# TOXICOLOGICAL INVESTIGATION OF MIR AIR DURING NASA 6
**(September 1997 to January 1998)**


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**May 1998**

## ACRONYMS

| | |
|---|---|
| **CPA** | **combustion products analyzer** |
| **DMCPS** | **decamethylcyclopentasiloxane** |
| **GC/MS** | **gas chromatography/mass spectrometry** |
| **GSC** | **grab sample canister** |
| **HNCTS** | **hexamethylcyclotrisiloxane** |
| **ISS** | **International Space Station** |
| **JSC** | **Johnson Space Center** |
| **LPC** | **limiting permissible concentration** |
| **OMCTS** | **octamethylcyclotetrasiloxane** |
| **SMAC** | **spacecraft maximum allowable concentration** |
| **SSAS** | **solid sorbent air sampler** |
| **WI** | **work instruction** |

# TOXICOLOGICAL ASSESSMENT OF MIR AIR DURING NASA 6

## 1. Introduction

Crewmembers 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 4$^{th}$ 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 for the first time to pollutant concentrations measured aboard Mir during NASA 6.

### 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.

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 approaching 100 ppm. The objective was to understand the cause of this reading since it was doubtful that carbon monoxide was actually present in the Mir atmosphere at such high concentrations.

### 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 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.

## 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 crewmembers 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 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 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$^{o}$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.

### 2.2 In flight Sampling of the Atmosphere

Canister "grab" samples were obtained by a crewmember 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 crewmember. The face cover of the badge was removed and the badge was attached to the crewmember'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 crewmember.

### 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 and freon 218 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

One of the GSCs was returned with a damaged valve seat; as a result, the sample was lost. Another GSC was returned indicating that no vacuum was present at sampling; however, the canister contained a sample which was not analyzed in detail.

## 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 (#1005), and second SSAS (#1003). 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 methods is shown in table 9. T-value data from the SSASs (tables 5 and 6) indicated that the compounds did not need separation into toxicological categories in order to determine that the T values by category were acceptable.

As part of the effort to understand the elevated responses of the CPA's carbon monoxide sensor during the flight, a comparison of the readings and levels of hydrogen found in canister samples was assembled. This comparison was made because the sensor is known to have a cross sensitivity to hydrogen, but this is not a problem when nominal concentrations of hydrogen are present. The results of that comparison are shown in figure 1 for mission days 33 to 113.

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 figure 2, carbon dioxide concentrations were within accepted limits during the mission. There were periods when this range was approached: 1) mid-November, and 2) late December, but the higher concentrations did not persist for more than a few days.

### 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 118% | 79 to 97% | 71 to 89% | not applicable |
| Mir-SSAS-1005 | 24 to 60% | 85 to 92% | 84 to 99% | 3 to 5% |
| Mir-SSAS-1003 | 46 to 59% | 82 to 91% | 76 to 89% | 10 to 16% |

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 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 and cartridges (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 87 and 92%.

## 4. Discussion

### 4.1 Air Quality Assessment Based on the Canister and Badge Samples

The air quality was generally acceptable during the NASA 6 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 is different from the one in Table 9 because of differences in the way formaldehyde was averaged into the calculations.

### 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 6. The criteria for the air to be toxicologically acceptable is that each T value be less than 1.0 using SMACs in the calculation. The summary below shows the outcome of the analysis.

| Toxicological Group | $T_{LPC}$ (Russian) | $T_{SMAC}$ (U.S.) | Major Component |
|---|---|---|---|
| nervous system depression | **2.38** | 0.32 | methanol |
| mucosal irritation | **2.39** | **1.29** | formaldehyde |
| carcinogens | 0.52 | 0.29 | acetaldehyde |
| hepatotoxicants | 0.17 | 0.01 | ethanol |
| cardiotoxicants | 0.50 | 0.29 | carbon monoxide |
| respiratory system injury | **35.5** | 0.54 | polymethylcyclosiloxanes |
| gonad injury | **24.3** | 0.37 | polymethylcyclosiloxanes (HMCTS excluded) |

According to this toxicological analysis, 4 toxicological groups are at least 2-fold above the 1.0 criterion used to define the "no risk" level of airborne contamination, which is based on the Russian LPCs. In contrast, only one toxicological group (irritants) is slightly above 1.0, indicating that most groups of pollutants have been maintained at the "acceptable risk" level as defined by the U.S. SMACs. It is apparent that the Russian toxicologistss need to reevaluate their LPC for polymethylcyclosiloxanes, which are a common component of spacecraft atmospheres. It is also clear that the joint decision to define acceptable air quality in terms of SMACs rather than LPCs was a wise decision on the part of the Environments Subgroup of Medical Working Group 8.

