International Space Station Food System

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Russia and the U.S. provide the current International Space Station (ISS) food system. Each country contributes half of the food supply in their respective flight food packaging. All of the packaged flight food is stowed in Russian provided containers, which interface with the Service Module galley. Each country accepts the other's flight worthiness inspections and qualifications. Some of the food for the first ISS crew was launched to ISS inside the Service Module in July of 2000, and STS-106 in September 2000 delivered more food to the ISS. All subsequent food deliveries will be made by Progress, the Russian re-supply vehicle. The U.S. will ship their portion of food to Moscow for loading onto the Progress. Delivery schedules vary, but the goal is to maintain at least a 45-day supply onboard ISS at all times. The shelf life for ISS food must be at least one year, in order to accommodate the long delivery cycle and onboard storage. Preservation techniques utilized in the US food system include dehydration, thermostabilization, intermediate moisture, and irradiation. Additional fresh fruits and vegetables will be sent with each Progress and Shuttle flights as permitted by volume allotments. There is limited refrigeration available on the Service Module to store fresh fruits and vegetables.

Astronauts and cosmonauts eat half U.S. and half Russian food. Menu planning begins 1 year before a planned launch. The flight crews taste food in the U.S. and in Russia and rate the acceptability. A preliminary menu is planned, based on these ratings and the nutritional requirements. The preliminary menu is then evaluated by the crews while training in Russia. Inputs from this evaluation are used to finalize the menu and flight packaging is initiated. Flight food is delivered 6 weeks before launch.

The current challenge for the food system is meeting the nutritional requirements, especially no more than 10 mg iron, and 3500 mg sodium. Experience from Shuttle/Mir also indicated insufficient caloric intake for many crewmembers. Additional thermostabilized and irradiated foods have been developed for ISS to improve the ease of preparation and overall acceptability. Dehydrated foods offer limited advantage, since water must be delivered to ISS.

An effort is underway to introduce other International Partner's food into the ISS food system. At first this will be one or two selected foods with the potential for more as the program matures. An increase in the variety of available foods would improve the overall acceptability.
Additional galley capability will be required when the crew size increases on ISS. Anticipated improvements include freezers, refrigerators and microwave ovens. All of the ISS food development efforts are devoted to improving the food acceptability and subsequent consumption and mission success.

Shuttle and ISS Food Systems Management

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Introduction

The provisioning of food for spaceflight is an extremely important aspect of the requirements for a human presence in space. While the food has an obvious impact on the health of crewmembers, it also plays a vital role in the habitability and psychological well being of the crew. U. S. space food systems began their long evolution with the on orbit consumption of applesauce from an aluminum tube by John Glenn more than 38 years ago (1). Since that time, the goal of the U. S. space food program has been to provide the most nutritious and palatable food system possible given the operational constraints of each spacecraft. This review will briefly summarize U. S. space food systems history, current operational systems and the direction of future space food development.

History of U. S. Space Food Systems

John Glenn's initial space dining experience with his tube of applesauce met spacecraft requirements, but was very incomplete from the human factors point of view. While the tubes prevented contamination of the cabin by food, the consumer could not see or smell the contents of the package. In addition, the food had to be in small enough particles to fit through the opening of the tube and thus was basically pureed (2).

Cubed foods were also part of early space food systems. Cubes were formed from cereal-based products subjected to high pressures (3). Cubes were then covered with a gelatin coating to prevent crumbs. Needless to say, these highly engineered foods were not equivalent to their traditional counterparts.

Dehydrated foods were included in early space food systems, but were consumed through a large tube that was built into the package. Again, there was no opportunity for the astronaut to smell the food. The "spoonbowl" packaged was developed during the Apollo program as a solution to the problem of eating dehydrated foods through these tubes. (4). After rehydration, the top of the spoonbowl package was cut open and the contents consumed with a spoon.

In addition to the spoonbowl, the Apollo program saw the introduction of retort pouched food items and irradiated foods. The retort-pouched items were thermally processed just like a canned food item, but in a flexible aluminum laminate pouch. This was the first package, which allowed the use of a utensil by the crewmember since it was used before the spoonbowl package. Irradiated foods utilized the foil laminate pouch but depended upon ionizing radiation to make them commercially sterile.

The Skylab food system actually proved to be the most sophisticated food system launched to date by the U.S. space program. The Skylab food system is the only one to utilize freezers and refrigerators for food and the first to provide a food warmer. (5).

