MSD007
TOXICOLOGICAL INVESTIGATION OF MIR AIR DURING NASA 4
(February 1997 to May 1997)

180-day Report

Principle Investigator: John T. James, Ph.D
NASA-JSC
Medical Operations Branch
Houston, TX 77058

Co-Investigators: Thomas F. Limero, Ph.D.
Steve W. Beck, M.S.
Lilly Yang, Ph.D.
Millie P. Martin, B.S.
Marilyn L. Matney, Ph.D.
Phillip A. Covington, B.S.
John F. Boyd, M.S.
Debra A. W. Lind, M.S.

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September 1997

TOXICOLOGICAL ASSESSMENT OF MIR AIR DURING NASA 4

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). Furthermore, excessive air pollution can confound biomedical experiments conducted aboard the spacecraft.

On February 23, 1997 an oxygen generator caused a fire that severely polluted the Mir atmosphere and forced the crew to don respiratory protection. Some air samples taken about 3 hours after the fire were returned on Soyuz in March and a report of their analysis has been issued. The present report includes important additional data from the period soon after the fire and nominal sampling data taken before and long after the fire.

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.

The mixing time required for air contaminants to reach a steady state will be less than 6 hours after hatch opening between the Mir and Shuttle.

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

The breath of crew members will not cause higher measurements of formaldehyde with the badge samplers.

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 for air quality during long-term missions.

Secondary objectives were to assess the rate of pollutant mixing when the Shuttle hatch is opened in the docked phase. There are specific pollutants that accumulate in Mir or in Shuttle air and can be observed to redistribute or be diluted after hatch opening between the two spacecraft. Another objective was comparison of 5 samples taken simultaneously from different locations within the Mir complex. A final objective was to assess whether formaldehyde in the exhaled breath of crew members was able to cause higher readings of formaldehyde in badge samples. This possibility had been voiced by the Russian side.

These objectives were altered by the solid fuel oxygen generator (SFOG) fire which occurred on February 23, 1997. All canister samplers were used immediately after the fire and both solid sorbent air samplers (SSASs) were cycled through the 5 remaining positions within 2 days after the fire. The results from SSAS facilitated the accomplishment of a new objective: to measure the scrubbing of fire-generated pollutants from the Mir atmosphere by the air revitalization system. The opportunity for such measurements has never occurred during space flight or during ground-based testing.

Two additional objectives emerged during or after the flight. Comparison of formaldehyde badge results with a formaldehyde-active-sampler (FAS) method were scheduled for STS-86; however, the opportunity developed to fly the comparison experiment on STS-84 during the docked phase, so the experiment was flown early. Requests from Russian and American plant scientists to quantify ethylene in the atmosphere were received after the mission. The original samples were depleted; however, ethylene appears in the gas chromatographic (GC) analysis for methane

and it was possible to use a postanalysis, single-point calibration to estimate the ethylene concentrations from the original chromatograms. Because of the stability and linearity of the GC procedure, we believe that the estimates provided are accurate; however, a formal method is under development with more appropriate standards.

1.3 Background and History of the Project

The 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.

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 standard operating procedures (SOPs). 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

Canister samplers 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°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.

The FAS method was adapted from U.S. Environmental Protection Agency (EPA) method TO-11A to confirm the accuracy of the badge samplers. The FAS method has the advantage that the sample stream is pumped through the sorbent cartridge so there is no dependence on ambient face velocity as in the badge method. Preflight the flows through representative cartridges were measured using the flight pump. These were later matched to postflight flows, which showed no significant change as a result of the flight.

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); however, sampling after the fire did not follow this procedure because the goal changed to assessment of the rate of scrubbing of the contaminants associated with the fire (see 2.5 for details).

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.

