NASA Technical Memorandum 84368

Composition and Analysis of a Model Waste for a CELSS

T. Wydeven

September 1983

NASA
National Aeronautics and
Space Administration

NASA Technical Memorandum 84368

Composition and Analysis of a Model Waste for a CELSS

T. Wydeven, Ames Research Center, Moffett Field, California

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

N84-11769#

SUMMARY

In order to make meaningful trade-off studies of candidate waste processing methods for application to a Controlled Ecological Life Support System (CELSS) in space, the waste input composition that is used when evaluating candidate methods should be the same. Therefore, a standardized waste composition was developed and analyzed for use in CELSS waste treatment studies. This report gives the composition and the results of the analysis of the model waste constituents.

INTRODUCTION

Shuler (refs. 1 and 2) presented a model waste for use in waste treatment systems evaluation. This model was based on a diet in which 81% (dry basis) of the dietary requirements of man would be met by fruits and vegetables grown in space and the remainder would be met from stored foods. A modest vegetarian diet was proposed by other investigators (refs. 3 and 4) for a CELSS in which 97% of man's daily nutritional requirements would be met by plants grown in space. The model waste recommended here is based on the modest vegetarian diet because with this diet almost all of man's nutritional needs can be met by plants grown in space. The primary impact on the waste treatment system of using the modest vegetarian versus the Shuler diet in designing the model waste is that a much greater amount of inedible waste biomass will have to be processed.

This report gives the composition and analysis of the model waste proposed for CELSS based on the modest vegetarian diet. Where appropriate, comparison is made with the model waste based on the reference 1 diet.

MODEL WASTE COMPOSITION

The origin of wastes expected in a CELSS which relies primarily on plants grown in space as a food source are plant wastes, food preparation wastes, the spent nutrient solution used for growing plants by aeroponics or hydroponics, wash water and human feces and urine. Trash (e.g., food packaging, worn-out clothing, etc.), was not included in the model waste designed here because it is currently anticipated that trash would be stored and returned to Earth during resupply missions. However, at some later date it may be desirable to include trash in the model if oxidation of trash to carbon dioxide is needed to replace carbon dioxide lost through leakage to space. Inclusion of trash in the input to the waste processor may also be advantageous if the additional heat of combustion of trash is needed to make a particular waste processing method self-sustaining; i.e., requiring no external heat. If trash is eventually included in the model waste, care must be exercised to exclude materials (e.g., halocarbon polymers) which could yield toxic products when oxidized.

If at some later date it is deemed necessary to include trash in the model waste then the trash composition proposed earlier may be used (ref. 5).

The composition of the model waste developed for a CELSS is given in table 1 along with the pertinent references used in developing the model. Studies of different fibers or additional protein in the diet, and the resulting effects on mineral balance were done using human volunteers whose fecal and urine specimens were collected and freeze-dried by the United States Department of Agriculture (USDA) Human Nutrition Laboratory, Grand Forks, North Dakota. However, the samples of the model waste were collected during the transitional periods when the diets of the volunteers were being modified. The fecal and urine samples were prepared for analysis, and were analyzed and distributed by Dr. John Carden, Georgia Institute of Technology, Atlanta.

Since it was anticipated that some CELSS researchers would require small samples (i.e., a few hundred milligrams), it was necessary to significantly reduce the particle size of the freeze-dried feces and then thoroughly mix the entire batch to obtain a representative sample. This was achieved by grinding 100-g lots of the feces in a blender, sieving through a 20-mesh (840-μm) grid, combining all lots into a large polyethylene bag and "shaking" to produce a uniform mixture. The homogenized batch was divided into 100-g samples and packaged in tight-sealing, wide-mouthed polyethylene bottles because of the hygroscopic nature of the freeze-dried

TABLE 1.- COMPOSITION OF CELSS MODEL WASTE

Constituent	Weight, g, man^{-1} day^{-1}		References
	Dry	Wet	
Urine	64	1,640	5
Feces	44	104	13
Inedible biomass[a]	4,400 (470)[b]	17,400 (1,900)[b]	3,4 1,2
Food preparation	20	60	5
Wash water	17	16,800	5
Spent nutrient	26	29,100	7
Total	4,500 (640)[b]	65,200 (49,600)[b]	--- ---
Percent solids	6.9 (1.3)[b]	--- ---	--- ---
Percent solids[c]	19.0 (7.7)[b]	--- ---	--- ---

[a]Inedible biomass was simulated by Cerophyl.

