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AEROSPACE FOOD TECHNOLOGY

A conference held at
the University of South Florida
Tampa, Florida
April 15–17, 1969

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA SP-202

AEROSPACE FOOD TECHNOLOGY

The principal addresses at a conference cosponsored by the National Aeronautics and Space Administration and the National Academy of Sciences at the Center for Continuing Education of the University of South Florida in St. Petersburg, Florida, April 15-17, 1969.

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FOREWORD

In my introductory remarks to the Conference on Nutrition in Space and Related Waste Problems held at the University of South Florida, Tampa, Fla., in 1964, I noted that "the support of man in any alien environment for a long period depends on the solution of multitudinous problems, both physical and psychological." During the intervening years much progress has been made in the manned space program and we have witnessed a manned lunar landing as well as other major accomplishments. However, the nutrition problems of longer manned missions that we discussed in 1964 are, in most instances, still with us today. The way to provide a diet that will maintain the health and well-being of a crewmember on a long space mission while he is being subjected to the stresses of space environment is still not resolved. It is true that advances have been made since 1965, and with proper research great strides will be made in the near future.

It is gratifying to note that several reports have been presented during this meeting of advances and new concepts in space feeding. One advance is the tendency toward use of natural foods that can be eaten in a conventional manner, i.e., with a spoon or fork. If food has enough cohesiveness it can easily be eaten in a conventional manner under conditions of weightlessness. The avoidance of unnatural or unfamiliar foods will facilitate the elimination of the psychological stress that accompanies the use of such a diet.

Although the Panel on Space Nutrition of the Space Science Board has played only a minor role in the organization of and participation in this conference, it has long followed with keen interest the NASA research program in nutrition. The panel has reviewed the work underway and also looked into special problem areas such as acceptability and palatability of diets. The panel will in the near future reassess the current status of plans for space diets and help identify the research most likely to solve the problems of feeding the astronaut on long space missions.

Although it was not possible for the panel to participate in the opening session, we look forward to the publication of the papers presented at this conference.

C.O. CHICHESTER
Chairman, Space Nutrition Panel of the Space Science Board
National Academy of Sciences - National Research Council

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WELCOME

The University of South Florida is once again honored to be the host of a Space Food Technology Conference sponsored by the National Aeronautics and Space Administration and the National Academy of Sciences. In the years intervening from the first conference in 1964 to the present one in 1969, a wealth of practical space-food utilization experience has been accumulated through the NASA Manned Space Flight Program. It is therefore fitting and appropriate to bring the focus of the accumulated operational experience and advanced technology development to bear on the problems of improvement of nutritional aspects for future manned space missions.

From a review of the spectrum and depth of the technical papers presented at this conference, I am confident that this conference report will provide a valuable springboard for new and unique advanced food research and technology studies.

JOHN S. ALLEN
President
University of South Florida

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INTRODUCTION

There have been remarkable strides in the general field of food technology in the last several decades. Any housewife can attest to this. It now is possible to serve a meal any day of the year, with very little effort, which is quite nourishing and which contains many foods that may rightfully be referred to as gourmet fare. Our better restaurants, even those in the center of our country, now regularly offer wines from both American and French vineyards, lobsters which 24 hours earlier were swimming in the cold waters off the coast of Maine, fruit fresh from the citrus groves of Florida, and trout direct from the lakes of the northwest states. This bill of fare, of course, is made possible by our excellent air transportation system.

Other areas of progress are equally noteworthy. For instance, many of our airlines are pioneering in the development and use of airborne microwave ovens. This technique represents a significant step forward in food preparation. Although this topic will be discussed later in the program, I would like at this time to compliment the airline industry and its suppliers for the advances they have made in the rapid preparation and dispensing of large volumes of food. Inasmuch as we in NASA are as concerned with aeronautics as with space activities, I look forward to working closely with airline representatives as we strive for additional improvements in food preparation both in the atmosphere and in space.

FOOD TECHNOLOGY AND THE SPACE PROGRAM

We have briefly surveyed recent progress in the development of food technology and found it to be quite good, so let us now examine the applicability of this technology to the needs of our space program. First, of course, are the requirements of the Apollo program. It appears that the needs of this program are being adequately met. There is no evidence of any nutritional problem and techniques for in-flight feeding seem to be successful. Freeze-dehydrated, rehydratable, and bite-sized foods have generally been used in these missions; however, in one instance a moist food which was eaten with a spoon was provided. This one attempt proved to be successful even under zero-G conditions and was considered by the astronauts involved to be one of the highlights of the in-flight feeding program to date.

In general, astronauts have accepted the techniques now being used for in-flight feeding and the type of food being provided. They recognized the constraints under which food must be stored and dispensed. However, a system that is perfectly tolerable on a 2-week mission may be quite intolerable on a mission lasting a number of months.

In a recent test of life-support components conducted by the McDonnell-Douglas Co., four men were kept in a closed cabin for 60 days. Although the primary purpose of this experiment was to test closed-loop oxygen and water systems, the experiment also afforded insight into the palatability of astronaut-type food over an extended period. It was found, as one would predict, that the quality as well as the appearance of food becomes increasingly important as time passes. A periodic change in type of food had a noticeably positive effect on the morale of the subjects.

As a final comment on the state of the art in our space-food program, I would like to quote directly from the closing remarks of the chairmen, Dr. C.O. Chichester, at a 1964 conference here at the University of South Florida: "At the moment it appears we have no clear-cut idea of how we are going to feed people for long space flights. As the flights become longer provision will have to be made; many methods have been suggested for solving the problem and thus we have a multiple pathway of investigation. The consensus seems to be that these methods must be investigated in a parallel fashion since we do not have the criteria nor do we have the knowledge at the present time to make any choice." I recognize that progress has been made since 1964, but I do feel that these remarks in some measure remain appropriate today.

RESEARCH REQUIREMENTS IN AN ADVANCED FOOD TECHNOLOGY PROGRAM

In NASA we use the term "pacing technology" to denote a technological area which represents a limiting factor in the progress of a particular program. In the early days of NASA, booster power was a pacing technology. On October 4, 1957, the Russians orbited Sputnik I with a payload of 184 lb. By 1958 they were able to place into orbit a payload of 2926 lb. The United States, on the other hand, placed an initial payload of 31 lb into orbit on January 31, 1958. It was quickly determined that, in our attempts to match or to exceed Russian progress in the exploration of space, booster power was a pacing technology. This situation prevailed until November 9, 1967, when the first Saturn V booster rocket was launched successfully. The triumph over booster power was achieved at tremendous cost, with a tremendous investment in facilities, and (I consider this to be possibly the most important characteristic of the program) with tremendous personal dedication on the part of the individuals involved. Now, for the first time, the question of payload weight can be handled in proper perspective in concert with other mission variables.

The important questions concerning long-duration missions no longer focus as directly on rocket technology as was once the case. Now it appears that the critical problems are likely to be the human-oriented problems. The problem of providing food, may in fact, represent a pacing technology. On this basis, our progress toward extended lunar exploration and interplanetary flight may be no faster than our progress with the problems of advanced food technology.

If we now consider the providing of food to be a pacing technology, what are the implications for establishing an appropriate research program? First, it is essential that long-range research goals be stated. Our commitment to a lunar landing in this decade in essence dictates the research and development requirements for booster power. The goals for a food technology program will not be as easily achieved as were previous goals but must be delineated nonetheless. Second, the requirements of an appropriate research program should be considered. The level of requisite funding, the necessary facilities, and the required personnel should be defined. In brief, a level of effort must be described which is appropriate for the achievement of the research goals. This procedure is precisely that of the Saturn V program which led to the development of such facilities as Michoud Operations.

In working toward the prescribed goals of an advanced food technology program, it will be necessary to make certain adjustments in our philosophy of research. One important change will involve greatly increased attention to the socio-psychological variables related to food intake. I am sure everyone in attendance today recognizes that over long periods of time these variables could become of greater importance than the actual nutritional structure of the food.

RESEARCH BENEFITS

Now let us assess the benefits which will accrue from a concerted program to advance the technology of food provisioning. The first benefit is obvious. NASA will be able to provide sustenance for astronauts on long-duration missions which will do much to ensure that they return in a healthy condition and in good spirits. This is no mean feat and is one which justifies an extensive research and development program. Another benefit would be assistance in the field of advanced technology for airline feeding. As a third benefit, there will be a direct economic return to our nation. New food processing techniques will create additional employment opportunities. Two of the later sessions in this conference will touch on this topic. The creation of new industries is an important economic result of technological advances.

Finally, there will be a direct personal benefit to the world, and this may well be the most important consequence of extended research in food processing. In a recent paper, Dr. Wernher von Braun stated that "We must adopt a more hard-headed attitude and consider not only whether a space project is technologically possible, but whether it has promise of contributing to the economy or the strength of the country." The contribution of our food processing research should be significant.

In 1955 the arable land per person in the world was generally agreed to be about 1-1/4 acre. By the year 2000 AD it is estimated that this acreage will decrease to a little more than 1/2 acre per person. This trend is causing considerable concern among world leaders. Inasmuch as food productivity is not evenly distributed over the world, the possibilities of serious famine in certain areas is quite real within the foreseeable future. Any increase in our understanding of ways to produce, prepare, store, and distribute food will be of tremendous importance for all nations.

I have attempted to stress the direct importance of this conference to NASA and to long-duration space missions under consideration for the future. At the moment, we consider the area of food preparation and in-flight feeding to be a pacing technology for future manned spaceflight. We also recognize that, in solving the problems in this field, you who are here today will make a contribution not only to NASA and the airlines but also to the economy of the United States and ultimately to the well-being of all nations.

WALTON L. JONES
Director, Biotechnology and Human Research Division
NASA Office of Advanced Research and Technology

SESSION I

Spacecraft Program

CHAIRMAN: J.W. HUMPHREYS

Director, Space Medicine

NASA Office of Manned Spaceflight

The present conference is sponsored by the National Aeronautics and Space Administration, the National Academy of Sciences, and the University of South Florida. As Director of Space Medicine for NASA, my primary concern is with man as he works in space today and in the near future. We work directly with the space crews, and we address ourselves to the program from that standpoint.

It certainly is evident from history that man can and will endure great discomfort in order to explore. Despite some opposite views, I think man will continue to explore. I am not perturbed by those who say we should "put man down," so to speak, and fly only unmanned operations, because I think man will not tolerate this. A man traveling in space needs only to be provided with a few necessities. His desire to explore and to learn furnishes his motivation. Man needs a habitable environment and that involves a great many factors. He needs a machine that he can effectively operate to reach his destination while performing his duties, and he needs provision for certain necessities of life such as food, water, and waste disposal.

Since the history of food in space is well known to all of you, I shall not present a detailed account, but rather the following brief comments. In Mercury and Gemini there were really no great problems or dissatisfaction with the food. I suspect this was true because the entire project was so new. We have encountered problems in Apollo, and I think it is not particularly strange that we have. The crews of Apollo 7, 8, and 9 have complained about the food, and this is understandable. Even though their food was essentially the same as the Gemini food (or was in Apollo 7), Wally Shirra and his crew stated rather vociferously that it wasn't any good, that they traded around, that they sampled all the packages, and that they did not eat at all. Certain improvements were made in Apollo 8 by giving the crew the so-called "wetpack," which they liked except for the potatoes; but the astronauts (Borman, Lovell, and Anders) said that even though they had flown for 14 days in Gemini and didn't mind it so much, they did mind it in Apollo. Similar reactions occurred in Apollo 9.

I think we have a reasonably good appraisal of nutritional requirements, although perhaps this is not yet a permanent standard, and I think we know the method of providing the essentials of a diet, at least for flights up to 20, 60, or 90 days' duration. The problem seems to consist of finding a way to influence the crews to eat the food that is provided. It must be made palatable, and, in addition, worthwhile.

The present method of space feeding seems to be satisfactory for the near future; at least it will sustain life. I believe, however, that we shall not be limited to compressed food, dehydrated food, etc. forever. We shall certainly be using larger volumes of food in the future. There is always the possibility of assembling spacecraft for long voyages off the Earth, in orbit, or even farther away and on these voyages there will also be different environments. Cooking with an electric stove today is impossible because of the gaseous environment of the spacecraft, but that may not always be the case. Zero G may or may not be continued, and I suspect that in the long run it will not. These different environments will give us opportunities to use techniques different from those employed today. We shall still have a preparation problem, but I believe that the preparation time previously criticized by the crews will not be so important as the crew numbers become larger and the voyages become longer.

The Apollo crews are very busy, but I believe that this is only temporary. Certainly, when crews reach a large size, food-service people will be required. We shall still have, however, a food preparation problem, and we shall still have a storage problem or a production problem. I think it is essential that we gain the attention of the entire community - academic, industrial, and governmental - and keep attention focused on this mundane subject of feeding. Development of subsystems involving food, water, and waste management has not kept pace with building of boosters and other sophisticated systems. We must demand adequate attention to these subsystems.

The Apollo Applications Program (AAP) embodies an entirely new concept. It is the beginning, the embryonic move or step, toward true understanding of man and his reactions in space. In Mercury, the objective was to project man into space and return him safely. In Gemini, it was to determine whether man could maneuver and work in space. Apollo has had only the objective of flying man to the Moon and bringing him back safely with some lunar samples. We have not yet had an opportunity to begin to study man in flight, but the whole AAP program is the beginning of a new era - one, if you like, of orbiting laboratories or orbiting observatories. It will be much more difficult and much more complex to produce a feeding system which answers the requirements of experimental protocols and also is compatible with the spacecraft environment and is within the state of the art.

Certain tradeoffs will be necessary. There are a great many medical, biological, and behavioral components involved in the AAP, habitability being one of them. We want to know the factors that can make man's life a little more pleasant and make man more effective in the space environment. Up to now, he figuratively has been flying around in the rumble seat of a Model T Ford (a Model A in Apollo), but the time to improve his situation has come. We cannot do this logically until we understand more about him and his reactions.

I would like to restress the point that the food system is not a system that can be considered alone. For example, the food system has a very close interface, and is dependent to a large extent, upon the water system. In Apollo, we have fuel cells which produce water and an excess of hydrogen gas; as a result, we have had a large amount of gas coming out of the water gun. In Apollo 9, the water gun produced about 60 percent gas and 40 percent water, which meant that the crew filled their food bag with gas. When they began to hydrate their food they encountered a great many bubbles, and they swung their bags around in order to try to eliminate some bubbles. This method did not work at all well - the result was large gas bubbles in place of small ones. This is only one of the many problems encountered. If one system is not functioning properly, another one cannot; there is not quite a domino effect, but almost.

The waste management system is also a very important one. The crewmen do not want to defecate because they hate to use the hand-held straddle trench we are supplying, and I do not blame them. This straddle trench is a bag with a sticky rim on top, and it is difficult to place it correctly. The men are loath to use the system, and until the system is improved they are going to continue to be loath to use it. We hope a better system will be on board in the MOL, the AAP, and other future flights.

One item which has not been widely mentioned is that in our system the food discipline of the crewmembers has been poor. I have said this to them, so I will say it in public: Food and water discipline is something that soldiers learn early or they do not survive. The space crews have not been very disciplined about their eating - they have picked, traded, and done as they pleased. That is permissible if no scientific metabolic information is to be obtained but food discipline must be enforced in flight if we are to determine whether a system is good and how it should be changed. It is particularly important in those flights in which we have experimental protocols that must be complied with.

Much has been said about disposal of the wastes - the bags, the excess food, etc. On flights in which we need to know the weight of remaining food, it is important that nothing be discarded. As you well know, so far we have designed all spacecraft and systems so that they will return to Earth everything not consumed in space, with the exception of urine droplets or a little waste water. I question whether it is the intent of the space treaty that we be forced to return to Earth all the trash accumulating on space voyages, and the point is currently under investigation. We have enough trash on Earth; wouldn't it be nice to discard some of it somewhere else!

J. W. Humphreys

The Apollo Food Program

MALCOLM SMITH

NASA Manned Spacecraft Center

The orbital Mercury Program flights of astronauts Glenn, Carpenter, Schirra, and Cooper demonstrated for food system planners that indeed man could consume and digest solid and liquid food in space. The experience gained in food packaging and in-flight handling led to the evolution of the Gemini and Apollo food systems and components. Prior to the Gemini program, engineers and biologists began in earnest to design and formulate foods and packages which were acceptable, nutritious, lightweight, low volume, low residue, high energy, and stable at spacecraft temperatures, which withstood launch vibration, could be consumed in zero gravity, contained no pathogens, withstood vacuum packaging and oxygen atmospheres, and would reconstitute with water or saliva. The Apollo and Gemini systems which evolved were the best possible under the circumstances. Any faults in the system then and now can be attributed to incomplete understanding of the definitions of food, acceptability, and nutrition as they apply to spaceflight.

The foods and packages often exceed physical requirements of the spacecraft, environment, and ground-based human test subjects. The nutrients provided exceed estimated metabolic requirements of the astronaut. Daily rations were balanced and calculated precisely. Food weights and dimensions were controlled and measured with microscopic accuracy. Volunteers ate the food for periods of up to 56 days without physiological or psychological aberrations. The astronauts were provided with a variety of these specially designed foods from which to select their in-flight menus. The flight foods were produced, packaged, and stowed on the spacecraft. Spacecraft were launched and missions completed successfully.

Despite all this, however, the astronauts did not eat, and invariably lost weight. What could have gone wrong? With 20-20 hindsight, it has become obvious that a part of the problem lies in our lack of complete understanding of the psychophysiology of eating. Man and his eating habits are not easily changed. Good nutrition begins with good food presented to the consumer in a familiar manner. A "good" spacecraft may be bigger, faster, more versatile and safer than the previous one. A "good" spacecraft food system is one which meets system requirements but is built around good foods that stimulate and satisfy hunger, that are readily prepared, that have a familiar flavor and texture, that provide diversion, relaxation, security, and adequate quantities of nutrients to maintain metabolic balance in the particular environment.

The initial Apollo food system was basically the same as that which was provided for the Gemini Program. The compressed and dehydrated ready-to-eat cube foods included meat, fruit, dessert, and bread types. The uniform shape, high caloric density, and variety of flavors made the food ideally suited for the engineering requirements of spaceflight. Dehydrated fruits, beverages, salads, desserts, meats, and soups which required water for rehydration prior to consumption were available. These "rehydratables" were packaged in a specially designed laminated plastic bag which had a valve for water insertion at one end and a tube or zero-G feeder at the other end through which the foods could be consumed. The 3/4-in. diameter of this feeder tube restricted the maximum food particle size to 1/8 by 1/4 in. A process to simulate a more natural meat texture had resulted in a significant improvement in flavor compared with that of the early Gemini products. Packages of these foods were arranged in meal units based upon nutrient balance and astronaut selection. Each meal was overwrapped in an aluminum-foil-plastic laminate which also served as a garbage bag for in-flight stowage of used food packages after each meal. The diet was designed to provide each astronaut in the command module with his estimated energy requirements of 2800 Kcal/day, 16 to 17 percent protein, 30 to 32 percent fat, and 50 to 54 percent carbohydrate. Certain foods were fortified with calcium lactate to provide a daily calcium intake of 1000 gm and a calcium-to-phosphorus ratio of approximately 2 to 1.

This approach to food management had been successful on the 14-day flight of Gemini 7 and had been verified by numerous ground-based altitude-chamber studies conducted by the USAF and NASA. A number of deficiencies were apparent in the baseline Apollo food system and development efforts to improve individual ration components for the Apollo Applications Program were being sponsored by NASA at the U.S. Army Natick Laboratories. The advances in foods and food systems which were being realized as a result of the USAF Manned Orbiting Laboratory (MOL) Program were available to NASA. These programs continue to be closely coordinated for the mutual benefit of both agencies.

At the time of the fire which resulted in the loss of the Apollo 1 crew and spacecraft, the food system met all of the engineering constraints of the mission while providing adequate nutrients. Most "creature comforts" such as improved foods and packaging, however, were relegated to the longer duration flights (28 and 56 days) of the Apollo Applications Program. As a result of the spacecraft fire in January 1967, each spacecraft system, subsystem, and component received thorough reevaluation and analysis to identify and reduce the hazards of flammable materials. Since nonflammable foods are an impossibility, our attention was directed toward finding a packaging material which would not support combustion in a pure oxygen environment. At this point in time, responsibility for design, procurement, and spacecraft integration of flight foods was transferred to the Medical Directorate at the Manned Spacecraft Center. Prior to this, our only responsibility in aerospace food systems had been in food and nutrition research with rather tenuous control of the actual flight item.

Extensive changes in the types of food and packaging will be implemented in an orderly manner for the forthcoming Apollo flights. These changes are necessary because: (1) In-flight food consumption is inadequate to maintain metabolic balance (negative energy, loss of tissue fluid, and electrolytes); (2) meal preparation and consumption requires too much time and effort; (3) water for reconstitution of dehydrated foods is off flavor and contains large quantities of undissolved hydrogen and oxygen gas; (4) functional failures occur in rehydratable food packages; (5) a system of foods and packaging which is more familiar in appearance, flavor, and method of consumption is needed, and (6) in-flight illness and anorexia must be reduced.

The demands for improvement have not emanated from the astronauts with quite the strength that the news media would lead one to believe. In fact, the demands have come from ourselves and the program managers once we realized that an improvement was possible that would result in a crew that would eat more during the mission and maintain a higher level of morale. The improved foods and packaging which have been integrated into the Apollo food system are not new to us or the rest of the consumer and scientific community. For instance, the first real breakthrough occurred with the most mundane and seemingly simple procedure that the Apollo 8 crew performed on Christmas Day during man's first successful lunar orbital mission. Borman, Lovell, and Anders opened a thermostabilized flexible can of turkey chunks and gravy and ate with a spoon! The dish required no water for rehydration since the normal water content (67-percent by weight) had been retained. This crew had experienced considerable problems with nausea and vomiting, a water supply with excessive gas and objectionable flavor, and an exciting mission of critical spacecraft maneuvers to escape the pull of Earth gravity and achieve lunar orbit. They were about 250 000 miles from home on Christmas Day and faced the possibility of being unable to escape the pull of the lunar gravity and the possibility of reentering the Earth's atmosphere at an angle that would deflect them back into Earth orbit with no chance of reentry before fuel or oxygen supplies were exhausted.

The meal was quite a morale booster. During the preflight menu selection period, the crew had specifically stated they did not want to have the wetpack on their mission. This was probably a result of their desire to prevent unrealistic demands on the system and personnel supporting their mission.

The Christmas dinner of the Apollo 8 mission was in one sense a last-minute affair; i.e., actual planning of the components did not start until 3 months prior to flight, but, in truth, development had started several years before for NASA and military ration use. The wetpack turkey and gravy was a heat-sterilized product in a flexible package. Similar products had been under development and field-tested by the U.S. Army Natick Laboratories as possible replacements for the canned combat rations, with the idea of reducing package weight and allowing the field soldier greater mobility while carrying the flexible containers in his pocket. The term wetpack came into use to describe and differentiate it from the nominal dehydrated Apollo foods which require the addition of water for rehydration prior to consumption. This type of food had not been used because of a number of disadvantages of food with normal moisture content. Since moisture is available for bacterial growth, heat sterilization and a failsafe hermetic seal is required. The weight of a wetpack with its 60 to 70 percent moisture content is approximately four times greater than that of the comparable dehydrated product. Vacuum packaging is virtually impossible in a high-moisture food and the absolute vacuum of outer space could cause rupture of the package from internal gas expansion during spacecraft decompression. The possibility of Cl. botulinum toxin also causes justifiable concern over the use of these products. Each of these potential problem areas was carefully evaluated and solved prior to the flight.

The success of the wetpacks in the Apollo 8 and 9 missions can be attributed to a combination of several factors: The men could see and smell what they were eating with relative ease compared with the complete containment afforded by the zero-G food package; the texture and flavor of the food was not affected by the characteristics of spacecraft water and frequent incomplete rehydration of the freeze-dehydrated item; and the wetpack does not require tedious installation of water, kneading, waiting, and manipulation prior to consumption. Overcoming these "little" irritants is an important part of a successful food system in any situation. Unfortunately, there has been a tendency to require that all food be of the wetpack type and this extreme swing of the pendulum was not easy to bring back into line.

We realize that a system based on all wetpack food would become just as monotonous and objectionable as that with the all-dehydrated approach. For Apollo 10 we shall include five new freeze-dehydrated foods which will be packaged in a "spoon-bowl" package. This package has a water inlet valve at one end similar to that of the nominal rehydratable food package. The main difference will be in the large zippered opening on the other end which will allow access to the rehydrated food with a spoon. With this large opening, the pieces of dehydrated meat and vegetables can be larger and thereby have a more familiar and acceptable mouth feel and flavor. Many of these foods are preferred over some of the wetpack items.

The use of a spoon while in weightlessness was no simple impulse. Simulations of weightlessness and eating from an open package with a spoon had been conducted by the U. S. Air Force in high-performance aircraft in parabolic flight patterns. Numerous foods, packages, and utensils have been tested in that program and in our own tests. While these aircraft tests are not a completely accurate simulation because of the short duration of the weightless condition, the results indicated that our spacecraft test would be successful without undue concern for dispersal of liquid food throughout the cabin. Subsequent use of open packages and utensils on the Apollo 9 flight was accomplished without difficulty. That crew even experimented with using the spoon to eat from the nominal rehydratable food package. In retrospect it is easy to see that spoon and bowl eating would be successful since in the absence of gravity liquid motion is controlled by forces that are negligible on Earth, e.g., surface tension, capillary action, cohesion, and adhesion.

Food system design for the Gemini and Apollo programs was constrained by requirements to prepare for worst case situations. The most significant progress in space food systems was realized on the Apollo 8 mission when the crew calmly went about their business of opening a package of thermostabilized turkey and gravy that had no zero-G feeder tube or valve for rehydration. The only support equipment provided was a pair of scissors to open the package and a 10-cent stainless-steel spoon. The crew ate their wetpack with ease and were highly pleased with the whole affair. The significance of this feat is not apparent to those who have not been intimately involved with the program of space food development and integration of life support equipment in manned spacecraft. The spoon and the "canned" turkey and gravy (heat processed and packaged in a flexible pouch) were significant in that some of the most difficult constraints to space food development were lifted in a matter of minutes while man first circled the Moon. The following items are a few of those constraints:

(1) Vacuum packaging of all food items

(2) Positive containment of liquid food during consumption

(3) Caloric density of food

(4) Tedious procedures for food preparation by rehydration

Design requirements for the Apollo food system were actually more stringent than those in the Gemini Program. This resulted in foods and packaging for Apollo that were quite similar to those used on Gemini. It was a generally accepted fact that the Apollo foods would be highly acceptable and would present no problems of any consequence. We had begun to believe that assumption ourselves, for, after all, the hot and cold water systems to be available in Apollo would permit the astronaut to prepare a really hot meal with a chilled beverage. We placed a great deal of reliance upon the characteristics and quality of the water system. We had good reason for this since ground-based simulators had proven the reliability of the fuel-cell-generated water system.

All spacecraft life support systems were exhaustively tested during an 8-day manned test of the command module (designated Spacecraft 2TV-1/101) which was exposed to the thermal and vacuum conditions of space. The test could not, however, simulate weightlessness. The astronauts in this test were quite well pleased with the food system and consumed virtually every morsel of food provided. The crew experienced some difficulty in rehydration of foods because of gas in the water supply. The quantity of undissolved gas was not consistent but averaged approximately 30 percent by volume. The crew solved this problem by venting the gas periodically from the food package during rehydration. Venting was accomplished by depressing the food-package water inlet valve. This worked satisfactorily because the gas and liquid food were readily separated in the package by gravity prior to venting. This technique would not work in orbit since, in the absence of gravity, liquids are no longer heavier than vapors and attempts to vent off gas trapped in the food package to allow insertion of adequate water for food rehydration result in venting liquid food as well as gas.

Only minor modifications in the fuel-cell water supply system were possible if launch schedules were to be maintained. One of the modifications implemented was to reduce the temperature of the hot water from 155° to 135° F. The higher temperature is very close to the boiling point of water at the nominal cabin pressure of 5 psia. The net result of this quantity of gas in the water supply is that the water is not hot enough to improve the rate of food rehydration, and by the time all of the required water is added and as much gas is expelled as possible the food is not hot and usually is incompletely rehydrated because of the small bubbles of gas dispersed throughout the package which prevent intimate contact of water with food. Also, after several cycles from the water dispenser, the food package could be distended to the point of bursting and still not have adequate water to rehydrate the food. (The Apollo 9 crew reported that the water supply was approximately 30 percent water and 70 percent undissolved gas.) All three flight crews have reported an off-flavor in the water that was not entirely due to the water chlorination procedures. This off-flavor is probably due to some of the materials used in the flexible tubing. The Apollo 9 crew found the water so distasteful that they consistently drank water that had been first mixed with one of the beverage powders.

The list of accomplishments that we can point to after only three Apollo flights is more extensive than the introduction of more familiar foods and methods of eating. Not quite so dramatic but equally as difficult and significant was the design of a nonflammable meal overwrap which also serves as a barrier to moisture and oxygen, a method of meal orientation, and a garbage bag. The quantity and variety of rehydratable beverages has been increased and modifications made to improve the reliability, use, and size of the rehydratable food package. Food and packaging processing, testing, and inspection procedures have been extensively revised in conjunction with the USAF MOL development program.

A new approach to supplying food to an astronaut in a full-pressure suit in a possible loss of cabin pressure has been developed and flight qualified. This contingency feeding system employs a pontube with a valve to control liquid food flow. It is inserted into the water inlet valve of a nominal rehydratable food package on one end, and at the other end is put through a port in the pressure suit helmet. The crewmember squeezes and sucks liquid from the food package through the pontube and into his mouth. A valve in the pontube allows gradual equalization of the suit pressure (3.5 psia) with the vacuum of the food package which helps to prevent rupture of the food package due to sudden pressure change. The food package is further restrained by a zippered nylon bag to prevent inadvertant rupture. The Apollo food sets also provide an oral hygiene kit which contains a tube of edible toothpaste, toothbrushes, and a spool of dental floss. In listing these accomplishments, we do not imply that they constitute the final answer to a requirement. Each can and will be optimized for future flights in spite of the heavy activity required to support missions that are launched on 2-month cycles and the austere staff of personnel available to work with the systems and problems.

In addition, for the future Apollo program food developments will center around more thermostabilized wetpacks, a larger variety of intermediate-moisture foods, a spoon-bowl package that will allow larger pieces of dehydrated foods, and a liquid nutrient dispenser for extravehicular use on the lunar surface that will supplement the nominal lunar module food supply.

The acceptance and effectiveness of the food system for a particular flight can be evaluated by the quantity of food consumed, the functioning of food preparation and dispensing equipment, postflight debriefing comments by the crews, changes in body weight, and biochemical and psychological measurements. These measurements leave a lot to be desired in both objectivity and accuracy. We have observed that the nature of preflight briefing on the food system has a direct effect on the overall acceptance of the foods. The more thoroughly the crews understand the purpose and design of foods, packaging, and menus, the more likely their reaction in flight will be favorable.

We must rely heavily upon the evaluation given by the consumer but a favorable postflight comment cannot be construed to mean success. Postflight inventory of returned foods and packages and examination of the pilot's log are not without inherent errors. Frequently, critical mission tasks must be performed and a crewmember will find it necessary to eat foods programmed (and color coded) for one of the other men. The inevitable swapping of foods occurs and these changes are not always recorded. At one point in the Apollo 7 mission a package of freeze-dehydrated tuna salad could have been traded for an entire meal. The preference for the salad was greater than the need for extra foods and the offer to trade was denied. One objective measurement of the effectiveness of the food is body weight changes. These measurements can be misleading and require careful examination of normal metabolic rates and weight fluctuations which are not always available.

As was observed during the Gemini program, changes in body weight show little or no correlation to mission activity, mission duration, food intake, and occurrence of in-flight illness Preflight and postflight body weights along with estimated caloric intakes of the crew of the first three Apollo missions are shown in table I. The values of caloric intake attributed to each man are arbitrary because we could not determine the amount of food trading that occurred. It will be noted that if our only criteria for successful mission food supply depended upon prevention of body weight loss we have failed miserably. Weight losses have been recorded on every American and Russian spaceflight to date. Weight losses will not be corrected only by providing better food and more of it. First, we must discover methods for insuring that food will be consumed. It is of little use to expend much effort to minimize the weight and volume of a flight food item if that item is to be carried into space and returned unconsumed. It is of prime importance to maximize consumption after which the food must be designed to provide the quantity of critical nutrients based on rhythmic demands of metabolism, and not on hunger stimuli.

TABLE I.-BODY WEIGHTS AND CALORIC INTAKE FOR FIRST THREE APOLLO MISSIONS

Mission		Body weight, lb				Energy, Kcal (Av daily in-flight caloric intake)
		Av preflight (F-28, F-14, F-5)	Launch day (F-O)	Recovery (R+O)	Recovery plus 1 day (R+1)	
APOLLO 7	CDR	195	194	188	191	1966
	CMP	153	157	147	151	2144
	LMP	157	156	148	154	1804
APOLLO 8	CDR	169	169	161	163	1477
	CMP	169	172	164	165	1688
	LMP	146	142	138	139	1339
APOLLO 9	CDR	161	159	154	156	1924
	CMP	181	178	173	181	1715
	LMP	164	159	153	157	1639

It has not been possible to measure the precise food intake for each astronaut. We know the quantity of food stowed preflight and the quantity returned. Meals and individual food packages are color coded (red, white, or blue) for each astronaut and it should be a simple matter to calculate the precise quantity of food consumed. It is inevitable that the crewmember will exchange foods or will eat an item from another man's meal if he does not have time to stop required mission tasks and prepare his meal. When this happens, the astronaut usually records the deviation in his log book. This system is not completely reliable, and understandably so when one considers the types of missions these men are on. What we obtain is a good estimate of each crewmember's food consumption and an accurate knowledge of the total food consumption by all three astronauts over the course of the mission.

Apollo astronauts have experienced varying degrees of in-flight illness. Symptoms of upper respiratory and gastrointestinal viral disease occurred in several of the Apollo 7 and 8 crewmembers. Nausea and vomiting experienced by one of the crew of Apollo 9 presented a real problem in the early stages of the flight, but the symptoms gradually disappeared and performance of mission tasks was highly satisfactory. Of course, the thought of food during this period aggravated the situation. During this flight, the problems with gas in the water supply and a very disagreeable flavor were most intense. During some periods, the crew was not able to drink the water at all and resorted to using rehydratable foods to mask the flavor of the water. The only foods that were satisfactory for this purpose were the beverage powders, fruit cocktail, and peaches. The limited supply of these items precluded their use as a sole source of energy, water, and electrolytes for all three astronauts. To help one of the crew maintain an acceptable metabolic balance, the other crewmen gave him their rehydratable beverages and fruits.

Also, it appears that our preflight diet and procedures require reevaluation, since most crewmembers have lost weight during the last few days prior to launch. Efforts to calculate precise preflight requirements and to provide well-balanced meals alone are not adequate to correct this situation. It is no secret that our intensive efforts to portion and balance inflight nutrients are of little value if the food is not eaten.

If the space food program has taken on a significant new face, it is in our efforts to improve the foods available, simplify food preparation procedures, improve the crew's understanding of our approach to nutrition, and emphasize the requirements to define in-flight food problems accurately now, before critical long-duration flights are undertaken. Concurrently with this approach, we have an active research program to define the nutrient content of actual and prototype flight foods and to define overall and critical nutrient requirements of the man. Even if it were possible to define nutrient requirements and provide the foods which made these nutrients available, all would be to no avail if we did not have an equally definitive program to determine the physical requirements to make food and food systems in the flight environment functional and psychologically acceptable. Therefore, in the Apollo Program we are placing less emphasis upon dietary manipulation and increased emphasis on systematic improvement of foods, packaging, and crew training to determine, or be able to predict, those foods which have the best chance of being consumed in the flight environment. As we gather this information on food acceptance, nutrient definition and modifications to maintain metabolic balance is accomplished. Of course, the conventional familiar foods are the most likely candidates, but we have no parochial interest in natural foods to the complete exclusion of synthetics. Indeed, for missions in the not-too-far-distant future spacecraft food supplies may be partially derived from chemical regeneration of metabolic waste. The best available food that will most efficiently meet the requirements of man and machine will always be used. To be acceptable a food must be processed, prepared, and served in the precise manner that makes it familiar and desirable in the first place.

One of the most frequent mistakes made by food system planners, especially for unique habitats, is that they neglect to recognize the subtle differences that will have significant impact on food acceptance. Food prepared in the finest restaurant in town will not necessarily be acceptable in a spacecraft, a submarine, or even in the home if the overall characteristics of the consumer and his particular environment are not considered.

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Manned Orbiting Laboratory Feeding System Requirements

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The feeding requirements for the Manned Orbiting Laboratory (MOL) are not the result of or developed by the feeding system. Rather, these requirements are imposed on the feeding system by conditions or factors external to it. The particular type of mission, the spacecraft design and engineering, and the very nature of space travel impose restrictions on the feeding system.

The mission of the MOL requires that two men be fed for 30 days. This requirement presents a great challenge because of the length of the flight. Much greater emphasis must be placed on the variety, acceptability, and convenience of the foods than would be necessary for a shorter flight. Variety and reduced repetition is essential to prevent food monotony, so a 6-day menu cycle has been established rather than the usual 3- or 4-day cycle. A sufficient number of acceptable foods must be available to fill the menu. A screening test is required during the development of a space food; each item must be rated at least 6.0 on a 9-point scale by a small, trained panel at two different stages of development. The true degree of acceptability will be measured by the results of long-term chamber simulator runs and crew-feeding tests. Each 6-day-cycle menu will be individually tailored by a computer to the preferences of each pilot. It is realized that the foods must be acceptable or sufficient nutrients will not be consumed.

Convenience influences acceptability, consumption, and morale and thus is a requirement levied on the feeding system. No one likes to spend time preparing food nowadays, least of all a pilot in a spacecraft. In an effort to minimize preparation time, the food for a day is divided into three snacks, a main meal, and a separate package of beverages (table I). In order that convenience can be measured, time requirements have been set. Ten minutes is allowed for the retrieval and preparation of each snack meal, and a total time (including consumption and waste stowage) of 45 minutes is allowed for the main meal.

Rehydration time and handling are factors in determining convenience, and as such become measured quantities. Any one item can take up to 10 minutes to be rehydrated, but the average time for all items must be 5 minutes or less. The manipulation time allowance, which is the time to retrieve, open, and inject water if necessary, is a maximum of 5 minutes for any one item with an overall average time of 2 minutes.

The food packages and overwrap are to be color coded to identify each crew member's food, and each cell of the food stowage liner will be identified as to day of use.

TABLE I. -TYPICAL MOL MENU FOR A DAY

Item	Gross energy, Kcal	Item	Gross energy, Kcal
Meal A		Meal D	
4 Bacon bars	102	4 Apricot cubes	132
4 Pineapple cubes	130	4 Peanut cubes	143
4 Strawberry cereal cubes	123	8 Cinnamon toast	97
	355		372
Meal B		Beverage composite	
4 Brownies	111	Cocoa	195
Shrimp cocktail	149	Tea, with lemon and sugar	31
Beef and gravy	193	Grapefruit drink	80
Corn bar	112	Orange drink	80
Chocolate pudding	313	Pineapple-grapefruit drink	80
	878	Orange-grapefruit drink	80
			546
Meal C			
4 Pineapple fruitcake	274	Total kcal this menu	2563
4 Coconut cubes	138	Av Kcal/day	2579
	412	Av wt food/day	539 g

SPACECRAFT DESIGN AND ENGINEERING CONSTRAINTS

The design and engineering of the spacecraft impose certain constraints on the feeding system. The MOL will have a food installation, where the pilots will eat, separate from the other work areas. This feeding console has two food stowage compartments, one above the other and one for each pilot. An area above the compartments contains the water dispensers, package opener, and other accessory items. Inside each compartment, which is approximately 25 by 15 by 17 inches, is a nylon food stowage liner. This liner is divided into 16 cells. Each cell is about 6 by 4 by 17 inches and will hold two ration packs, that is, food for one man for two days. One cell will be empty and will be used to store the food wastes from the first 2 days. The compartments provide 195 cu in. in which to store enough packaged food for one man for one day.

The weight allowance for one man for one day is 1.7 lb. If the food contains the desired 4.9 Kcal/g it must weigh about 1.17 lb; 0.53 lb , or about 33 percent of the total weight, is left for packaging.

The packaged foods must withstand maximum temperature and relative humidity of 100° F and 100 percent, respectively, and an atmosphere of 70 percent oxygen and 30 percent helium with a pressure of 5 ± 0.2 psia.

The water is provided by the fuel cell, and a silver ion generator provides for suppression or control of microbiological contaminants. The water has a pH of 6 to 8 and the system is capable of providing 22.6 fluid oz of potable water at 40° to 70° F and at 145° to 155° F at any one time. The cold water is dispensed in $\frac{1}{2}$-oz increments and the hot, in 1-oz increments. Both are transferred at the rate of 5 fluid oz/min with the delivery pressure maintained within 26 to 33 psia. The water system has a daily capability of about 2600 ml per crewman.

The packaging materials are restricted by the flammability and offgassing requirements which apply to all nonmetal materials in the spacecraft. There are established standards for determining these requirements.

SPACE TRAVEL CONSTRAINTS

Man requires a special feeding system when he travels in an artificial environment through the weightless voids of space. The food must be nutritionally adequate. The effects of the stress and conditions of space travel on the metabolic requirements of man are not completely known, but the figures in table II are based on our best experience to date. These requirements will be used as constraints in the computer selection of menus for individual crew members. Nutritional adequacy becomes especially important for a flight of 30 days. Caloric distribution of the ration has been set at 27 to 34 percent fat, 10 to 15 percent protein, and 50 to 58 percent carbohydrates.

TABLE II. -RECOMMENDED NUTRIENT ALLOWANCES FOR AEROSPACE RATIONS ESTABLISHED BY USAF SCHOOL OF AEROSPACE MEDICINE, BROOKS AFB, TEX.

Type	Gross Energy, Kcal	Fat, mg	N, mg	Ca, mg	P, mg	Mg, mg	Na, mg	Cl, mg	K, mg
Allowances/Kg lean body wt	45	1500	160	18	27	4	50	60	40
Allowances for average 60-Kg lean body wt/ man									
Mini	2600	78 000	9600	800	1200	240	2800	3500	2300
Maxi			15 500	1200	1800	400	4400	5000	4000

The foods must be compatible with the pilots; that is, they must neither produce gas nor cause constipation, diarrhea, or any other gastrointestinal upset. This can be best determined during the simulator tests at the School of Aerospace Medicine and the crew-feeding tests.

There are no firm requirements at this time as to the size of the individual bites of food or the rehydratable portions. These factors are being studied to determine the best and most efficient size or sizes.

Strict food safety is a requirement of all space-feeding programs. The use of a clean room for the production of MOL foods is required, as is minimum delay in processing to avoid excessive exposure of foods to oxygen and moisture. In addition, the producer must keep records of ingredient origin and production history for each end food item. The microbiological standards for MOL foods are given in table III. They are the same as or quite similar to those used for other spaceflights.

TABLE III. -MICROBIOLOGICAL STANDARDS FOR MOL FEEDING SYSTEMS ASSEMBLY

Microorganism	Count permitted	
Total aerobic plate count - - - - - - - - -	Total not greater than	10 000/g
Total coliform count - - - - - - - - - - -	Total not greater than	10/g
Fecal coliform count - - - - - - - - - - -	Negative in	1g
Fecal Streptococci count - - - - - - - - -	Not greater than	20/g
Coagulase positive Staphylococci - - - -	Negative in	5g
Salmonellae - - - - - - - - - - - - - - - -	Negative in	5g

When one travels in a closed environment in space, food wastes must be treated to prevent the formation of gas, growth of microorganisms, or production of any noxious or toxic substances for the days under ambient spacecraft conditions. The chemical agent 8-hydroxyquinoline sulfate has been used.

Foods for space travel must be specially packaged. The packaging and packing requirements are:

(1) Packaged food and overwrap:

(a) Evacuated and flushed 3 times with purified nitrogen at 2 to 3 psig and then evacuated to 2 mm or less mercury absolute pressure.

(b) 16 to 24 hr after sealing each package or pack is subjected to a vacuum integrity test.

(2) Packaging material:

(a) Peel strength, 200 g/in. width at 50 mm/min.

(b) Heat-seal strength, 1850 g/in. width at 50 mm/min.

(c) Burst pressure, greater than 9 psig.

The packaged food cannot be put on a spacecraft unless it has been tested to ensure that it will withstand the rigors of space travel under the conditions it may encounter. Therefore, the food items, in addition to the usual quality control and inspection during production, must undergo flight qualification testing. This consists of four tests, the 30-day environment, acceleration, vibration, and acoustical tests, as follows:

(1) Chamber environment, 30 days:

(a) Evacuate to 50 μ pressure and hold until temperature reaches $95^{\circ} \pm 5^{\circ}$ F.

(b) Repressurize with heated, humid gas composed of 70 percent oxygen and 30 percent helium.

(c) Temperature cycled 20 times between 95° F and room ambient temperature.

(d) Completion - examine package and food for defects.

(2) Acceleration: 5G forward and 2G aft when food in operative mode and 0.5G along two perpendicular lateral axes or 5G along three orthogonal axes; test duration, 2 min.

(3) Vibration: 10 to 2000 cps on each of three principal orthogonal axes; test duration, 3 min.

(4) Acoustical: 118 to 128 db over six typical octave bands.

In order to obtain space foods that meet the many specified requirements it is necessary to have good, realistic production documents for each item. The development of adequate space-food production documents is a requirement of our system.

CONCLUDING REMARKS

These are the requirements around which the feeding system must be designed. Although they are restrictive, a good feeding system can still be provided. By proper management and design it may be possible to gain some leeway in weight and volume. In cases where a significant improvement can be made in the feeding system by changing a requirement, attempts will be made to change the requirement.

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Quantifying and Improving Manned Orbiting Laboratory Food

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The contract for the Manned Orbiting Laboratory (MOL) Feeding System Assembly was awarded in September 1967 to the Whirlpool Corp., St. Joseph, Mich. At that time NASA flight food experience was based primarily on the manned Gemini flights. Apollo flights were anticipated but the food was designed and produced on the basis of the Gemini flight experience.

NASA did not fly a feeding system again until late in 1968. During this time, NASA relied quite heavily upon MOL food production and simulator testing for maintaining space-feeding expertise. Since the flight of Apollo 7 the flow of information has reversed, and the MOL feeding system optimization has benefited from NASA's flight experience.

The MOL feeding system contract is a straightforward document. The Gemini qualified feeding system is defined and quantified, allegedly in sufficient detail to allow production and flight qualification. Ample documentation exists to define the feeding systems used aboard the manned Gemini flights.

With the expectation that procurement of MOL feeding system foods for validation in simulator studies would be a simple matter, an order for food was initiated. The School of Aerospace Medicine was to conduct these simulator studies early in 1968 in response to requirements defined by the MOL Systems Office. The first production started soon after official notification of the food requirements. At this point the lack of sufficient quantification of the space foods became painfully apparent. It became evident that a comprehensive, integrated effort was a necessity in order to assure complete and accurate quantification of the food items listed on the MOL contract schedule. Forty-five items were included in this schedule. In September 1967 these foods were as follows, where GFP denotes Government furnished property from the U.S. Army Laboratories, Natick, Mass.

Rehydratable foods:

(1) Applesauce, instant (freeze dehydrated)
(2) Banana pudding
(3) Beef and gravy, dehydrated
(4) Beef with vegetables, dehydrated
(5) Beef pot roast, dehydrated
(6) Butterscotch pudding
(7) Canadian bacon and applesauce, dehydrated
(8) Chicken and gravy, dehydrated
(9) Chicken and vegetables, dehydrated

(10) Chicken salad, dehydrated

(11) Chocolate pudding

(12) Corn bar, cream style, dehydrated

(13) Corn chowder

(14) Fruit cocktail (bar)

(15) Peach bars

(16) Salmon salad

(17) Sausage patties (pork)

(18) Shrimp cocktail, dehydrated

(19) Spaghetti with meat sauce, dehydrated

(20) Toasted oat cereal

(21) Tuna salad

Beverages:

(22) Cocoa

(23) Grapefruit drink, GFP

(24) Orange drink, GFP

(25) Orange-grapefruit drink, GFP

(26) Pineapple-grapefruit drink, GFP

(27) Tea and sugar

Bite-size foods:

(28) Apricot cereal cubes

(29) Apricot cubes, GFP

(30) Bacon bars

(31) Beef bites, dehydrated

(32) Beef, sandwiches, dehydrated (bite size)

(33) Brownies, bite size

(34) Cheese sandwiches, dehydrated (bite size)

(35) Chicken sandwiches, dehydrated (bite size)

(36) Cinnamon toast, dehydrated (bite size)

(37) Coconut cubes, GFP

(38) Date fruitcake (bite size)

(39) Gingerbread (bite size)

(40) Peanut cubes, GFP

(41) Pineapple cubes, GFP

(42) Pineapple fruitcake (bite size)

(43) Sausage bites, dehydrated (pork)

(44) Strawberry cereal cubes

(45) Toasted bread, cubes, dehydrated

By September 1968 some of the food items had been changed and the following foods were on the schedule. GFP denotes Government furnished property; FI denotes food with improved to enhance texture, flavor, stability, and rehydratability; ID denotes an item dropped because it was deemed impractical to produce because of manufacturing problems, acceptability, and stability; and R&D denotes a food item deemed salvageable and returned to the laboratory for upgrading and improvement.

Rehydratable foods:

(1) Applesauce, instant (freeze dehydrated)

(2) Banana pudding, FI

(3) Beef and gravy, dehydrated, FI

(4) Beef with vegetables, dehydrated, FI

(5) Beef pot roast, dehydrated, FI

(6) Butterscotch pudding, FI

(7) Canadian bacon and applesauce, dehydrated

(8) Chicken and gravy, dehydrated, FI

(9) Chicken and vegetables, dehydrated, FI

(10) Chicken salad, dehydrated

(11) Chocolate pudding

(12) Corn bar, cream style, dehydrated, FI

(13) Corn chowder

(14) Fruit cocktail (bar), FI

(15) Peach bars

(16) Salmon salad

(17) Sausage patties (pork)

(18) Shrimp cocktail, dehydrated

(19) Spaghetti with meat sauce, dehydrated

(20) Toasted oat cereal

(21) Tuna salad

Beverages:

(22) Cocoa

(23) Grapefruit drink, GFP

(24) Orange drink, GFP

(25) Orange-grapefruit drink, GFP

(26) Pineapple-grapefruit drink, GFP

(27) Tea and sugar

Bite-size foods:

(28) Apricot cereal cubes

(29) Apricot cubes, GFP

(30) Bacon bars

(31) Beef bites, dehydrated, FI

(32) Beef, sandwiches, dehydrated (bite size): ID

(33) Brownies, bite size: ID R&D

(34) Cheese sandwiches, dehydrated (bite size): ID

(35) Chicken sandwiches, dehydrated (bite size): ID

(36) Cinnamon toast, dehydrated (bite size): ID

(37) Coconut cubes, GFP

(38) Date fruitcake (bite size)

(39) Gingerbread (bite size): ID R&D

(40) Peanut cubes, GFP

(41) Pineapple cubes, GFP

(42) Pineapple fruitcake (bite size)

(43) Sausage bites, dehydrated (pork)

(44) Strawberry cereal cubes

(45) Toasted bread, cubes, dehydrated

Representatives from the Whirlpool Corp. and the U. S. Army Natick Food Laboratory agreed that the production guides were not suitably standardized to serve as specifications. At this point, we undertook to involve the responsible technologists in defining the inconsistencies of the production guide system and suggesting corrective action. The most obvious inconsistencies were:

(1) The food production guides were not standardized in format or content.

(2) The quality assurance provisions were incomplete and awkward to administer.

(3) Food end-product requirements lacked definitization.

(4) Updating of analytical techniques with increased experience and product development had lagged.

(5) The production guides required incorporation of previously unrecorded changes in formulation and production procedures.

