SPACE STATION CONTAMINATION CONTROL STUDY
FINAL REPORT FOR PHASE 1
INTERNAL CONTAMINATION
9 FEBRUARY 1987

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SUBMITTED TO THE
GEORGE C. MARSHALL SPACE FLIGHT CENTER

UNDER CONTRACT
NAS8-36432

BY

BOEING AEROSPACE COMPANY
SEATTLE, WASHINGTON
98124

R. T. Ruggeri
Technical Leader

C. K. Mullen
Technical Advisor

T. J. Kramer
Program M

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ABSTRACT

Contamination inside Space Station modules has been studied to determine the best methods of controlling contamination. The work was conducted in five tasks that identified existing contamination control requirements, analyzed contamination levels, developed outgassing specification for materials, wrote a contamination control plan, and evaluated current materials offgassing tests used by NASA. We conclude that current contamination control methods can be made to function on the Space Station for up to 1000 days, but that current methods are deficient for periods longer than about 1000 days.

KEY WORDS

Space Station
Contamination Control
Outgassing
Offgassing
Contamination
Internal Contamination
Contamination Control Requirements
Contamination Control Plan
Molecular Contamination
Particulate Contamination
Experimental Contamination Measurements
Test 7
Test 16

SUMMARY

The document is the final report for the Space Station Contamination Control Study contract number NAS8-36432. The report covers the period between June 1985 and September 1986 and discusses contamination control for pressurized areas inside Space Station modules. During the contract we assessed the contamination control procedures used on the Space Shuttle and spacelab as well as standardized offgassing test for materials, assembled articles of equipment, and fully assembled spacecraft cabins. We have concluded that current contamination control procedures and tests are adequate for short spacecraft missions, but may be deficient for missions longer than approximately 1,000 days. Seven major recommendations are presented in the conclusion section (7.0) to improve contamination control in Space Station modules. These recommendations include improved methods of testing materials and equipment, on-orbit contamination testing, introduction of a contamination control board to regulate contamination control, and modified contamination requirements.

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SPACE STATION CONTAMINATION CONTROL

Internal Contamination

1.0 INTRODUCTION

Contamination control on the space station involves areas both inside space station modules and areas outside the modules where materials are exposed to the vacuum of space. This report covers the work accomplished under the initial funding increment of the present contract and deals only with molecular and particulate contamination inside space station manned modules. The work was subdivided into five subtasks. The subtasks have been numbered according to a method used in the original proposal which does not relate to the order of completion of the tasks.

The first subtask (2.2.2.2) is to identify internal contamination control requirements. Current contamination requirements for habitable areas of the space station have been identified. The next subtask (2.2.1.2) is an analysis of particulate and molecular contamination levels. The concentration of contaminants in the breathing air is known to depend on two factors: source rates (contaminant generation rates), and the rate of contaminant removal from the air. Neither source rates nor removal rates are accurately known at this time, so precise concentrations cannot yet be calculated. However, by analyzing relative magnitudes of sources and estimating removal rates we have identified the contaminants that are potential problems and deserve special attention on the space station. Subtask 2.2.3.2 is to develop outgassing specifications for materials used on the space station. A new method of evaluating materials or assembled articles as contamination sources has been developed under this subtask. The method provides a quantitative evaluation of the contamination potential of materials or articles based on only the results of standard 72-hour contamination tests. Subtask 2.2.4.2 is to write a contamination control plan for areas inside space station modules. The contamination control plan has been written and allocates the total allowed source rate to four subcategories: human beings, Space Station modules and permanent equipment, user supplied and portable equipment, and activities that produce contaminants. The final subtask (2.3.2) is to define the best methods of testing materials used inside space station modules. A number of test procedures were investigated experimentally in this subtask and a new long-term polymer degradation test is proposed for polymeric materials used on the space station.

Each of the five subtasks is summarized below and additional detail is provided in the subtask final reports which are included as appendixes.

2.0 SUBTASK 2.2.2.2 IDENTIFY INTERNAL CONTAMINATION CONTROL REQUIREMENTS

The internal contamination control requirements for manned areas inside the Space Station are driven by concerns for human health. The requirements are presented in the Program Definition and Requirements for Space Station, NASA document JSC 30000 (ref. 1). At the current time many requirements have not been quantified, and others are still changing.

In general, contamination inside Space Station modules involves the chemical composition of the breathing atmosphere, microbiology, particulates, radiation, toxicology, vibration, water quality, and waste management. In this work we limited the investigation to chemical and particulate contamination of the breathing atmosphere. Chemical contaminants are produced by polymers, human beings, and operations or activities inside the spacecraft, and they are removed from the internal atmosphere by the trace contaminant removal system (TCRS). Particles are produced primarily by abrasion and vibration and they are removed by filtration of the breathing atmosphere. Control of both sources and the systems required to remove chemical and particulate contaminants is required on the Space Station in order to ensure the atmosphere is healthful and make efficient use of Space Station resources.

The Space Station molecular contamination requirements are based only on human toxicology. These toxicological requirements are specified and controlled by the NASA toxicologist. The toxicologist determines the spacecraft maximum allowed concentration (SMAC) for each contaminant, and in addition he imposes restrictions on the total concentration of five different "toxicological" groups of contaminants. Each toxicological group contains from one to several hundred chemical species (see Table 1). The toxicologist is not responsible for prescribing the method of achieving acceptable concentrations of contamination.

*Table 1. Toxicological Groups of Contaminants**

Group 1, Irritants	Group 2, Asphyxiants	Group 3, Central nervous system depressants	Group 4, Systemic poisons	Group 5, Carcinogens
Alcohols	Carbon dioxide	Alcohols	Benzene derivatives	Arsenic compounds
Aldehydes	Carbon monoxide	Aliphatic hydrocarbons	Cadmiun	Asbestos
Ammonia	Hydrogen	Chlorofluorocarbons (freons)	Cyanides	Benzene
Esters	Inert gases	Esters	Cyanogens	
Halogens	Methane	Ethers	Furans	
Halogen oxides		Fluorocarbons	Halogenated hydrocarbons	
Hydrazines		Nitrous oxide	Hydrazine	
Ketones			Ketones	
Metal vapors			Mercaptans	
Nitrogen oxides (except nitrous oxide)			Mercury	
Silicones			Methanol	
Siloxanes			Naphthalenes	
Strong inorganic acids			Nitriles	
Strong organic acids			Organic nitrogens	
Strong inorganic bases			Silicones	
Strong organic bases			Siloxanes	
Sulfur oxides			Sulfides	
			Thio compounds	

* Some compounds are listed more than once if they have prominent effects in more than one toxicity category.

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The toxicological requirements for the Space Station will be different than those imposed on previous programs. The old requirements were based on test procedures and maximum allowed concentrations (MAC's) specified in NASA handbook 8060.1B (ref. 2). This document is under revision as are the MAC values. The new MAC's, called SMAC's, will no longer be a part of handbook 8060.1, but will be contained in a new document. Furthermore, the toxicologist has changed the toxic categories into which each contaminant falls. This has the effect of changing the contamination requirements for the Space Station.

The final report for this subtask was previously included in the 3rd monthly progress report and is also included here in Attachment A.

Particle contamination requirements are based on particle concentration in the air. Currently, the only requirement is for class 100000 air in the modules, and one or more areas of class 100 air. There are no requirements on particle release rates, fallout rates, or filtration rates at this time. Particulate requirements are contained in space station requirements document JSC-30000 and are summarized in the charts from the first meeting of the internal environment working group included here in attachment B.

3.0 SUBTASK 2.2.1.2 ANALYSIS OF PARTICULATE AND MOLECULAR CONTAMINATION LEVELS.

The focus of this subtask was modified slightly from our original plan. We had originally intended to model contamination sources and contamination removal systems and to calculate the concentration of contaminants in the air inside Space Station modules. We found that the information needed to perform the work as originally envisioned was unavailable. There were no materials or equipment lists that could be used to predict precise contamination source rates, and only preliminary estimates of the size and removal efficiency of the trace contaminant removel system (TCRS) were available. Thus, we decided that rather than perform the original analysis, we would use the available data and perform an analysis to identify the contaminants that would be the most difficult to control. The details of this analysis are discussed in the subtask report in attachment C.

In order to perform this analysis it was first necessary to establish a contamination control methodology. This was required because the NASA toxicologist regulates only the concentration of contaminants in the atmosphere, not the method of contamination control. In fact we found no governing basis for current contamination control methods. We will now discuss the basis for our contamination control methodology.

The basic equation describing the steady state concentration of any contaminant in a module is:

$$C_i = \frac{R_i}{G\varepsilon_i} \qquad (1)$$

C_i = conventration of i^{th} contaminant (mg/m^3)

R_i = Total generation rate of i^{th} contaminant (mg/hr)

G = Air processing rate in the TCRS (m^3/hr)

ε_i = Elimination efficiency of the i^{th} contaminant in the TCRS (dimensionless)

Equation 1 shows that the concentration depends on the ratio of the total source rate, R_i, and the rate air is processed through the TCRS. The total source rate depends on the types of polymers used inside the space station and their outgassing rates. The air processing rate and contaminant elimination efficiency depend on the design and operational characteristics of the TCRS. Thus, control of the contaminant concentration cannot be achieved by simply limiting the source rate (R_i) or building a TCRS with a large air processing rate. Both the numerator and the denominator in equation 1 must be controlled in order to assure control of the concentration of contaminants in a space station module.

The simplest method of controlling both the material dependent source rates (R_i's) and the TCRS dependent air processing rates ($G\varepsilon_i$) is to specify a maximum allowed source rate for each contaminant species. Such a specification would directly control the R_i in equation 1 and would provide the design basis for sizing the TCRS (i.e. $G\varepsilon_i$).

It is clear from equation 1 that the steady state concentration of any contaminant must be less than the SMAC. However, the group contribution method of assessing contaminant hazard effectively limits the total average concentration of all contaminants combined. Thus, chemicals in toxicological catagories that contain large numbers of contaminants are limited to a small percentage of the SMAC. An order of magnitude estimate of the maximum practical concentration is 1% of the SMAC. Contamination control methods for the Space Station should reflect the group contribution method of evaluating the total toxicological hazard inside space station modules.

Another aspect of contamination control that we have considered is the concept of a contamination time constant. On previous manned spacecraft the contamination time constant was not explicitly stated, but a value equal to the duration of the mission was used in contamination analyses. The duration of the space station mission is effectively infinite and a new time constant needs to be explicitly defined. In this work we defined two contamination time constants.

$$\tau_1 = \frac{VC_i^*}{R_i} \qquad (2)$$

$$\tau_2 = \frac{V}{G\varepsilon_i} \qquad (3)$$

τ_1 = time constant for contaminant buiuldup inside a module (hrs)

τ_2 = time constant for contaminant removal from the module atmosphere (hrs)

V = module volume (m^3)

C_i^* = maximum operational contaminant concentration (mg/m^3)

Other variables have been defined previously.

The first time constant (τ_1) represents the time required for the contaminant concentration to climb from zero to C_i^* with the TCRS inoperative. The second time constant is the time for the concentration to fall from C_i^* to 37% of C_i^* with the TCRS on, but no sources active in the module.

The magnitude of the contamination time constants needs to be considered. We have arbitrarily assigned τ_1 a value of 30 hours in this work. This is a relatively short time, but does provide a minimum safety margin in case of TCRS failure. We have also proposed that the ratio of (τ_2/τ_1) be specified to be greater than some large value. In this work we used the value of 10. This ratio assures two things:

1) The steady state concentration will be 1/10 of the value of C_i^* used in equation 2.

2) There will be a buffer period after failure of the TCRS before contaminant concentrations reach the maximum values, C_i^*. The value of the time constant ratio is not sacred, but values in the range between 10 and 100 are suggested.

We feel that the concept of contamination time constants is essential to contamination control on the space station. We also feel that the old procedure cannot be effectively applied without addressing this concept. A haphazard approach to this problem will be expensive at best and could represent a serious health and safety problem. We further recommend that this issue be discussed by a pannel concerned with both sources (outgassing) and removal rates (TCRS) prior to final design of the TCRS.

In this subtask we identified contaminants considered likely to be assigned a SMAC, and we estimated the SMAC value. We calculated the maximum allowed source rate from all sources by using the SMAC as C_i^* in equation 2 and estimating the air processing rate of the TCRS. Table 2 is a partial list of the results of these calculations (a complete list is included in attachment C). Column 1 is the name of the contaminant. Column 2 is the chemical group. Column 3 is the molecular weight. Columns 4 and 5 are MAC (SMAC) values expressed in parts per million and miligrams per cubic meter of air respectively. The maximum total source rate calculated from equation 2 with a 30 hour time constant is given in column 6. The next 4 columns show our allocation of the total source rate between four source type categories: (1) human beings (calculated biological source rate), (2) Space Station modules and equipment permanently attached to the modules (maximum module allocation), (3) portable equipment temporarily used on the Space Station (allocation for portable equipment), and (4) operations and activities taking place inside modules (allocated remainder). All rates were normalized for a single Space Station module. The biological rate is for six average human beings, and the "base rate" for each module was calculated as the total rate minus the biological rate. The lab module, portable equipment, and remainder rates were calculated as 10%, 35%, and 55% of the base rate respectively. This allocation is similar to that experienced on Spacelab, but we have allocated a remainder to account for activities such as laboratory experiments that take place inside Space Station modules. Activities were not considered a source of contamination on the Spacelab and

Table 2. *Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules*

Contaminant	Group	MOL Wt	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
Allyl alcohol (2-propen-1-ol)	Alcohols	58.08	0.200	0.481	35.36	0.00	3.54	12.38	19.45	55.0%	3.20
Amyl alcohol (1-pentanol)	Alcohols	88.15	10.000	36.529	2683.45	0.00	268.34	939.21	1475.90	55.0%	152.00
Amyl alcohol (TERT)	Alcohols	88.15	8.000	29.223	2146.76	0.00	214.68	751.37	1180.72	55.0%	0.00
Butoxy ethyl alcohol, 2-	Alcohols	118.20	2.500	12.246	899.56	0.00	89.96	314.85	494.76	55.0%	0.01
Butyl alcohol (1-butanol)	Alcohols	74.12	10.000	30.715	2256.35	7.20	224.91	787.20	1237.03	54.8%	6920.00
Butyl alcohol (SEC)	Alcohols	74.12	10.000	30.715	2256.35	0.00	225.63	789.72	1240.99	55.0%	0.70
Butyl alcohol (TERT) (2-methyl-2-propanol)	Alcohols	74.12	10.000	30.715	2256.35	0.00	225.63	789.72	1240.99	55.0%	15.80
Cyclohexanol	Alcohols	100.16	5.000	20.753	1524.53	0.00	152.45	533.58	838.49	55.0%	1288.00
Ethelyne glycol (1, 2-ethanediol)	Alcohols	62.07	45.000	115.748	8502.86	0.00	850.29	2976.00	4676.57	55.0%	9.50
ethyl alcohol (ethanol)	Alcohols	46.07	50.000	95.457	7012.27	24.00	698.83	2445.90	3843.55	54.8%	5208.00
hexyl alcohol, 2 (2-hexanol)	Alcohols	102.20	20.000	84.703	6222.31	0.00	622.23	2177.81	3422.27	55.0%	1.20
Isobutyl alcohol (2-methyl-1-propanol)	Alcohols	74.12	10.000	30.715	2256.35	0.00	225.63	789.72	1240.99	55.0%	726.00
Ispropyl alcohol (2-propanol)	Alcohols	60.09	40.000	99.605	7317.00	0.00	731.70	2560.95	4024.35	55.0%	2022.00
Methoxy butanol, 3-	Alcohols	104.17	10.000	43.168	3171.12	0.00	317.11	1109.89	1744.12	55.0%	0.00
Methyl alcohol (methanol)	Alcohols	32.04	3.000	3.983	292.61	8.50	28.41	99.44	156.26	53.4%	704.00
Octyl alcohol (1-octanol)	Alcohols	130.20	20.000	107.910	7927.05	0.00	792.71	2774.47	4359.88	55.0%	0.00
Phenol	Alcohols	94.11	0.500	1.950	143.24	570.00	-42.67	-149.35	-234.71	****%	7.90
Propyl alcohol (1-propanol)	Alcohols	60.09	30.000	74.704	5487.75	0.00	548.77	1920.71	3018.26	55.0%	25.30
2, 4-hexadienal	Aldehydes	96.00	1.500	5.967	438.36	0.00	43.84	153.43	241.10	55.0%	0.00
5-hexen-2-al	Aldehydes	100.18	40.000	166.058	12198.65	0.00	1219.86	4269.53	6709.26	55.0%	0.00
C5 aldehyde	Aldehydes	86.13	15.000	53.538	3932.93	0.00	393.29	1376.53	2163.11	55.0%	0.00
Acetaldehyde (ethanal)	Aldehydes	44.05	30.000	54.763	4022.89	0.54	402.23	1407.82	2212.29	55.0%	48.00
Acrolein (propanal)	Aldehydes	55.05	0.050	0.114	8.38	0.00	0.84	2.93	4.61	55.0%	0.06
Benzaldehyde (benzenecarbonal)	Aldehydes	105.10	20.000	87.107	6398.87	0.00	639.89	2239.60	3519.38	55.0%	11.00
Butyraldehyde (butanal)	Aldehydes	72.10	40.000	119.513	8779.42	0.00	877.94	3072.80	4828.68	55.0%	1470.00

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we feel that activities should be included as a source of contamination on the Space Station.

After the allocations were made, we identified a number of potential problems for the Space Station. We compared source rates with our list of maximum allowed rates and identified 10 chemical compounds with expected source rates (predicted offgassing rate) greater than our maximum total source rate (see Table 3). The list of predicted offgassing rates (column 12) was prepared by Lockheed under a contract with Boeing. Table 4 shows the results of another analysis. It shows 21 compounds with expected source rates greater than our maximum allowed lab module (column 8) plus portable equipment (column 9) rates combined, and there are 39 compounds with expected source rates (column 12) greater than our maximum allowed lab module (column 8) rate (see attachment C). In attachment C we also identify seventy compounds that may be difficult to control because they have small maximum total source rates (less than 20 milligrams per day), and 5 compounds with biological rates (column 7) greater than our maximum total source rate (column 6). With these lists we have identified a number of potential contamination problems and the chemical contaminants that are most likely to be involved.

In addition to the contamination analysis based on the toxicological requirements (SMAC values) we have investigated potential contamination problems unique to the Space Station. In this regard, we studied the potential hazards associated with the long term degradation of polymers. Polymer degradation takes place inside manned modules as a result of the radiation environment and oxidation by the oxygen in the breathing air. The radiation environment has two primary components: electrons and protons that originate outside the modules but have enough energy to penetrate the module's pressure hull, and ultraviolet light produced within the modules. Unfortunately there are no experimental data on the type of contaminants produced by this type of polymer degradation or on the rates of contaminant production. Therefore, we were forced to

Table 3. Contaminants from Table 1 with Predicted Offgassing Rates (Column 12) Greater than the Maximum Total Source Rate (Column 6)

Contaminant	Group	MOL Wt.	MAC (PPM)	MAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated biological source rate (mg/day)	Maximum module allocation (mg/day)	Maximum allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
butyl alcohol (1-butanol)	Alcohols	74.12	10.000	30.715	2256.35	7.20	224.91	787.20	1237.03	54.8%	6920.00
methyl alcohol (methanol)	Alcohols	32.04	3.000	3.983	292.61	8.50	28.41	99.44	156.26	53.4%	704.00
benzene	Aromatic hydrocarbons	78.11	0.100	0.324	23.78	0.00	2.38	8.32	13.08	55.0%	27.00
xylene, m-(1,3-dimethylbenzene)	Aromatic hydrocarbons	106.16	10.000	43.993	3231.70	0.00	323.17	1131.10	1777.44	55.0%	3539.00
3-chloropropene	Halocarbons-chlorocarbons	76.50	0.100	0.317	23.29	0.00	2.33	8.15	12.81	55.0%	34.00
trichloroethlene (trichloroethene)	Halocarbons-chlorocarbons	131.40	0.050	0.272	20.00	0.00	2.00	7.00	11.00	55.0%	40.00
ammonia	Inorganic compounds	17.03	12.500	8.822	648.03	2850.00	-220.19	-770.68	-1211.07	****%	2856.00
carbon monoxide	Inorganic compounds	28.01	15.000	17.411	1279.01	200.00	107.90	377.65	593.46	46.4%	1797.00
mercury	Inorganic compounds	200.61	0.001	0.004	0.31	0.00	0.03	0.11	0.17	55.0%	1.20
indole (2,3-benzopyrrole)	Organic nitrogens	117.10	0.100	0.485	35.65	150.00	-11.43	-40.01	-62.88	****%	70.00

Table 4. **Contaminants from Table 1 with Predicted Offgassing Rates (Column 12) Greater than the Sum of the Module Allocation (Column 8) and the Portable Equipment Allocation (Column 9)**

Contaminant	Group	MOL Wt	MAC (PPM)	MAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
butyl alcohol (1-butanol)	Alcohols	74.12	10.000	30.715	2256.35	7.20	224.91	787.20	1237.03	54.8%	6920.00
cyclohexanol	Alcohols	100.16	5.000	20.753	1524.53	0.00	152.45	533.58	838.49	55.0%	1288.00
ethyl alcohol (ethanol)	Alcohols	46.07	50.000	95.457	7012.27	24.00	698.83	2445.90	3843.55	54.8%	5208.00
methyl alcohol (methanol)	Alcohols	32.04	3.000	3.983	292.61	8.50	28.41	99.44	156.26	53.4%	704.00
phenol	Alcohols	94.11	0.500	1.950	143.24	570.00	-42.67	-149.35	-234.71	****%	7.90
benzene	Aromatic hydrocarbons	78.11	0.100	0.324	23.78	0.00	2.38	8.32	13.08	55.0%	27.00
xylene, m- (1,3-dimethylbenzene)	Aromatic hydrocarbons	106.16	10.000	43.993	3231.70	0.00	323.17	1131.10	1777.44	55.0%	3539.00
3-chloropropene	Halcarbons-chlorocarbons	76.50	0.100	0.317	23.29	0.00	2.33	8.15	12.81	55.0%	34.00
chlorobenzene	Halocarbons-chlorocarbons	112.56	7.500	34.984	256.90	0.00	256.99	899.46	1413.44	55.0%	1240.00
methylene chloride (dichloromethane)	Halocarbons-chlorocarbons	84.94	10.000	35.199	2585.73	0.00	258.57	905.00	1422.15	55.0%	1746.00
trichlorethylene (trichloroethene)	Halocarbons-chlorocarbons	131.40	0.050	0.272	20.00	0.00	2.00	7.00	11.00	55.0%	40.00
freon 113 (1,1,2-trichloro-1,2,2-trifluorethane)	Halocarbons-chlorofluoro-carbons	187.39	20.000	155.309	11408.99	0.00	1140.90	3993.15	6274.94	55.0%	9180.00
ammonia	Inorganic compounds	17.03	12.500	8.822	648.03	2850.00	-220.19	-770.68	-1211.07	****%	2856.00
carbon monoxide	Inorganic compounds	28.01	15.000	17.411	1279.01	200.00	107.90	377.65	593.46	46.4%	1797.00
mercury	Inorganic compounds	200.61	0.001	0.004	0.31	0.00	0.03	0.11	0.17	55.0%	1.20
cyclopentanone	Ketones	84.13	4.250	14.817	1088.46	0.00	108.85	380.96	598.65	55.0%	845.00
methyl ethyl ketone (2-butanone)	Ketones	72.10	20.000	59.756	4389.71	0.00	438.97	1536.40	2414.34	55.0%	3760.00
methyl isobutyl ketone	Ketones	100.16	5.000	20.753	1524.53	0.00	152.45	533.58	838.49	55.0%	1335.00
pyruvic acid (2-oxo-propanoic acid)	Organic acids	88.06	0.250	0.912	67.02	1260.00	-119.29	-417.53	-656.13	****%	0.00
indole (2,3-benzopyrrole)	Organic nitrogens	117.10	0.100	0.485	35.65	150.00	-11.43	-40.01	-62.88	****%	70.00
skatole (3-methyl indole)	Organic nitrogens	131.20	0.100	0.544	39.94	150.00	-11.00	-38.51	-60.52	****%	0.00

estimate the contaminant generation rates from laboratory data obtained under different conditions than will be encountered on the Space Station. The results of our calculations are shown in table 5. They show that radiation probably does not create a serious contamination problem, but carbon monoxide exceeds both the maximum module allocation and the maximum total source rate. Acetaldehyde, acetic acid, and acetone all exceed the tabulated maximum module allocation. Thus, we are concerned that these and other chemicals may be produced at rates higher than expected (compare column 2 with column 5), and some contaminants might overload the TCRS. We recommend further investigation and that additional experiments be performed under conditions simulating Space Station modules prior to final design of the TCRS.

Table 5. Production Rates for Volatile Contaminants Formed by Radiation Degradation of Polymers in a Space Station Module

Chemical species	Estimated outgassing rate from radiation (mg/day)	Maximum module allocation from table 1 (mg/day)	Maximum total source rate from table 1 (mg/day)	Predicted offgassing rate from table 1 (mg/day)
Methane	80	6496	65919	1300
Ethene	50	1280	12808	0.40
Ethane	130	1373	13731	166
Propene	180	3202	32025	0.50
CO	2600	108	1279	1797
CO_2	110			
Acetaldehyde	890	402	4023	48
Propionaldehyde	60	707	7072	87
Acetic acid	230	37	366	0.02
Acetone	7600	2652	26521	4212
MEK	180	439	4390	3760
Diethyl ketone	210			
Isopropanol	240	732	7317	2022

Polymer Mass = 1500 Kg
TC = 0.14

302P1-079/R2

4.0 SUBTASK 2.2.3.2 DEVELOP OUTGASSING SPECIFICATIONS FOR MATERIALS.

The objective of this subask was to develop a set of offgassing requirements for materials and assembled articles used on the Space Station. Under current contamination control programs there are no effective contamination requirements for individual equipment items, and there is no way of knowing if an article will be accepted for manifest on a spacecraft prior to the final contamination analysis which is performed only a few months prior to final spacecraft assembly at the Kennedy Space Center. This is obviously too late to allow modification of the equipment to meet the contamination requirements. Material acceptance criteria a and b, as described in NHB 8060.1B, will not be applicable on the Space Station because the mission duration is infinite and the definition of toxicological hazard has been changed. So the primary thrust of this subtask was to develop a new list of requirements or a new method of assessing the contamination potential of materials and articles so users and manufacturers can determine if equipment will pass the final contamination assessment and be accepted for flight. It was our objective to provide at least two years of advanced notice of the contamination potential of an article with these new requirements and methods. The results of this subtask are detailed in the final report included here as attachment D.

We determined at an early stage in this subtask that it would be extremely difficult to develop a set of acceptable requirements to achieve our objectives because of the lead time required to incorporate new requirements into existing procedures. Therefore, we have proposed the use of a "contamination index" (CI) on a trial basis. The contamination index should be evaluated and included in the contamination control record, but materials and articles would not be accepted or rejected on the basis of the CI.

The CI is a number which assesses the contamination potential of assembled articles and materials. It is based on past experience with the space shuttle crew cabin and the spacelab as reported in contamination assessment reports, and it incorporates the new toxicological requirements that will be used on the Space Station. The CI is easy to use and is very amenable to calculation on a desktop computer with typical spreadsheet software. It uses only test results from the standardized 72-hour offgassing test (Test 7 for materials, or Test 16 for articles) to evaluate the contamination potential of each material or article. Acceptable items have a CI less than 1.0 and unacceptable items have a larger CI. Details of the CI and examples of its use are presented in attachment D.

The CI is based on the new toxicological requirements and the maximum module allocation from table 1. As such it implicitly depends on the buildup time constant for contamination. It is based on the fact that, in past spacecraft, most contaminants originate from only a few sources. This means that individual contaminants can be traced to just a few items of equipment emitting at a relatively high rate rather than being released into the air at a lower rate by a large number of equipment items. This fact allows us to assess each item of hardware individually without considering the total contaminant load on the Space Station module.

The current method of assessing the toxicological hazard of articles used on spacecraft are criteria "A" and "B" as outlined in NHB 8060. 1B. Criterion A basically determines if a contaminant will reach its SMAC anytime during a spacecraft flight while the TCRS is inoperative. Criterion B assesses the toxicological hazard of each toxic group of contaminants and tests the interaction of all toxicological groups combined. Criterion A is superfluous because all equipment items failing criterion A will also fail criterion B. It is our opinion that this method of assessing the contamination potential of equipment could be successfully used on the space station if an appropriate mission time is defined. However, the CI has the advantage that is a quantitative value of the contamination potential instead of a go, no-go test. Thus we expect the CI to be a more accurate assessment of an articles contamination potential than current practice. This accuracy will be an advantage for space station because it could be used to rank payloads and develop contamination priorities.

5.0 SUBTASK 2.2.4.2 INTERNAL CONTAMINATION CONTROL PLAN

The culmination of the contamination control task for internal contamination was to produce a contamination control plan for the Space Station. This document has been presented previously in the 12th monthly report and is included here in attachment E.

The primary features of this contamination control plan are: the use of a contamination control board to regulate contamination control, the specification of maximum allowable source rates, allocation of the total source rate to four subcategories, continuous contamination monitoring inside the operational space station, on-orbit testing of the trace contaminant removal system (TCRS) and source rates, improved methods of testing materials and assembled hardware, and testing of polymers for long term degradation due to particulate and photon irradiation.

The contamination control board is needed to provide continuity of contamination control policies throughout all phases of space station development, from preliminary design through operation. The board should represent the interest of designers and those selecting materials of construction, the TCRS and environmental control and life support system, and the NASA toxicologist. The board will establish detailed requirements, such as maximum allowed source rates, set policy, and resolve contamination disputes.

The contamination control board will have the prime responsibility of assigning a set of maximum allowed source rates. These rates will establish a firm basis for designing the TCRS and clearly define areas of responsibility between contamination removal systems and sources generating contaminants. The maximum allowed source rates represent a quantitative definition of how much contamination can be generated by all sources combined, and the TCRS can be sized to safely remove this quantity of contaminant.

It is recommended that the contamination control board allocate the maximum allowed source rate among the following sources: biological, fixed hardware and permanent equipment, portable or user supplied hardware, and work activities. The first three allocations have been used on previous spacecraft such as spacelab, but we have not found any allocation for activities on previous flights. Without an activity allocation particulates, for example, could pass the contamination requirements during unmanned or pre-flight tests and fail to pass in operational modules.

The specification of maximum allowed source rates will also aid in designing an effective contamination monitoring system. Because of different source rates, different contaminants must be monitored with different frequencies and with different detection thresholds (sensitivities). Maximum source rates provide a rational method of determining the detection threshold and sampling frequency of each individual contaminant.

Our contamination control plan provides for on-orbit testing to accurately measure how the TCRS is operating and at what rate contaminants enter the breathing atmosphere. This testing should be performed in an operational module, and it can be automated so the test will not interfere with other operation.

In addition to these topics our contamination control plan discusses methods of testing materials (Test 7, NHB 8060.1), assembled articles (Test 16, NHB 8060.1), and modules in-flight. Also discussed, but not detailed, is a test to evaluate the long term degradation of polymers in the environment found inside manned modules. It is uncertain if long term polymer degradation is a serious contamination threat for the space station; therefore, we recommend performing tests to resolve this question before space station designs are finalized. Only minor modifications to the standardized 72-hour offgassing test (Test 7) are recommended. In general this test is adequate for its intended purpose. There are a number of improvements that could be made to the total spacecraft cabin offgassing test (Test 12, NHB 8060.1) and these are included in our recommendations for the new in-flight contamination test detailed below. Our essential critism of test 12 is that it does not permit source rates, or loading of the TCRS to be determined. Without this information the test is not a diagnostic tool, but mearly are expensive screening test. Our objective on the space station is to prevent problems and take corrective action before problems become serious. This contamination control plan is designed to do this within the framework of current NASA procedures.

6.0 SUBTASK 2.3.2 EXPERIMENTAL PROGRAM

The experimental work was designed to determine if current contamination tests for materials and apparatus are adequate for the space station. A number of modifications of the current materials test (test 7, NHB 8060.1B) were investigated experimentally in this work, and the current method of implementing the contamination control requirements on NASA spacecraft was analyzed with regard to its use on the Space Station. We have determined that the standardized 72-hour contamination test is adequate for short manned missions (up to approximately 100 days). The current tests are overly conservative, and therefore, expensive for mid-length missions (approximately 100 days to 1000 days), and they may be inadequate for missions longer than about 1000 days. A new long term polymer degradation test will be needed for materials that will be on the space station for more than about 1000 days. Details of the work conducted under this subtask are included in the final subtask report in attachment F. The results of this work have also been included in the contamination control plan.

This work was conducted to examine the tests used to evaluate materials offgassing and offgassing from assembled articles. We obtained five materials used on the spacelab or space shuttle and conducted standardized 72-hour offgassing tests according to the procedure specified in test 7. We examined the procedure to evaluate accuracy and precision of the basic test. The primary flaw we investigated was to determine if some chemicals could saturate the air inside the test chamber within 72 hours. We concluded that although this occurrance is possible it is unlikely to occur in these tests. However, it would not be difficult to modify the test to obtain additional data that would permit the identification of chemical contaminants that saturate the air in the test chamber. We developed procedures and a theoretical model of the offgassing test to facilitate identification of problem contaminants. The offgassing model could also be used to identify those contaminants that are produced inside polymers by chemical reaction as distinguished from those chemicals that were left over from the manufacturing process. The results of this study also confirmed that the diffusional process is controlled by diffusion in polymers not by diffusion through stagnant air.

Our tests showed large differences from data previously obtained at the facility at White Sands New Mexico. Conversations with experimenters at White Sands indicated that they had seen similar results between polymer samples from different lots. This illustrates that tests identifying contaminants evolved from polymers are not transferable, even to other "identical" brand name polymers. The implication of this observation are clear: tests must be conducted on each component of a spacecraft, not on an "identical" component.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Our primary conclusion is that NASA's current contamination control procedures and approach will function to control contamination on the Space Station; however, there are a few areas were procedures can be improved. In this section we summarize seven recommendations that will improve contamination control on the space station. These seven recommendations are included in the previous sections of this report and are presented in greater detail in the attachments.

First there should be a controlling body that represents all aspects of the contamination issue rather than leaving all control functions up to the NASA toxicologist. Contamination control requires cooperation between those responsible for contaminant sources, and those responsible for the TCRS in order to efficiently limit contaminant concentrations in space station modules. We recommend a single controlling body composed of representatives from these three groups. We further recommend that this body be formed as soon as possible to provide continuity for contamination control policies throughout all phases of space station design, construction, and operation.

Second, there should be two levels of contamination control requirements. The first level is what currently exists, SMAC's proposed and controlled by the NASA toxicologist. These requirements are necessary to assure human health and clean working conditions. The second level requirements should limit the maximum generation rate (source rate) of each contaminant in a space station module. These maximum rates should be set at the earliest opportunity because they provide a basis for both design of the TCRS and selection of materials and equipment for space station modules.

Third, there should be an allocation of contaminants to activities taking place inside manned modules. Previous contamination analyses have not made allowance for contamination production by activities, but this should be done for the Space Station. Particle generation by humans, for example, is directly associated with the type and

8.0 REFERENCES

1. Program Definition and Requirements for Space Station, JSC-30000.
2. Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments That Support Combustion, NHB 8060.1B, J 8400003.

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ATTACHMENT A

REPORT FOR SUBTASK 2.2.2.2

IDENTIFY CONTAMINATION CONTROL REQUIREMENTS

INTRODUCTION

The overall objective of this work is to develop a workable means of controlling contamination inside space-station manned modules. The chemical composition of the gaseous atmosphere inside the modules must be strictly controlled in order to assure the health and safety of the crew. This control is accomplished through the specification of maximum allowed concentrations (MAC's) of trace contaminants in the atmosphere. The MAC's constitute the first level "global" requirements for contamination control inside manned modules, but they represent only the goal which must be achieved and do not address the method of achievement. In order to assure that excessive concentrations of trace contaminants do not build up inside manned modules, it will be necessary to impose second-level "engineering" requirements on each contaminant source inside the modules. The first subtask of the contamination control plan is to establish the toxicological requirements for each manned module. The second subtask is to analyze the relative importance of each individual contaminant source, and the third subtask is to develop outgassing requirements for each source. These individual subtasks are discussed in greater detail below.

The first subtask (2.2.2.2) in the development of a contamination control plan (task 2.0A) is to establish the global contamination control requirements (MAC's) that must be satisfied. The MAC for each contaminant species is specified by the NASA toxicologist. The MAC's are independent of source rates or the ECLSS, even though the concentrations of trace contaminants inside manned modules depend on both source rates and the operating characteristics of the ECLSS. Official MAC's have not yet been established for the space station. Two sets of MAC's, 24-hour and 90-day, are being considered for the space station. The current 7-day MAC's from reference 1 and a supplemental list of 10-day MAC's (ref 2) is included in Appendix A. A third list of suggested MAC's and maximum source rates for the space station (ref 3) is also provided in Appendix A.

The second subtask (2.2.1.2) of the contamination control plan is to analyze particulate and molecular contamination levels. In this subtask we will determine maximum total source rates for each chemical and particulate species for which have been assigned a MAC. All materials, activities, and organisms that produce contaminants inside the space station contribute to the total source rates. Thus, as part of this subtask we will categorize the individual contaminant sources, and in the third subtask (2.2.3.2) we will develop outgassing requirements for each category of sources.

In parallel with the contamination control plan (task 2.0A) we are conducting an investigation of methods of testing materials for the production of contamination (task 2.3.2). In this task we will develop methods of testing materials and assemblies in order to assure that both the toxicological and outgassing contamination requirements are met. An area of particular concern to us is how long-term phenomena such as decomposition of polymers will be detected and predicted from short term tests conducted in the relatively brief period prior to construction of the space station. The test methods developed in this task will ultimately be incorporated into the contamination control plan document (task 2.2.4.2).

CONVERSION OF MAC'S TO TOTAL SOURCE RATES

One of our goals is to establish maximum outgassing rates for materials and equipment to be used on the space station. These requirements must reflect whatever MAC's are established by the NASA toxicologist (see Appendix A), but because final MAC's have not yet been determined, we have devised an algorithm that allows us to convert each MAC to a total outgassing rate.

The algorithm is based on the time required for the internal atmosphere (breathing air) to respond to a step increase in contaminant generation rate. The equation for the rate of change of the concentration of the i-th contaminant in a manned module is:

$$\frac{\partial C_i}{\partial t} = \frac{R_i - r_i}{V} \qquad (1)$$

C_i = concentration of the i-th contaminant, mole/liter
V = module volume, liters
t = time, seconds
R_i = generation rate of the i-th contaminant, mole/second
r_i = removal rate of the i-th contaminant, mole/second

The generation rate (R_i) is the total generation rate from all sources such as: humans, materials outgassing, chemical experiments, leaks, and the environmental control and the life support system (ECLSS). The removal rate (r_i) depends primarily on the operating characteristics of the ECLSS. We can write the removal rate as follows:

$$r_i^o = G\ C_i\ E_i \tag{2}$$

G = volumetric flow rate through the ECLSS, liter/second
C_i = i-th contaminant concentration in the atmosphere entering the ECLSS, mole/liter.
E_i = removal efficiency of the ECLSS for the i-th component, dimensionless.

We can now define two time constants:

$$T+_i = \frac{V\ C_{oi}}{R_i^o} \quad \text{and} \tag{3}$$

$$T-_i = \frac{V}{G} \tag{4}$$

R_i^o = the generation rate of the i-th contaminant at time zero (initial rate), mole/second.

The buildup time constant ($T+_i$) represents the time required for the i-th contaminant concentration to increase from zero to the MAC if $r_i = 0$ and $R_i = R_i^o$. The removal time constant ($T-_i$) represents the time for (C_i/C_{oi}) to fall from 1.0 to 1/e with $E_i = 1$ and $R_i = 0$.

Equation 1 can be written in terms of the two time constants as follows:

$$\frac{\partial(C_i/C_{oi})}{\partial t} = \frac{R_i}{R_i^o\ T+_i} - \frac{C_i\ E_i}{C_{oi}\ T-_i} \tag{5}$$

t = time

$T+$ = time constant for contamination buildup, seconds

$T-$ = time constant for contaminant removal, seconds

C_{oi} = the MAC's for the i-th species, mole/liter

We have developed two algorithms which could be used to convert MAC's to total initial source rates (R_i^o). The first algorithm is to simply assign a value to each buildup time constants (T+). For example, the buildup time constant for each chemical species could be set at 24 hours. This value would allow a degree of safety by assuring a relatively slow buildup of contaminants, and it is equal to the proposed time between measurements of the trace contaminant concentrations in the atmosphere of each module (ref 4). This algorithm has the advantage of being simple, but it neglects the ECLSS entirely.

The second algorithm assumes a constant value of the time constant ratio (T+/T-). T- would be established by ECLSS operating parameters, and T+ would then be obtained from the time constant ratio. Thereafter the two algorithms are identical. This method has the effect of limiting the steady state operating concentration C_i to a fraction of the MAC. This can be seen by equating the derivative in equation 5 to zero and solving the result for (C_i/C_{oi}). This algorithm would thus limit the nominal contaminant concentration to a small portion of the MAC, but this method has the computational disadvantage that many of the ECLSS operating parameters have not yet been determined.

Regardless of the algorithm we ultimately choose, equation 3 will be used to determine the total source (generation) rate of each chemical and particulate species for which MAC's have been specified by the JSC toxicologist. Our current working list of MAC's is for 7-day exposure and is presented in Appendix A. We expect the 90-day MAC's to be about half the 7-day values, but whatever values are eventually set, we will be able to easily convert each MAC to an initial rate through equation 3.

PARTICULATE MAC'S

The MAC values tabulated in Appendix A include a number of inorganic chemicals and solid compounds. The solids would presumably include particulate concentrations, but there are no generic particulate MAC's currently used on the space shuttle or planned for the space station (ref 4). We will continue to monitor the particulates requirements and plan to include them as a part of the next subtask ("Analysis of Contamination Levels, 2.2.1.2).

CATEGORIES OF SOURCES

One of our ultimate goals for the contamination control plan (task 2.0A) (ref 5) is to define material-specific outgassing requirements. The definition of the initial total source rates (R_i^o) is a first step in this direction, but many materials, assemblies, and animals may contribute to the overall rate. We will, therefore, propose engineering requirements limiting the outgassing rate from individual sources. Table 1 lists categories of sources we intend to consider in the next subtask (2.2.1.2).

Activities are considered a source in Table 1. This suggests that we may also divide the specific requirements according to location on the space station. There are four modules in the reference configuration II: two laboratory modules and two habitat modules. In our meeting with the NASA toxicologist (ref 4) we discussed the possibility that laboratories and habitat modules could be assigned different MAC's. At this time, a decision has not been made, but the toxicologist is considering assigning MAC's based on activities inside modules. Therefore, we are proceeding on the premise that there will be two sets of contamination requirements, one set for laboratory modules and one set for habitat modules. In the contamination analysis subtask (2.2.1.2) we will develop a method of subdividing each MAC between the various sources listed in Table 1.

TABLE 1

Categories of Outgassing Sources

Space Station Modules
Permanent Equipment
Humans
Animals
Portable (non-permanent) Equipment
Experiments
Activities

REFERENCES

1) Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion, NHB 8060.1B, Office of Transportation Systems, NASA, 1981.

2) New Temporary Spacecraft Maximum Allowable Concentrations (SMAC) List, memorandum SD/84-382, M. E. Coleman, Lyndon B. Johnson Space Center, 1985.

3) Space Station Environmental Control and Life Support System, Preliminary Conceptual Design, JSC-17727, Lyndon B. Johnson Space Center, 1982.

4) Private Communication with the NASA toxicologist, Martin Coleman, 31 October 1985.

5) 2nd Monthly Progress Report, Space Station Contamination Control Study, NAS8-36432, 15 October 1985.

APPENDIX A OF ATTACHMENT A

Maximum Allowed Concentration for Trace Contamination in Breathing Atmospheres on the Space Station

Pages A1 - A11	from Reference 1
Pages 1 - 11	from Reference 2
Pages A1 - A8	from Reference 3

APPENDIX D - MAXIMUM ALLOWABLE CONCENTRATIONS (MACs) OF ATMOSPHERIC CONTAMINANTS IN MANNED SPACECRAFT AND USAGE GUIDELINES

I. Maximum Allowable Concentrations (MACs) of Contaminants for Missions up to 7 Days*

	Mol. Wt.	MACs 7-Day ppm	(mg/M^3)
**1. Alcohols			
allyl alcohol (2-propen-1-ol)	58.08	0.5	(1)
n-amyl alcohol (1-pentanol)	88.15	35	(126)
isobutyl alcohol (2-methyl-1-propanol)	74.12	40	(121)
n-butyl alcohol (1-butanol)	74.12	40	(121)
sec-butyl alcohol (2-butanol)	74.12	40	(121)
tert-butyl alcohol (2-methyl-2-propanol)	74.12	40	(121)
cyclohexanol	100.2	30	(123)
ethyl alcohol (ethanol)	46.07	50	(94)
ethylene glycol (1,2-ethanediol)	62.07	50	(127)
2-hexyl alcohol (2-hexanol)	102.2	40	(167)
methyl alcohol (methanol)	32.04	40	(52.4)
octyl alcohol (1-octanol)	130.2	40	(213)
phenol	94.11	2	(7.7)
n-propyl alcohol (1-propanol)	60.09	40	(98.3)
isopropyl alcohol (2-propanol)	60.09	40	(98.3)
**2. Aldehydes			
acetaldehyde (ethanal)	44.05	30	(54.0)
acrolein (propenal)	56.06	0.05	(0.11)
benzaldehyde (benzenecarbonal)	106.1	40	(173)

*For missions longer than 7 days consult the NASA Toxicologist for MAC values.
**See Paragraph II.d., Page D-12.

		Mol. Wt.	MACs 7-Day ppm (mg/M^3)
	butyraldehyde (butanal)	72.10	40 (118)
	crotonaldehyde (trans-2-butenal)	70.09	0.6 (1.7)
	formaldehyde (methanal)	30.03	0.1 (0.12)
	furfural (2-furancarbonal)	96.08	2 (7.9)
	propionaldehyde (propanal)	58.08	40 (95.0)
	valeraldehyde (pentanal)	86.13	30 (106)
**3.	Aromatic hydrocarbons		
	benzene	78.11	0.1 (0.32)
	cumene (isopropylbenzene)	120.2	15 (73.7)
	decalin (decahydronaphthalene)	138.2	2 (11)
	ethylbenzene	106.2	20 (86.8)
	1,2-ethylmethylbenzene (1-ethyl-2-methylbenzene)	120.2	5 (25)
	indene (indonaphthene)	116.1	2 (9.5)
	mesitylene (1,3,5-trimethylbenzene)	120.2	3 (15)
	methyl styrene (2-phenylpropene)	118.2	30 (145)
	naphthalene	128.2	2 (10)
	propylbenzene	120.1	10 (49.1)
	pseudocumene (1,2,4-trimethylbenzene)	120.2	3 (15)
	styrene (ethenylbenzene)	104.1	10 (42.6)
	toluene (methylbenzene)	92.13	20 (75.3)
	m-xylene (1,3-dimethylbenzene)	106.2	20 (86.8)
	o-xylene (1,2-dimethylbenzene)	106.2	20 (86.8)
	p-xylene (1,4-dimethylbenzene)	106.2	20 (86.8)
**4.	Esters		
	n-amyl acetate	130.2	30 (160)

	Mol. Wt.	MACs 7-Day ppm (mg/M^3)
n-butyl acetate	116.2	40 (190)
cellosolve acetate (2-ethoxyethyl acetate)	132.2	30 (162)
ethyl acetate	88.10	50 (180)
ethyl formate	74.08	30 (90.9)
ethyl lactate	118.1	40 (193)
isobutyl acetate	116.2	40 (190)
isopropyl acetate	102.1	50 (209)
methyl acetate	74.08	40 (121)
methyl butyrate	102.1	20 (83.5)
methyl methacrylate	100.1	25 (102)
n-propyl acetate	102.1	40 (167)
**5. Ethers		
2,5-dimethylfuran	96.12	0.04 (0.16)
m-dioxane (1,3-dioxane)	88.11	5 (18)
ethyl butyl ether (1-ethoxybutane)	102.2	80 (334)
ethyl ether (diethyl ether)	74.12	80 (242)
furan (1,4-epoxy-1,3-butadiene)	68.07	0.04 (0.11)
2-methylfuran	82.10	0.04 (0.13)
methyl vinyl ether (methoxyethene)	58.08	50 (119)
isopropyl ether (diisopropyl ether)	102.2	50 (209)
tetrahydrofuran (1,4-epoxybutane)	72.10	40 (118)
HALOCARBONS		
6. Chlorocarbons		
butyl chloride (1-chlorobutane)	92.57	40 (151)
carbon tetrachloride (tetrachloromethane)	153.8	2 (13)

			MACs 7-Day
	Mol. Wt.	ppm	(mg/M^3)
chloroacetone (1-chloro-2-propanone)	92.53	0.05	(0.19)
chlorobenzene	112.6	10	(46.0)
chloroform (trichloromethane)	119.4	1	(4.9)
o-dichlorobenzene (1,2-dichlorobenzene)	147.0	5	(30)
ethyl chloride (chloroethane)	64.50	100	(263.7)
ethylene chloride (1,2-dichloroethane)	98.97	10	(40.5)
ethylidene chloride (1,1-dichloroethane)	98.97	25	(101)
isopropyl chloride (2-chloropropane)	78.54	85	(273)
methyl chloride (chloromethane)	50.49	20	(41.3)
methyl chloroform (1,1,1-trichloroethane)	133.4	30	(164)
methylene chloride (dichloromethane)	84.94	25	(86.8)
perchloroethylene (tetrachloroethene)	165.8	5	(34)
n-propyl chloride (1-chloropropane)	78.54	30	(96)
propylene dichloride (1,2-dichloropropane)	113.0	10	(42.2)
beta-trichloroethane (1,1,2-trichloroethane)	133.4	1	(5.5)
trichloroethylene (trichloroethene)	131.4	0.1	(0.54)
vinyl chloride (chloroethene)	62.50	0.1	(0.26)
vinylidene chloride (1,1-dichloroethene)	96.95	2	(7.9)
7. <u>Chlorofluorocarbons</u>			
chlorofluoromethane	68.48	50	(140)
chlorotrifluoroethane (1-chloro-1,2,2-trifluoroethane)	118.5	100	(484.5)
chlorotrifluoroethylene (chlorotrifluoroethene)	116.5	100	(476.4)
dichlorodifluoroethylene (1,2-dichloro-1,2-difluoroethene)	133.0	25	(136)
Freon 11 (trichlorofluoromethane)	137.4	100	(561.8)

	Mol. Wt.	MACs 7-Day ppm	(mg/M^3)
cyclohexene	82.14	60	(201)
cyclopentane	70.13	60	(172)
cyclopentene	68.12	60	(167)
cyclopropane	42.08	60	(103)
n-decane (decane)	142.3	40	(233)
1,1-dimethylcyclohexane	112.2	25	(115)
trans-1,2-dimethylcyclohexane	112.2	25	(115)
2,2-dimethylbutane	86.18	25	(88.1)
n-dodecane (dodecane)	170.3	40	(278)
ethane	30.07	1000	(1230)
ethylacetylene (1-butyne)	54.09	80	(177)
trans-1-methyl-3-ethylcyclohexane	126.2	25	(129)
ethylene (ethene)	28.05	300	(344.1)
n-heptane (heptane)	100.2	50	(205)
1-heptene	98.19	50	(201)
1-hexene	84.16	50	(172)
n-hexane (hexane)	86.18	50	(176)
isoprene (2-methyl-1,3-butadiene)	68.11	200	(557.0)
*methane	16.04	2700	(1771)
methylacetylene (propyne)	40.06	250	(409.5)
2-methyl-1-butene	70.13	500	(1434)
methylcyclohexane	98.18	15	(60.2)
4-methylcyclohexene	96.17	100	(393.2)
methylcyclopentane	84.16	15	(51.6)
3-methylpentane	86.17	500	(1762)
n-nonane (nonane)	128.3	60	(315)

		Mol. Wt.	MACs 7-Day ppm (mg/M³)
	Freon 12 (dichlorodifluoromethane)	120.9	100 (494.4)
	Freon 21 (dichlorofluoromethane)	102.9	5 (21)
	Freon 22 (chlorodifluoromethane)	86.47	100 (353.6)
	Freon 112 (1,1,2,2-tetrachloro-1,2-difluoroethane)	204.0	100 (834.2)
	Freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane)	187.4	50 (383)
	Freon 114 (1,2-dichloro-1,1,2,2-tetrafluoroethane)	171.9	100 (702.9)
	monochlorofluoroethylene (1-chloro-2-fluoroethene)	80.46	25 (82.2)
	Freon FE1301 (Halon 1301) (bromotrifluoromethane)	148.9	100 (608.8)
8.	Fluorocarbons		
	Freon 23 (trifluoromethane)	70.01	100 (286.3)
	perfluoroethylene (tetrafluoroethene)	100.0	50 (204)
**9.	Hydrocarbons		
	acetylene (ethyne)	26.04	500 (532.4)
	allene (propadiene)	40.07	50 (81.9)
	isobutane (2-methylpropane)	58.12	100 (237.6)
	n-butane (butane)	58.12	100 (237.6)
	1-butene	56.10	200 (458.0)
	cis-2-butene	56.10	100 (229.4)
	trans-2-butene	56.10	100 (229.4)
	1,3-butadiene	54.09	100 (221.2)
	isobutylene (2-methylpropene)	56.10	500 (1147)
	citrene (limonene(d))	136.2	100 (557.0)
	cyclohexane	84.16	60 (206)

	Mol. Wt.	MACs 7-Day ppm	(mg/M³)
1-nonene	126.2	50	(258)
n-octane (octane)	114.2	75	(350)
1-octene	112.2	50	(229)
isopentane (2-methylbutane)	72.15	100	(295.0)
n-pentane (pentane)	72.15	200	(590.0)
1-pentene	70.13	65	(186)
2-pentene	70.13	65	(186)
*propane	44.09	500	(901.4)
*propylene (propene)	42.08	500	(860.3)
tetradecane	198.4	50	(406)
1,1,3-trimethylcyclohexane	126.2	25	(129)
2,3,4-trimethylhexane	128.1	50	(262)
undecane (hendecane)	156.3	50	(319)
**10. Inorganic Acids			
chlorine	70.91	0.3	(0.87)
hydrochloric acid (hydrogen chloride)	36.47	1	(1.5)
hydrofluoric acid (hydrogen fluoride)	20.01	0.1	(0.082)
**11. Ketones			
acetone (2-propanone)	58.08	300	(712.5)
acetylbenzene (acetophenone)	120.1	50	(245)
cyclohexanone	98.15	15	(60.2)
diisobutyl ketone (2,6-dimethyl-4-heptanone)	142.2	10	(58.1)
mesityl oxide (4-methyl-3-penten-2-one)	98.15	10	(40.1)
methyl butyl ketone (2-hexanone)	100.2	10	(41.0)
methyl ethyl ketone (2-butanone)	72.10	20	(59.0)

		Mol. Wt.	MACs 7-Day ppm	(mg/M^3)
	methyl hexyl ketone (2-octanone)	128.2	20	(105)
	methyl isobutyl ketone (4-methyl-2-pentanone)	100.2	20	(82.0)
	methyl isopropyl ketone (3-methyl-2-butanone)	86.13	20	(70.4)
	methyl propyl ketone (2-pentanone)	86.13	20	(70.4)
	phorone (2,6-dimethyl-2,5-heptadiene-4-one)	138.2	20	(113)
12.	Mercaptans and Sulfides			
	carbon bisulfide (carbon disulfide)	76.14	5	(16)
	carbon oxysulfide (carbonyl sulfide)	60.07	5	(12)
	ethyl mercaptan (ethanethiol)	62.13	0.1	(0.25)
	ethyl sulfide (diethyl sulfide)	90.18	0.1	(0.37)
	hydrogen sulfide	34.08	2	(2.8)
	methyl sulfide (dimethyl sulfide)	62.13	1	(2.5)
	methyl mercaptan (methanethiol)	48.1	0.1	(0.20)
**13.	Nitrogen Oxides			
	nitric oxide	30.01	5	(6.1)
	nitrogen dioxide	46.01	0.5	(0.94)
	nitrogen tetroxide	92.02	0.5	(1.9)
	nitrous oxide	44.01	500	(899.8)
**14.	Organic Acids			
	acetic acid (ethanoic acid)	60.05	3	(7.4)
	butyric acid (butanoic acid)	88.10	5	(18)
	caprylic acid (octanoic acid)	144.2	25	(147)
	propionic acid (propanoic acid)	74.08	5	(15)
	pyruvic acid (2-oxo-propanoic acid)	88.06	1	(3.6)

		Mol. Wt.	MACs 7-Day ppm	(mg/M^3)
	valeric acid (pentanoic acid)	102.1	25	(104)
15.	Organic Nitrogens			
	acetonitrile (ethanenitrile)	41.05	4	(6.7)
	carbodiimide (cyanamide)	42.04	0.8	(1.4)
	uns-dimethyl hydrazine (1,1-dimethyl hydrazine)	60.10	0.1	(0.25)
	indole (1-benzo[b]pyrrole)	117.1	0.1	(0.48)
	monomethyl hydrazine (methylhydrazine)	46.07	0.04	(0.075)
	skatole (3-methyl indole)	131.2	0.1	(0.54)
**16.	Miscellaneous			
	ammonia	17.03	25	(17.4)
	carbon monoxide	28.01	25	(28.6)
	hexamethylcyclotrisiloxane	222.4	25	(227)
	hydrogen	2.016	3000	(247.3)
	hydrogen cyanide (hydrocyanic acid)	27.06	1	(1.1)
	sulfur dioxide	64.07	1	(2.6)

II. Usage Guidelines For MAC Values of Atmospheric Contaminants In Manned Spacecraft

The maximum allowable concentration (MAC) of most compounds listed above is the maximum concentration of that contaminant allowed in the spacecraft atmosphere, only if that compound exists alone. The spacecraft atmosphere, however, consists of a homogeneous mixture of compounds, many of which have similar effects that are additive. These potential additive effects must be considered in the assessment of the toxicological hazard of contaminant mixtures. The following guidelines for MAC usage provide for the potential summation of toxic effects of contaminants and must be observed in the application of MAC values to evaluate the safety of the spacecraft atmosphere.

a. The concentration of each contaminant in the spacecraft atmosphere must not exceed its MAC value.

b. For contaminants designated by an asterisk, each MAC value is valid when the contaminant is either alone or in mixtures of contaminants. These contaminants will be evaluated individually.

c. For each of the groups of contaminants, a group-limit concept will be utilized to evaluate the toxicological hazard of the group. In each group, the summation (T) of the ratios of concentration to MAC value of each member of the group (except asterisked members) must not exceed one. The following formula will be used:

$$\frac{C_1}{MAC_1} + \frac{C_2}{MAC_2} + \frac{C_3}{MAC_3} + \text{---} = T \leq 1$$

d. In addition, the interaction of contaminant groups that have potential additive effects must be evaluated toxicologically. These groups are identified by a double asterisk in the above table. For this evaluation, the summation (ΣT) of the T values of these groups must not exceed one, as shown by the following formula.

$$T_1 + T_2 + T_3 + \text{---} = \Sigma T \leq 1$$

e. MAC values for several compounds listed in the above table were established on the basis of limited toxicity data and must be considered provisional and subject to revision as more data become available.

f. The above guidelines are general guidelines to be used by the NASA toxicologist for evaluation of the toxic hazards of a homogeneous mixture of contaminants in the spacecraft atmosphere. Because of the complexity of this mixture, only general guidelines, and not fixed rules, for this evaluation are possible. In many instances a more comprehensive analysis of the data than is provided by these guidelines will be necessary for a valid toxicological evaluation.