### 4.2 Spatial Variations Found in Canister Samples Taken on January 12

As reported for earlier missions, the spatial variations in concentration found in samples taken from 5 different modules on January 12$^{th}$ showed less than a 25% variation from their mean concentration for most contaminants. The exceptions were acetaldehyde in Kvant 1 (54% high), isopropanol in Priroda (92% high), and 2-ethyl hexanol in Priroda (35% high). The 3 polymethylcyclosiloxanes showed a 2-3 fold variability in samples from the 5 locations. Some of these differences may be due to spurious analytical measurements; however, it is possible that sources localized in a single module could cause the apparent spatial variations.

### 4.3 Ethylene Concentrations in the Mir Atmosphere

Ethylene concentrations were stable during the entire NASA 6 mission. The range of concentrations was from 0.6 to 1.2 mg/m3 (0.5 to 1.0 ppm). 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 (12). The changes in growth pattern can be detected at about 0.1 ppm (12); hence, the ethylene concentrations found in the atmosphere of Mir could be expected to affect plant growth.

## 5. Conclusions

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.

## 6. Bibliography


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**Table 7. FORMALDEHYDE RESULTS BY SAMPLE TYPE**

| SAMPLE DATE | [1]PERSONAL SAMPLE (PPM) | [2]AREA SAMPLE (PPM) |
|---|---|---|
| | | |
| 10/13/97 | 0.036 | [3]0.061 |
| | | |
| 10/30/97 | 0.024 | 0.026 |
| | | |
| 11/20/97 | -- | -- |
| | | |
| 12/18/97 | 0.074 | 0.032 |
| | | |
| 1/12/98 | 0.055 | 0.018 |
| | | |

[1] Average of front and back badges
[2] Average of duplicate area badges
[3] Area locations were Baseblock and Kvant 2

**Table 8. Analyses of Contaminants in Canisters by Toxicological Category**

| Category | Compound(s) | 10/30/97 | 11/20/97 | 12/18/97 | 12/20/97 | 1/12/98 | 1/25/98 | Average - |
|---|---|---|---|---|---|---|---|---|
| | | (1)[a] | (1) | (1) | (1) | (5) | (1) | |
| Irritants | formaldehyde | 0.64 | (0.70)[b] | 0.78 | 0.78 | 0.44 | (0.44) | 0.63 |
| | acetaldehyde | 0.16 | 0.13 | 0.08 | 0.09 | 0.12 | 0.09 | 0.11 |
| | propenal | 0.68 | 0.33 | 0.00 | 0.33 | 0.33 | 0.33 | 0.33 |
| | 3-butene-2-one | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | 2-methyl-2-propenal | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1-butanol | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| | Total | | | | | | | **1.09** |
| Neurotoxicants | methanol | 0.02 | 0.02 | 0.03 | 0.01 | 0.03 | 0.02 | 0.02 |
| | carbon monoxide | 0.51 | 0.46 | 0.38 | 0.19 | 0.06 | 0.06 | 0.28 |
| | acetone | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| | Total | | | | | | | **0.31** |
| Respiratory System Injury | OMCTS | 0.10 | 0.10 | 0.10 | 0.12 | 0.11 | 0.11 | 0.11 |
| | HMCTS | 0.10 | 0.09 | 0.14 | 0.16 | 0.14 | 0.18 | 0.14 |
| | DMCPS | 0.12 | 0.49 | 0.31 | 0.26 | 0.20 | 0.18 | 0.26 |
| | Total | | | | | | | **0.51** |
| Carcinogens | furan | 0.23 | 0.23 | 0.23 | 0.23 | 0.13 | 0.00 | 0.17 |
| | 1,2-dichloroethane | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| | acetaldehyde | 0.16 | 0.13 | 0.08 | 0.09 | 0.12 | 0.09 | 0.11 |
| | Total | | | | | | | **0.30** |
| Gonad Injury | OMCTS | 0.10 | 0.10 | 0.10 | 0.12 | 0.11 | 0.11 | 0.11 |
| | DMCPS | 0.12 | 0.49 | 0.31 | 0.26 | 0.20 | 0.18 | 0.26 |
| | Total | | | | | | | **0.37** |
| "Explosives" | methane | 0.10 | 0.10 | 0.12 | 0.10 | 0.11 | 0.13 | 0.11 |
| | hydrogen | 0.16 | 0.13 | 0.09 | 0.07 | 0.02 | 0.03 | 0.08 |
| | Total | | | | | | | **0.19** |
| Cardiotoxicant | carbon monoxide | 0.52 | 0.49 | 0.38 | 0.19 | 0.06 | 0.06 | 0.28 |
| | Freon 82 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| | Total | | | | | | | **0.29** |
| Respiratory Physiology | carbon dioxide | 0.87 | 0.93 | 0.85 | 0.88 | 0.40 | 0.53 | **0.74** |
| Hepatotoxicity | dichloromethane | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 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.