A brief explanation of these inconsistencies is warranted at this time. The food production guides as represented to the MOL Systems Office had been used by NASA for procuring flight foods. However, the flexibility of these guides allowed NASA to modify and optimize foods from flight to flight. The early spaceflight experience was intense, and timely responsiveness for food modification was imperative. The documents were not in any way to be construed as specifications. The subsequent incorporation of these production guides into the MOL feeding system contract as specifications posed a unique contracting problem. The contractor assumed the challenge that these foods presented and attempted to produce foods described in the documents.

Previous NASA food-production history served as a sound basis on which to determine realistic end-product requirements. Reevaluation of sampling plans and quality assurance provisions in light of NASA production experience gave us workable, but admittedly incomplete, sampling techniques. Microbiological testing methods had been thoroughly reviewed during the Gemini flights and were improved in workability and reliability. However, the production techniques, raw ingredients, and testing procedures did not adequately reflect changing production methodology, and they added confusion and uncertainty to interpretation of the production guides.

The first delivery of MOL simulator foods represented a best effort on the part of the contractor to produce a product as it was intended. The documents used to produce this best effort were partially corrected prior to food production but were extensively revised and updated after the second MOL food simulator study in June 1968. The experience gained from the two MOL food shipments proved valuable to both MOL and NASA. We began to realize that if we ever intended to describe foods and feeding systems before the fact, we would need considerable effort expended on documenting and quantifying the end products. The contractor for both the Apollo and MOL feeding systems was the logical choice to assume this effort. Consequently, Whirlpool Corp. was directed to expend development effort, under the development portion of the MOL Feeding System Assembly contract, toward updating and definitizing production documents. Technical and editorial monitoring was and is carried out through the Aerospace Feeding Systems Liaison Officer at the Natick Labs.

The effort to date has resulted in 24 rewritten documents:

Title	Document Number
(1) Beef, rehydratable, dehydrated	3C
(2) Beef, bites, dehydrated	4C
(3) Chicken and gravy, dehydrated	7B
(4) Chicken and vegetable, dehydrated	8B
(5) Chicken salad, dehydrated	10B
(6) Cinnamon toast, dehydrated (bite size)	21B
(7) Cereal fruit cubes, dehydrated (bite size)	23B
(8) Toasted bread cubes, dehydrated (bite size)	24B
(9) Cocoa beverage powder	26B
(10) Freeze-dehydrated peach bar	27B
(11) Freeze-dehydrated fruit-cocktail bar	28B
(12) Puddings (apricot, banana, butterscotch, and chocolate)	29C
(13) Sugar-coated corn flakes and toasted oat cereal	30B
(14) Fruitcake (bite size)	34B
(15) Pea bar, sweet, dehydrated	35C
(16) Tea, instant w/sugar and lemon	37B
(17) Dehydrated soups (corn chowder, pea soup)	38B
(18) Corn bar, cream style, dehydrated	41C
(19) Applesauce, instant, frozen, dehydrated	46A
(20) Potato soup, frozen, dehydrated	49
(21) Cracker cubes, compressed	51
(22) Drink, natural fruit flavored, powdered	53
(23) Beverage breakfast, powdered	54
(24) Imitation ice cream mix, dehydrated, cubed	55

The objectives of this effort have been threefold: (1) to standardize the format and the content of all space-food production documents, (2) to establish realistic end-product requirements and quality assurance provisions, and (3) to reflect technological improvements in the food production documents. The rewriting effort will be completed shortly. The most critical requirement for food production documents today is assurance that the mechanism for timely inclusion of proven improvements in space foods is preserved. This demands the establishment of a meaningful and comprehensive feedback system. Both flight and simulator experience must be used to assure a practical and workable food system.

Ultimate quantification of the MOL feeding system will continue to be a fluid and challenging endeavor, responsive to NASA flight experience, food technology improvements, and MOL crew and simulator study input. The improvement of the foods we presently have in the MOL menu is largely dependent upon the reactions gained from test subjects involved in the simulator studies at the USAF School of Aerospace Medicine. Recent feedback from the manned Apollo flights has given us added insight into the acceptability and palatability of our present space foods. Improvement and modification of foods for aerospace use can be best accomplished when we consider the following requirements:

(1) Human factors criteria that play an important part in determining the method of food retrieval, preparation, consumption, and waste storage.

(2) Stability of the food when it is subjected to adverse environmental conditions, including heat, moisture, light, vacuum packaging, and acoustical vibrations.

(3) Nutritional composition of the food or its ability to furnish a definite nutrient pattern within the set volume and weight constraints.

With consideration of the aforementioned criteria, we undertook to design an evaluation system that would give us sufficient information to predict the success or failure of new and modified foods for use in space-feeding applications. We were obliged to consider such practical criteria as the number of high-cost samples we could constructively evaluate and the requirement for timely submission of recommendations. Experience has proven that a trained sensory evaluation panel evaluating space foods subjected to controlled temperatures and time provides valuable insight into the stability of the foods. The information proves valuable when a decision as to whether the food should be flown or subjected to additional testing is sought.

The MOL Feeding System Assembly contract has a provision stating that all developmental and production foods are to be submitted to a sensory panel for evaluation. Accurate panel results are dependent upon the size of the panel, the design of the test, and the analysis of the results, to name but a few variables. The most critical need, however, is to be able to assure reproducibility between different testing organizations.

With no real flight data early in the MOL contract period, we relied quite heavily upon the experience of the contractor and the technologists in determining and evaluating human factors elements. Gemini foods that had been upgraded and improved for Apollo were reexamined. Technical advances allowed us to incorporate more natural characteristics into the foods that were being squeezed from flexible pouches. Bite-size foods that did not require preparation after opening the package still posed problems. Coatings that had been designed to control crumbling in the critical Gemini flights took on less importance with Apollo and MOL.

Space food as we know it today is essentially the result of a cooperative NASA/MOL development and testing effort. Production experience coupled with simulator and flight experience has given us a food system that is essentially sound. Formulation changes that have proven more acceptable to simulator subjects and in limited crew testing have been incorporated into the MOL foods. Apollo has incorporated some of the more desirable immediate advancements in each flight. The original 45 space food items in the MOL schedule have grown to 54 food items:

Rehydratable foods:

(1) Applesauce, instant (freeze dehydrated)
(2) Banana pudding
(3) Beef and gravy
(4) Beef and vegetables
(5) Beef pot roast
(6) Butterscotch pudding
(7) Canadian bacon and applesauce
(8) Chicken and gravy
(9) Chicken and vegetables
(10) Chicken salad
(11) Chocolate pudding
(12) Corn bar (cream style)
(13) Corn chowder
(14) Fruit cocktail
(15) Peach bars
(16) Salmon salad
(17) Sausage patties
(18) Shrimp cocktail
(19) Spaghetti and meat sauce
(20) Toasted oat cereal
(21) Tuna salad
(22) Cheese soup
(23) Cream mushroom soup
(24) Veal in barbeque sauce
(25) Pea soup
(26) Lobster bisque soup
(27) Beef hash
(28) Cream of chicken soup
(29) Potato soup
(30) Sugar-coated corn flakes

Beverages:

(31) Cocoa
(32) Grapefruit drink

(33) Orange drink

(34) Orange-grapefruit drink

(35) Tea and sugar

Bite-size foods:

(36) Apricot cereal cubes

(37) Bacon bars

(38) Beef bites

(39) Date fruitcake

(40) Pineapple fruitcake

(41) Sausage bites

(42) Strawberry cereal cubes

(43) Toasted bread cubes

(44) Sugar cookie cubes

(45) Smoked beef bites

(46) Orange cereal cubes

(47) Custard cubes

(48) Creamed chicken bites

(49) Cheese cracker cubes

(50) Barbeque beef bites

(51) Cinnamon toasted bread cubes

(52) Graham cracker cubes

(53) Lemon cereal cubes

(54) Beef stew bites

Throughout the space-feeding program, from malted milk tablets in the first Mercury flights to our present dehydrated and thermostabilized foods, reliability and safety have been the watchword. A good portion of reliability can be attributed to food packaging. The food processing itself contributes largely to the initial food quality and the food's ability to resist extremes of environment when packaged properly. Classically, therefore, space foods are designed and produced to assure highly reliable foods after long-term storage. We wish to assure maximum flexibility of food availability for any flight configuration.

At the present time the foods we fly routinely will withstand temperatures of 100° F for 6 months or longer, and many of the foods will withstand up to 1 year at 100° F. Dehydrated foods can be expected to be subjected to these conditions without serious detriment to the flavor, but their acceptability is certainly not improved. NASA is presently in the process of a comprehensive 2-year study of space food stability and nutrient analysis. The results should give us valuable information about the expected changes in food on long-duration space missions. By combining several of the more desirable storage environments, e.g., by freezing dehydrated foods, we can expect to extend the storage life of current foods significantly. Frequently we are approached with the "new" concept of using ready prepared convenience foods, either fresh, refrigerated, or frozen. Stability remains the ill-defined quality characteristic that defies quantification and relegates these foods to short-term planned usage.

MOL and NASA made available to the U.S. Army Natick Laboratories sufficient financial assistance to construct an environmental-control food-processing facility. Construction of this facility will afford the research staff an environment wherein studies of processing variables may be quantified and optimized. Extraneous contamination can be controlled and frequently omitted from the food processing procedures. The ultimate results will help define and specify requirements for foods expected to endure long periods of storage or exposure to rigorous environmental conditions.

Variety and improvement of foods will continue as long as technology in food research is active. New-generation spacecraft will allow much of our food development and research to be reapplied to the next generation of spacecraft. Compression and miniaturization of operational rations have been studied for many years by the U.S. Army Natick Laboratories. This effort, closely allied with the space food development effort, should serve as a sound base for the new and unique feeding applications we anticipate for the future.

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EVALUATION OF SPACE FEEDING SYSTEMS

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The design specifications placed upon the feeding systems of space vehicles were numerous and restrictive. Many of the specifications taken independently were not difficult to attain; however, the effect of specification interactions created binding limitations. Consequently, the food developed for space missions and the associated packaging and other components and factors which made up the ultimate feeding systems were not completely verified. The USAF School of Aerospace Medicine at Brooks Air Force Base was assigned by the Manned Orbiting Laboratory (MOL) Systems Office the task of evaluating the MOL Baseline Feeding System to be used in meeting its 30-day flight requirements. This effort was jointly supported by NASA.

The objectives of this evaluation were to identify any deficiencies in the expanded Gemini/ Apollo systems, to perform a functional verification for 30 days, and to develop new criteria for future space feeding systems. The evaluation was divided into four areas: (1) life-support evaluation, which included studies of the nutritional value afforded by the food; (2) food acceptance and preference evaluation, which included the rating of individual foods, measurement of food consumption, and the psychological benefits provided; (3) systems interface, which included study of efficient use of weight and volume allowances, the reliability of systems components, the timeline production of metabolic, food, and packaging waste, and the potential for environmental contamination; and (4) human factors, which included simplicity, ease of handling, and safety.

PROCEDURES

The procedures used in this evaluation are described in published articles (refs. 1 and 2) which are too detailed to cover entirely here. Briefly, this research was accomplished in a low-pressure chamber (shown in fig. 1). The environment of this chamber was approximately that planned for the MOL vehicle, as follows:

(1) Chamber pressure: 27,000 ft or 258 to 260 mm Hg

(2) Temperature range: 23° to 25° C

(3) Humidity range: 30 to 60 percent

(4) Partial pressure of the constituent atmospheric gases:

  (a) Water vapor pressure: Approximately 10 mm $\pm$ 3

  (b) Oxygen partial pressure: 182 mm or 70 percent

  (c) Helium partial pressure: 76 mm or 18 to 20 percent

  (d) Carbon dioxide: $<$ 1.6 percent or $<$ 5 mm Hg

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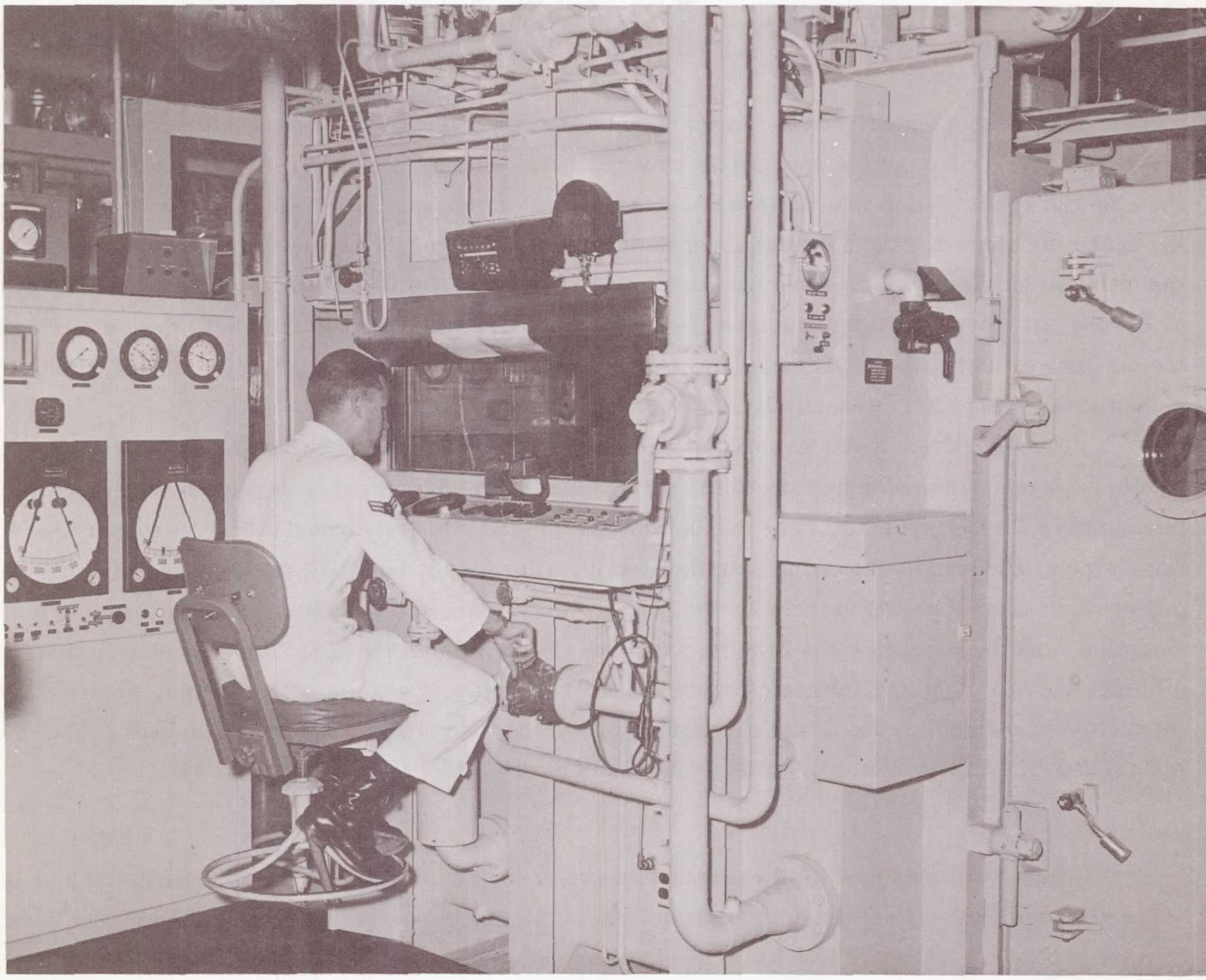

Figure 1. -Low-pressure chamber used to evaluate space feeding systems.

Volunteer airmen from the USAF Air Training Command were selected as subjects; selection criteria used were medical records, results from aptitude examinations, and personal interviews concerning motivation. Three studies were accomplished to evaluate the MOL Baseline Feeding Systems. Each study used four subjects who lived in the low-pressure environment for 32 days. The subjects were required to rate each food item after consumption. In addition, they were required to inspect the food packaging for air leaks and other failures, measure the size of food bites and main-meal entrees, observe evidence of crumbling in bite-size foods, note rehydration characteristics of powdered and main-meal entrees, subjectively measure the hardness of bite-size food, note changes in color of the foods, measure time required for rehydration of main-meal entrees, and measure temperatures of the food following rehydration. In addition, each subject was required to keep a log of his impressions of the foods day by day throughout the entire study.

The subjects were provided a menu designed to meet their individual nutritional requirements based on lean body weight measurements (ref. 3). The subjects were also required to consume all foods which were to be tested for a period of 12 days prior to the start of the study. Their individual likes and dislikes were then formulated into the study menus with the use of a computer (ref. 4). Metabolic balances were performed every 4 days of the study for 8 nutrients. Prior to and immediately following the 32-day study the subjects were given an extensive physical and psychological examination to detect any changes associated with the study.

RESULTS AND DISCUSSION

The digestibility of the major nutrients is shown in table I. These data demonstrate that these foods are exceptionally well utilized. The values are approximately 5 to 10 percent higher than those reported for standard rations served in military dining halls. Body weight changes for all subjects were maintained within 1 kg throughout the entire 32-day period. Changes in body composition, however, were noted which were attributed to the level of activity in the chamber. Positive balances for calcium, nitrogen, and phosphorus were maintained. Balances for potassium and magnesium were variable and frequently in the negative range; this was attributed to the marginal levels of these elements in the food. Balances for sodium and chloride were highly variable; this was attributed to the inactivity of certain subjects. Overall, it must be concluded that these foods are capable of providing adequate life support.

TABLE I. -UTILIZATION OF NUTRIENTS

Nutrient	Metabolic study		
	X	XI	XII
Protein	92.9	94.8	94.6
Fat	96.5	97.5	97.3
Energy	95.8	96.8	96.9
	Metabolizable, in %		
Energy	91.5	92.0	92.5

The food acceptance and preference studies must be analyzed with extensive considerations. All food ratings were above 6 on the 9-point hedonic scale. However, it must be pointed out that none of the subjects were trained in rating foods, and each subject was afforded the opportunity to eliminate unliked food from his menu. Previous research in this area has shown that food acceptance and consumption are not directly equatable. If allowed freedom of choice and rejection, certain foods rated 9 on a hedonic scale will not be consumed at the 100-percent level, whereas some foods rated lower than 9 are routinely consumed at the 100-percent level. In these studies with only freedom of choice permitted, all subjects had no problem in comsuming 100-percent of their menu.

The subjects' logs and critique forms provided many comments concerning food texture, flavor, and color that are worthy of note. The rehydratable entrees were criticized for loss of texture when forced through the feeding port of the zero-G feeder. The subjects also felt that the color of foods was less than desirable before hydration, particularly the spaghetti and meat sauce and the salmon salad. Additional green vegetables would provide more color.

Many subjects noted a change in flavor and taste on their return to ground level. They indicated that the food had more flavor when eaten at 1 atmosphere of pressure. Such flavor changes have been noted for precooked frozen foods also. It may be associated with odors concentrated in the chamber, or there may be some physiological change associated with taste in the low-pressure, altered gaseous environment.

In the study of systems interfaces, serious incompatibilities were revealed. In the second study, flight-qualified packaging was used, and 14.4 percent of the zero-G feeders failed. The failures were of three types: (1) Delamination with subsequent rupture of sealing layer, (2) leakage around the rehydration valve, and (3) valve failure due to improper tolerance on O-ring groove. The delamination was the result of poor adhesive in a lot of packaging material. All the deficiencies were corrected and the failure rate was less than 1 percent during the third study. The delamination was avoided by the use of a new lot of packaging material which was produced just prior to use. It was later shown in our laboratories that the adhesives used in the film laminate are moisture sensitive. Even the moisture in room air was sufficient to render the adhesives ineffective over a 60-day period. The leakage around the rehydration valve was corrected by the use of shrinkable Teflon to secure the valve in the package.

In evaluation of the utilization of weight and volume, it was shown that packaging constituted 35 percent of total weight. The individual packages of food were of a shape which prohibited efficient use of the allowable volume.

The timeline analysis of food preparation, food consumption, and waste management reveals excessive expenditure of time for these functions. The individual mealtime ranged from 18 to 42 minutes. Procedures for rehydration and consumption of foods are especially complicated and difficult to perform. During periods of intense activity, the tendency to avoid foods requiring rehydration is great. Frequently, subjects reported that they would start eating bite-size foods while waiting for the main meal entrees to rehydrate. This procedure would decrease their appetite because many of the bites were sweet dessert items.

Another problem associated with the feeding system design is the transfer of heat in rehydratable foods. Temperatures measured on hot foods were routinely lower than 100° F while cold foods were frequently above 55° F. The extent of heat exchange was attributed to both the lack of insulation afforded by the package and the time required for rehydration and consumption of the food.

The package material used for the food was found to have substantial resilience. This material provided excellent protection for the food but created problems with stowage. In addition, this resilience and the design of the zero-G feeder contributed to a high residual food level (food which could not be squeezed out of the zero-G feeder). The subjects made every effort to remove all the food; however, from 5 to 10 percent of the main-meal entrees was left in the zero-G feeders. The quantity of residual food is important since this necessitated the use of an antimicrobial agent which would not be needed if all food could be removed from the package.

Another important area of consideration under the topic of systems interfaces is the production of metabolic waste. Voiding in zero G is difficult, and the equipment used for storing and treating the waste is crude. The pilots have confided frequently that they would rather exist on insufficient nutrient intake than face frequent defecations. They will not eat any foods they suspect will promote frequent defecations. The foods presently used for space feeding provide excellent results in gastrointestinal bowel control. The data in table II show that both the number of defecations and the amount of fecal matter produced were reduced. In comparing this with data collected during the consumption of regular food, there is a 50-percent reduction in both the number of specimens voided and the quantity of materials used. Subjective measurements of flatus during these studies revealed that the amount was small enough to preclude discomfort from bowel extrusion.

TABLE II.-FECAL DATA FOR 32-DAY METABOLIC STUDIES

Study number	X	XI	XII
Number specimens	59	52	58
Number of days between specimens	2.2	2.5	2.2
Dry matter (g/subject/day)	16.4	20.6	16.0
Fecal moisture (g/subject/day)	30.7	44.3	31.3
Moisture (% of specimen)	65.2	68.3	66.2

In considering the human factors area, the present baseline system was found to be highly reliable but complicated. The time required for manipulation during preparation and eating was discussed above. In addition, the treatment of residual food to prevent degradation upon storage was found to be both time consuming and difficult. The antimicrobic agent used to treat the residual food is sealed in a separate area of the primary package in the form of a tablet. The removal of the tablet and its insertion into the used bag has a high fumble potential. Once it was in the bag, the subjects found the tablet difficult to break into pieces to assure even distribution in the bag.

The design of the zero-G feeder also presented minor safety hazards. Cut material around the mouthpiece caused occasional cuts on subjects' lips and fingers. It was also a constant threat to the eyes; however, no injury of the eyes occurred in these studies.

Another area of consideration is the size and shape of bite-size foods. There are several different sizes of food bites: 1.1-cm (11/16-in.) cubes; 0.6- by 2.5- by 2.5-cm (1/4- by 1- by 1-in.) bacon squares; 0.9- by 2.1- by 2.8-cm (3/8- by 7/8- by 1 1/8-in.) cinnamon toast; 3.2 cm by 2.5 cm by 1.6 cm (1 1/4 by 1 by 5/8-in.) sandwich bites. The subjects had difficulty in placing the larger bites in the mouth and chewing. The initial crushing of the bite was difficult if the depth of the bite was greater than 0.5 in.

The volume of food in the mouth was also important. These foods are dry and require saliva to rehydrate. A maximum volume of 0.40 cu in. was considered ideal. Some bites such as the fruitcakes were criticized for being too hard. Using a punch 1 cm in diameter closing at the rate of 10 cm/min, the optimum hardness for bite-size foods is approximately 25 kg/ sq cm.

At the conclusion of these studies, the feeding system was functionally verified. As a result of these studies, the following changes in the feeding system were made: (1) The rehydration container was redesigned in the following manner: A valve was installed with shrinkable Teflon to hold the valve to the package, the size of the beverage bags was increased, the quality of materials was improved, mouthpieces were widened to provide more convenient removal of the food, and the antimicrobic tablet was relocated and made smaller; (2) foods were improved by reducing rehydration times and making the texture more defined and natural; (3) bite sizes of foods were changed in shape and size and the integrity and hardness improved; and (4) the nutritional composition of these foods was defined and methods for planning a balanced and acceptable menu by using a computer program were established.

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Development of New Concepts for the Feeding System for the USAF Manned Orbiting Laboratory

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During the initial phase of the Manned Orbiting Laboratory (MOL) program, existing space feeding systems were evaluated for possible use. The time frame of this evaluation was 1965 to 1967, at which time the Gemini flight program was yet to be completed and the Apollo program was in its development phases. There was no qualified 30-day feeding system for space application. With the assistance of the U. S. Army Natick Laboratories, the USAF School of Aerospace Medicine (SAM), and the NASA Manned Spacecraft Center (MSC), an indepth review was held.

It was determined that the Gemini/Apollo feeding system would initially be considered for use on the MOL. It was felt that the greatest advantage could be derived by both MOL and NASA by concentrating efforts on improving the componentry of the already developed Gemini feeding system. Through development and expansion of that technology for use on MOL, most of which would occur during the Apollo flight time frame, mutual benefit could be obtained. The NASA development efforts in refining the Gemini feeding system for use in Apollo and our efforts in further expanding these concepts could be interwoven so as to benefit both agencies.

Although the history of feeding systems will not be detailed in this paper, it should be remembered that spaceflight systems were developed along lines stressing a normal progression of increasing complexity of accomplishment from Mercury to Gemini to Apollo. The unknowns were great; planning was accomplished in increments; 30-day flights in the days of Mercury, when space flight was measured in minutes to hours, were but a dream. Nevertheless, an attempt was constantly made to develop the feeding system as an integral part of the total space system. It was necessary to conceive of it in terms of the mission, systems capabilities, crew requirements, etc. It is to the great credit of NASA and all the agencies and contractors that have supported the efforts to date that the feeding systems development incorporated rational systems engineering. The application of dehydrated foods, the development of zero-G feeders and packaging materials, the delineation of nutritional requirements, etc. were no small effort.

The 14-day Gemini 7 flight was up to that date the most significant test in space of spacecraft systems, crew performance capabilities, and environmental control and life-support systems, one of which was the feeding system. As has been detailed elsewhere, the Gemini feeding system was configured to meet certain requirements; heat, vibration, and bacteriological criteria, nutritional levels, procedural use requirements, use in the confined compartment of the Gemini spacecraft, and utilization of fuel-cell water at its spacecraft temperature of 80° F were but a few of the environmental criteria.

In August 1967, after industry proposal evaluation, Whirlpool Corp. was selected to develop and produce the MOL Feeding System Assembly. This feeding system was to be composed of food substances prepared in the form of dehydrated bites which were to be eaten in the desiccated state and to be rehydrated during the process and various dehydrated foods and beverages which were to be rehydrated prior to eating and drinking. There were approximately 40 items available at that time. The U. S. Army Natick Laboratories supplied "Space Food Prototype Production Guides" for Whirlpool Corp. to incorporate into production specifications. Hot water to 155° F and cold water to 40° F was to be available for the rehydration. Twenty-six hundred cal/man/day was felt at that time to be the caloric requirement. Microbiological standards, as developed by the U. S. Army Natick Laboratories, were applied. Maximum organoleptic acceptability was to be sought.

The food was to be packaged in the Gemini developed zero-G feeders with a mouth spout and hydration valve arrangement. The feeders would be scissor-opened and the food and liquids squeezed into the mouth. The bite packages would be scissor-opened and the bites individually removed for eating. Rehydratables and beverages were in 5-oz-capacity bags. Bite-food bags varied in size. Food volume and weight were limited to 195 cu in. and 1.7 lb/man/day. An antimicrobial agent was attached to each rehydratable food package.

Procedural requirements detailed a desire to minimize preparation, feeding, and waste-disposal times. In order to make efficient use of the items available, a 4-day menu cycle of three small meals of 10 minutes each and one large meal of 45 minutes was desired. Mineral content was based on the recommendations of the National Research Council. The caloric distribution was to be 27 to 34 percent fat, 10 to 15 percent protein, and 50 to 58 percent carbohydrate.

It was felt that, in order to utilize the technical capabilities of SAM, the U. S. Army Natick Laboratories, and NASA MSC most properly, the MOL Systems Office should set up a quarterly conference to be attended by all these agencies. This would handle appropriate technical inputs and these quarterly food planning conferences were held from 1967 to 1969. Their format has recently been slightly changed so that the MOL Systems Office and NASA MSC are cochairmen for the Government Agency Food Technology Working Group which held its last meeting at Natick, Mass., in March 1969. This close working relationship has been singularly effective in integrating government-agency efforts toward the present and future requirements of the users, MOL and NASA.

During the development phase of the Whirlpool contract the objectives have been validating this system, developing production specifications, and improving and enlarging the variety of foods. Dr. Vanderveen, in a preceding paper entitled "Evaluation of Space Feeding Systems," has detailed the validation of the feeding system by adding information about the reliability of the zero-G feeders, delineating the metabolic characteristics of the food, adding to the battery of acceptance data for both initially considered food items and newly developed items, and improving rehydration information. Major Flentge, in a paper entitled "Quantifying and Improving Manned Orbiting Laboratory Food," has detailed efforts in developing production specifications and discussed the enlargement of the food-item list. In particular, more high-nutrient soups and puddings have been added, and the quality and type of bites have been significantly enlarged and improved.

By August 1968 it was felt that MOL had an acceptable feeding system which could be used for 30-day flights, but certain problem areas remained, or at least became more obvious. Since MOL was still in its development phases, an attempt was made to detail these problem areas and, in the time remaining, to solve them. Additionally, these problems would be common to the upcoming Apollo flights, and solutions for some of the more readily solvable problem areas could certainly be of benefit to Apollo. Also, valid flight information would be gathered during the Apollo flights and would be beneficial in bringing to light any new problem areas.

It was recognized that more natural foods should be developed - rehydratable meat chunks, more vegetables, and high-nutrient cold liquids, to name a few. The compressed bites should be normalized in size so that a bite would be normal to the mouth in both shape and consistency. Also foods should be utilized in a more usual manner, as dessert items, croutons to be used with soups, etc., and not be viewed as the main caloric constituent of any one meal. Food-storage times should be more completely determined and improved so as to give maximum selectability where flights occur over extended periods of time.

In the area of packaging, it was clear that the delivery system must be improved. The complexity and unnaturalness associated with the handling of multiple small packages and squeezing the rehydratables and liquids individually was both cumbersome and time consuming. The advantage of hot and cold water was not completely realized since preparation and rehydration times were long and the thermal conditioning of the food was certainly degraded because of the time required from preparation to actual eating. The multiplicity of packages presented a problem in formulating a normal menu plan. More realistic use of the antimicrobial agent was needed since significant weight was involved in incorporating a pill in each package, and time was involved in removing it, placing it in the package, crushing it, etc. Drinking methods were unnatural; liquids were squeezed into the mouth by rolling up the package like a toothpaste tube. The crew no longer was cramped into a small cabin, as in Gemini, and could now afford the freedom of intravehicular movement. For the first time a feeding station would be utilized and, in general, living would be more normal. The package-to-food ratio was prohibitive and, therefore, not only costly to booster capability but severely limited the important flexibility of meal planning. As an example, 2900 Kcal of food would require the full 195 cu in. of space and 1.7 lb alloted and would contain only 88 cu in. of actual food. Because of the energy requirements and the size of our crewmen it was recognized that as much as 3200 Kcal/man/day might be required. If two large crewmen flew at the same time they could not have the required amount of food. Certainly, food requirements should never be a criterion used for astronaut selection.

Also, of course, crew procedural requirements specified reduction in time and procedures and the development of more flexible meal grouping to offer maximum flexibility to the flight timeline people. Additionally, waste handling most certainly needed to be simplified.

With these areas delineated and with the growing confidence that was acquired during the Gemini program as to food delivery methods, a prototype package system was developed by Whirlpool Corp. This package would allow spoon feeding. With larger spacecraft volumes available and more known about the handling of foods in zero gravity, this old technology of eating with a spoon, which had been, naturally, considered by many groups previously both within industry and NASA, could become a reality. This concept was evaluated by MOL in a zero-G flight test run at Wright-Patterson Air Force Base in August 1968.

The test revealed that the method was indeed feasible. Food substances adhere well to the package, spoon, etc. Eating is simple and rapid. Simpler flexible hydration valves were evaluated and proved feasible. The entire eating process proved to be a more natural one; food packages could be lined up on the console and food spooned from each package with ease. The package remained open and food residue could be wiped off the spoon in the scooping process on the opening band. Foods could be mixed as when eating at the table. The food itself could be seen and the quantities desired placed in the mouth. This concept was immediately and successfully incorporated in the wetpack Christmas dinner eaten on Apollo 8 and more completely incorporated on Apollo 9.

I would like to point out the great value that direct participation by our crewmen has been throughout the MOL Food System Development Program. As an example of this, in January 1969, four crewmen were fed a complete menu cycle for a period of 4 days. They devoted themselves to the task of constructive evaluation of the food and commented on each food as it was eaten, as an individual item, as part of the meal itself, as part of the day's menu, and, finally, as part of the complete menu cycle itself. Their comments have been directly incorporated into the food design. As a part of the test, daily complete dental examinations were carried out by Drs. Hall and Brown of SAM, who were able to gather important information which has helped us to determine compressed bite size and texture more rationally. The crewmembers learned the importance of diet understanding in selecting foods. In order to have at least two crewmen evaluate each item at least once, a caloric intake of from 2800 to 3400 cal/day was required. The crewmen remained active and exercised daily. Their daily energy requirements, however, were judged to be close to those anticipated in orbit. It is of interest to note that all either retained their starting weights or gained weight. All the weight gains could be attributed to too high a caloric intake based on our estimates of 42 Kcal/Kg LBM/man/day.

With the concept of spoon feeding proven to be feasible, the next rational step was taken. A complete systems engineering analysis was undertaken by Whirlpool so as to redesign the MOL feeding system to incorporate this concept and its many possible ramifications, the details of which are discussed by Dr. Roth in his paper "Systems Analysis of Manned Orbiting Laboratory Feeding System."

I would, however, like to state some of the objectives of redefining the food delivery system and its overall impact on the total feeding system. It must be constantly kept in mind that in cases where system design time is available, maximum benefit can be derived from incorporating new concepts into existing systems if an integrated review of requirements and objectives is undertaken. Therefore, Whirlpool Corp. was directed to do a complete tradeoff analysis as part of this study. This required detailed objectives and requirements delineation and prioritization. Food storage dimensions became a prime factor and nutrient modularization and dimensional modularization became a necessity. Normal eating and drinking methods, rational combinations of foods, minimization of time, more appropriate package-opening techniques, realistic uses of antimicrobials, simpler waste stowage, decreasing the number of packages involved, normalization of compressed bites, increasing the volume of each liquid, decreasing the size of the puddings, enlarging the capability to carry 3200 Cal/man/day if required, retention of thermal heating and cooling of the food till eaten - all became important factors. Additionally, flexibility to incorporate newer food types, such as meat chunks and high-nutrient cold liquids, necessarily must be considered.

It is, therefore, recognized that food acceptability involves not only the quality of the food itself and its variety but also the time and convenience of preparing and eating, size of portions, stowage, etc. The MOL Systems Office has recently evaluated this new feeding systems approach and feels it now offers maximum use of foods and packaging, more convenience, and, therefore, total acceptability. It also offers maximum flexibility for planning purposes and allows for in-orbit ease of readjustment if required.

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Systems Analysis of Manned Orbiting Laboratory Feeding System

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The purpose of my discussion is to present the systems-analysis approach which Whirlpool Corp. is using to attempt to improve the overall feeding system for the Manned Orbiting Laboratory (MOL) program. It is my hope that this discussion will facilitate understanding of the problem of feeding man in a spacecraft in light of a total spacecraft system rather than by a shotgun approach of developing individual improved food items or hardware components. In my opinion, which is based on years of experience as a contractor on both the Gemini and Apollo feeding programs, a shotgun approach will do little to advance the overall state of the art.

As mentioned in other papers, the MOL baseline system emerged in the contract as an exact replica of the late Gemini feeding system, insofar as packaging and food items were concerned. The MOL system allocated a total storage volume per day for each astronaut's food of approximately 195 cu in. for a baseline menu of 2900-Kcal. The average volume of the dehydrated food in this 2900-Kcal menu was only 88 cu in. However, because of packaging and food-shape inefficiencies in this baseline system, this 88 cu in. of food, when oriented as efficiently as possible, completely filled the allocated available volume of 195 cu in.

Some of the packaging inefficiencies were related to shapes of foods used in the menu and others, to the nature of valves and other irregular components used in the package. The 195 cu in. of storage volume allocated per man day of food in MOL was in a theoretically very efficient "shoe box" shape of 3.7 by 6.3 by 8.3 in. However, with the baseline system, this storage space could not be efficiently utilized.

Figure 1 shows the dimensions of the current Apollo bite-size foods. These fairly regular foods form no regular pattern when attempts are made to package them together. The rehydratable foods presented an even more difficult problem to the systems integrator. First, the package incorporated a hard poppit-type water entrance valve and a hard waste-stabilization tablet which defied all attempts at efficient stowage and tended to crush bite-size foods in intimate contact. Second, the shapes and sizes of the rehydratable foods were purely arbitrary. The rehydratable foods acquired their current dimensions from the original development work, which was carried out by using Spam cans as molds for freezing experimental products prior to drying. These cans were inexpensive and handy for producing experimental samples. However, the arbitrary dimensions did not relate to any specific requirement of the feeding system. In general, a bar, the size of a Spam can and 1 in. thick, was not a satisfactory serving portion, nor was it dimensionally an integral factor of any available storage volume. The dimensions used in the baseline system were of no value from either the engineering or nutritional standpoint; they were merely a carryover from early development work.

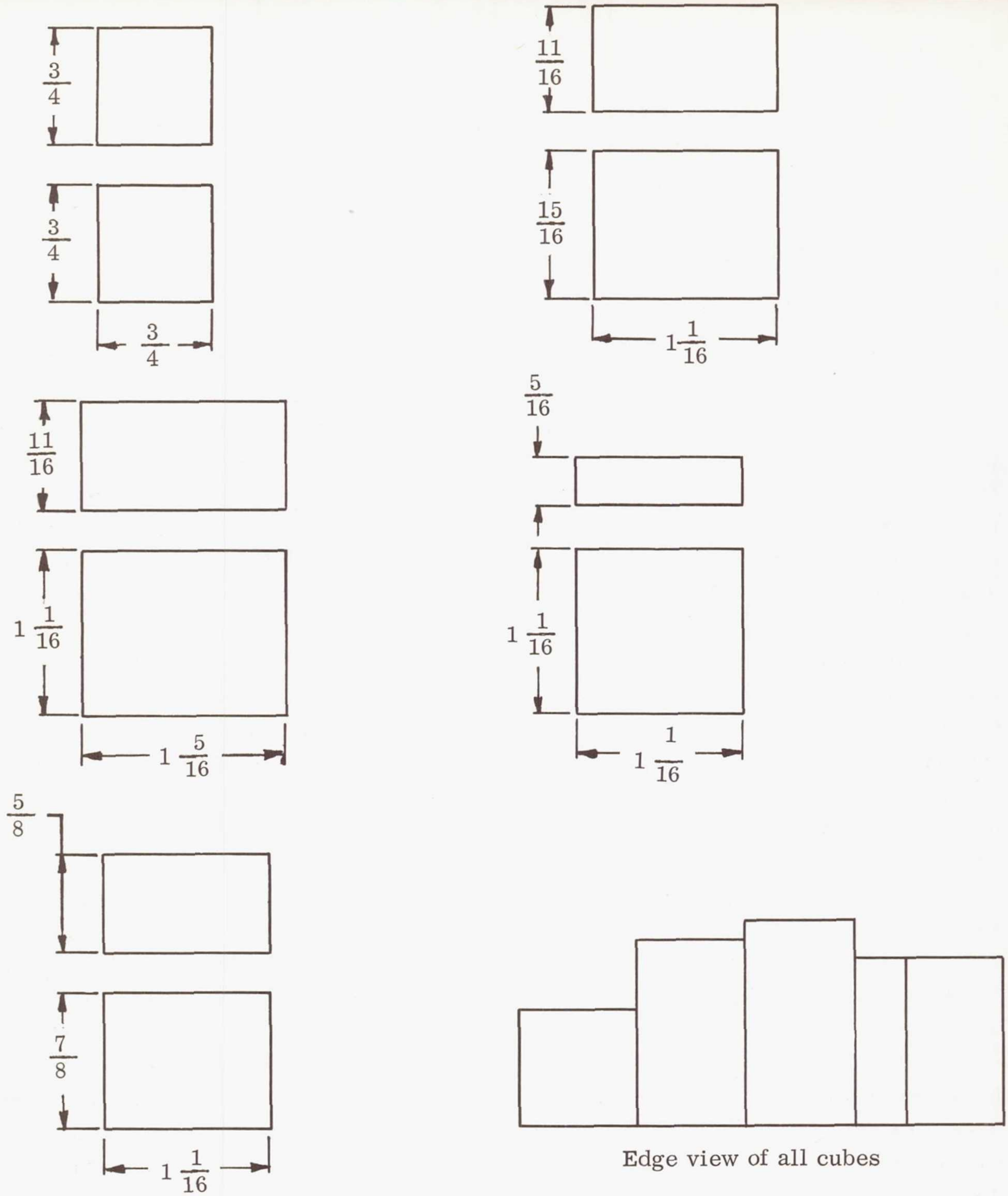

Figure 1. -Dimensions of current Apollo bite-size foods. Dimensions are in inches.

The baseline MOL foods were acceptable from both the nutritional and organoleptic standpoint if properly used, but under actual previous system application they left something to be desired. Considerable data presented by previous speakers attest to the fundamental acceptability of the foods. Our task at Whirlpool was to perform a systems analysis which could lead to an overall acceptable feeding system under actual spacecraft conditions. The remainder of this paper will be concerned with the nature of this systems analysis and the basic conclusions.

First, let us look at the interface charts (figs. 2 and 3) so that we can understand all that is involved in the system. At the center of the chart is a typical rehydratable food package. The broken lines are not within the scope of the feeding-system contract, but they are shown because they serve to describe the total system. After this look at the overall system, the analysis was undertaken.

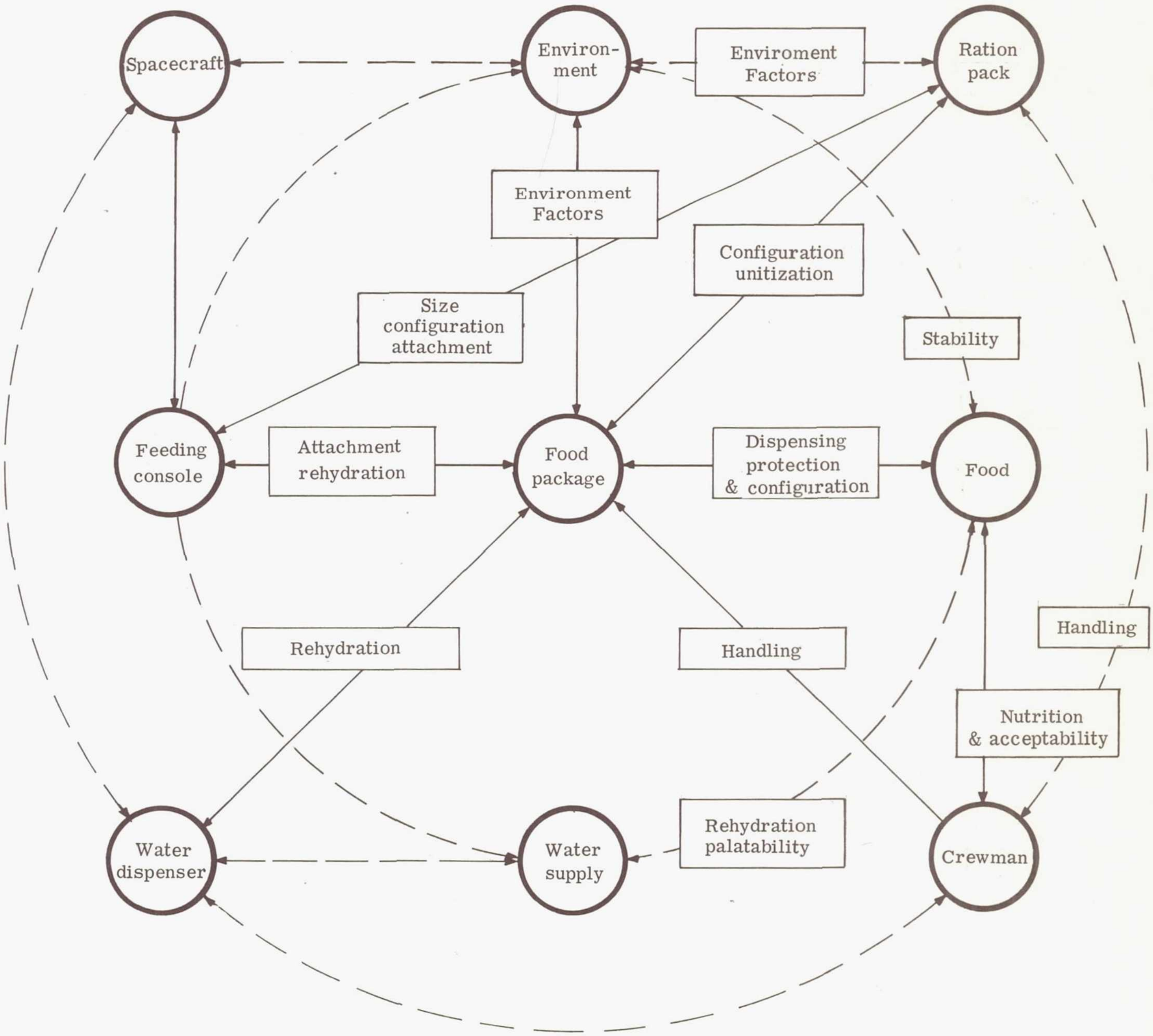

Figure 2.-Feeding-system interface chart. Rehydration interfaces not applicable to bite-size packages.

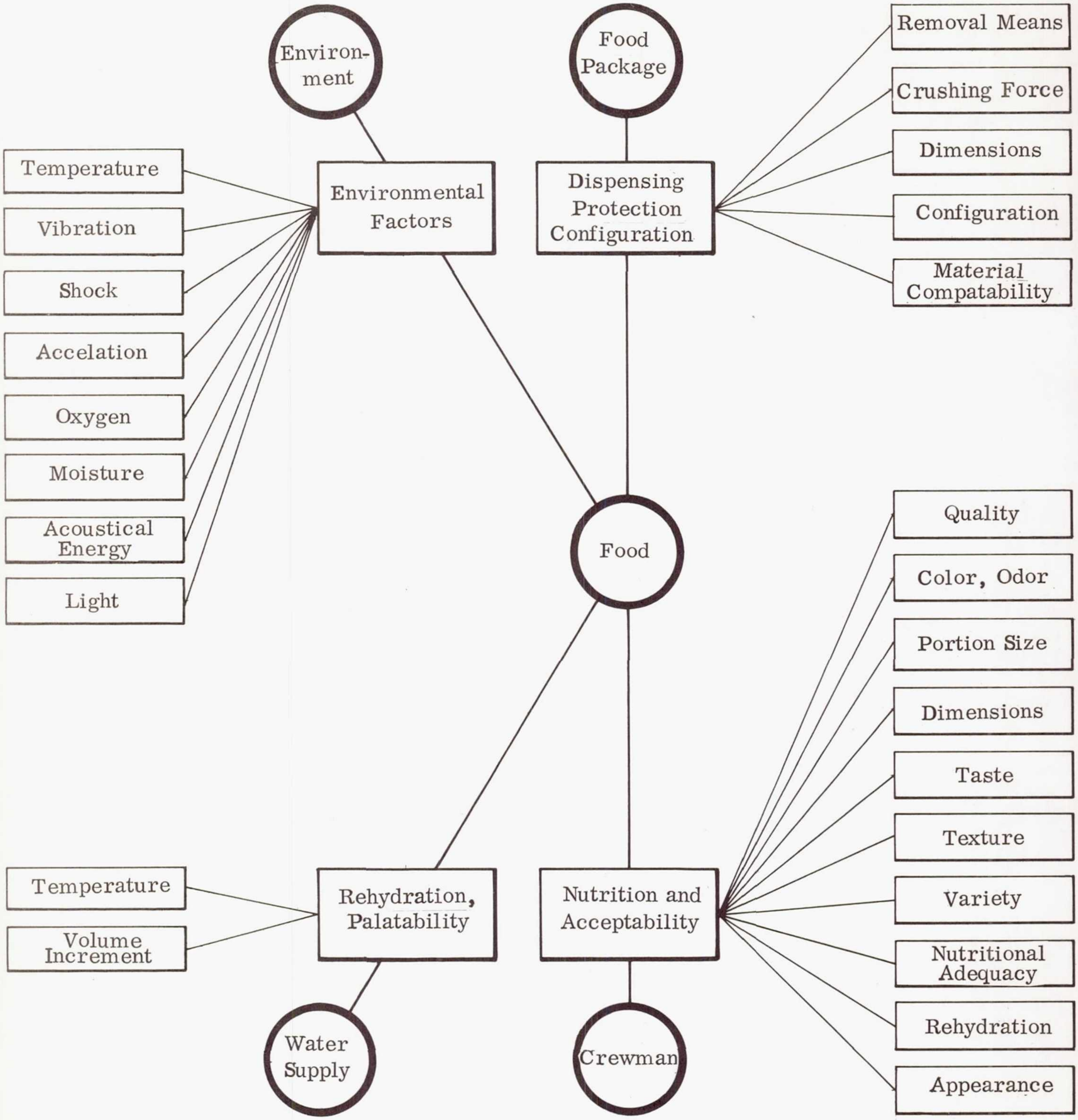

Figure 3.-Interface constraints imposed on foods.

Overall goals, in brief, from the food standpoint were to:

(1) Optimize baseline foods to provide satisfactory serving or portion sizes.

(2) Provide nutritional modularization, so that a serving of a given class of food would provide about the same nutritional content as any other serving of another food of the same class. (For example, all meat items should be nutritionally interchangeable.)

Overall goals, in brief, from the packaging standpoint were to:

(1) Make all food packages modular, the size being based on the fixed dimensions of the spacecraft compartment. In order to do this, and still to allow for the nutritional modularity, packages and contained food should have strictly fixed dimensions in two dimensions, with the third dimension variable to allow for weight adjustments of individual food items.

(2) Eliminate inefficient protuberances such as hard valves and disinfectant tablets.

(3) Allow for normal and efficient spoon-and-bowl-type eating.

(4) Provide efficient modularization of all types of foods, including rehydratables, bites, and beverages, with maximum interchangeability.

These were the basic goals. However, many other constraints were imposed by the system. These included:

(1) System integrity, i.e., minimization of loss of food to the atmosphere
(2) Identification of all foods and meals
(3) Accessibility of all foods
(4) Efficient food-waste handling
(5) Ability to open and close a package easily
(6) Ability to add water to rehydratable foods easily and reliably
(7) Containment in a ration pack
(8) Compatibility with all normal and emergency spacecraft environments
(9) Overall safety
(10) Overall noncomplexity
(11) Anthropometric compatibility

The foregoing criteria are illustrative, but certainly not all inclusive.

The study began with an analysis of the nutritional and dietetic aspects. The initial objective was to modify food portions to reflect normal portion sizes. This was done by using standard military and institutional food-portion recommendations as a guide. Generally, this modification resulted in increasing the portion size of "main dish" food items and decreasing the portion sizes of dessert items. It also resulted in a decrease in total number of food packages required per man day from an average of 22 to a maximum of 16.

Table I shows a comparison of portion sizes in the current menus with those in the recommended modified menus; the values are based on use of normal portion sizes. Generally, it can be noted that the portion size of meat- and soup-type foods increases and that of dessert-type foods decreases. This in itself should help to eliminate some of the valid complaints of too many sweets in the menu.