[b]These values were based on the Shuler et al. diet (refs. 1 and 2).

[c]After 90% removal of the water from the wash water and spent nutrient solutions.

material. Additional details concerning handling and analysis of the freeze-dried feces can be found in reference 6.

The freeze-dried urine received from the USDA also required grinding for particle size reduction and careful mixing. All operations on the urine samples had to be carried out in a dry atmosphere in a glove bag because of the hygroscopic nature of the material.

The following assumptions were made in arriving at the amount of inedible plant biomass requiring waste treatment in a CELSS:

(1) CELSS occupants would live on a modest vegetarian diet (ref. 3).

(2) Ninety-seven percent of the diet would be provided by plants grown in space. The remaining 3% of the dietary requirements (e.g., vitamins, seasonings, and miscellaneous condiments) would be store-bought (ref. 4).

(3) Crop yields are projected from controlled environment agriculture (CEA) (ref. 3).

With the aid of these assumptions it was projected that one man in one day would produce 17,400 g of inedible fresh (wet) biomass that would require waste processing (ref. 4).

Since a separate value for food preparation waste was not given in reference 4, it was assumed that the figure 17,400-g would include both inedible plant material and food preparation waste. Assuming a water content of 75% (ref. 7) for inedible fresh biomass, 17,400 g of wet inedible biomass would yield 4,400-g man^{-1} day^{-1} of dry inedible biomass.

It should be noted that the amount of inedible plant material requiring waste treatment is strongly dependent on the diet chosen for CELSS inhabitants. For example, Shuler (refs. 1 and 2) chose a different diet from that of the modest vegetarian and projected a value of approximately 470-g man^{-1} day^{-1} for the amount of dry inedible plant material that would require waste treatment. If the Shuler diet were used, 81% (dry basis) of the diet would be met by fruits and vegetables grown in space, and the remainder would be met from stored foods. Again, assuming a value of 75% for the water content of inedible plant material, the reference 1 diet would produce 1900-g of fresh inedible biomass man^{-1} day^{-1}. Therefore, the amount of fresh inedible plant material produced using the modest vegetarian diet is nine times greater than the amount from the reference 1 diet.

For the waste model selected here, the larger value for the amount of inedible plant material requiring waste treatment was chosen; because with the modest vegetarian diet, 97% of man's daily nutritional needs could be met by plants grown in space, thereby minimizing the amount of stored food. However, it is anticipated that refinements of the modest vegetarian diet could significantly reduce the amount of inedible plant material requiring waste treatment. For example, the modest vegetarian diet includes split peas (ref. 3). Split peas contribute 11.5% to man's nutritional needs while contributing 35.8% to the total amount of inedible plant material requiring waste treatment (ref. 4).

Cerophyl (Cerophyl Lab., Inc., Kansas City, Missouri) is used in the model waste to mimic inedible biomass, i.e., plant stems, leaves, stalks, etc. Cerophyl is a commercial animal feed consisting of dried and milled stems and leaves from young rye plants. The as-received individual lots of Cerophyl were ground separately and then combined and thoroughly mixed before packaging into 100 gram lots for distribution to CELSS investigators. Analysis was done on the well-mixed master batch.

Cerophyl was selected as a representative inedible biomass primarily because of its availability. However, it should be recognized that many of the different plants used for the modest vegetarian diet may have biomass compositions significantly different from young rye plants (Cerophyl). Therefore, as the model waste is further refined in the future, a mixture of the inedible portion of different plants should be used to simulate inedible biomass.

The food preparation or processing waste was designed and prepared by Professor M. Karel of M.I.T. In designing the food preparation waste, it was assumed that the CELSS population would be small, that plants would be grown hydroponically, and that animals would not be part of the CELSS. Two batches of simulated food processing wastes having the same nominal composition were prepared (see table 2). The only difference in the two batches is that they were prepared on two different occasions so that they represent, in a way, variation to be expected when the same process is performed on two occasions on raw materials, which are nominally the same. Details concerning the preparation of the food processing waste can be found in references 8 and 9.

