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S P A C E S C I E N C E B O A R D

Man in Space Committee

Working Group on Nutrition and Feeding Problems

SUMMARY REPORT

The Space Science Board has undertaken through its Committee on Man in Space to study a number of topics of importance to the practical realization of space flight. This report describes the results of discussions and inquiries into the problems of feeding and nutrition in space flights of various durations. The membership of the Working Group responsible for this paper and of the parent Committee is given in the appendix.

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INTRODUCTION

The human body is capable of utilizing stored metabolites so that the actual nutritional requirements of the individual can be subverted for a short time. This will vary widely among individuals and each individual may exhibit characteristic patterns of nutritional behavior. Under these conditions, the requirements in short-range flights can be materially different from those for long-range flights. Indeed, muscular efficiency may not change significantly over a period of four to six days. Unfortunately, mental activity begins to decline after twenty-four hours. Consequently the Working Group has arbitrarily divided the feeding requirements into two categories: short-term and long-term. Short-term requirements were defined as requirements for missions of less than 21 days. It must be noted, however, that dehydration can occur under adverse conditions in a matter of hours and so water requirements cannot be treated in the same fashion, but must be considered as a special case.

WATER REQUIREMENTS

Water requirements are extremely critical and the amount supplied should not under any circumstances be kept to a minimum, but rather a large margin of safety should be included. The data for simulated flight conditions available to the Group indicate a wide variation in individual requirements; moreover, the data were obtained from only a limited number of individuals. It is extremely important that additional data be obtained on a number of individuals under similar conditions as rapidly as possible.

The environmental conditions for which water requirements are now known do not approximate those which will be encountered in space flight. Under most terrestrial environmental conditions, the distribution of temperature and evaporation from the body approximates a paraboloid with the highest temperature and highest evaporation rate at the torso, but under the conditions of space flight this does not hold. No substantial data are available which would relate water requirements to the distribution of temperature and evaporation in space flight.

Water requirements, as indicated in the small amount of data available, show a very strong dependence upon suit inlet temperatures. The absolute control of this temperature is evidently a matter of some uncertainty and under these conditions, the water requirement of the individual may vary over an extremely wide range. In the absence of accurate control of suit temperature, water requirement can easily double. If this occurs the mission would probably have to be aborted, since it is very doubtful if proper electrolyte balance would be maintained at such high rates of water loss.

As noted above, the environmental conditions for which water requirements have been established do not resemble those to be expected in a space ship. Normal or even extreme conditions of the terrestrial environment usually include diurnal variations in temperature. These conditions will not obtain in the spacecraft; and again, this points to the absolute necessity of obtaining data preferably on individuals in prospect for flight. Unless this is done, the real dangers inherent in present uncertainties will persist. In addition to ground-based experiments, measurements of water intake should be made under actual flight conditions. Data from short-term flights should be used for extrapolation to longer missions.

FORMULA DIETS

The Working Group first considered the tacit assumption which now prevails, to wit "astronauts even on short-term missions require a diet of great variety". This assumption is apparently not supported by experimental evidence. In many parts of the world, the people subsist on a monotonous diet consisting of only a few types of food with no apparent ill effects, provided their basic nutritional requirements are satisfied. Experimental evidence from many sources (e.g. the Army Medical Research and Nutrition Laboratory) shows that individuals can be kept on a single disagreeable formula diet for as long as 60 days without suffering ill effects. Experiments now current at the Nutritional Department at MIT indicate that it is possible to furnish active students with a formula diet, monotonous but not disagreeable, for a period as long as 90 days with no adverse physical effects nor any measurable change in psychological state. Since highly motivated individuals are chosen for the initial space flights, it is unlikely that they would object to the monotony of a formula diet and would probably prefer its simplicity, certainly no ill effects would be expected over a short-term period by the feeding of a monotonous or formula diet. Also, there are definite possibilities for the development of a formula diet of greater acceptability than those which have been used. The Group concluded that there is no reason to anticipate adverse effects from the use of formula diets in short-term flights.

The Group feels, therefore, that formula diets would be extremely desirable for short-term flights for the following reasons.

1. A formula diet (a rehydrated liquid formula could be used) would considerably reduce the number of manipulations and the time required for inflight preparation when compared to a varied diet. These two considerations could contribute materially to the safety of a flight since (a) the astronauts would not be preoccupied with food preparation for so long a period, and (b) (more important, perhaps), the food could be dispensed without the removal of suit components, such as gloves. In principle, it would be possible to feed through tubes inserted through the helmet.

2. Storage requirements could be significantly simplified with this type of diet. Weight, however, would not be lowered without the development of more refined formulas than those now available.

