EMBRY-RIDDLE
Aeronautical University

Mission Certifications Engineering Report

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I. Introduction

The certification and safety proposal plans for the Earth-Mars transfer vehicle come with a comprehensive set of measures designed to ensure the safety and reliability of the mission across all phases of operation. These plans are held together to have the regulations set forth by various governing agencies, including NASA, the Federal Aviation Administration (FAA), the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), and all the space food safety standards.

The Safety Proposal addresses several key components and provisions for the mission, including the RS-25 rocket engines, VASIMR thrusters, Special Purpose Nuclear Reactor (SPNR), and astronaut food. Each of these systems requires specific safety considerations and certifications to follow federal regulations such as CFR Title 14 for commercial space transportation and CFR Title 21 for food and drugs.

II. RS-25 Engine Safety and Certification

The RS-25 engine, formerly known as the Space Shuttle Main Engine (SSME), has a proven track record of reliability and safety. With over 1.1 million seconds of testing and flight time, it is one of the most thoroughly tested and reliable rocket engines ever produced. The engine's safety features and performance characteristics include:

1. Robust Design: The RS-25 operates across an extreme temperature range from −253°C to 3,300°C (−400°F to 6,000°F), demonstrating its ability to withstand harsh conditions.
2. Throttle Capability: The engine can be throttled between 67% and 109% of its rated power level, allowing for precise control during different flight phases.
3. Redundancy: The use of multiple engines (six in this case) provides redundancy and increased safety.
4. Proven Technology: With its heritage from the Space Shuttle program and continued use in the Space Launch System (SLS), the RS-25 has undergone extensive testing and real-world applications.
5. Ongoing Improvements: NASA and Aerojet Rocketdyne continue to refine the RS-25, developing more affordable and efficient variants like the RS-25E5.

A. Safety Proposals and Certifications

The plans address ground operations, launch and ascent safety, orbital operations, emergency response protocols, and environmental impact assessments. For the RS-25 engines, specific safety considerations include:

1. Propellant Handling: Procedures for safe handling of liquid hydrogen and liquid oxygen, adhering to CFR Title 14 Part 420.66 regulations.
2. Engine Testing: Rigorous pre-flight testing protocols to ensure all six RS-25 engines are functioning optimally.
3. Flight Termination System: Implementation of a robust flight termination system capable of shutting down the RS-25 engines in case of an emergency.
4. Debris Mitigation: Measures to prevent unintended physical contact between the vehicle and payload after separation, as per CFR Title 14 part 417.129.
5. Energy Dissipation: Protocols for eliminating stored energy in the launch vehicle stages or components reaching Earth orbit, including draining remaining fuel and venting pressurized systems. [1][2]

These certification and safety proposals demonstrate a commitment to maintaining the highest standards of safety in space exploration, ensuring the protection of crew members, the public, and the environment throughout the mission's duration. By addressing potential risks and implementing robust mitigation strategies, these plans form the foundation for a successful and secure Earth-Mars transfer mission.

The RS-25 engines, with their extensive flight heritage and ongoing improvements, align well with the stringent safety requirements for human spaceflight as outlined in CFR Title 14 part 460.5. Their proven reliability and performance characteristics make them a suitable choice for this critical mission, providing the necessary thrust and efficiency for the Earth-Mars transfer vehicle. [3]

The propellent and oxidizer that are being used for this mission are very common liquid chemicals in the aerospace industry and have consistently demonstrated reliability and safety. The primary area of certification lies within the tanks. Safety with the tanks is paramount, thus for certification, the tanks must not have any sort of method of ignition within them. The tanks designed for this mission have addressed this, as the interior is only empty space. All components needed for the tanks are on the outside and will be turned off and stored properly prior to launch. Due to the common materials, propellant, and oxidizers used, the tanks and propulsion section can be certified under the CFR Title 14, part 25 and part 33. [4][5]

For additional details and information on the RS-25 engine, refer to the "4a. Engine System Report."

