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# **The Challenges in the Development of a Long Duration Space Mission Food System**

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## **KEYWORDS**

NASA, Food, Exploratory Missions, Integration

## **ABSTRACT**

The Advanced Food System at Johnson Space Center/NASA will be responsible for supplying food to the crew for long duration exploratory missions. These missions require development of both a Transit Food System and of a Planetary Food System.

The Transit Food System will consist of prepackaged food of extended shelf life. It will be supplemented with salad crops that will be consumed fresh. The challenge is to develop a food system with a shelf life of 3 – 5 years that will use minimal power and create minimal waste from the food packaging.

The Planetary Food System will allow for food processing of crops grown on the planetary surface due to the presence of some gravitational force. Crops will be processed to final products to provide a nutritious and acceptable diet for the crew. The food system must be flexible due to crop variation, availability, and shelf life. Crew meals, based on these crops, must be nutritious, high quality, safe, and

contain variety. The Advanced Food System becomes a fulcrum creating the right connection from crops to crew meals while dealing with issues of integration within a closed self-regenerative system (e.g., safety, waste production, volumes, water usage, etc.).

## INTRODUCTION

Within the next 20 years, the National Aeronautics and Space Administration will be working towards a manned space flight to another planet or the lunar surface. The duration of these missions may be as long as 2.5 years. The primary goal of the Advanced Food System in these long duration exploratory missions is to provide the crew with a palatable, nutritious and safe food system while minimizing volume, mass, and waste. The paramount importance of the Advanced Food System in lunar or planetary exploration should not be underestimated. The Advanced Food System provides not only the nutrients needed for the survival of the astronauts but it also enhances the well being of the crew by being a familiar element in an unfamiliar and hostile environment.

The development of the Advanced Food System will require a dual task approach. The Transit Food System will deliver a food system during the transit to another planet and the initial stay on it. The Lunar/Planetary Food System will provide the crew with the proper nutrition during the lunar or planetary stay (Figure 1). These two Food Systems are intrinsically different. The Transit Food System has to operate in microgravity while the Lunar/Planetary Food System will operate in partial gravity allowing for more flexibility and more Earth-like operations. The Transit Food System will include a stored food system similar to that used on International Space Station. The major technological hurdle for this stored food system involves the shelf-life extension of the products to 3 - 5 years, while maintaining acceptability, nutrient content and minimal packaging (1). Salad crops, which can be utilized fresh, are also being considered in the Transit Food System.

Stored foods and salad crops will also be used in the early stages of lunar or planetary stays until a permanent living base is constructed. Once a permanent lunar or planetary base is available, crops will be grown and will constitute the basis of the menu. These crops will generate oxygen for the crew, as well as providing food to them (2). Crops will be processed into food ingredients and prepared into final food items. As more crops become available, the amount of prepackaged food will be decreased to accommodate the larger volume of processed crop ingredients.

The Advanced Food System is required to develop menus that will supply adequate nutrition to the crew during the long duration missions. A baseline menu that provides a minimum of 100% of the United States Recommended Daily Allowance (USRDA) to the crew will be developed (3). However, consideration will be made to provide the crew with changes in the nutrient levels that may be required due to the longer duration missions (4). For example, the USRDA for calcium is 1000 mg/day. However, for longer space missions the recommended daily requirement for calcium is 1000-1200 mg. On the other hand, the daily recommended level of iron is lower for space travel (10 mg instead of 18 mg) based on space-induced changes in iron storage that have been observed (5).

The acceptability of the food system is of much higher importance due to the longer mission durations and the partial energy intake that is often observed in space flights (6). The decreased energy intake might significantly compromise the survival of the crew. A large variety of food items are

recommended to provide the crew choices and to avoid menu fatigue (7). The food will not only provide the needed nutrition but mealtimes will also provide a major socialization event. Highly acceptable foods can play a primary role in reducing the stress of prolonged space missions.

