0.00E+00
51	Dimethylpentane	2,4-dimethylpentane	100.21	20.00	208.00	2.67E-07	3.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.00E-02	2.00E-02	0.00E+00	0.00E+00	2.00E-02	0.00E+00	0.00E+00
52	Diethylpropane	3,3-dimethylpentane	100.21	20.00	208.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Dimethylpentane	2,3-dimethylpentane	100.21	20.00	208.00	0.00E+00	0.00E+00	2.00E-02	2.00E-01	0.00E+00	2.00E-02	2.00E-02	2.00E-02	1.70E-01	1.00E-02	0.00E+00	0.00E+00	2.00E-02	0.00E+00	-3.78E-02
54	Trimethylpentamethylene	Trimethylcyclopentane	112.22	3.00	170.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Octane	Octane	114.23	10.00	350.00	1.61E-05	1.93E-02	2.00E-02	8.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	6.00E-02	0.00E+00	1.00E-02	3.00E-02	4.00E-02	2.00E-02	-5.91E-02
56	Isooctane	2-methylheptane	114.23	20.00	200.00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	0.00E+00	0.00E+00	2.00E-02	0.00E+00	6.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Methylheptane	3-methylheptane	114.23	20.00	200.00	0.00E+00	0.00E+00	0.00E+00	4.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.00E-02	0.00E+00	0.00E+00	0.00E+00	6.00E-02	0.00E+00	0.00E+00
58	Nonyl hydride	Nonane	128.26	10.00	320.00	7.34E-06	8.81E-03	2.00E-02	4.00E-02	2.00E-02	7.00E-02	2.00E-02	5.00E-02	3.00E-02	3.00E-02	6.00E-02	9.00E-02	3.00E-02	4.00E-02	2.15E-01
59	Limonene	4-isopropenyl-1-methylcyclohexene	136.23	3.00	560.00	3.58E-06	4.30E-03	5.00E-02	7.00E-02	4.00E-02	7.00E-02	5.00E-02	7.00E-02	5.00E-02	2.00E-02	9.00E-02	2.00E-02	7.00E-02	7.00E-02	1.56E-01
60	Pinene	a-pinene	136.24	3.00		0.00E+00	0.00E+00	3.00E-02	1.00E-01	0.00E+00	0.00E+00	3.00E-02	0.00E+00	8.00E-02	3.00E-02	2.00E-02	0.00E+00	7.00E-02	4.00E-02	-1.58E-01
61	Decyl hydride	Decane	142.28	10.00	230.00	2.78E-05	3.34E-02	6.00E-02	5.00E-02	3.00E-02	6.00E-02	5.00E-02	6.00E-02	3.00E-02	2.00E-02	8.00E-02	1.00E-01	8.00E-02	1.30E-01	1.32E-01
	KETONES																			
62	Acetone	2-propanone	58.08	1.00	50.00	3.62E-03	4.35E+00	1.10E-01	2.70E-01	2.80E-01	2.80E-01	2.60E-01	3.00E-01	5.40E-01	2.80E-01	2.50E-01	3.20E-01	5.00E-01	2.40E-01	1.37E+00
63	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	7.21E+00	2.00E-02	7.00E-02	3.00E-02	1.00E-02	2.00E-02	3.00E-02	6.00E-02	2.00E-02	3.00E-02	6.00E-02	5.00E-02	5.00E-02	1.16E-01
64	Acetol	1-hydroxy-2-propanone	74.08	3.30	0.10	0.00E+00	0.00E+00	0.00E+00	1.40E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-01	0.00E+00	0.00E+00	1.60E-01	0.00E+00	0.00E+00	0.00E+00
65	Methylfuranone	3-methylfuranone	98.10	0.80	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-01	0.00E+00	0.00E+00	2.00E-01	0.00E+00	0.00E+00	0.00E+00
66	Pimelic ketone	Cyclohexanone	98.14	1.30	60.00	6.62E-04	7.95E-01	0.00E+00	5.00E-02	1.00E-02	1.20E-01	9.00E-02	1.10E-01	7.00E-02	1.40E-01	1.90E-01	3.00E-01	4.00E-01	3.10E-01	1.24E+00
67	Phenyl methyl ketone	Acetophenone	120.14	0.20	250.00	5.66E-07	6.79E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	3.00E-02	0.00E+00	2.00E-02	3.78E-02
	MISCELLANEOUS																			
68	Acetic acid	Ethanoic acid	60.05	0.50	7.40	1.42E-06	1.71E-03	0.00E+00	3.60E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.10E-01	0.00E+00	0.00E+00	4.50E-01	0.00E+00	0.00E+00	0.00E+00
69	Propanolamine	3-aminopropanol	75.11	0.30	0.10	0.00E+00	0.00E+00	0.00E+00	1.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Methyl diethylenediamine	Methylpiperazine	100.17	0.30	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-02	0.00E+00	0.00E+00	1.00E-02	0.00E+00	0.00E+00	0.00E+00
71	Diisopropylamine	Amino-2,3-dimethylbutane	101.19	0.30	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Octylamine	2-aminooctane	129.25	0.30	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Methyl sulfide	Dimethyl sulfide	62.14	4.00	2.50	1.88E-07	2.26E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Carbon bisulfide	Carbon disulfide	76.14	1.00	16.00	3.23E-05	3.88E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	0.00E+00	0.00E+00	0.00E+00
75	Dimethyldisulfide	Dimethyldisulfide	94.20	4.00	0.10	0.00E+00	0.00E+00	0.00E+00	1.30E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-02	0.00E+00	0.00E+00	9.00E-02	0.00E+00	0.00E+00	0.00E+00
76	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	2.02E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Triethylsilanol	Triethylsilanol	132.28	0.20	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Trimethyl methaneorthosiliconate	Methyltriethoxysilane	178.31	0.20	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
79	Octamethylcyclotetraoxosilane	Octamethylcyclotetrasiloxane	296.62	0.20	12.00	2.70E-04	3.24E-01	0.00E+00	1.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-01	0.00E+00	0.00E+00	1.10E-01	0.00E+00	0.00E+00	0.00E+00
80	Decamethylcyclopentaoxosilane	Decamethylcyclopentasiloxane	370.64	0.20	15.00	4.96E-05	5.95E-02	0.00E+00	9.00E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.00E-02	0.00E+00	0.00E+00	1.20E-01	0.00E+00	0.00E+00	0.00E+00
	NOTES:				TOTAL	(mg/day)	4.66E+01	VOLUME						Empty ATV	4.64E+01					3.62E+01
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	1.94E+00	(m^3)						ATV with Cargo	3.90E+01					