TABLE I. -COMPARISON OF DRY PORTION WEIGHTS AND VOLUMES

Food item	Current MOL portion sizes		Modified MOL portion sizes	
	Weight, g	Volume, cu in.	Weight, g	Volume, cu in.
Cereals				
Sugar-coated corn flakes	36.8	5.63	42.9	6.57
Toasted oat cereal	24.0	9.24	36.0	13.87
Fruits				
Applesauce	35.0	6.99	20.0	3.99
Fruit cocktail	21.0	7.25	21.0	7.25
Peaches	19.0	7.25	22.2	8.47
Vegetables				
Cream-style corn	22.5	7.25	22.5	7.25
Puddings				
Apricot	70.0	5.94	40.8	3.46
Banana	70.0	5.24	40.8	3.06
Butterscotch	70.0	5.93	52.5	4.45
Chocolate	70.0	5.51	52.5	4.13
Salads				
Chicken	41.0	6.80	41.0	6.80
Salmon	42.0	6.80	42.0	6.80
Tuna	42.0	6.80	42.0	6.80
Shrimp cocktail	31.0	6.80	20.7	4.54
Meats				
Beef and gravy	35.0	6.80	46.7	9.07
Beef hash	29.0	6.80	58.0	13.59
Beef pot roast	27.0	6.80	45.0	11.33
Beef with vegetables	22.0	6.80	58.7	18.14
Spaghetti with meat	21.0	6.80	56.0	18.12
Veal in barbecue sauce	38.0	6.80	63.3	11.32
Canadian bacon and applesauce	29.0	6.80	58.0	13.59
Sausage patties	40.0	5.80	40.0	5.80
Chicken and gravy	24.5	6.80	40.8	11.32
Soups				
Cheese	46.0	8.81	69.0	13.22
Cream of chicken	27.5	1.88	38.5	2.57
Cream of mushroom	30.0	6.59	52.5	11.53
Cream of tomato	35.0	5.19	49.0	7.26
Lobster bisque	39.0	7.46	54.6	10.44
Pea	49.0	6.10	58.8	7.32
Potato	40.0	4.42	56.0	6.19
Beverages				
Cocoa	42.0	3.56	58.8	4.98
	---	---	84.0	7.12
Tea	8.2	.56	13.1	.84
	---	---	19.7	1.27
Drinks				
Fruit drinks - class 1	21.0	1.37	31.5	2.05
	---	---	37.8	2.46
Fruit drinks - class 4	39.0	2.52	54.6	3.52
	---	---	66.3	4.28
Grapefruit drink - class 4	46.0	2.89	64.4	4.05
	---	---	78.2	4.92

After analysis of the food modularization, the next step was to perform a dimensional modularization, to determine optimum utilization of the available stowage space. The nutritional study indicated that a maximum of 16 packages per day, distributed as shown in table II, could meet the MOL requirements. Volume requirements for this distribution were determined to be as shown in table III.

TABLE II. -DETERMINATION OF MODULAR INCREMENTS

Type of food	Portions per ration	Volume factor	Modular increments per ration
Rehydratable	4	7	28
Liquid	4	5	20
Bite	8	2	16
			64

TABLE III. -FOOD AND PACKAGE VOLUME ASSUMPTIONS

Type of food	Average food volume, cu in.	Average food and package volume, cu in.	Maximum food and package volume, cu in.
Rehydratable	8.0	14	19
Liquid	3.5	10	11
Bite	3.5	4	5

The first engineering task was to determine the optimum modular shape for the food packages. Spacecraft interface constraints dictated that the ration (defined as food for 1 man for 1 day) fit within the dimensions shown in figure 4. There are obviously many possible dimensions for 16 packages within this overall dimensional limit. The first tradeoff study was performed to select the best dimension for individual food packages within this system.

Figure 5 shows a few of the possible configurations studied. (In these sketches, the first number indicates width and the second indicates height; e.g., 2 by 1 is 2 packages wide by 1 package high.) All configurations from 1 by 1 through 10 by 1 were examined; configurations over 11 were considered not feasible.

Tradeoff factors used in the study were:

(1) Package access

(2) Availability of space for mounting rehydration aperture

(3) Compatibility with hot-water-probe enclosure

(4) Anthropometric compatibility

(5) Maximum package depth

(6) Bite cross section

(7) Number of bites per modular face

(8) Minimum acceptable bite volume

(9) Maximum acceptable bite volume

(10) Flexibility of bite serving volume

(11) Permissible serving sizes as function of thickness

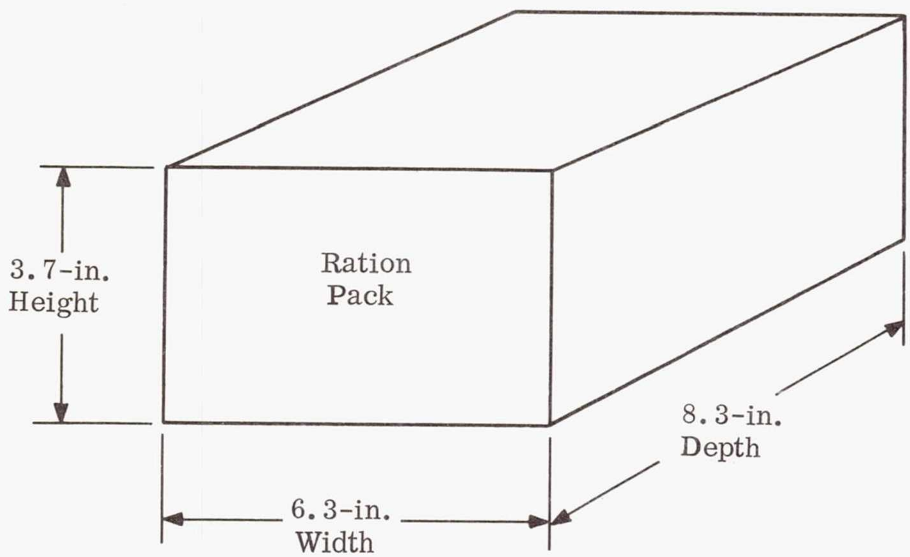

Figure 4. -MOL feeding system assembly.

All factors were assigned numerical ratings in the tradeoff study. In addition, go-no-go numbers were assigned, and any single no-go configuration eliminated a particular dimension. I cannot go into the total mathematics, but I would like to present one example. Figure 6 illustrates a fixed spacecraft system constraint, the hot-water-probe cavity dimensions. Any package dimension which does not permit access to the hot-water probe for rehydration obviously would be discarded from further consideration.

After a thorough systems analysis, which can only be mentioned here, the 5 by 1 dimension was selected as optimum for modularization of the MOL food packages. This resulted in a package dimension for all foods, bites, rehydratables, and beverages, as shown in figure 7. In order to make the system work most efficiently, a loose fill of rehydratable foods, rather than use of formed bars, was most desirable. With a variable length dimension, loose fill would allow for nutritional modularity between foods and for ease in adjusting portion sizes of a given menu for individual men of different body sizes and, therefore, different calorie intake requirements.

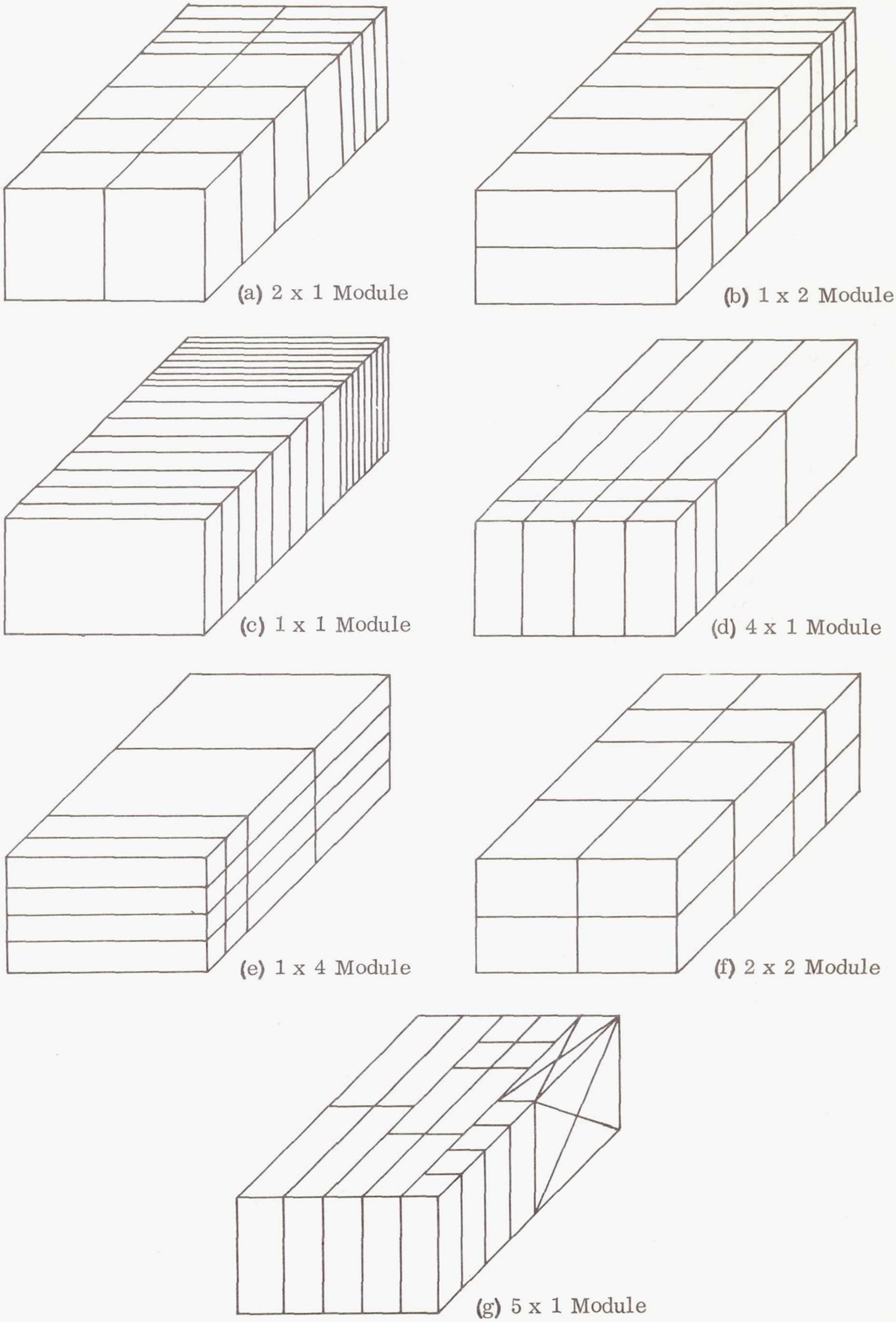

Figure 5.-Some food-package configurations studied.

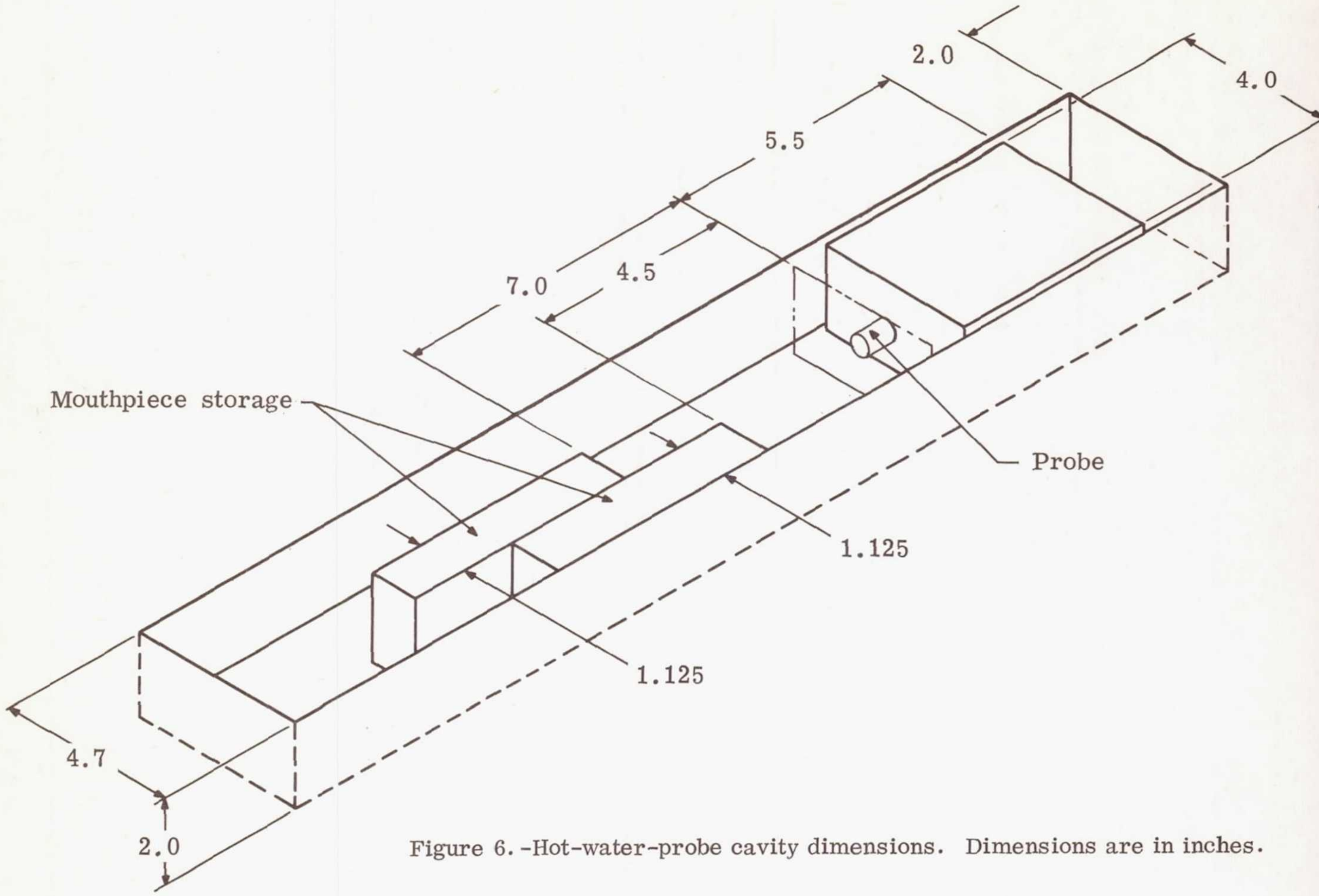

Figure 6. -Hot-water-probe cavity dimensions. Dimensions are in inches.

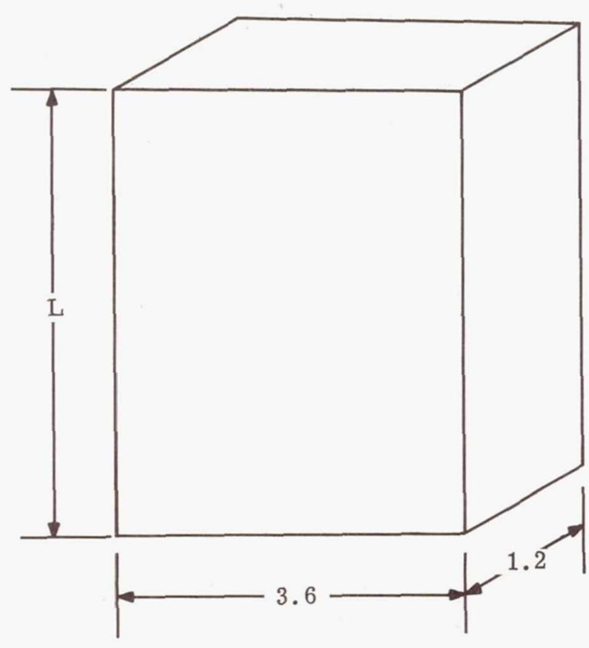

Figure 7. -Dimensions of package module. Dimensions are in inches.

Table IV shows, with samples of Apollo foods, that loose-fill foods (after vacuum packaging) require no more volume than formed bars. The modular packaging requirement also dictated a change in shape of the bites from shapes previously shown to wafers about $\frac{1}{2}$ in. thick by slightly over 1 in. square. Fortunately, this shape is in general agreement with Air Force dental research results on optimum size of bites.

TABLE IV. -COMPARISON OF FORMED AND PARTICULATE FOOD VOLUMES

Food item	Guide weight, g	Volume, cu in.		
		Formed bar	Loose fill	Vacuum packed
Shrimp cocktail	31	5.015	7.811	4.771
		5.381	8.665	5.259
		4.832	7.444	4.710
		5.320	7.933	5.137
Beef and vegetables	22	4.893	7.872	4.710
		4.893	7.811	4.710
		4.893	7.689	4.771
Spaghetti and meat sauce	21	4.527	8.177	4.283
		4.832	8.238	4.527
		4.771	8.055	4.466
		4.893	8.482	4.527
Chicken and vegetables	21	5.137	9.031	5.747
		5.137	8.299	5.442
		5.259	8.665	5.564
		5.259	8.909	5.625

After selection of dimensions of the modular packages, similar systems tradeoff studies were performed to establish the basis for package designs. In the case of the rehydratable package, separate tradeoff studies were first performed by selecting the rehydration aperture and package-closure concepts. The rehydration aperture concepts included:

(1) Maximum diameter
(2) Maximum length
(3) Requirement for adapter to mate with water probes
(4) Self-closing feature
(5) Reliability
(6) Potential for leakage around probes
(7) Potential for leakage during kneading

(8) Feasibility

(9) Valve-food interference

(10) Material requirements

(11) Tooling requirements

The package-closure concepts included:

(1) Compatibility with package face

(2) Capability to be folded over end of package

(3) Cross section of opening

(4) Tendency to be soiled by food removal

(5) Simplicity of operation

(6) Capability to be opened with one hand (on console)

(7) Capability to be opened with one hand (hand held)

The selected concepts were then used in developing the overall rehydratable package concept. Beverage and bite-size package studies were performed in a similar manner.

The tradeoff factors utilized in selecting the most feasible rehydratable food package concepts were functional factors, system factors, and program factors. The functional factors were:

(1) Manipulation

  (a) Insertion of water probes

  (b) Rehydration

  (c) Opening and reclosure

(2) Temperature maintenance

(3) Rehydration aperture

(4) Access to food

(5) Compatibility with unpressurized gloves

(6) Total operation time requirements

The system factors were:

(1) Weight

(2) Volume

(3) Reliability

The program factors were:

(1) Schedule (time to qualification)

(2) Unit cost

(3) Tooling cost

The tradeoff factors utilized in selecting the most feasible beverage package concepts were the same three factors. The functional factors were:

(1) Manipulation

  (a) Initial seal opening

  (b) Insertion and removal of clamp (if any)

  (c) Insertion and removal of straw (if any)

(2) Rehydration aperture

(3) Terminal seal

(4) Safety (protruding tabs)

(5) Ease of microbiological stabilization

The system factors were:

(1) Weight

(2) Volume

(3) Reliability

The program factors were:

(1) Schedule (time to qualification)

(2) Unit cost

(3) Tooling cost

The same tradeoff factors were utilized in selecting the most feasible bite package concepts. The functional factors were:

(1) Manipulation

(a) Insertion of accessory devices (if any)

(b) Opening and reclosure

(2) Cube retention

(3) Crumb retention

The system factors were:

(1) Weight

(2) Volume

(3) Reliability

The program factors were:

(1) Schedule (time to qualification)

(2) Unit cost

(3) Tooling cost

As I hope you can gather from the foregoing discussion, a thorough systems analysis and tradeoff study has been performed on the MOL feeding system. Preliminary design concepts have been evolved for a new baseline feeding system. These design concepts have been thoroughly integrated with the total spacecraft requirements and have met the basic goals of the study. Packaging efficiency of the ration has been improved, and flexibility of food portions usable within the ration has been greatly increased. Design concepts for packaging rehydratable foods, beverages, and bite-size foods have been developed. These design concepts are completely modular and provide for eating in a manner much as one does on Earth. Rehydratable foods are consumed with a spoon; beverages, through a straw. Design concepts for the foods provide for greater flexibility and improved anthropometric compatibility.

During the progress of the systems analysis, no attempt was made to establish detail design of the packages or radical changes in food production techniques. The systems engineers have set the ground rules. On the basis of the systems analysis, the designers and food technologists can now start the specific developments leading to provision of all the components as a complete integrated system.

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Apollo Applications Program Requirements

PAUL C. RAMBAUT
NASA Manned Spacecraft Center

Most of you are probably familiar with the Apollo Applications Program (AAP), the NASA mission which will succeed Apollo. The Apollo Applications concept has had a long history. However, it is only recently that its configuration has been more or less solidified.

The AAP is based largely upon the use of currently available hardware. A three-man space station will be assembled in orbit about 200 n. mi. above the Earth. This space station, or orbital assembly, will consist of a command and service module, a multiple docking adapter, and an orbital workshop. The orbital workshop is the true essence of AAP. It is actually the spent hydrogen fuel tank of the second stage, or SIVB stage, of the Saturn IB rocket.

Three AAP missions will be flown over a period of about 9 months. The first mission will be 28 days long and the other two will each be 56 days. The second 56-day mission will have an Apollo telescope mount added to the orbital assembly. All missions will employ the same SIVB tank, which will be left in orbit in a deactivated state between missions. The first two AAP flights are primarily medical missions, whereas the third has an astronomy objective.

The food system to be used on AAP will be substantially different from that used on Mercury, Gemini, Apollo, or MOL. This does not stem from a desire on our part to make things different simply for the sake of flying a novel system; in reality there is substantial pressure to utilize existing Apollo hardware, wherever practicable. The requirement that the AAP feeding system be different stems from two major factors: (1) Some flight foods used in the past are not satisfactory from a number of standpoints so there is a pressing requirement to achieve a better system, and (2) the requirements imposed upon the flight feeding system by the AAP mission profile are much more stringent than the requirements placed upon any previous flight feeding system. This is not because of more rigorous conditions, for indeed storage conditions will be better, but is rather because of a need to make a food system as good as a good conventional food source, yet also to allow for the conducting of a medical experiment.

The feeding system will be one which will meet a set of requirements which we consider reasonable in the light of the objectives of the AAP missions as well as of the constraints that the spacecraft will impose upon the foods and packages.

Two primary objectives of the AAP missions profoundly influence the design of the feeding system. First, there is an experiment on habitability, which is designated M487. Certain criteria which make a habitable environment are postulated in this experiment. The experiment provides the equipment inside the SIVB which will put this hypothesis to the test. The habitability of any environment is in large part a function of its food supply. It is the intent of M487 to make absolutely certain that there is nothing about the food system or any other system which will unnecessarily detract from habitability.

The AAP feeding system is one of the most critical elements of the overall life-support system of the AAP orbital assembly. Proper food consumption is essential for sustaining the health and performance of the astronauts. The quality of the food and the ease with which it may be prepared and consumed will have a profound effect upon the general psychological, as well as the physiological, well-being of the crew. Food which may be nourishing but which is not highly palatable and which is difficult to prepare and consume may adversely affect the morale and performance of the astronauts and will be incompletely consumed.

A second prime objective of AAP is to obtain medical data. A large complement of medical experimentation will be implemented on AAP in order to assess the effect of spaceflight upon the human and to gather predictive data regarding his ability to withstand weightless spaceflight of very prolonged duration. One part of this experimental package is designed to assess the effect of spaceflight upon musculoskeletal function. The core of the experiment is essentially a very precisely performed balance study, which is designated M070. Such a balance necessarily depends upon very accurate knowledge of the input and output of major metabolites.

The food must be sufficiently well defined that this knowledge of nutrient intake may be derived from minimal inflight data which will be recorded during the course of the experiment. The crew will adhere to a prearranged or nominal menu plan chosen by the principal investigator in advance. There will be available the crewman's daily log of items left unconsumed or of items consumed in a sequence which differs from the nominal menu. We will have an inflight logged recording and voice transmission regarding any residual, partially consumed food item which contains more than 1 percent of the original mass of food. Since these inflight mass measurements impose a burden on the crew, it is highly desirable that the food package be graduated in a manner which will allow a visual estimation of food mass remaining without mass measurement. As additional data, we will have assurance that the water content of any rehydratable food item will not differ from that prescribed by the instructions on the package.

We also propose to place on the AAP feeding system a number of nutritional requirements. It is essential that the recommended dietary allowances of all vitamins, minerals, essential fatty acids, and amino acids be met or exceeded by the nominal menu when completely consumed by the crew. The diet will be so designed that each crewman will consume each day about 800 mg of calcium. This might be accomplished either by distributing the calcium evenly in a constant calcium-to-calorie ratio throughout the food or by incorporating the calcium in items which the crewmember is most likely to consume first. Dietary phosphorus will be controlled in a similar manner.

The food flavor, texture, and appearance will be varied to obtain complete consumption. For purposes of designing the AAP feeding system, complete consumption will be considered the governing criterion for any increase or decrease in food variety. Complete consumption will ensure that the nutritional requirements of the crew are met as efficiently as possible without food waste. Menus and food items will be varied in moisture content, flavor, texture, nutrient composition, and particle size in a manner which will ensure complete consumption. We would like to avoid unnecessary variety. Consideration will be given to a modular food concept which will consist of a few basic items which can be manipulated to provide the necessary variety in flavor, texture, moisture, particle size, etc.

The balance experiment will impose a requirement for as much homogeneity as possible. Ideally, rehydratable foods will be homogenous to the extent that any 1-percent sample of any food in a particular package will constitute a representative sample of that food. This requirement will apply to the food both in wet and dry state. Therefore rehydration of food items must take place completely and uniformly.

All food items to be included in the AAP menus will be of known chemical composition. The permissible variance in the nutrient composition of any food item will depend upon the number of items fed, but it must be low enough to be compatible with an overall requirement to ascertain the intake of each nutrient over a 56-day period to within 1 percent.

The food will be packaged in a manner which will facilitate complete consumption. At least 99 percent of the contents of any food package must be readily available to the crewman. As all food residue exceeding 1 percent of the original content of a package must be weighed or otherwise estimated, the foods must be packaged in a manner which will encourage complete consumption.

In order to adhere to the nutritional and experimental requirements of M070 and yet allow flexibility in the choice of the crew's menu items, consideration will be given to means of manipulating the food supply as the flight progresses. Computer programs will be developed which will generate menu choices within the required experimental envelope on the basis of food reported consumed and food known to remain.

I have just gone through a lot of requirements which seem largely to arise from the effort to conduct an inflight metabolic experiment. However, the primary requirement is to provide a feeding system which meets the demands of habitability. If there are experimental requirements that turn out to be obviously incompatible with the provision of a palatable flight menu, those requirements will not be imposed.

Now that we have levied numerous nutritional and experimental requirements on the feeding system, we must consider the type of environment in which these foods will be expected to function. The food must, of course, withstand the rigors of a launch with its associated stresses. The foods and food packages which constitute the feeding system of which I speak will be launched in three different sorts of vehicles; the Command Module, the Multiple Docking Adapter, and the Apollo Telescope Mount. The containers in which the food will be stowed will maintain a nitrogen pressure upon the food packages of at least 1 psi. Temperature will be maintained between 40° and 85° F. The food must be able to withstand these conditions, at their extremes, and allow variation thereof for a period of at least 8 months.

The weight allowance for food and flexible packaging will be generous in that it will permit the provision of at least double the caloric needs of the crew in the form of dry food. The packages employed to protect the food will constitute only 10 to 12 percent of the weight of the food plus packaging.

The choice of the kinds of food is made considerably more flexible by the probable availability of a food-heating device such as a microwave oven and a food-cooling device (to 40° F). There will be a food-management area within the SIVB which will provide many of the amenities of a conventional eating location.

I have outlined the requirements of an AAP flight feeding system. These requirements will hopefully elicit solutions which are both imaginative and amenable to rapid implementation. I might reflect that much has been said of experimental requirements and of the supposed incompatibility of the two experimental sets which will be flown on AAP, i.e., habitability and medicine. AAP is, I like to believe, a precursor of much greater things to come. Before we progress to these future enterprises it is essential to glean all information possible from the opportunity which AAP will present. All experiments carried on AAP are of importance in this regard. We shall not compromise one for the other, but we shall optimize the quantity of information we obtain which will allow humans to endure mission profiles as removed from AAP as Apollo is from our first furtive orbital ventures.

SESSION II

SPECIAL PROGRAMS

CHAIRMAN: FRANK B. VORIS

Chief, Human Research Branch

NASA Office of Advanced Research and Technology

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Operational-Experience Food Service on Nuclear Submarines

J. D. BLOOM

Submarine Medical Research Laboratory

It is timely that a medical officer speak to you about operational experience in food service aboard nuclear submarines. In the past, primarily by reason of their lack of senority, medical officers were commonly introduced to the romance of the submarine with collateral duties of commissary officers.

Menu selection is a relatively easy matter. Guidelines are provided by the Navy recipe service. Variety is assisted by recognition of national holidays, birthdays, and minority group specialty dishes. There are relatively wide latitudes of flexibility in provisioning to take care of tastes of the various crews. Use of ration dense foods is encouraged.

Equipment is similar to that of any ship or galley charged with serving 100 to 150 persons. Space is minimal for food preparation, so special effort toward advanced planning is required. Particular attention is taken in food preparation to prevent prolonged standing of creamed items and to assure sufficient core cooking of poultry to eliminate bacterial contamination. All heating devices are electrically powered and special efforts must be taken to prohibit possibly toxic material from coming in contact with heat sources. Examples would include mercury thermostats and avoidance of Teflon in direct contact with heating elements. Cooking odors are exhausted through vents containing appropriate grease traps.

Food storage facilities include chill and freeze boxes and dry-storage areas. The refrigerant used is freon. Leaks of refrigerant are a potential source of halogenated hydrocarbon air contamination. Frequent and careful atmosphere monitoring is required.

Water is a relatively minor problem with the abundant power and still capability available. The major consumption of water is by equipment (reactor and storage batteries). Special care is taken not to distill water in polluted harbors. During in-port periods appropriate bacterial examination of potable-water storage tanks are made.

Liquid waste is discharged through the sanitary tank system. Solid wastes and debris are placed in synthetic bags, weighted, and discharged through a garbage ejector.

Any one of these items could be a subject of a lengthy discussion. Many of the problems and solutions have no relevance to the space mission. It is quite clear, however, that man, whether in outer or inner space, must eat and that failure to consider carefully all aspects of this need can have a profound influence on the completion of the mission.

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Psychological Effects of Substantial and Appetizing Menus for Submarine Personnel

CHARLES F. GELL

Submarine Medical Research Laboratory

Comparing the feeding capabilities of a modern submarine with those of a projected spaceship is, to a large degree, like comparing a good-sized restaurant with a standup coffee shop. At this stage of development there is little to invite comparison other than that in both the submarine and the space vehicle there are men confined who display the usual human trait of enjoying good food and being unhappy if their food is unpalatable.

In the Navy ships are described as "taut ships," "happy ships," and "good-feeding ships." Needless to say, a happy ship is also a good-feeding ship because, as we all know, food tastefully prepared and in comparative abundance is quite a morale factor insofar as all military men are concerned whether ashore or afloat.

The modern submarine has rather complete hotel facilities, which include a kitchen, a fresh meat freezer, an ice cream machine, a bakery with bakery goods available daily, sufficient storeroom space to carry large amounts of food stores, relatively adequate dining space, and even background music. The ship's cooks have the French chef attitude; that is, they try to titillate and stimulate the appetites of the crew. When we compare this with the present day spaceship and its inconveniences, plus the disadvantages that the weightless state imposes on the eating process for the astronauts, we have a rather weighted case for the submarine, which will require many years of further development of spaceship technological engineering to equalize.

Some reports of the feeding habits of submariners have been rather disquieting. Two reports, one as early as 1949, and one in 1951, said that submariners were great between-meal snackers and that their diet was largely carbohydrate with a great preference for sweets. These reports were not supported by data, and, in fact, were merely narrative observations of professional men riding in submarines on a temporary basis.

Although, given an open icebox 24 hours a day, there is a great tendency for fat boys to get fatter, certain feeding patterns appear to modify the feeding format of the average submarine sailor. As an example, while a submarine is a relatively large vessel, the cubic space for each man is definitely limited. The space for a man is 5 cu yd on an FBM type and only 2 cu yd on a fleet type. This relatively constricted space can very well affect the individual's physical exercise habits significantly so as to reduce his energy output, and in turn, reduce food requirements. A relatively old study conducted in 1949 which used oxygen consumption as an index of calorie requirements reported that 2400 calories per man was needed during a temperate-zone cruise in a fleet-type submarine. Shulte in 1951 (ref. 1) reported from the Submarine Medical Research Laboratory that an Arctic cruise of 42 days and a complement of 80 men utilized 4480 cal/man/day. Actually, a 5200 calorie equivalent per man of food had been provided. The average weight gain per man was $\frac{1}{2}$ pound.

Another factor that could have some influence in modifying eating habits on a submarine is the shifts in carbon dioxide concentration. Carbon dioxide tends to build up in a submarine between air scrubbings. There are some 200 particulate substances in the air which, with the day-to-day slight pressure variations of the various gaseous substances, may have some unknown effects upon appetite and food preferences.

Still another factor that may affect food intake by the individual is that in submarines the olefactory stimulus is relatively high. The difference threshold (JND, "just noticeable difference") is correspondingly high so that it takes a "wallop of odor" for the submariner to say, "I smell something." The odors of stale cigars or freshly peeled onions are not ordinarily noticed because the denominator of Weber's fraction is so high:

$$\frac{\text{Delta I}}{\text{I}} = \frac{\text{(Noticeable increment)}}{\text{(Absolute level of smell)}}$$

An interesting research area that has not been fully exploited is, what effect does the high absolute olefactory stimulus level have upon gustation in view of the intrinsic relationship of the two sensory modalities?

PSYCHOLOGICAL RELEVANCE OF FOOD

When asked why they volunteered for submarine service, 221 enlisted men gave the following reasons (ref. 2): Identification with a better class of men, 80 percent; extra pay, 61 percent; good food, 34 percent; educational opportunities, 25 percent; and thrills and excitement, 24 percent. Data pertaining to the prevailing beliefs and opinions related to food have been collected. For example, the response distributions of 185 officers and 256 enlisted men to the statement, "I believe the chow the submariners eat is the best you'll find anywhere in the Navy," indicated that 85 percent of the officer sample and 90 percent of the enlisted sample responded "true" (ref. 3). Along similar lines, when enlisted men who were qualified submariners and those who failed to qualify were asked what aspects of submarine life they most liked, the percentage distributions listed in table I resulted (see ref. 4). (The number of responders is indicated by f.) It can be seen in table I that the fifth most frequently mentioned "most liked" aspect of submarine life was the food served aboard the submarine. It should be noted that a larger portion of the sample of 175 men who were disqualified or failed to qualify for any number of reasons indicated that the food was a "much liked" aspect of submarine life than of the sample of 186 men who qualified.

TABLE I. -ASPECTS OF SUBMARINE LIFE REPORTED AS MOST LIKED BY QUALIFIED AND DISQUALIFIED SUBJECTS

Most-liked aspect	Qualified group		Disqualified group	
	f	%	f	%
Close interpersonal relations	49	26	32	18
High-caliber personnel	27	15	34	19
Good duty	27	14	15	9
Money	26	14	17	10
Food	13	7	22	13
Friendship	8	4	14	8
Travel and adventure	5	3	8	5
Working conditions	4	2	9	5
Operations	4	2	8	5
Morale	7	4	1	1
Other things	16	9	15	9
Total	186		175	
Chi square	18.52			
p (9 df)[a]	< 0.05			

[a] Since one of the expected values for morale was less than 5, the last two categories were combined, leaving 9 df.

FOOD PREFERENCES OF SUBMARINERS

Amounts and Kinds of Foods Consumed

The laws of physics relating the submarine's buoyancy to its mass and volume require that approximations of the expected consumption rate of foods of various weights be available prior to a long-submerged cruise. Examples of data of this kind are available. For example, in an older, diesel-powered Guppy II type submarine during a 42-day patrol, 87 men consumed 3547 lb of meat (21 percent of total), 6219 lb of vegetables (38 percent), 2137 lb of cereal (13 percent), 1132 lb of dairy products (7 percent), 943 lb of fruit (6 percent), 1038 lb of sweets (6 percent), 445 lb of legumes (3 percent), 356 lb of fatty foods (2 percent), and 726 lb of miscellaneous food products (4 percent). Although total food-consumption data from modern nuclear submarines are not available, on the 85-day submerged world circumnavigation of the Triton, the 225 officers, enlisted men, and civilian scientists consumed most of the 38 tons of provisions, including 1300 lb of coffee, 10 tons of meat, 935 lb of ice cream mix, 460 lb of cake mix, and lesser amounts of canned vegetables, bread, and so on.

Changes in Appetite and Food Preferences During Prolonged Submerged Cruises

Reference 5 contains individual subjective estimates of the daily food consumption of a random sample of the Nautilus crew during a 2-week submerged cruise. From the plots of averages for this sample of 30 men it appears that food consumption remained relatively constant although there was a great deal of individual variability within the group from day to day as the cruise progressed.

In the decade since 1959, more than 40 Fleet Ballistic Submarines (FBM's) have been commissioned. Manned by two crews of approximately 125 officers and enlisted men, this class of submarines has become the central focus for a great deal of research, including appetite and dietary research. Therefore, the rest of the paper will present data collected from FBM's during protracted submerged cruises in excess of 50 days.

When a dietary study was conducted on board the USS Nathan Hale (SSBN623) during one patrol, 50 enlisted volunteers provided data concerning daily food intake, daily meal and snack distributions, weekly appetite changes, weekly food preferences, pure taste thresholds and body weight values. These data (abstracted and slightly modified from ref. 6) are given in table II.

TABLE II.-SUBJECTIVE EVALUATION OF APPETITE DURING EACH WEEK OF STUDY

Week	Appetite										Number of subjects, N
	Much better		Better		Same		Worse		Much worse		
	f	%	f	%	f	%	f	%	f	%	
1	1	2	7	15	37	79	2	4	0	0	47
2	2	4	5	11	30	64	10	21	0	0	47
3	0	0	2	3	51	84	8	13	0	0	61
4	1	2	5	10	31	63	12	24	0	0	49
5	0	0	5	10	33	67	9	18	2	4	49
6	1	2	5	10	32	67	8	17	2	4	48
7	1	2	3	6	37	75	7	14	1	2	49

It is seen that, in general, from two-thirds to three-fourths or more of the crew reported that their appetite remained the same. However, as the cruise progressed disproportionately more of the sample reported their appetite to be worse than reported it to be better. Responses to a a direct question pertaining to which meals a man characteristically ate indicated that as the submerged cruise progressed more people missed the noon and evening meals while fewer missed breakfast.

Some rather gross information pertaining to changes in specific food appetite during extended periods of submergence can be inferred from a comparison of the relative frequency with which the same sample of crew members indicated the "best" and the "least liked" foods at different times during a 7-week cruise. These data pertaining to food preferences (abstracted and slightly modified from ref. 7) are contained in table III.

TABLE III. -BEST AND LEAST LIKED FOOD SELECTIONS

Foods	Prepatrol (control)		Second week		Fifth week		Seventh week	
	f	%	f	%	f	%	f	%
Best liked selections								
Meats	115	74.2	117	81.8	119	90.9	108	78.3
Green-yellow veg.	19	12.3	9	6.3	10	6.8	11	8.0
Carbohydrate veg.	14	9.0	13	9.1	12	8.2	11	8.0
Legumes	2	1.3	2	1.4	2	1.4	2	1.4
Desserts	5	3.2	2	1.4	4	2.7	6	4.3
Total Selections	155	---	143	---	147	---	138	---
Least liked selections								
Meats	23	16.8	18	13.6	0	0.0	16	12.9
Green-yellow veg.	82	59.9	65	49.3	66	57.4	57	45.9
Carbohydrate veg.	23	16.8	37	28.0	38	33.0	40	32.3
Legumes	9	6.5	12	9.1	11	9.6	11	8.9
Total Selections	137	---	132	---	115	---	124	---

The authors point out that the "most liked" and "least liked" foods are consistently meat and vegetables, in that order. Mentioned also is the possibility that carbohydrate-type vegetables are less liked as the cruise progresses.

In short, the report concluded that in general the hunger motivation of submariners is not remarkably changed on patrol. The changes that do occur are difficult to relate to any one aspect of the environment, but, in any event, are of a nature not considered alarming.

Additional data bearing on the question of specific food preferences are contained in an FBM study already mentioned (ref. 6). The authors simply asked the 50 men to answer the question, "If you could order dinner from (this) menu, what would your choices be ?" Frequency distributions of these choices for each week of the course are abstracted in table IV.

TABLE IV.-ANSWERS TO QUESTIONS "IF YOU COULD ORDER DINNER FROM (THIS) MENU, WHAT WOULD YOUR CHOICES BE?"

Food item	Number of men choosing item in week-						
	1	2	3	4	5	6	7
Appetizer							
Kadota figs	3	6	4	4	5	5	4
Seafood cocktail	35	36	38	41	37	36	37
Herring with sour cream	3	2	3	0	4	4	4
Salad							
Tomato aspic	16	13	16	17	16	17	16
Avocado	16	17	15	17	17	17	18
Red kidney bean	11	14	15	13	14	12	12
Soup							
Cream of tomato	13	16	15	17	21	14	14
Beef broth	23	20	21	23	18	20	26
Potato	8	9	10	9	10	13	7
Entree							
Spaghetti	22	24	26	25	24	22	27
Cold cuts	15	14	15	16	16	15	14
Pork sausages	7	7	6	8	9	10	7
Vegetables (2 choices)							
Rice	8	8	6	9	10	8	9
Spinach	15	15	18	11	11	13	13
Carrot	7	5	3	7	7	7	5
Cabbage	5	8	7	10	11	8	8
Corn	29	24	26	24	23	29	28
Broccoli	10	15	13	16	16	16	16
Potato	7	8	12	12		7	10
Beverage							
Black coffee	20	22	22	25	27	26	26
Coffee with sugar	16	15	13	15	14	13	15
Coffee with cream	5	7	10	6	7	5	6
Coffee with cream and sugar	2	11				1	
Dessert							
Banana pudding	28	31	28	29	26	31	29
Assorted cheeses	11	9	13	13	14	10	12
Assorted nuts	6	5	5	5	9	6	7

CONCLUDING REMARKS

It can reasonably be assumed from a review of the data presented in the present paper that:

(1) The Navy apparently has done well by its submarine sailors in the matter of supplying abundant and appetizing food on prolonged cruises.

(2) Although food does not seem to be a major concern to the submarine sailor, it is one in which critical attitudes could arise should it degenerate from its present high quality. One rarely compliments Mom's Sunday dinners because they are supposed to be good.

(3) Except for moderate deviations, the ingestion of food aboard a submarine seems to be not immoderate even though the icebox is always open. Choice of foods seem to be of a normal and satisfactory character. Between-meal snacking is not overdone.

(4) No specific submarine literature has been unearthed detailing erotic eating habits and preferences such as may be found in some confirmed neurotics. This, no doubt, is due to the procedure for the selection of potential submarine sailors, which is quite thorough.

It would appear that, until NASA is capable of engineering a rotating space ship which can provide a moderate G loading in its outer periphery, feeding in space will be unsatisfactory. Hopefully, residence on the Moon will provide a more congenial atmosphere for eating.

The results of the study in reference 6 are best presented by quoting the abstract of that report:

"Some previous reports indicated that submarine crewmen eat abnormally high amounts of carbohydrates and that their diet habits include many between meal snacks. If true, these facts would lead one to expect great oral health problems in submariners; particularly in those on patrol for long periods. A detailed dietary and oral health study was done aboard the USS Nathan Hale (SSBN623) to evaluate the problem. The findings essentially disprove the previously reported beliefs. It was found that the FBM crew ate an essentially well-rounded diet with only a moderate amount of between-meal snacking."

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Tektite I Food Developments

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General Electric Co.

Tektite I is a multiagency and industry program jointly sponsored by the Office of Naval Research, the National Aeronautics and Space Administration, and the Department of Interior, with participation by the U. S. Coast Guard. The prime contractor is the General Electric Co., which furnished the undersea habitat and assisted in program planning and scientific mission coordination.

On February 15, 1969, four U. S. Department of Interior scientists descended to the ocean floor in Great Lameshur Bay in the U. S. Virgin Islands and occupied the habitat. By March 18, 1969, the four aquanauts had established a new world's record for saturated diving by a single team. On April 15, 1969, the aquanaut team returned to the surface with over 58 days of marine scientific studies; this is nearly double the previous saturation diving record.

General Electric Co. engineering developed the underwater habitat with the emphasis on simplicity of design for living, operations, and maintenance. Food preparation, appliances, cooking, and cleanup were expected to require minimum time, so that the aquanauts could apply more time to the scientific mission. The scientific mission involved in situ studies of undisturbed fish, lobsters, and other biologic and geologic specimens in Lameshur Bay. (Perhaps the tempting sight of fish and lobsters swimming by changed the crew's "psychological needs" for food, but that is the latter part of this sea story.) An overall description of the scientific mission and habitat will give a picture of the program, the system, and the constraints on food.

SCIENTIFIC MISSION

Tektite I was man's first, long-term scientific mission into the sea. Almost every aquanaut activity had scientific significance, from the analysis of sleep to zooplankton distribution studies. The scientific mission categories were marine biology, marine geology, biomedical evaluations, and behavioral studies of an isolated group of men under stress. Stresses included unknown hazards of long-term saturation diving as well as the sharks and barracuda. The numerous similarities between the hydrospace and aerospace programs may be summarized by stating that in both the crews must take their environment along.

HABITAT DESCRIPTION

The habitat consists of two, interconnected, 18-ft-high cylinders installed on a base section. Each cylinder is $12\frac{1}{2}$ ft in diameter and is divided into upper and lower compartments. All compartments have 2-ft-diameter plexiglas observation ports. Atop one cylinder is an observation cupola for additional scientific observation of underwater life.

The Surface Control Center supplies 11.6 CFH of air to the habitat, which maintains the oxygen level at 160 mm partial pressure. This exchange of air is 0.34 percent of the total volume. One can consider the habitat a 99.66 percent closed atmosphere. Carbon dioxide (CO_2) is scrubbed with baralyme. That sea-water pressure in the main hatch is equaled by the $2\frac{1}{4}$-times-normal atmospheric pressure of the habitat, permits this hatch to remain open throughout the mission.

Aquanauts enter the habitat by opening the shark cage door, swimming through the base tunnel, and climbing a ladder through the main hatch into the wet room. Scuba equipment and wet suits are removed, rinsed, and stored in closets. As cleanliness and dryness are very important to health, a shower, hair dryer, and clothes dryer are put to constant use. Wet and dry laboratories permit dissection, preparation, and examination of specimens. The water, air pressure, communications, and electric umbilicals from the Surface Control Center enter the wet room near the ladder of the engine room.

Upon climbing the ladder into the engine room, one sees the large Environmental Control System in the center. It contains heat-exchanging, dehumidifying, filtering, and CO_2 scrubbing systems. The electric power system and controls, a large food freezer, a wash basin, a toilet, and a hot-water heater are installed along the room's perimeter. The interconnecting tunnel leads to the bridge.

The bridge provides for station monitoring, communications, and scientific equipment. A NASA atmospheric analyzer continuously monitors nitrogen, oxygen, water-vapor, and CO_2 partial pressures. Portable backup atmosphere monitors are used to check trace gases such as carbon monoxide (CO) and acrolein. A master communications panel interconnects each habitat compartment, the Surface Control Center, and way stations in the surrounding water. Additional communications systems include open microphones, a sound-powered phone, and a regular phone for talking to surface personnel. A dual television display is used to monitor crew activities in each compartment and nearby underwater areas.

Down the ladder from the bridge are the crew quarters. This section contains four bunks, refrigerator-freezer and oven-stove combinations, and a counter with a built-in sink. Radio and television provide evening entertainment while the crew sit on folding chairs and eat dinner at a fold-away table. Underneath the rug is an emergency hatch which permits the crew to escape to nearby way stations with emergency air bottles.

RESEARCH TEAM CONCEPT

Crew participation began early in the program when the research team concept was developed "to encourage team effort and spirit with the single purpose of a successful mission" (ref. 1). Initially, this concept was designed so that the crew could contribute to all phases of mission planning and operations. However, interest spread and all the engineers were soon deeply involved in developing Tektite on schedule. The time between proposal submittal and the start of the operational mission was $14\frac{1}{2}$ months.

FEEDING SYSTEM

Initial System Constraints

Food equipment originally consisted of a combination "Griddle and Pressure Cooking Fixture" developed for torpedo boats during World War II. The freezer stored 16 cu ft of food and there was an additional 2.2 cu ft of frozen food stored in the combination refrigerator-freezer.

Since the habitat environment was approximately a 99.66 percent closed atmosphere with limited scrubbing and filtering capability, cooking was limited initially to heating food, pressure cooking, occasional baking, and broiling precooked meats. Pressure cooking was eliminated during a test session called the "live-in." The cooking fixture was too complicated and all cooking would be under pressure in the regular mission regardless of the cooking vessel in use. Frying food represented a primary source of contaminants. In the frying process, animal fats were broken down into CO and acrolein.

Early in the closed-atmosphere studies by the General Electric Co., CO was found to appear and slowly increase in a two-gas spacecraft simulator. Detailed investigations found that small amounts of CO were continuously produced in the body and exhaled (ref. 2). Sjostrand demonstrated that it occurs through the breakdown in hemoglobin (ref. 3). Man exhales about 10 cc of CO per day. If the oxygen content is lower than normal, and the CO_2 content increased, the formation of CO is increased (ref. 4).

The four aquanauts could produce 40 cc of CO per day. Theoretically, on the basis of human-produced CO alone, the Air Force safety limit of 25 ppm for continuous occupancy would be reached on the 60th day. Actually, the CO level stabilized early at 20 ppm and remained there throughout the mission. The 0.34 percent hourly change in the habitat atmosphere was given as the probable reason that CO did not build up and pass safety limits.

Menu

The menu was developed through a series of iterations beginning with a 5-day repeating menu. As expected, the aquanauts complained of no variety and the vegetables were evaluated as "like occasionally."

An Air Force "food for space travel" report (ref. 5) had a 30-day mission menu that was distributed to the crew for comment. The crew commented, "This is more like it, but couldn't we have chili, enchaladas, tacos and tamales ?" Two members had started Sealab III training and had heard that previous Sealab crews lost their sense of taste during the mission. Their theory was that spicy food would help prevent everything from having a bland taste. These spicy foods were assigned to snack provisioning, since it was too late to obtain accurate caloric contents. An additional request was that 25 percent of all main meals be frozen TV dinners because 3 hours of swimming would make the crew too tired to prepare meals.

Final revisions to this menu occurred during the 3-day training period in December. Fresh eggs were requested, but no one knew if they could survive rapid pressure changes. At least one meal each week would be fully prepared by the crew, and would include muffins, biscuits, or layer cakes. Again no one knew whether standard batter would rise properly in the oven. Following this meeting, one food company searched the literature and found that baking under higher atmospheric pressures had never been reported. They recommended adding baking powder to the next batter if the first cake did not rise properly.

Training

Two pamphlets, "Basic Facts in Frozen Food Preparation" and "Basic Food Concepts," were developed and included in the training manual. Basic food concepts were emphasized to assure that proper nutrition was understood and applied to underwater diving. (For example, eating carbohydrates with animal protein prevents the liver from rendering animal protein unless for body growth and maintenance.) This led to discussions of how to keep warm while immersed in cool water for several hours. Sugar and carbohydrates were not the answer. The U. S. Navy diving manual (ref. 6) warns that hyperglycemia could occur by eating too many starches and sweets and thus causing an excess of insulin. Eating protein foods like meat beforehand will provide a longer and steadier supply of dextros and also provide extra heat through animal protein digestion.

Caloric Requirements

On the basis of a maximum swimming rate of 1 mile/hr, the aquanauts would expend 360 calories. One thousand additional calories in snacks were considered sufficient as the crew would neither be continuously swimming nor be in the water for more than 3 hours daily. The minimum of water temperature of 80° F was not considered an important caloric factor since the crew wore wet suits.

