15. WATER

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TABLE OF CONTENTS

15. WATER

The statement of water requirements for man in space operations must include an analysis of water balance in normal and emergency modes, as well as the purity standards for water.

Water Balance

In the adult man, water is approximately 60% of the body mass (73% of the lean body mass) and varies with age, fat content, and prior hydration. Body water is found in the cells of the body, around the cells, and in the blood vessels and lymphatic vessels. Each of these sites or compartments contains a given proportion of the total body water, with a division as follows: 2/3 of the total body water is in the cells (approximately 40% of lean body mass); 1/3 of the total body water is extracellular (approximately 20% of lean body mass), of which 1/4 is in the blood plasma and lymph (5% of lean body mass) and 3/4 in tissue fluid lying between the cells but outside of blood and lymphatic vessels (15% of lean body mass). The chemical anatomy of the several water compartments is known and is of great value in analyzing pathological states of hydration (24).

The internal water balance between the three body compartments is very much influenced by the continual and obligatory exchange of water between the man and his environment. There are continuous, obligatory losses of water from the body, that is, in the urine and feces and from the skin and respiratory tract. These losses are necessary for the purpose of carrying away waste products and also for temperature regulation; they must intermittently be made up by water taken in as liquid or as water in food or as the water produced chemically in the metabolism of food. Imbalance over a long enough period of time will produce dehydration or a water excess (overhydration) leading to edema (swelling), either of which has serious clinical consequences.

Water exchange in the intestinal tract is also sizable. In addition to the water ingested with food or taken in as liquid, a great deal of water is secreted along with digestive enzymes into the mouth, stomach, and intestines; water is re-absorbed later in the large intestine, with a small residue coming out in the feces.

A diagrammatic summary of the water exchanges between man and his environment is shown in Figure 15-1. Notice that the diagram shows the alimentary tract as being "outside" the body, and that large quantities of fluid move in and out of the alimentary tract during the course of a normal day. The diagram also makes it clear that vomiting or diarrhea would result in large losses of fluid as well as electrolytes. If either of these conditions persist, water balance is seriously upset.

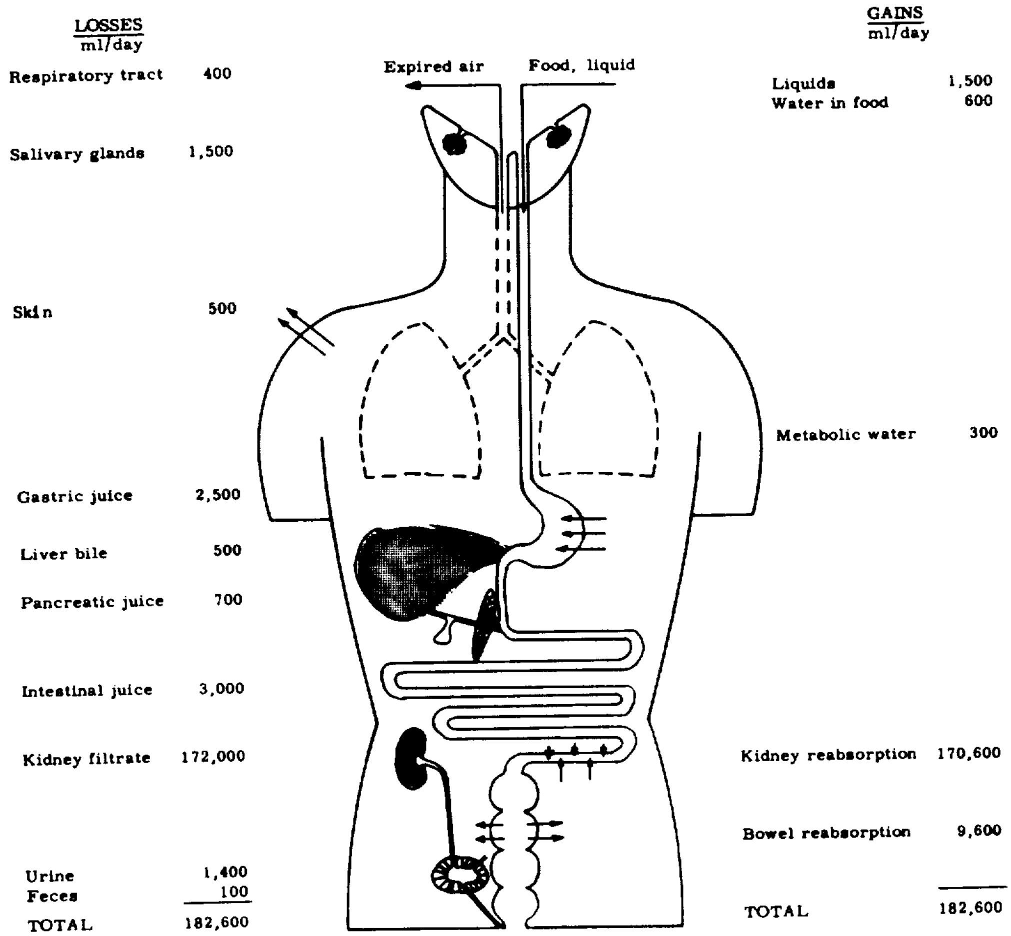

Figure 15-1

Diagram of Water Exchanges Between Man and Environments

(After Webb[108])

Water balance is defined as the difference between the input from all sources into the exchangeable water pool and the output from all sources as indicated in Table 15-2.

For primary factors in the calculation of water balance in logistic analysis it can be assumed that a male subject is at rest, quiet and comfortable and at a steady state so that such secondary factors in Table 15-2 as H_2O poly, H_2O nonexch, H_2O hydr, and H_2Oassoc, H_2O milk or H_2O misc. may be eliminated and the following balance equation used:

$$H_2O_{balance} = (H_2O_{fluid} + H_2O_{food} + H_2O_{ox})$$

$$- (H_2O_{fecal} + H_2O_{pulm} + H_2O_{derm} + H_2O_{urine})$$

Details are available on the extension of such an equation relating water balance to manifestations of metabolic activity as changes in body weight ($W_2 - W_1$), solids ingested (Sol_{ing}), solids excreted (Sol_{fecal}) and (Sol_{urine}), urinary nitrogen excretion (N_u) and respiratory activity such as oxygen uptake ($O_{2\ abs}$) and CO_2 expired ($CO_{2\ exp}$). The modified Peters-Passmore equation is (17, 36,72):

Figure 15-2

Sources and Avenues of Input and Output for the Exchangeable Water Pool

(After Johnson [36])

Source or avenue	Input	Output
Gastrointestinal	Beverage (H_2O_{fluid}) Moisture in food (H_2O_{food})	Feces (H_2O_{fecal}) Vomitus or saliva
Pulmonary	Absorption of gaseous or fluid water (H_2O_{pulm})	Vaporization(H_2O_{pulm})
Dermal	Absorption of gaseous or fluid water (H_2O_{derm})	Transpiration (H_2O_{derm}) Sweat (H_2O_{sweat}) Milk (H_2O_{milk})
Renal	----------	Urine (H_2O_{urine})
Circulatory	Infusion or injection (H_2O_{misc})	Hemorrhage (H_2O_{blood}) Exudation or transudation (H_2O_{misc})
Metabolic (H_2O_{met})	Oxidation (H_2O_{ox}) Condensation or polymerization (H_2O_{poly}) Release of nonexchangeable water of hydration ($H_2O_{nonexch}$)	Hydrolytic reactions (H_2O_{hydr}) Water associated with protein, fat, or glycogen (H_2O_{assoc})

$$H_2O_{balance} = (W_2 - W_1) + (1.3349\ CO_{2,\ exp} - 0.9566\ O_{2,abs} - 1.04\ N_u) + (Sol_{urine} + Sol_{fecal} - Sol_{ing}) \qquad (2)$$

In this equation, all values are given in grams. Examples of its use and limitations are available (36).

