Section 4

Environmental Health

4

Environmental Health

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BACKGROUND

The Environmental Health activity for the Extended Duration Orbiter Medical Project (EDOMP) was formed to develop an overall strategy for safeguarding crew members from potential airborne hazards anticipated on missions of extended duration. These efforts were necessary because of major modifications to the air revitalization system of the U.S. Space Shuttle and an increased potential for environmental health risks associated with longer space flights.

Degradation of air quality in the Shuttle during a space flight mission has the potential to affect the performance of the crew not only during piloting, landing, or egress, but also during space flight. It was anticipated that the risk of significant deterioration in air quality would increase with extended mission lengths and could result from: (1) a major chemical contamination incident, such as a thermodegradation event or toxic leak, (2) continual accumulation of volatile organic compounds to unacceptable levels, (3) excessive levels of airborne particles, (4) excessive levels of microorganisms, or (5) accumulation of airborne pathogens.

CRITICAL QUESTIONS

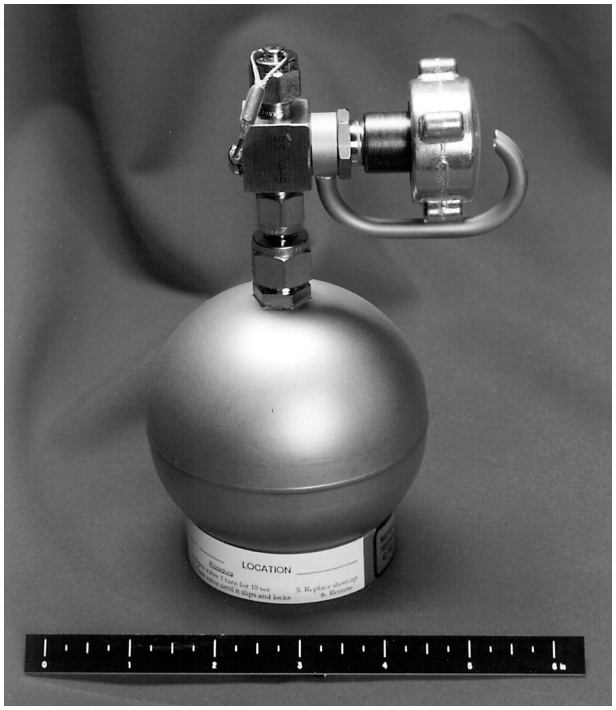
The critical questions addressed by the EDOMP Environmental Health activity were: (1) Do the concentrations of particulate and chemical pollutants, or airborne bacteria and fungi, accumulate to unacceptable levels during long duration flights? Do the levels increase continuously as a function of mission duration, or are stable levels reached after a few days of space flight? (2) Do changes in the population dynamics of microorganisms occur as the mission proceeds, resulting in changes in bacterial and fungal species present in the air and on surfaces? (3) What chemical pollutants should be monitored as a result of a contingency event, such as an accidental release of a pollutant from an experiment or a fluid system, or from overheating of onboard electronics? (4) What are the appropriate crew member exposure limits to chemical pollutants for long duration (up to 30 days) Shuttle flights? (5) What are the best air sampling techniques for monitoring particulates, chemical pollutants, and microorganisms in the Shuttle during long duration space flights?

Originally, the EDOMP was conceived to focus on 28-day orbital missions. Later, when the focus was reduced to flights of 16 days, the criticality of the questions listed above diminished. However, each remained important because of the potential for the space craft environment to affect crew health in subtle ways.

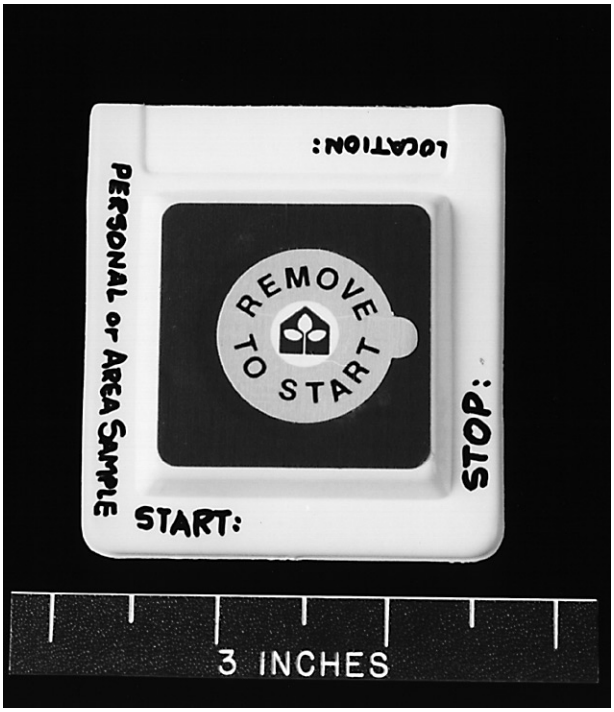
APPROACH

The EDOMP Environmental Health activity was conducted as three investigations explained below. Each was conducted as a Detailed Supplementary Objective (DSO). DSO 471 was conducted on two Shuttle missions to characterize respirable airborne particulate matter in the Shuttle atmosphere. DSO 488 was conducted on one Shuttle flight to measure formaldehyde, using passive dosimetry. DSO 611 was conducted on nine Shuttle flights to evaluate innovative air monitoring instrumentation and to characterize the Shuttle atmosphere. Principal investigators for these studies were: DSO 471, Dane Russo; DSO 488, John James; and DSO 611, Duane Pierson.