U.S. Government

MEMORANDUM

Lyndon B. Johnson Space Center **NASA**

REFER TO: SD4/84-382

DATE: JAN 1 8 1985

1985 JAN 21 2:10

INITIATOR: SD4/MEColeman:cch:1/7/85:5291

ENCL: 1

TO: LA/Manager, National Space Transportation Systems Program

CC: See Below

FROM: SA/Director, Space and Life Sciences

SIGNATURE: for Joseph P. Kerwin, M.D.

SUBJ: New Temporary Spacecraft Maximum Allowable Concentration (SMAC) List

Enclosed is a new list of temporary spacecraft maximum allowable concentration (SMAC) limits for chemical vapors in spacecraft atmospheres. All of these chemicals have been identified as being released during offgassing tests of spaceflight materials or have been of toxicological concern in payloads or other uses. These limits are based on reported animal or human toxicity levels or on industrial limits established by the U.S. Department of Labor (USDL). Those temporary SMAC's based on the USDL limits were usually set at only one-tenth to one-fifth the USDL 8-hour per day industrial limits. The lower permissible limits for space flight conditions were based on the possibility of 24-hour per day exposures and simultaneous exposure to other contaminants that are usually found in spacecraft atmospheres during space flight missions.

The enclosed temporary SMAC limits are subject to change, if indicated by additional toxicity data. In this event, all of the designated recipients of this memo will be notified of the new limits.

It is hoped that these new temporary SMAC limits will facilitate the toxicological evaluation of payload and other chemicals brought aboard spacecraft or will assist in evaluating the potential toxicity of chemicals released by offgassing or thermodegradation of nonmetallic materials used in spacecraft.

cc:
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EC3/C. E. Verostko
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JSC Form 1180 (Rev Jan 76) *INCREASED PRODUCTIVITY = LOWER COST* PAGE 1 OF

NASA-JSC

TEMPORARILY ASSIGNED SPACECRAFT MAXIMUM ALLOWABLE CONCENTRATION (SMAC) LIMITS OF ATMOSPHERIC CONTAMINANTS FOR MISSIONS UP TO TEN DAYS*

*For missions longer than 10 days, consult the NASA Toxicologist for temporary SMAC limits.

ORDER OF CHEMICAL GROUPS

1. Alcohols
2. Aldehydes
3. Aliphatic Hydrocarbons
4. Aromatic Hydrocarbons
5. Chlorocarbons
6. Esters
7. Ethers
8. Ketones
9. Nitriles
10. Organic Acids
11. Siloxanes
12. Miscellaneous Organic Compounds
13. Inorganic Compounds

GROUP	MW	ppm	mg/m^3
Alcohols			
t-amyl alcohol	88.15	16	30
2-butoxy ethyl alcohol	118.2	5	24.2
3-methoxy butanol	104.17	20	85.2
4-methyl butanol	88.19	20	72.1
Aldehydes			
glutaraldehyde	100.1	0.098	0.4
2,4-hexadienal	96.0	1.5	5.9
hexanal (caproic aldehyde)	100.18	1.2	4.9
5-hexen-2-al	100.18	40	164
isobutyraldehyde	72.12	15	44
propenal (acrolein)	56.06	0.05	.11
sorbaldehyde (2,4-hexadienal)	96.14	1.2	4.7
C_5 aldehyde	86.13 (as valeraldehyde)[1]	15	53
Aliphatic Hydrocarbons			
aliphatic hydrocarbons not on list (no elements other than hydrogen and carbon in the molecule)	-	-	5
1,2-dimethyl cyclopentane	98.16	10	40
2,5-dimethyl heptane	128.25	50	262
dodecane (C_{12})	170.27	40	278
3,5-dimethyl heptane	128.25	20	105
2,3-dimethylhexane	114.23	40	187
2,2-dimethyl pentane	100.20	100	409.6

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[1] A prototype given to show the approximate molecular weight of compounds of this type. The toxicity limits for the chemical category may be different from this specific compound.

GROUP	MW	ppm	mg/m^3
Aliphatic Hydrocarbons (Continued)			
2-methyl pentane	88.30	100	360
n-hexane	86.19	50	176
methyl ethyl cyclopentane	112.16	5	22.9
2-methyl-3-ethyl heptane	142.28	20	116.4
3-methyl pentane	86.19	50	176
pentadecane (C_{15})	212.41	50	434.4
methylcyclopentane	84.23	60	172.3
tetradecane (C_{14})	198.38	50	405.7
C_4 alkene	56.10 (butene)	100	229
C_6 saturated and unsaturated hydrocarbons	84.16 (hexene)	25	86
C_7 saturated and unsaturated hydrocarbons	98.18 (heptene)	50	201
C_8 saturated and unsaturated hydrocarbons	112.21 (octene)	50	229
C_9 saturated and unsaturated hydrocarbons	126.2 (nonene)	25	129
C_{10} saturated and unsaturated hydrocarbons	140.26 (decene)	20	116
C_{11} saturated and unsaturated hydrocarbons	154.3 (undecene)	20	12
C_{12} saturated and unsaturated hydrocarbons	168.3 (dodecene)	20	138
C_{13} alkanes (saturated)	184.4 (n-tridecane)	20	151

GROUP	MW	ppm	mg/m^3
Aromatic Hydrocarbons			
n-butyl benzene	134.2	10	55
indan (2,3-dihydroindene)	118.19	20	97
1-methyl-3-propyl benzene	134.2	2	11
napthalene	128.16	2	10.5
C_3 aromatic hydrocarbons	120.20 (propyl-benzene)[1]	3	15
Chlorocarbons			
3-chloropropene	76.5	0.2	0.63
dichloroacetylene	94.94	0.026	0.08
1,2-dichloroethylene (cis and trans)	96.94	10	43.1
Esters			
acetate, amyl	130.21	30	160.0
acetate, benzyl	150.19	10	61.3
acetate, cyclohexyl	142.22	30	124.2
acetate, 1,3-dimethylbutyl	144.24	16	94.2
acetate, 2-ethoxyethyl	132.18	30	161.9
acetate, 2-ethylhexyl	172.30	30	211.1
acetate, ethylisohexyl	172.30	30	211.1
acetate, heptyl	158.27	40	258.4
acetate, hexyl	144.24	16	94.2
acetate, 2-hexyl	144.24	40	235.5
acetate, 3-hexyl	144.24	40	235.5
acetate, isoamyl	130.20	30	159.5
acetate, isobutyl	116.18	40	189.7

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[1] A prototype given to show the approximate molecular weight of compounds of this type. The toxicity limits for the chemical category may be different from this specific compound.

GROUP	MW	ppm	mg/m3
Esters (Continued)			
acetate, phenyl	136.12	10	55.6
acetate, sec-amyl	130.20	30	160.0
acetate, sec-butyl	116.18	40	190.0
acetate, tert-butyl	116.18	40	190.0
acetate, vinyl	86.07	3	10.5
acetoacetate, ethyl	130.16	20	106.3
acetoacetate, methyl	116.13	20	94.9
butyrate, allyl	128.19	10	52.3
butyrate, amyl	158.27	40	258.4
butyrate, butyl	144.24	30	176.6
butyrate, ethyl	116.18	30	142.3
butyrate, isoamyl	158.24	30	193.8
butyrate, methyl	102.15	20	83.5
butyrate, propyl	130.21	30	159.5
butyrate, vinyl	114.16	20	93.2
2,3-epoxy butyrate, ethyl	130.16	10	53.2
3-ethoxy propionate, ethyl	146.21	30	179.1
formate, allyl	86.10	2	7.0
formate, amyl	116.18	30	142.5
formate, butyl	102.15	20	83.5
formate, cyclohexyl	128.2	20	104.7
formate, isoamyl	116.18	30	142.5
formate, isobutyl	102.15	20	83.4

GROUP	MW	ppm	mg/m^3
Esters (Continued)			
formate, isopropyl	88.12	10	36.0
formate, heptyl	144.24	20	117.8
formate, methyl	60.05	5	12.3
formate, propyl	88.12	20	72.0
formate, vinyl	72.09	1	2.9
isobutyrate, methyl	102.15	20	83.5
isovalerate, allyl	142.22	10	58.1
isovalerate, butyl	158.27	40	258.4
isovalerate, ethyl	130.21	30	159.5
isovalerate, isoamyl	172.30	40	281.3
isovalerate, isobutyl	158.27	40	258.4
isovalerate, methyl	116.18	30	142.3
isovalerate, propyl	144.24	40	235.5
hexanoate, 2-ethyl, methyl (caproate, 2-ethyl, methyl)	158.25	20	129.5
lactate, ethyl	118.15	20	96.5
methacrylate, butyl	142.22	25	145.4
methacrylate, ethyl	114.16	25	116.7
methacrylate, propyl	128.19	25	130.8
propionate, ethyl	102.15	30	125.1
propionate, isobutyl	130.21	30	159.5
propionate, methyl	88.12	20	72.0
propionate, propyl	116.18	20	94.9
propionate, vinyl	100.13	20	81.8

GROUP	MW	ppm	mg/m^3
Ethers			
2-ethoxy ethanol (cellusolve)	90.12	20	73.7
ethyl ethenyl ether (ethyl vinyl ether)	72.12	80	340.8
ethylene oxide (ethyl 2-propenyl ether)	44.05	10	18
1-propoxybutane (propyl butyl ether)	116	40	186.8
Ketones			
cyclopentanone	84.13	8.5	29.2
3,3-dimethyl-2-butanone			
mesityl oxide (isobutenyl methyl ketone)	98.16	5	25
C_6 unsaturated ketone	100.27 (as 2-hexenane)[1]	1	4
C_7 ketone (as 2-heptanone)	114.20	5	23.5
Nitriles			
acrylonitrile (vinyl cyanide)	53.06	1.3	2.9
2-methyl propane nitrile (isopropyl cyanide)	69.12	2.6	7.3
succinonitrile	80.09	1.2	3.9
Organic Acids			
benzoic acid	122.13	10	50.0
dichloroacetic acid	129	30	160
formic acid	46.03	1	1.9
maloric acid	104.07	1	4.3
o,m,p-nitrobenzoic acid	167.19	20	137
oxalic acid	90.04	0.2	0.74
oxalic acid, K salt	129.14	0.2	1.06
picric acid	229.11	0.002	0.02

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[1] A prototype given to show the approximate molecular weight of compounds of this type. The toxicity limits for the chemical category may be different from this specific compound.

GROUP	MW	ppm	mg/m^3
Siloxanes			
decamethyltetrasiloxane	326.7	12.5	167
hexamethyl disiloxane	162.42	15	96.6
octamethyl cyclotetrasiloxane	296.66	12.5	151.7
octamethyl trisiloxane	236.3	12.5	114
siloxane, dimer	78.1	16.4	52.4
siloxane, trimer	124.3	16.4	83.4
siloxane, tetramer	170.4	16.4	114
trimethyl silanol	90.21	0.5	1.8
Miscellaneous Organic Compounds			
camphor [(2.2.1) bicyclo (heptan-2-one, 1.7.7-trimethyl)]	152.26	20	125
carbon dioxide	44.0	An alarm sounds when CO_2 levels exceed 1%	
cacodylic acid (arsenic oxide, hydroxy dimethyl	138	0.0007	0.0037
dimethyl sulfite	110.13	0.222	1.0
dimethyl ammonium sulfate	110.13	0.1	0.76
1,4-dioxane	88.10	20	72
1,3-dioxolane (allyl diglycol carbonate)	74.081	12	36
n-ethyl morpholine	115.2	4	16
ethylene oxide	44.0	10	18
methyl morpholine	101.2	4	16.5
methylene iodide	268.0	10	110
triethyl amine	101.22	5	20.7

GROUP	MW	ppm	mg/m^3
Inorganic Compounds[2,3]			
ammonium perchlorate	116.5	0.2	0.1
antimony	121.76	.02	0.1
arsenic	74.92	0.00065	0.002
beryllium[3]	9.01	0.0011	0.0004
beryllium oxide[3]	25.01	0.00039	0.0004
bromine (Br_2)	159.83	0.020	0.13
bromine chloride	115.37	0.03	0.064
bromine dioxide	111.92	0.02	0.08
cadmium	112.41	0.0044	0.02
cadmium chloride	183.32	0.0022	0.016
cadmium oxide[2]	128.41	0.001	0.005
cadmium telluride	240.02	0.002	0.02
carbon disulfide	76.13	0.96	3.1
carbonyl sulfide (COS)	60.08	2	4.9
chlorine	70.91	0.2	0.58
chlorine dioxide	67.46	0.011	0.03
cobalt chloride	129.83	0.009	0.05
ferric chloride	162.22	0.03	0.2
fluorine	38.00	0.02	0.03
gallium	69.72	0.176	0.50
gallium antimonide	191.48	0.02	0.157
gallium arsenide	144.64	0.03	0.178

[2] The limit values on the inorganic solids are based on their fine dusts, or fumes, or the fine mists of their aqueous solutions.

[3] Many inorganic solids may be subjected to intense heat in furnaces used in the various experiments which could cause vaporization.

GROUP	MW	ppm	mg/m^3
Inorganic Compounds (Continued)			
hydrazine	32.05	0.04	0.052
hydrogen chloride	36.46	1.0	1.49
hydrogen fluoride	20.008	0.6	0.5
hydrogen peroxide	34.016	0.2	0.28
hydrogen sulfide	34.08	4	5.58
indium	114.82	0.0043	0.02
indium monochloride	150.22	0.003	0.02
indium oxide (In_2O_3)	277.64	0.009	0.1
iodine	253.82	0.010	0.10
lead	207.21	0.005	0.04
lead chloride	278.1	0.005	0.054
lead telluride	334.82	0.003	0.04
lead nitrate	331.23	0.001	0.016
lithium fluoride (most other F salts, same ppm)	25.94	0.47	0.5
lithium hexafluorarsenate (as As)	195.86	0.002	0.016
lithium perchlorate	107	0.042	0.184
mercury	200.61	0.001	0.006
mercuric iodide	454.45	0.00075	0.014
mercuric oxide	216.59	0.001	0.010
nickel	58.69	0.08	0.2
nickel compounds (water soluble)	--	0.008	0.02 (Ni)
nitrogen	28.02	81% or more at 14.7 psia sets off alarm	

GROUP	MW	ppm	mg/m^3
Inorganic Compounds (Continued)			
oxygen	32.00	19% low, 24.5% high at 14.7 psia-alarm	
ozone (O_3)	48.0	0.02	0.04
perchloric acid	100.47	0.024	0.1
phosphoric acid	98.04	0.050	0.2
potassium cyanide	65.11	0.477	1.27
potassium hydroxide	56.11	0.087	0.20
silver	107.87	0.0045	0.02
silver chromate	131.77	0.006	0.03
silver compounds (water soluble)	--	0.002	0.01 (as Ag+)
silver nitrate	169.89	0.001	0.008
silver oxide	247.76	0.0045	0.046
sulfur dioxide	64.06	0.5	1.31
sulfuric acid	98.08	0.025	0.10
tantalum	180.948	0.135	1.0
tellurium	127.61	0.004	0.02
thallium	204.39	0.0024	0.02
thallium monosulfate (as Th)	301.46	0.0016	0.02
thionyl chloride	119.0	0.3	1.3
tin	118.69	0.08	0.4
tin chloride (Sn^2 or Sn^4)	189.59	0.08	0.629
zinc	65.37	0.3	0.8
zinc chloride	136.38	0.0036	0.02

MAXIMUM ALLOWABLE CONCENTRATIONS AND PRODUCTION RATES OF AIRBORNE TRACE CONTAMINANTS

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Maximum Allowable Concentrations and Production Rates of Airborne Trace Contaminants

	MOLE WT.	PRODUCTION RATES			MAXIMUM ALLOWABLE CONCENTRATION			
		NONBIOLOGICAL		BIOLOGICAL 6 Men	14 days		long term	
		Initial (gm/Day)	Nominal (gm/DAY)	(gm/DAY)	mg/1	*PPM	mg/1	*PPM
1. Alcohols								
Allyl Alcohol	58.08	0.25	0.025				0.0005	0.2
Amyl Alcohol	88.15	0.25	0.025				0.036	10.
iso Butyl Alcohol	74.12	0.25	0.025		0.076	25	0.03	10.
n-Butyl Alcohol	74.12	2.50	0.25	0.008	0.076	25	0.03	10.
sec Butyl Alcohol	74.12	0.25	0.025				0.03	10.
tert-Butyl Alcohol	74.12	0.25	0.025				0.03	10.
Cyclohexanol	100.16	0.25	0.025				0.02	5.
Ethyl Alcohol	46.07	2.50	0.25	0.024	0.19	100	0.19	100.
Ethylene Glycol	62.07	0.25	0.025				0.114	45.
Methyl Alcohol	32.04	2.50	0.25	0.0085	0.013	10	0.0039	3.
Phenol	94.11	0.25	0.025	0.57			0.0019	0.5
n-Propyl Alcohol	60.09	2.50	0.25				0.075	30.
iso-Propyl Alcohol	60.09	2.50	0.25		0.12	50	0.098	40.
2. Aldehydes								
Acetaldehyde	44.05	2.50	0.25	0.0005	0.09	50	0.09	50
Acrolein	56.06	0.25	0.025				0.00012	0.05
Butyraldehyde	72.10	0.25	0.025				0.15	50
Crotonaldehyde	70.09	0.25	0.025				0.001	0.35
Formaldehyde	30.03	0.25	0.025				0.00012	0.1
Furfural	96.08	0.25	0.025				0.002	0.5
Propionaldehyde	58.08	0.25	0.025				0.118	50.
Valeraldehyde	86.13			0.005			0.175	50.
3. Aromatic Hydrocarbons								
Benzene	78.11	0.90	0.09		0.003	1	0.003	1.0
Cumene	120.19	0.25	0.025				0.025	5.
Decalin	138.24	0.25	0.025				0.005	1.
Ethyl Benzene	106.16	0.25	0.025		0.087	20	0.087	20.
Mesitylene	120.19	0.25	0.025		0.1	20	0.05	10

*One atmosphere total pressure

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Maximum Allowable Concentrations and Production Rates of Airborne Trace Contaminant (Con't)

		PRODUCTION RATES			MAXIMUM ALLOWABLE CONCENTRATION			
		NONBIOLOGICAL		BIOLOGICAL 6 Men	14 days		long term	
	MOLE WT.	Initial (gm/Day)	Nominal (gm/DAY)	(gm/DAY)	mg/l	PPM	mg/l	PPM
3. **Aromatic Hydrocarbons** (Cont'd)								
Naphthalene	128.16	0.25	0.025				0.005	1.
n-Propyl Benzene	120.19	0.25	0.025				0.044	9.
Styrene	104.14	0.25	0.025		0.1	25	0.085	20.
Toluene	92.13	2.50	0.25		0,19	50	0.075	20.
1,2,-Trimethyl Benzene	120.19	0.25	0.025				0.049	10.
m-Xylene	106.16	2.50	0.25		0.044	10	0.044	10.
o-Xylene	106.16	2.50	0.25		0.044	10	0.044	10.
p-Xylene	106.16	2.50	0.25		0.044	10	0.044	10.
4. **Esters**								
Amyl Acetate	130.18	0.25	0.025				0.053	10.
Butyl Acetate	116.16	0.25	0.025		0.12	25	0.12	25.
Ethyl Acetate	88.10	2.50	0.25		0.14	40	0.14	40.
Ethyl Formate	74.08	2.50	0.25				0.03	10.
Methyl Acetate	74.08	2.50	0.25		0.061	20	0.03	10.
Methyl Butyrate	102.13	0.25	0.025				0.03	7.
Methyl Methacrylate	100.12	0.25	0.025				0.041	10.
n-Propyl Acetate	102.13	0.25	0.025				0.084	20.
5. **Ethers**								
Dimethyl Furan (2,5)	96.12	0.25	0.025				0.003	0.6
1,4-dioxane	88.11	2.50	0.25		0.036	10	0.007	2.
Ethyl Butyl Ether	102.17	0.25	0.025				0.2	50.
Ethyl Ether	74.12	2.50	0.25				0.12	40.
Furan	68.07	0.25	0.025				0.003	1.
Methyl Furan	82.10	0.25	0.025				0.03	9.
Methyl Vinyl Ether	58.08	0.25	0.025				0.06	25.
iso-propyl Ether	102.17	0.25	0.025				0.12	30.
Tetrahydrofuran	72.10	0.25	0.025				0.059	20.

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Maximum Allowable Concentrations and Production Rates of Airborne Trace Contaminants (Con't)

	MOLE WT.	PRODUCTION RATES			MAXIMUM ALLOWABLE CONCENTRATIO			
		NONBIOLOGICAL		BIOLOGICAL	14 days		long term	
		Initial (gm/Day)	Nominal (gm/DAY)	6 Men (gm/DAY)	mg/l	PPM	mg/l	PPM
Halocarbons								
5. Chlorocarbons								
* Carbon Tetrachloride	153.84						0.	
Chloroacetone	92.53	0.25	0.025				0.00016	0.04
Chlorobenzene	112.56	0.25	0.025		0.046	10	0.035	7.5
* Chloroform	119.39						0.	
Chloropropane	78.54	0.25	0.025				0.084	25.
Dichlorobenzene	147.01	0.25	0.025		0.03	5	0.03	5.
1,1-Dichloroethane	98.97	2.50	0.25				0.04	10.
1,2-Dichloroethane	98.97	0.25	0.025				0.02	5.
Methyl Chloride	50.49	0.25	0.025				0.021	10.
*Methyl Chloroform	133.41						0.	
Methylene Chloride	84.94	2.50	0.25		0.087	25	0.035	10.
iso-Propyl Chloride	78.54	0.25	0.025				0.26	81.
Tetrachloroethylene	165.83	0.25	0.025		0.136	20	0.067	10.
*Trichloroethylene	131.39						0.	
Vinyl Chloride	62.50	2.50	0.25		0.26	100	0.127	50
Vinylidene Chloride	96.95	0.25	0.025		0.008	2	0.004	1.
Halocarbons								
7. Chlorofluorcarbons								
Chlorofluoromethane	68.48	0.25	0.025				0.024	8.5
Chlorotrifluoroethane	116.47	0.25	0.025				0.48	100.
Freon 11	137.38	2.50	0.25		0.028	5	0.028	5.
Freon 12	120.92	2.50	0.25				0.5	100.
Freon 21	102.93	0.25	0.025				0.42	100.
Freon 22	86.47	0.25	0.025				0.35	100.
Freon 113	187.39	0.25	0.025		3.83	500	0.15	20.
Freon 114 (sym)	170.92	2.50	0.25				0.7	100,

*Contaminant not allowed on space stations

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Maximum Allowable Concentrations and Production Rates of Airborne Trace Contaminants (Con't)

	MOLE WT.	PRODUCTION RATES			MAXIMUM ALLOWABLE CONCENTRATION			
		NONBIOLOGICAL Initial (gm/Day)	NONBIOLOGICAL Nominal (gm/DAY)	BIOLOGICAL 6 Men (gm/DAY)	14 days mg/l	14 days PPM	long term mg/l	long term PPM
Halocarbons (Cont'd)								
7. Chlorofluorcarbons (Cont'd)								
Freon 114 (unsym)	170.92	0.25	0.025				0.7	100
Freon 124	136.48	0.25	0.025		2.79	500	1.67	300
Trifluorochloroethylene	116.48	0.25	0.025		2.38	500	2.38	500
Halocarbons								
8. Fluorocarbons								
Freon 23	70.01	0.25	0.025				0.012	4.
Freon 125	120.02	0.25	0.025				0.025	5.
Tetrafluorethylene	100.02	0.25	0.025				0.205	50
9. Hydrocarbons								
Acetylene	26.04	2.50	0.25				0.18	170
iso-Butane	58.12	0.25	0.025				0.18	75
n-Butane	58.12	2.50	0.25				0.18	75
Butene-1	56.10	2.50	0.25				1.15	500
cis-Butene-2	56.10	0.25	0.025				0.18	80
trans-Butene-2	56.10	2.50	0.25				0.18	80
1,3-Butadiene	54.09	2.50	0.25				0.22	100
iso-Butylene	56.10	0.25	0.025				0.18	80
Cyclohexane	84.16	2.50	0.25		1.0	300	0.68	200
Cyclohexene	82.14	0.25	0.025				0.1	30
Cyclopentane	70.13	0.25	0.025				0.1	35
Cyclopropane	42.08	0.25	0.025				0.1	60
1,1-Dimethylcyclohexane	112.21	0.25	0.025				0.12	25
trans-1,2-Dimethylcyclohexane	112.21	0.25	0.025				0.12	25
2,2-Dimethylbutane	86.18	0.25	0.025				0.093	25
Ethane	30.07	2.50	0.25				0.18	150
Ethyl Acetylene	54.09	0.25	0.025				0.18	80

Maximum Allowable Concentrations and Production Rates of Airborne Trace Contaminants (Con't)

	MOLE WT.	PRODUCTION RATES			MAXIMUM ALLOWABLE CONCENTRATION			
		NONBIOLOGICAL Initial (gm/Day)	NONBIOLOGICAL Nominal (gm/DAY)	BIOLOGICAL 6 Men (gm/DAY)	14 days mg/l	14 days PPM	long term mg/l	long term PPM
Halocarbons (Cont'd)								
7. Chlorofluorcarbons (Cont'd)								
Freon 114 (unsym)	170.92	0.25	0.025				0.7	100
Freon 124	136.48	0.25	0.025		2.79	500	1.67	300
Trifluorochloroethylene	116.48	0.25	0.025		2.38	500	2.38	500
Halocarbons								
8. Fluorocarbons								
Freon 23	70.01	0.25	0.025				0.012	4.
Freon 125	120.02	0.25	0.025				0.025	5.
Tetrafluorethylene	100.02	0.25	0.025				0.205	50
9. Hydrocarbons								
Acetylene	26.04	2.50	0.25				0.18	170
iso-Butane	58.12	0.25	0.025				0.18	75
n-Butane	58.12	2.50	0.25				0.18	75
Butene-1	56.10	2.50	0.25				1.15	500
cis-Butene-2	56.10	0.25	0.025				0.18	80
trans-Butene-2	56.10	2.50	0.25				0.18	80
1,3-Butadiene	54.09	2.50	0.25				0.22	100
iso-Butylene	56.10	0.25	0.025				0.18	80
Cyclohexane	84.16	2.50	0.25		1.0	300	0.68	200
Cyclohexene	82.14	0.25	0.025				0.1	30
Cyclopentane	70.13	0.25	0.025				0.1	35
Cyclopropane	42.08	0.25	0.025				0.1	60
1,1-Dimethylcyclohexane	112.21	0.25	0.025				0.12	25
trans1,2-Dimethylcyclohexane	112.21	0.25	0.025				0.12	25
2,2-Dimethylbutane	86.18	0.25	0.025				0.093	25
Ethane	30.07	2.50	0.25				0.18	150
Ethyl Acetylene	54.09	0.25	0.025				0.18	80

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Maximum Allowable Concentrations and Production Rates of Airborne Trace Contaminants (Con't)

	MOLE WT.	PRODUCTION RATES			MAXIMUM ALLOWABLE CONCENTRATION			
		NONBIOLOGICAL		BIOLOGICAL	14 days		long term	
		Initial (gm/Day)	Nominal (gm/DAY)	6 Men (gm/DAY)	mg/l	PPM	mg/l	PPM
11. Ketones (Cont'd)								
Methyl Ethyl Ketone	72.10	2.50	0.25		0.059	20	0.059	20.
Methyl Isobutyl Ketone	100.16	0.25	0.025		0.082	20	0.041	10.
Methyl Isopropyl Ketone	86.13	2.50	0.25				0.07	20.
12. Mercaptans								
Ethyl Mercaptan	62.13			0.005			0.004	1.5
Methyl Mercaptan	48.10			0.005			0.002	1.
Propyl Mercaptan	76.15			0.005			0.082	26
13. Miscellaneous								
Ammonia	17.03	2.50	0.25	1.5	0.017	25	0.017	25
Carbon Monoxide	28.01	2.50	0.25	0.2	0.017	15	0.017	15
Hexamethylcyclotrisiloxane	222.38	0.25	0.025				0.24	3
Hydrogen	2.016	2.50	0.25	0.3			0.215	2600.
Hydrogen Sulfide	34.08			0.00045			0.0015	1
Sulfur Dioxide	64.07	0.25	0.025		0.0026	1	0.0026	1
14. Nitrogen Oxides								
Nitric Oxide	30.01	0.25	0.025				0.0012	1.0
Nitrogen Dioxide	46.01	0.25	0.025		0.0009	0.5	0.0009	0.5
Nitrogen Tetroxide	92.02	0.25	0.025				0.0009	0.25
Nitrous Oxide	44.01	0.25	0.025				0.047	26.
15. Organic Acids								
Acetic Acid	60.05	0.25	0.025				0.005	2
Butyric Acid	88.10	0.25	0.025				0.018	5.
Caprylic Acid	144.21			0.005			0.155	26.

Maximum Allowable Concentrations and Production Rates of Airborne Trace Contaminants (Con't)

	MOLE WT.	PRODUCTION RATES			MAXIMUM ALLOWABLE CONCENTRATION			
		NONBIOLOGICAL		BIOLOGICAL	14 days		long term	
		Initial (gm/Day)	Nominal (gm/DAY)	6 Men (gm/DAY)	mg/1	PPM	mg/1	PPM
5. Organic Acids (Cont'd)								
Propionic Acid	74.08	0.25	0.025				0.015	5.
Pyruvic Acid	88.06			1.26			0.0009	0.25
Valeric Acid	102.13			0.005			0.11	26.
6. Organic Nitrogens								
Acetonitrile	41.05	0.25	0.025		0.003	2	0.003	2
Cyanamide	42.04	0.25	0.025				0.045	26
Dimethyl Hydrazine	60.10	0.25	0.025				0.0001	0.04
Indole	117.14			0.15			0.0024	0.5
Monomethyl Hydrazine	46.07	0.25	0.025				0.000035	0.02
Skatole	131.17			0.15			0.0025	0.5
7. Organic Sulfides								
Carbon Disulfide	76.13	0.25	0.025				0.006	2.
Carbonyl Sulfide	60.07	0.25	0.025				0.005	2
Diethyl Sulfide	90.18	0.25	0.025				0.00037	0.1
Dimethyl Sulfide	62.13	0.25	0.025		0.0025	1	0.0025	1

Conversion of PPM to mg/liter (by volume)

$$X \text{ mg/liter} = \frac{(PPM)(P_T)(n_c)}{RT\,(10^3)}$$

where: PPM = parts per million

P_T = total pressure of mixture (atmospheres)

n_c = Molecular weight of contaminant (mole)

R = gas constant, $0.08205 \frac{\text{liter-atmos.}}{^{\circ}\text{K gm-mole}}$

T = Temperature of gas mixture ($^{\circ}$K) or ($^{\circ}$C + 273)

NOTE: 77°F = 25°C = 298°K

Maximum Allowable Concentrations and Production Rates of Airborne Trace Contaminants (Con't.)

Pertinent Chemical Synonyms

isobutanol = iso-Butyl Alcohol
n-Butanol = n-Butyl Alcohol
2-Butanone = Methyl Ethyl Ketone
Butyl Ethyl Ether = Ethyl Butyl Ether
Chlorodifluoromethane = Freon 22
Chlorotetrafluoroethane = Freon 124
Propylene Aldehyde = Crotonaldehyde = Trans-2-Butenal = Crotonic Aldehyde = β - Methylacrolein
Decahydronaphthalene = Decalin
1,1-Dichloroethene = Vinylidene Chloride
1,2-Dichloroethane = Ethylene Chloride=Ethylene Dichloride
Dichlorodifluoromethane = Freon 12
Dichlorofluoromethane = Freon 21
Dichlorotetrafluorethane = Freon 114
Diethyl Sulfide = Ethyl Sulfide = Thioethyl Ether
Ethanol = Ethyl Alcohol
p-Dioxane = 1,4-Dioxane = Dioxan
Methanol = Methyl Alcohol
2-Methyl Butanone-3 = 3-Methyl-2-Butanone = Methyl Isopropyl Ketone
Methoxyethene = Methyl Vinyl Ether = Ethenyl Methyl Ether
Pentanal = Valeral = n-Valeric Aldehyde = Valderaldehyde
Propanal = Propional = Propionic Aldehyde = Propionaldehyde
Propene = Propylene
Propyne = Propine = Methyl Acetylene = Allylene
Pentafluoroethane = Freon 125
Perchloroethylene = Tetrachloroethylene
Propanthiol = Propyl Mercaptan
isopropanol = iso-Propyl Alcohol
Propyl Chloride = Chloropropane
Trichlorofluoromethane = Freon 11
Trichlorotrifluoroethane = Freon 113
Trifluoromethane = Fluoroform = Freon 23
1,3,5-Trimethyl Benzene = Mesitylene
Valerone = Diisobutylketone

ATTACHMENT B

Meeting Notes from the First Internal Environment Working Group for the Space Station

INTERNAL ENVIRONMENT WORKING GROUP

CHAIRMAN: DUANE L. PIERSON, PH.D.

SCOPE

1. THE INTERNAL ENVIRONMENT WORKING GROUP (IEWG) SHALL DEFINE THE REQUIREMENTS FOR THE FOLLOWING ELEMENTS OF THE SPACE STATION INTERNAL ENVIRONMENT: GAS COMPOSITION/TEMPERATURE/HUMIDITY, MICROBIOLOGY, PARTICULATES, FIRE DETECTION/SUPPRESSION, RADIATION, TOXICOLOGY, VIBROACOUSTICS, WATER QUALITY, AND SANITATION MANAGEMENT.

2. THE IEWG SHALL FUNCTION IN AN ADVISORY CAPACITY TO THE SPACE STATION PROGRAM FOR THE PURPOSE OF RESOLVING ISSUES RELATING TO THE INTERNAL ENVIRONMENT THROUGHOUT THE REMAINDER OF THE PROGRAM.

INTERNAL ENVIRONMENT WORKING GROUP
(IEWG)

ENVIRONMENTAL ELEMENT	COORDINATOR
GAS COMPOSITION/PRESSURE /TEMPERATURE/HUMIDITY	J. WALIGORA
MICROBIOLOGY	D. PIERSON
PARTICULATES	S. NAKAMURA
FIRE DETECTION/SUPPRESSION	M. COLE
RADIATION	S. NACHTWEY
TOXICOLOGY	M. COLEMAN
VIBROACOUSTICS	A. POWELL
WATER QUALITY	R. SAUER
SANITATION MANAGEMENT	R. SAUER

INTERNAL ENVIRONMENT WORKING GROUP
PARTICIPANTS

JSC

EZ/K. HOUCK
KC2/J. QUELLER
NS3/M. COLE
ND5/S. NAKAMUA
PB3/D. HAINES
PB7/N. LANCE
PB8/N. BENKO
S. LUCZKOWSKI
PD4/D. KURTZ
SD5/D. HORRIGAN
J. WALIGORA
SP4/A. COPELAND
SD4/N. CINTRON
D. PIERSON
M. COLEMAN
R. SAUER
SD121/S. NACHTWEY

GSFC

400-6/D. THOMPSON
N. CAROSSO

KSC

MD/A. KOLLER

LARC

364/D. BREWER
L. GARRETT
J. HALL
463/A. POWELL

MSFC

EB3/R. HUMPHRIES
ES6/J. WATTS

LOCKHEED

I. SCHNEPP

MATSCO/GE

S. CORBIN
L. HAMPTON
J. HARTSFIELD
P. WESTMORELAND

MDAC

H. KELLEY
P. LEDOUX
C. SMITH

NSI

T. GALEN
R. IRBE
C. LAM
D. RUSSO

ROCKWELL

J. GREEN

II

B. MCKINLEY
C. WILLIS

WEBB-MURRAY

R. BRICKER
B. MAGEE
J. PUTNAM

INTERNAL ENVIRONMENT WORKING GROUP

<u>DATE</u>		<u>MILESTONE</u>
FEBRUARY 11-12, 1986	-	FIRST OFFICIAL IEWG MEETING
FEBRUARY 12, 1986	-	INDUCED ENVIRONMENT TELECON
FEBRUARY 19, 1986	-	NATURAL AND INDUCED ENVIRONMENTS PANEL MEETING
FEBRUARY 24, 1986	-	CCB
FEBRUARY 26, 1986	-	SIB
MARCH 4, 1986	-	IEWG COORDINATOR REVIEW
MARCH 14, 1986	-	IEWG MEETING (TELECON)

GAS COMPOSITION/PRESSURE/TEMPERATURE/HUMIDITY

- CURRENT JSC 30000 REQUIREMENTS:
  - LEVELS OR RANGES SPECIFIED IN TABLE 2-9
- RECOMMENDED REQUIREMENT CHANGES:
  - DECREASE HUMIDITY UPPER LIMIT (OPERATIONAL MODE) FROM 75% TO 60%
  - INCREASE VENTILATION LOWER LIMIT (OPERATIONAL MODE) FROM 5 FT/MIN TO 10 FT/MIN
  - DECREASE TEMPERATURE UPPER LIMIT (EMERGENCY MODE) FROM 90°F TO 85°F
  - DECREASE TEMPERATURE RANGE (90-DAY DEGRADED MODE) FROM 60-85% TO 65-80°F.
  - INCREASE TEMPERATURE UPPER LIMIT (OPERATIONAL MODE) FROM 75°F TO 80°F
  - CREW CONTROL OF TEMPERATURE ONLY IN OPERATIONAL MODE
- STATUS:
  - MSFC - REVIEW IMPACT OF FIRST 4 CHANGES ON ECLSS
  - JSC - DOCUMENT JUSTIFICATION FOR FIRST 4 CHANGES
  - OTHER NASA CENTERS - WILL REVIEW
- MAJOR ISSUES:
  - REDUCTION OF UPPER LIMITS OF HUMIDITY FROM 75% TO 60% MAY REQUIRE MAJOR REDESIGN OF ECLSS
- ESTIMATED RESOLUTION:
  - MARCH 14, 1986

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TABLE 2-9. RESPIRABLE ATMOSPHERE REQUIREMENTS

PARAMETER	UNITS	OPERATIONAL	90-DAY DEGRADED(1)	28-DAY EMERGENCY
CO_2 Partial Press	mmHg	3.0 max	7.6 max	12 max
Temperature	deg F	65-~~75~~ 80*	~~60-85~~ 65-80	60-~~90~~85
Dew Point(2)	deg F	40-50	35-70	35-70
Ventilation	ft/min	15-40	10-100	~~5~~10-200
O_2 Partial Press(3)	psia	2.7-3.2	2.4-3.8	2.3-3.9
Total Pressure(4)	psia	10.2 or 14.7	10.2 or 14.7	10.2 or 14.7
CO_2 Partial Press	N/m^2	400 max	1013 max	1600 max
Temperature	°K	291.5-2~~0~~97.1	288.8-302.6	288.8-305.4
Dew Point(2)	°K	277.6-288.8	273.9-294.3	273.9-294.3
Ventilation	m/sec	.076-.203	.051-.508	.025-1.016
O_2 Partial Press(3)	N/m^2x103	18.6-22.1	16.5-26.2	15.0-26.9
Total Pressure(4)	N/m^2X103	70.3-101.4	70.3-101.4	70.3-101.4
Dilute Gas	----	N_2	N_2	N_2
Trace Contaminants(7)	mg/m^3	TBD	TBD	TBD
Micro-organisms	CFU/m^3(5)	500(6)	750(6)	1000(6)

* In the Operational mode Temperature will be selectable ± 2°F

(1) Degraded levels meet "fail operational" criteria.

(2) Relative humidity shall be ~~within the range of 25-75 percent~~ not exceed 60% in Operational Mode or 75% in degraded or emergency mode.

(3) In no case shall the O2 partial pressure be below 15.0 N/m^2a/2.3 psia, or the O2 concentration exceed 25.9 percent of the total pressure at 101.4 N/m^2a/14.7 psia or 30 percent of the total pressure at 70.3 N/m^2a/10.2 psia.

(4) All systems shall be compatible with both 70.3 N/m^2a/10.2 psia and 101.4 N/m^2a/14.7 psia total pressure.

(5) Colony Forming Units (CFU).

TABLE 2-9. RESPIRABLE ATMOSPHERE REQUIREMENTS

PARAMETER	UNITS	OPERATIONAL	90-DAY(1) DEGRADED	28-DAY EMERGENCY
CO_2 Partial Press	mmHg	3.0 max	7.6 max	12 max
Temperature(2)	deg F	65-80	65-80	60-85
Dew Point(3)	deg F	40-50	35-70	35-70
Ventilation	ft/min	15-40	10-100	10-200
O_2 Partial Press(4)	PSIA	2.83-3.35	2.4-3.45	2.3-3.45
Total Pressure	PSIA	14.5-14.9	14.5-14.9	14.5-14.9
CO_2 Partial Press	N/m^2	400 max	1013 max	1600 max
Temperature(2)	°K	291.5-299.9	291.5-299.9	288.8-302.6
Dew Point(3)	°K	277.6-291.5	273.9-294.3	273.9-294.3
Ventilation	m/sec	.076-.203	.051-.508	.050-1.016
O_2 Partial Press(4)	$N/m^2 \times 10^3$	19.5-23.1	16.5-23.7	15.8-23.7
Total Pressure	$N/m^2 \times 10^3$	99.9-102.7	99.9-102.7	99.9-102.7
Dilute Gas	----	N_2		N_2

1. Degraded levels meet "fail operational" criteria.

2. In the operational mode temperature will be selectable ±2°F/1.1°C throughout the range.

3. Relative humidity shall not exceed 60% in the operational mode or 75% in the degraded or emergency modes.

4. In no case shall the O_2 partial pressure be below 15.0 N/m^2 (2.3 PSIA), or the O^2 concentration exceed 23.8% of the total pressure.

MICROBIOLOGY

- CURRENT JSC 30000 REQUIREMENTS:
  - DETECTION OF MICROBIAL LOAD REQUIREMENT
  - TBD

- RECOMMENDED REQUIREMENT CHANGES:
  - PERIODIC MONITORING OF CREW, SURFACES, AIR, WATER, FOOD, AND BIOLOGICAL SPECIMENS
  - ACCEPTABILITY LIMITS:
    - AIR ($\leq$ 1000 CFU PER CUBIC METER)
    - SURFACES ($\leq$ 100 CFU PER 25 SQUARE CENTIMETERS)
    - POTABLE WATER (0 CFU PER 100 MILLILITERS)
    - NON-POTABLE WATER (TBD)
    - FOOD (EXISTING STS REQUIREMENTS) (TBD)
    - BIOLOGICAL SPECIMENS (MUST MEET SPECIFIC PATHOGEN FREE LIST)
  - CONTAMINATION CONTROL MEASURES
    - MAINTAIN UPPER LIMIT OR HUMIDITY TO 60%
    - AIR FILTRATION OF 99.997% RETENTION OF PARTICLES $\geq$ 0.3 MICROMETERS
    - CONTAINMENT OF BIOLOGICAL SPECIMENS (PRECLUDE CONTAMINATION OF CREW AREA)

- STATUS:
  - MSFC AND GSFC - TENTATIVE AGREEMENT PENDING REVIEW
  - OTHER NASA CENTERS - WILL REVIEW

- MAJOR ISSUES
  - HUMIDITY REQUIREMENT MAY REQUIRE MAJOR REDESIGN OF ECLSS

- ESTIMATED RESOLUTION
  - MARCH 14, 1986

MICROBIOLOGICAL MONITORING REQUIREMENTS AND ACCEPTABILITY LIMITS

Monitoring Requirements

Sample Source	Preflight	Inflight	Postflight	Acceptability Limit
Crewmember	F-30, 14, 10 and 1 (ear, nose, throat, skin, sputum, blood (F-30 only), urine, feces)	Contingency	L+0 (ear, nose, throat, skin, sputum, urine, and feces)	Flight Surgeon evaluates preflight laboratory data and makes final decision pertaining to flight readiness of the crewmembers
Surfaces	Prior to Closeout	15 day intervals and within 12 hrs of crew exchange	-	Microbial growth may not exceed 100 CFU per 25 cm^2
Air	Prior to Closeout	10 day intervals and within 12 hrs of crew exchange	-	Levels of airborne microorganisms may not exceed 1000 CFU per cubic meter
Potable Water	N/A	Potable water will be held in a storage tank for 48 hrs and checked for sterility prior to use, and every 7 days until water is consumed.	- -	No viable microorganisms per 100 ml
Non-Potable Water	TBD	TBD	-	TBD
Food	Prior to shipping to KSC	Contingency	Contingency	Specifications in SD-T-0252A (Thermostabilized) and SD-T-0251B (Non-Thermostabilized) (See Appendix)
Biological Specimens	As required by HRPPC	Contingency	As required by HRPPC	All biological specimens must meet the specific pathogen free criteria as defined by the JSC Human Research

PARTICULATES

- CURRENT JSC 30000:
  - CLASS 10,000 AIR

- RECOMMENDED REQUIREMENT CHANGES:
  - CLASS 100,000 FOR 0.5 UM $\leq$ PARTICLES < 150 MICRONS
  - TBD LEVEL FOR PARTICLES > 150 UM
  - CLASS 100 AIR AVAILABLE FROM AT LEAST ONE OUTLET
  - MONITORING ON TBD BASIS

- STATUS:
  - JSC - IDENTIFY NEED SOURCE FOR CLASS 100 AIR
  - MSFC AND GSFC - REVIEWING CHANGES
  - OTHER NASA CENTERS - WILL REVIEW

- MAJOR ISSUES
  - NONE

- ESTIMATED RESOLUTION
  - MARCH 14, 1986

FIRE DETECTION/SUPPRESSION

- CURRENT JSC 30000:
  - FIRE DETECTION AND EXTINGUISHING CAPABILITY
  - NON-TOXIC EXTINGUISHANT WHICH IS ECLSS COMPATIBLE
- RECOMMENDED REQUIREMENT CHANGES:
  - CAPABILITY TO DETECT SMOKE AND INCIPIENT FIRE AS WELL AS VISIBLE FLAME
  - FIRE EXTINGUISHANT SHALL NOT PRODUCE TOXIC OR CORROSIVE THERMODEGRADATION PRODUCTS
- STATUS:
  - MSFC AND GSFC - REVIEWING CHANGES
  - OTHER NASA CENTERS - WILL REVIEW
- MAJOR ISSUES
  - NONE
- ESTIMATED RESOLUTION
  - MARCH 14, 1986

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RADIATION

- CURRENT JSC 30000:
  - EXPOSURE LIMITS SET FOR IONIZING AND NON-IONIZING RADIATION (LASER AND EM ENERGY)
- RECOMMENDED REQUIREMENT CHANGES:
  - IONIZING RADIATION LIMITS SET TO LIMITS UNDER CONSIDERATION BY NCRP SCIENTIFIC COMMITTEE #75
  - NON-IONIZING RADIATION (INCLUDING UV, LIGHT AND NEAR IR, AND RM) LIMITS SET TO THE ACGIH THRESHOLD LIMIT VALUES (TLV)
- STATUS:
  - MSFC AND GSFC - REVIEWING CHANGES
  - JSC - CONTINUOUS REVIEW PROCESS IN EFFECT
  - OTHER NASA CENTERS - WILL REVIEW
- MAJOR ISSUES
  - NONE
- ESTIMATED RESOLUTION
  - MARCH 14, 1986

TABLE 2-11. IONIZING RADIATION EXPOSURE LIMITS[1]

Constraints in REM[2]	Bone 5(cm)	Skin ~~(0.1mm)~~ .001cm	Eye (3mm)
~~1 Yr. Avg. Daily Rate~~	~~0.2~~	~~0.5~~	~~0.3~~
30 Day Max.	25.0	~~75.0~~ 150	~~37.0~~ 100
~~Quarterly Max.~~	~~30.0~~	~~80.0~~	~~40.0~~
Yearly Limit	~~60.0~~ 50	~~170.0~~ 300	~~85.0~~ 200
Career Limit	~~200.0~~ 100-200	600.0	~~300.0~~ 400

---

[1] This table expressed in International System of Units (SI) only due to common usage by the discipline.

[2] Radiation Absorbed Dose (RAD) in RAD's times a quality factor (q) to account for the different Relative Biological Effectiveness (RBE) of different radiations. For planning purposes, q = 1.2.

TABLE 2-11. PRELIMINARY IONIZING RADIATION EXPOSURE LIMITS[1]

EXPOSURE INTERVALS	DEPTH (5 CM)	EYE (0.3 CM)	SKIN (0.001 CM)
30 DAYS	25 REM[2]	100 REM	150 REM
ANNUAL	50	200	300
CAREER	100-400[3]	400	600

[1] THESE PRELIMINARY DOSE-EQUIVALENT LIMITS ARE BEING CONSIDERED BY NCRP SCIENTIFIC COMMITTEE #75 ON GUIDANCE ON RADIATION RECEIVED IN SPACE ACTIVITIES. BEFORE THEY CAN BECOME THE OFFICIAL POSITION OF THE NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENT (NCRP), THEY MUST BE APPROVED BY THE FULL COUNCIL. THIS APPROVAL IS EXPECTED BY SEPTEMBER 30, 1986.

[2] THIS TABLE IS EXPRESSED IN CONVENTIONAL UNITS DUE TO COMMON USAGE BY THE DISCIPLINE. THE SI UNIT IS THE SIEVERT (SV), WHICH IS EQUIVALENT TO 100 REM.

[3] THE CAREER DEPTH DOSE-EQUIVALENT LIMIT IS BASED UPON A MAXIMUM 3% LIFETIME RISK OF CANCER MORTALITY. THE TOTAL DOSE-EQUIVALENT YIELDING THIS RISK DEPENDS ON SEX AND AGE AT START OF EXPOSURE. THE CAREER DOSE-EQUIVALENT LIMIT IS APPROXIMATELY EQUAL TO:

200 + 7.5 (AGE - 30) REM, FOR MALES, UP TO 400 REM MAXIMUM
200 + 8/5 (AGE - 38) REM, FOR FEMALES, UP TO 400 REM MAXIMUM.

TOXICOLOGY

- **CURRENT JSC 30000:**
  - CONTAMINATION CONTROL SYSTEM MUST ADDRESS OFFGASSING, THERMODECOMPOSITION AND METABOLIC PRODUCTS, AND PARTICULATES
  - CAPABILITY TO DETECT TRACE GAS CONTAMINANTS AND PARTICULATES, ALERT CREW, AND IMPLEMENT CORRECTIVE ACTION
  - TRACE GAS LEVELS - TBD

- **RECOMMENDED REQUIREMENT CHANGES:**
  - MULTIPLE REQUIREMENTS SPECIFIED IN JSC TOXICOLOGY REQUIREMENTS FOR SPACE STATION
  - HIGHLIGHTS
    - SPACECRAFT MAXIMUM ALLOWABLE CONCENTRATIONS (SMAC) FOR VOLATILE CONTAMINANTS - NHB8060.1C
    - NON-METALLIC MATERIAL OFFGASSING TESTS
    - CHEMICAL DETECTORS AND ALARMS
    - TOXICOLOGICAL EVALUATIONS OF PAYLOADS AND PROCEDURES
    - ATMOSPHERIC ANALYZER - QUALITATIVE AND QUANTATIVE ANALYSIS
      - PORTABLE ANALYZERS

- **STATUS:**
  - MSFC AND GSFC - REVIEWING CHANGES
  - OTHER NASA CENTERS - WILL REVIEW

- **MAJOR ISSUES**
  - SMAC LEVELS UNDERGOING REVISION

- **ESTIMATED RESOLUTION**
  - RMXCEVACOMBLETED BY MARCH 14, 1986

VIBROACOUSTICS

- CURRENT JSC 30000:
    - ACOUSTICS
        - LIMITS SET FOR HEARING CONSERVATION, SPEECH COMMUNICATION, AND SLEEPING AREAS
    - VIBRATION - ACCEPTABLE VIBRATION ENVIRONMENT
    - VERIFICATION - PERIODIC MEASUREMENT OF ACOUSTIC NOISE
    - ACOUSTIC ISOLATION - MUST LIMIT EXCURSIONS TO LESS THAN AN AVERAGE OF 10DB ABOVE SPEC. PEAKS MUST NOT EXCEED 30 DB ABOVE SPEC.

