Chapter 3

NUTRIENT REQUIREMENTS AND WATER MANAGEMENT

1. Introduction

Nutrition is an important aspect, as it determines the space, water and energy necessary for agriculture sustaining a colony's population. Rational diets should be proposed in order to determine the nutrient requirements of a population. This is necessary for determining the food requirement of the colony and thus designing its agriculture. Water consumption is another important aspect. It includes domestic water consumption, agriculture consumption and industry consumption. Determining exactly what is the balance between comfort and cost is the essential aspect for modeling water consumption. What is acceptable in terms of comfort for a non-permanent space station or shuttle may not be acceptable for a permanent space colony. People living in the colony would expect a comfort similar to what they get on Earth.

Ensuring water quality both from aesthetic and health points of view is a vital aspect. Water quality and monitoring is discussed in the fourth section of the chapter.

STATE OF THE ART

Previous designs considered that water consumption onboard the settlement should be the same as on a non-permanent space station (the values presented in other projects were given in [4]). The solution proposed in [4] has been adopted in [14, 17]. Extremely low water consumption has been proposed in [13] (20L per day per capita). However, the space settlement has a permanent character. People will not be attracted to settle if the comfort is low. Living with just $11.3m^3$ of water per year is fine in terms of comfort for a period of two years or less (non-permanent character of space station) but is not acceptable for a permanent settlement. Moreover, the designs that follow [4] neglected the water consumption of industry and agriculture. I propose a water consumption model that includes industry, agriculture consumption and a fair level of comfort. The proposed model is compared with the consumption of England (one of the lowest water consumers) and Canada.

Some designs [13,14] proposed that water tank capacity should include the amount of water necessary for one week. Some recycling processes are continuous - such as recycling water vapor from the atmosphere. The proposed capacity was for one month, for recycling and safety reasons.

Water quality and monitoring has been discussed in other projects [13, 14]. Project [13] proposes the usage of ozone for water disinfection. [15, 17] do not discuss water quality/monitoring. Project [14] proposes chlorine dioxide, ozone, iodine and silver as effective disinfectants. All solutions are analyzed, along with advantages and disadvantages (such as disinfection by-products). However, project [14] only deals with ensuring water quality such that it will not affect health. Physical quality is an important aspect (how people rate water based on what they feel) and is analyzed. Physical quality of water also influences its utility.

Water disinfection methods used onboard spacecraft are also discussed, such as the MCV [7, 9] used onboard the space shuttle.

For the nutrition section of the chapter, the approach was to determine the needed quantity of proteins, lipids and carbohydrates for various activity profiles and the oxygen consumption. This approach is different, as it focuses on the energetic needs of a diet, rather than naming the aliments included in the diet. Without analysis of the energetic needs for a specific activity profile, the aliments included in the diet cannot be stated exactly. Previous projects [13] named aliments included in the diet, but did not the energetic analysis. Project [14] did the nutrient need analysis, but did not state the oxygen consumption for a given activity profile. In [15, 17] the matter was not discussed.

Ozone used as a disinfectant has not been discussed in detail. The analysis in [5] states that Bromate is a possible by-product of disinfection using ozone, other by-products were not determined up to now. This degree of uncertainty hinders the analysis.

2. Nutrient and oxygen requirements

THEORETICAL ASPECTS

An adequate diet must be ensured for people living onboard the space settlement and for the workers and builders in the lunar extraction/processing facility. Diets vary with occupation, age, sex, height, weight and location, as discussed in this section.

An adequate diet comprises providing the body with sufficient energy, carbohydrates, essential fatty acids and proteins, vitamins and water. Subsequently, the body needs for normal digestion cellulose fibers (the so-called “roughage”).

Metabolism is defined as the conversion of chemical energy of food into heat and mechanical work and partly the synthesis of endogenous substances.[1]

BMR (Basal Metabolic Rate) is defined as the minimal consumption of energy needed for survival in ideal environment conditions [1]. This comprises resting and thermal comfort. Any supplementary activity would require additional energy. For any energy consumption above the BMR we will define the “Working Metabolic Rate” (known as WMR, [1]). Both the BMR and the WMR vary with age, body weight, height and sex. The WMR varies with the occupation.