III. Launch Operations and Ground Certifications

For launch safety, public safety must be a top priority during all phases of the operation. The rules must address weather, vehicle and equipment status, and personnel readiness for launch and flight. Preflight safety regulations should ensure public safety, guided by a thorough safety analysis. Flight-commit criteria must specify conditions for launch, with a focus on tracking systems, requiring two sources before lift-off and one verified source until Earth orbit departure. Flight termination rules must define when to abort the mission. Special attention should be given to flight safety system deactivation after Earth departure. Crew shifts and rest periods must also be regulated to ensure peak performance. More information can be found outlined in CFR Title 14 part 417.113. [6]

For safety at the end of launch, the launch operator must have measures to prevent unintended physical contact between the vehicle and the payload after separation. This is particularly important given the complex nature of the interplanetary mission and the potential for debris generation in Earth orbit. To reduce any risks, the launch vehicle must be designed to avoid the release of energy from chemical, pressure, or kinetic sources that could lead to breakup. Additionally, a protocol must be in place to eliminate stored energy in the launch vehicle stages or components reaching Earth orbit. This involves draining any remaining fuel, keeping fuel line valves open, venting pressurized systems, fully discharging all batteries, and eliminating any other sources of stored energy. These measures are crucial not only for the immediate safety of the mission, but also for the long-term sustainability of Earth's orbital environment, especially considering the increasing concerns about space debris and its potential impact on future space operations. Further details are outlined in CFR Title 14 part 417.129.

For additional details and information on distribution and generation of power and trajectory orbits, refer to the reports on 'Power Generation and Electrical Diagram Engineering” and “Trajectory Determination”

IV. Zvezda Module

The Zvezda service module, an important component of the International Space Station (ISS), plays a huge role in the station's life support systems. While specific certifications are not explicitly documented, the module goes through a string of safety protocols and regulations. Zvezda's life support equipment operates together with other Russian-supplied environmental control systems, providing essential redundancy for crew safety. Prior to deployment, all Environmental Control and Life Support System (ECLSS) hardware undergoes rigorous testing, including life cycle, operational, and integration tests of flight hardware.

Since its installation, Zvezda has undergone several safety upgrades to enhance its reliability and mitigate potential risks. These improvements include updates to the oxygen generation system, improved airflow, and modernization of computer and avionics systems. Continuous monitoring by NASA and Roscosmos for over 25 years ensures the module's optimal performance, with particular attention given to addressing challenges such as the ongoing air leak issue identified in September 2019. While Zvezda may not meet all ISS program standards for safety and crew comfort, it's an important function in life support that undergoes evaluation and improvement to maintain the high safety standards required for human spaceflight. [9][10]

For additional details and information on the Zvezda Module Life Support, refer to the “Zvezda Engineering Report.”

V. VASIMR Safety Proposal

A. Ground Operations Safety

Ground operations for VASIMR electric thrusters require careful handling of propellants and high-power electrical systems. Safety protocols should include proper grounding procedures, protective equipment for personnel, and secure containment of propellants. Regular safety inspections and maintenance of ground support equipment are crucial to prevent accidents during pre-launch preparations. [11]

B. Launch and Ascent Safety

During launch and ascent, the VASIMR thrusters remain inactive. However, safety measures must be put in place to protect the propulsion system from launch vibrations and acceleration forces. Robust structural support and secure fastening of all components are essential. Additionally, fail-safe mechanisms should be implemented to prevent premature activation of the thrusters during this phase. [12]

C. Orbital Operations Safety

In orbit, the VASIMR thrusters present unique safety challenges due to their high-power operation and strong magnetic fields. Proper shielding must be in place to protect other spacecraft systems and crew from electromagnetic interference. Thermal management is critical, as the thrusters generate substantial waste heat that needs to be efficiently dissipated. [13]

D. Emergency Response and Contingencies

Emergency procedures should include rapid shutdown protocols for the VASIMR thrusters in case of system malfunctions. Redundancy in critical components and the ability to operate with fewer than seven thrusters are important contingency measures. Training for crew and ground control in handling thruster-related emergencies is essential. [14]

E. Regulatory Compliance

Compliance with space agency regulations and international space law is crucial. This includes adhering to debris mitigation guidelines and ensuring that the VASIMR thrusters' operation does not interfere with other spacecraft or violate orbital regulations. Regular compliance audits and documentation of safety measures should be maintained.

