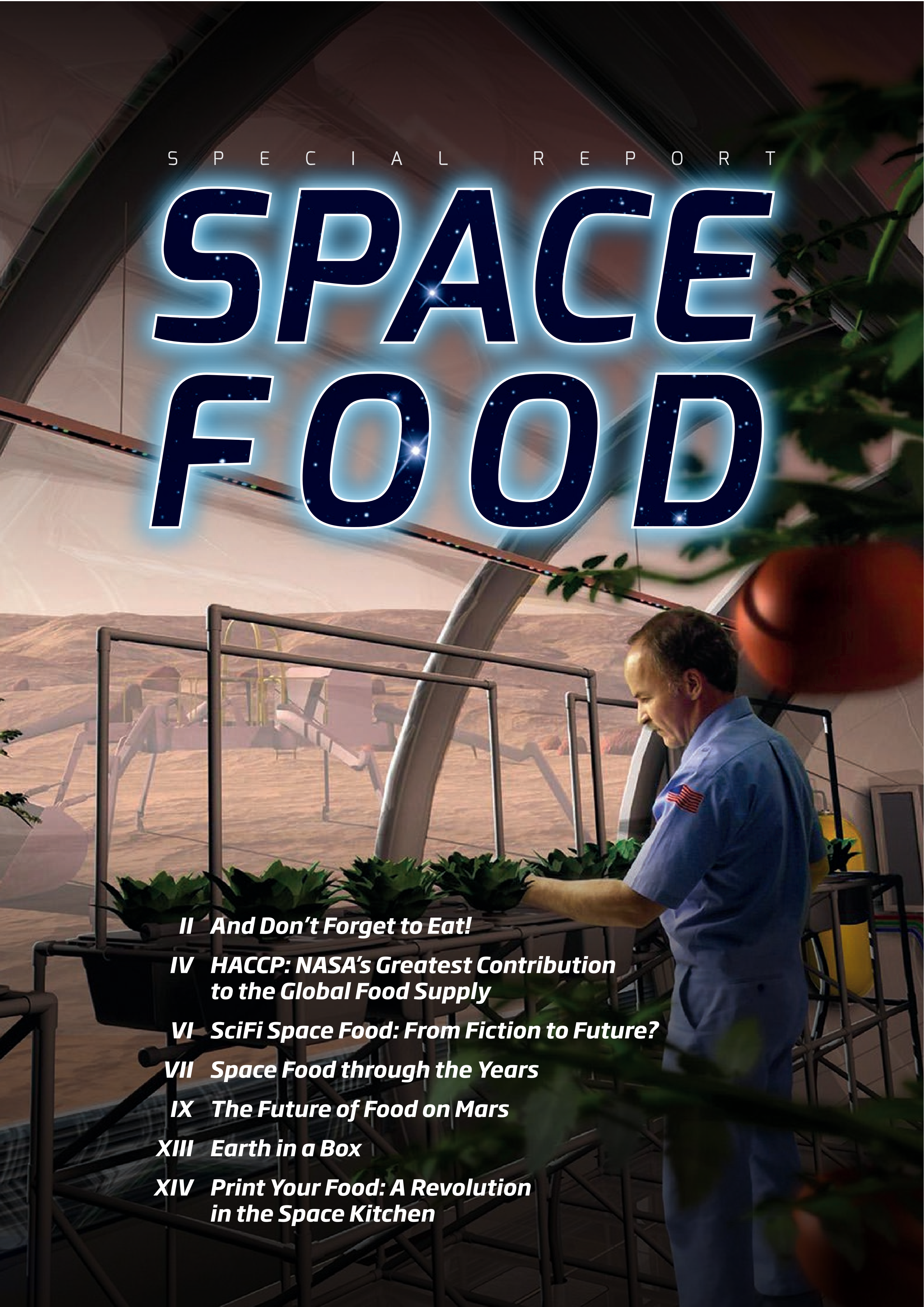
S P E C I A L   R E P O R T

SPACE FOOD



And Don't Forget to Eat!

By Tereza Pultarova

Is Nutrition Key to Success (Not Only) in Space?

Medieval seafarers were losing their teeth, suffering painful wounds, and dying in large numbers due to a condition caused by improper nutrition. And still, with the availability of fresh fish and the rather large size of the ships allowing storage of a decent amount of food compared with confined space capsules, one would say the medieval crews on vessels cruising the world's oceans in the Age of Discovery were in a much better situation than 20th and 21st century astronauts.

It took until 1932 to identify severe vitamin C deficiency to be the main cause of scurvy and to understand that it was actually the lack of fresh fruit and vegetables limiting the success of early maritime travel.

Though modern science has managed to advance the understanding of human nutritional needs up to the level of milligrams of micronutrients a day, getting the right balance in a diet of someone without access to any fresh supplies still remains a challenge. Especially when this 'someone' has one of the most demanding jobs one can imagine.

Charles Bourland, a retired space food scientist who served at NASA since the 1960s, admits that up until American space station Skylab in the 1970s, astronauts, including those landing on the Moon, consumed only about half the amount of food they should have consumed, given the demands of the situation.

"In fact, on Skylab, they had the best intake they've had. I guess the space station crews are getting closer to proper intake now but not even on a Space Shuttle did they have such a good intake as on Skylab," says Bourland, explaining that motion sickness and a packed work schedule have always had a bad effect on astronauts' food discipline.

While such a problem might go basically unnoticed on a short mission, once we consider a months-long journey to Mars and beyond, the astronauts might find themselves in life-threatening situations.

Can Poor Diet Trigger Dementia?

It's not only scurvy. Malnutrition is the root of many conditions and there is no doubt a malnourished crew would hardly perform according to expectations.

In the mid-2000s, NASA helped to discover that malnutrition might not be the result, but the cause of cognitive decay of some elderly people.

Focusing on micronutrients that are also among key nutritional concerns in human spaceflight, the researchers compared two groups of elderly people from Texas – healthy, active seniors and those obviously self-neglectful, displaying symptoms of depression and dementia.

After blood samples were taken and analyzed using a methodology developed for astronauts' nutritional assessment before long duration missions, the scientists have found that while healthy seniors had normal levels of vitamins B12 and D, folate and antioxidants, cognitively-impaired

Securing a balanced diet for astronauts on long duration missions is one of the biggest challenges.
Credits: Bill Ebbesen

Scurvy is one of the well-known conditions related to vitamin deficiencies. – Credits: The UK National Archives

self-neglectors displayed severe deficiencies.

"This study is an example of how NASA research and capabilities not only benefit astronauts, but can contribute to basic science and to public health," said Scott M. Smith, NASA nutritionist at the Johnson Space Center.

"I think that malnutrition may not just be an outcome but may actually be an initiating factor," he says.

Now, let's imagine a mentally (and physically) unfit crew landing on a desolate planet millions of kilometers away from Earth… That's a disaster waiting to happen.

Iron Overdose and Salt Cravings

According to Dr. Bourland, astronauts, similarly to Earthlings, need to consume some 2000 calories a day, with the exact amount depending on their body mass, gender, and activities.

Though many of their nutritional needs are identical to those of Earth-bound people, after more than 50 years of human spaceflight scientists have managed to tune the astronauts' diet to, at least partially, make up for the space-induced changes in a human body.

"They don't need as much iron for example," Bourland says. "In fact the requirements for males and females are the same for iron, while they are different here on the ground where females require more."

The reduced need for iron is a result of the decreased production of blood cells known to take place in space as less blood is needed to power the body.