Food Selection

Since frying was not permitted, all fried foods were purchased frozen ready to eat. Frozen-food priorities were also given to veal, steak, and TV dinners. Although food priorities were supposed to be complete before the mission started, several food items were missing, including dozens of fresh eggs, 48 TV breakfasts, 9 half-gallons of ice cream, and 24 pounds of hamburger, cake, and bread. This resulted in an interesting change that started toward the end of the first week of the mission as described in the following anecdotes:

> Feb. 16, Sunday evening, the crew was unable to find Mexican food. The test director told them where it was stored. Note: the crew did not follow the menu but went to snack provisions, an approved procedure since daily preferences are more important to the crew.
>
> End of first week, the crew requested the missing fresh eggs.
>
> Second week, an apple pie suddenly appeared on the television monitors. This pie was sent to the habitat by the dumbwaiter. Additional eggs were requested along with milk and vegetables.
>
> Third week, the crew began requesting more fresh foods. At the end of the first month an aquanaut's wife prepared a beef stroganoff dinner for the crew to celebrate their 30th day underwater.

During the second month, food lists were sent to the surface on the average of three times each week.

Preliminary reports from the crew indicate that eating turned out to be their major entertainment. Pre-prepared meals were poor. Individually prepared meals were good. There were intermittant annoyances with the refrigerator and stove. We do not know presently whether these annoyances were failures or a function of the high atmospheric pressure in baking.

If Tektite were to be designed over again, the following changes would be made:

(1) Add a fast potato baker, a toaster, and a waffle iron to the cooking equipment.

(2) Develop recipes designed to turn canned and frozen foods into more appetizing meals.

(3) Monitor food shipments to see that only frozen foods are frozen, refrigerated foods are kept cool, and nonfreezable food kept properly.

(4) Provide a food expert to develop a food subsystem.

In addition to these changes, for the future, consider the following questions:

(1) How long can different frozen foods remain safe to eat and palatable ? Could frozen eggs become infected with Salmonella ?

(2) What part of the appetite is a function of food preparation and cooking odors ?

(3) Does the complex sense of taste really change ?

(4) Should cooking be assigned as the primary activity of one crew member ?

(5) Space scientists are concerned about crew inactivity on such long-duration space missions as a voyage to Mars. Food preparation and cooking could use 6 hours every day. Is this the answer ?

Future interplanetary spacecraft and orbiting space stations are expected to be large enough for the crew to have canned foods for many meals. Tektite started in this direction, but the challenge is to provide technical advances, training, recipes, and menus to make basic canned foods and frozen foods into delicious dinners in closed atmospheres.

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Food Plans for Sealab III

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The food service planned for Sealab III is as interesting as that planned for space flights. Whereas most foods used or planned for use during space missions are considered "tomorrow foods" by the general public, all foods planned for Sealab III are "today foods" because they are available for restaurant and institutional feeding and many are even available in supermarkets for home use. Even though Sealab III will have no rated cook on board, and despite the cooking limitations imposed by the pressurized helium-nitrogen-oxygen atmosphere, aquanauts will eat meals of fried chicken, hamburgers and French fries, spaghetti and meat balls, chili, beef stew, and many other favorite foods of Navy men.

The need for variety and for familiar foods has been stressed by Captain George Bond, Chief Medical Officer and Principal Investigator for the Sealab III phase of the Navy's man-in-the-sea program. Since the Navy Subsistence Office had not participated in food plans for Sealabs I or II, Captain Bond has explained in detail how the experience gained during these operations had proven the importance of good food and an organized food service system. For Sealab I there was no clearly defined food service program and no planned menu. Because of the many technical problems to be resolved before the experiment food was of minor concern. Someone simply sent one of the divers to buy enough canned foods to provide meals for 3 weeks under the sea. The shopper, who happened to be extremely fond of Mexican foods, stocked Sealab I with cases of chili con carne and tamales, but with little else. It was probably fortunate that bad weather conditions shortened the 21-day experiment to 10 days, because the men had had more than enough of this food.

Although a reasonably varied menu consisting of canned foods and some dehydrated foods was used for Sealab II, the provision of nourishing, satisfying meals was, according to Captain Bond, one of the most annoying problems encountered in the 45-day operation. There were no organized meals; the divers prepared food when they wanted it, perhaps six or seven times a day! From time to time the men requested that some roasted, grilled, or fried meats be sent down to them because they were tired of meat-and-gravy combination dishes. Their pancakes scorched on the bottom and wouldn't cook on the top, fingers and toast burned, and peanut butter consumption rose steadily. Although the aquanauts averaged a 5-lb weight gain, there was general dissatisfaction with the food.

In May 1966, when the Navy Subsistence Office was requested to develop a food service system for Sealab III, Captain Bond and Comdr. Jackson Tomsky, On-Scene Commander for

Sealab III, briefed us about future plans and furnished some ground rules which would affect the food service system.

For successive 12-day periods, five 8-man teams would live in and work out of a habitat in ocean depths of 450 to 600 ft off San Clements Island, Calif. During the 60-day operation, experiments in oceanography, physiology, deep-sea ocean salvage, equipment performance, and construction would be carried out. Because of the physical demands, the complexity of tasks the teams would undertake, and the psychological effects of living under these unusual conditions, Captain Bond requested that meals furnish 4500 calories per man per day, be satisfying, and be as normal as possible within the following limitations:

(1) There would be no rated cook; the aquanauts would take turns preparing meals.

(2) Since there would be a predominantly helium atmosphere in the habitat there would be no fresh egg cookery, no frying, and no grilling, in order to avoid production of toxic gases in the Sealab environment. The helium atmosphere would also dull the men's senses of smell and taste.

(3) Foods would be under pressures of up to 270 psi; cans containing dry lightweight foods would crush to the point that they could not be opened.

(4) There would be only limited storage space for food: 7 cu ft chill, 27 cu ft freeze, and 75 cu ft dry storage. Replenishments were to be held to the minimum that would not seriously compromise the makeup of the menu.

In addition to menus, preparation instructions, loadout and replenishment schedules, recommendations on food preparation equipment, and coordination of requisitioning, procurement, and positioning of all food supplies were needed.

Figure 1 shows Sealab III. The overall length is $62\frac{1}{2}$ ft; its width, 19 ft; its height, 38 ft; and its weight, 299 tons. The galley is in the center section. Dry storage is overhead in the section to the right of the galley, and the freezer is in the lower right section. Galley equipment consists of an infrared oven, a 4-burner electric hotplate, a small refrigerator, and hot and cold running water. The sleeping/dining area is in the section to the right of the galley. Figure 2 shows an artist's conception of the surface support ship and Sealab III. The USS Elk River (IX - 501), built originally as a Landing Ship, Medium Rocket, was modified to support underwater programs such as Sealab III. This ship provides stowage for the various gases required in the Sealab experiment, the command and communications center for Sealab III, the physiological monitoring and medical center, two deck decompression chambers, and two personnel transfer capsules. Figure 3 shows the deck decompression chamber. The plan calls for four men to enter each chamber for compression to a pressure of 270 psi (requires 24 hr). Then, four men will enter each pressurized personnel transfer capsule (fig. 4) for descent to the habitat. When they arrive there, the Sealab III Food Service System will be put to the test.

In developing any food plan, the first logical step is to determine relative acceptance of different foods. Since the Navy Experimental Diving Unit is located about a block away from the Navy Subsistence Office, it provided an ideal, though unusual, site for a test galley and, in addition, a cooperative group of taste-test panelists: Navy divers in training for Sealab III. The first acceptance tests conducted were on the excellent freeze-dehydrated entrees developed by the Army

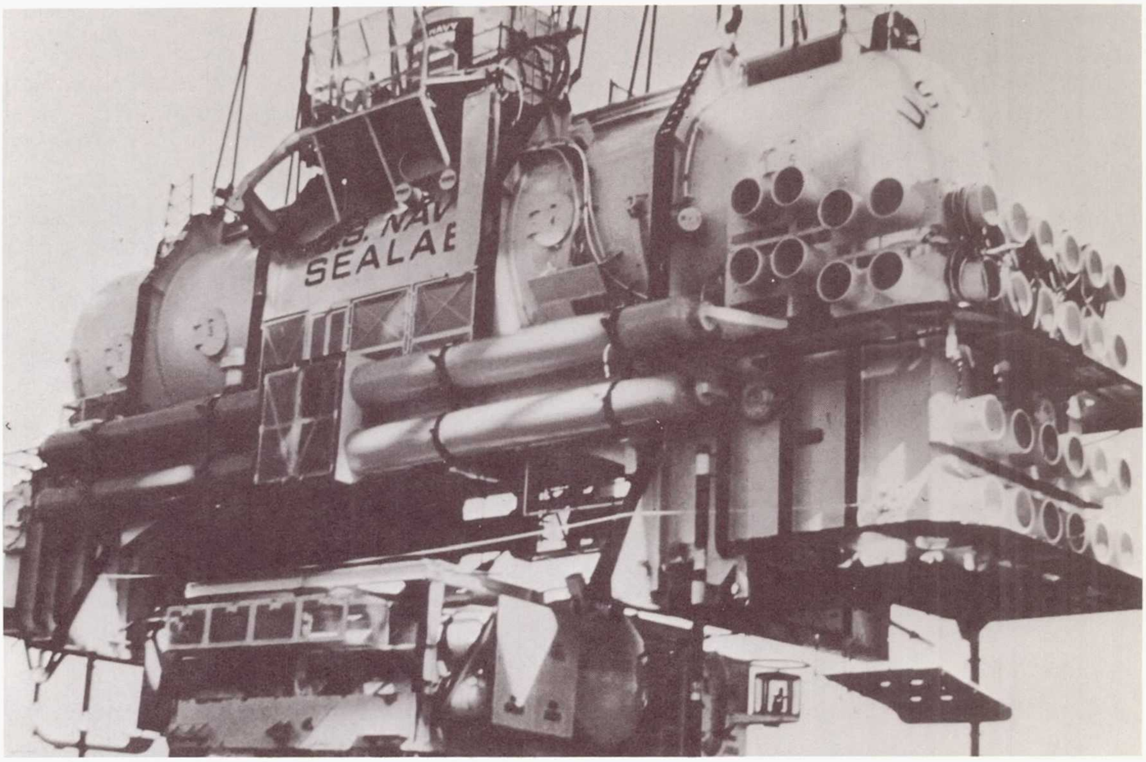

Figure 1. -Sealab III.

Natick Laboratories for the Long Range Patrol Ration. These entrees were ideal from the standpoints of stowage, stability, and ease of preparation. Although the divers thought the entrees were amazingly good, they rejected them completely as far as Sealab III food plans were concerned because of the small piece size and (in their opinion) the similar appearance of different entrees.

Next, the acceptances of precooked frozen entrees and selected canned entrees were tested. For maximum speed and ease of reconstitution of these entrees, a microwave oven was first necessary. Microwave tubes were tested under simulated atmospheric conditions of Sealab III and were ruled out because helium seepage rendered them inoperable. An infrared oven was then checked out and approved for use. Using the oven, we prepared and conducted acceptance tests on selected precooked frozen and canned entrees. The divers rated these entrees highly acceptable and stated that they would be willing to eat some of them as often as twice a week, and many, as often as once a week.

For maximum stowage efficiency and for simplification of the food service system aboard Sealab III, we developed a 6-day-cycle menu. Each team will repeat the cycle once during its 12-day stay on the bottom. Remembering that the Sealab II aquanauts had tired of meat and gravy

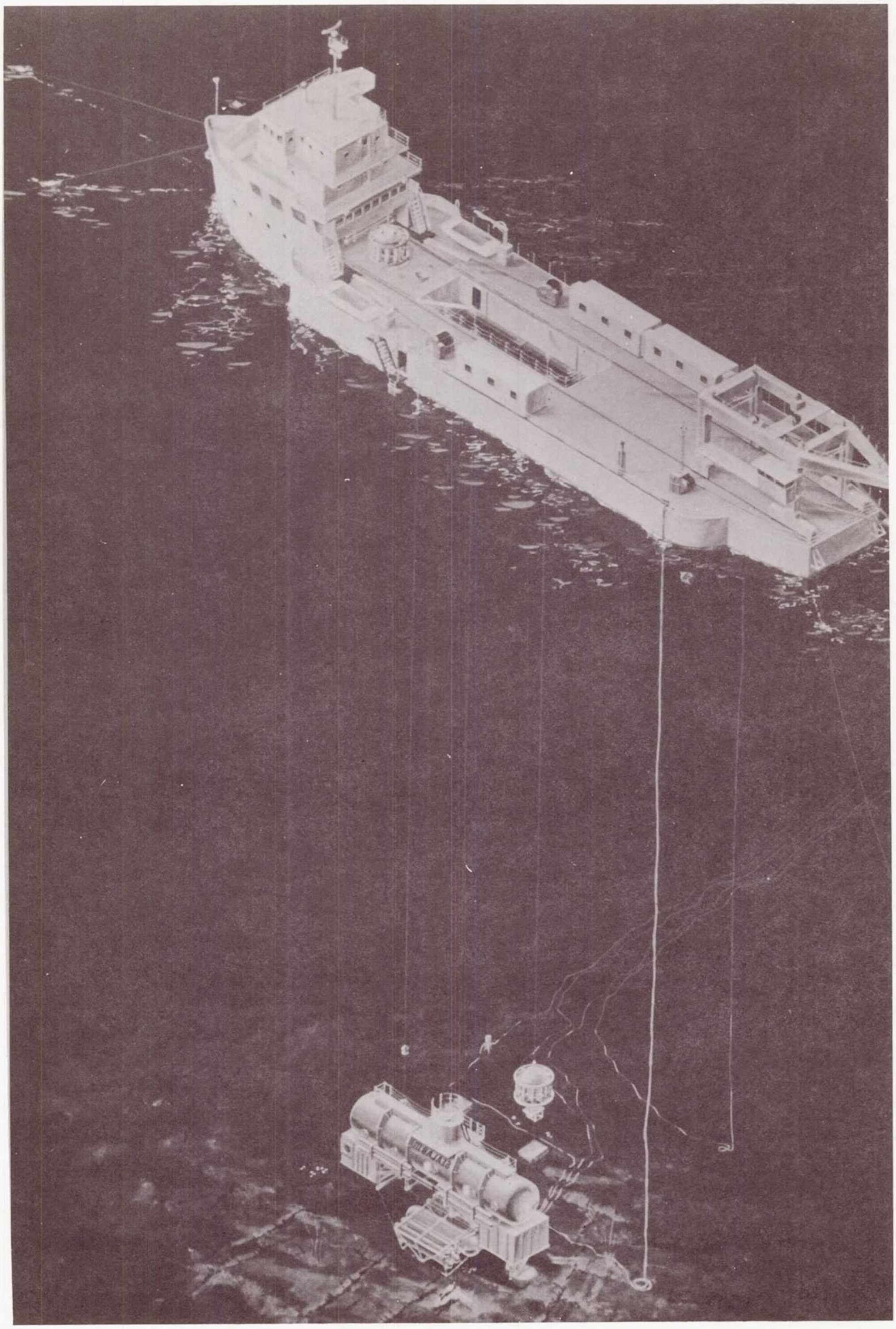

Figure 2.-Artist's conception of surface support ship and Sealab III.

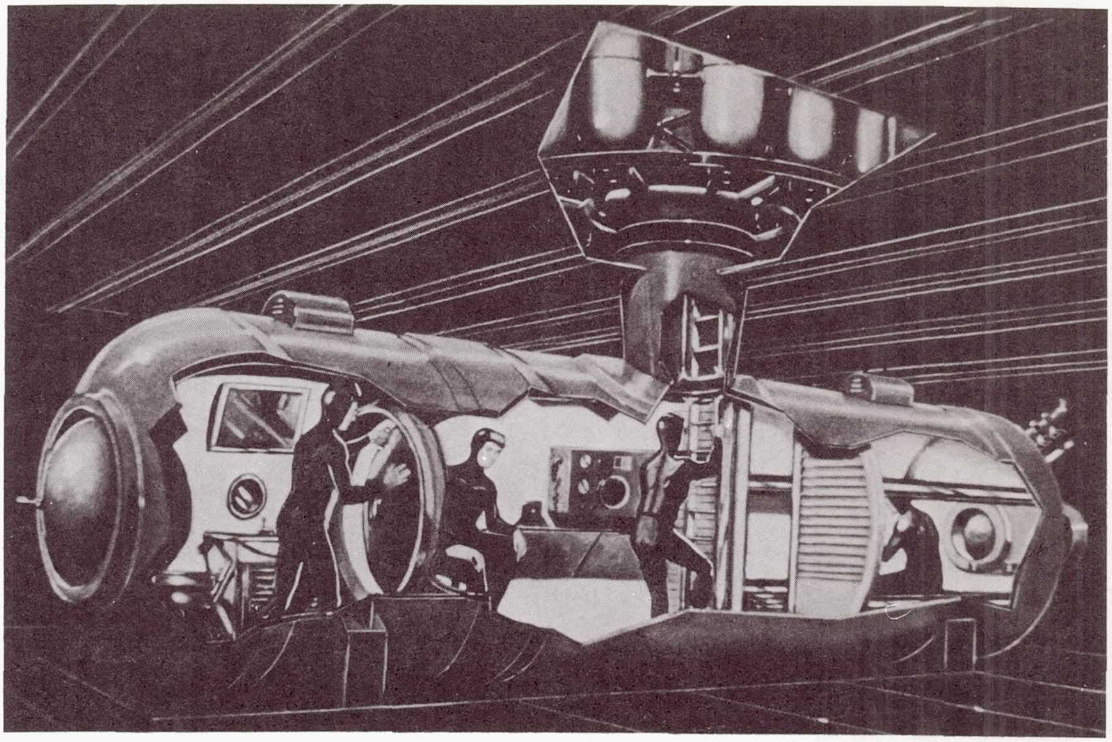

Figure 3. -Deck decompression chamber.

combinations, we made a special effort to find suitable precooked frozen or easy-to-prepare meats that were packed without gravy. The most easily obtainable and most common meat in this category was the frankfurter; another was boneless cooked ham. Two other popular entrees, fried chicken and hamburgers, both precooked and frozen without sauce or gravy, are also included in the menus and will help to satisfy the divers' desires for plain and familiar meats.

It was uncertain that we could serve hamburgers for awhile, though, because of a problem related to Sealab III's atmospheric conditions. When the precooked hamburgers were heated in the infrared oven, additional fat rendered off. Sealab medical officers were concerned that resulting acrolein production would be a problem in the Sealab III atmosphere. But we were determined to find a way to serve the aquanauts hamburgers, so we experimented. We found that placing the precooked frozen hamburgers in hamburger buns and wrapping them in aluminum foil eliminated the acrolein hazard. When the hamburger is heated, the fat renders into the bun. This method was tested in atmospheric conditions simulating those of Sealab III and no problems with acrolein resulted. Other entrees in the 6-day menu are pot roast of beef, chili con carne, beef shortribs, roast pork loin, roast turkey, Swiss steak, beef stew, and spaghetti and meat balls.

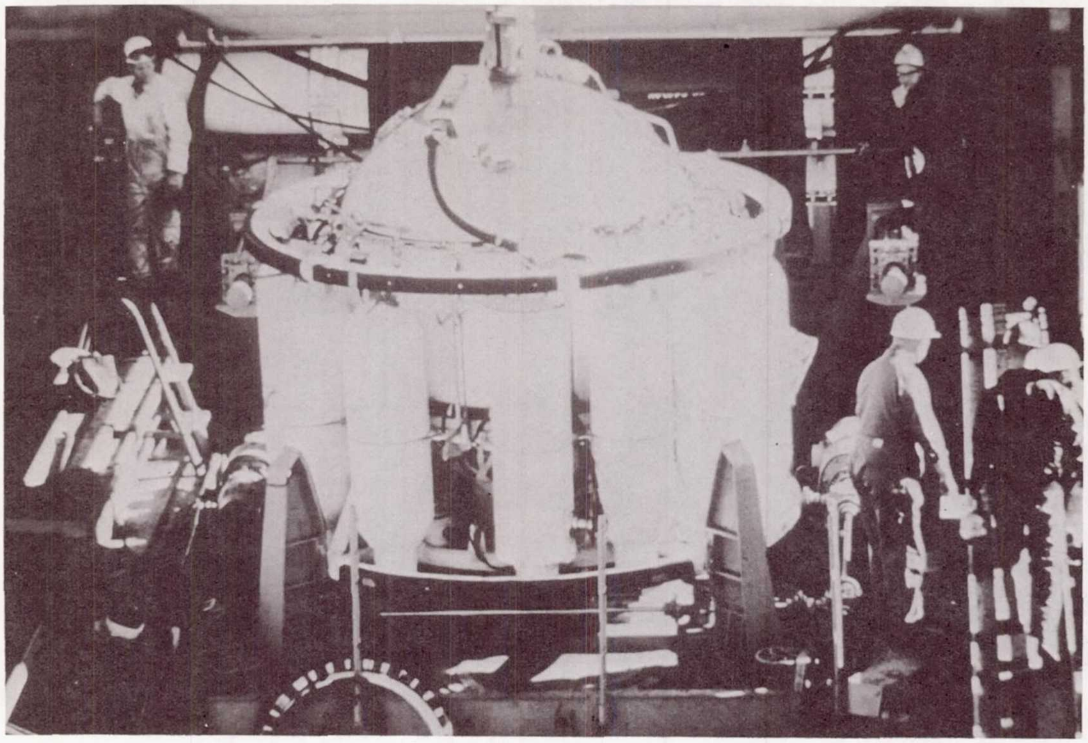

Figure 4. -Personnel transfer capsule.

Since fresh egg cookery was ruled out, breakfast menu planning was challenging. Although, after several failures, Sealab II aquanauts were able to prepare a "crepe" version of pancakes, we decided to take the work and worry out of their cooking with precooked, frozen pancakes. These, along with precooked frozen French toast, plain and cheese omelets, ham, and canned corned beef hash and creamed dried beef, will provide varied, hearty, and satisfying breakfasts.

The rest of the food items in the menus (vegetables, cereals, desserts, beverages, etc.) are all in either ready-to-eat or ready-to-heat-and-eat forms. Fresh bread and some pretrimmed fresh produce items will be furnished every 4 days by means of a pressurized container that is used to send mail and other supplies back and forth between the habitat and the surface support ship.

All dry-storage foods, frozen items to support the first three teams, and perishable bread and produce will be preloaded. Frozen foods for Teams 4 and 5 and perishable foods will be replenished according to an approved schedule.

The menus list items and quantities of each needed for 8 generous portions. Preparation instructions will guide each "cook of the hour" on what to do first and how to proceed, with step-by-step directions. The aquanauts will eat three regular meals together each day. A fourth meal, consisting of soup and sandwiches or snacks, will be available for each man to prepare when he wants it. Fruit juices, cocoa, milk, coffee, and tea are also provided in sufficient quantities for between-meal use if desired.

Daily weight checks on each aquanaut for 3 days before compression and for 3 days after decompression are planned. Other than weight check, no nutrition-related studies have been included in the physiological evaluations in Sealab III. No doubt there will be verbal reactions to the meals during the operation. In addition, in order to document the acceptance of individual menu items the aquanauts will complete food acceptance reports. An analysis of these reports along with data on usage of individual items will permit an objective evaluation of Sealab III's food service system.

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ADVANTAGES, PROBLEMS, AND EXPERIENCES OF IRRADIATED FOODS

EDWARD S. JOSEPHSON

U.S. Army Natick Laboratories

I appreciate having the privilege of attending the Aerospace Food Technology Conference and the opportunity to talk to you about irradiation-preserved foods. I shall cover a program supported by between $40 and $50 million of expenditures of the U. S. Government during the last 16 years and programs which, although not of this magnitude, are planned or are underway in 74 other countries.

The following quotation is from reference 1: "Soviet cosmonauts aboard the recent Soyuz 4 and 5 flights became the first men in space to eat irradiated foods. The four cosmonauts had with them radiation-preserved meats wrapped in polyethylene film, as well as dried meats in cans. On future flights, Soviet scientists expect to substitute irradiated vegetables, fruit salads, and dry soup mixes, as well as meats, for the vacuum freeze-dried foods which now constitute the basic diet of cosmonauts."

The Soviets see the advantages of irradiation-preserved foods in support of manned flights in space. I propose to present the current status of this process for food preservation so that you can decide whether, and to what extent, irradiated foods will fit into feeding systems for individuals and small groups in isolation and where resupply is not possible. (More information on the subject is included in refs. 2 to 10.)

IONIZING RADIATION

Definition

Ionizing radiation for food preservation is the employment of fast-moving subatomic particles or electromagnetic waves which are energetic enough to strip electrons from atoms or molecules of matter. Although there are a number of different classes of such radiation, only beta (or electron) and gamma radiations are of interest in food processing.

The way in which ionizing radiations act is not clearly defined. There are theories calling for direct hits, and those calling for indirect hits. Both of these types probably contribute to achieving the desired effect, which may be to inhibit sprouting of tubers during storage, to slow down the ripening of fruits, or to destroy microorganisms causing food spoilage. The direct-hit theory suggests that the nuclear rays (or high-speed electrons) strike the vital spot much in the same manner as a fast-moving projectile strikes its target. The indirect-hit theory suggests that the highly energetic particle subjects the molecule(s) near which it passes to an intense, transient electrical force. The organization of electrons within each molecule is disturbed and many molecules along the path of the particle become "excited" or ionized. In their highly reactive state, free ionized molecules enter almost instantly into reactions with one another and with neighboring molecules producing as their end products new substances strange to the chemistry of the cell. The unstable secondary products, notably free radicals and peroxides, relay the disturbance in turn to other molecules in the cell, thus enlarging the area and scope of injury.

Applications to Food Preservation

Some of the more promising applications of ionizing radiation to the treatment of food are shown in table I. At the highest irradiation doses, all food spoilage organisms and pathogens transmitted by food are killed; prepackaged meats, poultry, and seafood can keep for years without refrigeration and on the plate of the consumer will still have a degree of acceptance approximating that of fresh food freshly cooked. At the lowest irradiation doses, certain physiological functions associated with sprouting in tubers such as white potatoes and in bulbs such as onions will be disrupted; these foods will not spoil during storage for as long as 1 year because of sprouting. Exposure of fruits such as tomatoes, bananas, mangoes, and papayas to intermediate doses of ionizing radiation will slow down ripening, and give these foods an extended shelf life ranging from a few days to several weeks. One application not included in table I is the use of irradiation to shorten rehydration and cooking time of dehydrated vegetables. For example, with diced potatoes an irradiation dose of 8 megarads can shorten cooking time from approximately 20 minutes to less than 4 minutes.

Advantages

The irradiation process is attractive because there is only a slight temperature rise in the foods during the course of the treatment. It is considered a "cold process." The irradiated foods undergo minimal changes in texture, flavor, odor, and color so that on the plate of the consumer the irradiation-preserved food is almost indistinguishable from fresh food freshly prepared. The advantage of this process is that we can put freshlike food on the plate of the consumer on land, under the waters, in the air, and in outer space.

Another advantage of the process is its flexibility; that is, the process can be used to preserve a wide variety of foods in a range of sizes and shapes ranging from crates of potatoes to prepackaged flour in 50- or 100-pound sacks, to large roasts (beef, lamb, pork), turkeys, and hams, to sandwiches of sliced meat, fish, and chicken. The variety and dimensions of products that can be preserved by ionizing radiation fit in very well with present and anticipated future processing methods of the food industry. Astronauts and personnel at the bottom of the sea can have their meals and snacks in ready-to-eat form, in the form of slices or sandwiches, or as warm-and-serve or cook-and-serve items. Foods processed by ionizing radiation are compatible with the trend for greater convenience, simplicity in preparation, and reduction of labor in the kitchen. The shelf-life extensions without refrigeration are measured in days or weeks for certain fruits and vegetables and are from 3 to 5 years and possibly even longer in the case of meat, poultry, finfish, and shellfish.

TABLE I. -SOME POSSIBLE APPLICATIONS OF IONIZING RADIATION TO TREATMENT OF FOOD
[Information taken from ref. 2]

Group	Food	Main objective	Means of attaining objective	Dosage, Mrad
a	Meat, poultry, fish and many other highly perishable foods	Safe long-term preservation without refrigerated storage	Destruction of spoilage organisms and any pathogens present, particularly Cl. botulinum	[a]4 to 6
b	Meat, poultry, fish and many other highly perishable foods	Extension of refrigerated storage below 3^{o} C	Reduction of population of microorganisms capable of growth at these temperatures	0.05 to 1.0
c	Frozen meat, poultry, eggs, and other foods, including animal feeds, liable to contamination with pathogens	Prevention of food-poisoning	Destruction of Salmonellae	[b]0.3 to 1.0
d	Meat and other foods carrying pathogenic parasites	Prevention of parasitic disease transmitted through food	Destruction of parasites such as Trichinella spiralis and Taenia saginata	0.01 to 0.03
e	Cereals, flour, fresh and dried fruit, and other products liable to infestation	Prevention of loss of stored food or spread of pests	Killing or sexual sterilization of insects	0.01 to 0.05
f	Fruit and certain vegetables	Improvement of keeping properties	Reduction of population of molds and yeasts and/or in some instances delay of maturation	0.1 to 0.5
g	Tubers (e.g., potatoes), bulbs (e.g., onions), and other underground organs of plants	Extension of storage life	Inhibition of sprouting	0.005 to 0.015
h	Spices and other special food ingredients	Minimization of contamination of food to which the ingredients are added	Reduction of population of microbes in special ingredient	1 to 3

[a]There is evidence that a lower dose might suffice for certain cured products.

[b]A higher dose may be needed if pathogens with greater resistance to radiation are present.

With ionizing radiation we can provide foods high in nutritive value and foods high in morale value. We can provide better quality food than hitherto possible. The food can be disease free, that is, free of all pathogens associated with food-borne diseases. We can provide a larger variety of foods such as fresh fruits and shelf-stable meats and poultry which have the character of fresh food. Because the food can be prepackaged and precooked at one place prior to irradiation, the cost in money, time, and labor for food handling all the way to the ultimate consumer can be reduced. Further reductions in cost result from reducing requirements for refrigeration and refrigeration maintenance. Spoilage losses from insect infestation, sprouting, or refrigeration breakdown will be minimized. By providing a broader spectrum of foods through introduction of irradiated items, discord from food monotony, particularly during long voyages, will be reduced.

Legal Aspects

Ionizing radiation is the first entirely new method used to preserve food since Nicholas Appert discovered thermal canning in 1809. The irradiation process is the first major food-preservation method to appear since food regulatory agencies were established at the national level in many countries.

In the United States the food regulatory agency most directly involved is the Food and Drug Administration (FDA). In the case of meats and poultry, the Department of Agriculture (USDA) also has legal responsibility.

There are several statutes which control the use of ionizing radiation for food processing. Among the laws are the Food, Drug, and Cosmetic Act as amended in 1958. Under this law ionizing radiation is legally defined as a food additive. The Federal Meat Inspection Act and the Poultry Products Inspection Act have been on the books for a long time. In recent years, with the great interest in consumer affairs, we have seen passage in 1966 of the Fair Packaging and Labeling Act; in 1967, of the Wholesome Meat Act; and, in 1968, of the Wholesome Poultry Act.

The impact of the Food, Drug, and Cosmetic Act of 1958 is to outlaw all new food additives, including ionizing radiation, from commercial application. The law provides for exemption from this universal ban by petitioning the FDA for approval of new food additives. For food preservation by ionizing radiation, FDA's approval is required for each food processed in this fashion. The law also requires approval by FDA of packaging materials in contact with food during radiation processing.

Organizations Involved

Because of the high cost of developing the process for preserving foods by ionizing radiation and the uncertainty that petitions will be approved by FDA, most of the effort in the United States is sponsored by the U. S. Army and the Atomic Energy Commission (AEC). The Army's effort is primarily in the use of radiation sterilizing doses, i.e., doses above 1 Mrad. The AEC, on the other hand, is concerned primarily with applications of radiation doses below 1 Mrad.

The overall program in the United States is reviewed periodically by the Joint Committee on Atomic Energy, Congress of the United States. The Interdepartmental Committee on Radiation

Preservation of Foods, consisting of ten departments and independent agencies of the government (NASA is a member) assists in promoting early commercialization of radiation-preserved foods.

Ionizing radiation for food preservation is considered to be an important peaceful use of atomic energy. It is, therefore, part of the President's Atoms for Peace Program.

At the international level the following three agencies of the United Nations are concerned with preserving foods by ionizing radiation: the International Atomic Energy Agency, the Food and Agriculture Organization, and the World Health Organization.

Status

Except for proof of wholesomeness convincing to FDA, technology is sufficiently developed to support petitions for the irradiation-sterilized products listed in table II. These foods can vary in degree of doneness from partially cooked to ready to eat. Other irradiation-sterilized foods in various stages of development are ground beef (hamburger), pork sausage, corned beef, frankfurters, turkey, lamb, fish fillets, and prefried bacon.

TABLE II.-MINIMUM RADIATION DOSE REQUIREMENTS (MRD) FOR IRRADIATION-STERILIZED PRODUCTS

Product	Irradiation temp., $^{o}C \pm 10^{o}$ C	MRD, Mrad
Beef	-30	4.66
Beef	-80	5.70
Chicken	-30	4.48
Ham	-30	3.66
Ham	Ambient	2.90
Pork	-30	5.09
Pork	Ambient	4.56
Shrimp	-30	3.72
Bacon	Ambient	2.30
Codfish cakes	-30	3.17

The AEC, which concentrates its food-preservation program on low-dose applications of radiation geared primarily to the civilian market, has successfully processed cod, haddock, shrimp, clams, chicken, strawberries, tomatoes, citrus fruits, papayas, mangoes, peaches, bananas, and mushrooms.

Packaging is another important aspect of radiation sterilization. Most of the earlier work was done with the rigid metal can with an oleoresinous or epoxy-phenolic enamel because of its reliability as an impermeable and rugged container. Now the emphasis is on lighter weight and less expenseive flexible packaging materials which would not require critically short metals during a national emergency. U. S. Army and AEC researches have been successful to the extent that the following flexible packaging materials have been approved by FDA as food contactants for the irradiation process:

Up to 1 Mrad:

Nitrocellulose-coated cellophane

Saran coated cellophane

Glassine paper

Wax-coated paperboard

Nylon 11 film

Polystyrene film

Rubber hydrochloride film

Up to 6 Mrads:

Vegetable parchment

Polyethylene film

Polyethylene terephthalate film

Nylon 6 film

Vinyl chloride and vinyl acetate copolymer film

Up to 50 000 rads:

Kraft paper for wheat flour only

In radiation sterilization the need is for flexible materials which can withstand the stress of high radiation doses and low temperatures down to -40° C without loss of flexibility or impairment in functioning as an impermeable barrier to moisture, gases, and microorganisms. These materials must be sufficiently stable during irradiation processing that they do not impart off-odors, off-flavors, or toxic products to the food. Their all-around reliability must approach that of the rigid metal can. In order to reinforce strength of the material and keep out light that can accelerate adverse color changes, the food contactant materials are laminated to aluminum foil and other barrier materials. Two of the more promising laminates are shown in table III.

TABLE III. -FIRST SPECIMENS OF FLEXIBLE PACKAGING

Food-contacting film (inside)	Middle layer	Outside layer
Nylon-11, 2 mil	Aluminum foil, 0.5 mil	Mylar, 0.5 mil
Medium-density polyethylene, 2.5 mil	Aluminum foil, 0.35 mil	Paper (water resistant), 2 mil

The proof of success in radiation processing of foods is in the eating. We use expert and consumer taste panelists who rate the foods on the 9-point hedonic scale developed by Peryam and Pilgrim (ref. 11):

9 Like extremely

8 Like very much

7 Like moderately

6 Like slightly

5 Neither like nor dislike

4 Dislike slightly

3 Dislike moderately

2 Dislike very much

1 Dislike extremely

In table IV are shown the scores given by volunteers at Fort Lee, Va., who tested irradiated foods as components of meals of the type served in mess halls in the United States. An irradiated food is considered to be satisfactory if it receives a score above 5 on the 9-point scale. Although the irradiated foods scored slightly lower than their nonirradiated fresh counterparts (the control in the experiment), they scored well within the acceptable range and are considered to be satisfactory for incorporation into Army rations.

TABLE IV.-ACCEPTANCE OF IRRADIATION-STERILIZED MEATS, POULTRY, AND SEAFOODS

Item	Irradiated					Nonirradiated control	
	Dose, Mrad	Temp., °C	Storage, months	No. men rating	Av hedonic rating on 9-point scale	No. men rating	Av hedonic rating on 9-point scale
Ham	3.5-4.4	Ambient	2	570	5.84	739	6.45
Ham	4.5-5.6	-30	3	1657	5.87	1437	6.66
Chicken	4.5-5.6	-30	3	313	6.14	297	6.50
Chicken	4.5-5.6	-30	3	270	6.00	251	6.22
Pork	4.5-5.6	Ambient	5	305	7.27	345	7.28
Pork	4.5-5.6	-30	3	391	5.71	458	6.85
Beef	4.5-5.6	[a]-60	4	515	6.11	660	6.79
Beef	4.5-5.6	-185	3	502	6.25	710	6.79
Beef	4.5-5.6	-80	5	589	5.99	644	6.61
Shrimp	4.5-5.6	-30	7	247	5.79	446	6.25
Shrimp	4.5-5.6	-30	7	292	6.39	403	6.23
Codfish	4.5-5.6	-40	3	531	5.40	578	6.30

[a] -60° C at start of irradiation.

In table V are preference scores for irradiation-sterilized hams that have been served at experimental luncheons. The preference scores for these hams are in the same range as are those for apple pie and ice cream.

TABLE V. -ACCEPTANCE OF IRRADIATED HAM WHEN SERVED AS COMPONENT OF REGULAR MEALS

[Irradiated hams stored at room temp. for 1 to 12 months prior to serving; testing period, June 1966 to April 1969]

Dose, Mrad (+12 to +25%)	Irradiation temp., ^{o}C ($\pm 10^{o}$ C)	Items	No. men rating	Average acceptance rating on 9-point hedonic scale
4.5	-30	Baked ham with pineapple glaze	17	7.29
4.5	-30	- - - - - - - - - - - - - - - - -	46	6.95
4.5	-30	- - - - - - - - - - - - - - - - -	20	6.88
4.5	-30	- - - - - - - - - - - - - - - - -	19	6.80
3.5	-80	- - - - - - - - - - - - - - - - -	11	7.40
3.0	-80	- - - - - - - - - - - - - - - - -	22	6.91
3.5	-80	- - - - - - - - - - - - - - - - -	20	7.84
3.7	-30	- - - - - - - - - - - - - - - - -	15	6.87
4.5	-80	Baked ham with pineapple sauce	18	8.11
4.5	-80	Baked ham with orange-pineapple glaze	20	7.91
3.5	-80	Baked ham with orange glaze	12	8.16
4.5	-30	Baked ham with raisin sauce	15	7.20
3.5	-80	Baked ham with mustard glaze	20	7.58
4.5	-30	- - - - - - - - - - - - - - - - -	18	7.5
4.5	-30	- - - - - - - - - - - - - - - - -	18	7.29
4.5	-30	- - - - - - - - - - - - - - - - -	28	7.20
4.5	-30	Fried ham steaks	18	7.38
4.5	-30	Grilled ham steaks	15	8.26
3.7	-30	Baked ham	10	7.60
3.7	-30	- - - - - - - - - - - - - - - - -	20	6.69

Description of the Process

For most applications it is important to use good quality ultrafresh food as starting material. Radiation cannot reverse deterioration and spoilage of food once it has begun; it can only arrest or prevent these conditions. Nor should radiation be used as an excuse for poor sanitation practices; its intended use is for insurance against contamination which might occur in spite of all reasonable precautions.

Fruits and vegetables are irradiated in boxes or crates to minimize excessive and extraneous handling and to keep processing costs to a minimum. Meats, poultry, and fish fillets to be given pasteurizing doses to extend refrigerated shelf life should be wrapped and chilled without delay prior to irradiation.

For prepackaged meats, poultry, and seafood which are to be given sterilizing doses to promote long-term shelf stability without refrigeration, the first step is to remove as much of the inedible material as possible by deboning and trimming off gristle and excess fat. The next step is to inactivate the proteolyte enzymes in these foods. This is done by treating (blanching) to an internal temperature between 65° C and 75° C. The foods are then vacuum packaged and sealed while still hot in rigid metal cans or flexible packaging materials. The foods are then frozen without delay by blast freezer or liquid nitrogen to a temperature of -30° C and are exposed while held at $-30^{\circ} \pm 10^{\circ}$ C either to gamma rays (from Cobalt-60 or Cesium-137), X-rays, or electrons from an electron linear accelerator. Irradiation in the frozen state minimizes adverse chemical and physical changes which may occur so that the quality of the product (taste, color, odor, texture, and vitamins) is maintained.

Clostridium botulinum is the most radiation-resistant of all the microorganisms of concern in food preservation. A dose high enough to destroy the most radiation-resistant strain of this bacterium will automatically destroy all other organisms in food which are of food spoilage or public health importance. In determining the minimum radiation dose (MRD) for sterilization, we aim for a dose high enough to reduce in number by a factor of 1×10^{12} the most highly resistant strain of Cl. botulinum spores. This dose is different for each food and must be determined in every case by laboratory experiments.

Wholesomeness

Under existing statutes in the United States and in many other countries proof convincing to the appropriate health-regulating officials of safety for consumption (wholesomeness) of foods processed by ionizing radiation must be provided before these foods will be approved. In our research to appraise wholesomeness, the field is divided into four categories: Absence of induced radioactivity, microbiological safety, nutritional adequacy, and absence of carcinogens and other toxic products which may be formed by the exposure to ionizing radiation.

Under existing statutes FDA has interpreted the law concerning absence of induced radioactivity as absence of measurable induced radioactivity above the background radioactivity in food and packaging material in contact with the food. The maximum energy of the gamma rays from Cobalt-60 and Cesium-137 is below the threshold level for activation of elements normally occurring in food. Accordingly, foods processed by these two radioactive isotopes are universally regarded as free from induced radioactivity at the highest radiation doses shown in table I. Use of X-rays at energies below 5 million electron volts (MeV) at the radiation sterilizing doses shown in table I will not induce measurable radioactivity. In the case of electrons, an expert committee convened by FAO/IAEA/WHO in Rome, Italy, in April 1964, established 10 MeV as the maximum energy level generally regarded as below the threshold level for inducing measurable radioactivity in radiation-sterilized foods (ref. 2). The United Kingdom, however, has set the maximum figure for electrons at 5 MeV.

Microbiological safety in radiation-sterilized foods has been discussed previously. The use of doses required for reduction in numbers of the most radiation-resistant strains of Cl. botulinum by a factor of 1×10^{12} provides a wide margin of safety. In the radiation-pasteurization range, the problem of microbiological safety is complicated by the possibility of inducing radiation-resistant mutants and upsetting the ecological balance by eliminating vegetative food spoilage organisms associated with off-odor and color, thereby permitting Clostridia to germinate and produce toxin. The current thinking for radiation pasteurization is to use radiation doses low enough to permit microorganisms associated with obvious spoilage to survive in sufficient, though reduced, numbers to give the consumer ample warning.

The use of radiation-sterilizing doses is limited to meats, poultry, finfish,and shellfish because none of the other major classes of foods can withstand the high doses required. At the maximum radiation doses shown in table I, there is little or no impairment in the nutritional quality of the protein or in its availability and digestibility. Similar results have been reported for essential fatty acids. For most foods of animal origin, man does not depend upon skeletal muscle as a significant source for his daily vitamin needs. The major exception is pork which is a rich source of thiamine. At the request of USDA the percentage retention of thiamine in irradiation-sterilized canned pork loin and ham was investigated and compared with that of pork and ham from the same lots which had been made shelf stable by heat. The figures for the processed meats were compared with the untreated pork loin and ham from the same lots. The study was expanded to include riboflavin, niacin, and pyridoxine in addition to the thiamine. The data are shown in tables VI and VII and indicate that the four B vitamins studied are generally less susceptible to destruction by sterilization treatment at a 4.5 to 5.6 Mrad dose at $-30^{\circ} \pm 5^{\circ}$ C then by the conventional thermal treatment. It is concluded that the radiation-sterilization process as developed for those foods shown in table II will not significantly impair their nutritional quality. Similar studies for foods subjected to substerilizing doses are being conducted by the AEC and by investigators abroad.

The fourth aspect of wholesomeness--the freedom from carcinogenic or toxic products formed in food by irradiation--has been extensively studied by the U.S. Army Medical Department. Twenty-one foods representing all the major food classes in the diet of North Americans were fed to rats, mice, dogs, or monkeys for 2 years and, in the case of the rodents, for 4 generations. The level of irradiated food in the daily diet on a dry-weight basis was 35 percent. In reference 4 the U.S. Army Surgeon General reported that foods irradiated up to absorbed doses of 5.6 Mrads with a Cobalt-60 source of gamma radiation or with electrons with energies up to 10 MeV have been found to be wholesome, i.e., safe, and nutritionally adequate. Feeding studies sponsored by the AEC and by scientists abroad have not uncovered evidence to indicate that foods processed by ionizing radiation are not wholesome.

This issue, the ability to demonstrate that the irradiation process does not produce carcinogenic or toxic products which will harm the consumer, is the number 1 problem which must be solved before this process can be established commercially.

TABLE VI.-EFFECT OF PROCESSING ON THE VITAMIN CONTENT OF SHELF-STABLE CANNED HAM

[Data furnished by Mrs. Miriam H. Thomas, Nutrition Div., Natick Labs.]

Vitamin	Treatment	mg/100 g[a]	% retention
Thiamine	Control	3.82 ± [b]0.38	--
	4.5 Mrad at $-80^{o} \pm 5^{o}$ C	3.25 ± 0.79	85
	Thermally processed	1.27 ± 0.36	32
Riboflavin	Control	1.01 ± [b]0.18	--
	4.5 Mrad at $-80^{o} \pm 5^{o}$ C	1.25 ± 0.09	123
	Thermally processed	1.10 ± 0.24	109
Niacin	Control	31.5 ± [b]0.81	--
	4.5 Mrad at $-80^{o} \pm 5^{o}$ C	23.8 ± 2.92	76
	Thermally processed	14.6 ± 4.49	46
Pyridoxine	Control	1.11 ± [b]0.15	--
	4.5 Mrad at $-80^{o} \pm 5^{o}$ C	1.02 ± 0.12	92
	Thermally processed	0.64 ± 0.03	57

[a]Moisture, fat, salt-free basis.

[b]Average ± S.D. Three samples per treatment.

I am optimistic that these irradiated foods will ultimately become commonplace on our dining-room tables because of their generally excellent quality. I base my expectation that the wholesomeness question can be resolved not only on the results of the Surgeon General's research but on data from wholesomeness studies sponsored by the AEC and by reports from other countries. I am further encouraged because of the outcome of a meeting of experts convened by the World Health Organization in April 1969. From the deliberations of this group, the World Health Organization will recommend to all its member countries that irradiated potatoes and irradiated wheat and wheat flour be given iterim approval until June 30, 1974. This will allow time to accumulate sufficient additional wholesomeness data to support final approval for these foods.

Now, what are we doing to prove wholesomeness? The U. S. Army Medical Department is planning to resume animal feeding studies of ham, beef, chicken, pork, frankfurters, and luncheon meats to assess their safety for consumption. We expect this work to be completed by the middle 1970's when petitions will be submitted to FDA and to USDA for approval. The AEC is conducting wholesomeness studies on irradiated bananas, strawberries, and papayas to be followed by those on several varieties of fish.

TABLE VII.-EFFECT OF PROCESSING ON THE VITAMIN CONTENT OF SHELF-STABLE CANNED PORK LOIN

[Data furnished by Mrs. Miriam Thomas, Nutrition Div. Natick Labs.]

Vitamin	Treatment	mg/100 g[a]	% retention
Thiamine	Control	3.69 ± [b]0.22	--
	4.5 Mrad at -80° ± 5° C	3.14 ± 0.25	85
	Thermally processed	0.76 ± 0.08	20
Riboflavin	Control	1.02 ± [b]0.28	--
	4.5 Mrad at -80° ± 5° C	0.79 ± 0.06	78
	Thermally processed	0.82 ± 0.02	81
Niacin	Control	20.3 ± [b]5.1	--
	4.5 Mrad at -80° ± 5° C	15.9 ± 2.6	78
	Thermally processed	13.2 ± 1.8	65
Pyridoxine	Control	0.76 ± [b]0.05	--
	4.5 Mrad at -80° ± 5° C	0.75 ± 0.07	98
	Thermally processed	0.63 ± 0.07	84

[a]Moisture, fat, salt-free basis.

[b]Average ± S.D. Three samples per treatment.

Approvals

Those foods which have been approved for commercial production and sale and for unrestricted consumption are, by country:

Canada: Potatoes
Onions
Wheat, wheat flour

Israel: Potatoes
Onions

U.S.A.: Potatoes
Wheat, wheat flour

USSR: Potatoes
Grain
Dried fruits
Dry food concentrates
Fresh fruits and vegetables

The Soviet Union has the greatest number of approvals.

Those foods which have been approved for testing of experimental lots or for market testing, by country, are:

Denmark:	Potatoes to Greenland
Holland:	Potatoes
West Germany:	Potatoes
USSR:	Onions
	Dressed poultry packaged in plastic
	Partially processed raw beef, pork, and rabbit products packaged in plastic
	Kitchen-ready meat products (fried meat, steak) packaged in plastic
United Kingdom:	Foods for hospital patients requiring sterile diet as essential factor in medical treatment (e.g., organ transplant recipients)

Here, too, the Soviet Union has the longest list of approvals.

SUMMARY

(1) Ionizing radiation opens a new era for food preservation-the means to extend the shelf life of foods which, on the plate of the consumer, closely resemble fresh food.

(2) The irradiation process lends itself very readily to the concept of convenience. Irradiation-preserved foods can be offered as components of meals or as snacks in ready-to-eat form, in the form of slices or sandwiches, or as warm-and-serve or cook-and-serve foods. Foods processed by ionizing radiation require no preparation or simple preparation with reduction of labor in the kitchen.

(3) The irradiation process can provide high quality, nutritious, wholesome food of great morale value to individuals and small groups who are isolated, or where supply is difficult or impossible on land or sea, in the air, in space, or under the ocean.

(4) Proof of wholesomeness convincing to health authorities on the national level remains the number 1 problem to be resolved before ionizing radiation can be used commercially.

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SESSION III

Airline Experience

CHAIRMAN: R. TREUCHEL

Vice President, Marriott In-Flite Services

It is certainly a pleasure for me to share in your conference, lead the discussion of this panel of airline representatives, and represent the Marriott Corporation. We share more than a passing interest in the aerospace program. Although known to most of you as the company with the motor hotel at the Manned Space Center in Houston or the series of restaurants on the Sunshine State Parkway here in Florida, our Washington based operations stretch from Honolulu to Rome and Boston to Santiago, Chile, and cover every conceivable facet of the food-service and lodging field. Most of you represent some phase of pioneering in the space age and we have been pioneering in in-flight feeding service for commercial travel since 1927.

The in-flight catering industry presently stands on the brink of a new jet age that has been described by one aircraft manufacturer as the "spacious age." The subsonic superjets or airbuses and even the supersonic aircraft will be our partners in the remaining years of this century.

Contrary to some speculation, food service will continue to be an important part of air travel. The configuration of future meal service and its integral parts will be different, but so is today's in-flight dining experience different from the 1928 brown-bagged sandwiches and cardboard lap trays. Our industry needs more technology in frozen food and reconstituting processes and in packaging, transportation, and onship handling processes. Our industry needs to adopt the technology of cryogenics, liquid freon freezing, radiation, and freeze drying and to make extensive studies in the areas of reconstitution processes. In the past, the food-service industry has contented itself in being a follower in technology and discovery. If it is to survive as an identified and respected member of the business community, it must become a frontrunner and a leader in food technology.

We must do more to encourage and challenge young people to seek careers in our industry. Our colleges and universities must attract outstanding men and women to present curricula to excite the curious nature of the young. Our businesses must recognize the need for more food technologists and for those in pure research. The commercial food-service industry is in great need of this talent.

As your technologies and scientific studies bear fruit in the manned aerospace program, new areas of imagination will be sparked in the commercial field. New technology will be launched to improve and build a more efficient and total in-flight food-service program, geared to the volume and anticipated travel time of the new jet age.