ATV-1: NASA Data

			MOLECULAR	LIMITS IN AIR*		EQUIPMENT	ATV	NASA ATV OFFGASSING TEST DATA (mg/m^3)					NASA
	COMMON NAME	IUPAC NAME	WEIGHT	ZRL	ARL	RATE#	CARGO	Event 0	Event 1	Event 2	Event 3	Event 4	ATV RATE
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	0.0	23.7	67.7	112.9	204.7	mg/day
	ALCOHOLS												
1	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	9.42E+00	7.95E-02	2.45E-01	3.15E-01	3.90E-01	4.63E-01	2.06E+00
2	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	4.78E+00	8.60E-02	3.25E-01	5.00E-01	6.63E-01	9.17E-01	3.83E+00
3	Propyl alcohol	n-propanol	60.09	0.60	98.00	2.41E-04	2.89E-01	0.00E+00	1.25E-02	1.25E-02	8.33E-03	1.25E-02	9.00E-02
4	tert-butyl alcohol	2-methyl-2-propanol	74.12	0.10	150.00	7.38E-05	8.86E-02	0.00E+00	1.25E-02	1.25E-02	1.25E-02	1.25E-02	9.87E-02
5	Butyl alcohol	n-butanol	74.12	0.80	40.00	4.71E-03	5.65E+00	1.25E-02	1.25E-02	1.25E-02	3.00E-02	4.57E-02	1.04E-01
	ALDEHYDES												
6	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	1.30E-01	1.36E-01	1.45E-01	2.15E-01	2.27E-01	2.93E-01	5.57E-01
7	Acrolein	2-propenal	56.06	0.02	0.03	3.46E-06	4.15E-03	1.25E-02	1.25E-02	1.25E-02	1.25E-02	1.25E-02	0.00E+00
8	Proprionaldehyde	Propanal	58.08	1.00	14.00	3.19E-04	3.83E-01	4.60E-02	2.23E-02	4.15E-02	4.07E-02	5.57E-02	1.36E-01
9	Methacrolein	2-methyl-2-propenal	70.09	1.00	1.70	2.01E-06	2.41E-03	0.00E+00	1.25E-02	1.25E-02	1.25E-02	1.25E-02	9.87E-02
10	Butylaldehyde	Butanal	72.10	1.00	18.00	8.59E-04	1.03E+00	2.93E-02	1.88E-02	3.60E-02	4.13E-02	6.20E-02	1.72E-01
11	Valeraldehyde	Pentanal	86.13	1.00	21.00	7.84E-05	9.41E-02	2.43E-02	1.25E-02	1.25E-02	1.70E-02	1.73E-02	2.40E-02
12	Caproaldehyde	Hexanal	100.16	1.00	25.00	5.34E-05	6.41E-02	2.23E-02	1.25E-02	1.25E-02	1.25E-02	2.12E-02	2.21E-02
13	Enanthaldehyde	Heptanal	114.19	1.00	28.00	1.77E-05	2.12E-02	2.98E-02	1.98E-02	2.08E-02	8.33E-03	4.07E-02	2.36E-02
	AROMATIC HYDROCARBONS												
14	Benzene	Benzene	78.11	0.20	0.20	2.51E-05	3.01E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.33E-03	1.70E-02
15	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	2.38E+00	0.00E+00	1.25E-02	2.75E-02	4.03E-02	7.87E-02	2.94E-01
16	o-xylene	1,2-dimethylbenzene	106.16	5.00	220.00	5.56E-04	6.67E-01	0.00E+00	1.25E-02	2.85E-02	4.07E-02	7.93E-02	2.96E-01
17	m-/p-xylene	1,3-/1,4-dimethylbenzene	106.16	5.00	220.00	1.92E-03	2.30E+00	0.00E+00	1.25E-02	1.25E-02	1.25E-02	1.25E-02	9.87E-02
	ESTERS												
18	Methyl acetate	Ethanoic acid methyl ester	74.08	N/A	125.00	1.41E-04	1.69E-01	0.00E+00	0.00E+00	1.25E-02	1.25E-02	8.33E-03	4.47E-02
19	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	3.55E-01	0.00E+00	1.25E-02	2.65E-02	4.03E-02	6.27E-02	2.61E-01
20	Butyl acetate	Ethanoic acid butyl ester	116.16	2.00	190.00	7.46E-04	8.95E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-02	2.55E-02
21	Methoxypropyl acetate	Ethanoic acid 1-methoxy-2-propyl e	116.16	N/A	55.00	0.00E+00	0.00E+00	0.00E+00	1.25E-02	4.05E-02	5.62E-02	1.06E-01	3.84E-01
	CHLOROCARBONS												
22	Methyl chloride	Chloromethane	50.49	0.50	42.00	6.76E-06	8.11E-03	0.00E+00	0.00E+00	1.25E-02	1.25E-02	1.25E-02	5.32E-02
23	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	2.58E+00	0.00E+00	1.25E-02	1.25E-02	1.25E-02	1.25E-02	9.87E-02
24	Chloroform	Trichloromethane	119.38	N/A	5.00	1.76E-05	2.11E-02	0.00E+00	0.00E+00	1.25E-02	1.25E-02	1.25E-02	5.32E-02
25	Tetrachloroethylene	Tetrachloroethene	165.83	N/A	34.00	7.28E-04	8.74E-01	0.00E+00	1.25E-02	3.05E-02	4.50E-02	7.50E-02	2.97E-01
	HYDROCARBONS												
26	C4-alkane as butane	C4-alkane as n-butane	58.12	10.00	104.00	5.13E-06	6.16E-03	2.08E-02	3.05E-02	5.00E-02	6.17E-02	9.10E-02	2.68E-01
27	Pentane	n-pentane	72.15	10.00	590.00	9.54E-05	1.14E-01	0.00E+00	0.00E+00	0.00E+00	4.17E-03	1.25E-02	3.43E-02
28	Hexamethylene	Cyclohexane	84.16	3.00	210.00	3.79E-04	4.55E-01	0.00E+00	0.00E+00	1.25E-02	1.25E-02	1.23E-02	5.28E-02
29	Dipropylmethane	Heptane	100.21	10.00	208.00	5.60E-05	6.72E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-02	2.55E-02
30	C7 alkane as heptane	C7-alkane as n-heptane	100.21	10.00	208.00	5.60E-05	6.72E-02	0.00E+00	1.25E-02	3.30E-02	5.33E-02	9.43E-02	3.54E-01
31	Isoheptane	2-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-02	2.55E-02
32	Diethylmethylmethane	3-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00	6.25E-03	0.00E+00	1.25E-02	1.25E-02	1.25E-02	3.81E-03
33	Dimethylpentane	2,3-dimethylpentane	100.21	N/A	208.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-02	1.25E-02	5.17E-02
	KETONES												
34	Acetone	2-propanone	58.08	2.00	50.00	3.62E-03	4.35E+00	1.00E-01	2.40E-01	3.45E-01	4.37E-01	6.03E-01	2.27E+00
35	Methyl vinyl ketone	3-buten-2-one	70.00	N/A	0.43	1.60E-07	1.92E-04	6.25E-03	1.25E-02	1.25E-02	1.25E-02	1.25E-02	4.94E-02
36	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	7.21E+00	2.08E-02	1.88E-02	3.60E-02	4.13E-02	6.20E-02	1.22E-01
37	Methyl propyl ketone	2-pentanone	86.13	N/A	70.00	4.03E-06	4.84E-03	6.25E-03	1.25E-02	1.25E-02	1.25E-02	1.25E-02	4.94E-02
38	Cyclohexanone (pimelic ketone)	Cyclohexanone	98.14	1.30	60.00	6.62E-04	7.95E-01	1.05E-01	4.15E-01	5.65E-01	7.77E-01	1.13E+00	4.69E+00
39	Methyl isobutyl ketone	4-methyl-2-pentanone	100.16	N/A	140.00	1.41E-03	1.69E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-02	2.55E-02
	MISCELLANEOUS												
40	Carbon monoxide	Carbon monoxide	28.01	5.00	10.00	2.03E-03	2.43E+00	0.00E+00	0.00E+00	0.00E+00	9.50E-02	1.17E+00	2.59E+00
41	Acetonitrile	Methyl cyanide	41.05	N/A	7.00	1.70E-08	2.04E-05	6.25E-03	1.25E-02	1.25E-02	8.33E-03	1.25E-02	4.06E-02
42	Carbon bisulfide	Carbon disulfide	76.14	1.00	16.00	3.23E-05	3.88E-02	0.00E+00	0.00E+00	1.25E-02	1.25E-02	1.25E-02	5.32E-02
43	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	2.02E-01	1.25E-02	1.45E-01	3.20E-01	5.03E-01	8.90E-01	3.34E+00
	NOTES:				TOTAL	(mg/day)	4.97E+01	VOLUME	Empty ATV	4.64E+01			2.32E+01
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	2.07E+00	(m^3)	ATV with Cargo	3.90E+01			
	#1.23E-02 represents the scientific notation, 1.23 x 10^{-2}				Equipment Mass (kg)		1200						