In fact, consuming too much iron in space could build up toxicity. An iron-overdosed astronaut would become dizzy and tired and could suffer from headaches and weight loss, feel nauseous and short of breath.

With too much iron in the system, the body also cannot absorb zinc properly. In the long term, without reducing his or her iron intake, the astronaut could develop serious problems including liver damage, arthritis, or heart conditions.

Similarly, the balance between potassium and sodium becomes rather delicate in space. Those two compounds maintain the fluid balance of the human body, regulate blood pressure, power cells, and enable neural signal transmission. Some studies even suggest these two elements contribute to healthy bones.

However, as the water economy of the organism changes in space, so does the sodium-potassium equilibrium. Researchers have concluded that, on average, astronauts tend to consume too much sodium and too little potassium. The high content of sodium makes many types of terrestrial food, which would otherwise qualify for spaceflight, in fact, unsuitable.

"Space nutritionists are actually trying to reduce the sodium content because there was some evidence that high sodium might contribute to vision problems they've had on some of the missions," says Bourland, explaining that, as the sense of taste worsens in space, astronauts tend to crave more salt and always find a way to get it.

"On some of the early Shuttle missions, they took some of the salt away from them," Bourland recalls. "Unfortunately, [the astronauts] had salt tablets that they have to take before reentry to retain more fluid and they got some of them and they ground them up and made their own salt."

Leafy Vegetables and the Lack of Sunlight

While early seafarers were suffering from the lack-of-vitamin-C-induced scurvy, in the case of astronauts, vitamin D deficiency becomes a major issue.

Throughout the evolution of men, nature was able to take care of this matter, equipping humans with the ability to synthesize vitamin D in their skin when exposed to sunlight.

However, spacecraft have to be shielded from the Sun, as without the presence of protective atmosphere, the solar rays become too powerful.

Low levels of vitamin D hinder absorption of calcium in the bones and increase bone loss - already a major problem during space flight.

Last year, NASA scientists discovered that the deficiency of folate, the substance identified to be responsible for the cognitive impairments in the elderly, might be one of the causes of vision changes experienced by about 20% of astronauts after an ISS mission. The role of vitamin B12 in this process is yet to be identified.

Like it or not, we are what we eat and space science has helped to advance our understanding of nutrition, not only to secure success of space missions, but also to improve the quality of life for those bound to Earth.

A can of space food floating aboard the ISS. – Credits: ESA

HACCP: NASA's Greatest Contribution to the Global Food Supply

By Merryl Azriel

It is nearly impossible to overestimate the impact that the Hazard Analysis and Critical Control Point (HACCP) system has had on the global food supply. HACCP was invented in 1959 by a collaboration of scientists from NASA, the US Army Research Laboratories, and NASA's space food contractor, Pillsbury. By the turn of the century, it was in use in every corner of the globe.

In 1959, the only accepted method for ascertaining food safety was testing of the finished product. A single batch of food could contain a good bit of variability, so testing 1% of the finished product was no guarantee that the remaining 99% was acceptable. To ensure 100% of a batch of food was safe, it was necessary to test 100% of the batch. Of course, with food testing generally being destructive, that left nothing to actually be eaten.

NASA needed a better way to ensure the foods it sent to space would not make its astronauts sick. The agency started from the systems it knew best and derived a quality methodology inspired by the Failure Modes and Effects Analysis (FMEA) approach to risk management. The philosophy of this approach was to analyze the raw materials that go into a process along with "critical points" at which contamination can take place. By monitoring materials and critical points, the scientists could have confidence in the final product even with limited testing. Critical points could be anything from transportation transfer points where handling could expose raw materials to humidity and high temperatures, to the telephones in manufacturing facilities that collect bacteria which can be introduced to the food system. Some of the earliest critical points identified industrially related to cooking temperatures for canned goods, which must be high enough to ensure no bacteria are sealed inside cans and left to grow.

Once a critical point is identified, analysts devise monitoring approaches and acceptable limits to guard against contamination at that point. For the example of cooking canned goods, monitoring might involve taking temperature readings from multiple positions in a batch to ensure the temperature limit is met. If a sample failed the monitoring testing, corrective actions would be put in place such as increasing the cooking time, improving mixing to ensure uniform heating, or increasing the minimum temperature requirement.

HACCP started out as a set of three principles summarized as: 1) Identify hazards, 2) Determine critical control points, and 3) Establish monitoring procedures. Over time, an additional four principles were added to ensure adequate documentation and provide a pathway to recover from failures. Today's seven principles are illustrated above.

The HACCP system involves seven steps:

1. Analyse hazards
Analyse the whole food production process and identify hazards posed to the safety of food

2. Determine critical control points (CCPs)
Determine critical controlpoints at which hazards can be controlled or eliminated. Common CCPs in food production are in the following process steps: purchase of raw materials, cold storage of raw materials, cooking, cold- and hot-holding of prepared food.

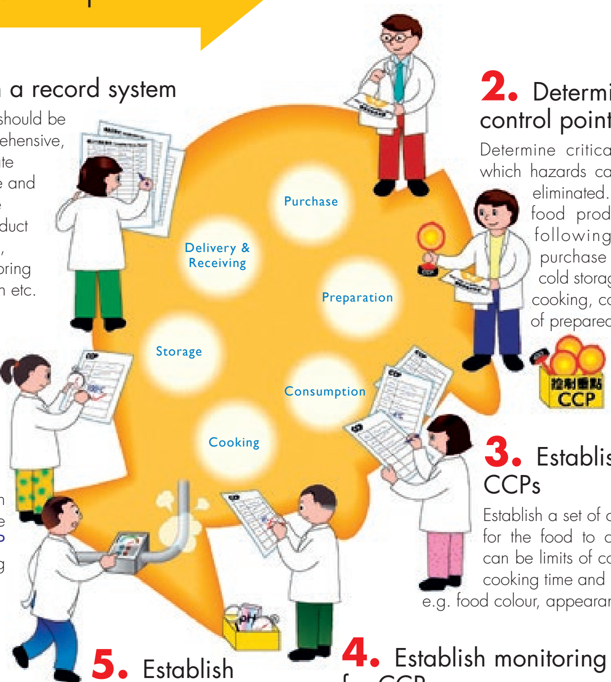
3. Establish limits for CCPs
Establish a set of clear limits for CCPs for the food to comply with. These can be limits of cooking temperature, cooking time and physical properties, e.g. food colour, appearance, texture, etc.

4. Establish monitoring procedures for CCPs
The puposeof monitoring procedures is to assure that the food meets the limits set for CCPs, e.g. the temperature limit, or cooking or cooling time limit. Major monitoring procedures include visual inspections and physical measurements such as temperature readings. Besides, the frequency and time of the monitoring procedures should be specified.

5. Establish corrective actions
Establish corrective actions in advance for CCPs so as to correct deviations of the limits quickly and prevent unsafe products from entering into the market.

6. Establish verification procedures
Establish verification procedures to ensure that the HACCP system is functioning properly.

7. Establish a record system
A HACCP system should be supported by comprehensive, effective and accurate records for reference and review. They include records on food product safety, process steps, food storage; monitoring and corrective action etc.



HACCP is now deployed worldwide, as demonstrated by this HACCP guidance, taken from the Hong Kong Food and Environmental Hygiene Department's website. It is reproduced under a license from the Government of Hong Kong Special Administrative Region. All rights reserved.