The exchange of water with the environment under basal conditions can be depicted as a balance diagrammatically as shown in Figure 15-3. In this diagram a normal or standard value for water intake and water output is shown in large letters and beside each value is shown a range of high and low values which may occur under certain conditions. As the diagram suggests, if intake exceeds output, there may be an accumulation of excess water in the tissue spaces, which is edema. Conversely, if water loss exceeds water intake, a deficit is initiated and as it accumulates, progressively severe symptoms from dehydration appear and lead ultimately to death. The pointer scale on the diagram is marked in terms of percent of body weight either gained or lost.

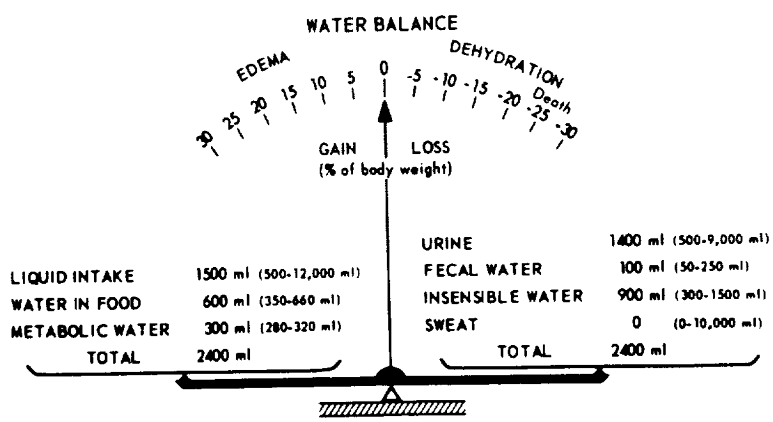

Figure 15-3

Diagram of Normal Water Balance

(After Kanter and Webb (38))

Water Requirements

The practical water requirements in space operations have been analyzed: (7, 38, 59, 62, 63, 108, 111, 112). The amount of water required is a complex function of activity, local temperature, humidity, windspeed, ambient atmospheric pressure and composition as well as adequacy of the cooling system in the space cabin suit environment (76, 108). In extravehicular operations the ambient thermal conditions and adequacy of the thermal control system of the suit are key factors. The general relationship between ambient temperature and fluid intake on Earth is seen in Figure 15-4.

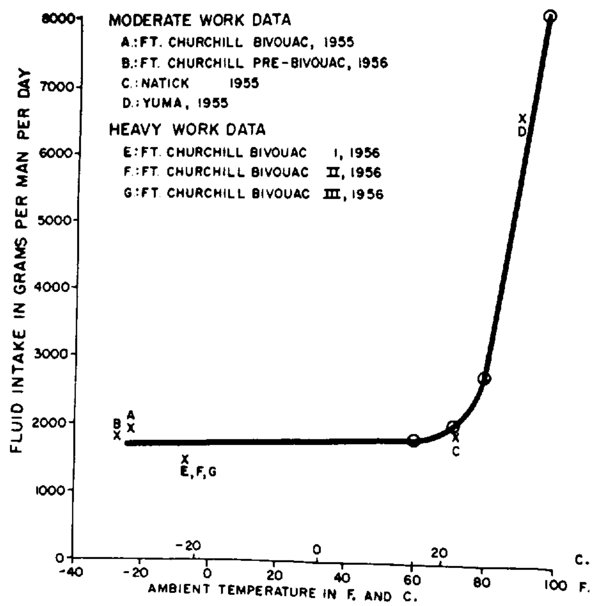

Figure 15-4

The Relation of Fluid Intake and Mean Ambient Temperature for Military Personnel

(After Welch et al (110))

Water Requirements in Normal Operating Modes

Review of the actual fluid requirements in space flight has prompted the Space Medicine Advisory Group to recommend that the amount of ingestible water per man should be 2.5 liters per day (1 cc per calorie of food) (104). This value may be high for a sedentary astronaut in a comfortable thermal environment (58). Water intake should be sufficient to maintain the urine at a specific gravity of 1.015 or less at a volume of at least 1 to 1 1/2 liters per day to avoid the development of urinary gravel and should be consumed in definite quantities on a programmed schedule (12, 30). This recommendation is for sedentary astronauts inside an orbiting vehicle within a cabin functioning at a normal comfortable mode.

In the more variable environment of the Apollo mission the general water requirements have been geared to the metabolic and space suit parameters as shown in Figure 15-5. (7). The estimates have been made for men of $2.0 m^2$ surface area with no arbitrary safety factors added. The Earth reentry phase is not considered as a special case. The routine operation of the LEM is inside pressure suits and on duty all of the time. Emergency decompression of the command module assumes pressurized suits and activity at 150% greater than normal on-duty load. It is also assumed that there is no convective or radiative loss to the cabin. In the LEM emergency decompression, the same elevation of work output is assumed as in the command module in emergency mode. On the lunar surface, the maximum continuous metabolic rate is 1600 BTU/hr with peak loads of 2000 BTU/hr. The lunar suit will be capable of limiting sweat loss to 100 gm/hr (.22 lb/hr) by providing a heat loss of about 2000 BTU/hr. (117). (See Figure 6-52a). Emergencies such as failure of cabin ventilation or suit cooling may superimpose higher thermal loads and water losses.

Studies of water requirements in space cabin simulators have elucidated the interaction between dietary, thermal, and atmospheric variables in determining water consumption (58, 88). In a series of 11 experiments

Table 15-5

Estimates of Metabolic Rate, Thermal Balance, and Water Requirements for Apollo Crew Members
(See text)
(After Billingham (7))

	PER MAN		COMMAND MODULE ROUTINE FLIGHT	COMMAND MODULE EMERGENCY DECOMPRESSION	LEM ** ROUTINE FLIGHT		LEM *** EMERGENCY DECOMPRESSION	LUNAR SURFACE EXTRAVEHICULAR (LCG OPERATION)*
			PER DAY	PER DAY	PER HOUR	PER DAY	PER HOUR	PER HOUR
Metabolic Rate Data	Heat Output	BTU	11,200	12,000	520	12,400	800	1,600
	Oxygen	lb	1.84	1.97	.085	2.04	.13	0.26
	Carbon Dioxide	lb	2.12	2.27	.098	2.40	.15	0.13
Thermal Data	Heat due to insensible water loss (Lungs, Skin)	BTU	2,600	2,700	1.5	2,750	150	250
	Latent Heat (Sweat)	BTU	1,370	7,430	170	3,990	572	230
	Sensible Heat to gas steam	BTU	7,230	1.870	235	5,660	78	0
	Sensible Heat to water	BTU	- - - -	- - - -	- -	- - - -	- -	1,120
Water Requirements Data	Urinary Loss	g	1,200	1,200	50	1,200	50	50
	Sweat Loss	g	597	3,240	74	1,740	250	100 max.
	Lung Loss	g	1,130	1,180	50	1,200	65	109
	Total Water Requirement	g	2,930	5,620	174	4,140	365	259
	Total Water Requirement	lb	6.5	12.4	.38	9.1	.80	.57

* LCG = Liquid Cooled Garment
** Both men are likely to be on duty most of the time
*** Work output per man will be higher than Command Module Emergency Decompression Phase

with 40 subjects, ad lib and total water intake were not altered by either dehydrated food, liquid food, continuously wearing pressure suits, or confinement in the AMRL Evaluator. However, an increase of 9°C in environmental temperature caused a three-fold increase in both ad lib water intake and insensible water loss and nearly doubled the total water intake. In four of eight ambient environment experiments, the mean ad lib water intake was less than one liter; in two experiments, the mean total water intake was in the 1.5 to 1.8 liter range. In the last experiments of the series, pressurization in a full pressure suit with a pressure differential of 3.7 psi for four to five days caused a decrease in insensible water loss. The subjects subsisted on a 900 calorie Apoll contingency or emergency (39) diet containing less than 50 ml of water and hac a total water intake ranging from 0.68 to 1.30 liters per day. (See Table 14-13 Insensible water loss (IW) and urine/total water (U/TW) index data were compu for all experiments. These data provide a means for assessing water balance under simulated space conditions.