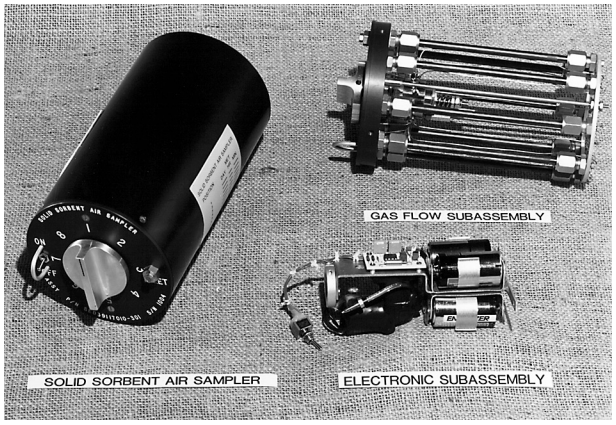
The accumulation of chemical pollutants was evaluated by sampling air contaminants periodically during each extended flight and determining whether concentrations were increasing with time. Instantaneous samples were obtained with grab sample containers (GSC). Each GSC was used to collect a 0.35 liter air sample (Figure 4-1a). Time integrated samples were obtained with the Solid Sorbent Air Sampler (SSAS). The SSAS method employed a concentration technique, whereby volatile organic compounds from larger volumes (1 to 2 liters) of air were trapped onto the sorbent resin (Figure 4-1b). Therefore, the SSAS provided greater sensitivity for specific pollutants. On the other hand, the GSC could trap volatile contaminants that were poorly adsorbed on the SSAS. Consequently, these methods complemented each other.



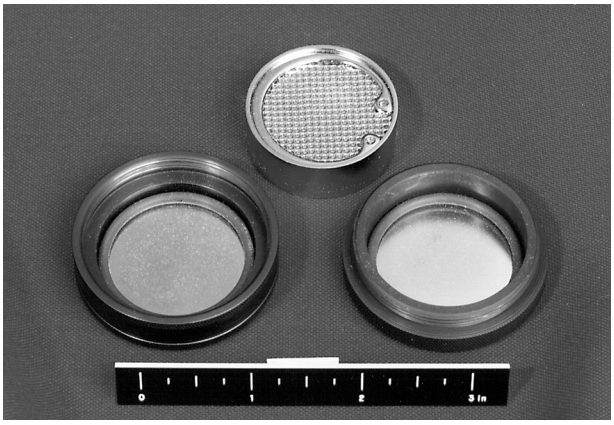
a. Grab Sample Container (GSC)



c. Formaldehyde Monitor



b. Solid Sorbent Air Sampler (SSAS)



d. Archival Organic Sampler (AOS)

Figure 4-1. Air sampling devices.

Formaldehyde, an important pollutant for measurement, was not quantified well by either method. Therefore, a badge specific for trapping formaldehyde was developed for use in the Shuttle. This badge formed the basis for a Formaldehyde Monitoring Kit (FMK), developed for this investigation. A single monitor is pictured in Figure 4-1c. An archival organic sampler (AOS) was developed to provide a lightweight, passive device capable of obtaining a time integrated sample of volatile organic air pollutants (Figure 4-1d).

The question of the concentration, composition, and size distribution of airborne particles led to the development of two instruments by the Particle Technology Laboratory at the University of Minnesota [1]. These instruments were the Shuttle Particle Sampler (SPS) and Shuttle Particle Monitor (SPM). Two SPSs and one SPM were flown on each of two Space Transportation System (STS) missions, STS 32 and STS 40. Each SPS employed a multistage impactor and filtering system to separate and trap particles, over a 24-hour sampling period, into fractions of <2.5 µm, 2.5 to 10 µm, 10 to 100 µm, and >100 µm. After the devices were returned to the laboratory, the particulate mass in each size range was determined gravimetrically, and the elemental

e. Combustion Products Analyzer (CPA)

Figure 4-1. Continued.

composition of the two smaller particle fractions was determined by X-ray fluorescence. The SPM provided a real time, in situ measurement of particulate concentration by nephelometry, employing photometric detection of light scatter. The instruments complemented each other because the SPS facilitated size distribution studies averaged over time, and the SPM facilitated measurement of temporal changes in particle concentrations, but recorded only particles of less than 100 µm and was blind to the size distribution.

Technologies currently available for sampling airborne microoganisms were assessed in ground based tests of office buildings. Off-the-shelf air samplers were evaluated for technical performance and compatibility with space flight applications. Following extensive ground based testing [2], the candidate samplers were flight certified and flight tested aboard the Shuttle. Air samples were collected with Microbial Air Samplers (MAS) from the middeck, flight deck, and in the Spacelab (when present) two days before launch and at least three times during flight. The goal was to collect two samples, one each for bacteria and fungi, at the three locations in the Shuttle/Spacelab every other day during the mission. The microbial contaminants in the air were collected and allowed to grow during the mission, and returned to the laboratory at the Johnson Space Center (JSC), where each bacterial and fungal species was identified and quantified. This approach provided the needed information to assess the levels and species of airborne bacteria and fungi as a function of time in orbit.

The risk associated with accidental chemical releases was addressed by the development of a Combustion Products Analyzer (CPA) shown in Figure 4-1e. Experience with nominal Shuttle flights has shown that the greatest threat to air quality comes from accidents involving over-heating or pyrolysis of electronic components [3]. The CPA was designed to quantify carbon monoxide (CO), hydrogen fluoride (HF), hydrogen chloride (HCl), and hydrogen cyanide (HCN) at concentrations that could pose a threat to crew member health after thermodegradation of electronic components. The CPA was jointly developed by the Space and Life Sciences Directorate and the Shuttle Program Office at JSC.

