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Bioregenerative Life Support Systems Test Complex (BIO-Plex) Food Processing System; A Dual System

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ABSTRACT

A Bioregenerative Life Support Test Complex, BIO-Plex, is currently being constructed at the Johnson Space Center (JSC) in Houston, TX. This facility will attempt to answer the questions involved in developing a lunar or planetary base. The Food Processing System (FPS) of the BIO-Plex is responsible for supplying food to the crew in coordination with the chosen mission scenario. Long duration space missions require development of both a Transit Food System and of a Lunar or Planetary Food System. These two systems are intrinsically different since the first one will be utilized in the transit vehicle in microgravity conditions with mostly resupplied foods, while the second will be used in conditions of partial gravity (hypogravity) to process foods from crops grown in the facility.

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. Microgravity imposes significant limitation on the ability to handle food and allows only for minimal processing. The challenge is to develop food systems similar to the International Space Station or Shuttle Food Systems but with a shelf life of 3 – 5 years.

The Lunar or Planetary Food System will allow for food processing of crops due to the presence of some gravitational force (1/6 to 1/3 that of Earth). Crops such as wheat, soybean, rice, potato, peanut, and salad crops, will be processed to final products to provide a nutritious and acceptable diet for the crew. Not only are constraints imposed on the FPS from the crops (e.g., crop variation, availability, storage and shelf-life) but also significant requirements are present for the crew meals (e.g., RDA, high quality, safety, variety). The FPS 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., safe processing, waste production, volumes, air contaminations, water usage, etc.).

Options for the first test, for duration of 120 days, currently scheduled for late 2003 are outlined.

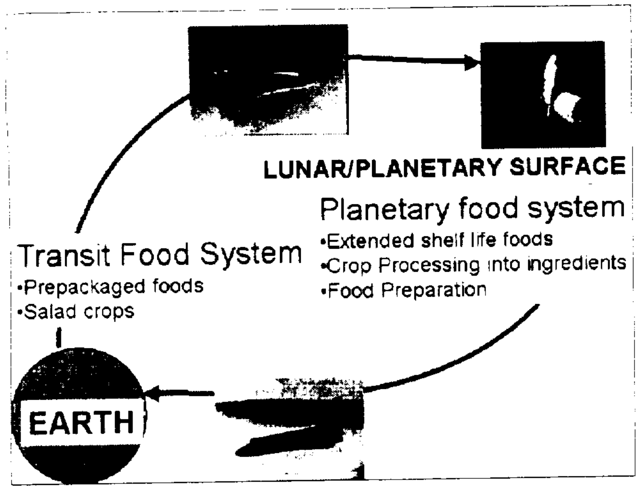

Figure 1: The FPS is a combination of two food systems; a prepackaged transit food system and a lunar/planetary that includes processed crops.

Stored foods and salad crops will also be used in the early stages of lunar or planetary stay 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 lunar/planetary menu. These crops will generate oxygen for the crew, as well as providing food to them (Barta and Henninger, 1994). 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 FPS 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 (National Research Council, 1989). 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 (NASA, 1996). 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 (Alfrey et al., 2000).

The acceptability of the food system is of much higher importance due to the longer mission durations and a partial energy intake (that is often observed in space flights; Lane and Smith, 1999) 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 (Vodovotz et al., 1997). 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.

This paper will discuss the goals and challenges of the FPS and the approach that will be taken to provide a safe, acceptable, and nutritious food system for lunar/planetary exploration. BIO-Plex will be the test-bed facility used to verify adequacy and functionality of the design system.

TRANSIT FOOD SYSTEM

PREPACKAGED FOOD SYSTEM - The first BIO-Plex test will represent the transition period from Earth to a planet. 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 (ISS). The preservation methods used for the Shuttle and International Space Station are thermal processing, freeze drying, irradiation, intermediate moisture foods. Additional preservation methods such as freezing and non-thermal processing techniques (e.g. pulsed electric field processing, ultra-high hydrostatic pressure) will be evaluated.

One of the biggest challenges for exploration class 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. Shelf life determination will include accelerated shelf life testing. 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.

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. Packaging materials that are biodegradable, reusable, or edible will be evaluated for use in the Transit Food System. It is estimated that the waste generated by the packaging will be a major contributor to the total waste produced during transit.

SALAD CROPS - Growing salad crops in the transit vehicle is being considered. Salad crops will be available for the initial 120-day BIO-Plex test. These crops will include carrots, tomatoes, lettuce, radish, spinach, chard, cabbage, and onion (Barta et al., 1999). White and sweet potatoes may also be available for the 2nd half of the 120-day BIO-Plex test (representing the situation that might be possibly found during the early stages of permanence on a planet). 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 and potatoes 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.

LUNAR/PLANETARY FOOD SYSTEM

CROP PROCESSING – After the first BIO-Plex test, subsequent tests will represent the exploratory missions once a base has been established on the lunar or planetary surface. The second BIO-Plex test is expected to provide about half of the food system through the processed crops (Figure 2). The FPS will consist of larger proportions of processed crops in subsequent BIO-Plex tests.