It should be noted that in the design and preparation of the food processing waste by Dr. Karel, a different diet (the 1974 Thrifty Diet), and the 1977 NASA-Ames study base diet (refs. 8 and 9) were used. Therefore, the constituents of the food preparation waste do not correspond to the constituents of the vegetarian diet (ref. 3).

TABLE 2.- ELEMENTAL COMPOSITION OF THE MODEL WASTE FREEZE-DRIED FOOD PREPARATION SAMPLES

Element	Average concentration, $\mu g\ g^{-1}$	
	Batch #1	Batch #2
Mg	4,600 ±200	4,800 ±300
Ca	19,000 ±1,000	15,000 ±600
Na	710 estimate	1,000 estimate
K	7,400 ±600	8,600 ±1,000
Zn	78 ±20	77 ±14
Cu	31 estimate	26 estimate
Mn	170 ±20	160 ±16
Fe	150 ±15	130 estimate
V	6 estimate	5 estimate
Si	1,100 ±300	660 estimate
B	13 ±2	10 ±2
C	43.93%	43.55%
H	6.34%	6.45%
N	2.40%	2.87%
P	6,300 ±1,000	7,200 ±1,000

The amount of food preparation waste (i.e., 20-g man^{-1} day^{-1} (dry weight)), used in the model waste was taken from a report by the Bioenvironmental Systems Study Group (BSSG) (ref. 5). Shuler (private communication) has suggested a value of 40 g man^{-1} day^{-1} (dry weight) as a realistic estimate for the amount of food preparation waste. Since the amount of food preparation waste is small compared to the amount of inedible plant material, and since the composition of the food preparation waste and inedible plant material will probably not be greatly different, the different amounts suggested by the BSSG and Shuler should not have a significant impact on any waste treatment system being evaluated for a CELSS.

The amount of wash water and wash water solids included in the model waste was taken from the work of the BSSG (ref. 5). The composition of wash water solids was given by reference 10 and is shown in table 3. It is not anticipated that the soap contained in wash water will be regenerated in a CELSS. Therefore, provisions must be made to remove its products of waste treatment from the recycle loop. Without such provisions in the recycle loop the concentration of these products will continuously increase.

Another waste stream within a CELSS that will require processing is the spent nutrient solution from the plant growth chamber. The spent nutrient solution will contain organic compounds exuded by the plants, possibly some algae and fungi, most likely bacteria, some plant roots, and the remaining nutrients not taken up by the plants during their growth. The mineral content of a typical spent nutrient solution is given in reference 2, and the amount and type of salts suggested for preparing this solution are also given in table 4. Shuler (ref. 11) has added to this list boric acid as a boron source, and cinnamic acid to represent the organic compounds exuded by plants. The amount of spent nutrient solution was derived from the study of reference 7.

TABLE 3.- COMPOSITION OF SYNTHETIC WASH WATER

Constituent	Amount, g, man^{-1} day^{-1}
Lactic acid	1.54
Urea	0.90
Glucose	0.13
Soap (sodium dodecylbenzene-sulfonate; $C_{12}H_{25}-C_6H_4-SO_3Na$)[a]	5.17
Other organics (urea)	0.34
Insoluble constituents (cellulose)	5.92
Inorganics (50 wt% NaCl + 50 wt% KCl)	3.07
Water	16,800
Percent solids	0.1

[a]( ) compound used to prepare synthetic wash water.

TABLE 4.- COMPOSITION OF THE SYNTHETIC SPENT NUTRIENT SOLUTION

Constituent	Amount, g, man^{-1} day^{-1}
NaCl	17
K_2HPO_4	1.3
$CaSO_4 \cdot 2H_2O$	1.6
$MgSO_4 \cdot 7H_2O$	0.99
$FeSO_4 \cdot 7H_2O$	0.016
H_3BO_3	0.0052
$ZnCl_2$	0.0052
$CuSO_4 \cdot 5H_2O$	0.0026
Cinnamic acid	5.1
Water	29,100
Percent solids	0.089

Since the wash water and spent nutrient solutions in the model waste are large-volume, dilute solutions, they are good candidates for concentration by a technique such as hyperfiltration (reverse osmosis) prior to waste treatment of the residue. Assuming 90% removal of water from the wash water and spent nutrient solutions prior to waste treatment, the percent solids in the model waste would increase by the amounts shown in table 1. However, it remains to be determined if these more concentrated feed streams can be transported and handled by the waste treatment processes currently being proposed for a CELSS.