The need for long term spacecraft maximum allowable concentrations (SMACs) was addressed by placing the 30-day EDOMP effort into an activity already

underway to set 180-day SMACs for the International Space Station (ISS). Air pollutants were prioritized, and documentation of the limits was prepared by JSC toxicologists. Each document and SMAC was reviewed and approved by the National Research Council's Committee on Toxicology (NRCCOT).

METHODS

Investigations Using Existing Hardware

Solid Sorbent Air Sampler (SSAS)

The SSAS consisted of eight tubes filled with approximately 0.5 gm Tenax adsorbent through which air could be pumped at rates that permitted sampling of volumes from 0.5 liters to 2.0 liters in 24 hours. Preparations before flight included thermal cleaning and proof testing of each tube, using a gas chromatograph/mass spectrometer (GC/MS) to verify that no pollutants remained trapped on the sorbent. The rate of air flow through each tube was measured with a bubble flow meter. During flight, a crew member turned on the device and set the selector knob to one of the sorbent tube positions. A sample was normally taken for 24 hours and the device returned to the park position and turned off. The cycle could be repeated once for each of the seven available tubes in the SSAS. After the flight, each tube was thermally desorbed, and the released contaminants were quantified using GC/MS. The air flow through each tube was measured again to confirm that it had not changed significantly during the flight. Specific procedures evolved during the EDOMP. Details of the latest method were documented by the JSC Toxicology Laboratory [4].

Grab Sample Containers (GSC)

Grab sample containers were flown on all Extended Duration Orbiter (EDO) flights and used primarily to obtain instantaneous samples near the end of a mission. The canisters, SUMMA®-treated to minimize wall effects, were originally cylindrical, but were replaced during the EDOMP with spherical canisters of 0.35 liter volume. Before flight, these canisters were thoroughly evacuated, cleaned, and proofed using the GC/MS. During flight, a crew member opened the valve so that spacecraft air could enter the GSC until a pressure equilibrium occurred. The valve was then closed and the sample stowed and returned to the JSC Toxicology Laboratory for analysis. Analytical procedures included GC/MS and a separate GC procedure to quantify highly volatile compounds including methane (CH_4), carbon monoxide (CO), and hydrogen (H_2). Specific details of the procedure changed during the EDOMP. The latest procedures are illustrated in NASA standard operating procedures [5, 6].

Investigations Requiring Equipment Development

Shuttle Particle Monitor (SPM)

The SPM was flown on STS-32 and STS-40. Minor modifications were made between the flights to eliminate the need for continuous battery power to the data logger and to improve the resolution and detection limits. The minimum, maximum, and average particle concentrations were recorded continuously in 15-minute intervals during the operational time in flight. Preflight and postflight checks of the instrument zero confirmed that it did not drift during the handling and flight process. During flight and before deployment, the instrument was subjected to a zero set procedure involving its response to clean air delivered from a zero module system. The SPM was calibrated by calculating its average voltage response during the period when it was operated alongside the SPS, and comparing this SPM voltage to the mass of particles found in all size ranges in the SPS.

Shuttle Particle Sampler (SPS)

Two SPSs were flown on STS-32 and STS-40. The SPSs obtained particle samples in four size ranges over sampling periods of approximately 24 hours each. During postflight analyses, the largest particles were vacuumed from the 100 µm inlet filter onto a weighed filter, and the remaining three fractions were trapped directly on filters inside the sampler. The weight differences before and after particle loading determined the mass of each particulate fraction. Elemental analysis in the range of 11 to 82 atomic mass units (amu) was performed on the two smallest particle collections by x-ray fluorescence (XRF), a nondestructive method. Individual particles in the two largest particulate fractions were assessed by scanning electron microscopy (SEM) for morphology and elemental composition by energy dispersive spectroscopy. Both of these latter two methods were destructive.

Combustion Products Analyzer (CPA)

The CPA, flown on every Shuttle flight since late 1989, consisted of four electrochemical sensors designed to measure HCl, HF, HCN, and CO in the event of a combustion problem during a mission. A comprehensive evaluation of the CPA was performed at the White Sands Test Facility before flight tests. This evaluation involved exposure of the CPA to thermodegradation products from selected materials used in the Shuttle, including wiring insulation, polyurethane foam insulation, circuit boards, and materials containing polyvinyl chloride. Before flight, each of the sensors was zeroed and calibrated in a dynamic flow chamber. During flight, crew members took daily readings to account for any baseline drift in the sensors. This was especially important for the CO sensor which responded to hydrogen as it accumulated in the spacecraft

f. Reuter Centrifugal Sampler (RCS)

Figure 4-1. Continued.

air. In the event of a suspected combustion problem, flight rules indicated the use of the CPA in conjunction with other criteria to assess whether the atmosphere posed a risk to crew member health. After flight, the instrument was evaluated to determine the stability of the zero and calibration settings.