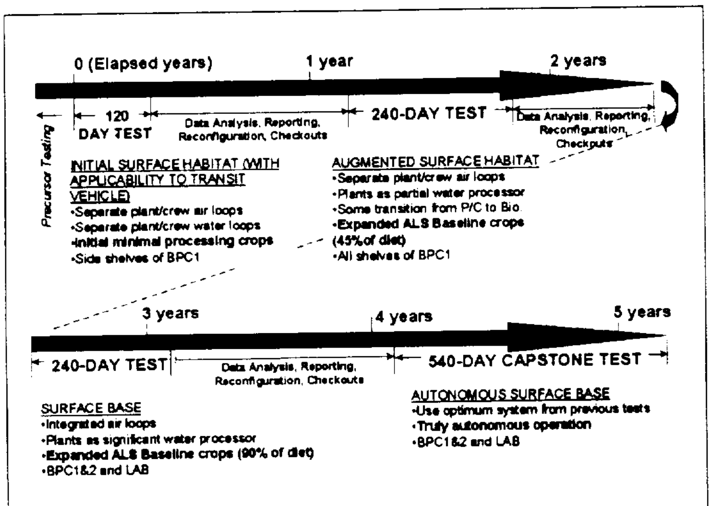

Figure 2: Proposed BIO-Plex human testing sequence (Tri, 2000)

Some of the crops that will be grown hydroponically are wheat, soybeans, peanuts, rice and dried beans (Barta et al., 1999). As more crops become available, the FPS will replace some of the prepackaged food with food that will be prepared from the ingredients processed from the harvested crops.

The FPS will maximize the use of the crops that are grown by the Biomass Production System (BPS). The FPS will design and develop food processing procedures and equipment for converting BIO-Plex 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 (Vodovotz et al., 1997). The equipment and processing areas shall be easily cleaned and sanitized (Figure 3).

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

Figure 3: Technological challenges in food processing

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 test articles for the BIO-Plex are the gluten/starch separator, dehuller/floater, tempeh processor, grain mill, steamer, expeller, and extruder.

The FPS must balance the constraints of the crop varieties and the requirements of making the crew meals (JSC, 2000). Crop variation (quality, crop yield, and nutrient content) is expected possibly as a consequence of water recycling within the BPS. 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 in protein. 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 (Vodovotz and Barta, 1998).

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 FPS will design packaging and determine storage requirements for each of the bulk ingredients.

The BIO-Plex FPS will consider the constraints of the other systems within BIO-Plex (Figure 4). As the FPS is developed, it must integrate with the Air Recovery System (ARS), Water Recovery System (WRS), BPS, Solid Processing System (SPS), Thermal Control System (TCS), Habitability Accommodation System (HAS), and Advanced Control System (ACS) systems. The FPS will consider the availability of power, volume, and water availability as the entire food system is developed.

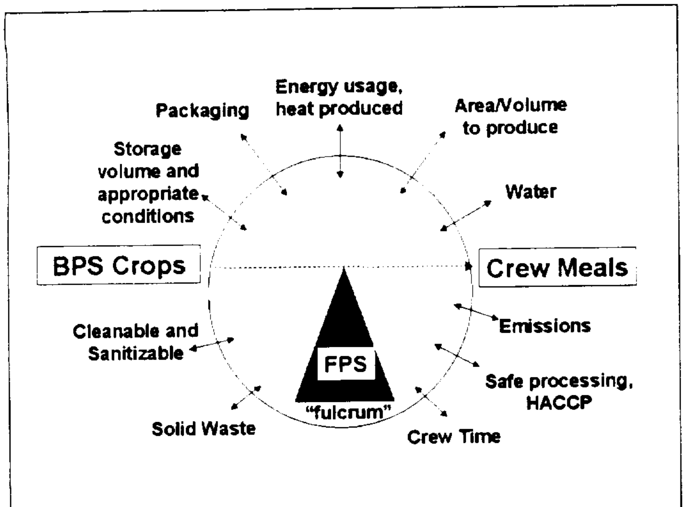

Figure 4: Issues to optimize in FPS while maintaining balance (JSC, 2000)

Water usage will be kept at a minimum. The equipment will be designed to use minimal water during food processing and clean-up. Since commercially available food processing equipment does not have the requirement of minimizing water usage, the FPS will have to significantly modify existing equipment. If the commercially available equipment cannot be modified, the food processing equipment will be redesigned.

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 recycled several times to insure that the maximum amount of nutrients has been recovered from the water. Air contamination and noise will also be kept at a minimum.

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 will supplement the food that is produced from the crops. These developed recipes will use minimal crew time and will provide a safe and acceptable food supply. The FPS 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 COTS 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 the BIO-Plex.

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. Potable water needs and wastewater production by FPS 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 FPS 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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ACRONYMS

FPS: Food Processing System

BIO-Plex: Bioregenerative Life Support Test Complex

HACCP: Hazard Analysis Critical Control Points

STOW: Soymilk, Tofu, Okara, Whey Processor

SPS: Solid Processing System

BPS: Biomass Production System