For estimating the evaporative losses expected in unusual work, space suit or survival situations, Thermal Environment, (No. 6) should be consulted. Water requirements for sanitation purposes are covered below.

Minimum Water Requirements for Emergency Modes

Under emergency conditions of water limitation the minimal basal requirement for water becomes significant and may be the controlling factor limiting life. The absolute minimum obligatory output has been found to be 280-300 ml/day (24, 82). Assuming a minimal insensible H_2O loss of 500 ml/day and zero fecal loss, the total water input must equal 800 ml which is in close agree ment with empirically derived value of 1 liter/day (82). This figure is the absolute minimum and is still hazardous in that it assumed that the environmer is so controlled and stress-free that insensible loss is kept to its lowest level and there are no excessive losses through excess activity, sweating, obligatory diuresis, and other pathways.

The water requirements above basal for increments in activity, osmotic load to the kidney and hyperventilation due to activity have been discussed in detail and are summarized in Table 15-6. (36, 108).

Table 15-6

Basal Minimum Water Requirement and Increments for Osmotic Balance, Activity, and Thermal Environment of a 70 Kg Man

(After Johnson (36))

		References
Basal minimum	= Renal + Dermal + Pulmonary = 800 ml	(1, 6)
Renal increment for osmotic adjustment	= ±(Predicted excretion, mOsm/day-400) × 2	(80)
Insensible water increment for caloric output	$= \frac{\text{(Estimated kcal above basal)}}{0.58 \times 4}$	(6, 68)
Sweat increment for temperature, humidity, air motion, work, and clothing	= 6 ×(predicted 4-hr sweat rate)	(49, 52)
Pulmonary increment for hyperventilation	= (Estimated pulmonary minute volume - 10) × (Absolute humidity of expired air - Absolute humidity of inspired air)	(111)

Osmotic Increment. The obligatory water requirement for excreting the osmotic load brought to the kidney is about 200 ml per day for each increment of 100 milliosmols per day. There is an optimum; for intakes below about 700 milliosmols per day, there is a loss of body water attributable to hyposmotemia. For such a situation, increasing the water intake does no good; there is a loss of water by way of the kidney, which must have a normal osmotic load from which to elaborate urine.

Activity Increment. Under moderate conditions about 25 percent of the heat load is dissipated by the insensible water loss. Sweat has virtually the same heat of evaporation as water, 0.58 kcal per gram. A daily increase from resting at 2000 kcal to moderate activity at 3000 kcal will require an increment of about 400 ml of water (i.e., 1000 x 1/4 x 1/0.58) for heat dissipation.

Thermal Environment. Although in formal algebraic respects the thermal heat load of the environment is equivalent to the caloric effect of activity, yet there is a physiological difference, and the combined impact of temperature and humidity and other factors must be accounted for (See Figure 15-5, Ref. 1, and sections on evaporative heat loss in Thermal, (No.6) (8, 108). The internal production of heat, especially in work, is mainly a mathematical function of body mass and external work rate. The dissipation of heat from the body and the effects of heat and humidity are mainly a function of the body's surface area. In Table 15-6, the formulation of the water requirement as related to the thermal environment is the predicted 4-hour sweat rate index of McArdle et al (49). This calculated sweat output, however, is for rather restricted conditions and is not valid where strenuous exercise is involved (8). For operations requiring space suit activity, other estimations must be made of evaporative water loss (108). This is especially true in liquid-cooled space suits where uneven heating and cooling of the skin may alter the expected sweat response (13, 41). (See Figures 6-51 to 6-53.)

Figure 15-6 indicates that in contrast to the small savings in the water economy that can be made by juggling the osmotic balance and the aqueous vapor pressure of the ambient air, the losses that may be produced by changing the rate of dermal loss, pulmonary loss, and renal loss are large. Sweating may go on at the rate of a liter an hour all day long (20). Increasing the pulmonary ventilation from resting at about 10 liters per minute to moderate work at 30 liters per minute can increase the pulmonary loss by a factor of 3. On the other hand, an extra osmotic load equivalent to 10 g NaCl per day can increase the urinary water loss by only 300 ml per day. The turnover of total body water may range from 2 percent per day to more than 20 percent per day. Renal loss can,possibly,be safely reduced to 500 ml per day. Losses through the lung and skin may be minimized by reducing physical work, maintaining a cool environment with the highest practical humidity, and keeping sweating low by using other modes of heat loss such as conduction.

In calculating water requirements, the metabolic water available from foods will play a role. Table 15-7 represents these relationships.

Table 15-7

Products of Oxidation of 1 Gram of Foodstuff in the Body

(After Peters (72))

Substance	O_2 consumed, g	CO_2 produced, g	H_2O produced, g	Heat produced, kcal
Monosaccharides, e.g., glucose	1.067	1.467	0.600	3.8
Disaccharides, e.g., sucrose	1.122	1.543	.579	4.1
Starch	1.185	1.629	.556	4.3
Fat (lard)	2.876	2.805	1.071	9.3
Protein	1.382	1.522	.396	4.1
Urinary N [a]	8.638	9.513	2.475	25.6

[a] The factor 6.25 is assumed to correct urinary N to protein catabolized.

By multiplying the total weight of each dietary component in grams times the grams of water per gram of foodstuff of Table 15-7 and summing the values, the total metabolic water is obtained. For the most diverse diets of 3000 kcal/day, a range of 300 to 400 gms/day of water can be expected. Thus, the nature of the diet offers little variation in metabolic water. Nomogram 14-6f of Nutrition, (No. 14) can be used for rapid estimation of metabolic water.

The osmotic increment over basal requirements for water may be critical in emergency conditions. There is an irreducible level of urine production related to the amount of electrolytes which must be excreted each day to maintain osmotic balance in the body. The kidney responds to a water deficit situation by excreting increasingly concentrated urine. The maximum osmotic level, or urine concentration which it can normally produce is about 1.4 osmoles/liter (24). The quantity of osmotically active material which must be excreted each day is a function of the dietary composition. (See Table 15-8). On a pure carbohydrate diet, or a diet consisting of only fat and carbohydrate, the osmotic load is minimal. That is, the end products of metabolism of fat and carbohydrate do not produce electrolytes to be secreted in the urine, only water and CO_2. The metabolism of protein, however, does produce osmotically active material, principally urea. The minimum urine flow on a pure carbohydrate diet in the face of water deficit is 4 to 5 ml per hour (96 to 120 ml per day) whereas with a high protein diet, the minimum urine flow is 20 to 25 ml per hour (480 to 600 ml per day) (43).

In the face of an emergency demand for minimal urine flow to conserve water, the effect of the protein content of a 3000 kcal/day diet on minimum urine volume for the day would be as shown in Table 15-8.

Table 15-8

Dietary Control of Minimal Urine Volumes

(After Webb[108])

	Total Solutes*	Minimal Urine Volume**
Diet 1 (50% Protein)	1892 milliosmols	1400 ml/day
Diet 2 (30% Protein)	1212 milliosmols	880 ml/day
Diet 3 (10% Protein)	523 milliosmols	310 ml/day
Diet 4 (0% Protein)	180 milliosmols	100 ml/day

*Assuming constant low values for sodium 40 meq/day, chloride 65 meq/day, and potassium 70 meq/day, and computing urea from the quantity of nitrogen available in the protein of the diet.

**Using the average maximal concentrating ability of the kidney at 1.4 osM/liter.

Dehydration and Overhydration Syndromes

Dehydration means the failure of replacement of water and electrolytes through inability to find or take fluids and salts to make up for output. The spectrum of dehydration as a function of weight loss has been summarized in chart form as shown in Figure 15-9. The terminal sequence in fatal dehydration involves decreasing volume of extracellular fluid, near-complete retention of sodium salts through the action of the adrenal hormone, aldosterone, and a rising concentration of electrolytes all over the body (43, 50).