ATV1-Consolidated Data

			MOLECULAR	LIMITS IN AIR*		EQUIPMENT	ATV	CONSOLIDATED
	COMMON NAME	**IUPAC NAME**	WEIGHT	ZRL	ARL	RATE$^{\#}$	CARGO	ATV RATE
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	mg/day
	ALCOHOLS							
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	1.52E+00	1.26E-02
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	9.42E+00	7.68E+00
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	4.78E+00	7.34E+00
4	Propyl alcohol	1-propanol	60.09	0.60	98.00	2.41E-04	2.89E-01	3.00E-02
5	tert-butyl alcohol	2-methyl-2-propanol	74.12	3.30	120.00	7.38E-05	8.86E-02	4.25E-01
6	Butyl alcohol	n-butanol	74.12	0.80	40.00	4.71E-03	5.65E+00	7.41E-01
7	Carbolic acid	Phenol	94.11	0.10	7.70	4.83E-04	5.80E-01	4.40E-01
	ALDEHYDES							
8	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	1.30E-01	7.77E-01
9	Proprionaldehyde	Propanal	58.08	1.00	14.00	3.19E-04	3.83E-01	4.53E-02
10	Methacrolein	2-methylpropenal	70.09	1.00	1.70	2.01E-06	2.41E-03	3.30E-02
11	Butylaldehyde	Butanal	72.10	1.00	4.00	8.59E-04	1.03E+00	1.16E-01
12	Valeraldehyde	Pentanal	86.13	1.00	4.00	7.84E-05	9.41E-02	8.00E-03
13	Caproaldehyde	Hexanal	100.16	1.00	4.00	5.34E-05	6.41E-02	1.53E-01
14	Benzaldehyde	Benzenecarbonal	106.12	1.00	4.00	1.99E-05	2.39E-02	1.33E-01
15	Enanthaldehyde	Heptanal	114.19	1.00	4.00	1.77E-05	2.12E-02	8.00E-03
16	Caprylaldehyde	Octanal	128.22	1.00	4.00	4.32E-06	5.18E-03	3.93E-02
17	Pelargonaldehyde	Nonanal	142.24	1.00	4.00	0.00E+00	0.00E+00	6.53E-02
18	Capraldehyde	Decanal	156.27	1.00	4.00	0.00E+00	0.00E+00	1.35E-01
	AROMATIC HYDROCARBONS							
19	Benzene	Benzene	78.11	0.20	0.20	2.51E-05	3.01E-02	3.13E-02
20	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	2.38E+00	9.17E-01
21	Styrene	Ethenylbenzene	104.14	0.25	43.00	3.13E-05	3.76E-02	3.93E-02
22	m-/p-xylenes	1,3-/1,4-dimethylbenzenes	106.16	5.00	220.00	2.03E-03	2.43E+00	2.90E-01
23	o-xylene	1,2-dimethylbenzene	106.16	5.00	220.00	5.56E-04	6.67E-01	9.08E-01
	ESTERS							
24	Methyl acetate	Ethanoic acid methyl ester	74.08	N/A	125.00	1.41E-04	1.69E-01	1.49E-02
25	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	3.55E-01	4.75E-01
26	Butyl acetate	Ethanoic acid butyl ester	116.16	2.00	190.00	7.46E-04	8.95E-01	1.25E-01
27	Methoxypropyl acetate	Ethanoic acid 1-methoxy-2-propyl e	116.16	N/A	55.00	0.00E+00	0.00E+00	1.28E-01
28	Ethyl butanoate	Butanoic acid ethyl ester	116.16	N/A	80.00	0.00E+00	0.00E+00	1.16E-01
29	Cellosolve acetate	Ethanoic acid 2-ethoxyethyl ester	132.16	N/A	160.00	7.46E-04	8.95E-01	7.83E-01
	ETHERS							
30	Glycol methylene ether	1,3-dioxolane	74.08	16.60	N/A	0.00E+00	0.00E+00	2.60E-01
31	**CHLOROCARBONS**							
32	Methyl chloride	Chloromethane	50.49	0.50	42.00	6.76E-06	8.11E-03	1.77E-02
33	Methylene chloride	Dichloromethane	84.93	5.00	10.00	2.15E-03	2.58E+00	2.26E-01
34	Chloroform	Trichloromethane	119.38	0.03	5.00	1.76E-05	2.11E-02	1.77E-02
35	Trichloroethylene	Trichloroethene	131.39	1.50	10.00	8.62E-05	1.03E-01	8.73E-03
36	Tetrachloroethylene	Tetrachloroethene	165.83	N/A	34.00	7.28E-04	8.74E-01	2.05E-01
	HYDROCARBONS							
37	C4-alkane as butane	C4-alkane as n-butane	58.12	10.00	104.00	5.13E-06	6.16E-03	8.93E-02
38	Isoprene	2-methyl-1,3-butadiene	68.12	3.00	3.00	0.00E+00	0.00E+00	1.97E-02
39	Amyl hydride	Pentane	72.15	10.00	590.00	9.54E-05	1.14E-01	1.13E-02
40	Hexylene	1-hexene	84.16	N/A	180.00	0.00E+00	0.00E+00	4.53E-01
41	Methylpentamethylene	Methylcyclopentane	84.16	3.00	52.00	2.97E-05	3.56E-02	6.30E-03
42	Hexamethylene	Cyclohexane	84.16	3.00	210.00	3.79E-04	4.55E-01	1.77E-02
43	Hexane	Hexane	86.18	5.00	180.00	6.95E-05	8.34E-02	7.17E-02
44	Diethylmethylmethane	3-methylpentane	86.18	20.00	1800.00	5.97E-06	7.16E-03	1.97E-02
45	Isohexane	2-methylpentane	86.18	20.00	1800.00	0.00E+00	0.00E+00	5.83E-02
46	Triethylmethane	3-ethylpentane	100.21	N/A	1800.00	2.88E-07	3.46E-04	2.23E-02
47	Dipropylmethane	Heptane	100.21	10.00	200.00	5.60E-05	6.72E-02	2.33E-02
48	Dimethylpentane	2,2-dimethylpentane	100.21	20.00	208.00	2.59E-05	3.11E-02	6.30E-03
49	Isoheptane	2-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00	6.87E-02
50	Dimethylpentane	2,3-dimethylpentane	100.21	20.00	208.00	0.00E+00	0.00E+00	1.73E-02
51	Isooctane	2,2,4-trimethylpentane	114.23	N/A	180.00	0.00E+00	0.00E+00	2.38E-01
52	Trimethylpentane	2,3,3-trimethylpentane	114.23	N/A	180.00	0.00E+00	0.00E+00	6.20E-02
53	Dimethylhexane	2,4-dimethylhexane	114.23	N/A	180.00	0.00E+00	0.00E+00	1.20E-02
54	Dimethylhexane	2,5-dimethylhexane	114.23	N/A	180.00	0.00E+00	0.00E+00	5.73E-03
55	Nonyl hydride	Nonane	128.26	10.00	320.00	7.34E-06	8.81E-03	7.17E-02
56	Limonene	4-isopropenyl-1-methylcyclohexene	136.23	3.00	560.00	3.58E-06	4.30E-03	5.20E-02
57	Decyl hydride	Decane	142.28	10.00	230.00	2.78E-05	3.34E-02	4.40E-02
	KETONES							
58	Acetone	2-propanone	58.08	1.00	50.00	3.62E-03	4.35E+00	2.67E+00
59	Methyl vinyl ketone	3-buten-2-one	70.00	N/A	0.43	1.60E-07	1.92E-04	1.65E-02
60	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	7.21E+00	2.19E-01
61	Methyl propyl ketone	2-pentanone	86.13	N/A	70.00	4.03E-06	4.84E-03	1.65E-02
62	Pimelic ketone	Cyclohexanone	98.14	1.30	60.00	6.62E-04	7.95E-01	6.21E+00
63	Methyl isobutyl ketone	4-methyl-2-pentanone	100.16	N/A	140.00	1.41E-03	1.69E+00	2.08E-01
64	Ethyl isobutyl ketone	5-methyl-3-hexanone	114.18	N/A	60.00	2.15E-06	2.58E-03	2.93E-01
65	Phenyl methyl ketone	Acetophenone	120.14	0.20	250.00	5.66E-07	6.79E-04	1.26E-02
	MISCELLANEOUS							
66	Carbon monoxide	Carbon monoxide	28.01	5.00	10.00	2.03E-03	2.43E+00	2.59E+00
67	Acetonitrile	Methyl cyanide	41.05	N/A	7.00	1.70E-08	2.04E-05	1.35E-02
68	Carbon bisulfide	Carbon disulfide	76.14	1.00	16.00	3.23E-05	3.88E-02	1.77E-02
69	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	2.02E-01	1.92E+00
70	Hexamethyldioxosilane	Hexamethyldisiloxane	162.48	0.20	9.00	8.52E-06	1.02E-02	9.33E-02
71	Hexamethylcyclotrioxosilane	Hexamethylcyclotrisiloxane	222.40	0.20	9.00	2.11E-04	2.53E-01	6.47E-01
72	Octamethylcyclotetraoxosilane	Octamethylcyclotetrasiloxane	296.62	0.20	12.00	2.70E-04	3.24E-01	4.00E-01
73	Decamethylcyclopentaoxosilane	Decamethylcyclopentasiloxane	370.64	0.20	15.00	4.96E-05	5.95E-02	3.23E-01
	NOTES:				TOTAL	(mg/day)	5.22E+01	39.76
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	2.18E+00	
	$^{\#}$1.23E-02 represents the scientific notation 1.23 x 10^{-2}				Equipment Mass (kg)		1200	
					VOLUME	Empty ATV	4.64E+01	
					(m^3)	ATV & Cargo	3.90E+01	

