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Advanced Food Technology Workshop Report – Volume I

Space and Life Sciences Directorate
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HABITABILITY AND ENVIRONMENTAL FACTORS DIVISION

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ADVANCED FOOD TECHNOLOGY WORKSHOP REPORT

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ADVANCED FOOD TECHNOLOGY WORKSHOP REPORT

1 PREFACE

The Advanced Human Support Technology (AHST) Program conducts research and technology development to provide new technologies and next-generation systems that will enable humans to live and work safely and effectively in space. One program element within the AHST Program is Advanced Life Support (ALS). The goal of the ALS program element is to develop regenerative life support systems directed at supporting National Aeronautics and Space Administration's (NASA) future long-duration missions. Such missions could last from months to years and make re-supply impractical, thereby necessitating self-sufficiency. Thus, subsystems must be developed to fully recycle air and water, recover resources from solid wastes, grow plants, process raw plant products into nutritious and palatable foods, control the thermal environment, while reducing the overall system mass. ALS systems will be a combination of physico-chemical and biological components depending on the specific mission requirements. For example, it is anticipated that ALS systems used for a planetary transit vehicle will be primarily physico-chemical. More complex systems using biological elements would be used on planetary bases where it would be uneconomical to have resupply. The same combination of physico-chemical and biological systems is anticipated for the Advanced Food System. In the transit vehicle, the food system will primarily be a prepackaged food system with the possible addition of salad crops that can be picked and eaten with limited preparation. On the lunar or planetary evolved base, the food system will be a combination of the prepackaged menu items and ingredients that are processed from the grown crops. Food processing and food preparation will be part of this food system.

In order to be able to direct NASA's research and technology efforts in the area of advanced food system development, the technologies currently available on Earth for food packaging, food preservation and processing must be identified and the viability of these technologies assessed. However, there are specific challenges that need to be addressed for a long duration mission and planetary or lunar stay that are not currently important to the food industry. For example, if commercially available miniaturized processing equipment are not available, they will need to be designed and fabricated prior to the mission. The food industry, due to its need for high throughput, puts less consideration on volume and mass of the equipment, water usage, etc. Minimizing mass, volume, water, and air contaminants are very important features of the Advanced Food System. Another example of NASA-unique requirements is food packaging materials. Several materials, which have high potential for NASA, are not being considered by the food industry due to the packaging materials higher costs that the industry cannot afford with its lower profit margins. However, if the material is more effective in the protection of the food or is lower in mass, NASA would likely consider the technology.

A workshop titled "Advanced Food Technology" (AFT) was held in Houston, Texas on April 3 – 5, 2002. The main objective of the AFT Workshop was to provide input to NASA so that a research and technology development strategy could be developed for the Advanced Food System. Food science experts from academia, industry, and government were brought together to help evaluate technologies in food packaging, food preservation, and post-harvest processing. These technologies were discussed in terms of both their applicability for use in future long duration manned space flights beyond low earth orbit and in terms of their capabilities, strengths, weaknesses, mass, volume, water usage and other attributes where known. Technology assessment forms and/or spreadsheets were filled out to provide more detailed data of many of the technologies. Volume II of this report contains the workshop assessment forms, a list of participants, and other information applicable to summarizing this workshop.

Since many of these technologies are emerging and are at a low Technology Readiness Level (TRL; Appendix A), not all the requested information was available. Due to the uncertainty in some of the technologies, the participants were asked to give estimates that would be accurate within an order of magnitude. Technology and information gaps were identified.

Although this document is a report summarizing the results from the Advanced Food Technology Workshop, it will not only be used in that manner. As these technologies are further developed or new technologies emerge, this document will be updated. The information in this document will be reviewed bi-annually to determine whether there is adequate new information for a document revision. The intent is to have a dynamic document that the research community can use to identify technology gaps that they can contribute towards solving.

2 EXECUTIVE SUMMARY

2.1 Workshop Planning and Development of Pre-Workshop Documents

In order to prepare the participants, several documents were provided to the participants in advance of the workshop. One document summarized background material to better understand the needs of the Advanced Food System. At the end of the document was a list of appropriate references and websites that the participants could use to further understand the Advanced Food System.

Workshop assessment forms were also developed for each of the three working groups. The intent was to gather as much data as possible on the food technologies. The assessment forms were developed through a collaboration of the Advanced Food team and the Systems Integration, Modeling, and Analysis (SIMA) group. These forms were sent one month in advance to the workshop participants and the filled out forms were compiled prior to the workshop. These compiled forms were available at the workshop for further discussion.

A teleconference was conducted with the external leads one week prior to the workshop. In addition, there was a meeting with the NASA leads one week prior to the workshop. Both meetings were to provide the leads with an opportunity to ask questions and make suggestions.

2.2 Participants

An effort was made to bring together experts in the food science field, along with current NASA researchers. Expertise was drawn from academia, food industry, food consultants, laboratories, and the federal government. Twenty-two of these experts participated in the workshop. The intent was to provide a forum for discussion and brainstorming on each technology that was discussed by the participants.

2.3 Invited Talks

During the first morning of the workshop, Dr. Donald Henninger, Program Element Manager ALS, provided the participants with an overview of ALS. Dr. Michele Perchonok spoke specifically about the Advanced Food System and the objectives of the AFT Workshop. Vickie Kloeris provided a historical and current perspective on the NASA food system. Dr. Michael Ewert spoke to the group about the SIMA Element within the ALS Program Element and how some of the data produced by the AFT Workshop would be used and a definition of Equivalent

System Mass (ESM). ESM calculations are based upon cost equivalencies for volume, power, and cooling as defined in Drysdale and Hanford (2002). ESM calculations provide a way to compare two or more options that could be used in a given mission.

In an effort to provide the participants with as much discussion time as possible, several of the invited talks were conducted during the lunch break. During the lunch break on the first day, Dr. David Wolf (astronaut aboard MIR and various shuttle flights) provided some insight on the food system. He spoke specifically about food acceptability, preparation, and packaging aboard MIR and Shuttle. During his talk he answered several questions asked by the participants. Also during the lunch break, Dr. Alan Holland spoke about the psychosocial issues of long duration space flight and terrestrial testing such as the Lunar-Mars Life Support Test Project (LMLSTP) 90 day test.

On the second day, during the lunch break, Dr. Scott Smith (Manager of the Johnson Space Center (JSC) Nutritional Biochemistry Laboratory) spoke about the nutritional requirements for both short and long duration space missions. Results from Skylab, Shuttle, and International Space Station (ISS) nutritional were provided. Dr. Helen Lane (Principal Coordinating Scientist) completed the lunchtime discussions by reviewing the Critical Path Roadmap.

2.4 Workshop Structure and Function

The workshop participants were divided into three working groups (Food Packaging, Food Preservation, Post-Harvest Processing). Each working group was led by one external lead and one NASA co-lead. The goal was to have a technology assessment form filled out for every technology discussed during the workshop. Prior to each day of the workshop, there were meetings with the external and NASA leads to address any issues that had arisen the day before. At the end of each day, the external leads presented an updated summary of their discussions to the entire workshop group. The interaction between the three working groups created good discussion and synergism between the three groups.

2.4.1 Food Packaging

The Food Packaging working group developed a potential list of the packaging materials that could be used. Emphasis was on the packaging materials and equipment needed to produce these materials that would help reach the goal of a prepackaged food system with a shelf life of 3 – 5 years. However, some discussion did occur on the food packaging needs on the planetary or lunar surface.

2.4.2 Food Preservation

The Food Preservation working group assessed many conventional and emerging technologies that would provide the Advanced Food System with food that had a shelf life of 3 – 5 years. These technologies were discussed both in terms of the prepackaged food system, produced terrestrially, and the foods that could be preserved on the planetary or lunar surface.

2.4.3 Post-harvest Processing

The Post-harvest Processing working group considered the technologies that were needed to produce edible ingredients and/or menu items from the crops grown on the planetary or lunar surface. Technologies and Hazard Analysis Critical Control Points (HACCP) procedures were also discussed for the storage of the crops prior to processing and for the minimally processed crops such as salad crops.

2.4.4 Summary of Findings

A total of thirty-two technologies were assessed – ten Food Packaging, fifteen Food Preservation, and seven Post-harvest Processing. In addition to the more in-depth consideration of these technologies, another 48 technologies (eight Food Packaging, fifteen Food Preservation, and twenty-five Post-harvest Processing) were considered in spreadsheet form. Particular areas that require significant research and technology development include the following: 1) miniaturization of food processing equipment; 2) further testing of the preservation methods for all types of foods; 3) integration of the various technologies (e.g., testing the use of a certain packaging material with a given preservation method).

For purposes of this report, some of the technologies that were submitted for a specific working group were placed into another working group's section. For example, water activity was submitted to the packaging working group as a hurdle technology. A hurdle technology, which combines several preservation technologies together, establishes "hurdles" to the deleterious effect, such as microorganism growth, and aids in obtaining the desired shelf life. Specifically, the discussion included how decreasing water activity (water available to participate in chemical, microbial, and enzymatic reactions within foods) would aid in increasing the shelf life of the food in cooperation with the correct barrier packaging. However, since reducing water activity can be a drying technology, it was moved to the preservation group's section. Another example was that ozone treatment which was transferred from the preservation group to the post-harvest processing group since ozone treatment would be used most likely for the vegetable crops. There were other occurrences of transfers to provide for a better organized report. Since the reorganization occurred after the workshop, the working groups did not have the opportunity to discuss these technologies during their sessions.

3 INTRODUCTION

3.1 Background and Purpose of Workshop

Successful manned long duration missions will require that the crew maintain their health and well-being. 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. A loss in nutrition or well-being of the crew will affect the crew performance during a mission. Thus a food system that is safe, nutritious and highly acceptable will be vital.

Due to the duration of the mission and the potential distance from Earth, an assumption was made that there will be limited opportunity for resupply. Hence, as the Advanced Food System is developed, both extended shelf life foods and post-harvest processing of crops into acceptable and nutritious food ingredients must be considered. The food system must integrate with the other life support subsystems and develop a food system that minimizes the use of volume, mass, water, air, and energy. The food system must also be developed so that there is minimal contamination of the water and air subsystems.

Assessment of potential technologies and development of a strategy for development of an Advanced Food System is essential in order to develop a food system for long duration space missions. Therefore, NASA invited a team of food science experts from academia, industry, and government to help assess current and emerging technologies in food packaging, food preservation, and post-harvest processing. In preparation of the workshop, the participants were provided with a charter and background material with details about the current ALS program element and Advanced Food System to better understand the objectives of the workshop.

When completing the assessment forms, the participants were asked to consider AFT requirements for three possible mission scenarios. These possible scenarios were selected from the ALS Reference Missions Document (RMD) (JSC-39502). The participants were instructed to complete the assessment forms only if the technology met one or more of the AFT requirements (listed below) in that mission.

- Mars Transit Vehicle: Approximately 180 day transit from Earth to Mars each way. The primary food system will be prepackaged food. Minimally processed foods such as salad crops may be grown in a growth chamber. Water is probably the only resource that might be desired. Top-Level AFT Requirements: Prepackaged food Items with a shelf life of 3 – 5 years that are safe, acceptable and provide the correct nutrition. Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops.
- Mars Surface Habitat Lander: Approximately 600 day stay on Mars per mission. A plant chamber would be available and would be responsible for growing more than just garden crops, and grown food would be the primary diet. Top-Level AFT Requirements: Prepackaged food Items with a shelf life of 3 – 5 years that are safe, acceptable and provide the correct nutrition. Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops.
- Evolved Mars Base: Approximately 600 day stay on Mars per mission. However, the base may be fully functional for more than 10 years. This mission relies on plants for nearly all of the diet (approximately 90%). Top-Level AFT Requirements: Post-harvest procedures or technologies to aid in providing acceptable, safe, and nutritious salad crops and other processed food crops. Some food preservation technologies may be used to preserve the processed ingredients.

3.2 Charter of the Workshop

Advanced Life Support (ALS) systems will be required for long duration human space missions. Recycling of air and water, crop production and processing into storable items or food, and solid waste processing are key elements of an ALS. Processing of crops into consumable food under long-duration space missions will require unique technological adaptations to Earth-based processes.

It is intended that the Advanced Food System will:

- *Be safe and satisfy the nutritional, psychological and acceptability needs of the crew;*
- *Develop a separate packaged stored food system with a shelf life of 3–5 years that can be used for transit and exploration missions;*
- *Design, build and maintain food processing equipment for converting raw crops to edible ingredients and products.*

The goal of the proposed AFT workshop is to provide input to NASA to develop a research and technology development strategy for the ALS Advanced Food System. NASA's requirements for food processing in future exploration missions will be presented to the invited workshop participants.

The workshop will be structured into three functional components of the Advanced Food System: 1) food preservation technologies; 2) food packaging; and 3) post-harvest processing technologies. Since acceptability is of importance to the Advanced Food System, sensory experts will also be included in the working groups.

It also is anticipated that the workshop participants will assess current and propose alternative food processing technologies that have the potential to fulfill the requirements for NASA's long-term missions. Each candidate food processing technology will be independently assessed in terms of established criteria including mass, power, volume, reliability, use of expendables, technology readiness level, volatiles, shelf life, acceptability, crew time, and operational scenarios (e.g. microgravity vs. hypogravity; vehicle vs. planetary surface applications). Evaluations will also include an assessment of the technology readiness and its suitability for use in space-based ALS in the context of specific mission scenarios.

Mission scenarios that will adequately describe the requirements of the Advanced Food System will be provided. This will help the workshop participants understand the constraints of food processing, crop production, and food packaging. Each technology assessment will be done on the basis of the mission scenarios. Tools will be provided to record data needed on each technology. Assessment of the technologies will include identification of limitations of the technology in the context of NASA mission applications and possible approaches to overcoming these limitations.

The recommendations and findings of this workshop are expected to serve as a guideline to solicit and conduct research in ALS in the area of advanced food technology.

4 RESULTS AND DISCUSSION

4.1 Food Packaging

4.1.1 Introduction

The Food Packaging working group identified and analyzed technologies that would provide protection for the food from spoilage and chemical reactions. In other words, the package must be free of holes or tears and the seal must be maintained so that spoilage organisms cannot contaminate the food. In addition, the food within the package must not be exposed to factors that may contribute to additional chemical reactions. For example, the package for a high lipid-containing food will require a barrier to oxygen to prevent oxidation of the food, which would result in rancidity.