We recently completed a 7-acre structure, costing over 11 million dollars, dedicated to research, technology, and manufacture of quality products for our business. Our company - in its research, quality control, and manufacturing process - is making extensive studies into quality control of its products. We are looking to imaginative packaging to maintain the integrity of the components. Along with the various airlines, we will be jointly studying and refining the problems of reconstitution and transportation of products from manufacturing to storage to in-flight consumption.

We have some excellent men and organizations represented here today. It will be my pleasure to be chairman during the presentation of their remarks.

R. Treuchel

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Airline Versus Space Feeding

PAUL A. BUCK
Cornell University

The purpose of this paper is to introduce creative ideas for space feeding by comparing airline and aerospace feeding systems. Use of the metric system to divide the astronaut's day, primarily in relation to his eating schedule, is discussed.

Universities (and I suggest NASA is similar to a university) as organizations tend to resist change. Despite involvement with dynamic youth, the aim of a university is to add small increments of knowledge to existing or old knowledge. Similarly, you and I have so many deeply ingrained concepts and prejudices about our food that in order to look at a new feeding system we may need to be jolted. The same "shock" may be needed in order to think creatively of space food. We speak of space food - but isn't it conventional food eaten in space?

An airplane pilot, before he takes off, checks the weather, checks the airplane, and checks the fuel, but have you ever seen the pilot go aft to ask the stewardess if the coffee is on board? No. He takes it for granted, as it is not part of safety. But for the relaxation of the passengers and for their mental calm, eating plays an important role.

The airlines realize that you and I buy our tickets partly because of the service that they provide. The passengers may be a captive audience on board, but at the ticket counter they are discriminating purchasers. If you are going to buy one airline's ticket in preference to another airline's ticket, your choice is largely based on the impression that you have from the service provided. You want a feeling of security when you are on board, so the atmosphere the airline wants to create is associated with the security of mother's or grandmother's kitchen. The home cooking concept is an illustration of the kind of confidence you transfer to the pilot and to the airline stewardess. You recognize the food that is served attractively by pretty airline stewardesses, and this helps to enforce your feeling of security.

In classifications of food service, eight groups of feeding establishments are well recognizable:

(1) Hotels and fancy restaurants
(2) Motels, drive-ins, etc.
(3) Clubs, resorts, etc.
(4) In-plant feeding, cafeterias, etc.
(5) Hospitals, state institutions, etc.
(6) Primary and secondary schools
(7) Universities, dormitories, etc.
(8) Transportation industries

Although the airline feeding system frequently has been listed under the category of transportation, to me the proper listing is with hotels and fancy restaurants (category 1) or clubs, resorts, etc. (category 3). The care that is given to menu selection and preparation, holding, transporting, and serving of food is similar to that given to gourmet dining. This same care has been devoted to our space food, even though the emphasis in our space program has been on the engineering phases.

Another similarity in the airline and aerospace feeding systems is in the major factors considered in the selection of a menu. Both systems require careful attention to weight, volume, preparation, convenience, and low degree of flatulence of the food. Although the airlines are serving only one or two meals per flight and aerospace food may be eaten for weeks, variety also is a factor for both systems. For example, if a passenger boards his next flight even a month later and receives a steak or lobster menu the same as that on the previous flight, he reacts to the monotony just as the astronaut reacts to a monotonous menu.

A third similarity is in the role of food to the physical and emotional state of the person. Food becomes important to the pilot on long flights so that he will retain acuity. How often does one shoelace break when you are in a rush? Both shoelaces, except perhaps that one is one thread weaker than the other, are the same, but you have put more stress on the broken one. Similarly, a man in an airplane or a spacecraft cannot perform best if he is under tension. Food can be used to relieve tensions, especially those of a passenger doing nothing, for whom tension may build up. When you go to a restaurant with only a few minutes for your meal and the waitress doesn't come immediately to take your order, and, after she does take it, does not serve your meal for several minutes, you are under so much tension that you gulp the food and do not appreciate the taste. But suppose you went into the same restaurant, on the same time schedule, under the same necessity to be served quickly, and the waitress did just one thing: brought a loaf of bread with a knife and said, "Cut a piece of bread, your meal is coming, and here is your salad." How much easier it now is to wait for the remainder of your meal! How less tense you are! How much better the food tastes!

The astronauts in Mercury, Gemini, and Apollo flights were very busy performing tasks. As flights become longer, an astronaut will at times be an idle passenger prone to tension. Participation in food service can contribute to relieving this tension. The astronaut has been like the airplane pilot, concerned about the engineering, yet not realizing that his ability to perform tasks may depend upon his blood sugar and his state of relaxation. When you tie your shoelace, if you are under tension, your shoelace breaks.

By film we have watched while an astronaut turned a spoon upside down and the food didn't drop. Would this have been just as good an experience if the astronaut had turned himself upside down? Because we rely on our Earth conventions and expect to use a spoon in a conventional manner to put food in our mouth, we must be jolted to think about an astronaut's turning a sommersault to eat the food instead of eating it by turning a spoon over. The reason the astronaut turned the spoon over to make his demonstration was his Earth orientation, not the space orientation. Even an astronaut in space carries along these Earth prejudices. We must break through our Earth prejudices if we plan to develop improved space feeding systems. We must begin fairly soon, because when there are three astronauts and the pilot and the copilot are busy the third man becomes a passenger with possibilities of boredom and tension.

Another problem is our Earth bound time system; perhaps we should consider adopting a metric time system. How many breakfasts should an astronaut eat? Should he have a breakfast every time he sees the sunrise as he circles the Earth? How many luncheons should an astronaut have on the way to the Moon when he is in sunshine all the time? Should he have breakfasts, noonday meals, and dinners? What schedule is followed in Alaska, with its almost 24 hours of sunshine? To keep the conventionalism of the U. S., you draw your curtains. Why keep these stateside concepts in our astroaquarium? Why not adopt the metric system of time and also adopt some of the pleasures of a siesta? A proper day for an astronaut might be 4 hours of work and 5 or 6 hours of rest. He could enjoy relaxation, work, and sleep in a metric system. Let us divide the day into 10 equal parts and divide those 10 equal parts into 10 to make 100. It is time we started challenging ourselves to do this. There is still a reason to keep a day and a year, but there is no reason to keep seconds, minutes, and hours. If a day is divided into 10 periods of time, nutritional snacking may be a very valid feeding schedule. Research with animals indicates that they are healthier when they eat frequent snacks than when they eat three meals a day.

Further, let us consider the S.Q. of the food - a concept similar to our I.Q. The abbreviation S.Q. denotes a partly coined term, "satisficing quotient," which denotes the degree to which the foods are satisfactory in terms of nutrition and are satisfying to the eater. Perhaps this concept will influence you to think of space feeding in terms of the restaurant industry, in which we tend to discuss the recreational value of food. The ability to relax or relieve tension is an important concept when a husband and wife dine in a restaurant. While she is taken away from the boredom of washing dishes, he is relieved of the tension resulting from the office. Every good restaurant man knows that you do not come to a restaurant to buy only food. Food bought in a grocery store and cooked at home is a lot cheaper than is food bought in a restaurant. One goes to a restaurant because he wants to relax, he wants to be entertained, and he desires an attractive atmosphere. Relaxation, entertainment, and charm are the "rec" of the word recreation.

If you have ever taken children to a restaurant after they have been confined in a station wagon for hours, you appreciate the entertainment value of a children's menu. The decor is the charm. When you take your wife to eat in a restaurant you go to a place that has a bit of charm. The atmosphere and aesthetic value are important concepts for space food and in the space age we can have concepts of charm. The charm can be accomplished not just by candlelight; it can be accomplished by the food. A dry sandwich is not charming, but there is something charming about a snack of a well-prepared chicken leg. The taste of a chicken leg from the refrigerator with a can of beer is scrumptious.

Entertainment need not be a miniskirted stewardess, although that is excellent entertainment. It can be that participation that you and I enjoy when we barbecue. In fact, give a husband the challenge and he will continue barbecuing even though it starts to rain; he will even drive the car out of the garage to continue barbecuing. Gathering around the barbecue pit is entertaining. The astronaut also needs "rec" entertainment in his feeding system. We can give the astronauts the entertainment of spreading items on bread. I understand that in the next Apollo there will be cheese to be spread on crackers. Let us give the astronaut this opportunity to participate. Snacks are popular because reaching in the refrigerator and making your own selection is participation.

With the metric system, we will not be bound to breakfast every time the sun rises, or to lunch because it is midday. With the metric system, the challenge of new ideas can be carried into the food. Our job as scientists is to be concerned with nutrition, but this is not the astronaut's job. The participation, the relaxation, and the entertainment lead to the challenge of nutritious snacks. All of us, including myself, must accept the challenge to think of space food instead of conventional Earth food in space. As we start thinking of space food, we realize that it is no longer the three meals that we are so accustomed to on Earth. When we leave this conference perhaps we can do more than just lightly talk about the metric system. Perhaps we can use it to think of space food. I am not advocating champagne flights, but to me food without beverage or food without some gourmet aspect of participation will not produce a good feeding system for aerospace travel.

The hospitality that you and I cultivate in our homes is the thing I am asking you to think about in terms of our space feeding system. It is my personal belief that risks of aborting missions increase if we ignore food. Insurance companies tell us that we cause accidents when we are under tension. If we are going to prevent accidents, we must work as a team and consider food an important part of the whole system.

Pan American World Airways: Present and Future Plans

J. P. TREADWELL

Pan American World Airways, Inc.

"Welcome Aboard Flight 1 to London! Our flight time today will be 3 hours, and, immediately after takeoff, we will be offering cocktails and dinner. Included in your choice this evening, may we suggest a dehydrated, low-residue, easily disposable, unappetizing, and misshapen meal. Water guns on request." What's wrong with that? If it is good enough for the astronauts, is it not good enough for us in the airline industry?

How is the airline really different from space travel? It doesn't have a gravity problem: it is not in a zero-G situation. There are not the particularly long missions which the astronauts face, but in some ways there really is no difference. We of the airlines must also design our systems with space in mind. I am not talking about astronomical space; I'm talking about space in a capsule or space in an aircraft. We certainly must take into consideration weight and packaging and must utilize research in all possible fields. Let us look at the airline. What is our immediate future and how can we benefit future food systems whether they be weightwatcher or weightless?

Professor Buck mentioned in great detail some of our prejudices, and I will not linger on these except to say that food is indeed a creature comfort. "Creature comfort" is not my term but one that has been used by psychologists to tell us that people and their habits cannot change as quickly as can their technology. We would like to throw our prejudices out of the window and say that we are free of them, but we cannot. So we must live with them, try to bring favorable ones into our everyday lives, and, in that way, hopefully add Professor Buck's "rec" (relaxation, entertainment, and comfort).

One of the basic differences between the airlines and space travel is that, at least at this stage, the airlines are selling something, and we need to pamper people in order to sell tickets. What kind of creature comforts can we provide? I shall discuss this from the viewpoint of the 747's. How many seats do you suppose that opening announcement I made would sell? None. Food is not something that is just eaten. It's also seen, and it's felt, and it's heard. It is a textured item and we are used to it in its current earthbound form.

Let me tell you a little about Pan Am. We started producing frozen food in 1950. We were forced into production by an operational need of moving meals from New York to Karachi or Beirut where the quality of food wasn't what we had hoped it to be. We've progressed beyond that now; last year we produced 11 000 000 meals in our two frozen-meal kitchens, at New York and San Francisco. We meet the volume demands and the demands of the latest technology. Many people have said, "You have the big jets. How are you going to handle all those people on an individual basis?" This is indeed a big problem.

Let us consider Kennedy International Airport alone because it is our largest station. In 1973 we plan to have at one time at one terminal building eight 707's and six 747's during a peak hour. This means we shall have about 3300 passengers per hour. It will indeed be difficult to cater to this large number.

We've found that the public doesn't really understand that the creature comforts are going to be vastly increased on this airplane. Seat spacing is going to be increased; the number of aisles is going to be increased. All the compartments are going to be color coded and segmented so that a passenger can get his baggage much quicker, he can board much quicker, and he can sit down much quicker. He will have space to put things. He won't find that his bag is 2 inches too large to shove under his seat and be told by the stewardess that he can't put it in the hatrack. All these things have been taken into consideration through the learning curve of our previous experiences.

We are dealing with the same things the space industry is. We are utilizing the polycarbonates (Lexan) in our galleys for light weight. Titanium is used in the engines. We are even considering plastic wine bottles which save 40 percent in space and weight. Tetrapak liquor seems unappetizing but the packaging geniuses make it an attractive and "entertaining" package.

The 747 will have six galleys, and we are going to feed 350 people at the same time. Each galley complex, of which there are three, has an average of 52 sq ft of galley, which is quite small. We shall have 9 ovens and 10 coffeemakers, and 15 000 pieces of equipment will go on and off each airplane at each transit. This is a logistic nightmare.

Think ahead to the time when volume will be a problem not with astronauts but with people, the general public, traveling between planets, to the Moon, and so forth. Granted that it is stargazing, but are we not really moving in the direction of volume? Well, if there were ever any lesson to learn about volume, we are going to be learning it, and I hope not the hard way. The modular concept and containerization are here and are being used and, although these things are not of immediate importance to the Apollo program, they are lessons that I think will be of benefit eventually to your industry.

We find that people psychologically relate to airlines as in the Pavlov's dog experiment. They board an airplane in January and have chicken; then, a year later, after 364 days of meals, they board another airplane and have chicken again. What happens? We are considered a chicken airline; they say we have nothing but chicken onboard. The problem is simple to identify but not so simple to solve. My budget this year for food and supplies alone is $ 43 000 000 and that is to be used not only for chicken but for all the foods we put aboard. At this point we use about 90 different entrees to try to satisfy the palate, and by the palate, as I mentioned before, we mean not only the mouth taste but also the texture, the sound, and the sight.

Another approach is that referred to as "demand" type food service. The same enclavement, so to speak, that the astronaut is faced with, i.e., being rigid in one seat for a long period of time, faces our passengers to a lesser degree. Take, for example, the 302 economy passengers in the 747. They are trapped and are a captive audience. We have been finding out through studies that passengers do not necessarily want to eat when they are told to eat. They may not want to eat when the stewardess is ready to serve them, so we are creating what we call "demand" food service, i.e., a system to allow the passenger to eat when he wants to. It could also be called a snack service.

On the 747 on our Polar flight which goes from San Francisco to London, or from Seattle to London, or from Los Angeles to London, we will be serving at a full configuration 1000 meals in 12 hours. What kind of automatons are going to be able to do this? What happens to the old chef? What happens to the skilled worker? Today, we have 3600 stewardesses. Can you imagine the degree of variance of food preparation if you were to hand them a recipe that started from scratch? No, we must give them a convenience food that is foolproof. Our stewardesses are very well prepared but the same degrees of difference occur in those girls that occur in every one of us here in this room. Each will do things differently, so we must be sure that our technology designs foods that can be prepared by somebody who is not a culinary genius.

For this tremendous volume of frozen meals that we have been discussing, we must design basic sauces, of which there are about 6, and create up to 1100 variations through food flavorings, while maintaining the psychological presentation of the food and at the same time using some of the latest protein products. We want to increase the amount of protein that the passenger gets, because more and more people are becoming weight conscious and more and more people are becoming less active. So fish protein and basic sauces in a convenient prepackaged form will be used. Containerization will solve some of the logistic problems of frozen food. Then, as the volume increases, we will need lightweight, one-way, insulated shipping containers.

Some other products with which we are working include high-heat plastics, which provide food containers, or plates, that are disposable, lightweight, and low in cost and will withstand temperatures of up to 600° F. Also being considered is a high-heat, polyethelene, moisture-proof material which can be placed in a dry-heat environment (600° F).

In short, ladies and gentlemen, there necessarily must be many interfaces between your technology and our technology. Volume factors affect passenger travel, whether in the atmosphere or in space.

Japan Air Lines: Present and Future Plans

TOSHIMITSU IKEGAMI
Japan Air Lines

First I shall, with the help of a few statistics, give and define the present food planning policy of Japan Air Lines. Second, I shall try to explain what is perhaps the primary motivating force behind the final selection of our menus; and, third, I shall briefly state our future aims.

Our food service policy, at present, is to serve Western style food as the principal or main diet because of its universality. Japanese food, our national diet, is served as an additional or alternative specialty.

From April 1, 1968, to March 31, 1969, we spent $4 000 000 for the main or Western diet, $560 000 for Japanese food, and $1 560 000 for beverages and other subsidiary foods. Together these expenditures amounted to 33 percent of our total transportation service expenses for international flights. Currently we have flight routes across the Pacific and Atlantic Oceans, to Southeast Asia, to the Middle and Near East, to Europe via both the Polar and Southern routes, and to the Soviet Union.

Our food service plan consists of two elements: a "meal plan" and a "menu plan." The meal plan is used to determine which meal - breakfast, lunch, dinner, or snack - is to be served and the order of service along every flight route. The menu plan determines the components of each meal.

In principle, we have six different menus for each meal at each meal loading station and these are rotated. However, these menus may be and are modified to suit the general tendency of diet preferences of our passengers. This is done in the belief that in general we are not in a position to dictate the meaning of "good food" to our passengers. On the contrary, we feel obligated to comply with the tastes of our passenger as much as possible, in order to make his short sojourn with us a pleasant one.

It is on this note of service that I would like to introduce what is perhaps the primary motivating force behind our food planning service. The essence of this force or attitude is captured in the Japanese phrase "furusato-no-aji." Translated directly it means "a taste of food of the native land." As implied, this phrase has a nostalgic connotation and is often used to describe the feeling that a man who comes from the countryside but now lives in the big city gets when he eats some food, the taste of which triggers a flood of memories of a dish prepared with simple typical local food materials and cooked by his mother in her own and simple way. However, to those of us who study food service in Japan, this phrase has a broader meaning. It is used as a symbolic term to express the strong conservative nature of an inherent diet habit of either an individual or a nation. Of course, a diet habit may gradually change, at least on the surface, as in the case of an individual who changes his place of abode or occupation. This, in turn, may be reflected in nations that absorb foreign cultures and blend them with their own. But, despite changes, one's furusato-no-aji remains, albeit subconsciously, and from time to time this feeling surfaces, particularly in extraordinary situations. An example of such a situation is the following: In Japan a hospital gives a person recovering from a serious illness a nutritious well-balanced modern hospital meal, but sometimes the patient rejects it, preferring instead a bowl of plain white rice gruel with a piece of dried plum. This simple meal has in many cases served to spur the patient on the road to full recovery. This same simple meal may have been given to him by his mother in his childhood when he suffered from dyspepsia.

Today more and more people are traveling by air. For a great many of them flying and going abroad present a new experience - a time of heightened excitement. To one passenger, this excitement may manifest itself in the excitement or tension created when he contemplates the new experiences he will encounter - different people, customs, languages, and situations. To a person on his way home, this tension may be a result of the accumulated fatigue produced by a heavy business or trip schedule.

One of the human elements which is readily influenced by such tension, as you well know, is the appetite. Tension spoils one's regular appetite, and here we would like to suggest that furusato-no-aji surfaces to one's consciousness. I can point to quite a few Japanese friends who, though thoroughly accustomed to a Western style diet, in times of tension dash for the nearest Japanese restaurant if one is available upon landing in a foreign city. I also have an American friend who under similar circumstances feels a strong desire for a good old American style hamburger.

I know that we do make - I hope infrequently - mistakes because of improper preparation or service of food which incurs passenger complaints. However, today I find that one of the greatest and perhaps the most important reason for passenger dissatisfaction with in-flight meals is the gap that exists between the food we offer and the food each passenger expects consciously or subconsciously according to his own or his nation's peculiar diet habit. If our food happens to divert, even partially, from our passenger's expectation, he might show not only displeasure but also a strong negative reaction against the whole meal. Use of the best quality nutritious food prepared in the fanciest fashion will not solve this problem. Rather, a totally different approach must be used.

Of course the ideal in-flight food service plan would be one wherein the furusato-no-aji of each individual passenger is met. We should have the diet history of each passenger, dating back to his childhood, showing the food he liked and how his mother prepared it. But this, of course, is a practical impossibility since in-flight food service is a form of mass feeding, within a limited time and limited to the facilities of an airplane.

We, however, are at least able to survey carefully and analyse the different historical and cultural backgrounds of each nation or country; and with this information we can attempt to grasp an individual nation's peculiar diet habit so that we can meet our passengers' satisfaction by preparing menus either to comply with, or, more importantly, avoid conflicts with his furusato-no-aji.

Take, for example, the American dish of ham steak and applesauce which is served as a main dish on our lunch or dinner menus. American people are able to enjoy in combination the taste of ham with the sweetness of applesauce. However, to the average Japanese such a combination is unpalatable. You probably would have the same feeling for a combination of dill pickles with ice cream. We therefore serve ham steak with applesauce to our first-class passengers along with two or three other choices. This dish is included only on menus of our trans-Pacific flights where, in comparison with our other routes, the ratio of American to non-American passengers is quite high. Accordingly, we do not serve this dish in the economy class on any route where no alternative dish is offered.

Another example is that beef steaks prepared out of Tokyo are prepared on the well-done side of medium because our statistics show that the majority of passengers outbound from Tokyo prefer their steaks this way. On inbound flights leaving Europe's gateway cities, steaks are prepared on the rare side of medium because of the opposite trend indicated by statistics. In order to cope with the sense of furusato-no-aji of our own Japanese passengers, we are promoting Japanese food service with more varieties than ever, especially for flights returning to Japan. Two years ago, we started to serve Japanese food as a part of a regular Western style dinner course. A Japanese dish was offered as one of the choices of the main courses for first-class passengers. Today, not only Japanese passengers but many non-Japanese passengers as well enjoy Japanese food. The latter try Japanese food because they find it both fun and adventuresome to try something different in addition to their traditional native foods. We sincerely believe that such a delicate consideration of the various diet tendencies of passengers based on cautions observation is essential to maintain good in-flight food service.

As for our future aims, we shall of course continue to grow technologically. We shall revise serving procedures such as food preparation in the flight kitchen and loading methods on the ground to cope with the demands the Jumbo and SST age will usher in. However, in the area of food selection and service, where today such things as filet mignon by tube or cream of mushroom soup by tablet are in vogue, we shall remain conservative. By conservative, I mean we shall continue to meet the needs of our passengers and present foods prepared and served in a manner that will indeed make aeroflight dining a pleasure. We shall continue to try to meet the spirit - if not the letter - of the Japanese phrase furusato-no-aji which again translated directly means "a taste of food of the native land."

In closing, let me be so bold as to suggest that this spirit be incorporated in the planning of your astronauts' aerospace diet. I hope I have given you some food for thought.

SESSION IV

FOOD TECHNOLOGY

CHAIRMAN: HERBERT SHEPLER

Secretary, Space Nutrition Panel of the Space Science Board

National Academy of Sciences - National Research Council

Dr. Chichester, who is the Chairman of the Space Nutrition Panel of the Space Science Board, was to have welcomed you in the name of the Space Science Board, National Academy of Sciences, but he is unable to attend and has asked me to welcome you in his place.

This is the second meeting that the Space Science Board and NASA have collaborated in at the University of South Florida in the last 4 years with the objective of improving the diet for our spaceflight crews. I feel that the meeting we had here 4 years ago was very useful and one from which the space program derived definite benefits. However, we cannot stand still in the field of nutrition research, and, since our country has made considerable progress since 1964 along this line, I think it behooves all of us in this field to provide the best information available for the programs of the future. I believe we should continue to emphasize the importance of continuing national research in the field of nutrition and nutrition technology. Already certain advances made in some aspects of nutrition and food handling have resulted in benefits for everyone. It appears probable that knowledge gained in the studies the space agency has undertaken may even prove of value in the war against hunger.

Herbert Shepler

Food Development and Experiences

ROBERT M. WEISS
The Pillsbury Company

The food industry, in support of the special nutritional requirements of the aerospace and military programs, has conducted much research which has resulted in the evolution of many different products. I would like to share with you the results of some selected research undertaken by The Pillsbury Co. Further, I hope to encourage all of us to reevaluate our individual and collective technical information (especially spinoff technology) to determine the way in which it might be used as a baseline in solving future aerospace nutritional problems.

In 1966 The Pillsbury Co. undertook a research contract to create a rod-shaped contingency food designed to sustain a flight crew when they must remain sealed within their pressure suits. This effort resulted in the delivery of 12 different flavors of 4 different types of rod-shaped foods in the fruit, vegetable, meat-analog, and confection areas.

During the course of the research, much information was generated governing the manner in which the physical structure of food materials could be controlled. Materials from soft plastic to hard brittle and from a smooth texture to a chunky texture were developed without varying the nutritional value. Further, through the selection of special ingredients and formulas, properties such as water activity could be modified to meet desired end requirements. This effort resulted in the delivery of a low-cost, highly stable, reasonably acceptable, unique food form.

Beginning in 1962 and continuing to the present date, we have been involved in the creation of a wide variety of compressed food bars. These compressed bars, the principal components of which are natural foods, can be combined with one or more other compressed bars in variable ratios, the result being a wide, individually tailored menu array. Further, accessory flavors in the form of small cubes allow the modification of base foods to individual taste preferences. Some of the bars may be eaten both in a rehydrated form and as is, thus providing for greater texture variability.

An obvious problem of the dual-function bar is the high flavor intensity of an as-is bar as compared with that of its rehydrated counterpart. Current work has shown that flavor-contributing components can be effectively encapsulated within materials of controlled solubility in such a manner that both food forms become highly palatable. In fact, such highly seasoned foods as chile con carne are more bland in the unrehydrated form. Compressed foods provide an opportunity for achievement of extremely high nutritional densities while continuing use of a high proportion of natural foods.

Currently in excess of 5.75 Kcal/g can be provided in a hydratable bar. Because of the low bulk of this food system, an individual can be sustained at a daily caloric intake of approximately

2500 cal for a period of 7 to 10 days from a food storage container no larger than an ordinary shoe box. Although this food is being primarily designed to meet military requirements, it has become a food form worthy of consideration for aerospace use. Nutritionally variable edible coatings and binders provide physical strength and crumb contamination control while, in addition, allowing the food scientist to strengthen nutritional deficiencies of the natural foods embodied within the bar.

Recently completed taste-panel evaluations have shown a high degree of acceptability for all of the 46 meal items currently under investigation. The level of acceptance, as recorded on a 9-point hedonic scale, is shown by scores of 6 or better given by more than two-thirds of the taste-panel members. The average of the mean hedonic ratings of the foods currently under evaluation is 6.7, as compared with an average of 5.9 for the food bars developed in 1967.

We also undertook the development of a low-cost process for manufacturing bite-size foods, primarily in the bakery and cereal food areas. This effort required the application, and in some instances modification, of previously developed technologies plus the evolution of some new techniques. For example, the protein-encapsulated vegetable-oil—carbohydrate dispersion, which provided the base for rod-shaped foods, was combined with specially prepared cereal and bakery ingredients in such a manner as to create a formulated food in a recognizable "natural" form. The technique which evolved allows for the creation of a wide variety of flavors and textures in any desirable shape from a single-process system.

The material normally used for coating was used as a binder integral with the other food components. The danger of capsule contamination by broken food can therefore be greatly minimized. This nutritionally balanced food form has a caloric density in excess of 4 cal/g.

Another interesting food development project, although it was not related to human foods on the surface, at least, was the development of a primate diet in pellet form. Prior to our involvement in this ongoing program, the pellets were prepared by compacting the specified ingredients by means of standard high-pressure pelletizing techniques. Since this pellet is dispensed from a mechanical feeder not sealed from the spacecraft environment, very rigid specifications were imposed upon the manufacture of this food. Some of these specifications were as follows: (1) The pellet was $3/4 \pm 0.020$ in. square, with a thickness dimension of 0.190 to 0.205 in.; (2) it must have a breaking strength in excess of 15 lb when center-loaded between knife-edge supports 1/2 in. apart, and (3) when dropped 6 in. for 120 times upon a nonresilient surface the weight loss must be less than 1 percent. All the above parameters were to be maintained throughout an ambient atmosphere spectrum of 40- to 72-percent relative humidity and 35° to 80° F.

It had been concluded after many months of effort prior to our involvement in the program that standard pelletizing techniques could not successfully meet these specifications. The current pellet is manufactured by adjusting the pH of the casein in the diet to put it in a water-dispersible form. This material is then complexed with sucrose, vegetable oil, and some of the vitamins and spray-dried in a special low-temperature drier. This processing results in a powder containing less than 2 percent moisture. When combined with the remaining vitamins and minerals in the diet, it can be pressed into dense, homogeneous pellets meeting, or exceeding, all the required performance criteria. Dimensional tolerances, for example, are now maintained within 0.005-in. variance.

My only reason for including this example is to demonstrate the opportunities available to food scientists if they look upon their ingredients as modifiable organic and inorganic chemicals rather than as material for use "as is." I feel the major import of this kind of research is the realization that a food form readily recognizable and acceptable by the consumer can have radically modified physical characteristics without sacrificing any of the nutritional criteria.

Another interesting aspect of this work is an indication that vitamin viability has been maintained throughout the high-temperature, high-moisture storage period at original formula levels. This may be due in part to the highly impervious character of this particular food. Additional research has shown that this food can be modified (again without nutritional compromise) to have textural variations ranging from those of soft caramels to glass.

This is obviously but a part of the total food technology that has been evolved in support of special feeding needs. What then of the future? Greater and greater demand will be placed upon the food and packaging technologists to create human food compatible with long-duration missions. We all realize the final approach will be a considerable departure from existing foods and processing techniques. Simultaneously we must create demonstratable improvements in acceptability of these foods at their point of consumption. Some examples of possible ultimate results from our efforts are:

(1) Extremely low-residue foods aimed at near-zero fecal loads

(2) Near-zero packaging requirements

(3) Foods containing selected microorganisms or designed to control or modify intestinal microflora in a manner to give desired end results

(4) Foods that may, because of their fibrous, plastic, brittle, liquid, or other physical characteristics, be used as structural components of the space vehicle prior to their use as human fuel.

We have heard a call for more natural food because history has shown that these foods have greater acceptability. Is not the desired end product more naturally acceptable foods? That is a much broader concept. Manmade foods can be designed to avoid the many limitations imposed by so-called natural food. The final system will undoubtedly be a marriage of many forms of human fuel. As we embark upon any program of human-fuel research and development, let us stay sufficiently broad in our approaches to stimulate real creativity. Time constraints have always been a convenient excuse for not stretching for truly new approaches. I suggest we use time and money constraints as a stimulus to our creativity and a challenge to the quality of our results.

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MEAT-TYPE-FOOD DEVELOPMENT AND EXPERIENCES

R. L. PAVEY
Swift & Company

The efforts of Swift & Co. in the development and production of space foods have been geared mainly to problems of production rather than to development of new meat-type items. Constant efforts have been made toward improving product quality in regard to safety, nutritional value, and physical characteristics for our astronauts, while also improving production rate and end-item uniformity.

Meat items and some other ingredients used in their production are highly variable in composition. This is especially true of the water content of meats and vegetables. In the case of meats, which are the main components of our products, the fat content is highly variable within the same grade and cut of meat. This fat content is difficult for even an experienced meat technologist to judge to a figure closer than ±5 percent. Since water content is inversely related to the fat content, it is very difficult to control the dry-matter content and, therefore, the dry weight of meat space food items. A fat-content variance of ±5 percent (e.g., 10 percent rather than 15 percent, or, in the other direction, 20 percent) would result in as much as ±5 percent variance in dry-matter content. Since approximately 100 g is the wet weight of a meat-type meal unit, this results in approximately a ±5 g variance in final product weight.

During Project Gemini the product was cut to a physical dimension which could be fairly well controlled and it was attempted to minimize the weight variance by precisely judging fat content of the meat used. However, variances of as much as 5 to 6 g in final product weight occurred, and in many cases products had to be reprocessed to meet weight requirements.

During the latter phase of Project Apollo, permission was obtained to cut products to a dry weight rather than to a physical dimension. The reason for this was that weight was considered more critical than dimension, in that weight was very closely related to nutritional factors. Producing meal units having prescribed dry weight requires that dry-matter content be determined on each product lot produced prior to cutting the bars in order that adjustments can be made in weights by varying the thickness of the products. This has greatly helped in achieving more uniform specified product weights but not necessarily more uniform nutritional content, except for calorie value, which is more uniform to some degree. In order to provide a high degree of uniformity in nutritional value, all ingredients used which are found to be highly variable in nutritional content would have to be predetermined and adjusted prior to preparation. This would be extremely costly because of the production quantities required for each production lot. A 30 kg batch on a wet-weight basis is considered a gigantic order. A 10- to 15-kg batch is closer to the norm. Preparing such a small production batch is extremely costly because of the high costs of labor for preparation and cleanup, inspection, and maintenance in relation to returns for a small number of items. Such a procedure is also time consuming. This is critical when one is working with a very highly perishable product such as meat.

Much thought and effort have been devoted to reducing production costs and improving the uniformity of products. These efforts have been severely limited by the very small volumes of production required, which do not lend themselves to automation or justify equipment development. During Project Gemini, almost all items were basically individually handmade.

Sandwiches were made in the conventional manner by using an individual sandwich mold to provide proper filling thickness. They were then individually dipped in gelatin and cut by hand one at a time into bite-size pieces. It was possible to cut 6 to 9 bite-size sandwiches from one large sandwich, the number depending on the shape of the slice of bread and the number of holes in the bread. Bread with fewer holes, especially made for sandwich preparation, is now sliced lengthwise rather than across the loaf in the conventional manner. This reduces the time required in making the sandwich and 39 to 42 bite-size sandwiches can be cut from each large sandwich by using a three-unit stamp cutter. Coating of the bite-size sandwiches, however, is still a one-by-one procedure.

In the case of meat bites, the product formula was initially layered in trays to a depth equal to the thickness of the bite required. After chilling, the product was cut into bites by hand using a crude cookie-type cutter. This, of course, was slow, and in many cases the bites were highly variable in thickness because of trays that were not level or errors in layering the proper thickness. There was also a 30- to 40-percent loss of material because of rounded corners, miscuts, etc. Currently the material is molded into logs of proper height and width and long enough for 30 bites to be cut from each log with a saw after the product is frozen. This has greatly increased the rate and efficiency of production, and weight can be adjusted by varying the thickness of the bites. These bites must still be coated by hand on a one-by-one basis, however.

Rehydratable bar products were initially prepared by weighing each component into a can-type mold, mixing these with a spatula, and freezing. The frozen product was removed from the can and three bars were cut from each mold. The total formula is now premixed and molded into logs of the proper width and long enough for approximately 24 bars to be cut from each log. This results in more uniform mixing and reduces the labor in mold filling, removal, and cutting. The weight of the bars, on the basis of predetermined drying yields, can be adjusted by varying the thickness of the bar being cut.

Perhaps the greatest improvement in rehydratable products has been in the use of textured beef and chicken. This process provides a binding characteristic within the meat piece which reduces the shredding or falling apart of the meat when it is diced into small pieces. This, in conjunction with an increase in the size of the mouth piece of the rehydratable pouch which permits an increase in the dice size of the meat particle, has resulted in a larger particle size. This process, we feel, has greatly improved the eating characteristics of these items, especially in the case of chicken products.

There are three future areas of research for improving these food items that are believed to be worthy of considerable effort. The first, and one in which it is believed much improvement can be made in a relatively short time, requires a critical look at flavors or spice levels in existing rehydratable items. It is believed that these items could be made more tasty simply by altering the levels of their spices, by modifying the spice formula, or, perhaps, by modifying some processing procedures. This, however, would require a considerable amount of preparation and testing. It is not believed necessary to freeze-dry and rehydrate these items for this purpose until after any major changes are made. It is proposed that the initial evaluation and recommendations be performed by a professional profile panel. After the major modifications have been made it is also believed that our astronauts should be permitted to evaluate and make recommendations on these products before a final formula is established. Again, it is believed this could be done without freeze-drying and rehydrating as long as processing is done in the same manner as that to be followed in production. It must be granted, however, that some flavor loss or alteration does occur during freeze-drying. Perhaps it may be possible to provide means for the astronaut to spice his own food to suit his own taste.

A second area worthy of consideration follows from the new concept of spoon and bowl feeding. This should greatly affect factors such as particle size and consistency of the products, and it may affect other factors relating to food preparation and formulation. It appears highly conceivable that grilled steak, pork chops, and ham could be prepared and consumed in this manner although such items have not been used before. It is proposed that these possibilities be investigated. Such items should greatly enhance mealtime in space.

A third area that I consider worthy of investigation is the concept of using the intermediate moisture or moisture mimetic agent foods to replace or improve the acceptability of the current very dry and fragile bite-size meat items. These moist items would also provide a much higher weight and caloric density than do our current bite-size items. This concept could be applied toward new items or to improvement of our current items. The use of such a concept should greatly improve the mouth feel or texture of the product and also provide improved flavor characteristics. It is conceivable that these products can be compressed or extruded and, therefore, would be more uniform in physical dimension and weight. Such items may or may not require a coating to be applied to the outside surface to prevent crumbs. It is also conceivable that these products may be provided not only in bite-size cube form but also in strips or sticks which would permit the astronaut to bite off and chew a part of the material and not be forced to place the entire piece in his mouth before chewing. In this way he could adjust the size of the bite to suit himself.

My remarks in regard to our current efforts and proposed future efforts for space feeding are now concluded. I feel that great strides can be made to provide more enjoyable mealtimes for our astronauts in the future and that such will result from this conference.

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General Foods Corporation Product Development as Related to Aerospace Food Problems

BEN F. BUCHANAN

General Foods Corporation

Although General Foods Corp. has had no direct contract responsibility in the NASA food development program, we accepted the invitation to participate in this conference because we felt that some of our experiences in the development of new food products might be of interest and bear some relevance to some of the aerospace feeding problems. Part of my message is well exemplified in the sentence, "The need for long lead time for future manned aerospace flights and world needs present and future is evident." We might add two further needs which must always be a part of any food-product development program, namely, recognition of the voice of the consumer, and adequate funding to attain the objectives sought.

Before we become specific about food products let us review some facts relative to the food business and the relationship of new products to the vitality of a company. The food business is the largest business in the world, and quite logically so, since every individual needs, above everything else, food to sustain life. (In this context water is considered to be a food.) An adequate food supply represents strength to the individual, strength to the nation, and strength to any endeavor involving man. In the United States alone the consumer food budget is over 100 billion dollars per year. Of this, 40 billion is in the fresh-food category (meats, milk, eggs, and vegetables), and 60 billion is in processed foods. About 22 billion dollars worth of the processed foods are perishable; the remaining 38 billion is for the shelf-stable processed foods. It is this last classification to which we will address ourselves primarily.

A viable, prosperous, growing food business requires constant new product development, product improvement, process development, and process improvement, and these efforts are supported by an expenditure in this country of over 400 million dollars per year in research and development. Satisfying the demands and needs of the consumer and maintaining growth in a food company requires a constant flow of new products. Fifty percent of the items on the supermarket shelf today were not there 10 years ago. The profitable and useful life of a new product follows the traditional curve shown in figure 1, from which it is evident that new products must be brought to market continuously year after year to sustain company growth from new products.

Many new product needs come from the consumer. It is the consumer whose wishes and desires must be satisfied, and the development of a new product should always give a high priority to the voice of the consumer. These needs are then translated into new product ideas by the technical researcher. New product ideas may also originate with other personnel of a company such

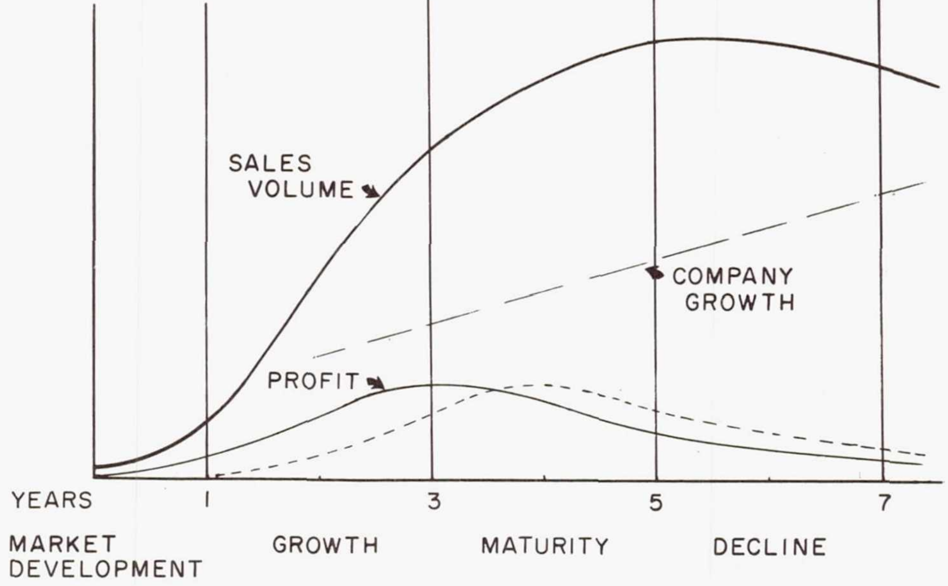

Figure 1.-New product development cycle.

as market researchers, salesmen, or purchasing personnel, or come from government laboratory research, university research, and consulting laboratories.

It is interesting that the most compelling reason for selection of a new food item by the consumer is the desire for variation and change, with convenience running a close second. These two considerations account for almost 50 percent of the reasons for choice of a new food item. Next come taste and flavor and then curiosity, which account for another 30 percent. Other reasons include "because it's new," and expectation of good quality, price, better packaging, and free samples. Of interest is the fact that the consumer selects an item "to please the family" less than once in 200 selections of a new food product. Nutrition rarely ever shows as a reason; this means that the food company must build nutrition into its products as an incidental acceptability factor.

Because of the high mortality rate of new product ideas, many must be reviewed, evaluated, and sometimes reevaluated to produce one winner. On the average 60 new product ideas are needed to result in one successful marketable product. Of these 45 are lost in the preliminary screening, 8 more during concept testing, 4 in the intensive research and development stage, and 2 more at the test market stage, thereby leaving only 1 which reaches national distribution. Incidentally, about 40 percent of the total costs are consumed in research and development by the time the one product reaches a successful market distribution, a fact pointing up again the need for adequate R&D funding.

Recent trends in new product development have been in the direction of technically designed foods, that is, foods specially fabricated to meet certain consumer demands, storagability requirements, packaging and transportability characteristics, etc. Instant banana pudding is an example of such a product; it applies the concepts of a highly popular flavor with convenience. An instant fruit-drink mix offers the consumer a shelf-stable, uniform, nutritious, acceptable fruit-flavored drink by the simple addition of cold water. Recent advances in freeze-dried products offer the consumer high flavor acceptability with the convenience of rapid rehydratability. For example, freeze-dried coffee resulted from over a dozen years of painstaking application of flavor technology with unique engineering processing techniques to attain the acceptable, marketable product; when instantly reconstituted it resembles as nearly as possible a freshly brewed cup of coffee and makes unnecessary the time-consuming bother of preparing the brew from roasted and ground coffee. These samples of technically designed products are just as acceptable, refreshing, and nutritious to the man in space as to the earthbound consumer and serve only as illustrations of the efforts made to meet the desires and demands of the consumer. Of high significance in the development of all technically designed foods is the opportunity offered for carefully controlled, high-quality standards in the product with precise uniformity day after day and year after year.

One category of technically designed foods receiving much attention recently is that of intermediate moisture products which must be shelf-stable, ready to eat, soft to the touch, moist to the bite, acceptable in flavor and texture, satisfying, nutritious, and packagable. Some items known to the consumer for many years which might be classified as intermediate moisture products are dried fruits, honey, and maple syrup. Even such a product as catsup, although in the higher moisture range, is stable by virtue of its high acidity and salt content. The soft, moist pet foods recently developed and now in the marketplace represent the application of modern technologies in the production of highly acceptable, nutritious foods for our pets. These same principles will soon manifest themselves in the development of human foods and should represent an ideal line of products for the astronaut.

Similar and closely related is the area of moisture mimetic product prototype development being pursued by General Foods Corp. along with the intermediate moisture investigations under partial support from the U. S. Army Natick Laboratories. It has been our objective to treat compressed bars of dehydrated foods in such a manner as to give the impression of moistness when eaten. It was therefore necessary to add certain materials which resembled moistness in the mouth yet retained a moisture content in the bar of less than about 2 percent. Selection of such additives must take into consideration flavor and acceptability along with nutrition, effect on appearance, bulk, stability, and rehydration. In all cases it has been our aim to limit the additive content to 20 percent by weight of the bar, maintain a minimum calorie content of 4 Kcal/g, and obtain a compressed bar which is easily sheared by the incisors at temperatures between 30° and 100° F. In addition, this bar must be chewable without becoming crumbly or difficult to swallow, withstand dropping to a concrete floor from a height of 3 ft, and be rehydratable in hot or cold water within a 15-min period.

Examples of additives which simulate moistness are glycerol, honey solids, dextrose, sucrose, fructose, sorbitol, fats, and oils. In addition, many additives induce salivation, among which are salts, fruit solids, and organic acids such as malic, citric, and tartaric. Invariably combinations of additives serve better than any one alone and the optimum combination will depend upon the particular food product under study. Obviously, combinations to be used for essentially meat items would differ from those for vegetables, cereals, fruits, dairy items, or mixed dishes. In all cases, however, it was found that to obtain best results certain of the salivation-inducing agents must be used along with the additives which simulate moistness.

It was found that the moisture mimetic composition is best introduced into the compressed-dehydrated or, frequently, freeze-dehydrated food bar by way of emulsion technology. A typical emulsion formulation is:

Water	50
Fats	22
Sucrose	12
Gum arabic	10
Emulsifiers (mono & diglycerides)	4
Sodium caseinate	2

Emulsions represent a suitable and convenient means of attaining compatibility and reproducibility with a wide range of compositions and of serving as a binding agent for the base materials because their rheological characteristics permit efficient coating of the freeze-dried base materials. As an example, 80 parts of freeze-dried chicken in $\frac{3}{8}$-inch dices were blended with 20 parts of the above emulsion, pressed into bars and frozen, and freeze-dried; the result was unusually acceptable dry chicken bars of high nutritional value and high calorie content. A wide variety of other dry meat, vegetable, and fruit bars having a moist sensation when eaten has been prepared.

To evaluate moisture mimetic foods for acceptability a taste/texture profile panel was specifically trained to judge prototype samples against similar bars made without addition of the moisture mimetic composition. To do so a special terminology was developed to describe characteristics of differentiation such as initial moisture sensation, plasticity, amount of salivation, ease of chewing, crumbliness, cohesiveness of the chewed mass, dehydration of the mouth, ease of swallowing, stickiness on the teeth, aftereffect thirst, and general palatability. In applying these evaluation criteria to a number of moisture mimetic bars it was shown that an increase of 2 to 3 points was attained on a 10-point acceptability rating scale over similar bars without addition of the moisture mimetic agent. For example, a chicken stew bar was increased in acceptability from a 2.5 rating to 5.5, plain chicken from 3.0 to 5.0, and cereal bar from 3.5 to 6.5. These are surprisingly moist-appearing items when eaten, yet are typically freeze-dried products with moisture content below about 2 percent. Typical products are shown in figure 2.

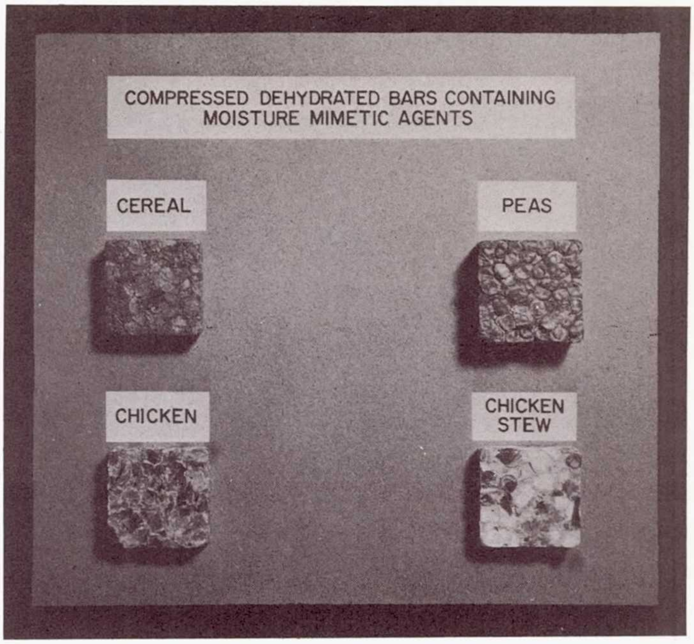

Figure 2.-Compressed dehydrated bars containing moisture mimetic agents.

The foregoing are just some examples of technically designed foods of the future which are not only for the average consumer but are also for the military and the astronaut, or aquanaut, since they fit admirably into the rigid projected requirements of stability, compactness, high caloric and nutritional value, convenience, and variety. Much more time and effort is needed to achieve their acceptance by the critical consumer, but they are on the threshold of reality.

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SESSION V

Long-Mission-Duration Programs

CHAIRMAN: LEO FOX

Deputy Director, Biotechnology and Human Research Division

NASA Office of Advanced Research and Technology

You have heard quite a bit to date about approved missions, Gemini, Mercury, and Apollo missions. The talks this morning will be relative to potential future missions which are, as yet, undefined - missions such as Extended Lunar Base Operations, Space Station Operations, Space Base Operations, and, eventually, Planetary Exploration. In some of these long-term missions which are being planned for the future, expendable supplies will not be used. Regenerative life-support systems will be utilized to supply essentials such as oxygen and water. We would like to close this regenerative loop by also regenerating at least part of the food. When we consider the possibility of regenerating food from metabolic wastes, we do so from two approaches: (1) By means of physicochemical means and (2) by biological means. In this context, the first talk will be given by Dr. Jacob Shapira of the Ames Research Center, who will talk about a physicochemical method of regenerating food.

Leo Fox

FOOD SYNTHESIS BY PHYSICOCHEMICAL METHODS

JACOB SHAPIRA
NASA Ames Research Center

As space missions become longer and longer, it is obvious that at some point a system that will at least partially recover useful foods from metabolic products will offer net mission advantages. A number of predictions have been made as to the mission duration that would be required before regeneration of food would be expected to result in savings. By using only very fragmentary information, the General Dynamics Co. in 1966 concluded that, for a 6000-man-day mission (i.e., a Mars mission with a 10-man crew), physicochemical regeneration of carbohydrates would result in savings in weight and volume of the food supply system (refs. 1 and 2). In a similar study, the Lockheed Missiles and Space Co. came to a very similar conclusion (refs. 1 and 3).

RATIONALE FOR SPACE DIETS CONTAINING REGENERATED NUTRIENTS

Food in its most basic sense is any substance taken into and assimilated by a plant or animal to keep it alive and enable it to grow. The substances themselves, depending upon the source, are generally very complex mixtures of organic materials and inorganic salts. However, the major materials required by man are relatively limited in number and are composed primarily of protein, fat, and carbohydrate.

The protein components of our diet are a large number of complex polymers of approximately 20 simple organic compounds, amino acids, of which only 8 are essential to a man since they cannot be synthesized by the body. The minimum requirement for protein has been variously estimated to be between 50 and 75 g/day.

Fats are mostly composed of glycerol combined with long-chain saturated and unsaturated fatty acids. Only a few of the polyunsaturated fatty acids are considered to be essential to humans and they are required in very small amounts, perhaps as little as 1 to 2 g/day.

The carbohydrates in our diet are polymers of relatively simple organic compounds, primarily the hexose sugar glucose. It is not known whether there is a minimal requirement for carbohydrate. However, a diet which contained exclusively protein and fat might be expected to cause difficulties in metabolism because of the very high nitrogen load and the ketosis associated with very high fat diets. In addition, our diet contains relatively small amounts of various salts, nucleic acids, vitamins, and trace elements.

In the typical American diet the major chemical components are as shown in table I. Note that one-half the calories are derived from the hexoses present in the carbohydrates, about one-third the calories are from fatty acids in the fat, and the remainder are composed of the amino acids in the protein and the glycerol content of the fat. The minerals, vitamins, and other components of the diet contribute virtually no calories.