Of more immediate concern are the milder stages of water loss which might be expected to occur in space flight, and the effect of this minimal "dehydration" on performance and tolerance to stress. Small amounts of water loss can easily become cumulative if continued day after day, as experience with troops in hot climates has shown (2). In manned space flight, as experienced by both the USSR and the USA, a consistent weight loss of approximately 2-5% of body weight has occurred in every astronaut or cosmonaut (108, 109). This consistent observation is apparently independent of the duration of flight, weight losses in this range having been recorded in flights of three orbits (4 1/2 hours) up to missions lasting 4, 8, and 14 days. Similar weight losses have been reported from some of the space cabin simulation work done at the USAF School of Aviation Medicine. Since water was freely

DEHYDRATION WEIGHT LOSS - % initial weight

0 (NORMAL WEIGHT)

Thirst

2 — Stronger thirst, vague discomfort and sense of oppression, loss of appetite.

Increasing hemoconcentration.

4 — Economy of movement.

Lagging pace, flushed skin, impatience; in some, weariness and sleepiness, apathy; nausea, emotional instability.

6 — Tingling in arms, hands, and feet; heat oppression, stumbling, headache; fit men suffer heat exhaustion; increases in body temperature, pulse rate and respiratory rate.

Labored breathing, dizziness, cyanosis.

8 — Indistinct speech.

Increasing weakness, mental confusion.

10 — Spastic muscles; positive Romberg sign (inability to balance with eyes closed); general incapacity.

Delirium and wakefulness; swollen tongue.

Circulatory insufficiency; marked hemoconcentration and decreased blood volume; failing renal function.

Shriveled skin; inability to swallow.

15 — Dim vision.

Sunken eyes; painful urination.

Deafness; numb skin; shriveled tongue.

Stiffened eyelids.

Cracked skin, cessation of urine formation.

20 — Bare survival limit

Death

Figure 15-9

Spectrum of Dehydration

(After Kanter and Webb[38] from the data of Adolph[2], Beeson and McDermott[4] and Goldberger[25]) available to these men, there remains a question of why they did not respond to the weight loss (water loss) by drinking.

The normal water replacement is triggered by thirst. The basic mechanism of thirst and its alteration by different conditions has received much study (31, 92, 96, 97, 107, 113, 114). Failure of water replacement in space flight has been analyzed as a manifestation of the "voluntary dehydration" of Adolph and Laddell (2, 76) and the "involuntary hypohydration" of Greenleaf (30). The process referred to is that seen in men who are working in heat or otherwise losing water at a high rate (8). These men seldom replace water as rapidly as it is lost, and during the period when body weight is reduced there is a water depletion which may amount to 1-2% of body weight. Many people in hot industrial situations and people who live in hot climates carry such a weight deficit through the day and make it up in the evening. Complete rehydration does not occur during the day because the men do not voluntarily increase their water intake sufficiently. Apparently neither water loss alone nor water and salt lost together produce thirst corresponding to a depletion of body water of 2-3% of body weight (30). It is thought that there are 2 liters of "free circulating water" which are expendable without gross physiological disturbance. In men who are habitually overhydrated, "voluntary dehydration" may possibly be a loss of this free circulating water. The effect of zero gravity on this response is not clear (108). In appropriate thirst responses or individual idiosyncrasy may precipitate a water deficit and must be guarded against by scheduled drinking (12, 52). Ideally, the rehydration should occur by taking small amounts of water frequently during the time the water loss is high. Drinking large amounts of water may produce diuresis, with a net loss of body water. Also drinking large amounts of water may provoke gastric distress and vomiting. It is better to make up water loss as it is occurring by continually drinking small amounts of water. By this method the body weight can be maintained unchanged in the face of sweat rates as high as 950 gm/hr (8).

The alteration of the physical and chemical properties of sweat and factors affecting the water balance in confined spaces is now under study (37).

The data of Figure 15-9 indicate the deficit in function which may be expected in more severe forms of dehydration. Dehydration in the range of only 1-3% of body weight causes a higher heart rate in submaximal work and a significantly decreased time to exhaustion to maximal work (10, 15, 42, 79). Walking time, especially in hot environments, can be reduced up to about 50% by dehydration of up to 4% (18). Isometric muscle strength begins to deteriorate at 4.0% weight loss; deterioration appears in a modified Harvard step test at 4-4 1/2%; submaximal oxygen intake for a given exercise deteriorates at greater than 4%(30). It has been shown that physiological strain can be reduced when men were required to work in hot, humid climates if before working they overhydrate by drinking two liters of water. This improvement was shown by a lesser strain in the overhydrated man than in men who replaced water only as it was lost (60).

Of special interest to lunar operations is the progressive decrease in orthostatic tolerance as water deficits of 1 to 5% are imposed (2, 5). Dehydration can synergize with heat and prior deconditioning by bed rest to exaggerate orthostatic intolerance (19). Decrease in body weight of only 1-3% can decrease tolerance to positive ($+G_z$) acceleration (28, 29, 30, 99) (See also zero gravity in Acceleration #7).

The effect of varying degrees of dehydration on thermal sweat output is still open to question (15, 27, 71, 75, 81). The rate of dehydration, its chronicity, and simultaneous salt or food deprivation appear to be key factors in determining the response of thermal sweat rate to dehydration. Not clear is the extent to which the 2-3% dehydration in weightlessness will alter subsequent sweating responses during extravehicular operations.

Heat training leading to acclimatization for particular heat conditions of extravehicular, orbital, and lunar operations would be helpful in several ways (108). The sweating and cardiovascular response to heat stress would be more appropriate; the training would teach the subject when and how to drink to avoid dehydration; and he would be less likely to succumb to heat prostration during mild stress.

Survival time after water deprivation in space operations will be a complex function of many simultaneous thermodynamic variables (See Thermal (No. 6). The data for survival time under different ambient conditions on Earth are given in Figure 15-10. These can be used for post-landing emergencies. For emergency situations, alleviating thirst by carbohydrate mouth coolants is under study (94). This may prolong the functional capacity in absence of water sources.

Advanced humidity control systems are now under study (73, 70). Failure of humidity control in suits and cabins may lead to annoying if not serious maceration and infection of the skin with secondary effects on human performance (14, 44, 46, 85, 98, 100, 108). The skin disorders that can arise from heat and excess humidity are: (98)

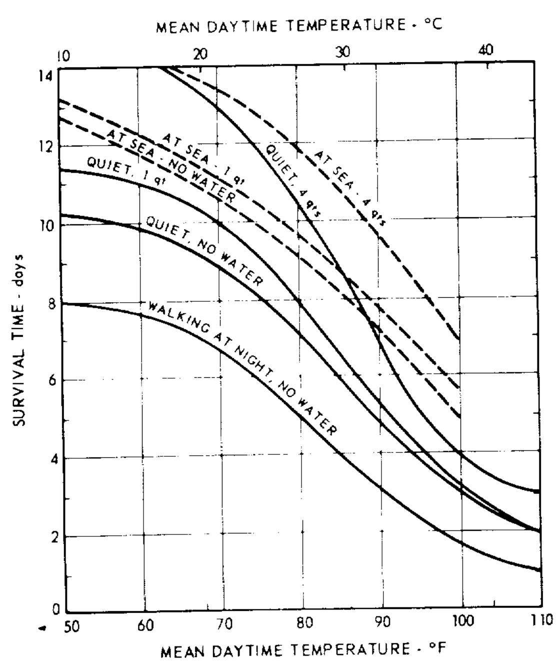

Figure 15-10

Effects of Water Deprivation on the Survival Time in Different Thermal Environments on Earth

Predicted survival times on land and sea are shown when men have no water, or 1 quart per man, or 4 quarts per man, total supply. The man on land is expected to rest, and not to try to walk out of the situation, but to stay in whatever shade he can muster. The effect of walking only at night is shown in the lowest curve. The survival time is set by dehydration.