- RECOMMENDED REQUIREMENT CHANGES:
    - RECOMMENDATIONS FROM NRC COMMITTEE ON HEARING BIOACOUSTICS AND BIOMECHANICS (CHABA)
    - ACOUSTICS
        - INCREASE LIMIT FOR HEARING CONSERVATION FROM 70DB TO 80DB
        - INCREASE LIMIT IN COMMUNICATION AREAS FROM 50DB TO 55DB
    - VIBRATION
        - LIMITS SPECIFIED FOR 3 FREQUENCY RANGES BETWEEN .1 AND 100 HZ
        - SEPARATE LIMITS SPECIFIED FOR HEAD AND FINGER CONTROL AND VISUAL OBSERVATIONS

- STATUS:
    - MSFC, GSFC, LANGLEY AND JSC - REVIEWING CHANGES
    - OTHER NASA CENTERS - WILL REVIEW

- MAJOR ISSUE
    - COMMUNICATION LEVELS NEED EXPANSION
    - SLEEP LEVELS MAY NEED REVISION
    - VIBRATIONAL SPECIFICATIONS NEED REVISION

- ESTIMATED RESOLUTION
    - MARCH 14, 1986

WATER QUALITY

- **CURRENT JSC 30000:**
  - POTABLE, HYGIENE, WASH, AND EXPERIMENTAL WATER NEEDS PROVIDED
  - MEANS TO CONTROL AND MONITOR WATER QUALITY PARAMETERS

- **RECOMMENDED REQUIREMENT CHANGES:**
  - ADJUSTED WATER QUANTITIES FOR POTABLE, HYGIENE, EVA, AND EXPERIMENTAL NEEDS (TABLE 10)
  - MONITORING REQUIREMENTS (TABLE 2-10B)
  - BACTERICIDE LEVELS
  - WATER QUALITY SPECIFICATIONS (TABLE 2-10C)
  - RESTORATION OF WATER QUALITY
    - CAPABLE TO RESTORE WATER QUALITY FOLLOWING CONTAMINATION EVENT

- **STATUS:**
  - MSFC AND GSFC - REVIEWING CHANGES
  - OTHER NASA CENTERS - WILL REVIEW

- **MAJOR ISSUES**
  - MONITORING SCHEDULE - TOO MANY TBD'S
  - NEED TO DEFINE WATER QUALITY SPECIFICATIONS - TOO MANY TBD'S
  - TOTAL ORGANIC CARBON (TOC) REQUIREMENT OF < 100 PPB; WATER RECLAMATION TECHNOLOGY LIMITED TO 1-50 PPM

- **ESTIMATED RESOLUTION**
  - MONITORING SCHEDULE - MARCH 14, 1986
  - TOC RESOLUTION - MAY 6, 1986

TABLE 2-10 MINIMUM WATER QUANTITY REQUIREMENTS

CLASS UNITS OPERATIONAL MODE

PARAMETER	UNITS	OPERATIONAL	DEGRADED[1]	EMERGENCY
POTABLE[2]	LB/MAN-DAY	6.26-11.35	6.26	6.26
HYGIENE	LB/MAN-DAY	12-25	12	0
EVA[3]	LB/MAN-DAY	TBD	TBD	TBD
EXPERIMENT	LB/MAN-DAY	TBD	TBD	0

[1] DEGRADED LEVELS MEET "FINAL OPERATIONAL" CRITERIA

[2] BASED ON 2950 KCAL/CM-DAY IVA WORK RATE

[3] BASED ON TBD KCAL/HR EVA WORK RATE

TABLE 2-10B ON-ORBIT WATER MONITORING SCHEDULE

PARAMETER	PROCESS CONTROL (CONTINUOUS)	BATCH CONTROL (PRIOR TO USE)	PERIODIC (WEEKLY/MONTHLY)
Conductivity	X	X	-
pH	X	X	-
Turbidity	TBD	TBD	-
Color	-	TBD	-
Temperature	X	-	-
Complete Physical Properties[1]	-	X	TBD
Ammonia	TBD	TBD	-
Iodine	X	X	-
Specific Ions	TBD	TBD	-
Complete Inorganic Constituents[1]	-	TBD	TBD
TOC	X	X	TBD
TOC less	-	TBD	TBD
Carboxylic Acids	-	TBD	TBD
Complete Organic Constituents[1]	-	TBD	TBD

TABLE 2-10B ON-ORBIT WATER MONITORING SCHEDULE (CONTINUED)

PARAMETER	PROCESS CONTROL (CONTINUOUS)	BATCH CONTROL (PRIOR TO USE)	PERIODIC (WEEKLY/MONTHLY)
TOTAL BACTERIA	-	TBD	TBD
ANEROBES	-	TBD	TBD
YEAST AND MOLDS	-	TBD	TBD
BACTERIAL ID[1]	-	TBD	TBD
VIRUS	-	TBD	TBD
RADIONUCLIDES[1]	-	TBD	TBD
DISSOLVED GAS	-	X	-
FREE GAS	X	X	-

[1] AS SPECIFIED BY JSC-SPEC-SD-W-0020

TENTATIVE SPACE STA[illegible]N WATER QUALITY REQUIREMENTS

		WATER USE				
		POTABLE	PERSONAL HYGIENE	EXPERIMENTS	SYSTEMS	MOST LIMITING VALUE-REMARKS
PHYSICAL						
TOTAL SOLIDS (SUSPENDED/DISSOLVED)	MG/L	TBD <100	TBD <500	TBD	TBD	SYSTEMS-HX SCALING; EXPERIMENTS
CONDUCTIVITY	U MHOS/CM	-	-	TBD	TBD 1.0	SYSTEMS-HX, EVAP COOLING/SCALING
SURFACE TENSION	DYNES/CM	TBD NR	TBD NR	TBD	72	SYSTEMS
COLOR, TRUE	PT/CO	15	15	TBD	NR	POTABLE-TS, ORGANICS, PARTICULATES
TASTE AND ODOR	TIN/TUN	<3	<3	TBD	NR	POTABLE
PH		6.0-8.0	5.0-8.0	TBD		POTABLE
PARTICULATE		40 U	40 U	TBD	40 U	SYSTEMS
POTASSIUM PERMAGENATE CONSUMPTION		NR	NR	TBD	PASS	SYSTEMS ORGANICS
TURBIDITY	NTU	11	11	TBD	TBD	POTABLE-DISINFECTION
DISSOLVED GAS	NO FREE @ 35°C	NONE	NONE	TBD	TBD	POTABLE; SYSTEMS-NONE RELEASED
FREE GAS	STP	NONE	NONE	TBD	TBD	POTABLE; SYSTEMS
IONIC (INORGANIC)	(MG/L)					
AMMONIA		0.5	0.5	TBD	NR	POTABLE
ARSENIC		0.01	0.01	TBD	NR	POTABLE
BARIUM		1.0	1.0	TBD	NR	POTABLE
CHLORIDE		250	TBD	TBD	NR	POTABLE
CHROMIUM		0.05	0.05	TBD	NR	POTABLE
COPPER		1.0	1.0	TBD	NR	POTABLE
FLUORIDE		1.0	1.0	TBD	NR	POTABLE
IODIDE		15	TBD	TBD	NR	POTABLE
IRON		0.3	0.3	TBD	NR	POTABLE
LEAD		0.05	0.05	TBD	NR	POTABLE
MANGANESE		0.05	0.05	TBD	NR	POTABLE
MAGNESIUM		0.05	0.05	TBD	NR	POTABLE
CALCIUM		TBD	TBD	TBD	NR	POTABLE
MERCURY		0.002	0.002	TBD	NR	POTABLE
NICKEL		0.05	0.05	TBD	NR	POTABLE
NITRATE (NO3-N)		10	TBD	TBD	NR	POTABLE
POTASSIUM		340	TBD	TBD	NR	POTABLE
SELENIUM		0.01	0.01	TBD	NR	POTABLE
SILVER		0.05	0.05	TBD	NR	POTABLE
SULFIDE		0.05	0.05	TBD	NR	POTABLE
SULFATE		250	TBD	TBD	NR	POTABLE
ZINC		5.0	5.0	TBD	NR	POTABLE

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WATER USE

	Potable	Personal Hygiene	Experiments	Systems	Most Limiting Value-Remarks
Organics (ug/L)					
TOC	TBD <500	TBD <10,000	TBD	TBD	Potable
TOC (Less Non-Toxicants)	TBD <100	TBD <1,000	TBD	TBD	Potable
Organic Acids	TBD <100	TBD	TBD	TBD	Potable
Cyanide	200	TBD	TBD	TBD	Potable
Phenols	1	1	TBD	TBD	Potable
Halogenated Hydrocarbons	TBD < 10	TBD	TBD	TBD	Potable
Organic Alcohols	TBD <100	TBD	TBD	TBD	Potable
Aesthetics (Minimum) (mg/L)					
Cations	TBD 30	NR	NR	NR	Potable
Anions	TBD 30	NR	NR	NR	Potable
CO_2 mg/L	TBD 15	NR	NR	NR	Potable
Microbial					
Bacteria (Total Count) CFU/100 mL					
Anaerobes	0	0	TBD	10	Potable
Aerobes	0	0	TBD	NR	Potable
Gram Positive	0	0	TBD	NR	Potable
Gram Negative	0	0	TBD	NR	Potable
E-Coli	0	0	TBD	NR	Potable
Enteric	0	0	TBD	NR	Potable
Virus	0	0	TBD	NR	Potable
Yeast and Molds	0	0	TBD	NR	Potable
	0	0	TBD	NR	Potable
Bactericide (mg/L)					
Residual (Halogens) (Minimum)	0.5	0.5	TBD	NR	Potable
Residual (Halogens) (Maximum)	4.0	6.0	TBD	NR	Potable
Radiological (pCi/L)					
Alpha 90 Sr	10	TBD	TBD	NR	Potable
Alph 226 Ra	3	TBD	TBD	NR	Potable
Beta 3 H	1000	TBD	TBD	NR	Potable

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SANITATION MANAGEMENT

- CURRENT JSC 30000:
  - WASTE MANAGEMENT - A MEANS OF COLLECTING AND PROCESSING WASTE PRODUCTS SHALL BE PROVIDED AND SHALL MEET MAN SYSTEMS REQUIREMENTS AND INTERFACES. METHOD TO PROCESS SOLID WASTES INTO INERT PRODUCTS SHALL ALSO BE PROVIDED.
  - HOUSEKEEPING - MODULE DESIGN SHALL FACILIATE CLEANING. PROVISIONS PROVIDED FOR TRASH COLLECTION, COMPACTION, AND BIOLOGICAL STABILIZATION.
- RECOMMENDED REQUIREMENT CHANGES:
  - NONE, SINCE THIS HAS ONLY RECENTLY BEEN IDENTIFIED AS AN IEWG DISCIPLINE AREA
- STATUS:
  - IDENTIFICATION OF SANITATION MANAGEMENT PROBLEM AREAS IN PROGRESS
- MAJOR ISSUES
  - NONE
- ESTIMATED RESOLUTION
  - PRELIMINARY DEFINITION - MARCH 14, 1986

INTERNAL ENVIRONMENT WORKING GROUP

CHAIRMAN: DUANE L. PIERSON, PH.D.

TECHNICAL AREAS

- GAS COMPOSITION/PRESSURE/TEMPERATURE/HUMIDITY
- MICROBIOLOGY
- PARTICULATES
- FIRE DETECTION/SUPPRESSION
- RADIATION
- TOXICOLOGY
- VIBROACOUSTICS
- WATER QUALITY
- SANITATION

TECHNICAL AREA: GAS COMPOSITION/TEMPERATURE/PRESSURE/HUMIDITY

2.2.9.2.2 MODULE TEMPERATURE AND HUMIDITY CONTROL

2.2.9.2.2.1 RESPIRABLE ATMOSPHERE

THE RESPIRABLE ATMOSPHERIC COMPOSITION, PRESSURE, TEMPERATURE, HUMIDITY, AND VENTILATION LEVELS PROVIDED BY THE ECLSS SHALL MEET THE REQUIREMENTS IN TABLE 2-9.

2.2.9.2.2.2 CREW CONTROL

2.2.9.2.2.2.1 OPERATIONAL MODE

DURING NORMAL OPERATIONAL CONDITIONS CREW CONTROL OF TEMPERATURE WITHIN THE RANGE SPECIFIED IN TABLE 2-9 SHALL PROVIDE CREW COMFORT AND THERMAL BALANCE FOR NORMAL MISSION ACTIVITIES INCLUDING EXERCISE AND PERSONAL HYGIENE ACTIVITIES.

2.2.9.2.2.2.2 EMERGENCY MODE

DURING 28 DAY EMERGENCY CONDITIONS, THE TEMPERATURE RANGE SPECIFIED IN TABLE 2-9 SHALL PROVIDE FOR CREW THERMAL BALANCE IN COMBINATION WITH EXTRA NOMINAL CLOTHING ASSEMBLIES AND RESTRICTED LEVELS OF ACTIVITY.

TABLE 2-9. RESPIRABLE ATMOSPHERE REQUIREMENTS

PARAMETER	UNITS	OPERATIONAL	28-DAY EMERGENCY
CO_2 Partial Press	mmHg	3.0 max	12 max
Temperature (1)	deg F	65-80	60-85
Dew Point (2)	deg F	40-50	35-70
Ventilation	ft/min	15-40	10-200
O_2 Partial Press(3)	PSIA	2.83-3.35	2.3-3.45
Total Pressure(4)	PSIA	14.5-14.9	14.5-14.9
CO_2 Partial Press	N/m^2	400 max	1600 max
Temperature	°K	291.5-299.9	288.8-302.6
Dew Point(2)	°K	277.6-291.5	273.9-294.3
Ventilation	m/sec	.076-.203	.050-1.016
O_2 Partial Press	$N/m^2 \times 10^3$	19.5-23.1	15.8-23.7
Total Pressure(4)	$N/m^2 \times 10^3$	99.9-102.7	99.9-102.7

Dilute Gas

1. In the operational mode temperature will be selectable ±2°F/1.1°C throughout the range.
2. Relative humidity shall be within the range of 25-75 percent.
3. In no case shall the O_2 partial pressure be below 15.0 N/m^2 (2.3 PSIA), or the O_2 concentration exceed 23.8% of the total pressure.

TECHNICAL AREA: MICROBIOLOGY

2.2.10.2.2.1.1.2 MICROBIOLOGICAL REQUIREMENTS

A MICROBIAL CONTAMINATION CONTROL PLAN MUST BE IMPLEMENTED TO ENSURE THE HABITABILITY OF THE SS OVER ITS PROJECTED OPERATIONAL LIFETIME. THE PLAN WILL ADDRESS THE MAJOR ELEMENTS CONTRIBUTING TO THE ENVIRONMENTAL BIOBURDEN: CREWMEMBERS, SURFACES, AIR, WATER, FOOD, WASTE, BIOLOGICAL SPECIMENS AND OTHER ELEMENT IMPACTING THE MICROBIOLOGICAL ENVIRONMENT. JSC DOCUMENT (TBD) DEFINES THE REQUIREMENTS (MONITORING AND ACCEPTABILITY LIMITS) FOR ELEMENTS RELATIVE TO MICROBIAL CONTAMINATION AND SHOULD BE CONSULTED FOR SPECIFICS.

2.2.10.2.2.1.1.3 MONITORING REQUIREMENTS

PERIODIC MONITORING OF THE CREWMEMBERS, SURFACES, AIR, WATER, FOOD, AND BIOLOGICAL SPECIMENS SHALL BE CONDUCTED AS SCHEDULED IN TABLE 2-15.

2.2.10.2.2.1.1.4 ACCEPTABILITY LIMIT VALUES

THE MICROBIOLOGICAL ACCEPTABILITY LIMITS FOR CREWMEMBERS, SURFACES, AIR, POTABLE WATER, NON-POTABLE WATER, FOOD, AND BIOLOGICAL SPECIMENS ARE GIVEN IN TABLE 2-15.

Technical Area: MICROBIOLOGY

2.2.10.2.2.1.1.5 Decontamination

Decontamination is indicated when acceptablity limits are exceeded or sensory factors indicate microbial contamination has occurred. Decontamination procedures, antimicrobial agents, and supporting equipment shall be provided to counteract and control all microbial contamination events.

2.2.10.2.2.1.1.5.1 Verification

Following decontamination measures, the previously contaminated entity shall be retested and verified to be safe (within acceptability limits).

2.2.10.2.2.1.1.6 Contamination Control Measures

2.2.10.2.2.1.1.6.1 Crew

A Health Stabilization Program (TBD) will be implemented by the JSC Medical Sciences Division to ensure the health status of the crewmembers prior to all SS missions.

2.2.10.2.2.1.1.6.2 Biological Specimens

All experimental protocols utilizing biological specimens aboard the SS must be submitted for approval to the JSC Human Research Policy and Procedures Committee (HRPPC) and the designated JSC safety panel.

Technical Area: MICROBIOLOGY

2·2·10·2·2·1·1·6·2·1 Specific Pathogen Free

All experimental animals to be utilized aboard the SS must meet the Specific Pathogen Free (SPF) criteria as specified by the HRPPC.

2·2·10·2·2·1·1·6·2·2 Cross-Contamination

All animal husbandry and experimentation activities will be conducted in facilities that prevent cross-contamination between crewmembers and biological specimens. Verification test results will be submitted to the HRPPC and the JSC Microbiology Section.

2·2·10·2·2·1·1·6·2·3 Subsystems

Design of the personal hygiene facility, the whole body shower, waste management system, and other aerosol generating facilities must provide a level of containment that minimizes release of aerosols into the module. These facilities must not be located in the close proximity to the galley or HMF. The operation of these facilities must not contaminate the SS air, water, or surfaces in excess of acceptability limits in Table 2-15.

TECHNICAL AREA: MICROBIOLOGY

2.2.10.2.2.1.1.6.2.4 AIR FILTRATION

AIR FILTRATION PROVIDING 99.97% RETENTION OF PARTICLES ≥ 0.3 MICROMETERS IS REQUIRED. FILTERS MUST BE EASILY ACCESSIBLE FOR INSPECTION AND REPLACEMENT.

2.2.10.2.2.1.1.6.2.5 HUMIDITY

THE RELATIVE HUMIDITY MUST NOT EXCEED SIXTY PERCENT FOR TIME INTERVALS GREATER THAN 3 HOURS PER 24 HOUR PERIOD; WATER ACUMULATION IN ECLSS MUST BE PREVENTED.

2.2.10.2.2.1.1.6.2.6 SURFACES

ALL SURFACES SHALL BE NON-POROUS, EASILY CLEANABLE, NON-PARTICULATE GENERATING AND SHALL NOT ALLOW FOR WATER ACCUMULATION.

TECHNICAL AREA: MICROBIOLOGY

2.2.10.2.2.1.1.7 ONBOARD CAPABILITIES

2.2.10.2.2.1.1.7.1 INFLIGHT DIAGNOSTIC CAPABILITY

INFLIGHT DIAGNOSTIC MICROBIOLOGICAL CAPABILITY WILL RESIDE IN THE HEALTH MAINTENANCE FACILITY (HMF). INFLIGHT SAMPLING OF CREWMEMBERS WILL OCCUR ON A CONTINGENCY BASIS ONLY. EQUIPMENT NECESSARY FOR SAMPLE COLLECTION, IDENTIFICATION OF INFECTIOUS AGENTS, AND ANTIBIOTIC SUSCEPTIBILITIES WILL BE CONTAINED IN THE HMF. ALL PROCEDURES FOR HANDLING POTENTIAL INFECTIOUS MATERIALS WILL BE BIOLOGICALLY CONTAINED. SPECIFIC DETAILS ARE GIVEN IN JSC TBD.

2.2.10.2.2.1.1.7.2 ENVIRONMENTAL CAPABILITIES

MICROBIAL (BACTERIA AND FUNGI) QUANTITATION AND PATHOGEN IDENTIFICATION WILL BE PROVIDED. MEANS FOR THE STABILIZATION AND STORAGE OF ENVIRONMENTAL ISOLATES WILL BE PROVIDED.

2.2.10.2.2.1.1.8 EQUIPMENT SOURCE

ALL SAMPLING, MONITORING, DIAGNOSTIC, AND RELATED EQUIPMENT SHALL BE GOVERNMENT FURNISHED EQUIPMENT (GFE).

MICROBIOLOGICAL MONITORING   IREMENTS AND ACCEPTABILITY LIMITS
Monitoring Requirements

Sample Source	Preflight	Inflight	Postflight	Acceptability Limit
Crewmember	F-30, 14, 10 and 1 (ear, nose, throat, skin, sputum, blood (F-30 only), urine, feces)	Contingency	L+0 (ear, nose, throat, skin, sputum, urine, and feces)	Flight Surgeon evaluates preflight laboratory data and makes final decision pertaining to flight readiness of the crewmembers
Surfaces	Prior to Closeout	15 day intervals and within 12 hrs of crew exchange	-	Microbial growth may not exceed 100 CFU per 25 cm^2
Air	Prior to Closeout	10 day intervals and within 12 hrs of crew exchange	-	Levels of airborne microorganisms may not exceed 1000 CFU per cubic meter
Potable Water	N/A	Potable water will be held in a storage tank for 48 hrs and checked for sterility prior to use, and every 7 days until water is consumed.	- -	No viable microorganisms per 100 ml
Non-Potable Water	TBD	TBD	-	TBD
Food	Prior to shipping to KSC	Contingency	Contingency	Specifications in SD-T-0252A (Thermostabilized) and SD-T-0251B (Non-Thermostabilized) (See Appendix)
Biological Specimens	As required by HRPPC	Contingency	As required by HRPPC	All biological specimens must meet the specific pathogen free criteria as defined by the JSC Human Research

Technical Area: PARTICULATES

2.2.10.2.2.1.1.1 Particulate Levels

All internal habitable volumes shall have a control system to provide adequate air circulation and filtration to control airborne particulate levels to less than (a) 3,530,000 particles per cubic meter (100,000 particles per cubic foot) for particles $\geq$ than 0.5 micrometers in size, and (b) TBD particles per cubic meter (TBD particles per cubic foot) for particles $\geq$ than 150 micrometers.

2.2.10.2.2.1.1.1.1 Filtration

Appropriate filtration providing TBD % retention of particles $\geq$ than 0.3 micrometers must be provided. The filtered air system shall provide a source of air containing less than 3530 particles per cubic meter (100 particles per cubic foot) for particles $\geq$ than 0.3 micrometers in size.

2.2.10.2.2.1.1.1.2 Monitoring

The airborne particulates shall be monitored in all modules at TBD intervals. The monitoring system will have the capability to quantitate airborne particulates and provide size distribution parameters.

TECHNICAL AREA: PARTICULATES

2.2.10.2.2.1.1.1.3 INTERNAL SURFACES

INTERIOR SURFACES SHALL BE CONSTRUCTED OF NONPOROUS, ANTI-STATIC, CLEANABLE, AND NON-PARTICULATE GENERATING MATERIAL.

Technical Area: FIRE DETECTION/SUPPRESSION

2.1.11.1.12 Fire Detection and Extinguishment

2.1.11.1.12.1 Fire Detection

The capability for detecting smoke or fire in all Space Station volumes containing a gaseous environment capable of supporting combustion shall be provided. The detection system shall be capable of detecting any incipient fire in the early stages such as overheated electrical conductor insulation, shorted electrical components, or other potential ignition sources prior to the occurrence of visible fire. The detection system shall also be responsive to any visible fire source.

2.1.11.1.12.2 Fire Extinguishment

Capability shall be provided for extinguishing any fire in the space station. The extinguishing agent shall be compatible with the ECLSS, nontoxic to personnel, and shall not produce toxic or corrosive by-products when exposed to high temperatures.

Technical Area: RADIATION

2.2.10.2.2.2 Radiation

2.2.10.2.2.2.1.A Ionizing Radiation Limits

The Space Station shall provide necessary protection to ensure that the maximum tolerable dosage limits of the equipment and crew are not exceeded. The maximum exposures for each crewmember are shown in Table 2-11. Sufficient protection shall be provided to allow continuous crew occupancy for up to one year.

2.2.10.2.2.2.1.B Ionizing Radiation Monitoring

Radiation monitoring capabilities shall be provided as Government Furnished Equipment (GFE).

2.2.10.2.2.2.2 Non-Ionizing Radiation Limits

2.2.10.2.2.2.2.A Laser Energy

Exposure of eyes and skin shall not exceed the Threshold Limit Values (TLV's) set and proposed by the American Conference of Governmental Industrial Hygienists (ACGIH) referenced in "TLV's® Threshold Limits Values for Physical Agents in the Work Environment Adopted by ACGIH with Intended Changes for 1985-86."

Technical Area: RADIATION

2.2.10.2.2.2.2.B Ultraviolet Radiation

Exposure of eyes and skin to man-made sources of ultraviolet radiation or to solar ultraviolet radiation through windows, helmet, or suit must not exceed the Threshold Limit Values (TLV's) set by the American Conference of Governmental Industrial Hygienists (ACGIH). See Appendix TBD for extract and supplementary material for solar ultraviolet radiation.

2.2.10.2.2.2.2.C Light and Near-Infrared Radiation

Exposure of eyes and skin shall not exceed the Threshold Limit Values (TLV's) set and proposed by the American Conference of Governmental Industrial Hygienists (ACGIH) referenced in "TLV's® Threshold Limits Values for Physical Agents in the Work Environment Adopted by ACGIH with Intended Changes for 1985-86."

2.2.10.2.2.2.2.D Radiofrequency/Microwave Radiation

Exposure of eyes and skin shall not exceed the Threshold Limit Values (TLV's) set and proposed by the American Conference of Governmental Industrial Hygienists (ACGIH) referenced in "TLV's® Threshold Limits Values for Physical Agents in the Work Environment Adopted by ACGIH with Intended Changes for 1985-86."

TABLE 2-11. PRELIMINARY IONIZING RADIATION EXPOSURE LIMITS[1]

Exposure Intervals	Depth (5 cm)	Eye (0.3 cm)	Skin (0.001 cm)
30 Days	25 rem[2]	100 rem	150 rem
Annual	50	200	300
Career	100-400[3]	400	600

[1] These preliminary dose-equivalent limits are being considered by NCRP Scientific Committee #75 on guidance on Radiation Received in Space Activities. Before they can become the official position of the National Council on Radiation Protection and Measurement (NCRP), they must be approved by the full council. This approval is expected by September 30, 1986.

[2] This table is expressed in conventional units due to common usage by the discipline. The SI unit is the sievert (Sv), which is equivalent to 100 rem.

[3] The career depth dose-equivalent limit is based upon a maximum 3% lifetime risk of cancer mortality. The total dose-equivalent yielding this risk depends on sex and age at start of exposure. The career dose-equivalent limit is approximately equal to:

200 + 7.5 (age - 30) rem, for males, up to 400 rem maximum
200 + 8/5 (age - 38) rem, for females, up to 400 rem maximum.

TECHNICAL AREA: RADIATION

2.2.10.3.1.2 OBSERVATION WINDOWS

OBSERVATION WINDOWS SHALL BE PROVIDED FOR THE PURPOSE OF EVA MONITORING, PROXIMITY OPERATIONS, MANIPULATOR OPERATIONS, CUSTOMER OPERATIONS, PHOTOGRAPHIC TASKS, AND GENERAL OFF-DUTY VIEWING. AIDS TO SUPPORT WORK-RELATED TASKS SHALL BE PROVIDED AT EACH WINDOW. OPTICAL CHARACTERISTICS OF ALL WINDOWS SHALL BE MAINTAINABLE. ULTRAVIOLET TRANSMISSION SHALL BE LIMITED AS NOT TO INTERFERE WITH SAFE VIEWING.

TECHNICAL AREA: TOXICOLOGY

2.2.10.2.2.1 TOXICOLOGY

2.2.10.2.2.1.1 SPACECRAFT MAXIMUM ALLOWABLE CONCENTRATION (SMAC) LIMITS

LEVELS OF VOLATILE CONTAMINANTS IN HABITABLE AREAS OF THE SS SHALL NOT EXCEED THE 90-DAY SMAC VALUES (TBD) LISTED IN NHB 8060.1C. SHORT-TERM EXPOSURES TO CONTAMINANTS UP TO THE ACGIH OR OSHA INDUSTRIAL EXPOSURE LIMITS ARE PERMITTED PROVIDED THAT THESE EXPOSURES DO NOT EXCEED TWELVE HOURS AND DO NOT OCCUR MORE FREQUENTLY THAN TWICE IN A WEEK.

2.2.10.2.2.1.1.1 TOXIC PARTICULATES

EXPOSURE LIMITS FOR TOXIC PARTICULATE MATTER MUST BE ESTABLISHED BY THE JSC TOXICOLOGY SECTION ON A CASE-BY-CASE BASIS.

2.2.10.2.2.1.2 MATERIALS SELECTION

ALL NONMETALLIC MATERIALS OR ASSEMBLED FLIGHT ARTICLES WILL BE SUBJECTED TO OFFGASSING TESTS PRIOR TO CERTIFICATION FOR USE IN THE HABITABLE AREAS OF THE SS. TEST CONDITIONS WILL BE THE SAME AS THOSE SPECIFIED IN NHB 8060.1C OR IN SUBSEQUENT REVISIONS.

Technical Area: TOXICOLOGY

2.2.10.2.2.1.2.1 Preflight SS Offgassing

Each fully configured SS module shall undergo preflight offgassing analysis. Procedures shall be identical to those specified in JSC document TBD. A minimum of 5 samples will be taken for each module over a period of 72 hours.

2.10.2.2.1.2.2 Dermal Toxicities

Fabrics, physiological measuring instruments and other items that come into direct body contact with crewmembers must be established by the JSC Toxicology Section not to present significant dermal irritancy/allergenicity potential. It must also be established that rinsing of clothing during laundering is sufficient to preclude skin irritancy from residual laundry detergents.

2.10.2.2.1.3 Toxicological Assessment of Payload and Utility Chemicals

All procedures that involve the use of toxic payload and all utility chemicals will be reviewed by the JSC Toxicology Section. Any potential SS toxic contamination that could result from a payload will also be presented to the JSC Human Research Policy and Procedures Committee (HRPPC) and the designated JSC Safety panel.

TECHNICAL AREA: TOXICOLOGY

2.10.2.2.1.3.1 CONTAINMENT

THE DESIGN OF THE CONTAINMENT VESSELS USED WITH CHEMICAL PAYLOADS WILL BE REVIEWED AND CERTIFIED BY THE DESIGNATED JSC SAFETY PANEL.

2.10.2.2.1.3.2 DETECTORS AND ALARMS

CHEMICAL DETECTORS PRODUCING AUDIBLE AND VISUAL ALARMS FOR SPECIFIC CHEMICAL TYPES WILL BE MAINTAINED IN CLOSE PROXIMITY TO CHEMICALS SPECIFIED BY THE JSC TOXICOLOGY SECTION AND THE DESIGNATED JSC SAFETY PANEL AS WARRANTING A LEAK DETECTION SYSTEM.

2.10.2.2.1.4 ADEQUATE ATMOSPHERIC DECONTAMINATION SYSTEMS

THE SS ATMOSPHERIC DECONTAMINATION SYSTEMS MUST BE ADEQUATE FOR MAINTAINING A SAFE LIVING ENVIRONMENT. THE SYSTEM MUST PREVENT CONTAMINATION EXCEEDING LEVELS SPECIFIED IN PARAGRAPH 2.2.10.2.2.1.1., EVEN ON THE WORST CASE BASIS OF MAXIMUM CONTAMINATION GENERATION RATES. THE CAPABILITY MUST ALSO EXIST TO DECONTAMINATE MODULES IN THE EVENT OF THE MAXIMUM POSSIBLE CHEMICAL SPILL OR A LARGE SCALE THERMODEGRADATION OF MATERIALS. FOLLOWING CLEAN-UP, THE CONTAMINATED AREA MUST BE RE-TESTED TO CERTIFY HABITABILITY.

TECHNICAL AREA: TOXICOLOGY

2.10.2.2.1.4.1 WASTE MANAGEMENT

THERE MUST BE AN ONBOARD WASTE MANAGEMENT SYSTEM THAT CAN ADEQUATELY CONTAIN OR ABSORB TOXIC AND ODOROUS GASES GENERATED BY PUTREFACTION OF ALL ONBOARD SUBSTANCES THAT MAY UNDERGO BACTERIAL DECOMPOSITION. CHEMICAL PRESERVATIVES, DISINFECTANTS, AND BIOCIDES MUST NOT PRESENT A TOXICITY HAZARD.

2.10.2.2.1.5 ONBOARD ATMOSPHERIC ANALYSIS

A NEAR REAL-TIME ONBOARD ANALYZER(S) WILL BE PROVIDED TO MONITOR LEVELS OF ATMOSPHERIC CONTAMINANTS. THE ONBOARD ANALYZER MUST:

A. BE A BROAD-SPECTRUM, MULTICOMPONENT ANALYZER
B. PROVIDE FOR THE NEAR REAL-TIME DETECTION, UNEQUIVOCAL IDENTIFICATION, AND QUANTITATION OF VOLATILE CONTAMINANTS
C. PROVIDE A HIGH LEVEL OF SENSITIVITY (TBD)
D. PROVIDE A HIGH LEVEL OF QUANTITATIVE ACCURACY (TBD)
E. PROVIDE FOR ON-LINE AND REMOTE SAMPLE INTERFACE CAPABILITY

Technical Area: TOXICOLOGY

2-10-2-2-1-5-1 Central and Remote Capabilities

The onboard atmospheric analysis capability will consist of at least one central unit meeting the requirements specified in paragraph 2-10-2-2-1-5. A secondary system consisting of a small portable unit will be available in each module. The portable units will supplement the central unit(s) and provide presumptive identification. All sampling equipment, analyzers (control and portable) and related items shall be Government Furnished Equipment (GFE).

2-10-2-2-1-6 SS Atmospheric Sampling Procedures

2-10-2-2-1-6-1 Methods for Atmospheric Sampling

Specific methods for sampling the SS atmospheres from all modules and transfer of these samples to the onboard central analyzer must be provided.

2.10.2.2.1.6.2 FREQUENCY OF ATMOSPHERIC SAMPLING

THE ATMOSPHERE IN EACH HABITABLE SS MODULE MUST BE ROUTINELY SAMPLED FOR CHEMICAL CONTAMINATION ANALYSIS AT A MINIMUM OF 24 HOUR INTERVALS. ATMOSPHERIC SAMPLES MUST ALSO BE TAKEN IN DESIGNATED AREAS AS SOON AS POSSIBLE AFTER:

A. PHYSICAL EVIDENCE OF A LEAK OR SPILL
B. PHYSICAL EVIDENCE OF A FIRE OR THERMODEGRADATION
C. ACTIVATION OF A CHEMICAL SPILL ALARM
D. ANY INDICATION OF TOXIC CONTAMINATION (E.G., UNUSUAL ODOR) IS REPORTED BY A CREWMEMBER OR OTHERWISE BECOMES EVIDENT

2.10.2.2.1.7 TOXICOLOGICAL ASSESSMENT OF ATMOSPHERIC ANALYSIS RESULTS

THE ONBOARD ANALYZER(S) WILL PROVIDE DATA PERTAINING TO TOXIC CONTAMINANT LEVELS TO THE CREW AND MISSION CONTROL FOR IMPLEMENTATION OF APPROPRIATE COUNTERMEASURES AS NEEDED.

THE DATA GENERATED BY THE ONBOARD ATMOSPHERIC ANALYZER WILL BE RELAYED DAILY OR AS NEEDED TO THE JSC TOXICOLOGY SECTION FOR QUANTITATIVE ANALYSIS AND TOXICITY ASSESSMENT. IF TOXIC CONTAMINATION IN THE SS IS INDICATED, THE FLIGHT MEDICAL DIRECTOR WILL BE NOTIFIED AND GIVEN A TOXICOLOGICAL ASSESSMENT OF THE SS LIVING ENVIRONMENT AND A CONTINGENCY PLAN FOR DEALING WITH THE SITUATION.

Technical Area: TOXICOLOGY

2.10.2.2.1.8 **Contingency Plans**

A detailed contingency plan dealing with the toxic contamination of a SS module must be formulated. The contingency plan will include:

2.10.2.2.1.8.1 The availability of the JSC Toxicology Section for consultation with the SS medical officer on such items as protective measures, anticipated adverse effects, antidotes, and recommended supportive treatments.

2.10.2.2.1.8.2 The following protective measures will be available to all crewmembers in each module:

A. Breathing masks and clothing
B. Removal of spilled chemicals from the skin and eyes
C. Medical supportive measures
D. Antidotes if available

2.10.2.2.1.8.3 A detailed decontamination plan and adequate means of removing any spilled contaminants from the SS modules within a specified time (TBD), must be available to enable resumption of normal activities in these modules (see paragraph 2.10.2.2.1.4).

TECHNICAL AREA: TOXICOLOGY

2.10.2.2.1.9 OTHER PROGRAM SUPPORT

THE JSC TOXICOLOGY SECTION SHALL BE CONSULTED IN RESOLVING ALL TOXICOLOGY RELATED MATTERS DURING SS DEVELOPMENT AND OPERATION.

TECHNICAL AREA: VIBROACOUSTICS

2.2.10.2.2.1.1.1.4 VIBROACOUSTICS

2.2.10.2.2.1.1.1.4.1 ACOUSTICS

THE NOISE EXPOSURE SHALL BE SPECIFIED IN TERMS OF THE EQUIVALENT A-WEIGHTED SOUND PRESSURE LEVELS. THE MAXIMUM ALLOWABLE CONTINUOUS BROAD BAND SOUND PRESSURE EXPOSURE LIMITS PRODUCED BY THE SUMMATION OF ALL THE INDIVIDUAL SOUND PRESSURE FROM ALL SOURCES, INCLUDING ALL OPERATING SYSTEMS AND SUBSYSTEMS CONSIDERED OVER A 24-HOUR PERIOD, SHALL NOT EXCEED THE LIMITS FOR THE AREA LISTED BELOW:

2.2.10.2.2.1.1.1.4.1A ALL AREAS FOR HEARING CONSERVATION PURPOSES: L_{EAQ} (24 HR) $\leq$ 80 dB INCLUDING EVA.

2.2.10.2.2.1.1.1.4.1B AREAS INVOLVING SPEECH COMMUNICATION: $L_A \leq 55$ dB, REVERBERATION TIME ≤ 1 SECOND. AIDED COMMUNICATION REQUIRED IT NOISE LEVEL IS EXCEEDED.

2.2.10.2.2.1.1.1.4.1C AREAS INVOLVING SLEEP: 40 dB $\leq L_A \leq$ 45 dB. ALL NOISE SOUND PRESSURE LEVELS SHALL BE MEASURED AND/OR TRANSLATED TO THE EXTERNAL AUDITORY MEATUS OF THE CREWMEMBER.

Technical Area: VIBROACOUSTICS

2.2.10.2.2.1.1.1.5 Vibration

Provision of an acceptable vibration environment must be considered from the standpoints of use of occupied space, type of vibration and direction of vibration. Vibration levels shall not exceed:

Vibration-Habitability:

$A<1\mathrm{x}10^{-1}\mathrm{m/sec}^2, 0.1\leq f\leq 0.3\mathrm{Hz}$

$A\leq 5\mathrm{x}10^{-2}\mathrm{m/sec}^2, 1\leq f\leq 8\mathrm{Hz}$

$A\leq 6.25\mathrm{x}10^{-3}\mathrm{m/sec}^2, 8\leq f\leq 100\mathrm{Hz}$

Vibration-Task Performance:

$A\leq 5\mathrm{x}10^{-3}\mathrm{m/sec}^2$ FOR HEAD OR FINGER CONTROL to 5 mm or 2.5N

$A\leq 5\mathrm{x}10^{-3}\mathrm{m/sec}^2$ FOR VISUAL OBSERVATION OF DETAILS SUBTENDING LESS THAN 2 min OF ARC

2.2.10.2.2.1.1.1.6 Verification

Means shall be provided for periodic measurement of acoustic noise and vibration levels to verify that exposure limits are not being exceeded.

TECHNICAL AREA: VIBROACOUSTICS

2.2.10.2.2.1.1.1.7 ACOUSTIC ISOLATION

IF ACTIVITIES INVOLVE THE GENERATION OF DISTURBING NOISE, APPROPRIATE ACOUSTIC ISOLATION SHALL BE PROVIDED TO REDUCE THE AVERAGE NOISE LEVEL TO LESS THAN AN AVERAGE OF 10 dB ABOVE THE BASELINE NOISE SPECIFICATION. NOISE PEAKS, REGARDLESS OF DURATION, CANNOT EXCEED 30 dB OVER THE BASELINE NOISE SPECIFICATION.

TECHNICAL AREA: WATER MANAGEMENT

2.2.9.1.4 WATER MANAGEMENT

THE SPACE STATION ECLSS SHALL PROVIDE WATER FOR INGESTION, FOOD, HYGIENE, HOUSEKEEPING, EVA, AND EXPERIMENT NEEDS IN SUFFICIENT QUANTITY AND QUALITY TO PRECLUDE ADVERSE ACUTE, CHRONIC, AND LATE EFFECTS ON CREW HEALTH. WATER QUALITY SHALL BE VERIFIED ROUTINELY PRIOR TO CREW USE, SHALL BE MAINTAINED BY ACTIVE MEASURES. THE WASTE MANAGEMENT SYSTEM SHALL ACT TO EXCLUDE HAZARDOUS AND TOXIC MATERIALS FROM THE ATMOSPHERE AND WATER RECLAMATION SYSTEM. THE SPACE STATION SHALL HAVE THE CAPABILITY TO RESTORE ACCEPTABLE WATER QUALITY ON-ORBIT FOLLOWING AN EVENT WHICH COMPROMISES WATER QUALITY.

TECHNICAL AREA: WATER MANAGEMENT

2.2.9.2 DESIGN AND PERFORMANCE REQUIREMENTS

2.2.9.2.4 WATER MANAGEMENT

THE SPACE STATION ECLSS SHALL PROVIDE WATER WHICH CONFORMS AT A MINIMUM TO THE SPECIFICATIONS FOR QUANTITY, QUALITY VERIFICATION, AND QUALITY MAINTENANCE DETAILED IN SUCCEEDING PARAGRAPHS. WATER IS SUBDIVIDED INTO FOUR GENERAL CATEGORIES, DEPENDING ON INTENDED USE. POTABLE WATER IS THE CLASS OF WATER SUITABLE FOR DIRECT INGESTION BY THE CREW VIA DRINKING, FOOD RECONSTITUTION, OR FOOD PREPARATION. HYGIENE WATER IS WATER SUITABLE FOR CUTANEOUS EXPOSURE. EVA WATER IS WATER INTENDED FOR EVA PURPOSES INCLUDES COOLANT AND CONSUMABLE WATER. EXPERIMENT WATER IS THE CLASS OF WATER WHICH IS INTENDED FOR SUPPORT OF EXPERIMENTAL APPARATUSES, ANIMALS, AND REACTIONS. WASTE WATER RECOVERY AND WATER RECYCLED PROCESSES SHALL BE USED TO THE EXTENT WHERE THEY CAN REDUCE INITIAL LAUNCH WEIGHT PENALTY AND RESUPPLY WEIGHT PENALTY.

TECHNICAL AREA: WATER MANAGEMENT

2.2.9.2.4.1 WATER QUANTITY

THE SPACE STATION ECLSS SHALL PROVIDE AN ADEQUATE SUPPLY OF WATER TO SUPPORT THE FULL RANGE OF ANTICIPATED CREW ACTIVITIES INCLUDING INGESTION, FOOD PREPARATION, PERSONAL HYGIENE, HOUSEKEEPING, AND EXPERIMENTS. THE ACTUAL QUANTITIES REQUIRED DEPEND ON CREW WORK RATE, ENVIRONMENT, SPACE STATION OPERATIONAL CAPACITY, FOOD WATER CONTENT, EVA CHARACTERISTICS, AND SPECIFIC EXPERIMENT NEEDS. TABLE 2-10 SPECIFIES MINIMUM CREW NEEDS FOR FOUR WATER QUALITY CLASSES IN THREE SPACE STATION OPERATIONAL MODES.

2.2.9.2.4.1.1 POTABLE WATER

POTABLE WATER SHALL BE PROVIDED BY CLOSED-LOOP RECOVERY PROCESS.

2.2.9.2.4.1.2 HYGIENE WATER

A RECOVERY PROCESS WITH A MINIMUM CAPACITY OF 12 LB/MAN-DAY SHALL BE USED TO RECOVER WATER FROM SHOWERS, HANDWASHERS AND UTILITY WASHERS.

TABLE 2-10 MINIMUM WATER QUANTITY REQUIREMENTS

CLASS UNITS OPERATIONAL MODE

PARAMETER	UNITS	OPERATIONAL	DEGRADED[1]	EMERGENCY
POTABLE[2]	LB/MAN-DAY	6.26-11.35	6.26	6.26
HYGIENE	LB/MAN-DAY	12-25	12	0
EVA[3]	LB/MAN-DAY	TBD	TBD	TBD
EXPERIMENT	LB/MAN-DAY	TBD	TBD	0

[1] DEGRADED LEVELS MEET "FINAL OPERATIONAL" CRITERIA

[2] BASED ON 2950 KCAL/CM-DAY IVA WORK RATE

[3] BASED ON TBD KCAL/HR EVA WORK RATE

TECHNICAL AREA: WATER MANAGEMENT

2.2.9.2.4.2 WATER QUALITY

THE SPACE STATION ECLSS SHALL PROVIDE POTABLE, AND EXPERIMENT WATER WHICH CONFORMS TO THE SPECIFICATIONS FOR PHYSICAL PROPERTIES AND DOES NOT EXCEED THE MAXIMUM ALLOWABLE CONCENTRATIONS FOR INORGANIC SOLUTES, ORGANIC CHEMICALS, MICROORGANISMS, AND RADIONUCLIDES AS SET FORTH BY JSC DOCUMENT TBD AND SUMMARIZED IN TABLE 2-11. THE ECLSS SHALL PROVIDE HYGIENE WATER WHICH MEETS THE LIMITS ESTABLISHED BY JSC DOCUMENT TBD AND SUMMARIZED IN TABLE 2-11. IN ALL CASES OF CONFLICT BETWEEN SPECIFICATIONS, THE WATER SHALL CONFORM TO THE MOST RESTRICTIVE LIMIT.

TECHNICAL AREA: WATER MANAGEMENT

2.2.9.2.4.3 WATER QUALITY VERIFICATION (MONITORING)

ECLSS WATER QUALITY SHALL BE VERIFIED ROUTINELY PRIOR TO USE ACCORDING TO THE ON-ORBIT MONITORING SCHEDULE SHOWN IN TABLE 2-10B. PROCESS CONTROL INSTRUMENTATION SHALL OPERATE CONTINUOUSLY TO VERIFY PROPER FUNCTION OF THE WATER RECLAMATION AND RECYCLE SYSTEM. BATCH CONTROL INSTRUMENTATION SHALL OPERATE INTERMITTANTLY TO VERIFY ACCEPTABILITY OF AN ISOLATED VOLUME OF WATER PRIOR TO ITS CONSUMPTION OR ADDITION TO THE "USE" SUPPLY. PERIODIC MONITORING INSTRUMENTS SHALL PROVIDE THE CAPABILITY FOR DETAILED ANALYSIS OF WATER CONSTITUENTS FOR ASSESSMENT OF QUALITY AND IDENTIFICATION OF PROBLEMS, AND FOR BATCH CONTROL AT A HIGHER LEVEL OF RELIABILITY. RESUPPLY WATER MUST MEET THE ON-ORBIT PERIODIC MONITORING REQUIREMENTS. ON-ORBIT SAMPLING AND ANALYSIS SHALL BE AUTOMATED, WHERE POSSIBLE, TO CAUSE MINIMUM IMPACT ON CREW SCHEDULE.

TABLE 2-10B ON-ORBIT WATER MONITORING SCHEDULE

PARAMETER	PROCESS CONTROL (CONTINUOUS)	BATCH CONTROL (PRIOR TO USE)	PERIODIC (WEEKLY/MONTHLY)
CONDUCTIVITY	X	X	-
pH	X	X	-
TURBIDITY	TBD	TBD	-
COLOR	-	TBD	-
TEMPERATURE	X	-	-
COMPLETE PHYSICAL PROPERTIES[1]	-	X	TBD
AMMONIA	TBD	TBD	-
IODINE	X	X	-
SPECIFIC IONS	TBD	TBD	-
COMPLETE INORGANIC CONSTITUENTS[1]	-	TBD	TBD
TOC	X	X	TBD
TOC LESS	-	TBD	TBD
CARBOXYLIC ACIDS	-	TBD	TBD
COMPLETE ORGANIC CONSTITUENTS[1]	-	TBD	TBD

TABLE 2-10B ON-ORBIT WATER MONITORING SCHEDULE (Continued)

PARAMETER	PROCESS CONTROL (CONTINUOUS)	BATCH CONTROL (PRIOR TO USE)	PERIODIC (WEEKLY/MONTHLY)
Total Bacteria	-	TBD	TBD
Anerobes	-	TBD	TBD
Yeast and Molds	-	TBD	TBD
Bacterial ID[1]	-	TBD	TBD
Virus	-	TBD	TBD
Radionuclides[1]	-	TBD	TBD
Dissolved Gas	-	X	-
Free Gas	X	X	-

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[1] As specified by JSC-SPEC-SD-W-0020

TECHNICAL AREA: WATER MANAGEMENT

2.2.9.2.4.4 WATER QUALITY MAINTENANCE

THE ECLSS SHALL ACTIVELY INSURE THAT POSITIVE WATER QUALITY IS MAINTAINED. THE WATER SYSTEM SHALL MAINTAIN A LEVEL OF RESIDUAL BACTERICIDE AS SET FORTH IN JSC-SPEC-SD-W-0020 TO PREVENT BACTERIAL COLONIZATION AND OVERGROWTH. POTABLE WATER FROM THE ECLSS SHALL BE CONDITIONED TO ESTABLISH MINIMUM LEVELS OF CONSTITUENTS REQUIRED POSITIVE AESTHETIC CHARACTER OF THE WATER AS SPECIFIED IN JSC-SPEC-SD-W-0020. THE SYSTEM DESIGN SHALL GIVEN SPECIAL ATTENTION TO ISOLATION OF VERIFIED WATER FROM THE WASTE FEED FOR THE RECLAMATION SYSTEM, NON RECLAIMED WASTES AND BRINE, AND EVA WASTE WATER.

2.2.9.2.4.5 WATER QUALITY RESTORATION

THE ECLSS WATER SYSTEM SHALL HAVE THE CAPABILITY FOR COMPLETE SYSTEM PURGE, FLUSH, STERILIZATION, AND RECHARGE ON-ORBIT FOLLOWING A COMPROMISE IN WATER QUALITY. THE DESIGN OF THE WATER SYSTEM SHALL ACCOMMODATE REPLACEMENT OF SPENT EXPENDABLE AND DAMAGED COMPONENTS WITHOUT CONCOMMITANT CONTAMINATION OF THE REMAINDER OF THE SYSTEM OR THE VEHICLE.

TENTATIVE SPACE STATION WATER QUALITY REQUIREMENTS

WATER USE

		Potable	Personal Hygiene	Experiments	Systems	Most Limiting Value-Remarks
Physical						
Total Solids (Suspended/Dissolved)	mg/L	TBD <100	TBD <500	TBD	TBD	Systems-HX Scaling; Experiments
Conductivity	u mhos/cm	-	-	TBD	TBD 1.0	Systems-HX, Evap Cooling/Scaling
Surface Tension	dynes/cm	TBD NR	TBD NR	TBD	72	Systems
Color, True	Pt/Co	15	15	TBD	NR	Potable-TS, Organics, Particulates
Taste and Odor	TIN/TUN	<3	<3	TBD	NR	Potable
pH		6.0-8.0	5.0-8.0	TBD		Potable
Particulate		40 u	40 u	TBD	40 u	Systems
Potassium Permagenate Consumption		NR	NR	TBD	Pass	Systems Organics
Turbidity	NTU	11	11	TBD	TBD	Potable-Disinfection
Dissolved Gas	No Free @ 35°C	None	None	TBD	TBD	Potable; Systems-None Released
Free Gas	STP	None	None	TBD	TBD	Potable; Systems
Ionic (Inorganic)	(mg/L)					
Ammonia		0.5	0.5	TBD	NR	Potable
Arsenic		0.01	0.01	TBD	NR	Potable
Barium		1.0	1.0	TBD	NR	Potable
Chloride		250	TBD	TBD	NR	Potable
Chromium		0.05	0.05	TBD	NR	Potable
Copper		1.0	1.0	TBD	NR	Potable
Fluoride		1.0	1.0	TBD	NR	Potable
Iodide		15	TBD	TBD	NR	Potable
Iron		0.3	0.3	TBD	NR	Potable
Lead		0.05	0.05	TBD	NR	Potable
Manganese		0.05	0.05	TBD	NR	Potable
Magnesium		0.05	0.05	TBD	NR	Potable
Calcium		TBD	TBD	TBD	NR	Potable
Mercury		0.002	0.002	TBD	NR	Potable
Nickel		0.05	0.05	TBD	NR	Potable
Nitrate	(NO_3-N)	10	TBD	TBD	NR	Potable
Potassium		340	TBD	TBD	NR	Potable
Selenium		0.01	0.01	TBD	NR	Potable
Silver		0.05	0.05	TBD	NR	Potable
Sulfide		0.05	0.05	TBD	NR	Potable
Sulfate		250	TBD	TBD	NR	Potable
Zinc		5.0	5.0	TBD	NR	Potable

WATER USE

	Potable	Personal Hygiene	Exper-iments	Systems	Most Limiting Value-Remarks
Organics (ug/L)					
TOC	TBD <500	TBD <10,000	TBD	TBD	Potable
TOC (Less Non-Toxicants)	TBD <100	TBD <1,000	TBD	TBD	Potable
Organic Acids	TBD <100	TBD	TBD	TBD	Potable
Cyanide	200	TBD	TBD	TBD	Potable
Phenols	1	1	TBD	TBD	Potable
Halogenated Hydrocarbons	TBD < 10	TBD	TBD	TBD	Potable
Organic Alcohols	TBD <100	TBD	TBD	TBD	Potable
Aesthetics (Minimum) (mg/L)					
Cations	TBD 30	NR	NR	NR	Potable
Anions	TBD 30	NR	NR	NR	Potable
CO_2 mg/L	TBD 15	NR	NR	NR	Potable
Microbial					
Bacteria (Total Count) CFU/100 mL	0	0	TBD	10	Potable
Anaerobes	0	0	TBD	NR	Potable
Aerobes	0	0	TBD	NR	Potable
Gram Positive	0	0	TBD	NR	Potable
Gram Negative	0	0	TBD	NR	Potable
E-Coli	0	0	TBD	NR	Potable
Enteric	0	0	TBD	NR	Potable
Virus	0	0	TBD	NR	Potable
Yeast and Molds	0	0	TBD	NR	Potable
Bactericide (mg/L)					
Residual (Halogens) (Minimum)	0.5	0.5	TBD	NR	Potable
Residual (Halogens) (Maximum)	4.0	6.0	TBD	NR	Potable
Radiological (pCi/L)					
Alpha 90 Sr	10	TBD	TBD	NR	Potable
Alph 226 Ra	3	TBD	TBD	NR	Potable
Beta 3 H	1000	TBD	TBD	NR	Potable

SANITATION MANAGEMENT

<u>General</u>

- Surfaces
- Odors
- Stabilization
- Disinfectants
- Surface Active Agents

<u>Specific</u>

- Handwasher/Shower
  - Water
  - Cleansing Agent: Cross Contamination
  - Rinsing
  - Drying
  - Air Flow
  - Waste Water
  - Waste Disposal: Tissues, Wipes, Cleansing Agent Containers, Towels
  - Material Containment - E.G. Droplets, Lint
- Laundry
  - Water
  - Cleansing Agent
  - Clothing Bedding, Towels, Cleanliness: Dirt, Grime, Microbial, Cleansing Agent Removal
  - Disinfection
  - Odors

- METABOLIC WASTE MANAGEMENT
  - FECES
    - ODOR CONTROL - ODOR CONTROL
    - PARTICULATE CAPTURE
    - FLATUS CONTROL
    - CROSS CONTAMINATION
    - ANAL CLEANSING
    - TISSUES
    - STABILIZATION
    - DISINFECTION SCHEDULE
  - URINE
    - ODOR CONTROL
    - SPLASH
    - CROSS CONTAMINATION
    - INTIMATE CONTACT
    - STABILIZATION
    - CLEANING
    - DISINFECTION SCHEDULE
    - WATER
    - GENITAL CLEANSING
  - MENSTRUATION
    - URINE COLLECTION
    - ABSORBANT MATERIAL DISPOSAL
  - DISHWASHER
    - SAME AS LAUNDRY EXCEPT UTENSILS, DISHES

- Housekeeping
  - Microbial
  - Surface Cleansing
  - Cleansing Agent(s)
  - Disposal of Wastes
  - Schedule
  - Surfaces, Cleanable, Non Odorous
  - Particulates
- Trash Management
  - Putrescible
    - Stabilization
    - Collection
    - Particulates
    - Compaction
  - Stable Materials
    - Collection
    - Particulates
    - Compaction
- Personal Hygiene
  - Skin Care
  - Hair Care
  - Hair Cutting
  - Nail Trimming
  - Deodorants

EMU

- MAINTENANCE
  - SCHEDULE
  - CLEANING - DISINFECTION
- WASTE MANAGEMENT
  - FECES
  - URINE
  - PERSPIRATION
- WATER SUPPLY
- FOOD SERVICE

ATTACHMENT C

REPORT FOR SUBTASK 2.2.1.2

ANALYSIS OF PARTICULATE AND MOLECULAR CONTAMINATION LEVELS IN SPACE STATION MODULES

Table of Contents

Table of Contents (Continued)

SUMMARY

This analysis was conducted to determine the maximum allowed source rates and anticipated removal rates of molecular and particulate contamination inside manned modules of the space station. Maximum allowed concentrations of contamination and operating characteristics of the environmental control and life support system (ECLSS) were used to calculate maximum allowed source rates for each contaminant. Portions of each total source rate were allocated to individual constituents of the module: structural and permanent module equipment, crew, and portable equipment. Outgassing rates are discussed, long term degradation rates of polymers are estimated, and contamination effects on the space station are considered. Particulate contamination sources and removal rates are also discussed, and three possible methods of controlling contamination on the space station are considered.