The primary objective of the Food Packaging working group was to define the packaging materials that would meet the needs of the Advanced Food System (e.g., a shelf life of 3 – 5 years). Furthermore, how and when in the process the food is filled into the package and how the package is sealed was discussed. Finally, the working group considered the impact on solid waste management, food and packaging mass and volume, and crew time.

Since the food is often preserved within the food package, the Food Packaging working group, when evaluating the technologies, considered the environment in which the packaging material would be used. Not all packaging materials can be used for a given preservation method. It is possible that the material would not withstand the heat or pressure of the preservation method. For example, new non-foil ultra high oxygen barrier film has been used in the hot-fill process but not proven for use in retorting. It is also possible that a material cannot be used since it prevents the viability of the preservation method. For example, a packaging material that contains a metal cannot be used when microwaves are part of the preservation method.

In addition to evaluating technologies, the Food Packaging working group spent some time discussing options to aid NASA in their current and future endeavors. Some of these suggestions were:

- Information previously gained by NASA pertinent to food and food systems needs to be shared with food and packaging experts.

- Packaging integration and consultation is needed in the NASA working group.
- Immediate application of barrier technology is applicable to eliminate double packaging of some foods.
- Much of the cutting edge packaging technology resides in industry and not in universities. Information gathering should include this segment of the industry through attendance at conferences such as Pack Expo and Interpack.
- Broad application of a single package type and style has value to minimize inventory and possible confusion.
- Reusable packaging may have Equivalent System Mass (ESM) benefits as well as function and appeal benefits.
- Create a database from NASA, NASA Specialized Center of Research and Training (NSCORT), NASA Research Announcements (NRA), and current packaging technologies for food systems.

4.1.2 Major Activities of the Food Packaging Working Group

- Definition of Food Packaging working group responsibilities.
- Evaluate technologies submitted prior to workshop including assessing TRL for commercially available technologies.
- Overview of technologies and processes not specifically evaluated in working group including packaging materials, equipment to produce the materials, equipment to seal the materials, and hurdle technologies to augment the current food and packaging materials to increase the shelf life of the food. Hurdle technology deliberately combines existing and new preservation techniques to establish a series of preservation factors (hurdles) that the microorganisms in question are unable to overcome (jump over). These hurdles may include temperature, water activity, acidity, redox potential, preservatives, and others.

4.1.3 Assessing TRLs for Commercially Available Technologies

An attempt was made to be consistent in the TRL determination between all technologies. It was determined that if the technology was only a concept, a prototype, or had only been tested in the laboratory, a TRL of 1 - 2 was assessed. A low TRL rating was also given to a technology if the Food and Drug Administration (FDA) had not approved it for use with food. A TRL of 3 was given to a technology if it had been used commercially but not in the environment that may be needed for NASA. For example, the oxygen scavenging film has been used for the hot fill preservation method but has not been used for the retort process in the U.S. even though the expectations are that the package would be stable during the process. Finally, a TRL of 6 was given to a technology only if it met all the requirements including shelf life, waste mass, volume, etc. A summary of TRLs and technology gaps can be found in Table 3 in Section 5.

4.1.4 Overview of Technologies

The Food Packaging working group was successful in evaluating eleven different technologies. However, one technology, water activity, was introduced as a hurdle technology. Since there was insufficient time to fill out assessment forms for every technology, other technologies were only briefly discussed during the workshop. The Food Packaging working group felt that producing the packaging material on the planetary or lunar base was not practical until the base was fully established for many years. For that reason, the working group did not discuss any of the packaging equipment options. However, there was some discussion on the options for equipment needed to hermetically seal or close the food within the package. These technologies were as follows:

- Tabletop vacuum heat sealer: This sealer can be used for several packaging applications including high barrier, ultra high barrier, modified atmosphere packaging (MAP), and dry products. It could be used with all flexible pouch applications as well as for compaction of waste (non-human) and articles that need storage. Commercially available earth sealers are available with the following specifications: Equipment Mass, 94 kg; equipment volume= 0.64 x 0.51x 0.46 M = 0.15 M^3; Power usage = 120 volts/ 13 amp; Water usage= none; crew time= process dependent. Equipment cleanup is minimal (clean up of spill only and there is no chemical usage. The average equipment life time is 10 years with proper maintenance.

Recommend optimization for space use

- Heat sealer: An impulse sealer to seal pouches of liquids. It can be as simple as hand held sealer or equipment mount with the capability of mechanical headspace evacuation before sealing.
- Screw cap closure: Manual, unless steam flush is needed.
- Sanitation Station: The station provides a mean to clean and sanitize containers if multiple use containers are used.

The Food Packaging working group also discussed another eight technologies. Much of the discussion was in response to questions that arose during the end-of-day presentations. These technologies were not discussed in depth since the consensus of the group was that these technologies were not recommended based on the needs and requirements of the Advanced Food System. The technologies were as follows:

- **Cold Plasma SiOx (Silicon Oxide) deposition for barrier containers**. A glass layer is deposited on a polymer substrate for barrier improvement. There are issues of cracking and fracturing. Tetra Pak and Toppan are commercial manufacturers of this material.
- **Antimicrobial films and packaging**. Very limited effectiveness.
- **Gas flush (Active MAP) technology**. Crew safety and weight restrictions make compressed gas technology unfavorable.
- **Aseptic packaging**. This is an appropriate technology for earth prepared foods. Packaging materials for transit and evolved base would support chemical sterilization, but the packaging equipment complexity and weight make this approach impractical for the base. There are safety issues with hydrogen peroxide and other sterilants. Using presterilized bags (Scholle type) or cups (Portion Pack-style) may make most sense if a sterile container is desired.
- **Edible films for food packaging/ biodegradable**. The areas of edible and biodegradable packaging do not currently meet the mission constraints of 3 – 5 year shelf life. The best edible films are at least 100 times less effective as a gas barrier than the worst structural polymer. They do not readily seal and cannot be used with processing and preservation systems. There are safety issues with the biological nature of these products as well as microbial issues of stability. Edible films could be used for short term storage of the crops or processed ingredients.

- **Producing packaging materials from a waste stream**. The many hazards associated with producing lignin based packaging make this technology an unlikely candidate for non-terrestrial use. Permeability and performance characteristics of biomass packaging materials do not meet mission criteria. Since many multiple steps are required, crew time would be significant.
- **Single use rigid metal cans**. Double seam cans are not considered appropriate.
- **Metal Squeeze tubes**. This technology is not considered appropriate.

4.1.5 Evaluation of Submitted Technologies

4.1.5.1 Retort Pouch

This packaging material is used for foods that will be thermally processed at high temperatures. The basic flexible package material will begin with a lamination of an external protective film such as polyester and/or nylon; aluminum foil as the principal oxygen/water vapor/microbiological barrier; and cast polypropylene as the internal sealant. Oxygen and water vapor permeability should be effectively zero.

The prepared wet food product is packed in the flexible barrier package pouch structures and then thermally sterilized for microbiological stability. Flavor scalping, when the packaging material selectively absorbs flavor constituents from the food product, can occur, leading to downgraded consumer acceptance in as few as six months. Other biochemical changes such as Maillard browning and lipid oxidation can also occur. The shelf life of these items is probably adequate for three to five years, but should be confirmed.

This technology is already being utilized in the Shuttle and ISS food system as well as for the Military Meals-Ready-to-Eat program.

4.1.5.2 High Barrier Packaging Materials for Intermediate Shelf Life Foods

This non-foil packaging material can be used with form-fill-seal packaging systems. It is currently used with a wide range of hot-filled and cold-filled pumpable foods. These materials can withstand temperatures between –20^{o}F to 212^{o}F and are microwaveable. The high oxygen and moisture barriers of these materials provide increased protection of flavor. This material has increased strength and superior protection against puncture and abrasions.

This packaging material has an oxygen barrier system for holding oxygen sensitive foods for 12 to 15 months at 68^{o}F, 1 atmosphere pressure, and 75% relative humidity. Since shelf life is dependent upon temperature and partial pressure of reactive gases during storage, longer shelf life (3-5 years) may be possible with colder storage temperatures (0^{o}F) and lower oxygen partial pressures.

The majority of the uses for high barrier packaging material includes heat treatment required for filling followed by the need for storage at chilled or frozen temperatures prior to use. For liquid products, the package is hot filled at 185^{o}F to 195^{o}F to kill any spoilage and vegetative pathogenic bacteria. However, the material can also be used to complement high acid shelf stable, intermediate moisture foods, and dehydrated products. For the shelf stable reduced water activity products, it may be necessary to purge the package with an inert gas (e.g., nitrogen) to reduce oxygen prior to sealing. An oxygen scavenging system may also be used to scavenge residual oxygen in the package headspace.

Identified technology gaps include the affect of elevated temperature and increased oxygen and possibly energy input of low dose radiation on shelf life.

4.1.5.3 Bulk Packaging for Dry Flowables

This technology would be used to store dried food products such as bulk grains or flours. The packaging is heat sealable and can utilize vacuum packaging similar to other packaging systems. Packages can be formed to specific shapes. Manual or automated equipment for filling and sealing the bag are commercially available. To conserve space, a vacuum source or package compression device could be incorporated into the packaging equipment.

Heat sealable, high abuse, high moisture barrier pre-made thermoplastic bags are available. The material's durability and moisture vapor transmission rate properties protect the dried food products against excessive moisture gain during extended storage and product spillage.

Dust is a significant hazard during filling. Dust must be controlled by keeping the dust enclosed by using a connector specific for dry flowables (fitment), which will allow direct transfer into the bulk package. These fitments are commercially available from several suppliers including Fresco, Sholle, Fran Rica, and Liqui-Box.

4.1.5.4 Liquid Crystal Polymers

Liquid Crystal Polymers (LCP) have exceptional oxygen and moisture barrier properties and high physical property performance compared to standard packaging polymers. Due to the higher costs of LCPs, typical commercial applications have LCPs being combined in very small amounts with other materials such as LDPE and PET to gain benefit of their performance. The LCPs can be used for foods that are hot-filled, retorted, microwaved and vacuum packed. Because of the exceptional barrier properties, the containers should be vacuum or gas flushed packaged to remove headspace oxygen.

LCPs can be used in film and semi-rigid container designs. It can be considered for barrier laminate in multi layer structures or as monolayer material. A monolayer material would be easier to process through the Solid Waste Management System or for reuse. If the material is considered for reusable applications, the result is potential savings on materials.

4.1.5.5 Passive MAP of Fresh Salads

Modified atmosphere packaging (MAP) is used to extend the shelf life of vegetable and fruit crops and could be used on the planetary or lunar surface. Passive modification of a package atmosphere is based on the relationship matching the oxygen, carbon dioxide, and water vapor transmission rates of the packaging material at the intended storage temperature (32 - 40^{o}F). Modifying the atmospheric composition and hence minimizing the respiration rate can increase the shelf life of the salad crop. It is important not to select films of insufficient permeability because of the hazard of creating anaerobic conditions or injuriously high levels of CO_2. As a comparison, active MAP gas flushes the packaged food and requires compressed gases. Since compressed gases may not be available on the planetary or lunar surface, the Food Packaging work group did not consider active MAP. MAP, whether passive or active, does require storing the vegetable crop at refrigerated temperatures.

The technology is widely used in the food service and retail markets. Passive MAP mechanically removes excess gas from a packaged food. Then the specialized packaging is used to extend the shelf life by minimizing the respiration of the crop. Passive MAP can provide a shelf life of 10 to 14 days at a storage temperature 40^{o}F. A crop such as lettuce would have a shelf life of 7 days at 40^{o}F without the use of MAP as long as it is kept intact and not cut or torn. If passive MAP were not used, the crops could be stored in minimal packaging such as minimum gauge material and reusable bags such as sandwich or Zip Lock™ bags.

Whether passive MAP or "pick and eat" methods are used, the salad crops' shelf life relies on production and post harvest handling practices that minimize the exposure of the salad crops to conditions that could accelerate product deterioration. Practices such as optimizing harvest time, minimizing physical injury to the vegetables, rigorous hygiene practices and cooling quickly after harvest will aid in optimizing the product quality. If these practices are not conducted, it is possible to initiate large populations of undesirable spoilage organisms and deteriorations due to enzymatic activity.

4.1.5.6 Ultra-High Oxygen Barrier Film Based on Oxygen Scavenging

Ultra-high oxygen barrier film contains an oxygen scavenger as part of the packaging material. Removing oxygen helps maintain product freshness, extends shelf life, and protects color. This technology is independent of the type of food. It will work with dry or moist products. The film is an alternative to current scavenging products such as sachets, labels and coatings. The oxygen sorption capacity is not currently as effective as sachets. However, since the scavenging component is built into the film, it does not require that the sachet be removed prior to consumption and does not change the look or feel of the package. In the Cryovac version of the film, scavenging begins when the film is activated by a high intensity ultraviolet light installed on the processor's packaging line.

Combining the oxygen scavenger with foil packaging would reduce overwrap. In addition, foil based pouches for retort products are susceptible to flex cracking that can result in an increase in oxygen permeability of the pouch. The combination of a foil laminate oxygen barrier retort pouch and an oxygen scavenging over-wrap provides a package that will compensate for any flex cracking. The oxygen scavenging over-wrap would be applied after the retort process using gas flush packaging technology.

This technology currently has only been tested for hot fill but should work for other preservation methods such as thermally processed or microwave application. The oxygen scavenging process would be activated prior to packaging the food in the primary retort package. Use of oxygen scavenging material in retorting has been discarded in military R&D, since retorting effectively drives oxygen within the food system into the food.

This technology could be used for any of the three missions. However, the largest advantage would probably be for the transit mission prepackaged food system. The technology would be used primarily for those foods susceptible to oxidation such as high fat foods.

4.1.5.7 Nanocomposites

Polymer nanocomposites when used can help achieve packaged food shelf life of 3-5 years. There also exists the possibility of reducing the weight of a given packaging system due to the increased barrier and strength (increased rigidity) achieved by the nanocomposites. The form and convenience of this packaging material is similar to other high barrier laminate films. It can be used for thermostabilized, microwaveable, or hot fill processed foods. The material can be processed by the same method as the unfilled, i.e., extruded, blown film, thermoformed, etc. Depending on the required oxygen and water barrier properties, it is possible to have some weight improvement over the current material being used for the Shuttle and ISS food system.

