SPACE SCIENCE BOARD

Report of the

AD HOC COMMITTEE ON WATER QUALITY STANDARDS FOR LONG-DURATION MANNED SPACE MISSIONS

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Report of an ad hoc Committee
on
Water Quality Standards for Long-Duration
Manned Space Missions

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MISSION OF THE COMMITTEE

Through panels and working groups the Space Science Board of the National Academy of Sciences attempts to anticipate scientific questions and problems that may arise in the course of the nation's space program or to respond to them as they become apparent. As this program progresses toward the achievement of longer manned missions, now being planned in minutest detail years in advance of anticipated accomplishments, new types of problems are emerging. Among such problems is the provision of a safe and adequate supply of water for drinking and other personal uses by space travelers.

Simple arithmetic shows the impossibility of storing sufficient water for, say, a Mars flight estimated to last 1000 days. With a 10-man crew, each needing about 10 lbs. of water per day for all purposes, the total water requirement would be 50 tons, occupying almost 1700 cubic feet of space. Since present, or even foreseeable, booster capacity cannot accept such a penalty in weight or volume, reclamation of water must be performed on lengthy, manned missions in space.

The process required for reclamation of water must provide not only for physical collection of reclaimed water, but also for removal of contaminants or pollutants degrading the wholesomeness or the palatability of the water. It must include separation of the water from impurities, maintenance and control of chemical and biological quality, temporary storage facilities and a safe delivery system.

Early in 1967 the Space Science Board appointed an ad hoc committee to set chemical, physical and biological standards for reclaimed water intended for human consumption on spacecraft. Using the guides provided by the U. S. Department of Health, Education, and Welfare, Public Health Service (PHS) Drinking Water Standards, 1962 (PHS Pub. No. 956) and seeking consultation from sources within PHS, NASA, Department of the Air Force, the scientific community and industry, the SSB Committee met on March 10, 1967, and again on May 15, 1967, in formal sessions to consider water quality standards for long-duration space missions.

GENERAL OBSERVATIONS

Water supplies for long-duration space flights need to be at least as wholesome and acceptable as those provided by municipalities conforming to the PHS drinking water standards. Yet is not suitable to adopt over-all these detailed standards as requirements for drinking water produced by recovery systems in space flight. The quality of the raw water for space recovery is far different from that used for municipal supplies. Moreover, the water used in long-term space missions will be recycled through the human system many times during the course of the flight, providing opportunity for continuing concentration of trace materials. Greater stringency in requirements, particularly with regard to biological quality, is needed to maintain requisite wholesomeness in these circumstances.

On the other hand a number of the PHS limits on chemical constituents have been based on considerations of potential accumulated dose during a complete lifetime or have had reference to complete populations, including infants, aged or infirm persons and other types of persons with minimal resistance. Presumably, participants in space flights will be robust, healthy adults and the period of ingestion for water of space-flight quality will not exceed a few years. A number of the PHS requirements for chemical quality therefore can be relaxed to some extent without significant deterioration in the wholesomeness of the water for the specific conditions of space flight.

There is another important distinction between municipal drinking water standards and those for long-duration space flights. The former are operating standards to be employed on water as it is being distributed to the municipality. In these circumstances it is possible to allow occasional failure to meet requirements fully, provided the failure is not great or prolonged and provided corrective measures are instituted promptly. In contrast, the standards recommended for water quality in space flight must be regarded for the most part pragmatically as performance standards to be met or exceeded by recovery systems during testing periods. According to information received from agencies concerned with space travel, ability to test water for conformity with standards during actual flight will be minimal, except for sensory evaluation; and ability to take corrective measures, except for certain standardized procedures, will also be minimal. Because complete monitoring is not feasible, possible adjustments are limited, and the same source of water must be used whether it meets standards or not, it is intended that the recommended standards be met under all conditions of performance testing and on an individual basis, not simply on an average basis.

It is recommended that performance testing be of sufficient duration to evaluate the quality of water produced by recovery systems not only when new and in prime condition, but also following some of the anticipated replacements and repairs to be done by crews during space flights. Trends in parameters of water quality should be given weight, as well as minimal attainment of numerical requirements. If deterioration in quality, as measured by any parameter, occurs during the testing period, even though limits are not exceeded at any time, the testing should be prolonged until it is shown that requirements are still satisfied when steady-state operation has been achieved.