Formaldehyde Monitor Kit (FMK)

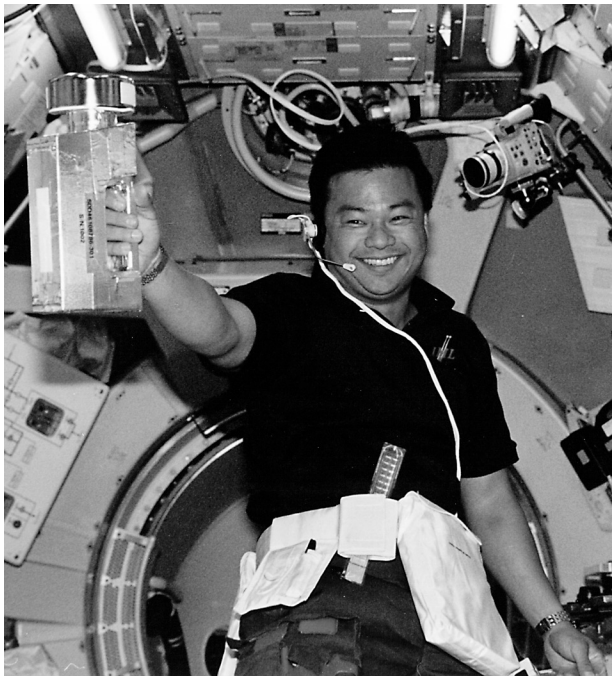
Formaldehyde was not detected by any of the methods described above unless it was at extremely high concentrations. The 30-day SMAC limit for formaldehyde was set at 0.05 mg/m^3 based on its irritant properties. After assessing several methods, it was found that a badge made by Air Quality Research (Durham, NC) could detect airborne formaldehyde at concentrations below the SMAC limit if sample times were at least 8 hours. Before flight, monitors from a specific lot were evaluated for their formaldehyde uptake rate and for satisfactory background (blank) levels. During flight, a crew member removed a seal and either placed the badge in an area of the spacecraft with adequate air flow, or wore the badge during waking hours. At the end of the sampling period, the sampling orifice was resealed and the device stowed for return to the JSC laboratory. Formaldehyde trapped by the badge, and in appropriate controls, was quantified by the Chromotropic Acid Procedure [7].

Archival Organic Sampler (AOS)

An effort was undertaken to develop, evaluate, and test during flight, a small, lightweight passive sampler for the collection of volatile organic contaminants (VOC). The utility of the AOS was its simplicity and ability to be used as a personal monitor or placed at various locations within a spacecraft for spatial variation studies. Ground based and flight tests were conducted to compare results obtained by the AOS and the SSAS [2].

Microbial Air Sampler (MAS)

From ground based evaluations of microbial air samplers [2], emerged three instruments that were the most promising candidates for use in the Shuttle. These three air samplers were: (1) a Reuter Centrifugal Sampler (RCS) (Figure 4-1f), (2) an RCS Plus (Biotest Diagnostics Corp., Denville, NJ) (Figure 4-1g), and (3) the Burkard air sampler (Burkard Manufacturing Co., Ltd., Rickmansworth, Hertfordshire, U.K.) (Figure 4-1h). All



g. Reuter Centrifugal Sampler Plus (RCS Plus)

h. Burkhard Air Sampler

Figure 4-1. Concluded.

three air samplers were small, portable, and battery powered. The RCS and RCS Plus were centrifugal impactors in which airborne microbes impacted onto a growth medium contained in 34 plastic wells on a plastic strip. The Burkard air sampler used an impactor with 100 holes of 1 mm diameter and a 90 cm Petri dish to collect airborne microorganisms. In addition to rigorous ground based testing, each of these samplers was used in flight on one or more EDO missions.

Air sample locations in flight consisted of the flight deck and middeck of the Shuttle, and in the Spacelab, when present, in the payload bay. Each air sampler used was set to collect 100 liters of air. Air sampling was scheduled every other day during the mission at a low activity time to minimize disturbance of airborne particulate and microbe levels. In all air samplers, trypticase soy agar was used for growth of bacteria, and rose bengal agar was used to culture fungi. Sample strips, or Petri plates in the case of the Burkard sampler, were incubated at ambient temperature on the middeck of the crew compartment for 2 to 13 days until return to Earth for analysis. Upon receipt of the samples in the laboratory, the bacterial and fungal colonies were quantified and subcultured for identification procedures. Bacterial isolates were subcultured on trypticase soy agar, and fungal isolates were subcultured on Saboraud's agar. Identification of the bacterial isolates was completed using the Vitek AutoMicrobic System (BioMerieux, France) or the Biolog Automated System (Biolog Inc., Hayward, CA).

Surface sampling for microorganisms was also conducted before and after EDO missions because bacteria and fungi recovered from surfaces reflected the microbial content of the air. Calcium alginate swabs were used to sample 10 to 15 selected surfaces in the crew compartment of the Shuttle and the Spacelab. Each swab, moistened with phosphate buffered saline, was used to sample a 25 cm^2 area, then placed into a tube containing 2 ml of trypticase soy broth for return to the JSC laboratory where it was analyzed for bacteria and fungi.

Setting 30-day Spacecraft Maximum Allowable Concentration (SMAC) Values

For a given compound, the process used to set exposure limits for long missions, including EDO flights, started with a search of the toxicological literature for all data available on the inhalation toxicity of that compound. If inhalation data were lacking, information from noninhalation routes of exposure and from structurally similar compounds was used. The resulting information was assembled and the most important studies reviewed for quality and completeness. A document reviewing the literature and providing explicit rationale for each SMAC limit was prepared, based on guidelines provided by the NRCCOT. The rationale included methods for species extrapolation, time extrapolation, cancer modeling, pharmacokinetics, and other factors for the effects of spaceflight on susceptibility to chemical toxicity. Each document was reviewed by members of the NRCCOT and the supporting rationale was presented at a meeting of the NRCCOT. Changes were made, as appropriate, prior to publication by the NRCCOT. These limits were used to assess the air quality during EDO flights according to published methods [8].

