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PROVISIONAL AEROSPACE WATER STANDARDS – 1964

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Foreword

This study was conducted at the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, mainly over a 15-month period starting in late 1962, and was accomplished under Project 7164, "Biomedical Criteria for Aerospace Flight," Task 716410, "Aerospace Sanitation and Personal Hygiene," with Dr. Arnold R. Slonim as Task Scientist. The coauthor of this report is Mr. Arthur J. Roth, Jr., chemist in charge of the Dubuque (Iowa) City Health Department Laboratory, who was available for this study via two separate short tours of duty as a Lieutenant Colonel in the Air Force Reserve. Arrangement for Mr. Roth to perform additional work on the project at AMRL was accomplished via Contract AF 33(657)-8521 with the University of Dayton.

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This technical report has been reviewed and is approved.

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Abstract

Provisional potable water standards, patterned after the 1962 USPHS Drinking Water Standards, have been formulated for application to aerospace systems. In comparison with USPHS standards, the recommended maximal allowances have been raised (relaxed) at least 80%, with the majority increased from two- to five-fold, for the following 16 out of 20 chemical constituents: alkyl benzene sulfonate, arsenic, barium, cadmium, chloride, copper, cyanide, iron, lead, manganese, nitrate, phenols, selenium, silver, total dissolved solids, and zinc. Four constituents, carbon chloroform extract, chromium, fluoride and sulfate, remain relatively unchanged. The radiological requirements are the same as USPHS for radium[226], strontium[90] and gross beta emitters. The only change in the physical properties concerning turbidity, color, odor and taste in these standards as compared with USPHS is a fivefold increase in the turbidity level. For the microbiological quality of water, it has been recommended (at this time) that the potable water be free of all microorganisms to minimize potential health hazards to aerospace personnel. The importance of selection of materials for aerospace systems, improvement in analytical methods (e.g., detection of organic contaminants), and resolution of problems needing attention to the development of permanent potable water standards is discussed.

SECTION I.
Introduction

Developments in water reclamation techniques have progressed rapidly in recent times. Recovery of water from urine, sweat, expired air, etc., can now be accomplished by various change-of-phase, membrane filtration, and physical-chemical processes. Such diversified techniques have resulted in the manufacture of equipment containing many different types of materials, so that the quality of the product water has differed considerably from one process to the other and between units of the same process. The water quality of a number of techniques had been reported to conform to United States Public Health Drinking Water Standards; whereas, the quality of others has never been evaluated. Therefore, as recognized previously (ref 1), a need exists to standardize the quality of water produced by all techniques under consideration for aerospace systems.

The only standards available for use in the aerospace industry up to the present time have been those developed for industrial and domestic consumers by the United States Public Health Service (USPHS) in 1946 (ref 2) and 1962 (ref 3). The formulation of USPHS Water Standards has been a complex undertaking, involving numerous reports, conferences and symposia, by scientists of many disciplines (e.g., ref 4-11). The criteria that were adopted were adequately based on analytical and toxicity data, estimated at lifetime exposures for the national population, and to some extent on esthetic factors, threshold limit values in air, fish kill data, and other safeguards for human consumption, as well as mechanical clogging problems. On the other hand, conditions in aerospace systems leading to water quality control differ from those for industrial and domestic consumers. Water will be consumed by healthy astronauts for only limited periods of time (versus lifetime exposures) and will be derived from different sources (urine, fuel cells, etc.) rather than natural ones, such as brackish rivers; also it may be in contact with materials that are not used in present plumbing supplies. Thus, different criteria for determining water potability exist for aerospace applications than for public health.

Information concerning the types of water reclamation techniques to be used in space systems, the identification and toxicology of specific materials in spacecraft water supplies, the effects of space flight conditions on human physiology in general, etc., are not available at the present time to permit an entirely different approach to formulating aerospace potable water standards. On the contrary, in this first attempt to adapt requirements of water quality control to aerospace systems, every effort was made to follow closely the most recent USPHS Standards (ref 3) and modify the levels of acceptability in accordance with our present state of knowledge or estimation of developments in space technology. It is noteworthy that the most recent (1962) USPHS Water Standards considered man's changing environment and so added radiological requirements not presented in previous standards. Similarly, it is proposed that these standards represent an interim or provisional guide and serve only as a foundation upon which to make further modifications as would be required in time.

These aerospace standards present information upon which is based the recommended level of acceptability for each constituent. The threshold limits are shown in table I and are compared with the threshold levels adopted in the 1946 and 1962 USPHS Standards (ref 2, 3). Patterned after the latter, the constituents are presented under the major categories of chemical, radiological, microbiological and physical properties. The values of almost all constituents conform to the analytical methods described in *Standard Methods* (ref 12).

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TABLE I

RECOMMENDED MAXIMAL ALLOWANCES

Constituent	USPHS Standards 1946	USPHS Standards 1962	Provisional Aerospace Standards — 1964
	CHEMICAL (values in mg/l)*		
Alkyl Benzene Sulfonate (ABS)	—	0.5	1.0
Arsenic (As)	0.05	0.05	0.5
Barium (Ba)	—	1.0	2.0
Cadmium (Cd)	—	0.01	0.05
Carbon Chloroform Extract (CCE)	—	0.2	0.2
Chloride (Cl)	250	250	450
Chromium (Cr^{6+})	0.05	0.05	0.05
Copper (Cu)	3.0	1.0	3.0
Cyanide (CN)	—	0.2	0.5
Fluoride (F)	1.5	1.7 (ca 52C)	2.0
Iron (Fe)	0.3 ($\bar{c}$ Mn)	0.3	1.0
Lead (Pb)	0.1	0.05	0.2
Manganese (Mn)	0.3 ($\bar{c}$ Fe)	0.05	0.1
Nitrate (NO_3)	—	45	100
Phenols	0.001	0.001	0.05 (<0.01$\bar{c}$ halogen)
Selenium (Se)	0.05	0.01	0.05
Silver (Ag)	—	0.05	0.5
Sulfate (SO_4)	250	250	250
Total Dissolved Solids (TDS)†	500	500	1000 ($\bar{c}$ low sulfates)
Zinc (Zn)	15	5	15
	RADIOLOGICAL (values in $\mu\mu c/l$)		
Radium[226] (α emitter)	—	3	3
Strontium[90] (β emitter)	—	10	10
Gross Beta emitters (in absence of α and Sr^{90})	—	1000	1000
	BACTERIOLOGICAL (fermentation and/or membrane filter tests)		
Fermentation a) Max. No. of test tubes showing fermentation:	3/5	3/5	0/5
or b) MPN (most probable No.):	9.2	9.2	0
Membrane Filter (Max. No. of organisms per 50-ml sample):	—	3	0
	PHYSICAL		
Turbidity (Jackson units)	10 ppm‡	5	25
Color (PtCl$_6$ color units)	20	15	15
Threshold Odor No. (subjective)	—	3	3