The percent solids in the recommended model waste can be put into perspective by comparing it with the percent solids currently used or suggested for use in different CELSS waste treatment methods. In an experimental study of aerobic digestion for treatment of CELSS wastes, Shuler and coworkers (ref. 11) used a feed stream containing 1.6% solids.

If the concentration of carbon in the waste feed stream is above 2 to 5 wt % and the oxidation is carried out in an adiabatic reactor, the heat generated during supercritical water waste oxidation is self-sustaining at 550° C (ref. 12). The percent carbon in the recommended model waste is 2.8 wt %. Therefore, without concentrating the wash water and spent nutrient solutions, the percent carbon in the model waste is within the range in which the supercritical water waste treatment process requires no external heat.

ANALYSIS OF SELECTED MODEL WASTE CONSTITUENTS

The urine, feces, Cerophyl (inedible biomass) and food preparation wastes were analyzed by Dr. John Carden. Since the wash water and spent nutrient solutions will be prepared from reagent-grade chemicals at the time of need, they were not analyzed.

The urine, feces, Cerophyl, and two different batches of food preparation wastes were analyzed for P, B, C, Ca, Cu, Fe, H, K, Mg, Mn, N, Na, Si, S, V, and Zn. The analyses for P, B, Ca, Cu, Fe, K, Mg, Mn, Na, Si, V, and Zn were done by inductively coupled plasma optical emission spectroscopy (ICPOES); while C, H, and N were determined using a Perkin-Elmer Model 240-CHN analyzer; and S was determined using a modified Dumas method. Details concerning the preparation and handling of samples for analysis can be found in reference 6. Results from the analysis of urine, feces, Cerophyl, and two batches of food preparation waste are given in tables 2 and 5.

Based on the analytical results shown in tables 5-7, and the composition of the synthetic wash water and spent nutrient solutions (tables 3 and 4), the amount of some major elements in the model waste were calculated and are given in table 7.

TABLE 5.- ELEMENTAL COMPOSITION OF THE MODEL WASTE FREEZE-DRIED URINE, FREEZE-DRIED FECES, INEDIBLE BIOMASS (CEROPHYL) SAMPLES

Element	Average concentration, μg g^{-1}		
	Urine	Feces	Inedible biomass (Cerophyl)
Mg	2,100 ±200	6,600 ±600	1,100 ±200
Ca	4,500 ±200	25,000 ±3,000	3,900 ±500
Na	68,000 ±6,000	18,000 ±1,000	1,300 ±400
K	42,000 ±5,000	28,000 ±4,000	41,000 ±4,000
Zn	13 ±4	270 ±40	29 ±6
Cu	19 ±4	40 estimate	13 ±4
Mn	ND	170 ±14	84 ±9
Fe	7 ±3	430 estimate	460 estimate
V	4 ±2	6 estimate	3 estimate
Si	150 estimate	400 ±40	did not digest
B	14 ±3	15 ±1	8 estimate
C	17.58%	41.92%	40.63%
H	4.93%	6.59%	5.57%
N	21.69%	8.26%	4.21%
S	1.80%	ND	0.11%
Cl	1.6%	2.1%	---
P	14,000 ±3,000	14,000 ±2,000	4,100 ±800

TABLE 6.- AMOUNTS OF SOME MAJOR ELEMENTS IN THE MODEL WASTE[a]

Element	Amount, g, man^{-1} day^{-1}
C	1,820 (241)[b]
H	251 (34.9)
N	202 (38.5)
K	184 (24.8)
P	19.7 (3.81)
Na	18.4 (13.4)

[a]Using average elemental composition of the two batches of food preparation waste.

[b]( ) values based on the Shuler et al. diet (ref. 1).

TABLE 7.- AMOUNTS OF SOME MAJOR ELEMENTS IN THE MODEL WASTE[a]

Element	Amount, g, man^{-1} day^{-1}
C	1,820 (241)[b]
H	251 (34.9)
N	202 (38.5)
K	184 (24.8)
P	19.7 (3.81)
Na	18.4 (13.4)

[a]Using average elemental composition of the two batches of food preparation waste.

[b]( ) values based on the Shuler et al. diet (ref. 1).