RESULTS AND DISCUSSION

Accumulation of Chemical Air Pollutants

Data collected during the EDOMP indicate that VOCs in the cabin atmosphere were generally below their SMAC limits. Moreover, the data clearly indicate that most pollutants reached an equilibrium concentration within the first few days of a mission. Exceptions to this were hydrogen, methane, and dichloromethane. Of these three, only dichloromethane, with a 30-day SMAC of 20 mg/m^3, has significant toxic properties. Data from STS-40, 42, 45, and 49 show accumulations of up to 0.79 mg/m^3 in missions of 2 weeks or less (Table 4-1). In view of the 30-day SMAC of 20 mg/m^3, this accumulation is of no concern for missions of less than one month.

There is no evidence at this time that nominal levels of VOCs typically seen in the cabin air during extended duration missions are detrimental to crew members. However, a VOC of particular concern was formaldehyde, found to be present in spacecraft air at concentrations above the 30-day SMAC limit of 0.05 mg/m^3 for each of the three EDO missions in which the monitors were flown (Table 4-2).

It was hoped that sampling of VOCs could be simplified by application of a passive device. However, pilot studies with the AOS indicated that results were not comparable to those obtained with the SSAS [2]. The Teflon seals used in the AOS were found to be inadequate, resulting in contamination during unexposed periods. This contamination was significant, and alternate sealing materials were studied. Ultimately it was determined that leakage around the seals could only be prevented by a total redesign. This effort was discontinued.

Table 4-1. Accumulation of dichloromethane in spacecraft air (mg/m^3)

STS Mission	*SSAS Sample Number*						
	1	2	3	4	5	6	7
40	0.09	0.10	0.14	0.13	0.17	—	0.32
42	0.32	0.40	0.44	0.46	0.56	0.50	0.70
45	0.27	0.49	0.51	0.60	0.71	—	—
49	0.17	0.53	0.79	0.75	0.65	0.71	0.56

Table 4-2. Formaldehyde concentrations in spacecraft air (mg/m^3)

STS Mission	*Type of sample*	*Range of Concentrations*
56	area	0.037 - 0.065
	personal	0.048 - 0.056
59	area	0.049 - 0.072
	personal	0.056 - 0.080
67	area	0.033 - 0.039
	personal	0.042 - 0.074

Assessment of Particulate Air Pollutants

The total mass of particles averaged 56 mg/m^3 on STS-32 and 35 mg/m^3 on STS-40 (Table 4-3). In neither mission was there a temporal increase in the particulate concentration. As expected, the size distribution showed a strong enrichment in the heavier particles that did not settle out of the spacecraft atmosphere. Elemental analysis suggested that most of the particles were organic in origin [1], which is reasonable given the high density of human occupation of the spacecraft.

Table 4-3. Particle masses from the SPS on STS-32 and STS-40

Particle Size (μm)	*Mass Concentration (μg/m^3)*		*Normalized percent*	
	STS-32	*STS-40*	*STS-32*	*STS-40*
<2.5	2	2	4	7
2.5 to 10	19	5	33	13
10 to 100	5	3	10	9
>100	30	25	53	71
Totals	56	35	100	100

Assessment of Accidental Chemical Releases

Although accidental air contamination problems originated from a variety of sources, the dominant source was thermodegradation of electronic devices (Table 4-4). Burning of electronic circuits or wiring could have serious effects on air quality because of the toxic fumes generated from pyrolysis of materials such as Teflon, Kapton, and epoxy resin. Of the nine toxicological incidents occurring from STS-35 to STS-55, four were the result of electronic burns. These incidents are summarized in a report by J. T. James *et al.* [3]. The need for real-time monitoring of critical combustion products was established several years ago as evidenced by the aforementioned incidents. This need culminated in the development of the Combustion Products Analyzer that has flown on every Shuttle mission since October 1989.

Table 4-4. Air contamination incidents in the space shuttle

STS Mission	*Contamination Concern*	*Analytical Results*
28	Teleprinter cable short	SSAS sample showed nothing unusual
31	High benzene in preflight sample	Benzene, found at 0.5 mg/m^3 in preflight sample, was scrubbed down to 0.01 mg/m^3 late in mission
35	Odor of burning electronics near the data display units (2 failures)	SSB sample showed 0.01 mg/m^3 benzene, which was later reproduced from ground pyrolysis of identical electronic components
37	Odors in galley area	SSB showed no unusual contaminants
40	Noxious odors from refrigerator/ freezer	SSB sample showed no clear evidence of contamination. Ground studies of burned motor showed released ammonia and formaldehyde
49	Odor from airlock after EVA	Acetaldehyde (0.6 mg/m^3) was unusualy high in SSB sample
50	Burning odor near American Echo Research Imager	SSB sample showed unusually high concentration of dichloromethane
53	Crew experienced nasal congention possibly due to air contaminant	No unusual contaminants found in SSB sample
54	Odors in area of waste control system	Two incompletely identified organic compounds were found
55	Noxious odors from contingency waste container	Three dimethyl sulfides found at concentrations that would produce a noxious odor

Microbial Contamination

Air samples were collected during the flight phase of 14 Shuttle flights. The mission duration ranged from 5 days to 16 days, with four different Shuttle vehicles being used in the study. Quantification results of airborne bacteria and fungi recovered during four different missions (STS-42, 47, 58, and 65) are shown in Figure 4-2. In general, bacterial levels increased moderately as the mission proceeded, whereas the fungal levels tended to decrease. Bacterial levels ranged from a few hundred colony forming units per cubic meter of air (CFU/m^3) early in the mission to more than 1000 CFU/m^3 in the final days of the STS-47 and 58 missions. The fungi ranged from undetectable levels, usually late in the mission, to a few hundred CFU/m^3 in samples taken early in the mission.