TABLE I.-MAJOR CHEMICAL COMPONENTS OF TYPICAL AMERICAN DIET

Material	Weight/day, g	Kcal/day
Hexoses	315	1260
Amino acids	90	400
Fatty acids	90	900
Glycerol	10	40
	505	2600

It should be emphasized that it makes no difference to the body whether these substances come from a food of natural origin or are synthesized by in vitro biological or physicochemical methods. The main consideration is that the material be safe and acceptable as food.

Equations can be written for the catabolism of food substances by the body. In the case of (1) protein (meat), (2) fat (tripalmitin), and (3) carbohydrate (starch), these equations on a per mole carbon basis are, respectively,

$$(1)\quad C_{1.00}H_{1.67}O_{0.22}N_{0.27} + 1.00\ O_2 \rightarrow 0.80\ CO_2 + 0.30\ H_2O + C_{0.20}H_{1.07}O_{0.32}N_{0.27}$$

$$(2)\quad C_{1.00}H_{1.92}O_{0.12} + 1.42\ O_2 \rightarrow 1.00\ CO_2 + 0.96\ H_2O$$

$$(3)\quad C_{1.00}H_{1.67}O_{0.83} + 1.00\ O_2 \rightarrow 1.00\ CO_2 + 0.83\ H_2O$$

A net equation can be written for the catabolism of the diet shown in table I as follows, again on a per carbon basis:

$$C_{1.00}H_{1.74}O_{0.46}N_{0.08} + 1.12\ O_2 \rightarrow 0.94\ CO_2 + 0.72\ H_2O + C_{0.06}H_{0.30}O_{0.09}N_{0.08}$$

It is seen that 94 percent of the carbon of our food is exhaled as carbon dioxide and that 83 percent of the hydrogen is converted to water. Only relatively small amounts of material are excreted in the urine and feces.

Now let us postulate a system in which the carbon dioxide and water would, by chemical means only, be converted into carbohydrate. And further, let us postulate that this carbohydrate would comprise about 85 percent of the diet. The remainder of the diet would be composed of other essential components of the foods more difficult to synthesize such as protein, fat, vitamins, and the like which would be carried along on the mission. Catabolism of such a diet by the body is shown by the following equation:

$$C_{1.00}H_{1.67}O_{0.72}N_{0.04} + 1.01\ O_2 \rightarrow 0.97\ CO_2 + 0.75\ H_2O + C_{0.03}H_{0.17}O_{0.05}N_{0.04}$$

It should be noted that an even greater proportion of this diet is converted to carbon dioxide and water than that of a typical diet and that, for all practical purposes, excretion products other than carbon dioxide and water can be discarded from a regenerative system. More than sufficient carbon dioxide and water are produced to permit resynthesis of the 85 percent of the diet which is carbohydrate. Such a diet containing 85 percent carbohydrate should be safe and acceptable and in fact may be healthier than the current American diet with its excessive fat and protein.

Serious consideration has been given to the problem of synthesis of protein (ref. 4) and fat (ref. 5) in the aerospace environment. Unfortunately, it appears that very complicated processes will be required for their synthesis, and in all likelihood automatic systems would not be economical even for long-duration space missions.

SELECTION OF PURE NUTRIENTS

The hypothesis is: certain carbohydrates or carbohydratelike nutrients present in our diets can be made a major fraction of regenerated food. Any such substance must be safe and acceptable as food, comprise a significant portion of the diet, and be readily synthesized with high reliability (ref. 6).

During normal metabolism, large food molecules are broken down to successively smaller molecules which might be synthesized relatively easily. It was hoped that some of these might be tolerated when ingested in large amounts. This did not prove to be the case. For example, the trioses, glyceraldehyde, and dihydroxyacetone which arise from the catabolism of glucose could be tolerated by rats in only small amounts.

The literature was examined for reports of compounds which could be consumed in very large amounts for prolonged periods. There are few such compounds. The known toxicology of one of these, glycerol, is compared with that of the normal blood sugar, glucose, in table II (ref. 7).

TABLE II. -TOXICITY OF GLUCOSE AND GLYCEROL

Compound	Animal	Route	LD, mg/kg
Glucose	Rabbit	Oral	20 000
Glucose	Rabbit	Intravenous	17 000
Glucose	Dog	Oral	10 000
Glycerol	Rabbit	Oral	27 000
Glycerol	Mouse	Oral	31 500
Glycerol	Rat	Oral	27 500
Glycerol	Guinea pig	Oral	7 750

In several species, it can be seen that gylcerol administered orally is probably no more acutely toxic than glucose, which is known to be highly acceptable as a large percentage of the diet. Other low-molecular-weight compounds which have been reported to have low toxicity are diglycerol, triglycerol, polyglycerol, propandiol, and triacetin. This last compound is the simplest even-chain fat and arises from the esterification of glycerol with acetic acid.

Glycerol has been administered to both normal and ill individuals in large amounts for extended periods. In the classical study of Johnson, Carlson, and Johnson (ref. 8), 14 subjects each consumed 110 g/day of glycerol for 50 days. This amount of glycerol represented about 20 percent of the calorie requirements of the subjects, and no deterimental effects were observed. In the same study, animals were fed even larger amounts of glycerol for 50 weeks; again, there was no evidence of toxicity.

In recent years, there have been reports concerning the administration of glycerol to over 1000 patients with glaucoma (ref. 9), increased intracranial pressure (ref. 10), and diabetes (ref. 11). Patients have consumed as much as 300 g/day, which is more than one-half their food requirement. It is apparent that glycerol can safely be made a substantial part of the diet, whether it comes from a natural source, such as fat, or is synthesized from metabolic products.

The evidence for the safety of ingestion of propylene glycol, triacetin, and some other compounds by humans is limited. However, they are generally recognized as safe by the U. S. Food and Drug Administration (ref. 12). These materials have been tested rather extensively on animals and there is good reason to believe that they can also be safely consumed in significant amounts by humans.

The situation with the formose sugars which arise from the self-condensation of formaldehyde is more tenuous. All studies thus far reported indicate that the unpurified mixture causes a gastrointestinal disturbance when fed to animals. This may be due to the presence of a limited number of components of the mixture whose formation can be avoided by appropriate choice of conditions and/or catalyst. Alternatively, undesired components could be removed from the crude product by fractionation.

SELECTION OF PHYSICOCHEMICAL PATHWAYS

The starting materials available for the physicochemical syntheses are carbon dioxide and water. There are currently available prototype apparatuses for electrolysis of water in either the liquid or gas phase to produce oxygen, which can be recycled through the spacecraft cabin, and the byproduct hydrogen (ref. 13). A process also fairly well developed utilizes this hydrogen to produce methane and water (ref. 14). The water is of high purity and can be either electrolyzed to oxygen and hydrogen or consumed by the crew. The methane may possibly be cracked to produce carbon and hydrogen, although this reaction appears to be difficult to accomplish in practice.

Accordingly, the methane produced as the byproduct of the atmosphere control system was considered to be available for food synthesis. The pathway envisioned for the synthesis of glycerol and the formose sugars was:

$$CO_2 \longrightarrow CH_4 \longrightarrow HCHO \begin{array}{l} \nearrow (HCHO)_3 \longrightarrow \text{Glycerol} \\ \searrow \text{Formose Sugars} \end{array}$$

Thus, the methane would be converted to formaldehyde (HCHO) which could be condensed directly to formose sugars or condensed to trioses which would be catalytically reduced to glycerol. Possible pathways leading from methane to propylene glycol, acetic acid, and other simple molecules which might be used as food will not be discussed. However, it should not be difficult to conceive of methods for accomplishing the desired conversions.

It is of interest to write a completely balanced set of equations describing some of these conversions:

Reaction	ΔH
$24\ H_2O \longrightarrow 24\ H_2 + 12\ O_2$	+1638.2 Kcal
$6\ CO_2 + 24\ H_2 \longrightarrow 6\ CH_4 + 12\ H_2O$	-362.4
$6\ CH_4 + 6\ O_2 \longrightarrow 6\ HCHO + 6\ H_2O$	-468.6
$6\ HCHO \longrightarrow C_6H_{12}O_6$	-135.2
$6\ CO_2 + 6\ H_2O \quad C_6H_{12}O_6 + 6\ O_2$	+672.0

The net equation for the synthesis of a hexose (via the formose reaction) is identical to the net equation of photosynthesis, although it should be emphasized that photosynthesis proceeds by a quite different and considerably more complex pathway. It should also be noted that the sole energy-requiring reaction in the sequence is the electrolysis of water required for the recovery of oxygen. The remainder of the reactions are exothermic. Further, the reverse of the net equation is the action that occurs in the body during catabolism of carbohydrate. There are always sufficient starting materials produced to close the cycle, even neglecting the carbon dioxide and water produced from the stored components of the diet.

SYNTHESIS OF FORMALDEHYDE FROM CARBON DIOXIDE AND HYDROGEN

A NASA contractor, the General American Research Division of the General American Transportation Corp., is currently in the process of assembling a breadboard prototype apparatus which will accept carbon dioxide, hydrogen, and oxygen as starting materials and produce only formaldhyde and water (ref. 15). All intermediates and byproducts are recycled. A representation of this apparatus is shown in figure 1. In the main recycle loop on the right side of the figure, methane is oxidized at 675° C in a reactor containing sodium tetraborate coated pellets. Conversion during each pass was relatively low, but with a recycle ratio of 35 the yield was approximately 35 percent. The recycle gas composition was 30 percent methane, 10 percent oxygen, 45 percent nitrogen, 0.2 percent nitrous oxide catalyst, 15 percent carbon oxides, and 1 percent hydrogen.

In the recycle loop shown on the left of figure 1, a small fraction of the main loop gases is processed in a Sabatier catalytic reaction wherein byproduct carbon oxides are reconverted to methane. The initial feed of carbon dioxide also enters the system in this loop.

The crude laboratory system required about 50 W to compensate for insulation losses and other inefficiencies. However, no external heating would be required if the combined heat exchanger and insulation system were more than 85 percent effective. The first laboratory system could produce approximately 40 g/day of formaldehyde, but subsequent prototype systems will produce appreciably more.

SYNTHESIS OF GLYCEROL FROM FORMALDEHYDE

Various methods have been evaluated for the synthesis of glycerol from formaldehyde (ref. 15) and considerable progress has been made toward implementing the scheme requiring conversion of formaldehyde to trioses and their subsequent catalytic reduction to glycerol (ref. 16).

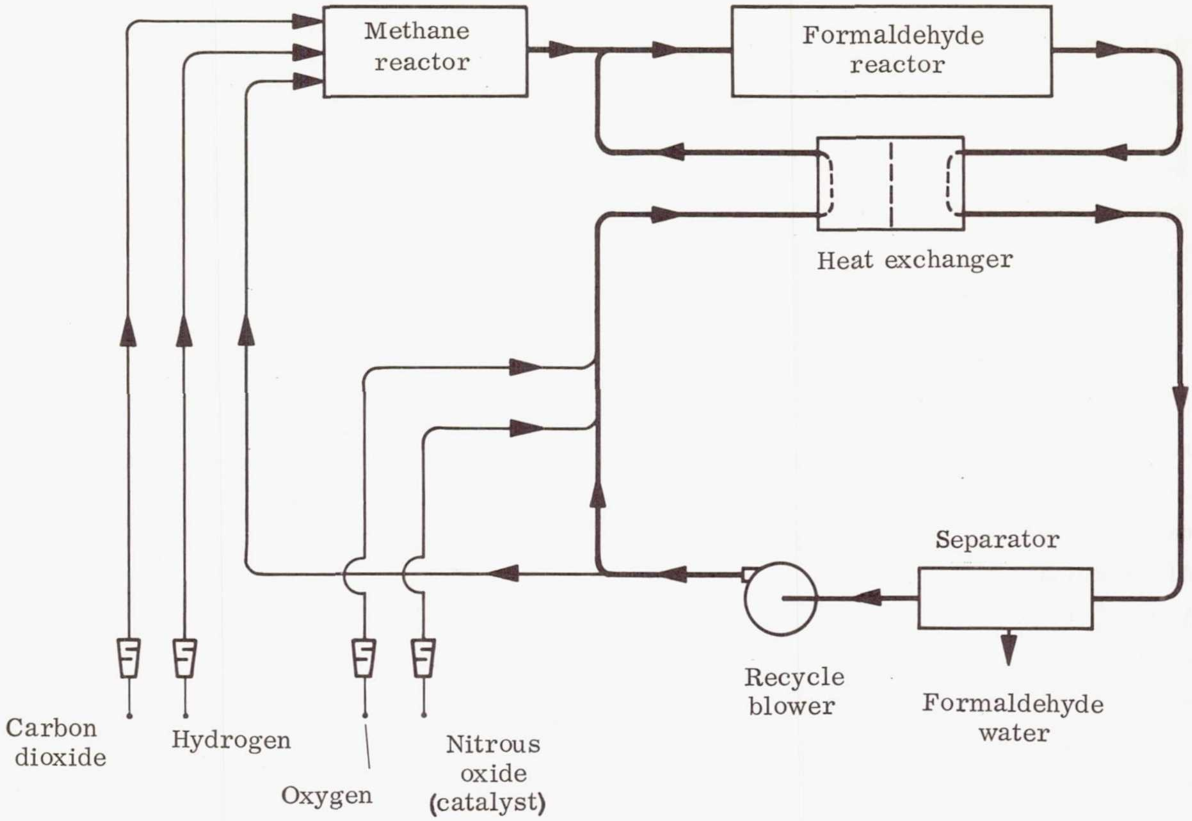

Figure 1.-Apparatus for producing formaldehyde and water.

Extensive studies have been made related to the selection of optimum conditions for the condensation and selection of the best heterogeneous catalyst. Several catalysts based upon calcium oxide or ferric oxide on alumina have been found. Glyceraldehyde was found to be desirable as a cocatalyst because it greatly reduced the induction period for the autocatalytic reaction and had a desirable directive effect on the products formed. The most suitable hydrogenation catalyst was found to be ruthenium on carbon. There is a continuing effort to develop a laboratory prototype apparatus that will continuously convert formaldehyde to glycerol.

SYNTHESIS OF FORMOSE SUGARS FROM FORMALDEHYDE

The formose reaction whereby formaldehyde condenses to produce a complex mixture of sugars has been investigated intermittently for over 100 years (refs. 6 and 17). Recently, a new type of reactor was developed for the synthesis of formose which permitted much greater control of the reaction than had previously been possible and also permitted the collection of data relevant to the kinetics of the reaction (refs. 18 and 19).

By using a 500-ml stirred tank reactor maintained at 60° C, it is possible to convert up to 900 g/hr of formaldehyde into formose sugars. The concentration of formaldehyde has been varied between 4 and 30 percent in aqueous solution and usually with a 0.1 molar ratio of the catalyst calcium hydroxide. Depending upon space velocities, conversions of 30 to 100 percent can be obtained reproducibly. A method has been developed that permits facile examination of the formose produce for its composition (ref. 20).

The observed kinetics can be explained by using rate expressions similar to those employed for analysis of heterogeneously catalyzed reactions. Complexing-decomplexing steps in the homogeneous system are equivalent to adsorption-desorption steps in the heterogeneous system (refs. 19 and 21). It appears that decomplexing of the product may be the rate-limiting step, whereas the distribution of products is governed by the nature and concentration of the catalyst.

FABRICATION OF FOODS

It should not be expected that crews of long-duration space missions will readily consume the pure nutrients synthesized onboard without modification or the addition of flavorings. However, it is not difficult to envision using glycerol, which is quite sweet, and sugars in a variety of acceptable foods. For instance, they might be used as sweeteners for coffee and tea; alternatively, they might serve as the basis for flavored soft drinks. If, or rather when, it becomes possible to convert these materials to higher polymers such as starch, the only major limitation will be in the ingenuity of the cook. One can readily foresee starch-based foods such as potato soup, pancakes, and pasta based on regenerated materials becoming quite acceptable food items.

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Biological Foods

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Several biological systems of varying complexity have been proposed to fulfill the triple role of food production, atmosphere regeneration, and waste removal in spacecraft. It should be noted that production of food in spacecraft (in contrast with that in planetary stations and fixed bases) is thought of only in terms of a multiple role, otherwise food would be carried aboard as it is for submarines. (I suppose a case could be made for the recreational value of gardening, but it probably assumes an exceptional breed of spacemen.) All of the bioregenerative systems have drawbacks, but some might have advantages over a purely chemical system.

The system most studied is based on growth of green algae, usually Chlorella. In this scheme, carbon is recycled by photosynthetic reduction of carbon dioxide; the nitrogen and minerals of human excreta are utilized to support growth of the microscopic green plants and thereby cycle these nutrients as well. Higher plants can function similarly but less efficiently, in that their rate of growth is slower and a larger portion of plant tissue is not capable of photosynthesis. The most likely candidates among higher plants are duckweed and other fairly primitive plants and a few of the more traditional food plants that have a large leaf surface and reasonable growth rate, such as endive, Chinese cabbage, radish, and sweet potato.

The only bacterial system given serious consideration so far involves coupling an autotrophic hydrogen-fixing bacterium, Hydrogenomonas eutropha, with electrolysis of water to return breathable oxygen and food in the form of bacterial cells. Other suggestions have utilized as yet uncharacterized bacteria in conjunction with chemical atmosphere-regeneration schemes. In one, a methane-fixing organism would be used with the Sabatier carbon dioxide removal system. Other researchers have proposed bacterial conversion of formose sugars or fatty acids from chemical food-synthesis systems. In all cases urine contributes the nitrogen needed for bacterial growth.

Two different fungal systems are potentially useful. The simpler forms, molds and yeasts, can grow in media containing urine and feces with sugars added. Mushrooms may be grown on cellulose and nutrients from human wastes. These systems use oxygen and produce carbon dioxide but could be linked with a chemical atmosphere-regenerative system or be used to process further the inedible portions of higher plants.

The most elaborate schemes anticipate using algae or higher plants as food for one or more animal intermediates. Water fleas, fish, rabbits, and fowl all have had proponents among scientists who seek stability in ecologic diversity and who hope to provide more acceptable and nutritious food in this way. The very complex systems are probably best reserved for planetary habitation or major space laboratory stations where they can serve a dual role as biological test subjects before they are eaten.

Typical compositions of leaves, algae, fungi, and bacteria are given in table I. All of these items are quite high in protein content on a dry-matter basis. Their ratios of carbon to nitrogen are much different from that in normal human diets. In general, the higher the growth or cell-division rate of the organism, the higher the protein (and nucleic acid) content. These rapid growth rates are necessary if the systems are to recycle oxygen effectively within reasonable weight and volume limits.

TABLE I. -PUBLISHED TYPICAL COMPOSITIONS OF BIOMASSES

Dry solids	Amount, %, in-			
	Leaves	Algae	Fungi	Bacteria
Protein (N x 6.25)	20 to 40	40 to 60	30 to 50	65 to 85
Lipids	5 to 9	4 to 10	2 to 7	6 to 8
Ash	9 to 15	6 to 9	6 to 9	2 to 4
Carbohydrate (by diff.)	40 to 60	25 to 45	40 to 55	5 to 20
Fiber	[a]8 to 15	2 to 9	1 to 10	Nil

[a]Includes leaf ribs but not stems and roots.

Leaves, algae, and fungi are rich in carbohydrate, but in the cases of the microorganisms variants or methods are known for increasing the content of lipids. The usual means of changing composition within a given strain is by altering the nutrient medium. Estimates of ash content vary, often because mineral-rich media are not thoroughly removed when the cells are harvested.

All biomasses contain some indigestible solids, usually in the form of polysaccharides or complex carbohydrates. Leaves and algae are particularly offensive in this respect. Sometimes this indigestible material interferes with absorption of nutrients within the cells. This occurs when the indigestible material is included in the cell wall and the cells are not ruptured before consumption. If the unabsorbed residues reach the lower ileum and colon where they can be acted upon by bacteria, they produce both excessive intestinal gas and a number of short-chain organic compounds that have a laxative effect. This may cause poor absorption of the diet in general.

Hydrogenomonas accumulates lipid if deprived of nitrogen or oxygen, as do a number of other bacteria. This lipid is chiefly a polymer of beta-hydroxybutyric acid, which we have shown cannot be absorbed from the animal intestine. In this instance there is no interference with protein digestibility, most probably because the lipid is intracellular.

This brief discussion of composition serves to illustrate two basic judgments to be made before qualifying biomasses as human food. The first is to assess the closeness of fit between the composition of the product and nutritional needs of man (i.e., the C/N ratio). The second is to detect the presence of substances that have no nutritional value but that do have physiologic effects (e.g., cellulose). Neither of these factors can be established conclusively on the basis of present knowledge of either nutritional needs of man in space or attributes of the biomasses. But some informed guesses are permissible, and these must be made to set the direction of research programs that will supply the facts by the time such systems are absolutely required, perhaps by about 1984 for the Mars mission.

Distorted ratios of carbohydrate, protein, and fat would be present in the diet if major dependence for food were placed on a chemical system (high carbohydrate or low-fat protein), a biological system (high protein, low fat or carbohydrate), or a minimum-weight, stored-food system (high fat, low protein and carbohydrate). We have explored the tolerance of healthy men to these patterns, in those cases for which published information was inadequate. On the basis of our own and other studies we have concluded that dietary protein may vary between 45 and 300 g/day, provided that quality is assured in the former case and adequate water intake in the latter. Fat tolerance is in the range of 200 to 250 g/day, provided that all the fatty acids are not saturated and long chain. A minimum of 7 g of some oils could meet the accepted minimum need for essential fatty acids. Maximum capacity to absorb and metabolize carbohydrate has not been determined, but the amount which can be absorbed is much greater than 600 g/day. From several lines of evidence, the least amount of carbohydrate that will prevent ketosis is about 70 g/day.

The protein quality of biomasses (the digestibility and amino acid balance) is obviously important in view of these tolerance limits. In comparison with animal proteins, the amino acid pattern of leaves is best among those of the biomasses. The other products are somewhat poorer, particularly with respect to methionine, but compare favorably with the milk protein casein and good quality plant proteins, such as soybean. Studies recently completed in our laboratory have indicated that slightly less than 50 g of protein from ethanol-extracted Chlorella (courtesy of Dr. R. L. Miller, Brooks AFB), commercial Torula yeast, and casein will support nitrogen balance in man, in contrast to 35 to 40 g of egg protein. In rat studies bacterial protein also compared favorably with casein. Thus, any of the biomasses could theoretically meet all of the protein needs of the crew.

One of the most important of the nonnutritional factors that may limit consumption of unprocessed cells is the amount of purines present as nucleic acids. Purine is degraded by man to uric acid which is sparingly soluble in tissue fluids and may precipitate as stones in the urinary tract or crystals in the joints. Unfortunately, high levels of dietary protein also increase urinary uric acid, presumably by stimulating endogenous synthesis. The biomasses contain roughly 1 g of ribonucleic acid (RNA) per gram of protein. To be perfectly safe, it might be necessary to limit intake of cells to 20 to 40 g of protein per day, the amount depending on individual tolerance limits. If consumption is increased to the maximum allowable protein intake, the least amount of processing that could be considered is removal of purines from the cells; this would require a new direction in food technology.

Nucleic acids are by no means the only undesirable coincidental compounds present in biomasses. The list includes among others the carbohydrates alluded to earlier, pigments, minerals, nitrates, glycosides, amines, and steroids. Many are innocuous at low dosages but harmful to lethal at high-intake levels. Recently, we found that men cannot tolerate even very small amounts of either of two bacteria tested: H. eutropha and A. aerogenes. Subjects became acutely ill from a few grams of dry cells, with symptoms reminiscent of food poisoning.

On the basis of the present most optimistic view, consumption of crude biomasses is limited to the function of providing protein (plus a few vitamins and minerals) to accompany a chemically regenerated or stored-aboard diet high in fat or carbohydrate (table II). Regeneration of this order of magnitude (7 g of nitrogen and 260 Kcal) is of doubtful value in a spaceship. After they have been fully processed to remove nucleic acids, fiber, toxins, and other unwanted substances, leaves, algae, or yeast could form the major portion of a diet. Bacteria could provide about one-half of the needed food, on the basis of the composition of present candidates. The processing steps would be quite extensive and it would be a challenge to produce edible products recognizable as food and acceptable to the crew.

TABLE II. -AMOUNT OF BIOMASS USEFUL IN SPACE DIETS

Biomass - - - - - -	Leaf	Algae & yeast	Bacteria
Yield from crude product			
Protein/man/day, g - - -	~ 25-30	~ 40	?
Energy/man/day, Kcal -	~ 260	~ 280	?
Yield after complete processing			
Protein/man/day, g - - -	185	300	300
Energy/man/day, Kcal -	2800	2200	1360

Long-Term Space Mission Requirements

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Spaceflights for the Mercury, Gemini, and Apollo programs (table I), are extremely brief compared with flights for future programs now in the planning stages. Apollo Applications Program (AAP) missions have been designed to last 28 or 56 days, the minimum time being twice the length of present accomplishments. The missions for AAP, however, are only intermediate in length.

TABLE I.-LENGTH OF ORBITAL FLIGHTS

Astronaut or mission	Date	Duration
Mercury		
John H. Glenn, Jr.	Feb. 20, 1962	4 hr 56 min
M. Scott Carpenter	May 24, 1962	4 hr 56 min
Walter M. Schirra, Jr.	Oct. 3, 1963	9 hr 14 min
L. Gordon Cooper, Jr.	May 15, 1963	34 hr 20 min
Gemini		
Gemini 3	Mar. 23, 1965	Approx 15 hr
Gemini 4	June 3, 1965	4 days
Gemini 5	Aug. 21, 1965	8 days
Gemini 6	Oct. 25, 1965	2 days
Gemini 7	Dec. 4, 1965	14 days
Gemini 6-A	Dec. 15, 1965	1 day
Gemini 8	Mar. 16, 1966	3 days
Gemini 9	May 17, 1966	3 days
Gemini 9-A	June 3, 1966	3 days
Gemini 10	July 18, 1966	3 days
Gemini 11	Sept. 12, 1966	3 days
Gemini 12	Nov. 11, 1966	4 days
Apollo		
Apollo 7	Oct. 11, 1968	11 days
Apollo 8	Dec. 21, 1968	6 days
Apollo 9	Feb. 3, 1969	10 days

The purpose of this paper is to discuss space missions beyond the AAP, which are classified as long term. It should be emphasized that these concepts are only possibilities at the present time. No definite programs have been implemented, although considerable effort has been expended during initial planning stages. Attention will be focused on three concepts of space exploration. They are designated as the Earth-Orbit Program, the Lunar Program, and the Planetary Program. These three programs will be discussed individually.

EARTH-ORBIT PROGRAM

Future Earth-orbit programs will begin with the AAP. Subsequent Earth-orbit missions will increase both in crew size and mission time. In the next decade the launching of an Earth-orbiting space station manned by a crew of 8 to 12 individuals is a distinct possibility. The duration of such a flight would be about 180 days. (This is about 13 times longer than any previous flight). Flights within this time frame and longer ones must be classified as long-term space missions.

Near the latter part of the decade a space-station facility which will support men and equipment on a permanent basis will be assembled in space. Such a station could have the capability of housing 50 to 100 individuals in an Earth-like artificial-gravity environment. The space station would be equipped with a hangar and docking area. Space shuttle vehicles traveling between the station and the Earth would provide logistical support, thereby resupplying expendable materials. Resupply would probably be reserved for expendables and subsystems which require open-loop operation. This space station could also serve as a centralized storage facility for expendables and equipment which could be utilized for subsequent planetary missions.

LUNAR PROGRAM

Lunar landings during Apollo and post Apollo lunar exploration will utilize small vehicles, and crews will be confined to the immediate area of the spacecraft. Future exploration will require multiman vehicles and additional supporting systems for increased stay times. Concepts for the establishment of a lunar base are being developed. Such a structure would be somewhat permanent. Conceivably, a lunar base could be resupplied with expendable materials and crew members could be rotated periodically.

PLANETARY PROGRAM

Another category of long-term space missions is that of planetary exploration. For such missions a spacecraft could be launched from Earth or from a permanent base such as a space station. Present plans call for a Mars-Venus manned fly-by during the latter part of the next decade and a Mars orbital mission or landing by the year 1984. These flights would be extended nonresupply missions which would require 420 to 540 days for completion.

The requirements for a feeding system may not be identical for all of the long-term missions categorized earlier. Unique features associated with each program will need to be satisfied. Missions will vary with respect to crew size, extent of activity, and environmental conditions. The extreme conditions on the lunar surface are quite different from the artificial-gravity environment in a large space station. There is one common denominator, however; as the length of manned spaceflights and exploration increases, the problems associated with life support multiply and become more complex and much more speculative.

As previously noted, the space station could be resupplied periodically with expendables, including food. The requirements for a feeding system will be quite flexible and not so restrictive as those for past and present systems. It is anticipated that conventional methods of food preparation and eating will be compatible with the environment within the space station. Hardware and equipment will be provided which will heat and cool foods prior to consumption. It is also conceivable that the technique of resupply for the lunar exploration programs could also be applicable for a portion of the nutritional requirements. Because of the factors of space and weight, which will not be restricted, recycling methods may be quite feasible on the lunar surface.

Extended planetary missions with no resupply will require a highly reliable feeding system. Such reliability may result in some redundancy. A nominal system might be designed to include several food sources, with provisions for complete failure of one or more sources. With this approach, failure of a single food source would compromise overall food acceptance but not the available nutrients required to maintain crew health and performance.

At some point a closed life-support system must be integrated into the program. The objective of closing loops is to reduce the weight of expendable supplies, life-support equipment, and supporting equipment for electric power. At some point the penalties for resupply or for an adequate supply for the duration of the mission will exceed those for regeneration. This point was illustrated in a study by the Convair Division of the General Dynamics Co. (ref. 1). Closed-loop systems for the regeneration of water and the recovery of oxygen will probably be used first (100 to 1000 man days). The feasibility of regenerating food from wastes in a closed system is more distant, but such a concept could be integrated into the feeding systems during the next decade. In fact, systems could be qualified on missions for which resupply is the core of a feeding system.

Recently the Soviet Union conducted a 1-year test of life-support systems. Three human subjects spent 1 year in a sealed chamber. Air and water were regenerated; food consisted of vacuum-dried products and fresh vegetables from a "cosmic" greenhouse. Dehydrated foods include such items as salmon, chocolate, cottage cheese, and prune paste. To provide variety, a repeatable 5-day menu was devised. During the second and third stages this diet was augmented by fresh vegetables (which included cabbage, cress, cucumber, greens, and dill) from the greenhouse (refs. 2 to 6).

The following statement was made in a report issued by the Space Science Board (ref. 7): "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."

Several life-support systems have been proposed whereby food is produced from biological wastes. Biological systems which have been investigated include algae, bacteria, higher plants (hydroponics), herbivorous invertebrate animals, fungi, and plant cultures. The Space Science Board in 1966 (ref. 8) suggested that: "Consideration should also be given to the production of higher plants or animals that may be more palatable to humans. It has been shown, for example, that sweet potatoes grow well in hydroponic culture utilizing the end products of the stabilization of human wastes." Chemical synthesis, including the synthesis of carbohydrates, lipids, and amino acids, has also been suggested as a possible alternative to biological systems.

Inherent advantages and disadvantages are associated with each biological and chemical system. Each system must be evaluated in terms of purifying and converting the material into an edible form, food acceptability and palatability, nutritional adequacy, efficiency, compatibility with the total life-support system, logistical support, mission duration, and the number of individuals involved.

In reference 9 several statements were made on this subject: "There are two significant areas with a high probability of future research and development effort. These pertain to the nutritional aspects of the food-waste loop and the ultimate acceptance or rejection of the produced food by the crew. The crew acceptance of the synthesized food may well prove to be the major restraint in this method of closing the ecology."

Feeding systems for long-term aerospace missions must provide adequate nutrients which will maintain the original health of the flight crews and maintain a high level of crew performance, behavior, and morale. It was stated in a report by the Space Science Board (ref. 10): "As flights become longer, the attitudes of the astronauts will increasingly affect the success of missions. It will be necessary to have an intensive and extensive knowledge of the dynamics of man's behavior in respect to food and to be able to predict man's performance."

Long-term studies similar to the one conducted by the Soviet Union could provide important data in the development of future concepts for long-term missions. Studies conducted in the United States have been of less than 60 days' duration. More long-term research needs to be conducted. Possible areas of research as outlined by the Space Science Board (ref. 11) might include:

(1) The analysis from a storage stability standpoint of the presently available take-along foods
(2) The study of changes in dietary appeal due to long confinement
(3) The toxicological properties in foods which may be used
(4) The effect of dietary regimens on waste production
(5) The investigation of continued long-term consumption of unconventional food materials on intestinal flora and motility
(6) The effect of diet on flatus
(7) The investigation of changes in metabolic balance under the stresses of flight

In summary, each program - Earth orbital, lunar exploration, and planetary - has unique concepts associated with it. An all-inclusive approach will not completely satisfy the requirements for these long-term space missions. Life-support systems will probably be integrated into long-term feeding systems. It is doubtful, however, that a feeding system designed for any long-term mission will be completely dependent upon food production within the spacecraft as the sole source of nutrients.

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U.S. ARMY FOOD R&D PROGRAM

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The food technology aspects of military rations and space foods and the problems associated with their development have been covered in numerous publications (refs. 1 to 6).

Proper design criteria are required for any feeding system or subsystem. For military field rations these are:

(1) Acceptability: liked by majority of troops

(2) Stability: 6 months at 100° F

(3) Nutritional adequacy: calories and essential nutrients

(4) Utility: meets specific serving requirements

With the use of these criteria, a food product or feeding system can be developed or modified to meet any major operational situation. The same criteria can also be applied to a system for feeding in space.

A product which has outstanding military utility in the field still must address the supply and delivery systems involved. These criteria, when properly defined and applied, force the development of a product or a ration that is integrated with the system. For example, they preclude perishable foods in a ration which has to be carried by the soldier and wherein resupply is not feasible for several days. Obviously, utility and stability have not been correctly addressed if ice cream were proposed for such a situation. A product or combination of products is required which is light in weight, easily prepared or requires no preparation, nutritionally adequate, and stable enough to meet the requirements of the long military supply line. All new products and ration prototypes must undergo intensive evaluation against these criteria. This includes testing against the specific technical requirements which have been established through translation of the military requirements.

FREEZE-DRYING

Some 12 to 15 years ago, after the needs for new field rations that would meet changing battlefield tactics were analyzed, freeze-drying was chosen as the method of food preservation which had the potential of providing products and rations that would best fulfill the maximum number of criteria.

Up to that time the freeze-drying of food had been largely a laboratory curiosity. However, work in our laboratories and in closely related research groups demonstrated that it could be a practical method of preservation. Today, freeze-drying is being used both for military and civilian products. Admittedly, the high cost of processing is still a disadvantage, and a product selected for this method of preservation must show an advantage in some characteristics such as flavor, stability without refrigeration, convenience, or light weight before the product can be successfully marketed to either a military or civilian customer.

The Army Food R&D Program has developed or modified and introduced into the military supply system more than 45 new items. Many of these are freeze-dried and range from peas to shrimp. They are used in garrison meals as well as in the combat area.

In addition to these 45 components complete rations are under development. One which has been completed but is not yet in the supply system is the quick-serve meal. All of 21 meals developed are precooked and are ready to eat after the addition of hot or cold water. From the technology which evolved through the development of these meals came the first-generation Food Packet, Long Range Patrol. This was the first freeze-dried ration actually to be used. Each packet contained an entree item such as chili, beef stew, or chicken and rice. Eight different entrees were available. The first-generation packets were well received, but required approximately 20 minutes to rehydrate in hot water and much longer when the water was unheated.

When the first requirements for foods for space were received by the Army, this background of freeze-drying technology was available for immediate application. However, if freeze-dried products were to be used, reconstitution by means of cabin-temperature water was limited to no more than 10 minutes. New technology had to be developed to meet these requirements. Without the background of experience from the Army program, a much longer leadtime would have been required to provide the 26 items which have been developed. (This illustrates what we have experienced many times in R&D work; that is, when you build an inventory of research and development information and experience, you never know in what direction or when it may be applied.)

However, the story does not end here. From combat patrol experience in the jungles and rice paddies of Vietnam, it was found that 20 minutes was frequently longer than could be allowed for preparation of the long-range-patrol food packet while on patrol missions. The need was recognized to shorten the rehydration time in hot and cold water, and, if possible, to make the products acceptable when consumed without rehydration, that is, suitable for eating out of hand like popcorn.

Using the technology developed for space foods, the products were reengineered, they were tested in pilot-plant production, and a suitable procurement document was written in less than 3 months. Unlike most combat rations, these new "LURPs," as they are known in Vietnam, receive fan mail. Many letters have been received saying that they are excellent and requesting information as to how they can be obtained for future use or for sending home so that Mom and Dad can see how good they are. Procurement of these packets currently runs around 10 to 12 million per year. Considering the small number of troops (less than 10 percent in Vietnam) that are actually being subsisted on combat rations, this indicates a very high usage rate. Needless to say, the eight entrees (pork with escalloped potatoes, beef stew, beef hash, beef with rice, chicken stew, chicken with rice, spaghetti with meat sauce, and chili) of the long-range-patrol food packet could not have been completely reengineered in the time frame indicated without the use of the technology developed for space foods. These products rehydrate in 5 minutes or less with hot or cold water and may be eaten out of hand (fig. 1).

Figure 1. -Long-range-patrol food packet.

FLEX CANNING

The technology of flex canning is being developed to reduce package weight by eliminating the use of metal cans for heat-processed items such as meats, vegetables, fruits, and baked goods in individual serving sizes. The packaging materials and the process have been described by Rubinate and Szczeblowski (refs. 7 and 8). The pouch material now used is a 3-ply laminate consisting of 0.0005-inch polyester, 0.00035-inch aluminum foil, and 0.003-inch modified polyolefin as the food contactant. The special polyolefin will withstand a retort temperature of 250° F. The process is normally carried out in a retort using steam-air or water-air mixtures with sufficient time at the above temperature to provide for thermostabilizing of the product. Carefully controlled balancing air pressure is used to prevent bursting of the pouch during processing. A wide variety of products (fig. 2) and processes for them have been developed.

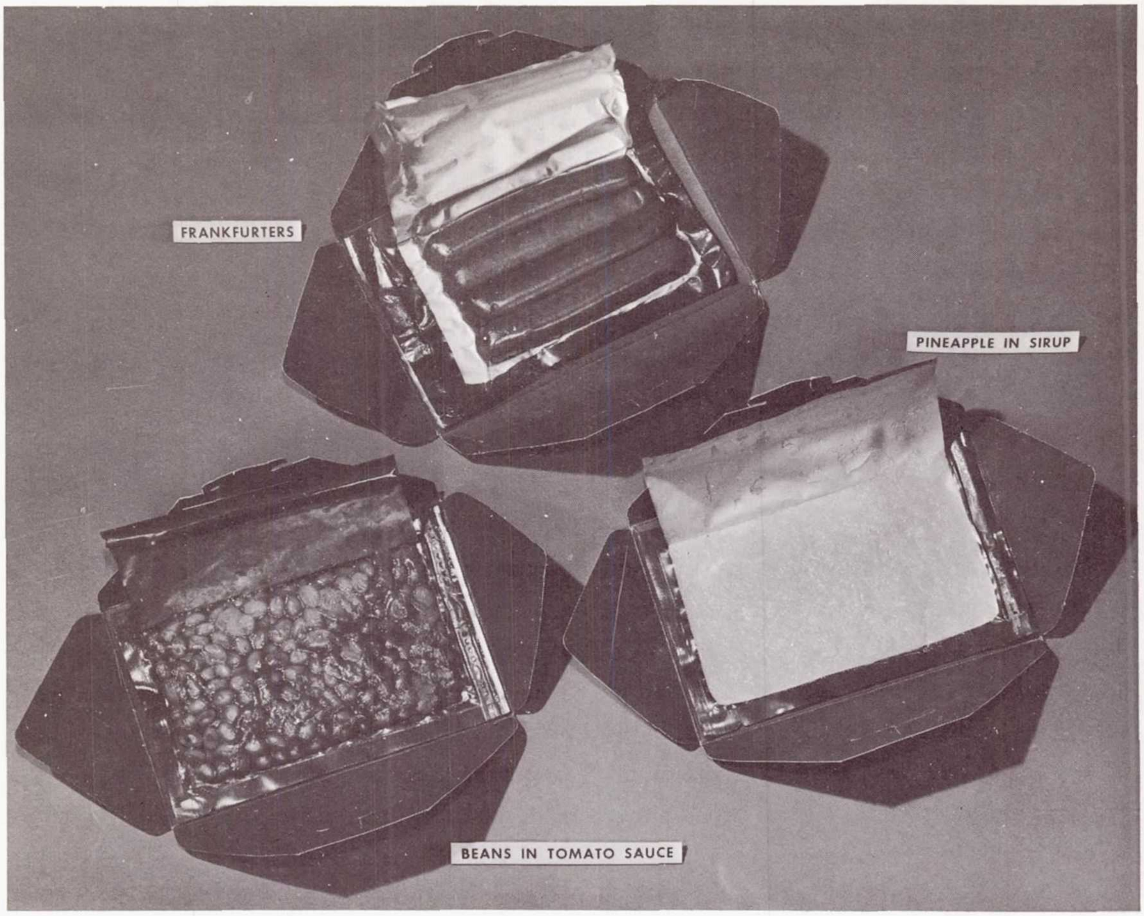

Figure 2. -Flex-canned foods.

The texture and flavor of the cake and bread products have been difficult to control because of a tendency of these products to compress when thermally processed in the sealed pouch. To date we do not have a fully acceptable breadlike product although some cake items ranging from satisfactory to excellent have been developed (fig. 3).

The availability of technology for moist products in flexible packages from the Army ration development program made it possible to provide turkey and gravy as a Christmas dinner entree for the flight of Apollo 8. The product was consumed from the pouch with a spoon. A few months before the flight, the U. S. Air Force, in a series of parabolic flights, determined that spoon eating in weightlessness was feasible. This turkey and gravy product (fig. 4) was developed, processed, and safety-tested at the U. S. Army Natick Laboratories in approximately 5 weeks following the decision to use it. This quick response would not have been possible without the technology which was at hand from the military ration program. Additional products have been developed especially for space feeding purposes and were used on Apollo 9. Others are planned for subsequent flights (figs. 5 and 6).

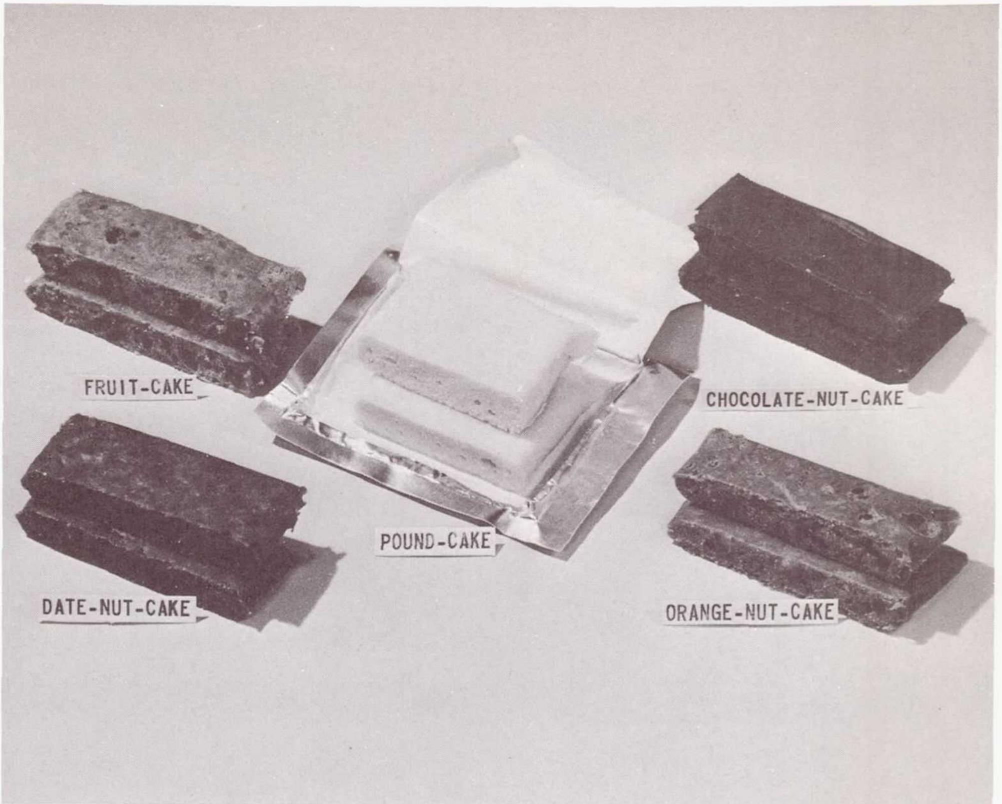

Figure 3. -Cake items suitable for processing in sealed pouches.

Figure 4. -Turkey and gravy, a thermostabilized wet meat product.

Figure 5.-Thermostabilized wet meat products in closed containers.

Figure 6.-Thermostabilized wet meat products in open containers.

FUTURE OUTLOOK

As was mentioned earlier, the development of rations for field use requires constant concern for the logistics involved. If the food is to be carried on the soldier's person, both weight and volume become extremely important. In 1963 a series of contracts supporting an extensive effort on the subject of compression or compaction were initiated. A number of contracts were awarded to provide the background of research upon which to build a technology for advancing the state of the art. On the whole these contracts were successful, although because of a reduction in funds the data developed were insufficient to permit writing of production guides for foods that could be used as such or combined suitably into meals. With funds provided by NASA, a contract was awarded for the development of prototypes along the line of meal components. These efforts have been described by Durst (ref. 9) and Brockmann (ref. 10). It was shown that by using the technology available, products such as beef, chicken, rice, potatoes, and vegetables could be combined with a calorie-containing matrix (developed from previous contract work on edible coatings) and compressed to provide 20,000 to 22,000 Kcal in approximately 10 lb and a volume of 408 cu in., a volume slightly larger than a shoe box. By various combinations of compressed sauce or gravy-mix cubes with compressed food bars, it was possible to provide 32 familiar foods (fig. 7). Admittedly, some of the foods were not highly acceptable but they provided a beginning.

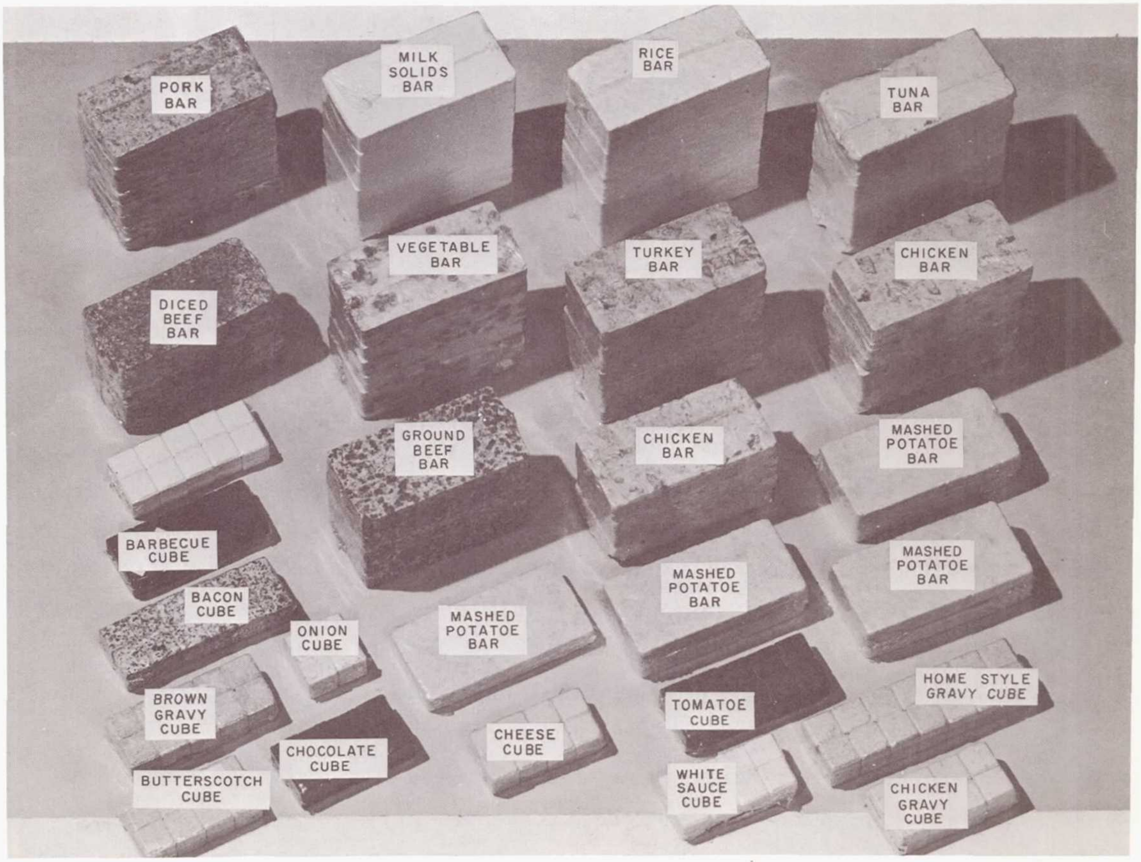

Figure 7.-Compressed sauces, gravy mixes, and food bars which, when combined, will provide 32 familiar foods with a total of 20,000 Kcal.

One can quickly see that this approach may have application for extended space flights or where prepositioned food supplies would be required. Menus could be planned using products based on these prototypes which would provide the weight and space savings that might be essential. Occasional supplementation with frozen foods such as steaks or other specialty items might assure the overall acceptance of such menus. Extension of this work is underway to improve the acceptance of the food items prepared from these basic "building blocks."

Work is continuing on the compression of individual products such as peas (fig. 8), carrots, cherries, shrimp, meat balls, and sausage. Just recently we have been able to provide a memory in freeze-dried beef chunks. This beef, with added flavoring, can be compressed. Upon the addition of water, it will come back to its original shape. Meat balls behave the same way.

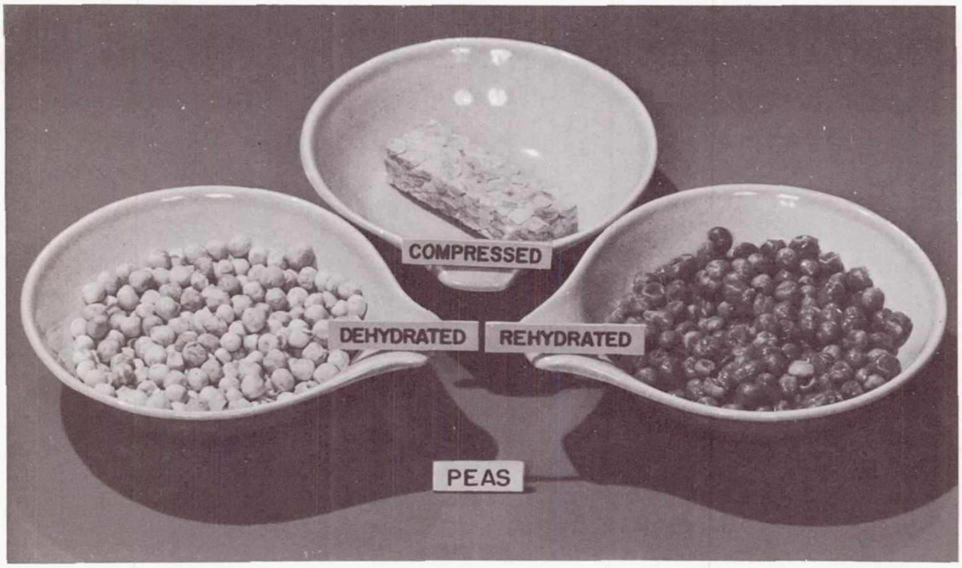

Figure 8.-Dehydrated, compressed, and rehydrated peas.

The procedure used with most products is as follows: the items are freeze-dried, then equilibrated to approximately 6 to 8 percent moisture and compressed at pressures from 500 to 1500 psi. After compression, redrying is accomplished either in a vacuum or convection oven. As might be expected, the appropriate procedure for each product has to be determined. For example, the cherries are successfully compressed without the addition of added moisture. Little or no noticeable damage is apparent in the reconstituted product if the compression phase is properly conducted (fig. 9).