F. Critical Component Separation and Safety Precautions

The integration of a nuclear reactor with VASIMR engines in a spacecraft design necessitates strict commitment to safety protocols, primarily due to the essential risks associated with nuclear power and high-energy plasma propulsion. The reactor must be physically isolated from the VASIMR engines and other critical systems to minimize potential catastrophic failures. This separation is important because the intense radiation and heat generated by the reactor could compromise the integrity of the superconducting magnets used in VASIMR, potentially leading to a loss of plasma containment. Moreover, the reactor's radiation can cause material degradation and electronic component failures if not properly shielded, which could result in critical system malfunctions during long-duration missions. [15][16]

G. Potential Hazards and Mitigation Strategies

The proximity of a nuclear reactor to large quantities of propellant presents significant risks that must be carefully managed. A reactor malfunction or coolant system failure could lead to overheating, potentially causing a horrible situation. If this were to occur near propellant tanks, it could trigger a catastrophic explosion or release of radioactive material. To reduce these risks, multiple layers of safety systems must be implemented, including independent cooling circuits, redundant power systems, and advanced radiation monitoring equipment. Additionally, the design must incorporate fail-safe mechanisms that can rapidly shut down the reactor and isolate it from other systems in the event of an emergency. The use of advanced materials capable of withstanding extreme temperatures and radiation environments is also essential to enhance the overall safety and reliability of the spacecraft's nuclear propulsion system. [17][18]

H. Environmental Impact

The environmental impact of VASIMR thrusters in space should be carefully evaluated. While they offer efficient propulsion, the long-term effects of their plasma exhaust on the space environment must be studied. Measures to minimize any potential negative impacts, such as optimizing thrust profiles to reduce space debris creation, should be implemented.

I. FAA Approval Process

To obtain FAA approval, a detailed safety case must be presented, demonstrating that all aspects of the VASIMR propulsion system meet or exceed safety standards. This includes providing extensive test data, failure mode analyses, and operational procedures. Collaboration with FAA officials throughout the development process can help streamline the approval process and ensure all requirements are met.

For additional details and information on the Variable Specific Impulse Magnetoplasma Rocket, refer to the "VASIMR VX-200SS System Configuration Report"

VI. Idaho National Laboratory SPNR Safety Proposal

A. Ground Operations, Transportation, and Packaging Safety

The transport of the SPNR from Idaho National Laboratory to Cape Canaveral must comply with Department of Transportation (DOT) and Nuclear Regulatory Commission (NRC) regulations for radioactive material shipment.

The use of specialized Type B packaging to contain the reactor core and components will be needed for the reactor. The reactor must fit in with the TRUPACT-II Package. Radiation levels during transport will be monitored by ensuring the reactor is constantly observed and notifying the transportation team should a spike in radiation occur. Escort vehicles and predetermined secure routes will be implemented to ensure the reactor is securely transported and minimizes threats. Emergency response plans for potential accidents will be created in response to any transportation risks, packaging risks, and spikes in radiation anytime on the ground [21].

B. Launch Pad Operations

At Cape Canaveral, handling and loading of the SPNR onto the Starship rocket will require restricted access zones around the reactor to be set in place prior to the arrival of the reactor. Once the reactor is in place and secured, proper storage precautions will be taken to ensure no components are active and all radioactive materials are secured. Specialized equipment for reactor handling will be needed to facilitate safe transportation of the reactor and packaging. Contingency plans for launch pad emergencies will be made for the most likely and most dangerous emergencies.