(Adapted by Kanter and Webb(38) from data of Adolph(2), Nutall(68) and U.S. Air Force(102))

Intertrigos--in the groin, axilla, and external otitis.

Superficial fungus infections--dermatophytosis, candidiasis.

Superficial pyodermas and cellulitis--folliculitis, furunculosis, tropical impetigo, etc.

Occlusion of pores and follicles--prickly heat (miliaria), tropical acne, and anhidrotic heat exhaustion.

A hydrated stratum corneum (the superficial layers of the epidermis) invites invasion and growth of bacteria and fungi. This hydration occurs particularly if sweat cannot evaporate, as would be true with the wearing of impermeable clothing (100).

The condition of prickly heat, or miliaria, is common in people in hot climates and particularly hot, humid climates. (44, 46). The condition can be annoying, or become more and more severe until the patient is disabled. The condition results from a plugging of the sweat-gland duct either superficially or deep. Miliaria and other anhydrotic disorders of the skin arising from poor moisture dissipation are currently under study (26).

Treatment of the various dehydration and overhydration syndromes in space operations has received recent consideration (14). It is hard to separate the thermal from the dehydrative aspects of the problem.

Wash and Waste Water Requirements

Past estimates for the minimum "wash" or sanitation water requirements have been from 500 to 1800 ml/man day depending on duration and type of mission (54, 101). Subjects have spent periods of 6 weeks in space cabin simulators without washing (85). There was severe body odor but no major problems. Lack of tooth brush water resulted in gingivitis. Estimates for missions of two or more months duration with moderate water restriction have run from 1 to 6 gallons/day (9, 16, 34, 64). In more advanced missions where less restrictive weight limitations may be in force, the water requirements may be expanded to encompass the more typical military and exploratory usage indicated in Table 15-11. The hygienic aspects of wash water requirements have been covered in a recent review (23). It is felt that normal earthly hygienic conditions including washing of clothes can be easily attained with 6-12 gallons/day, but that less than 6 gallons could easily be tolerated without too much inconvenience.

Table 15-12 covers the breakdown of "wash" water use projected for future space missions giving projected maximum and minimum for each category.

The handling of waste water is also a problem (33, 74, 93). Table 15-13 can be used as a rough estimate for inputs into waste storage or recycling systems. Simple arithmetic shows the impossibility of storing sufficient water for missions of about 1000 days. With a 10-man crew, each needing about 10 lbs. of water per day for all purposes, the total water requirement would be 50 tons, occupying almost 1700 cubic feet of space. Since present, or even foreseeable, booster capacity cannot accept such a penalty in weight or

Table 15-11

Comparison of Total Water Requirements

(After Celentano and Amorelli et al[16])

a) Water Requirement in Military & Exploratory Situations.

Organization	Gallons Per Man-Day
IGY polar expedition	11
Military advanced bases	
(World War II)	
Allied	10
United States	25
U.S. Air Force	
Permanent bases	150
Advanced bases	75
U.S. Navy	
Permanent bases	100
Advanced bases	25 to 50
Surface vessels	25
Submarines	20
Space System (Recommendation for Hygiene equivalent to that on Earth)	6

b) Consumption of Fresh Water Aboard Ship.

Use	Gallons Per Man-Day
Drinking	0.5 to 1.0
Kitchen	1.5 to 4.0
Washing	5.0 to 20.0
Laundry	5.0 to 10.0

Table 15-12

Conservative Estimates of Daily Water Requirement for Sanitation Purposes to Attain Hygiene and Comfort Equivalent to Earth Conditions

(After Roth[77] from data of Ingram et al[34])

	Liquid wastes, kg/man-day		Solid wastes, kg/man-day	
	Minimum	Maximum	Minimum	Maximum
Food preparation	1.0	4.0	0.010	0.040
Personal hygiene	1.5	4.5	.015	.045
Clothes washing	3.0	4.0	.030	.040
Cabin cleansing	1.0	5.0	.010	.050
Subtotal	6.5	17.5	.065	.175
Total	6.565 to 17.675			

Table 15-13

Daily Human Metabolic Waste Production

(After Roth[77])

	Reference					
	Liquid wastes, kg/man-day		Solid wastes, kg/man-day		Average metabolic wastes, kg/man-day	
	Minimum	Maximum	Minimum	Maximum		
CO_2	1.0	1.0	-----	-----	1.03	1.03
Perspiration and respiration	.80	3.48	-----	-----	1.0 to 3.5	1.00
Urine	1.2	1.5	0.060	0.075	1.52	1.39
Feces	.053	.08	.017	.020	.182	.114
Total	3.13 to 6.155				3.732 to 6.232	3.534

volume, reclamation of water must be performed on lengthy, manned mission in space.

Advanced humidity control (70) and water recovery systems using isotopi heating (22, 57) and vacuum distillation with vapor compression recovery of latent heat (67) are currently under study.

Water Purity

The standards for both "wash" water and drinking water must be consider Potability standards for drinking water are being developed which will modify existing U.S. Public Health Service and World Health Organization Drinking Water Standards (103, 115). These are shown in Figure 15-14. In some areas these are overly stringent because of their applicability to the entire range of population through their whole lifetime including infants and the infirm (89, 91 101,103,105). They protect aquatic life from chromates and copper and meet threshold limits of taste in the case of copper, iron, zinc, and manganese. They are standards of excellence but are probably far too severe as criteria f the maintenance of health and well-being for space crews. However, it also seems reasonable to require more stringent bacterial standards to cover long periods of storage after passage through water reclamation and recycling devices (48, 87, 89, 91). Summaries of the physiological effects of individual contaminants are available (89). Data are also available on the water-soluble atmospheric contaminants which may enter water supplies (90). (See Contam inants No. 13).

The following analysis is taken directly from a recent NAS-NRC review o water quality standards for long-duration manned space missions (61). In dis tribution of water to municipalities, it is possible to allow occasional failure t meet requirements fully, provided the failure is not great or prolonged and provided corrective measures are instituted promptly. In contrast, the stand recommended for water quality in space flight must be regarded for the most part pragmatically as performance standards to be met or exceeded by recove systems during testing periods. Ability to test water for conformity with standards during actual flight will be minimal, except for sensory evaluation; and ability to take corrective measures, except for certain standardized proc dures, will also be minimal. Because complete monitoring is not feasible, possible adjustments are limited, and the same source of water must be used whether it meets standards or not, it is intended that the recommended stand be met under all conditions of performance testing and on an individual basis, not simply on an average basis. It was recommended that performance testir be of sufficient duration to evaluate the quality of water produced by recovery systems not only when new and in prime condition, but also following some of the anticipated replacements and repairs to be done by crews during space flights. Trends in parameters of water quality should be given weight, as we as minimal attainment of numerical requirements. If deterioration in quality as measured by any parameter, occurs during the testing period, even though limits are not exceeded at any time, the testing should be prolonged until it is shown that requirements are still satisfied when steady-state operation has b achieved.

Determination	USPHS	WHO
Bacterial:		
Coliform bacteria, per 100 ml	1.0	[a] 0.05 [b] 1.0
Physical:		
Turbidity, silica scale units	5	------
Color, cobalt scale units	15	------
Odor, maximum threshold number	3	------
Chemical, mg/liter:		
Alkyl benzene sulfonate	0.5	------
Ammonia	--------	[a] 0.5
Arsenic	[c] 0.05	[a] [b] 0.2
Barium	[c] 1.0	------
Cadmium	[c] 0.01	[a] 0.05
Calcium	--------	[b] 200
Carbon chloroform extract	0.2	------
Chloride	250	[a] 350
Chromium (hexavalent)	[c] 0.05	[a] [b] 0.05
Copper	1.0	[a] 3.0
Cyanide	0.2	[a] [b] 0.01
Fluoride	[c] 1.6–3.4	[a] 1.5
Iron	0.3	[b] 1.0
Lead	[c] 0.05	[a] [b] 0.1
Magnesium	--------	[a] 125
Magnesium + sodium sulfate	--------	[b] 1000
Manganese	0.05	[a] 0.1
Nitrate, as NO_3	45	[a] 50
Phenolic compounds	0.001	[a] 0.001
Selenium	[c] 0.01	[a] [b] 0.05
Silver	[c] 0.05	------
Sulfate	250	[a] 250
Total solids	500	[b] 1500
Zinc	5.0	[a] 5.0
Radiological, pc/liter:		
Radium-226	[c] 3	------
Alpha emitters	--------	[a] [b] 1
Strontium-90	[c] 10	------
Beta emitters	[c] 1000	[a] [b] 10

[a] WHO European Standards of 1961.
[b] WHO International Standards of 1958.
[c] Mandatory. Others are recommended by USPHS.