The Advanced Food System, whether the transit or planetary portion of the food system, must consider the requirements of the life support elements. The Advanced Food System will impact the Air Recovery, Water Recovery, Solid Processing, Thermal Control, and Biomass Production Elements. The needs and constraints of the other life support elements must be balanced with the Advanced Food System to provide a well-integrated life support system for long duration space missions.

## **TRANSIT FOOD SYSTEM**

### **PREPACKAGED FOOD SYSTEM**

The majority of the food items in the Transit Food System will be prepackaged foods that will resemble the products used on Shuttle and International Space Station. The preservation methods used for the Shuttle and International Space Station are thermal processing, freeze-drying, irradiation, and intermediate moisture foods. Additional preservation methods that may provide higher quality foods will also be evaluated. It is anticipated that the food in the transit food system will be stored at ambient or room temperature. If the food were kept frozen, more power would be required to maintain the food at the correct temperature. It would also take more power to heat the food from a frozen state to a serving temperature.

One of the biggest challenges for these 2.5 year long missions will be to provide acceptable food with a shelf life of 3 – 5 years. The shelf life of the prepackaged foods will be evaluated to insure safety from microbial growth throughout as well as sensory acceptability of the food items. Changes in nutrient content over the foods' shelf life will also be determined. Development of rapid method analysis is highly recommended to provide the crew (and the ground-support) a tool to determine both safety and nutritional value of the food items at the time of consumption. Any analysis conducted during the mission must minimize the volatiles or waste. Any products from this analysis will need to be filtered out prior to any recycling of the air or water.

The packaging system requires further consideration. It will need to be compatible with the processing and storage conditions, volume constraints and requirements from the Solid Processing System. It is estimated that the waste generated by the packaging will be a major contributor to the total waste produced during transit. The use of packaging materials that are biodegradable, reusable, or edible will be evaluated in order to put less "strain" on the Waste Processing Element. The Waste Processing Element will also be significantly impacted if much of the food is discarded prior to consumption. It is very important that the food maintains its shelf life (safety and acceptability) throughout the duration of the mission.

### **SALAD CROPS**

Growing salad crops in the transit vehicle is being considered. These crops will include carrots, tomatoes, lettuce, radish, spinach, chard, cabbage, and onion (8). The crops will be incorporated in the

menu along with the prepackaged food. The fresh tasting salad crops will provide variety in the menu, texture, and color. This variety should provide increased psychological benefit.

To ensure a safe implementation of salad crops in the food system, adequate sanitation, processing, and storage requirements must be established. A hazard analysis critical control points (HACCP) plan will be developed for each process. The shelf life and packaging conditions of these crops shall also be determined. As in the prepackaged food system, safety, acceptability and nutritional content will be considered when determining shelf life. The Water Recovery Element and Waste Processing Element will be provided estimates of water and waste impact.

## **LUNAR/PLANETARY FOOD SYSTEM**

### **CROP PROCESSING**

Once the planetary base has been established, crops will be grown hydroponically. These crops will not only be a source of food but will also provide bio-regeneration of the oxygen and carbon dioxide. Some of the crops that will be grown hydroponically are white and sweet potatoes, wheat, soybeans, peanuts, rice and dried beans (8). As more crops become available, the Advanced Food System will replace some of the prepackaged food with food that will be prepared from the ingredients processed from the harvested crops.

The Advanced Food System will maximize the use of the crops that are grown by the Biomass Production Element. The Advanced Food System will design and develop food processing procedures and equipment for converting crops to bulk ingredients. These technologies must satisfy mission constraints, including maximizing safety and acceptability of the food and minimizing crew time, storage volume, power, water usage, and the maintenance schedule (7). The equipment and processing areas shall be easily cleaned and sanitized (Table 1).

The Advanced Food System will consider the constraints of the other systems (Figure 2). As the Advanced Food System is developed, it must integrate with the Air Recovery, Water Recovery, Biomass Production, Solid Processing, and Thermal Control Elements. The Advanced Food System will consider the availability of power, volume, and water availability as the entire food system is developed.