C. Pre-Launch

Comprehensive system checks of both the SPNR and Starship rocket will be done to ensure that all safety measures are in place and that the reactor is shut off. The payload bay must be checked to ensure the payload is stable in the payload bay and that it is properly packaged. Verification of reactor shutdown state will be done prior to sealing it in the TRUPACT-II packaging. Package will be checked to make sure all procedures are followed for storage in the payload bay [21].

D. Launch and Ascent Safety

To ensure safety during the launch , the following safety measures will be put in place. As mentioned previously, the reactor will be placed in the TRUPACT-II packaging which is certified by the U.S. Nuclear Regulatory Commission (NCR). The TRUPACT-II is surrounded by approximately 25 cm of rigid closed-cell polyurethane foam, which acts as an excellent impact-energy absorber. 6.4 - 9.5 mm thick stainless steel skin lines outside of the package providing further protection. Aluminum honeycomb spacer assemblies are at each end of the ICV for additional protection. The TRUPACT-II has thorough thermal protection in the case of extreme heat exposure. The polyurethane foam is flame-resistant and helps retard heat input during hypothetical fire accident conditions. A thin layer of ceramic fiber insulation lines the cavity between the containment vessel and outer skin [20][21].

The package will also contain an automatic parachute system. This is a further layer of protection that will be activated if the sensor detects the package is freely falling and will deploy. Though the package can sustain a fall, slowing down the package will limit the terminal velocity and help keep the reactor from being damaged. Additional sensors aboard the package will be used to ensure the status of the package and its contents are monitored should something happen. Should a sensor go off, appropriate steps to respond to likely issues will be handled [22].

E. Reactor Startup and Operation

Once in LEO, safety measures will include:

1. Controlled reactor startup procedures
2. Continuous monitoring of reactor parameters
3. Redundant control and safety systems

F. Emergency Response and Contingencies

The safety proposal outlines procedures for various emergency scenarios, including rapid shutdown protocols for the nuclear reactor in case of system malfunctions. Training for crew and ground control in handling issues relating to the reactor is critical for compliance with regulations [22].

While the Atomic Energy Commission no longer exists, its functions are now divided between the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC). The safety proposal addresses compliance with:

1. NRC regulations on nuclear materials and reactor safety
2. NASA safety standards for space nuclear systems
3. FAA regulations on commercial space transportation (CFR Title 14 part 450)

G. Risk Assessment and Mitigation

A comprehensive risk assessment will be conducted, considering potential failure modes of the nuclear reactor system. This includes analyzing risks associated with nuclear contamination, radiation risk, and system failures.

Mitigation strategies should be developed for each identified risk, with regular reviews and updates to the risk management plan.

H. Environmental Impact

The environmental impact of nuclear reactors in space should be carefully evaluated. While the reactor offers efficient power output, the long-term effects of their radiation on the space environment and astronauts must be studied. Measures to minimize any potential negative impacts, such as optimizing radiation protection to reduce risk to astronauts and other systems should be considered and implemented.

I. FAA Approval

The proposal will follow the FAA's case-by-case evaluation process for radionuclide launches, as outlined in 14 CFR § 450.45(e)(6). To obtain FAA approval, a detailed safety case must be presented, demonstrating that all aspects of the nuclear reactor meet or exceed safety standards. This includes providing extensive test data, failure mode analyses, and operational procedures. Collaboration with FAA officials throughout the development process can help streamline the approval process and ensure all requirements are met.

J. Backup Plan for Nuclear Reactor Failure with Fuel Cells

In the context of space missions, fuel cells are an essential backup power solution if the nuclear reactor abroad the Earth-Mars transfer vehicle experiences a malfunction. Fuel cells are highly reliable, capable of consistently generating electricity if there is a continuous supply of fuel. This reliability ensures that critical systems remain operational during unexpected outages, providing a dependable safety net for mission-critical operations. Additionally, fuel cells offer clean energy benefits, particularly when using hydrogen as a fuel source, as they produce minimal emission. This feature aligns with the environmental sustainability goals of modern space exploration.