The analysis indicates that current methods of contamination control are adequate to limit molecular outgassing and particulate contamination, but they are not the most "user friendly" contamination control method. The analysis also indicates that long term polymer degradation may be a significant contamination source, but insufficient data are available to unambiguously establish rates for this process. Additional data on long term degradation of polymers and an accelerated test for evaluating this process are needed to minimize the potential negative impact of contamination produced by this mechanism. Adequate quantitative models of particulate contamination sources and removal rates in orbiting modules do not exist. Control of particulate contamination will therefore be based on empirical correlations and limited data.

INTRODUCTION

The space station represents a new concept in space vehicles. It is intended to be a platform for the commercialization of space, and to attract a wide variety of users with many different backgrounds and objectives. Past experience has demonstrated that safety and efficiency of operation are impaired by excessive levels of contamination in habitable areas of space vehicles. It is therefore imperative to control the level of contamination on the space station.

Many sources of contamination exist on any spacecraft. Some typical sources are polymeric materials, lubricants, motors, human beings, activities, and experiments. These sources produce a wide variety of contaminants that are usually present at low or trace concentrations in the atmosphere inside spacecraft. Contaminants affect human beings in complex ways which depend on a number of factors such as the concentration of contaminants in the breathing air, synergism with other contaminants that are present, individual human physiology, radiation exposure, and the atmospheric pressure in the crew cabin. Our ultimate objective in task 2 is to establish the best method of controlling contamination inside space station modules. We reported the contamination control requirements established for the habitable areas of the space station in subtask 2.2.2.2 (ref. 1). The objective of this analyses (subtask 2.2.1.2) is to establish the maximum source rate, the removal rate, and the expected concentration of each contaminant inside space station modules. In the next subtask (2.2.3.2) we will use the data obtained in this analysis to develop specifications to limit the rate at which contaminant enter the breathing air, and the final subtask (2.2.4.2) is to write a contamination control plan for the habitable areas of the space station.

A complete analysis of contaminant levels in the space station modules requires toxicological information, data on the rate at which the environmental control and life support system (ECLSS) removes contaminants, and contamination monitoring capability. This study is not concerned with all these aspects of contamination control. It is only concerned with how to determine contamination source rates, and how to control contaminant loads in habitable volumes of the space station.

In this report we will first discuss a number of groundrules and assumptions that were made in order to make the calculations that constitute this analysis. The groundrules establish module volume, mass of polymeric material in a module, ECLSS operating characteristics, and toxicological requirements that must be satisfied. Next we consider the sources of contamination and the major factors that affect source rate. Then the important aspects of contamination specific to the long life of the space station are discussed, and finally particulate contamination is investigated. Next the primary methods of contamination control are considered. The current method of contamination control and three new methods are discussed and finally the conclusions of this subtask are presented.

In this report contamination is defined as molecular or particulate contamination. Biological contamination and radiation are sometimes classified as contamination, but they are not part of this study.

GROUNDRULES AND ASSUMPTIONS

In order to perform the calculations for this analysis, a number of groundrules were established, such as the mass and volume of manned modules, operating characteristics of the ECLSS, and the types of contamination sources on the space station. The mass, volume, and type of material, that will eventually be used inside manned modules are currently unknown, but a model of a contamination module has been developed by analogy with the space shuttle crew cabin.

MODULE VOLUME

The volume of a habitat module was estimated by assuming the modules to be 43.9 feet long by 14.0 feet in diameter. This results in a volume of 191 cubic meters (6758 cubic feet). This volume is 5 percent less than the value of 200 cubic meters for the gross volume assumed by Lin (ref. 2). The habitable volume was assumed to be 50% of the gross volume by analogy with Lin. Thus the habitable volume was 95.5 cubic meters.

MODULE MASS

The mass of polymeric material in a manned module was estimated by analogy with previous spacecraft such as Apollo, Spacelab, and the shuttle. The mass of "non-metallic" material to total spacecraft mass averaged 0.16 for both Apollo and Spacelab (ref. 3). The mass of a fully equipped manned module was assumed equal to the shuttle payload mass, i.e., between 9000 kg (19800 lbm) and 16000 kg (35200 lbm). This leads to a total mass of polymeric material between 1440 kg and 2560 kg. These values bracket the mass of polymeric materials in the crew cabin of the shuttle. Thus the shuttle was used as a model of a space station manned module, and masses of individual polymers were obtained by scaling. The shuttle crew cabin contains approximately 1700 kg of polymeric material (ref. 4).

MAXIMUM ALLOWED CONCENTRATIONS (MACS)

The effect of contaminants on humans depends primarily on the concentration of contaminant in the air and the duration of human exposure to the contaminant. It is the job of the NASA toxicologist to evaluate the effect of each toxic contaminant on humans and to establish maximum concentrations for each contaminant in the breathing air. These maximum values are called "maximum allowed concentrations" (MAC's). Four sources of information were used to estimate MAC values for this study (refs. 5-8). The MAC values determined in the previous subtask (2.2.2.2) are presented in appendix A.

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM CHARACTERISTICS

In order to calculate outgassing rate limitations from the MAC's imposed by the NASA toxicologist, it is necessary to know some of the operating characteristics of the ECLSS. The ECLSS has a number of functions: thermal control, maintenance of oxygen partial pressure, carbon dioxide removal, and trace contaminant removal are the primary functions. In this analysis we are only concerned with the trace contaminant removal system (TCRS).

Breathing air is drawn through the TCRS at an estimated rate of 9.44 liters per second (20 cubic feet per minute) (ref. 1). This apparatus was assumed to be a high temperature catalytic oxidizer with gas scrubbers both before and after the oxidizer. Detailed data for this apparatus is not available so a removal efficiency of 90% was assumed for each chemical species. This is a relatively conservative estimate of the removal efficiency, and it is expected that the vast majority of chemicals will be more efficiently removed. However, this value was selected because the health and safety of the crew is involved. Contaminants may also be removed by the humidity control function of the ECLSS, considered in this analysis.

MOLECULAR CONTAMINATION

SOURCES AND SOURCE RATES

Molecular contamination is produced by many sources inside space station modules. The most important sources include humans, polymer outgassing, and experiments and activities. In this analysis we have not considered the last category quantitatively because space station users and source rate data are not yet available. Humans continually generate a small number of contaminants at various rates. Polymers produce many more contaminant species than humans and a variety of production mechanisms may operate in each polymer. One mechanism is outgassing. This mechanism involves small molecules, present in the polymer that diffuse to the surface and evaporate into the air. Another mechanism in the generation of mobile contaminants inside polymers by chemical reaction. The mobile species then diffuse through the polymer and evaporate into the air in a manner analogous to outgassing. In general both outgassing and chemical reaction occur continously in all polymers, but in practical terms outgassing is more important for new polymers and reactions that produce contaminants are usually slow and become most important in old polymers. Estimates of both outgassing and long term degradation of polymers as contamination sources are discussed in more detail below.

The concentration of trace contaminants is the quantity that must ultimately be controlled on the space station. The rate of removal of a contaminant by the TCRS is proportional to its concentration in the breathing atmosphere. Thus the removal rate increases as the contaminant concentration increases until the rate of removal equals the rate the contaminant enters the atmosphere. At this point the contaminant concentration levels off at the "steady state" concentration. In order to meet the requirements of NHB 8060.1B, the steady state concentration of each chemical species must be below its MAC.

A number of chemicals outgas from each source, and a number of sources outgas each chemical. MAC's are specified for individual chemical species. This places a limitation on the total outgassing rate of individual chemicals from all sources, however in order to control the total rate we must control the individual outgassing rates from each sources.

Outgassing

A large number of parameters affect the outgassing rate of contaminants from polymeric materials. The primary factors are the type of host polymer, its glass transition temperature, the diffusant species (contaminant) and its molar volume, the temperature, the thickness or shape of the polymer, and the concentration of contaminant in the polymer. It is exceedingly difficult to define a method of contamination control, or a test to measure outgassing rates, that considers all these factors and provides a failsafe basis for contamination control. Our approach in this analysis is to use the MAC's to determine the maximum allowed source rate and then to define a method of controlling contamination within acceptable limits.

The method we have used to calculate maximum source rates is based on the steady state concentration of each contaminant in the breathing air (ref. 1,9). It was assumed that the time constant for contamination buildup must be at least 10 times the time constant for contaminant removal inside a module. (Reference 1 is included as appendix B of this report.) This ratio of time constants assures that the steady state concentration of contaminants is no less than 11% of the MAC (see ref. 1, appendix B). The time constant for contaminant removal from the module by the ECLSS was calculated to be about 3 hours. Thus the minimum time constant for contaminants to build up in the modules was set at 30 hours. This is approximately the time required for each contaminant to reach its MAC from an initial concentration of zero with the ECLSS completely disabled. Maximum total outgassing rates for each contaminant are listed in the table in appendix A.

As a further refinement of the rate calculations, contaminant source rates are allocated among four types of sources located in each module: permanent equipment, portable equipment, human crew, and all other sources. Permanent equipment is considered to be all structural components and apparatus that is a permanent part of the module. It does not include portable equipment that is intended to be moved from module to module or any equipment supplied by space station users who rent space or facilities. Portable equipment is that supplied by users or that is frequently moved or modified. Biological sources were assigned the highest priority and all following percentages are based on the "net rate" which is the difference between the "total rate" (see appendix A) and the biological rate. The biological source rates were based on a crew of six average persons. For the purposes of this analysis permanent equipment was assumed to produce 10% of the net rate. This percentage is only an estimate but represents a realistic compromise between the needs of the system designers and space station users. Portable equipment was assumed to produce about 35% of the net rate. Portable equipment is used by both space station systems and commercial users. This leaves about 55% of the total contamination budget for all other, unassigned, sources. The unassigned classification includes contamination produced by laboratory experiments, activities, and accidents, and any desired safety margin. The calculated rates for all source groups are shown in appendix A.

The rate data in appendix A show that freon 124 has the largest source rate which is nearly 125 grams per day, and beryllium has the smallest source rate: 2 E-5 grams per day. These rates differ by nearly 7 orders of magnitude, and the lowest source rates and their corresponding concentrations may require special measurement techniques and apparatus. This suggests that the quantity of some contaminants permitted on the space station must be strictly limited, but source rates for most organic contaminants can be determined with modern gas chromatographs or mass spectrometers. This conclusion is demonstrated below.

Approximately 10 nanograms of organic material can be detected by either a gas chromatograph or a mass spectrometer. This translates to a typical gas phase concentration of roughly 1 part per million by volume. The minimum outgassing rate that can be measured in the standard 72-hour test with a 1 PPM detection sensitivity is roughly 0.2 micrograms of contaminant per gram of sample per day. On the space station individual contaminants may be produced by from one gram to 100 kilograms of host polymer. Using these figures, minimum total outgassing rates between 1 E-7 grams per day and 0.020 grams per day can be detected in the standard outgassing test.

Table 1 is a list of all compounds from appendix A that have a total source rate less than 0.020 grams (20 milligrams) per day. There are 70 compounds listed in table 1. Three hundred and ninety-two compounds are tabulated in appendix A. Most of the compounds listed in table 1 are evolved from less than 100 kilograms of host material. Thus, we have the capability to determine and predict accurately the source rates of the vast majority of chemical contaminants listed in appendix A.

Another interesting aspect of the data in appendix A is that five compounds show biological production rates larger than the tabulated total rate. These chemicals are

Table 1. Contaminants With a Total Source Rate Less Than 20 mg/Day (Page 1 of 3)

List of Contaminants

Group	Contaminants	MOL wt	MAC (PPM)	MAC (mg/m**3)	Total rate (mg/day)	Biological rate (mg/day)	Lab module rate (mg/day)	Portable equipment rate (mg/day)	Rate remainder (mg/day)	Remainder % of total
Aldehydes	acrolein (propenal)	55.05	0.050	0.114	8.38	0.00	0.84	2.93	4.61	55.0%
Aldehydes	formaldehyde (methanal)	30.03	0.100	0.124	9.14	0.00	0.91	3.20	5.03	55.0%
Aldehydes	glutaraldehyde	100.10	0.049	0.203	14.93	0.00	1.49	5.23	8.21	55.0%
Aldehydes	propenal (acrolein)	56.06	0.025	0.058	4.27	0.00	0.43	1.49	2.35	55.0%
Ethers	dimethylfuran, 2,5	96.12	0.020	0.080	5.85	0.00	0.59	2.05	3.22	55.0%
Ethers	uran (1,4-epoxy-1,3-butadiene)	68.07	0.020	0.056	4.14	0.00	0.41	1.45	2.28	55.0%
Ethers	methylfuran, 2	82.10	0.020	0.068	5.00	0.00	0.50	1.75	2.75	55.0%
Halocarbons-chlorocarbons	chloroacetone (1-chloro-2-propanone)	92.53	0.040	0.153	11.27	0.00	1.13	3.94	6.20	55.0%
Halocarbons-chlorocarbons	dichloroacetylene	94.94	0.013	0.051	3.76	0.00	0.38	1.32	2.07	55.0%
Halocarbons-chlorocarbons	vinyl chloride (chloroethene)	62.50	0.050	0.130	9.51	0.00	0.95	3.33	5.23	55.0%
Inorganic compounds	antimony	121.76	0.010	0.050	3.71	0.00	0.37	1.30	2.04	55.0%
Inorganic compounds	arsenic	74.92	0.000	0.001	0.07	0.00	0.01	0.03	0.04	55.0%
Inorganic compounds	beryllium	9.01	0.001	0.000	0.02	0.00	0.00	0.01	0.01	55.0%
Inorganic compounds	beryllium oxide	25.01	0.200	0.207	15.24	0.00	1.52	5.33	8.38	55.0%
Inorganic compounds	bromine (Br2)	159.83	0.010	0.066	4.87	0.00	0.49	1.70	2.68	55.0%
Inorganic compounds	bromine chloride	115.37	0.015	0.072	5.27	0.00	0.53	1.84	2.90	55.0%
Inorganic compounds	bromine dioxide	111.92	0.010	0.046	3.41	0.00	0.34	1.19	1.87	55.0%
Inorganic compounds	cadmium chloride	183.32	0.001	0.080	0.61	0.00	0.06	0.21	0.34	55.0%
Inorganic compounds	cadmium oxide	128.41	0.001	0.003	0.20	0.00	0.02	0.07	0.11	55.0%
Inorganic compounds	cadmium telluride	240.02	0.001	0.010	0.73	0.00	0.07	0.26	0.40	55.0%
Inorganic compounds	cadmium	112.41	0.002	0.010	0.75	0.00	0.08	0.26	0.41	55.0%
Inorganic compounds	chlorine dioxide	67.46	0.006	0.015	1.13	0.00	0.11	0.40	0.62	55.0%
Inorganic compounds	cobalt chloride	129.83	0.005	0.024	1.78	0.00	0.18	0.62	0.98	55.0%
Inorganic compounds	ferric chloride	162.22	0.015	0.101	7.41	0.00	0.74	2.59	4.07	55.0%
Inorganic compounds	fluorine	38.00	0.010	0.016	1.16	0.00	0.12	0.40	0.64	55.0%
Inorganic compounds	gallium	69.72	0.088	0.254	18.68	0.00	1.87	6.54	10.27	55.0%

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Table 1. Contaminants With a Total Source Rate Less Than 20 mg/Day (Page 2 of 3)

List of Contaminants

Group	Contaminants	MOL wt.	MAC (PPM)	MAC (mg/m**3)	Total rate (mg/day)	Biological rate (mg/day)	Lab module rate (mg/day)	Portable equipment rate (mg/day)	Rate remainder (mg/day)	Remainder % of total
Inorganic compounds	gallium antimonide	191.49	0.010	0.079	5.83	0.00	0.58	2.04	3.21	55.0%
Inorganic compounds	gallium arsenide	144.64	0.015	0.090	6.60	0.00	0.66	2.31	3.63	55.0%
Inorganic compounds	hydrazine	32.05	0.020	0.027	1.95	0.00	0.20	0.68	1.07	55.0%
Inorganic compounds	hydrogen fluoride (hydrofluoric acid)	20.01	0.100	0.083	6.09	0.00	0.61	2.13	3.35	55.0%
Inorganic compounds	hydrogen peroxide	34.02	0.100	0.141	10.36	0.00	1.04	3.62	5.70	55.0%
Inorganic compounds	indium	114.82	0.002	0.010	0.75	0.00	0.08	0.26	0.41	55.0%
Inorganic compounds	indium monochloride	150.22	0.002	0.009	0.69	0.00	0.07	0.24	0.38	55.0%
Inorganic compounds	indium oxide (In2O3)	277.64	0.005	0.052	3.80	0.00	0.38	1.33	2.09	55.0%
Inorganic compounds	iodine	253.82	0.005	0.053	3.86	0.00	0.39	1.35	2.12	55.0%
Inorganic compounds	lead	207.21	0.003	0.021	1.58	0.00	0.16	0.55	0.97	55.0%
Inorganic compounds	lead chloride	278.10	0.003	0.029	2.12	0.00	0.21	0.74	1.16	55.0%
Inorganic compounds	lead nitrate	331.23	0.001	0.007	0.50	0.00	0.05	0.18	0.28	55.0%
Inorganic compounds	lead telluride	334.82	0.002	0.021	1.53	0.00	0.15	0.54	0.84	55.0%
Inorganic compounds	lithium fluoride (most other F salts,same ppm)	25.94	0.235	0.253	18.56	0.00	1.86	6.49	10.21	55.0%
Inorganic compounds	lithium hexafluorarsenate (as As)	195.86	0.001	0.008	0.60	0.00	0.06	0.21	0.33	55.0%
Inorganic compounds	lithium perchlorate	107.00	0.021	0.093	6.84	0.00	0.68	2.39	3.76	55.0%
Inorganic compounds	mercuric iodide	454.45	0.000	0.007	0.53	0.00	0.05	0.18	0.29	55.0%
Inorganic compounds	mercuric oxide	216.59	0.001	0.004	0.33	0.00	0.03	0.12	0.18	55.0%
Inorganic compounds	mercury	200.61	0.001	0.004	0.31	0.00	0.03	0.11	0.17	55.0%
Inorganic compounds	nickel	58.69	0.040	0.097	7.15	0.00	0.71	2.50	3.93	55.0%
Inorganic compounds	nickel compounds (water soluble)	150.00	0.004	0.025	1.83	0.00	0.18	0.64	1.00	55.0%
Inorganic compounds	ozone (03)	48.00	0.010	0.020	1.46	0.00	0.15	0.51	0.80	55.0%
Inorganic compounds	perchloric acid	100.47	0.012	0.050	3.67	0.00	0.37	1.28	2.02	55.0%
Inorganic compounds	phosphoric acid	98.04	0.025	0.102	7.46	0.00	0.75	2.61	4.10	55.0%
Inorganic compounds	potassium hydroxide	56.11	0.044	0.101	7.43	0.00	0.74	2.60	4.09	55.0%
Inorganic compounds	silver	107.87	0.002	0.010	0.74	0.00	0.07	0.26	0.41	55.0%

Table 1. Contaminants With a Total Source Rate Less Than 20 mg/Day (Page 3 of 3)

List of Contaminants

Group	Contaminants	MOL wt.	MAC (PPM)	MAC (mg/m**3)	Total rate (mg/day)	Biological rate (mg/day)	Lab module rate (mg/day)	Portable equipment rate (mg/day)	Rate remainder (mg/day)	Remainder % of total
Inorganic compounds	silver chromate	131.77	0.003	0.016	1.20	0.00	0.12	0.42	0.66	55.0%
Inorganic compounds	silver compounds (water soluble)	200.00	0.001	0.008	0.61	0.00	0.06	0.21	0.33	55.0%
Inorganic compounds	silver nitrate	169.89	0.001	0.004	0.26	0.00	0.03	0.09	0.14	55.0%
Inorganic compounds	silver oxide	247.76	0.002	0.023	1.70	0.00	0.17	0.59	0.93	55.0%
Inorganic compounds	sulfuric acid	98.08	0.013	0.051	3.73	0.00	0.37	1.31	2.05	55.0%
Inorganic compounds	tellurium	127.61	0.002	0.011	0.78	0.00	0.08	0.27	0.43	55.0%
Inorganic compounds	thallium	204.39	0.001	0.010	0.75	0.00	0.07	0.26	0.41	55.0%
Inorganic compounds	thallium monosulfate (as Th)	301.46	0.001	0.010	0.73	0.00	0.07	0.26	0.40	55.0%
Inorganic compounds	tin	118.69	0.040	0.197	14.45	0.00	1.45	5.06	7.95	55.0%
Inorganic compounds	zinc chloride	136.38	0.002	0.010	0.75	0.00	0.07	0.26	0.41	55.0%
Mercaptans and sulfides	ethyl mercaptan (ethanethiol)	62.13	0.050	0.129	9.46	5.00	0.45	1.56	2.45	25.9%
Mercaptans and sulfides	methyl mercaptan	48.10	0.050	0.100	7.32	5.00	0.23	0.81	1.28	17.4%
Miscellaneous	any unidentified compound, typical values illustrated, MAC is .10 mg/M3	100.00	0.024	0.100	7.35	0.00	0.73	2.57	4.04	55.0%
Miscellaneous organic compound	cacodylic acid (arsenic oxide, hydroxydimethyl)	138.00	0.000	0.002	0.15	0.00	0.01	0.05	0.08	55.0%
Miscellaneous organic compound	dimethyl ammonium sulfate	110.13	0.050	0.228	16.76	0.00	1.68	5.87	9.22	55.0%
Organic acids	picric acid	229.11	0.001	0.009	0.70	0.00	0.07	0.24	0.38	55.0%
Organic nitrogens	dimethyl hydrazine (1,1-dimethylhydrazine)	60.10	0.040	0.100	7.32	0.00	0.73	2.56	4.03	55.0%
Organic nitrogens	monomethyl hydrazine (methylhydrazine)	46.07	0.020	0.038	2.80	0.00	0.28	0.98	1.54	55.0%

listed in table 2. The total source rate values could be increased by decreasing the time constant for contaminant buildup, but the assumed value of 30 hours is not overly conservative. The only variables that enter into the total rate calculation are the volume of the module, the MAC, and the time constant. These calculations show that the 5 chemicals listed in table 2 have buildup time constants less than 30 hours and must receive special consideration if they are to be adequately controlled. This may require special apparatus or an increased flowrate through the TCRS.

Long Term Degradation of Polymers

As a part of the analysis of contamination source rates we have considered the possibility that polymers will degrade on the space station in some manner not previously considered or at a rate unimportant in past spacecraft. The most obvious difference between the space station and previous spacecraft is the duration of the mission. The lifetime of the space station is 15 to 30 years as opposed to 84 days for skylab and about 7 days for the shuttle. Polymers can age considerably in the 15 years showing change in such properties as modulus and color. These changes are a clear indication that slow chemical reactions are taking place, and we must determine if contaminants are generated by these reactions and if so at what rate.

There are basically four mechanisms that lead to long term degradation of polymers: thermal degradation, photochemically induced reactions, radiation, and (absorption of ionizing) chemical oxidation. All these mechanisms involve the formation of free radicals in polymer chains, followed by subsequent chemical reaction of the radicals. This type of reaction scheme produces small molecules that diffuse to the surface of the host polymer and escape into the surrounding atmosphere. Most of these small molecules

Table 2. Contaminants With a Biological Source Rate Greater Than the Total Source Rate

List of Contaminants

Group	Contaminants	MOL wt.	MAC (PPM)	MAC (mg/m**3)	Total rate (mg/day)	Biological rate (mg/day)	Lab module rate (mg/day)	Portable equipment rate (mg/day)	Rate remainder (mg/day)	Remainder % of total
Alcohols	phenol	94.11	0.500	1.950	143.24	570.00	-42.67	-149.35	-234.71	****%
Miscellaneous	ammonia	17.03	12.500	8.822	648.03	2850.00	-220.19	-770.68	-1211.07	****%
Organic acids	pyruvic acid (2-oxo-propanoic acid)	88.06	0.250	0.912	67.02	1260.00	-119.29	-417.53	-656.13	****%
Organic nitrogens	indole (2,3-benzopyrrole)	117.10	0.100	0.485	35.65	150.00	-11.43	-40.01	-62.88	****%
Organic nitrogens	skatole (3-methyl indole)	131.20	0.100	0.544	39.94	150.00	-11.00	-38.51	-60.52	****%

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are contaminants and our job is to determine how fast they are produced and what factors affect the production rate.

Thermal Degradation

Most polymers can undergo depolymerization under appropriate temperature conditions. Thermodynamic considerations show that above a certain temperature the monomer is in thermodynamic equilibrium with the a polymer of N units. The degree of polymerization (N) decreases as the temperature increases, (i.e., depolymerization increases at higher temperatures. The Gibbs free energy for the depolymerization reaction is exponential in reciprocal temperature. Thus the practical effect is that the depolymerization begins suddenly at a temperature called the ceiling temperature. Typical ceiling temperatures are shown in table 3. The lowest value in the table is -30 degrees Celsius for polyacetaldehyde, but typical ceiling temperatures are considerably higher than the temperature inside the space station (21 degrees Celsius) or the normal service temperature of most polymeric materials. Thus we have concluded that the thermal degradation rate of polymers is not a significant problem, and the associated generation of contaminant species can be ignored if the polymer passes the standard 72-hour test at 50 degrees Celsius.

Table 3. Ceiling Temperatures of Typical Polymers (ref. 10)

Monomer	Ceiling temperature (°C)
Acetaldehyde	-30.
Tetrahydrofuran	84.
Methylstyrene	61.
Ethene	355.
Butene -1	470.
Styrene	384.
Butadiene	547.
Methylmethacrylate	197.
Formaldehyde	118.
Tetrafluoroethene	600.
Vinylidene chloride	570.

Photochemical Degradation

Photochemical degradation of polymers occurs when light with a wavelength shorter than about 300 nanometers is absorbed by the polymer. Usually photons are absorbed by particular "chromophoric" groups. The concentration of chromophors is a characteristic of each individual polymer. Oxygen-containing functional groups such as carbonyl, hydroxyl, and peroxide are strong chromophores. Absorbed photons generate free radicals in the polymer matrix, and the free radicals subsequently undergo chemical reaction. The presence of oxygen has a significant influence on the chemical reactions as well as on the absorption of photons. Oxygen usually increases the degradation rate, but it can retard degradation in some materials. The presence of oxygen generally inhibits crosslinking reactions and increases the rate of formation of small molecules and contaminants. Typically the rate of absorption of oxygen is autocatalytic, i.e. it increases with time and the degree of degradation, but at very long times this process may reverse.

A calculation was performed to determine typical rates of contamination production from photodegradation of polymers inside a manned module. The calculations were based on data for the production of methanol from polymethylmethacrylate in a vacuum. This system exhibits a high quantum yield for methanol, but the yield may be greater in the presence of oxygen.

This calculation requires data on the photon flux and dose absorbed by the polymer. We did not have this type of information for the space station so ordinary fluorescent room lights were used as a basis for calculations. The power absorbed by the polymer was estimated as 2.5 Watts in the wavelength band between 200 and 300 nanometers. This assumption and a specific energy of 4.79 E-7 Joules per mole of photons results in a dose rate of 5.22 E-8 Einsteins per second. The photon yield is 0.48 (ref. 10), and the calculated source rate is about 69 milligrams of methanol per day. This rate is 24% of the total source rate for methanol tabulated in appendix A, and indicates that the long term degradation of polymers by ultraviolet light may be a significant source of some contaminants. The most likely contaminant species produced by this process are small organic compounds containing oxygen, such as carbon monoxide, methanol, acetic acid, acetaldehyde, and formaldehyde. Methane is also frequently produced by photochemical degradation. Of these compound carbon monoxide and formaldehyde are the two most likely to constitute a significant contamination problem on the space station.

Polymer Degradation by Ionizing Radiation

Free Radical Formation

Ionizing radiation degrades polymers by forming free radicals in the polymer matrix which then react chemically to produce chain fragments and crosslink the polymer. When fragments are formed they can diffuse to the surface of the polymer and escape into the surrounding atmosphere as contaminants. This process is similar to outgassing of plasticizers, but the contaminants originate directly from the host polymer. The rate of generation of free radicals in polymers depends on a number of parameters such as the absorbed dose of radiation, the type of radiation (gamma, electron, proton, and alpha), the temperature, the polymer, and the presence of oxygen in the atmosphere surrounding the polymer. We will discuss these factors in greater detail below.

Radiation Environment Inside Manned Modules

The particle radiation flux outside space station modules as a function of particle energy is illustrated in figure 1. The particle flux depends on a number of orbit parameters. The data in figure 1 represents a nominal space station orbit. In general there is a much higher flux of electrons than protons outside the space station.

Inside the space station the primary radiation is high energy protons. Figure 2 shows the absorbed dose of proton, electron, and gamma (bremsstrahlung) radiation inside space station modules as a function of depth in aluminum. These data apply to the same orbit conditions as figure 1. The corresponding figure for any polymer would be nearly identical to figure 2, and we have therefore based our calculations on the data shown here. Figure 2 shows that most of the electrons are stopped by the skin of the manned module's pressure hull. Each depth unit in figure 2 represents 3.70 millimeters (0.146 inches) of aluminum. Thus the radiation dose rate in thick polymers inside the pressure vessel is about 0.15 rads per day, and it is primarily due to high energy protons.

Degradation Products

The chemical species formed as polymers degrade by the radiation mechanism depends strongly on the host polymer and the atmosphere surrounding the polymer. In a vacuum, typical degradation products are: hydrogen, methane, carbon monoxide, carbon dioxide, methyl formate, dimethyl ether, formaldehyde, sulphur dioxide, acetaldehyde, and pyruvic acid (ref. 10). Many of these compounds contain oxygen and all are on the list of contaminants that have been assigned a MAC by the NASA toxicologist. In the presence of an atmosphere containing oxygen the degradation products are expected to contain more oxygen, and the fraction of carbon monoxide is expected to increase.

ORBITAL RADIATION STUDY

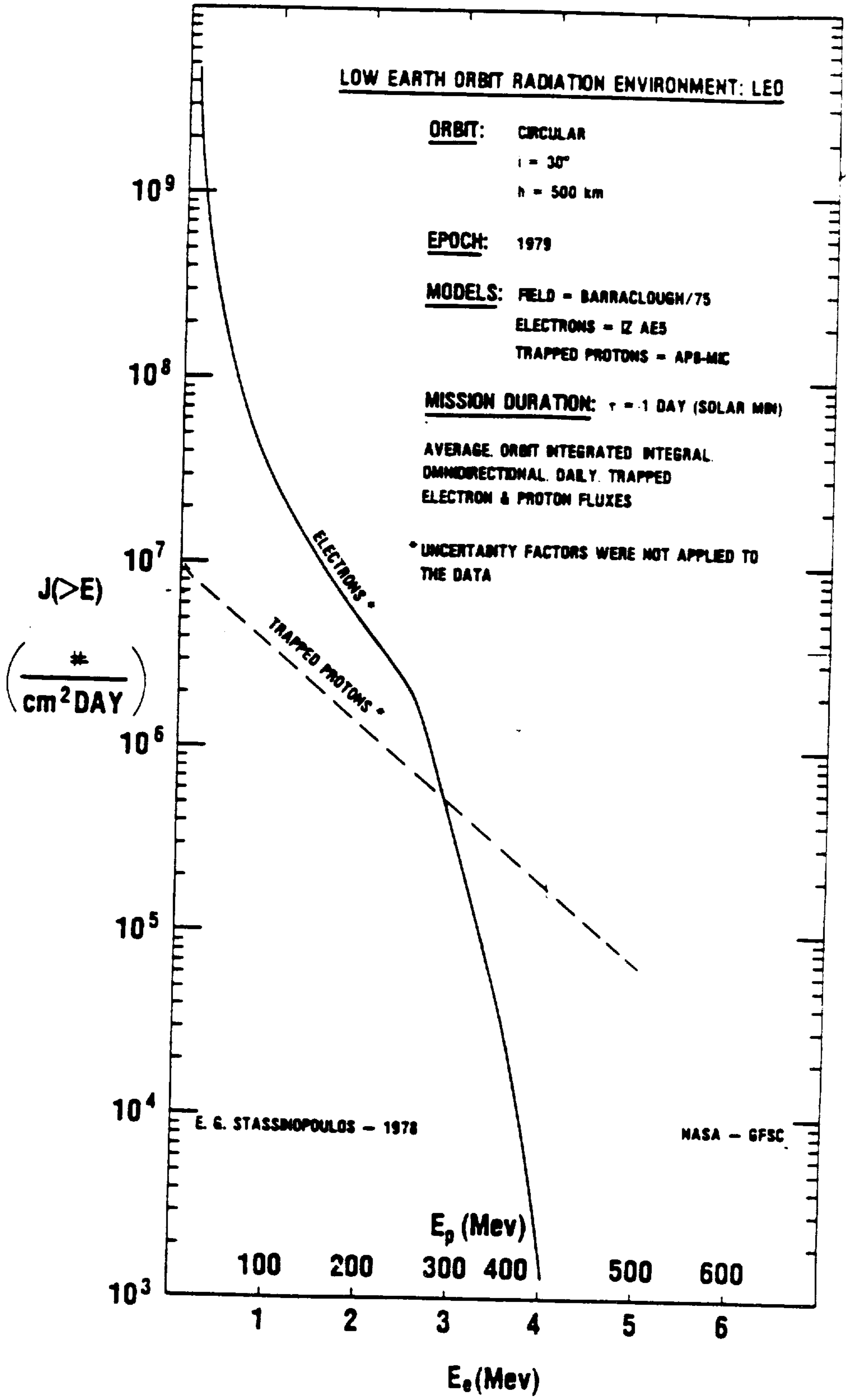

Figure 1. Radiation Environment of Electrons and Protons Outside a Spacecraft in Low Earth Orbit

ORBITAL RADIATION STUDY

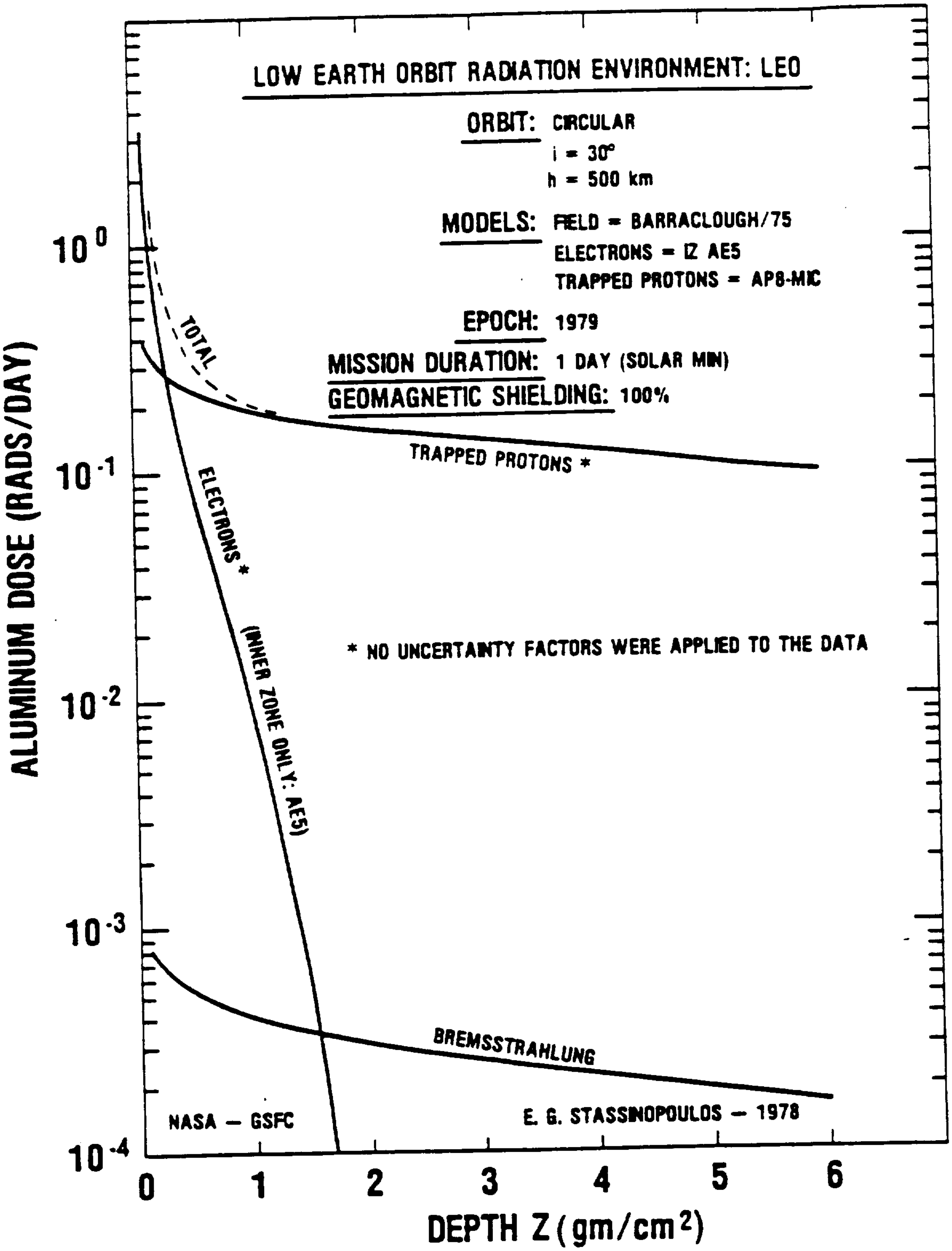

Figure 2. Dose Rate Versus Depth for Aluminum in Low Earth Orbit

Degradation Kinetics

The initial reaction sequence for polymer degradation by proton radiation is the formation of a free radical that then either breaks or cross links the polymer chain. The cross linking reaction increases the stiffness of the polymer, and the chain breaking reaction reduces the chain molecular weight and forms smaller molecules. When oxygen is present it can react with the free radicals to form peroxy radicals which then undergo subsequent reaction. The presence of oxygen generally increases the quantum yield for production of small molecules and simultaneously increases the photochemical degradation rate. Furthermore the degradation rate under oxygen atmospheres often exhibits autocatalysis. That is the rate increases with the passage of time as degradation increases.

Little quantitative data exists on the degradation products and their production rates in polymers irradiated with high energy protons. This is due to the unusual nature of this type of radiation environment and to the difficulty in obtaining an appropriate proton flux. We have based the following analysis on readily available data for the degradation by gamma radiation of polypropylene in an oxygen containing atmosphere. The dose rate inside manned modules is nearly seven orders of magnitude lower than the experimental dose rate, but an extrapolation of this magnitude is generally accepted as state of the art by experts in the field (ref. 11-14). Assuming the dose rate extrapolation is acceptable, the calculated degradation rate is expected to be lower than the rate on the space station because the experimental data that the calculations are based on are for gamma radiation, and the same dose of high energy proton radiation is expected to initiate many more free radicals. Also, when radiation degrades polymers in the presence of ultraviolet light there is a synergistic effect that increases the degradation rate.

The source rate calculations are based on a dose rate of 0.15 rads per day (fig. 2). The extrapolated yield for the incorporation of oxygen into the polymer is 1.18 E 3 molecules per electron volt of absorbed energy. This leads to an oxygen reaction rate of 1.83 E-8 moles of oxygen per gram of polymer per day. All the oxygen that reacts will not be released as contamination. We assumed that 10% of the oxygen would be incorporated into contaminant molecules. Thus, the contaminant production rate is 1.8 E-9 mole per gram of polymer per day. Assuming an average mole weight of contaminant of 100 grams per mole the production rate is 0.18 micrograms of contamination per gram of polymer per day. On the surface this production rate appears to be well below the NASA standard of 100 micrograms per gram of polymer per 72 hours, but this may be an erroneous conclusion. We will investigate this possibility further below.

We have a list of the degradation products produced by polypropylene (ref. 10) irradiated with gamma radiation in the presence of oxygen. These data were obtained by different researchers than those who provided the rate data used above. We have assumed a mass of polymeric material in each manned module of 1500 kilograms. The source rate of each contaminant was calculated, and the results are illustrated in table 4. Table 4 also shows the maximum allowable source rates for each contaminant. The maximum allowable limits shown in the table are based on the lab module and total outgassing rates shown in appendix A, but the limits shown here have been reduced by a factor of 100 from those in appendix A to allow a safety margin. The safety margin is needed because our calculations ignored the effects of ultraviolet radiation, and considered gamma instead of proton radiation.

Table 4 shows that the rate of production of 4 compounds (carbon monoxide, acetaldehyde, acetic acid, and acetone) exceed the maximum allowable lab module outgassing rate, and carbon monoxide production is greater than the maximum allowed total rate.

Table 4. Source Rates of Contaminants Formed by Radiation Degradation in a Manned Module

	Outgassing rate (mg/day)	Maximum allowable lab mod. rate (mg/day)	Maximum allowable total rate (mg/day)
Methane	0.8	64.96	659.19
Ethene	0.5	12.80	128.08
Ethane	1.3	13.73	137.31
Propene	1.8	32.02	320.25
CO	26.	1.08	12.79
CO_2	1.1		
Acetaldehyde	8.9	4.02	40.23
Propionaldehyde	0.6	7.07	70.72
Acetic acid	2.3	.37	3.66
Acetone	76.	26.52	265.21
MEK	1.8	4.39	43.90
Diethyl ketone	2.1		
Isopropanol	2.4	7.32	73.17

This is strong evidence that long term degradation of polymers could be a significant contaminant source on the space station, and additional investigation of this mechanism is warranted.

PARTICULATE CONTAMINATION

Our objective in this analysis is to apply sound engineering principles and quantitatively determine source rates and removal rates for particles in the atmosphere inside space station modules. When the source and removal rate are known it is a simple matter to calculate particle concentrations in the breathing atmosphere. The following analysis is based on a thorough search of all major technical data bases accessible through our library. Abstracts from approximately one hundred fifty references published in the past 10 years were examined in detail. Our conclusion is that no reliable, quantitative models of particle dynamics are available for the pressurized atmosphere inside space vehicles.

SOURCES

Particulate contamination is present in every environment humans inhabit or anywhere natural or man-made activity occurs. In general there are two populations of particles. Each population is produced by a different mechanism. The populations are described by their size distributions, and usually a bi-modal size distribution is measured in any finite air volume. The large-particle distribution has a mean size of about 10 microns. These particles are produced by mechanical activity such as frictional wear, and manufacturing and human activity. The second population of particles have a mean size of about 1 micron and are generally referred to as in-situ or accumulation-mode particles. These particles cannot be traced back to mechanical activity. They are considered to be formed by natural processes such as electrostatic attraction of molecules. Eventually the molecules grow into a "clump" with a physical size approximately 1 micron in diameter. Another mechanism that produces submicron size particles is condensation about condensation nuclei. Condensation nuclei are composed of meterorite dust, natural or man-made combustion products (soot), and volcanic dust. Condensation nuclei are present everywhere in the earth's atmosphere in varying number densities.

Primary sources of particles in the larger size distribution are people, industrial processes, and equipment operation. The major type of particulate contamination produced by people is epidermal skin pieces which can vary in size from a few microns to noticeably large flakes. The skin flakes pose no threat to human health but do present a problem in controlled areas where there is a human activity. Processing operations and manufacturing activities produce the largest quantity of particulate contamination in the environment. Figure 3 shows the number density of 5 micron or greater diameter particles in the STS Orbiter Processing Facility (OPF) between July 1, 1985 and July 19, 1985 (ref. 17). The highest concentrations of particles occurred during mechanical operations such as opening the main doors or the transfer doors.

Any equipment or components within the OPF will have particulate contamination deposit on it from the air. Thus, the particle density in the environment affects surface cleanliness levels. The fallout rate for particles in the OPF facility is shown in figure 4 (ref. 17). The lines with constant slope represent MIL-STD-1246 requirements. The figure shows that the naturally occurring distribution of particles deviates from the military standard. The key aspect of deciding how to ensure that a surface inside the OPF remains at or below a specified cleanliness level is the ability to predict both the particle fallout rate and the size distribution. When this type of data is available one can predict the end item cleanliness level and quantify the amount of particle contamination on a surface.

When rockets are launched the particles present on a surface will dislodge from the surface because of the launched induced vibrations. Thus a module assembled in a class

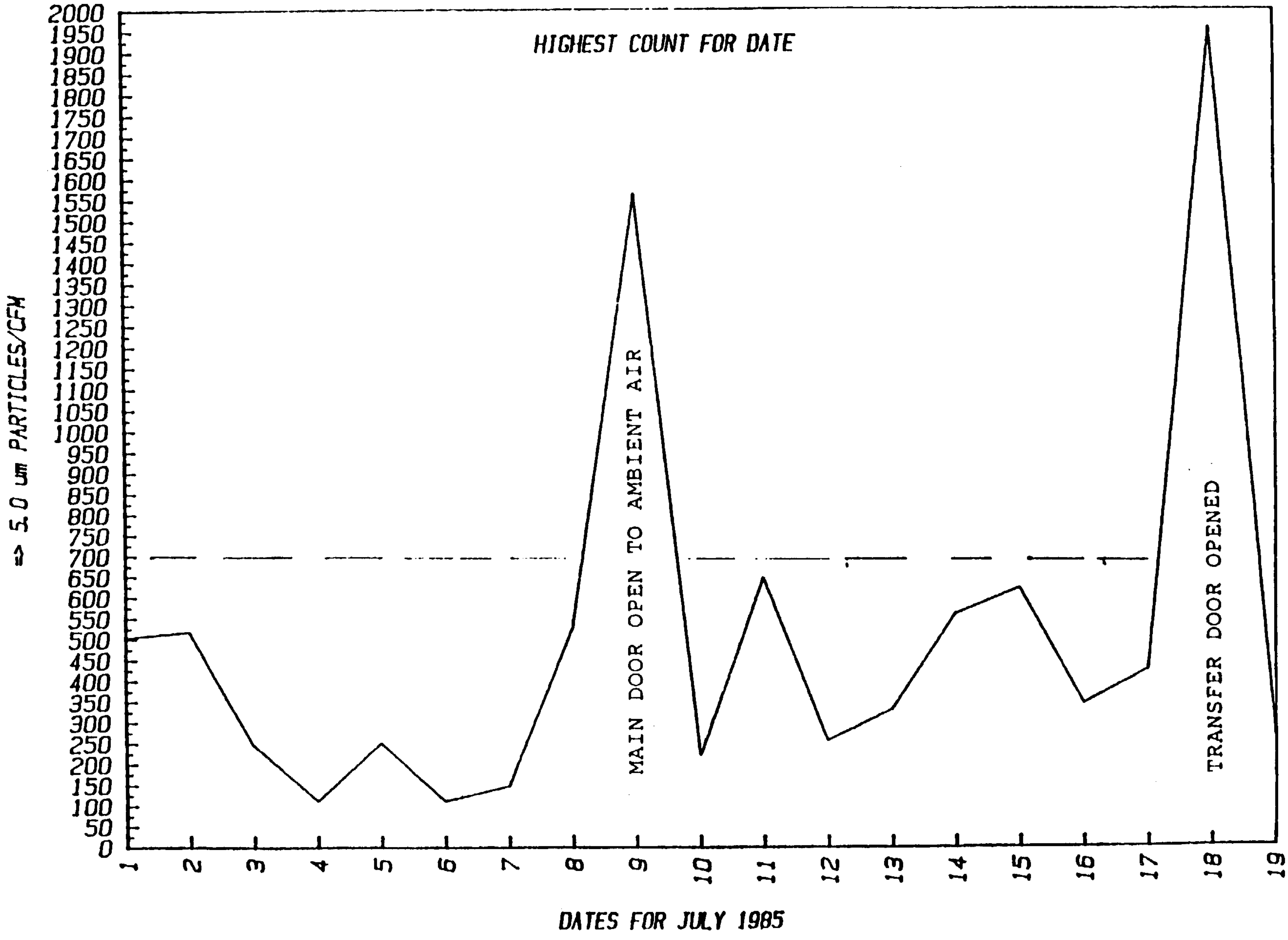

Figure 3. Airborne Particulate Counts in the Orbiter Processing Facility, July 1-19, 1985

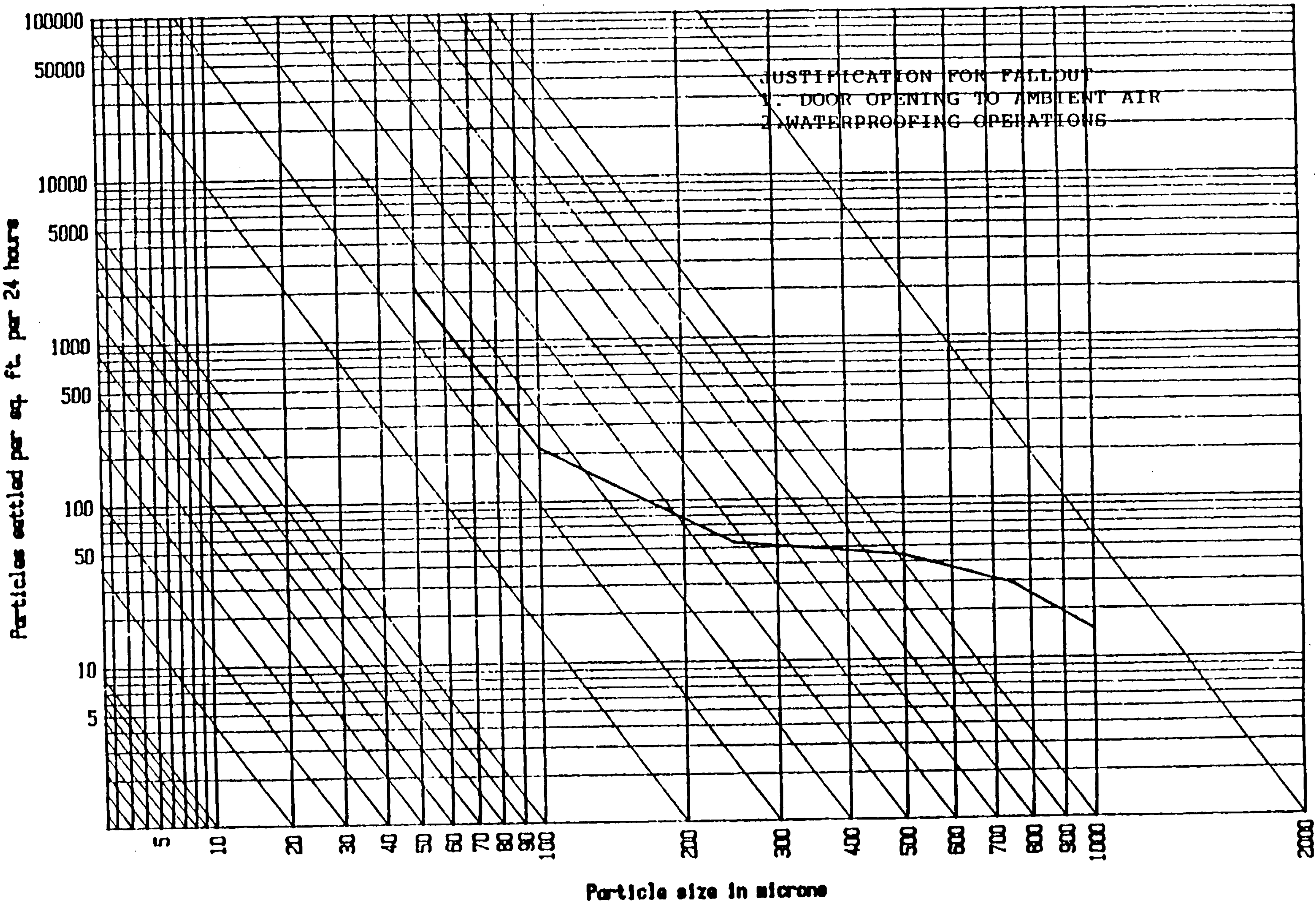

Figure 4. Average Particle Fallout Rates in the Orbiter Processing Facility, July 1985

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10,000 cleanroom which meets a surface cleanliness requirement at launch time may not be able to meet the same requirement upon reaching orbit because a percentage of the particles which resided on the surfaces are now suspended in the environment and will not settle out via the same mechanisms as they would on earth.

The number and distribution of particles dislodged during launch has been explored analytically by Hamberg (ref. 18) and a redistribution model has been developed. Hamberg assumes that all particles are dislodged from a surface during launch and are subsequently redistributed over all surfaces. Mathematically the model is described by the following equation:

$$\frac{N}{A} = \frac{\Sigma\,(N_i/A_i)\,A_i}{\Sigma\,A_i}$$

where, N/A = final uniformally redistributed particles per square foot with a diameter equal to or greater than 5 microns.

(Ni/Ai) = Original number of particles with a diameter equal to or greater than 5 microns per square foot on a surface Ai.

Ai = Area of surface i

Thus the final particle count on a surface after detachment and redistribution is not only a function of it's initial particle count but also the particle count on all other surfaces.

The primary assumption in this model is that all dislodged particles will eventually redeposite on a surface regardless of size. This is a very conservative assumption and does not account for the various mechanisms effecting particle depositions. Also, adhering to the above assumptions implies that the cleanliness level of the environment on orbit will eventually reach a level equal to the prelaunch level. This is inconsistent with the physical mechanisms controlling particle fallout in spacecraft.

On earth the major forces affecting the airborne stability of suspended particles are gravitational sedimentation, inertial impaction, and diffusion or Brownian motion. Gravitational sedimentation is a classical relationship between gravity and the viscous air resistance of the particle as described by Stoke's law. During launch the induced accelerations mask out gravitational effects, thus gravitational sedimentation is not a primary mechanism for particle motion during this period. On orbit the gravitational sedimentation mechanism is a minimum and other mechanisms dominate particle fallout.

Inertial impaction occurs when a high velocity aerosol stream is directed against an obstacle and changes direction abruptly. Small and low-density particles with low inertia will follow the air stream and do not penetrate into the surface boundary layer where deposition takes place. Particles with large inertia do not follow the air flow, but pass through the boundary layer and deposit on the surface of the obstacle. The velocity of the air in a module is low, as is deposition of small particles due to inertial impaction.

Diffusion and Brownian motion of molecules are governed by molecular collisions. According to the Einstein equation particles with diameters roughly equal to the mean free path of gas molecules can diffuse through the gas. Since the ambient pressure inside modules is 14.7 psia, only particles less than about 70 nanometers in diameter will diffuse, and this mechanism will thus contribute little to the rate of deposition on surfaces.

REMOVAL RATES

In order to control airborne particulate contamination within a specified volume, we must know the rate at which contaminants enter the volume and the procedures for removing the contaminants. The two major sources of particulates are release from surfaces and activities occurring within the controlled area. Surfaces are contaminated primarily from fallout of particles during ground operations. Thus, while module air can in principle be cleaned by on orbit filtration it is conservative to assume that the cleanliness of air inside a module is no cleaner than the air introduced into the module during assembly and ground operations. Therefore if a class 10,000 clean level is to be maintained throughout the life of the module, the air introduced into the module on the ground must be at least class 10,000. Also, the activities occurring within the module must not produce particulate contaminants at rates greater than those than can be removed by the filtering systems.

In order to control contamination within a clean area the following rules should be observed:

a. Restrict operations which generate large quantities of particles.
b. Provide personnel with clothing and training to minimize particle sources and reduce production rates.
c. Design buildings and facilities that will accommodate the planned operation while providing the required air cleanliness level.

Particle concentrations can also be reduced by increasing the rate of removal of the particles from the air. Particles can be removed from air by several methods:

a. Precipitation in electric fields.

b. Inertial entrapment.

c. Impingement on sieves such as High Efficiency Particulate Filters (HEPA).

Electric fields and HEPA filters are the most efficient of these methods.

The inside of each space station module will be exposed to a dense protron flux, therefore, dielectric materials will obtain an electric charge, i.e., become ionized. The primary mechanisms controlling the motion of ionized particles inside a module are electric fields, and forced air convection. The most practical and efficient method of removing charged particles from modules is a forced air system which draws air through an ion trap. The particle size and removal rate of the ion trap system depends on the electric fields present in the module and the charging properties of the particles in the proton environment.

The best method of removing uncharged particles from air is a HEPA filter system. HEPA filters are porous, dry filters that remove particles from the air by a sieving mechanism. Typical HEPA filters have an efficiency of 99.97% for particles with diameters 0.3 microns or greater. HEPA filters are the only type of sieving filters that provide sufficient filtration for a class 10,000 clean area. One potential problem with using HEPA filters on the space station is that they could pick up an electrostatic charge. This could significantly reduce the efficiency of the filters for particles with the same type of charge.

METHODS OF CONTAMINATION CONTROL

The intent of all contamination control procedures is to limit the concentration of contaminants in the breathing atmosphere to levels that are safe for humans. It is not our responsibility to determine the safe concentration of each contaminant, but we must develop an effective means of controlling contaminant concentrations.

The concentration of a contaminant in the breathing air can easily be calculated if the total source rate, removal rate, and initial concentration are known. In general both these rates and the contaminant concentration are functions of time. Source rates vary with both time and temperature and removal rates depend on the age of the catalyst in the catalytic oxidizer, catalyst temperature, and the air flowrate through the TCRS. In order to simplify the general problem we have assumed that the source rate and the removal rate are constant. It was also assumed that the air inside the modules is well mixed. This is probably a good assumption because the air is constantly being circulated and refurbished by the ECLSS. Under these assumptions the concentration of a contaminant in the air depends only on the source and removal rates.

