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M. A. Golub and T. Wydeven, Ames Research Center, Moffett Field, California

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Moffett Field, California 94035-1000

Summary

A compilation of generation rates and chemical compositions of potential waste streams in a typical crewed space habitat, reported in a prior NASA Technical Memorandum and a related journal article, has been updated. This report augments that compilation by the inclusion of the following new data: those data uncovered since completion of the prior report; those obtained from Soviet literature relevant to life support issues; and those for various minor human body wastes not presented previously (saliva, flatus, hair, finger- and toenails, dried skin and skin secretions, tears, and semen), but included here for purposes of completeness. These waste streams complement those discussed previously: toilet waste (urine, feces, etc.), hygiene water (laundry, shower/handwash, dishwash water and cleansing agents), trash, humidity condensate, perspiration and respiration water, trace contaminants, and dust generation. This report also reproduces the latest information on the environmental control and life support system design parameters for Space Station Freedom.

Introduction

For relatively short-duration human space missions, as in space shuttle flights, essential consumables (e.g., food, water, oxygen) are provided at launch, and the wastes generated are returned to Earth, in what is called open-loop life support. However, for future long-duration human space missions – as in Space Station Freedom or, at a still later date, the establishment of a lunar base or a piloted mission to Mars – it is essential to close as fully as possible the major life support functions by recycling water and air, by treating or recycling various waste products, and by growing plants for food. Partial closure of the atmospheric and water loops is now achievable, but further closure is expected to result in minimizing launch weight by reducing the need for large quantities of expendables and may even eliminate resupply requirements (Evanich, 1988).

As one facet of developing a fully regenerative or closed-loop life support system for extended human space missions where resupply is not feasible, waste management or processing must be perfected, and this calls for an identification and characterization of the potential waste feed streams in a typical crewed space habitat. Towards that end, we recently presented a compilation of generation rates and chemical compositions of the *major* waste streams emanating from humans and equipment in a closed environment in space (Wydeven and Golub, 1990, 1991) that need to be factored into NASA's Physical/Chemical Closed-Loop Life Support Research Project (P/C CLLS). This report aims to update and extend that compilation by the inclusion of the following data not considered in the prior reports: those data obtained from Soviet literature relevant to life support systems for space, and those for various *minor* human wastes. Besides including some additional data uncovered since completion of the prior reports, we also reproduce the latest information on the Environmental Control and Life Support System (ECLSS) design parameters for Space Station Freedom (Anon., 1990).

As before, we consider in this report a hypothetical long-duration, human space mission in which food is supplied at launch, no recycling processes or scientific experiments are involved, and no plant growth (for food and/or oxygen and water regeneration) occurs. Thus, we disregard at this stage such waste streams as inedible biomass, those resulting from on-board experiments, and secondary streams arising from the processing of primary streams, such as ash from incineration of trash. For an examination of waste streams present in a space habitat having higher plants as a source of food, see the paper by Wydeven et al. (1989); and for a survey of waste recycling issues in bioregenerative life support and related matters, see the recent issue of *Advances in Space Research* (MacElroy et al., 1989).

As in the prior reports, this one is again concerned with waste management for extraterrestrial closed environments and not with that of the "mundane" terrestrial sphere, which is also a closed environment. However, the waste streams for a typical crewed space habitat have their counterparts on Earth, and where differences exist between the two types of closed systems, they are more of a quantitative character than qualitative. Indeed, one may think of the Space Station environment as a miniature model of the Earth. Thus, one may foresee the development of innovative schemes for adapting terrestrial waste management and recycling practices to future long-duration manned space missions, taking into consideration, of course, such factors as zero or partial gravity in space vis-à-vis Earth gravity, and different types of optimal power or energy sources used in space and on Earth. Reciprocally, novel procedures developed specifically for space application may well result in important spin-offs for waste management at the terrestrial level.

The authors express their appreciation to David A. Chaumette, M.S. in Aero-Astronautics from Stanford University, who carried out a detailed literature survey that forms the basis for this updated report on waste streams in a space environment. Thanks are also due Mark G. Ballin, of NASA Ames Research Center, for making available the ECLSS regenerative life support data (daily inputs and outputs) presented in table 1.