Moreover, fuel cells provide adaptability, allowing them to be adapted to meet various power demands across different mission architectures. This flexibility makes them suitable for integration into diverse mission scenarios, ensuring they can efficiently support both small and large-scale operations. This quick start-up capability of many fuel cells systems is particularly advantageous in emergency situations where immediate power restoration is necessary. Furthermore, with a steady fuel supply, fuel cells can operate over extended periods, making them an excellent long-term backup solution during prolonged outages or unforeseen disruptions in reactor functionality. Integrating fuel cells into the safety proposal plan underscores a commitment to maintaining uninterrupted power and enhancing mission resilience in the face of potential nuclear reactor challenges [22].

For additional details and information on the Nuclear Reactor, refer to the “Power Generation and Electrical Diagram Engineering Report”

VII. Astronaut Food and Nutrition Certification

NASA's food system for long-duration space missions represents a complex, meticulously engineered approach to ensuring astronaut nutrition, safety, and performance. This technical brief comprehensively examines the regulatory frameworks, technical requirements, and critical considerations for developing food systems that can sustain human health in extreme environments. By integrating rigorous scientific standards from the FDA, USDA, and NASA's own specifications, the food system addresses unique challenges such as microgravity food preparation, extended shelf-life requirements, nutritional adequacy, and crew psychological well-being. The document provides an in-depth exploration of food processing techniques, packaging innovations, safety protocols, and historical lessons learned from previous space missions, ultimately demonstrating the critical role of nutrition in enabling successful human space exploration. [23]

A. Regulatory Framework (Guidance and Requirements)

Astronaut food systems are governed by a string of regulations to ensure safety, quality, and nutritional adequacy for long-duration space missions. These include:

1. FDA Food Code: Provides best practices for safe food handling.
2. Food Safety.gov: News, updates, and advice on safely handling and storing food to prevent foodborne illness.
3. Food Safety Modernization Act (FSMA): Mandates preventive controls to avoid foodborne illnesses.
4. Current Good Manufacturing Practice (CGMP): Ensures proper food production and handling (Title 21 CFR Part 117). [31]
5. Control of Communicable Diseases: Regulations on food safety, handling, and illness prevention for interstate shipments (Title 21 CFR Part 1240). [32]

6. Hazard Analysis Critical Control Point (HACCP): Systematic approach to identifying and controlling food safety hazards.
7. Interstate Conveyance Sanitation (Title 21 CFR Part 1250): Regulates food preparation, storage, and handling during transport. [33]
8. US Dept of Agriculture (USDA): Recall alerts, statistics, response updates, and tips on food handling and preparation.
9. Food Safety and Inspection Service (FSIS): ensuring food safety by inspecting meat, poultry and egg products
10. National Institutes of Health (NIH) standards: Recommended dietary intake (DRIs) for essential micro- and macronutrients.

These frameworks ensure compliance with federal, state, and international standards for food safety. [24]

B. NASA-Specific Requirements

NASA's standards, as detailed in NASA-STD-3001 Volume 2 Revision D, outline technical requirements for astronaut food systems, including:

1. [V2 7001] Food Quality: The food system shall provide the capability to maintain food safety and nutrition during all phases of the mission.
2. [V2 7003] Food Caloric Content: The system shall provide each crewmember with an average of 12,698 kJ (3,035 kcal) per day, or an average energy requirement value determined using appropriate equations and activity factors for the mission gravity and planned level of physical activity.
3. [V2 7111] Food Safety: The program shall maintain flight food safety throughout the product's life cycle.

