TOXICOLOGICAL INVESTIGATION OF MIR AIR DURING NASA 7
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ACRONYMS

CPA	**combustion products analyzer**
DMCPS	**decamethylcyclopentasiloxane**
GC/MS	**gas chromatography/mass spectrometry**
GSC	**grab sample canister**
HMCTS	**hexamethylcyclotrisiloxane**
ISS	**International Space Station**
JSC	**Johnson Space Center**
LPC	**limiting permissible concentration**
LTCO	**low temperature catalytic oxidizer**
OMCTS	**octamethylcyclotetrasiloxane**
SFOG	**solid fuel oxygen generator**
SMAC	**spacecraft maximum allowable concentration**
SSAS	**solid sorbent air sampler**
WI	**work instruction**

TOXICOLOGICAL ASSESSMENT OF MIR AIR DURING NASA 7

1. Introduction

Crew members aboard spacecraft are continuously exposed to pollutants in the respirable air. These pollutants originate from materials offgassing, systems leaks, use of utility chemicals, payload leaks, human metabolism, and microbial metabolism. If pollutant concentrations reach high levels, the crew can experience disturbances in cardiac rhythms, eye and respiratory irritation, headache and disorientation, and be at higher risk for development of chronic disease (e.g. cancer, hepatotoxicity). Furthermore, excessive air pollution can confound biomedical experiments conducted aboard the spacecraft.

On the basis of an agreement made during the 4th meeting of the Environments Subgroup of Medical Working Group 8 (protocol of 29 April 1998), a method to toxicologically assess air quality was agreed to by Russian and U.S. experts for the International Space Station (ISS). According to that agreement, air pollutants are grouped by their mode of toxic action and then their combined effect is calculated using Russian standards to define a no risk condition and U.S. standards to define an acceptable risk condition. The respective risk levels are met if the toxicity index for each toxicological group is below 1.0 based on average concentrations and the appropriate set of standards (see section 2.4). This approach will be applied to pollutant concentrations measured aboard Mir during NASA 7.

1.1 Hypotheses to be Tested

Mir air will meet NASA's standards for crew health during long-term exposure of astronauts to trace contaminants. The standards are specified in JSC 20584.

Mir air will meet Russian standards for crew health during long-term exposure of cosmonauts to trace contaminants (GOST P 50804-95 and Environments Subgroup Protocol, 29 April 1998).

Spatial variations in contaminant concentrations inside the Mir complex will be small (<25%).

Ethylene concentrations will be stable and sufficiently high in concentration to potentially affect plant-growth experiments (ie. concentrations greater than 0.1 ppm).

1.2 Objectives of the Experiment

Our primary objective was to periodically sample Mir air at various locations in the complex to assess the effect of airborne pollutants on crew health. Air samples were analyzed in the NASA-JSC Toxicology Laboratory and the results compared to NASA standards and Russian standards for air quality during long-term missions.

A secondary objective was to continue the assessment of pollutants in various modules at one specific time. The goal was to determine spatial variations within the Space Station Mir complex during nominal operating conditions.

Another objective was to measure ethylene concentrations in air samples to provide data useful to plant-growth scientists. Very low concentrations of ethylene are known to affect the growth and viability of many types of plants.

A final objective emerged during the flight when the combustion products analyzer (CPA) carbon monoxide sensor gave readings exceeding 400 ppm after a thermal failure in the low temperature catalytic oxidizer (LTCO). Our objective following this incident was to understand the accuracy of this reading and assess whether there was a threat to crew health.

1.3 Background and History of the Project

The primary goal of our effort is to determine whether the crew has been exposed to concentrations of air pollutants that could pose a health threat. The planning for these investigations has been the subject of several meetings of the Environments Subgroup of Medical Working Group 8 (1,2) and a report on the various sampling methods and analytical approaches has been published (3). In past Shuttle and Mir missions, formaldehyde concentrations have exceeded NASA's spacecraft maximum allowable concentrations (SMACs). Data from Mir 19 suggested that periodic releases of this irritant into the air may be occurring, and some experiments are believed to have leaked formaldehyde during the Mir 18 flight (4,5). During NASA 2, many of the formaldehyde measurements were above long-term exposure limits, hence, formaldehyde was a major component of the irritant toxicity group (6). In addition, spikes of some of the freons used in the coolant loops have been detected in the atmosphere (7). Early concerns about benzene in the Mir atmosphere have not been confirmed by more recent findings. During NASA 5 the concentrations of ethylene glycol, as estimated with detector tubes, were relatively high and persistent as a result of a coolant-loop leak in early June 1997 (8). All other data for NASA 5 was lost as a result of samplers being isolated in the depressurized Spektr module. A fire in the solid fuel oxygen generator (SFOG) in early 1997 caused us to fly an experimental CPA to help manage risks to crew health if another fire were to occur (9). NASA 6 results showed that Mir air met U.S. standards for toxic pollutants, but did not seem to meet Russian norms for certain toxicological categories (10).