Waste Stream Data

Life Support and Personal Requirements

Table 1 presents the most recent estimates for the ECLSS design parameters for Space Station Freedom (Anon., 1990), showing nominal, daily inputs per person of oxygen, food and various water supplies together with daily outputs of metabolic products and assorted waste waters. This table also offers a direct comparison with the corresponding waste stream production rates for a typical crewed space habitat given previously (see table 1 in each of the two papers by Wydeven and Golub, 1990, 1991). Except for the absence of data on trash and on certain toilet and hygiene solid wastes (e.g., toilet paper, cleansing agents), the daily outputs indicated in the present table constitute an update of the waste streams given earlier. The ECLSS design parameters shown in table 1 assume that each occupant of a space habitat will require about 31 kg/day of supplies. Recently, Hightower (1990) depicted an idealized P/C CLLS system in which there is 100% reclamation of air and water, but excluding recycling of solid wastes and food, and which reduces the daily input from 32 kg/day to 3.5 kg/day. These input values were based on Hightower's estimate for the following non-recyclable supplies (in kg/day): maintenance supplies (1.3), plastic and paper supplies (0.7), moist food (1.0) and nitrogen (0.5). The special supply of nitrogen is needed to replace leakage of air to space, while the corresponding loss of oxygen ($\approx$ 0.15 kg/day) is assumed to be recoverable via electrolysis of excess water.

As observed before, the principal contributor to solid waste in the short-duration closed space environments examined to date, such as space shuttle flights, has been trash. By way of addition to the wet weight formation rates of trash given previously for Space Shuttle Flights STS-29 and -30 (1.49 and 1.62 kg/person-day, respectively), Shuttle Flight STS-35 (63 man-days versus 25 and 20 for STS-29 and STS-30, respectively) generated only 1.14 kg/person-day (Grounds, 1990). This reduction in weight formation rate was achieved in large measure by the replacement of polyethylene square beverage packages, used in STS-29 and STS-30, by Teflon-lined aluminum foil beverage pouches used in STS-35. A corresponding reduction in volume formation rate of trash was also observed for the latter flight: 0.24 ft^3 ($\equiv 0.68 \times 10^{-2}$ m^3) per person-day for STS-35 versus 0.49 and 0.47 ft^3 ($\equiv 1.39$ and 1.33×10^{-2} m^3) per person-day for STS-29 and STS-30, respectively. The pouches were reported to reduce the volume of the beverage packages by 48%, and their weight by 56% (Grounds 1990, private communication), as compared to the plastic square beverage packages. Flight STS-35 was notable also for having been the first shuttle flight that employed a prototype trash compactor intended to provide data necessary for the design of a compactor for Space Station Freedom; compacted trash, which was collected in 11 bags, consisted of 60% aluminum food cans, 30% empty beverage pouches, 5% uneaten food and 5% paper, and amounted to about 33% by weight of the total trash. As for the solids content of the trash in the three shuttle flights mentioned, they were all quite similar: 72.7, 64.7 and 73.2 weight %, for STS-29, -30 and -35, respectively. No breakdown of the trash comparable to that reported for Space Shuttle Flight 51D (see table 8 in Wydeven and Golub, 1990, or table 5 in Wydeven and Golub, 1991) was reported for those three "STS" flights.

A recent report issued in the UK (Oakley et al., 1989) for the European Space Agency proposed categorizing spacecraft wastes into a limited number of general classes, based on the phase of the material and whether the material might be suitable for regeneration or recycling. The categories and their overall production rates are as follows: Biodegradable liquid waste (e.g., hygiene and metabolic water, toilet and extravehicular activity, or EVA, waste water), 24.51 kg/person-day; biodegradable solid waste (e.g., trash, hygiene and toilet solids), 0.31 kg/person-day; non-biodegradable but reusable solid waste (e.g., charcoal, lithium hydroxide cartridges, clothing, towels), 1.19 kg/person-day; metabolic gaseous waste (e.g., CO_2, EVA CO_2, CH_4), 1.7 kg/person-day; and non-regenerable solid waste (e.g., food and medical containers, books, papers, pens, wipes), 0.4 kg/person-day. Two other categories for which no information was available are non-regenerable liquid waste (e.g., products from scientific experiments) and non-regenerable non-metabolic gases (volatiles from materials outgassing). The foregoing categories total 28.11 kg/person-day of waste, which is not very different from the total of 31.0 kg/person-day indicated in table 1.