The Shuttle food system regressed somewhat by eliminating the freezers and refrigerators due to volume and power limitations. The generation of water by the Shuttle fuel cells provided an abundant supply of water on orbit and forced the food system in the direction of a high percentage of dehydrated food items (6). The initial packaging system for the Shuttle rehydratable foods and beverages was a rigid package, which interfaced with a meal tray and permitted the crewmember to restrain packages during a meal. This enabled the crewmember, for the first time, to consume food from more than one package at a time, thus creating a more typical meal atmosphere. These two rigid packages were later modified to more flexible versions to reduce trash and stowage space and are described in the next section.

Current Shuttle Food System (7)

The current Shuttle food system is divided into the following categories of food items that are described below with the packaging methods for each category (Figure 1). There are approximately 150 items in the current Shuttle food list.

Shuttle beverages are packaged in a foil laminate pouch with a septum adapter assembly sealed in one end. Powdered beverages are sealed in single serving portions inside each pouch. The septum adapter assembly houses a septum which serves as a one way valve to allow water to be added to the beverage via a needle which is part of the rehydration station on the Shuttle galley. A straw is used to consume the beverage after rehydration. The straw includes a clamp, which is used by the crewmembers between sips to pinch off the flow of liquid through the straw in the microgravity environment. Examples include coffees, teas, and fruit flavored drinks.

The rehydratable food package utilizes the same septum adapter assembly as the beverage package but is a clear package formed from a five-layer coextrusion of nylon, ethylene vinyl alcohol, polyethylene and linear low-density polyethylene. After rehydration of the food product, the crewmember cuts open the lid of the package and consumes the food from the package using a fork or a spoon. Examples include freeze-dried entrees, freeze-dried vegetables and cereal products.

Most thermostabilized food items are packaged in the retort pouch. This pouch is a laminate of polyester, aluminum foil and polypropylene. The food items in these packages are single serving, ready to eat items, but most require warming by the crewmember prior to consumption. A few thermostabilized items are packaged in traditional aluminum cans with a full panel pull out lid. Examples include entrees and vegetables in the retort pouch and fruits in the aluminum cans.

Intermediate moisture and natural form food items are packaged in the bite-sized package. This package is a pouch of the same material as the rehydratable food package, which is heat-sealed on all four sides. Items packaged in the bite-sized package are ready to eat without any preparation and are in single serving portions. Examples include cookies, crackers, nuts, dried fruit and dried beef.

Irradiated food items are another category of foods utilized in the Shuttle food system. These meat items are packaged in the retort pouch and are made shelf stable by exposure to ionizing radiation. As with the thermostabilized entrees, crewmembers generally heat these foods prior to consumption although it is not required. The package is cut open and the food is consumed with a fork or a spoon.

Fresh food items are also provided in limited quantity in the Shuttle food system. Fresh foods are stowed about 48 hours prior to the launch, maintained at ambient temperatures and are limited to those items, which can be safely stowed without refrigeration for several days prior to consumption. Fresh food items are generally not packaged (fresh fruit) or are interim packaged in resealable plastic food stowage bags. Examples of fresh food items include apples, oranges, carrot sticks, candy, cookies, crackers and bread. The most popular bread item on the Shuttle is the flour tortilla, which is used by crewmembers to roll up foods and create a sandwich without having to deal with two pieces of bread in microgravity. Fresh tortillas are provided for the first part of Shuttle missions and a vacuum packaged tortilla with an extended shelf life is provided for the latter part of lengthier Shuttle flights.

Food accessories provided in the Shuttle food system include individually packaged portions of condiments such as ketchup, mustard and mayonnaise; liquid salt and pepper dispensed by dropper bottle; straws for the beverages; utensils (including scissors); and a meal tray. The Shuttle hardware provides a galley for food preparation, which includes a rehydration station for adding water to food and beverages and a forced air convection style oven for heating food products.

International Space Station (ISS) Food System

The ISS food system is being implemented in two phases. The first phase is the ISS Assembly Phase food system and the second phase is the ISS Assembly Complete food system. The Assembly Complete food system cannot be implemented until the U. S. provided Habitation Module is added to the International Space Station near the end of the assembly sequence.