2. Research Methods and Operations

The process leading to toxicological assessment of spacecraft air can be broken into 4 steps. Preflight preparations of the sampling devices are conducted in the NASA-JSC Toxicology Laboratory to ensure that each sampler is clean and can perform as expected. In-flight activities consist of sample acquisition by crew members and appropriate recording of time and sample location. After flight, the samplers are returned to the NASA-JSC Toxicology Laboratory for analysis according to laboratory work instructions (WIs). Once the analytical data are complete, the toxicologist reviews and assembles the data according to toxicological category, applies standard equations to determine air quality, and addresses each of the hypotheses.

2.1 Preflight Preparation of the Air Sampling and Analytical Devices

Grab sample canisters (GSCs) of approximately 350 ml volume (Scientific Instrumentation Specialists, Moscow, ID) were obtained from the company with SUMMA electropolished interior surfaces. The canisters were maintained under controlled conditions during all steps of processing. The preflight preparations were conducted in the following sequence: 1) high vacuum leak check, 2) cleaning and proofing to 5 ppb by gas chromatography/mass spectrometry (GC/MS) for each target compound, 3) evacuation to $<10^{-5}$ torr, 4) addition of 10 ml of 1.51 ppm surrogate standards of acetone-13C, chlorobenzene-D5, and fluorobenzene-D5, and 5) labeling of samplers for use in flight.

The solid sorbent air sampler (SSAS), built for NASA by Valco, Houston, TX, was prepared for flight as follows: 1) each of the 8 tubes was cleaned with ultrapure nitrogen at 250°C and proofed to 5 ppb, 2) each tube was dosed with 20 ml of the same surrogate mixture as used for the canisters, 3) fresh batteries were placed in the unit and the flow through each tube was measured in triplicate using a small volume of clean, humidified air, and 4) the unit was labeled for use during the mission.

Formaldehyde badges (model PF-20) were obtained from Air Quality Research, Research Triangle Park, NC. Preflight preparation involved the following steps: 1) independent determination of the formaldehyde uptake rate of at least 3 badges from each lot, 2) reconfiguration of the commercial badges to fit NASA flight configuration, 3) using a known formaldehyde vapor concentration to dose positive controls that fly with the sampling badges, and 4) packaging badges into kits of 12 badges (including positive controls and unexposed controls) for use during flight.

Preparation of the CPA included the usual functional checkouts performed for the Shuttle unit and preparation of a cable so that the unit could be recharged using Mir power. The CO, HCN, and HCl sensors were zeroed using clean air and the CO sensor was calibrated to read 50 ppm against a 50 ppm standard.

2.2 In flight Sampling of the Atmosphere

Canister "grab" samples were obtained by a crew member by removing the dust cover on the inlet, holding the canister away from the body, opening the valve for approximately 10 seconds, closing the valve, replacing the dust cap, and marking the time and place of sampling. The time-integrated SSAS samples were taken by turning the selector knob to the desired tube and turning on the unit power switch. Normally, approximately 24 hours, later, the power switch was turned off and the selector turned to the park position (position 8).

The formaldehyde badges were used to obtain both personal samples and area samples. All of the personal samples were acquired in pairs with one badge on the back and the other on the front of the crew member. The face cover of the badge was removed and the badge was attached to the crew member's shirt or to a location near the command post with good air flow. At the end of the exposure period (approximately 12 hours for personal samples and 24 hours for area samples), the badge was removed and resealed by a crew member.

The CPA was used to periodically to establish baseline readings, primarily to determine the effect of hydrogen accumulations on the readings of the carbon monoxide sensor. The instrument was used extensively for several days after the burn in the LTCO to follow trends in the carbon monoxide concentrations. An unscheduled canister sample was taken approximately 28 hours after the burn to determine if combustion products were present in the air as a result of the LTCO burn.