*Mg and alkalinities (as $CaCO_3$) in 1946 but not 1962 USPHS Standards are excluded
†Na, Ca, Mg, K, SO_4, Cl, NO_3, PO_4, CO_3, HCO_3, etc., in various combinations
‡Silica scale

SECTION II.
Chemical Properties

As indicated in table I, the public health standards for the chemical quality of drinking water were more strict in 1962 than 1946; i.e., the maximal allowable concentrations were lowered for several constituents (Cu, Pb, Mn, Se and Zn), and there was an addition of five constituents. All 20 chemical constituents listed in the 1962 USPHS Water Standards have been found also in various samples of water reclaimed from urine, wash water, etc., so that no attempt has been made to exclude any of them in developing standards at this time for aerospace systems. However, it is anticipated that in the future many of these constituents will be either nonexistent or virtually inaccessible to aerospace water supplies by elimination of the source, such as galvanized hardware (Cd, Cr, Pb, Zn), cleaning solutions (ABS), additives in food (As, CN), etc. Until this is done, all constituents have to be considered to the point of building up to a potential hazard in a closed system. The criteria used in recommending the threshold limit value for each constituent are described below.

Alkyl Benzene Sulfonate (ABS)

Although ABS represents a typical anionic surfactant resulting from the use of regular detergents, the threshold for this constituent includes other similar sulfonated cyclic compounds, especially the anionic types that are present in over 75% of household detergents. This group of compounds is relatively nontoxic, e.g., six subjects on an oral dose of 100 mg/l of purified ABS for 4 months showed no significant toxicologic effect (ref 3). Other types of surfactants (the nonsulfonates, etc.) are considered with the soluble organics discussed later; the toxicities of the principal surfactants are generally discussed elsewhere (ref 5). In the event detergents of any type are excluded from use in aerospace systems, this constituent can be eliminated from further consideration. At the present time, however, the recommended level for aerospace standards has been set at 1 mg/l, beyond which there would be considerable frothing and unfavorable odor and taste characteristics. In case there would be interaction between detergent and the urinoids from urine in a water reclamation system, it may be cause to lower the threshold from 1.0 to 0.5 mg/l to prevent the decomposition of organics resulting in the unpleasant odors and taste.

Arsenic (As)

Within the last 2 years, there is evidence that the human body can tolerate much higher levels of arsenic than has been reported in the literature.* It is expected, therefore, that the present restrictions on inorganic As in the diet and in tobaccos would be removed to permit a higher threshold limit for ingestion of this element. At the present time, a level of 0.5 mg/l has been recommended as the maximal acceptable level for aerospace standards. Although this figure represents a tenfold increase over the 1962 USPHS level, it is still slightly less than the threshold limit assigned for healthy adults (ref 5).

Barium (Ba)

This element, used occasionally for atmosphere control, is easily removed and rendered inactive in the presence of sulfate or other anions. On the other hand, the relative insolubility of some barium salts can be reversed by iron, magnesium or aluminum ions. Although the toxicity of barium in high concentrations is known, the maximum permissible level of this element in water has not been determined (ref 3). Thus, based on the threshold limit of Ba in air (0.5 mg/m³),

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*Dr. H. E. Stokinger (USPHS, Cincinnati, Ohio): Personal communication, March 1963.

as recommended by the American Conference of Governmental Industrial Hygienists in 1958 and again in 1963 (ref 13), as well as on esthetic factors, a limit of 1 mg/l Ba was set by USPHS for the 1962 water standards. Based also on the above limit of Ba in air along with factors estimating volume of air intake, percent Ba absorption into circulation from lungs and intestine, and a daily water intake of 2 liters, Stokinger and Woodward (ref 5) calculated an oral intake of 4.17 mg or 2 mg/l Ba per day. They recommended that this value, with emphasis more on toxicologic than esthetic considerations, be used as the threshold in water for healthy adults. Therefore, the level of 2 mg/l Ba has been adopted as the upper limit for aerospace standards.

Cadmium (Cd)

If galvanized hardware and cadmium platings are excluded from spacecraft, the probability of eliminating this element from consideration in drinking water would be very high. Occasionally, however, Cd appears as a food contaminant. All animal studies on dietary Cd thus far have shown an accumulative effect of this element in the soft tissues of the body. However, since it was reported in 1949 that individuals can tolerate long-continued absorption of Cd from water containing about 0.05 mg/l of this constituent without any history of symptoms (ref 3), this level has been adopted for aerospace standards. It represents a fivefold increase over that recomended by USPHS, but below that based on calculations of the threshold limit value of Cd in air (ref 5).

Carbon Chloroform Extract (CCE)

The amount of organic material in drinking water is usually low, so that efforts to identify and quantitatively measure this fraction have not received much attention over the years. Organic analysis by the Water Quality Network, USPHS, has involved first adsorption on activated carbon, followed by extraction with chloroform to form a carbon chloroform extract, which is then subjected to a variety of analytical measurements. Extraction with alcohol yields a carbon alcohol extract (which contains carbohydrates, synthetic detergents, etc.). Much of the taste and odor of waters, especially those polluted by admixing with industrial wastes, can be traced to the chloroform extractable fraction. The CCE group of compounds is composed of organic acids, bases and neutral fractions; the latter is divided into aliphatic, aromatic and oxygenated subfractions, with the aromatic group containing most of the odoriferous constituents (ref 14). In view of the fact that an excess of 200 micrograms/liter is indicative of pollution and has been found in only a very small percentage of municipal water supplies and that the nature of the constituents in CCE is not clearly defined (ref 6, 14), the USPHS has set 200 μg/l as the maximal limit in drinking water, a threshold value that has been adopted for aerospace standards. No doubt, the urine and atmosphere will be potential sources of organic contaminants in aerospace systems. If in future analysis of recovered water, the CCE is found to be consistently over 200 μg/l, but its constituents to be well-defined, nontoxic and esthetically acceptable, then increasing the recommended maximal allowance should be considered. On the other hand, if the CCE content of reclaimed water is negligible or omits some of the organic components present, or is impractical in view of the very large sample size required, it may be necessary to substitute another test as an indicator of organic contamination.