Trace Contaminants in Space Shuttle Flights

As a follow-up to the data on trace contaminant load models given in table 11 of Wydeven and Golub (1990), table 2 of this report presents the results of a series of analyses by the Toxicology Group at NASA Johnson Space Center of the cabin air taken during Space Shuttle Flights STS-30 through STS-36. The aim of these analyses (involving gas chromatography and mass spectrometry) was to help determine the effectiveness of the contamination control measures designed to maintain a clean, safe living environment during the space missions. In all cases, the detected contaminants were well below their spacecraft maximum allowable concentrations (SMAC). In one flight (STS-31), benzene was found at a typically high levels in the inflight sample, although the concentration (0.01 mg/m^3) was well below the 7-day SMAC of 0.32 mg/m^3. Most of the substances listed in table 2 are probably not derived from human excretions but from materials used in the Shuttles. Methane is probably intestinal; acetone and 2-propanol may come in part from human metabolism; and ethanol (alcohol) has been used as a surface wipe to avoid formation of water droplets at zero G.

Waste Stream Data from Soviet Literature

The rates of excretion into the air environment of a very wide assortment of organic compounds present in various human wastes were recently reported by Dmitryiev et al. (1987) who employed a gas-chromatograph/mass spectrometer and a computer library of spectra for the analysis of complex mixtures. The waste products, obtained from the exhaled air, intestinal gas, urine, saliva, perspiration and feces excreted by 56 healthy individuals, provide another list of contaminants to complement those given in table 11 of the prior report (Wydeven and Golub, 1990) and that may be expected to appear in the closed environment of a space habitat. Of the 136 compounds listed by the Soviet workers, only 74 are given in table 3, and their ordering in that table follows that in the previously cited table of trace contaminants for ease in comparison of the corresponding entries. It should be noted that some of the compounds in table 3 (e.g., the various halocarbons) presumably arose from non-human sources (as in outgassing of plastic materials). Apart from indicating the content of toxic metabolites, table 3 provides data concerning compounds that may be significant for biomedical evaluation of individuals subjected to the confined atmosphere of a spacecraft. The special merit of table 3 is that it offers metabolic rates for the bulk of compounds emanating from human waste for which such rates were stated as zero in the aforementioned table 11. Where non-zero metabolic rates were given for some of the compounds in the latter table, the metabolic rates from table 3 are similar to those in table 11 in a few instances but dissimilar in others. This is illustrated in table 4, where the metabolic rates for 9 compounds reported in the Soviet study (converted to mg/person-day by multiplying the total excretion in µg/h by 24 [h] and dividing by 56 [persons]) are compared with those given in table 11. Evidently, the new data on metabolic rates of different compounds should be factored into the trace contaminant load models for Space Station Freedom, although in all cases the data for overall generation rates of contaminants (for two different models) given in table 11 of the prior report do exceed the corresponding metabolic rates.

In a review article on habitability and life support in a space station, Nefedov and Adamovich (1988), drawing upon ground-based studies of small sealed environments, listed the following major trace contaminants identified in human expired gas, with maximal amounts in mg/m^3 given in parentheses: acetaldehyde (0.1), formaldehyde (0.1), acetone (0.35 ± 0.30), methyl ethyl ketone (0.12 ± 0.02), propionaldehyde (0.1), ethanol (0.86 ± 0.50), methanol (0.19 ± 0.10), propanol (0.1), isopropanol (0.1), formic, acetic, propionic, isovaleric and valeric acids (0.41 ± 0.08), ammonia (0.51 ± 0.07), dimethyl amine (0.1), methane (1.24 ± 0.07), ethane (0.1), ethylene (0.1), propane (0.1), hexane (0.1) and carbon monoxide (nonsmokers, 4.9 ± 1.1; smokers, 14.3 ± 4.2). The foregoing list of compounds and their concentrations can be regarded as supplementing the information given in column 3 of table 3. It was stated that Soviet scientists set maximum acceptable levels of virtually all the above compounds as a function of space flight duration, but such data were not given for Salyut or Mir. It was also stated, but with few details, that a total of 200 synthetic materials, including many toxic sustances, have been identified as products of polymer outgassing. The article also mentioned the supplies needed to support a cosmonaut for each day of normal human existence during spaceflight: 800 g oxygen, 2500 g potable water and about 700 g food (3000-3500 calories) – daily inputs that are very close to the corresponding numbers given in column 2 of table 1.