A Slow Start

It's kind of ironic that NASA actually didn't follow the HACCP process for a long time," says retired NASA food scientist Charles Bourland. Bourland played a key role in the development of modern space food in his 30 year career with NASA, from 1969 to 1999. He explains that, in typical NASA fashion, the organization was reluctant to transition from a system that appeared to be working to the new-fangled HACCP. "They were doing the old NASA system where they were inspecting everything," recounts Bourland. "For years we had a total plate count of 10,000, anything over 10,000 was not acceptable for food for space." Total plate count is a measure of the number of microbial colonies living in a particular sample. According to Bourland, a count of 10,000 is "practically sterile," as most food is perfectly safe at counts of 20,000 or even 30,000. As a trained microbiologist, this misapplication of resources in testing to an inappropriate standard frustrated Bourland and he went to work trying to change the system. The limit was driven by the fear that even low levels of microorganisms could lead to in-flight illness for immune-compromised astronauts. This fear was eventually laid to rest and Bourland's argument carried the day. "I fought that for years and I finally convinced them," he says. "Now they do a true HACCP."

Before NASA saw the light, however, Pillsbury took the system for a test drive.

Contamination Drives Adoption

In March 1971, a customer discovered bits of glass in a farina product produced by Pillsbury – and widely used as infant food. Glass shards in baby food was predictably bad for sales and Pillsbury's CEO at the time was determined to not only reassure the public, but also to safeguard against any future recalls under his watch. He called in company microbiologist – and co-creator of HACCP – Howard Bauman and gave the go-ahead to implement HACCP at the company.

Just a few days later, Bauman was introducing HACCP publicly for the first time at the National Conference on Food Protection, sponsored by the American Public Health Association. The audience was not impressed, but by the end of 1971 they were forced to reconsider. In June, a man died after tasting canned vichyssoise made by Bon Vivant. The can was contaminated with botulism and eventually the brand's entire product line was recalled. Shortly thereafter, Campbell recalled its chicken soup after identifying botulism in a batch. Fortunately no one was sickened from that incident, but the botulism streak was not yet complete. The next to fall was Stokley-Van Camp's canned green beans. By that point, the public was on edge and the research director of the National Canners Association called for help: "We just don't think the canning industry can tolerate any more bad publicity," he said. The US Food and Drug Administration (FDA) was under the gun for not providing better consumer protection. In short, HACCP's time had come.

In 1972, Pillsbury representatives delivered the first HACCP training course to FDA inspectors. Use of the system around the world predictably followed on the heels of any major food poisoning or contamination incident, spreading from canning to meat processing plants to fast food restaurants, from the United States to Australia, Europe, and Asia. Two decades later, any remaining holdouts adopted the system when a joint task force of five US government food safety and health agencies recommended it, followed shortly thereafter by the United Nations' World Health Organization. The system is now required by food and drug agencies and associations around the globe. NASA, of course, is still a loyal adherent to the remarkable system it instigated over 50 years ago.

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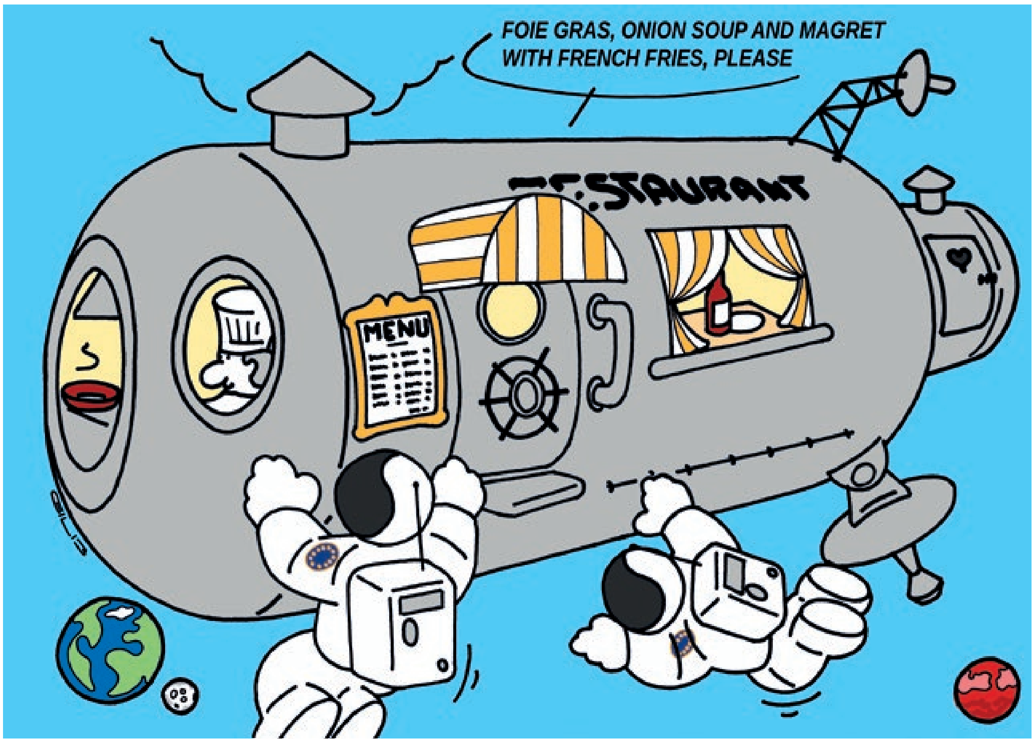
Vegetables being prepared for freeze drying at NASA's Johnson Space Center Space Food Systems Laboratory. HACCP principles still keep astronauts' food supply safe throughout its complex processing. – Credits: NASA

SciFi Space Food: From Fiction to Future?

By Merryl Azriel



Space dining. – Credits: Gilles Labruyere.
Gilles is Principal Mechanical Engineer of the Aeolus satellite at ESA, and previously of Envisat. He has been drawing space related cartoons since 1994.

Science fiction has always exerted a strong influence on scientific and engineering creativity and development. What has once been imagined becomes an object of pursuit, and before you know it we have cell phones, touch screens, and robotic vacuum cleaners. So if we want an idea of what space food will look like in the future, what better place to turn than the seething mass of ideation that is science fiction?

The most iconic of all fictional space foods derives from Star Trek's replicator. With a swirl of light and sound, this magical-seeming contraption produces food and drink in any form and flavor – dishes included – built up from the atomic level. Leftovers and dirty dishes are simply placed back in the replicator, where they are deconstructed and turned into the next dish. The replicator idea has received fresh attention with the success of 3D printing technology (*see Print Your Food: A Revolution in the Space Kitchen*, p.XIV). While not yet able to turn a plate into your next soufflé, 3D printed foods have the potential to ward off food fatigue on long missions without the inconvenience and volume of individual packaging, shelf life, and form factor constraints.

Recycling is a common theme in space food both fictional and real. The International Space Station effectively recycles urine – as astronaut Don Pettit describes it "turning yesterday's coffee into today's coffee." But fiction has gone even further, such as in the Dr. Who episode Gridlock (2007) in which the population of New New York spends decades commuting through exit-less traffic tubes in hovering, self-sufficient cars. With no access to supplies en route, each car is equipped with a contraption to turn the occupants' waste into cracker-like wafers for sustenance.

Dystopian fiction plumbs even darker depths in the hunt for food. The concept of unwitting cannibalism introduced in films such as *Soylent Green* and *Cloud Atlas* suggests the logical but repugnant step of recycling dead humans (or human-like "fabricant" clones) to maintain the living. It is not difficult to imagine the solution being a logical temptation on harsh planetary colonies in which the nutrients that go to feed any individual are precious and colonists cannot afford waste of any variety.