Chloride (Cl)

This anion is the major inorganic constituent in urine and perspiration (ref 15) and may be the largest single component of the total dissolved solids or residue of the water reclamation system. Because of this and, to a larger extent, the relative absence of any laxative effects with chloride salts, a higher concentration of chlorides has been recommended for potable water than of sulfate or other anions. On the other hand, chloride concentrations in water are limited by undesirable tastes. The upper limit of detection of chloride as NaCl by a panel of tasters was found to

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be 450 mg/l, a value within a range reported also to affect the taste of coffee (ref 3). It is recommended, therefore, that concentrations of chloride for aerospace systems do not exceed 450 mg/l. The relation of this constituent to other dissolved ions and to phenol, respectively, are discussed below.

Chromium (Cr^{6+})

Chromium ions have varying degrees of toxicity; the hexavalent ones are considered carcinogenic to man when inhaled. However, it is not known if cancer will result from oral ingestion of any of the three valence forms of Cr, nor is the lifetime toxic exposure level known of the chromate (CrO$_3$) ion (ref 3). Trivalent chromium, sometimes present in traces in food, is relatively insoluble and nontoxic. The maximal limit of 0.05 mg/l Cr set by the USPHS in 1946 and 1962 incorporates a large safety factor. There is little doubt that aerospace crews could ingest water containing much higher levels of Cr without any effects, especially in view of the 1-year studies performed on rats as well as the 3-year high Cr ingestion by one family (ref 3) and the limit of Cr calculated from its threshold value in air (ref 5). However, until more information on Cr toxicity from oral ingestion is available, 0.05 mg/l Cr, the only mandatory limit of the USPHS standards, has been adopted at this time as the recommended threshold for aerospace standards.

Copper (Cu)

The level of copper was reduced by USPHS from 3 mg/l in 1946 to 1 mg/l in 1962 because of its unpleasant taste, which is detectable above 1 mg/l by some individuals. This element is relatively nontoxic, and only a small fraction of ingested Cu is absorbed and retained in the body; the absorbed metal reaches almost all tissues, the highest being found in the liver, brain, kidney and bone marrow (ref 16). Large doses of Cu may cause emesis, whereas prolonged oral ingestion may produce liver damage (ref 3). A maximal level of 3 mg/l Cu, which is nontoxic and one-half of the limit recommended by others (ref 5), should not be prohibitive to trained aerospace crews and is recommended for aerospace water standards.

Cyanide (CN)

Much information concerning cyanide toxicity stems from fish kill data. However, it is known that cyanide in concentrations up to 10 mg is converted in the body to thiocyanate, which is nontoxic; whereas, five times this amount in a single dose is fatal to man (ref 3). On the other hand, if chloride is present in the water along with cyanide, a cyanogen chloride complex would form, inactivating the CN to about $\frac{1}{20}$ of its normal toxic level. The USPHS in 1962 preferred a level of 0.01 mg/l CN but placed a ceiling of 0.2 mg/l in drinking water, representing a safety factor of about 100 (ref 3). A level of 0.5 mg/l CN, which still retains a safety factor and is well below the 19 mg/l limit calculated from threshold values in air (ref 5), is recommended for aerospace standards. To consider levels of CN higher than 0.5 mg/l at this time, it seems, would require additional studies on daily oral ingestion of high doses of CN in water free of chlorine or other inactivating substances over a long period of time.

Fluoride (F)

This constituent, which is well known for its role in preventive dentistry, has been reported to cause mottled teeth and bone changes in concentrations as low as 8 mg/l in water consumed over a long period of time (ref 3). An inverse relationship between the optimal fluoride content in water and the ambient temperature of exposure, especially in children (since water intake is directly related to temperature), has been noted and tabulated in the 1962 USPHS Drinking Water Standards. For example, the optimal and upper limit of fluorides at 70F are 0.9 and 1.2 mg/l, respectively, and at 90F are reduced to 0.7 and 0.8 mg/l, respectively; at the lowest temperature

range given, 50 to 53.7F, the highest upper limit value is 1.7 mg/l. However, water supplies containing up to (but not exceeding) twice the optimal level of F at any given temperature range are not cause for rejection (ref 3); e.g., the maximal acceptable limit at about 70F is 1.8 mg/l or at about 50F is 2.4 mg/l (twice the optimal value). It seems reasonable that individuals beyond the formative years could tolerate a daily oral ingestion of fluoride in water up to 2 mg/l or slightly more without incurring any harmful effects, such as enzymatic inhibition or other symptoms of F poisoning that result from ingestion of very high doses (ref 16).

Iron (Fe)

There is no limitation to iron concentration in water based on toxicity, but rather on its strong taste and staining characteristics. Owing to poor intestinal absorption (less than 10% from food), relatively large quantities of Fe (e.g., 15 mg) are ingested daily by man to satisfy his nutritional requirements, which along with rates of absorption and utilization are at variance among different investigators, partly because of difficulties encountered in Fe balance studies (ref 16). Ferrous salts are readily absorbed from the intestine, whereas most ferric salts must first be reduced to the ferrous form. Generally, Fe in water is a nuisance to industry and to domestic consumers because it deposits in pipes, forms sludge, promotes the growth of certain bacteria and imparts undesirable color to water, in addition to its bitter taste, which is detectable at 1.8 mg/l (ref 3), and to its staining laundry in concentrations as low as 0.3 mg/l (ref 3); the latter figure has been used as the threshold limit in the 1962 USPHS standards. However, a level of 1 mg/l in water, although above the minimal staining level, is nontoxic and generally has an undetectable taste; thus it is recommended as the upper limit for aerospace water standards.