2.3 Post-flight Analyses of the Samples

Canister samplers were analyzed by GC and GC/MS according to WIs in the NASA/JSC Toxicology Laboratory. Estimates of ethylene concentrations were made from the GC data. The GC/MS method is an adaptation of the U.S. Environmental Protection Agency's TO-14 method; the primary adaptations being the inclusion of standards for the many polar compounds found in spacecraft air and a separate analysis for freon 82 (perfluorodimethylcyclohexane) and freon 218 (perfluoropropane) using reduced trapping temperatures in the GC/MS inlet. Each SSAS tube was tested for flow after the flight, then thermally desorbed into 500 ml canisters similar to flight canisters except for volume. The canisters were then analyzed in the same way as flight canisters except that there were no GC analyses. Filters were removed from each of the formaldehyde badges and extracted with formaldehyde-free water. The aqueous extracts were analyzed for formaldehyde by a chromotropic acid-spectrophotometric method.

2.4 Toxicological Assessment of the Analytical Data

Toxicological assessment of the analytical concentration data consisted of looking at the combined effects of the mixture of contaminants within a specific toxicological category (e.g. irritants, carcinogens, neurotoxicants, etc.). For each toxicological group, the toxicity index (T_{grp}) was calculated by summing the ratios of the measured concentrations (Cn) to the appropriate exposure limit (L_n). The limit is either the SMAC or the limiting (or extreme) permissible concentration (LPC).

$$T_{grp} = C_1/L_1 + C_2/L_2 + \ldots C_n/L_n$$

According to the Russian method, LPC values for 360 days of exposure were used. According to the U.S. method, for most compounds the 180-day SMAC was used; however, when a 180-d SMAC was not available, the 7-day SMAC was used. The air is considered acceptable if $T<1$ for each toxicological category. Details of the procedure are in JSC 20584 or in the Russian official standard GOST P 50804-95, part 6.2.2.3 (validity date 1/7/96).

2.5 List of Pre-, In-, and Postflight Anomalies

No anomalies were observed.