All contamination control methods must be based on one of three general philosophies: limit the quantity of each contaminant allowed in a module, limit the rate at which contaminants enter the breathing atmosphere, or increase the rate of removal of contaminants from the air until the contaminant concentration is reduced to a safe level. The first philosophy is the basis for the method of contamination control currently used by NASA, but one of the other philosophies could form the basis of a new method, for the space station.

CURRENT METHOD OF CONTAMINATION CONTROL

The method NASA is currently using to control contamination inside spacecraft involves two phases. First the materials used on the spacecraft must be screened for contamination content. Samples of each material are tested to determine what contaminants they produce and the rate of contaminant production is determined in a standardized test. These data are used to eliminate materials that produce excessive amounts of contamination and to predict the rate at which each contaminant is released into the breathing atmosphere on a spacecraft. The basic philosophy behind these screening tests is to restrict the quantity of contamination that is allowed inside a spacecraft. In the second phase of contamination control measurements are made of contaminant concentrations in the spacecraft. Measurements are made first in ground tests and then in flight. The breathing gas is sampled for post flight contamination analysis. The second phase testing is used primarily as a verification procedure for the screening and analytical predictions made during the first phase of contamination control.

The existing method of controlling contamination has been successful in the sense that the measured concentration of each contaminant has rarely been greater than the MAC, but the question now is, is this method the best one to implement for the space station program? The space station program is unique in that the user payloads will be constantly changing, and unlike the shuttle program there will not be complete payload changes at discrete time intervals. Rather, partial payload changes will be occurring frequently. The second unique aspect of the space station is the duration of the flight. Both space station systems and users equipment will be expected to function for many years without contaminating the breathing atmosphere or degrading the performance of other equipment such as the ECLSS. Another difference in this program is the desire to attract commercial users and the subsequent need for systems and controls to be as user friendly as possible.

The current method of contamination control suffers from a number of deficiencies. The first level control philosophy is to screen out materials that produce excessive contamination, but the screening criterion is a mass specific limit. Materials producing more than 100 micrograms of contamination per gram of host material are rejected. This criterion in no way limits the amount of a particular material or its contaminants that can be placed in a space station module, but this method can reduce the general level of contamination. A second problem with the current contamination control approach is that it relies heavily on the results of the standardized 72-hour test. A great number of these tests have been conducted on a large number of materials, but the results are still controversial. One of the primary problems with the 72-hour test is that the outgassing rate depends on many parameters which are not specified in the test procedure. For example the procedure does not prescribe the temperature, the mass of sample, the surface area of the sample, the sample preparation procedure, or the method of sampling the gas for analysis of contaminants. All these factors affect the test results and therefore the offgassing rate which is later used to predict contaminant concentrations in the spacecraft.

Another problem with heavy reliance on the 72-hour test is that there is no way of insuring that the polymer specimen that is tested is identical to the polymer that is eventually used in assemblies on the spacecraft. The contaminants that are released into the atmosphere are invariably trace components of the host polymer. These chemicals are such things as unreacted monomer, plasticizer, unevaporated solvent, degradation products, impurities, unreacted initiator, and antioxidant. None of these chemicals is a main component of a polymer and many are unwanted and uncontrolled in the manufacturing process. Thus, different batches and lots of the "same" polymer produce significantly different contaminant signatures in the 72-hour test.

Age is another factor that changes the type and quantity of contamination produced by different polymers. Contaminants diffuse out of the host polymer at different rates. Relative diffusion rates depend greatly on the type of polymer, the diffusing species, and the temperature. We have attempted to obtain age data from a number of polymer manufacturers, but they have been reluctant to provide this information. Furthermore, unless we also have information on the temperature history of the host polymer, the usefulness of the age data is questionable. It therefore appears that we must accept the fact that rate data obtained with a small specimen of material in the 72-hour test is not highly accurate, and the contaminant concentrations calculated from these rate data are subject to considerable error.

Another problem with the current method of contamination control is that it was not designed to be user friendly. The selection criteria (less than 100 micrograms of organic contamination per gram of specimen) are fairly strict, and will preclude many "off the shelf" items of equipment from use on the space station. Furthermore, this contamination control method was not designed for a system of continuously rotating payloads, and no provisions were made for separating contaminant allocations among the space station structure, permanent equipment, users, portable equipment, experiments, and activities. It is therefore appropriate that we reevaluate the possible contamination control methods in light of the new requirements of the space station, available test procedures, and past experience.

MODIFIED CONTAMINATION CONTROL METHOD #1—Limitation of Contaminant Content in Materials.

This method of contamination control is basically the method currently being used on unmanned spacecraft for internal and external contamination control. In this method the amount of each contaminant species in a host material is limited on a per unit mass (gram) or per unit volume (cm^3) bases. For example, material A would be constrained to contain less than 0.1% by weight hexane.

This is an indirect method of controlling the contaminant level in the breathing atmosphere because there is no control over the outgassing rate or over how much of a given host material can be used in a module. However, contamination in the breathing atmosphere can be limited in this manner. The technique works because it lowers the rate at which contaminants diffuse out of host materials. The outgassing rate from a given material is uncontrolled and could, in principle, take any value, but this method controls the average total outgassing rate.

Previously in this subtask we demonstrated the effectiveness of this type of indirect contamination control by calculating the concentration of contaminants in the breathing air inside a manned module (ref. 15). The calculation was made for generic contaminants with molecular weights between 50 and 1000. We assumed that each space station module contained 6112 kg of polymeric material with a density of 1.30 g/cm^3 with an exposed surface area of 9.403 E6 cm^2. The model was based on empirical diffusion correlations and assumed the temperature inside the module to be below the polymer's glass transition temperature (T_g). The results of this analysis are presented in Tables 5-7.

*Table 5. Outgassing Flux (g/(cm^2*s))*

Time	Contaminant mole weight				
	50	100	200	500	1000
1 year	5.42×10^{-11}	1.86×10^{-12}	1.86×10^{-12}	5.94×10^{-26}	7.93×10^{-43}
2 years	1.17×10^{-11}	1.32×10^{-12}	5.19×10^{-16}	4.20×10^{-26}	5.60×10^{-43}
5 years	1.18×10^{-13}	8.33×10^{-13}	3.28×10^{-16}	2.66×10^{-26}	3.54×10^{-43}
10 years	5.51×10^{-17}	5.89×10^{-13}	2.32×10^{-16}	1.88×10^{-26}	2.51×10^{-43}
20 years	1.21×10^{-23}	4.17×10^{-13}	1.64×10^{-16}	1.33×10^{-26}	1.77×10^{-43}

Table 6. Outgassing Rate (g/s)

Time	Contaminant mole weight				
	50	100	200	500	1000
1 year	$5. \times 10^{-4}$	$2. \times 10^{-5}$	$7. \times 10^{-9}$	$6. \times 10^{-19}$	$7. \times 10^{-36}$
2 years	$1. \times 10^{-4}$	$1. \times 10^{-5}$	$5. \times 10^{-9}$	$4. \times 10^{-19}$	$5. \times 10^{-36}$
5 years	$1. \times 10^{-6}$	$8. \times 10^{-6}$	$3. \times 10^{-9}$	$3. \times 10^{-19}$	$3. \times 10^{-36}$
10 years	$5. \times 10^{-10}$	$6. \times 10^{-6}$	$2. \times 10^{-9}$	$2. \times 10^{-19}$	$2. \times 10^{-36}$
20 years	$1. \times 10^{-16}$	$4. \times 10^{-6}$	1.5×10^{-9}	$1. \times 10^{-19}$	$2. \times 10^{-36}$

Table 7. Space Station Contaminant Concentration (mg/m^3)

Time	Contaminant mole weight				
	50	100	200	500	1000
1 year	60.0	2.06	0.001	0.000	0.000
2 years	13.0	1.46	0.001	0.000	0.000
5 years	0.131	0.922	0.000	0.000	0.000
10 years	0.000	0.652	0.000	0.000	0.000
20 years	0.000	0.462	0.000	0.000	0.000
Low MAC	0.100	0.100	0.100	0.100	0.100
Typical MAC	100.	100.	100.	100.	100.

Table 5 presents the outgassing flux in grams per square centimeter per second. As the table shows the flux is a function of the age of the polymer and mole weight of the diffusant. The flux is also a function of temperature, polymer thickness, and concentration of contaminant inside the polymer. In this analysis we assumed a temperature of 50°C, an average thickness of 0.50 centimeters, and an initial concentration of 0.01 grams of contaminant per gram of polymer. The table also shows that the flux of contaminants heavier than about 200 g/mole is very low. Table 6 shows the results of the same model expressed as the mass of contaminant emitted into a space station module each second.

In order to calculate the expected contaminant concentration in the breathing atmosphere inside a space station module we must know the flow rate through the TCRS as well as the removal efficiency (ref. 16). In this calculation we have assumed a flowrate of 9.44 liters per second (20 ft^3/min) and a removal efficiency of 0.9.

Table 7 shows the calculated contaminant concentration as a function of time and molecular weight. Also shown are a typical MAC value (100 mg/m^3) and a very low MAC value (0.1 mg/m^3) that corresponds to a very toxic species. Table 7 shows that only light and moderate molecular weight contaminants might exceed either the typical or the low MAC. These results indicate that most contaminants can be adequately controlled by requiring a total contaminant mass fraction less than 0.01 in the parent polymer. However, this analysis also illustrates the many factors that determine the contaminant concentration in the breathing atmosphere, and it does not address the problem of long term polymer degradation as a contaminant source.

Because this method of contamination control is similar to the method currently used by NASA, it has the advantage of being familiar to most people in the contamination control field. It has two primary disadvantages. It is an indirect control method that achieves its objective by placing overly stringent controls on many materials. This is necessary because materials produce contamination at different rates and no control is placed on the total rate, but this method of control is not user friendly in the sense that the actual outgassing rates of many assembled articles and systems are forced to be lower than necessary. This means that some equipment is unnecessarily precluded from use on the space station, thereby increasing the cost to use space station facilities. The second disadvantage of this method is that it is subject to abuse. When materials or assemblies are assigned outgassing specifications per unit mass it is easy to meet requirements simply by increasing the mass of the assembly. Circumventing the controls is more difficult if each material used in the module is tested instead of large assemblies, but abuse of regulations can still occur. If this type of abuse becomes widespread, still lower contamination limits will be required, and additional hidden costs will be incurred by space station users.

An advantage of this method of contamination control is that no "mission" priorities need be established. Each source of contamination is treated individually without regard to the relative important of the source material or assembly to mission objectives. This makes the controller's job easy, but at the expense of levying overly stringent contamination controls on many users. From the user's point of view this method is uniform and objective, thus avoiding "political" problems so prevalent in more subjective methods of contamination control, but it is not a flexible method and does not allow for changing priorities. This method is the simplest to implement, but it requires a vast amount of material testing and accepts the difficulties and cost of implementing this type of test program.

MODIFIED CONTAMINATION CONTROL METHOD #2—Limitation of each Contaminant Source Rate

This method seeks to control the contaminant concentration in the breathing atmosphere by limiting the rate at which each contaminant enter the atmosphere. This is a direct method of contamination control. This method assumes that the rate of contaminant removal from the atmosphere is known, and any concentration of contaminant in the atmosphere can be achieved by this method.

A primary advantage of this method is that it provides direct control over the contaminant concentration in the breathing atmosphere. The primary difficulty it presents is budgeting outgassing limits for individual systems, assemblies, and subassemblies on the space station. Allocation of individual contaminant source limits for systems, assemblies, and subassemblies is necessary because these sources all contribute to the total outgassing rate, and the total rate cannot be controlled without controlling its constituents. Thus, a method must be devised to limit the outgassing rate from each system, assembly, and subassembly.

Implementation of this control method would require the testing of finished assemblies rather than component materials. Fewer tests would be required than for method 1, but these tests would be more elaborate and time consuming than those required by control method number 1. Furthermore, the demand for test facilities would be cyclical and might at times limit the rate of contamination testing. Another disadvantage is that assigning individual outgassing rates to systems, assemblies, and subassemblies entails a degree of subjectivity and makes this method somewhat less attractive than method 1. However, this method could be easily implemented as a computer model which users would access interactively in order to assess their equipment and evaluate it with regard to outgassing specifications.

MODIFIED CONTAMINATION CONTROL METHOD #3—Control Trace Contaminant Removal Rate

In this method limitations on the source rates are relaxed or not specified at all for some systems or assemblies. Control of contaminants in the breathing atmosphere is achieved by adjusting the removal rate of each contaminant through the TCRS. This is a direct control method like method-2, but here we are increasing the TCRS as needed to achieve the desired objective. This method has been used in the past on manned spacecraft as a backup means of contaminant control, but it could be employed as the primary contamination control method on the space station.

This is probably the most user friendly means of contamination control. The user sees very few restrictions and what source rate limitations are imposed should be lenient. The burden of contamination control falls on the design of the sensor system that detects contaminants and measures the concentration in the breathing atmosphere, and on the TCRS system which must be larger than that required by contamination control methods one or two.

The choice of contamination control method is primarily one of expedience and economics. Each method has advantages and limitations, and a definition of overall objectives is required before the optimum method of contamination control can be established. For the space station it appears that method three is the method of choice, but the decision to pick this method must be made early in the program because it affects the design and construction of the TCRS, the contamination monitoring equipment, and the operational frequency of contamination tests in space station modules.

CONCLUSIONS

This analysis was conducted to determine the anticipated magnitude of contamination source rates and the removal rates from space station modules. Both molecular and particulate contamination have been considered. The analysis required us to make a number of assumptions about the operating characteristics of the environmental control and life support system which is the primary means of removing contaminants from the air.

At this time few quantitative data are available for space station modules and systems, and a model is needed in order to make calculations and predict contamination source rates. We conclude that at this time the best model of a space station module is the crew cabin of the space shuttle, and we have used the data from STS-9 as a direct analog of a space station module in this work.

Most of the chemicals on the toxicologist's list of contaminants are organic compounds. Our analysis showed that gas chromatographs or mass spectrometers are sufficiently sensitive to accurately measure outgassing rates of almost all the organic contaminants. This conclusion is probably valid for the other compounds listed in table 1, but in this analysis no attempt was made to identify individual species whose rates could not be accurately determined with this equipment.

We have proposed that the time constant for buildup of each contaminant inside a space station module be limited to a maximum of 30 hours, and we have concluded that this requirement is feasible for all contaminants except those listed in table 2. All the compounds in table 2 have primarily biological origins, and will require special contamination management practices. We further conclude that the ratio of the time constant for contaminant buildup should be 10 times that for contaminant removal. This will limit the steady state concentration of each contaminant to 11% of the MAC.

Long term degradation of polymeric materials by proton and ultraviolet radiation will take place and produce a number of small organic contaminants inside space station modules. Experimental data on radiation degradation in a radiation atmosphere similar to that inside modules does not exist. Rate calculations based on degradation by gamma radiation only (no ultraviolet) suggests that contamination could be produced by the long term degradation mechanism at a rate great enough to force contaminant concentrations above the MAC. Futhermore, this type of degradation typically increases in rate as degradation proceeds inside polymers. We expect the rate of contaminant release from this source to increase with the age of the module, and we recommend that this type of degradation be investigated further. Also, experimental tests should be conducted in a radiation environment that simulates that expected inside manned space station modules.

No quantitative models of particle source rates or removal rates are currently available, and few empirical data have been published. The empirical models derived from Earth bound experience are not applicable on the space station primarily because the effects of gravity are important on earth but electrostatic field effects dominate in space. As a result neither source nor removal rates can be accurately predicted, and particle control will be based primarily on Earth based empirical data and untested models. This is clearly an area that would benefit from additional study, improved models, and additional experimental data.

This analysis has also shown that all contamination control methods are based on one of three basic philosophies. We have reviewed these philosophies in light of the needs of the space station and space station users and conclude that any of the three proposed methods can be use to adequately control contamination on the space station, and method number 3 is best from the users point of view.

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APPENDIX A OF ATTACHMENT C

CONTAMINANT SOURCE RATES FOR ONE SPACE STATION MODULE

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Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt.	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
Allyl alcohol (2-propen-1-ol)	Alcohols	58.08	0.200	0.481	85.36	0.00	3.54	12.38	19.45	55.0%	3.20
Amyl alcohol (1-pentanol)	Alcohols	88.15	10.000	36.529	2683.45	0.00	268.34	939.21	1475.90	55.0%	152.00
Amyl alcohol (TERT)	Alcohols	88.15	8.000	29.223	2146.76	0.00	214.68	751.37	1180.72	55.0%	0.00
Butoxy ethyl alcohol, 2-	Alcohols	118.20	2.500	12.246	099.56	0.00	89.96	314.85	494.76	55.0%	0.01
Butyl alcohol (1-butanol)	Alcohols	74.12	10.000	30.715	2256.35	7.20	224.91	787.20	1237.03	54.8%	6920.00
Butyl alcohol (SEC)	Alcohols	74.12	10.000	30.715	2256.35	0.00	225.63	789.72	1240.99	55.0%	0.70
Butyl alcohol (TERT) (2-methyl-2-propanol)	Alcohols	74.12	10.000	30.715	2256.35	0.00	225.63	789.72	1240.99	55.0%	15.80
Cyclohexanol	Alcohols	100.16	5.000	20.753	1524.53	0.00	152.45	533.58	838.49	55.0%	1288.00
Ethelyne glycol (1, 2-ethanediol)	Alcohols	62.07	45.000	115.748	8502.86	0.00	850.29	2976.00	4676.57	55.0%	9.50
ethyl alcohol (ethanol)	Alcohols	46.07	50.000	95.457	7012.27	24.00	698.83	2445.90	3843.55	54.8%	5208.00
hexyl alcohol, 2 (2-hexanol)	Alcohols	102.20	20.000	84.703	6222.31	0.00	622.23	2177.81	3422.27	55.0%	1.20
Isobutyl alcohol (2-methyl-1-propanol)	Alcohols	74.12	10.000	30.715	2256.35	0.00	225.63	789.72	1240.99	55.0%	726.00
Ispropyl alcohol (2-propanol)	Alcohols	60.09	40.000	99.605	7317.00	0.00	731.70	2560.95	4024.35	55.0%	2022.00
Methoxy butanol, 3-	Alcohols	104.17	10.000	43.168	3171.12	0.00	317.11	1109.89	1744.12	55.0%	0.00
Methyl alcohol (methanol)	Alcohols	32.04	3.000	3.983	292.61	8.50	28.41	99.44	156.26	53.4%	704.00
Octyl alcohol (1-octanol)	Alcohols	130.20	20.000	107.910	7927.05	0.00	792.71	2774.47	4359.88	55.0%	0.00
Phenol	Alcohols	94.11	0.500	1.950	143.24	570.00	-42.68	-149.36	-234.72	-163.9%	7.90
Propyl alcohol (1-propanol)	Alcohols	60.09	30.000	74.704	5487.75	0.00	548.77	1920.71	3018.26	55.0%	25.30
2, 4-hexadienal	Aldehydes	96.00	1.500	5.967	438.36	0.00	43.84	153.43	241.10	55.0%	0.00
5-hexen-2-al	Aldehydes	100.18	40.000	166.058	12198.65	0.00	1219.86	4269.53	6709.26	55.0%	0.00
C5 aldehyde	Aldehydes	86.13	15.000	53.538	3932.93	0.00	393.29	1376.53	2163.11	55.0%	0.00
Acetaldehyde (ethanal)	Aldehydes	44.05	30.000	54.763	4022.89	0.54	402.23	1407.82	2212.29	55.0%	48.00
Acrolein (propanal)	Aldehydes	55.05	0.050	0.114	8.38	0.00	0.84	2.93	4.61	55.0%	0.06
Benzaldehyde (benzenecarbonal)	Aldehydes	105.10	20.000	87.107	6398.87	0.00	639.89	2239.60	3519.38	55.0%	11.00
Butyraldehyde (butanal)	Aldehydes	72.10	40.000	119.513	8779.42	0.00	877.94	3072.80	4828.68	55.0%	1470.00

Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
Crotonaledhyde (trans-2 butenal)	Aldehydes	70.09	0.350	1.017	74.68	0.00	7.47	26.14	41.07	55.0%	0.00
Formaldehyde (methanal)	Aldehydes	30.03	0.100	0.124	9.14	0.00	0.91	3.20	5.03	55.0%	0.02
Furfural (2-furancarbonal)	Aldehydes	96.08	0.500	1.991	146.24	0.00	14.62	51.18	80.43	55.0%	0.00
Glutaraldehyde	Aldehydes	100.10	0.049	0.203	14.93	0.00	1.49	5.23	8.21	55.0%	0.00
Hexanal (caproic aldehyde)	Aldehydes	100.18	0.600	2.491	182.98	0.00	18.30	64.04	100.64	55.0%	43.00
Isobutyraldehyde	Aldehydes	72.12	7.500	22.415	1646.60	0.00	164.66	576.31	905.63	55.0%	0.00
Propenal (acrolein)	Aldehydes	56.06	0.025	0.058	4.27	0.00	0.43	1.49	2.35	55.0%	0.00
Propionaldehyde (propanal)	Aldehydes	58.08	40.000	96.273	7072.24	0.00	707.22	2475.29	3889.73	55.0%	87.00
Sorbaldehyde (2,4-hexadienal)	Aldehydes	96.14	0.600	2.390	175.60	0.00	17.56	61.46	96.58	55.0%	1.50
Valeraldehyde (pentanal)	Aldehydes	85.13	30.000	105.834	7774.54	5.00	776.95	2719.34	4273.25	55.0%	21.00
Butene-1, 2-methyl	Aliphatic hydrocarbons	70.13	250.000	726.547	53372.13	0.00	5337.21	18680.24	29354.67	55.0%	0.00
Cyclohexene, 4-methyl	Aliphatic hydrocarbons	96.17	50.000	199.264	14637.95	0.00	1463.80	5123.28	8050.87	55.0%	253.00
C04 alkene	Aliphatic hydrocarbons	56.10	50.000	116.239	8538.93	0.00	853.89	2988.63	4696.41	55.0%	0.00
C06 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	84.16	12.500	43.595	3202.48	0.00	320.25	1120.87	1761.36	55.0%	0.00
C07 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	98.18	25.000	101.714	7471.95	8.50	747.19	2615.18	4109.57	53.4%	0.00
C08 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	112.21	25.000	116.250	8539.69	0.00	853.97	2988.89	4696.83	55.0%	0.00
C09 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	126.20	12.500	65.372	4802.20	0.00	480.22	1680.77	2641.21	55.0%	0.00
C10 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	140.26	10.000	58.124	4269.77	0.00	426.98	1494.42	2348.37	55.0%	0.00
C11 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	154.30	10.000	63.942	4697.17	0.00	469.72	1644.01	2583.45	55.0%	0.00
C12 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	168.30	10.000	69.744	5123.36	0.00	512.34	1793.18	2817.85	55.0%	0.00
C13 alkanes (saturated)	Aliphatic hydrocarbons	184.40	10.000	76.415	5613.47	0.00	561.35	1964.72	3087.41	55.0%	0.00
Acetylene (ethyne)	Aliphatic hydrocarbons	26.04	170.000	183.447	13475.99	0.00	1347.60	4716.60	7411.79	55.0%	26.00

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Contaminant	Group	MOL Wt.	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
Crotonaledhyde (trans-2 butenal)	Aldehydes	70.09	0.350	1.017	74.68	0.00	7.47	26.14	41.07	55.0%	0.00
Formaldehyde (methanal)	Aldehydes	30.03	0.100	0.124	9.14	0.00	0.91	3.20	5.03	55.0%	0.02
Furfural (2-furancarbonal)	Aldehydes	96.08	0.500	1.991	146.24	0.00	14.62	51.18	80.43	55.0%	0.00
Glutaraldehyde	Aldehydes	100.10	0.049	0.203	14.93	0.00	1.49	5.23	8.21	55.0%	0.00
Hexanal (caproic aldehyde)	Aldehydes	100.18	0.600	2.491	182.98	0.00	18.30	64.04	100.64	55.0%	43.00
Isobutyraldehyde	Aldehydes	72.12	7.500	22.415	1646.60	0.00	164.66	576.31	905.63	55.0%	0.00
Propenal (acrolein)	Aldehydes	56.06	0.025	0.058	4.27	0.00	0.43	1.49	2.35	55.0%	0.00
Propionaldehyde (propanal)	Aldehydes	58.08	40.000	96.273	7072.24	0.00	707.22	2475.29	3889.73	55.0%	87.00
Sorbaldehyde (2,4-hexadienal)	Aldehydes	96.14	0.600	2.390	175.60	0.00	17.56	61.46	96.58	55.0%	1.50
Valeraldehyde (pentanal)	Aldehydes	85.13	30.000	105.834	7774.54	5.00	776.95	2719.34	4273.25	55.0%	21.00
Butene-1, 2-methyl	Aliphatic hydrocarbons	70.13	250.000	726.547	53372.13	0.00	5337.21	18680.24	29354.67	55.0%	0.00
Cyclohexene, 4-methyl	Aliphatic hydrocarbons	96.17	50.000	199.264	14637.95	0.00	1463.80	5123.28	8050.87	55.0%	253.00
C04 alkene	Aliphatic hydrocarbons	56.10	50.000	116.239	8538.93	0.00	853.89	2988.63	4696.41	55.0%	0.00
C06 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	84.16	12.500	43.595	3202.48	0.00	320.25	1120.87	1761.36	55.0%	0.00
C07 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	98.18	25.000	101.714	7471.95	8.50	747.19	2615.18	4109.57	53.4%	0.00
C08 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	112.21	25.000	116.250	8539.69	0.00	853.97	2988.89	4696.83	55.0%	0.00
C09 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	126.20	12.500	65.372	4802.20	0.00	480.22	1680.77	2641.21	55.0%	0.00
C10 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	140.26	10.000	58.124	4269.77	0.00	426.98	1494.42	2348.37	55.0%	0.00
C11 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	154.30	10.000	63.942	4697.17	0.00	469.72	1644.01	2583.45	55.0%	0.00
C12 saturated and unsaturated hydrocarbons	Aliphatic hydrocarbons	168.30	10.000	69.744	5123.36	0.00	512.34	1793.18	2817.85	55.0%	0.00
C13 alkanes (saturated)	Aliphatic hydrocarbons	184.40	10.000	76.415	5613.47	0.00	561.35	1964.72	3087.41	55.0%	0.00
Acetylene (ethyne)	Aliphatic hydrocarbons	26.04	170.000	183.447	13475.99	0.00	1347.60	4716.60	7411.79	55.0%	26.00

Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
Butadiene, 1,3-	Aliphatic hydrocarbons	54.09	100.000	224.149	16465.98	0.00	1646.60	5763.09	9056.29	55.0%	4.70
Butane (ISO) (2-methylpropane)	Aliphatic hydrocarbons	58.12	75.000	180.637	13269.59	0.00	1326.96	4644.36	7298.28	55.0%	95.00
Butane (n-butane)	Aliphatic hydrocarbons	58.12	75.000	180.637	13269.59	0.00	1326.96	4644.36	7298.28	55.0%	1.60
Butane, 2 ,2-dimethyl	Aliphatic hydrocarbons	86.18	25.000	89.282	6558.69	0.00	655.87	2295.54	3607.28	55.0%	3.20
Butene-1	Aliphatic hydrocarbons	56.10	200.000	464.957	34155.73	0.00	3415.57	11954.50	18785.65	55.0%	40.00
Butene-2 (CIS)	Aliphatic hydrocarbons	56.10	80.000	185.983	13662.29	0.00	1366.23	4781.80	7514.26	55.0%	0.00
Butene-2 (TRANS)	Aliphatic hydrocarbons	56.10	80.000	185.983	13662.29	0.00	1366.23	4781.80	7514.26	55.0%	0.00
Butylene (ISO) (2-methylpropane)	Aliphatic hydrocarbons	56.10	80.000	185.983	13662.29	0.00	1366.23	4781.80	7514.26	55.0%	0.00
Citrene (limonene (d))	Aliphatic hydrocarbons	136.20	50.000	282.206	20730.88	0.00	2073.09	7255.81	11401.99	55.0%	6.00
Cycloheptane	Aliphatic hydrocarbons	70.13	35.000	101.717	7472.10	0.00	747.21	2615.23	4109.65	55.0%	0.00
Cyclohexane	Aliphatic hydocarbons	84.16	60.000	209.255	15371.90	0.00	1537.19	5380.17	8454.55	55.0%	624.00
Cyclohexane, 1, 1, 3,trimethyl	Aliphatic hydrocarbons	126.12	25.000	130.660	9598.31	0.00	959.83	3359.41	5279.07	55.0%	0.00
Cyclohexane, 1, 1-dimethyl	Aliphatic hydrocarbons	112.21	25.000	116.250	8539.69	0.00	853.97	2988.89	4696.83	55.0%	24.00
Cyclohexane, 1, 2-dimethyl (TRANS)	Aliphatic hydorcarbons	112.12	25.000	116.156	8532.84	0.00	853.28	2986.50	4693.06	55.0%	95.00
Cyclohexane, 1-methyl-3-ethyl (TRANS)	Aliphatic hydrocarbons	126.20	12.500	65.372	4802.20	0.00	480.22	1680.77	2641.21	55.0%	0.00
Cyclohexane, methyl	Aliphatic hydrocarbons	98.18	7.500	30.514	2241.58	0.00	224.16	784.55	1232.87	55.0%	69.00
Cyclohexeme	Aliphatic hydrocarbons	82.14	30.000	102.116	7501.47	0.00	750.15	2625.52	4125.81	55.0%	35.00
Cyclopentane	Aliphatic hydrocarbons	70.13	35.000	101.717	7472.10	0.00	747.21	2615.23	4109.65	55.0%	130.00
Cyclopentane, 1,2 -dimethyl	Aliphat hydrocarbons	98.16	5.000	20.339	1494.08	0.00	149.41	522.93	821.75	55.0%	0.00
Cyclopentane, methyl	Aliphatic hydrocarbons	84.16	15.000	52.314	3842.98	0.00	384.30	1345.04	2113.64	55.0%	51.00
Cyclopentene	Aliphatic hydrocarbons	68.12	30.000	84.687	6221.09	0.00	622.11	2177.38	3421.60	55.0%	0.00

Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt.	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
Cyclopropane	Aliphatic hydrocarbons	42.08	60.000	104.628	7685.95	0.00	768.60	2690.08	4227.27	55.0%	0.00
Decane (n-decane)	Aliphatic hydrocarbons	142.30	20.000	117.938	8663.74	0.00	866.37	3032.31	4765.06	55.0%	0.08
Dodecane (n-dodecane)	Aliphatic hydrocarbons	170.30	20.000	141.145	10368.49	0.00	1036.85	3628.97	5702.67	55.0%	5.50
Ethane	Aliphatic hydrocarbons	30.07	150.000	186.915	13730.78	0.00	1373.08	4805.77	7551.93	55.0%	166.00
Ethylacetylene (1-butyne)	Aliphatic hydrocarbons	54.09	80.000	179.319	13172.79	0.00	1317.28	4610.48	7245.03	55.0%	0.00
Ethylene (ethene)	Aliphatic hydrocarbons	28.05	150.000	174.359	12808.40	0.00	1280.84	4482.94	7044.62	55.0%	0.40
Heptane (n-heptane)	Aliphatic hydrocarbons	100.20	25.000	103.807	7625.68	0.00	762.57	2668.99	4194.12	55.0%	79.00
Heptane, 2, 5-dimethyl	Aliphatic hydrocarbons	128.25	25.000	132.867	9760.41	0.00	976.04	3416.14	5368.23	55.0%	0.00
Heptane, 2-methyl-3-ethyl	Aliphatic hydrocarbons	142.28	10.000	58.961	4331.26	0.00	433.13	1515.94	2382.19	55.0%	2.00
Heptane, 3, 5-dimethyl	Aliphatic hydrocarbons	128.25	10.000	53.147	3904.16	0.00	390.42	1366.46	2147.29	55.0%	0.00
Heptene-1	Aliphatic hydrocarbons	98.19	25.000	101.725	7472.71	0.00	747.27	2615.45	4109.99	55.0%	113.00
Hexane (n-hexane)	Aliphatic hydrocarbons	86.18	25.000	89.282	6558.69	0.00	655.87	2295.54	3607.28	55.0%	81.00
Hexane, 2, 3, 4-trimethyl	Aliphatic hydrocarbons	128.10	25.000	132.712	9748.99	0.00	974.90	3412.15	5361.95	55.0%	0.00
Hexane. 2. 3-dimethyl	Aliphatic hydrocarbons	114.23	20.000	94.674	6954.74	0.00	695.47	2434.16	3825.11	555.0%	0.40
Hexene-1	Aliphatic hydrocarbons	84.16	25.000	87.190	6404.96	0.00	640.50	2241.74	3522.73	55.0%	0.00
Isoprene (2-methyl-1, 3-butadiene)	Aliphatic hydrocarbons	68.11	100.000	282.248	20733.93	0.00	2073.39	7256.87	11403.66	55.0%	148.00
Methane	Aliphatic hydrocarbons	16.04	1350.000	897.342	65918.73	960.00	6495.87	22735.55	35727.30	54.2%	1300.00
Methylethyl ethylcyclopentane	Aliphatic hydrocarbons	112.16	2.500	11.620	853.59	0.00	85.36	298.76	469.47	55.0%	0.00
Methylacetylene (propyne)	Aliphatic hydrocarbons	40.06	125.000	207.511	15243.74	0.00	1524.37	5335.31	8384.06	55.0%	8.70
Nonane (n-nonane)	Aliphatic hydrocarbons	128.30	30.000	159.503	11717.06	0.00	1171.71	4100.97	6444.38	55.0%	0.00

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Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group32.500	MOL Wt.94.451	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
Nonene	Aliphatic hydrocarbons	126.20	25.000	130.743	9604.40	0.00	960.44	3361.54	5282.42	55.0%	1.70
Octane (n-octane)	Aliphatic hydrocarbons	114.20	37.000	175.101	12862.89	0.00	1286.29	4502.01	7074.59	55.0%	66.00
Octene	Aliphatic hydrocarbons	112.20	25.000	116.239	8538.93	0.00	853.89	2988.63	4696.41	55.0%	22.00
Pentadecane (C15)	Aliphatic hydrocarbons	212.41	25.000	220.057	16165.37	0.00	1616.54	5657.88	8890.95	55.0%	0.00
Pentane (ISO) (2-methylbutane)	Aliphatic hydrocarbons	72.15	50.000	149.495	10981.89	0.00	1098.19	3843.66	6040.04	55.0%	3.20
Pentane (n-pentane)	Aliphatic hydrocarbons	72.15	100.000	298.990	21963.78	0.00	2196.38	7687.32	12080.08	55.0%	135.00
Pentane, 2, 2-dimethyl	Aliphatic hydrocarbons	100.20	50.000	207.614	15251.35	0.00	1525.14	5337.97	8388.24	55.0%	86.00
Pentane, 2-methyl	Aliphatic hydrocarbons	88.30	50.000	182.958	13440.07	0.00	1344.01	4704.02	7392.04	55.0%	0.00
Pentane, 3-methyl	Aliphatic hydrocarbons	86.17	50.000	178.544	13115.86	0.00	1311.59	4590.55	7213.72	55.0%	2.80
Pentane, 3-methyl	Aliphatic hydrocarbons	86.19	25.000	89.293	6559.45	0.00	655.95	2295.81	3607.70	55.0%	0.00
Pentene (pentene-1)	Aliphatic hydrocarbons	70.13	32.500	94.451	6938.38	0.00	693.84	2428.43	3816.11	55.0%	35.00
Pentene-2	Aliphatic hydrocarbons	70.13	32.500	94.451	6938.38	0.00	693.84	2428.43	3816.11	550.%	0.00
Propane	Aliphatic hydrocarbons	44.11	250.000	456.969	33568.96	0.00	3356.90	11749.14	18462.93	55.0%	0.50
Propylene (propene)	Aliphatic hydrocarbons	42.08	250.000	435.949	32024.80	0.00	3202.48	11208.68	17613.64	55.0%	0.50
Tetradecane (C14)	Aliphatic hydrocarbons	198.38	25.000	205.522	15097.62	0.00	1509.76	5284.17	8303.69	55.0%	0.00
Undecane (hendecane)	Aliphatic hydrocarbons	156.30	25.000	161.927	11895.14	0.00	1189.51	4163.30	6542.33	55.0%	14.00
CO3 aromatic hydrocarbons	Aromatic hydrocarbons	120.20	1.500	7.472	548.87	0.00	54.89	192.10	301.88	55.0%	0.00
Benzene	Aromatic hydrocarbons	78.11	0.100	0.324	23.78	0.00	2.38	8.32	13.08	55.0%	27.00
Benzene, 1, 2, 3-trimethyl	Aromatic hydrocarbons	120.19	10.000	49.807	3658.80	0.00	365.88	1280.58	2012.34	55.0%	0.00
Benzene, 1-methyl-3-propyl	Aromatic hydrocarbons	134.20	1.000	5.561	408.53	0.00	40.85	142.99	224.69	55.0%	2.70

Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt.	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
Benzene, n-butyl	Aromatic hydrocarbons	134.20	5.000	27.806	2042.65	0.00	204.26	714.93	1123.46	55.0%	2.40
Benzene, n-propyl	Aromatic hydrocarbons	120.19	9.000	44.826	3292.92	0.00	329.29	1152.52	1811.11	55.0%	269.00
Cumene (isopropylbenzene)	Aromatic hydrocarbons	120.19	5.000	24.903	1829.40	0.00	182.94	640.29	1006.17	55.0%	11.00
Decilin (decahydronaphthalene)	Aromatic hydrocarbons	138.24	1.000	5.729	420.83	0.00	42.08	147.29	231.46	55.0%	0.00
Ethyl benzene	Aromatic hydrocarbons	106.16	20.000	87.985	6463.41	0.00	646.34	2262.19	3554.87	55.0%	182.00
Ethylmethylbenzene, 1, 2 (1-ethyl-2-methylbenzene)	Aromatic hydrocarbons	120.20	2.500	12.543	914.78	0.00	91.48	320.17	503.13	55.0%	0.00
Indan (2, 3-dihydroindene)	Aromatic hydrocarbons	118.19	10.000	48.978	3597.92	0.00	359.79	1259.27	1978.86	55.0%	0.00
Indene (indonaphthene)	Aromatic hydrocarbons	115.10	1.000	4.770	350.39	0.00	35.04	122.63	192.71	55.0%	118.00
Mesitylene (1, 3, 5-trimethylbenzene)	Aromatic hydrocarbons	120.20	3.000	14.943	1097.73	0.00	109.77	384.21	603.75	55.0%	2.00
methyl styrene (2-phenylpropene)	Aromatic hydrocarbons	118.20	15.000	73.473	5397.34	0.00	539.73	1889.07	2968.53	55.0%	1.20
Napthalene	Aromatic hydrocarbons	128.16	1.000	5.311	390.14	0.00	39.01	136.55	214.58	55.0%	5.00
Pseudocumene (1, 2, 4-trimethylbenzene)	Aromatic hydrocarbons	120.20	1.500	7.472	548.87	0.00	54.89	192.10	301.88	55.0%	16.00
Styrene (ethenylbenzene)	Aromatic hydrocarbons	104.10	10.000	43.139	3168.99	0.00	316.90	1109.15	1742.95	55.0%	9.50
Toluene (methylbenzene)	Aromatic hydrocarbons	92.13	20.000	76.357	5609.21	0.00	560.92	1963.22	3085.07	55.0%	1351.00
Xylene, m- (1, 3-dimethylbenzene)	Aromatic hydrocarbons	106.16	10.000	43.993	3231.70	0.00	323.17	1131.10	1777.44	55.0%	3539.00
Xylene, o (1, 2-dimethylbenzene)	Aromatic hydrocarbons	106.16	10.000	43.993	3231.70	0.00	323.17	1131.10	1777.44	55.0%	106.00
Xylene, p (1, 4-dimethylbenzene)	Aromatic hydrocarbons	106.16	10.000	43.993	3231.70	0.00	323.17	1131.10	1777.44	55.0%	780.00
Acetate, 1, 3-dimethylbutyl	Esters	144.24	8.000	47.818	3512.74	0.00	351.27	1229.46	1932.01	55.0%	0.00
Acetate, isobutyl	Esters	116.18	20.000	96.290	7073.46	0.00	707.35	2475.71	3890.40	55.0%	245.00
Acetate, tert-butyl	Esters	116.18	20.000	96.290	7073.46	0.00	707.35	2475.71	3890.40	55.0%	0.00
Acetate, 2-ethoxyethyl (cellosolve acetate)	Esters	132.18	15.000	82.163	6035.70	0.00	603.57	2112.50	3319.64	55.0%	545.00

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Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
Acetate, 2-ethylhexyl	Esters	172.30	15.000	107.102	7867.69	0.00	786.77	2753.69	4327.23	55.0%	0.00
Acetate, 2-hexyl	Esters	144.24	20.000	119.546	8781.86	0.00	878.19	3073.65	4830.02	55.0%	0.00
Acetate, 3-hexyl	Esters	144.24	20.000	119.546	8781.86	0.00	878.19	3073.65	4830.02	55.0%	0.00
Acetate, amyl	Esters	130.18	10.000	53.947	3962.92	0.00	396.29	1387.02	2179.60	55.0%	79.00
Acetate, benzyl	Esters	150.19	5.000	31.119	2286.03	0.00	228.60	800.11	1257.32	55.0%	0.00
Acetate, butyl	Esters	116.16	25.000	120.342	8840.31	0.00	884.03	3094.11	4862.17	55.0%	948.00
Acetate, cyclohexyl	Esters	142.22	15.000	88.404	6494.15	0.00	649.42	2272.95	3571.78	55.0%	0.00
Acetate, ethyl	Esters	88.10	40.000	146.035	10727.70	0.00	1072.77	3754.69	5900.23	55.0%	371.00
Acetate, ethylisohexyl	Esters	172.30	15.000	107.102	7867.69	0.00	786.77	2753.69	4327.23	55.0%	0.00
Acetate, heptyl	Esters	158.27	20.000	131.174	9636.05	0.00	963.61	3372.62	5299.83	55.0%	0.00
Acetate, hexyl	Esters	144.24	8.000	47.818	3512.74	0.00	351.27	1229.46	1932.01	55.0%	0.00
Acetate, isoamyl	Esters	130.20	15.000	80.932	5945.29	0.00	594.53	2080.85	3269.91	55.0%	3.20
Acetate, isopropyl	Esters	102.10	20.000	84.620	6216.22	0.00	621.62	2175.68	3418.92	55.0%	3.20
Acetate, methyl	Esters	74.08	10.000	30.699	2255.13	0.00	225.51	789.30	1240.32	55.0%	11.00
ACetate, n-propyl	Esters	102.13	20.000	84.645	6218.05	0.00	621.80	2176.32	3419.93	55.0%	585.00
Acetate, phenyl	Esters	136.12	5.000	28.204	2071.87	0.00	207.19	725.15	1139.53	55.0%	0.00
Acetate, sec-amyl	Esters	130.20	10.000	53.955	3963.53	0.00	396.35	1387.23	2179.94	55.0%	0.00
Acetate, sec-butyl	Esters	116.18	20.000	96.290	7073.46	0.00	707.35	2475.71	3890.40	55.0%	0.00
Acetate, vinyl	Esters	86.07	1.500	5.350	393.02	0.00	39.30	137.56	216.16	55.0%	0.00
Acetoacetate, ethyl	Esters	130.16	10.000	53.938	3962.31	0.00	396.23	1386.81	2179.27	55.0%	0.00
Acetoacetate, methyl	Esters	116.13	10.000	48.124	3535.21	0.00	353.52	1237.32	1944.36	55.0%	0.00
Butyrate, 2, 3-epoxy ethyl	Esters	130.16	5.000	26.969	1981.15	0.00	198.12	693.40	1089.63	55.0%	0.00
Butyrate, allyl	Esters	128.19	5.000	26.561	1951.17	0.00	195.12	682.91	1073.14	55.0%	0.00
Butyrate, amyl	Esters	158.27	20.000	131.174	9636.05	0.00	963.61	3372.62	5299.83	55.0%	0.00
Butyrate, butyl	Esters	144.24	15.000	89.660	6586.39	0.00	658.64	2305.24	3622.52	55.0%	0.00
Butyrate, ethyl	Esters	116.18	15.000	72.217	5305.10	0.00	530.51	1856.78	2917.80	55.0%	0.00
Butyrate, isoamyl	Esters	158.24	15.000	98.362	7225.67	0.00	722.57	2528.98	3974.12	55.0%	0.00
Butyrate, methyl	Esters	102.13	7.000	29.626	2176.32	0.00	217.63	761.71	1196.97	55.0%	0.00
Butyrate, propyl	Esters	130.21	15.000	80.939	5945.74	0.00	594.57	2081.01	3270.16	55.0%	0.00
Butyrate, vinyl	Esters	114.16	10.000	47.308	3475.24	0.00	347.52	1216.33	1911.38	55.0%	0.00
Formate, isoamyl	Esters	116.18	15.000	72.217	5305.10	0.00	530.51	1856.78	2917.80	55.0%	0.00
Formate, isobutyl	Esters	102.15	10.000	42.331	3109.63	0.00	310.96	1088.37	1710.30	55.0%	0.00
Formate, allyl	Esters	86.10	1.000	3.568	262.10	0.00	26.21	91.74	144.16	55.0%	0.00

Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt.	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
formate, amyl	Esters	116.18	15.000	72.217	5305.10	0.00	530.51	1856.78	2917.80	55.0%	0.00
formate, butyl	Esters	102.15	10.000	42.331	3109.63	0.00	310.96	1088.37	1710.30	55.0%	0.00
formate, cyclohexyl	Esters	128.20	10.000	53.126	3902.64	0.00	390.26	1365.92	2146.45	55.0%	0.00
formate, ethyl	Esters	74.08	10.000	30.699	2255.13	0.00	225.51	789.30	1240.32	55.0%	0.80
formate, heptyl	Esters	144.24	10.000	59.773	4390.93	0.00	439.09	1536.83	2415.01	55.0%	0.00
formate, isopropyl	Esters	88.12	5.000	18.258	1341.27	0.00	134.13	469.44	737.70	55.0%	0.00
formate, methyl	Esters	60.05	2.500	6.221	457.01	0.00	45.70	159.95	251.35	55.0%	0.06
formate, propyl	Esters	88.12	10.000	36.517	2682.53	0.00	268.25	938.89	1475.39	55.0%	0.00
formate, vinyl	Esters	72.09	0.500	1.494	109.73	0.00	10.97	38.40	60.35	55.0%	0.00
hexanoate, 2-ethyl, methyl	Esters	158.25	10.000	65.579	4817.42	0.00	481.74	1686.10	2649.58	55.0%	0.00
isobutyrate, methyl	Esters	102.15	10.000	42.331	3109.63	0.00	310.96	1088.37	1710.30	55.0%	0.00
isovalerate, allyl	Esters	142.22	5.000	29.468	2164.72	0.00	216.47	757.65	1190.59	55.0%	0.00
isovalerate, butyl	Esters	158.27	20.000	131.174	9636.05	0.00	963.61	3372.62	5299.83	55.0%	0.00
isovalerate, ethyl	Esters	130.21	15.000	80.939	5945.74	0.00	594.57	2081.01	3270.16	55.0%	0.00
isovalerate, isoamyl	Esters	172.30	20.000	142.802	10490.25	0.00	1049.03	3671.59	5769.64	55.0%	0.00
isovalerate, isobutyl	Esters	158.27	20.000	131.174	9636.05	0.00	963.61	3372.62	5299.83	55.0%	0.00
isovalerate, methyl	Esters	116.18	15.000	72.217	5305.10	0.00	530.51	1856.78	2917.80	55.0%	0.00
isovalerate, propyl	Esters	144.24	20.000	119.546	8781.86	0.00	878.19	3073.65	4830.02	55.0%	0.00
lactate, ethyl	Esters	118.15	10.000	48.961	3596.70	0.00	359.67	1258.85	1978.19	55.0%	205.00
methacrylate, butyl	Esters	142.22	12.500	73.670	5411.80	0.00	541.18	1894.13	2976.49	55.0%	0.00
methacrylate, ethyl	Esters	114.16	12.500	59.135	4344.05	0.00	434.40	1520.42	2389.23	55.0%	36.00
methacrylate, propyl	Esters	128.19	12.500	66.402	4877.92	0.00	487.79	1707.27	2682.86	55.0%	0.00
methacrylate, methyl	Esters	100.12	10.000	41.490	3047.84	0.00	304.78	1066.74	1676.31	55.0%	24.00
propionate, 3-ethoxy ethyl	Esters	146.21	15.000	90.884	6676.35	0.00	667.63	2336.72	3671.99	55.0%	0.00
propionate, ethyl	Esters	102.15	15.000	63.496	4664.45	0.00	466.44	1632.56	2565.45	55.0%	0.00
propionate, isobutyl	Esters	130.21	15.000	80.939	5945.74	0.00	594.57	2081.01	3270.16	55.0%	0.00
propionate, methyl	Esters	88.12	10.000	36.517	2682.53	0.00	268.25	938.89	1475.39	55.0%	0.00
propionate, propyl	Esters	116.18	10.000	48.145	3536.73	0.00	353.67	1237.86	1945.20	55.0%	0.00
propionate, vinyl	Esters	100.13	10.000	41.494	3048.14	0.00	304.81	1066.85	1676.48	55.0%	0.00
2-ethoxyethanol (cellosolve)	Ethens	90.12	10.000	37.346	2743.42	0.00	274.34	960.20	1508.88	55.0%	1035.00
dimethylfuran, 2,5	Ethens	96.12	0.020	0.080	5.85	0.00	0.59	2.05	3.22	55.0%	0.00
dioxane,1,4-	Ethens	88.11	2.000	7.303	536.45	0.00	53.64	187.76	295.05	55.0%	0.00

Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
ethyl butyl ether (1-ethoxybutane)	Ethers	102.17	50.000	211.696	15551.21	0.00	1555.12	5442.92	8553.16	55.0%	0.00
ethyl ethenyl ether (ethyl vinyl ether)	Ethers	72.12	40.000	119.546	8781.86	0.00	878.19	3073.65	4830.02	55.0%	0.00
ethyl ether (diethyl ether)	Ethers	74.12	40.000	122.861	9025.39	0.00	902.54	3158.89	4963.97	55.0%	52.00
ethylene oxide (ethyl 2-propenyl ether)	Ethers	44.05	5.000	9.127	670.48	0.00	67.05	234.67	368.76	55.0%	0.00
furan (1,4-epoxy-1,3-butadiene)	Ethers	68.07	0.020	0.056	4.14	0.00	0.41	1.45	2.28	55.0%	1.60
iso-propyl ether (diisopropyl ether)	Ethers	102.17	30.000	127.018	9330.72	0.00	933.07	3265.75	5131.90	55.0%	0.00
m-dioxane (1,3-dioxane) (formal)	Ethers	88.11	2.000	7.303	536.45	0.00	53.64	187.76	295.05	55.0%	0.00
methyl furan	Ethers	82.10	9.000	30.620	2249.35	0.00	224.93	787.27	1237.14	55.0%	1.00
methyl vinyl ether (methoxyethene)	Ethers	58.08	25.000	60.171	4420.15	0.00	442.02	1547.05	2431.08	55.0%	0.00
methylfuran, 2	Ethers	82.10	0.020	0.068	5.00	0.00	0.50	1.75	2.75	55.0%	0.00
propoxybutane, 1-(propyl butyl ether)	Ethers	116.00	20.000	96.141	7062.50	0.00	706.25	2471.88	3884.38	55.0%	55.00
tetrahydrofuran (1,4-epoxybutane)	Ethers	72.10	20.000	59.756	4389.71	0.00	438.97	1536.40	2414.34	55.0%	95.00
3-chloropropene	Halocarbons-chlorocarbons	76.50	0.100	0.317	23.29	0.00	2.33	8.15	12.81	55.0%	34.00
butyl chloride (1-chlorobutane)	Halocarbons-chlorocarbons	92.57	20.000	76.722	5636.00	0.00	563.60	1972.60	3099.80	55.0%	3.00
carbon tetrachloride (tetrachloromethane)	Halocarbons-chlorocarbons	153.84	1.000	6.375	468.32	0.00	46.83	163.91	257.57	55.0%	1.60
chloroacetone (1-chloro-2-propanone)	Halocarbons-chlorocarbons	92.53	0.040	0.153	11.27	0.00	1.13	3.94	6.20	55.0%	0.00
chlorobenzene	Halocarbons-chlorocarbons	112.56	7.500	34.984	2569.90	0.00	256.99	899.46	1413.44	55.0%	1240.00
chloroform (trichboromethane)	Halocarbons-chlorocarbons	119.39	0.500	2.474	181.72	0.00	18.17	63.60	99.95	55.0%	9.50
chloropropane	Halocarbons-chlorocarbons	78.54	26.000	84.622	6216.34	0.00	621.63	2175.72	3418.99	55.0%	0.00
dichloroacetylene	Halocarbons-chlorocarbons	94.94	0.013	0.051	3.76	0.00	0.38	1.32	2.07	55.0%	0.00

Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt.	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
dichloroethylene, 1,2-(cis and trans)	Halocarbons-chlorocarbons	96.94	5.000	20.086	1475.52	0.00	147.55	516.43	811.53	55.0%	0.00
ethyl chloride (chloroethane)	Halocarbons-chlorocarbons	64.50	50.000	133.644	9817.49	0.00	981.75	3436.12	5399.62	55.0%	545.00
ethylene chloride (1,1-dichloroethane)	Halocarbons-chlorocarbons	98.97	10.000	41.013	3012.83	0.00	301.28	1054.49	1657.06	55.0%	0.00
ethylene chloride (1,2-dichloroethane)	Halocarbons-chlorocarbons	98.97	5.000	20.507	1506.41	0.00	150.64	527.24	828.53	55.0%	20.00
ethylene chloride (1,3-dichloroethane)	Halocarbons-chlorocarbons	98.97	5.000	20.507	1506.41	0.00	150.64	527.24	828.53	55.0%	0.00
isopropyl chloride (2-chloropropane)	Halocarbons-chlorocarbons	78.54	42.500	138.325	10161.33	0.00	1016.13	3556.47	5588.73	55.0%	0.00
methyl chloride (chloromethane)	Halocarbons-chlorocarbons	50.49	10.000	20.923	1537.01	0.00	153.70	537.95	845.35	55.0%	0.30
methyl chloroform (1,1,1-trichloroethane)	Halocarbons-chlorocarbons	133.40	15.000	82.921	6091.41	0.00	609.14	213.99	3350.27	55.0%	229.00
methylene chloride (dichloromethane)	Halocarbons-chlorocarbons	84.94	10.000	35.199	2585.73	0.00	258.57	905.00	1422.15	55.0%	1746.00
o-dichlorobenzene (1,2-dichlorobenzene)	Halocarbons-chlorocarbons	147.00	2.500	15.229	1118.74	0.00	111.87	391.56	615.31	55.0%	11.00
perchloroethylene (tetrachloroethene)	Halocarbons-chlorocarbons	165.80	5.000	34.354	2523.63	0.00	252.36	883.27	1387.99	55.0%	553.00
propyl chloride (1-chloropropane)	Halocarbons-chlorocarbons	78.54	15.000	48.820	3586.35	0.00	358.64	1255.22	1972.49	55.0%	0.00
propylene dichloride (1,2-dichloropropene)	Halocarbons-chlorocarbons	113.00	5.000	23.414	1719.96	0.00	172.00	601.99	945.98	55.0%	47.00
trichloroethane (1,1,2-trichloroethane)	Halocarbons-chlorocarbons	133.40	0.500	2.764	203.05	0.00	20.30	71.07	111.68	55.0%	2.40
trichloroethylene (trichloroethene)	Halocarbons-chlorocarbons	131.40	0.050	0.272	20.00	0.00	2.00	7.00	11.00	55.0%	40.00
vinyl chloride (chloroethene)	Halocarbons-chlorocarbons	62.50	0.050	0.130	9.51	0.00	0.95	3.33	5.23	55.0%	1.60
vinylidene chloride (1,1-dichloroethene)	Halocarbons-chlorocarbons	96.95	1.000	4.018	295.13	0.00	29.51	103.30	162.32	55.0%	0.02
chlorofluoromethane	Halocarbons-chlorofluorocarbons	68.48	8.500	24.121	1771.96	0.00	177.20	620.19	974.58	55.0%	0.00