The BMR is averaged for a 70kg adult at $7\,{}^{MJ}\!/_{day}\ (\approx 127W)$ [1]. For various occupations, the WMR is [1]:

- For office work: $11\,{}^{MJ}\!/_{day}$ [average]
- For women performing heavy work: $15\,{}^{MJ}\!/_{day}$ [average]
- For men performing heavy work: $20\,{}^{MJ}\!/_{day}$ [average]

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[1] This definition is after **[1]**

- Maximum energy consumption [heaviest work]: $50\,{}^{MJ}\!/\!_{day}$

The energy needs are covered by three basic nutrients, namely carbohydrates, proteins and fats. A minimal quantity of proteins is needed to provide the essential amino acids. For humans, there are nine essential amino acids that cannot be synthesized by the organism: valine, threonine, phenylalanine, leucine, lysine, histidine, methionine, tryptophan and isoleucine. The majority of plant proteins are deficient in one or more of the essential amino acids. The minimal protein intake should be $0.5\,{}^{g}\!/\!_{day}$ per kilo of body weight, but the functional minimal intake is twice the minimal amount. Half of the functional minimal intake should be supplied in the form of animal proteins to ensure that the essential amino acids are furnished to the body.

The energy requirement is largely satisfied by degradation of carbohydrates and fats. Fats are largely superfluous – except for the essential fatty acids (linoleic acid, for example) and for fat-soluble vitamins. Fat-soluble vitamins (A, D, E and K) are necessary for a healthy organism, as lacks in these vitamins have severe effects – night blindness (A avitaminose), rickets (D avitaminose) and disturbances in blood clotting (K avitaminose). Fats have the largest caloric value out of all nutrients, $38.9\,{}^{kJ}\!/\!_{g}$. Carbohydrates have a caloric value of $17.2\,{}^{kJ}\!/\!_{g}$ (approximately equal to that of proteins) and comprise sugars and glycogens. For a normal diet, the energetic contribution of fats is 25-30%, but the requirements may rise up to 40% in physically demanding conditions. The energetic contribution of carbohydrates is normally 60%. The minimal contribution is 10%.

Other dietary requirements are comprised of mineral substances – calcium ($0.8\,{}^{g}\!/\!_{day}$ minimal requirement), iron ($10\,{}^{mg}\!/\!_{day}$ m.r. in males, $15\,{}^{mg}\!/\!_{day}$ in females), iodine ($0.15\,{}^{mg}\!/\!_{day}$ m.r.) and trace elements ($As, F, Cu, Si, V, Sn, Ni, Se, Mg, Cr, Co$). Notice that trace elements are vital, but are poisonous if administrated in large amounts.

Vitamins are vital in metabolism – they activate enzymes and some are coenzymes. Vitamins cannot be synthesized in sufficient amounts by the body. The vital vitamins are: $A, B_1, B_2, B_6, B_{12}, C, D_2, D_3, E, H, K_1, K_2$, folic acid, niacinamide and pantothenic acid.

The average energy consumption is 25% for fats, 12% for proteins and 63% for carbohydrates [2]. The average caloric values for fats, proteins and carbohydrates are:

$$c_{fats} = 38.9\left[{}^{kJ}\!/\!_{g}\right];$$

$$c_{proteins} = 17.2\left[{}^{kJ}\!/\!_{g}\right];$$

$$c_{carbohydrates} = 17.2\left[{}^{kJ}\!/\!_{g}\right].$$

The **physical caloric value** is defined as the utilizable energy content of the food made available by its combustion (breakdown into molecules of H_2O and CO_2 with consumption of O_2). It is denoted by C_{pc}.

Fats and carbohydrates are completely oxidized, while proteins can only be broken down to urea. The physiological caloric value is defined as the quantity of energy released in the organism after combustion of a specific nutrient (protein, fat, carbohydrate). It is denoted by C_{pl}. In all computations, we use for nutrients the value of C_{pl}.