Several specialized pieces of equipment are being utilized in studying the parameters of compression and texture in order to better understand what happens. By use of a universal test instrument with custom features we are attempting to determine the effect of storage at ambient and elevated (100° F) temperatures on compressed dehydrated food. Early subjective data obtained in

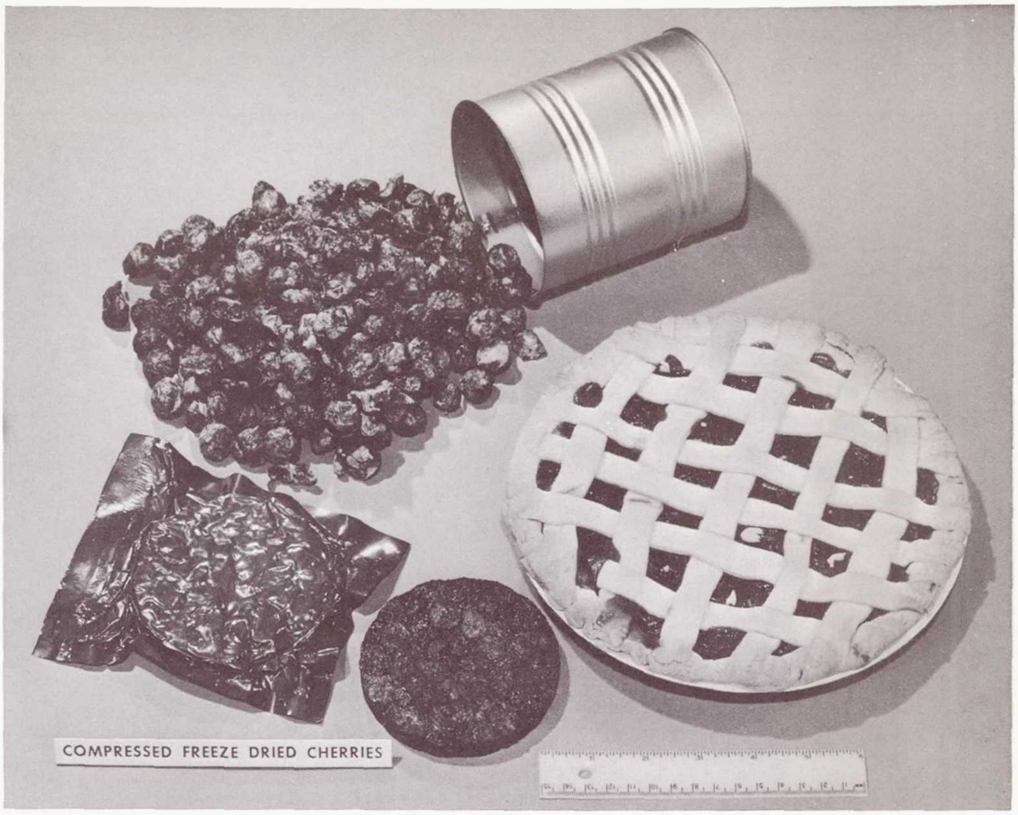

Figure 9. -Compressed freeze-dried cherries.

conjunction with storage studies focused attention on objectionable texture changes which occurred in storage. Although hardening is the most common complaint, we have found that not all cubes of the type presently used as space food harden during storage. Tables I and II and figures 10 and 11 show that the hardening or softening which take place during storage depends upon the nature of the material.

TABLE I. -TEXTURAL CHARACTERISTICS OF COMPRESSED SPACE FOOD CUBES

Sample	Storage time, mo	Hardness, kg, at storage temperature-	
		40° F	100° F
Cheese crackers	3	12.8	15.2
Custard	3	17.2	28.1
Sugar	3	15.8	16.5

TABLE II. -TEXTURAL CHARACTERISTICS OF COMPRESSED FOOD BARS (marine packet)

Sample	Hardness, kg, at storage condition-	
	Initial	100° F for 6 mo
Beef jerky	10.2	15.5
Cereal with lemon	2.6	3.3
Date fig	2.3	2.2
Lemon starch-jelly candy	5.6	1.0

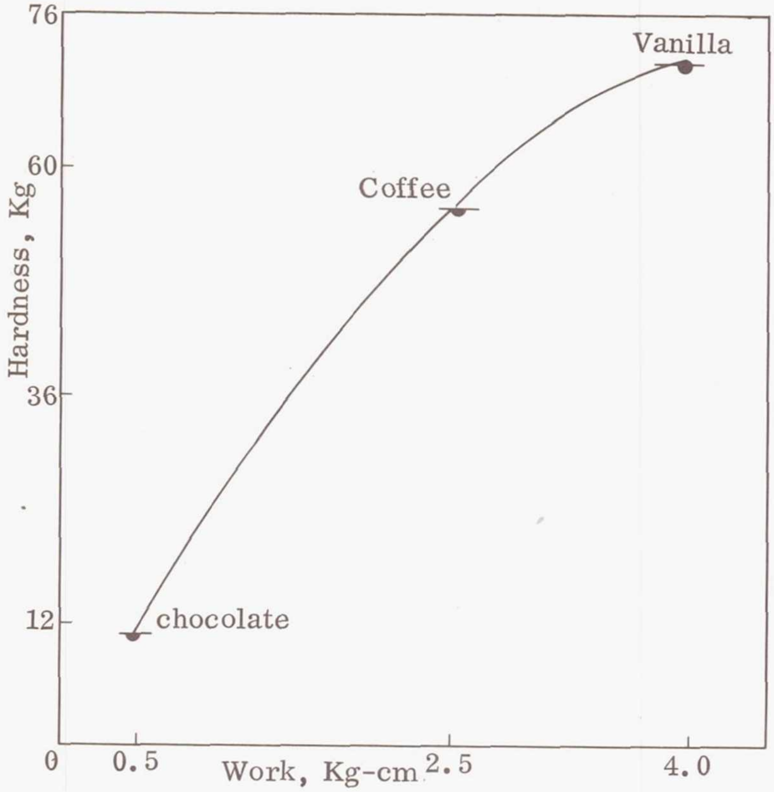

Figure 10. -Crushing work and penetration hardness of dehydrated compressed ice cream cubes after storage at 100° F for a period of 6 months.

From research to date we can project that the weight and volume advantages of compressed freeze-dried products will enable the provision of a wide variety of products at approximately 3.76 cal/cc, as compared with the present average of approximately 1.41 cal/cc for uncompressed products. Defining the parameters for successfully compressing a variety of dehydrated food is continuing.

Additional varieties of freeze-dried foods will be needed to support flights of long duration or in any situations where prolonged consumption of dehydrated diets is necessary. For example, how about a rare steak? Although it is generally not considered possible, as it loses red color when stored, we have indications that if a steak does not come in contact with oxygen after it is

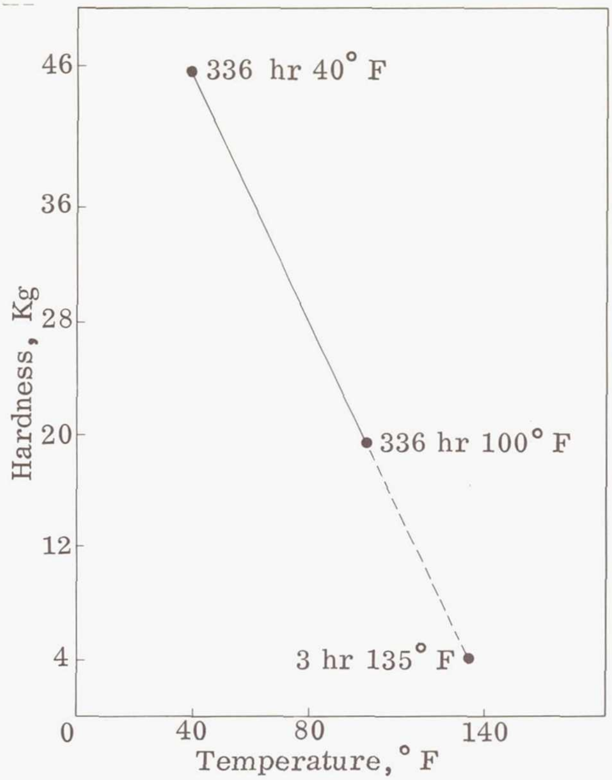

Figure 11. -Effect of storage temperature on compressed chocolate cubes.

placed in the freeze dryer we can have a rare steak of normal appearance. Also, we have data to indicate that oxygen-sensitive products, like carrots, have a markedly improved keeping quality if exposure to oxygen is minimized throughout processing and storage (figs. 12 and 13). There is a marked reduction in flavor deterioration when oxygen is totally eliminated. A glove-box technique was used for removing the product from the freeze dryer. In order to reduce the oxygen to this low level a palladium catalyst was employed in an atmosphere containing 5 percent hydrogen and 95 percent nitrogen. This technique is practical, especially for small lots of product. The palladium hydrogen system is being used commercially in England.

Continued research in the areas of texture and flavor, coupled with that of compression or densification, should provide products with greatly improved flavor and texture plus the marked advantage of drastic reduction in volume.

Intermediate-moisture foods are receiving attention by the food scientists and technologists. Natick Laboratories has awarded contracts to apply this technology to products of military importance. Under one contract a wide variety of prototype products has been developed. Carrots, apples, and pork and beef, for example, have a moist mouth feel resembling the natural products in appearance, flavor, and texture and they also provide added calories per cc. Under normal storage conditions, no special packaging or refrigeration is required.

With NASA support, experiments have been carried out with a modified microwave oven. The smallest available commercial lkW unit (110V-AC 2450 MH) was reworked to reduce its weight by 39 percent and its volume, by 45 percent. The cavity is now 10 by 10 by 5 in. and will accommodate a small tray which can be used to quickly rehydrate and heat the rehydrated food or to heat

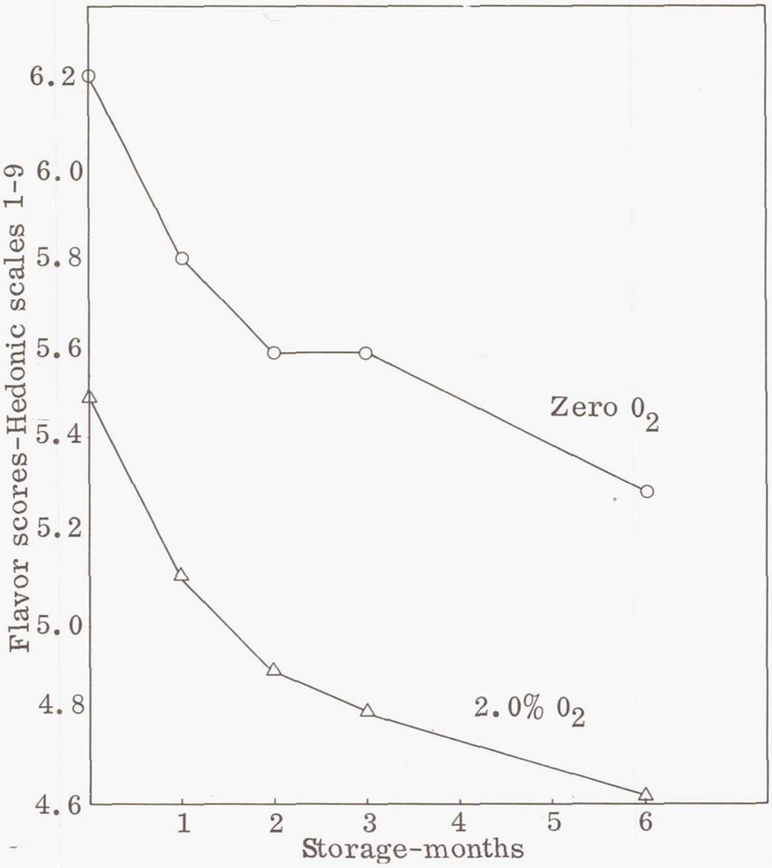

Figure 12. -Storage evaluation of freeze-dried beef chunks by a consumer panel of 30 judges.

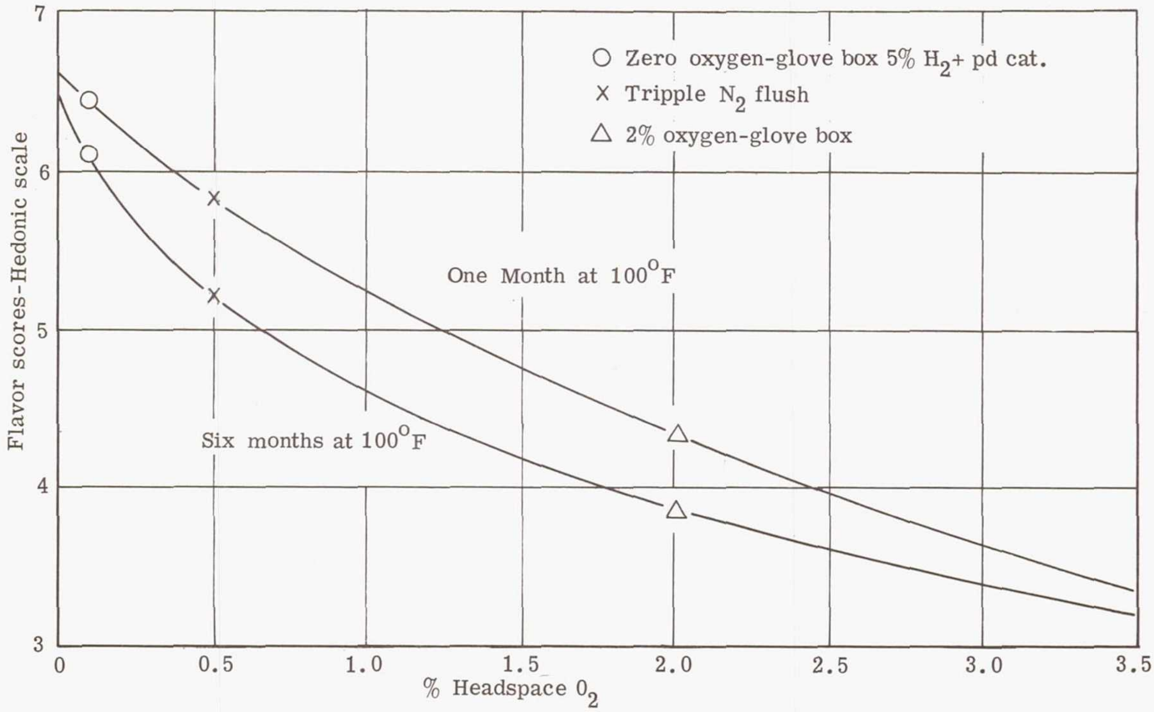

Figure 13. -Relation of flavor scores and oxygen levels of freeze-dried carrot dice in storage.

regular prepared food. The baking of bread and cakes at 6 psia in a special glass tube placed in the cavity is being investigated. Preliminary results indicate apparent feasibility of preparing bread from a special mix. However, to date, cakes have not been successful. Further reduction in weight and volume of the heating device can be achieved by use of smaller magnetrons, other types of oscillators, and solid-state components.

Using funds provided by NASA and the Air Force, Natick Laboratories now has under construction a room in which food can be processed in a controlled environment. It will enable the determination of contamination levels of products as they come into the room and pass through the various unit processes, and thus give a much better understanding of methods for controlling microbiological levels in food.

The work described clearly shows the mutual benefits that have been gained from the rather large R&D program carried out at the U. S. Army Natick Laboratories. The technology developed for Army field rations has been quickly brought to bear on the unique requirements of NASA and the Air Force. However, meeting these requirements has, in turn, been of considerable benefit to the Army program. A continuation of these combined efforts has the potential for providing a feeding system which would have maximum utility and acceptability for future missions.

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SESSION VI

EQUIPMENT/SYSTEM INTEGRATORS

CHAIRMAN: JOSEPH N. PECORARO

Biotechnology and Human Research Division

NASA Office of Advanced Research and Technology

We have heard that preparing food which will be safe, nutritious, and tasteful for crews of aerospace vehicles is a complex problem. Solving it requires contributions by food technologists, nutritionists, psychologists, and engineers. The previous speakers have discussed the status of current and planned food systems for space travel, the military (U. S. Navy, Army, and Air Force), and the airlines. Each has distinct problems, but common goals - to make food more attractive in appearance, more tasteful, more nutritious, and more manageable. In this final session, we will coordinate the views of engineers about equipment, of the systems integrators who have the task of providing the hardware for preparing the food, and of those whose functions include integrating the processed food and preparation hardware within the vehicles.

As much as possible, food should resemble that to which the crew is accustomed. It is obvious that the best food management system would be a kitchen in which food preparation could start from a basic stock of conventional foods and there could be relatively free choice of the composition of an individual's diet. Since this is not possible nor practicable in limited space, it is important that experts in all of the disciplines represented here cooperate so that deviation from the "normal" diet can be minimal and the physical form of the food can be sufficiently acceptable not to compromise the mission.

We hope that in this session one can identify research needed on conventional food, primarily in processing, preparation, and packaging of foods, and on system design to satisfy the requirements of vehicle constraints and environment. (I would like to invite the speakers to modify their papers, if they wish, as a result of discussions during this session.) In the case of some vehicles these requirements must not be in conflict with maximum acceptability of the food and its stability at possible temperature extremes. We as engineers can contribute to the solutions of problems of safe storage, minimum packaging volume, preparation, and ease of handling when in use.

I would like to cite two examples in which engineers have assisted the food technologist. Several years ago an edible soluble packaging film made from a new type of corn grown in Nebraska (ref. 1) was developed commercially. This new film is chemically produced from highly amylose starch. The film is unusual in that it is soluble in either hot or cold water and is a digestible food item. It also meets the most rigid food packaging standards. Another food packaging technique with market potential is aerosol dispensing. Food packaging has been encouraging, but the use of aerosol cans for processed foods appears extremely limited at this time, because of volume and safe storage problems.

In May 1963, AMRL through the General American Transportation Corp. completed a feasibility study of methods for heating foods during aerospace flight (ref. 2). Some of the methods considered included induction and dielectric heating and an internal resistance heating probe within the food container. As a result of laboratory evaluation it recommended that the internal-probe technique be developed along with the necessary food container. It concluded that a three-container food warmer based upon this technique would weigh approximately 4 lb and have an overall efficiency greater than 75 percent. The food containers developed for this technique should contain an internal pocket for accommodiating the internal heating probe. The solution to this requires cooperation of the vehicle and the food processing engineers.

A microwave oven for the household will shortly be mass produced and may be in wide use by the mid 1970's. This will necessitate preparing fully cooked products and packaging them in suitable containers for microwave heating. The aerospace industry has been a leading proponent of this new product development program and needs the cooperation of the processing industry. Our speakers this afternoon will address themselves to this technical area.

Joseph N. Pecoraro

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Werner Sell
Equipment Development

WERNER SELL

Giessen University

I am grateful for the opportunity to participate in this conference. I am probably the only one attending who comes directly from Old Europe. German and other European universities have not yet given sufficient consideration to food technology and technical equipment. This I can verify from my own experience, as at the present time I am one of a few teaching this subject at two universities.

More than 40 years ago I installed a cooking appliance in an airplane - maybe the very first one. This was a milestone and a few years later I turned completely toward engineering and commerce in this branch. About 4 years ago, by courtesy of the Whirlpool Corp., I obtained their layout of a spacecraft kitchen for a 3-man crew for a 3-week flight. This all seemed somewhat unrealistic at that time.

Professor Paul Buck had objections to the conservative cycle of meals the astronauts are required to maintain. I definitely agree. There is no relationship between space and the basic time periods of our daily life. Even when considering future commercial air transport we find similar conditions. Please imagine you are sitting in an SST plane above the middle of the Atlantic! What is Mr. Treadwell of Pan Am going to serve you: Breakfast or lunch? Leaving Paris or London for New York at noon you expect lunch! But because of the local time difference you arrive at Kennedy Airport 3 hr earlier, just in time for breakfast. The question arises: From which coast will you determine the relative meal time?

Some speakers have mentioned the microwave oven, and one pleaded for ovens equipped for defrosting, rewarming fresh grilled steaks from the deep-frozen condition, etc. May I add to these considerations a Werner Sell high-temperature oven which has been developed in my company and uses a method of fast-circulated hot air? This oven is the result of extensive research and 15 years in service. Steady improvements have resulted in a tiny box with the following advantages:

(1) Regulated temperature within all areas of the oven. Food serving temperature controlled within 3 to 5 percent. A continuous regular thermostat makes it possible to adjust the temperature between 50° and 250° C (120° to 480° F).

(2) Very short defrosting time from -18° to 80° C (0° - 176° F). This time is dependent on the weight and the layer thickness of the foods, as well as on the available electric energy. The defrosting time of the ovens is between 20 and 30 min.

(3) When the thawing time is properly adjusted according to the instructions, the food will not boil, burn, or brown around the edges.

(4) Normal ovens defrost and cook at 390° F. With Juno ovens it is possible to defrost at 266° F, because of the heat circulation system and ventilation; thus the use of plastic dishes is permitted.

(5) The oven is well suited for grilling steaks and poultry.

(6) It is also possible to bake cakes and small baked goods in this oven. The baking time is significantly shorter than in the usual baking ovens without air circulation.

(7) Moreover, it is possible to bake or boil eggs in this oven.

(8) It is no problem to keep food warm for a specific period of time.

The electric power requirements are 3600 W for heating and 200 V for the motor.

In case there is any chance for a spaceship cabin to accommodate such equipment, we would be well prepared to develop a special small and lightweight oven with high efficiency. On my return to Germany I will carry with me a lot of problems and ideas, and I deeply hope that Europe will contribute its part in these great tasks.

Airborne Microwave Oven Development

CALVIN HAGBERG AND DAVID GRAFF

Atherton Division
Litton Industries

For those not familiar with heating by microwave, a brief explanation is in order. Food is placed in an oven cavity and heated by molecular agitation. When exposed to microwave energy the water molecules in the food try to aline themselves with the rapidly time-varying electromagnetic field. The water molecules oscillate at 2 450 000 000 cps. The oscillating molecules rub against each other and heat is generated by this intermolecular friction. Heat transfer by convection and/or conduction is a secondary process which occurs after the outer surface of the food has been exposed to the microwave excitation. For maximum speed in cooking with microwaves it is desirable to heat the product from all six sides. Materials such as glass, paper, plastics, and ceramics are used to package the food product since they allow microwave energy to pass through them with no retardation. All types of food in any state of preservation (fresh, refrigerated, or frozen) can be used provided that they are properly prepared. The microwave oven does not perform magic; the product turned out of the oven is only as good as the product put in. However, because of the speed with which the oven heats, few detrimental effects occur and the product may have better appearance, quality, and nutritional value.

HISTORICAL BACKGROUND

In the summer of 1963 Litton Industries was approached by a major airline to undertake the development of a microwave oven for the in-flight preparation of meals. As with many new concepts, an incubation period was necessary between initial conception and a working unit. In April 1965 the first flight test of a prototype oven was conducted jointly by the airline, Litton, and the FAA.

This first Litton airborne unit was designated the T-20 model. It was a single magnetron oven, weighing 86 lb, operating at 2450 Mc, and providing approximately 1200 W of power in the oven cavity. The T-20 design utilized many of the commercial state-of-the-art concepts prevalent at the time but used 400-cycle components.

With most revolutionary concepts two design approaches may be taken; one is to make it as simple as possible and add on only when necessary, whereas the other is to provide as many systems as possible within the given space envelope and extract them after new and less complicated solutions are available. The nature of the T-20 microwave oven dictated following the later approach. Therefore, the design incorporated sensing devices to ensure complete protection against any possible RF interference. A sophisticated mechanism was devised which raised and lowered as well as rotated the food product. Although from an operational standpoint this conservative approach was less than successful, we cannot discount the impact this design and the operational flight tests made on the state of the art of airborne microwave ovens. Both the airline and Litton take credit for pioneering a concept which will be the forerunner of a valuable tool for in-flight feeding in the age of the jumbo jets and supersonic transports.

After a complete review of the in-flight tests which included both domestic and trans-Atlantic flights, the design underwent a series of changes which culminated in the specifications for the present Model E-30. The feeding objectives included the boarding of only frozen prepared foods to be heated to order. This plan allowed foods to be returned to inventory if not used and ideally would make it possible to feed a passenger in less than 2 min.

The E-30 airline microwave oven is a double magnetron unit weighing 110 lb, operating at 2450 Mc, and providing approximately 2400 W of power in the enlarged oven cavity. The new concept deleted a number of the original requirements and concentrated on simplicity, reliability, serviceability, and reduced weight while it retained an acceptable heating pattern for the food products to be used in flight. The cavity was enlarged to permit handling of greater quantities. Advancement in the general state of the art of all types of microwave ovens and the old cliche that "necessity is the mother of invention" explain the drastic changes that took place in the evolution of the E-30 sensing devices.

A primary concern during the initial T-20 development had been the effect of RF leakage from the oven on the many navigational and communication systems of the aircraft. No interference was detected at any time during the FAA - observed flight tests or the operational flight-test program. The T-20 had both a no-load sensor and a door-seal sensor which were programmed to shut off the heating cycle in the event that there was no load in the oven or that the leakage from the door exceeded a given level. Both these devices were extremely sensitive and required intricate electronic circuitry which resulted in nuisance shutoffs during operation and increased the cost of the equipment. A light load such as a Danish roll lacked sufficient density to prevent the no-load sensor from actuating. Accumulated moisture running down the front of the oven over the seal was sufficient to actuate the door-seal sensor.

New advances in the state of the art brought inexpensive and reliable solutions to both problems. A lossy glass or ceramic shelf now serves as a medium which can absorb the microwave energy, thus negating the requirement for a no-load sensor. The glass or ceramic is not too lossy to permit bottom heating of the food product; thus no extensive detrimental effect on the cooking pattern occurs. The shelves are capable of absorbing the energy for periods of time exceeding the maximum setting of the timer.

The success of seal-plate and choke-type doors in over 25 000 commercial applications has virtually eliminated the necessity for a door-seal sensor. Simplicity in design has provided adequate protection and reliability at reduced initial and sustaining cost. The E-30 oven which has a seal-plate-type door was tested before and after 30 days of flight testing and no leakage even close to allowables established by reference 1 was measured.

HEATING PATTERN CONTROL

One of the major problems facing microwave oven designers is directing the waves uniformly to the food product. Since the heating is by direct interception of the RF waves and not by conduction or convection, hot and cold spots can occur. Some early designers utilized the rotating-shelf concept to balance the exposed food product to the energy. Other concepts broke up the direction of the waveforms by putting stirrers in the feedbox or waveguide. The T-20 utilized both approaches. The result was a near-perfect heating pattern for nearly all types of food products regardless of their geometric configuration or their density. However, the complexity and reliability of the mechanical system required to provide this optimum heating pattern were not compatible with the aircraft environment. Therefore, only the stirrer concept is used in the present E-30. The approach has been quite successful and it is possible to obtain a uniform heating pattern over a $1\frac{1}{2}$-sq-ft area.

COMPONENTS

The primary and most dramatic improvement in the E-30 design is in weight reduction. New components and new electric concepts permitted a 30-percent reduction in weight. The new components also improved reliability and permitted use of modular construction techniques which improve serviceability.

The magnetron used in the T-20 was of an electromagnet type and weighed 13 lb. It was prone to filament failures, especially in the shock and vibration environment of an aircraft. The new L-5181 tubes have permanent magnets and weigh 6.5 lb. New construction techniques make it possible to fabricate a magnetron which can withstand shock and vibration and provide 4000 to 5000 hr of operation.

A plate transformer is required to raise the input voltage from 200 to 3500 V and to protect the magnetrons from transient voltages present in the aircraft electric system. New design techniques and new high-temperature epoxies have been instrumental in reducing the weight by 50 percent. The transformer in the Model E-30 weighs 13 lb. The original T-20 transformer weighed 26 lb.

PRESENT STATE OF DEVELOPMENT

The E-30 concept was reduced to practice in early 1968 and underwent an in-flight evaluation during the summer of 1968. Results of these flights were very encouraging. No serious operation or technical problems were encountered. The feeding objectives were achieved, and several airlines are currently designing in-flight feeding systems which include a Litton E-30 microwave oven as an integral part. Litton is engaged in a full-scale marketing effort for both new aircraft installations and older aircraft retrofits.

E-31 AND SPEED OVEN DEVELOPMENT

Two other programs influenced to a large extent the state of the art of airborne microwave ovens. The first was the development of the E-31 oven. The E-31 is a single-magnetron oven operating at 2450 Mc providing approximately 1100 W to the oven cavity. It weighs 82 lb and has a volume of 4.3 cu ft. The E-31 was developed specifically for the presidental fleet and is a 400-cycle version of a standard commercial model. These ovens have been in operation for 14 months. The success of this equipment has demonstrated the ability of the electric components to withstand the aircraft shock and vibration environment.

The Speed oven is a large-cavity, 4-magnetron, 400-cycle oven developed for an advanced concept of a U. S. Army field kitchen. It is designed to feed 200 men or to supply 5000 men with bakery products. The ovens used in the Speed kitchens have demonstrated good reliability under actual field operations. At last report the ovens had over 800 hr of operation without magnetron failure.

CONCLUDING REMARKS

The state of the art of airborne microwave ovens has improved significantly during the last 6 years. We are now able to provide 22 W/lb of oven, whereas originally we could provide only 14 W/lb. The use of solid-state power supplies could conceivably increase this ratio even more.

The use of microwave ovens for any mode of transportation depends to a large degree on the total feeding system. The type of food, food packaging, food storage, and oven must be compatible. The microwave oven system is superior to more conventional methods for small amounts of food and individual meals. Full power is attained in seconds; no warmup of the oven is required. Therefore, the actual high electric power drawn from the vehicle power system is required only during the actual cooking time.

Although cooking by microwave in aircraft is a relatively new development, it has made significant advances in the last few years. The speed, cleanliness, and reliability of the concept make it an ideal system for all forms of transportation.

Design Considerations for Microwave Heating of Space Food

WILLIAM STONE

Raytheon Company

This is a conference to discuss aerospace food technology, and at first thought such discussion seems far removed from my experience in Raytheon's Industrial Microwave Processing Department. Our concern has been the speedy processing of large quantities of food but this is not applicable in space vehicles. If NASA were considering conveyances with many passengers, we could discuss our conveyorized microwave system for heating meals quickly; however, I have been led to believe that it may be some time before this will be necessary. It appears that we must think small and light for NASA.

Along the foregoing lines the use of highly efficient microwave heating should be considered if hot meals are desired. This leads to the question: Why should microwaves be used in a space application instead of a forced-air convection oven or some other more conventional form of electric heater ? The answer is the claim to fame of microwave heating; energy is converted to heat inside the food and is not used to heat the walls and air inside the oven.

I know of no unit currently available that would satisfy the needs of a space vehicle. There is, however, a 91-lb microwave oven being mass produced by our Amana division. This appliance was designed for the consumer market wherein heavy emphasis is placed on chrome trim, portability, and price.

A redirection of emphasis, with reliability, weight, and size as the prime requirements, could produce a usable piece of equipment for space vehicles. Factors to be considered in such a design are power supply, energy source, applicator (or, as it is commonly called, oven), construction materials, controls, food, and radiation.

Reliable, light-weight power supplies now exist for space applications. There is no doubt that a design specifically for this application is not too far away.

There are many factors to be considered in the selection of an energy source, which is the heart of a microwave heating system. Of prime importance is the power output. This should be the minimum amount necessary to heat the food, since this amount is directly related to the amount of power drain from the vehicle's electric system. Frequencies other than the commonly used 2450 mHz could be investigated. The FCC has allocated three other frequencies for this usage, namely, 915, 5850, and 22 125 mHz. Very little has been done at the two higher frequencies where parameters are generally smaller.

Our experience in producing high-power microwave generators which have efficiencies over 80 percent could be extrapolated to a lower power generator. To replace the present fairly heavy electromagnet, a permanent magnet utilizing Raytheon's new light-weight samarium cobalt magnet material might be considered.

Since the applicator (oven) is the part of the equipment which contains the food, its design should be conditioned by the size and shape of the food package to be heated. This requires an interface between microwave-oven and space-food designers. Most present-day microwave ovens are designed to be universal in use so that any process from heating a cup of soup to completely cooking a large roast is possible. An exception is the small unit in coin-operated vending machines used to heat sandwiches which are stored in a nearby refrigerator.

The use of strong light-weight materials in the frame and power supply is one area which warrants investigation. It may be possible to save considerable weight in the cavity by painting, plating, or laminating a microwave conductive coating over a light-weight plastic form to replace the usual, heavy stainless-steel cavity.

A wide variety of controls exist which function very well and extremely reliably. It appears that not much more than a weight-reduction program need be launched.

From a microwave engineer's point of view, the food should always have the same dielectric parameters, be of uniform density, and completely load the cavity electrically. As previously mentioned, microwave engineers and food technologists should jointly discuss these problems.

The intent of the design should be to cook food - the heat should not be wasted on equipment or people. Many excellent radiation containment techniques that may be made lighter in weight for use in a space vehicle now exist.

In summation, the design of a microwave heating unit for space vehicles is quite feasible within the current state of the art.

Integral Heating Equipment Development

JOHN M. MAHLUM
3M Company

The 3M Co. is pleased to have been invited to say a few words in explanation of integral heating. A number of speakers have referred to our development as a new concept for cooking food and they mentioned our laboratory work as well as our activities with the commercial airline industry.

Frankly, it is much too early in the development of this concept to articulate specifically on costs, performance under varied conditions, etc., and, therefore, we are not yet at the point where we are actively selling this method in any specific form to the public. We do have great confidence in the potential of this technology. We do have behind us a substantial amount of laboratory work and, as reported by others, a successful evaluation by American Airlines of this system. Tests have been run for 7 weeks under normal operating conditions where our system has been used to reconstitute typical airline frozen meals with fine results in terms of quality of food and performance of the equipment.

Integral heating is accomplished from a resistive coating applied to a surface area. The coating can be applied in a variety of manners, its composition is of a variety of materials, and it is applied to become an integral portion of the surface areas from which it is intended to deliver heat directly to food. It uses the principle of low watt density, is unrestricted in terms of the surface area required, can accomplish contours of any kind, and basically has the capability for "putting the heat where you want it." It is not restricted to one composition of materials and, of course, the choice of materials and the manner of processing same is proprietary to 3M.

Integral heating provides:

(1) More efficient heat transfer. The low mass and large surface area is supplemented by choice of low-thermal-capacity materials which give up their heat quickly to their surroundings, i.e., food.

(2) Quick response. The surface heats extremely fast and also cools extremely fast when energy inputs are reduced. It is therefore controllable and responsive to critical demands.

(3) Minimal residual heat problems. Conventional flame or high-watt-density heating elements, such as a calrod type, are nonexistent. Heat developed on the cooking surface is removed by the food, with the "heating surface" temperature climbing the temperature scale parallel to the food being heated and rarely exceeding a surface temperature of more than 10 percent that of the food.

(4) Easy programing. Control of the input energy with electric-electronic components permits a variety of performance levels. This, in turn, makes it possible to match the requirements of the food with simple control adjustments giving the integrally heated 3M system the maximum possible versatility.

In lay terms we may say that, in the average home, two-thirds of the energy of all conventional cooking devices is wasted. Integrally heated surfaces operate at better than 90-percent efficiencies. It can also be said that integral heating operates with the fast response of gas, with the convenience of electricity, and without the danger of either.

As a means of explaining the system further, we will use the 3M in-flight food service system as a reference. The hardware for this system has been developed and used in flight tests and can be said to be generally commercially acceptable. Such a system can operate in commercial aircraft and military aircraft; aboard ships and submarines; in land-based facilities such as hospitals, colleges, and restaurants; and in almost any facility where for some reason there is an advantage to preparing the food, chilling or freezing it, and bringing it back to edible temperature at a later date or at a remote location from that where it was prepared.

The design of the system includes the following equipment:

(1) An outer oven shell. This unit is thermally insulated and can be installed permanently or temporarily into the area where you wish to do your cooking. The control units are appended to this shell and this becomes your operational center. Let me emphasize that this is not a classic oven - the walls do not get hot and there is no induced air circulation.

(2) An interior oven shell or rack. This rack contains electrodes which carry the electric energy to the dish; it has a series of trays which slide in and out and nest the dish. It also serves as the means by which the dish and food is moved to and from the kitchens.

(3) A casserole dish. This is the item which is integrally heated. It transforms the electric energy to heat and delivers the heat to the food. A combination of these three pieces of equipment in a variety of styles makes up the system. Each of the three components is necessary for the system to operate properly.

I would like to comment now on general performance requirements in developing any new food service system. There is always an interchange phase of going from the old method to the new. We found it essential that this system of ours be versatile. We therefore have programmed it to handle all three types of food preparation - frozen, chilled, and previously cooked and held as warm. Performance in general had to be fast and we have established a parameter of reconstitution of 10 to 12 oz of frozen food mixes (i.e., meat, vegetable, and starch) in 15 min or less, and we also built into the system the capacity of holding the desired temperature for a substantial period of time. Also the unit is capable of being utilized as either an oven or refrigerator, or a combination of these two.

The reliability of the system and its parts is of course a primary concern. It is necessary to have interlocking components, that is, a free interchange of parts to the system from one unit to the other. All parts have been designed to withstand physical demands and operational demands of both refrigeration and heating plus those of the more mundane facts of life such as commercial dishwashing facilities. It is interesting to note that in this system we are limiting the potential liability or failure of the oven to function down to the lowest possible minimum. That is, each individual service of a meal is where the energy transfer is made, and therefore it is most likely that our liability is related to that one unit rather than to the total system.

There are many advantages that can be built into a new system and we have attempted to appraise these. Of course, the concern for storage and hence the need for stackable units is a consideration in any high volume operation. We have selected stainless-steel welded construction for its obvious characteristics of strength, cleanliness, and general acceptability when exposed to food environments.

The casserole was designed to withstand tremendous physical abuse and choice of a china or glass porcelain innerface was made because of its heatproof, stainproof, scratchproof, odorproof, rustproof, fadeproof, and ageproof properties. Not the least of its properties is its low bacteria retention level, which is superior to that of almost any other material. The casserole was designed to withstand cryogenic temperatures as low as -350° F and will operate at surface temperatures of 600° F, which is the generally accepted maximum cooking temperature. We have, in fact, eliminated the intense heat source or high-watt density factor found in most ovens.

Our total performance is accomplished with a lower power consumption. We use a given amount of power to get the job done and this is a prerequisite. However, our efficiency results in less power waste; therefore, the power consumption per unit time is substantially less than that of conventional ovens.

Since there is no concern for airflow within the oven shell, the oven itself can be of almost any size and shape. Styling is also a factor and the system permits choice of size, shape, and color and generally is unrestricted. Use of modern updated electric-electronic materials permits versatility in controls and performance of the system.

I would like to make a few statements on the general premise from which we justify our performance claims. Table I is a study of the heat balance required to process a typical 10-oz food mix from a 0° F storage temperature to a 180° F "piping hot" condition. Note that less than 5 percent of the total BTU requirements are needed to raise the food temperature from 0° to 32° F. Approximately 45 percent of the energy is required to accomplish the heat of fusion or melting and an additional 45 percent is required to accomplish the sensible heat from 32° to 180° F. Approximately 8 percent of the total energy demand is used in bringing the casserole dish to proper temperature, and, thus, it can be said that in this example approximately 92 percent of the energy drawn is put to a worthy cause, that of heating the food. Using materials of low thermal capacity is working in favor of the system. I might point out that in a frozen storage condition the food will also stay cold longer inasmuch as the casserole dish does not deliver heat to the food and thus warm it up. One might compare the casserole dish to a thermos bottle. It works ideally whether the end product is to be hot or cold.

Table II indicates that we can transfer the power or watts required for a given meal to a heating-time relationship and we say arbitrarily that if you deliver 240 W for 15 min you will accomplish the delivery of BTU's consistent with our previous heat balance study.

TABLE I. -HEAT BALANCE

Process	[a] BTU	% total
10 oz of food		
Heat to raise from 0° F to 32° F (10/16) x 0.5 x 32 =	10	4.8
Heat to thaw (10/16) x 144 =	90	43.1
Heat to raise from 32° F to 180° F (10/16) x (180 - 32) =	92.5	44.3
Casserole		
Heat to casserole 0.9 x 0.1 x 180 =	16.3	7.8
Total	208.8	100.0

[a] 208.8 BTU = 61 W-hr.

TABLE II. -POWER LEVEL AND HEATING TIME

Heating time, min	Power level, W
60	61
30	122
20	183
15	244

In any and all heating systems it is necessary to transfer energy from a source to that which you want to receive it. Figure 1 is an enlargement of a casserole or heating surface bottom; the circles indicate the four points of temperature level. We use a typical convection oven as an illustration. At the top we will assume that we have a 1200° to 1800° F calrod unit. We depend on air to bring this heat to the proximity of our container carrying the food. In passing through this air space, it eventually encounters a stationary air film. As indicated, this is a thin film of air surrounding the surface of any material. There is, of course, a temperature drop at the point where it hits this air film. At this point a severe loss of efficiency, or a large Δ T, is realized. This large temperature drop is inherent in all air-conducting systems and it is minimized somewhat by high-velocity air movement. At the point where the energy or heat reaches the casserole or dish bottom, it passes through the casserole bottom at some predictable rate and emerges to contact the food. The net heat or BTU absorption of the food is a small portion of that generated at the power source. The 3M Co. is successfully introducing the source temperature at the casserole bottom, completely bypassing air films, and therefore realizing a very low Δ T drop from its delivering point until it reaches the food. In addition to that, as we have mentioned before, the thermal capacity of the dish is restricted. This principle guides our thinking in developing integrally heated devices. We look, forward to any comments you might have regarding possible applications of this principle.

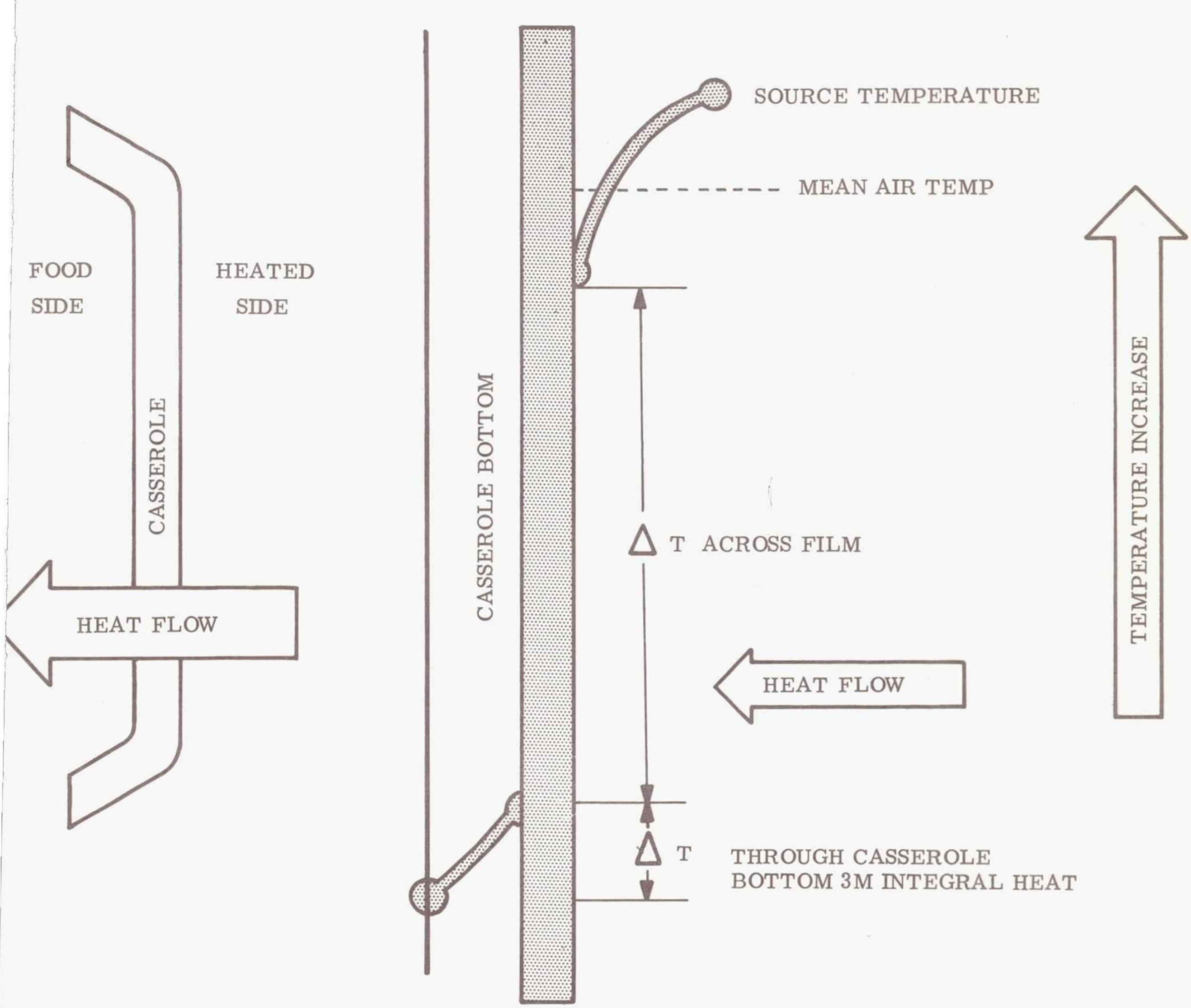

Figure 1. -3M Co. integral heating.

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Boeing 747 Lower Lobe Galley System Integration

C. V. LINDOW
The Boeing Company

System integration for practical purposes is the assembling of many components, with proper forms of interaction and interdependences, into a whole system to perform some function. The system that I shall discuss is the Boeing 747 lower lobe galley and its function to store prepared meals and beverages and to enable trained personnel to present them to the passengers in an elegant and timely manner. I am, therefore, discussing only that part of the food and beverage provisioning and serving system that begins at the entrance to the airplane.

First, let us consider the reason that we are interested in a lower lobe galley on any airplane. The net effect of lower lobe galleys on airlines is illustrated by listing the advantages and disadvantages as follows.

Advantages to airline:

(1) Increased main-deck seating capacity

(2) Utilization of cargo/baggage loading equipment to service galleys

(3) Minimized main deck congestion during passenger loading

(4) Minimized ramp congestion during ground servicing

(5) Equipment interchangeability with other airplane types

Disadvantages to airline:

(1) Reduced lower lobe cargo capacity

(2) Increased airplane empty weight

(3) Increased airplane cost

A principal advantage to the airlines is an increase in the main-deck seating capacity of any airplane of a given length, and this is a function of the original main-deck galley and seating arrangement. In the case of the 747 the capacity can vary from 4 additional passengers to over 30.

Since a lower lobe galley is on the same level as the cargo and baggage area, the cargo/baggage loading equipment can be utilized to service the galleys. This eliminates the high-lift commissary service truck, an expensive piece of equipment. If we do not need to service galleys through the main-deck doors, passenger loading and cabin cleaning can be continued without interference from the galley loading. If we have fewer vehicles on the ramp through use of the cargo vehicles for galley servicing, we have less congestion in an extremely congested place. Some airlines have an additional incentive - that of equipment interchange with other airplane types.

There are some disadvantages to the airlines. First, the overall cargo capacity is reduced because of the space that is taken up by the lower lobe galleys. In the case of the 747, this amounts to about 2000 cu ft of cargo capability. The airplane empty weight is increased because of structural provisions, elevators, and other factors. And, of course, the airplane costs more. It is clear then that a lower lobe galley is not optimum for all airlines and is therefore an option on the 747.

The principal system requirements are as follows. In the food category we need to store and serve two complete meals with a beverage service on long flights. For the 747, this requires the storage of 800 meals. It is necessary to be able to serve a beverage and an adequate meal on flights as long as those between Chicago and New York; such long flights require 400 complete meals. Particularly on long flights we need to provide a reasonable choice of entrees, say 20 percent, and to reduce the spoilage and waste of unused frozen entrees. Incidentally, the prime mode of operation of the 747 lower lobe galley is based on the use of frozen entrees. A second mode is to use chilled foods rather than the frozen entrees, and a third mode, which we do not expect to be used very often, is to load warm entrees onto the airplane and keep them warm.

In the seating area there is a requirement to increase the number of passenger seats to the maximum consistent with the cabin arrangement and at the same time to maintain and enhance the already considerable passenger appeal of the basic 747.

In the ground servicing area it is desirable to reduce the congestion from maintenance, commissary, and cabin-cleaning personnel and eliminate the obstruction of passenger movement adjacent to the galley and in the cross-aisle areas. Eliminating the galley replenishing activity on the main deck of the airplane enables earlier passenger loading and tends also to reduce the through-stop or turnaround times of the airplane. It eliminates high-lift commissary service trucks, those with beds extended to about 17 ft. We would rather use the lower 10-ft cargo/baggage loading system for loading the galleys and so reduce wear and tear on the interior and exterior of the airplane.

In the technical area we must maintain a satisfactory level of noise, ventilation, lighting, and temperature in the lower lobe galleys for the benefit of the attendants who work there during the flight. Safety, reliability and maintainability must be kept at their present levels, and weight must be kept to a minimum. The airplane structural and system changes must be minimized to reduce costs and flow times. In addition, it is necessary to meet U. S. Public Health Service Regulations.

In the management area we have a requirement to create a common 747 lower lobe galley for two of our airline customers and a requirement to utilize some equipment interchangeability on the Boeing 747 and the McDonnell Douglas DC-10 airplanes of those particular airlines. We, of course, have a Boeing requirement to design for a broad 747 market appeal.

Now, if we assess the meaning of system integration in the framework of the foregoing requirements (fig. 1), we have a Boeing 747 lower lobe galley, McDonnell Douglas has a DC-10 lower lobe galley, and in each case there are Airline A requirements and Airline B requirements. Boeing is striving for a common 747 and McDonnell Douglas is striving for a common DC-10. We all recognize that in both cases there will be requirements unique to each airline. The task at this stage is to reconcile all these requirements to yield, as far as possible, a common lower lobe galley

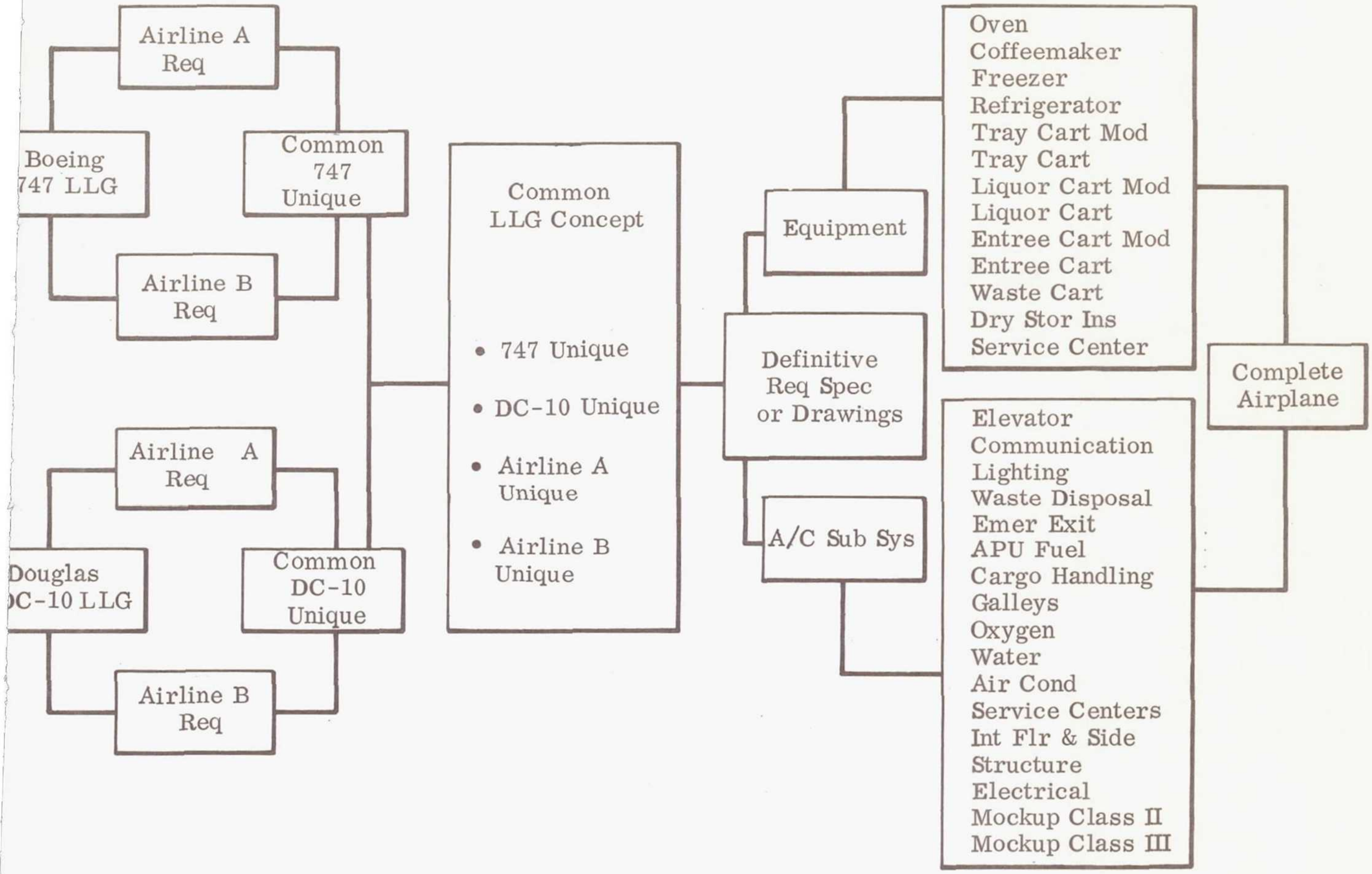

Figure 1. -747 lower lobe galley system integration.

concept. At the same time there will continue to be certain situations unique to the 747 or DC-10 and, within these, features peculiar to each airline. Out of this work come definitive requirement specifications for purchased equipment or drawings for equipment which is built inhouse. Additionally, most of our aircraft subsystems are affected to some extent. Integrating all these factors results in a complete airplane, including a completely functional lower lobe galley system.