Frank Herbert's *Dune* novels explore another aspect of recycling the dead with "deathstills." On the desert planet Arrakis, water is so rare that every drop must be preserved, so all water from the dead of the Fremen desert dwellers is removed using the deathstill and returned to communal reservoirs. Might such a measure be necessary on Mars one day? It is difficult to rule it out.

Despite these flights of fancy, the majority of science fiction envisions food in future space looking a lot like the food we eat today. Produced through hydroponics or in petri dishes, these versions of the future may not represent a lack of imagination so much as an acknowledgement of the reality that food, along with its preparation and form, is an important cultural element in every human society that has ever existed. Odds are, it will remain so for some time to come.

Space Food through the Years

By Merryl Azriel

Introduction

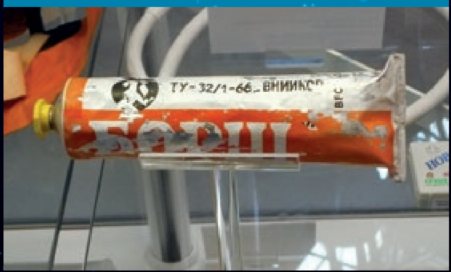
When humans first ventured into space, no one was quite sure whether bodily functions – such as swallowing and digestion – would even work properly. Yuri Gagarin effectively dispelled that feared limitation by successfully consuming tubes of meat paste and chocolate sauce. But that was just the beginning of the space food challenge, as experience and technology helped hone dense nutritional packages into something that more closely resembling recognizable, even appetizing, food. The journey is far from over, with production of fresh food in space the ultimate hurdle to deep space exploration and independence from the continuous stream of resupply vessels that maintains the International Space Station crew today. Nevertheless, space food has come a long way since 1961.

ISS Expedition 20 shares a meal. – Credits: NASA

Toothpaste Tubes

The first space food consisted of viscous fluids packaged in aluminum tubes: Gherman Titov had soup puree, John Glenn had applesauce and beef-vegetable puree. The tube form was effective for use in microgravity: by simply squeezing the tube, an astronaut could dispense a controlled quantity of food without leaving bits floating in the spacecraft. They were deeply unpopular, however: "I could not rid myself of the sensation that I was about to squeeze a whole tube of toothpaste into my mouth," related Titov in his book *I Am Eagle*. Below, a tube of Russian borscht soup.

Image Credits: Photographed by Wikipedia user Aliazimi at the Smithsonian Air and Space Museum



Gelatin Coated Cubes

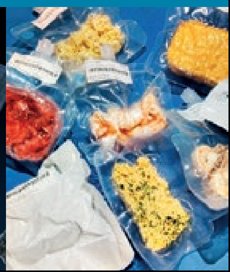
Bite size cubes were another feature of early space food. It quickly became apparent that even food designed to be eaten in one bite could generate crumbs – particularly during the high vibrational loads experienced under launch conditions – that posed an inhalation hazard in microgravity. They also had a tendency to form a sticky/greasy surface coating as a result of the vacuum packaging process. So in the days of Gemini, cubes were coated with a layer of gelatin designed to circumvent these problems. Cubes were made in all kinds of flavors including strawberry cereal, bacon and egg, and pea.

Image Credits: NASA

Rehydratable Freeze Dried Foods

Rehydratables made their appearance early in the US space program, but throughout Gemini they remained fairly cumbersome and unappetizing. Room temperature water was added to a plastic pouch, kneaded to form a reconstituted paste, then squeezed into the mouth through a tube. Apollo saw two changes that radically improved the acceptability of rehydrated foods: hot water and the spoon-bowl (pictured, below left), which allowed astronauts to spoon foods out of their pouch packaging rather than mushing them into baby food. With the new system, shrimp cocktail became a perennial favorite.

Image Credits: NASA



Coke

Astronauts have access to a variety of flavored drinks while in space, but soda and other carbonated beverages are not among them. As pressure vessels, packaged soda poses a hazard inside a spacecraft and carbon dioxide bubbles can quickly come out of solution making a foam out of the entire fluid – a potential (and sticky) disaster. If the bubbles stay in, astronauts are faced with another problem: wet burbs. In space, gaseous bubbles don't separate out from other fluids in the stomach, so when they come up, so does everything else. Starting in 1985, Coca-Cola, and to some extent Pepsi, tried to solve these problems. They designed special space cans with controlled dispensing; Coca-Cola tried baffles, Pepsi based theirs on a shaving cream can construction. Coca-Cola later tried dispensing from a chilled fountain while on orbit into a bag-within-a-bottle to maintain constant pressure. They even tried mixing in the carbon dioxide in space, although that machine ended up not working. Ultimately, they were able to make a drinkable coke, but never able to do anything about wet burping, and carbonated beverages are not available on ISS today.
Image Credits: Nat Hansen

Bread

One of the most famous space food stories is that of John Young sneaking a corned beef sandwich aboard Gemini 3. The escapade ended up not being worth the trouble since the bread turned dry and crumbly due to the high oxygen environment. Both the USSR and the US sent up sanctioned bite-size rolls, but astronauts on longer missions always talk about missing real bread. During Apollo, NASA gave bread a second chance: the crew was provided with fresh bread (pictured here), flushed with nitrogen before packaging to prevent its rapid oxidation. It really didn't work very well: once again due to high oxygen levels, the bread tended to mold quickly. Today, ISS crews prefer to use tortillas as a bread alternative due to their long shelf life and low crumb production.
Image Credits: NASA

Alcohol

Cosmonauts have a long history of drinking in space, on the recommendation of their doctors. While vodka is the top Russian drink on Earth, cognac took precedence in space. A quick drink was seen as a way to recover from the strenuous work and psychological tension of long term spaceflight. Eleutherococcus tincture was also prescribed for medicinal purposes. Despite hosting experiments on beer fermentation, NASA has never permitted alcohol consumption during missions; on the occasions when offered a drink, NASA's astronauts (reportedly) dutifully declined: in the picture below, for instance, astronauts Thomas Stafford and Deke Slayton toast their crewmates with vodka-labelled tubes of borscht during the Apollo-Soyuz Test Project.
Whether consumption of alcoholic beverages takes place on ISS – against NASA regulations – is kept tightly under wraps, with the notable exception of a 2008 video by Ukranian cosmonaut Yuri Malenchenko demonstrating the properties of fluids in microgravity with a shot of vodka on the occasion of his birthday.
Image Credits: NASA

Kimchi

It's a general rule when an astronaut goes on a mission, he or she takes with them at least a sampling of national dishes. Japanese astronauts bring inari, ramen, and rice (an array of typical Japanese foods can be seen on the right). Taikonauts are big on dumplings and lotus seeds. Cosmonauts tend towards beets and fish. Generally, these foods are made space-ready using the typical cans and pouches with no more than the usual fuss. When South Korea's first astronaut took to orbit, though, she faced a major challenge. Kimchi, the quintessential South Korean dish, is loaded with the bacteria from its fermentation process – and bacteria's access to space is strictly limited (*see HACCP: NASA's Greatest Contribution to the Global Food Supply* p.IV). Millions of dollars went into overcoming the challenge. The resultant space kimchi was irradiated to kill the bacteria and reduce the odor, which could be unpleasant in an enclosed spacecraft, by 30-50%. Roscosmos approved the dish for the 2008 flight of Yi So-yeon (seen on the left).
Image Credits: Korea Aerospace Research Institute, NASA

The Future of Food on Mars

By Michelle La Vone

A manned mission to Mars poses a long list of concerns related to physiological and psychological well-being. Scientists know that food is, in a large sense, the ultimate determinant of survivability in a foreign and hostile environment. But how will the space crew ensure they receive adequate nutrition with taste to boot?