3. Results

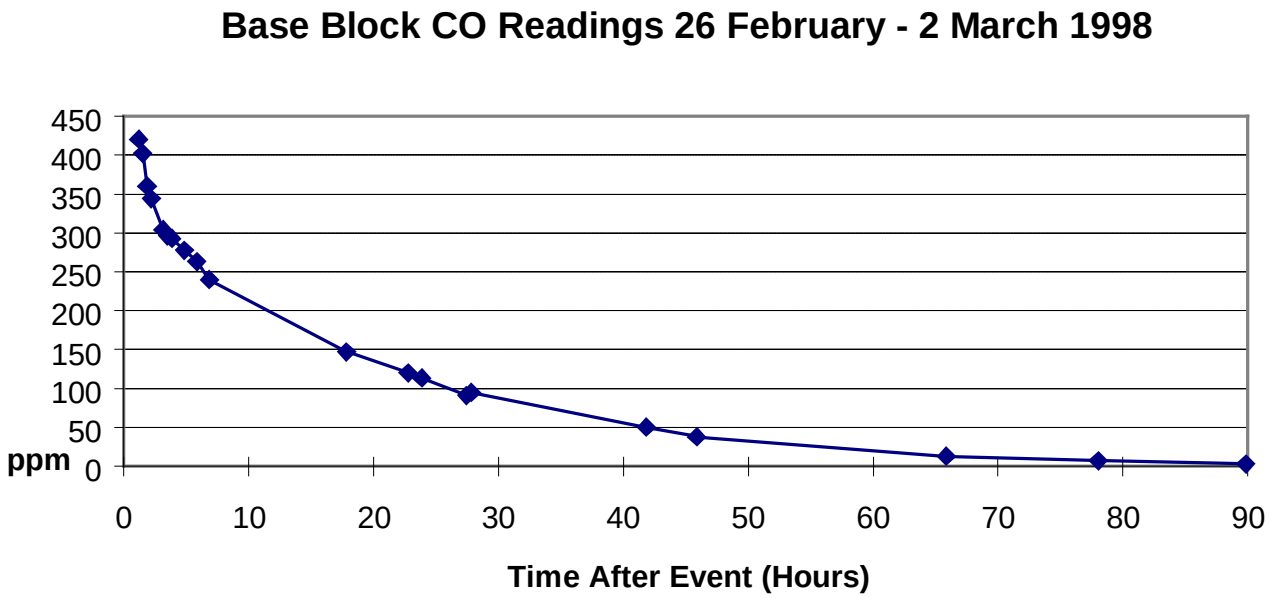
3.1 Analytical Measurements

The detailed analytical results found by GC and GC/MS are presented in tables 1 to 3, and the T values for individual contaminants are presented in tables 4 to 6. The results are given in the following order: canister samples, first SSAS (#1013), and second SSAS (#1011). Sulfur hexafluoride was found in all canisters, but was not quantified because the compound is nontoxic and standards were not readily available. We have reported estimated concentrations of ethylene based on GC data using a single-point calibration (table 1). In table 7 the formaldehyde results have been summarized from the spectrophotometric analysis of the badges exposed on orbit. The T values for each important toxicological category are presented in table 8 for the canister data and the results of comparison of the U.S. and Russian assessment methods is shown in table 9. T-value data from the SSAS (tables 5 and 6) were not separated into toxicological categories.

Inspection of tables 1 to 3 shows that samples taken on or after 5/25 showed measurable concentrations of a C7-oxygenated hydrocarbon. Because a default SMAC of 0.1 mg/m3 was applied, the T value from this compound was a major contributor to the total T-value in tables 4 to 6. A better SMAC to apply to this measurement would be 0.8 mg/m3, which is from the group SMAC for unsaturated ketones (15 ppm), a worst-case possibility for the C7-oxygenated hydrocarbon. Hence, the T value contribution from this compound should be approximately an order of magnitude below those given in tables 4, 5, and 6. The C7 oxygenated hydrocarbon was not included in the toxicological assessment in tables 8 and 9.

Although the SSAS is a time-integrated, sorbent method and the canister samples are instantaneous, non-sorbent samples, the methods give quite similar results for samples taken at about the same time. When the GSC sample from 3/6 and the SSAS sample from 3/6 to 3/7 are compared (column 2 of tables 1 and 2) the analytical results are nearly identical except for n-butanol, carbonyl sulfide, hexamethylcyclotrisiloxane (HMCTS), and limonene. A further comparison of the methods can be made by comparing column 8 of table 1 with column 3 of table 3; these were samples taken in Kvant 2 at about the same time. Again the analytical results were comparable, with the noted exception of acetaldehyde, which was much higher in the SSAS sample. Apparently, during the time of the SSAS sampling there was a new source of acetaldehyde because the measurement in the base block (2.2 mg/m3) compared well with the measurement in Kvant 2 (2.7 mg/m3). Both values were approximately 10-fold higher than other SSAS values, or any of the canister values, taken during NASA 7. It is interesting to note that the ethanol values were unusually high in the SSAS at the same time (34 and 42 mg/m3). Acetaldehyde is a metabolite of ethanol in humans.

During NASA 7 a serious toxcological incident occurred, but the significance was not immediately recognized. Apparently improper operation of the LTCO caused smoke and a major release of carbon monoxide into the Mir atmosphere. The CPA gave very high readings of CO (see figure); however, the crew was seen on down-link video a few hours after the incident and appeared to be doing well. At first the high readings were thought to be due to hydrogen interference, but there was no apparent source for hydrogen releases at this time. Some time later symptoms consistent with CO poisoning were reported. A canister sample was taken approximately 28 hours after the incident and later ground analysis showed a value of 130 ppm, which confirmed that the CPA readings were approximately correct or a little low. The figure below illustrates that the crew received a substantial exposure to CO from the LTCO incident and suggests that positive actions must be taken to prevent this sort of failure during operation of the LTCO on the ISS.



Carbon dioxide is a major pollutant from human metabolism, and the risk of toxicological effects is significant when average concentrations exceed 5-6 mmHg (7-day SMAC = 5.3 mmHg) for long periods of time. As shown in table 4, carbon dioxide concentrations were near or slightly above this norm in GSC samples taken from 3/27 to 6/04.

A comparison of the last 2 columns of table 1 shows the rapid decrease in most pollutants as Mir air is diluted by the generally less-polluted Shuttle air after hatch opening. Most measured contaminants, except isopropanol and bromotrifluoromethane, decrease in Mir within 2 hours of hatch opening. Both of these contaminants tend to be higher in the Shuttle atmosphere, so they increase in the Mir atmosphere after the hatch has been opened. Finally a comparison of the samples taken from 5 locations on 5/25 indicates that pollutants were uniformly distributed within the Mir complex.