ATV2

			MOLECULAR	LIMITS IN AIR*		EQUIPMENT	ATV	ESA ATV OFFGASSING TEST DATA (mg/m^3)											ESA ATV
	COMMON NAME	IUPAC NAME	WEIGHT	ZRL	ARL	RATE#	CARGO	SP 1	SP 2	SP 3	SP 4	SP 5	SP 6	SP 7	SP 8	SP 9	SP 10	SP 11	TERMINAL RATE
			g/mole	mg/m^3	mg/m^3	mg/day/kg	mg/day	3.25	6.25	8.50	19.00	24.00	39.75	48.25	65.50	73.50	98.00	147.00	mg/day
	ALCOHOLS																		
1	Methyl alcohol	Methanol	32.04	0.20	9.00	1.27E-03	5.08E-01												0.00E+00
2	Ethyl alcohol	Ethanol	46.07	10.00	2000.00	7.85E-03	3.14E+00	1.16E-01	1.27E-01	1.98E-01	1.39E-01	1.84E-01	3.06E-01	1.59E-01	3.88E-01	2.66E-01	2.39E-01	3.59E-01	-1.47E-01
3	Isopropyl alcohol	2-propanol	60.09	1.50	150.00	3.99E-03	1.59E+00	6.49E-02	1.24E-01	1.83E-01	1.63E-01	2.93E-01	4.81E-01	3.03E-01	6.31E-01	4.77E-01	5.40E-01	7.93E-01	1.75E+00
4	Propyl alcohol	1-propanol	60.09	0.60	98.00	2.41E-04	9.64E-02												0.00E+00
5	Cyclobutanol	Cyclobutanol	72.11	6.60	0.10	0.00E+00	0.00E+00												0.00E+00
6	Isobutyl alcohol	2-methyl-1-propanol	74.12	0.10	120.00	8.47E-04	3.39E-01												0.00E+00
7	tert-butyl alcohol	2-methyl-2-propanol	74.12	3.30	120.00	7.38E-05	2.95E-02												0.00E+00
8	Butyl alcohol	n-butanol	74.12	0.80	40.00	4.71E-03	1.88E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-02	9.46E-02
	Propylene glycol	1,2-propanediol	76.10	N/A	4.80	2.68E-07	1.07E-04	8.09E-01	1.09E+00	1.04E+00	3.81E-01	5.45E-01	3.00E-01	1.02E-01	5.11E-02	5.42E-02	0.00E+00	0.00E+00	-1.12E+00
9	Isooctanol	2-ethylhexanol	130.23	3.30	0.10	9.85E-06	3.94E-03	1.41E-02	1.80E-02	1.84E-02	2.12E-02	2.44E-02	2.93E-02	3.16E-02	3.17E-02	3.24E-02	3.59E-02	4.48E-02	9.78E-02
10	Hydroxynaphthalene	Naphthol	144.19	0.50	0.10	0.00E+00	0.00E+00												0.00E+00
	ALDEHYDES																		
11	Acetaldehyde	Ethanal	44.05	1.00	4.00	1.09E-04	4.34E-02	9.24E-02	1.23E-01	1.76E-01	5.55E-02	6.50E-02	8.48E-02	8.64E-02	1.04E-01	1.08E-01	7.28E-02	8.05E-03	-2.90E-01
12	Acrolein	2-propenal	56.06	0.02	0.03	3.46E-06	1.38E-03	1.52E-02	2.02E-02	2.46E-02	1.77E-02	1.66E-02	2.65E-02	2.59E-02	2.02E-02	1.95E-02	2.47E-02	2.57E-02	-4.34E-02
13	Methacrolein	2-methylpropenal	70.09	1.00	1.70	2.01E-06	8.04E-04												0.00E+00
14	Butylaldehyde	Butanal	72.10	1.00	4.00	8.59E-04	3.44E-01												0.00E+00
15	Valeraldehyde	Pentanal	86.13	1.00	4.00	7.84E-05	3.14E-02												0.00E+00
16	Furaldehyde	Furfural	96.09	0.60	7.90	0.00E+00	0.00E+00												0.00E+00
17	Caproaldehyde	Hexanal	100.16	1.00	4.00	5.34E-05	2.14E-02												0.00E+00
18	Benzaldehyde	Benzenecarbonal	106.12	1.00	4.00	1.99E-05	7.96E-03	6.91E-02	6.38E-02	7.57E-02	7.77E-02	7.41E-02	7.92E-02	8.77E-02	7.14E-02	9.50E-02	9.74E-02	7.55E-02	3.88E-01
19	Enanthaldehyde	Heptanal	114.19	1.00	4.00	1.77E-05	7.08E-03												0.00E+00
20	Caprylaldehyde	Octanal	128.22	1.00	4.00	4.32E-06	1.73E-03												0.00E+00
21	Pelargonaldehyde	Nonanal	142.24	1.00	4.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.35E-02	3.40E-02	0.00E+00	3.78E-02	3.35E-02	1.09E-02	1.16E-02	1.74E-01
22	Capraldehyde	Decanal	156.27	1.00	4.00	0.00E+00	0.00E+00												0.00E+00
	AROMATIC HYDROCARBONS																		
23	Benzene	Benzene	78.11	0.20	0.20	2.51E-05	1.00E-02												0.00E+00
24	Toluene	Methylbenzene	92.15	8.00	60.00	1.98E-03	7.93E-01	2.22E-02	3.51E-02	3.93E-02	4.27E-02	5.94E-02	7.54E-02	6.84E-02	8.22E-02	7.95E-02	9.05E-02	1.15E-01	3.30E-01
25	Styrene	Ethenylbenzene	104.14	0.25	43.00	3.13E-05	1.25E-02												0.00E+00
26	Ethylbenzene	Ethylbenzene	106.16	2.00	50.00	1.50E-04	5.99E-02												0.00E+00
27	m-/p-xylenes	1,3-/1,4-dimethylbenzenes	106.16	5.00	220.00	2.03E-03	8.10E-01	2.52E-02	2.83E-02	2.95E-02	2.77E-02	2.87E-02	2.86E-02	2.99E-02	2.91E-02	2.93E-02	3.04E-02	3.17E-02	1.17E-02
28	o-xylene	1,2-dimethylbenzene	106.16	5.00	220.00	5.56E-04	2.22E-01	2.65E-02	3.34E-02	3.52E-02	4.01E-02	4.34E-02	4.72E-02	5.40E-02	5.49E-02	5.91E-02	6.29E-02	7.50E-02	2.29E-01
29	Propylbenzene	Propylbenzene	120.20	2.00	49.00	2.15E-04	8.60E-02												0.00E+00
	ESTERS																		
30	Ethyl acetate	Ethanoic acid ethyl ester	88.11	4.00	180.00	2.96E-04	1.18E-01												0.00E+00
31	Methyl methacrylate	2-methyl propenoic acid methyl ester	100.12	0.30	100.00	1.30E-04	5.19E-02												0.00E+00
32	Butyl acetate	Ethanoic acid butyl ester	116.16	2.00	190.00	7.46E-04	2.98E-01												0.00E+00
	ETHERS																		
33	Tetrahydrofuran	1,4-epoxybutane	72.11	3.00	120.00	6.93E-05	2.77E-02												0.00E+00
34	Glycol methylene ether	1,3-dioxolane	74.08	16.60	0.10	0.00E+00	0.00E+00												0.00E+00
35	Propylcellosolve	Ethylene glycol monopropyl ether	104.15	0.20	0.10	0.00E+00	0.00E+00												0.00E+00
	CHLOROCARBONS																		
36	Methylene chloride	Dichloromethane	84.93	16.60	10.00	2.15E-03	8.60E-01												0.00E+00
37	Chloroform	Trichloromethane	119.38	0.03	5.00	1.76E-05	7.04E-03												0.00E+00
	Tetrachloroethylene	Tetrachloroethene	165.83	N/A	34.00	7.28E-04	2.91E-01	1.99E-02	2.83E-02	3.00E-02	3.19E-02	4.17E-02	4.92E-02	4.69E-02	5.28E-02	5.33E-02	6.01E-02	7.65E-02	2.38E-01
	Tetrafluorohexane	3,3,4,4-tetrafluorohexane		N/A	0.10	0.00E+00	0.00E+00	2.49E-02	2.23E-02	2.44E-02	2.49E-02	2.36E-02	2.36E-02	1.50E-02	2.19E-02	1.50E-02	2.12E-02	2.23E-02	-4.38E-02
	HYDROCARBONS																		
	Propylene	Propene	42.08	N/A	860.00	2.56E-06	1.02E-03	4.81E-02	8.05E-03	8.01E-02	5.96E-02	8.59E-02	1.77E-01	8.77E-02	1.78E-01	1.69E-01	1.49E-01	3.06E-01	1.52E+00
	Isobutene	2-methylpropene	56.11	N/A	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.76E-01	2.07E-01	2.01E-01	2.12E-01	1.95E-01	5.21E-01	3.21E-01	4.26E-01	6.96E-01	8.65E-01
	Isobutane	2-methylpropane	58.12	N/A	240.00	1.10E-05	4.40E-03	3.85E-01	7.27E-01	8.76E-01	1.24E+00	1.77E+00	2.42E+00	2.20E+00	2.93E+00	2.96E+00	3.44E+00	4.09E+00	1.85E+01
38	Isoprene	2-methyl-1,3-butadiene	68.12	3.00	3.00	0.00E+00	0.00E+00												0.00E+00
39	Amyl hydride	Pentane	72.15	10.00	590.00	9.54E-05	3.82E-02												0.00E+00
40	Methylpentamethylene	Methylcyclopentane	84.16	3.00	52.00	2.97E-05	1.19E-02												0.00E+00
41	Hexamethylene	Cyclohexane	84.16	3.00	210.00	3.79E-04	1.52E-01												0.00E+00
42	Hexane	Hexane	86.18	5.00	180.00	6.95E-05	2.78E-02												0.00E+00
43	Diethylmethylmethane	3-methylpentane	86.18	20.00	1800.00	5.97E-06	2.39E-03												0.00E+00
44	Isohexane	2-methylpentane	86.18	20.00	1800.00	0.00E+00	0.00E+00												0.00E+00
45	Hexahydrotoluene	Methylcyclohexane	98.18	3.00	60.00	6.09E-05	2.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.21E-02	1.36E-02	1.58E-02	1.75E-02	1.93E-02	2.76E-02	1.36E-01
46	Dimethylpentamethylene	Dimethylcyclopentane	98.19	3.00	170.00	0.00E+00	0.00E+00												0.00E+00
	Triethylmethane	3-ethylpentane	100.21	N/A	1800.00	2.88E-07	1.15E-04	0.00E+00	0.00E+00	0.00E+00	4.44E-02	4.60E-02	0.00E+00	5.66E-02	6.25E-02	6.33E-02	7.10E-02	5.82E-02	1.16E-01