3. It is possible, by careful choice, to develop a diet which will materially decrease fecal production. Since disposal is apt to be a problem, particularly in crowded conditions, this factor must be seriously considered.

4. Perhaps the most important reason for considering such a diet in short-term flights, is the consequent simplification of experimental determinations of nutritional condition of the astronauts. Formula diets could readily be adapted to the determined metabolic requirements of the individual astronaut. Investigation of nutrition under the combined stresses of space flight appears extremely important to the Working Group.

5. Packaging problems will be simplified by the use of formula diets. The varied diet now proposed creates problems in packaging which have yet to be solved and the space ship specifications preclude the use of simple packaging methods for these diets.

The Group does not wish to leave the impression that formula diets would be monotonous in the extreme since they can be varied with respect to flavor and color with no difficulty.

WASTE AND FLATUS

The problem of waste production is intimately related to the nutrition and feeding of the astronaut. The Group was of the opinion that this problem is one of the major ones in both short and long term missions. In can be solved or at least simplified by taking advantage of effects brought about by dietary changes. Any diet should be adjusted, even on a short range basis, for the minimum production of solid waste materials. Since the diets can be tailored to minimize the production of fecal matter, processing other than for storage, probably does not have to be considered in short missions. However, the packaging for storage presents a problem and great care must be taken to inactivate the biota of the waste products.

It is apparent that water will be sequestered by net accumulation in the feces. The net loss would approximate 40 to 60 grams per man per day under normal conditions. If in longer flights processing of fecal matter is indicated, the Group believes that water is likely to be the only material found in sufficient quantity in fecal matter to warrant recovery.

It would be well to prepare the astronauts before flight, by feeding them low residue diets for a number of days, in order to minimize problems during flights. From the experimental standpoint it is important that fecal waste produced in flight be packaged separately and a record of time of production be kept. This would facilitate the nutritional analysis required even on short-term flights.

Flatus can conceivably be a problem in short-term feeding and differing dietary patterns markedly effect its production. The effect of flatus can be serious, particularly at low absolute pressures. Also, since the composition of flatus is not innocuous, it is conceivable that, in time, considerable concentrations of toxic gases may accumulate. The purification of the recirculated atmosphere must take this problem into consideration, but, in any event, the diet should be planned to minimize the problem. This can be done by planning dietary intakes and this should be a major consideration in planning. Since variation in the production of waste products is, to some extent, an individual characteristic, it is important to test the proposed feeding regime on individual astronauts before flight.

The production of urine and its storage is of importance, particularly on short-term flights. The desired analyses necessitate the individual packaging and labelling of urine specimens. In the initial flights, it is necessary to minimize processing, in other words, the recovery of water from urine should not be contemplated, since individually packaged and labelled urine specimens are required for the analyses of metabolic wastes.

METABOLISM

An accurately measured intake of nutrients, calories, and water is a requisite for determining metabolic demands imposed in any space flight. Insufficient knowledge is at hand to predict total metabolic requirements under the numerous stresses which can be anticipated. Simulator studies are of great importance even for short duration flights.

It was the opinion of the Group that such experiments have not yet been performed since the available data is largely restricted to water and even here not enough data are available for reasonable predictions.

Additional experiments are urgently required to determine the metabolic demands for minerals -- in particular, the electrolyte balance of calcium, potassium, sodium, and phosphorus. Under conditions of high water utilization, large mineral losses are to be expected. Failure to replace these can cause an imbalance which will impair the efficiency of the individual to the extent of endangering the flight. Respiratory quotients, caloric demands, sterol excretion, and nutrient requirements under various regimes should be determined. These experiments can be performed under simulated conditions, but in addition, the flights of short duration will present one of the best opportunities for the collection of data.

Analysis of samples taken in flight -- both of urine and fecal matter -- should be made. Respiratory quotients can be determined in flight, blood samples should be taken before and immediately after flight for the analysis of selected components (in simulator studies these could be taken periodically), and nutritional intakes (which would be facilitated by formula diets) must be measured and analyzed. The relation of nutrient, excretion, and other biochemical parameters to food intake and work periods under flight conditions should also be determined. The most important of these data can only be obtained under flight conditions, hence the planned short-term flights should include these investigations as part of their objectives.

SHORT RANGE TECHNOLOGY

In reviewing the technological aspects of space feeding, the Group was impressed by the many practical difficulties in providing for food storage and accessibility in spacecraft under design. For example, the space allocated in the Gemini vehicle for food storage seemed to be an afterthought on the part of the air frame designers*. The volume did not appear large enough and was disposed in a manner that would make manipulations for feeding anything but liquid formula diets undesirably difficult. The subsequent storage of waste in the same space seemed almost impossible under normal conditions using the varied diet. Food would have to be removed or rearranged if the waste material was added to the compartment or more food removed.