Polyakov et al. (1986), in a study of the effective reclamation by reverse osmosis of wash water likely to be encountered in long-duration spaceflight, indicated that the total impurities in that water was about 1 g/l, the principal constituents being the detergents (a mixture of alkyldimethylbenzylammonium chloride, or Catamine AB, and alkyldimethyl-amine oxide, amounting to 174 mg/l). Although the nature of that hygiene water was not discussed, the weight percent solids (≈0.1%) was comparable to that (≈0.08-0.15%) obtained for the combined laundry and shower/hand-wash water given in table 1 of each of the two papers by Wydeven and Golub, 1990, 1991). From an analysis of the wash water recovered from showering with detergents, Berlin and Chekanova (1987) concluded that the composition of the wash water was comparable for men and women, despite the fact that the latter were allowed cosmetics, perfumes, creams and deodorants. This indicated that the sex of crewmembers can be disregarded in the design of water reclamation systems for spacecraft. Nevertheless, women's wash water showed a higher chloride content than that for men: 39.14 vs. 20.54 mg/l, with standard deviations of 11.35 and 9.49 mg/l, respectively, for a group of essentially healthy men and women 25 to 50 years of age (12 each). Menstruation had only a slight effect on the composition of wash water from females. It was also noted that the composition of the wash water depended on the health status of its users, in particular, when the subjects had a cold or elevated blood pressure.

To conclude this survey of pertinent Soviet literature, we mention the work of Pak et al. (1989) who examined the hygienic aspects of wash water reclamation systems. The major parameters characterizing used shower water were bichromate oxidizability, electroconductivity and chloride ion concentration (as in the prior work of Berlin and Chekanova 1987) plus pH. The total concentration of microorganisms in the wash water, without the use of detergents, was $10^4 - 10^5$ microbial bodies per ml, which concentration was reduced to $8 \times 10^2 - 6 \times 10^3$ microbial bodies per ml when detergents were used. Microbial parameters for women were close to those of men. The most numerous microorganism was staphylococcus, while other organisms found represented the natural microflora of human skin. This work confirmed the desirability of using detergents with disinfecting properties. However, the concentrations of organic substances in the used wash water, as measured by oxidizability, increased from $\approx$120-310 mg O_2/l, without the use of detergents, to $\approx$1350-1730 mg O_2/l, with the use of detergents. At the same time, the concentrations of chlorides increased from $\approx$16-23 mg/l to $\approx$34-40 mg/l, the organic contaminants arising from surface dirt on the skin as well as products of secretion of sebaceous and sweat glands.

Minor Human Body Waste Streams

Table 5 constitutes an addendum to the two tables 1 of Wydeven and Golub (1990, 1991) in presenting production rates and solid contents of the following minor waste products generated by the human body: saliva, flatus, hair, finger- and toenails, dried skin, tears and semen. Details on these minor waste streams were omitted from the prior report partly for convenience but mainly because they were deemed inconsequential from the standpoint of their masses relative to those of the other waste streams discussed in that report. However, for purposes of completeness in updating that report and also because the minor body wastes might have an impact on the trace contaminant load or the waste management system, especially in prolonged confinement in a spacecraft, such streams merit inclusion here.

The chemical compositions of flatus, skin secretions and tears are shown in tables 6-8. Saliva, which is approximately 99.4% water, contains a wide assortment of electrolytes, nitrogen compounds, enzymes, vitamins and miscellaneous organic compounds, all of which can contribute but very small amounts to the contaminant load, and then only if the saliva leaves the body. For information on the range in composition of some 65 substances present in saliva, the reader may consult the comprehensive survey by Webb (1964), which also contains more complete compositional data on the other streams indicated in table 5, e.g., hair, nails and semen. Finally, that survey also lists the following composition in weight percent of ear wax: total lipids (44), protein (24) and residue (32).

Conclusions

As a sequel to our prior NASA Technical Memorandum and related journal article dealing with the generation rates and chemical compositions of the major waste streams in a typical crewed space habitat, this report provides comparable information on various minor human body wastes not discussed earlier, as well as a survey of recent Soviet literature relative to waste stream definitions, and offers some new data uncovered since completion of the previous report, including the ECLSS design parameters for Space Station Freedom.

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Table 1. Environmental control and life support system (ECLSS) design parameters[a]

Daily inputs per person – nominal		Daily outputs per person – nominal		Waste stream values
Item	Amount, kg	Item	Amount, kg	from previous work, kg/person-day[b]
Oxygen	0.83	Carbon dioxide	1.00	1.00
Food, dry	0.62	Respiration and perspiration water	2.28	1.80-2.48
Water in food	1.15	Urine	1.50	1.21-2.05
Food preparation water	0.79	Water in feces	0.09	0.0750-0.111
Drinking water	1.61	Sweat solids	0.02	0.016-0.02
Oral hygiene water	0.36	Urine solids	0.06	0.059
Hand/face wash water	1.81	Feces solids	0.03	0.0205-0.03
Shower water	5.44	Hygiene water[c]	7.18	5.4-5.5[d]
Clothes wash water	12.47	Latent hygiene water	0.44	e
Dish wash water	5.44	Clothes wash water	11.87	12.5[f]
Flush water	0.49	Latent clothes wash water	0.60	
		Latent food preparation water	0.04	e
		Dish wash water	5.41	5.4
		Latent dish wash water	0.03	e
		Flush water	0.49	0.494[g]
Total	31.0	Total	31.0	

[a] For Space Station Freedom, from NASA SSP 30262 (Anon., 1990).