The identities of bacteria and fungi recovered from the air samples are shown in Figure 4-3. Fifteen species or groups of bacteria were recovered from the samples collected during flight. It is probable that many of the bacterial genera were of human origin. Bacteria commonly found in the gastrointestinal tract (*Enterococcus faecalis*) and the respiratory tract (*Klebsiella pneumoniae*) were recovered during some missions. *Staphyloccus* spp., *Micrococcus* spp., *Enterobacter* spp., and *Bacillus* spp. were recovered from the air in the crew compartment during more than 85% of the missions. *Staphylococcus aureus* was recovered during 57% of the missions. Even though fungal levels were generally low, *Aspergillus* spp. and *Penicillum* spp. were recovered in 60% or greater of the missions. Eleven other species or groups of fungi were recovered one or more times.

The results of bacteria recovered from 10 surface sites in the crew compartment, during each of 13 space flight missions, are shown in Figure 4-4a. Again, those typically associated with humans were among the most common bacteria isolated from Shuttle surfaces. In examining the data from more than 70 missions, 40% of the surface sampling sites exhibited a tenfold or more increase during the mission [9]. The results of fungi isolated from the same 10 surface sites during the same 13 space flight missions are shown in Figure 4-4b. As in the air, *Aspergillus* spp. and *Penicillum* spp. were the most common genera found on interior surfaces. Unlike bacteria, fungi were not as commonly found on surfaces and rarely exhibited increased numbers during the mission. Pierson *et al.* [9, 10] have previously reported using DNA fingerprinting technology, such as restriction fragment length polymorphism (RFLP) analysis and repeated sequence polymerase chain reaction (PCR), to demonstrate transmission of *Staphylococcus aureus* and *Candida albicans* between Shuttle crew members. DNA fingerprinting may also be used to assess the dissemination of microbes throughout the internal environment.

Setting 30-day Chemical Spacecraft Maximum Allowable Concentration (SMAC) Values

As part of the EDOMP, approximately fifty 30-day SMACs were set and documented by JSC toxicologists in cooperation with the NRCCOT. In many cases new data and methods of risk analysis led to 30-day SMACs that were far below existing 7-day SMACs (Table 4-5).