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

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

PHYSICAL REQUIREMENTS

The recommended standards for physical properties are:

1.	Turbidity (Jackson units)	not to exceed 10
2.	Color (platinum - cobalt units)	not to exceed 15
3.	Taste	none objectionable
4.	Odor	none objectionable
5.	Foaming	none persistent more than 15 seconds

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

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

CHEMICAL REQUIREMENTS

Recommended upper limits for chemical constituents in milligrams per liter are:

Arsenic	0.5
Barium	2.0
Boron	5.0
Cadmium	0.05
Chemical Oxygen Demand (dichromate method)	100.0
Chloride	450.0
Chromium (hexavalent)	0.05
Copper	3.0
Fluoride	2.0
Lead	0.2
Nitrate and Nitrite (as Nitrogen)	10.0
Selenium	0.05
Silver	0.5
Sulfate	250.0
Total Solids	1000.0

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

The limits for arsenic, barium, boron, cadmium, hexavalent chromium, fluoride, lead, nitrate and nitrite, selenium and silver have been based on potential toxic or adverse physiologic effects. The recommended limits are in many instances greater than those of the PHS drinking water standards, but they are considered well within limits of safety for consumption by healthy adults for periods of three years.

The standard for Chemical Oxygen Demand (dichromate) is included to guard against excessive carry-over of organic matter in recovery systems utilizing urine or feces as sources of water. Virtually nothing is known about the possible build-up of toxic, perhaps volatile, organic materials in water that has been recycled many times through the human system.

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

BIOLOGICAL REQUIREMENTS

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

Of great concern, on the other hand, is the potential multiplication of microorganisms in any part of the recovery system accompanied by production of toxic metabolities such as endotoxins or exotoxins. Accumulation of organic and inorganic materials in the water-recovery system as a result of continual recycling may well create a suitable nutrient medium for such growth, particularly in filters or columns of adsorbent. For example, spores of *Clostridium botulinum* are found not uncommonly in the human intestinal tract. If these spores, normally harmless on ingestion, are seeded on a filter or adsorbent or in interstices where nutrient materials may accumulate and low redox potentials may be produced, then they could vegetate readily and produce their potent toxin. Traces of this in the final product water would be disastrous. A similar situation would result from the growth of *Staphylococcus* species and production of their enterotoxin.

Another possible consequence of recycling is the accumulation of relatively nonpathogenic organisms such as Aerobacter aerogenes, Pseudomonas aeruginosa and numerous types of fungal spores. Relatively large numbers of such organisms may overwhelm the normal tolerance of man to ingestion or inhalation of small numbers of them, resulting in acute gastroenteritis or pulmonary disease. In addition, ear infections may be caused by Pseudomonas and by fungi, such as Aspergillus.

Moreover, some mycoplasma (PPLO) and viruses are excreted in urine or feces. Other viruses of respiratory types may be concentrated in cabin condensate. While such agents, particularly the viruses, would not be expected to increase in the absence of viable tissue cells, positive control of them should be demonstrated for any water-recovery system.

Because of the diverse natures and modes of hazard of possible biological contaminants in water-recovery systems for space use, the Committee found no justification for the establishment of standards based on individual types of microorganisms. It was considered that the goal should be essential sterility and that total counts of aerobic, facultative and anaerobic organisms would be the best indications of attainment of this condition. A maximum of 10 viable microorganisms per milliliter was considered to be a realistic criterion for "essential sterility."

It was considered essential, moreover, that this criterion of essential sterility be applied to all parts of the recovery system beyond the initial phase separation step and not simply to the finished product water.

The Committee felt strongly that some positive form of sterilization was needed at some point in the recovery-storage-delivery system immediately after phase separation. In addition it was felt that there should be provision for periodic heat treatment of the subsequent portions of the system to forestall hazards of possible bacterial or fungal growth.

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

To examine for total aerobic microorganisms 10-ml samples should be filtered through 0.45 micron membrane filters, the membranes placed in sterile petri dishes on pads moistened with trypticase soy broth or on plates of trypticase soy agar and the dishes incubated for seven days at 35°C, followed by counting of the total colonies produced. A similar procedure should be followed for total anaerobic organisms except that incubation is to be carried out under anaerobic conditions.

To test for common viral agents the filtrates from the aerobic and anaerobic samples should be concentrated in an ultracentrifuge and the pelleted material tested on suitable tissue cultures for cytopathic effects. Suitable tissue cultures can be selected on the basis of studies made with the raw fluid prior to its submission to the recovery process.

It is also recommended that the recovery system be challenged with a large inoculum of an identifiable cytopathogenic virus during performance testing when the resulting product water is not to be consumed and that its elimination from the product water be demonstrated by the foregoing techniques.

Full monitoring of biological quality should be maintained at all stages of evaluation of water quality from recovery systems where this is feasible. When full monitoring cannot be maintained, maintenance of the standard for total aerobic and anaerobic counts together is considered satisfactory and when monitoring must be even more restricted than this, maintenance of the standard in terms of total aerobic count alone is suitable.