The ISS Assembly Phase food system was implemented with the arrival of the Expedition 1 crew at the ISS in November 2000. This food system consists of a combination of U. S. Shuttle space foods and Russian space foods in an approximate 50/50 mix. U.S. astronauts and Russian cosmonauts will be consuming, on a daily basis, foods provided by both the U. S. and Russia. Russian space food items include items from the same general categories as those of the Shuttle food system. Thermostabilized, rehydratable, powdered beverages, intermediate moisture and natural form food items are all types of foods provided by the Russian space food system. The packaging of Russian food items is, however, different from that of the U. S. food system. Food items are being transported to the ISS via both the Progress (non-crewed Russian re-supply vehicle) and the Shuttle. Food is currently being stowed in Russian provided food containers, which are sized to fit in storage areas in the Service Module of the ISS. The Service Module, which was constructed by the Russians, currently serves as the living module for the ISS crew and includes a rehydration station for adding water to foods and some heaters, which are sized to fit the Russian food packages. The U. S. provides a suitcase style food warmer that plugs into an outlet in the Service Module and is used to heat U. S. food packages that do not fit into the Russian provided heaters. The food preparation equipment in the Service Module is designed to support an ISS crew of three people.

Proposed for addition late in the ISS assembly sequence, the U. S. Habitation module is slated to provide refrigerators and freezers for food as well as a galley and wardroom table that will support the assembly complete crew of seven. With the addition of refrigerated and frozen food items this Assembly Complete food system will enhance the current food system both psychologically and nutritionally. Quantities of refrigerated and frozen food will be limited and will likely represent about 25% of the menu for a crew of seven. Thus, the current food categories, both U. S. and Russian, will continue to be a part of the Assembly Complete food system. The addition of refrigerated and frozen food items will give greater diversity to the ISS food system by allowing the provision of types of foods that are very difficult to provide in ambient forms. An example of this would be dairy products, such as milk and cheese, which can be provided in powdered form, but are not very acceptable in that form, and are thus not often consumed. This limits the variety in the diet that can potentially lead to reduced food consumption due to menu fatigue during long duration stays on orbit. Reduced consumption can lead to deficiencies of certain nutrients associated with these foods. The use of refrigerated and frozen food items should enable a reduction in the overall sodium content of the on orbit diets of crewmembers. Thermostabilized food items tend to be higher in sodium than their fresh or frozen counterparts, causing space food diets to be higher in sodium than desired. High sodium content in the diets of crewmembers during extended duration spaceflight is of concern due to the bone loss observed in crewmembers in microgravity (8). However, limitations in power available to support the ISS food system are causing potential constraints for the implementation of the Assembly Complete food system.

Future Space Food Systems

The next food system developed for spaceflight by the U. S. will likely be an "Exploration Class" food system. This would be a food system that would be utilized for an exploration mission such as a trip to Mars. Two different types of food systems will probably be needed to support this type of mission.

First, a stored food system with a shelf life of about five years will be necessary for the initial trip to Mars. Mission scenarios call for an approximate three year round trip mission with a food supply being sent ahead of the crew and waiting for them on Mars upon their arrival. With launch opportunities to Mars occurring only once about every two years and since this food supply will include food for the initial return trip from Mars, a five year shelf life will be required for this stored food system. Although there are food items, notably some thermostabilized entrees, which have this type of shelf life, the variety of foods available are far too limited to provide the nutritionally balanced diet required for the crew of such a long duration mission. Thus, research and development is required in this area.

The second type of food system likely to be utilized for an exploration mission would be one based on an advanced life support system. In advanced life support system scenarios currently under development at the Johnson Space Center, plants are grown to help recycle the air and water in closed habitats that would be occupied by crews on the surface of the Moon or Mars. These plants are food crops, which, after harvesting, are to be processed by the crew into ingredients that can be utilized to provide a significant portion of the food system. Research is needed to develop the processing equipment and procedures that will enable crewmembers to safely process these crops in the closed habitat environment given numerous constraints such as limited habitat space, limited water, limited power and weight limits on the amount of equipment that can be transported from the Earth (9).

Summary

Space food systems have evolved over the almost forty years of crewed spaceflight. The U. S. space food system has strived to provide the most earth like food system possible within the operational constraints of each mission scenario. The current U.S. food system has significantly increased the variety of foods available. In addition, the foods are provided in much more traditional forms than in the early days of the space program. As the era of the International Space Station (ISS) continues, food system designers expect to see, at ISS Assembly Complete, a return to refrigerated and frozen food which was previously available on a limited basis during the Skylab program. Beyond the ISS, lies the significant challenge of providing a food system which can keep a crew healthy and happy for a three year round trip mission to Mars. The solution to this challenge will have potential applications to food systems for underdeveloped countries here on Earth.

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Figures