Notice that $C_{pl} = C_{pc}$ for fats and carbohydrates, while for proteins $C_{pc}\left(23 \, {}^{kJ}\!/_{g}\right) > C_{pl}\left(17.2 \, {}^{kJ}\!/_{g}\right)$.

The **Caloric Equivalent** (**CE**) is the oxygen volume required to oxidize various nutrients (reveals the oxygen consumption). The average CE for carbohydrates is $18.8 \, {}^{kJ}\!/_{L}$, for fats $17.6 \, {}^{kJ}\!/_{L}$, while for proteins $16.8 \, {}^{kJ}\!/_{L}$.

Note: The metabolic rate can be computed as $CE \cdot V_{O_2}$, where V_{O_2} is the oxygen volume. The respiratory quotient (**RQ**) is defined as $RQ = N_{CO_2} / N_{O_2}$ and shows the ratio between the number of resulted CO_2 mol and the number of O_2 mol required for the oxidation process. As an example, let's consider the oxidation of the glucose:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O,$$

for which $RQ = 1{,}00$.

NUMERICAL RESULTS – ACTIVITY PROFILES

The energy requirements for fats/proteins/carbohydrates and O_2 consumption per day are computed for three different activity profiles[2].

The energetic needs for various workloads and the oxygen consumption have been computed. The method I used is better suited for such computations because it offers flexibility for computing various cases. The accuracy of the computations has been checked with results from literature.

I. Office work

Office work (or similar *light* work) implies a total energy consumption of $11000 \, {}^{kJ}\!/_{day}$. The total intake of fats, proteins and carbohydrates in a normal diet and the required oxygen volume are presented in Table III.1.

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[2] All computed values are averages. The computations have been made considering the person's weight as 70 [kg].

Table III.1. Nutrient and Oxygen requirements per day for people performing office/light work [averages].

Office/light work	**Fats**	**Proteins**	**Carbohydrates**
Energy intake/day [kJ/day]	2750	1320	6930
Required mass/day [g/day]	70.69	76.74	402.9
Required Oxygen volume/day [l/day]	156.25	78.57	368.61
Total Oxygen volume/day [m^3]	**0.603**		

Notice that the volume of O_2 required for degrading a specific nutrient is obtained as:

$$V_{O_2} = \text{[Energy intake/day]/CE} \qquad (1)$$

For example, the required Oxygen volume/day/person for fats, for a person performing light work is:

$$V_{O_2-fats} = \frac{2750}{17.6}[l] = 156.25\,[l].$$

Computations for the required Oxygen volume per nutrient/day are based on (1).

II. *Women performing heavy work*

Heavy work implies a total energy consumption of $15000\, {}^{kJ}\!/_{day}$ for women (as they have a slower metabolism than men). The total intake of fats, proteins and carbohydrates in a normal diet and the required oxygen volume for this activity profile are presented in Table III.2.

Table III.2. Nutrient and Oxygen requirements per day for women performing heavy work.

Women performing heavy work	**Fats**	**Proteins**	**Carbohydrates**
Energy intake/day [kJ/day]	3750	1800	9450
Required mass/day [g/day]	96.4	104.65	549.41
Required Oxygen volume/day [l/day]	213.06	107.14	502.65
Total Oxygen volume/day [m^3]	**0.822**		

III. *Men performing heavy work*

Heavy work implies a total energy consumption of $20000\, {}^{kJ}\!/_{day}$ for men. The total intake of fats, proteins and carbohydrates in a normal diet and the required oxygen volume are presented in Table III.3.

Table III.3. Nutrient and Oxygen requirements per day for men performing heavy work.

Men performing heavy work	**Fats**	**Proteins**	**Carbohydrates**
Energy intake/day [kJ/day]	5000	2400	12600
Required mass/day [g/day]	128.53	139.53	732.55
Required Oxygen volume/day [l/day]	284.09	142.85	670.21
Total Oxygen volume/day [m^3]	**1.097**		

Note: To these nutrient quantities, cellulose fibers or other "roughage" should be added, considering a 50% quantity of the total nutrient quantity. For example, men performing heavy work would require additionally 500.305[g] of fibers to ensure proper digestion.