3.2 Quality Control and Quality Assurance

Quality assurance and control is an essential part of sample acquisition and analysis. Three surrogate compounds were added before flight to each canister and to each tube in the SSASs, and the SSAS flow rates were checked before and after flight. The surrogate compounds were selected to be representative of various classes of compounds found in most air samples. The surrogate recoveries and flow-rate changes were as follows:

Sampler Group	acetone-C13	fluorobenzene-D5	chlorobenzene-D5	flow differences (+/- from mean)
Mir-canisters	91 to 110 %	87 to 112 %	77 to 119 %	not applicable
Mir-SSAS-1005	39 to 85 %	99 to 117 %	99 to 119 %	5 to 7 %
Mir-SSAS-1003	38 to 66 %	92 to 121 %	102 to 134 %	5 to 7 %

The SSAS tubes include only those tubes that were used during the flight to sample air. The low recoveries of acetone from the SSAS have been observed consistently in earlier sampling with the SSAS. The recent addition of a dual-sorbent system has improved, but not totally solved, this recovery problem.

Another quality assurance procedure was pressure tracking of each canister to detect any leaks. Typically, the pressure was reduced from about 14 psia to about 7 psia as aliquots were removed from the canisters for analysis by GC and GC/MS. Before the GC/MS was used for sample analysis, it had to pass daily calibration checks for 66 compounds and ion abundance criteria for bromofluorobenzene. Positive and negative controls were flown with the formaldehyde badges (trip controls), or kept in the laboratory to determine recoveries from samples with known dosing and suitably-delayed analysis. The recoveries from the 2 trip-control badges were 89 and 95 %.

4. Discussion

4.1 Air Quality Assessment Based on the Canister and Badge Samples

The air quality was generally acceptable during the NASA 7 mission as shown in table 8. The only toxicological group that had a T_{grp} greater than 1.0 was the irritant group. The value was only slightly above the acceptability limit when averaged over the available measurements. Note that this value (1.16) is different from the value that would be obtained by summing all irritants in table 9 (1.00) because table 9 includes only target compounds, whereas, table 8 includes additional irritant compounds that were found in the samples. For example, dimethyldisulfide is not on the target list, but contributed 0.08 to the irritant group T value. It is likely that this compound, which is not often reported, came from microbial metabolism, as occurred during the STS-55 flight of the Shuttle.

4.2 Comparison of U.S. and Russian Methods for Air Quality Assessment

The pollutants targeted for the ISS are shown in table 9 along with average concentrations found in canister samples during NASA 7. Note that the extremely high carbon monoxide concentrations after the LTCO burn have not been included in the analysis since the analysis addresses only nominal conditions. The criteria for the air to be toxicologically acceptable is that each T value be less than 1.0 using long-term SMACs in the calculation. The summary below shows the outcome of the analysis.

Toxicological Group	T_{LPC} (Russian)	T_{SMAC} (U.S.)	Major Components
nervous system depression	**3.65**	0.15	methanol, ethanol
mucosal irritation	**2.18**	1.00	formaldehyde, butanol, propenal
carcinogens	0.34	0.37	furan, acetaldehyde
hepatotoxicants	**1.70**	0.02	ethanol
cardiotoxicants	0.22	0.11	carbon monoxide
respiratory system injury	**16.5**	0.28	polymethylcyclosiloxanes
gonad injury	**11.2**	0.17	polymethylcyclosiloxanes (HMCST excluded)

According to this toxicological analysis, 5 toxicological groups were at least 2-fold above the 1.0 criterion used to define the “no risk” level of airborne contamination, which was based on the Russian LPCs. In contrast, when U.S. SMACs were used to calculate T values, no toxicological group was above 1.0. This shows that pollutants were maintained at the “acceptable risk” level during nominal conditions.

4.2 Ethylene Concentrations in the Mir Atmosphere

Ethylene concentrations gradually decreased during the NASA 7 mission from 2.1 to 0.4 mg/m3 (table 1). The effect of the plant hormone ethylene on growth was first established by the Russian physiologist Dimitry Neljubow in 1901 when he noted that ethylene in illuminating gas causes a triple response in pea seedlings. That response was inhibition of stem elongation, increased stem thickening, and a more horizontal growth pattern. The response of the seedling is in proportion to the ethylene concentration and can be used as a bioassay for the presence of ethylene (11). The changes in growth pattern can be detected at about 0.1 ppm (11); hence, the ethylene concentrations found in the atmosphere of Mir could be expected to affect plant growth.