"The variety and acceptability of the food system is critical to maintain adequate consumption," says Dr. Grace Douglas, a project lead at the Johnson Space Center in Houston for NASA's Advanced Food Technology Project. "Ensuring the variety and acceptability of the food over the long duration of these missions is just as important to nutritional maintenance as providing stable nutrition in the food itself." That means finding ways to provide the astronauts not only with food that has a little pizazz, but also with efficient methods of food production that minimize crew time and reduce stress.

Space food researchers have delved into the concepts of home-cooking, bioregeneration, and astrogardening to develop a system that's sustainable, affordable, efficient, and transportable.

Welcome home, Mars crew. Let's grab something to eat! (Photo taken by the Curiosity Rover in July 2013.) – Credits: NASA/JPL/Caltech

Space Cubes Again? How to Avoid Menu Fatigue with In-Space Cooking

In 2013, six researchers gathered together in a Mars-simulated environment known as the HI-SEAS (Hawaii Space Exploration Analog and Simulation) dome on an abandoned lava field in Hawaii. They conducted a variety of experiments related to sleep, hygiene, and robotic companionship, but their main purpose was to see how home cooking would impact astronaut morale and nutrition.

"The study provided an opportunity to bring together a number of key questions in food system design for space life support," says Cornell University associate professor Dr. Jean Hunter, one of the study's key investigators. "Are crewmembers happier with the convenience of prepackaged foods or the creative opportunities of cooking for themselves? How exactly is food quality related to mood? What are the costs and inefficiencies of a crew-cooked food system?"

Hunter and co-investigator Dr. Kim Binsted of the University of Hawai'i at Manoa designed the study based on the premise that Mars gravity is one-third of Earth's and can hold things in place for food prep, like mixing and cutting.

The crew was provided with hundreds of boxes of shelf-stable ingredients and pre-packaged meals, meaning that on the no-cooking days, they ate like any regular astronaut would.

The six researchers derived cooking inspiration from their ethnic backgrounds and submissions from a publicly announced HI-SEAS recipe contest. Winning entries included a "spam'n'egg baowich" (with "baos" referring to Chinese buns), "campfire hash" (ingredients included a whole lot of rehydrated vegetables and some Mexican spices), and "dark matter cake" (using coffee, cocoa powder, and mayo).

"Cooking is a great way to express caring for your fellow members by making their favorite dishes, or simply by putting effort into making a meal as tasty as possible," says Binsted. "Cooking and eating together is like social glue."

The researchers returned home from faux Mars in August. "We're still working hard on the data analysis. This isn't the kind of study that yields definitive, exciting findings immediately. We've got a lot of slogging to do," says Hunter. "[That said], the crew strongly believes that their home-cooked food was a key contributor to crew morale."

Although hands-on tasks are known to engage and uplift the human spirit, cooking on Mars may produce a negative or neutral effect over time. After all, passion and excitement for an activity fades fast when its sense of novelty is replaced with necessity. Additionally, cooking on Mars presents another issue: no easy resupply.

"Even if they [the crew] eat prepackaged foods from individual storage lockers, the more desirable items will be consumed earlier and the less desirable items will tend to accumulate, unless traded among crewmembers. Going to a crew-cooked food system kicks the problem up a notch, because it's harder to predict which ingredients will be used intensively," Hunter explains. "We packed couscous for the crew according to its usage at the Mars Desert Research Station over a couple of years of two-week crews. But this [HI-SEAS] crew took a real liking to it, ran through what we thought would be a whole mission's worth in a month, and clamored for more."

That said, according to NASA food scientist Dr. Charles Bourland, astronauts on the ISS use a menu to skirt the problem of food shortage. "They have a pantry up on the space station so they can get whatever they want. We didn't ever believe that would work," he said. But, it has. "They plan the food based on a menu and they apparently follow that menu somewhat, but they don't ever run out of anything." Something similar could easily be done on Mars.

The best bet, Hunter suggests, is to rely on a hybrid food system based on a combination of prepackaged foods, shelf-stable ingredients, and greenhouse-grown foods, although the ultimate solution likely will boil down to costs.

Russian cosmonaut Valery Korzun monitors plant growth inside the Lada chamber on board the ISS. – Credits: NASA

"For a mission lasting a year or more, I think that home cooking with dehydrated foods and a few fresh herbs and salads will be feasible, with prepackaged 'ready' foods as a backup on busy days or when equipment needs repair. The larger the crew, the greater the economic advantage of cooking and gardening on Mars," she says. "However, only very large, long-term colonies are likely to grow staple crops and approach food self-sufficiency."

Eating Fresh: Hydroponic Bioregeneration

Scientist Dr. Raymond Wheeler believes that in time, bioregeneration can sustain large crops for long duration missions. He's even not too hesitant to suggest the possibility of "growing" other edible life forms, too, like fish.

"The gravity on Mars greatly simplifies things. Water runs downhill, heat rises, animals can stand up, fish can swim normally," he says, adding that bringing animals into space could help reduce inedible food waste. That said, engineering a perfectly-fitting protective goat suit may still be a century off.

As it stands now, silkworms have been considered, mainly by Chinese and Japanese scientists, as a promising means to fertilize plants while providing astronauts with substantial animal protein. The challenge here is self-evident, at least for American astronauts. It all comes back to those cultural preferences. Home-cooked silkworm stew with ginger, anyone?

Before the Mars crew ingests anything like goat milk or silkworms, scientists first must tackle the challenges associated with growing edible plants. This means recognizing and understanding plant physiology — like changes in root growth and nutrient uptake — in microgravity. It also means addressing issues like lighting and temperature.

Using a variety of shelf stable ingredients and dehydrated foods, the HI-SEAS crew experimented with ways to create concoctions that not only satisfied the stomach but excited the pallet. Pictured above is lemon dill pasta salad. – Credits: Sian Proctor

A selection of current space food. – Credits: NASA

In 2009, University of Florida's Dr. Anna-Lisa Paul and colleague Dr. Robert Ferl studied mouse-ear cress in detail and came across an encouraging find: that even without gravity to guide them, the plant's roots in space grow in the direction that maximizes nutrient availability and uptake.

For decades, scientists have thought that a certain feature of root growth known as "skewing" — a growth behavior plants use to navigate obstacles on Earth — was dependent on gravity, as suggested by countless experiments of growing plants on slanted surfaces whose roots skewed left or right, not directly along the surface.

"What our data showed was that gravity is in fact not required for skewing," Paul says, "and further, that inherent features of cell growth and root development form the basis for the behavior."

The skewing data help illustrate the fact that plants can grow normally with almost zero gravity, and this supports the notion that plants will do "just fine" on Mars, where gravity is one-third of Earth's.

Currently, NASA is funding a Vegetable Production System project, or VEGGIE. VEGGIE is a 7 kg chamber about the size of a microwave oven used for lettuce, cabbage, peas, and other vegetables. NASA plans to send the system to the ISS later this year. The system relies on light provided from multi-colored LEDs and draws in ambient air to cool the chamber and supply the plants with carbon dioxide.

The intent of the project was to create a very simple low-cost system capable of growing edible plants in space.