47	Dipropylmethane	Heptane	100.21	10.00	200.00	5.60E-05	2.24E-02	0.00E+00	0.00E+00	0.00E+00	1.40E-02	1.54E-02	1.98E-02	1.83E-02	2.42E-02	2.30E-02	2.71E-02	3.26E-02	1.10E-01
48	Dimethylpentane	2,2-dimethylpentane	100.21	20.00	208.00	2.59E-05	1.04E-02												0.00E+00
49	Methylhexane	3-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00	3.63E-02	4.59E-02	4.88E-02	6.36E-02	6.88E-02	8.66E-02	9.19E-02	1.06E-01	1.10E-01	1.24E-01	1.56E-01	5.95E-01
50	Isoheptane	2-methylhexane	100.21	20.00	29.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.45E-02	5.18E-02	5.68E-02	6.61E-02	6.76E-02	7.88E-02	8.13E-02	9.27E-02	1.09E-01	4.12E-01
51	Dimethylpentane	2,4-dimethylpentane	100.21	20.00	208.00	2.67E-07	1.07E-04												0.00E+00
52	Diethylpropane	3,3-dimethylpentane	100.21	20.00	208.00	0.00E+00	0.00E+00	2.69E-02	3.23E-02	0.00E+00	0.00E+00	0.00E+00	4.97E-02	4.59E-02	4.96E-02	5.04E-02	5.49E-02	6.59E-02	1.69E-01
53	Dimethylpentane	2,3-dimethylpentane	100.21	20.00	208.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.62E-02	4.70E-02	5.51E-02	5.81E-02	6.74E-02	7.10E-02	7.39E-02	9.37E-02	3.54E-01
54	Trimethylpentamethylene	Trimethylcyclopentane	112.22	3.00	170.00	0.00E+00	0.00E+00												0.00E+00
55	Octane	Octane	114.23	10.00	350.00	1.61E-05	6.44E-03												0.00E+00
56	Isooctane	2-methylheptane	114.23	20.00	200.00	0.00E+00	0.00E+00												0.00E+00
57	Methylheptane	3-methylheptane	114.23	20.00	200.00	0.00E+00	0.00E+00												0.00E+00
58	Nonyl hydride	Nonane	128.26	10.00	320.00	7.34E-06	2.94E-03												0.00E+00
59	Limonene	4-isopropenyl-1-methylcyclohexene	136.23	3.00	115.00	3.58E-06	1.43E-03	6.25E-02	7.83E-02	7.72E-02	6.46E-02	8.36E-02	1.53E-01	1.56E-01	1.69E-01	1.39E-01	1.52E-01	2.22E-01	-2.43E-01
60	Pinene	a-pinene	136.24	3.00	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.41E-02	6.37E-02	5.63E-01
	Hendecane	Undecane (C11 compounds)	156.31	N/A	320.00	2.51E-05	1.00E-02	5.55E-02	7.35E-02	7.97E-02	1.13E-01	1.35E-01	1.62E-01	1.88E-01	2.02E-01	2.12E-01	2.37E-01	2.91E-01	9.79E-01
61	Dihexyl	Dodecane (C12 compounds)	170.34	N/A	280.00	6.91E-07	2.76E-04	5.54E-01	7.76E-01	8.22E-01	1.12E+00	1.18E+00	1.43E+00	1.49E+00	1.68E+00	1.67E+00	1.84E+00	2.08E+00	5.05E+00
		C13 compounds		N/A	0.10	0.00E+00	0.00E+00	9.21E-02	1.25E-01	1.19E-01	1.69E-01	1.76E-01	2.09E-01	2.08E-01	2.32E-01	2.39E-01	2.63E-01	2.93E-01	9.03E-01
		Heptamethylheptene		N/A	0.10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.43E-02	1.60E-02	1.54E-02	1.69E-02	1.52E-02	0.00E+00	-5.31E-02
61	Dodecane	C15 compounds	170.34	N/A	0.10	0.00E+00	0.00E+00	6.56E-02	1.19E-01	1.09E-01	1.45E-01	1.77E-01	2.07E-01	1.71E-01	2.33E-01	1.98E-01	2.44E-01	2.63E-01	3.47E-01
	KETONES																		
62	Acetone	2-propanone	58.08	1.00	50.00	3.62E-03	1.45E+00	7.33E-02	1.07E-01	1.28E-01	1.82E-01	2.05E-01	3.25E-01	2.76E-01	3.98E-01	3.66E-01	4.67E-01	5.36E-01	2.01E+00
	Methyl vinyl ketone	3-buten-2-one	70.00	N/A	0.43	1.60E-07	6.40E-05	1.31E-01	8.05E-03	0.00E+00	0.00E+00	0.00E+00	8.05E-03	6.72E-02	1.41E-01	8.47E-02	8.20E-02	7.28E-02	-7.15E-01
63	Methyl ethyl ketone	2-butanone	72.11	0.25	30.00	6.01E-03	2.40E+00												0.00E+00
64	Acetol	1-hydroxy-2-propanone	74.08	3.30	0.10	0.00E+00	0.00E+00												0.00E+00
65	Methylfuranone	3-methylfuranone	98.10	0.80	0.10	0.00E+00	0.00E+00												0.00E+00
66	Pimelic ketone	Cyclohexanone	98.14	1.30	60.00	6.62E-04	2.65E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.06E-02	3.92E-02	3.69E-02	3.61E-02	4.41E-02	0.00E+00	-1.89E-01
67	Phenyl methyl ketone	Acetophenone	120.14	0.20	250.00	5.66E-07	2.26E-04												0.00E+00
	MISCELLANEOUS																		
68	Acetic acid	Ethanoic acid	60.05	0.50	7.40	1.42E-06	5.69E-04	1.01E-01	0.00E+00	8.77E-02	1.98E-01	1.35E-01	2.35E-01	1.91E-01	1.28E-01	8.10E-02	3.03E-01	7.21E-02	-1.21E+00
69	Propanolamine	3-aminopropanol	75.11	0.30	0.10	0.00E+00	0.00E+00												0.00E+00
70	Methyl diethylenediamine	Methylpiperazine	100.17	0.30	0.10	0.00E+00	0.00E+00												0.00E+00
71	Diisopropylamine	Amino-2,3-dimethylbutane	101.19	0.30	0.10	0.00E+00	0.00E+00												0.00E+00
72	Octylamine	2-aminooctane	129.25	0.30	0.10	0.00E+00	0.00E+00												0.00E+00
73	Methyl sulfide	Dimethyl sulfide	62.14	4.00	2.50	1.88E-07	7.52E-05												0.00E+00
74	Carbon bisulfide	Carbon disulfide	76.14	1.00	16.00	3.23E-05	1.29E-02												0.00E+00
75	Dimethyldisulfide	Dimethyldisulfide	94.20	4.00	0.10	0.00E+00	0.00E+00												0.00E+00
76	Trimethylsilanol	Trimethylsilanol	90.21	0.20	37.00	1.69E-04	6.75E-02	1.31E-01	8.05E-03	0.00E+00	0.00E+00	0.00E+00	8.05E-03	8.05E-03	3.73E-02	8.05E-03	5.09E-02	5.55E-02	-2.76E-02
	Trimethylsilylfluoride	Trimethylfluorosilane	92.19	N/A	0.10	0.00E+00	0.00E+00	6.36E-02	4.31E-02	6.05E-02	1.35E-01	6.41E-02	8.28E-02	7.65E-02	1.09E-01	1.15E-01	1.42E-01	1.27E-01	8.03E-01
77	Triethylsilanol	Triethylsilanol	132.28	0.20	0.10	0.00E+00	0.00E+00												0.00E+00
	Hexamethyldioxosilane	Hexamethyldisiloxane	162.48	0.20	9.00	8.52E-06	3.41E-03	2.25E-02	2.83E-02	2.57E-02	4.06E-02	5.37E-02	7.45E-02	8.63E-02	1.09E-01	1.09E-01	1.35E-01	1.85E-01	7.95E-01
78	Trimethyl methaneorthosiliconate	Methyltriethoxysilane	178.31	0.20	0.10	0.00E+00	0.00E+00												0.00E+00
	Hexamethylcyclotrioxosilane	Hexamethylcyclotrisiloxane	222.40	0.20	9.00	1.62E-04	6.46E-02	4.71E-01	3.47E-01	3.90E-01	4.06E-01	3.34E-01	3.81E-01	3.24E-01	4.05E-01	3.99E-01	3.70E-01	4.62E-01	1.09E+00
	Octamethyltrioxosilane	Octamethyltrisiloxane	236.54	N/A	40.00	2.11E-04	8.44E-02	1.35E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-02	1.67E-02	1.65E-02	1.64E-02	1.71E-02	2.25E-02	2.68E-02
79	Octamethylcyclotetraoxosilane	Octamethylcyclotetrasiloxane	296.62	0.20	12.00	2.70E-04	1.08E-01	1.20E+00	1.03E+00	1.04E+00	1.16E+00	1.02E+00	9.98E-01	9.81E-01	1.05E+00	1.03E+00	1.13E+00	1.09E+00	1.12E+00
80	Decamethylcyclopentaoxosilane	Decamethylcyclopentasiloxane	370.64	0.20	15.00	4.96E-05	1.98E-02	1.11E+00	1.22E+00	1.17E+00	1.10E+00	1.18E+00	1.04E+00	1.03E+00	1.01E+00	8.43E-01	9.85E-01	1.06E+00	-3.44E+00
	Dodecamethylcycloheptaoxosilane	Dodecamethylcyclohexasiloxane	444.93	N/A	0.10	0.00E+00	0.00E+00	5.51E-01	3.90E-01	3.76E-01	5.22E-01	4.60E-01	4.28E-01	4.80E-01	4.90E-01	3.98E-01	4.67E-01	5.38E-01	-1.56E+00
80	Tetradecamethylcycloheptaoxosilane	Tetradecamethylcycloheptasiloxane	519.09	0.20	15.00	0.00E+00	0.00E+00	1.04E-01	4.08E-02	3.95E-02	5.19E-02	5.44E-02	7.24E-02	7.11E-02	7.35E-02	5.97E-02	7.40E-02	8.52E-02	-1.81E-01
		Unidentified compounds	N/A	N/A	0.10	0.00E+00	0.00E+00	8.06E-02	5.54E-02	1.36E-01	5.42E-02	7.76E-02	8.98E-02	8.50E-02	9.94E-02	6.45E-02	4.95E-01	1.10E-01	1.45E+00
	NOTES:				TOTAL	(mg/day)	1.60E+01	VOLUME						Empty ATV	4.64E+01				4.12E+01
	*ZRL = zero risk level; ARL = acceptable risk level as defined by SSP 50260 (MORD)					(mg/h)	6.66E-01	(m^3)						ATV with Cargo	3.90E+01			ULF-5 Stage Rate	291 mg/h
	#1.23E-02 represents the scientific notation 1.23 x 10^{-2}				Late Load Mass (kg)		400												