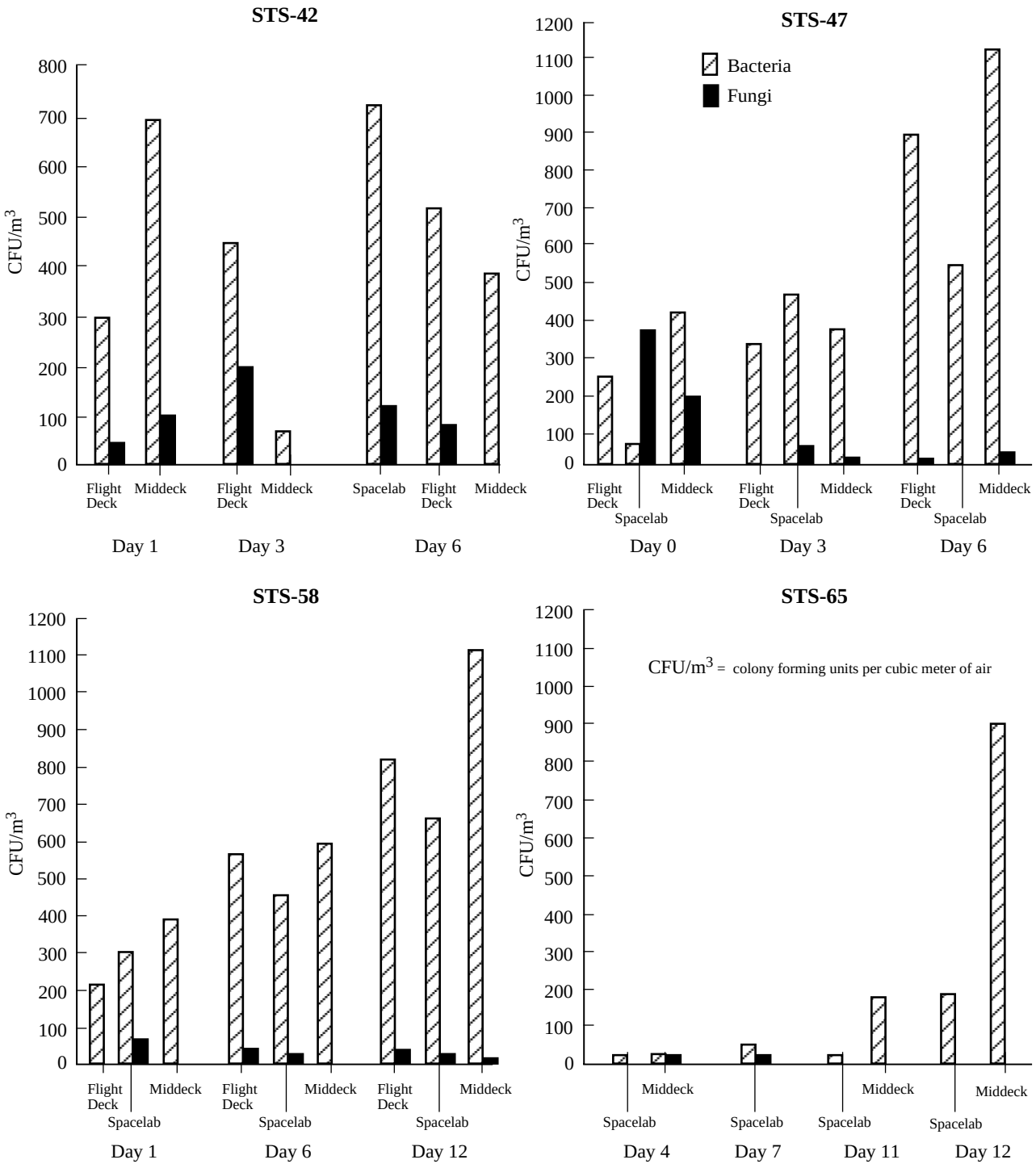


Figure 4-2. Microbial quantitation of spacecraft air.

COUNTERMEASURES/ POTENTIAL COUNTERMEASURES

Chemical Contaminant Countermeasures

The major finding from the EDOMP chemical contamination study was that formaldehyde concentrations exceeded the SMAC limit for 30 days of exposure. The sources of formaldehyde were thought to be a small contribution from crew metabolism and a major contribution from equipment off-gassing. To reduce the latter contribution, a method was implemented to detect formaldehyde during hardware off-gas acceptance testing. With that method, formaldehyde was quantified in gaseous samples

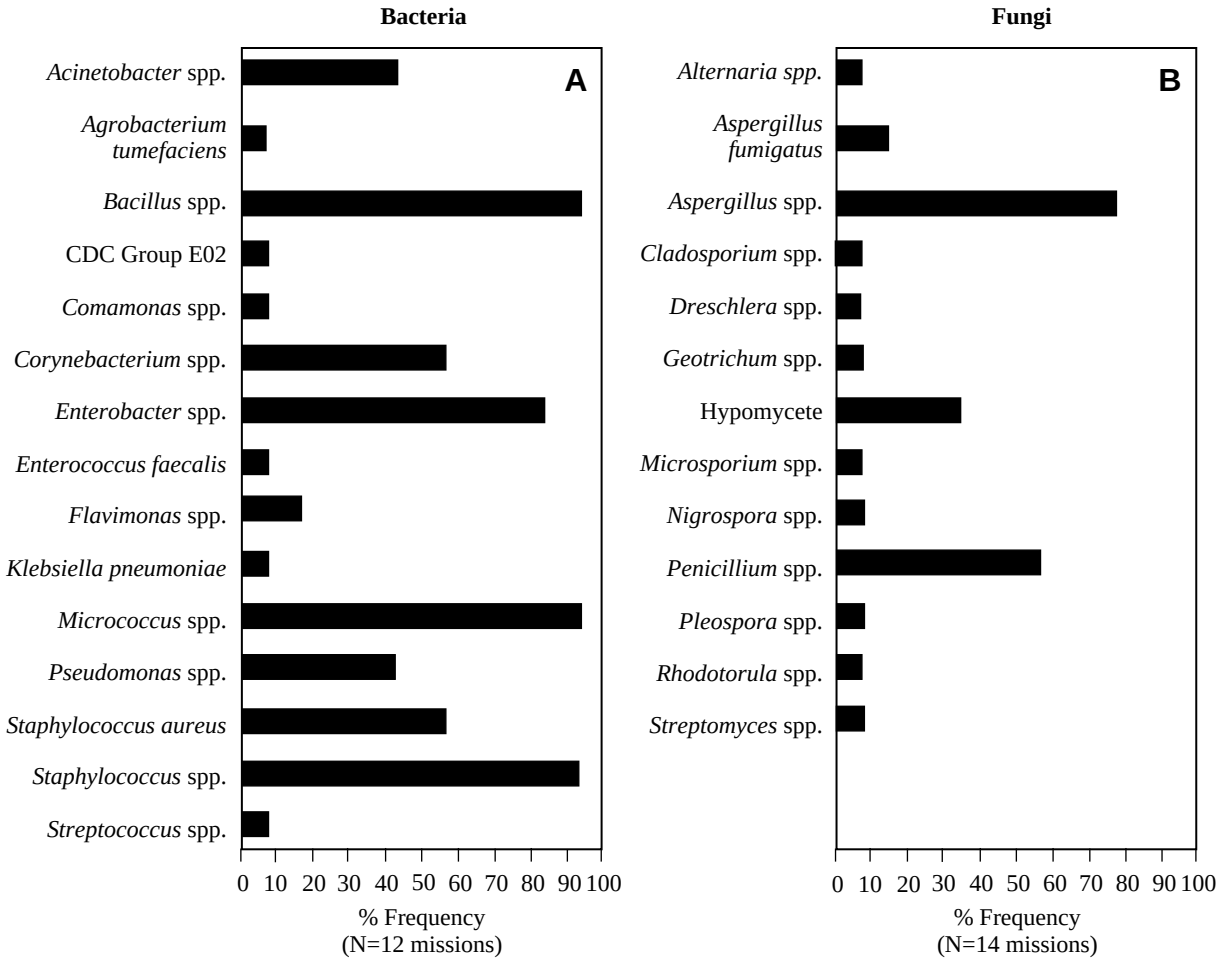


Figure 4-3. Microorganisms isolated from inflight air samples.