[b] From table 1 of Wydeven and Golub (1990). Note: The separate entries in this column for (a) urine (as water) + urine solids, (b) respiration and perspiration water + sweat solids, and (c) water in feces + feces solids, when combined correspond to the wet weight formation rates for urine, perspiration & respiration water, and feces, respectively, given in table 1 of the cited report.

[c] Hygiene water output (7.18) ≡ Total hygiene water input (0.36 + 1.81 + 5.44) - Latent hygiene water output (0.44).

[d] Shower/hand wash water in Wydeven and Golub (1990).

[e] These three latent waters were combined and indicated in table 1 of Wydeven and Golub (1990) as humidity condensate of 0.52 kg/person-day, which is virtually the same as the corresponding sum (0.51 kg/person-day) of the daily outputs of these same latent waters given in column 4.

[f] This entry (12.5) clearly corresponds to the sum of clothes wash water (11.87) + corresponding latent water (0.60) indicated in column 4.

[g] Urinal flush water in Wydeven and Golub (1990).

Table 2. Atmospheric analysis of Space Shuttle Flights[a,b]

Contaminant	STS-30	STS-31	STS-32	STS-33	STS-34	STS-36
Methane	12.000	---	51.813	25.013	11.638	41.727
Acetone (Propanone)	2.858	0.013	1.095	0.653	0.185	0.704
Hexamethylcyclotrisiloxane	0.304	0.213	0.070	0.066	---	0.086
Dichloromethane	0.441	0.153	0.465	0.294	0.101	0.327
2-Propanol	0.447	0.709	1.685	0.318	---	0.513
Ethanol	10.227	2.059	4.738	6.105	2.390	21.157
Octamethylcyclotetrasiloxane	0.091	0.090	0.016	0.180	0.006	0.203
Decamethylcyclopentasiloxane	---	---	---	---	---	0.348
1,1,2-Trichloro-1,2,2-trifluoroethane	---	0.872	---	1.624	---	---
Toluene	0.026	0.056	0.009	---	---	---
Benzene	---	0.011	---	---	---	---
1,2-Dimethylbenzene (o-xylene)	0.025	---	---	---	---	---
1,3-Dimethylbenzene (m-xylene)	0.041	---	---	---	---	---
1,4-Dimethylbenzene (p-xylene)	0.031	0.011	0.002	---	---	---
Ethylbenzene	---	0.012	0.001	---	---	---
C6-Alkane	---	0.014	---	---	---	---
Carbon disulfide	---	0.009	---	---	---	---
1,1,1-Trichloroethane	---	0.280	---	---	---	---
C9-Alkane	---	0.021	---	---	---	---
2-Butanone	---	0.203	---	---	---	---
C10-Alkanes	---	0.600	---	---	---	---
C11-Alkanes	---	0.730	---	---	---	---
C3-Substituted benzenes	---	---	0.112	---	---	---
Acetic acid, n-butyl ester	---	---	0.009	---	---	---

[a] Data in table are concentrations of contaminants in mg/m^3.

[b] Data obtained from Summary Reports for Spacecraft Cabin Atmospheric Analyses prepared by C. L. Huntoon, and supplied through the courtesy of M. E. Coleman, both of NASA Johnson Space Center, Houston, TX.

Table 3. Principal Organic Compounds from Human Wastes Excreted into the Air Environment[a]