During the STS-84 docked phase the badge and FAS methods were compared in 2 sessions. In session one, 3 badges were exposed simultaneously for 25.3 hours and 4 cartridge samples were taken in the first half of this session over intervals ranging from 22 to 56 minutes. In the second session, 3 badges were exposed simultaneously for 10.4 hours and 4 cartridge samples were taken separately during intervals from 21 to 59 minutes within the 10.4 hour interval. The actual sampling was not performed according to the sampling plan, so data were not ideal for comparison of the 2 methods in flight.

2.3 Post-flight Analyses of the Samples

Canister samplers were analyzed by GC and GC/MS according to work instructions (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. EPA'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. After their return, the FAS cartridges were eluted with 5 mL of acetonitrile. After dilution to a known volume, samples were analyzed by high pressure liquid chromatography using an ultraviolet absorption detector at 360 nm. By comparison to standards and blanks, and knowing the sampling volume (time), the original airborne concentration was calculated.

2.4 Toxicological Analyses of the Analytical Data

Toxicological analysis of the analytical concentration data consists of looking at the combined effects of the mixture of contaminants within a specific toxicological category (e.g. irritants, carcinogen, neurotoxicant, etc.). For each toxicological category, the toxicity index (T) is calculated by summing the ratios of the measured concentrations to the appropriate SMAC. 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. The calculation is identical to that given in the Russian official standard GOST P 50804-95, part 6.2.2.3 (validity date 1/7/96); however, the Russians use quite different values for maximum allowable concentrations.

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

A fire in the solid fuel oxygen generator at 2245 on February 23, 1997 (DMT) caused an abrupt reordering of priorities for air sampling, sample return, and sampler replacement. Approximately 3 hours after the fire the

remainder of the 12 canisters sent on STS-81 were used and 4 of these were returned on a Soyuz in early March. These canisters were analyzed and a report issued (8). Five replacement canisters were sent up on Progress and these, along with the remaining 8 from STS-81, were returned aboard STS-84. At the time of the fire, 2 tubes in each SSAS had been used as scheduled to take air samples (1/22 and 2/12), but after the fire the remaining 5 tubes in each SSAS were used to acquire air samples. Replacement SSASs were not sent up on the Progress and the used SSASs were returned on STS-84. Also at the time of the fire, 8 formaldehyde badges had been deployed on schedule; however, the remaining 12 were used immediately after the fire. Four prefire and 12 postfire badges were returned on Soyuz and their analysis described (8). Another formaldehyde monitoring kit (containing 10 sampling badges) was sent up on Progress in March and the nominal sampling plan was continued. These 10 badges, along with the 4 remaining prefire badges were returned on STS-84.

3. Results

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 (#1002), and second SSAS (#1004). Sulfur hexafluoride was found in all canisters, but was not quantified because the compound is nontoxic and standards were not readily available. For the first time we have reported estimated concentrations of ethylene based on GC data using a single-point calibration. In table 7 the formaldehyde results have been summarized from the spectrophotometric analysis of the badges exposed on orbit. The badge results are compared to the FAS results obtained during the STS-84 docked phase in table 8. The T values for each important toxicological category are presented in table 9 for the canister data. T-value data from the SSAS (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 below 1. The only time overall SSAS T-values were greater than 1 was immediately after the fire.

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	101 to 128 %	97 to 111 %	82 to 116 %	not applicable
Mir-SSAS-1002	3 to 31 %	72 to 92 %	66 to 84 %	0.3 to 2.0 %
Mir-SSAS-1004	16 to 100 %	104 to 115 %	92 to 103 %	7 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 will solve 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 90 and 94 % and recoveries from the 2 cartridge trip controls were 80 and 81 %.