**Table 9. PRIORITY TRACE CONTAMINANTS FOR ASSESSMENT OF AIR QUALITY UNDER NOMINAL ISS OPERATING CONDITIONS: APPLICATION TO NASA 6 DATA**

| Compound[a] | Russian 360-d[b] LPC (mg/m$^3$) | U.S. 180-d[c] SMAC (mg/m$^3$) | NASA 6 average concentr. (mg/m3) | $T_{LPC}$ | $T_{SMAC}$ | Toxic Group[f] |
|---|---|---|---|---|---|---|
| hydrogen[d] | 1600 | 340 | 29 (7-55) | 0.02 | 0.09 | --[d] |
| methane[d] | 3300 | 3800 | 420 (380-510) | 0.13 | 0.11 | --[d] |
| pentane | 10 | 590 (7d) | 0.17 (0.05-0.36) | 0.02 | 0.00 | unknown |
| hexane | 5 | 180 (7d) | not detected | | | |
| heptane | 10 | 200 (7d) | not detected | | | |
| formaldehyde (area) | 0.05 | 0.05 | 0.04 (0.02-0.07) | 0.84 | 0.84 | 2 |
| acetaldehyde | 1.0 | 4.0 | 0.47 (0.32-0.63) | 0.47 | 0.12 | 2,3 |
| aliphatic aldehydes (benzaldehyde) | 1.0 | 4.0 to 8.0 | trace | 0.00 | 0.00 | 4 |
| propenal | 0.02 | 0.03 | 0.01 (tr-0.02) | 0.50 | 0.33 | 2 |
| methanol | 0.2 | 9.0 | 0.21 (0.13-0.43) | 1.05 | 0.02 | 1 |
| ethanol | 10.0 | 2000 | 1.49 (0.9-2.2) | 0.15 | 0.00 | 1,4 |
| 2-propanol | 1.5 | 150 | 0.06 (tr-0.27) | 0.04 | 0.00 | 1,2 |
| 1-butanol | 0.8 | 40 | 0.27 (0.19-0.47) | 0.34 | 0.01 | 2 |
| ethylene glycol | 10 | 13 | not measured | --- | --- | 1,2,8 |
| acetone | 2.0 | 50 | 0.32 (0.27-0.44) | 0.16 | 0.01 | 1 |
| 2-butanone | 0.25 | 30 | trace | 0.10 | 0.00 | 2 |
| benzene | 0.2 (180d) | 0.2 | not detected | ---- | ---- | 3,9 |
| toluene | 8.0 | 60 | 0.15 (0.10-0.18) | 0.02 | 0.00 | 1,2 |
| xylenes | 5.0 | 220 | 0.38 (0.25-0.47) | 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) | not det.-trace | --- | 0.15 | 3 |
| ammonia | 1.0 | 7.0 | not measured | | | |
| ethyl acetate | 4.0 | --- | trace | -- | --- | --- |
| carbon monoxide | 5.0 | 10.0 | 2.9 (tr-5.2) | 0.58 | 0.29 | 1.5 |
| polymethylcyclosiloxanes | 0.2 | 9-15[g] | 6.5 (4.0-9.4) | 35.5 | 0.54 | 6,7 |
| dichloromethane | 5.0 | 10.0 | 0.12 (0.06-0.21) | 0.02 | 0.01 | 4 |
| 1,2-dichloroethane | 0.5 | 1.0 | trace | 0.05 | 0.02 | 3 |
| Freon 218 | 150 | 85,000 | 57 (23-198) | 0.38 | 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, 1994-1998) 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] Values of 50-75 were mistakenly entered by the U.S. side in the original protocol of 29 April 1998

**Figure 1a. Hydrogen in Mir Atmosphere-NASA 6**

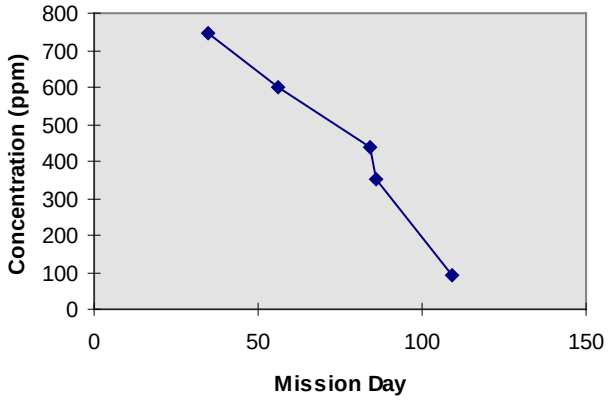
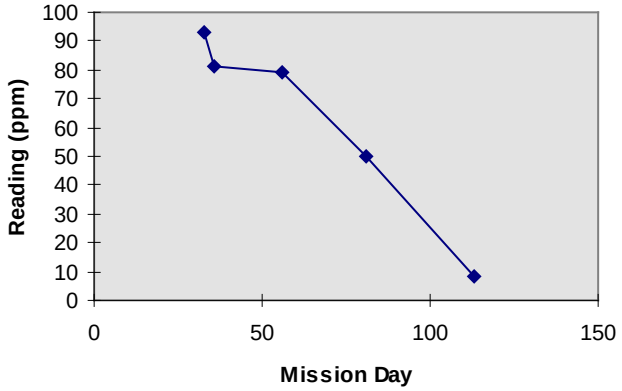