Category	Substance	Excretion, µg/h				
		In exhaled air	Sweat	Urine	Feces	Total[b]
Alcohols	Butanol	6.82×10^2	6.61×10^2	9.39×10^2	7.44×10^3	9.72×10^3
	Ethanol	9.68×10^2	6.35×10^2	8.15×10^2	1.02×10^4	1.26×10^4
	Isopropanol	4.12×10^3	8.35×10^2	3.47×10^3	1.36×10^4	1.90×10^4
	Cyclohexanol	7.04×10^2	6.86×10^2	1.14×10^3	9.61×10^3	1.21×10^4
	3-Methyl-1-butanol	7.54×10^2	4.97×10^2	1.03×10^3	8.35×10^3	1.06×10^4
	Methanol	2.68×10^2	1.21×10^2	6.64×10^2	1.63×10^3	2.68×10^3
Aldehydes	Formaldehyde	30.2	22.4	55.6	8.57×10^2	9.65×10^2
	3-Methylbutanal	32.3	26.8	58.4	9.32×10^2	1.11×10^3
	2-Methylpropanal	38.3	34.8	64.3	1.36×10^3	1.50×10^3
	Ethanal (Acetaldehyde)	1.21×10^2	1.47×10^2	1.86×10^2	5.92×10^3	6.37×10^3
	Pentanal	28.1	25.4	51.9	8.48×10^2	9.82×10^2
	Hexanal	35.4	28.3	61.7	7.91×10^2	9.16×10^2
	Octanal	33.1	31.6	59.4	7.86×10^2	9.10×10^2
Ketones	Acetone	3.31×10^2	2.24×10^2	3.56×10^2	1.24×10^4	1.33×10^4
	Methyl ethyl ketone	1.12×10^4	1.97×10^4	4.54×10^4	8.97×10^4	1.66×10^5
	2-Butanone	2.20×10^2	1.33×10^2	2.97×10^2	1.34×10^3	2.21×10^3
	Methyl isobutyl ketone	1.23×10^2	1.16×10^2	1.48×10^2	7.63×10^2	1.15×10^3
	2-Hexanone	1.36×10^2	1.02×10^2	1.74×10^2	8.07×10^2	1.22×10^3
	4-Heptanone	1.12×10^2	97.6	1.36×10^2	5.41×10^2	8.87×10^2
Aliph. hydrocarbons	Methane	2.52×10^4	1.24×10^4	9.87×10^3	2.15×10^5	2.62×10^5
	Cyclohexane	2.76×10^2	2.14×10^2	9.36×10^2	1.74×10^3	3.17×10^3
	Propane	1.17×10^4	4.38×10^3	2.64×10^3	7.53×10^4	9.40×10^4
	Isopentane	2.13×10^3	1.08×10^3	2.66×10^3	1.81×10^4	3.30×10^4
	Ethylene	2.24×10^2	1.56×10^2	1.27×10^3	3.81×10^4	3.98×10^4
	Butylene	1.14×10^2	94.3	6.64×10^2	5.34×10^3	6.21×10^3
	Ethane	1.34×10^4	6.31×10^3	4.78×10^3	9.26×10^4	1.17×10^5
	Isoprene	1.35×10^3	8.75×10^2	6.56×10^3	1.64×10^4	2.52×10^4
	Pentane	2.46×10^3	1.17×10^3	3.03×10^3	2.05×10^4	2.72×10^4
	1-Heptene	87.3	65.4	5.12×10^2	1.21×10^3	1.87×10^3
	Methyl cyclopentane	2.33×10^2	1.64×10^2	8.44×10^2	1.52×10^3	2.76×10^3
	2-Methyl pentane	3.22×10^2	2.68×10^2	1.86×10^3	2.95×10^3	5.40×10^3
	3-Methyl pentane	3.04×10^2	2.14×10^2	1.26×10^2	2.61×10^3	3.25×10^3
	Cyclobutane	1.82×10^2	1.01×10^2	5.41×10^2	1.33×10^3	2.15×10^3
	Cyclopentane	1.94×10^2	1.37×10^2	6.37×10^2	1.47×10^3	2.44×10^3