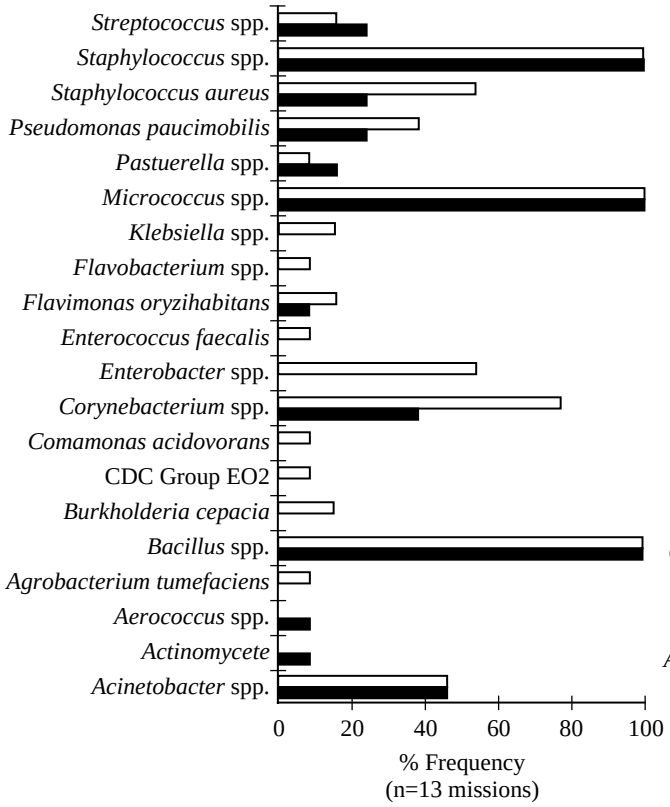
by Fourier Transform infrared spectroscopy (FTIR) at a wavelength of 3.45 µm. Since adding this method to the standard off-gas test procedure, several items of flight equipment have been rejected based on high releases of formaldehyde during the test. Results from CPA measurements following a thermodegradation incident could provide useful real-time data to the crew and entire incident management team. A new flight rule, which includes the use of CPA readings, has been written to aid in the management of a thermodegradation incident.

Microbial Countermeasures

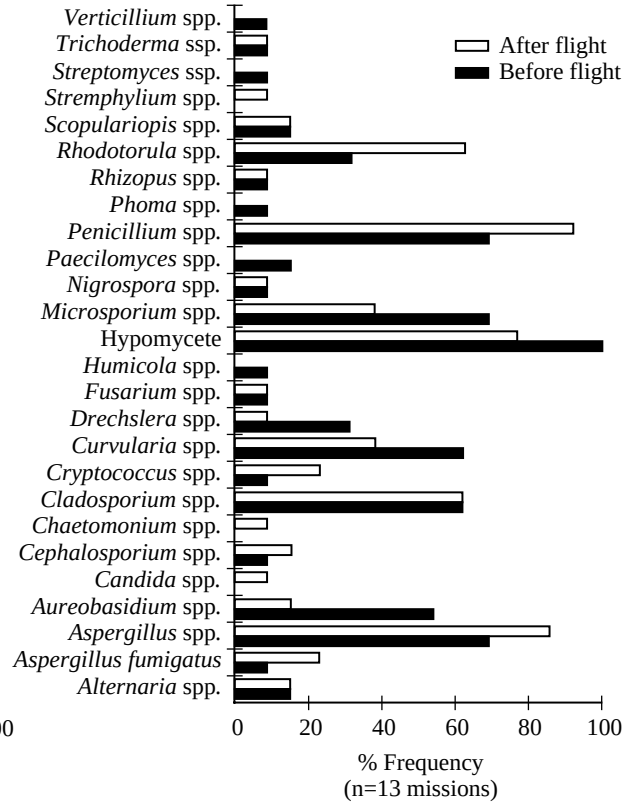
Airborne bacterial levels tended to increase and fungal levels tended to decrease as the mission proceeded. Not uncommonly, the levels of airborne bacteria exceeded the ISS acceptability limit of 1000 CFU/m^3. The fungal levels were routinely low, but occasionally fungi also exceeded the ISS acceptability limit. The planned environmental control system for ISS incorporates microbial air filters, with 99.97% retention of particulates 0.3 µm and larger, to ensure biologically safe air. The Shuttle environmental control system employed stainless steel mesh that allowed particulates smaller than 70 µm in diameter to pass through. Bacteria and fungal spores range from less than 1 µm to as much as 10 µm

Table 4-5. Decreases in selected SMAC values for the EDOMP

Compound	*Previous 7-day SMAC (mg/m^3)*	*New 30-day SMAC (mg/m^3)*
acetaldehyde	84	4
acetone	700	50
carbon monoxide	30	10
1,2-dichloroethane	40	2
ethylene glycol	130	13
methanol	50	9
methyl ethyl ketone	60	30
dichloromethane	90	20



a. Bacteria isolated from ten U.S. Space Shuttle surface sites



b. Fungi isolated from ten U.S. Space Shuttle surface sites

Figure 4-4.

in diameter. Whereas many were entrapped in the stainless steel mesh, some microbes were clearly small enough to pass through the filtration system. The addition of microbial filtration material could easily be incorporated into a filter configuration that would remove greater than 90% of airborne bacteria, fungi, particulates, dust mite antigen, pollen, and other allergens. Clearly, such modification to the air filtration system on the Shuttle would greatly improve the biological air quality in the crew compartment.

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