4. Discussion

4.1 Air Quality Assessment Based on the Canister and Badge Samples

The mission air quality assessment (table 9) was based on canister and badge samples taken during nominal conditions. An incidental finding was that the knobs and valve bodies of the canisters used to take samples soon

after the fire were heavily corroded. The pollutants in samples acquired soon after the SFOG fire were not considered representative of the general air quality, so they were not included in this analysis. Seven canister samples, three taken simultaneously on May 12, were considered in the assessment and the area formaldehyde results given in table 7 were considered. The spacing of the samples was very uneven because all available canisters were used immediately after the fire and none were available until more were taken to Mir in April. Since the total T values (table 4) ranged from 1.93 to 3.44, the compounds contributing more than 0.01 to these values were analyzed by toxicological category as shown in table 9. Fluorotrimethyl silane and 2-methylfuran were difficult to assign to toxicological categories because of the paucity of toxicological data. Silanes are known to be moderately irritating and not very systemically toxic, so the fluorotrimethyl silane was assigned to the irritant group. The toxicity of 2-methylfuran was deduced from very limited information on 2-ethylfuran suggesting that this alkylfuran is primarily nephrotoxic, but also can cause hepatotoxicity in mice (9). Despite these additions, the time-averaged T values for each toxicological category were less than 1.0, indicating acceptable air quality by U.S. standards.

4.2 Spatial Variations Found in Canister Samples Taken on May 12

Three canister samples were taken almost simultaneously at 1015 on 12 May 1997. Most compounds showed little variability among the three samples; however, a few showed variability greater than a factor of 2. These were acetaldehyde (0.06 to 0.23 mg/m3), octafluoropropane (32 to 180 mg/m3), hexamethylcyclotrisiloxane (0.92 to 2.1 mg/m3), and 2-ethyl hexanol (0.07 to 0.21 mg/m3). Some of the variability can be attributed to analytical variability when concentrations are near 0.1 mg/m3 or below. The siloxane compound has often shown variable concentrations; however, the large difference in the octafluoropropane concentrations is difficult to explain in terms of analytical variability. The 3 samples were run in sequence on the same day and perfluorodimethylcyclohexane was quantified in the same run and found to be similar in all 3 samples (2.8 to 3.0 mg/m3). It is possible that a source local to the Specktr module (e.g. a coolant loop) was releasing octafluoropropane at the time the sample was taken in that module. As in earlier reports, we conclude that spatial variations in the Mir atmosphere are generally small for almost all compounds.

4.3 Contribution of Crew Member's Breath to Formaldehyde Mesasurements

The results of the air sampling with personal badges worn on the front and back of crew members shows clearly that formaldehyde from the breath does not contribute significantly to formaldehyde readings (table 7). Samples acquired from the front of the crew member showed formaldehyde concentrations the same or below those found in badges worn on the back. Furthermore, area and personal samples taken at the same time agree well with each other.

4.4 Comparison of Badge and FAS Methods for Formaldehyde

Because formaldehyde concentrations were very low during the docked phase, the on-orbit comparison of badge and FAS methods was quite limited. One would not expect the measurements to be identical with the methods because the badge integrates the formaldehyde concentrations over a long sampling period, whereas the FAS acquires samples in short segments of time. Samples acquired during the first session show good agreement between the methods at extremely low concentrations (8 ppb vs. 10 ppb); however, the results from session 2 indicate slightly higher (8 ppb vs. 30 ppb) readings from the badges when compared to the FAS. This result emphasizes the difficulty of comparing analytical methods based on in-flight measurements since one cannot vary the test concentrations over suitable ranges.

Another opportunity to compare these methods occurred when high formaldehyde concentrations were indicated by the badges in use in the Lunar Mars Life Support Test Project (LMLSTP), Phase II. During this 60-day human test the formaldehyde concentrations approached 0.20 ppm. On 7 February 1997 the badge method indicated a concentration of 0.14 ppm. At the same time impinger samples and FAS cartridges were used to take samples. The 2 impinger results were 0.14 and 0.15 ppm, and the 4 FAS results were 0.16, 0.14, 0.14, and 0.14 ppm. These findings confirm the validity of the badges when compared to the other methods. No further validation testing is planned (10).