DISCUSSION

In past designs, such as the NASA 1975 Summer Study [12], the average space diet included significant quantities of meat (40g per person per day) and approximately 0.5 eggs per day in prepared food. According to the Study, a person would require 24g of egg per day. An egg weights in average 54g. Thus a person would need per day approximately $0.(44)$ eggs in prepared food. According to the same study, a hen lays five eggs per week in average. If we consider that people will only eat eggs five days per week, then the ratio is 1 egg per 1 hen per day. The total egg consumption for a population of 100'000 is about 44'444. That means that we need over 40'000 laying hens! The space required is so high, that only if we send the poultry on an annex station (just for growing poultry, for example), separate to the torus, it will be feasible. We consider as feasible a value of 1 egg per person per ten days. An alternative source of proteins has to be found in order to compensate animal proteins' lack.

We consider that animal protein will be largely substituted by soy. Soy has been proven by various studies as a good protein alternative. It contains 38% proteins and 15% fibers (the "roughage" necessary for a normal digestion). High concentrations of iron, calcium, zinc, B vitamins and E vitamin are found in soy. It has been recognized in over 150 studies as an alternative to proteins found in meat, eggs and milk. Moreover, consumption of soy instead of meat ensures a healthy diet – lower levels of cholesterol and provides the body with an anti-carcinogen (phytoestrogen). Tofu has been used in space meals (on the ISS, for example). Soy represents a feasible, cheap alternative to animal proteins. A regular diet on the space settlement should be based on soy, rather than on meat.

3. Water consumption computation

Water is the basic ingredient of life. The water content of the body has to be strictly regulated. The water balance comprises that all water losses must be counter-balanced by water intake and production. Water results from metabolism processes. Water balance is achieved via the ECF (Extra-Cellular-Fluid).

The average water intake consists of [1]:

- Drinks $\left(1.3\, {}^{L}\!/_{day}\right)$;
- Water in the composition of solid food $\left(0.9\, {}^{L}\!/_{day}\right)$;
- Water resulting from metabolism processes $\left(0.3\, {}^{L}\!/_{day}\right)$.

The average water output consists of:

- Urine $\left(1.5\, {}^{L}\!/_{day}\right)$;
- Water contained in feces $\left(0.1\, {}^{L}\!/_{day}\right)$;
- Water lost in expired air/sweating $\left(0.9\, {}^{L}\!/_{day}\right)$.

The average water intake/output in normal conditions is $2.5\, {}^{L}\!/_{day}$.

The per capita water consumption may be computed using the following categories:

- Domestic water
- Water required for agriculture
- Water used in industrial processes
- Commercial and institutional water.

The quantity per capita for each category is computed considering the municipal water needs for various locations, presented in different surveys. Data has been collected from the Canadian survey [3] and has been compared to Britain's average water consumption. All values state for water consumption per capita per day.

The minimal water requirement onboard a spacecraft is 31L per capita per day. This value has been computed in [4] taking into account that the people stay onboard a spacecraft or onboard a non-permanent space station less than two years. The space settlement has a permanent character, so consumption needs are different. We look at the settlement as a nice place to live and work in, where people afford a normal life with all utilities. 5,5 Liters for shower per day per capita for a lifetime is <u>not</u> acceptable. Moreover, the Space Station Freedom water requirements do not include any industry/agriculture water (see Table III.4).

Table III.4. Water requirements of Space Station Freedom (NASA SSP 30362, 1990). This represents a minimal domestic water requirement per day per person. From http://oregonstate.edu/~atwaterj/io.htm, [4].