Since nanocomposites materials are 100% polymer structure, there are some advantages. This material will be easier to incinerate and can more easily be reused than other packaging materials. With added research, they could be reused as a fuel or could be remolded into other items such as temporary packaging or spare parts for equipment.

4.1.5.7.1 AEGIS™ Nanocomposite Barrier Resins

Aegis™ OX polymerized nanocomposite, oxygen-scavenging barrier nylon resin is specially formulated for high oxygen and carbon dioxide barrier performance, even in high humidity. It is commercially available for a host of co-injection molded PET bottle applications, including bottles and orange juice containers.

Another grade, Aegis™ NC, can be used as a coating or as the base resin for cast or blown films. Aegis™ NC does not possess the oxygen scavenger present in Aegis™ OX. The major application for Aegis™ NC coatings will be as a replacement for nylon 6 coatings in paperboard juice cartons. Aegis™ NC provides the cartons with approximately 3 times better oxygen barrier than nylon 6, greater rigidity for less bulging, and is less hygroscopic. In films, Aegis™ NC can be used as a nylon replacement for process meat and cheese packaging.

The new family of resins nearly doubles the heat resistance of nylon 6 and increases tensile modulus, flexural modulus and flexural strength by 30 to 50 percent allowing the design of thinner, lighter and better performing parts. There is a potential for less flavor scalping.

This packaging material provides the opportunity to move toward all polymer material and away from foil. This material is a possible candidate for high barrier shelf stable foods in a semi-rigid container. There may be the opportunity to decrease mass. The packaging material is easier to incinerate than some other materials.

4.1.5.7.2 Triton Nanocomposites

Triton's patented nanotechnology is based on the inclusion of inert inorganic fillers that exhibit a platelet nanostructure. These additives can readily be compounded with a base resin such as nylon, polyethylene terephthalate (PET), and ethylene-vinyl alcohol (EVOH). By adjusting the chemistry and the processing conditions, these nanofillers naturally self-assemble and develop a matrix. This matrix improves the oxygen barrier properties of current polymers. The barrier properties may be improved enough to compete with foil. The water vapor transmission rate may not necessarily be improved by nanocomposites.

The Triton nanocomposites have not been assessed for long term stability yet. Thermoformed trays are currently being evaluated for long term stability in a US Army program. Studies suggest that these materials have already shown to have sufficient barrier properties to achieve at least a 3-year shelf life without refrigeration. Currently there is no FDA approval for food contact with these packaging materials.

4.1.5.8 AMCOR PET with Oxygen Scavenger

Amcor North America is promoting a proprietary blend of PET that would have better oxygen barrier properties than glass or EVOH blend containers. There is limited information of the proprietary blend of PET with oxygen scavenger. The scavenger system has not been specified. It can only be assumed that the improved barrier properties over glass results from the material blend and an improved closure system. If indeed the barrier properties are correct, then strong, lightweight containers are possible. It is even possible that they might be reusable. This packaging would be appropriate for semi-rigid containers and reusable containers and for low moisture, hot fill foods. This material is FDA compliant.

4.1.5.9 Odor Absorbent Packaging

Active packaging systems, which remove gases by adsorption or absorption, have been previously reported in scientific literature and patent applications. The focus of most of these packaging systems has been oxygen and ethylene removal. The use of active packaging systems to selectively remove off-flavor compounds and improve the flavor quality of foods is a potential new concept.

Odor absorbent packaging can be used in combination with base polymers such as PET, low density polyethylene (LDPE), and Polypropylene (PP). It is usually put in the primary layer. The technology uses odor absorbent compounds to eliminate off odors produced during long storage. The odors producing compounds that should be targeted in the technology are aldehydes and ketones associated with lipid oxidation and cooked odors. Ketones are found in beverages and foods such as ultra high temperature (UHT) milk.

Depending upon the surface area required to achieve the effective removal of off-flavor compounds, the active portion of the container (e.g., beverage) may be limited to the closure. Limiting this technology to the closure would place the active portion of the package at the headspace where most of the volatile compounds are concentrated. The use of polymeric amines in packaging to remove volatile food components may be an effective means to remove unpleasant flavor notes since ketones and aldehydes contain a functional carbonyl group that readily reacts with amines.

Similar technology is being used as odor absorbers in trash disposal, which might be useful to NASA for solid waste management and dirty clothes.

4.2 Food Preservation

4.2.1 Introduction

The Food Preservation working group identified and analyzed technologies that could be used to preserve foods. This working group concentrated on the methods that would extend the shelf life of foods. For the transit food system, there is a requirement that the food have a shelf life of three to five years. In other words, the food has to be safe, nutritious and acceptable for the duration of its shelf life.

The Food Preservation working group had the challenge of considering these technologies both as Earth-based as well as planetary-based. In trying to separate the responsibilities of the Food Preservation working group from the post-harvest processing group, only the technologies that significantly extended the shelf life of the food or crop was considered by the Food Preservation working group. For example, ozone sanitation, submitted to the Food Preservation working group was transferred to Post-Harvest Processing since this sanitization will only extend the shelf life of the fresh vegetables for approximately one week.

4.2.2 Major Activities of the Food Preservation Working Group

- Definition of the Food Preservation working group responsibilities
- Overview of technologies and processes not specifically evaluated in working group
- Evaluating technologies submitted prior to workshop

4.2.3 Assessing TRLs for Commercially Available Technologies

During the workshop, the Food Preservation working group did not develop criteria for determining TRL levels. However, since the workshop, criteria have been developed to use for TRL determination. Each technology is TRL assessed for use on Earth as well as for use on the planetary or lunar surface. The following criteria are being used for TRL levels:

Earth Based Technologies:

- For the conventional technologies that have flown (e.g., retort) and the food has a 3 - 5 year shelf life - TRL 9
- For the conventional technologies that have flown (intermediate moisture) and the food has less than a 3 year shelf life (or the packaging/storage has to be revised) - TRL 6
- For emerging technologies with commercial items available with a 3 - 5 year shelf life - TRL 4 (product still needs to be fit into a package that can be used in microgravity)
- For emerging technologies with commercial items available with a less than 3 year shelf life - TRL3 (package design and extend shelf life)
- For emerging technologies with non-commercial items - TRL 2

Lunar or Planetary Based Technologies

- Conventional Technologies - TRL 3 (needs to be miniaturized and tested, etc.)
- Emerging Technologies - TRL 2

A summary of TRLs and technology gaps can be found in Table 3 in Section 5.

4.2.4 Overview of Technologies

The Food Preservation working group categorized their technologies into three basic areas. The first group, conventional technologies, included preservation technologies that have been established commercially and some have been used in current or earlier space mission food systems. Discussing and/or providing assessments on these technologies provided a baseline so that other technologies could be compared to what has already been established.

The other two classifications of technologies were emerging technologies. Some of these technologies are commercially available for certain foods (e.g., high pressure processing of high acid foods) but the total potential still needs to be determined. The Food Preservation working group separated the emerging technologies into thermal and non-thermal processes.

The Food Preservation group, in addition to the technology assessment forms, developed a very extensive spreadsheet (Appendix B) including many more technologies. Much of the information in the spreadsheet was completed after the workshop. In the case of this spreadsheet, none of the technologies that had been transferred to other working groups were removed.

4.2.5 Evaluation of Submitted Technologies

At the onset of the workshop, there were fifteen technologies and accompanying assessment forms to be addressed. The Food Preservation working group extensively reviewed some of the assessment forms and then spent the remainder of their time filling out the spreadsheet and adding more technologies to the list.

Some of the technologies discussed below are those technologies that were extensively reviewed by the working group. Some of the other technologies are the conventional technologies that were not discussed at the workshop since so much in known about them, such as retorting. However, since it is important to understand these conventional technologies and their attributes these conventional technologies are discussed below.

4.2.5.1 <u>Retort</u>

This conventional technology is used today to render food products incapable of supporting growth of pathogens and spoilage microorganisms and free of enzyme activity. Such processed products are commercially sterile. The technology could be extended to achieve complete sterility, if necessary. Developed food items are filled into cans, retort pouches or jars and then processed with air-overpressure or water-overpressure for specified times and temperatures.

For prepackaged food items manufactured on Earth, the technology exists. Sample items are the Military's meals ready-to-eat (MRE) or heat-and-serve applications found commercially for the consumer market. Package sizes can range from individual to multiple servings. NASA is currently using retort pouch applications for many of the food products used on Shuttle and ISS.

For lunar or planetary evolved base, a scaled-down version of the equipment would be necessary. Thermal process testing of the system in microgravity and hypogravity environments will be needed to validate time/temperature heating parameters. Such a system would allow for preservation of some harvested crops beyond their normal shelf life. Acceptability of the foods after processing would need to be evaluated.

The preservation technology cannot exist without the accompanying packaging equipment for the retort pouches. Hence, the packaging equipment and materials would also need to be available. In addition, replacement parts (e.g., seal jaws) would need to be available as they wear out over time.

4.2.5.2 Hot Fill and Hold

The hot fill and hold conventional technology requires foods to be at a pH less than 4.6 for processing. The temperatures are inadequate for bacterial spore destruction when the foods are low acid (pH $\geq$4.6). The food is hot filled into rigid or flexible packages and held at high temperatures (e.g., 180 ^{o}F – 185^{o}F) in a pasteurizer. The shelf life would be within the range of 1 – 5 years. Liquids and semi-solid foods can utilize this process.

4.2.5.3 Drying

Drying has been used by civilizations for thousands of years. The original drying was completed by air drying the foods outside with the help of the sun and wind. Drying of food products does not inactivate microorganisms. However, by drying the foods, the water activity, the water available for chemical reactions, is reduced to a level that slows down or minimizes microbiological growth, enzymatic activity and biochemical activity. Drying can be used as a hurdle technology. In other words, the drying technology can be used in conjunction with decreased pH, thermal pasteurization and other technologies to further increase the shelf life. If a longer shelf life is desired, the food must be packaged in a high barrier film to minimize the reintroduction of moisture into the food.

While current systems in Earth's atmosphere utilize the application of heat to evaporate moisture from food, the technology may be modified (and possibly made more efficient) if the drying chamber utilized a vacuum (i.e., no atmosphere; venting to a vacuum). Taking advantage of environmental conditions on the lunar or planetary surface to facilitate the drying process could be advantageous.

The following two technologies are specific drying technologies that could be utilized.

4.2.5.3.1 Freeze Drying

During the freeze drying process, the food is frozen and then the ice is sublimated due to the application of heat under vacuum. This drying method maintains the cell structure of food and therefore tends to maintain more of the original taste and aroma of the food. With the proper packaging, these foods will limit microbial growth providing a safe food for an extended period of time (5-20 years). However, flavor, color, and texture will change and the acceptability of the products will decrease prior to the 5-year period of time, especially if the storage temperatures exceed ambient. Freeze dried foods are currently being used on Shuttle and ISS.

4.2.5.3.2 Osmotic Dehydration

Osmotic dehydration is achieved by soaking the food pieces in a lower water activity solution of water and salts and/or sugars. Osmotic pressure causes water to diffuse from the food pieces and into the solution while the humectant takes the place of water in the food. Performance enhancing ingredients such as calcium, and folic acid can be infused into the foods with this technology. The moisture is typically reduced to a moisture of about 15% and a water activity of less than 0.85. Controlled water activity is currently used for starch dishes such as pasta, rice, noodles, some soft bakery goods, and some cooked animal protein products.

This technology is used to dry fruits and is currently being utilized commercially by Kraft Foods for their product "It's Pasta Anytime". Foods dried in this manner are also considered intermediate moisture foods. In addition to the lower water activity using osmotic dehydration, shelf life may also be controlled through pH, application of heat, or other technologies.

4.2.5.4 Membrane Filtration

Membrane filtration, a conventional technology, may be categorized according to the range of particle sizes, determined by molecular weight cutoff (MWCO), retained by the system. There are five general size categories: particle filtration (50-1000 microns), microfiltration (.05-2.0 microns), ultrafiltration (.005-.15 microns), nanofiltration (.005-.05 microns) and reverse osmosis (.002 or less microns). A pressure is applied to drive the filtrate through the membrane while the retentate may be expelled or run indefinitely back over the membrane surface.

For preservation practices, bacteria and yeasts may be separated from a food product through ultrafiltration; however, the membrane itself must be treated regularly to prevent microbial growth. Also, fouling is a major concern in any membrane filtration process.

This technology is currently used in industry for various processing objectives. Examples in industry representing different MWCO's include protein concentration, sugar clarification and water purification.

4.2.5.5 Irradiation

Irradiation was considered by the Food Preservation working group to be an emerging nonthermal technology. Although irradiation has been used for several years, more data needs to be collected. Irradiation involves the use of gamma rays, X-rays or electrons, and uses energy levels that assure no induction of radioactivity in the irradiated product. It retards natural occurring processes such as ripening or senescence of raw fruits and vegetables and is effective to inactivate spoilage and pathogenic microorganisms.

NASA has exclusive authority from the Food and Drug Administration (FDA) to use this technology for sterilization and the product is made under U.S Army R&D collaboration. Irradiation will result in a shelf life of 2 - 5 years. The product must be frozen to achieve stability without major off-flavors. A wide range of products can be used with this technology though currently NASA is using it primarily to preserve meats. Irradiation processing for the lunar or planetary surface may not be feasible for some time due to the weight of shielding needed and requirements for either isotope source or cooling systems for electrical or x-ray irradiation.

4.2.5.6 Ohmic Heating

Ohmic heating, an emerging thermal technology, has the unique advantage that a product containing liquid, solid, or solid-liquid mixtures can, with proper formulation, be heated rapidly with a uniform thermal profile. This ensures significant quality retention in comparison to conventional thermal processing treatments, where heat transfer to the interior dictates process time, resulting in significant quality loss. Ohmic heating will also eliminate bacterial spores. Ohmic heating has the advantage over microwaves, of a more uniform and easily predictable electric field distribution; thus the most minimally processed locations may be identified with greater confidence than microwave or radiofrequency heating. In order for ohmic heating to be successful, the food should possess at least a slight electrical conductivity. Since fats and oils do not conduct electricity, ohmic heating cannot be used specifically for these products.