Water usage will be kept at a minimum. The equipment will be designed to use minimal water during food processing. Since commercially available food processing equipment does not require minimizing water usage, the Advanced Food System will have to significantly modify existing equipment. If the commercially available equipment cannot be modified, the food processing equipment will be redesigned. An attempt will be made to allow for the recycling of water during the food processing step.

The wastewater will be kept at a minimum also. Since the wastewater may have a minimum of reusable nutrients in it, the wastewater will be cycled through filters several times to insure that the maximum amount of nutrients has been recovered from the water. Processing equipment must be easily cleanable to insure minimal water usage. Air contamination and noise will also be kept at a minimum.

In order to keep volume and mass at a minimum, an attempt will be made to develop food processing equipment that is multipurposed. An example of this equipment is the Soymilk, Tofu, Okara, and Whey

Processor (STOW). The STOW can be used to process soybeans into all usable ingredients. The STOW, with minimal changes, will produce silken or regular tofu that is soft, firm, or extra firm in texture. Other possible pieces of food processing equipment are the gluten/starch separator, dehuller/floater, tempeh processor, grain mill, steamer, expeller, and extruder (10). Some of these pieces of equipment share parts such as motors which will have minimize volume and mass.

The Advanced Food System must balance the constraints of the crop varieties and the requirements of making the crew meals (9). Crop variation (quality, crop yield, and nutrient content) is expected possibly as a consequence of water recycling within the Biomass Production Element. A variation of nutrients in the growing solution will be reflected in the harvested crops' composition and, consequently, it might affect the functionality of the ingredients produced and their performance in the final food products (both processing conditions and product properties). For example, it is expected that the protein content of the hydroponically grown wheat will be higher. The higher protein content will not only cause a need for increasing the mixing time of the dough but it will also affect the quality of the bread and pasta produced from the wheat flour. Testing methods will be developed to predict the ingredients' functionality based upon their proximate analysis and, consequently, modification of the food preparation procedures will be implemented (11). If variability in functionality of the crops is not predicted then the consequences may be significant. Of largest concern is that the unusable harvested food will provide less food and therefore a potential loss of nutrition to the crew. Furthermore, the unusable portion of the food will put more of a strain on the Waste Processing Element.

The bulk food ingredients produced from the crops must be free of chemical and microbial contamination. HACCP procedures and testing methods will be established to determine the safety and shelf life of each ingredient. The Advanced Food System will design packaging and determine storage requirements for each of the bulk ingredients. Again, the impact on the Air Recovery, Waste Recovery, and Waste Processing Elements will need to be considered and integrated within the entire life support system.

## FOOD PREPARATION

The final task of the Lunar/Planetary Food System is food preparation in the galley. A menu will be designed that incorporates the foods made by processed crops in addition to resupply items. The resupply items, which supplement the food that is produced from the crops, will be kept at a minimum. These developed recipes will use minimal crew time and will provide a safe and acceptable food supply. The Advanced Food System will use prepackaged food as required to provide a nutritious diet for the crew. The menu will provide enough variety to prevent "burn-out" of the menu.

Several items have been identified for possible use during food preparation in the galley. They are a combination microwave/convection oven, dehydrator, bread maker, pasta maker, juice/pulper, food processor, bagel maker, blender, rice cooker, scale, and dryer oven. Some of these items may require minor modifications prior to use in a long duration exploratory mission.

Safety and acceptability will be the criteria in determining the shelf life of menu items prepared from the bulk crop ingredients. Storage conditions and acceptable food packaging will be determined that will allow for minimum weight and volume with maximum shelf life and usability.