Figure 15-14

Municipal Drinking Water Standards in Current Use

(After McKee[51])

Biological quality was of particular concern to the Panel. It was felt strongly that, however rigorous pre-flight testing was, there would still be a prospect of introducing potentially harmful organisms into the supposedly pure-water side of the recovery system during takedown operations or by adventitious circumstances not encountered during testing. Accordingly, it was the strong recommendation of the Panel that any recovery system include a positive sterilizing procedure at some point following the phase separation step, even though the unit might be capable of producing a near sterile water under optimal conditions without such a procedure.

The Panel could think of no method except heat treatment, to pasteurization temperatures at least, that it considered acceptable; yet it did not want to exclude other methods of treatment, if they were available or could be devised, that would be as universally and reliably lethal to all forms of microbial life as heat treatment.

Table 15-15 presents the recommended standards for physical properties:

Table 15-15

Comparative Physical Properties Limits for Water Purity in Spacecraft

Test	NAS-NRC for Spacecraft (61)	Municipal USPHS (103)
1. Turbidity (Jackson Units)	not to exceed 10	5
2. Color (platinum-cobalt units)	not to exceed 15	15
3. Taste	none objectionable	same
4. Odor	none objectionable	maximum threshold No.3
5. Foaming	none persistent more than 15 seconds	—

Palatability and aesthetic acceptability are considered very important characteristics for water supplies in space flight. The severe stresses of a long space voyage in closely confined quarters should not be increased by any objectionable appearance or flavor in the water supply. Moreover, lack of adequate quality in these respects will tend to discourage normal intake of water and thus will decrease health and vigor below the optimal level.

Since the standards for taste and odor are subjective to some extent as a result of variations in individual sensitivity and experience, it is recommended that, if feasible, final evaluation of recovery systems for these properties be done by persons expected to participate in the space flights.

Recommended upper limits for chemical constituents in spacecraft water supplies (milligrams per liter) are given in Table 15-16 (61).

Some of the recommended standards for chemical quality have been based primarily on the adverse sensory properties that would be imparted to water by concentrations in excess of the limits. Those for chloride, copper sulfate and total solids fall in this category. All are well below levels at which harmful physiological effects would be experienced. It was felt unnecessary to set

Table 15-16

Recommended Upper Limits for Chemical Constituents in Spacecraft Water Supplies

	NAS-NRC for Spacecraft (48)	U.S.P.H.S. (103)	W.H.O. (115)
Arsenic	0.5	0.005	0.2
Barium	2.0	1.0	–
Boron	5.0	–	–
Cadmium	0.05	0.01	0.05
Chemical Oxygen Demand (dichromate method)	100.0	–	–
Chloride	450.0	250.0	350.0
Chromium (hexavalent)	0.05	0.05	0.05
Copper	3.0	1.0	3.0
Fluoride	2.0	1.6-3.4	1.5
Lead	0.2	0.05	0.1
Nitrate and Nitrite (as Nitrogen)	10.0	–	–
Nitrate, as No.3	–	45.0	50.0
Selenium	0.05	0.01	0.05
Silver	0.5	0.05	–
Sulfate	250.0	250.0	250.0
Total Solids	1000.0	–	–

specific limits for iron and manganese because undesirable concentrations of these materials would be manifest in unacceptable color or turbidity.

The limits for arsenic, barium, boron, cadmium, hexavalent chromium, fluoride, lead, nitrate and nitrite, selenium and silver have been based on potential toxic or adverse physiologic effects. The recommended limits are in many instances greater than those of the PHS drinking water standards, but they are considered well within limits of safety for consumption by healthy adults for periods of three years. The standard for Chemical Oxygen Demand (dichromate) is included to guard against excessive carry-over of organic matter in recovery systems utilizing urine or feces as sources of water. Virtually nothing is known about the possible build-up of toxic, perhaps volatile, organic materials in water that has been recycled many times through the human system.

The Panel recognized that there are many other toxic inorganic or organic substances which might, in special circumstances have some likelihood of occurrence in the water treated in space recovery systems. Examples are substances entrained from the cabin atmosphere in condensate water. They felt unable, however, to list all possible substances that might be encountered and considered it unrealistic to establish standards for hypothetical hazards. Accordingly, the list of chemical standards may be incomplete and may need supplementation if there are possibilities of toxic substances from unusual materials of construction or from substances employed in other parts of the operation of the space vehicle. Whenever possible, the Panel felt, control over such materials should be maintained by preventing their entrance into the spacecraft.

New techniques for rapidly monitoring total solids, total organic carbon, chemical oxygen demand, and other factors, are under development (21, 83 84, 91).

Biological requirements were also specified by the NAS-NRC (61). A numb of features peculiar to the design and operation of water-recovery systems for space travel make the normal coliform tests used for municipal supplies of little value and increase the importance of the total count of microorganisms as a measure of microbiological quality of water. In systems regenerating water solely from urine, wash waters and condensate water, coliforms will not be a particularly reliable method for indicating extent of microbiological contamination. Moreover, recirculation of typical enteric organisms from discharges of the few individuals concerned in a space flight is not likely to be the major hygienic problem even when the recovery system may utilize fecal matter as well as other sources of water for raw material.

Of great concern, on the other hand, is the potential multiplication of microorganisms in any part of the recovery system accompanied by production of toxic metabolites such as endotoxins or exotoxins. Accumulation of organic and inorganic materials in the water-recovery system as a result of continual recycling may well create a suitable nutrient medium for such growth, particularly in filters or columns of absorbent. For example, spores of Clostridium botulinum are found not uncommonly in the human intestinal tract. If these spores, normally harmless on ingestion, are seeded on a filter or absorbent or in interstices where nutrient materials may accumulate and low redox potentials may be produced, then they could vegetate readily and produce their potent toxin. Traces of this in the final product water would be disastrous. A similar situation would result from the growth of Staphylococcus species and production of their enterotoxin. Another possible consequence of recycling is the accumulation of relatively nonpathogenic organisms such as Aerobacter aerogenes, Pseudomonas aeruginosa and numerous types of fungal spores. Relatively large numbers of such organisms may overwhelm the normal tolerance of man to ingestion or inhalation of small numbers of them, resulting in acute gastroenterit or pulmonary disease. In addition, ear infections may be caused by Pseudomor and by fungi, such as Aspergillus. Moreover, some mycoplasma (PPLO) and viruses are excreted in urine or feces. Other viruses of respiratory types may be concentrated in cabin condensate. While such agents, particularly the virus would not be expected to increase in the absence of viable tissue cells, positive control of them should be demonstrated for any water-recovery system.

Because of the diverse natures and modes of hazard of possible biological contaminants in water-recovery systems for space use, the Panel found no justification for the establishment of standards based on individual types of microorganisms. It was considered that the goal should be essential sterility and that total counts of aerobic, facultative and anaerobic organisms would be the best indications of attainment of this condition. A maximum of 10 viable microorganisms per milliliter was considered to be a realistic criterion for "essential sterility." It was considered essential, moreover, that this criterio of essential sterility be applied to all parts of the recovery system beyond the initial phase separation step and not simply to the finished product water. The Panel felt strongly that some positive form of sterilization was needed at some point in the recovery-storage-delivery system immediately after phase separation. In addition it was felt that there should be provision for periodic heat treatment of the subsequent portions of the system to forestall hazards of possible bacterial or fungal growth.