In transit, ohmic heating could be used to heat the food. The system is lightweight, and requires only an electrical power supply, and food packages that can be accommodated between electrodes. Space requirements are therefore minimal in comparison to most other heating technologies (it has been used for vending and dispensing applications). It is also suited to the available energy sources (electricity) in transit, which can be turned on or off at will. Therefore, this technology can be used for simple heating of foods for consumption. A further use for in-transit ohmic heating would be in sterilization of waste product streams.

Ohmic heating may be well suited for a lunar or planetary surface processing device, due to its simplicity. On the planetary or lunar surface, ohmic heating may be used to create products (e.g. tomato sauce, vegetable purees), which can be sterilized and held for future consumption. This approach may also be useful in sterilizing any excess plant food harvest which cannot be consumed immediately, but may need storage prior to future consumption.

4.2.5.7 High Pressure

High pressure processing (HPP), also known as high hydrostatic pressure (HHP) or ultra high pressure (UHP) processing, is an emerging non-thermal processing technology. The process subjects food products to pressures between 100 and 700+ Mpa. Commercially used for food safety and extended shelf life, as a “cold pasteurization” method, HPP can be a semi-continuous, continuous, or pulsed process. High pressure can kill microorganisms by interrupting their cellular function without the use of heat that can damage the taste, texture, and nutritional value of the food. The "mechanism" of high-pressure based bacteria kill is low energy and does not appear to promote the formation of new chemical compounds, "radiolytic" by-products, or free-radicals. Since covalent atomic bonds are not broken by HPP, vitamins, and flavor are basically unchanged. Texture frequently can also be retained but will depend on the initial structure. For example, the texture of high air content foods will likely be changed by HPP.

Current HPP development is attempting to extend its application to the production of high quality shelf stable low acid foods. When combined with a moderate starting (pre-compression) temperatures of 70 to 95^{o}C, all spoilage and pathogenic spores appear to be destroyed with very short (less than 1 to 2 minutes) HPP-enhanced thermal treatment. These short treatment times combined with the quality stabilizing effects of pressure, result in minimal thermal damage to heat sensitive foods. In addition, under these conditions, it is likely that all viruses and even prions might be inactivated.

Factors which are likely important to HPP are process pressure, process temperature (-20^{o}C to 121^{o}C), water activity, and pH. HPP can be considered a hurdle process where the presence of additional microorganism compromising agent or condition, can typically result in synergistic inactivation effects.

The types of foods to be subjected to this technology would need to be investigated, as optimum products should be formulated to take advantage of HPP characteristics. For example, the ability of HPP to induce better water binding may be utilized to make enhanced gels and prevent water separation during storage. High fat containing foods can increase the adiabatic heating, which may or may not improve process effectiveness. Cellular wall damage can result in softening in fruits and vegetables resulting in a loss of apparent freshness but may be compensated by formulation. Protein denaturation can result in product color and appearance changes and may limit the usefulness of HPP treatment pressures above 200 to 300 Mpa for raw protein products such as uncooked meats.

Although a growing application, HPP still at this time has limited experience in the food industry. Process costs are related to operating pressure, hold time at pressure, and operating costs for maintenance, power, and labor. Current production cost appears to justify the production of higher quality value added products. The capital cost of high-pressure equipment increases with increasing operating pressure.

4.2.5.8 Induction Heating

Inductive heating, an emerging thermal technology, may be differentiated from ohmic heating in that the heating element does not come in contact with the food product or surface that is in contact with the food product. In inductive heating, electric coils placed near the food product generate oscillating electromagnetic fields that send electric currents through the food. Additionally, use of flowing food material may be used as the secondary coil of a transformer. Advantages of induction heating include rapid heating and high energy efficiency.

4.2.5.9 Pulsed Electric Field

High voltage pulsed electric field (PEF) treatment, an emerging non-thermal technology, is a potential technology to replace or partially substitute thermal processes. Microorganisms in foods can be inactivated with pulsed electric fields at ambient or refrigerated temperatures for a short treatment time of less than a second. Due to the lower temperatures and short process time, the fresh-like quality of food is preserved.

Pulsed electric field treatment creates a disparity of charges across cell membranes resulting in eventual bacterial membrane leakage and rupture. The properties of the system and the food product will influence the efficacy of the treatment. Some treatment variables influencing antimicrobial effects are electric field strength, number of pulses, duration of pulses and pulse wave shape. Some product variables influencing antimicrobial effects are food ionic and dielectric strengths. Concurrent thermal treatment may act synergistically with PEF as the critical potential for membrane breakdown decreases as temperature increases.

The advantage of PEF technology is its non-thermal treatment of foods and the resulting benefits. A disadvantage is the difficulty in treating non-homogeneous food materials. Dielectric differences between phases may hamper electric conductivity resulting in loss of antimicrobial effect.

4.2.5.10 Ultrasound

Ultrasound, an emerging non-thermal technology, utilizes the energy generated by sound waves of 20,000 or more vibrations per second. The ultrasonic shock waves disrupt cellular structural and functional components to a point of cell lysis.

Presently, most developments of ultrasonics for food applications are for evaluating internal properties of food rather than for antimicrobial purposes. Scale-up from laboratory to industrial food processing presents challenges for application of ultrasonics. There appears to be potential for use of ultrasonics in combination with other preservation processes.

4.2.5.11 Ultraviolet Light

Ultraviolet (UV) processing, an emerging non-thermal technology, involves using radiation with wavelengths ranging from 315-400nm (UVA), 280-315nm (UVB), 200-280nm (UVC), and in some instances 100-200nm (vacuum UV). The antimicrobial effects are mainly due to DNA damage; crosslinking between neighboring pyrimidines prevents DNA transcription.

There has been experimental work performed using UV radiation on food containers, food surfaces and liquids and the FDA is considering allowing UVC to be used to eliminate pathogens from fruit juices. The success of UV application depends on the material surfaces being clean and free from any dirt, which would absorb the radiation and hence protect the bacteria. To achieve microbial inactivation, the UV exposure must reach at least 400 J/m^2 in all parts of the product.

4.2.5.12 Light Pulse

Pulsed light sterilization, an emerging non-thermal technology, can use broad spectrum (170-2600nm) or UV only (200-400nm) wavelengths. Currently this technology is being used most often to sterilize food packaging materials. The major mechanism of inactivation is derived from the difference in cooling rates of the organism and its surrounding environment or support surface. The incremental increase in absorbed energy by the microorganism leads to overheating and eventual membrane rupture. The germicidal effect, caused by DNA damage, of UVC radiation (200-280nm) can be considered a component but is considered unnecessary if the temperature rise of a single light pulse exceeds the rate of cooling between pulses.

Advantages of using this sterilization method for packaging include:

- Minimal thermal stress for PVC or other plastics used
- Sterilization takes a fraction of a second
- Hazards associated with UVC can be eliminated
- Reduction or elimination of chemical disinfectants and preservatives

This method may also be used for pasteurization of select clear liquid of food products. However, the effects are limited by the ability of the food surface to absorb the pulsed light and the possible detrimental effects on product sensory attributes.

4.2.5.13 Arc Discharge

High voltage arc discharge, an emerging non-thermal technology, is a method to pasteurize liquid foods by applying rapid discharge voltages through an electrode gap below the surface of aqueous suspensions of microorganisms. This method inactivates microorganisms and enzymes. When rapid high voltages are applied to these liquids, molecules are ionized resulting in the generation of toxic substances (oxygen radicals and other oxidizing compounds), which inactivate the microorganisms. Enzymes are also inactivated by high voltage arc discharges. Inactivation is attributed to oxidation reactions mediated by free radicals and atomic oxygen. There is no significant temperature increase during treatment by arc discharge.

Unfortunately, the electrolysis can result in breakdown of food components leading to unknown types and concentrations of chemical contaminants. Inactivation of microorganisms has been attributed to oxidation reactions mediated by free radicals and atomic oxygen. The free radicals serve to inactivate certain intracellular components required for cellular metabolism. The major drawbacks of this electrical method, however, are contamination of the treated food by chemical products of electrolysis and disintegration of food particles by shock waves.

4.2.5.14 Oscillating Magnetic Fields

Oscillating magnetic field (OMF), an emerging non-thermal technology, is applied in the form of constant amplitude or decaying amplitude sinusoidal waves. The magnetic field may be either homogeneous, where the field intensity is uniform throughout the area enclosed by a magnetic coil, or heterogeneous, where the field intensity decreases as the distance from the center of the magnetic coil increases. This technology is still being researched as inconsistent results of microbial inactivation studies make it impossible to clearly state the effects of magnetic fields on microbial populations.

Multiple hypotheses have been presented regarding the mechanism of microbial inactivation. A weak OMF could weaken bonds between ions and proteins used in metabolism and membrane integrity. Covalent bonds within deoxyribose nucleic acid (DNA) may be disrupted leading to loss of growth ability. In any case, the mechanism(s) of inactivation and any resistant pathogens need identification.

4.3 Post-Harvest Processing

4.3.1 Introduction

The Post-Harvest Processing (PHP) working group identified and assessed technologies that would manufacture palatable food ingredients and/or finished products from raw crops on the lunar or planetary surface. Ingredients would include products not generally consumed directly but used in other product formulations, such as flour, sugar, or concentrates. Finished products, such as tofu and bread, may be eaten directly or used in other product formulations or recipes. Each processing technology must provide a food that is acceptable, nutritious and safe. The technologies considered were limited to those that could utilize the raw crops listed as possible candidates by the biomass production system (BPS). In the technology assessments, characteristics of these crops were assumed to be optimum for use with the particular technology.

The PHP working group identified possible technologies by considering whether the processing capabilities existed in commercial equipment or in an existing prototype. Within technologies, the required unit operations or processes, i.e., size adjustment, heat treatment, fermentation, etc., were identified. Additionally, support technologies or processes that would assist in the implementation of the technology were discussed.

Occasionally, logistics behind the use of the technology were discussed. Logistics would include whether the product manufacture would be “just in time” or if large quantities of product were to be processed and stored for later use. On more than one occasion, multi-use capabilities of a technology were discussed. Multi-use included employing an entire technology or a component of that technology for other purposes.

4.3.2 Major Activities of the PHP Working Group

- Definition of the PHP working group responsibilities
- Assessing TRL for commercially available technologies
- Overview of technologies and processes not specifically evaluated in working group
- Evaluating technologies submitted prior to workshop

4.3.3 Assessing TRLs for Commercially Available Technologies

Interpretation of the TRL rating system was needed to proceed with assessing the various technologies. Many commercial technologies exist that perform the various operations required to perform the PHP needs. Many of the technologies submitted before the workshop exist only in the food industry for processing large quantities of food in a short period of time. However, these commercial technologies would be considered impractical for validation in a laboratory or test-bed environment. It was agreed that some level of modification would need to take place before validation could take place.

A set of criteria were developed that would provide consistent TRL determinations on each of the processes. If a single unit commercial equipment existed that could perform all of the required unit operations to produce an ingredient or food product, a TRL of 3 was assessed. This was considered to be an appropriate rating since the existing commercial equipment satisfied the proof-of-concept criteria for a TRL 3 rating. If only the individual components (not combined within a single unit) of a technology existed commercially then a TRL of 2 was assessed.

A summary of TRLs and technology gaps can be found in Table 3 in Section 5.

4.3.4 Overview of Technologies

While the PHP workgroup was successful in evaluating seven different technologies, there was insufficient time to fill out forms for every technology determined to be relevant to PHP. Therefore, a list of food related unit operations/processes and technologies or specific equipment associated with those processes, as well as what type of mission and comments regarding the use of such a technology, was developed. These operations/processes are shown in Table 2. The processes in bold were discussed in more detail by the PHP working group.

Table 2. Post-harvest Processing Unit Operations, technologies, related mission and comments regarding use. Technologies in bold were evaluated within the workgroup.

Single Food Unit Operations and Processes	**Technologies/Specific Equipment**	**Mission** Transport Vehicle (TV), Surface Habitat (SH) or Evolved Base (EB)	**Comments**
Separation	Centrifuge	SH, EB	Solid/liquid separation
Separation	Solvent-based extractor	EB	Oil extraction
Separation	Screens & Sieves	SH, EB	Solid/solid separation
Separation	Press	EB	Oil extraction
Separation	Ultrafiltration/reverse osmosis	SH, EB	Juices and concentrates
Size adjustment	Food processor	TV, SH, EB	Chopping, dicing, slicing, shredding
Size adjustment	Peeler	SH, EB	Peeling
Size adjustment	Homogenizer	SH, EB	Homogenization
Size adjustment	**Extruder**	SH, EB	Extrusion, mixing, pumping
Heat Transfer	Combo convection/microwave oven	TV, SH, EB	Transfer vehicle - for stored food only Cooking, frying and roasting
Heat transfer	Blancher	SH, EB	Stabilization
Heat transfer	Refrigerator	TV, SH, EB	Cooling
Heat transfer	Drier	SH, EB	Used to dry grain or pods, milled materials
Heat transfer	Freezer	TV, SH, EB	Used for processing such as making frozen dried tofu - a meat analog
Heat transfer	Retort (Pressure cooker)	SH, EB	Stabilization
Heat transfer	Heater/warmer (stove top)	TV, SH, EB	Transfer vehicle - for stored food only
Heat transfer	Controlled environment chamber	SH, EB	Humidity, temperature, gases, pressure, light exclusion, irradiation
Mass transfer	Conveyor; auger	SH, EB	
Mixing	Multipurpose mixer	SH, EB	Blending and kneading

Single Food Unit Operations and Processes	**Technologies/Specific Equipment**	**Mission** Transport Vehicle (TV), Surface Habitat (SH) or Evolved Base (EB)	**Comments**
Fluid flow	Pumps	SH, EB	
Fluid flow containment	Tanks, vessels, pots	TV, SH, EB	For soaking, cooking, reacting, treating, holding
Controlled environment storage	Modified atmosphere packaging	TV, SH, EB	
Chemical treatment	Hydrogenator	EB	Oils
Chemical treatment	Coagulation	EB	Tofu
Biological treatment	**Fermentor/Bioreactor**	SH, EB	Syrups from starch-rich components: sweet potato, white potato & wheat. Tempeh and mushroom production
Biological treatment	Incubator	EB	Fermentation, bioreactor, tempeh & mushroom production
Combination Food Unit Operations and Processes			
Size adjustment and heat transfer	**Fruit and Vegetable Processor**	SH, EB	Juice and concentrates (purees and sauces)
Size adjustment and separation	**General Purpose Mill**	SH, EB	Flours, powders, size reduction; example - Satake for rice products
Size adjustment, separation, and heat transfer	**Soymilk, Tofu, Okara, Whey Processor (STOW)**	SH, EB	Soymilk, tofu, okara, whey
Heat transfer	**Low Temperature Controlled Atmosphere System**	SH, EB	Refrigerator/freezer, controlled atmosphere & environment

Single Food Unit Operations and Processes	**Technologies/Specific Equipment**	**Mission** Transport Vehicle (TV), Surface Habitat (SH) or Evolved Base (EB)	**Comments**
Heat transfer	Freeze drier	SH, EB	Freeze drying using planetary atmosphere
Mixing and heat transfer	**Breadmaker**	SH, EB	Bread, pasta and jam

4.3.5 Evaluation of Submitted Technologies

There were nine technologies and accompanying assessment forms submitted prior to the workshop. There was consolidation of some of these technologies as multiple copies of one technology (i.e., extrusion) were submitted. The breadmaker and fermentor/bioreactor technologies, not submitted prior to the workshop, were added at the workshop. In total, seven technologies were evaluated. All of the evaluated technologies were believed to be appropriate for lunar or planetary evolved base use. Each of these technologies will require HACCP procedures to be developed to insure the safety and quality of the food and/or ingredients.