INPUT	**kg/pers/day**
Oxygen	0.83
Dry food	0.62
Water in food	1.15
Food preparation water	0.79
Drinking water	1.61
Oral hygiene water	0.36
Hand and face wash water	1.81
Shower water	5.44
Clothes wash water	12.47
Dish wash water	5.44
Urinal/commode flush water	0.49
TOTAL	**31.01**

Some previous space settlement designs adopted this model ([14]), while some designs used extreme water consumption, of only 20L/day ([13]). It is not realistic, as it doesn't meet the requirements of an industry, agriculture and it solely meets the minimal requirements for domestic consumption. The space settlement has to allow its inhabitants a life close to that on Earth. Water consumption on the station should be of the same magnitude as on Earth. The values from the Canadian water consumption survey and from the British survey have been compared. Taking into account all of modern society needs and comparing the water consumption of two countries (Canada, UK), we have proposed a model for the settlement's water consumption. The proposed model ensures the minimal industry consumption and comfort for a permanent residence.

Canada has the average per capita water consumption per year of 1600 cubic meters. Britain has the average of 300 cubic meters. The values presented in survey [3] have been analyzed. Taking into account that a very limited water quantity for the settlement is affordable, the averages considered as providing sufficient comfort for permanent residence in space are presented in Table III.5.

The total per capita yearly water consumption for the settlement's inhabitants is lower than UK's, which in turn is one of the lowest three water consumers in the world, about 6.3 times lower than the consumption in Canada. However, the consumption per capita for the inhabitants of Space Station Freedom is 11.3 cubic meters per year. The comfort ensured by this consumption is good for periods of less than two years, but it is not suitable for a permanent residence.

Table III.5. Average per day per capita water consumption for each category; total water consumption per month per person, for a population of 1000 people and for a final population of 100'000 people.

Category	**Per day per capita water consumption [m^3]**	**Per capita per month water consumption [m^3]**
Domestic water w/o food and drinks	0.3	9
Water found in food and drinks	0.003	0.09
Water used in industry	0.03	0.9
Water required in agriculture	0.27	8.1
Commercial and institutional water	0.1	3
Total per day per capita consumption [m^3]	0.703	
	TOTAL monthly water consumption per capita [m^3]	**21.09**
	TOTAL monthly water consumption for 1000 people [m^3]	21090
	TOTAL monthly water consumption for 100000 people [m^3]	2109000
Total per year per capita Consumption [m^3]	**253.08**	
Comparison with UK average per year per capita consumption [m^3]	300	
Comparison with Canada average per year per capita consumption [m^3]	1600	
Comparison with average water consumption on Space Station Freedom [4] per capita per year [m^3]	11.31865	

Water recycling takes about one month. Some processes are continuous, such as recycling the water vapor present in the atmosphere. Therefore, the water reservoir should include enough water for sustainment of the settlement for a period of one month. Water tank capacity should be computed taking into account this aspect.

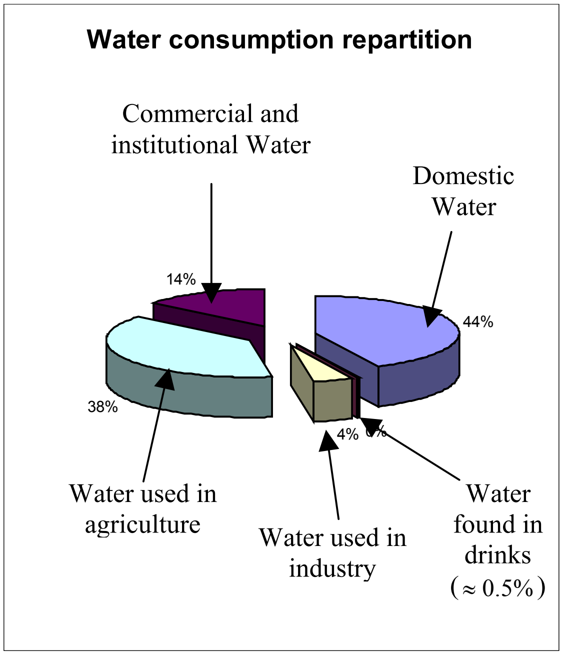

Figure III.1. Water consumption repartition [in percentages]. Notice that the domestic water comprises most of the water consumption, followed by the water used in irrigation (agriculture) and the institutional water.

4. Water quality and monitoring

Water quality defines good drinking water from both health and aesthetics points of view. It depends on:

- Microbial quality
- Chemical quality
- Radiological quality
- Physical quality.