Lead (Pb)

This element is a cumulative poison in the body, attacking soft tissues as well as bone. The common sources of lead intake in the body are food, inhaled air, tobacco, and water, with food the largest contributor averaging about 0.3 mg/day (ref 3). Most of the lead if ingested in low concentrations is excreted because of poor intestinal absorption, which is about 8% (ref 16). Over a long period of time, the maximal tolerated dose from all sources without producing evidence of Pb poisoning is estimated to fall in the range of 0.5-0.6 mg/day (ref 3). Beyond 0.6 mg, positive Pb balance develops (ref 16). It is important, therefore, for long-term aerospace missions to eliminate or reduce to a minimum the lead content of various sources, which, e.g., for conventional manned aircraft, consist of battery platings, parts and solder joints of electronic and other equipment, smoking, etc. Assuming that a total body intake of Pb from food and spacecraft atmosphere does not exceed 0.35 mg/day (e.g., 0.30 from food and 0.05 from all other sources), a maximal allowance for water of 0.2 mg/l is recommended for aerospace standards. If, on the other hand, the concentrations of Pb from all sources in a spacecraft are consistently high, then the level in water may have to be reduced to a figure in the range of 0.05-0.1 mg/l. The recommended level of 0.2 mg/l, although four times the recent USPHS figure, is well below one-fifth that permitted for healthy adults, based on calculations of the threshold limit value of Pb in air (ref 5).

Manganese (Mn)

This element, which is poorly absorbed from the intestine with much of it excreted in the feces (ref 16), is relatively nontoxic; however, it does present a nuisance to industrial and domestic consumers that limits its concentration in water. "Domestic complaints arise when the Mn level exceeds 0.15 ppm regardless of the iron content" (ref 3). Aside from its undesirable coloring and taste qualities in water, Mn in low concentrations (e.g., over 0.1 mg/l) causes sludge formation in water, because of its utilization by certain microorganisms, and serious depositions

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in pipes and other hardware. Therefore, to avoid any plating out of Mn in a water reclamation system, it is recommended that an upper limit of 0.1 mg/l should not be exceeded for aerospace standards. This figure is twice that recommended in the 1962 USPHS standards, but only one-tenth that recommended for adults based on the threshold limit value of Mn in air (ref 5).

Nitrate (NO$_3$)

Nitrate poisoning has been a serious problem in infants for many years, a fact that has compelled the USPHS to add nitrate to the 1962 water standards as well as Federal regulation of nitrite or nitrate in beef (or fish) limited to 200 mg/l. High concentrations of nitrite or nitrate (which is converted by intestinal flora to nitrite) affects primarily blood hemoglobin. The levels of NO$_3$ that cause poisoning in infants (i.e., 10-20 mg/l NO$_3$-nitrogen) are quite harmless to adults. The limit of 45 mg/l NO$_3$ (10 mg/l NO$_3$-nitrogen) in the USPHS standards is based mainly on infant poisoning and to a small extent includes a marginal factor to account for errors in analyses of samples that may be delayed, contaminated by bacteria, or have false values due to the presence of interfering substances, e.g., chlorides and phenols (ref 3). In aerospace applications, nitrates are excreted by man in significant amounts in urine (i e., averaging over 300 mg/l based on a normal vegetable content in the diet) and, in addition, have the ability to support the growth of almost all organisms present in water; thus, nitrates are an important fraction to consider in any urine purification system. In view of these considerations, a limit of 100 mg/l NO$_3$ (and/or NO$_2$), a level nontoxic to adults, is recommended for these standards.

Phenols

This group of organic compounds refers to many types of variously substituted hydroxybenzene, including the aminated, halogenated, and methylated derivatives. The interaction of phenols with halogens, especially chlorine, resulting in undesirable taste and odor in water is well known. Phenol concentrations in water as high as 5000 mg/l had no effect on rats. The problem, as pointed out by the USPHS, is not one of toxicity, but rather of taste and odor (ref 3). The USPHS limit of 1 μg/l is applicable to chlorinated waters. Phenols in concentrations of about 50 micrograms per liter in water that is either unchlorinated or contains halides (e.g., chloride salts) rather than halogens (e.g., HOCl or free chlorine) would be tolerable; thus, an upper limit of 0.05 mg/l phenols is recommended for these standards. However, should an appreciable amount of free chlorine exist in the reclaimed water, it may be necessary to reduce this suggested maximal allowance to below 0.01 mg/l.*

Selenium (Se)

Carcinogenic studies in rats and, to a less extent, reports of other disease states in higher animals have been used by the USPHS as a basis for reducing the upper limit of Se from 0.05 mg/l in 1946 to 0.01 mg/l in 1962. However, much more information is needed to determine the threshold level for human consumption of this element, which is normally excreted in the urine (ref 15) and present in aerospace electronic equipment. The 0.05 mg/l level appears reasonable at this time for adults at less than lifetime exposure and is recommended for aerospace standards until or unless additional data become available to alter this figure, which is well below that calculated by Stokinger and Woodward (ref 5) for healthy adults based on the threshold limit of Se in air.

Silver (Ag)

Although this element was considered by USPHS primarily for its use in water as a disinfectant, silver has gained wider usage, especially in electronic equipment, and thus can be expected to

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*Burke, G. W., Jr. (USPHS, Washington, D. C.): Personal communication, September 1963.

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exist in spacecraft. The USPHS level of 0.05 mg/l Ag is tentatively based on a calculated estimate that 50 μg/l of Ag could be ingested from a daily intake of 2 liters of water for a period of about 27 years before 1 gram of Ag could be deposited in the integument of the body (assuming 100% turnover of Ag from ingestion to skin deposition). Beyond this end-point (1 gram Ag), the condition of argyria would develop (ref 3). A tenfold increase in the 0.05 mg/l level for a consumption period of 10 years would still be within the 1-gram-Ag-skin-deposition threshold set by USPHS regardless of the turnover rate. Therefore, a level of 0.5 mg/l, which still retains a safety factor and is well below the general limit of 10 mg/l assigned for Ag or other moderately toxic inorganic substances (ref 5), is recommended as the threshold of Ag for aerospace standards.