4.3.5.1 Fermentor/Bioreactor

A generalized chamber for the implementation of biological (microbial and enzymatic) reactions would allow for the production of many products from a relatively small amount of reactant. This technology would rapidly produce desired products, require little crew involvement time, produce little solid waste, and demand low levels of consumable material. However, the introduction of microbes into an enclosed environment presents obstacles to this technology's implementation. If suitably developed, however, this technology could theoretically be used in a lunar or planetary evolved base.

Enzymatic conversion of starch to more simple sugars would provide a valuable ingredient for use in other product formulations. This ability would greatly reduce the amount of consumable sugar transported and the associated storage problems (i.e., Maillard reaction, glass transitions) associated with sugars. Advancement in microbiological functionality in food component production has led to an ability to create almost any food ingredient from nutrient feeds. The production of a bioreactor may have lasting benefits, as microbiological conversion technologies/processes become more commonplace in the food industry.

4.3.5.2 Soymilk, Tofu, Okara, and Whey Processor (STOW)

The STOW prototype is currently being evaluated at the JSC for use in a lunar or planetary evolved base. This technology converts raw soybeans into soymilk, tofu, okara and whey. Soymilk and tofu may then be used as end products or as ingredients for other product formulations. Okara and whey are generally not consumed as end products and research is now being conducted to use them in other product formulations. Advantages of this equipment include high automation for decreased crew involvement time while maintaining manual control capability and production of multiple food ingredients from one piece of equipment. One disadvantage to the STOW would be the possibility of high solid waste generation.

The STOW is considered a first generation prototype continually being evaluated and redesigned to optimize performance as well as lower size/weight requirements, power consumption, waste generation and water use.

Being the first existing piece of NASA food processing equipment to be evaluated in a laboratory environment, there is great interest in developing further capabilities for this unit. As research continues, abilities may be added or removed. Also, the development history of the STOW may be used to identify appropriate development procedures for future technologies within this group.

4.3.5.3 Breadmaker

Today, commercially available bread-making units exist with the ability to produce many types of bread, pasta and jam. One such unit (Breadman TR3000) integrates a touch-screen liquid crystal display (LCD) for process control. These commercial units are relatively lightweight and easy to clean. Three commercial units evaluated at NASA/JSC use a paddle design for mixing and kneading. All breadmaker technologies emit volatiles that may impact air recirculation systems.

Questions regarding the feasibility of this design concept in a hypogravity environment, as well as the durability of existing commercial units, have initiated research at NASA/JSC to investigate the use of another design concept. A Swedish group has developed an alternative design concept that uses a novel mixing/kneading design. This group has provided a prototype for evaluation within the food processing system development facility (FPSDF) at NASA/JSC. This unit is called the "Bready" and is controlled via a computer interface or through direct operation on the unit.

ESM comparisons of the commercial units and the Bready can be made. Determination of power usage, crew time, consumables, etc can be used in the comparison.

4.3.5.4 Extruder

Extrusion is a flexible, continuous, rapid, highly automated and low gravity dependent technology, which converts food ingredients into a wide variety of finished products. It works by forcing semisoft materials through a specially shaped mold or nozzle using a ram/piston or screw (single or twin) thereby subjecting the food to a high shear and pressure environment. Heating or cooking may be concurrent. Cooking is extremely rapid as extrusion inputs both mechanical and thermal energy into the product. Extrusion can create a wide variety of products including expanded snack products, dry breads, pasta, confectionary, and vegetable protein meat analogs.

There are advantages and disadvantages in using extrusion for a surface habitat or evolved base. The advantages include versatility in the types of food produced, high productivity within a relatively short amount of time and energy efficiency. Some disadvantages include the possibility of high solid waste generation and reduction in ingredient stores if there is difficulty in achieving a steady state. This may be attributed to lack of operator competence or ingredient variability.

Commercial extruders are made from heavy metals or alloys and require significant amounts of power to operate. Smaller, more lightweight version of an extruder needs to be developed for NASA use.

4.3.5.5 General Purpose Mill

A grinder or mill would convert grains into flours. Commercially, separate milling equipment exists for processing wheat grains or rice. As both crops are considered viable for a lunar or planetary evolved base, there is a need for a single unit grinder. The type of grinding mechanism can vary in milling equipment and decisions regarding this need to be made.

Mill operation can be relatively easy and this equipment can manufacture a consistent product. However, with grain milling, there is a tendency for dust development. This dust may not only be a nuisance to those in an enclosed environment but may also be extremely hazardous, as grain dust has been known to be extremely flammable.

Questions regarding logistics of flour production also need to be answered. A major concern is whether or not production will be "just in time" or if large quantities of grain will be processed and the resulting flours stored for later use.

4.3.5.6 Fruit and Vegetable Processor

A processor to convert fruits and vegetables into juices, concentrates and other products does not currently exist as a single unit. However, the individual units such as a slicing/dicing section for overall product size adjustment as well as fluid separation, a filtration section (ultra or reverse osmosis), and a concentration section (heat transfer evaporator) do exist. Research is needed to combine the existing individual components into a single unit.

4.3.5.7 Low Temperature-Controlled Atmosphere System

The low temperature-controlled atmosphere system (LTCAS) is a crosscutting technology that could be used for both post-harvest processing as well as storage of raw crops, processed ingredients and food products. This technology could be used on a transport vehicle as well as a lunar or planetary evolved base. This technology may contain multiple storage environments within one unit to process different types of products at the same time. LTCAS could be used in a post-harvest processing capacity to perform quick ripening and other chemical modifications to ingredients before use in other production processes.

The Maytag ClimateZone™ Technology, with its capability of individual temperature controlled storage environments, can extend the storage life of produce by setting the ideal temperature for the produce to slow ethylene production and ripening which lead to produce spoilage. Cold air is pumped through multiple chambers surrounding the storage drawers rather than directly on the produce to prevent air from drying produce.

4.3.5.8 Ozone Sanitation of Salad Crops

Ozone can be generated by small, relatively light weight ozone generators. An electrical current is required to power the ozone generator. The ozone produced is bubbled through water to produce ozonated water, which can be used to sanitize salad crops. From a more practical standpoint, fresh produce can be immersed in a container of water that has an inlet tube connected to an ozone generator. The container is then tightly sealed and ozone can be bubbled through the water for a few minutes to sanitize the produce.

Ozone has a far broader antimicrobial spectrum than chlorine and is capable of destroying spoilage and pathogenic microorganisms on fresh produce without leaving any chemical residues. Hydrogen peroxide solution concentrations of 0.5 to 2 ppm are effective against pathogens in clean water with no soil or organic matter. In practice, even concentrations of 10 ppm are difficult to obtain and concentrations of 5 ppm or less are more common. A unique characteristic of ozone is that it decomposes to form pure oxygen.

There are some hazards associated with ozone sanitation. There have been reports that ozone may induce resistance to subsequent fungal attacks in some horticultural products. Because of its strong oxidizing potential, ozone is toxic to humans and must be generated on-site. Prolonged exposure to more than 4 ppm ozone in air can be lethal. Ozone volatiles have a pungent odor that can be detected by humans at 0.01 to 0.04 ppm. Occupational Safety and Health Administration (OSHA) has set worker safety limits in air of 0.1 ppm exposure over an 8 hour period and 0.3 ppm over a 15 minute period. At concentrations in water above 1 ppm, off-gassing can result in concentrations in the air that exceed OSHA limits of 0.1 ppm.

Since water is a precious commodity in space environments, the ozonated wash water can be reused for sanitizing more fresh produce and thus reduce water usage. Ozone decomposes quickly in water with a half-life of 15 to 20 minutes in clean water but less than a minute in containing suspended soil particles and organic matter.

5 CONCLUSIONS

Many of the technologies assessed have potential to aid the Advanced Food System in reaching its objectives. Several food packaging technologies have improved barrier properties while having decreased mass. Some technologies could be reusable and others would incinerate more efficiently. The major technology gap in the food packaging area is that these technologies have not all been tested for use with some of the thermal and non-thermal preservation processes.

There are several food preservation methods that are emerging and have not been tested with a large variety of foods. However, many have the potential to provide highly acceptable and nutritious food items with a 3 – 5 year shelf life. It is very possible that several different food preservation methods will be utilized for the future transit food system.

Several post-harvest processes are available. The major technology gap is that most of the technologies need to be miniaturized. Prior to final determination of post-harvest processing technologies crops, crop yields and the final menu needed to provide the crew with a nutritious menu must be determined.

A list of each of the technologies, the TRL levels, and the identified technology gaps are in Table 3. The workshop did not assess all the possible technologies. Based on the limited time and that new technologies continue to emerge, further assessments will be needed. The requirements of a NASA Advanced Food System are unique. For that reason, it is recommended that “thinking outside the box” be a priority during the development of the Advanced Food System.

Table 3: Summary of assessed technologies

Working Group	Technology	TRL*	Identified Technology Gaps to reach TRL 5
Food Packaging	Retort Pouch	9	• N/A
Food Packaging	High barrier packaging materials for intermediate shelf life foods	6	• Effect of elevated temperature and increased oxygen and possibly energy input of low dose radiation on shelf life.
Food Packaging	Bulk Packaging for dry flowables	6	• N/A
Food Packaging	Liquid crystal polymers	5	• Since cost is not the major concern further research should be conducted to optimize the barrier properties of the structures containing LCPs. • The investigation on multi-use food containers for packaging products grown and processed in space.
Food Packaging	Passive MAP of fresh salads	5	• To determine whether the extra 7 days of shelf life is worth the effort for passive MAP.
Food Packaging	Ultra-high oxygen barrier film based on oxygen scavenging	3	• Test technology for preservation methods such as thermally processed and microwave processed foods • Determine whether there are any off-gassing issues
Food Packaging	AEGIS ™ Nanocomposite Barrier Resins	3	• Validation of manufacturer's claims and specific application trials. • Assessment of product quality and shelf life of food packaged in multiplayer film incorporating nanolayers.
Food Packaging	Triton Nanocomposites	2	• Full scale production and evaluation of multiplayer film incorporating nanolayers • Assessment of product quality and shelf life of food packaged in multiplayer film incorporating nanolayers.

Working Group	Technology	TRL*	Identified Technology Gaps to reach TRL 5
Food Packaging	AMCOR PET with Oxygen Scavenger	3	• Validation of manufacturer's claims and specific application trials. • Assessment of product quality and shelf life of food packaged in multiplayer film incorporating nanolayers.
Food Packaging	Odor absorbent packaging	2	• Selective removal of off-flavor compounds and improve the flavor quality of foods has not been tested
Food Preservation	Retort – thermal	9	• N/A
Food Preservation	Hot Fill and Hold – thermal	9	• N/A
Food Preservation	Drying – thermal	6	• N/A
Food Preservation	Freeze Drying – non-thermal	6	• N/A
Food Preservation	Osmotic Dehydration – non-thermal	6	• N/A
Food Preservation	Membrane Filtration – non-thermal	6	• N/A
Food Preservation	Irradiation – non-thermal	4	• The recommended dose, for many food products, is under revision. Processing criteria are still under development with limited food product approvals • X-rays have not been commercialized as extensively as gamma irradiation or ebeams
Food Preservation	Ohmic Heating – thermal	4	• Develop proof-of-concept and refine to optimization
Food Preservation	High Pressure – non-thermal	4	• Additional research into the inactivation kinetics and inactivation mechanisms of bacteria and bacteria spores to better understand this technology and enable regulatory rule making • Research into product formulation to optimize • Additional developments into equipment integration into food production lines
Food Preservation	Induction Heating – thermal	2	• Develop proof-of-concept and refine to optimization

Working Group	Technology	TRL*	Identified Technology Gaps to reach TRL 5
Food Preservation	Pulsed Electric Field – non-thermal	2	• Determine which formulations of foods can effectively use this technology • Develop proof-of-concept and refine to optimization
Food Preservation	Ultrasound – non-thermal	2	• Scale-up from laboratory to industrial food processing • Additional research into the inactivation kinetics and inactivation mechanisms of bacteria and bacteria spores
Food Preservation	Ultraviolet Light – non-thermal	2	• Additional research into the inactivation kinetics and inactivation mechanisms of bacteria and bacteria spores
Food Preservation	Light Pulse – non-thermal	2	• Develop proof-of-concept and refine to optimization
Food Preservation	Arc Discharge – non-thermal	1	• Develop proof-of-concept and refine to optimization • Determine which formulations of foods will not result in chemical reactions that create contamination
Food Preservation	Oscillating Magnetic Fields – non-thermal	1	• Additional research into the inactivation kinetics and inactivation mechanisms of bacteria and bacteria spores • Develop proof-of-concept and refine to optimization
Post-Harvest Processing	Fermentor/Bioreactor	4	• Creation of unit for evaluation within laboratory environment • Use of technology to convert relevant biomass production system (BPS) generated crops into useful food products or ingredients
Post-Harvest Processing	STOW	4	• Complete evaluation in laboratory environment
Post-Harvest Processing	Breadmaker	4	• Complete evaluation in laboratory environment
Post-Harvest Processing	Extruder	3	• Reduction in size and weight through prototype development for validation within a laboratory environment. • Assessment of product quality using relevant crops developed by biomass production system (BPS).