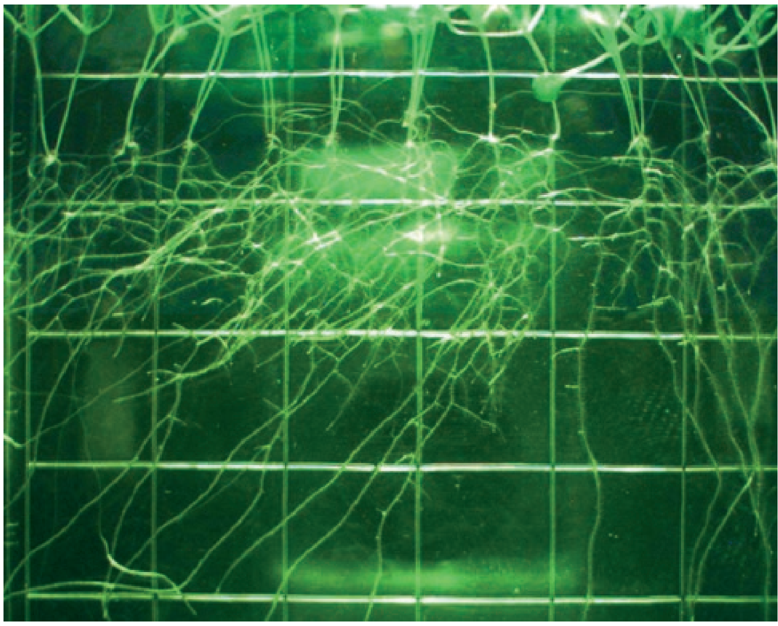
"VEGGIE is a great first step to demonstrate small amounts of food production on the ISS from plants. Something that might be similar to VEGGIE could then be used in a transit mission to and from Mars," says Wheeler, who served as a NASA liaison for the chamber's development, adding that evolution will breed the ultimate food production system. "You expand infrastructure over time."

Wheeler also served as the NASA liaison for another low-cost growth chamber, Lada, developed by the Space Dynamics Laboratory (SDL) at Utah State University Research Foundation in cooperation with the Russian Institute of Biomedical Problems. First used in 2002, the Lada chamber has grown crops of peas, mizuna, tomato, radish, and wheat.

"Our latest Lada-grown crop, Mizuna, still shows some extra oxygen stress gene activity, but physically the plants look and taste like Earth-grown comparison plants," says Dr. Gail Bingham, a senior research scientist at SDL and manager of Lada's VPU-P3R project. "In addition, since space is limited in the crew cabin, small high-yielding varieties are critical. Extensive work is being done to develop smaller, high-yielding plants that could support space flight."

The plants are frozen and carried back to Earth to test for any signs of harmful bacteria and physiological and genetic stress. "The Russians have certified Lada-grown veggies for consumption; the US has not," says Bingham, explaining that the US is hesitant to label the plants as safe because some microorganisms in space have been known to become more virulent.

These space-grown plants may not only serve a physiological function for the crew members but a psychological one as well. In 2012, ISS NASA astronaut Don Pettit dedicated a blog to "little zuc," a sprouting zucchini grown aeroponically (with a root ball and sprinkle of water), who was quoted saying "I have new leaves! I am no longer naked to the cosmos." And in 2010 and 2011, four of the six researchers in the ESA Mars 500 experiment indicated their mental health was helped by the presence of plants, at least by a little, according to Bingham. He said that in the end, it comes down to individual and cultural preferences. "The Russian crew members that run the Lada experiments have the 'dacha' tradition of growing gardens and would be more dependent on having living plants along," he offers. "However, anyone that has



A plate of Arabidopsis plants grown on the space station demonstrate skewing behavior. – Credits: Anna-Lisa Paul and Robert J. Ferl, University of Florida

Artist's conception of a future Martian greenhouse. – Credits: NASA

been on the station or on a long camping trip with preserved food will tell you the psychological value is tremendous to get something in your mouth that has some turgor and crunch."

The idea of bioregeneration extends not just to in-orbit growth chambers but also to surface-based greenhouses.

"There are no fundamental restrictions to growing plants on orbit, or in a Martian greenhouse, other than paying attention to basic needs of the plants and the cost of creating and transporting the engineering to meet those needs," says Paul. "This is one reason we as a community are thinking that an excellent option of a greenhouse on the moon or Mars is one that runs at a lower atmospheric pressure. Plants do fine at low pressures — although they do respond by engaging a number of metabolic pathways in response to it — and it would take far fewer resources to support such a greenhouse."

Mars greenhouses could capitalize on natural light instead of LEDs, but that would result in direct exposure to radiation from the sun or solar storms, requiring astronauts to suit up every time they tended to the plants. Because of these logistical issues, scientists have also entertained the idea of using "farmer robots." As one example, ESA is engaged in the design and development of a humanlike mechanical arm that could one day provide crop surveillance, cutting of leaves and weeds, progressive harvesting, transport of crops to storage sites, and more.

Being Resourceful: Using Martian Soil

The Phoenix Mars Lander mission has already determined that Martian soil has a pH and salt content similar to that of Earth's, even though the nitrogen content is remarkably lower. It has also detected perchlorates — chemicals toxic to humans — widespread in the soil. Some scientists are optimistic there is a work around. The base question, perchlorates aside, is whether or not Mars soil could actually produce plants. Netherlands scientist Dr. Wager Wamelink has been one of the first to study NASA-supplied artificial Mars soil (composed of sand taken from a Hawaiian volcano) in a controlled environment. He found that plant species germinated on the Mars soil, but growth thereafter was stunted.

"I think that I will be able to cultivate plants on the Martian-like soil NASA now provides within five years," says Wamelink. "Actually, the soil looks very promising and to be one of the more productive soils, even compared to some Earth soils. Doing it on Mars is something else."

In Conclusion

Fresh foods definitely offer an improvement to the current space meals and will likely be a requirement, not a perk, to future Mars habitation. Combining the fresh foods with prepackaged ingredients over a stove top could bring a rare sense of satisfaction in the desolate Mars landscape. Scientists still have decades' worth of research to conduct and not just for the purpose of settling Mars.

"I see the whole effort of understanding bio regenerative life support for space as having a lot of parallels for understanding sustainable living on Earth," says Wheeler. "I think as we learn about one, we learn about the other."

Anna-Lisa Paul says, "The more we understand how plants respond to novel environments like spaceflight, the more we understand about the fundamentals of how we, and the biology that surrounds us, can adapt to a changing world."

Earth in a Box

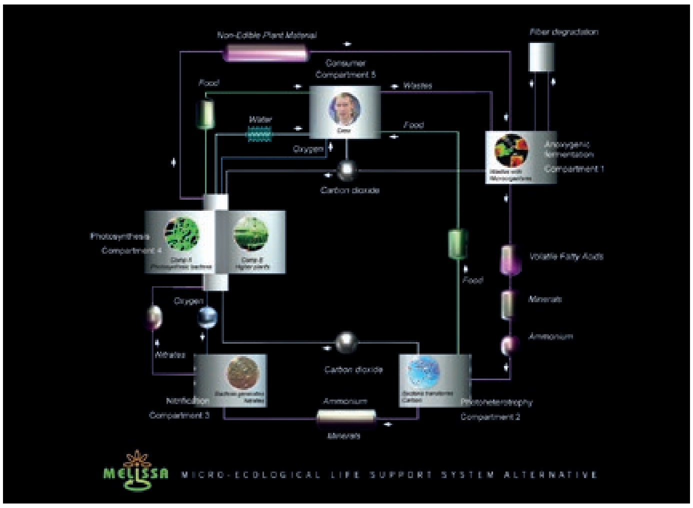
By Tereza Pultarova

Spacecraft travelling to Mars and beyond should be as self-sustainable as possible, enabling the crew to survive solely with the resources brought from Earth – recycling food, waste, water, and oxygen.