The first three categories impact health. Physical quality is related to the appearance, taste and odor of water. The physical properties of water also include its hardness, pH, turbidity and percentage of dissolved oxygen. Each category will be discussed and explained, along with monitoring concerns.

The goal is to provide the settlements inhabitants with clean water that has good aesthetic properties and that can be used in all activities (domestic water, industry water, agriculture water and so on).

Monitoring of water quality depends on:

- Which characteristics are analyzed (e.g. chemical composition, microbial composition);
- Sample collection frequency and variation of collection point;

- The usage of more than one sampling technique;
- Comparison and evaluation of sample results;
- Rapid decisions if any problem is depicted.

The sample locations should be:

- Storage tanks;
- Pipe leaving the disinfection facility;
- Various distribution points and major pipes.

There are three possibilities to disinfect water:

- Chemical disinfection (by usage of chlorine, iodine or ozone, silver ions [6]);
- Radiation disinfection (usage of UV);
- Thermal disinfection.

Chemical disinfection is widely used and has been proven to work in various space applications. It is – at the present state of art – the cheapest disinfection method. Only this disinfection method is analyzed in detail.

MICROBIAL QUALITY

A common health risk is the presence of microorganisms in drinking water. Disease-causing microorganisms (bacteria, viruses and protozoa) may be found in water as a result of contamination. Microorganisms may be eliminated from the water supply by treatment processes – water filtration and disinfection. The easiest (at the present date) way of determining whether a water supply has suffered contamination is to check it for indicator microorganisms. Such organisms can be determined rather easily and show if the water is contaminated. Water contamination is determined by the presence of thermotolerant coliforms (E. Coli, for example) or coliforms, which produce infectious gastrointestinal diseases. These two groups of bacteria are complementary. However, their absence does not guarantee that the water is not contaminated with other health-threatening microorganisms. Some cyano-bacteria produce toxins that may remain in the water even after the microorganisms have been removed. “Nuisance” micro-organisms do not prejudice health, but modify the physical properties of water.

Monitoring and prevention

The most common contamination prevention method is to eliminate microorganisms using chlorine or iodine. However, water should be tested for the presence of toxins resulting from algae. Such toxins may cause asthma, neuro-muscular disorders or liver damages. The number of cyano-bacteria should be less than 1000/mL. Australian experts advised in [5] at least twice a week inspections for microbial contamination.

Prevention methods:

- Ensure that the settlement's visitors/newcomers do not have any infectious disease that may be transmitted via water/air;
- Filtration and settling of water;
- Periodic checks of integrity of distribution system;
- Proper disinfection of water before it enters the distribution system;
- Maintenance of a residual disinfectant throughout the distribution system;

Samples should be checked at least twice per week for indicator microorganisms. The results should be averaged over a period of 12 months. The performance is satisfactory if 95% of all samples did not contain any thermotolerant coliforms and if 98% of all samples did not contain any coliforms. If the results were poorer, the disinfectant concentration should be raised. In extreme cases, iodine may be used as a disinfectant. [5]

CHEMICAL QUALITY

Some inorganic chemicals and some organic compounds prove of concern if present in large quantities in drinking water, as they are either toxic, have adverse health effects (some are carcinogenic), or change the aesthetic qualities of water.

Inorganic chemicals comprise carbonates and chlorides, which may result from addition of chemicals for disinfection (chlorine) or from corrosion of pipes and fittings.

Organic compounds are classified in:

- Disinfection by-products;
- Other organic components (toxins produced by cyano-bacteria, for example).

Disinfection by-products pose a lower health risk than water that has not been disinfected. Proper disinfection is an essential process in rendering the water safe to drink.

Inorganic chemicals are chlorine, chlorine dioxide and iodine. All are disinfectants. Iodine should be used only as an emergency disinfectant. The aesthetic concentration for chlorine and chlorine dioxide is $0.6\,{}^{mg}\!/\!_{L}$, but the ratio may rise up to $5\,{}^{mg}\!/\!_{L}$ in order to maintain effective disinfectant residuals throughout the distribution system. Iodine may be administrated with a maximum concentration of $0.15\,{}^{mg}\!/\!_{L}$. Chlorate and chloride are by-products.