Additional relevant requirements include:

1. [V2 7002] Food Acceptability: The system shall provide food that is acceptable to the crew for the duration of the mission.
2. [V2 7007] Food Microorganism Levels: Microorganism levels in the food and production area shall not exceed specified limits.
3. [V2 7100] Food Nutrient Composition: The system shall provide a food system with a diet including the nutrient composition indicated in the Dietary Reference Intake (DRI) values as recommended by the National Institutes of Health, with exceptions adjusted for spaceflight.
4. These requirements ensure that the food system for space missions meets the necessary standards for safety, nutrition, and acceptability throughout all mission phases.

C. Certification Process

The certification process for space food systems involves multiple stages to ensure safety, quality, and compliance with regulations:

Facility Certification:

1. Facilities must comply with applicable federal, state, and local laws and regulations, as well as industry Good Manufacturing Practice standards.
2. Access is limited to prevent food adulteration.
3. Temperature and foreign object debris (FOD) control measures must be in place.
4. Facilities must control microbial and particulate contaminants.

Personnel Training:

1. All personnel working directly with food must receive food handling training equivalent to or exceeding the requirement for obtaining a food handler's permit (ServSafe® certification or equivalent).
2. Personnel must avoid behaviors that can contaminate food, properly wash and care for hands, and wear appropriate personal protective equipment (PPE) when handling exposed food and packaged food for flight.

Food Testing:

1. Microbiological testing ensures compliance with NASA-STD-3001 [V2 7007] Food Microorganism Levels.
2. Packaging integrity tests verify resistance to environmental factors such as vibration, acceleration loads, radiation, temperature, humidity, zero-pressure, and decompression.

Documentation:

1. Detailed records demonstrating compliance with federal food regulations and laws must be maintained for inspection at any time.
2. Documentation includes standard operating procedures, technical specifications of food, and applicable drawings to ensure consistent and quality work.

Sourcing:

1. All food and ingredients must be sourced from major chain grocery stores or food companies with quality assurance systems that audit suppliers for compliance with federal, state, and local food regulations and laws.
2. Imported items must meet FDA Food Safety Modernization Act (FSMA) requirements for the Foreign Supplier Verification Program (FSVP). [24]

D. Nutritional Considerations

Astronaut diets are carefully tailored to meet individual needs using NIH-recommended Dietary Reference Intakes (DRIs). These guidelines ensure that the nutritional requirements of each crew member are met, with specific adjustments for spaceflight conditions:

1. Vitamin D: Intake is increased to counteract the limited UV exposure in space, which affects natural Vitamin D synthesis.
2. Protein: Adjustments are made based on activity levels and mission-specific needs, such as extravehicular activities (EVAs), to support muscle maintenance and overall health.
3. Micronutrients: Special attention is given to calcium, potassium, and iron to address physiological changes in microgravity, such as bone density loss and fluid redistribution. [26]

E. Energy Requirements

Energy needs are calculated using terrestrial energy requirements as a baseline, modified by mission-specific activity factors. NASA uses the Estimated Energy Requirement (EER) formula to determine caloric intake:

For men aged 19 and older:

$$EER = 662 - 9.53 \cdot (Age) + (Activity\ Factor) \cdot (15.9) \cdot (Body\ Mass) + 539.6 \cdot (Height)$$

For women aged 19 and older:

$$EER = 354 - 6.91 \cdot (Age) + (Activity\ Factor) \cdot (9.36) \cdot (Body\ Mass) + 726 \cdot (Height)$$

Maintaining energy balance is critical for crew health and performance:

1. Historical data shows that astronauts often consume only ~70% of their predicted energy requirements during flight, leading to weight loss and reduced performance67.
2. Strategies include increasing food palatability and providing high-energy snacks.