To achieve something like that, researchers have to recreate processes that function on Earth by default, an Earth-like ecosystem in a box.

One project to do just that, named MELISSA (Micro-Ecological Life Support System Alternative), is currently underway under the auspices of the European Space Agency. So far, supporting a 40-strong rat crew, MELISSA can supply 100% of the oxygen the animals need and about 20% of their food.

Whereas the technology for recycling water and exhaled carbon dioxide has already been proven in flight, including fecal waste into the loop and eventually retrieving edible food is yet to be perfected.



A self-sustainable ecosystem such as ESA's MELISSA, will be crucial for any future manned deep space mission. – Credits: ESA

How Does It Work?

An aquatic ecosystem in principle, MELISSA consists of five compartments colonized by thermophilic, anaerobic, photoheterotrophic, nitrifying, and photosynthetic bacteria; higher plants; and the rat crew.

Waste produced by the crew together with non-edible parts of higher plants and the microbial biomass is collected in the **liquefying compartment**. Anaerobic bacterial strains transform this waste into a liquid mixture of ammonium, hydrogen, carbon dioxide, volatile fatty acids, and minerals which is then transported further down the system.

In the **photoheterotrophic** compartment, hydrogen and carbon dioxide are separated from the rest of the products. While carbon dioxide can be sent directly to the plants and algae compartment, handling of hydrogen requires special care due to its high explosiveness.

Inside the **nitrifying compartment**, ammonium is transformed into nitrates, providing the most favorable source of nitrogen to fertilize the higher plants and algae and boost biomass production.

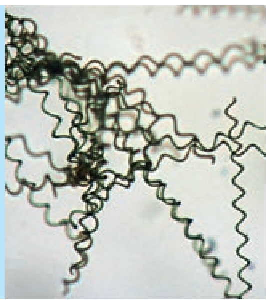
The **photoautotrophic** compartment consists of two parts: the algae sub-compartment colonized by cyanobacteria and the higher plant compartment where crops such as wheat, tomato, potato, soybean, rice, spinach, onion, and lettuce are grown. Both sub-compartments, with the help of light, further purify the liquid waste turning it into drinking water and produce oxygen on the way.

The fifth compartment is the crew's living quarters.

"We have already connected all compartments on the liquid phase for a preliminary demonstration," says Christophe Lasseur, who is managing the MELISSA project on behalf of ESA. "We have connected the spirulina and the mice-crew compartment for 6 weeks to demonstrate carbon dioxide and oxygen recovery and we plan to fly spirulina at the end of 2014 onboard the ISS."

What Would a MELISSA-Supported Crew Eat?

The food produced by MELISSA would be purely vegetarian. Some of the proposed plants belong to staple crops, such as wheat, potatoes, durum wheat, lettuce, beet, kale, or soybean. However, some rather unusual foods would also be harvested. Due to its high content of essential micronutrients and its incredible purifying capabilities compared with higher plants, micro-algae, such as spirulina, would become an important part of the system and thus of the crew's diet. Spirulina, rich in protein and basically all essential nutrients and vitamins, is a popular food supplement consumed by many Earthlings to boost health and immunity.



Print Your Food: A Revolution in the Space Kitchen

By Carmen Victoria Felix

Over the course of 2013, NASA has set its sights on 3D printing, a technology that has the potential to cut space mission costs by enabling printing of various parts of the International Space Station (ISS) hardware while in orbit. According to recent developments, 3D printing may also shape the future of space food for long duration missions.

Long term storage, preservation, and transportation of food has always been a challenge, especially while maintaining all the nutrients required for a balanced diet, whether on Earth or in space. So far, there has been limited food storage capacity on ISS, and continuous resupply has been needed. However, regular resupply won't be possible over the course of a long mission to Mars that would require further reduction of cargo mass and volume. Now, with an unexpected development in the space industry, 3D printing might offer a solution by allowing astronauts to print their own food while in space.

NASA Paves the Way

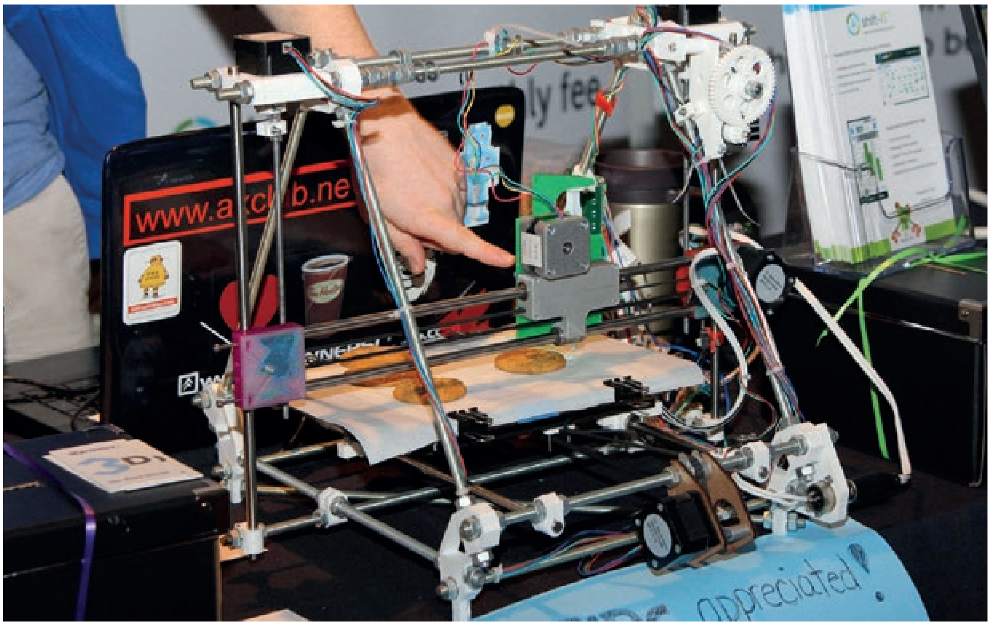
Earlier this year, NASA announced its decision to fund a project to develop a device that can produce on-demand food production similar to Star Trek's fictional replicator – a science fiction device capable of replicating food, water, uniforms, spare parts, and common objects. Systems and Materials Research Corporation (SMRC), based in Texas, received a six-month contract and a grant of $125,000 from the Agency through the Small Business Innovation Research (SBIR) program. The company will look into the feasibility of a space 3D food printer that would include all the nutrients astronauts need while reducing waste, storage demands, and preparation time.

Would You Like a Space Pizza?

