of limited experimental data the range of applicability requires further investigation.

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Atmospheric Toxicants in Manned Space Stations

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THE occurrence of toxic hazards in space environmental systems is recognized, but suitable methods of amelioration have not been postulated. As such, it is necessary to establish criteria, develop techniques, and design performance parameters for the control and evaluation of undesirable vapors and particulate materials with which man will be confronted in his future extended space missions. Several pitfalls are encountered when an attempt is made to apply the existing available knowledge, since these are based on eight-hour work days and five-day week exposures. Bioastronautics is not concerned with such studies but rather with longterm exposures of a continuous nature with what is hoped will be relatively low concentrations. Direct extrapolation of the industrial-compiled exposures to space requirements are, of course, not feasible. Perhaps the greatest discrepancies will be found in the interactions and resultant formations of the low-level contaminants within the environment.

In a previous paper[1] compilations were made of the effluents produced by man. Similar lists are also available which indicate what compounds might be produced in a particular industrial operation or in a specific facility. What pathways these substances might follow is problematical, and the listing of the materials per se is of an academic nature and serves as a baseline, but is probably not definitive with respect to procuring a suitable habitat.

The interaction among vaporous components may operate synergistically or antagonistically; i.e., the final aggregate product may be more or less toxic than the precursors. An example of that is the interaction of hydrogen chloride and ethyl alcohol, both of which have been identified as occurring in restricted atmospheres.[2] The resultant ethanol is much less toxic than its precursors. Numerous examples with opposite results may be cited, however. For reactions involving the major atmospheric gases, the final composition within the orbital space station must be specified. To date, this has been a controversial topic. If a single gaseous system of oxygen is utilized there will be pertinent basic oxidation processes, whereas the addition of nitrogen may lead to the formation of toxic nitrogen oxides or other such derivatives. The inert gases have been implicated in certain biological reactions especially from a neural aspect.[3] The difficulties in analysis of these evasive materials further complicate their interactions.

Traversing space will lead to radiation of the capsule and its sealed environment. The radiation may come from artificial sources, the inner and outer Van Allen belts, solar flares, or galactic sources. The reaction of radioactive materials may profoundly alter the profile of the atmospheric components and it must be assumed that such interactions will be deleterious. Extensive investigations are being conducted on the direct effects of radiation on man but the indirect, insidious interplay with his habitable atmosphere have been largely neglected. Likewise, photochemical reactions and the effects on the formation of undesirable elements must be considered. Photochemical processes are now assigned as one of the major roles in the formation of the smog. The scope of these physiochemical complexes is magnified in the small confined area of a space station and further compounds the problems facing the astronauts. Chemical reactions of a diverse nature will be involved with lighting aboard and will be affecting the formed contaminants.

Particulate matter is an all-inclusive entity for such things as dust, sprays, fumes, and living organisms. Classification is based largely on the particle size and has not been adequately characterized. It may, however, react with the spacecraft atmosphere to become atmospheric dispersoids. A problem which can be solved only in a weightless or reduced gravitational environment is the change in settling rate which has been to date a principal criterion in characterizing these materials. As man enters space, living particulates, his microbiota, will accompany him. Such materials will react with the trace components to present another facet in the field of microbiology and possibly exobiology.

The chemistry of surfaces is receiving a new impetus as more of the critical properties of micro particles are uncovered. Such constituents, although of minor magnitude, have in earth-bound stations exhibited their potency by causing corrosion and other physical phenomena on surfaces of instrumentation and living areas of submarines.[4] Consider that metal surfaces become pitted and corroded; then the mucous membranes and other sensitive surfaces of man are also affected, probably to a greater degree. A normal atmosphere consists of a mixture of ions of varying size; each moving with a variable speed dependent upon their size. Beneficial results have been ascribed to them in regards to asthmatic and upper respiratory conditions, the negative ions showing a therapeutic effect, whereas the positive ions have been assumed to be innocuous. These, it would appear, could easily be attached to trace materials if their ionized state is retained for a suitable duration. As such, this would present another facet to the complex space station atmosphere.

Water will be present in the orbiting space capsule for drinking purposes, personal hygiene, cooking, and other uses. It is also present in large amounts as ambient humidity in the atmosphere. The interaction of the micro materials with that of water constitutes a large science in itself and might well change the profile of the mission. Aerosols and condensation nuclei are resultant products. Aerosols will play an integral role in the atmosphere of space stations. Toxicologists have shown that the formation of an aerosol greatly increases the damage done to man after ingestion, as compared with the same material before being placed in colloidal suspension. The formed particle is of significance, since particles of different sizes are retained to a different degree in the lungs. Condensation nuclei resemble aerosols in that they are liquid or solid, submicroscopic airborne particles, each of which can act as a nucleus for the formation of a water droplet. These materials are formed, however, only by supersaturated water vapor. The moisture content is important as well as the particle size in the necessary condensation process. The various operations involved in life support instrumentation aboard a manned space vehicle should present numerous opportunities for the formation of such nuclei.