Organic by-products are chloroacetic acids, chlorophenols, chloropicrin (all results of chlorination) and formaldehyde. Organic compounds that may result from water industrial contamination are [5] Vynil chloride (carcinogen, used in PVC manufacturing), Xylene (solvent for plastic bonding), tetrachloroethene (solvent and metal degreaser). The maximal concentrations in water of these compounds are:

$0.0003\,{}^{mg}\!/_{L}$ for Vynil, $0.6\,{}^{mg}\!/_{L}$ for Xylene, and respectively $0.05\,{}^{mg}\!/_{L}$ for tetrachloroethene. All these compounds are extremely toxic if found in larger quantities. However, if the metal processing industry and the chemicals industry are placed on the lunar facility, these compounds do not threat the space settlement's inhabitants. Precautions for industrial contamination of water should apply mainly for the lunar facility.

Pesticides are extremely toxic. They include agricultural chemicals, such as herbicides, nematicides, miciticides and rodenticides. The best prevention method is to ensure that no pests are brought to the settlement. Pesticides, if ever used on the settlement, should be found in concentrations below $0.005\,{}^{mg}\!/_{L}$ [average].

WATER DISINFECTANTS ONBOARD SPACECRAFT [6], [7], [8], [9]

Elemental iodine has been proven as a highly efficient disinfectant, being used in all American designed water systems. [6] The Russian space program, on the other hand, uses silver ions. Both elemental iodine and silver ions are effective biocides.

Elemental iodine has been used to disinfect water supplies onboard spacecraft as early as the Apollo program (began in 1969). For the lunar module, the adopted solution was to prefill the water tanks with a concentration if iodine of $12\,{}^{mg}\!/_{L}$. The resulted residual disinfectant concentration was less than $0.5\,{}^{mg}\!/_{L}$. The same solution has been used for the Skylab mission, but iodine concentrations were monitored in order to maintain the residual disinfectant concentration between 0.5 and $0.6\,{}^{mg}\!/_{L}$. If the concentration dropped, the water tanks would receive additions of disinfectant. The additional disinfectant was a solution of potassium iodide and elemental iodine in a molar ratio of two to one.

The Space Shuttle benefits of a new water disinfection system, called the MCV (stating for Microbial Check Valve). This device controls the release of elemental iodine in water. The Space Shuttle produces high purity water (resulting from the fuel cells). That water is then passed through an MCV unit, which provides a residual iodine concentration ranging between 0.5 and $4\,{}^{mg}\!/_{L}$.

Iodine has been proven to work as an excellent disinfectant in various space missions. Iodine may be used as a primary disinfectant for the settlement's water supply. However, Australian specialists (in report [5]) recommend that it should only be used as an emergency disinfectant, and that chlorine (or chlorine dioxide) is currently used widely for water disinfection. As both solutions have been proven viable, we consider them both feasible as applied to the space settlement.

Monitoring and prevention

- Daily water chemical composition checks[3];
- Maintenance of (when possible) an "aesthetic" concentration limit of disinfectants;
- Specific checks on industrial chemicals and by-products, and, if used, on pesticide concentrations in water.

RADIOLOGICAL QUALITY

Drinking water (in normal conditions) will contribute only a very low proportion to a person's total radiation exposure. The health hazard related to radiation is cancer.

The guidelines for determining radiological quality have followed levels for gross alpha and beta concentrations [5]:

- Gross alpha activity concentration should be below $0.1 {}^{Bq}\!/\!_{L}$;
- Gross beta activity concentration should be below $0.5 {}^{Bq}\!/\!_{L}$.

If the dose is exceeded, sampling is required to identify radionuclides and their activity concentrations. Reduction of the dose can then be achieved by reduction of the concentration of a specific radionuclide in excess. To ensure that the requirements are met, the water tanks should be emplaced in well radiation-shielded parts of the settlement.