Table 3. Continued

Category	Substance	Excretion, μg/h				
		In exhaled air	Sweat	Urine	Feces	Total
Arom. hydrocarbons	Xylene	3.92×10^2	1.28×10^2	7.74×10^2	1.47×10^3	2.76×10^3
	Toluene	9.63×10^2	8.38×10^2	1.85×10^3	3.44×10^3	7.09×10^3
	n-Propyl benzene	61.3	44.5	2.39×10^2	4.08×10^2	7.53×10^2
	Ethyl benzene	8.54×10^2	6.45×10^2	2.44×10^3	4.25×10^3	8.19×10^3
	Benzene	5.24×10^3	1.44×10^3	7.53×10^3	1.35×10^4	2.77×10^4
	1-Methyl-3-ethylbenzene	81.2	69.2	2.94×10^2	7.05×10^2	1.15×10^3
	1-Methyl-4-ethylbenzene	1.03×10^2	83.4	4.36×10^2	8.17×10^2	1.44×10^3
	1-Methyl-2-ethylbenzene	92.4	72.6	3.98×10^2	7.96×10^2	1.36×10^3
	Phenol	3.23×10^2	5.21×10^2	4.13×10^2	2.84×10^3	7.70×10^3
	p-Cresol	1.92×10^3	7.14×10^2	2.43×10^3	1.69×10^4	2.20×10^4
Esters	Butyl acetate	2.76×10^2	1.92×10^2	7.38×10^2	1.95×10^3	3.16×10^3
	Isobutyl acetate	1.62×10^2	1.37×10^2	4.47×10^2	8.64×10^2	1.61×10^3
	Isoamyl acetate	2.54×10^2	2.03×10^2	8.65×10^2	1.72×10^3	3.04×10^3
	Ethyl acetate	3.52×10^2	2.83×10^2	9.64×10^2	2.87×10^3	4.47×10^3
	Ethyl hexanoate	1.23×10^2	94.8	1.59×10^2	7.13×10^2	1.09×10^3
	3-Methyl-2-butylacetate	72.4	58.7	1.97×10^2	6.59×10^2	9.87×10^2
Ethers	1,4-Dioxane	7.68×10^2	5.48×10^2	1.07×10^3	5.33×10^3	7.72×10^3
	Diphenyl ether	1.75×10^2	1.37×10^2	3.37×10^2	9.24×10^2	1.57×10^3
	Furan	4.27×10^2	2.31×10^2	5.48×10^2	7.36×10^3	8.57×10^3
Halocarbons	Dichloromethane	1.32×10^2	1.18×10^2	2.18×10^2	6.03×10^2	1.07×10^3
	Chlorobenzene	1.12×10^2	87.9	2.13×10^2	5.93×10^2	1.01×10^3
	Tetrachloroethylene	1.05×10^2	83.8	2.54×10^2	5.47×10^2	9.90×10^2
	1,1,1-Trichloroethane	33.5	28.7	1.11×10^2	1.96×10^2	3.69×10^2
	Chloroform	1.75×10^2	1.24×10^2	7.03×10^2	9.75×10^2	1.98×10^3
	Trichloroethylene	1.17×10^2	94.5	5.79×10^2	6.09×10^2	1.40×10^3
	Methyl chloride	1.51×10^2	1.02×10^2	2.63×10^2	8.33×10^2	1.35×10^3
Organic nitrogens	Methyl amine	4.21×10^2	5.63×10^2	8.14×10^3	2.26×10^4	3.17×10^4
	Isopropyl amine	3.49×10^2	1.48×10^2	6.83×10^3	1.76×10^4	2.49×10^4
	Acetonitrile	2.36×10^2	2.03×10^2	4.48×10^2	8.29×10^2	1.72×10^3
	Indole	0.06	0.09	0.15	2.09	2.39
	Methylpiperazine	19.4	15.7	61.3	1.13×10^2	2.09×10^2
	Methacrylonitrile	17.4	19.3	52.4	79.3	1.68×10^2

Table 3. Concluded

Category	Substance	Excretion, µg/h				
		In exhaled air	Sweat	Urine	Feces	Total
Sulfur compounds	Dimethyl disulfide	18.4	17.5	40.3	1.86×10^2	2.62×10^2
	Ethylene sulfide	28.5	16.6	75.3	1.28×10^2	2.48×10^2
	Ethyl mercaptan	2.34	1.56	16.9	3.06×10^2	3.27×10^2
	Methyl mercaptan	1.62	1.24	12.6	1.35×10^2	1.50×10^2
Miscellaneous	Formic acid	8.11×10^3	6.38×10^3	8.99×10^3	7.67×10^4	1.00×10^5
	Acetic acid	1.58×10^3	1.27×10^3	1.44×10^3	9.21×10^4	9.64×10^4
	Menthol	1.81×10^2	92.7	9.52×10^2	1.08×10^3	2.31×10^3
Inorganic	Carbon monoxide	2.71×10^4	5.03×10^3	1.62×10^3	1.53×10^5	1.87×10^5

[a] Dmitriyev et al. (1987) listed 136 compounds the principal ones in 12 categories being presented in the above table. The data may be compared with those for the principal constituents of trace contaminant load models seen in table 11 of the prior report (Wydeven and Golub 1990).

[b] To convert to metabolic rates in mg/person-day multiply each entry by 24 [h] and divide by 56 [persons].