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Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
chlorotrifluoroethylene (chlorotri-fluoroethene)	Halocarbons-chlorofluorocarbon	116.50	100.000	482.776	35464.72	0.00	3546.47	12412.65	19505.60	55.0%	0.00
chlorotrifluoroethane (1-chloro-1,2,2-trifluoroethane)	Halocarbons-chlorofluorocarbons	118.50	100.000	491.064	36073.56	0.00	3607.36	12625.75	19840.46	55.0%	2.40
dichlorodifluoroethylene (1,2-dichloro-1,2-difluoroethene)	Halocarbons-chlorofluorocarbons	133.00	25.000	137.788	10121.91	0.00	1012.19	3542.67	5567.05	55.0%	0.80
dichlorodifluoroethylene (1,2-dichloro-1,2-difluoroethene)	Halocarbons-chlorofluorocarbons	133.00	12.500	68.894	5060.95	0.00	506.10	1771.33	2783.52	55.0%	0.00
freon 11 (trichlorofluoromethane)	Halocarbons-chlorofluorocarbons	137.38	5.000	28.465	2091.05	0.00	209.10	731.87	1150.08	55.0%	174.00
freon 112 (1,1,2,2-tetrachloro-1,2-difluoroethane)	Halocarbons-chlorofluorocarbons	204.00	50.000	422.688	31050.66	0.00	3105.07	10867.73	17077.86	55.0%	103.00
freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane)	Halocarbons-chlorofluorocarbons	187.39	20.000	155.309	11408.99	0.00	1140.90	3993.15	6274.94	55.0%	9180.00
freon 114 (1,2-dichloro-1,1,2,2-tetrafluoroethane)	Halocarbons-chlorofluorocarbons	170.90	100.000	708.210	52025.08	0.00	5202.51	18208.78	28613.79	55.0%	0.00
freon 114 (unsym)	Halocarbons-chlorofluorocarbons	170.92	100.000	708.292	52031.17	0.00	5203.12	18210.91	28617.14	55.0%	0.01
freon 12 (dichlorodifluoromethane)	Halocarbons-chlorofluorocarbons	120.90	100.000	501.010	36804.17	0.00	3680.42	12881.46	20242.29	55.0%	14.00
freon 124	Halocarbons-chlorofluorocarbons	136.48	300.000	1696.719	124641.00	0.00	12464.10	43624.35	68552.55	55.0%	750.00
freon 21 (dichlorofluoromethane)	Halocarbons-chlorofluorocarbons	102.90	5.000	21.321	1566.23	0.00	156.62	548.18	861.43	55.0%	5.50
freon 22 (chlorodifluoromethane)	Halocarbons-chlorofluorocarbons	86.47	100.000	358.332	26323.05	0.00	2632.30	9213.07	14477.67	55.0%	467.00

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Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt.	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
freon fe1301 (halon 1301) (bromotrifluoromethane)	Halocarbons-chlorofluoro-carbons	148.90	50.000	308.521	22663.94	0.00	2266.39	7932.38	12465.17	55.0%	474.00
monochlorofluoroethylene (1-chloro-2-fluoroethene)	Halocarbons-chlorofluoro-carbons	80.46	12.500	41.678	3061.69	0.00	306.17	1071.59	1683.93	55.0%	0.00
freon 125	Halocarbons-fluorocarbons	120.02	5.000	24.868	1826.81	0.00	182.68	639.38	1004.75	55.0%	0.00
freon 23 (trifluoromethane)	Halocarbons-fluorocarbons	70.01	4.000	11.605	852.49	0.00	85.25	298.37	468.87	55.0%	0.00
perfluoroethylene (tetrafluoroethene)	Halocarbons-fluorocarbons	100.00	50.000	207.200	15220.91	0.00	1522.09	5327.32	8371.50	55.0%	0.00
antimony	Inorganic compounds	121.76	0.010	0.050	3.71	0.00	0.37	1.30	2.04	55.0%	0.00
arsenic	Inorganic compounds	74.92	0.000	0.001	0.07	0.00	0.01	0.03	0.04	55.0%	0.00
beryllium	Inorganic compounds	9.01	0.001	0.000	0.02	0.00	0.00	0.01	0.01	55.0%	0.00
beryllium oxide	Inorganic compounds	25.01	0.200	0.207	15.24	0.00	1.52	5.33	8.38	55.0%	0.00
bromine (Br2)	Inorganic compounds	159.83	0.010	0.066	4.87	0.00	0.49	1.70	2.68	55.0%	0.00
bromine chloride	Inorganic compounds	115.37	0.015	0.072	5.27	0.00	0.53	1.84	2.90	55.0%	0.00
bromine dioxide	Inorganic compounds	111.92	0.010	0.046	3.41	0.00	0.34	1.19	1.87	55.0%	0.00
cadmium chloride	Inorganic compounds	183.32	0.001	0.008	0.61	0.00	0.06	0.21	0.34	55.0%	0.00
cadmium oxide	Inorganic compounds	128.41	0.001	0.003	0.20	0.00	0.02	0.07	0.11	55.0%	0.00
cadmium telluride	Inorganic compounds	240.02	0.001	0.010	0.73	0.00	0.07	0.26	0.40	55.0%	0.00
cadmiun	Inorganic compounds	112.41	0.002	0.010	0.75	0.00	0.08	0.26	0.41	55.0%	0.00
carbon disulfide	Inorganic compounds	76.13	0.480	1.514	111.24	0.00	11.12	38.93	61.18	55.0%	0.00
carbonyl sulfide (COS)	Inorganic compounds	60.08	1.000	2.490	182.89	0.00	18.29	64.01	100.59	55.0%	5.40

Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
chlorine	Inorganic compounds	70.91	0.100	0.294	21.59	0.00	2.16	7.56	11.87	55.0%	0.00
chlorine dioxide	Inorganic compounds	67.46	0.005	0.015	1.13	0.00	0.11	0.40	0.62	55.0%	0.00
cobalt chloride	Inorganic compounds	129.83	0.004	0.024	1.78	0.00	0.18	0.62	0.98	55.0%	0.00
ferric chloride	Inorganic compounds	162.22	0.015	0.101	7.41	0.00	0.74	2.59	4.07	55.0%	0.00
fluorine	Inorganic compounds	38.00	0.010	0.016	1.16	0.00	0.12	0.40	0.64	55.0%	0.00
gallium	Inorganic compounds	69.72	0.088	0.254	18.68	0.00	1.87	6.54	10.27	55.0%	0.00
gallium antimonide	Inorganic compounds	191.48	0.010	0.079	5.83	0.00	0.58	2.04	3.21	55.0%	0.00
gallium arsenide	Inorganic compounds	144.64	0.015	0.090	6.60	0.00	0.66	2.31	3.63	55.0%	0.00
hydrazine	Inorganic compounds	32.05	0.020	0.027	1.95	0.00	0.20	0.68	1.07	55.0%	0.00
hydrogen chloride (hydrochloric acid)	Inorganic compounds	36.46	0.500	0.755	55.50	0.00	5.55	19.42	30.52	55.0%	0.00
hydrogen fluoride (hydrofluoric acid)	Inorganic compounds	20.01	0.100	0.083	6.09	0.00	0.61	2.13	3.35	55.0%	0.00
hydrogen peroxide	Inorganic compounds	34.02	0.100	0.141	10.36	0.00	1.04	3.62	5.70	55.0%	0.00
hydrogen sulfide	Inorganic compounds	34.08	2.000	2.825	207.49	0.00	20.75	72.62	114.12	55.0%	0.50
indium	Inorganic compounds	114.82	0.002	0.010	0.75	0.00	0.08	0.26	0.41	55.0%	0.00
indium monochloride	Inorganic compounds	150.22	0.002	0.009	0.69	0.00	0.07	0.24	0.38	55.0%	0.00
indium oxide (In2O3)	Inorganic compounds	277.64	0.004	0.052	3.80	0.00	0.38	1.33	2.09	55.0%	0.00
iodine	Inorganic compounds	253.82	0.005	0.053	3.86	0.00	0.39	1.35	2.12	55.0%	0.00
lead	Inorganic compounds	207.21	0.003	0.021	1.58	1.58	0.16	0.55	0.87	55.0%	0.00
lead chloride	Inorganic compounds	278.10	0.003	0.029	2.12	0.00	0.21	0.74	1.16	55.0%	0.00

Table 1. Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules

Contaminant	Group	MOL Wt.	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
lead nitrate	Inorganic compounds	331.23	0.001	0.007	0.50	0.00	0.05	0.18	0.28	55.0%	0.00
lead telluride	Inorganic compounds	334.82	0.002	0.021	1.53	0.00	0.15	0.54	0.84	55.0%	0.00
lithium fluoride (most other F salts,same ppm)	Inorganic compounds	25.94	0.235	0.253	18.56	0.00	1.86	6.49	10.21	55.0%	0.00
lithium hexafluorarsenate (as As)	Inorganic compounds	195.86	0.001	0.008	0.60	0.00	0.06	0.21	0.33	55.0%	0.00
lithium perchlorate	Inorganic compounds	107.00	0.021	0.093	6.84	0.00	0.68	2.39	3.76	55.0%	0.00
mercuric iodide	Inorganic compounds	454.45	0.000	0.007	0.53	0.00	0.05	0.18	0.29	55.0%	0.00
mercuric oxide	Inorganic compounds	216.59	0.001	0.004	0.33	0.00	0.03	0.12	0.18	55.0%	0.00
mercury	Inorganic compounds	200.61	0.001	0.004	0.31	0.00	0.03	0.11	0.17	55.0%	1.20
nickel	Inorganic compounds	58.69	0.040	0.097	7.15	0.00	0.71	2.50	3.93	55.0%	0.00
nickel compounds (water soluble)	Inorganic compounds	150.00	0.004	0.025	1.83	0.00	0.18	0.64	1.00	55.0%	0.00
ozone (03)	Inorganic compounds	48.00	0.010	0.020	1.46	0.00	0.15	0.51	0.80	55.0%	0.00
perchloric acid	Inorganic compounds	100.47	0.012	0.050	3.67	0.00	0.37	1.28	2.02	55.0%	0.00
phosphoric acid	Inorganic compounds	98.04	0.025	0.102	7.46	0.00	0.75	2.61	4.10	55.0%	0.00
potassium cyanide	Inorganic compounds	65.11	0.238	0.644	47.27	0.00	4.73	16.55	26.00	55.0%	0.00
potassium hydroxide	Inorganic compounds	56.11	0.043	0.101	7.43	0.00	0.74	2.60	4.09	55.0%	0.00
silver	Inorganic compounds	107.87	0.002	0.010	0.74	0.00	0.07	0.26	0.41	55.0%	0.00
silver chromate	Inorganic compounds	131.77	0.003	0.016	1.20	0.00	0.12	0.42	0.66	55.0%	0.00
silver compounds (water soluble)	Inorganic compounds	200.00	0.001	0.008	0.61	0.00	0.06	0.21	0.33	55.0%	0.00
silver nitrate	Inorganic compounds	169.89	0.001	0.004	0.26	0.00	0.03	0.09	0.14	55.0%	0.00

Table 1. *Recommended Maximum Source Rate Allocation for Trace Contaminants Inside Space Station Manned Modules*

Contaminant	Group	MOL Wt	Expected SMAC (PPM)	Expected SMAC (mg/m**3)	Maximum total source rate (mg/day)	Calculated Biological source rate (mg/day)	Maximum module allocation (mg/day)	Allocation for portable equipment (mg/day)	Allocated remainder (mg/day)	Allocated remainder (% of total)	Predicated offgassing rate (mg/day)
silver oxide	Inorganic compounds	247.76	0.002	0.023	1.70	0.00	0.17	0.59	0.93	55.0%	0.00
sulfur dioxide	Inorganic compounds	64.06	0.250	0.664	48.75	0.00	4.88	17.06	26.81	55.0%	0.00
sulfuric acid	Inorganic compounds	98.08	0.013	0.051	3.73	0.00	0.37	1.31	2.05	55.0%	0.00
tantalum	Inorganic compounds	180.95	0.068	0.506	37.18	0.00	3.72	13.01	20.45	55.0%	0.00
tellurium	Inorganic compounds	127.61	0.002	0.011	0.78	0.00	0.08	0.27	0.43	55.0%	0.00
thallium	Inorganic compounds	204.39	0.001	0.010	0.75	0.00	0.07	0.26	0.41	55.0%	0.00
thallium monosulfate (as Th)	Inorganic compounds	301.46	0.001	0.010	0.73	0.00	0.07	0.26	0.40	55.0%	0.00
thionyl chloride	Inorganic compounds	119.00	0.150	0.740	54.34	0.00	5.43	19.02	29.89	55.0%	0.00
tin	Inorganic compounds	118.69	0.040	0.197	14.45	0.00	1.45	5.06	7.95	55.0%	0.00
tin chloride (Sn2 or Sn4)	Inorganic compounds	189.59	0.040	0.314	23.09	0.00	2.31	8.08	12.70	55.0%	0.00
zinc	Inorganic compounds	65.37	0.150	0.406	29.85	0.00	2.98	10.45	16.42	55.0%	0.00
zinc chloride	Inorganic compounds	136.38	0.002	0.010	0.75	0.00	0.07	0.26	0.41	55.0%	0.00
C06 unsaturated ketone	Ketones	100.27	0.500	2.078	152.62	0.00	15.26	53.42	83.94	55.0%	0.00
C07 ketone (as 2-heptanone)	Ketones	114.20	2.500	11.831	869.11	0.00	86.91	304.19	478.01	55.0%	0.00
acetone (2-propanone)	Ketones	58.08	150.000	361.025	26520.92	1.20	2651.97	9281.90	14585.84	55.0%	4212.00
acetylbenzene (acetophenone)	Ketones	120.10	25.000	124.424	9140.16	0.00	914.02	3199.06	5027.09	55.0%	1.60
cyclohexanone	Ketones	98.15	7.500	30.505	2240.90	0.00	224.09	784.31	1232.49	55.0%	292.00
cyclopentanone	Ketones	84.13	4.250	14.817	1088.46	0.00	108.85	380.96	598.65	55.0%	845.00
diisobutyl ketone (2,6-dimethyl-4-heptanone)	Ketones	142.20	5.000	29.464	2164.41	0.00	216.44	757.54	1190.43	55.0%	711.00
mesityl oxide (isobutenyl methyl ketone) (4-methyl-3-penten-2-one)	Ketones	98.16	2.500	10.169	747.04	0.00	74.70	261.46	410.87	55.0%	47.00

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methyl butyl ketone (2-hexanone)	Ketones	100.20	5.000	20.761	1525.14	0.00	152.51	533.80	838.82	55.0%	0.00
methyl ethyl ketone (2-butanone)	Ketones	72.10	20.000	59.756	4389.71	0.00	438.97	1536.40	2414.34	55.0%	3760.00
methyl hexyl ketone (2-octanone)	Ketones	128.00	10.000	53.043	3896.55	0.00	389.66	1363.79	2143.10	55.0%	0.30
methyl isobutyl ketone	Ketones	100.16	5.000	20.753	1524.53	0.00	152.45	533.58	838.49	55.0%	1335.00
methyl isopropyl ketone (3-methyl-2-butanone)	Ketones	86.13	10.000	35.692	2621.95	0.00	262.20	917.68	1442.07	55.0%	4.70
phorone (2,6-dimethyl-2,5-heptadiene-4-one)	Ketones	138.20	10.000	57.270	4207.06	0.00	420.71	1472.47	2313.88	55.0%	0.00
ethyl mercaptan (ethanethiol)	Mercaptans and sulfides	62.13	0.050	0.129	9.46	5.00	0.45	1.56	2.45	25.9%	0.00
hydrogen sulfide	Mercaptans and sulfides	34.08	1.000	1.412	103.75	0.54	10.32	36.12	56.76	54.7%	0.00
methyl mercaptan	Mercaptans and sulfides	48.10	0.050	0.100	7.32	5.00	0.23	0.81	1.28	17.4%	0.00
propyl mercaptan	Mercaptans and sulfides	76.15	26.000	82.047	6027.18	5.00	602.22	2107.76	3312.20	55.0%	0.00
carbon disulfide	Mercaptans and sulfides	76.13	2.000	6.310	463.51	0.00	46.35	162.23	254.93	55.0%	44.00
carbonyl sulfide	Mercaptans and sulfides	60.07	2.000	4.979	365.73	0.00	36.57	128.00	201.15	55.0%	0.00
diethyl sulfide	Mercaptans and sulfides	90.18	0.100	0.374	27.45	0.00	2.75	9.61	15.10	55.0%	0.00
dimethyl sulfide	Mercaptans and sulfides	62.13	1.000	2.575	189.14	0.00	18.91	66.20	104.02	55.0%	0.30
ammonia	Inorganic compounds	17.03	12.500	8.822	648.03	2850.00	-220.20	-770.69	-1211.08	-186.9%	2856.00
any unidentified compound typical values illustrated, MAC is .10mg/M3 Miscellaneous		100.00	0.024	0.100	7.35	0.00	0.73	2.57	4.04	55.0%	0.00
carbon monoxide	Inorganic compounds	28.01	15.000	17.411	1279.01	200.00	107.90	377.65	593.46	46.4%	1797.00
hydrogen	Inorganic compounds	2.02	2600.000	217.212	15956.39	300.00	1565.64	5479.74	8611.01	54.0%	156.00

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hydrogen cyanide (hydrocyanic acid)	Inorganic compounds	27.06	0.500	0.561	41.19	0.00	4.12	14.42	22.65	55.0%	0.00
1,3-dioxolane (allyl diglycol carbonate)	Miscellaneous organic compound	74.08	6.000	18.419	1353.10	0.00	135.31	473.58	744.20	55.0%	0.00
cacodylic acid (arsenic oxide, hydroxydimethyl)	Miscellaneous organic compound	138.00	0.000	0.002	0.15	0.00	0.01	0.05	0.08	55.0%	0.00
camphor [(2,2,1) bicyclo (heptan-2-one)1,7,7-trimethyl)]	Miscellaneous organic compound	152.26	10.000	63.097	4635.07	0.00	463.51	1622.28	2549.29	55.0%	0.00
dimethyl ammonium sulfate	Miscellaneous organic compound	110.13	0.050	0.228	16.76	0.00	1.68	5.87	9.22	55.0%	0.00
dimethyl sulfite	Miscellaneous organic compound	110.13	0.111	0.507	37.21	0.00	3.72	13.02	20.47	55.0%	0.00
ethylene oxide	Miscellaneous organic compound	44.00	5.000	9.117	669.72	0.00	66.97	234.40	368.35	55.0%	0.00
methyl morpholine	Miscellaneous organic compound	101.20	2.000	8.387	616.14	0.00	61.61	215.65	338.88	55.0%	0.00
methylene iodide	Miscellaneous organic compound	268.00	5.000	55.530	4079.20	0.00	407.92	1427.72	2243.56	55.0%	0.00
n-ethyl morpholine	Miscellaneous organic compound	115.20	2.000	9.548	701.38	0.00	70.14	245.48	385.76	55.0%	213.00
triethyl amine	Miscellaneous organic compound	101.22	2.500	10.486	770.33	0.00	77.03	269.62	423.68	55.0%	0.00
acetonitrile (ethanenitrile)	Nitriles	41.05	2.000	3.402	249.93	0.00	24.99	87.47	137.46	55.0%	83.00
acrylonitrile (vinyl cyanide)	Nitriles	53.06	0.650	1.429	104.99	0.00	10.50	36.75	57.74	55.0%	0.00
isopropylcyanide (2-methyl propane nitrile)	Nitriles	69.12	1.300	3.724	273.54	0.00	27.35	95.74	150.45	55.0%	0.00
succinonitrile	Nitriles	80.09	0.600	1.991	146.29	0.00	14.63	51.20	80.46	55.0%	0.00
nitric oxide	Nitrogen oxides	30.01	1.000	1.244	91.36	0.00	9.14	31.97	50.25	55.0%	0.00

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nitrogen dioxide	Nitrogen oxides	46.10	0.200	0.382	28.07	0.00	2.81	9.82	15.44	55.0%	0.00
nitrogen tetroxide	Nitrogen oxides	92.02	0.250	0.953	70.03	0.00	7.00	24.51	38.52	55.0%	0.00
nitrous oxide	Nitrogen oxides	44.01	26.000	47.418	3483.34	0.00	348.33	1219.17	1915.83	55.0%	0.00
acetic acid (ethanoic acid)	Organic acids	60.05	2.000	4.977	365.61	0.00	36.56	127.96	201.08	55.0%	0.02
benzoic acid	Organic acids	122.13	5.000	25.305	1858.93	0.00	185.89	650.63	1022.41	55.0%	0.00
butyric acid (butanoic acid)	Organic acids	88.10	5.000	18.254	1340.96	0.00	134.10	469.34	737.53	55.0%	0.00
caprylic acid (octanoic acid)	Organic acids	144.20	25.000	149.391	10974.28	5.00	1096.93	3839.25	6033.10	55.0%	0.00
dichloroacetic acid	Organic acids	129.00	15.000	80.186	5890.49	0.00	589.05	2061.67	3239.77	55.0%	0.00
formic acid	Organic acids	46.03	0.500	0.954	70.06	0.00	7.01	24.52	38.53	55.0%	0.00
maloric acid	Organic acids	104.07	0.500	2.156	158.40	0.00	15.84	55.44	87.12	55.0%	0.00
nitrobenzoic acid,o,m,p-	Organic acids	167.19	10.000	69.284	5089.57	0.00	508.96	1781.35	2799.26	55.0%	0.00
oxalic acid	Organic acids	90.04	0.100	0.373	27.41	0.00	2.74	9.59	15.08	55.0%	0.00
oxalic acid, K salt	Organic acids	129.14	0.100	0.535	39.31	0.00	3.93	13.76	21.62	55.0%	0.00
picric acid	Organic acids	229.11	0.001	0.009	0.70	0.00	0.07	0.24	0.38	55.0%	0.00
propionic acid (oropanoic acid)	Organic acids	74.08	5.000	15.349	1127.57	0.00	112.76	394.65	620.16	55.0%	0.00
pyruvic acid (2-oxo-propanoic acid)	Organic acids	88.06	0.250	0.912	67.02	1260.00	-119.30	-417.54	-656.14	-979.1%	0.00
valeric acid	Organic acids	102.13	26.000	110.039	8083.46	5.00	807.85	2827.46	4443.15	55.0%	0.00
carbodiimide (cyanamide)	Organic nitrogens	42.04	0.800	1.394	102.38	0.00	10.24	35.83	56.31	55.0%	0.00
dimethyl hydrazine (1,1-dimethylhydrazine)	Organic nitrogens	60.10	0.040	0.100	7.32	0.00	0.73	2.56	4.03	55.0%	0.00
indole (2,3-benzopyrrole)	Organic nitrogens	117.10	0.100	0.485	35.65	150.00	-11.44	-40.02	-62.89	-176.4%	70.00
monomethyl hydrazine (methylhydrazine)	Organic nitrogens	46.07	0.020	0.038	2.80	0.00	0.28	0.98	1.54	55.0%	0.00
skatole (3-methyl indole)	Organic nitrogens	131.20	0.100	0.544	39.94	150.00	-11.01	-38.52	-60.53	-151.6%	0.00
decamethyltetrasiloxane	Siloxanes	326.70	6.250	84.615	6215.84	0.00	621.58	2175.54	3418.71	55.0%	7.00
hexamethyl disiloxane	Siloxanes	162.42	7.500	50.480	3708.27	0.00	370.83	1297.89	2039.55	55.0%	0.08
hexamethyl cyclotrisiloxane	Siloxanes	222.38	3.000	27.646	2030.90	0.00	203.09	710.81	1116.99	55.0%	47.00

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octamethyl trisiloxane	Siloxanes	236.30	6.250	61.202	4495.88	0.00	449.59	1573.56	2472.73	55.0%	379.00
octamethyl cyclotetrasiloxane	Siloxanes	296.66	6.250	76.835	5644.29	0.00	564.43	1975.50	3104.36	55.0%	71.00
siloxane, dimer	Siloxanes	78.10	8.200	26.539	1949.56	0.00	194.96	682.34	1072.26	55.0%	32.00
siloxane, tetramer	Siloxanes	170.40	8.200	57.903	4253.58	0.00	425.36	1488.75	2339.47	55.0%	237.00
siloxane, trimer	Siloxanes	124.30	8.200	42.238	3102.81	0.00	310.28	1085.98	1706.55	55.0%	24.00
trimethyl silanol	Siloxanes	90.21	0.250	0.935	68.65	0.00	6.87	24.03	37.76	55.0%	12.00

ATTACHMENT D

SUBTASK 2.2.3.2 FINAL REPORT
INTERNAL OUTGASSING SPECIFICATIONS FOR MATERIALS

TABLE OF CONTENTS

INTERNAL OUTGASSING SPECIFICATIONS FOR MATERIALS (SUBTASK 2.2.3.2)

Introduction

Our original concept for this subtask was to write a set of quantitative outgassing specifications for materials used in the Space Station, but since that time we have gained a better understanding of the nature of the contamination problem as well as NASA's method of controlling contamination and we no longer feel that this objective is desirable. The primary difficulty with establishing a rigid set of outgassing requirements is that each material emits many different contaminants, and it is difficult to balance the complexity of the contamination control system against the need for simple and understandable requirements. Thus, rigid requirements result in either an inflexible system or a lack of contamination control. Later in this report we will propose an alternative to the original concept of writing specifications to control contamination sources inside the Space Station.

At present, NASA is using a contamination control philosophy based primarily on analysis and preflight testing. This basis is acceptable from the standpoint of controlling contamination, but it is not user friendly because equipment designers and Space Station users do not know the analytical procedures or have access to all data. Therefore, the users have no practical guidelines to use as a basis for contamination control.

The current system has no contamination requirements for materials or assembled articles of equipment that can be effectively employed as design guidelines during preliminary design or prior to completion of the final contamination analysis of the total spacecraft. In fact it is not currently possible to know if a particular assembled article that has been acceptance tested as a contamination source will meet the established requirements because there are no acceptance criteria for individual equipment items. The final contamination analysis is conducted, often long after the contamination tests have been completed, for the fully assembled spacecraft. The spacecraft is then accepted or rejected without considering individual items of equipment. Thus, there is no need for this system to evaluate the contamination potential of individual contamination sources.

In this report we have attempted to resolve the needs of those designers and engineers who try to select materials and establish equipment designs with the current method of contamination control. We propose ranking each article with a contamination index (CI). The index will be based on the results of the standard 72-hour outgassing test and will be independent of any other article or items of equipment that may be used on the Space Station. This will provide a quantitative means of ranking equipment as contamination sources while retaining the flexibility of the current contamination control method.

Outgassing Specifications

The current outgassing specifications for the Space Station are based on toxicological requirements for human health. It is the responsibility of the NASA toxicologist to establish these requirements for each spacecraft and mission. The requirements take the form of limits placed on the concentration of each contaminant species in the air inside the spacecraft. The basic contamination limit is called the "maximum allowed concentration" or MAC (ref. 1). A MAC has been established for all chemicals.

In addition to the MAC's a second requirement is placed on groups of chemicals that have similar physiological effects (ref. 2). The second requirement effectively lowers the average concentration of contaminants in the air to values on the order of 1% of the MAC. This fact has significant impact on the outgassing specifications as well as the contamination monitoring system and the environmental control and life support system (ECLSS).

The second contamination requirement is called the "T" limit and applies to each of five "toxicological groups" of chemicals. The five toxicological groups are (ref. 2): asphyxiants, systemic poisons, central nervous system depressants, irritants, and carcinogens. Each contaminant is in one or more of these groups. The T limit applies to the total concentration of all chemicals in a single toxicological group. Since there are a large number of contaminants in each toxicological group, on average the concentration of each contaminant is reduced to about 1% of its MAC.

The use of the five toxicological groups is a change from the method of contamination control used for the Space Shuttle and other previous space programs, but it has been used in a number of toxicological assessments of the Shuttle and Spacelab. The five-toxicological-group method has been proposed for the Space Station (ref. 3). Therefore, any effective contamination control plan or outgassing specifications for the Space Station need to reflect this new system.

Contamination Index

A need exists for a means of assessing the contamination potential of materials and assemblies before the materials list is complete or the payload equipment manifest is established. To this end we propose a system in which each material or assembly is ranked as a contamination source. We propose to use a contamination index (CI) for the Space Station. The CI will apply to each equipment item or individual material and will be based on the results of the standard 72-hour outgassing test. The CI will be independent of any other equipment that may be placed on the Space Station. This will assure that the CI can be determined as soon as the outgassing tests have been completed. The CI will be a relative measure of the contamination potential of articles, but will not replace or substitute for the final contamination analysis in the current contamination control procedure. It is likely that in time, as we gain experience with the CI, we may be able to determine a cutoff value above which articles will be rejected, but the CI has been developed as a measure of the relative contamination potential of articles of equipment. The use of the CI will permit those evaluating Space Station payloads to include contamination as a selection criterion. Then contamination can be allocated in a manner analogous to that currently used to allocate power usage or heat generation.

Basis for the Contamination Index

The contamination index is based on data obtained in the Spacelab contamination assessment (ref. 4), and Space Shuttle crew cabin offgassing report (ref. 5). The Spacelab data shows outgassing test results for both fixed equipment and payload equipment used in the Spacelab. The Space Shuttle report shows the same type of data for materials. The Shuttle data were used as the basis of an analysis to determine how many contamination sources produced each contaminant, and also what fraction of each contaminant was produced by its single largest source. The results of this investigation are shown in figures. 1 through 4.

Figure 1 shows the number of contaminants versus the number of sources producing each contaminant. It shows that 48 contaminants (36% of all contaminants) have only a single source, and 67% of all contaminants have 5 or fewer sources. Figure 2 is similar to figure 1 ,but the abscissa is in intervals of 10 sources. Thus, the first bar shows that 99 contaminants (74% of all contaminants) have from 1 to 10 sources, and the second bar shows that 16 contaminants have between 10 and 20 sources.

Figures 3 and 4 deal with the percentage of a particular contaminant contributed by its single largest source (the load percentage). Figure 3 shows that 82 contaminants (61% of all contaminants) have a primary source that contributes between 90% and 100% of that contaminants total source rate, and nine contaminants have a primary source that contributes between 80% and 90% of the contaminant load in the crew cabin. These data also show that 89% of all contaminants have a primary source that produces more than 50% of that contaminant's total load.

Figure 4 is a breakdown of the load-percentage distribution for load percentages between 90% and 100%. This figure shows that 61 contaminants (46% of all contaminants) are produced by a primary source that contributes between 99% and 100% of the contaminant's total load.

These results show that for the most part, each contaminant is produced by a small number of sources and that of those contaminants

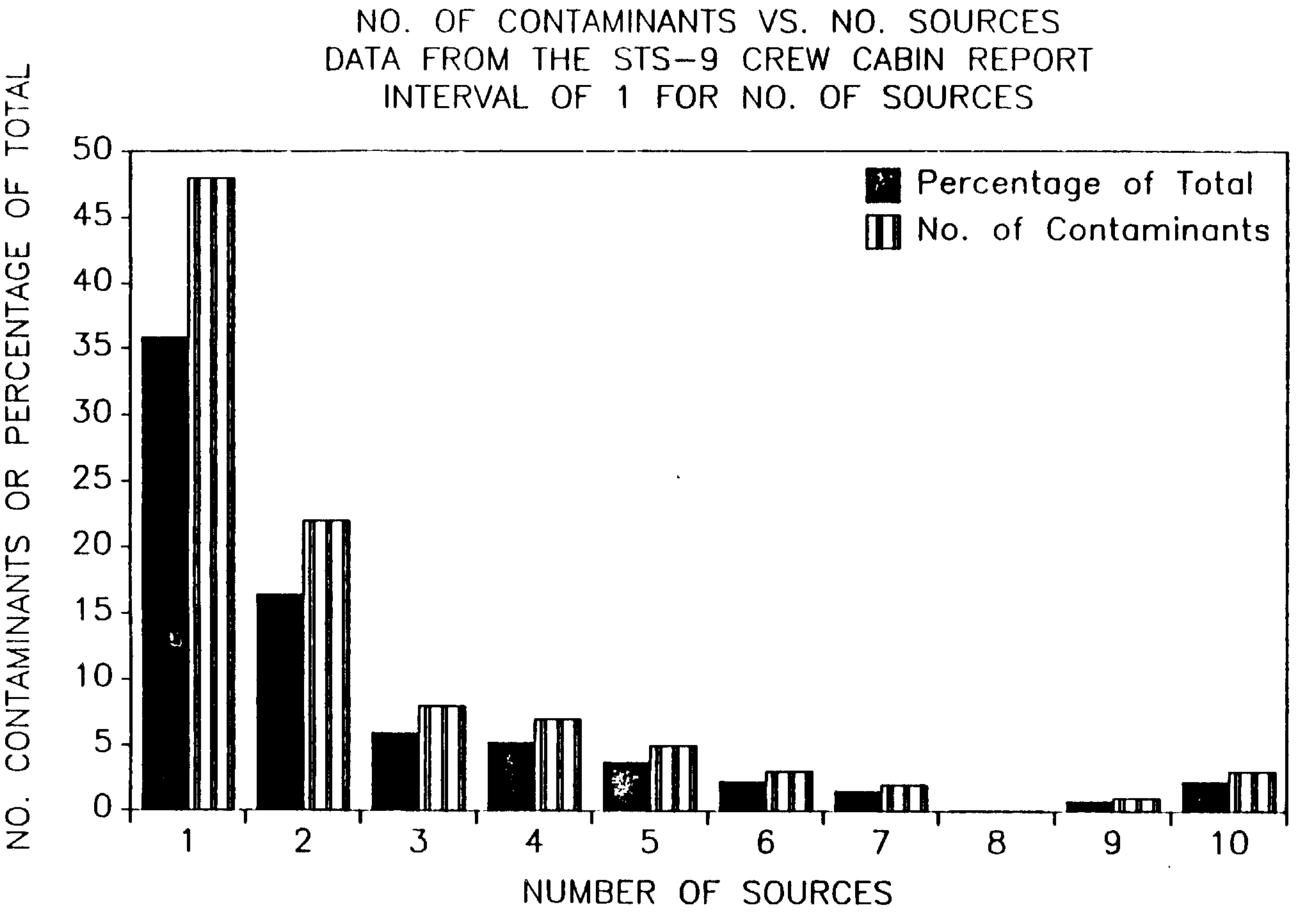

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Figure 1. Distribution of contaminants by number of sources.

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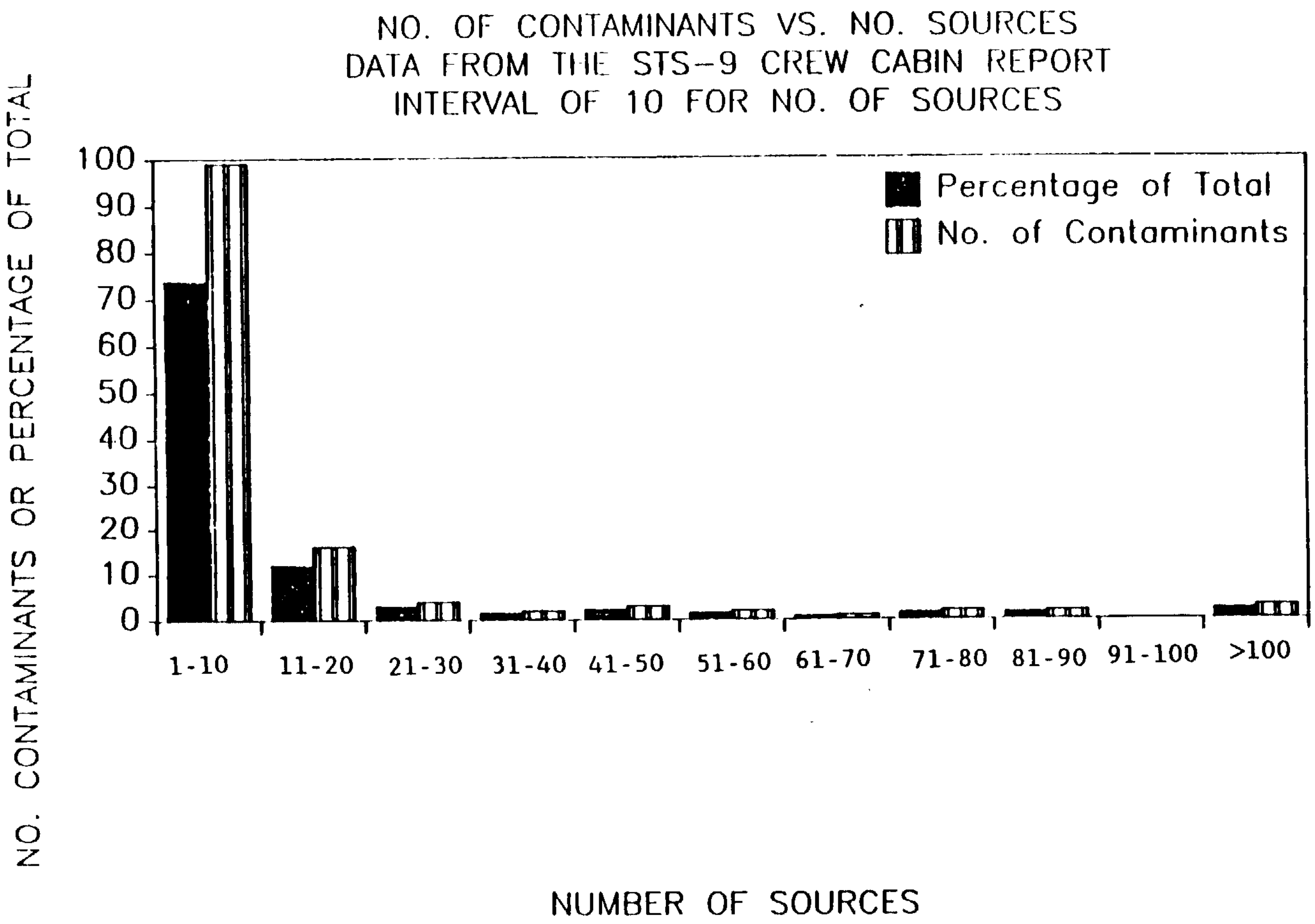

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Figure 2. Distribution of contaminants by number of sources.

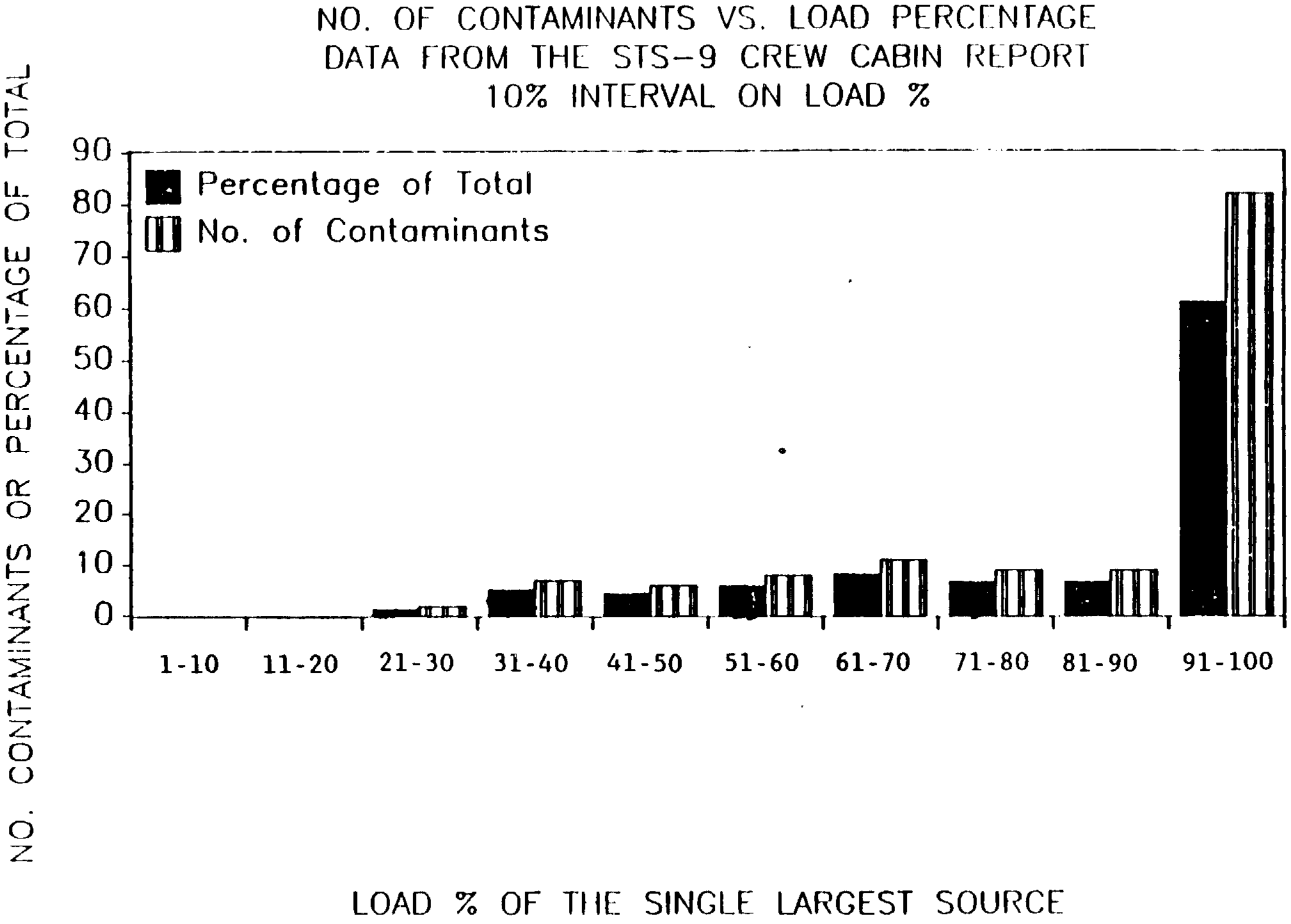

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Figure 3. Distribution of contaminants by load percentage of the single largest source.

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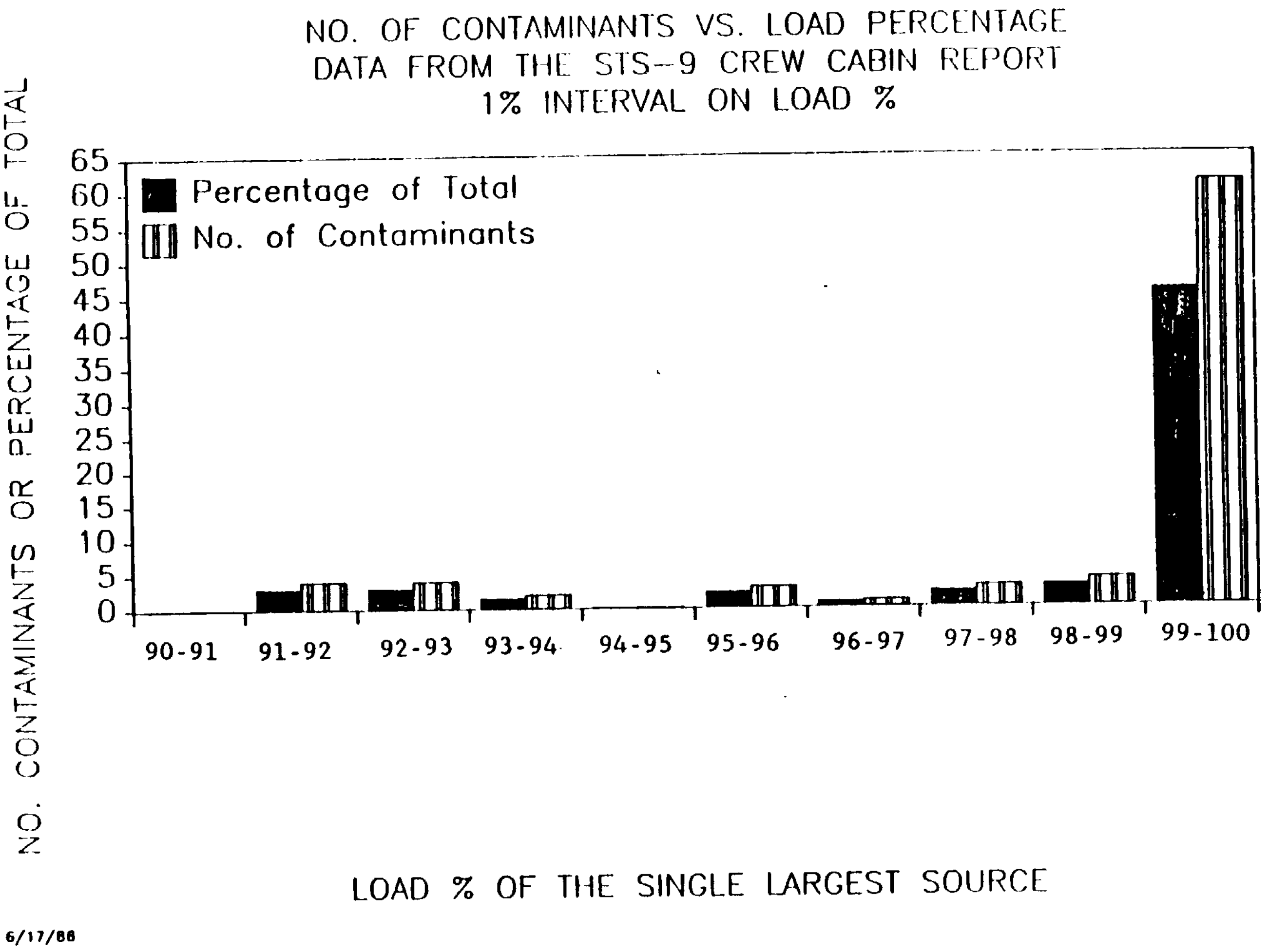

Figure 4. Distribution of contaminants by load percentage of the single largest source.

produced by more than one source, one source usually dominates the total source rate in the spacecraft. We have used these facts to develop the contamination index.

The proposed contamination index is as follows:[1]

$$CI = 0.25\Sigma_g[(T_g/0.1)^2] \qquad (1)$$

T_g = Group contamination parameter for the g-th toxicological group

CI = Contamination index

The T-parameter is defined as:[1]

$$T_g = \Sigma_i(R_i/Rmax_i)_g \qquad (2)$$

R_i = The total production rate for the i-th contaminant in group g

$Rmax_i$ = The maximum allowable rate for the i-th contaminant in group g

The summation in equation 2 is carried out over all contaminants in the same toxicological group. The individual terms in the T parameter summation are normalized outgassing rates. We will discuss the normalized rate again later. The group contamination parameter (T_g) is related to that used in the Space Shuttle contamination reports (ref. 2) except that it is based on total offgassing rates instead of "projected spacecraft concentrations" (PSC). The use of offgassing rates instead of the PSC has no effect in this application, because the T parameter can also be defined in terms of the PSC if desired. Rates have been used in this work because they are easier to use than PSCs, and they relate more directly to the offgassing test results.

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1) Sigma = The summation over all five toxicological groups.

This definition of the contamination index is not the only possible choice, but it does have a number of desirable characteristics. First it reflects the toxicological groups and the current method of controlling contamination on the Space Station. The factor of 0.25 in equation 1 is a weighting factor. All toxicological groups are weighted equally. This feature could be modified if desired and a different weighting factor could be applied to each toxicological group, but at this time there is no indication that unequal weighting factors are desirable. The weighting factor was chosen to yield a maximum acceptable CI of approximately one. The value of 0.25 was chosen even though there are 5 toxicological groups because one toxicological group usually has a very small T value.

Another feature of the proposed contamination index is that contaminants with large T parameters are weighted more strongly than those with small T parameters. This is desirable because on average we must reduce the number of contaminants produced at a rate near the maximum allowable rate ($Rmax_i$).

The factor of 0.1 in the denominator of equation 1 is used to scale the T parameter. It provides a safety factor and assures that any toxicological group with a T parameter greater than 0.2 will yield an unacceptably high CI. In a more advanced CI the scaling factor might be different for each toxicological group, but we chose not to add this complexity at this time. In any case the scaling factor should never be allowed to be larger than 0.5 because T could then be greater than 1.0 without the CI being greater than 1.0 .

It should be remembered that the CI is one parameter used to represent the overall contamination potential of an article of equipment. There will usually be many different contaminants emitted by each article of equipment, and each contaminant produces a different effect in humans and on other equipment. Any parameter that tries to represent complex phenomena in simple terms is in danger of being misused, but we feel that the CI is a good relative measure of contamination sources overall. Thus, most materials and assemblies with a CI less than 1.0 should be acceptable contamination sourced in the Space Station.

Application to Different Areas Within the Space Station

At this time there is only one set of contamination specifications for all areas within the Space Station. This situation may changed, but no plans to designate areas of modules according to contamination potential have been proposed. Thus, at this time the only contamination specifications that must be reflected in the CI are the MAC values and toxicological group (T) limits.

In previous work conducted under this contract we proposed four classifications of contamination sources. Maximum total rates were suggested for: 1) fixed or permanent equipment, 2) portable equipment and payloads, 3) activities and experiments, and 4) humans (ref. 4). We recommend that the CI also be applied separately to each of these four classes of contamination sources. Implementation of this procedure requires that each material or piece of apparatus be assigned to one of the equipment categories listed above. Also, maximum source rates must be established for each contaminant in each source category. In principle, the maximum rates could be tailored for each module on the Space Station, but this is a refinement to the basic concept presented here.

Example

As an example of how the CI works we have calculated the CI for four pieces of equipment used on Spacelab-3. The results are shown in table 1. The first two items are fixed equipment and the last two items are portable or "Payload" hardware. The first entries in the table are, a description of the item, its mass, and its fraction of the total spacecraft mass (f_i). The table also shows all contaminants produced by the article in the 72-hour outgassing test. The second column in the table shows the toxic group, or groups that each contaminant belongs

Table 1.

Outgassing Rates and Contamination Index for Selected Spacelab-3 Hardware Items.

SPACELAB CONTAMINATION AS A MODEL FOR THE SPACE STATION

FIXED EQUIPMENT (SPACELAB HARDWARE)

FIXED EQUIPMENT- tone generator
MASS= 5.255 kg f1= 3.091E-03

CONTAMINANT	TOXIC GROUP	OFFGASSING RATE (mg/day)	MAXIMUM ALLOWED RATE (mg/day)	FRACTION OF MAX RATE	WEIGHTED FRACTIONAL RATE	GROUP TOXICITY				
						IRRITANTS	ASPHYXIANTS	CNSD	SYSTEMIC POISONS	CARCINOGENS
Acetone	Irr.,CNSD,SP	2.333E-02	2.652E+03	8.797E-06	2.846E-03	8.797E-06		8.797E-06	8.797E-06	
Alcohol,i-propyl	Irr.,CNSD	9.641E-01	7.317E+02	1.318E-03	4.262E-01	1.318E-03		1.318E-03		
Alcohol,n-butyl	Irr.,CNSD	1.400E-02	2.249E+02	6.227E-05	2.014E-02	6.227E-05		6.227E-05		
Butyraldehyde	Irr.,CNSD	2.400E-02	8.779E+02	2.733E-05	8.842E-03	2.733E-05		2.733E-05		
Carbon Monoxide	Asph.	2.533E-02	1.099E+02	2.305E-04	7.456E-02		2.305E-04			
Chlorobenzene	SP	4.200E-02	2.570E+02	1.634E-04	5.287E-02				1.634E-04	
Ethylbenzene	SP	9.334E-03	6.463E+02	1.444E-05	4.672E-03				1.444E-05	
Hexane,n	CNSD	8.000E-03	6.559E+02	1.220E-05	3.946E-03			1.220E-05		
Methyl Chloroform, 1-1-1 tri	SP	6.606E-01	6.091E+02	1.085E-03	3.508E-01				1.085E-03	
Methyl Ethyl Ketone	Irr.,CNSD,SP	1.387E-01	4.380E+02	3.167E-04	1.025E-01	3.167E-04		3.167E-04	3.167E-04	
Methyl Isobutyl Ketone	Irr.,CNSD,SP	6.600E-02	1.525E+02	4.329E-04	1.400E-01	4.329E-04		4.329E-04	4.329E-04	
Toluene	SP	9.340E-01	5.609E+02	1.665E-03	5.387E-01				1.665E-03	
Trichlorotrifluoroethane	CNSD	5.200E-02	1.141E+03	4.558E-05	1.475E-02			4.558E-05		
unknown(alcohol,n-amyl)	Irr.,CNSD	1.240E-01	2.683E+02	4.622E-04	1.495E-01	4.622E-04		4.622E-04		
Xylene	SP	8.467E-02	3.232E+02	2.620E-04	8.476E-02				2.620E-04	
Xylene,o	SP	5.200E-02	3.232E+02	1.609E-04	5.206E-02				1.609E-04	
				6.267E-03	2.027E+00	2.628E-03	2.305E-04	2.686E-03	4.109E-03	

Contamination Index = 7.763E-4

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Table 1. Outgassing Rates and Contamination Index for Selected Spacelab-3 Hardware Items.

FIXED EQUIPMENT- spacelab flight unit

MASS- 54.2 kg T1- 3.188E-02

CONTAMINANT	TOXIC GROUP	OFFGASSING RATE (mg/day)	MAXIMUM ALLOWED RATE (mg/day)	FRACTION OF MAX RATE	WEIGHTED FRACTIONAL RATE	GROUP TOXICITY IRRITANTS	ASPHYXIANTS	CNSD	SYSTEMIC POISONS	CARCINOGENS
Acetate, n-butyl	Irr.,CNSD	1.207E-01	8.840E+02	1.365E-04	4.282E-03	1.365E-04		1.365E-04		
Acetete, 2-ethoxyethyl	Irr.,CNSD	2.413E-02	6.036E+02	3.998E-05	1.254E-03	3.998E-05		3.998E-05		
Acetone	Irr.,CNSD,SP	1.689E-01	2.652E+03	6.370E-05	1.998E-03	6.370E-05		6.370E-05	6.370E-05	
Alcohol, i-propyl	Irr.,CNSD	1.858E+01	7.317E+02	2.540E-02	7.966E-01	2.540E-02		2.540E-02		
Alcohol, n-butyl	Irr.,CNSD	2.413E-02	2.249E+02	1.073E-04	3.365E-03	1.073E-04		1.073E-04		
Carbon monoxide	Asph.	1.492E+01	1.079E+02	1.382E-01	4.336E+00		1.382E-01			
Dimethylcyclohexane,1-2 (trans)	CNSD	4.827E-02	8.533E+02	5.657E-05	1.774E-03			5.657E-05		
Dimethylheptane,3-5	CNSD	2.896E-01	4.802E+02	6.031E-04	1.892E-02			6.031E-04		
Ethylbenzene	SP	1.448E-01	6.463E+02	2.241E-04	7.028E-03				2.241E-04	
Ethylheptane,2-methyl-3-	CNSD	3.020E-01	4.269E+02	7.074E-04	2.219E-02			7.074E-04		
Hexamethylcyclotrisiloxane	Irr.,SP	5.792E-01	3.708E+02	1.562E-03	4.899E-02	1.562E-03			1.562E-03	
Hexane,3-3-dimethyl	CNSD	1.689E-01	8.540E+02	1.978E-04	6.205E-03			1.978E-04		
Methane	Asph.,CNSD	2.510E+01	6.496E+03	3.863E-03	1.212E-01		3.863E-03	3.863E-03		
Nonane,n	CNSD	2.172E-01	1.172E+03	1.853E-04	5.813E-03			1.853E-04		
Octamethylcyclotetrasiloxane	Irr.,SP	1.448E+00	5.644E+02	2.566E-03	8.048E-02	2.566E-03			2.566E-03	
Octane	CNSD	2.896E-01	1.286E+03	2.252E-04	7.063E-03			2.252E-04		
Tetrachloroethylene	SP	2.655E-01	2.524E+02	1.052E-03	3.300E-02				1.052E-03	
Toluene	SP	1.062E+00	5.609E+02	1.893E-03	5.938F-02				1.893E-03	
Trichlorofluoromethane	CNSD	5.430E+00	2.091E+02	2.597E-02	8.146E-01			2.597E-02		
Xylene	SP	6.033E-01	3.232E+02	1.867E-03	5.855E-02				1.867E-03	
				2.050E-01	6.428E+00	2.987E-02	1.421E-01	5.755E-02	9.227E-03	

Contamination Index = 6.120E-1

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Table 1.

Outgassing Rates and Contamination Index for Selected Spacelab-3 Hardware Items.

PAYLOAD EQUIPMENT (PORTABLE)

PAYLOAD EQUIPMENT= drop dynamics module
MASS= 17.54 kg fi= 1.032E-02

CONTAMINANT	TOXIC GROUP	OFFGASSING RATE (mg/day)	MAXIMUM ALLOWED RATE (mg/day)	FRACTION OF MAX RATE	WEIGHTED FRACTIONAL RATE	GROUP TOXICITY IRRITANTS	ASPHYXIANTS	CNSD	SYSTEMIC POISONS	CARCINOGENS
Acetate, n-butyl	Irr.,CNSD	2.345E+00	3.094E+03	7.579E-04	7.346E-02	7.579E-04		7.579E-04		
Acetone	SP	5.802E+00	9.282E+03	6.251E-04	6.058E-02				6.251E-04	
Methyl Chloroform	SP	1.680E+01	2.132E+03	7.882E-03	7.640E-01				7.882E-03	
Tetrachloroethylene	SP	3.073E+01	8.833E+02	3.479E-02	3.372E+00				3.479E-02	
Tetrahydrofuran	Irr.,CNSD,SP	1.291E+00	1.536E+03	8.406E-04	8.147E-02	8.406E-04		8.406E-04	8.406E-04	
				4.490E-02	4.352E+00	1.599E-03	0.000E+00	1.599E-03	4.414E-02	

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Contamination Index = 4.884E-2

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Table 1

Outgassing Rates and Contamination Index for Selected Spacelab-3 Hardware Items.