For biological standards of drinking water for space use, the Panel specifically recommends that aliquots of the water, cultured separately for total aerobic organisms, total anaerobic organisms and total cytopathic viruses, yield no more than a sum total of 10 organisms per ml.

The latest methods for the examination of water and waste water have recently been reviewed and are applicable to physical and chemical analysis of spacecraft water supplies (3). In the case of microbiological quality, the following methodology was recommended by the NAS-NRC (61). To examine for total aerobic microorganisms 10-ml samples should be filtered through 0.45 micron membrane filters, the membranes placed in sterile petri dishes on pads moistened with trypticase soy broth or on plates of trypticase soy agar and the dishes incubated for 7 days at 35°C, followed by counting of the total colonies produced. A similar procedure should be followed for total anaerobic organisms except that incubation is to be carried out under anaerobic conditions.

To test for common viral agents, the filtrates from the aerobic and anaerobic samples should be concentrated in an ultracentrifuge and the pelleted material tested on suitable tissue cultures for cytopathic effects. Suitable tissue cultures can be selected on the basis of studies made with the raw fluid prior to its submission to the recovery process. It was also recommended that the recovery system be challenged with a large inoculum of an identifiable cytopathogenic virus during performance testing when the resulting product water is not to be consumed and that its elimination from the product water be demonstrated by the foregoing techniques.

Full monitoring of biological quality should be maintained at all stages of evaluation of water quality from recovery systems where this is feasible. When full monitoring cannot be maintained, maintenance of the standard for total aerobic and anaerobic counts together is considered satisfactory and when monitoring must be even more restricted than this, maintenance of the standard in terms of total aerobic count alone is suitable. In the last instance, membrane filter kits can be used to monitor aerobic organisms during flight. Of all the methods developed for rapid analysis of organisms in water, only the luciferin luciferase system has approached within an order of magnitude the requirement of detecting 10 organisms/ml (45, 91).

Water from fuel cells and from several systems of urine recovery has been found to be satisfactory for human consumption (11, 48, 54, 55, 56, 66, 69, 78, 91, 95, 105, 116). However, the contaminants exceed the standards set for municipal water supplies. A detailed compilation of the analytical results of water reclaimed mainly from urine and chamber atmosphere, including any chemical and physical treatment of source and/or product materials was used directly in the following summary (55, 91). These data are of value in setting human standards and in predicting the suitability of using the water for physicochemical work in space laboratories. A synopsis of the results of 146 tests on water reclaimed from urine by some representative techniques is shown in Table 15-17a. These include membrane electrodialysis, in which the urine was

Table 15-17

Reclamation of Water from Various Sources in Space Cabin Simulation
(After Slonim et al[91])

a. Analyses of Water Reclaimed from Urine by Various Techniques

	Reclamation Technique				
Constituent	Membrane Electrodialysis	Thermoelectric Distillation	Ultrafiltration	Vacuum Distillation	Vapor Compression
pH	6.3-7.7	6.2-9.0	7.0-8.4	4.9-9.7	6.8-10.1
Conductivity*	182-3500	210-1080	1800**	41-1750	—
Color†	—	<5-20	—	<5-5	<5-5
Turbidity†	<25->25	<25**	<25->25	0**	<25**
Odor†	...	0**	—	+**	1.6-111
values in mg/l:					
Tot. Hardness‡	—	4-116	10-48	<1-484	2-18
Tot. Alkalinity‡	...	56-414	100-174	16-350	16-120
COD	36-2300	<1-630	16-2100	17-2045	18-730
Tot. Carbon (Org.)	7.8-985	1-362	—	<0.5-790	—
Urea	2-300	<0.1-350	214**	0-120	—
ABS	—	<0.02-1.2	0.03**	—	<0.01-0.15
Calcium	—	1.6-48	8.8**	<1-92	0.08-4.8
Magnesium	—	0.5-13	4.3**	<0.3-62	0.12-<2
Sodium	12-495	2-330	56-212	<1-170	0.5-78
Potassium	9-250	1.4-100	17-269	<0.2-200	<0.1-19
Arsenic	0.01-0.16	<0.01-0.32	0.02-0.23	<0.01-0.02	<0.01-0.03
Ammonia (NH_3/N)	2.5-59	12-100	25-95	0.1-78	0-47
Sulfate	15-100	<1-205	60-150	<1-100	<1-176
Chloride	13-530	1.5-110	144-290	<1-460	<1-21
Nitrate (NO_3/N)	<0.1-24	<0.1-2.8	<0.1-350	<0.1-1.1	<0.01-0.8
Tot. Phosphate	<0.01-240	<0.01-21	<0.01-44	<0.05-23	<0.01-1.2
values in μg/l:					
Zinc	5-104	<3-165	<3-12	<5-55	<0.7-26
Cadmium	<10-<20	<1-30	<3-<10	<5-14	<0.3-<10
Boron	19-256	1-200	3-21	<5-105	6-880
Phosphorus	24->1000	60->1000	<5-<15	<20-500	<5->1000
Iron	4->800	2-390	<2-21	<3-20	<0.3->500
Molybdenum	<4-60	<5-78	<5-<10	<5-425	<1-18
Manganese	<1-16	<0.5-53	0.8-<3	<2.5-64	<0.1-11
Aluminum	<3-760	43->1000	<13-75	<10-75	50-4000
Beryllium	<0.02-<0.05	<0.01-<0.14	<0.03**	<0.03-<0.09	<0.01-<0.05
Copper	<2-39	<0.9-205	<2**	<3-11	0.8-24
Silver	<0.5-6	<0.5-20	<0.3-<0.5	<0.5-5	<0.1-<0.5
Nickel	<2-23	<3-13	<3-<5	<5-17	<0.3-21.5
Cobalt	<3-<21	<3-<14	<3-<5	<5-<12	<0.3-<5
Lead	<5-<20	<5-<18	5<-<10	<10-490	<0.6-<5
Chromium	<1-105	<1-65	<1-<3	<2.5-15	<0.5-23
Vanadium	<13-<40	<5-<20	<5-<10	<10-<15	<0.7-<10
Barium	<1-75	1-114	5-6	<1-75	0.1-47
Strontium	<1-11	<1-179	<1-27	<1-165	0.3-20
Mercury	<30-560	15-250	<20-<25	<50**	<20-115
Number of Samples:	24	70	4	21	27

Range of values include results of any chemical or physical treatment during processing of water. Techniques are briefly explained in text.

* Values are expressed in micromhos per centimeter (μmhos/cm).

† Color - $PtCl_6$ units; Turbidity - Jackson units; Odor - Threshold odor numbers

‡ Values are expressed as amount of $CaCO_3$

** Denotes only a few samples were tested for constituent.

\+ Trace of odor present.