The contributions of the Armed Forces Food and Container Institute and other contractors in circumstances like these seemed most commendable, but the Group felt that much difficulty could be avoided if those responsible for the provision of food and its storage were called in during the early stages of spacecraft and mission planning.

* No information was available to the Group concerning the food planning for Apollo.

The packaging of food materials, both dehydrated and liquid, has proceeded satisfactorily under the Food and Container Institute supervision. The environmental conditions which are specified for the packaging for the storage of foods, however, give some concern. If packaging materials are to be designed to withstand very high relative humidity and large variations in temperature, additional technological investigations are required since containers which will meet these demands are not yet available. In any case, packaging and storage is intimately related to the way in which the food is used. It is imperative in packaging that serious consideration must be given to the ease with which the food may be reached and eaten. The best food packaged perfectly is of no value if the astronaut cannot readily remove it from the package and deliver it to his digestive tract. There is no doubt that these problems could be more readily avoided if individuals informed on feeding problems were to participate in the initial design of the spacecraft.

If dehydrated formula foods are fed in short-term missions, additional work is required on the rehydration of such formulas. The Group feels the present methods of water measurement under weightless conditions are not satisfactory, and better methods will have to be contrived. The problem of rehydration of solid foods is of concern. The methods now contemplated are not satisfactory and could lead to difficult or hazardous situations, when the individual attempts to replace the water removed from dehydrated solid foods.

Assuming there would be no possibility of physically removing waste products from the capsule, much additional investigation is needed on the collection and inactivation of the waste. An inactivating compound of low volatility which can easily be distributed through the fecal matter is required. The consequences of poor mixing or incomplete activation could be fatal to the mission. The present level of work on this problem is considered to be inadequate. Refrigeration or dehydration are alternative solutions, but introduce other problems.

LONG-TERM NUTRITIONAL PROBLEMS

As mentioned previously, there is a dearth of metabolic information, even for short duration flights, and without this information it is impossible to extrapolate changes in metabolic patterns to longer flights. However, using scattered information it is possible to hypothesize certain changes which may be encountered. Decalcification of bone, with attendent formation of calculi, and changes in water holding capacity of the body may be anticipated. It is also possible that changes in proportion of fat to lean body mass could be experienced and should be considered in nutritional planning. Nutritional requirements are related to size, particularly lean body mass, to sex, to physiological state, and to individual metabolic rates. Therefore, individuals for space flight should be screened with these factors in mind if it is desirable to minimize food intake in long flights.

The factors which influence the total nutritional requirements of the individual will also influence his mental and physical responses to stress. If the problems could be delineated through investigations based on short flights and simulator studies, it would be possible to adjust the nutritional intake of the crew so that matabolic changes would be minimized.

A satisfactory basis for extrapolation of nutritional requirements is badly needed. The Group feels it can not over-emphasize the need for proper metabolic studies, including trials in simulators and short space flights. These studies would not only provide a basis for extrapolation but would minimize the number of new variables introduced as the complexity and duration of flights were raised.

SYNTHETIC FOODS

The development of food materials other than those derived directly from animal or vegetable origin may be of interest. Possible advantages of such diets may be low residue per unit mass, ease of storage, ease of rehydration, and ease of manipulation. Since the molecular configuration of physiologically active amino acids and fatty acids is highly restricted, the economic separation of these from synthetic mixtures is questionable. Experiments with amino acid diets, high energy carbohydrates and high energy fat materials have only recently been initiated. The nutritional properties of diets composed of purified substances still require evaluation on human subjects; the problems of feeding of these products; their effects on digestion, water intake, electrolyte balance; and the total composition of such diets must be elucidated before their use is contemplated, even on short-term missions.

FOOD PRODUCTION IN SPACE

The frame of reference for long-term feeding in space depends entirely upon the ability to lift a payload of stored food. Ultimately one must arrive at a point at which it is more economical to produce food for the space traveler than it is to carry it aloft. The circumstances which would apply in such a case are not at present predictable and will vary for each mission. If sufficient propulsive energy is available, the duration of missions which can be provisioned with stored food may be quite considerable. However, in emergencies in which a mission lasts longer than planned, survival may depend on the ability to produce food extraterrestrially. Without considering details, it can be recognized that a time will eventually be reached when it is desirable or necessary to produce food beyond the confines of Earth.

It should be clear, however, that as space flights become more routine and as the flights become of longer duration, food variety will become a metter of some concern. However, since good nutrition can be adequately maintained for an indefinite period through the use of a properly constituted formula diet, variety in food is primarily a matter affecting the morale rather than nutritional state of crew members.