PHYSICAL QUALITY

Physical quality is a largely subjective notion. People rate water based on what they feel, namely its taste, its odor and its appearance. A variety of factors determine these qualities, namely:

- Hardness;
- Turbidity;
- Total quantity of dissolved solids;
- pH;
- Quantity of dissolved oxygen;
- Temperature.
- Taste, odor;
- True color.

The first six factors influence the subjective appearance of water and its utility. The physical guidelines are based more on aesthetic considerations. The values (for the

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[3] Australian experts suggest that if the serviced population is 100'000 or above, samples should be at least 6 per week. For an initial settlement population of 10'000, the ratio should be at least 1 sample per week and 1 additional sample per month. [5]

mentioned six categories) that may impact health lie beyond the acceptable aesthetic characteristics. Color and turbidity (the impression of a cloud of fine particles suspended in water) influence the appearance of water. Its taste is influenced by its pH, temperature and total quantity of dissolved solids. The hardness (concentration of calcium and of magnesium salts), pH and temperature influence the way we "feel" the water. All these factors contribute to the rating of physical water quality.

The hardness of the water (mainly the concentration of $CaCO_3$) influences the encrustation in pipes. The pH, the total quantity of dissolved solids and the water temperature influence the pipe and fittings corrosion.

Extreme pH values affect health, while pH values under 6.5 accelerate pipe corrosion. pH values between 8 and 8.5 decrease the efficiency of chlorination, while values of pH over 8.5 cause taste problems. The study [5] shown that a value of pH up to 9.2 may be tolerated. The optimum pH was depicted between 6.5 and 8.5.

Water with a $CaCO_3$ concentration below $60\,{}^{mg}\!/_{L}$ may be corrosive, as depicted in [5]. Between $200\,{}^{mg}\!/_{L}$ and $500\,{}^{mg}\!/_{L}$ scaling problems may appear. The **optimum** hardness has been depicted ranging between 60 to $200\,{}^{mg}\!/_{L}$.

The **optimal** total quantity of dissolved solids has been depicted as $500\,{}^{mg}\!/_{L}$ (according to [4]).

The quantity of dissolved oxygen influences the growth of microorganisms in water. For example, a low oxygen concentration allows the growth of nuisance microorganisms. These alter the taste and color of water and may also cause the water to stain (for example laundry). This is not a health concern, but it is essential in rendering the water acceptable aesthetically and suited for all utilities. The **optimum** dissolved oxygen concentration should be in the range 85%-100%. [5]

The settlement's water distribution should stick to the optimum values (or close to that range), as high changes in pH, hardness or total dissolved solids concentration may determine rapid pipe/fittings corrosion and poor aesthetic quality. A too low oxygen concentration will determine the appearance of "nuisance" bacteria and will determine a poor water quality. All these aspects should be taken into account when designing the settlement's water distribution/recycling and disinfection system.

5. Conclusions

Nutrient requirements, along with oxygen consumption for different activity profiles have been analyzed. Nutrient requirements should be used as guidelines for ensuring healthy diets for people living onboard a space colony.

Water management has been discussed. A model for the water consumption of the settlement has been proposed, based on the requirements of a non-permanent space station [4] and on the per capita needs of citizens living in Canada and England. The proposed model states that people onboard the settlement must have a normal life – including terms of comfort. Past designs have neglected this aspect [13, 14, 15, 16, 17]. The water consumption must include agriculture and industry. The proposed per capita per year water consumption is lower than England's (one of the lowest consumers) but ensures the comfort required for a permanent residence.

Water quality and monitoring has been discussed, along with analysis of previously proposed water disinfection methods. Water disinfection methods used in space applications – the Apollo program, the MCV used onboard the Space Shuttle and the Russian space program. Importance of water physical quality has been stated.

FURTHER WORK

The unanswered questions include the actual aliments that enter the diet – based on the proposed nutrient consumptions per activity (subject only scarcely discussed) and the structural concerns related to the high quantity of water that is required for a 100'000 population. Further work would also include detailing the usage of ozone as a disinfectant. State of art does not detail the disinfection by-products related to the usage of ozone, fact that hinders the analysis.

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