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Table 1 Variables which may affect trace constituents

Total pressure	Allowable concentration of toxicants
Gaseous composition	Regenerative life support systems
Relative humidity	Emergency conditions
External radiation	Equipment stored aboard
Physical irritants	Launching, orbiting, and reentry forces
Foodstuffs	Background levels
Physical activity of crew	Detoxification mechanisms
Type and amount of absorbents aboard	Relative concentrations

Oxygen will continue to play a prominent role in man's atmosphere, and it can be assumed that oxidative processes will be occurring continually. Numerous air pollution studies have shown that incomplete oxidation of certain materials produces large amounts of trace contaminants. Since most of man's sub-systems carried aboard will not operate at 100% efficiency, incomplete oxidation may present a significant problem for the astronauts. Certain oxidative processes are hazardous, however, while similar ones are benign. For example, with methyl alcohol, only partial oxidation is achieved with the resultant formation of formaldehyde, whereas with ethyl alcohol, sealed-cabin environmental studies[2] indicate that its oxidation is complete, and there is no formation of toxic aldehydes.

Thermal degradation presents many inherent difficulties. In some instances, toxicants may be degraded to nontoxic materials, whereas the opposite is also true; probably the latter occurs more frequently. An example in a sealed atmosphere has been shown in the studies aboard nuclear submarines. Freon (CCl_2F_2) has been employed for air conditioning. At slightly elevated temperatures this material was decomposed into hydrogen fluoride, hydrogen chloride, chlorine gas, and fluorine. This is an example of a material which is generally considered to be nontoxic but produces several lethal by-products. At high temperatures Freon is broken down into carbonyl chlorides, known as phosgene in chemical warfare. Such degradation in the submarine has forced surfacing; however, in our space vehicle, one cannot anticipate having the privilege of calling off a mission when the environment becomes adverse.

Table 1 indicates the numerous variables which may affect an orbiting laboratory. Almost none of these has been clearly defined in our present ground investigations, as such endeavors must be undertaken in both locales to establish the role each will have in a manned space environment.

The interactions of all of the contaminants can show combined synergism and/or antagonism with all of the described factors. This would constitute a profile of combined biophysical and biochemical stressors. Certainly, atmospheric specialists are not overly familiar with any of the reactions just expressed for an orbiting station and the summation of such reactions would be only problematical. However, it must be assumed that the effects would be deleterious and would endanger man's performance and his space vehicle to the extent that they might be noxious, obnoxious, or even lethal with the possible consequence of aborting the mission.

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Weight Minimization of a Step Rocket by the Discrete Maximum Principle

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Nomenclature

c^n = propellant exhaust velocity of stage n
M^n = ratio of initial thrust to weight of rocket n
n = number of stages (appear as superscripts)
V = design velocity of rocket system
W_L = rocket system payload weight
w^n = initial gross weight of step n
d^n = portion of stage n jettison weight which is constant
$\alpha^n w^n$ = portion of stage n jettison weight dependent of step weight
$\beta^n M^n x^n$ = portion of stage n jettison weight dependent of thrust
$\sigma^n w^n$ = total jettison weight of stage n
x_1^n = initial gross weight of rocket $n = x_1^{n-1} + w^n$
θ^n = velocity ideally added during stage n
a^n = $-\beta^n M^n - \alpha^n$
b^n = $1 - \alpha^n$

Introduction

A SKETCH of a three-stage step rocket system is shown in Fig. 1. The difference of weight between two consecutive stages is called the step weight, and weight remaining after the jettison of the last stage is called the rocket payload. The purpose of such a rocket system is to attain the specified final velocity carrying the desired rocket payload. If the number of stages and the material and propellant for constructing the rocket system have been decided, the problem is to determine the optimum size of each stage, so that the gross weight of the system is minimized.

Two-stage[1] and three-stage[2] optimization problems have been solved by differential calculus; in order to make hand calculation possible, simplifying assumptions have been made which are quite reasonable for many problems, and the results are found to compare favorably with actual practice.[3] The simplifying assumptions, however, must be verified by comparison with solutions obtained by removing all or some of the assumptions. Also, many practical problems may have to be solved by use of other approaches, e.g., the dynamic programming algorithm.[3]

In the present work, the discrete maximum principle solution of the problem formulated by Dyke[3] is obtained, using his definitions of terms.

Formulation

When the discrete maximum principle algorithm is employed, the problem can be reformulated as follows (Fig. 2):

$$x_1^n/(x_1^{n-1} + \sigma^n w^n) = \exp(\theta^n/c^n) \tag{1}$$

If we assume that the jettison weight is a function h of w and θ and that c, M, d, α, β, and σ are constants for each step rocket,

$$\sigma^n w^n = h[w^n;\ \theta^n] \tag{2}$$

A combination of Eqs. (1) and (2) gives

$$x_1^n = T_1^n(x_1^{n-1};\ \theta^n) \tag{3}$$

For the first stage,

$$x_1^1 = T_1^1(w_L;\ \theta^N) \tag{4}$$

The optimization problem is to choose a sequence of θ^n at each step so that the initial gross weight of the rocket system is minimized and a designated velocity V for the rocket payload is attained.

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