4.3 Risk to Crew Health from the LTCO Burn

The LTCO incident is of particular concern because it was a serious threat to crew health and was not recognized until well after the crew had been exposed to unhealthy concentrations of carbon monoxide. Prevention of such an incident aboard the ISS is the best strategy to decrease the risk to crew health during LTCO operation. However, it is unclear whether modifications are needed in training, in operational procedures, or in the hardware to prevent a recurrence. The ISS will have an improved combustion products analyzer that can provide first alert if carbon monoxide is suddenly released into the air. The new analyzer also has much less cross sensitivity to hydrogen, so its readings will be more reliable than the experimental instrument used on the Mir.

5. Conclusions

Except after the LTCO burn, the air quality was found to be acceptable by criteria defined by the Environments Subgroup of Medical Working Group 8 (based on U.S. SMACs); however, the "no risk" level, as defined by that group using Russian LPCs, was not achieved. Spatial variations in pollutant concentrations were found to be small between the 5 modules tested. As in past missions, the ethylene concentrations were sufficiently high to affect the growth of some plants. The LTCO burn presented a serious environmental health concern.

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Table 7. FORMALDEHYDE RESULTS BY SAMPLE TYPE

SAMPLE DATE	[1]PERSONAL SAMPLE (PPM)	[2,3]AREA SAMPLE (PPM)
2/5/98	[4]trace	0.03
3/6/98	<0.05	trace
3/27/98	--	trace
3/31/98	[5]trace	--
4/28/98	--	trace
4/2998	trace	--
5/25/98	trace	[6]0.07

[1] Average of front and back badges
[2] Average of duplicate area badges
[3] Area locations were Baseblock
[4] Detected above background, but below the detection limit. A value of ½ the detection limit was used in averaging values.
[5] Only front badge reported.
[6] Only 1 badge deployed.

Table 8. Analyses of Contaminants in Canisters by Toxicological Category

Category	Compound(s)	2/27/98	3/6/98	3/27/98	4/29/98	5/25/98	5/29/98	6/4/98	Average -
		(1)[a]	(1)	(1)	(1)	(5)	(1)	(1)	
Irritants	formaldehyde	(0.18)[b]	0.18	0.38	0.50	1.00	(1.00)	(1.00)	0.61
	acetaldehyde	0.05	0.03	0.02	0.06	0.08	0.11	0.05	0.06
	propenal	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	3-butene-2-one	0.06	0.06	0.00	0.06	0.06	0.06	0.06	0.05
	2-met-2-propenal	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.01
	1-butanol	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	2-butenal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	dimethyldisulfide	0.00	0.12	0.00	0.12	0.10	0.12	0.12	0.08
	Total								**1.16**
Neurotoxicants	methanol	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.02
	carbon monoxide	14.77	0.15	0.06	0.11	0.15	0.06	0.11	0.11[c]
	acetone	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	ethanol	0.00	0.00	0.00	0.00	0.03	0.02	0.01	0.01
	Total								**0.15**
Respiratory System Injury	OMCTS	0.05	0.06	0.07	0.08	0.09	0.17	0.09	0.09
	HMCTS	0.07	0.09	0.11	0.07	0.10	0.25	0.10	0.11
	DMCPS	0.07	0.08	0.15	0.07	0.06	0.09	0.08	0.08
	Total								**0.28**
Carcinogens	furan	0.23	0.23	0.23	0.23	0.23	0.23	0.00	0.23
	1,2-dichloroethane	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	acetaldehyde	0.05	0.03	0.02	0.06	0.08	0.11	0.05	0.06
	2-methyl furan	0.19	0.00	0.00	0.19	0.08	0.19	0.00	0.09
	benzene	0.28	0.12	0.00	0.00	0.00	0.00	0.00	0.06
	Total								**0.46**
Gonad Injury	OMCTS	0.05	0.06	0.07	0.08	0.09	0.17	0.09	0.09
	DMCPS	0.07	0.08	0.15	0.07	0.06	0.09	0.08	0.08
	Total								**0.17**
"Explosives"	methane	0.11	0.11	0.13	0.15	0.18	0.18	0.18	0.15
	hydrogen	0.01	0.01	0.01	0.08	0.06	0.07	0.05	0.04
	Total								**0.19**
Cardiotoxicant	carbon monoxide	14.77	0.15	0.06	0.11	0.15	0.06	0.11	**0.11**[c]
Respiratory Physiology	carbon dioxide	0.39	0.38	0.96	0.99	1.14	1.20	1.47	**0.93**
Hepatotoxicity	dichloromethane	0.01	0.01	0.01	0.02	0.01	0.02	0.01	**0.01**