Now that we have outlined the tasks of system integration, let us look at some of the resulting configurations and solutions. Figure 2 shows a typical interior arrangement of the 747. Forward of the wing is a forward lower lobe galley complex. In the case of the 747, there is also an aft lower lobe galley complex aft of the wing. Each complex is composed of a lower lobe galley and a 2-unit service center on the main deck.

Figure 3 is a view through the airplane cross section. On the right-hand side of the airplane are 3 refrigerated modules about 60 in. long, each of which contains 4 tray carts and has stowage areas above which can accommodate refrigerated food or dry stowage. On the left side of the airplane is a freezer module, which is controlled to 0^{o} F for frozen food or 40^{o} F for chilled food and can contain 480 entrees and ice cubes. Remember that there are 2 identical galleys on the 747, and the airplane can carry 960 entrees. The next module is the liquor-cart module, which contains 4 liquor carts set up for two complete liquor services. The third module, which is partly obscured behind the elevator, contains the entree and waste carts and on it a dry-stowage module. Above the shelf 4 ovens are fixed to the airplane; each is designed to reconstitute 60 entrees in 35 min.

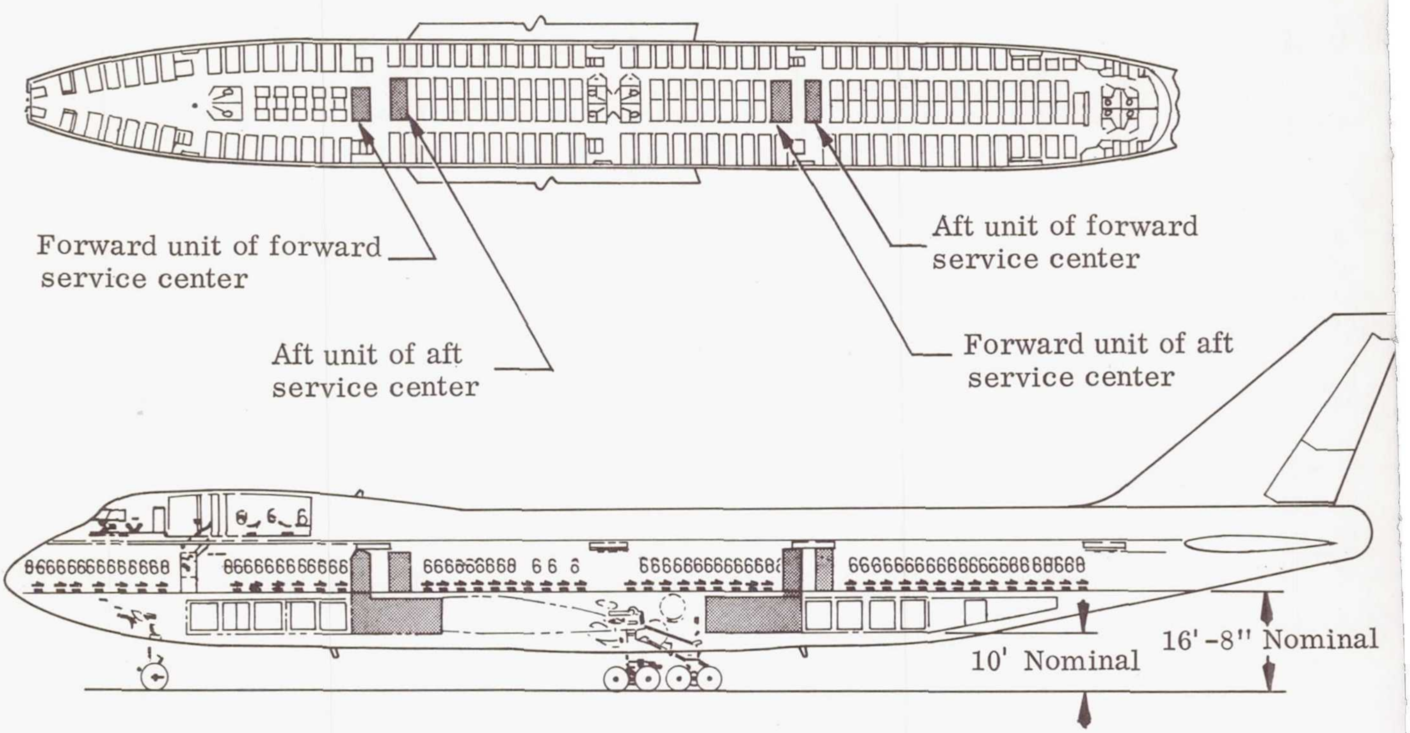

Figure 2.-Interior arrangement of the lower lobe galley for the 747.

The small box above the entree module is the electric control center for the galley. The elevator on the left can be used either for moving stewardesses or carts. The elevator on the right is open and is used for carts only. These emerge in the service center on the main deck.

Figure 4 shows the two elevator doors, coffeemakers, and dry stowage above the counter, with a mechanical refrigerator and dry stowage below. An intercom system is provided so that main-deck and lower lobe attendants can talk without going through the airplane telephone system. On the other side of the cross aisle is the aft unit of the forward service center (fig. 5). On the two ends of the units are closets accessible from the longitudinal aisles of the airplane, with magazine racks above, There are three additional coffeemakers, thus providing six in each service center. A waste cart is positioned in the right-hand outboard position under an opening in the counter through which waste may be thrown into the top part of the waste cart. The bottom part of the waste cart has separate drawers to enable the separation of soiled reusable articles from disposable items. The aft unit contains spaces wherein two additional carts can be stored, and these are serviced with electric connectors for keeping entree-cart contents heated, if required.

All the vendor-supplied equipment that I have mentioned is being procured under Boeing specifications as shown in table I. You will note that all the equipment except that indicated will fit and function on both the 747 and DC-10.

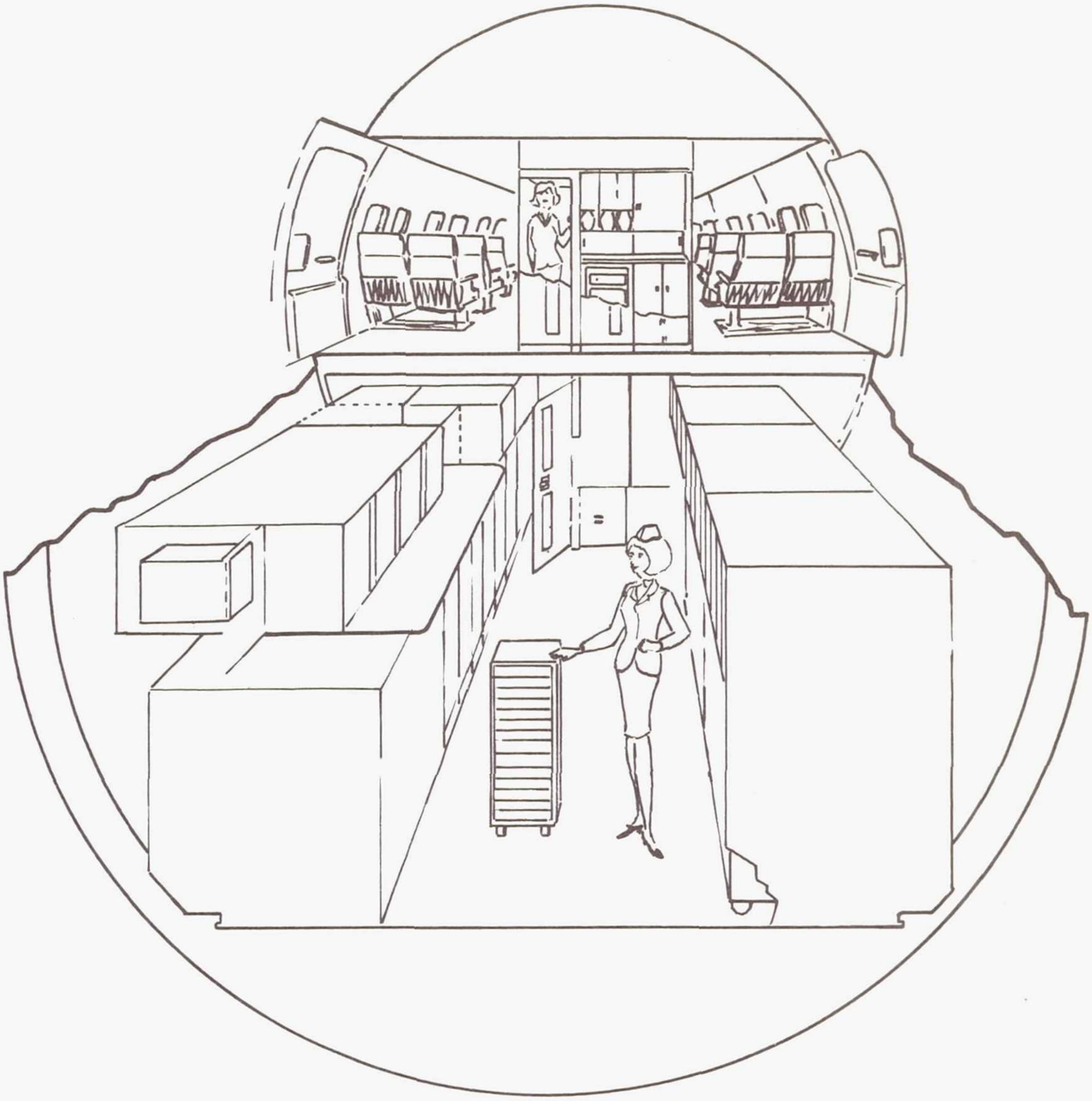

Figure 3. -Cross section of airplane.

One of the primary means of deciding whether system integration has been accomplished is to carry out a system test. Figure 6 shows the logic for the lower lobe galley and module handling system tests. Vendors provide prototypes and preproduction articles and perform qualification testing on the articles they provide. Some of these articles are run through the Boeing-Everett laboratories to accomplish component and subsystem verification tests. Those that pass the tests go to our lower lobe galley functional test vehicle for verification of performance in a whole system. From there then we have two paths - those items which are involved in our lower lobe galley module/ cargo/baggage handling subsystem go into that particular part of our organization to be tested in appropriate test vehicles. The others go into our first aircraft of this type for ground testing and for flight testing. To explain this more fully, our lower lobe galley functional test vehicle (fig. 7) is the equivalent of part of the forward section of our airplane; it is set on the floor so that we can

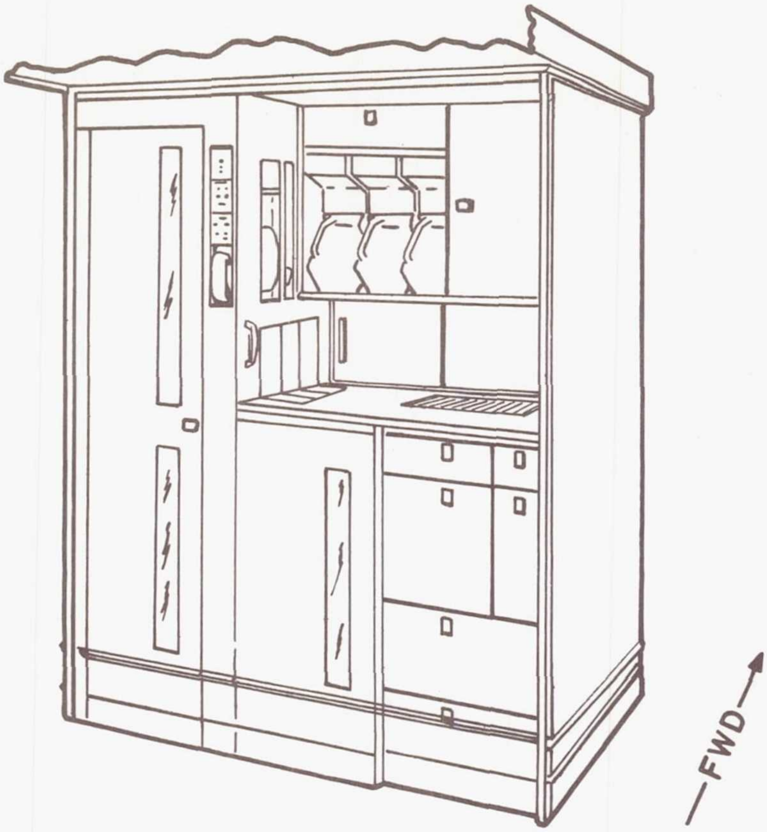

Figure 4. -Forward unit of forward service center of 747 lower lobe galley.

work conveniently with it throughout the program. After completion of this testing we will be satisfied that the system will in fact function in accordance with the standards which we have established. The airlines then will provide hostesses and procedures appropriate to their meal services.

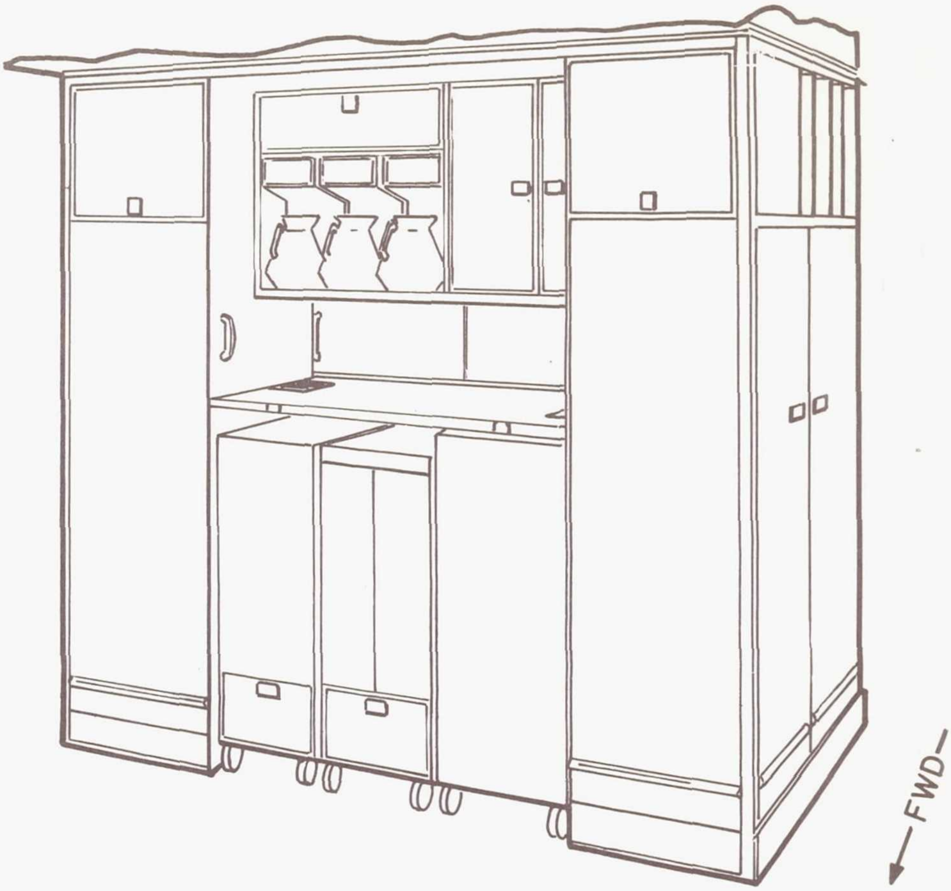

Figure 5. -Aft unit of forward service center of 747 lower lobe galley.

TABLE I. -747 LOWER LOBE GALLEY PROCUREMENT SPECIFICATIONS AND VENDORS

Number	Title	Vendor
60B50102	Oven assembly, general purpose, electric	Sell Haus
60B50103	Coffeemaker, electric	REF Dynamics
60B50104	[a]Galley service centers	Hitco
60B50105	[a]Elevator system	Airesearch
60B50107	Liquor cart assembly - lower lobe galley	
60B50108	Tray cart assembly - lower lobe galley	
60B50109	Entree cart assembly - lower lobe galley	
60B50110	Waste cart assembly - lower lobe galley	
60B50197	Cart base assembly - lower lobe galley	
60B50111	Insert, refrigerator/freezer - service center	REF Dynamics
65B50112	Coffee server retainer	
60B50165	[a]Sink/equipment console - lower lobe galley	Hitco

[a] Will fit and function on both 747 and DC-10 except as noted.

TABLE I. - Continued

747 LOWER LOBE GALLEY PROCUREMENT SPECIFICATIONS AND VENDORS

Number	Title	Vendor
60B60010	Tray cart refrigerated module	Fairchild Hiller
60B60011	Freezer module	Fairchild Hiller
60B60022	Liquor and entree cart modules	Fairchild Hiller
60B50172 and 60B50179	Stowage drawers, miscellaneous - lower lobe galley	

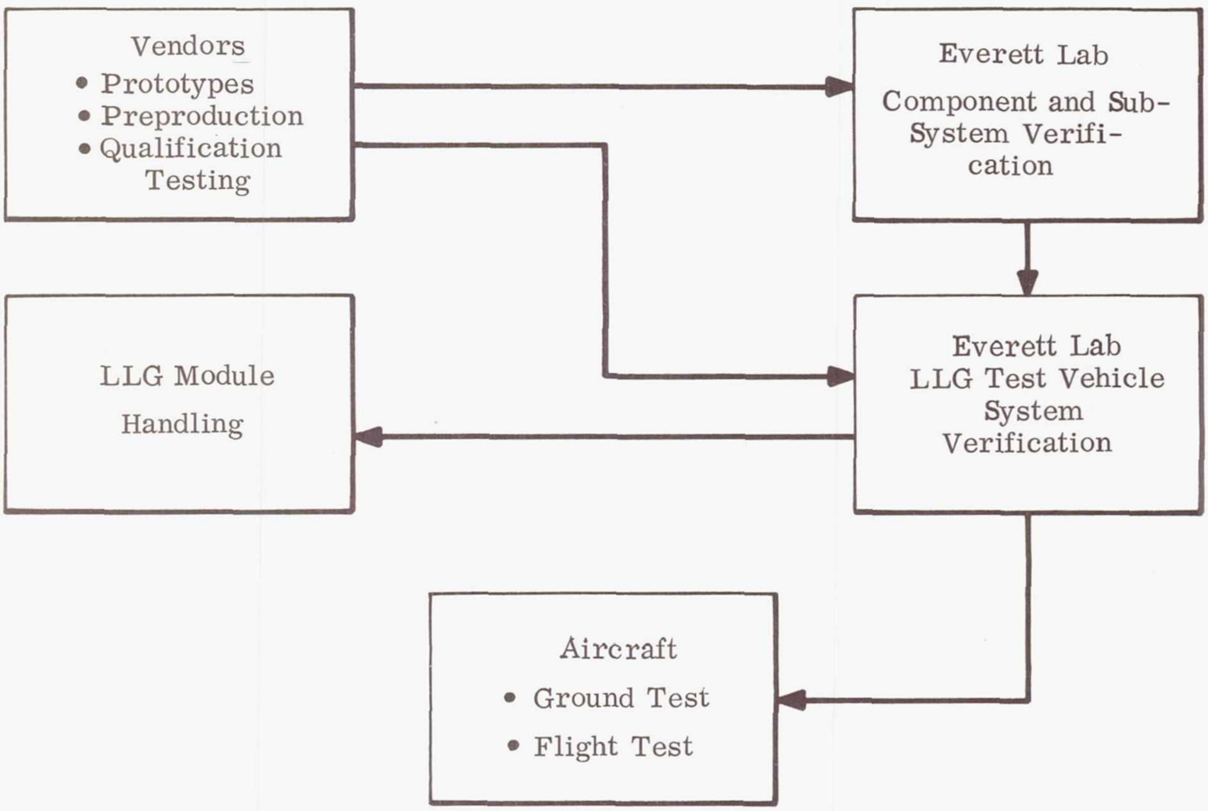

Figure 6. -Logic for lower lobe galley and module handling system test.

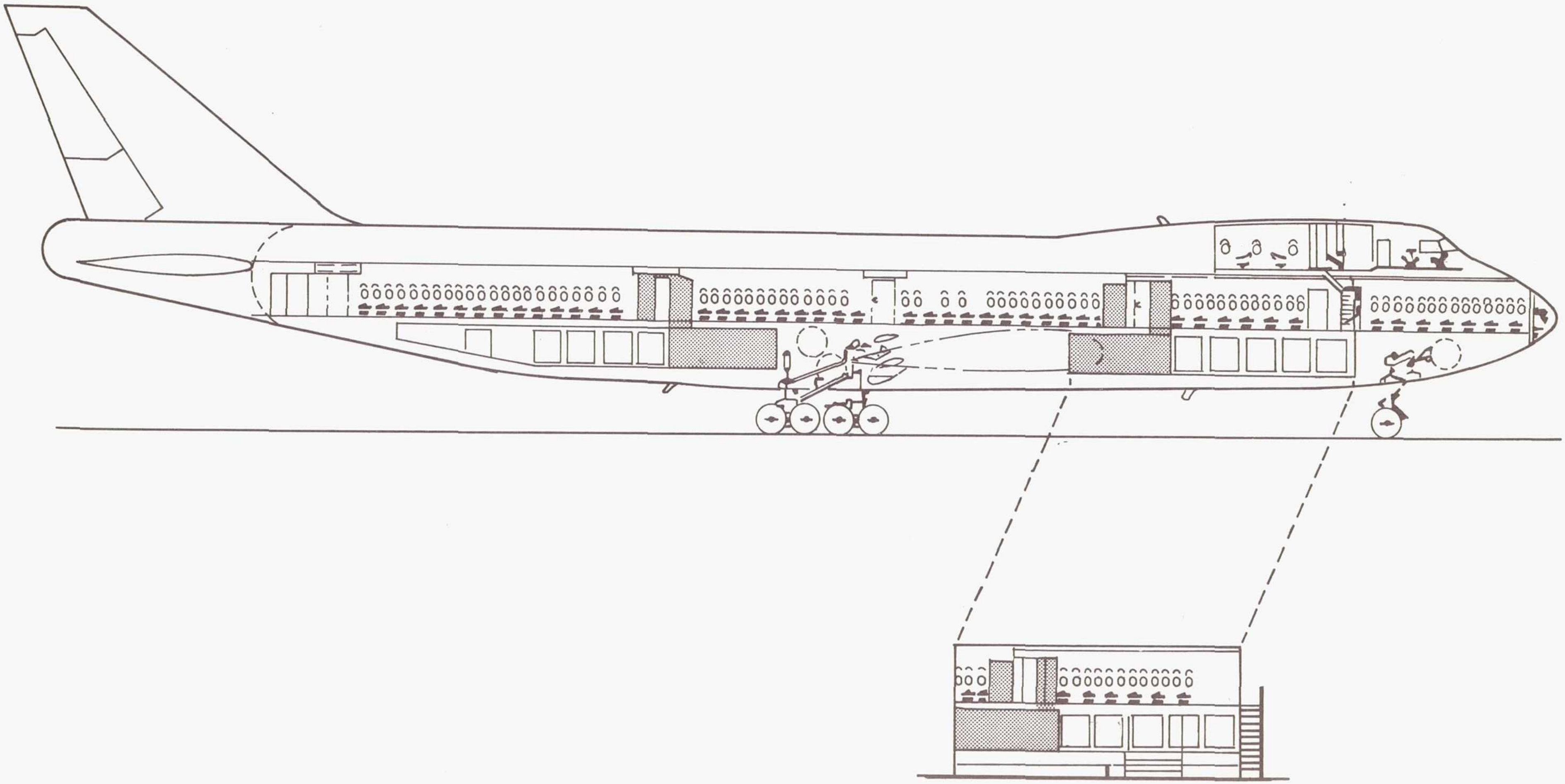

Figure 7. -Lower lobe galley test vehicle

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Food System Integration Responsibilities of Airframe Manufacturers

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(Presented by B. F. Monroe)
Lockheed-California Company

A majority of the world's commercial air carriers are involved in a profit-motivated business venture in competition with other carriers. Achievement of a favorable profit picture requires good management, a good route structure, aircraft that will operate reliably and economically, service to maintain a satisfied clientele, and an active promotional campaign to maintain and, hopefully, expand the volume of service.

The airframe manufacturer is directly involved in the design and production of an aircraft that will operate reliably and economically and incorporate features that will permit the airline to provide service of a quality necessary to maintain a satisfied clientele. Reliable and economical operation is a direct result of establishing design criteria commensurate with the operational use of the aircraft, developing sound structural and functional system design, selection or development of qualified components, conducting a comprehensive test program leading to certification, and providing postdelivery field-service logistic support. These factors must obviously be backed up by adequate levels of in-service maintenance provided by the air carrier. The airframe manufacturer's involvement in providing service of a quality to maintain a satisfied clientele is indirect since the ultimate responsibility must lie with the individual carrier. The airframe manufacturer is directly responsible for producing equipment incorporating features with the capability of providing services within a latitude acceptable to the carrier's customers. Quick-change kits, cargo systems, and food service equipment are typical examples of this area of responsibility.

The introduction of the passenger into the operational environment adds complexity almost beyond belief to the air carrier's normal equipment concerns. The bulk of passenger fare revenue is paid by the experienced traveler and generally to support business activities. Surveys have indicated that this experienced traveler is not always aware of the number of engines that propel the aircraft, is less aware of the airframe manufacturer, and smiles politely when made aware of the number of hydraulic systems, the advantages of full power over manual reversion flight controls for large aircraft, and the flexibility of the electric system where the generators may operate either in parallel or isolated. This passenger is mainly concerned about his immediate surroundings, the cabin crew, and the food and beverage service. Adherence to flight schedules and prompt baggage delivery round out the passenger's criteria for evaluation of the air carrier.

The air carrier whose services are oriented toward the fare-paying passenger is compelled to seek ways to cause these passengers to wish to return for subsequent trips. Since, from the passenger's viewpoint, there is little to offer in the area of differences of basic equipment, or aircraft, between carriers, individuality must be expressed in terms of the cabin decor, spacious accommodations, in-flight entertainment, and food and beverage service offered. Food and beverage service provides an excellent source of in-flight entertainment, especially on short-duration flights, and complements the in-flight motion pictures to occupy virtually the entire time required for a transcontinental flight. In terms of support requirements, the food and beverage service is fully as complex as many other aircraft functional systems when compared to their interface with both the aircraft and ground equipment. Recognition of this service and its importance places the airframe manufacturer in the position of system integrator with prime responsibility in the area of the aircraft and a secondary role for ground equipment and support facilities.

SCOPE OF INTEGRATION TASK

Developing an operational food service must be a joint responsibility of the airframe manufacturer and the air carrier. The economics of most air carrier operations would preclude acquisition of all new equipment and facilities especially designed for the new generation of aircraft. New support equipment must, obviously, be acquired to support the requirements unique to new aircraft, but the major portion of the equipment and facilities will be upgraded only as required as the new aircraft is integrated into parallel operation with the carrier's fleet. As the older aircraft are phased out of operation and their facilities and equipment become obsolete, the ground-based part of the system will be upgraded systematically to, or perhaps beyond, the requirements desired for the most efficient operation with the aircraft.

The major elements comprising the air carrier's food system are the aircraft galley, the service vehicle(s), and the commissary. Although the integration of the galley and the aircraft is primarily the responsibility of the airframe manufacturer, it is design oriented toward current operational equipment and facilities to minimize obsolescence, improve system efficiency, and improve airborne equipment performance. Cooperative pooling of equipment by air carriers can impact this process of optimization for both airborne and ground equipment as well as for facilities. The air carrier, necessarily, has the primary responsibility for adapting the ground equipment and facilities to accept the new aircraft as it enters service. This adaptation or upgrading of facilities must be accomplished in a timely and systematic manner to accept not only the new aircraft but subsequent models. The airframe manufacturer must contribute to this planning effort by defining the interface between the aircraft and the ground equipment and facilities.

SYSTEM INTEGRATION TASKS

The design of a galley system and its integration into the aircraft requires that the airframe manufacturer define the objectives of the system, develop equipment performance and aircraft support requirements, describe the elements of the airborne system, and specify the details of the interface between the aircraft and the ground equipment and facilities.

The objective of the aircraft food system is to provide high-quality, palatable, nutritious food in an attractive manner to the passengers within the constraints of time as established by the specific flight segment. The food that is to be served to the passenger must be of a quality at least as high as that served in a good restaurant. The food must be attractively arranged, at the appropriate temperature, and presented to the passenger in a manner reflecting a personal interest in him. The nutritional value of the food is subject to debate, but it is anticipated that this quality should fall into the same general pattern of food service objectives.

Food service system requirements will be based upon the above objectives and will consider the aircraft as it is to be placed in service. Establishment of these requirements will be accomplished after a review of the air carrier's route structure, commissary facilities, support equipment, and operating personnel. This process becomes more complicated when the galley system is provided as an integral part of a type of aircraft to be delivered to several carriers. Providing a common galley system is not as impossible as it may appear. Equipment performance is generally determined by the time constraints of the shortest flight on a carrier's route structure and the storage volumes and weights established by the quality of food service. Since most carriers feel that the 60-min block time is the shortest flight for a full hot-meal service, this time becomes the design point for the airborne equipment. The minimum cabin crew requirements are established by the cognizant Government regulatory agency and generally the carriers are able to perform all food service to the passengers with this crew complement. Short, high-density flights may require additional cabin attendants to perform an adequate and timely food service. The storage volumes required by most carriers to support their food service do not vary appreciably and when one analyzes the flow of food service to the passengers, equipment location, and storage space allocation, the standard galley starts to come into focus. For carriers whose service requires storage volumes in excess of those available, optional galley support units can be provided, possibly by removing passenger seats or reducing seat pitch to gain the required space.

The commissary plays a vital role in the food system and, although its operation and equipment is the prime responsibility of the air carrier or his caterer, the airframe manufacturer must consider the capability of this facility in designing and equipping the galley. The food prepared in this commissary must be tailored to the capability of the airborne equipment, and the food must be prepared prior to the loading of the galley. When precooked hot food is brought aboard the aircraft, the capability to hold this food at the proper temperature must be provided. Cold foods must be kept cool either by insulation or by refrigeration. Hot foods must be kept at temperature without overcooking or excessive drying. Cooking of raw foods and reconstituting of frozen foods is gaining in popularity, and improved ovens are required to perform this task. Beverage service presents requirements for coffeemakers, water boilers, ice making or storage, soft drinks and liquor. The commissary is charged with the responsibility of providing the food and beverages, tailored to the capability of the galley and its operating personnel. Additionally, the commissary is responsible for refurbishing galley equipment on the return cycle from the aircraft and disposal of waste. The handling of the galley equipment in this ground-based pipeline presents some rather rigorous design criteria for the airframe manufacturer supplying the galley and for the commissary operator in procurement of handling and processing equipment.

The United States Public Health Service regulations cross all boundaries from the commissary to the galley and establish handling, cleaning, and food processing requirements.

The commissary van or galley transporter is required to close the gap between the aircraft galley for both the galley loading and unloading cycles. This vehicle must contain adequate facilities to store all food and support equipment in a manner that will not degrade the quality of the airborne food service. In the event that one vehicle is used so that traffic and congestion about the aircraft is minimized, it must also be capable of providing adequate volume to accept the returning galley equipment and waste. This return-cycle volume is generally greater than that required for loading the galley because of the disarray typical of the hurried postservice pickup aboard the aircraft. The commissary van must also be capable of positioning itself properly to permit loading and unloading of galley equipment.

AIRCRAFT AND GALLEY INTEGRATION

The airframe manufacturer is responsible for integrating the galley into the aircraft after the basic requirements have been established in conjunction with the air carrier. The type of service is, necessarily, established by the carrier and is, in turn, reflected in food service system requirements. These requirements are the basis for establishment of the design criteria for the galley system and its equipment.

The galley system and its elements will be developed to permit performance in compliance with customer requirements. The galley concept, as related to food preparation and service capability, must then be established. Once the concept is determined, galley size and location will be established. The size of the galley will be partially dependent upon the concept of food service mode, handcarried tray or cart delivery service, but principally established by the heating, cooling, storage, and beverage support equipment. The location of the galley facilities will consider factors such as potential seat loss, service class divisions, traffic flow during food service to the passengers, ground-service access, weight, and cost. For either cabin-level or lower-deck galleys the number of units will be determined by ground-servicing and cabin-traffic flow during passenger service. The location of the galley on the cabin level or lower deck will be based on tradeoffs involving the comparative value of passenger seats, cargo capacity, and anticipated load factors. The Lockheed L-1011 underfloor galley releases sufficient cabin-level space to permit increasing seating capacity by 20 seats. When the lower-deck galley is adopted, food service carts are required to transport the food and beverage to the passengers. Elevators are used to move the carts between the cabin and the galley. These carts may be used in service to individual passengers or secured in a convenient position and so that they function as a satellite from which food is served to the passenger and to which waste is returned. Hot beverage service will be provided from the cabin-level galley units. When the lower-deck galley concept is utilized, hot beverage service from the galley is impractical and it is advantageous to locate food service support units at strategic locations on the cabin level.

Once the galley size and location have been established, the equipment and storage arrangement will be configured. Individual pieces of equipment will be located with consideration to their frequency of use, working height, weight of material handled, and other factors. When locating equipment one should also consider grouping the electric, water, drain, and communication services to achieve minimum complexity and weight and maximum safety. The design of the galley units and the equipment must be in compliance with certain Government regulator documents. Federal aviation regulations are primarily concerned with the structural and flight safety aspects of the galley units and require qualification through test or analysis, in some instances, for certification. The U.S. Public Health Service establishes the standards for galley sanitation, and aircraft operated by carriers within this country must operate galleys certified by this agency.

The galley system as installed in the aircraft interfaces with the electrical, environmental control, water, lighting, and possibly hydraulic systems. Structural attachments are required, and the units must be trimmed in a manner compatible with the area of the aircraft in which they are located.

Electric power is required by virtually all functional equipment within the galley system. The load requirements of the ovens will be the greatest single factor. This load will depend on the types of food to be prepared and the amount of time allocated for cooking or heating. The air carrier's philosophy for entree preparation can grossly impact this oven requirement by requiring power only for holding hot food at temperature or cooking of raw frozen food. The trend of improving quality of food will result in a greatly increased use of precooked frozen foods and later, raw foods, as ovens with improved performance are developed. Coffeemakers and water boilers used to support the hot beverage service will probably be the next largest electric power users. Brew time or water heating rates will establish peak loading and the old-mode power will fall within these peak requirements. The use of an icemaker aboard the aircraft will present a fairly large electric power requirement almost completely dependent upon ice production rates. The electric power consumption by the cold-storage units is relatively small by comparison, as is that of bun warmers, hotplates, and hot cups. The total electric load analysis for the galley system will consider all individual loads and the typical duty-cycle characteristics in the flight service environment. Peak loads and equipment duty cycle will then be integrated into the electric system total power loading and control. The electromagnetic interference characteristics of the galley equipment must also be considered for compliance with standards established for the aircraft.

The galley and its equipment will be dependent upon the environmental control system (ECS) for cooling and ventilation. Heat generated by the ovens, coffeemakers, hotplates, etc., will be rejected to the cabin area. For the lower deck galley this heat will be rejected to the galley itself, which will be established as a separate temperature zone of the ECS. Mechanical refrigeration systems must be provided with condenser cooling air and equipment cavities in galley cabinetry will be ventilated. Cabin exhaust air can be utilized for this function before it is ducted overboard through the pressurization outflow valves. Greasy or moisture-laden vapors generated by the galley must be ducted overboard in a manner that will preclude accumulation of grease with a resultant fire hazard and that will minimize condensation within the aircraft in inaccessible areas that will promote corrosion.

Water and drain facilities will be required at all water stations and to the coffeemakers and water boilers. Flow rates for the water supply must be established along with the acceptable pressure range. Equipment characteristics and water system performance must be properly established to ensure compatibility. The types of connections to these services must be specified with consideration for the reliability, maintenance characteristics, and installation peculiarities. Special attention must be given to the design of all equipment to insure proper draining when the aircraft is subjected to cold-climate environments. Design of the equipment and the water system interface must also consider U.S. Public Health Service standards.

The task of integrating the galley installation with the aircraft structure will vary considerably with the galley location. The greatest variance will be between the cabin-level and lower-deck galleys. Cabin-level galley units must be designed to resist crash loads while lower-deck installations will be designed on the basis of limit flight loads. Cabin-level installations will vary somewhat in mounting requirements between centerline and side-wall units. The structural integrity of the floor beams must be ascertained or provided for the cabin-level installation. Generally, overhead stabilizing structure will provide the lightest weight cabin-level installation. The lower-deck installation is of a quite different character since the galley becomes an integral part of the aircraft with somewhat simpler equipment installations. The larger centralized volume of this type of galley permits a more localized and efficient equipment installation. Corrosion and odor control practices consist of eliminating areas that could trap liquids and sealing off areas that could absorb or trap liquids. Special paints or coatings may be utilized in areas likely to be exposed to liquids to minimize corrosion. Design standards should be established to facilitate cleaning by providing smooth surfaces and rounded corners, sealing all faying surfaces, and utilizing the maximum practical number of flush fasteners. Spillage and condensation should always accumulate in accessible locations where cleanup is readily accomplished.

The successful integration of a galley system into an aircraft requires that a few basic ground rules be followed. These rules are common to installations involving two or more systems and are as follows:

(1) Establish performance requirements
(2) Define design criteria and constraints
(3) Describe system elements
(4) Determine interfaces
(5) Design system installations
(6) Communicate constantly with affected groups

L-1011 GALLEY SYSTEM

Lockheed-California Company organized the L-1011 Preliminary Design Group early in September 1966. At this time, studies were conducted out of which the basic galley system evolved. The Lockheed L-1011 incorporates a galley under the floor of the passenger cabin. This galley is but one part of the airborne food service system which also includes two elevators, three cabin-level service centers and the food and beverage service carts. This galley system is included as an integral part of the basic aircraft.

The underfloor galley occupies an envelope 239 in. long, 164 in. wide, and 74 in. high and is located forward of the wing box. The lower corners of this volume are cut off by the main structural rings and leave a flat floor width of 96 in. The total usable volume of this envelope is 1 584 cu ft. The entire compartment is sealed off from the aircraft and liquid flow paths follow down the sidewalls along internal contour and lead out onto the galley floor, where spillage is observable for easy cleanup. All galley equipment is hung from the floor beams or mounted on standoffs from the sidewalls to maintain an uninterrupted flow path down the walls and out onto the sealed floor. A secondary seal in the form of plastic pans is provided beneath the galley floor to insure against possible leakage through the galley floor reaching the bilge area of the aircraft where it would create corrosion problems. Warm air from the electric load center, which is located between the secondary seal and the galley floor, is circulated to dry any leakage and to keep the galley floor warm.

The underfloor galley is equipped with ovens, cold-storage units, an icemaker, dry-storage cabinets, a work counter, a bun warmer, a waste-disposal area, an intercom, and a cabin interphone. The galley is air-conditioned and lighted and provides parking areas for 18 food and beverage service carts. The ovens to be developed for the galley will be of an advanced design capable of reconstituting frozen entrees, or cooking raw frozen entrees, in a nominal 20 min. The oven will also be capable of cooking raw chilled food or heating chilled precooked food. Cold-storage units installed in the galley will be capable of holding chilled foods at 38° F or frozen foods at -10° F. An icemaker provided as a part of the galley equipment will have a bin capable of maintaining ice in a dry condition and will hold 50 lb. The icemaker has a production capacity of 30 lb clear ice/hr. A special cold storage (38° F) compartment with a capacity of 10 cu ft is an integral part of the icemaker.

Dry-storage cabinets are installed for items that can be stored at ambient temperature. Storage compartments are provided for miscellaneous waste in compartments on both sides of the galley in the bottom of the storage cabinets. These compartments have a fire rating of Class D. A work counter including a wash basin is located on the left side of the aircraft at the aft end of the galley. Through a window over the work counter the No. 1 engine and leading edge of the wing are visible.

The galley intercom system connects to a station in each of the cabin-level service units. This system permits unattended area-type communication in the galley area and provides handsets at the cabin stations. Any station may signal and call any other station. A cabin interphone, one of 10 stations, is located in the galley. The galley is provided with 500 CFM of fresh air and is a separate temperature control zone.

The galley is lighted with flush ceiling lights utilizing cold-cathode lamps. These lights are approximately 48 in. long and are spaced on 20 in. centers. Parking space is provided for the food and beverage service carts beneath the equipment and storage cabinets on both sides of the galley. The carts are parked and secured in a transverse position with respect to the aircraft and are accessible to service while parked.

The L-1011 galley is serviced through a door located midway in the right side of the galley. This door incorporates a window through which the No. 3 engine and leading edge of the wing can be seen. Food service carts are loaded singly into the galley from the commissary van through this 32-in.-wide door. The door opens inward and upward into the galley. The attendants will not occupy the galley during takeoff and landing. They will be provided with rough air seats outboard on either side of the elevator enclosure and mounted on the aft galley bulkhead. In-flight access to the electric load center will be provided through the aft galley bulkhead.

Two enclosed elevators are used to transport either personnel or food service carts between the underfloor galley and the cabin level. The elevators are powered indirectly by the four aircraft hydraulic systems. Two systems are normally allocated to each elevator to provide power source redundancy. Cross manifolding of the elevator hydraulic systems permits operation of each elevator from any one of the four systems. The elevators can be controlled from both the galley and cabin levels as well as from within the car. Safety features preclude operation when the enclosure doors are open or when other potentially hazardous conditions exist. Emergency egress hatches are provided in the top of the elevator cars. A ladder is provided in each car for access to the hatch. Lights are provided within the elevator car as well as in the shaft. Food cart tiedown fittings are provided within the car and on the car top. When the elevator cars are in the down position, food service carts may be stored on top of the car and accessible to the cabin level. The elevator will travel from the galley to cabin level in approximately 8 to 10 sec.

The midcabin service center is at the cross aisle immediately forward of the wing. This unit encloses the elevator shaft on the cabin level. The unit is approximately 42 by 90 in. and is situated transverse in the aircraft symetrically about the aircraft centerline. Four 32-oz coffeemakers are installed in this unit, two on each side of the elevator enclosure. A small work counter is provided under each coffeemaker installation and one wash basin. Storage space is provided above each coffeemaker. Storage space during takeoff and landing for two food service carts is provided, one on each outboard face of the service center. The entire service center is trimmed to be compatible with the cabin decor.

A forward service center is installed immediately aft of the flight station with the operating face forward. This unit contains a 32-oz coffeemaker and an extra hotplate. Space is provided for a hot cup and a water station is installed in the right-hand outboard side of the unit. Miscellaneous storage space is provided to support the beverage service. Space is provided to store one beverage cart within the unit transverse with respect to the aircraft centerline. The top of the unit opens upward to 90° exposing shelf space shielded from the passengers' view and providing a partial storage space for two food carts within the unit and secured in a longitudinal position. The single cart is stored for takeoff or landing. A galley intercom handset is installed in the service center.

An aft coffee bar is installed forward of the aft service door on the right-hand side of the aircraft. This unit is a configuration similar to the overhead coat-storage compartments and lower storage unit. This unit incorporates one 32-oz coffeemaker and two extra hotplates. Space is provided for a hot cup. Storage space is provided in both the overhead unit adjacent to the coffeemaker and in the lower floor-mounted enclosure. A galley intercom handset is installed in the coffee bar.

A total of 18 food and beverage carts are provided with the galley system. This cart complement includes 6 beverage carts, 8 coach-class carts, and 4 first-class service carts. These carts are to be utilized for 56 first-class and 200 coach passengers. The carts are 16.5 in. wide, 36 in. long, and 36 in. high. The service carts carry insulated containers on top of the basic cart. These containers are used to carry entrees, salads, or desserts. The cart incorporates 6 swiveling casters, arranged in pairs at the sides of the cart, on each end and in the middle. The center casters are lowered 1/8 in. to enhance cart maneuverability. The carts incorporate a retention system that will engage a flat-headed bolt or mushroom mounted in the floor for unattended storage positions. A jack-pad type of brake is provided for attended positioning and a tether system for in-aisle service. This tether attaches to the passenger seat arms, which are stressed to accept in-flight loads imposed by a tethered cart. The cart's structure and doors are symetrically arranged with respect to the ends of the cart.

The beverage cart supports the food service with soft drinks, liquor, wine, beer, ice, garnishes, etc. This cart has the capacity to serve 50 passengers. The cart incorporates a pressurized cobra-head dispenser system that provides carbonated water, sweet water, drink mix, and four cola syrups. A liquor module carries 105 liquor miniatures in dispenser tubes. This liquor module is removable and lockable. Space is provided for glasses, 10 pounds of ice, drink garnishes, quart bottles, beer, miscellaneous soft drinks, napkins, and a cash drawer. A stowable top provides a sanitary dust cover when the cart is not in use.

The first-class food cart incorporated features necessary to accept a variety of modules necessary to support cold food, entree, and dessert courses. When the cart is set up for cold food, it contains the table supplies such as tablecloth, napkin, silverware, salt and pepper, wine glasses, coffee cups, cold and dry food, bread, butter, china, and wines. The lower portion of the cart is allocated to waste pickup from the beverage service. When this cart is arranged for the entree course, it will contain the hot food, china, coffee cups, and wine and provide waste pickup space in the bottom portion of the cart. After completion of service, this cart will be used for this course-waste pickup and receptacles and containers are provided for this purpose. After the initial cold food service, this cold food cart will be returned to the galley and reconfigured to a dessert cart. In this configuration, the cart will carry the desserts, coffee cups, extra silverware, liquer glasses, liquers, wines, and miscellaneous afterdinner items. The lower portion of the cart is available for waste.

The coach food cart contains both preset trays with cold and dry foods and the hot-entree portion of the passengers' meals. The cart has a top-mounted container or holding oven that is insulated and electricly heated when connected to the ship's power. This holding oven's insulation helps maintain the temperature of the entree portions during the period of transit from the galley to the passengers. This configuration of cart permits the cabin crew to serve the passenger his complete meal in one operation, thereby reducing in-aisle traffic and delays in passenger service. Each cart serves 27 coach-class passengers. This cart will be utilized to serve first-class passengers on short flights with a cruise time of less than 1 hour.

The L-1011 galley system has been developed to provide the air carrier with a more efficient and cost-effective food system, maximum service flexibility, and the simplest interface with ground equipment and the commissary. Efficiency is inherent with the utilization of the advanced food preparation facilities and of food service carts to localize passenger food service and waste pickup. Cost effectiveness is derived from the relocation of the galley from the high-priced seating area of the cabin to the relatively less expensive cargo area. Costs are also reduced by the utilization of advanced cooking and cold storage equipment in the galley, permitting maintenance of frozen entree inventories, and cooking only actual food service requirements. Maximum service flexibility is offered the carrier through the variety of entrees that may be offered to the passenger and through the integrated use of the carts and cabin-level galley units. Finally, the features of single-cart loading through a separate galley service door combined with latitudes in on-board equipment operation simplify the ground equipment and facility requirements by reducing needs for special handling equipment and storage facilities.

Galley system developments have resulted from analysis, design, and construction of functional galley system elements and from actual food service testing. Efforts are continuing in all areas to refine the system to the optimum point by the time the L-1011 enters service in 1971.

Closing Remarks

WALTON L. JONES
NASA Office of Advanced Research and Technology

The prime reason for this conference, as you have already been informed, was that NASA believed that certain aspects of planning and applying food technology to long-term spaceflights required further research. We felt that the best way to review work done in this area was to invite the persons working in the various disciplines to a common conference.

I should like to point out that the first A in NASA stands for aeronautics. I am responsible for the aeronautics human factor studies. This is a new field for NASA, and, at the moment, we cannot really contribute anything that would improve upon the fine work pioneered by the airline industry. As a matter of fact, we are uncertain about the extent to which we should become involved; however, we are willing to participate provided we can make a beneficial contribution. Mr. Webb, when he was Administrator of NASA, urged us to act as catalysts in areas in which we saw that research or technology was lacking and to try, through various means, to get the needs filled. The question is, what can NASA do in support of research in this area?

We hope that the answer lies in several programs now underway. For example, drawing on our space technology knowledge we are developing an electrolysis process which supplies oxygen to airplanes by electrolyzing water. Both military and civilian carriers would benefit, primarily from a cutback in their logistics problems. For example, it now takes 5 liters of liquid oxygen to provide 1 liter of converted gaseous oxygen per man. If our project is successful we shall be able to produce from 1 pint of water sufficient oxygen for one man for a 10-hr mission.

Another project involves utilizing energy-absorption techniques to provide a more useful airline seat. These techniques have been used in the military services for some time but have not found their way into civilian use. We are also investigating the possibility of incorporating certain convenience items into the seat. The seats may have an impact on future food-handling techniques. We expect delivery of a prototype in midsummer. The Ames Research Center is monitoring both of these projects.

I would like to call your attention to the fact that two different requirements have been discussed here. One of them is posed by previously designed systems. You heard some of the problems of trying to squeeze objects into predetermined spaces; that is the worry of the people engaged in the human factors area and consequently the reason that they have been belaboring the point. Any help that you can give them would certainly be appreciated. Dr. Humphrey, as you know, heads the effort for the Apollo human factors program. His area is space medicine, and he and I work very closely together.

The other requirement is that posed by future systems not constrained by weights and volumes. Hence, I urge all of you not to limit your thoughts to constraints of weights and volumes for the future. I feel sure that for long-term spaceflights we are going to have to consider man as a "subsystem" whose requirements must be met. You have heard enumerated many requirements for a man who is a consumer. Well, a man who is an astronaut will not be very different. He will be doing work that we want him to perform, so we must keep him efficient, happy, and working for us. This will not be an easy job on a long mission. There are going to be constraints on this man; he will have limitations on his movement and his living conditions. We feel we should be considering the value of food and food management in maintaining his morale.

I believe that many good ideas have been discussed in this conference. We did not expect to formalize any here this last afternoon. We will review the material presented and will expect to hear from some of you. We want to put together a good Apollo Applications Program.

We have had many disciplines here; this is NASA's traditional approach to research. Mr. Webb prided himself on heading one of the first Federal agencies to utilize this technique. I think it has paid off, and we expect even greater dividends in the future.

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