4.5 Dynamics of Mir Pollutants as Found in the SSAS after the Fire

The results from the 2 SSAS units provided nearly ideal sampling of pollutants associated with the SFOG fire. Two "baseline" samples had been obtained 31 and 10 days before the fire and 5 samples were obtained at average times of 5 h, 8 h, 12 h, 20 h, and 32 h after the fire. Inspection of the data in tables 2 and 3 showed that the following compounds were associated with the fire: isopropanol, benzene, toluene, styrene, and 2 nitriles. Also linked to the fire, although less clearly, were acetone and perfluorodimethylcyclohexane. Certainly some of these compounds such as benzene, styrene, toluene, and the nitriles can be associated directly with polymer fires; however, the origin of isopropanol, acetone, and the freon may have been indirect. For example, these could have come from the fire extinguishant or from excess outgassing of hot materials in the vicinity of the fire. Regardless of the origin of the products, all were removed to near-baseline concentrations within 32 h as illustrated in figure 1 for the base block samples. Correspondingly, the total T values from the core-module SSAS show prefire values of 0.5, these go to 4.4 for the 5 h postfire sample, and decrease to 0.77 by 32 h after the fire. These SSAS measurements confirm that the Mir air revitalization system has considerable capacity to remove fire-associated pollutants very rapidly. Russian experts had predicted 90% removal in 36 h and this result confirms that prediction (11).

4.5 Additional Fire-Associated Compounds from the Canister Samples

The canister results (table 1) indicate several additional compounds that may be associated with the fire. These include chloromethane, bromomethane, 1,3-butadiene, and carbon monoxide. In the samples taken approximately 3 hours after the fire the carbon monoxide concentrations were near the 24-hour SMAC of 20 mg/m3. The highest concentration (23 mg/m3) was found in the base block, which is adjacent to the Kvant module where the fire occurred. Indications from previous data were that carbon monoxide was being effectively scrubbed from the atmosphere (8). The halomethanes may have originated from reaction between atmospheric methane and halogenated products from the fire, and 1,3-butadiene may have originated from a polymeric material burned or overheated during the fire. Polyvinyl chloride (a source of organochlorine compounds and hydrogen chloride) was thought to be a major component of the material burned during the fire (11).

4.7 Ethylene Concentrations in the Mir Atmosphere

Ethylene concentrations were remarkably stable during the entire NASA 4 mission, even in samples taken soon after the fire. The range of concentrations was from 1.3 to 1.9 mg/m3 (1.1 to 1.7 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 Mir complex continues to exhibit air quality which substantially meets U.S. standards for human-rated spacecraft during nominal conditions. Spatial variations in pollutants from module to module were small for most compounds. Average formaldehyde concentrations were well within U.S. and Russian long-term exposure limits. The accuracy of the badges has been confirmed by comparison to the FAS method, primarily based on data from the ground-based LMLSTP. Paired sampling on the front and back of crew members demonstrated that there was no detectable formaldehyde contribution from the breath. Ethylene concentrations in the atmosphere were sufficiently high to cause effects on plant growth.

The SFOG fire and subsequent air sampling by the crew enabled us to detect many pollutants associated with the fire. Carbon monoxide concentrations in canister samples taken about 3 hours after the fire were near the 24 hour SMAC for carbon monoxide. Data from the SSAS before and after the fire demonstrated that the fire generated toxic pollutants (e.g. benzene), but that these pollutants were scrubbed to nominal concentrations within 32 hours.

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TABLE 7. RESULTS FOR BADGE SAMPLES DEPLOYED DURING NASA 4

LAB TRACKING NUMBER	SAMPLE DESCRIPTION	EXPOSURE START DATE	FORMALDEHYDE CONCENTRATION PPM

AA01820	[1]Personal-F	1/23/97	0.05
AA01821	[1]Personal-B	1/23/97	0.06
AA01822	[2]Area (BB)	1/23/97	0.05
AA01823	[2]Area (BB)	1/23/97	0.04
AA01721	Personal-F	4/16/97	0.01
AA01722	Personal-B	4/16/97	0.01
AA01723	Area (BB)	4/16/97	0.01
AA01724	Area (BB)	4/16/97	0.01
AA01725	Personal-F	5/12/97	0.01
AA01726	Personal-B	5/12/97	0.01
AA01727	Area (BB)	5/12/97	0.01
AA01728	Area (BB)	5/12/97	0.01
AA01729	[3]Area (Kry)	5/12/97	0.01
AA01730	[3]Area (Kry)	5/12/97	0.01