(From the data of Metzger et al[55])

Table 15-17 (continued)

b. Analyses of Water Reclaimed from Chamber Atmosphere

Constituent	Unfiltered Condensate	Filtered Condensate
pH	5.6-7.5	6.8-7.6
Conductivity	142-660	310-600
Color	<5-40	<5-20
Turbidity	<25->25	—
Odor	0-38	—
values in mg/l:		
Tot. Hardness	<1-100	6-40
Tot. Alkalinity	44-234	110-192
COD	130-2300	43-350
Tot. Carbon (Org.)	26-590	15-87
Urea	0-5	<0.1
ABS	<0.02-0.17	—
Calcium	<1-18	—
Magnesium	<0.1-14	—
Sodium	<0.5-21	1.5-70
Potassium	<0.5-22	<1-16
Arsenic	<0.01	<0.01-0.08
Ammonia (NH_3/N)	15-200	5-49
Sulfate	<1-18	1-150
Chloride	<1-50	<1-31
Nitrate (NO_3/N)	<0.1-1.6	<0.1-0.6
Tot. Phosphate	<0.01-2	<0.05
values in μg/l:		
Zinc	5-1020	<8-35
Cadmium	<10-200	<8-10
Boron	5->340	47-300
Phosphorus	<10-388	30-450
Iron	4-290	31-235
Molybdenum	<5-110	<10
Manganese	<1-197	1.5-18
Aluminum	<3-900	<13-750
Beryllium	<0.03-<0.05	<0.03
Copper	<2->250	2-21
Silver	<0.3-2	<0.5-4
Nickel	<3-20	<5-23
Cobalt	<3-<5	<5
Lead	<5-105	<10-10
Chromium	<1-28	<3-35
Vanadium	<5-<20	<10
Barium	33->500	19->50
Strontium	<1-33	<2-43
Mercury	<20-80	—
Number of Samples:	22	19

Dehumidification of the atmosphere was accomplished during a four-man experiment in the AMRL Life Support System Evaluator. The filtered condensate was produced by passage through activated carbon and two membrane filters (0.15 micron).

Legend - Same as Table 15-17a

(From the data of London and West[47])

Table 15-17 (continued)

c. Analyses of Water Produced from Different Fuel Cells

Constituent	Polystyrene-type Membrane	KOH-saturated Membrane
pH	2.8-3.6	6.7-11.5
Conductivity	345-4000	8.3-930
Color	5-45	0-29
Turbidity	0-7	0-7
Color	0-+	0-+
values in mg/l:		
Tot. Hardness	8-12**	—
Total Solids	120->1000	<10-424
COD	200-270**	—
Tot. Carbon (Org.)	40-89**	—
Urea	<0.1**	—
ABS	<0.02**	—
Phenols	0.01-0.4	—
Ammonia (NH_3/N)	0.5-2.8	0.1-5.6
Sulfate	3.5-35	1-2.5
Chloride	3.5-9.3	0.8-3.8
Chlorine	—	0**
Nitrate (NO_3/N)	1.2-2.5	1.5**
values in μg/l:		
Zinc	85-190**	—
Cadmium	<10-<11**	—
Boron	50-85**	—
Phosphorus	200-450**	—
Iron	59-290	0-70
Molybdenum	<5-<6**	—
Manganese	0-450	150-750
Aluminum	105-170**	—
Beryllium	<0.03**	—
Copper	2.5-135**	—
Silver	<0.5-4.5**	—
Nickel	<5-12**	—
Cobalt	<5-<6**	—
Lead	<10-<11**	—
Chromium	<3-6.1**	—
Vanadium	<10-<11**	—
Barium	3-18.5**	—
Strontium	<1-<2**	—
Mercury	100**	—
Number of Samples:	10	4

Legend - Same as Table 15-17a

(From the data of London and West [47])

Table 15-17 (continued)

d. Bacterial Analyses of Water Produced by Various Sources

Sample	Bacteria/ml
Urine, raw (pooled and stored)	3×10^3 - 20.5×10^6
Water Reclaimed from Urine	
Compr. Dist.—Absorp. Filtr. (CDAF)	18×10^6†
CDAF + Pall Filter	Neg - 6.5×10^6
Electrodialysis + Pall Filter	Neg - 32×10^6
Electro Process	Neg - 123×10^6
Electro Process + Pall Filter	Neg - 2×10^4
Electro Process + CDAF	Neg - 22×10^3
Membrane Permeation	7×10^3 - 24×10^3
Thermoelectric Distillation	44×10^6 - 91×10^6
Thermoelectric + Pall Filter	Neg - 103×10^6
Ultrafiltration	Neg - 73×10^7
Water Reclaimed from Chamber Atmosphere	
Unfiltered Condensate	2×10^3 - 8×10^6
Condensate + Pall Filter	Neg - 73×10^7
Water Produced from Fuel Cells	
Polystyrene-type Membrane*	Neg - $>10^7$‡
KOH-saturated Membrane	Neg†

* Fresh water samples from this process only were not available; all other water samples were analyzed immediately upon collection.

† Three or less samples were analyzed.

‡ Only one of eight samples was contaminated.

(From the data of London and West[47])

pretreated with oxalic acid and silver nitrate and then filtered through activated carbon; thermoelectric distillation, in which the urine was either pretreated with trimethyl nitromethane and also carbon-filtered, treated with iodine, treated with chromate and sulfuric acid, or not treated at all; ultrafiltration, in which the urine was pretreated with urease and filtered, with citric acid added to the filtrate; vacuum distillation, in which the urine was untreated or passed over a low temperature catalyst; and vapor compression, in which the urine was untreated, filtered through a membrane, or pretreated with merthiolate and carbon-filtered. It can be seen that seven chemical constituents (ABS, As, Cl, Cr, Fe, Pb and NO_3) plus all three physical constituents (color, turbidity and odor) in only these five processes exceed the 1962 USPHS threshold values.

The results of 41 analyses on dehumidification water obtained during a four-man experiment in the AMRL Evaluator are synopsized in Table 15-16b. (91) In addition to all three physical characteristics, four chemicals (Ba, Cd, Pb and Mn) exceed the 1962 USPHS levels. Filtering the condensate through activated carbon plus two 0.15 micron filters improved the quality, but still the organic content remained high although less than the unfiltered samples. The levels for total dissolved solids (TDS) reported for urine and condensate (55) were not tabulated here, since it was noticed that in samples of high organic content, losses of volatile constituents by the direct heat evaporation method were very large resulting in lower values of TDS in many cases than some of the components present; nevertheless, both urine and condensate showed very large TDS levels exceeding the 1962 USPHS and 1964 Aerospace Threshold Limits. (89). Other workers (106)reported a high level for copper in their chamber condensate; the level of 2 mg/l Cu exceeds also the 1962 threshold value. They reported also other high values (up to 4 mg/l) for Ca, Si and Zn in their condensate and lower values (0.2 to 2 mg/l) for Al, Cr, Fe and Ti.

The results of analyses of 14 samples from two different fuel cells are shown in Table 15-17c. For the first time, a new test for total solids, which includes dissolved and suspended matter, was applied to some of the samples. (86). It can be seen that color, turbidity, manganese, phenols and total solids exceed the 1962 USPHS levels. In addition, a fluoride content of 2 mg/l, which exceeds the public health limit, was reported in water samples taken from one of the polystyrene-type fuel cells used in a human evaluation experiment (48). The organic content of water from this type of fuel cell was very high at times, as measured by both COD and total organic carbon.

In summary only three of a total of 20 chemical constituents listed by USPHS were not reported above, viz., carbon chloroform extract (CCE) cyanid (CN) and selenium (Se) for reasons outlined in Reference (91). Excluding CCE and CN, of 18 chemical constituents analyzed in all, 14 have been shown to exceed the 1962 USPHS threshold levels; only selenium, silver, sulfate and zinc have been lower than the public health limit. Moreover, the three physical characteristics of color, turbidity and odor have exceeded also the USPHS levels in case of almost all processes. Hydroquinones from fuel cells still remain a problem (32).

The bacterial content of the water samples taken from all three major water sources are shown in Table 15-17d. With the exception of raw urine and samples taken from the polystyrene-type fuel cell, all samples were collected aseptically and analyzed immediately. The highly positive results obtained with water from urine and chamber atmosphere reflect more the lack of proper biological controls than the failure of the technique to produce biologically clean water. For, whenever special care was taken with the technique (e.g., cleaning apparatus prior to test, proper handling of waste sample, etc.) the water was negative for bacteria in most cases. A more detailed analysis and the significance of these bacteriological data is available (47).

The purity standards of Tables 15-15 and 16 take into account the levels of contaminants found in Table 15-17. Reduction of these levels will impose an unrealistic design problem. In view of lack of clinical problems arising after ingestion of these reclaimed waters by humans, these water standards appear acceptable.

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