The primary objective of a feeding program on long flights is to supply a diet to the individual which is adequate in terms of nutritional balance. The nutritional requirements of the crew will be influenced by activity, physical and psychological stresses, individual size of the members, individual metabolic rates, etc. The food intake will then have to be adjusted to meet these requirements. The use of drugs, low temperatures, and other external means to alter metabolic patterns should not be contemplated until there is sufficient physiological information on their effects to warrant consideration. Work in this area should not be discourage, however, for it is necessary to know the nutritional requirements of each astronaut and the way in which these are altered by the conditions of space flight in order to estimate the needs in long missions. Without this information, the food supplied for the longer flights may be too much, too little, or improperly balanced with regard to essential nutrients. The first consideration is important because of the severe limitations on total weight which can be carried, and the last because of danger to the crew. Where dependence would not be on stored food alone, but on food produced en route, more exact information on requirements is needed to determine the size and capacity of food production units to be used.

Regardless of the source of energy (which is not of direct concern of this Group) it must be delivered in a form suitable for the food production process.

Several suggestions have been made for the production of food materials. Among these are methods employing (i) photosynthetic organisms and tissue cultures (e.g. bacteria, algae, duckweed), (ii) nonphotosynthetic organisms and cultures (e.g. hydrosomonas, fungi, protozoa, heterotrophically grown algae) and (iii) higher animals and plants. In contrast to the production of living tissues, reprocessing of waste materials by chemical treatment or the actual synthesis of high energy chemical compounds have been suggested.

In this context, the Group wishes to emphasize two points: (1) no system has yet been demonstrated as workable in the economical production of food in space; (2) the systems considered produce materials which may be converted to food, but are not food as such.

Algal cultures have had the most extensive investigation as food in space, but the technological problems of using this material as a food source have not yet been solved. It is apparent from the investigations to date that algae will require treatment before they can be used directly as a food material. In limited trials difficulties have been experienced with amino acid deficiencies, digestibility, high residues, and gastric distress; also a large proportion of the protoplasm is not available to the human body. Processing methods which would be applicable in space travel and the possibility of a secondary conversion by other animals or plants should be systematically investigated, with appropriate biological advice. At present the relative scarcity of pure algal cultures still hampers work in this field.

Investigations of their value as potential food sources should be extended to many more representatives of the animal and plant kingdoms. Also, the conversion of potential food sources to edible and assimilable material should be investigated. The possibility of a multiple conversion either sequential or simultaneous appears attractive. An example of a sequential conversion is the photosynthetic fixing of energy by algae, their subsequent utilization by an organism such as a snail or slug, and finally consumption of the animal by man. It is also possible to convert primary materials to available food by microbial, chemical or enzymatic means.

For answering the questions and solving the problems of long-term feeding in space the Group believes it important to marshal a much greater proportion of the available investigators and resources. It is also essential to facilitate communication between investigators.

SUMMARY

The more important considerations to which the Working Group wishes to draw attention are listed below.

1. Varied diets are not thought to be essential though they may be important for morale purposes in the case of flights of long duration.

2. The use of formula diets is recommended for early missions of the shorter kind because of the advantages of:

a) simplicity
b) ease of handling and storage
c) minimization of residue
d) control of flatus
e) facilitation of metabolic studies
f) adaptability to provide nutrient requirement of individual astronaut

3. Careful consideration should be given to:

a) minimizing waste production
b) methods for inactivation of waste material

4. It is important that urine samples be collected in the early shorter missions and preserved with a minimum of processing for later analysis.

5. Planning for long flights requires metabolic data from shorter flights and from studies with simulators.

6. Water requirements cannot be reliably predicted on the basis of present knowledge. Further study of this problem is necessary.

7. Problems of feeding and food storage should be considered during the initial stages of spacecraft design. Accessibility and ease of handling must be considered.

8. The potential advantages of synthetic foods are recognized but it is recommended that they not be used until additional research, development, and testing verify their suitability.

9. Very long duration missions may require production of food in the spacecraft. Further study of the production of the nutritionally important substances and their conversion into edible food is necessary before the practicality of such procedures can be assured. These studies would be aided by a more plentiful supply of pure algal cultures.

10. Major emphasis for the production of food during the flight has centered about algae. Other organisms, photosynthetic and chemosynthetic, should receive increased attention.

11. Ready solutions for the problems of astronaut feeding are not to be expected for any but the shortest missions. Increased efforts to inform workers in the field as to the nature and magnitude of these problems and to involve them in efforts directed toward their solution is strongly recommended.

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APPENDIX

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