Sulfate (SO_4)

The limitations placed on sulfate by USPHS are based mainly on undesirable (metallic) tastes and laxative effects. The activity of sulfate is greatly influenced (e.g., potentiated) by the presence of certain other ions; for example, sulfate has a laxative effect at lower concentrations as the magnesium level is increased in water (ref 3). Therefore, the quality of the water is important in assessing the maximal allowances of specific constituents such as sulfates and chlorides. The taste tests tabulated by USPHS for several sulfates showed detection of the sulfates of Na and Ca at a minimal level of 250 mg/l (below 200 mg/l for the anion, itself); whereas, a laxative dose is obtainable from consuming 2 liters of water containing a slightly higher level of either Na or Mg sulfate (i.e., 300 or 390 mg/l, respectively, with the effect less in the case of $CaSO_4$ (ref 3). Higher SO_4 levels (over 600 mg/l) could be tolerated by those individuals accustomed to such waters. Unless personnel are trained to tolerate high SO_4 levels both as to the taste and cathartic aspects, and depending upon the quality of the water (e.g., concentration of total dissolved solids), it appears at this time that the USPHS recommended level of 250 mg/l SO_4 should not be exceeded for aerospace standards.

Total Dissolved Solids (TDS)

This category (also referred to as Total Residue) includes all soluble ions, some of which have been discussed above, and organic constituents, predominantly the nonvolatile organics. However, in regular (municipal) drinking water, the main body of dissolved solids are made up of inorganic salts. In addition to the common cations and anions found in drinking water such as Na, K, Mg, Mn, Ba, Ca, Fe, Cl, SO_4, NO_3, PO_4, CO_3, and HCO_3, other constituents that exist in manned spacecraft or chamber facilities, not mentioned heretofore, may contribute appreciably to the total solids in aerospace water supplies. These may arise from urine and perspiration and from various components or sustenance units in the space cabin, and may include Al, Br, I and Si (all present in urine in addition to Zn, which is discussed separately below), Sb, Li, Pt, some rare metals especially those forming soluble halogenated complexes (e.g., Ga and In), some atmospheric components (e.g., the organics found in Mercury spacecraft, ref 17), and other types of organic constituents. If any of these constituents about which little information exists are found to be consistently present in water, additional toxicity studies will be necessary before the development of future potable water standards.

The significance and specific allowances of some of the individual dissolved ions have been discussed above; others have not, partly because of the relative ease with which the body eliminates them if taken orally in excess (e.g., Ca, Mg, Al, I, and PO_4). This is brought about as a result of poor intestinal absorption, hormonal control or rapid renal clearance. Because of poor or slow absorption, high concentrations of Ca, Mg and Al salts, as well as PO_4, have varying degrees of laxative or astringent action (ref 16). Taste and laxative thresholds of average individuals for magnesium start at about 400 mg/l and 500 mg/l, respectively; taste thresholds are tabulated

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also for Na, K, Ca, Cl, SO₄ and HCO₃ ions by USPHS (ref 3). Too much sodium causes water retention in the body; the upper limit of Na intake, apart from its laxative effect as Na₂SO₄, may have to be determined, especially under aerospace conditions.

Antimony contamination of water at a military installation plus the presence of this element in certain medications has prompted the U. S. Navy to add this constituent to those listed and adopted after the 1962 USPHS Drinking Water Standards (ref 18). Because of the similarity of Sb toxicity to that of As, the levels recommended for Sb were the same as the USPHS levels for As, viz., 0.01 mg/l preferred, with a ceiling of 0.05 mg/l. If Sb is identified as a contaminant in aerospace water supplies (not reported thus far), it may have to be included in future aerospace standards, probably at a threshold level comparable to that of As.

Generally, the level of 500 mg/l of total dissolved solids established by USPHS, based mainly on taste and laxative effects, is too low for aerospace applications, especially in view of the reported (ref 3) existence in this country of over 100 public drinking water supplies containing over 2000 mg/l TDS, which has been tolerated after a long period of adaptation by local residents. Individuals who are unaccustomed to such high concentrations of dissolved solids could be trained to adapt to moderately high TDS levels, providing the SO₄ and, to a less extent, Cl concentrations are kept to a minimum. In the present USPHS water standards, one-half (250 mg/l) of the recommended 500 mg/l TDS should not be exceeded by either sulfate or chloride. However, for aerospace applications, a level of 1000 mg/l TDS is recommended, with a proportional ceiling placed on sulfates, chlorides and all other solids (e.g., CO₃, NO₃, Mg, Ca, organics, Na, and Zn) in a range as follows:

250 - 450 mg/l	Chlorides
150 - 250 mg/l	Sulfates
600 - 300 mg/l	Remaining dissolved solids
1000 mg/l	TDS

It can be seen from this recommended range of dissolved solids that if the SO₄ content were 150 mg/l instead of a maximal level of 250 mg/l, with the Cl level not exceeding 250 mg/l, the amount of all other dissolved solids could be doubled (i.e., from 300 to 600 mg/l). A level of 2000 mg/l TDS in emergency, approved earlier by the U. S. Air Force (ref 19), appears reasonable for aerospace missions.

Zinc (Zn)

This element is relatively nontoxic, even at concentrations that produce cloudiness in water, i.e., 15-25 mg/l. Slightly above this range, the water takes on a milky appearance, i.e., at 30 mg/l, and has a distinctive metallic taste at 40 mg/l (ref 3). Only at much higher concentrations do Zn salts produce gastrointestinal effects and cause emesis. Because of the undesirable esthetic factors of cloudiness and taste, the USPHS reduced the level of Zn from 15 mg/l in 1946 to 5 mg/l in 1962. On the other hand, several civilian and military water supplies have used waters containing up to about 40 mg/l Zn without any harmful effects (ref 3). In view of this fact and that cloudiness occurs at a level of about 15 mg/l Zn in water, it is recommended that an upper limit of 15 mg/l Zn be used for aerospace standards. It may be possible to raise this figure to 25 mg/l if the recovered water is of high quality, that is, low in interfering ions such as As, Cd, Pb, and SO₄. On the other hand, were the latter to be at maximal allowable concentrations, cloudiness might develop at or below 10 mg/l and thus require a reduction in the recommended allowance of 15 mg/l.