[1]Personal-F refers to a badge worn as a personal monitor in the breathing zone. Personal-B refers to a badge worn as a personal monitor and attached to the back.
[2]Area (BB) badges placed side by side in the base block (Mir core module)
[3]Area (Kry) badges placed side by side in the Krystall module

TABLE 8. RESULTS FOR FASC STUDY CONDUCTED DURING STS-84 DOCKED PHASE

SAMPLE TYPE	SESSION #1 (FD 3) FORMALDEHYDE CONC.	SESSION #2 (FD 4) FORMALDEHYDE CONC.
Area Badge	0.01 ppm	0.04 ppm
Area Badge	0.01 ppm	0.03 ppm
Area Badge	<0.01 ppm	0.03 ppm
	avg. = 0.01 ppm	avg. = 0.03 ppm
Cartridge #1	6 ppb	8 ppb
Cartridge #2	8 ppb	8 ppb
Cartridge #3	8 ppb	8 ppb
Cartridge #4	8 ppb	8 ppb
	avg. = 8 ppb	avg. = 8 ppb

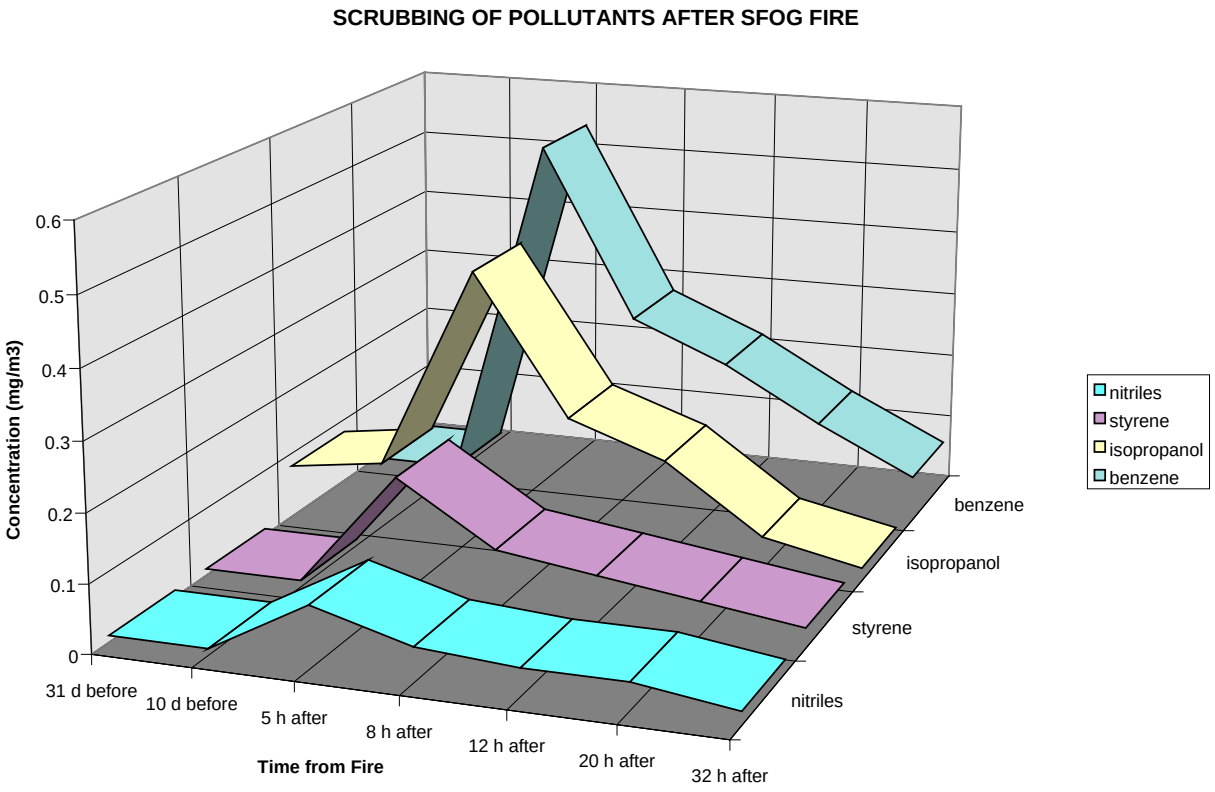
Table 9. Analyses of Contaminants in Canisters by Toxicological Category (excludes samples after fire)