F. Space Food System Design

Space Food System Design involves a complex interplay of factors crucial for mission success and crew well-being. Expanding on the pre-mission considerations and key aspects, we can outline a comprehensive view of space food system requirements:

Pre-Mission Considerations

Shelf Life

1. Foods must remain stable for up to five years for Mars missions.
2. Preservation methods include freeze-drying, thermostabilization, and irradiation.
3. Nutritional stability must be maintained throughout the shelf life.

Packaging

1. Packaging must be vibration-resistant and prevent contamination.
2. Labels include preparation instructions compatible with microgravity conditions.
3. Packaging must meet safety and gaseous barrier specifications while minimizing mass and volume.

Menu Development

1. Menus balance personal preferences with standard options to maintain morale and nutrition.
2. As mission length increases, menu cycle length must increase to provide variety.
3. For ISS, a standard menu provides eight categories for a 7-to-9-day usage rate.

Key Aspects of Space Food Systems

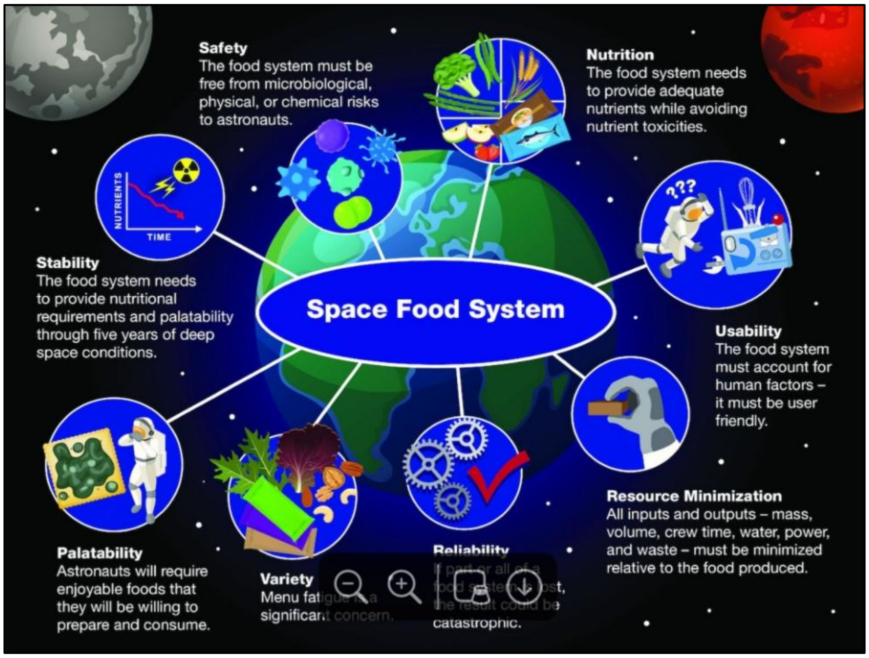

Fig. 1 Visual Diagram of the Space Food System

Safety
1. Food must be free from microbiological, chemical, and physical contaminants.
2. Rigorous testing and adherence to FDA and NASA standards is required.
3. Microbiological safety is monitored by the NASA JSC Microbiology Laboratory.

Nutrition
1. Must meet Dietary Reference Intake (DRI) values with spaceflight-specific adjustments.
2. Provides an average of 3,035 kcal/day per crew member.
3. Balanced macronutrients and essential micronutrients are important.

Usability
1. Food preparation must be compatible with microgravity environments.
2. Easy to prepare and consume to minimize crew time.
3. New food preparation equipment must satisfy safety and spaceflight requirements.

Resource Efficiency
1. Optimization of packaging mass and volume.
2. Minimization of water usage for food preparation.
3. Consideration of power constraints, especially for shorter missions.

Reliability
1. Extended shelf life (up to 5 years).
2. Consistent food quality and predictable nutritional content.
3. Packaging integrity must withstand launch and spaceflight environments.

Variety
1. Diverse menu options to prevent menu fatigue.
2. Inclusion of fresh food when possible.
3. Provision of condiments to allow flavor adjustments.