Working Group	**Technology**	**TRL***	**Identified Technology Gaps to reach TRL 5**
Post-Harvest Processing	General Purpose Mill	3	• Manufacture of a mill able to process both wheat and rice. • Validation within a laboratory environment
Post-Harvest Processing	Fruit and Vegetable Processor	2	• Combination of individual components into a single unit • Evaluation of single unit in a laboratory environment
Post-Harvest Processing	Low Temperature-Controlled Atmosphere System	2	• Creation of unit able to perform all of the desired processes • Evaluate in laboratory environment
Post-Harvest Processing	Ozone Sanitation of Salad Crops	2	• Validation within a laboratory environment • Determine safety of process

* Stated TRL is Earth-based for Food Packaging and Food Preservation and Planetary-based for Post-Harvest Processing.

6 FUTURE DIRECTIONS

6.1 Evaluation of the Overall Advanced Food System

In order to complete the assessment initiated with the workshop, two more activities must be completed; 1) integrate the three working groups and 2) determine the ESM of the entire food system.

6.1.1 Integration of the three working groups

The objective of this workshop was to begin to assess potential food preservation, food packaging and post-harvest processing technologies for the ALS Advanced Food System. Due to the organization of the workshop and the time limitation, the assessment of each technology was performed independently of other technologies. For example, each packaging technology was assessed independent of food preservation technologies or the foods it could be used for. It became clear during the group discussions at the end of each workshop day that even within the Advanced Food System, food packaging, food preservation, and crop processing areas must be integrated to obtain a true assessment of a technology. Figure 1 indicates that there is a commonality between each of the working groups. Hence, the assessment of the separate technologies is only the first step to a total evaluation of the food system. There must be the opportunity to integrate these "subsystems" within the Advanced Food Systems prior to the development of a final food system.

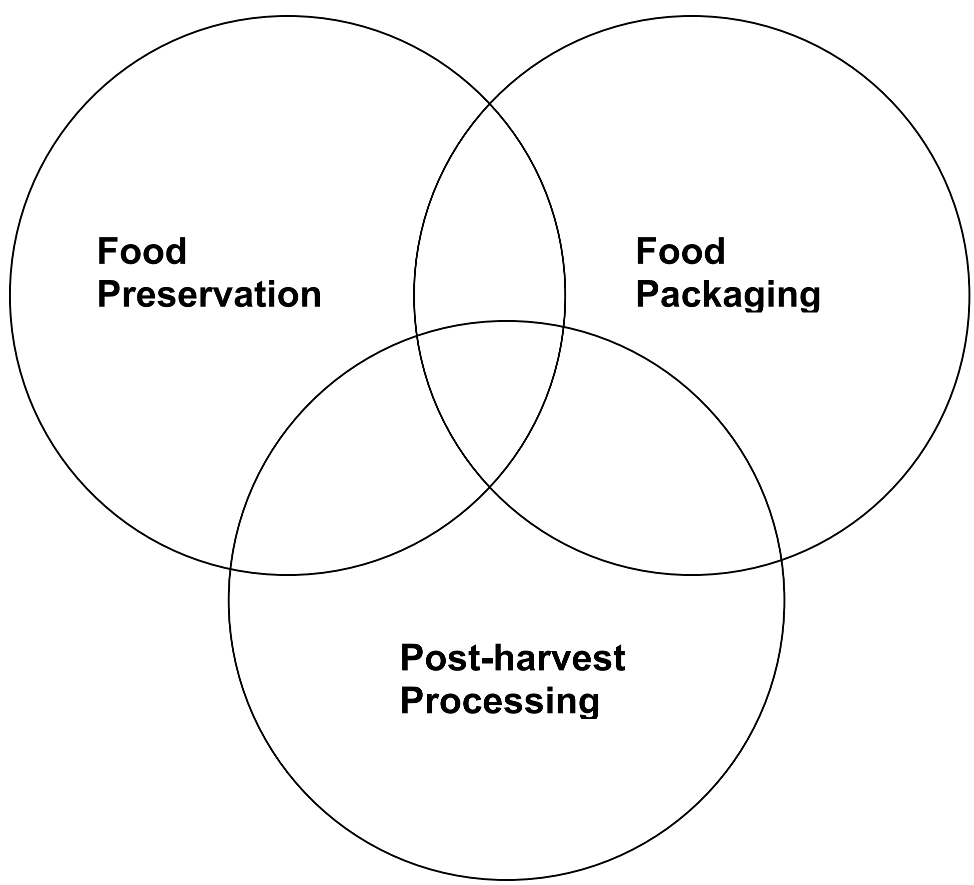

Figure 1: There is an overlap between each of the working groups.

6.1.2 ESM determination of total system impact

ESM has been used at NASA as an analysis tool to provide comparisons between technologies. Assessing a technology and determining the ESM of a single technology, although worthwhile, may be just a beginning since the technologies are not independent of one another. It is possible that the ESM of a combination of technologies involving food preservation, food packaging, and/or post-harvest processing technologies may need to be integrated into one ESM measurement for a total system impact. Furthermore, in order to utilize all the crops, provide the crew with the correct nutrition, and provide the crew with a menu that incorporates variety and highly acceptable foods, several different food preservation methods and post-harvest processing technologies will be required. Therefore, it will not be useful to trade between two technologies unless the results are similar food ingredients. For example, two technologies that produce tofu can be traded but a technology that produces tofu and another technology that produces bread should not be traded since both food items may be needed to attain the nutrition and variety in the menu.

In addition to the ESM calculation, variety, nutrition, acceptability, and other qualitative factors need to be accounted for in determining which technologies should be chosen for an Advanced Food System. A proposed model, Food Metric Value, allows for these attributes and may be used to aid in the technology assessments (Cruthirds 2002). The use of this model has been limited due to the lack of qualitative data. However, as the data becomes available, the use of the Food Metric Value will be very helpful in the final assessment of food system technologies.

6.2 Integrate Between Other Life Support Systems

In addition to integration within the Advanced Food System, integration must also occur between each of the other life support system, including solid waste management, air revitalization, water recovery, thermal, biomass production, habitability etc. (Figure 2). Each technology or combination of technologies should be evaluated in terms of how the technology will affect these other systems as well as what the technologies may require from these other life support systems. It is possible that a technology that ranks very high within the Advanced Food System may adversely affect the other systems such that it is an unacceptable technology for use in a long duration space mission. Similarly, a technology that is very acceptable to one life support system may adversely affect the Advanced Food System. For example, an increase in oxygen partial pressure may decrease the shelf life of a food by increasing the rate of oxidation within the food.

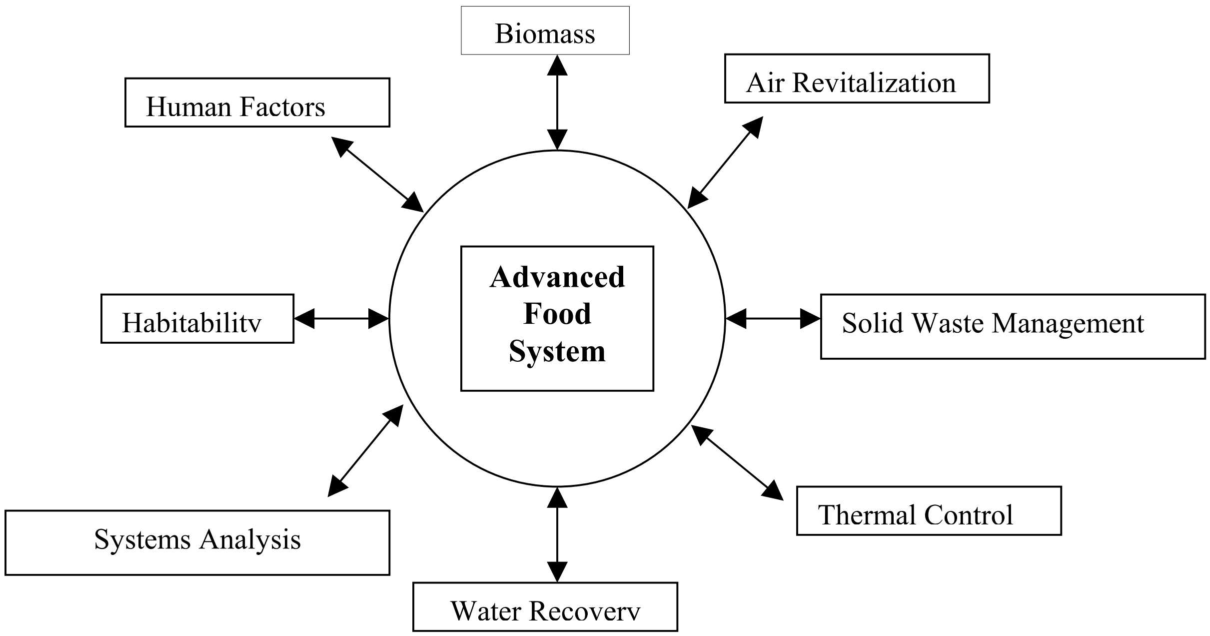

Figure 2: Integration between all ALS elements is very important when developing an Advanced Food System

6.3 Research Priorities

Although this document is a report summarizing the results from the Advanced Food Technology Workshop, it will not only be used in that manner. As these technologies are further developed or new technologies emerge, this document will be updated. The information in this document will be reviewed bi-annually to determine whether there is adequate new information for a document revision. The intent is to have a dynamic document that the research community can use to identify technology gaps that they can contribute towards solving.

The results from the Advanced Food Technology Workshop will be integrated into a long term plan for development of the Advanced Food System. The first step to developing the Advanced Food System Strategic Plan is the Advanced Food System Roadmap, which is in development and should be available on the Advanced Life Support website (www.advlifesupport.jsc.nasa.gov) by June 2003.

This workshop identified many technology gaps. Each technology that is developed for the Advanced Food System must provide the required attributes to the food system, including safety, nutrition, and acceptability. It is anticipated that the duration of the exploration class missions can be at least 2.5 years. One of the biggest challenges for these missions will be to provide acceptable food with a shelf life of 3 – 5 years. Shelf life can be defined as the time when a product no longer maintains its safety, quality, or adequate nutritional content.

The acceptability of the food system is of much higher importance in a long duration space mission. A large variety of food items are recommended to provide the crew choices and to avoid menu fatigue. Highly acceptable foods can play a primary role in reducing the stress of prolonged space missions.

In an attempt to determine how to organize research priorities, Figure 3 was developed to determine which areas of research would result in the biggest effect. In general, as the mission progresses from a transit mission to a mission with a planetary or lunar habitat, the food system technologies will progress from the base of the pyramid to the tip of the pyramid. Although the use of the prepackaged food system will be used less as the crops and post-harvest processing is initiated on the surface habitat, it is expected that some prepackaged food items will still be used throughout the mission. There are three parts to the pyramid.

- Prepackaged stored food system
- Salad Crops
- Baseline crops

6.3.1 Prepackaged stored food system

At the base of the pyramid is the prepackaged food system. This food system will be utilized in the transit vehicle and will be the initial food system on the planetary or lunar base. The prepackaged food system will use the results from both the food preservation and food packaging working groups. The majority of the food items in the stored food system will be prepackaged foods that will resemble products currently used on Shuttle and ISS. Packaging materials with high barrier properties to ensure a longer shelf life will be very important for the stored food system. It will need to be compatible with the processing and storage conditions, volume and mass constraints and create minimal solid waste. Packaging materials that are biodegradable, reusable, or edible will be evaluated for use in the stored food system.

In addition to the preservation methods currently used for the Shuttle and ISS, additional emerging thermal and non-thermal preservation technologies will be evaluated. These technologies may provide higher quality and better nutritional retention than the current methods. The challenge facing NASA is that most commercial shelf-stable, packaged foods have a shelf life of less than one year with the exception of canned food items deeming it necessary for NASA to initiate much of the development of these stored food items. Whatever technology that is used, product development, an area not addressed during the workshop, will be an integral part of the prepackaged food system. The variety, nutrition, acceptability, and shelf life of the food will depend significantly on its formulation.

6.3.1 Minimally processed salad crops

The next level of the pyramid includes the vegetable crops or minimally processed crops. It is possible that these crops could be grown on the transit vehicle and will likely be the first crops grown on the planetary or lunar surface. Hence, research and technology development on these items, which include technologies from the food packaging and post-harvest processing working groups, would provide the next largest effect. Since these foods may not include any processing which would kill any microorganisms and inactivate enzymes, it is necessary to develop handling procedures that will insure the safety of the crew and the quality of the products. In addition, if the crops are not used immediately after harvest, storage conditions will need to be determined. Although the minimally processed crops may not provide a significant amount of the nutrition, they will provide a psychological benefit by providing bright colors, crunchy textures, and fresh aromas.

6.3.3 Baseline crops post-harvest processing

Finally, the baseline crop processing is at the top of the pyramid. This portion of the pyramid is the most technically challenging and will take the most resources. There are at least seven crops and each of the crops may require more than one post-harvest process to provide the required variety. Once the menu or menu items are determined, then the necessary technologies can be identified. Although the baseline crop processing will incorporate all three workshop working groups, the post-harvest processing technologies will take priority in developing the technologies.