Category	Compound(s)	2/12/97 (1)[a]	4/16/97 (1)	5/10/97 (1)	5/12/97 (3)	5/19/97 (1)	3-Month Average
Irritants	formaldehyde	(1.12)[b]	0.25	0.25	0.25	(0.25)	
	acetaldehyde	0.04	0.02	0.02	0.03	0.02	
	propenal	0.33	0.33	0.00	0.33	0.00	
	3-butene-2-one	0.06	0.06	0.06	0.06	0.06	
	dimethyldisulfide	0.00	0.12	0.12	0.12	0.12	
	fluorotrimethyl silane	0.23	0.09	0.06	010	0.01	
	Total	1.78	0.87	0.51	0.89	0.46	0.90
Neurotoxicants	methanol	0.02	0.02	0.01	0.01	0.01	
	carbon monoxide	0.60	0.06	0.46	0.57	0.16	
	Total	0.62	0.08	0.47	0.58	0.17	0.38
Respiratory System Injury	OMCTS	0.06	0.05	0.01	0.09	0.05	
	HMCTS	0.06	0.06	0.01	0.15	0.08	
	DMCPS	0.09	0.04	0.00	0.05	0.08	
	Total	0.21	0.15	0.02	0.29	0.21	0.18
Carcinogens	furan	0.23	0.23	0.23	0.23	0.23	
	1,2-dichloroethane	0.02	0.02	0.02	0.02	0.02	
	Total	0.25	0.25	0.25	0.25	0.25	0.25
Gonad Injury	OMCTS	0.06	0.05	0.01	0.09	0.05	
	DMCPS	0.09	0.04	0.00	0.05	0.08	
	Total	0.15	0.09	0.01	0.14	0.13	0.10
"Explosives"	methane	0.16	0.17	0.17	0.17	0.11	
	hydrogen	0.02	0.01	0.04	0.04	0.02	
	Total	0.18	0.18	0.21	0.21	0.13	0.18
Cardiotoxicant	carbon monoxide	0.60	0.06	0.46	0.57	0.16	
	Freon 82	0.01	0.01	0.01	0.01	0.00	
	Total	0.61	0.07	0.47	0.58	0.16	0.38
Respiratory Physiology	carbon dioxide	1.07	0.92	0.87	0.89	0.74	0.90
Hepatotoxicity	dichloromethane	0.03	0.01	0.01	0.01	0.01	
	2-methylfuran	0.19	0.00	0.19	0.13	0.00	
	Total	0.22	0.01	0.20	0.14	0.01	0.12
Nephrotoxicity	2-methylfuran	0.19	0.00	0.19	0.13	0.00	0.10

[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. Area and personal samples were averaged for a given date.

FIGURE 1


SCRUBBING OF POLLUTANTS AFTER SFOG FIRE
Concentration (mg/m3)
0.6
0.5
0.4
0.3
0.2
0.1
0
31 d before
10 d before
5 h after
8 h after
12 h after
20 h after
32 h after
Time from Fire
benzene
isopropanol
styrene
nitriles
nitriles
styrene
isopropanol
benzene