**Figure 1b. Sensor Readings (CO)**



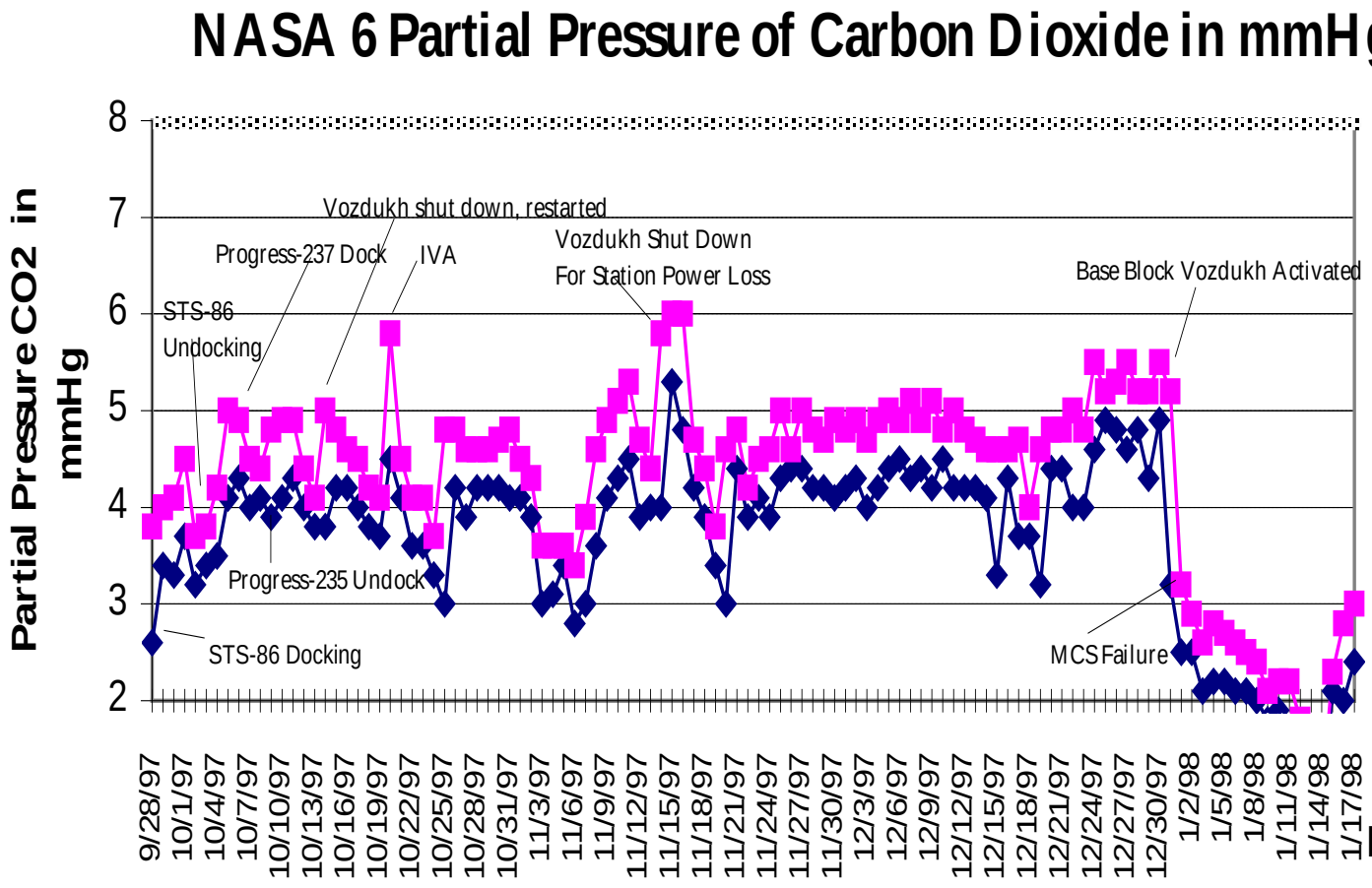



**Figure 2. Carbon Dioxide Measurements**