PAYLOAD EQUIPMENT= camera and magazine
MASS= 3.03 kg   fi= 1.782E-03

CONTAMINANT	TOXIC GROUP	OFFGASSING RATE (mg/day)	MAXIMUM ALLOWED RATE (mg/day)	FRACTION OF MAX RATE	WEIGHTED FRACTIONAL RATE	GROUP TOXICITY IRRITANTS	ASPHYXIANTS	CNSD	SYSTEMIC POISONS	CARCINOGENS
Alcohol, Amyl	Irr.,CNSD	4.067E-02	939.21	4.330E-05	2.429E-02	4.330E-05		4.330E-05		
Alcohol, i-butyl	Irr.,CNSD	7.233E-02	789.72	9.159E-05	5.139E-02	9.159E-05		9.159E-05		
Alcohol, n-butyl	Irr.,CNSD	1.163E+00	787.21	1.477E-03	8.286E-01	1.477E-03		1.477E-03		
Butyraldehyde	Irr.,CNSD	1.570E-01	3,072.80	5.111E-05	2.867E-02	5.111E-05		5.111E-05		
Benzene	SP,Car.	6.666E-03	8.32	8.012E-04	4.495E-01				8.012E-04	8.012E-04
Toluene	SP	1.534E-02	1,963.22	7.813E-06	4.383E-03				7.813E-06	
Acetete, n-butyl	Irr.,CNSD	1.274E-01	3,094.11	4.117E-05	2.310E-02	4.117E-05		4.117E-05		
Acetate, i-butyl	Irr.,CNSD	5.534E-02	2,475.71	2.235E-05	1.254E-02	2.235E-05		2.235E-05		
Methylchloroform	SP	2.903E-01	2,131.99	1.362E-04	7.640E-02				1.362E-04	
Trichlorotrifluoroethane	SP	2.800E-02	3,994.15	7.009E-06	3.933E-03				7.009E-06	
Heptane	CNSD	7.333E-03	2,615.18	2.804E-06	1.573E-03			2.804E-06		
Pentane, n-	CNSD	1.700E-02	7,687.32	2.212E-06	1.241E-03			2.212E-06		
Acetone	Irr.,CNSD,SP	3.533E-02	9,281.90	3.807E-06	2.136E-03	3.807E-06		3.807E-06	3.807E-06	
Methul Ethyl Ketone	Irr.,CNSD,SP	2.300E-02	1,536.40	1.497E-05	8.397E-03	1.497E-05		1.497E-05	1.497E-05	
Methyl Isobutyl Ketone	Irr.,CNSD,SP	8.834E-02	533.58	1.656E-04	9.289E-02	1.656E-04		1.656E-04	1.656E-04	
Carbon Monoxide	Asph.	9.833E-02	377.65	2.604E-04	1.461E-01		2.604E-04			
Unknown (Butyl Methacrylate)	Irr.,CNSD	4.133E-02	1,894.13	2.182E-05	1.224E-02	2.182E-05		2.182E-05		
				3.150E-03	1.767E+00	1.932E-03	2.604E-04	1.937E-03	1.137E-03	8.012E-04

Contamination Index = 2.372E-4

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to. Column three shows the average offgassing rate of each contaminant obtained in the 72-hour test, and column four shows the corresponding maximum allowed rate. Notice that maximum allowed rates for fixed equipment are different than those for portable equipment. Column five is the offgassing rate expressed as a fraction of the maximum rate, i.e.. the normalized outgassing rate. This column and all those farther to the right have been summed and the sums are shown below the dotted line at the bottom of each column.

Column six, "Weighted fractional rate", is equal to the entry in column five divided by f_i. This entry shows the ratio of the total generation rate of a module relative to the maximum allowable rate, for the hypothetical case of the whole module outgassing at the same rate as the test article. Column six represents a uniform allocation of contaminants among all sources. This allocation method is the simplest approach to contamination control, but it will be shown here to be a poor choice for the Space Station. According to this simple allocation method, contaminants with column-6 entries greater than 1.0 exceed the maximum allowable outgassing rate. For example, the "drop dynamic module" (Table 1, page 3) outgasses tetrachloroethylene with a weighted fractional rate 3.372 times the maximum allowed rate. Thus, if each contaminant is allocated equally by mass to all items of equipment, many items that could be permitted to fly will be excluded from the Space Station. The drop dynamics module, for example, was found to be an acceptable contamination source for the Spacelab, and was flown on Spacelab-3 because it did not exceed the established contamination limits. Also note that the CI of the drop dynamics module is less than one. This example illustrates that a simple contamination criterion allocating the same quantity of each contaminant to every article is an unsatisfactory and overly restrictive way to control contamination.

The last five columns in table 1 are the normalized outgassing rates ("Fraction of maximum rate", column 5) grouped according to toxic category. Notice that several contaminants are in more than one

13, 14, 15, 16.

of the five toxicological groups (acetone for example). The sum of the entries in each column is listed at the bottom of the column. The tabulated sums are equivalent to the toxicological (T) limits, except that they are based on rates rather than PSCs.

Another example of the complexity of contamination control and the use of the CI is provided by carbon monoxide. Carbon monoxide is emitted from the spacelab flight unit at a fast rate. This unit produces nearly 14% of the carbon monoxide allocated to all fixed equipment. Nevertheless this apparatus was used on the Spacelab, and the CI for this item is less than 1.0, as shown in table 1.

The CI is shown for each of the four hardware items listed in table 1. All four items have CIs less than 1.0, and each item was used on the Spacelab-3 flight. The CIs range from 0.000237 for the "camera and magazine" to 0.612 for the "Spacelab flight unit". In terms of relative ranking according to the CI the "Spacelab flight unit" is the largest contamination source, followed by the "drop dynamics module", the "tone generator", and then the "camera and magazine". This is the same relative ranking these items have under the current group toxicity method of contamination control used by the NASA toxicologist. We therefore conclude that this CI is accurately reflecting the relative magnitude of these four contamination sources, and since the CI is below 1.0 we also expect that all these items are sufficiently modest contamination sources that a final contamination analysis would permit them to be used on the Spacelab, or the Space Station.

Conclusions

During this subtask we tried to establish a set of offgassing requirements that could be applied to both materials and assembled articles intended for use on the Space Station. Other objectives were that the requirements be quantitative, usable, and available prior to the final contamination analysis. We considered the possibility of performing the contamination acceptance tests earlier in the launch schedule, but found this solution unworkable. The contamination analysis (based on MAC values and projected spacecraft concentrations) of necessity requires a final equipment manifest and completion of all contamination tests before it can be performed. Thus, changing the contamination test schedule would do nothing to establish effective contamination guidelines for equipment designs, during the development phase for example. For these reasons we found it impractical to define an acceptable set of rigid contamination requirements, but we have developed an alternate method of achieving the goals listed above by employing a new parameter called the contamination index (CI).

The CI is based on the results of the standard 72-hour outgassing test and the toxicological requirements used to control contamination inside Space Station modules. We have tested the concept of the CI for a limited number of equipment items flown on Spacelab-3, and we find the CI to be easy to use. In these tests the CI was a good relative measure of the contamination generated by each item. In addition the CI was scaled so that equipment with a CI less than approximately 1.0 were acceptable contamination sources on the Spacelab. We expect the same CI to apply to the Space Station, but the scaling factor could be changed to either increase or decrease the CI for the Space Station. The CI has the advantage that it can be calculated immediately following the 72-hour outgassing test and it provides a quantitative assessment of an item's contamination production.

It is important to remember that the CI is a new parameter and has been tested on a limited number of equipment items. We recommend that additional verification of the CI be performed. For example we should calculate the CI for some articles that have failed a final contamination analysis, but this was not possible with the data we have available at this time.

We recognize the need for contamination guidelines that will permit Space Station users to make early assessment of contamination sources. One method of achieving this objective is by using the CI. We expect that if this index or another similar one is used in the manner described above, Space Station users will have sufficient information to select materials and design equipment prior to completion of the final contamination analysis, and NASA personnel can quantify the contamination potential of equipment proposed for the Space Station. This will facilitate the full utilization of Space Station resources and enhance contamination control capabilities on the Space Station.

LIST OF REFERENCES

1) R.T. Ruggeri, sixth monthly status report, "Space Station Contamination Control Study", contract # NAS8-36432, George C. Marshall Space Flight Center, NASA, Feb. 1986.

2) M.E. Coleman, "Postflight Report for STS 51-B Atmospheric Analysis", Memo SD4-85-206, Lyndon B. Johnson Space Center, NASA, 9/18/85.

3) M.E. Coleman, private communication, 15 April 1986.

4) P.W. Fredrick, "Spacelab Mission 3 Aggregate Trace Contaminant Assessment", Memo EP45(84-148), George C. Marshall Space Flight Center, NASA, 1984.

5) M.W. Steinthal, "Orbiter Crew Cabin Offgassing Report for STS-9", JSC-16457, Lyndon B. Johnson Space Center, NASA

ATTACHMENT E

INTERNAL CONTAMINATION CONTROL PLAN FOR THE SPACE STATION

TABLE OF CONTENTS

INTERNAL CONTAMINATION CONTROL PLAN FOR THE SPACE STATION

1.0 Scope

This document contains the contamination requirements for all pressurized areas of the Space Station manned modules. The contamination requirements described here are based on toxicological requirements imposed by the NASA toxicologist, but the requirements presented here in no way mitigate or affect the toxicological requirements. These contamination requirements are intended to control the source and removal rates of all molecular and particulate contaminants in the breathing atmosphere inside Space Station modules. Although these requirements are based primarily on the toxicological requirements for human health, it is within the scope of this document that requirements may be based on other factors such as safety, hardware, or ease of operation. Where possible the basis of the requirement will be stated if it is other than toxicity to humans.

2.0 Reference Documents

1. JSC 07700, Vol. xiv, Space Shuttle Payload Accommodations.
2. JSC 30000, Space Station Program Definition Control Requirements.
3. JSC Sn-C-0005B, Specification, Contamination control Requirements for the Space Shuttle Program.
4. NASA Handbook 8060.1C.
5. JSC 20149, General Specification, Space Station Requirements for Materials and Processes.

3.0 Definitions

3.1 Contaminant

Any chemical or mixture of chemicals in solid, liquid, or vapor form that has been designated as a contaminant by either the contamination control board or the NASA toxicologist.

3.2 Source

The origin of a contaminant. Contamination Sources include but are not limited to materials, fixed equipment, portable equipment, space station modules, human beings, experiments, and activities.

3.3 Source Rate

The rate a contaminant is generated by one or more sources. Usually expressed as micrograms/day for molecular contaminants and number/hour for particulates.

3.3.1 Single Source Rate

The rate a contaminant is generated by a single source.

3.4 Trace Contaminant Removal System (TCRS)

Any apparatus used to remove contaminants from the breathing atmosphere in Space Station modules.

3.5 Maximum Allowable Source Rate

The maximum allowed rate of generation of a specific contaminant from all combined sources in one Space Station module.

3.6 Group Representative Contaminant

The contaminant with the largest maximum allowed source rate in a particular toxicological group. Under normal circumstances this is the contaminant with largest SMAC in a particular toxicological group.

3.7 Total Toxic Hazard Index

The index used by the NASA toxicologist to assess the physiological hazard of a single toxicological category. See reference document 4.

3.8 Toxicological Category

Classifications of chemical compounds by toxicological effect. (Irritants, asphyxiants, central nervous system depressants, systemic poisons, and carcinogens). See reference document 4.

3.9 Spacecraft Maximum Allowed Concentration (SMAC)

The maximum allowed concentration of a particular contaminant in the breathing air inside space station modules. Usually expressed in units of milligrams per cubic meter of air.

3.10 Contamination Index

An index specified by the contamination control board for each contaminant source in space station modules.

3.11 Contamination Control Board

The governing body controlling all contamination requirements and practices except those related to human health which are the province of the NASA toxicologist.

4.0 Applicability and Authority

4.1 Contamination Control Board

The contamination control board shall have authority over all rules and regulations of this document.

4.2 Contamination Sources

These contamination requirements apply to all materials and assembled articles used in or placed on, the Space Station. In addition, limitations are placed on the contamination source rate from materials, assembled articles, human beings, and certain activities and procedures occurring inside Space Station modules.

5.0 Requirements

5.1 Ground Operations

Contamination requirements for ground operations are contained in JSC 07700, Vol. XIV (document 1) above and the appropriate ICD. However nothing in these documents shall affect the requirements stated below.

5.2 STS Operations

Contamination requirements for the STS shall be independent of those stated below, and are included here by reference as above in section 5.1 (reference document 3).

5.3 Space Station Operations

5.3.1

A Maximum Allowable Source Rate shall be specified for each contaminant by the contamination control board.

5.3.1.1

Maximum source rates for contaminants generated by portable equipment, fixed equipment, human beings, and activities and experiments shall be specified by the contamination control board.

5.3.2

The TCRS shall be capable of removing each contaminants such that its steady state concentrations in the breathing air is less than 10% of the SMAC when the contaminant is being generated at the maximum allowable source rate.

5.3.2.1

The TCRS shall further have the capability of simultaneously maintaining the steady state concentrations of all group representative contaminants at less than

10% of their SMAC while all group representative contaminants are being generated at their maximum allowable source rate

5.3.3

The trace contaminant removal system shall be capable of removing contaminants from the air such that the total toxicity hazard index shall not exceed 0.5 under any combination of contaminant source rates consistent with sections 5.3.2 and 5.3.3 above and reference 4.

5.3.4

The requirements of this document are in addition to and independent of those imposed by the NASA toxicologist. All materials and payloads shall meet the contamination requirements contained in JSC 30000, NHB 8060.1C and JSC 20149 (reference documents 2, 4, and 5). In addition, all materials and assembled articles shall have a contamination index less than 1.0 prior to launch and at all times while in a space station module.

5.3.5

Any out of bounds condition on an operational space station module shall be reported to the contamination control board as soon as possible, but always within 12 hours.

5.3.6

All assembled articles and where possible all materials shall be tested prior to use on the Space Station for offgassed contamination in accordance with NHB 8060.1C (modified test 7 - appendix 2) and for long term degradation according to test 102 detailed in appendix 3. No item shall pass these tests by similarity with another item. Each item shall be tested individually.

5.3.6.1

All pre-flight testing and contamination analysis shall be conducted by persons and in facilities certified and approved by the contamination control board.

5.3.7

Each operational Space Station module shall be tested for contamination in the breathing air according to test 101 (appendix 1) at least once per year. These tests shall be conducted in such a way that the source rate of each contaminant can be quantitatively determined and compared with the maximum source rates specified by the contamination control board. The results of the contamination test shall be reported within 3 days to the contamination control board and the NASA toxicologist.

5.3.8 Contamination Monitoring

5.3.8.1

Equipment shall be provided to detect and monitor all contaminants specified by the contamination control board or the NASA toxicologist.

5.3.8.1.1

The concentration of particle and molecular contaminants in the breathing air shall be monitored on a continuous basis.

5.3.8.1.2

Particle fallout rates shall be monitored on a continuous basis. The contamination control board shall specify the physical location and orientation of witness plates or other measurement apparatus. The contamination control board shall specify the measurement apparatus, type of fallout surface, and measurement frequency of the particle fallout tests.

5.3.8.1.2.1

The contamination control board shall define the type of collection surfaces used in the particle fallout tests. Recommended surfaces are glass, teflon, aluminum, and polyethylene.

5.3.8.1.3

Molecular contamination fallout onto surfaces shall be monitored on a continuous basis. The contamination control board shall specify the physical location and orientation of witness plates or other measurement apparatus. The contamination control board shall specify the measurement apparatus, type of fallout surface, and measurement frequency of the molecular fallout tests.

5.3.8.2

The contamination control board shall specify the sampling rate of the monitoring equipment for each contaminant.

5.3.8.3

The contamination control board shall specify the detection threshold, sensitivity, and accuracy of the monitoring equipment for each contaminant. Unless prescribed otherwise, the detection threshold concentration of contaminants shall be 0.1% of the spacecraft maximum allowed concentration (SMAC).

5.3.8.4

The contamination control board shall specify an alarm threshold concentration for each contaminant. Unless prescribed otherwise the alarm threshold shall be 10% of the SMAC.

5.3.8.5

All alarms and abnormal contamination readings shall be reported to the contamination control board within 12 hours.

APPENDIX A OF ATTACHMENT E

New Test Proposed for In-Flight Contamination Assessment of Space Station Modules

NEW TEST PROPOSED FOR IN-FLIGHT CONTAMINATION ASSESSMENT OF SPACE STATION MODULES

1.0 Scope

This test prescribes the procedure to be used to determine contamination source rates inside operational space station manned modules.

Source rates and the removal efficiency of the operational trace contaminant removal system (TCRS) will be determined by monitoring the concentration of each contaminant in the breathing air following substitution of a second, well calibrated replacement TCRS for the operational TCRS.

2.0 Definitions

2.1 Trace Contaminant Removal System (TCRS)

Any apparatus used to remove contaminants from the breathing atmosphere in Space Station modules.

2.2 Replacement TCRS

The calibrated and certified trace contaminant removal system that will be substituted for the normal TCRS.

2.3 Operational TCRS

The trace contaminant removal system used in normal, everyday operation of the space station.

2.4 Contamination Index

An index specified by the contamination control board for each contaminant source in space station modules.

2.5 Contaminant

Any substance in either gaseous, liquid or solid form that has been designated a contaminant by either the NASA toxicologist or the contamination control board.

2.6 Contamination Control Board

The governing body controlling all contamination requirements and practices except those related to human health which are the province of the NASA toxicologist.

2.7 Operational Contaminant Detection System

The apparatus normally used to perform routine daily measurements of contaminants in the breathing atmosphere of space station modules.

2.8 Source

The origin of a contaminant. Contamination Sources include but are not limited to materials, fixed equipment, portable equipment, space station modules, human beings, experiments, and activities.

2.9 Source Rate

The rate a contaminant is generated by one or more sources. Usually expressed as micrograms/day for molecular contaminants and number/hour for particulates.

3.0 Criteria for Acceptability

Acceptance by the NASA toxicologist, and a contamination index less than 1.0 for each Space Station module and contents.

4.0 Test Conditions

The test shall be conducted in operational space station modules, but all doors and hatches shall be closed and no access shall be permitted to the module during the test. The number of persons inside a module shall be minimized during the contamination test.

5.0 Test Procedure

5.1 Calibration

The replacement TCRS apparatus shall be calibrated for all contaminants found in routine atmospheric samples and such additional contaminant species as shall be specified by the NASA toxicologist or the contamination control board.

The calibration procedure shall consist of supplying a gas mixture of known composition to the inlet of the replacement TCRS apparatus and measuring the composition and flowrate of each specified contaminant species in the stream outlet from the replacement TCRS unit.

Appropriate analytical apparatus such as gas chromatographs, mass spectrometers and spectrophotometers shall be used to perform chemical analysis of both the inlet and exhaust gas from the replacement TCRS.

Calibrations shall be conducted over a range of contaminant concentrations sufficient to span the contaminant concentration in the breathing atmosphere.

A calibration of all analytical apparatus shall be performed immediately prior to and following each test of a space station module.

Calibration gas mixtures shall be certified for composition before and after use on the space station, and at least once every six months.

The operational contaminant detection system may be used to determine contaminant concentrations in the breathing air provided such use and procedures are approved by the NASA toxicologist and the contamination control board. All apparatus used to collect and analyze samples of the breathing air must be calibrated immediately prior to and following use in this test.

5.2 Test Procedure

Contaminant source rates shall be determined in each space station module at locations specified by the NASA toxicologist or the contamination control board at least once every six months. The source rates shall be determined by accurately measuring the contaminant removal rate through the replacement TCRS.

The replacement TCRS hardware shall be calibrated per the specifications of section 5.1 prior to use in this test procedure.

5.2.1 Test Duration

The test shall be conducted for a period not less than 8 hours or until all disturbances in contaminant concentration caused by performing the test have been eliminated and a steady state has been achieved.

5.3 Reporting

The test results, test procedure, source rate of each contaminant, removal efficiency of the operational TCRS, and removal efficiency of the replacement TCRS shall be reported and submitted for approval of the NASA toxicologist and the contamination control board within 3 days of completion of the test.

APPENDIX B OF ATTACHMENT E

Recommended Modification of Test 7 Procedures -
Determination of Offgassed Products Test.
(Test 7 is a portion of NHB 8060.1B)

Modifications to the original test 7 are written in italics and identified in the right hand margin.

MODIFIED TEST 7 - DETERMINATION OF OFFGASSED PRODUCTS TEST

1. Purpose

This establishes the criteria for a screening test to determine the suitability of nonmetallic materials for use in the space vehicle crew compartment environments. The criteria are established with respect to production of potentially toxic volatile offgassed products.

2. Definitions

The following definitions apply to the terms as used in this test procedure:

a. Offgassing. The evolution of gaseous products from a liquid or solid material.

b. Offgassed Product. An organic or inorganic compound evolved from a liquid or solid material.

c. Maximum Allowable Concentration (MAC). The maximum concentration of an offgassed product that is allowed in the spacecraft for a specified flight duration. MAC values for manned spacecraft are contained in Appendix D.

3. Criteria for Acceptability

a. The quantity of each offgassed product, as determined from either a standard quantity of a material or the actual quantity used in the spacecraft, shall not result in a projected spacecraft concentration in excess of the MAC value for that product.

b. The toxicological summation of the total offgassed products of a material shall be evaluated for potential toxicity in accordance with the MAC guidelines of Appendix D (not included here, see NHB 8060.1B) by the responsible NASA toxicology group.

bb. *The contamination index of a material or assembled article shall not exceed 1.0.*

c. Final acceptance of material shall be determined by the responsible NASA medical office from an assessment of the potential toxicity of the total quantity of offgassed products from all contaminant generating items for a given mission. (Anodized metal panels and other similar protective treatments and untreated metal panels do not require testing for toxicity.)

4. Test Conditions - Temperature, Pressure and Atmosphere

The test pressure, temperature and gas mixture conditions for the pertinent materials type shall be designated by the cognizant center program office. These conditions shall represent the most hazardous atmosphere anticipated in the spacecraft. The test atmosphere shall be the worse case atmosphere as defined by the applicable program office except that the pressure shall be slightly below ambient at the test laboratory. *Unless specified otherwise the test temperature shall be 50°C and the test pressure shall be 0.75 atmosphere absolute.*

5. Test Equipment

a. Test Chamber. The test chamber shall have a minimum volume of two liters. It shall have a configuration and be fabricated of *aluminum*. Valves and seals used shall contain no soft goods that contribute detectable offgassing to the chamber. Appropriate instrumentation will be used to provide and monitor the required temperature and pressure in the test chamber. The chamber shall be constructed so as to permit direct gas sample introduction from the chamber to the analytical equipment.

b. Chamber Vacuum, Pressurization and Thermal Cleaning Equipment. The equipment shall consist of the following items (Figure 4-6) and/or any other equipment that the test laboratory requires to assure chamber certification as specified in subparagraph 6.

(1) Vacuum pump with a free air displacement of at least 100 liters per minute and an ultimate vacuum capability of 1.0×10^{-3} Torr or lower pressure.

(2) Pressure gage accurate to ±0.03 psia; 0 to 15 psia range (nominal).

(3) Vacuum gage capable of measuring 10^{-4} Torr.

(4) Manifold with valves for interconnection of the chamber, vacuum pump, pressure gage, vacuum gage, K-bottles *and analytical equipment*.

(5) Heat gun rated at 1000 watts (nominal).

(6) Liquid nitrogen dewar.

(7) K-bottles (commercially supplied bottles) of oxygen and nitrogen with suitable regulators. Oxygen and nitrogen used shall be of sufficient purity to minimize analytical interferences. Oxygen and nitrogen complying with MIL-O-27210, Type 1 and MIL-P-27401C, Type 1, Grade A, respectively, as amended below, have been found suitable for this use. Cylinders of premixed test atmospheres should meet the requirements below.

Recommended Maximum Limits (ppm by volume) for Selected Impurities in Oxygen and Nitrogen

	Oxygen	Nitrogen
Carbon Monoxide	2.0	2.0
Carbon Dioxide	10.0	10.0
Total Hydrocarbons, as CH_4	2.0	2.0
Halogenated Compounds	0.5	0.5
Water	7.0	7.0

c. Heating Source. The heating unit or oven shall maintain the test chamber *and gas sampling manifold* at the designated test temperature ±5°F. The temperature during sample thermal conditioning shall be recorded.

d. Analytical Equipment. The analytical equipment shall consist of the following types of equipment and any other instruments the test laboratory requires to assure accuracy and precision in the offgassed products analyses:

(1) Gas Chromatograph System. The gas chromatography system shall employ detectors capable of responding to the offgassing products listed in Appendix D (not included here, see NHB 8060.1B). As supplementary detectors, the following are recommended: electron capture, flame photometric, nitrogen/phosphorus flame ionization, and photoionization detectors. The separatory columns shall have the capability of separating light organic and inorganic gases, organic sulfides and mercaptans, halogenated hydrocarbons, representative aliphatic and aromatic hydrocarbons including aldehydes, ketones, alcohols, and esters.

(2) Recording Infrared Spectrophotometer with 10-Meter or Greater Path length Infrared Gas Cell. The cell shall have provisions for heating to test temperature and maintaining temperature to ±5°F.

(3) Mass Spectrometer. The mass spectrometer range shall be 10 to at least 600 amu; resolution shall be at least 1200 at mass 600 (resolution is defined as $m/\Delta m$ when Δm is measured at peak half height). The sensitivity shall be such that a 10 nanogram/second sample will produce identifiable spectra of acetone or toluene.

(4) Gas sampling system suitable for the transfer of measured volumes of gas samples from the test chamber to the analytical instruments *while maintaining the gas sample at the test temperature between the test chamber and the analytical equipment.*

(5) Calibration standards as required to calibrate detectors. The calibration gas used with flame ionization detectors shall be propane; working

standards shall be referenced to propane standards from the National Bureau of Standards. *Absolute calibrations of each contaminant shall be performed at least twice a year, and the calibration results shall be reported. A calibration chemical shall be designated for each type of chemical, e.g. alcohols, aldehydes, ketones, aromatic compounds, etc.*

(6) *The analytical equipment should have a detection threshold of 0.1% of the SMAC for each contaminant, and an accuracy not less than ±15% of the measured value over the range from 0.1% of SMAC up to the SMAC.*

6. Sample Chamber Certification

a. Cleaning. The sample container shall be cleaned, heated, and purged with air or nitrogen by some suitable method to reduce residual container contamination (background).

b. Leak Check. Connect the chamber to the vacuum and pressurization system (see Figure 4-7). The chamber shall be evacuated to less than 1 Torr and checked for leaks. The chamber shall be acceptable for use if the pressure rise due to leaks does not exceed 2 millitorr per minute.

c. Cleanliness Certification. Before loading the sample into the chamber, the chamber shall be filled with the test atmosphere or nitrogen to 6.0 psia and conditioned for 72 ± 1 hour at test temperature. Alternatively the container may be conditioned for 24 ± 1 hour at test temperature plus 35°F. The chamber atmosphere shall then be analyzed for residual contamination (background). The chamber shall be certified as clean for use if the concentrations of the residual volatiles (background) are sufficiently low to permit detection and quantitation of offgassed products from the test specimen (see paragraph 8).

7. Test Specimens Preparation

a. Categories. All the materials to be tested shall be classified into two categories: weight and specialized items.

b. Samples Based on Weight

(1) Materials which are essentially two dimensional and require application to a substrate (e.g., films, coatings, primers, inks, paints, adhesives, tapes, thin film lubricants, etc.) shall be applied to clean aluminum substrates 0.003- to 0.020-inch thickness. Samples may be applied to both sides of the substrate. A sufficient number of substrates with sample shall be prepared so as to provide a net sample weight of 5.0 ± 0.25 grams per liter of test chamber volume. The *weight*, total sample surface area *and sample thickness* shall be reported.

NOTE: In some cases (e.g., inks and other very thin film) it may not be possible to attain the required weight of 5.0 ± 0.25 grams per liter of test chamber volume. In these cases, the maximum practical quantity of sample less than 5.0 ± 0.25 grams per liter of test chamber volume shall be tested.

(2) Materials which are essentially two dimensional and are not applied to a substrate (e.g., fabrics, photographic film and similar materials) shall be cut to convenient test dimensions. Heat shrinkable tubing shall be shrunk to simulate actual use configuration. A sufficient quantity of sample shall be cut so as to provide a sample weight of 5.0 ± 0.25 grams per liter of test chamber volume. *Sample weight, total surface area, and thickness shall be reported.*

(3) Materials which are essentially three dimensional (e.g., foams, insulation padding, potting and molding compounds, cast or formed objects, thick plastics, liquids, etc.) shall be tested as closely as possible to the use configuration and cut to provide a sample weight of 5.0 ± 0.25 grams per liter of test chamber volume. Liquids shall be placed in suitable nonreactive dishes. *Sample weight, total surface area, and thickness shall be reported.*

c. Specialized Items. It must be recognized that some materials may not meet the above requirements and must be specially handled. This will most often occur with nonhomogeneous materials. These materials will be tested in the manner designated by the test engineer in charge. The manner of testing and sample preparation shall be fully reported. The desirable ratio of test material weight to test chamber volume is 5 ± 0.25 grams per liter.

8. Test Procedure

a. Place a clean, *measured, and* weighed specimen prepared per subparagraph 7 in the test chamber.

b. Connect the chamber to the vacuum and pressurization system shown in Figure 4-6. Evacuate the chamber to 0.2 ± 0.05 psia and backfill with the test atmosphere to 2.0 ± 0.05 psia. Reevacuate to 0.2 ± 0.05 psia and backfill with test atmosphere to a pressure such that the chamber will be at test pressure when the test atmosphere is at test temperature. The test atmosphere composition may be obtained by partial pressure addition of oxygen and nitrogen during the loading step or by use of a premixed test gas.

c. Heat the chamber *and gas sample manifold* to test temperature ±3°C for a period of 72 ± 1 hour.

d. Measure and record the chamber pressure *at the beginning and end of the 72-hour period.*

NOTE: The pressure gage or transducer may be an integral part of the chamber or it may be integral with the analytical system. The gage or transducer shall be accurate to ±0.1 psia.

e. Sample and analyze the offgassed products in the chamber at test temperature. *Gas samples should be analyzed after 24, 48 and 72 hour intervals.* The quantitative analysis shall be initiated within ± 1 hour *of the prescribed* conditioning period. Any non-compliance to the time or temperature shall be reported with the test data.

f. The identity and quantity of each analyzable offgassed product, excluding water vapor and carbon dioxide, shall be recorded on the reporting format.

NOTE: Some offgassed components may be present at levels too minute for identification. These shall be reported as "unidentified component" and the quantities expressed in micrograms per gram of sample.

g. All charts, equipment calibration information and test data will be retained in the event that further identification or evaluation is necessary.

9. Reporting

Test data shall be reported in accordance with instructions contained in paragraph 208 on a form similar to Figure 4-8 and will include the identity of organic and inorganic offgassed products and their quantities in micrograms/gram from the material. Water and carbon dioxide shall not be reported. All pertinent test conditions shall be reported. Data to be reported must be verified by an authorized center quality assurance office. *The physical properties of the test specimen shall be reported, including the exposed surface area, thickness, mass, and density.*

10. Certification

a. The contamination control board *shall certify all laboratories and facilities authorized to perform this test.*

b. *A standard calibration material shall be subjected to this test procedure at least once every year in order to maintain certification of the testing laboratory or institution. The results of this test shall be reported to the contamination control board.*

APPENDIX C OF ATTACHMENT E

Proposed New Test to Determine Long Term Degradation of Polymers

TEST 102 PROPOSED LONG TERM DEGRADATION OF POLYMERS

1.0 Scope

This test prescribes the procedures and equipment to evaluate contaminants produced by the long term degradation of polymeric materials used inside spacecraft.

2.0 Definitions

TBD

3.0 Criteria for Acceptance

TBD

4.0 Test Conditions

TBD

5.0 Test Procedures

TBD

ATTACHMENT F

SUBTASK 2.3.2, EXPERIMENTAL PROGRAM

SUBTASK 2.3.2, EXPERIMENTAL PROGRAM

EXPERIMENTAL PROGRAM

INTRODUCTION

The experimental program was conducted to identify improvements that can be made in the procedures currently used to test materials and assembled equipment as contamination sources inside manned spacecraft. The experiments concentrated on evaluating Test 7 detailed in NASA handbook 8060.1B. Our approach was to set up an apparatus similar to that specified in Test 7 and then to conduct Test 7 as prescribed, but to take additional data that allowed us to develop a mathematical model of the offgassing process. Then procedures were modified to determine the effect of the changes on experimental results. Some areas that were examined were: sample preparation, gas purging procedures, gas sampling procedures, test duration, and temperature variation. In general, we found the current procedures to be acceptable, but a number of improvements are recommended.

APPARATUS

Analytical Equipment. All chemical analysis was performed by gas chromatography using a Perkin Elmer, model Sigma 2000 gas chromatograph (GC). Either a single column or a dual column GC method was used, and contaminants were identified by retention time. Three types of columns were employed: Carbowax 20-M, (as a single column), or AT-1000 and OV-101 (in parallel). A temperature programming method was used to assure good resolution of all contaminant peaks. Absolute calibrations of peak height versus mass were used. Reagent grade chemical samples were used as calibration standards.

Test Equipment. Figure 1 is a diagram of the test apparatus used in this study. The ultimate vacuum achievable with this system was 2.5 Torr. The accuracy of the

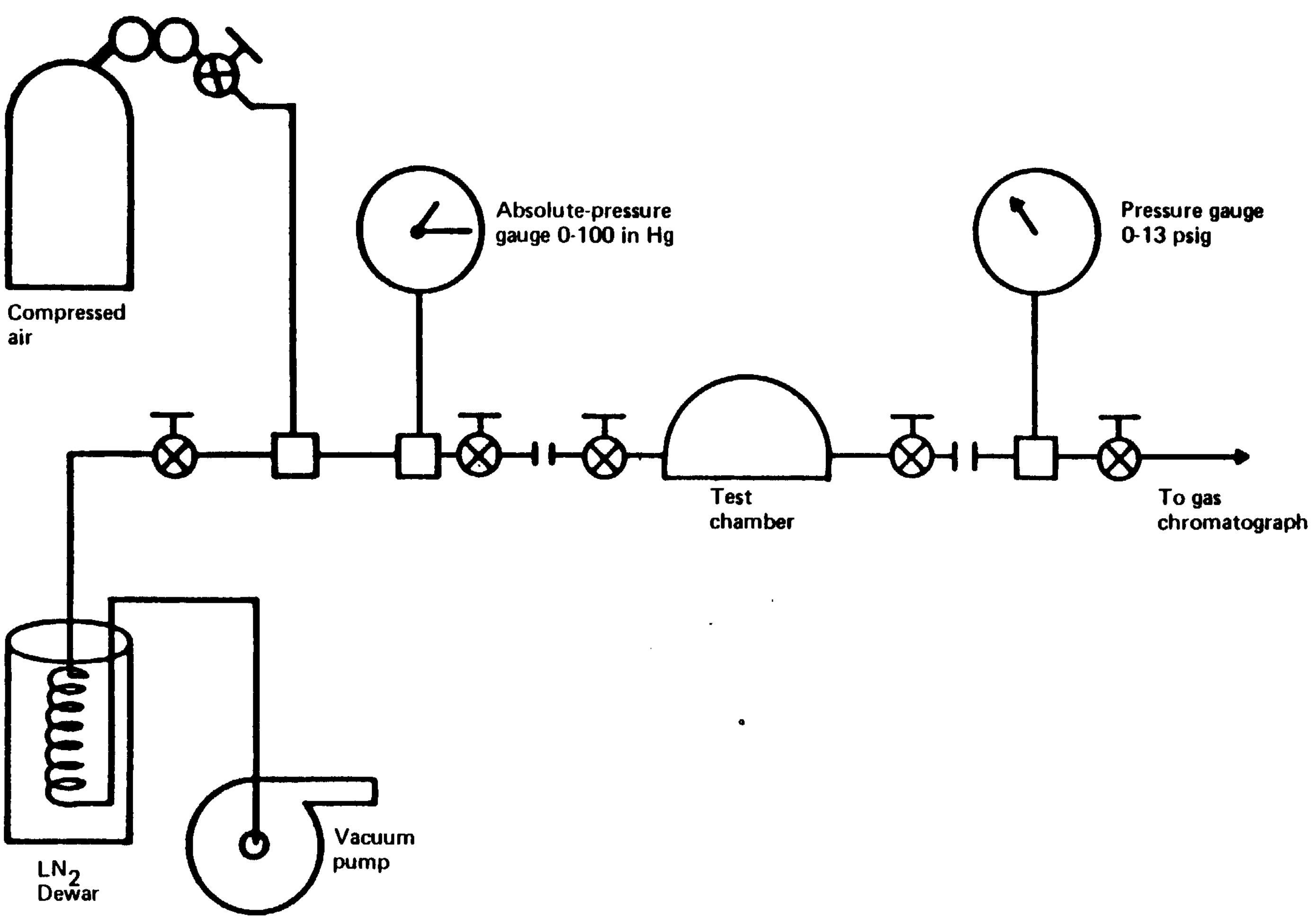

Figure 1. Test Apparatus for Checkout of the Standardized 72-Hour Test Procedure

pressure gauges was also 2.5 Torr. The test chamber was a 2.15 liter 316-stainless steel pressure vessel purchased from the Parr Instrument Company, Moline, Illinois and fitted with two stainless steel valves. The plumbing between the test chamber and the GC (low pressure manifold) was stainless steel one-eighth inch tubing. All other tubing in the gas transfer manifold (high pressure manifold) was one-quarter inch copper.

MATERIALS

Candidate materials were selected from the crew cabin offgassing report for STS-9. Materials that produced either a large quantity of contamination or a large fraction of a particular contaminant were selected. The materials that were selected are listed in table 1. Table 1 also shows the manufacturer of the material, summarizes the sample preparation, and shows if offgassing tests were performed. Two materials arrived too late in the program to be tested, as shown in the table.

Sample Preparation

Coatings and Adhesives. Coatings were applied to an aluminum substrate according to manufacturers specifications. A summary of the application methods is presented in Appendix A. Tests were conducted on 50 square inches of each coating (two, 5 in. by 5 in. specimens).

Acrylic Film Tape. The one sample of acrylic film double sided tape was used as supplied from the manufacturer. One side of the tape was applied to one side of a 25 square inch panel of aluminum for the offgassing tests.

Polymer Beads. The nylon and polypropylene specimens were supplied in the form of solid beads. They were used as supplied without modification.

Table 1. Materials Obtained for Offgassing Test Evaluation

Material	Type	Manufacturer	Samples prepared	Tested
Super Koropon 515-700	Paint primer	De Soto	12-17-85, 1.4 mil on 2024 clad Al	Yes, 50°C
Chemlok 220/205	Adhesive	Hughson Chemicals	12-17-85, 0.6 mil on 2024 clad Al	Yes, 50°C
Acrylic film tape, 465	Adhesive tape	3M	Use as received	Yes, 50°C
30% glass filled nylon	Beads	RTP	Use as received	Yes, 50°C
20% glass filled polypropylene	Beads	RTP	Use as received	Yes, 50°C
Sylgard 184 silicon	Adhesive	Dow Corning	1-30-86, 1 cm thick on 2024 Al	No
Conductive epoxy 02-GY-3	Paint primer	Deft	1-30-86, 1.5 mil on 2024 Al	No

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EXPERIMENTAL PROCEDURE

Experiments were conducted in 5 steps. First, specimens were cut from a single large sample of material. The mass and physical dimensions of the specimens were measured and recorded, and the samples were placed in the test chamber. Then the test chamber was closed and sealed shut. Second, the room air trapped inside the test chamber was purged. The purge was accomplished as a series of evacuations and repressurizations with clean dry nitrogen gas. First the test chamber was evacuated to an absolute pressure of less than 25 Torr. Then the chamber was pressurized to an absolute pressure greater than 1956 Torr. This procedure was repeated a total of three times followed by a final evacuation to 25 Torr and pressurization to 838 Torr. Then all valves were closed and the test chamber was removed from the "high pressure" gas transfer manifold.

The third step was to offgas contaminants from the test specimen into the test chamber maintained at 50 degrees Celsius. For this stage the test chamber was placed in a thermostatically controlled oven for the desired time interval.

The fourth step was to withdraw a sample of gas from the test chamber. The pressure inside the test chamber was always slightly greater than the ambient pressure, and samples were obtained by simply allowing the gas to vent out of the test chamber through a 5.0 mililiter gas trap that was part of the GC's injection system. Prior to sampling the gas, the low pressure manifold was connected to the injection system of the GC, and both were purged with clean nitrogen gas. Then the test chamber was connected to the low pressure manifold as shown in figure 1, and the flow valves were opened. Gas from the test chamber was allowed to bleed off through the GC's injection system for 2.0 minutes, and then the five mililiter gas trap was automatically switched out of the low pressure manifold line and into the injection line of the GC. A reproducible injection of gas was obtained with this procedure. Pressures in the test chamber were recorded before and after sampling to permit us to calculate the fraction of gas that escaped from the test chamber during sampling.

The fifth step of the experimental procedure was to quantitatively determine the concentration of the contaminants present in the sample extracted from the test chamber. This work was largely automated and controlled by the computer in the GC.

EXPERIMENTS

Experiments were conducted to evaluate, standardized 72-hour offgassing test procedures, interpretation of 72 hour test data, application of the 72-hour test results, calibration procedures, and sample injection procedures. The individual experiments will be discussed in greater detail below.

NASA currently relies heavily on the results of the standardized 72-hour offgassing test to provide offgassing rate data that is the basis of all contamination analyses required by the NASA toxicologist. The contamination analyses require the offgassing rate data to calculate the concentrations of contaminants in the breathing atmosphere inside Space Station modules. Currently only 72-hour offgassing rates are used in the contamination analyses. In this work we investigated the ability of the 72-hour offgassing test to provide accurate rate data for these analyses.

Another objective of this work was to determine if the current test is capable of providing all data needed for the Space Station. Offgassing tests for the Space Station need to assess the long term offgassing potential of materials used inside manned modules, and we must assess the ability of the standardized test to provide long-term rate data. If the current test is inadequate, it must be modified or a new test must be adopted.

If long-term data are to be obtained at reasonable cost, accelerated offgassing tests may be used. The most common method of accelerating offgassing test is to increase the temperature of the test chamber. The problem with this procedure is that it also increases the likelihood of contaminants saturating the air inside the test chamber. Thus, some contaminants could reach thermodynamic equilibrium inside the test chamber, and if this were to happen the offgassing rate measured in the 72-hour test would be lower than the rate in a Space Station module.

Another possible method of obtaining long-term offgassing rates is to extend the test period beyond 72 hours. Test specimens might also approach thermodynamic equilibrium in this type of test, and a major deficiency of the current 72-hour test is that there is no way of analyzing the test data to determine if a particular contaminant is approaching thermodynamic equilibrium or not. We have evaluated both the current test and potential accelerated tests to determine if contaminants are approaching thermodynamic equilibrium.

Test Results

Seventy-two Hour Test. Offgassing tests were conducted on selected materials to determine the characteristics of the standardized test. The investigation was conducted with S.K. primer. This material contained a number of contaminants that we expected would exhibit high offgassing rates. Furthermore, we had obtained results from standardized 72- hour offgassing tests conducted at the White Sands test facility which could be used for comparison to our results.

Samples of S.K. primer were prepared in accordance with the White Sands method and then tested according to test 7 procedures except that gas samples were withdrawn from the test chamber and analyzed after 6, 12, 18, 24, 30, 36, 42, 48, 72, 96, and 120 hours. In order to reduce dilution of the gas in a single test chamber, five identical chambers containing identical test specimens were used. Thus, the air in chamber number one was analyzed at 6, 36, and 120 hours. The air in chamber number two was sampled at 12, and 42 hours, and so on for the other test chambers.

In this portion of the work contaminants were identified only by number. This procedure was adopted to reduce analysis and calibration time without sacrificing our ability to determine the important characteristics of the 72-hour test. In another portion of this work, selected contaminants were identified by gas chromatographic analysis. Those results will be presented later.

The results of the S. K. primer tests are presented in figures 2-11. These figures shown the concentration of ten individual contaminants (identified as chromatograph peaks) versus time. The measured data are shown as points, and a 3-parameter fit of the data are shown as a solid line. The best 3-parameter fit to the data was obtained for contaminant number six (peak 6). The other contaminants are generally well represented by the 3-parameter offgassing model.

The data clearly show that the offgassing rate is not constant over the first 120 hours of the offgassing test. In fact the parametric fit shows that the initial offgassing rate is very high and then falls as time increases. This offgassing behavior is typical of contaminants whose offgassing rate is diffusion limited. These contaminants are usually solvents, plasticizers, and unreacted monomer present inside the host polymer at the beginning of the test, but not those chemicals formed continuously in the host polymer by chemical reaction. Only peak number 3 shows behavior that could be interpreted as reaction rate controlled instead of diffusion controlled.

A second observation of the experimental data is that no contaminant is approaching thermodynamic equilibrium after 120 hours. This means that the time constant for diffusion of the contaminants we have considered in this work is greater than 120 hours. This observation provides confidence in the offgassing rates obtained in standardized 72-hour tests.

In order to refine our conclusions based on these tests, a quantitative model of offgassing from polymers was developed. The test results form the basis of the model that is shown schematically in figure 12. The model assumes that each contaminant is