APPENDIX C—PREDICTED GENERATION RATES BY FLIGHT FOR ASSEMBLY MISSIONS 2A THROUGH 3A

Tables 46 through 50 contain a trace contaminant generation summary for STS-88/2A, STS-96/2A.1, STS-101/ 2A.2a, STS-106/2A.2b, and STS-92/3A, respectively.

Table 46. STS-88/2A trace contaminant generation summary.

Compound	Basic Node (mg/hr)	+ Shuttle IMV (mg/hr)	+ Shuttle and Crew (mg/hr)	+ FGB IMV (mg/hr)	+ 2A Stowage (mg/hr)
Methanol	0.028	15.2	0.12	0.12	0.0288
Ethanol	0.627	168.8	1.1	76.7	0.6454
2-propanol	0.585	269.7	214.4	236.6	0.6022
n-propanol	0.0973	0.0973	0.16	0.16	0.1002
2-methyl-2-propanol	0.0149	4.22	0.0149	0.0149	0.0153
n-butanol	0.0777	4.28	0.13	14.94	0.08
Ethanal	0.0258	13.48	0.09	0.09	0.0266
2-propenal	0.0049	1.69	0.0049	0.0049	0.0001
Propanal	0.0197	4.22	0.06	0.06	0.0203
2-methyl-2-propenal	0.0149	0.0149	0.0149	0.0149	0.0153
Butanal	0.0196	4.22	0.0196	0.0196	0.202
Pentanal	0.0062	4.21	0.0082	0.0082	0.0064
Hexanal	0.0062	4.21	0.0082	0.0082	0.0064
Heptanal	0.0062	4.21	0.0082	0.0082	0.0064
Methylbenzene	0.0432	4.25	0.11	0.11	0.0445
1,2- & 1,3-dimethylbenzenes	0.0391	4.24	0.051	13.02	0.0403
1,4-dimethylbenzene	0.0149	4.22	0.021	14.84	0.0153
Ethylbenzene	0.0149	4.22	0.075	4.7	0.0153
Butyl acetate	0.0062	4.21	0.025	0.025	0.0064
Dichloromethane	0.0822	11.86	3.45	12.71	0.0846
Trichlorofluoromethane	0.0149	4.22	0.0149	0.0149	0.0153
Trichlorotrifluoroethane	0.0496	4.25	0.0496	0.0496	0.051
2-propanone	0.154	23.7	2.1	20.62	0.1585
2-butanone	0.0778	4.28	1.02	1.02	0.0801
Cyclohexanone	0.0259	0.0259	0.0259	0.0259	0.0267
Hexamethylcyclotrisiloxane	0.0149	158.12	143	143	0.0153
Octamethylcyclotetrasiloxane	0.106	67.39	47.2	47.2	0.1091
Carbon monoxide	–	92.5	1.83	1.83	–
Hydrogen	–	319.6	4.4	4.4	–
Methane	–	773.7	9.75	9.75	–

Table 47. STS-96/2A.1 trace contaminant generation summary.

Compound	Basic Node (mg/hr)	+ Shuttle IMV (mg/hr)	+ Shuttle and Crew (mg/hr)	+ FGB IMV (mg/hr)	+ 2A Stowage (mg/hr)
Methanol	0.0288	15.2	0.12	0.12	0.0318
Ethanol	0.6454	168.8	1.08	76.7	0.7132
2-propanol	0.6022	269.7	214.4	236.6	0.6654
n-propanol	0.1002	0.1002	0.16	0.16	0.1107
2-methyl-2-propanol	0.0153	4.22	0.0153	0.0153	0.0169
n-butanol	0.08	4.28	0.13	14.95	0.0884
Ethanal	0.0266	13.48	0.087	0.087	0.0294
2-propenal	0.0001	0.0001	0.0001	0.0001	0.0001
Propanal	0.0203	4.22	0.06	0.06	0.0224
2-methyl-2-propenal	0.0153	0.0153	0.0153	0.0153	0.0169
Butanal	0.202	4.4	0.202	0.202	0.2041
Pentanal	0.0064	4.21	0.0086	0.0086	0.0071
Hexanal	0.0064	4.21	0.0086	0.0086	0.0071
Heptanal	0.0064	4.21	0.0086	0.0086	0.0071
Methylbenzene	0.0445	4.25	0.11	0.11	0.0492
1,2- & 1,3-dimethylbenzenes	0.0403	4.24	0.0523	13.02	0.0445
1,4-dimethylbenzene	0.0153	4.22	0.0213	14.84	0.0169
Ethylbenzene	0.0153	4.22	0.0753	4.71	0.0169
Butyl acetate	0.0064	4.21	0.0254	0.0254	0.0071
Dichloromethane	0.0846	11.86	3.45	12.71	0.0935
Trichlorofluoromethane	0.0153	4.22	0.0153	0.0153	0.0169
Trichlorotrifluoroethane	0.051	4.26	0.051	0.051	0.0564
2-propanone	0.1585	23.71	2.11	20.63	0.1751
2-butanone	0.0801	4.29	1.02	1.02	0.0885
Cyclohexanone	0.0267	0.0267	0.0267	0.0267	0.0295
Hexamethylcyclotrisiloxane	0.0153	158.1	143	143	0.0169
Octamethylcyclotetrasiloxane	0.1091	67.4	47.2	47.2	0.1205
Carbon monoxide	–	92.5	1.83	1.83	–
Hydrogen	–	319.6	4.4	4.4	–
Methane	–	773.7	9.75	9.75	–

Table 48. STS-101/2A.2a trace contaminant generation summary.

Compound	+ 2A.1 Stowage (mg/hr)	+ Shuttle IMV (mg/hr)	+ Crew (mg/hr)	+ FGB IMV (mg/hr)
Methanol	0.0318	15.2	0.12	0.12
Ethanol	0.7132	168.9	1.15	76.8
2-propanol	0.6654	269.8	214.5	263.7
n-propanol	0.1107	0.1107	0.17	0.17
2-methyl-2-propanol	0.0169	4.22	0.0169	0.0169
n-butanol	0.0884	4.29	0.14	14.95
Ethanal	0.0294	13.49	0.089	0.089
2-propenal	0.0001	0.0001	0.0001	0.0001
Propanal	0.0224	4.23	0.062	0.062
2-methyl-2-propenal	0.0169	0.0169	0.0169	0.0169
Butanal	0.2041	4.41	0.2041	0.2041
Pentanal	0.0071	4.21	0.0091	0.0091
Hexanal	0.0071	4.21	0.0091	0.0091
Heptanal	0.0071	4.21	0.0091	0.0091
Methylbenzene	0.0492	4.25	0.12	0.12
1,2- & 1,3-dimethylbenzenes	0.0445	4.25	0.056	13.02
1,4-dimethylbenzene	0.0169	4.22	0.023	14.84
Ethylbenzene	0.0169	4.22	0.077	4.71
Butyl acetate	0.0071	4.21	0.026	0.026
Dichloromethane	0.0935	11.87	3.46	12.72
Trichlorofluoromethane	0.0169	4.22	0.0169	0.0169
Trichlorotrifluoroethane	0.0564	4.26	0.0564	0.0564
2-propanone	0.1751	23.7	2.12	20.64
2-butanone	0.0885	4.29	1.03	1.03
Cyclohexanone	0.0295	0.0295	0.0295	0.0295
Hexamethylcyclotrisiloxane	0.0169	158.1	143	143
Octamethylcyclotetrasiloxane	0.1205	67.4	47.2	47.2
Carbon monoxide	–	92.5	1.83	1.83
Hydrogen	–	319.6	4.4	4.4
Methane	–	773.7	9.75	9.75

Table 49. STS-106/2A.2b trace contaminant generation summary.