[a] Number of air samples available for averaging on the date above (except formaldehyde)
[b] Values in parenthesis are more than 3 days from the date in the column, but were the closest available. Results from area samples were used for a given date.
[C] High value on 2/27/98 was not included in the average since it was not representative of nominal air quality.

Table 9. PRIORITY TRACE CONTAMINANTS FOR ASSESSMENT OF AIR QUALITY UNDER NOMINAL ISS OPERATING CONDITIONS: APPLICATION TO NASA 7 DATA

Compound[a]	Russian 360-d[b] LPC (mg/m^3)	U.S. 180-d[c] SMAC (mg/m^3)	NASA 7 average concentr. (mg/m3)	T_{LPC}	T_{SMAC}	Toxic Group[f]
hydrogen[d]	1600	340	14 (2-28)	0.01	0.04	--[d]
methane[d]	3300	3800	560 (430-690)	0.17	0.15	--[d]
pentane	10	590 (7d)	0.04 (0.02-0.12)	0.00	0.00	unknown
hexane	5	180 (7d)	not detected	--	--	
heptane	10	200 (7d)	not detected	--	--	
formaldehyde (area)	0.05	0.05	0.03 (trace-0.09)	0.6	0.6	2
acetaldehyde	1.0	4.0	0.23 (0.09-0.44)	0.23	0.06	2,3
aliphatic aldehydes (benzaldehyde)	1.0	4.0 to 8.0	trace	0.00	0.00	4
propenal	0.02	0.03	trace	0.50	0.33	2
methanol	0.2	9.0	0.17 (0.07-0.30)	0.85	0.02	1
ethanol	10.0	2000	17 (1.4-57)	1.7	0.01	1,4
2-propanol	1.5	150	0.07 (0.05-0.11)	0.05	0.00	1,2
1-butanol	0.8	40	0.48 (0.27-0.64)	0.60	0.01	2
ethylene glycol	10	13	not measured	---	---	1,2,8
acetone	2.0	50	0.44 (0.27-0.70)	0.22	0.01	1
2-butanone	0.25	30	trace	0.10	0.00	2
benzene	0.2 (180d)	0.2	trace (not det-0.06)	0.06	0.06	3,9
toluene	8.0	60	0.12 (0.08-0.15)	0.02	0.00	1,2
xylenes	5.0	220	0.34 (0.20-0.43)	0.08	0.00	2
styrene	0.25	43 (7d)	trace	0.10	0.00	unknown
isopropyl benzene[d]	0.5	49 (7d)	not detected	---	---	---[d]
furan	(3.0)[e]	0.11 (7d)	trace	---	0.23	3
ammonia	1.0	7.0	not measured			
ethyl acetate	4.0	---	0.12 (trace-0.34)	0.03	---	---
carbon monoxide	5.0	10.0	1.1 (tr-1.5[g])	0.22	0.11	1,5
polymethylcyclosiloxanes	0.2	9-15	3.3 (2.2-5.6)	16.5	0.28	6,7
dichloromethane	5.0	10.0	0.14 (0.08-0.19)	0.03	0.01	4
1,2-dichloroethane	0.5	1.0	trace	0.05	0.02	3
Freon 218	150	85,000	89 (67-110)	0.59	0.00	1

[a] Compounds are grouped by structural classes
[b] Russian limits listed in GOST P 50804-95
[c] U.S. limits documented in Spacecraft Maximum Allowable Concentrations for Selected Airborne Contaminants, National Research Council (V1 to V4, 1994-1999) and in JSC 20584.
[d] Monitored for engineering operations
[e] Tetrahydro furan
[f] Toxicity Groups: 1-nervous system effects, 2- mucosal irritant, 3-carcinogen, 4-hepatotoxicant, 5-cardiotoxicant, 6-respiratory system injury, 7-gonad injury, 8-nephrotoxicity, and 9-immunotoxicity
[g] Measurement of 150 mg/m3 after the LTCO burn was not included