SECTION III.
Radiological Properties

The USPHS and all other Federal agencies receive their guidance on limits of exposure to radioactivity in the environment, particularly water, food and air, from the recommendations of the Federal Radiation Council (FRC). One of their basic recommendations about all radiation exposures is quoted in the 1962 USPHS standards: "There can be no single permissible or acceptable level of exposure without regard to the reason for permitting the exposure. It should be general practice to reduce exposure to radiation, and positive effort should be carried out to fulfill the sense of these recommendations. It is basic that exposure to radiation should result from a real determination of its necessity."

The FRC guidelines are predicated upon three ranges of transient rates of daily radionuclide intake, with each range having a precise graded scale of control activity. The range values recommended are the sum of radioactivity from air, food, and water, and represent average daily dose rates over a one-year period. Although all three ranges are presented for the radionuclides considered by FRC, the upper limit of the range concerning "quantitative surveillance and routine control" (Range II) is important for limiting expected daily exposures to radio activity; these upper limits in micromicrocuries per day are 20 for Ra^{226}, 100 for I^{131}, 200 for Sr^{90}, and 2000 for Sr^{89}. (The upper limit for each nuclide is increased tenfold in Range III concerning the "application of additional control measures as necessary," but is one-tenth for periodic surveillance in Range I.) Only two of the four radionuclides are considered by USPHS for drinking water standards. Iodine^{131} and Strontium^{89} have not been found in significant amounts in public water supplies so as to be necessary for routine monitoring; however, Sr^{89} might be high in the presence of increased levels of Sr^{90} (ref 3).

USPHS has established an upper limit in drinking water of 3 $\mu\mu$c/liter on Ra^{226} and 10 $\mu\mu$c/liter on Sr^{90}. Only upon contamination of ground water due to pollution by radium-containing wastes would the radium level, expectedly, be exceeded. The major sources of Sr^{90} have been both nuclear fallout in air and food. The limit of 10 $\mu\mu$c/l is estimated to be much higher than the highest level presently found in public water supplies. Where excessive amounts of either Ra^{226} or Sr^{90} exist in the water, recourse to the sum total environmental exposure along FRC guidelines must be considered. Thus, high levels of Ra^{226} and Sr^{90} would be acceptable, providing the radioactivity from all other sources in addition to that in water does not exceed intake levels recommended by FRC for control action, i.e., the upper limit of Range II (ref 3).

In addition to the two radionuclides above, an upper limit of 1000 $\mu\mu$c/liter of gross beta activity has been set by USPHS, providing that zero to negligible amounts exist of alpha emitters and Sr^{90}. Any excess of this total gross beta limit must be analyzed to determine if exposure by the specific nuclide or nuclides will not exceed the FRC recommended thresholds (ref 3).

The recommendations of the FRC that have become part of the 1962 USPHS standards and later adopted by the U. S. Navy (ref 18) are recommended also without change at this time for application to aerospace standards.

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SECTION IV.
Microbiological Properties

The microbiological quality of water described in the 1962 USPHS water standards, similar to the 1946 standards, is based primarily on the presence of the coliform group of bacteria in water as determined by specific tests, although consideration is given to other types of micro-organisms in potable water. According to the definition in *Standard Methods* (ref 12), adopted by USPHS, the "coliform group includes all of the aerobic and facultative anaerobic, Gram-negative, nonspore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35C." This group "includes organisms that differ in biochemical and serological characteristics and in the natural sources and habitats." Characteristically, *Escherichia coli* inhabit human and animal intestines; *Aerobacter aerogenes* and *A. cloacae* are present on various types of vegetation and in materials used in joints, pump valves and pipelines. The intermediate-aerogenes-cloacae (IAC) subgroups, which usually exist in soil and old polluted waters, exist also in fecal discharges but not to the same degree as *E. coli*; thus because of relative dominance, *E. coli* are referred to as "fecal coli" and the IAC group as "nonfecal." The latter seem to survive longer in water and are more resistant to chlorination than the former, so that "the presence of fecal coliforms indicates recent and possibly dangerous pollution," whereas the IAC organisms suggest "less recent pollution or the existence of defects in water treatment or distribution" (ref 3).

Examination of water to determine its bacteriological quality for USPHS standards is performed by the mutliple-tube fermentation tests or membrane filter technique, or both (ref 3, 12). In the former, at least a single standard sample is used consisting of five equal 10-ml or 100-ml portions of water. The limit of acceptability depends upon the number and portion size of the samples analyzed and the time period. For example, of the 10-ml portions, the presence of coliform organisms shall not exceed 10% in any single month or three out of five portions per standard sample if the latter occurs in (a) two consecutive samples, (b) more than one sample per month if less than 20 are examined per month, or (c) more than 5% of the samples when 20 or more are examined per month. However, water containing three positives out of five 10-ml portions of a standard sample should not be rejected unless good quality water is unobtainable in two consecutive samples. Different values exist for the 100-ml portion size (ref 3, 12). Another but similar type of fermentation test adopted by USPHS uses an estimate of the most probable number (MPN) of coliforms in a standard sample composed of five standard (10-ml or 100-ml) portions. The MPN threshold values also vary according to the conditions of the test. Where coliform bacteria are present in three out of five standard portions, the MPN for the 10-ml size shall be less than 9.2 coliform bacteria/100 ml or less than 0.92 coliform/100 ml for the 100-ml portions (ref 3, 12). A different test added to the recent USPHS standards is the membrane filter technique. In this test, an arithmetic mean coliform density is used and is different also for different volumes of sample filtered, time period, etc.; e.g., the threshold coliform colonies per standard sample are 3/50 ml, 4/100 ml, 7/200 ml, or 13/500 ml (the acceptability conditions being similar to those for the 10-ml size of the first fermentation test discussed above) (ref 3, 12). Only the limit of the smallest sample size, 3/50 ml, with a threshold level less rigid than the other three, is presented as the USPHS value in table I.