Table 4. Comparison of metabolic rates in two reports[a]

Compound	Report I[b]	Report II[c]
Butanol	1.33	4.17
Ethanol	4.00	5.41
Methanol	1.50	1.15
Ethanal (acetaldehyde)	0.09	2.73
Pentanal	0.83	0.42
Acetone	0.20	5.71
Methane	160	112
Indole	25	1.02×10^{-3}
Carbon monoxide	23	80

[a] Data are given in units of mg/person-day.

[b] From table 11 in Wydeven and Golub (1990).

[c] Calculated from data of Dmitryiev et al. (1987) as indicated in "total" column of table 3 of this report.

Table 5. Production rates and solid contents for minor human body wastes

Waste stream	Wet weight formation rate, g/person-day	Weight percent solids, %
Saliva	500-1500[a]	0.6[a]
Flatus	(100-2800)[b]	
Hair	0.04-0.3[c]; 0.02-0.03[d]	99.6[c]; 95.9[e]
Nails	0.010[f]	88-99.93[f]
Skin	0.57-3.00[g]	30.6[h]
Tears	0.7-1.0[i]	1.8[i,j]
Semen	(0.2-6.8)[k]	11.3[l]

[a] From Lentner (1981), pp. 114-115. Daily production rate estimated at 500-1500 ml/day, and specific gravity essentially 1.00.

[b] Discharged gas in ml/day for normal individuals on ordinary (cabbage-free) diet; single emissions are between 25 and 100 ml (Webb, 1964).

[c] From Webb (1964). Various values cited for facial hair.

[d] From Webb (1964). Various values cited for scalp, facial and body hair.

[e] From Lentner (1981), p. 224.

[f] Datum from Webb (1964) for fingernails; corresponding datum for toenails is estimated at 0.0025 g/day. Hygroscopic nature of keratin causes considerable variation in water content.

[g] Loss of dried surface skin, from Webb (1964). For skin secretions (table 7), the weight percent solids is 68.3%.

[h] From Lentner (1981), p. 224.

[i] From Webb (1964). Estimate based on secretion rate of 0.031-0.041 g/h.

[j] From Best and Taylor (1961), p. 1314.

[k] Weight in g/ejaculate, after at least 3 days of abstinence (Lentner, 1981, p. 185).

[l] From Lentner (1981), pp.185-186, given a water content of 918 g/l and a mean density of 1.035.

Table 6. Chemical composition of flatus[a]

Substance	Formula	Cabbage-free diet, mean, %	Cabbage- and milk-free diet, mean, %
Carbon dioxide	CO_2	9.0	9.7
Oxygen	O_2	3.9	5.5
Methane	CH_4	7.2	3.1
Hydrogen	H_2	20.9	12.0
Nitrogen	N_2	59.0	70.0
Hydrogen sulfide	H_2S	0.0003	0.0002

[a] Data from Webb (1964).

Table 7. Major components of skin secretions[a]

Component	Weight percent
Water	31.7
Epithelial cells and protein	61.75
Fat	4.16
Butyric, valeric, and caproic acids	1.21
Ash	1.18

[a] From Webb (1964), which presents data on fatty acids in human skin lipids and on major alcohols of the waxes and sterol esters of human skin surface lipids.

Table 8. Solids content of tears[a]

Component	Percent
Ash	1.05
Total nitrogen	0.158
Nonprotein N	0.051
Urea	0.03
Proteins (albumin and globulin)	0.669
Sugar	0.65
Chlorides (as NaCl)	0.658
Sodium (as Na_2O)	0.60
Potassium (as K_2O)	0.14
Ammonia	0.005

[a] From Best and Taylor (1961). Total solids in tears is given as 1.8%.

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M. A. Golub and T. Wydeven

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(415) 604-3200 or FTS 464-3200

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13. ABSTRACT *(Maximum 200 words)*

A compilation of generation rates and chemical compositions of potential waste streams in a typical crewed space habitat, reported in a prior NASA Technical Memorandum and a related journal article, has been updated. This report augments that compilation by the inclusion of the following new data: those data uncovered since completion of the prior report; those obtained from Soviet literature relevant to life support issues; and those for various minor human body wastes not presented previously (saliva, flatus, hair, finger- and toenails, dried skin and skin secretions, tears, and semen), but included here for purposes of completeness. These waste streams complement those discussed previously: toilet waste (urine, feces, etc.), hygiene water (laundry, shower/handwash, dishwasher water and cleansing agents), trash, humidity condensate, perspiration and respiration water, trace contaminants, and dust generation. This report also reproduces the latest information on the environmental control and life support system design parameters for Space Station Freedom.

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