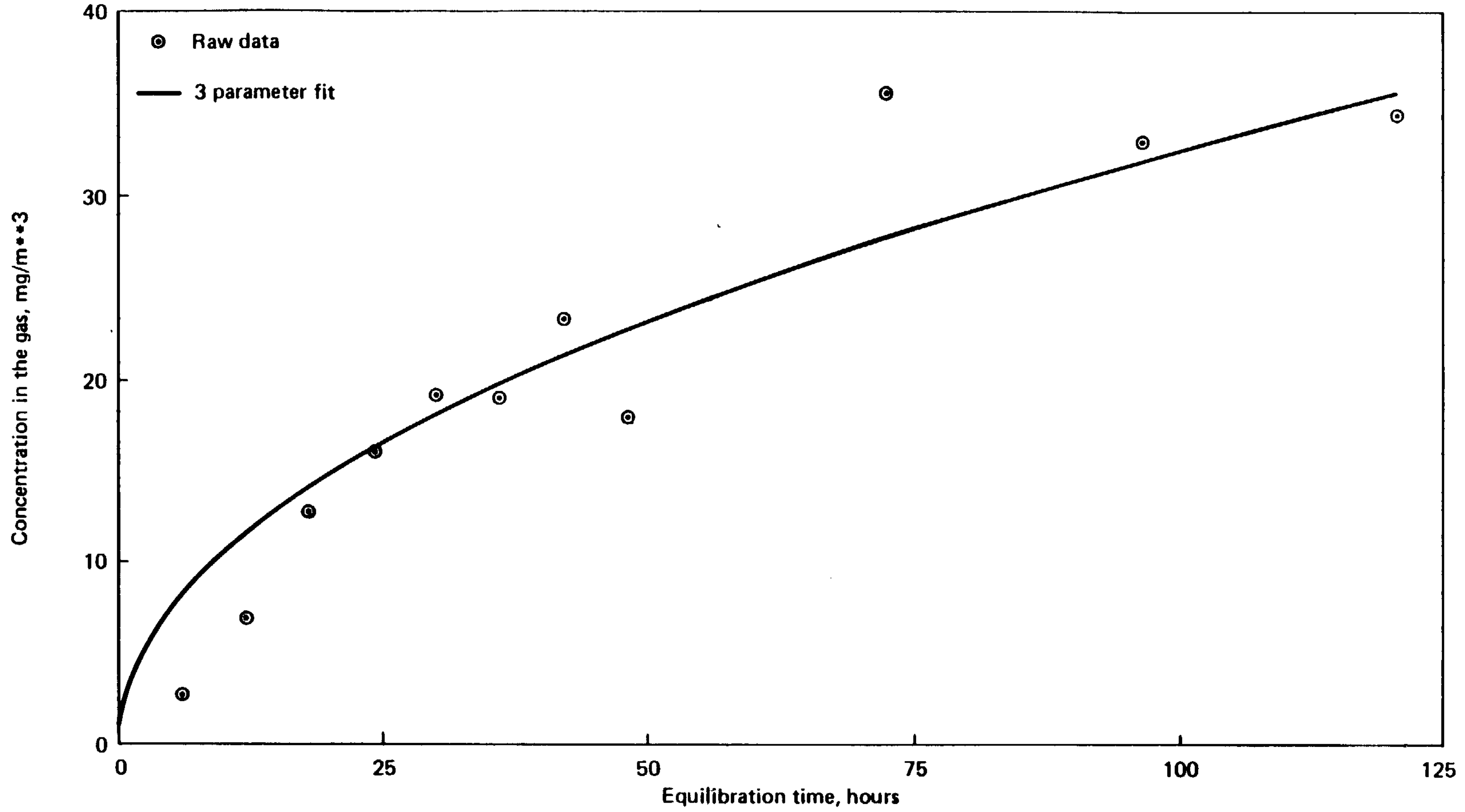

Figure 2. Experimental Offgassing Results for a G.C. Peak Number 1

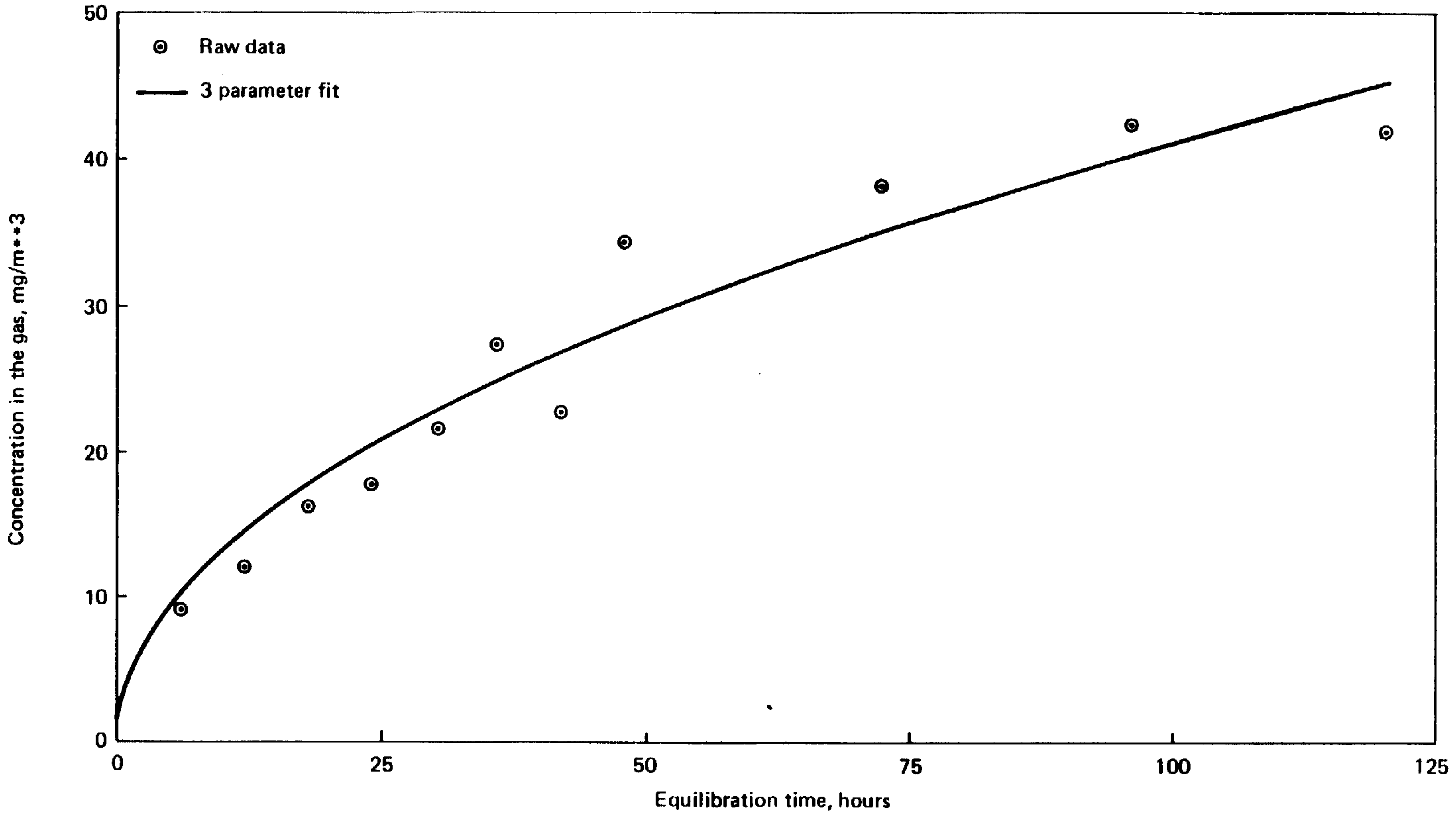

Figure 3. Experimental Offgassing Results for G.C. Peak Number 2

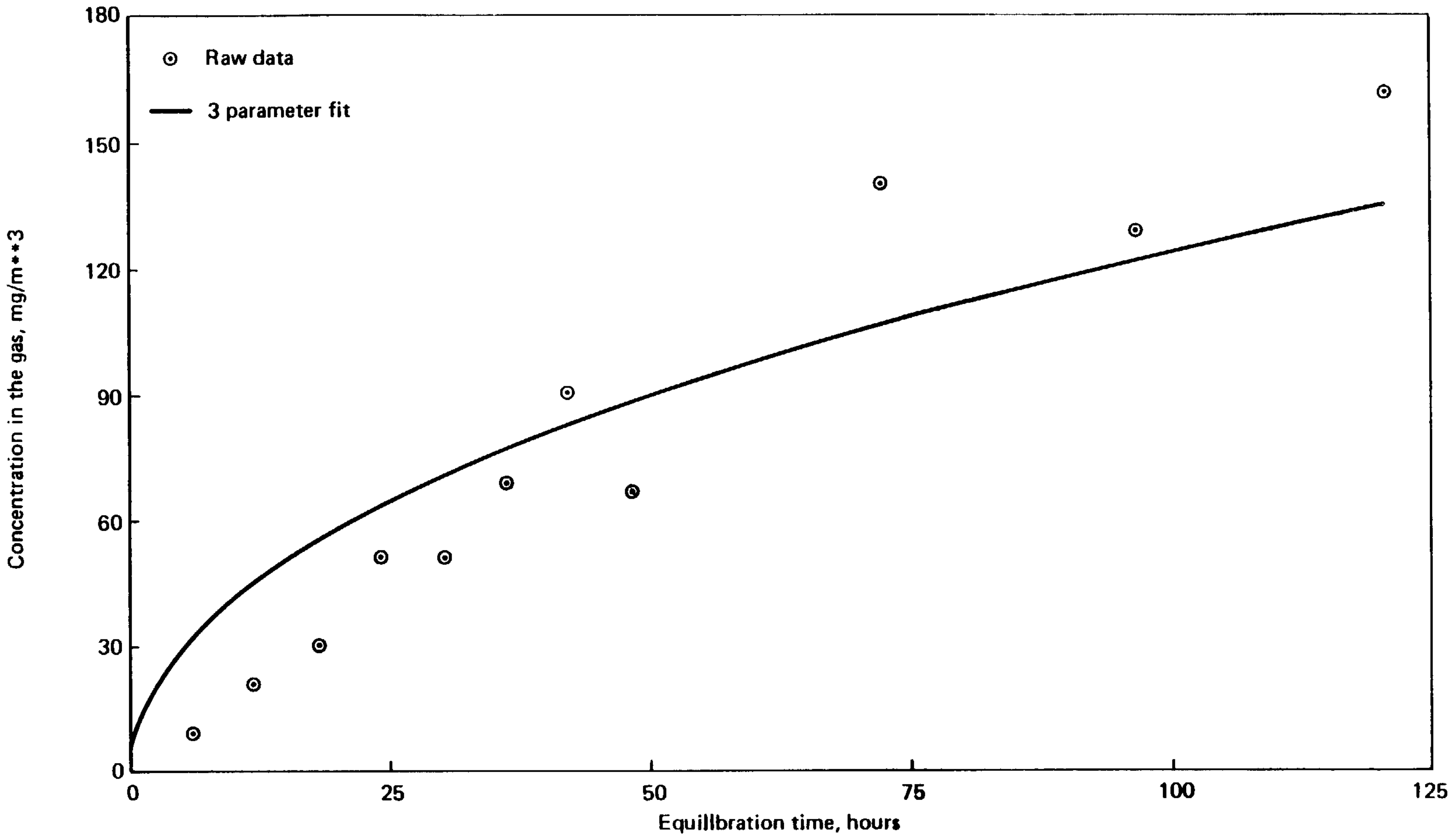

Figure 4. Experimental Offgassing Results for a G.C. Peak Number 3

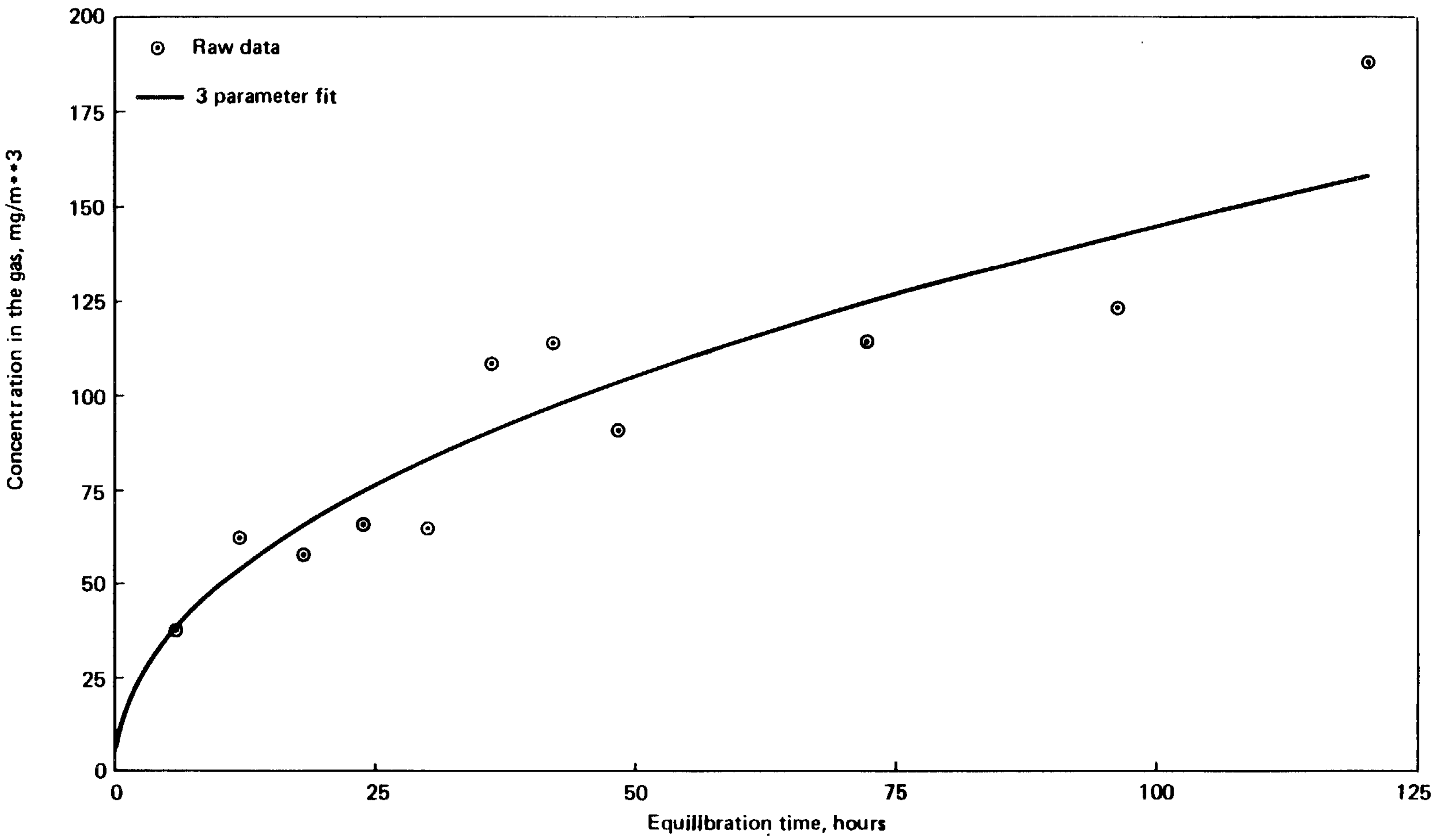

Figure 5. Experimental Offgassing Results for a G.C. Peak Number 4

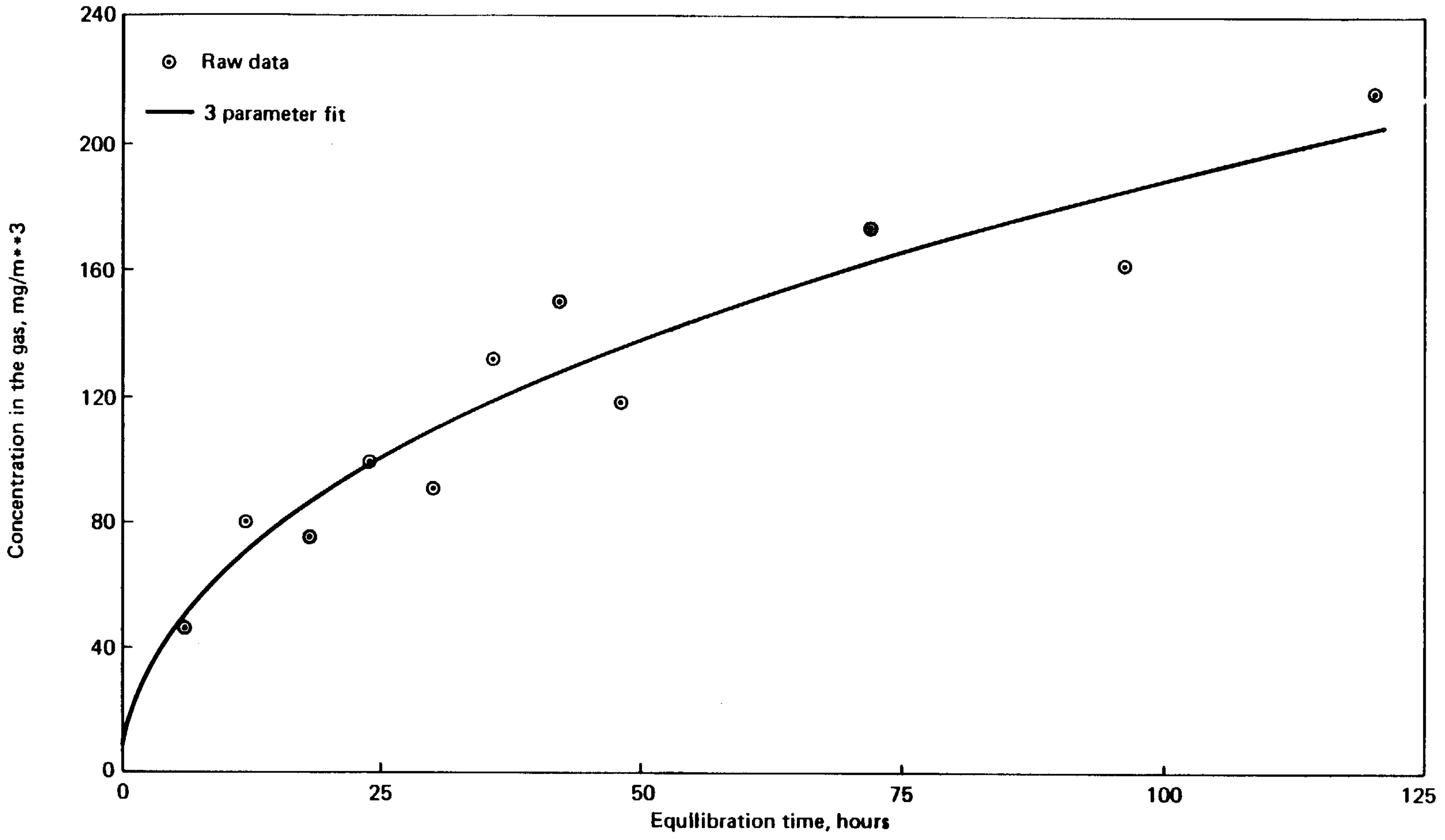

Figure 6. Experimental Offgassing Results for a G.C. Peak Number 5

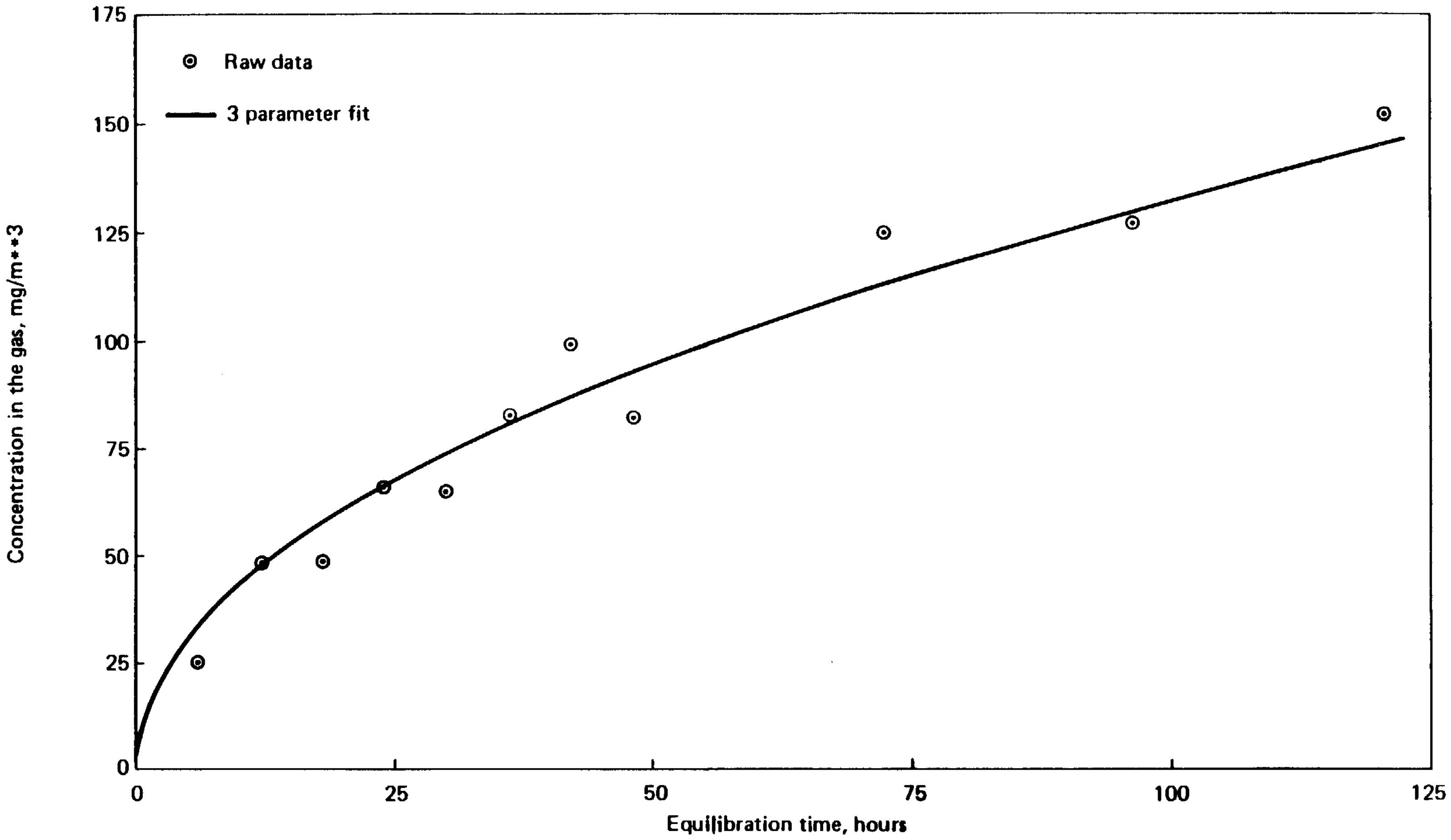

Figure 7. Experimental Offgassing Results for a G.C. Peak Number 6

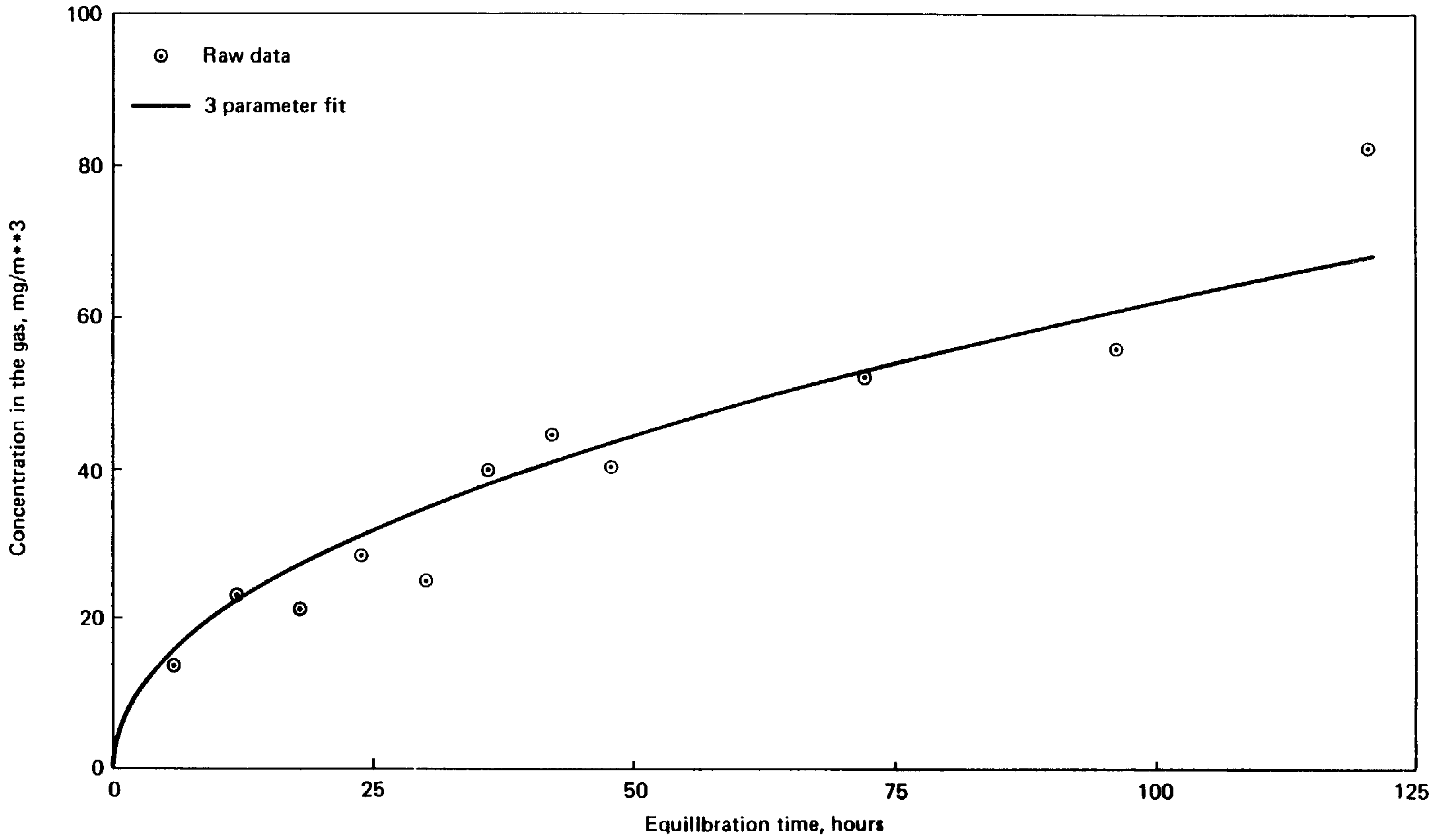

Figure 8. Experimental Offgassing Results for a G.C. Peak Number 7

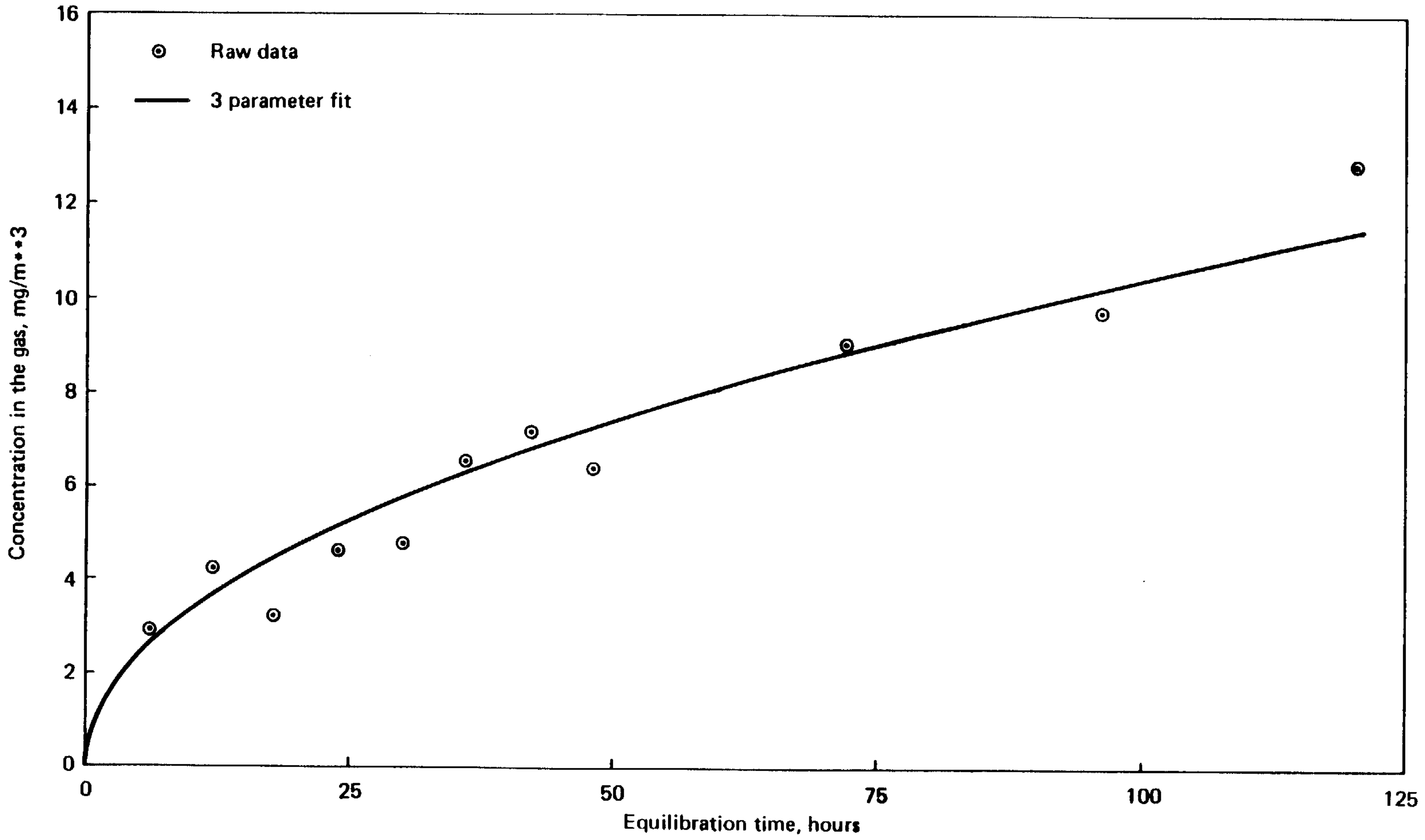

Figure 9. Experimental Offgassing Results for a G.C. Peak Number 8

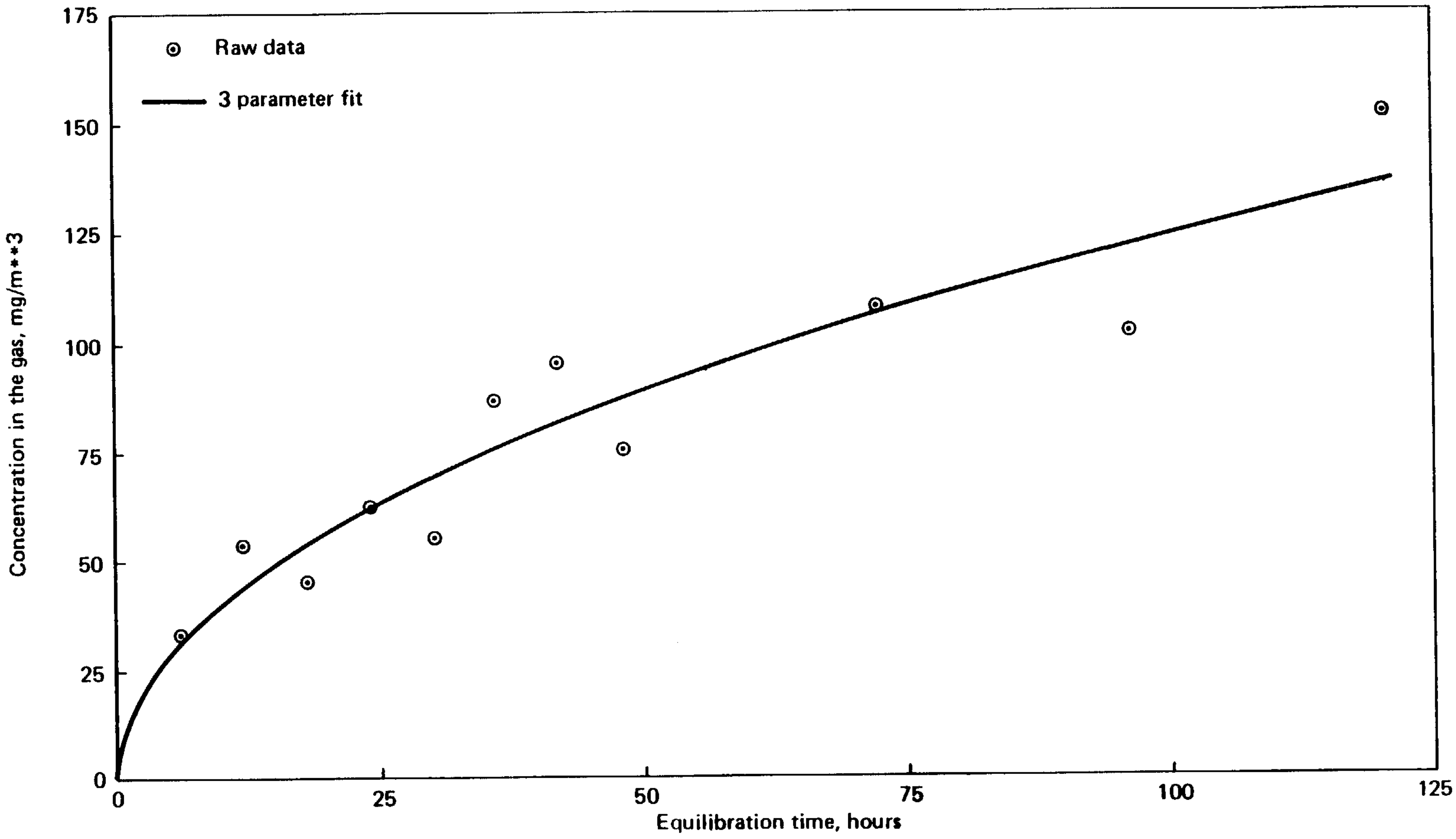

Figure 10. Experimental Offgassing Results for a G.C. Peak Number 9

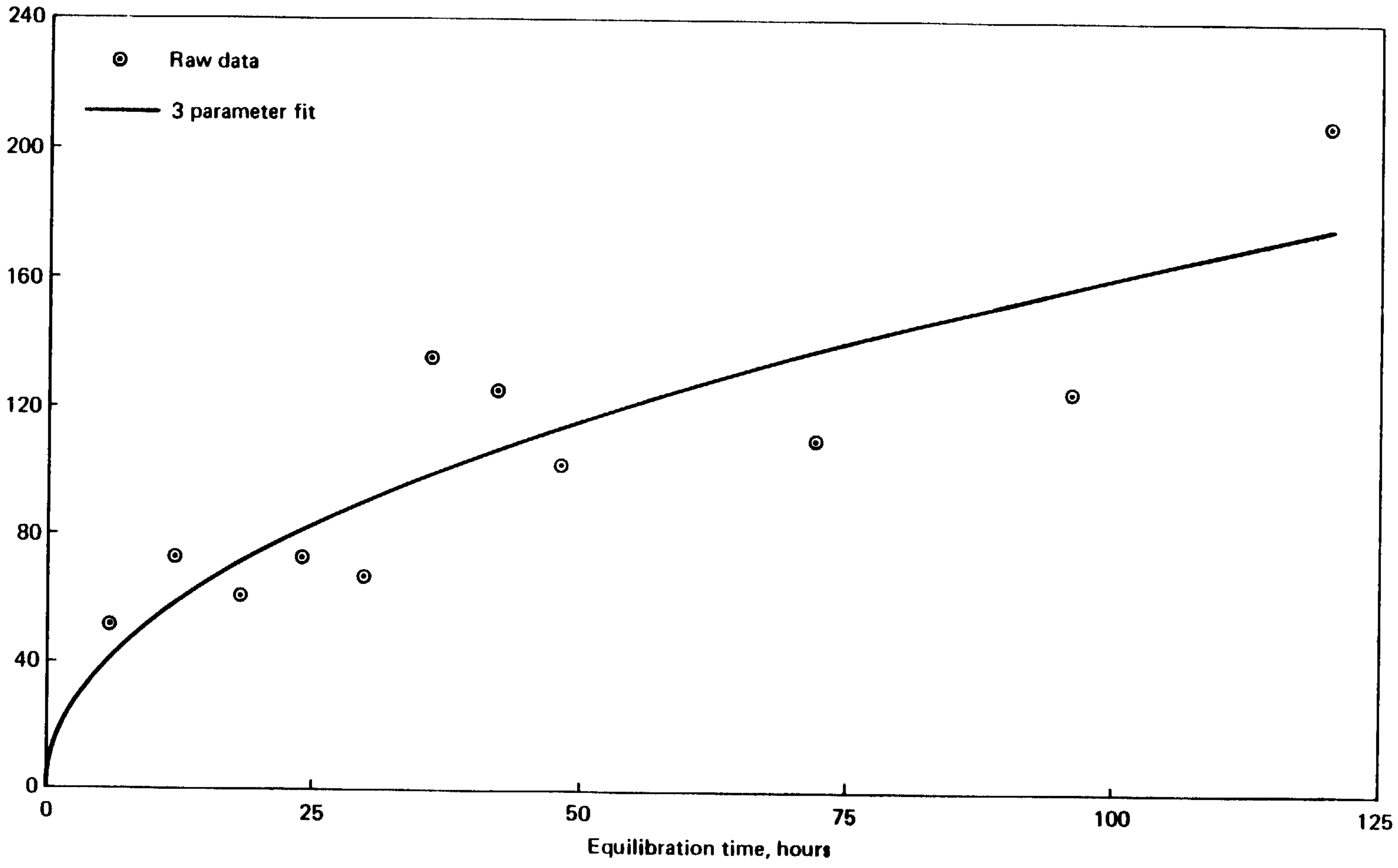

Figure 11. Experimental Offgassing Results for G.C. Peak Number 10

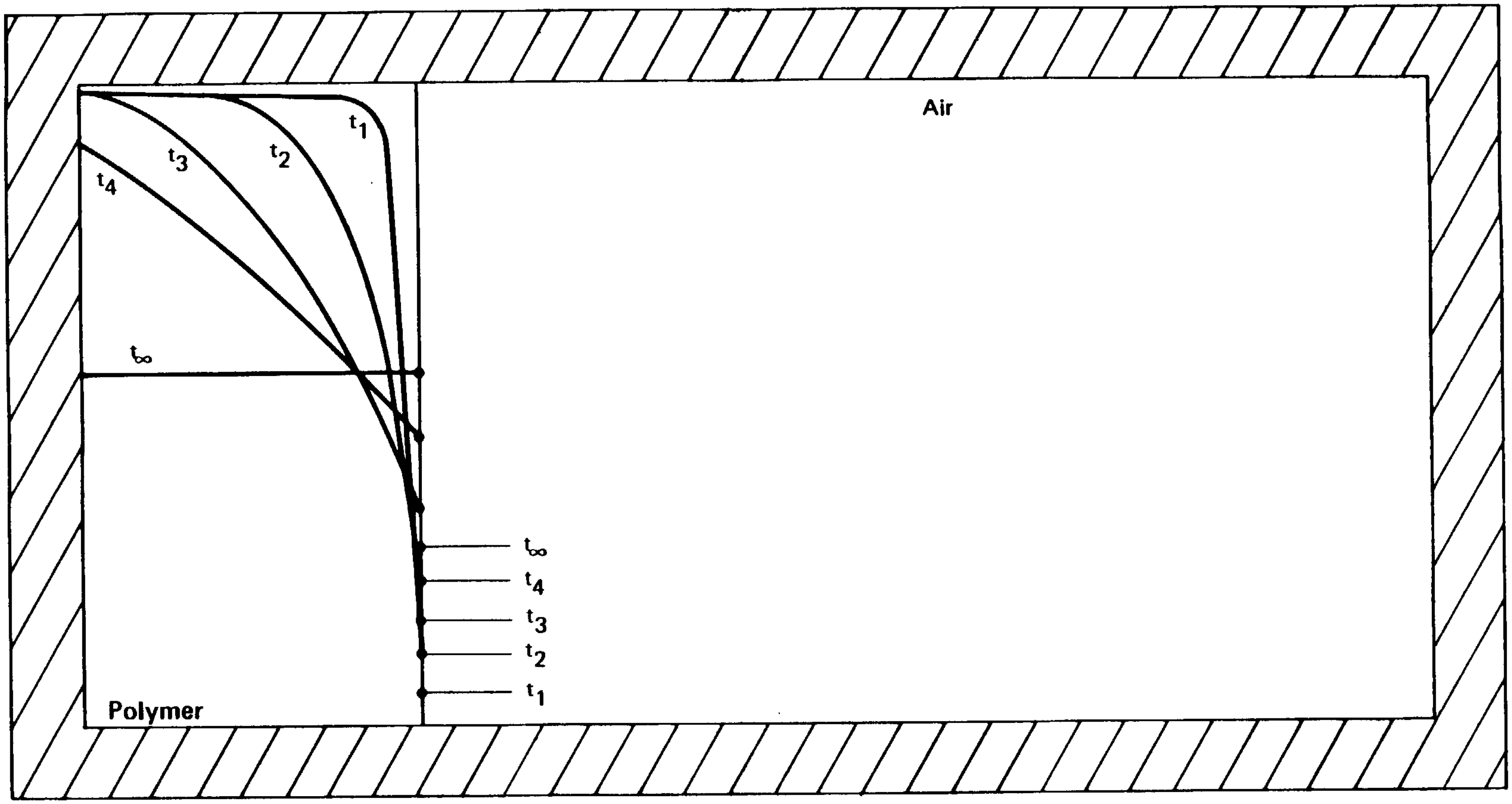

Figure 12. Diffusion Model Showing Contaminant Concentration Profile Inside a Sealed Test Chamber Versus Time

present in the host polymer at the start of the test and is not formed by chemical reaction. It further assumes that at time zero the contaminant is uniformly distributed throughout the host polymer, and that the concentration of contaminant on the air surrounding the polymer is zero. Figure 12 shows that the concentration of contaminant in the polymer decreases and the concentration in the air increases as time increases from t_1 to t_∞. Each contaminant is assumed to diffuse independently of all other contaminants, and each diffusion coefficient is assumed to be constant, i.e. independent of, position or direction inside the polymer, time, or the concentration of any contaminant.

This diffusion model only considers the aspects of diffusion occurring inside the polymer, but in the 72-hour test, diffusion also takes place in the air trapped inside the test chamber. We will now consider the justification for our approach.

In the 72-hour test, contaminants first diffuse inside the host polymer toward the surface. When they reach the surface they evaporate into the air and then diffuse through the air away from the polymer. This process thus involves diffusion through 2 media and is represented by a complex mathematical model (ref. 1). The model can be simplified considerably, however, by realizing that diffusion in air at atmospheric pressure is much faster than diffusion in typical polymers. Diffusion coefficients of large molecules in air are on the order of 0.1 square centimeters per second (ref. 2), while those in polymers range from about 10^{-7} square centimeters per second to many orders of magnitude less (ref. 3).

The time constant for diffusion provides an estimate of the time required for a contaminant to diffuse completely through a material, and is equal to the square of the material's thickness divided by the diffusion coefficient of the contaminant. If a relatively thin polymer is used in the test, the polymer thickness is on the order of 3×10^{-3} centimeters, and the time constant for diffusion through the polymer is greater than 90 seconds. A similar calculation can be applied to diffusion in the air inside the test chamber. The radius of the test chamber used in this work is about 5 centimeters. Thus the time constant for diffusion in the air is about 250 seconds, and is relatively independent of the contaminant species. This calculation indicates that the time constant for diffusion of the most mobile contaminants (small molecules) through a polymer are of the same order as those for diffusion in the air inside the test chamber, but both time constants are much shorter than the age of the polymers used in contamination tests. In the tests performed in this work the polymers were about 30 days old when tested, but offgassing tests performed for the Space Station will usually be conducted on specimens that have offgassed into room air for more than 30 days. The polymer specimens actually tested for the space station will therefore be depleted in contaminants with polymer time constants shorter than 2.6×10^6 seconds, and we can assume that the time constant for diffusion of the contaminants still in the polymer is much greater than that for diffusion through the air inside the test chamber (250 seconds).

Under the assumption of a small time constant for diffusion in the air, the mathematical model of diffusion in the 72-hour test apparatus becomes identical to that described by Crank (ref. 1, p. 56) for diffusion from a solid into a well stirred medium. This model predicts the concentration of a particular contaminant in the air as a function of three parameters: the quantity of contaminant that would ultimately leave the polymer after infinite time (M_∞), the equilibrium thermodynamic partition of contaminant between the polymer and air (α), and the time constant for diffusion in the polymer (τ). In general we can determine M_∞ and α independently in separate experiments, but a diffusion experiment is required to determine the diffusivity D which is included in τ. In this work we used the experimental data to determine all three parameters. The mathematical equation for the quantity of a particular contaminant that has left the polymer after t seconds is:

$$M_t = M_\infty \{ 1.- \sum (2\alpha \ (1+\alpha)/(1+\alpha+(\alpha q_n)^2))\exp(\frac{-q_n{}^2 t)}{\tau} \ \} \qquad (1)$$

$$\tan(q_n) = -\alpha q_n \qquad (2)$$

$$\alpha \ = V_g/(V_s K) \qquad (3)$$

$$\tau \ = \ell^2/D \qquad (4)$$

V_g = the volume of gas in the test chamber

V_s = the volume of solid (polymeric) material

K = the thermodynamic partition coefficient for a contaminant

ℓ = the thickness of the polymer

D = the diffusivity of the contaminant in the polymer

q_n = the nth root of equation 2

M_∞ = the quantity of contaminant that will leave the polymer after infinite time.

A number of conclusions can be drawn from the success of the mathematical model in describing the results of the offgassing tests. First we can obtain quantitative values for the three parameters in the model. This establishes the value of M_∞, the thermodynamic partition coefficient (K), and the diffusion coefficient (D) in the polymer. In this work these parameters were calculated to determine if they were reasonable and as a check on the validity of the model. All parameters had reasonable values. Thus, we concluded that the model was acceptable within experimental error, and that other features and assumptions of the model are also correct.

The primary conclusion of the model is that the rate of contaminant release into the air is controlled by diffusion inside the polymer and is not significantly retarded by diffusion through air. For the Space Station this means that the offgassing rate is independent of the atmospheric pressure inside the modules, and offgassing experiments need be conducted at only one atmospheric pressure. Thus experiments conducted at White Sands at approximately 10-12 psia are comparable to tests conducted at sea level.

Another conclusion is that the rates obtained in the 72-hour offgassing test are average rates for the 72-hour period of the test. If the 72-hour rates are used in the contamination analyses for the Space Station conservatively high estimates of contaminant concentrations will be obtained for times greater than 72 hours and vice versa for times less than 72 hours. This conclusion applies to all diffusion controlled contaminants but not to contaminants produced by chemical reaction. Some reaction-produced contaminants will exhibit offgassing rates that increase with time as polymer degradation proceeds, and low contaminant concentrations may be predicted if only 72-hour rate data are used. A deficiency of the the standardized 72-hour test is that it does not distinguish between those contaminants that are produced by chemical reaction in the polymer and those contaminants present in the polymer at time zero. Thus, all conclusions we draw that are based on the offgassing model or the results of the 72-hour test apply only to those contaminants present in the host polymer at time zero. The large majority of contaminants found in previous spacecraft fall into the diffusion controlled group not the reaction produced group.

Another conclusion we can draw from the offgassing model is that for the most part the approach to thermodynamic equilibrium in the standardized 72-hour test is of no practical consequence. Figure 13 shows the quantity of o-xylene offgassed from a sample of S.K. primer in the standardized test and compares it to the anticipated quantity of o-xylene offgassed in the Space Station at the same temperature. The approach to equilibrium after 120 hours in the test chamber results in about 5% less xylene being emitted than would be emitted from the same material on the Space Station. This is within the engineering accuracy of the analytical technique used to predict contaminant concentrations on the Space Station. Figure 14 shows a similar example based solely on the contamination model using only conservative estimates of

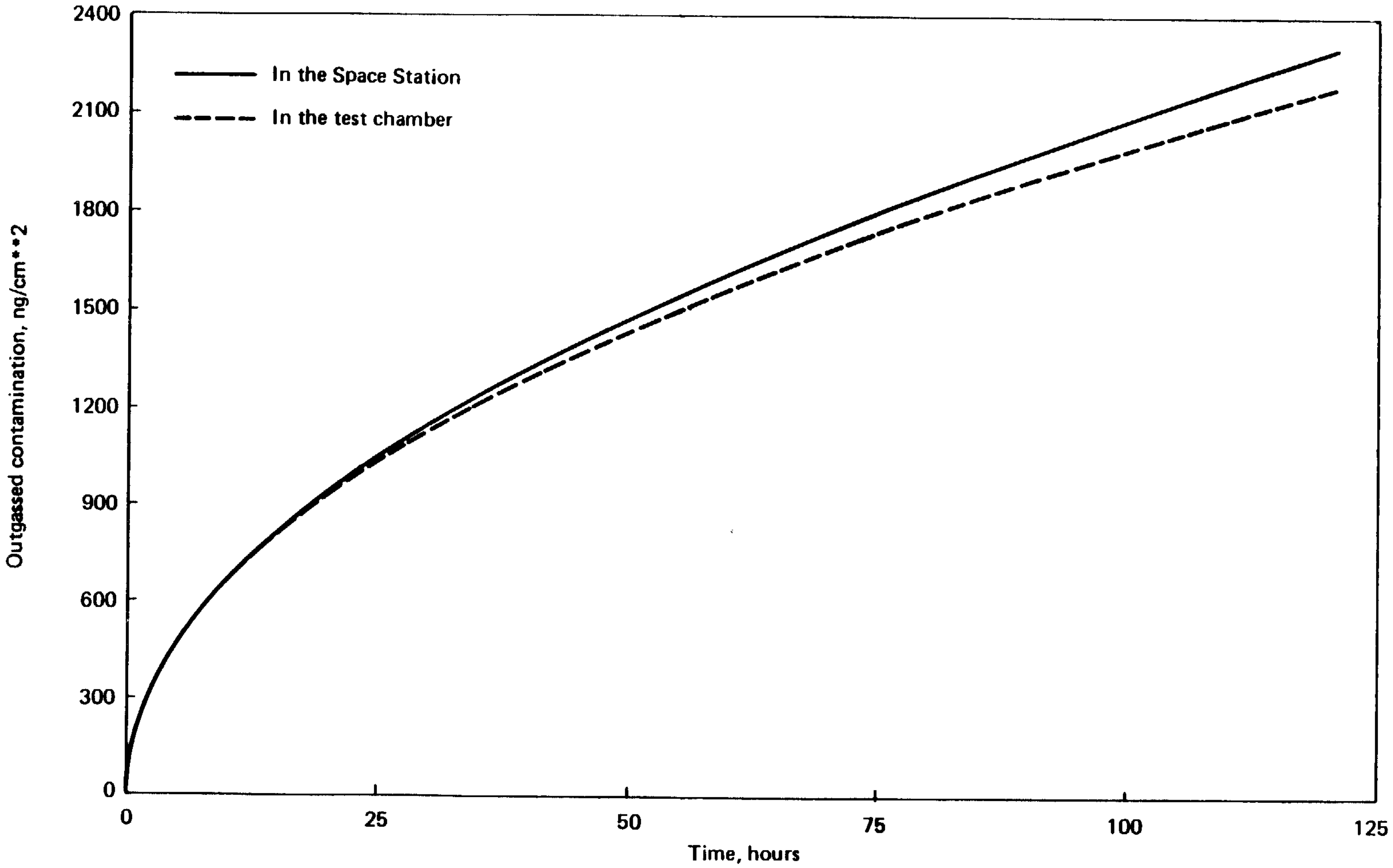

Figure 13. Xylene Offgassed From S.K. Primer. A Comparison of Theoretical Rates on the Space Station With Offgassing Test Results

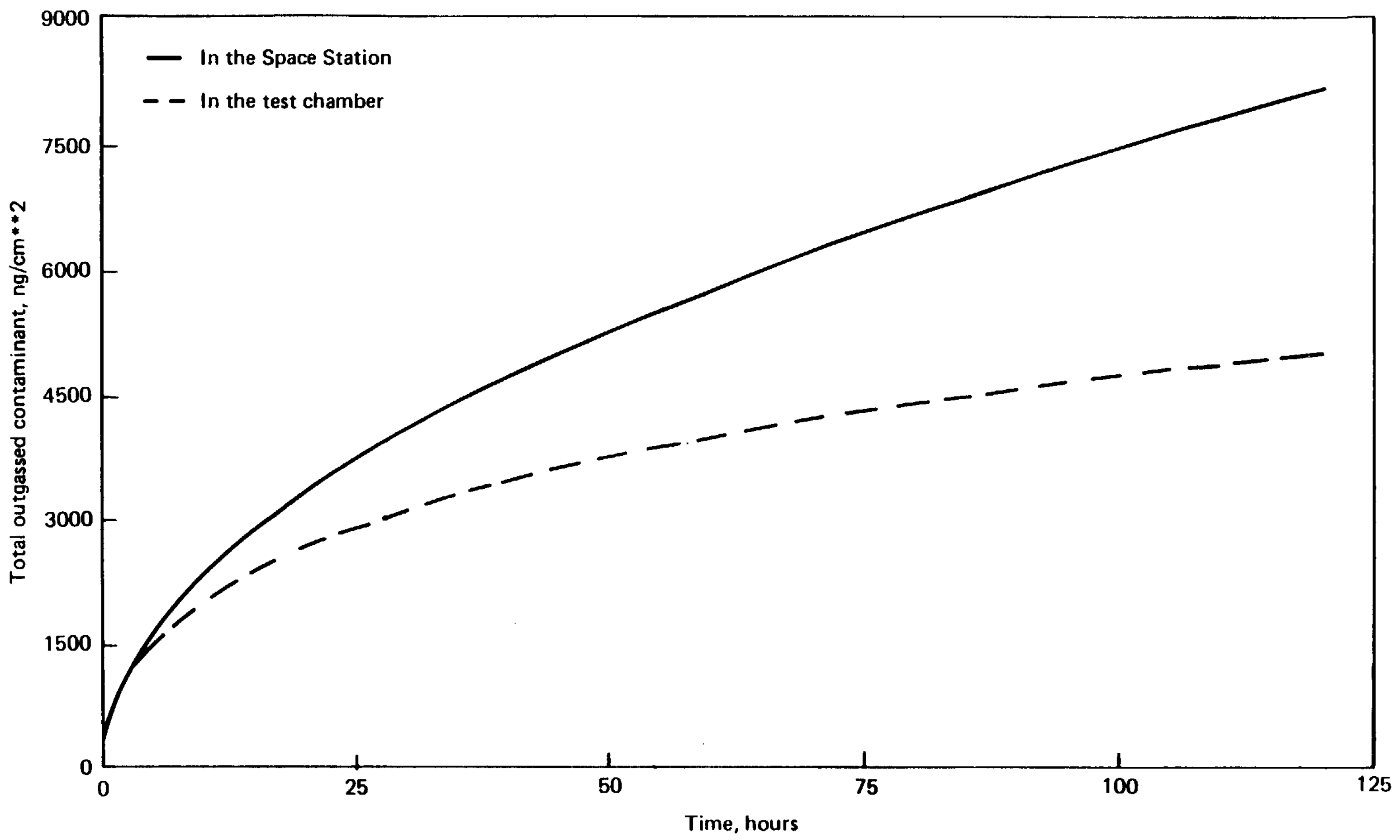

Figure 14. Theoretical Worst Case Comparison of a Hypothetical Contaminant Offgassing in the Space Station and in the Standardized Test

the 3 model parameters. This figure shows an offgassing quantity in the Space Station about 50% greater than that obtained in the standardized test.

The offgassing model indicates that the standardized 72-hour test is generally adequate for assessing offgassing rates of diffusion-controlled contaminants encountered during short missions, but the standardized test alone is inadequate for long missions such as will be experienced by articles on the Space Station. We further conclude that simply increasing the duration or the temperature of the standardized test is inadequate to make the test acceptable for Space Station applications. In addition, the standardized test is flawed because it cannot identify contaminants that are approaching thermodynamic equilibrium or identify those contaminants that are formed primarily by chemical reaction. For these reasons we conclude that additional tests should be developed to assess the offgassing rates of materials proposed for the Space Station.

Identification of Contaminants. In order to compare the results obtained in this work with the work done at White Sands we performed several offgassing tests in which the chemical contaminants were identified. Gas chromatography was the method used to identify contaminants. The results of two tests are presented in tables 2-3. Both tables show all chemical contaminants identified in the White Sands tests. Our apparatus was not set up to quantitatively determine the concentrations of all compounds. The compounds that were quantitatively identified are indicated in the figures by a "yes" in the column labeled calibration standard.

Table 2 compares the test results for Chemlok adhesive after a 120 hour long test with the 72-hour White Sands test results. Six of the contaminants found in White Sands tests were investigated in this work. Four of the chemicals were detected at very low levels in both sets of tests as indicated by a value of zero micrograms of contaminant per gram of sample. The other two contaminants show a significant contrast between the two sets of experiments. These results are explained by the fact that a different

Table 2. Chemlok Adhesive 120-Hour Test Results

Chemical compound	White Sands test (μg/g)	BAC experiments	
		Offgassing (μg/g)	Calibration standard
Benzene	0	0	Yes
CO	1.4	–	No
Hexane	0	0	Yes
Mestyl oxide	90	–	No
Methyl alcohol	0	0	Yes
Methyl ethyl ketone	0	0	Yes
Methyl isobutyl ketone	4000	35.5	Yes
Xylene	100	9548	Yes

Table 3. S. K. Primer 72-Hour Test Results

Chemical compound	White Sands test (μg/g)	BAC experiments	
		Offgassing (μg/g)	Calibration standard
Benzene	0	0	Yes
Butyl acetate	35	–	No
C_{10} hydrocarbons (ring)	11	–	No
C_{10} hydrocarbons (straight)	6	–	No
C_8 unsaturated hydrocarbons	25	–	No
CO	24	–	No
Cyclohexanone	55	–	No
Hexane	0	0	Yes
Mesityl oxide	25	–	No
Methyl alcohol	0	0	Yes
Methyl ethyl benzene	2	–	No
Methyl ethyl ketone	6	807	Yes
Methyl isobutyl ketone	0	0	Yes
T. F. freon	52	–	No
Toluene	14	–	No
Tri substituted benzene	13	–	No
Xylene	135	2280	Yes

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batch of Chemlok adhesive was tested in this work than was used at White Sands. The manufacturer of the Chemlok adhesive considers the two materials to be identical, but it is clear from our test results that different solvents were used in the two batches. This result means that type acceptance of materials should not be employed on the Space Station, and every equipment item and material used on the Space Station should be tested for contamination.

Table 3 is similar to table 2 but the results are for S.K. primer after a 72-hour offgassing test. In this example the results are not as dramatic as in table 2, but they also show significant differences in the relative magnitudes of contaminant offgassing. This fact again points up the need to test every item manifested for use on the Space Station.

Calibration Procedure. In the course of performing the tests in which contaminants were identified we performed an absolute calibration of the gas chromatograph for a number of chemicals. As a check on the purity of the calibration chemicals and the calibration procedure, the results of these calibrations were compared to published values reported in the literature. This comparison is presented in table 4. The table shows that all contaminants tested except methyl alcohol had a relative sensitivity within plus or minus 10% of the published value. This degree of uncertainty is expected and is associated with differences between individual flame ionization detectors.

The calibration procedures used here were essentially the same used at White Sands, and the results of the comparison between this work and the published relative sensitivities indicates that the calibration procedures are acceptable. This result also indicates that the procedures and hardware used in the offgassing tests are acceptable and cross contamination between samples or specimens did not occur in these tests.

Table 4. Gas Chromatograph Calibration Results for Carbowax 20M Column Configuration

Compound	Retention time (min)	Contaminant concentration in air (mole/l)	10^{-15} times area per mole	10^{-13} times area per gram	Sensitivity (mole/liter)	Sensitivity (PPM)	Rel. Sens.	
							BAC	Literature
Benzene	1.38	1.166 × 10-5	1.322	1.652	7.6 × 10-14	1.9	1.08	1.12
Hexane	0.95	7.960 × 10-6	1.256	1.457	8.0 × 10-14	1.9	1.03	1.03
Methyl alcohol	1.36	2.568 × 10-5	0.155	0.485	6.4 × 10-13	15.7	.13	0.23
Methyl ethyl ketone	1.32	1.160 × 10-5	0.6475	0.898	1.5 × 10-13	3.8	55	0.01
o-xylene	3.17	1.311 × 10-6	1.364	1.285	7.3 × 10-14	1.8	1.13	1.02
m-xylene	2.61	6.980 × 10-6	1.364	1.285	7.3 × 10-14	1.8	1.13	1.04
p-xylene	2.61	6.980 × 10-6	1.364	1.285	7.3 × 10-14	1.8	1.13	1.00

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CONCLUSIONS

The following conclusions are based on experimental work conducted in phase 1 of the current contract.

1. The standardized 72-hour offgassing tests (Test 7 and Test 16, NHB 8060.1B) can provide accurate offgassing rate data at 50°C and near atmospheric pressure. The accuracy of the tests can be sensitive to experimental procedure and care must be exercised to maintain and record temperatures and other test conditions. Condensation of offgassed contaminants can be expected to occur on all surfaces. This means that surface temperatures and temperature changes can significantly affect offgassing results.
2. The standardized 72-hour tests are deficient in the sense that products produced by chemical reaction and compounds that have saturated the air cannot be identified. The standardized test could easily be modified to correct these deficiencies. The model of the 72-hour test we have developed could serve as the basis for modifying the 72-hour tests.
3. Most compounds offgassed in the 72-hour test do not reach air saturation in 72 hours.
4. The 72-hour tests are unable to provide offgassing data on long-term degradation rate of polymers or to identify contaminant compounds produced by this type of degradation.
5. A new test should be developed to determine the chemical compounds produced by long term polymer degradation and to quantitatively measure their rate of production in polymers exposed to the environment inside manned Space Station modules.
6. Increasing the test duration or increasing the temperature above 50°C will not improve the quality of data for Space Station applications.

7. Current calibration procedures used at the White Sands test facility are appropriate and adequate.
8. Neither assembled articles of equipment nor materials should be qualified for use on the Space Station without undergoing an offgassing rate test. Items should not be passed by similarity with other equipment that has been tested. Only items that have themselves passed the tests should be approved.

REFERENCE

1. J. Crank, *The Mathematics of Diffusion*, 2nd Ed., Clarendon Press, Oxford, 1975.

2. J. O. Hirshfelder, C. F. Curtiss, and R. B. Bird, *Molecular Theory of Gases and Liquids*, John Wiley and Sons Inc., New York, 1954.

3. D. W, Van Krevelen, *Properties of Polymers, Their Estimation and Correlation with Chemical Structure*, 2nd Ed., Elsevier Scientific Pub. Co., New York, 1976.

APPENDIX A OF ATTACHMENT F

Procedures for Preparing Specimens

SUPER KOROPON SAMPLE PREPARATION

SUPER KOROPON FLUID RESISTANT PRIMER

Primer base - 515-700

Curing solution - 910-704

Mix ratio 1:1 by volume

Spray applied undiluted at room temperature to nominal 1.0 mil

Thickness, air dried for 24 hours minimum

SUBSTRATE - 2024 CLAD ALUMINUM 0.020 INCH THICK

ALUMINUM SURFACE PREPARATION

1. Vapor degrease (trichloroethylene)
2. Alkaline clean (BAC 5514) 10 minutes
3. Hot water rinse 5 minutes
4. FPL etch/sodium dichromate - sulfuric acid etch 15 minutes
5. Cold water rinse 10 minutes
6. Air dry at 160°F

CHEMLOK ADHESIVE SAMPLE PREPARATION

CHEMLOK 220/205 RUBBER TO METAL BONDING AGENTS

Primer - Chemlok 205

Spray applied undiluted at ambient temperature to nominal 0.2 mil thickness

Nominal 0.2 mil thickness

Air dried for 1 hour at ambient temperature before application of adhesive

Adhesive - Chemlok 220

Spray applied diluted with xylene (75%) at ambient temperature to nominal 0.4 mil thickness

Air dried

SUBSTRATE - 2024 CLAD ALUMINUM 0.020 INCHES THICK

ALUMINUM SURFACE PREPARATION

1. Vapor degrease (trichloroethylene)
2. Alkaline clean (BAC 5514) 10 minutes
3. Hot water rinse 5 minutes
4. FPL etch/sodium dichromate-sulfuric acid etch 15 minutes
5. Cold water rinse 10 minutes
6. Air dry at 160°F

30% GLASS FILLED NYLON
NYLON 6/6 RTP299X50542FR

A) Date of Manufacture - July 23, 1985

B) Type of Material - Conductive nylon 6/6, flame retardant

C) General Manufacturing Process - Injection molded

D) History of Material Since Manufacturing - Dried before shipment, packaged in moisture resistant containers during shipment. Stored in large barrels at room temperature in large injection molding facility.

E) Maximum Storage and Cure Temperatures - Stored at room temperature

F) Glass Transition Temperature of Each Polymer Component - ?

G) Chemical Constituents - Monomer-amide, contains carbon fiber and a flame retardant

H) Previous Outgassing Test - See memo "Specimens for Space Station Contamination Contract"

20% GLASS FILLED POLYPROPYLENE
POLYPROPYLENE RTP199X23835

A) Date of Manufacture - June 1985

B) Type of Material - Mineral filled conductive thermoplastic

C) General Manufacturing Process - Injection molded

D) History of Material Since Manufacturing - Dried before shipment, packaged in moisture resistant containers during shipment. Stored in large barrels at room temperature in large injection molding facility.

E) Maximum Storage and Cure Temperatures - Stored at room temperature

F) Glass Transition Temperature of Each Polymer Component - ?

G) Chemical Constituents - Monomer-propylene, mineral filled contains carbon black and glass fiber

H) Previous Outgassing Test - See memo "Specimens for Space Station Contamination Contract"

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TITLE          = Space station contamination control study: Interna
TITLE          = l combustion, phase 1
TITLE SUPP     = Final Report
AUTHOR         = RUGGERI, ROBERT T.
CONTRACT NUM   = NAS8-36432
REPORT NUM     = NASA-CR-179323
REPORT NUM     = NAS 1.26:179323
SALES AGY PRIC= Limited Distribution
MAJOR TERMS    = OUTGASSING
MAJOR TERMS    = PROCEDURES
MAJOR TERMS    = SPACE STATIONS
MAJOR TERMS    = SPACECRAFT CONTAMINATION
MINOR TERMS    = DECONTAMINATION
MINOR TERMS    = ENVIRONMENTAL QUALITY
ABST AUTHOR    = Author
FORM OF INPUT = HC

       ABSTRACT =  Contamination inside Space Station modules was stu
                   died to determine the best methods of controlling
                   contamination. The work was conducted in five task
                   s that identified existing contamination control r
                   equirements, analyzed contamination levels, develo
                   ped outgassing specification for materials, wrote
                   a contamination control plan, and evaluated curren
                   t materials of offgassing tests used by NASA. It i
                   s concluded that current contamination control met
                   hods can be made to function on the Space Station
                   for up to 1000 days, but that current methods are
                   deficient for periods longer than about 1000 days.

***************    END OF ADABAS RECORD #    270220    ***************
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