According to USPHS (ref 3): "The presence of any type of coliform organism in treated drinking water suggests either inadequate treatment or access of undesirable materials to the water after treatment . . The presence of coliform organisms in treated water calls for definitive action for their elimination. Insofar as bacterial pathogens are concerned, the coliform group

is considered a reliable indicator of the adequacy of treatment ... Whether these considerations can be extended to include rickettsial and viral organisms has not been definitely determined." In addition to the coliforms, fecal streptococci are also indicators of fecal pollution of water. The subject of enteric viruses in water is discussed also by USPHS, and the development of methodologies to examine them in order to form a basis upon which standards may be established is encouraged (ref 3). Standards for the bacteriological examination of water, in addition to those of the USPHS, are found in several armed services manuals (e.g., ref 18, 20), including emphasis on some pathogenic organisms (ref 21). In application to aerospace standards, especially as they relate to closed manned space systems of long duration, the only measure that appears safe at this time is to provide bacteria-free water for the astronauts. Research is required to determine if any nonpathogenic organism in water would be harmless under long-term space conditions.

SECTION V.
Physical Properties

The limits established for the physical quality of water, such as taste, odor, color and turbidity, are based primarily on consumer acceptability: "Drinking water should contain no impurity which would cause offense to the sense of sight, taste, or smell" (ref 3). Thus, the levels set by the 1962 USPHS water standards of 5 units of turbidity, 15 units of color (reduced from 20 in 1946) and a threshold odor (or taste) number of 3 represent subjective thresholds of a large number of people. The particular tests, adopted by USPHS and others, to determine the physical properties of water are described in the more recent editions of *Standard Methods*.

Turbidity

Turbidity in water is usually the result of suspension of finely divided particles as well as organic matter, including microorganisms. The standard method for the determination of turbidity is the Jackson candle method, which consists of a special glass tube (or cylinder) calibrated in Jackson units, a candle made of beeswax and spermaceti, and a vertical alignment support (all referred to as a Jackson turbidimeter). Turbidity is an "expression of the optical property of a sample that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample." Therefore, the measurement of turbidity is based on the light path through a suspension that just causes the image of the flame of a standard candle to disappear or be indistinguishable against background illumination when the flame (the top of which is 3 inches below the cylinder bottom) is viewed through the suspension within a few minutes. The longer the light path, the lower the turbidity (ref 12). Jackson units represent various levels of flame disappearance measured from the inside bottom of the Jackson tube as sample is poured in from the top; e.g., 2.3 cm represent 1000 Jackson units, and 4.5, 7.3, 21.5 and 72.9 cm represent 500, 300, 100 and 25 units, respectively. The present USPHS turbidity threshold is 5 Jackson units, which represents clear water; however, 25 Jackson units of chemically acceptable water, although somewhat cloudy, should not be the cause for rejection by aerospace crews, and thus this figure is recommended as the upper limit for aerospace water standards.

Color

True color of a water sample is defined in *Standard Methods* as that of turbidity-free water, in view of the fact that even a slight turbidity causes the sample color to be noticeably higher than after the turbidity has been removed. If turbidity is present and has not been removed by centrifugation, the color of the original sample is reported as "apparent" color, which includes not only the color due to substances in solution, but also that due to suspended matter. The standard method to measure color is called the platinum-cobalt method, the unit of color being that produced by 1 mg/liter of platinum in the form of the chloroplatinate ($PtCl_6$) ion. Color measurements are determined visually by comparison with known concentrations of standard solutions (prepared by dilution of a stock standard or by varying the ratio of cobalt to platinum) or by the use of special, calibrated, glass color discs held at the end of metallic tubes containing glass comparator tubes (ref 12). Because water becomes colored and esthetically unacceptable above 15 units on the platinum-cobalt scale, the USPHS reduced the threshold limit from 20 in 1946 to 15 units in 1962. It is recommended at this time that 15 units be established, also, as the upper limit for aerospace standards. It is anticipated that if a particular substance consistently producing a color of over 15 units in reclaimed water were identified and found to be otherwise unoffensive to a trained spacecrew, a slightly higher color level may be acceptable.

Threshold Odor (or Taste) Number

It is generally accepted that odor tests can be conducted for longer periods (less fatiguing) and at higher temperatures, and are more sensitive than taste tests. However, certain inorganic salts not accompanied by odor require evaluation by the sense of taste only, e.g., the salts of Fe, Zn, Mn, Cu, Na and K (ref 12). Because of day to day variations in individual sensitivity to taste and smell, tests are usually conducted by a panel consisting of a large number of observers; sometimes, calibrating standards such as n-butyl alcohol are used to standardize odor tests and orthochlorophenol for taste tests. According to procedures in *Standard Methods*, taste tests, which vary with temperature, should be made at 40C (i.e., near body temperature), whereas odor tests should be done at either 40 or 60C (referred to as cold or hot threshold tests, respectively). Odor tests at the higher temperatures occasionally detect odors missed at the lower temperatures and vice versa, so that odor data are recorded usually with the temperature of observation. Odor-free water (via passage through activated carbon) is used both as a standard reference blank and for preparing dilutions of samples, which are sniffed lightly or tasted (held in mouth for several seconds) in a series of concentrations starting with the most dilute specimen. The number of times the water sample has to be diluted with odor-free water for the odor to be just detectable by the odor test is the threshold odor number. For results from a large panel of subjects, this number can be expressed as the geometric (not arithmetic) mean or median of the individual threshold values (ref 12). According to USPHS, an acceptable sample is one which should not have to be diluted with odor-free water by a dilution factor greater than 3 to produce a just detectable odor. A level greater than this in drinking water may indicate contamination more likely by organic constituents. It is recommended that the USPHS threshold odor (or taste) number of 3 be adopted for these standards. Since "a threshold number is not a precise value" (ref 12), a figure above threshold, i.e., beyond 3 but below 4, might be tolerated by astronauts. Increasing the recommended number from 3 to 4 represents an increase in dilution of only 8%; however, depending upon the constituents present causing a detectable odor, this small difference may be objectionable.