A HACCP plan will be established for all galley procedures. Appropriate requirements for cleaning and sanitizing the food preparation area will be determined. Sanitizing procedures should not require significant power or water usage. Furthermore, the sanitizers used must be reusable or easily removed from the closed environmental system. Potable water needs and wastewater production by Advanced Food System during food preparation will be determined. Solid waste production will also be determined during food preparation. Crew time will be minimized for all galley procedures including food preparation and later cleaning and sanitizing.

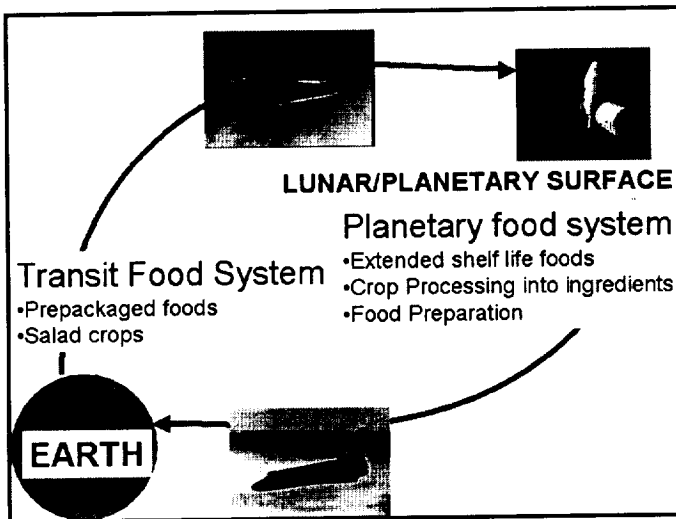
## CONCLUSION

There are many challenges when providing a food system for lunar or planetary missions. Whether the Advanced Food System menu consists of prepackaged food or menu items derived from processed crops, certain requirements must be maintained. The menu must be safe, nutritious, and acceptable. The total menu should provide enough varied choices to the crew to aid in the psychological needs of the crew. The food system will minimize the volume, mass, and power and water usage while integrating with the other BIO-Plex systems.

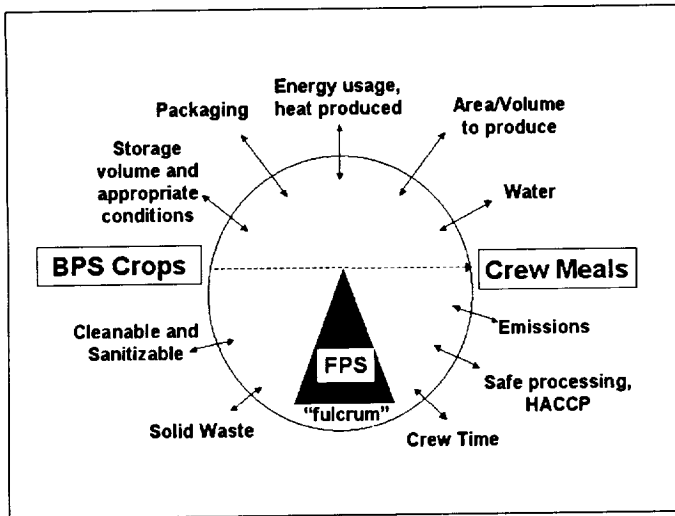
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**FIGURE 1: THE ADVANCED FOOD SYSTEM IS A COMBINATION OF TWO FOOD SYSTEMS; A PREPACKAGED TRANSIT FOOD SYSTEM AND A LUNAR/PLANETARY THAT INCLUDES PROCESSED CROPS.**



**FIGURE 2: ISSUES TO OPTIMIZE IN ADVANCED FOOD SYSTEM WHILE MAINTAINING BALANCE (9)**

- Maximize safety
- Minimal water usage
- Minimal power usage
- Minimal waste generated
- Minimal volume usage
- Easy to sanitize
- Minimal air contamination
- Minimal noise generated
- Multipurpose
- Automated/Minimal crew time

**TABLE 1: FOOD PROCESSING EQUIPMENT CONSTRAINTS**