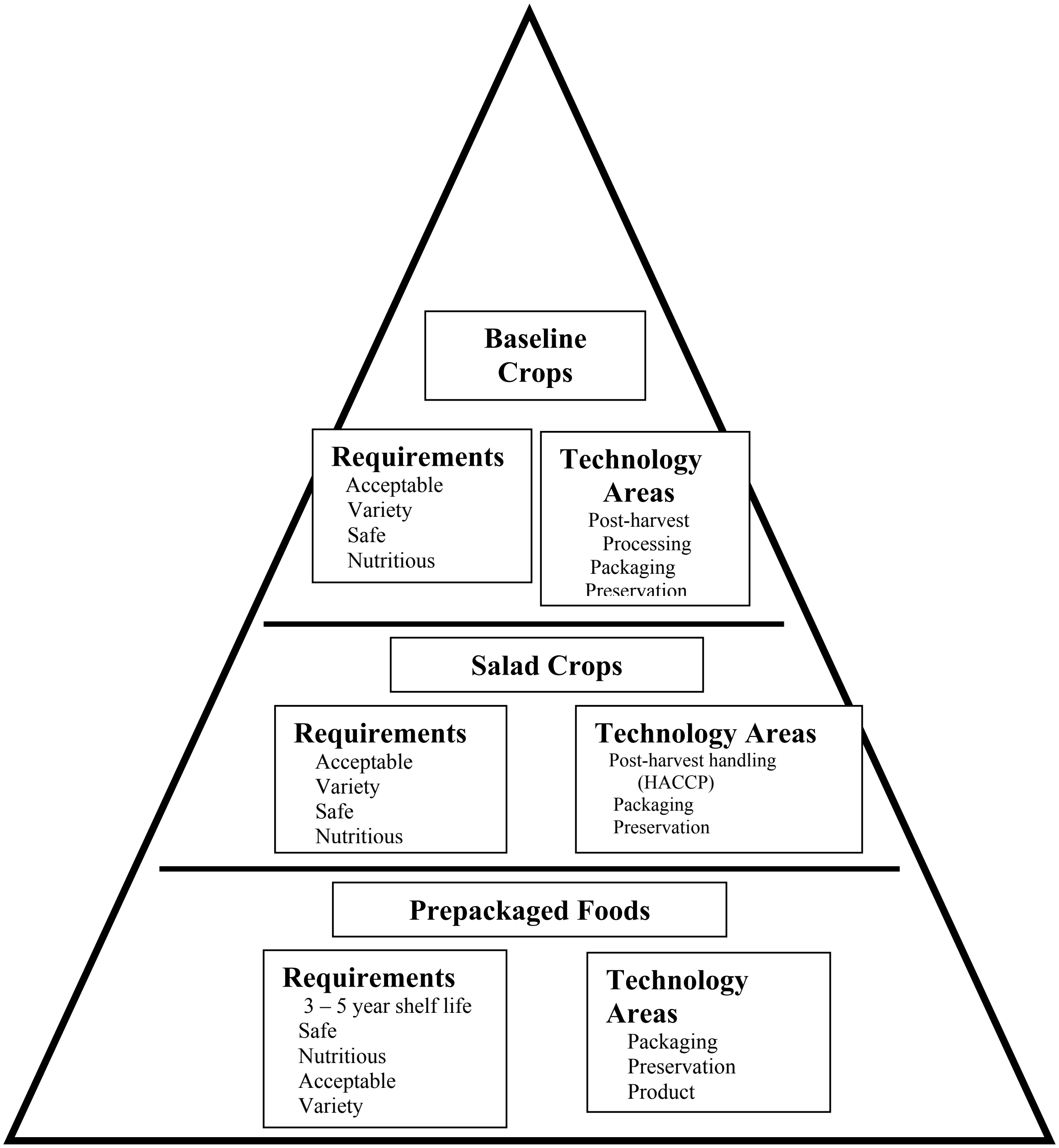

Figure 3: Advanced Food System Pyramid

Food processing procedures and equipment for converting crops to bulk ingredients will need to be designed and developed. 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. Each of the pieces of processing equipment will need to be miniaturized from commercially available food processing equipment.

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). Processing conditions to adjust to these changes as well as other functional changes for the crops will need to be determined. The inability to use the crops efficiently will result in less nutrition to the crew and more waste.

6.3.4 Menu development

Several menus will need to be developed depending on the mission and the foods and/or ingredients available. In a long duration mission, food is expected to become the central thread of the social interactions among the crew, and its psychological benefits will prove to be quite significant to the mental health of the crew.

The menus developed will need to incorporate the nutritional requirements during a long duration mission. These nutritional needs may be different from our needs on Earth due to the increased radiation exposure and lower gravity.

In the determination of the menu, several small appliances may be needed in the galley of the surface habitat. Although several commercially available food preparation appliances may be used for food preparation in the galley, some of these items may require minor modifications prior to use. In order to minimize crew time and maximize crew safety, preparation and clean-up procedures will need to be established.

7 ACRONYM LIST

AFT	Advanced Food Technology
AHST	Advanced Human Support Technology
ALS	Advanced Life Support
Aw	Water activity
BPS	Biomass production system
DNA	Deoxyribose nuclei acid
EB	Evolved base
ESM	Equivalent System Mass
EVOH	Ethylene-vinyl alcohol
FDA	Food and Drug Administration
FPSDF	Food Processing System Development Facility
ISS	International Space Station
HACCP	Hazard analysis critical control point
HHP	High hydrostatic pressure
HPP	High pressure processing
JSC	Johnson Space Center
LCD	Liquid crystal display
LCP	Liquid crystal polymer
LDPE	Low density polyethylene
LMLSTP	Lunar-Mars Life Support Test Project
LTCAS	Low temperature-controlled atmosphere system
MAP	Modified atmosphere packaging
MRE	Meals ready-to-eat
MWCO	Molecular weight cutoff
NASA	National Aeronautics and Space Administration

NRA	NASA Research Announcements
NSCORT	NASA Specialized Center of Research and Training
OMF	Oscillating magnetic field
OSHA	Occupational Safety and Health Administration
PEF	Pulsed electric field
PET	Polyethylene terephthalate
PHP	Post-harvest processing
PP	Polypropylene
RMD	ALS Reference Missions Document
SBIR	Small Business Innovation Research
SH	Surface habitat
SIMA	Systems Integration, Modeling, and Analysis
STOW	Soymilk, Tofu, Okara, Whey Processor
TRL	Technology Readiness Level
TV	Transport vehicle
UHT	Ultra high temperature
UHP	Ultra high pressure
UV	Ultraviolet

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APPENDIX A

TECHNOLOGY READINESS LEVELS *

BASIC RESEARCH

RESEARCH TO PROVE FEASIBILITY

TECHNOLOGY DEVELOPMENT

TECHNOLOGY DEMONSTRATION

SYSTEM DEVELOPMENT

SYSTEM TEST/ OPERATIONS

1. BASIC PRINCIPLES OBSERVED AND REPORTED
2. TECHNOLOGY CONCEPT AND/OR APPLICATION FORMULATED
3. ANALYTICAL AND EXPERIMENTAL CRITICAL FUNCTION AND/OR CHARACTERISTIC PROOF-OF-CONCEPT
4. COMPONENT AND/OR BREADBOARD VALIDATION IN LABORATORY ENVIRONMENT
5. COMPONENT AND/OR BREADBOARD VALIDATION IN RELEVANT ENVIRONMENT
6. SYSTEM/SUBSYSTEM MODEL OR PROTOTYPE DEMONSTRATION IN A RELEVANT ENVIRONMENT (GROUND OR SPACE)
7. SYSTEM PROTOTYPE DEMONSTRATION IN A SPACE ENVIRONMENT
8. ACTUAL SYSTEM COMPLETED AND "FLIGHT QUALIFIED" THROUGH TEST AND DEMONSTRATION
9. ACTUAL SYSTEM "FLIGHT PROVEN" THROUGH SUCCESSFUL MISSION OPERATIONS

* From SSP 50198 (11/22/95)

Appendix B:

Preservation Technologies

Preservation Technologies - Table 1

Technology	Function/Principle	Potential Hazards	Safety Features	Storage Requirements	Shelf life (years)
Emerging Thermal Technologies					
Ohmic Heating	Involves the passage of alternating (or other waveform) electrical currents through the food to heat it by internal energy generation in order to inactivate pathogenic and spoilage microorganisms.	Electric current utilized. Crew operator burning. Microbial spoilage.	Current transducers;frequency controls; suitable electrodes	Ambient temperature for commercially sterile products	3-5 yr
Microwave Sterilization	A polarization of the water molecules occurs when an electric field is applied (microwaves) throughout the food system. The molecules acquire a random orientation and heat is delivered instantly throughout the product to produce microbial lethality.	Leakage of electromagnetic fields at frequencies 915, 2450, 5800, and 24225 MHz. Crew operator burning. Microbial spoilage.	The system must be isolated to avoid leakage of electromagnetic waves.	Refrigeration to ambient temperature.	3-5 yr
Radio Frequency	A polarization of the water molecules occurs when an electric field is applied (radiofrequency) throughout the food system. The molecules acquire a random orientation and heat is delivered instantly throughout the product to produce microbial lethality.	Leakage of electromagnetic fields at frequencies 13.56 MHz, 27.12 MHz, and 40.68 MHz. Crew operator burning. Microbial spoilage.	The system must be isolated to avoid leakage of electromagnetic waves.	Ambient temperature.	3 years
Induction Heating	Electric coils placed near the food product generate oscillating electromagnetic fields by sending electric currents through the food and increasing its temperature. Heat generated inactivates microorganisms.	High electromagnetic fields. Crew operator burning. Microbial spoilage.	The system must be isolated to avoid leakage of electromagnetic waves.	To be determined	unknown
Emerging Nonthermal Technologies					
Irradiation	Involves the use of gamma rays, X-rays or electrons, using energy levels that assure negative induction of radioactivity in the irradiated product. It controls naturally occurring processes such as ripening, or senescence of raw fruits and vegetables, and	Isotope source: free radicals formation, gas emission from cooling system. Microbial spoilage.	Radiation shielding	Refrigeration or room temperature	less than three months (low dose) ; 3-5 yr (high dose)
High pressure	Microbial and enzymatic inactivation by application of high pressures between 100 - 1100 MPa and practical exposure times of less than 20 min	High pressure from the mechanical equipment.Microbial spoilage.	Good sealing system during process	Refrigeration or room temperature	HHP alone - less than 3 months. HHP / Heat - 3-5 years
Ultrasound	Sound waves of 20,000 or more vibrations per second can inactivate bacteria and enzymes. Presently, most industrial developments of ultrasonics (sonication) for food applications are nonmicrobial in nature. Other vibration frequencies are under considerat	Noise. Microbial spoilage.			unknown
Pulsed Electric Fields	High-voltage electric pulses (25 - 70 kV/cm) are applied for a few microseconds to inactivate microbes by electrical breakdown and electroporation. Enzymes might also be inactivated. Batch or continuous process.	High voltage pulses. Microbial spoilage.	Security system shielding. Monitoring and control of energy. High energy discharge system.	Refrigeration	less than 3 months
Arc Discharge	Delivery of highly reactive ozone and UV radiation by electric arc discharge (like PEF) to inactivate microorganisms and enzymes in liquid systems.	Ozone generation (toxic), UV radiation and high voltage. Microbial spoilage.	Security shielding system. High energy discharge system.	Refrigeration	less than 30 days

Preservation Technologies - Table 1

Technology	Function/Principle	Potential Hazards	Safety Features	Storage Requirements	Shelf life (years)
Light Pulse	Electromagnetic energy, in a wavelength range from 170 to 2600 nm, is used to inactivate microorganisms (including viruses) by applying short duration flashes for surface disinfection.	Blindness. Crew operator burning.Microbial spoilage.	Light source wrapping in order to avoid exposure to light flashes.	Refrigeration	less than 30 days
Ultraviolet Light	UV light (254 nm) may be used to inactivate all types of microorganisms by damaging their DNA when doses between 0.5 to 20 J/ m2 are applied.	Blindness, UV radiation. Crew operator burning. Microbial spoilage.	Crew operator protection by use of UV source wrapping	Refrigeration	less than 30 days
Oscillating magnetic fields	It has been suggested that magnetic fields in the 5 - 50 Tesla range, with frequencies between 5 - 500 kHz have a bactericidal effect.	Magnetic field pulses. Microbial spoilage.	Appropriate shielding		unknown
Plasma	An aggregation of mobile positively charged particles created by an electrical discharge between electrodes placed within a liquid food. It can inactivate undesirable bacteria present in the food.	Generation of unsafe gas emisions. Microbial spoilage.			unknown
Ozone	It is produced by bubbling water by ozonizers. The product (fruit or vegetable) is immersed into the ozonated water.	Ozone toxicity.Microbial spoilage.		Refrigeration	less than 30 days
Chemical & Biochemical Methods	Chemical preservation is based on the addition of only GRAS (generally recognized as safe) preservatives to foods, such as buffers, chelating agents, antioxidants, stabilizers and thickeners and antimicrobial agents. Biochemical preservation such as ferm	Hand eye and irritation. Microbial contamination from utilized microorganisms.		Freezing to ambient temperatures	in most cases - less than 3 months.
NonThermal Methods as Hurdles	Combination of preservation factors to ensure microbial stability or safety, and quality. It is highly desirable to have synergistic effects among preservation factors.	Depends on the combined technologies.Microbial spoilage.		Depends on selected technologies	in some specific cases could reach 5 years
Conventional Technologies					
Retort Sterilization	Water or steam application under pressure and temperature conditions to low or high acid foods, in cans or retortable pouches, to render products free from pathogens and spoilage microorganisms.	High pressure and temperature.Steam. - Crew operator burning or accident due to pressure release. Microbial spoilage.	Time and temperature controls.	Frozen to ambient. It depends on the food item	1 to 5 years
Hot fill and hold	Rigid or flexible packages are hot filled with high pH foods and hold at high temperature in a pasteurizer.	High temperature - steam. Crew operator burning. Microbial spoilage.	Monitoring of temperature, pressure, and time. Pressure releaser.	Frozen to ambient. It depends on the food item	1 to 5 years
Aseptic processing/ packaging	Filling and hermetically (airtight) sealing of a previously heat-treated commercially sterile food into a separately sterilized package or container in a sterile environment.	Crew operator burning. Microbial spoilage.		Sterile environment or packaging, refrigeration or ambient temperature	3 - 5 yr (with exceptions like milk)
Acidification	Addition of acids as acidulants and as preservatives. For example, phosphoric acid reduces pH, acetic acid also provides flavor and sodium salts of propionic acid have antimicrobial properties.	Hand and eye irritation. Microbial spoilage.	Use of gloves and safety glasses.	Refrigeration to ambient temperature	Product / combined method (0.5 yr - 5 yr)