Compound	+ 2A.2a Stowage (mg/hr)	+ Shuttle IMV (mg/hr)	+ Crew (mg/hr)	+ FGB IMV (mg/hr)
Methanol	0.037	15.2	0.13	0.13
Ethanol	0.829	169	1.27	76.9
2-propanol	0.7734	269.9	214.6	236.8
n-propanol	0.1287	0.1287	0.19	0.19
2-methyl-2-propanol	0.0197	4.22	0.0197	0.0197
n-butanol	0.1027	4.31	0.15	14.97
Ethanal	0.0342	13.49	0.094	0.094
2-propenal	0.0001	0.0001	0.0001	0.0001
Propanal	0.026	4.23	0.066	0.066
2-methyl-2-propenal	0.0197	0.0197	0.0197	0.0197
Butanal	0.2077	4.41	0.2077	0.2077
Pentanal	0.0073	4.21	0.0093	0.0093
Hexanal	0.0073	4.21	0.0093	0.0093
Heptanal	0.0073	4.21	0.0093	0.0093
Methylbenzene	0.0572	4.26	0.13	0.13
1,2- & 1,3-dimethylbenzenes	0.0517	4.26	0.064	13.03
1,4-dimethylbenzene	0.0197	4.22	0.026	14.84
Ethylbenzene	0.0197	4.22	0.08	4.71
Butyl acetate	0.0073	4.21	0.026	0.026
Dichloromethane	0.1087	11.88	3.47	12.73
Trichlorofluoromethane	0.0197	4.22	0.0197	0.0197
Trichlorotrifluoroethane	0.0656	4.27	0.0656	0.0656
2-propanone	0.2035	23.75	2.15	20.67
2-butanone	0.1029	4.31	1.04	1.04
Cyclohexanone	0.0343	0.0343	0.0343	0.0343
Hexamethylcyclotrisiloxane	0.0197	158.1	143	143
Octamethylcyclotetrasiloxane	0.1401	67.4	47.6	47.6
Carbon monoxide	–	92.5	1.83	1.83
Hydrogen	–	319.6	4.4	4.4
Methane	–	773.7	9.75	9.75

Table 50. STS-92/3A trace contaminant generation summary.

Compound	+ 2A.2b Stowage (mg/hr)	+ Shuttle IMV (mg/hr)	+ Crew (mg/hr)	+ FGB IMV (mg/hr)
Methanol	0.0396	15.2	0.13	0.13
Ethanol	0.8873	169.1	1.33	76.9
2-propanol	0.8276	269.9	214.6	236.8
n-propanol	0.1377	0.1377	0.2	0.2
2-methyl-2-propanol	0.0211	4.23	0.0211	0.0211
n-butanol	0.1099	4.31	0.16	14.98
Ethanal	0.0366	13.49	0.097	0.097
2-propenal	0.0001	0.0001	0.0001	0.0001
Propanal	0.0278	4.23	0.068	0.068
2-methyl-2-propenal	0.0211	0.0211	0.0211	0.0211
Butanal	0.2095	4.41	0.2095	0.2095
Pentanal	0.0079	4.21	0.0099	0.0099
Hexanal	0.0079	4.21	0.0099	0.0099
Heptanal	0.0079	4.21	0.0099	0.0099
Methylbenzene	0.0612	4.27	0.13	0.13
1,2- & 1,3-dimethylbenzenes	0.0553	4.26	0.067	13.03
1,4-dimethylbenzene	0.0211	4.23	0.027	14.84
Ethylbenzene	0.0211	4.23	0.081	4.71
Butyl acetate	0.0079	4.21	0.027	0.027
Dichloromethane	0.1163	11.89	3.48	12.74
Trichlorofluoromethane	0.0211	4.23	0.0211	0.0211
Trichlorotrifluoroethane	0.0702	4.28	0.0702	0.0702
2-propanone	0.2178	23.77	2.17	20.69
2-butanone	0.1101	4.32	1.05	1.05
Cyclohexanone	0.0367	0.0367	0.0367	0.0367
Hexamethylcyclotrisiloxane	0.0211	158.1	143	143
Octamethylcyclotetrasiloxane	0.15	67.4	47.2	47.2
Carbon monoxide	–	92.5	1.83	1.83
Hydrogen	–	319.6	4.4	4.4
Methane	–	773.7	9.75	9.75

APPENDIX D—PREDICTED TRACE CONTAMINANT CONCENTRATIONS FOR ASSEMBLY MISSIONS 2A THROUGH 3A

Tables 51 through 53 contain predicted versus measured concentrations for STS-88/2A, STS-96/2A.1, and STS-101/2A.2a. Tables 54 and 55 contain predicted concentrations for STS-106/2A.2b and STS-92/3A.

Table 51. Predicted versus measured concentrations for STS-88/2A.

	Standard (mg/m^3)		Node 1 Ingress (mg/m^3)		Node 1 Egress (mg/m^3)	
Compound	**NASA SMAC***	**Russian LPC****	**Predicted**	**Measured**	**Predicted**	**Measured**
Methanol	9	0.2	0.34	0.21	0.59	0.4
Ethanol	2,000	10	1.2	0.63	1.2	0.93
2-propanol	150	1.5	1.4	2.6	1.7	Trace
n-propanol	98	–	0.0008	Trace	0.0014	–
2-methyl-2-propanol	120	–	0.023	Trace	0.0001	–
n-butanol	80	0.8	0.022	Trace	0.082	Trace
Ethanal	4	1	0.16	0.07	0.085	0.44
2-propenal	0.03	0.02	0.013	Trace	0.0002	–
Propanal	95	–	0.029	–	0.0008	–
2-methyl-2-propenal	1.7	–	0.0001	–	0.00016	–
Butanal	120	–	0.022	Trace	0.000014	Trace
Pentanal	110	–	0.021	Trace	0.00006	Trace
Hexanal	4.9	–	0.019	Trace	0.00005	Trace
Heptanal	5.6	–	0.017	Trace	0.00004	Trace
Methylbenzene	60	8	0.021	Trace	0.0008	Trace
1,2- & 1,3-dimethylbenzenes	220	5	0.019	Trace	0.061	Trace
1,4-dimethylbenzene	220	5	0.019	Trace	0.07	Trace
Ethylbenzene	130	–	0.019	Trace	0.023	–
Butyl acetate	190	2	0.018	Trace	0.0001	Trace
Dichloromethane	10	5	0.11	0.05	0.25	Trace
Trichlorofluoromethane	560	–	0.028	–	0.0002	–
Trichlorotrifluoroethane	400	–	0.024	Trace	0.0004	Trace
2-propanone	52	2	0.16	0.14	0.19	Trace
2-butanone	30	0.25	0.025	Trace	0.0073	Trace
Cyclohexanone	60	–	0.0001	Trace	0.0002	Trace
Hexamethylcyclotrisiloxane	90	0.2	0.00007	0.31	0.00008	1.5
Octamethylcyclotetrasiloxane	281	0.2	0.0003	0.23	0.0004	0.96
Carbon monoxide	11	5	0.86	Trace	0.03	Trace
Hydrogen	340	–	4.6	–	6.7	1.9
Methane	5,300	3,342	11.2	Trace	15.8	Trace

* 7-Day SMAC.

** 360-Day LPC.

Table 52. Predicted versus measured concentrations for STS-96/2A.1.

	Standard (mg/m^3)		**Node 1 Ingress (mg/m^3)**		**Node 1 Egress (mg/m^3)**	
Compound	**NASA SMAC***	**Russian LPC****	**Predicted**	**Measured**	**Predicted**	**Measured**
Methanol	9	0.2	1.5	0.38	0.16	0.33
Ethanol	2,000	10	4.8	0.58	8.7	2.1
2-propanol	150	1.5	1.9	0.14	0.22	0.33
n-propanol	98	–	0.0012	–	0.0012	–
2-methyl-2-propanol	120	–	0.00013	–	0.00012	–
n-butanol	80	0.8	0.00068	Trace	0.084	Trace
Ethanal	4	1	0.36	0.20	0.37	0.73
2-propenal	0.03	0.02	0.00087	–	0.00096	–
Propanal	95	–	0.0011	–	0.0017	–
2-methyl-2-propenal	1.7	–	0.00019	–	0.0019	–
Butanal	120	–	0.0015	–	0.0015	–
Pentanal	110	–	0.00005	–	0.00006	Trace
Hexanal	4.9	–	0.00004	–	0.00006	Trace
Heptanal	5.6	–	0.00004	Trace	0.00005	Trace
Methylbenzene	60	8	0.00032	Trace	0.00077	Trace
1,2- & 1,3-dimethylbenzenes	220	5	0.00025	Trace	0.062	Trace
1,4-dimethylbenzene	220	5	0.0001	Trace	0.07	Trace
Ethylbenzene	130	–	0.0001	Trace	0.023	–
Butyl acetate	190	2	0.00004	–	0.00015	–
Dichloromethane	10	5	1.1	0.05	2.2	Trace
Trichlorofluoromethane	560	–	0.00021	–	0.00021	–
Trichlorotrifluoroethane	400	–	0.0004	Trace	0.0004	Trace
2-propanone	52	2	0.16	0.09	0.56	0.18
2-butanone	30	0.25	0.0008	Trace	0.0078	–
Cyclohexanone	60	–	0.00016	Trace	0.00016	Trace
Hexamethylcyclotrisiloxane	90	0.2	0.00008	0.16	0.00008	0.09
Octamethylcyclotetrasiloxane	281	0.2	0.00039	0.35	0.00039	0.12
Carbon Monoxide	11	5	–	Trace	0.03	Trace
Hydrogen	340	–	14.2	0.68	20.5	2.5
Methane	5,300	3,342	32.4	11	46.9	25

* 7-Day SMAC.