CONCLUSIONS

A model waste based on a modest vegetarian diet has been developed. Its use is recommended for evaluating candidate waste treatment processes for a CELSS. The composition and analysis of the model waste is included. It should be emphasized that the model waste recommended here has not been optimized. Therefore, it is anticipated that improvements in the model will be forthcoming as more information concerning dietary requirements, and crop yields becomes available.

REFERENCES

1. Shuler, M. L.; Nafis, D.; and Sze, E.: The Potential Role of Aerobic Biological Waste Treatment in Regenerative Life Support Systems, 11th Intersociety Conference on Environmental Systems, Paper 81-ENAs-20, San Francisco, Calif., July 1981.

2. Nafis, D.; and Sze, E.: Biological Waste Treatment Design for a Closed Ecological Life Support System, Master of Engineering Design Project, School of Chemical Engineering, Cornell University, 1980.

3. Hoff, J. E.; Howe, J. M.; and Mitchell, C. A.: Nutritional and Cultural Aspects of Plant Species Selection for a Controlled Ecological Life Support System, NASA-CR-166324, March 1982.

4. Gustan, E.; Vinopal, T.: Boeing Aerospace Co., Regenerative Life Support Research/Controlled Ecological Life Support System (RLSR/CELSS) Program Planning Support (Transportation Analysis). NASA Contract NAS2-11148, Draft Final Report, August 1982.

5. Bioenvironmental Systems Study Group of the Society of Automotive Engineers. Evaluation and Comparison of Alternative Designs for Water-Solid Waste Processing Systems for Spacecraft, NASA Contract NASw-2439, Final Report, July 1975.

6. Carden, J. L.; and Browner, R.: NASA Interchange for Joint Research, Interchange NCA2-OR260-102, Georgia Institute of Technology, Final Report, June 1982.

7. Johnson, R. D.; and Holbrow, C.: Space Settlements — A Design Study, SP-413, 1977.

8. Modell, M.; Karel, M.; and Carden, J., Development of a Prototype Experiment for Treating CELSS and PCELSS Wastes to Produce Nutrients for Plant Growth, NASA Grant NSG-2403, M.I.T., Department of Chemical Engineering, Cambridge, Massachusetts. Progress Report for July 1, 1979 to December 31, 1980.

9. Karel, M.: Evaluation of Engineering Foods for Controlled Ecological Life Support Systems, NASA CR-166359, June 1982.

10. Putnam, D. F.; and Wells, G. W.: Definition of Reverse Osmosis Requirements for Spacecraft Washwater Recycling, OSW Report 861, Department of the Interior, Office of Saline Water, November 1972.

11. Shuler, M. L.; Sze, S.; and Rollins, S.: The Feasibility of an Activated Sludge-Ultrafiltration Unit for Use in Closed Ecological Life Support Systems, American Chemical Society, Division of Microbial and Biochemical Technology, Paper MICR-12, September 1982.

12. Timberlake, S. H.: Hong, G. T.; Simson, M.; and Modell, M.: Supercritical Water Oxidation for Waste Treatment: Preliminary Study of Urea Destruction, Twelfth Intersociety Conference on Environmental Systems, Paper 820872, July 1982.

13. Webb, P., ed.: Bioastronautics Data Book, NASA SP-3006, August 1964.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-84368		

4. Title and Subtitle	5. Report Date
COMPOSITION AND ANALYSIS OF A MODEL WASTE FOR A CELSS	September 1983
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
T. Wydeven	A-9350
	10. Work Unit No.
9. Performing Organization Name and Address	T5306
Advanced Life Support Office Ames Research Center Moffett Field, CA 94035	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code
	199-60-52

15. Supplementary Notes Point of Contact: T. Wydeven, M/S 239-4, Ames Research Center, Moffett Field, CA 94035 (415) 965-5738 FTS 448-5573. This is the 24th in a series of CELSS reports.

16. Abstract

In this report a model waste based on a modest vegetarian diet is given, including composition and elemental analysis. Its use is recommended for evaluation of candidate waste treatment processes for a Controlled Ecological Life Support System (CELSS).

17. Key Words (Suggested by Author(s))	18. Distribution Statement
CELSS, Life Support Systems Waste treatment Waste processing Model waste	Unclassified - Unlimited Subject Category: 54

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	13	A02

*For sale by the National Technical Information Service, Springfield, Virginia 22161