Preservation Technologies - Table 1

Technology	Function/Principle	Potential Hazards	Safety Features	Storage Requirements	Shelf life (years)
Pickling	Addition of salt and acid generation through fermentation. Proteolytic and other spoilage organisms are not tolerant to salt above 2.5%. During fermentation lactic acid organisms produce acid, and salt and acid strongly inhibits proteolytic and other spoi	Microbial spoilage.		Ambient temperature	2 - 3 yr
Concentration (water removal)	Preservation through reduction of water activity of liquid foods by removing water and reducing the product’s weight and volume . This technology increases food stability. In some cases sugar addition is involved.	Crew operator burning. Microbial spoilage.	Control valves	Ambient temperature, refrigeration, freezing	3 - 5 yr
Membrane (nano & micro filtration, R.O.)	Food concentration or separation takes place from size difference and osmotic pressure difference among the components of a liquid food. Membrane technologies, depending on the particle size of the retentate, can be divided into reverse osmosis (R.O.), na	Microbial spoilage.			in most cases - less than 6 months.
Air dehydration	Hot air removes moisture from foods due to a combined heat and mass transfer action.	Crew operator burning.	Appropriate controls of time and temperature	Ambient or lower temperature	product dependent - in some cases 5 years
Osmotic dehydration	Water immersion in a hypertonic solution (i.e. sugar, salt, sorbitol, or glicerol) to increase product's stability by lowering available water for microbial growth. Could be enhanced under vacuum conditions (V.O.D.).	High BOD from utilized solution. Microbial spoilage.		Refrigeration to ambient temperature	low acid foods - to be determined. High acid foods - 3 - 5 years
Freeze drying	Ice in frozen meals is sublimated due to the application of low heat under vacuum in order to separate water (gas) from the food. This drying method maintains the original taste and aroma of the food.	Hazardous chemical use, and generation of unsafe gas emissions.	Protected equipment for refrigeration gas lines, as well as heat platens (oil lines).	Ambient temperature; low relative humidity, atmospheric pressure, low oxigen conditions	3 - 20 yr ambient temperature
Controlled atmosphere	Foods are stored in enclosures where air incorporation has been changed by the addition of some specific gases such as nitrogen, oxigen, and /or carbon dioxide.	Microbial spoilage.	Sealed design	Controlled atmosphere, generally combined with refrigeration or freezing	alone or refrigerated (5 ºC) -1 yr; combined with freezing (-20ºC) - 3 - 5 yr
Refrigeration	Low temperature reduces respiration and microbial spoilage of fresh food products.	Gas release. Power failure. If power failure occurs spoilage reactions create odor and solid waste.	-	Refrigeration	product dependent - in general less than 1 month
Freezing	Food preservation process at low temperatures (generally below -18ºC) that immobilizes water in a food as ice within an amorphous matrix.During frozen storage, the environmental conditions are maintained at subfreezing levels with minimum fluctuations in	Gas release. Power failure. If power failure occurs spoilage reactions create odor and solid waste.		-20º C	3 - 5 yr

Preservation Technologies - Table 2

Technology	Product quality	Packaging	Gravity dependence	Equipment Mass	Equipment Volume	Power Requirement	Water Requirement	Crew time
Emerging Thermal Technologies								
Ohmic Heating	Good	Flexible pouches with electrodes for processing. Aseptic.	no	low	low	high	low	low
Microwave Sterilization	Excellent	Aseptic or non-metallic flexible/rigid container, polymer trays	no	low	intermediate	intermediate	low	low
Radio Frequency	Good	Poly tray	no	intermediate	intermediate	intermediate	not required	low
Induction Heating	Good	Metallic and plastic.	no	low	intermediate	high	low	low
Emerging Nonthermal Technologies								
Irradiation	Excellent	Pouches of multilayered flexible polymeric films, flexible light weight containers	no	high	high	high	low	Intermediate
High pressure	Excellent	Batch - semirigid containers Semicontinous - aseptic	no	high	intermediate	intermediate	low	intermediate
Ultrasound	Good	Aseptic	no	intermediate	intermediate	high	low	low
Pulsed Electric Fields	Excellent	Aseptic. Plastic bags; plastic and glass bottles.	no	high	intermediate	high	low	intermediate
Arc Discharge	Good	Aseptic	unknown	high	intermediate	high	low	low
Light Pulse	Fair to good	Liquids -aseptic or transparent packaging. Solids - to be determined	yes	intermediate	intermediate	high	low	intermediate
Ultraviolet Light	Fair to good	Transparent package for processing (if necessary).	yes	low	low	low	low	intermediate
Oscillating magnetic fields		Prior to processing - non ferric. After processing - plastic bags	unknown					
Plasma		unknown	unknown	low	low	intermediate	low	low
Ozone	Good	unknown	no	low	low	low	low	low
Chemical & Biochemical Methods	Excellent	Multiple options but product / methods dependent	no	low	low	low	low	intermediate

Preservation Technologies - Table 2

Technology	Product quality	Packaging	Gravity dependence	Equipment Mass	Equipment Volume	Power Requirement	Water Requirement	Crew time
NonThermal Methods as Hurdles	Excellent	Multiple options but product / methods dependent	Depends on selected technologies			low	intermediate	intermediate
Conventional Technologies								
Retort Sterilization	Good	Retortable pouches or cans	no	high	intermediate	low	intermediate	low
Hot fill and hold	Good	Plastic bags.	unknown	high	intermediate	low	low	low
Aseptic processing/packaging	Good	Sterile packages. Rigid, semirigid, flexible	no	high	intermediate	intermediate	high	high
Acidification	Good	Glass or plastic sealed jars	no	low	low	low	intermediate	intermediate
Pickling	Excellent	Glass or plastic sealed jars, bags, and cans	unknown	low	low	low	intermediate	intermediate
Concentration (water removal)	Good	Sealed cans - dark container	no	intermediate	intermediate	intermediate	intermediate	intermediate
Membrane (nano & micro filtration, R.O.)	Excellent	Sealed container	no	low	low	low	intermediate	low
Air dehydration	Good	Flexibility of packaging	no	low	low	low	low	low
Osmotic dehydration	Excellent (raw food) ; Good (processed food)	Vaccum / N2 in foil laminate	no	low	low	low	high	low
Freeze drying	Excellent (raw food) ; Good (processed food)	Vaccum packaging, foil laminate	unknown	intermediate	intermediate	intermediate	low	low
Controlled atmosphere	Excellent	Multiple options but product dependent	unknown	low	high	high	low	low
Refrigeration	Excellent	Storage containers	no	low	low	low	not required	low
Freezing	Excellent	High barrier film or container	no	intermediate	intermediate	intermediate	low	low

Technology	Automation	Equipment Clean up	Equipment Life time	Equipment parts to replace	Potential Detriments/Benefits	Reliability	Process Monitoring	Product Controls
Emerging Thermal Technologies								
Ohmic Heating	yes	high (liquid)/ low (solid)			-	high	Temperature and current sensors	Feedback (PID)
Microwave Sterilization	yes	low	high		Rapid heating and drying.	high	Frequencies and processing time.	
Radio Frequency	yes	low	moderate		Rapid heating and drying. Higher penetration in the food and lower temprature increments than microwave.	high	Selected frequency	Heating time and temperature
Induction Heating	yes	low	high			high		
Emerging Nonthermal Technologies								
Irradiation	yes	low	high			high	Radiation doses (radiometers)	
High pressure	yes	low	high			high	Time, temperature, and pressure sensors	
Ultrasound	?	low	high			low	Frequency	
Pulsed Electric Fields	yes	moderate	high	Treatment chamber, high voltage electrodes, plastic and metallic tubing system.	Cleaning water could be recycled and used at the facility.	high	Monitoring of high voltage, frequency of pulses, flow system and temperature.	
Arc Discharge		moderate	high	Treatment chamber, high voltage electrodes, plastic and metallic tubing system.	Cleaning water could be recycled and used at the facility.	low	Monitoring of high voltage, frequency of pulses, flow system and temperature.	
Light Pulse	yes	low	moderate	Pulsed gas-filled flashlamps.	Heating of food between 50º C and 100º C.	high	Flashing frequency pulses. Number of pulses. Light intensity.	
Ultraviolet Light	yes	moderate	moderate	UV lamps and tubing system parts.	The cleaning water could be recycled and used at the facility.	high	Liquid flow control. UV dose measured by a radiometer.	

Oscillating magnetic fields	yes					low	Time, magnetic field, frequency	

Technology	Automation	Equipment Clean up	Equipment Life time	Equipment parts to replace	Potential Detriments/Benefits	Reliability	Process Monitoring	Product Controls
Plasma	yes	low	high		Does not cause secondary pollution	high		
Ozone	no	low	moderate		Ozonated water can be reused by a mixture of ozonization agent and filtration	high	-	-
Chemical & Biochemical Methods	no	intermediate	low / high			high		
NonThermal Methods as Hurdles		intermediate			Synergy of applied methodologies	high		
Conventional Technologies								
Retort Sterilization	yes	low	high	Temperature and pressure sensors, valves, and seal jaws for packaging equipment .	Process heat could be captured and used in facility	high	Automated monitoring of process at each of critical control points.	Temperature, time and pressure data.
Hot fill and hold	yes	low	high		Capture heat to use in facility	high	Feasible. Monitoring of pressure, time, temperature, etc.	Data acquisition device to monitor critical control points.
Aseptic processing/packaging	yes	high	high			high	Temperature, pressure, and flow	
Acidification	no	moderate	long			high	pH	pH and acidity
Pickling	no	intermediate	high		High water usage and waste	high	none	pH
Concentration (water removal)	no	high	high		Reduction in packaging, transportation, and storage.	high	Soluble solids, temperature, volume, liquid flow	Temperature
Membrane (nano & micro filtration, R.O.)	yes	high	moderate	Membranes	Reduction in storage	high	Concentration (soluble solids)	pH and temperature
Air dehydration	no	low	high	Heat elements and sensors to monitor moisture of the drying air at minimal cost.	Recovered heat may be used for facility	high	Weight, time and temperature.	Temperature and air velocity.
Osmotic dehydration	no	high	high		Waste	high		
Freeze drying	yes	low	high	vacuum pump features	Storage savings	high	Temperature and pressure	Temperature and pressure
Controlled atmosphere	yes	low	high		Gases can also be used for other purposes	high	Temperature, gas pressure and composition	Temperature

Technology	Automation	Equipment Clean up	Equipment Life time	Equipment parts to replace	Potential Detriments/Benefits	Reliability	Process Monitoring	Product Controls
Refrigeration	no	low	high		Power consumption	high	Temperature sensor to monitor internal temperature.	Temperature
Freezing		moderate	high		Power consumption	high	Temperature and current sensors and recorders	Temperature

Preservation Technologies - Table 4

Technology	TRL EARTH	TRL MARS	Source/ supplier	Process in package?	Types of Foods
Emerging Thermal Technologies					
Ohmic Heating	4	2		yes	All foods (solid, liquid, or solid liquid mixtures, with some electrical conductivity. e.g. tomato puree sauce, vegetable purees
Microwave Sterilization	4	2	Alfastar, Berstoff, Le Houlme, Omac, Toppan	yes (non metallic).	All foods except dry products.
Radio Frequency	4	2		yes	Many types of foods.
Induction Heating	2	2		yes (metalic and plastic)	All foods
Emerging Nonthermal Technologies					
Irradiation	4	2	Food Tech Services / Nation's Pride; Surebeam (Tita Corp.);IBA Food Safety Division; MDS Nordion; Steris, Isomedix Services; Natick Soldier Systems Center fo High Dose	yes	Dried foods, fresh fruits and vegetables, meat and poultry products
High pressure	4	2	Avure Technologies	yes	All moist foods. (e.g. juices, sauces, stews, soups, meats, purees)
Ultrasound	2	1		no	Liquid systems
Pulsed Electric Fields	2	2		yes	Homogenous liquid products.
Arc Discharge	1	1		no	Homogenous liquid products.
Light Pulse	2	2		yes (transparent)	Surface processing only or transparent liquids in thin stream.
Ultraviolet Light	2	2		yes (transparent)	Surface processing only or transparent liquids in thin streams.
Oscillating magnetic fields	1	1		yes (non-ferric)	unknown
Plasma	1	1		no	
Ozone	2	3	-	no	Fruits and vegetables.
Chemical & Biochemical Methods	2	2		yes	All foods
NonThermal Methods as Hurdles	4	2		yes	All foods

Preservation Technologies - Table 4

Technology	TRL EARTH	TRL MARS	Source/ supplier	Process in package?	Types of Foods
Conventional Technologies					
Retort Sterilization	9	3	FMC FoodTech Food Processing Systems, Lagarde Autoclaves, Stock R & L, Stork (Steristork, Europe).	yes	All foods. Liquids, semi-solid foods.
Hot fill and hold	9	2		yes	All foods. Liquids, semi-solid foods.
Aseptic processing/packaging	6	2	Tetra - Pack, Excell-O, Pure Pak, International Paper Company, Scholle bag in box system, Fran-Rica bags and Aseptic drum systems, Dole canning system,	no / yes	Liquid and semiliquids
Acidification	6	3		no	all foods
Pickling	6	3		yes	Vegetables and fruits among other foods
Concentration (water removal)	6	2		no	Liquid foods like fruit juices, dairy products, syrups
Membrane (nano & micro filtration, R.O.)	6	2		no	Liquids (fruit juices, milk, non-pure water)
Air dehydration	6	3		no	Fresh solid foods
Osmotic dehydration	6	2	Cherry Central; Oregon Freeze Dry; Tree Top (fruit); Graceland; Bryon Foods	no	Slices or pieces of fruits and vegetables.
Freeze drying	6	2	Oregon Freeze Dry; Hanover Foods; CVC; Dry blenders; Alpine Aire	no	Liquids and semisolids. Fruits and vegetables. Meats. Dairy products.
Controlled atmosphere	6	2		yes	All foods
Refrigeration	6	3	Maytag Corporate partner - NASAFTSC	yes	Fruits and vegetables. Meats.
Freezing	9	3	Maytag corporate partner, others	yes	All foods (e.g. fruits, vegetables, juices, meats, dairy products, and bakery goods)