Palatability
1. Foods must taste appealing to encourage consistent nutritional intake.
2. Consideration of altered taste perception in space.
3. Sensory attributes are rated using a 9.0-point Hedonic Scale.

Stability
1. Long-term microbiological stability.
2. Resistance to environmental stressors.
3. Consistent nutritional and sensory qualities throughout mission duration. [25]

Additional Considerations

Environmental Factors

1. No refrigeration or freezers available on ISS for food storage.
2. Limited water availability for rehydration.
3. Microgravity effects on food preparation and consumption.

Mission-Specific Requirements

1. Adaptation to mission duration and destination (Moon, Mars).
2. Consideration of potential incorporation of bioregenerative foods for longer missions.
3. Balance between prepackaged foods and potential fresh food production.

Crew Factors

1. Accommodation of individual dietary preferences and requirements.
2. Provision of familiar "Earth-normal" food to facilitate acceptability.
3. Consideration of psychological aspects of food in confined environments.

G. Technological Needs

1. Development of space-ready appliances for food preparation.
2. Innovative packaging solutions for extended shelf life.
3. Potential integration with life support systems for longer missions.

By addressing these multifaceted requirements, the space food system aims to support crew health, performance, and overall mission success for future exploration of the Moon, Mars, and beyond.

H. In-Mission Operations

1. Preparation in Microgravity:
    a. Specialized equipment like rehydration units and conduction ovens is used.
    b. Flameless cooking methods minimize fire risks.
    c. The ISS Galley in the USOS includes a conduction food warmer and a Potable Water Dispenser with metered hot or ambient temperature water.
    d. Food preparation must be compatible with microgravity environments and easy to prepare to minimize crew time.
2. Stowage and Waste Management:
    a. Dedicated stowage locations prevent cross-contamination.
    b. Waste management systems handle packaging and uneaten food.
    c. Food may be stowed in various configurations, as long as the packages are protected from chemicals, puncture or damage during transport and in mission.
    d. Packaging must be vibration-resistant and prevent contamination.

I. Risks of Inadequate Nutrition

Inadequate nutrition can lead to:

1. Weight loss, muscle atrophy, and bone density loss.
2. Immune system impairments.
3. Cognitive performance decrements during critical operations.

Historical examples include:

1. Weight loss during the Apollo missions due to inadequate caloric intake.
2. The 1897-1899 Belgica Expedition experienced beri beri (thiamine deficiency) leading to death, shortness of breath, irregular heart rate, and edema.
3. The 1910-1913 Terra Nova Expedition saw weight loss due to inadequate caloric intake (1500-3000 kcal less than expended) and inadequate wound healing due to Vitamin C deficiency.

J. Technical Challenges

Long-duration missions present unique challenges:

1. Developing nutrient-dense foods with extended shelf lives.
    a. Foods must remain stable for up to five years for Mars missions.
    b. Preservation methods include freeze-drying, thermostabilizing, and irradiation.
2. Designing packaging that withstands radiation and environmental stressors.
    a. Packaging must withstand vibration, acceleration loads, radiation, and various environmental factors (temperature, humidity, zero-pressure, and decompression).

3. Addressing taste perception changes in microgravity by providing condiments like hot sauce.
    a. Some crews have noted that spicier foods are desired due to the lack of smell or taste.
    b. Condiments are flown to allow crewmembers to individually alter the flavors of the foods.

K. Training and Documentation

Astronauts undergo training on:

1. Food preparation in microgravity environments.
2. Hygiene practices to prevent contamination during meal consumption.
3. In-flight food safety
    a. Proper food preparation, consumption, and clean up
    b. Food hardware's reuse frequency

Detailed documentation ensures consistency in processes and compliance with regulatory standards, including records demonstrating compliance with federal food regulations and laws. [27][28][29][30]

For additional details and information on the Astronauts Zvezda Life Support Module refer in the "Zvezda Engineering Report"

VIII. References

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