** 360-Day LPC.

Table 53. Predicted versus measured concentrations for STS-101/2A.2a.

	Standard (mg/m^3)		Node 1 Ingress (mg/m^3)		Node 1 Egress (mg/m^3)	
Compound	**NASA SMAC***	**Russian LPC****	**Predicted**	**Measured**	**Predicted**	**Measured**
Methanol	9	0.2	3.3	0.69	0.26	0.21
Ethanol	2,000	10	13.6	0.56	17.2	0.58
2-propanol	150	1.5	2.7	0.22	0.25	13
n-propanol	98	–	0.0023	Trace	0.0022	Trace
2-methyl-2-propanol	120	–	0.00014	–	0.027	Trace
n-butanol	80	0.8	0.0009	Trace	0.28	Trace
Ethanal	4	1	1.3	0.21	1.03	0.1
2-propenal	0.03	0.02	0.00019	–	0.000072	Trace
Propanal	95	–	0.0054	Trace	0.0061	Trace
2-methyl-2-propenal	1.7	–	0.00034	–	0.00033	–
Butanal	120	–	0.0018	Trace	0.0018	Trace
Pentanal	110	–	0.000054	Trace	0.000067	Trace
Hexanal	4.9	–	0.000047	Trace	0.000059	Trace
Heptanal	5.6	–	0.000039	Trace	0.00005	Trace
Methylbenzene	60	8	0.00036	Trace	0.00083	Trace
1,2- & 1,3-dimethylbenzenes	220	5	0.00029	Trace	0.062	Trace
1,4-dimethylbenzene	220	5	0.00012	Trace	0.071	Trace
Ethylbenzene	130	–	0.00011	Trace	0.024	Trace
Butyl acetate	190	2	0.000043	–	0.00015	Trace
Dichloromethane	10	5	3.1	0.08	4.4	Trace
Trichlorofluoromethane	560	–	0.0004	–	0.00039	–
Trichlorotrifluoroethane	400	–	0.00047	Trace	0.00046	Trace
2-propanone	52	2	0.59	0.11	1.09	0.2
2-butanone	30	0.25	0.0012	Trace	0.0088	Trace
Cyclohexanone	60	–	0.00018	Trace	0.00018	Trace
Hexamethylcyclotrisiloxane	90	0.2	0.000086	0.09	0.000085	0.6
Octamethylcyclotetrasiloxane	281	0.2	0.00043	Trace	0.00043	0.52
Carbon monoxide	11	5	–	–	0.03	–
Hydrogen	340	–	20.5	–	24.6	2.5
Methane	5,300	3,342	46.9	22	56.5	24

* 7-Day SMAC.

** 360-Day LPC.

Table 54. Predicted concentrations for STS-106/2A.2b.

	Standard (mg/m^3)		Concentration (mg/m^3)		
Compound	NASA SMAC*	Russian LPC**	Prescrub	Ingress	Egress
Methanol	9	0.2	2.2	0.68	0.084
Ethanol	2,000	10	49	0.48	4.5
2-propanol	150	1.5	45.7	0.019	0.019
n-propanol	98	–	7.6	0.0014	0.0013
2-methyl-2-propanol	120	–	1.2	0.00016	0.00016
n-butanol	80	0.8	6.1	0.00073	0.27
Ethanal	4	1	2.0	0.21	0.23
2-propenal	0.03	0.02	0.0059	0.0000022	0.0000022
Propanal	95	–	1.5	0.00083	0.0014
2-methyl-2-propenal	1.7	–	1.2	0.00023	0.00023
Butanal	120	–	12.3	0.0015	0.0015
Pentanal	110	–	0.43	0.000054	0.000068
Hexanal	4.9	–	0.43	0.000048	0.00006
Heptanal	5.6	–	0.43	0.00004	0.000051
Methylbenzene	60	8	3.4	0.0004	0.00085
1,2- & 1,3-dimethylbenzenes	220	5	3.1	0.0003	0.062
1,4-dimethylbenzene	220	5	1.2	0.00012	0.07
Ethylbenzene	130	–	1.2	0.00012	0.023
Butyl acetate	190	2	0.43	0.000044	0.00015
Dichloromethane	10	5	6.4	0.071	0.92
Trichlorofluoromethane	560	–	1.2	0.00025	0.00025
Trichlorotrifluoroethane	400	–	3.9	0.00051	0.0005
2-propanone	52	2	12	0.0093	0.32
2-butanone	30	0.25	6.1	0.00093	0.0077
Cyclohexanone	60	–	2	0.00021	0.00021
Hexamethylcyclotrisiloxane	90	0.2	1.2	0.0001	0.000099
Octamethylcyclotetrasiloxane	281	0.2	8.3	0.0005	0.0005
Carbon Monoxide	11	5	0.03	–	0.03
Hydrogen	340	–	24.73	24.73	29.34
Methane	5,300	3,342	56.84	56.84	67.34

* 7-Day SMAC.
** 360-Day LPC.

Table 55. Predicted concentrations for STS-92/3A.

Compound	Standard (mg/m^3)		Concentration (mg/m^3)		
	NASA SMAC*	Russian LPC**	Prescrub	Ingress	Egress
Methanol	9	0.2	0.44	0.46	0.18
Ethanol	2,000	10	12.5	4.4	8.3
2-propanol	150	1.5	7.4	0.024	0.024
n-propanol	98	–	1.2	0.0015	0.0015
2-methyl-2-propanol	120	–	0.19	0.00017	0.00017
n-butanol	80	0.8	1.3	0.0012	0.088
Ethanal	4	1	0.56	0.33	0.39
2-propenal	0.03	0.02	0.0009	0.0000024	0.0000023
Propanal	95	–	0.25	0.0011	0.0018
2-methyl-2-propenal	1.7	–	0.19	0.00025	0.00025
Butanal	120	–	1.9	0.0016	0.0015
Pentanal	110	–	0.071	0.000059	0.000072
Hexanal	4.9	–	0.071	0.000052	0.000063
Heptanal	5.6	–	0.071	0.000044	0.000054
Methylbenzene	60	8	0.55	0.00043	0.00088
1,2- & 1,3-dimethylbenzenes	220	5	0.56	0.00034	0.062
1,4-dimethylbenzene	220	5	0.26	0.00014	0.07
Ethylbenzene	130	–	0.21	0.00013	0.023
Butyl acetate	190	2	0.071	0.000048	0.00016
Dichloromethane	10	5	2	0.88	1.9
Trichlorofluoromethane	560	–	0.19	0.00028	0.00028
Trichlorotrifluoroethane	400	–	0.63	0.00054	0.00054
2-propanone	52	2	2.3	0.12	0.5
2-butanone	30	0.25	0.99	0.001	0.0079
Cyclohexanone	60	–	0.33	0.00022	0.00022
Hexamethylcyclotrisiloxane	90	0.2	0.19	0.00011	0.00011
Octamethylcyclotetrasiloxane	281	0.2	1.3	0.00053	0.00053
Carbon monoxide	11	5	0.03	–	0.03
Hydrogen	340	–	29.49	29.49	30.59
Methane	5,300	3,342	67.68	67.68	70.32

* 7-Day SMAC.

** 360-Day LPC.

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14. ABSTRACT

During the International Space Station's (ISS's) on-orbit assembly and outfitting, a series of engineering analyses was conducted to evaluate how effective the passive trace contaminant control (TCC) methods were relative to providing adequate operational margin for the active TCC equipment's capabilities aboard the ISS. These analyses were based on habitable module and cargo vehicle offgassing test results. The offgassing test for the fully assembled module or cargo vehicle is an important preflight spacecraft evaluation method that has been used successfully during all crewed spacecraft programs to provide insight into how effectively the passive contamination control methods limit the equipment offgassing component of the overall trace contaminant generation load. The progression of TCC assessments beginning in 1998 with the ISS's first habitable element launch and continuing through the final pressurized element's arrival in 2010 are presented. Early cargo vehicle flight assessments between 2008 and 2011 are also presented as well as a discussion on predictive methods for assessing cargo via a purely analytical technique.

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