SECTION VI.
General Discussion

In comparison with the 1962 USPHS Drinking Water Standards, which were more rigid than the previous editions, these aerospace potable water standards are more relaxed, especially concerning the chemical quality of the water. The maximal allowable concentrations of 16 out of 20 chemical constituents are raised at least 80%, with the majority increased two- to fivefold, over the USPHS limits. The only change in the radiological and physical properties is a fivefold increase in the turbidity level. The most startling comparative change, perhaps, is the recommendation at this time that potable water be free of all microorganisms. The presence of organisms in potable water will no doubt be the subject of considerable discussion and debate in the future. Some individuals may or may not share the opinion of Dr. Julius Sendroy* who states: "To allow the presence of any type of microorganism in potable water aboard a spacecraft is to court disaster." Until future studies can establish that certain microorganisms would be harmless in potable water under any adverse aerospace conditions, it seems reasonable at this time to maintain the highest level of biological standards as a healthsafe measure for aerospace personnel. Concomitant with strict biological standards, the judicious selection of waste water to be purified for consumption is recommended to enhance the production of sterile water. Urine, respiratory and other atmospheric waters, and water from fuel cells are considered as prime sources for drinking water; whereas, highly contaminated liquid wastes (e.g., feces, food refuse, washings, etc.) could serve other purposes (e.g., hygiene, atmosphere control, etc.).

Although all the types of materials to be used for sustaining spacecrews, such as food and hardware, are not known at this time, it seems reasonable, nevertheless, to predict that certain of the constituents considered in these standards may be either eliminated entirely or reduced to inconsequential levels, thereby simplifying the chemical portion of the standards in time. Such constituents may include cadmium, zinc and lead if galvanized hardware were excluded from spacecraft. In addition, proper selection of materials in or for sustenance equipment, hygienic devices, additives in food, etc., may result in the elimination in water supplies of various types of detergents, arsenic, chromium, manganese, cyanide, fluoride, other inorganic, as well as some organic constituents. The extent to which the chemical standards are contracted would depend upon the degree to which materials are screened out of aerospace systems.

The measurement of organic contamination of aerospace water supplies along with the limit of acceptability may have to be reevaluated shortly. Many water-soluble contaminants, predominantly organic in nature, have been identified in spacecraft atmospheres. Whether or not these, as well as organic constituents from other sources, can be reflected in a single analysis of a water sample or require separate analyses and threshold limits of individual organic groups has to be determined. A carbon chloroform extract (CCE) analysis, for example, appears at this time to be impractical in view of the large sample size, complex instrumentation, long analysis time, and unknown specificity. Another test for organic contamination (e.g., total organic carbon) may be more reliable as well as practical. The application of these standards to spacecraft contaminants in general, along with other considerations, is discussed elsewhere (ref 22).

From the preceding information, it can be seen that these standards do not extend beyond the scope of the recent USPHS Drinking Water Standards. Because of our lack of knowledge concerning the nature of long-term manned aerospace systems, we are limited, in the beginning of

*Personal communication (Naval Medical Research Institute), June 1963.

our goal to provide a safe, dependable water supply for spacecrews, to consider only those problems that have been challenging to public health personnel over the years. The many valid questions that they have raised are very appropriate also to the development of aerospace standards. Some of these questions (with some modification) concern what areas the standards should cover. For example, how many and what types of chemical constituents should be included or excluded? What bases should be selected for microbiological and physical requirements and analyses, e.g., how can the presence of viruses be monitored especially in view of the existence of about 76 known pathogenic viruses, some of which have yet to be cultured (ref 7)? Would chemical or physical treatment be required to disinfect the water, and, if so, what type, at what concentration, for how long and where in the recycling system should treatment be employed?

In addition to the above, other important problems that have a direct bearing on these standards deserve attention or reiteration at this time. These entail investigations of methods to store and dispense potable water aseptically, including stability tests of suitable disinfectants or preservatives. Second, toxicity studies of certain constituents under altered environments such as those found in spacecraft; e.g., lead is more soluble at higher temperatures and thus presents a greater hazard, and freons may be narcotic at levels in spacecraft when normally they are systemically nontoxic.* Third, the judicious selection of dietary intake to reduce sources of certain constituents, e.g., decrease in certain salts. Fourth, studies on the ill-defined carbon chloroform extract to determine its validity as a measure of organic contamination or of the fraction responsible for undesirable taste and odor. Fifth, various engineering problems must be considered also. These include what materials are best suited to a water reclamation unit that are relatively biologically and chemically inert and how to manage the recycling system if a loading effect were incurred, for example, by any of the major constituents in urine, such as urea, Cl, Na, K, PO_4, and SO_4. Finally, of great importance to the subject matter is the identification of those contaminants that are common to most aerospace water supply units; this can be determined by complete analyses of water produced from all types of techniques and equipment. Such information would enable the development of standards having some degree of ubiquity that is similar to the public health standards. The latter applies to all drinking water in spite of the fact that the vast network of rivers in this country vary greatly in quality. Thus, many problems must be resolved or sufficient analytical data provided before the establishment of permanent aerospace potable water standards. Until this goal is achieved, these standards must be considered provisional in nature and serve only as a reference for future modifications and development.

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*Dr. J. L. Svirbely (USPHS, Cincinnati, Ohio). Personal communication, August 1963.

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13. ABSTRACT

Provisional potable water standards, patterned after the 1962 USPHS Drinking Water Standards, have been formulated for application to aerospace systems. In comparison with USPHS standards, the recommended maximal allowances have been raised (relaxed) at least 80%, with the majority increased from two- to five-fold, for the following 16 out of 20 chemical constituents: alkyl bensene sulfonate, arsenic, barium, cadmium, chloride, copper, cyanide, iron, lead, manganese, nitrate, phenols, selenium, silver, total dissolved solids, and zinc. Four constituents, carbon chloroform extract, chromium, fluoride and sulfate, remain relatively unchanged. The radiological requirements are the same as USPHS for radium^{226}, strontium^{90} and gross beta emitters. The only change in the physical properties concerning turbidity, color, odor and taste in these standards as compared with USPHS is a fivefold increase in the turbidity level. For the microbiological quality of water, it has been recommended (at this time) that the potable water be free of all microorganisms to minimize potential health hazards to aerospace personnel. The importance of selection of materials for aerospace systems, improvement in analytical methods (e.g., detection of organic contaminants), and resolution of problems needing attention to the development of permanent potable water standards is discussed.

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