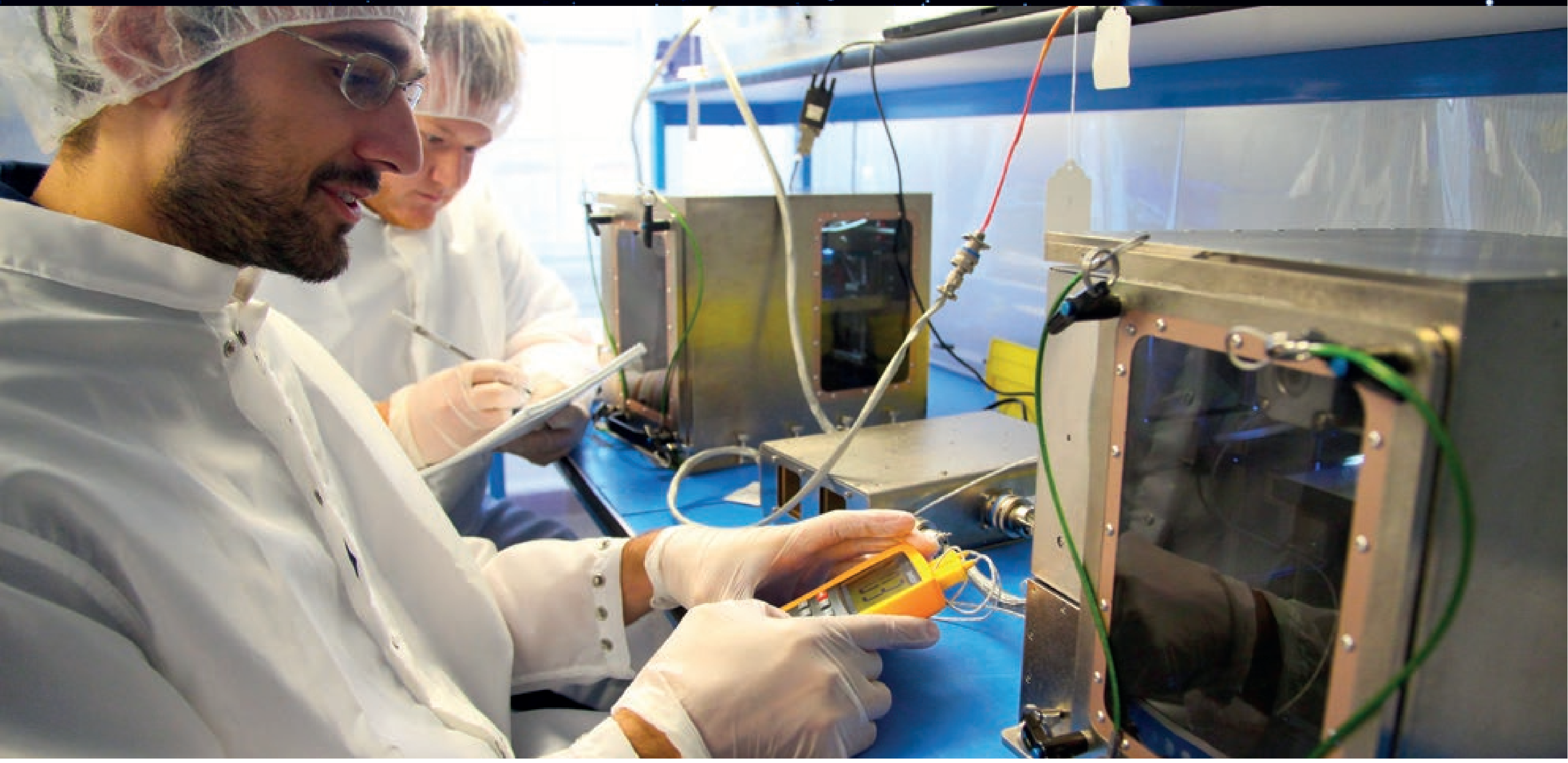
SMRC's technology has already proven its ability to print chocolate bars, and now it will be used for something more elaborate. Lovers of Italian food will be delighted to know that SMRC has planned to test its 3D printer by printing a space pizza. David Irvin, the director of research at SMRC, pointed out that pizza is the ideal candidate because it consists of a variety of nutrients and flavors and has several layers, which can be easily created by the 3D printing technology. With a pizza, the technology's ability to produce solid food, flexible mass, and melted substances can be tested all together.

How Would It Actually Work?

The system will include a micro and macronutrient storage system providing maximum shelf life for the nutrients, a mixing system to create a solution from the nutrients, and a 3D dispenser to add flavor and texture. All the starches, proteins, and fats would be stored in powdered form in containers. When a crewmember chooses a dish from a menu, the ingredients will be mixed and blended with water and oil. This final mixture will then be heated and sprayed layer by layer, following a predefined recipe, until completion. Astronauts will be able to communicate with Earth and receive new and personalized recipes.



Using a modified RepRap, 3Dprintler 3D printed icing on cookies at TechLinks Ottawa in November. – Credits: 3Dprintler



SQ & MA Lead Matthew Napoli works with a printer in the Made in Space clean room. – Credits: Signe Brewster

In addition to the advantage of saving storage space and creating ready to eat meals, SMRC's 3D printing would reduce waste to zero by entirely eliminating packaging – a bonus for long distance missions.

The Advantages of 3D Printing in Space

The printer would provide a complete set of nutritious food with a pre-printed shelf life of up to three decades, perfectly suitable for long duration missions beyond low Earth orbit (LEO). The device will be designed to deliver starch, protein, and fat, creating food with more natural structure, texture, and even flavor and aroma, than the current space food, which undergoes heavy processing like thermo stabilization, sterilization by ionizing radiation, and freeze-drying. This new technology could make it possible to produce food that would meet the nutritional requirements of each individual crewmember, improving health and providing a wider range of food options to avoid monotony.

However, the scientific community is not unanimous in its enthusiasm for the food 3D printing vision. Dr. Gail Bingham, a senior research scientist at the Space Dynamics Laboratory (SDL) at Utah State University Research Foundation, thinks the printed food would not feel and taste like naturally grown and cooked food, lacking robustness and freshness. "I find it hard to believe that food produced that way will be much different than some of the pasty, gooey things that kids find in their lunch boxes and quickly tire of," he says. "I am not an expert, and may have a lot to learn. I think forming the cell structure that provides a lot of the enjoyment of our fresh food will be hard to replicate."

NASA has been interested in 3D printing not only for use on long duration missions, but also due to the huge implications the capability to print objects and tools in orbit would have. Similarly to the Star Trek replicator, which could create any object as long as its specific molecular sequence was known, 3D printers in space would enable replacing lost tools or broken parts without the need to wait for resupply. That would, of course, save a lot of money.

In the summer of 2014, NASA plans to launch a 3D printer to the ISS. Developed by Made in Space, the device will test space manufacturing of spare parts and tools. The printer will have a set of pre-defined blueprints, but will also have the ability to receive code from Earth for customized tools. In the future, it might become possible to 3D print an entire spacecraft in space, something NASA is certainly looking forward to.

Not Only for Space

Since 1984, when the first 3D printer was created, the technology has been used to prototype and manufacture items for a wide range of industries, creating spare parts for automobiles, human tissue replacements, clothes, footwear, jewelry, eyewear, and now food.

If this technology truly takes off, it may bring about a significant change in the global economy by reducing the cost of common objects. Instead of having to buy things, consumers would simply download blueprints and 3D print whatever they might need.

Taking into account current predictions of the population growth, some analysts foresee the number of people on Earth nearly doubling over the next 100 years, reaching 12 billion. Food printing may eventually offer the solution to tackle famine. It could be used to conveniently support operations in inaccessible locations and disaster zones, while reducing the demands of transportation and waste management.

In the meantime, SMRC continues with the first six month SBIR phase, which, if successful, would ensure the company a phase two contract and the possibility to continue the development. It will most likely be some years before 3D food printing will be tested in space.

Credits: NASA

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