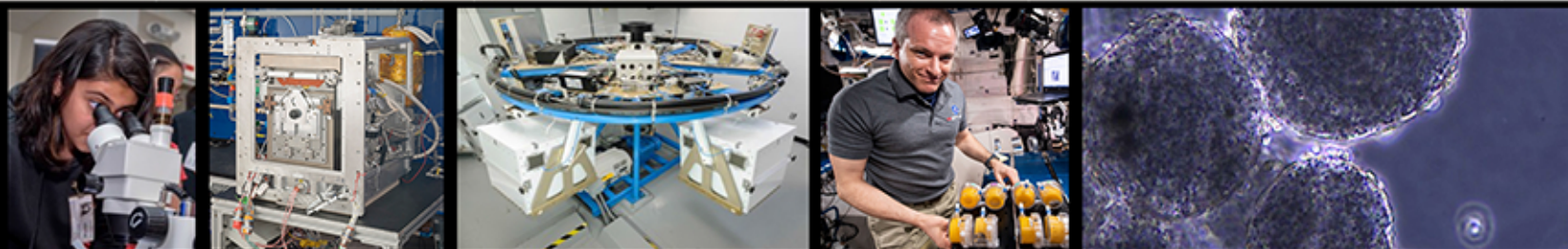


National Aeronautics and
Space Administration



NASA Ames Research Center **Space Biosciences Division**



Not just surviving, but thriving

Life is challenged by the extreme environments of space. Before humans can live and work long-term in deep space – beyond our current gateway and space outpost, the International Space Station (ISS) – we are going to require advanced scientific and technological developments, and more research to understand the limitations of our physical and biological systems. What are the effects of microgravity and deep space radiation on our bodies and behavior? How will we mitigate risks faced by future space crews and support them during exploration missions? The Space Biosciences Division is focused to meet these challenges to support exploration on the Moon, Mars, and beyond.

The research we do – whether on the ground or in space – is exciting, unique, and demanding. Much of the work is cross-disciplinary, requiring people with sharp minds, technical expertise with good hands-on skills, and the ability to work well in teams. Our diverse teams determine the hypotheses that need to be tested and experiments to be done, then develop specialized equipment to conduct the experiments.

For astronauts to live and thrive in space they will need breathable air, clean water, and nutritious food. We need to provide all this and in ways that maximize reuse and recycling of precious resources. To address these needs, Space Biosciences is developing technologies to recycle air and water, process solid waste, and generate new food products through physical-chemical devices as well as bioengineered organisms. Producing on-demand consumable nutrients, research managed in the BioNutrients program may provide additional vitamins and other nutrients in regions where food is scarce.

Our unique ground facilities conduct hypergravity studies that cannot be performed in any other NASA facility. Our centrifuges can help evaluate the effects of acceleration on human and flight hardware systems. The human-rated centrifuge facilities provide a test bed for optimizing human performance, evaluating crew technologies and integrating human systems into the flight environment. Non-human-rated centrifuges accommodate different types of experimental payloads such as small animal and plant habitats and experimental hardware and enable researchers to evaluate the effects of hypergravity on biological specimens.

To understand the health risks facing astronauts and develop new treatments and mitigation strategies, scientists must learn how space affects living organisms. Currently, space experiments are conducted on board the International Space Station, but the upcoming BioSentinel mission is the first of many planned for deep space. Based on a CubeSat spacecraft, BioSentinel will look at the effects of space radiation to living organisms (like yeast) over long durations.

The work done in the Space Biosciences Division is exciting, adventurous, and far from over. Scaling beyond low-earth orbit will require ingenuity, imagination, logistics, and extensive research testing. There are technological challenges; that is certain. But the importance for human deep space exploration goes beyond obstacles: it is a shared human desire to advance scientific understanding and forge a long-term pathway to the stars.

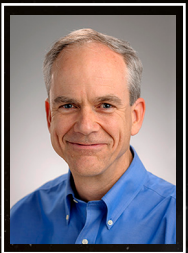
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Space Biosciences Overview

In the Space Biosciences Division at NASA's Ames Research Center, we perform the biological research and technology development necessary to tackle the challenges of living in the extreme environments of space and to enable NASA's long-term human exploration mission. In addition to designing and conducting ground and spaceflight experiments, we develop advanced research platforms to enable the broader scientific community to conduct life science experiments in altered gravity and to develop advanced technologies to sustain life in space.

Flight Systems Implementation Branch

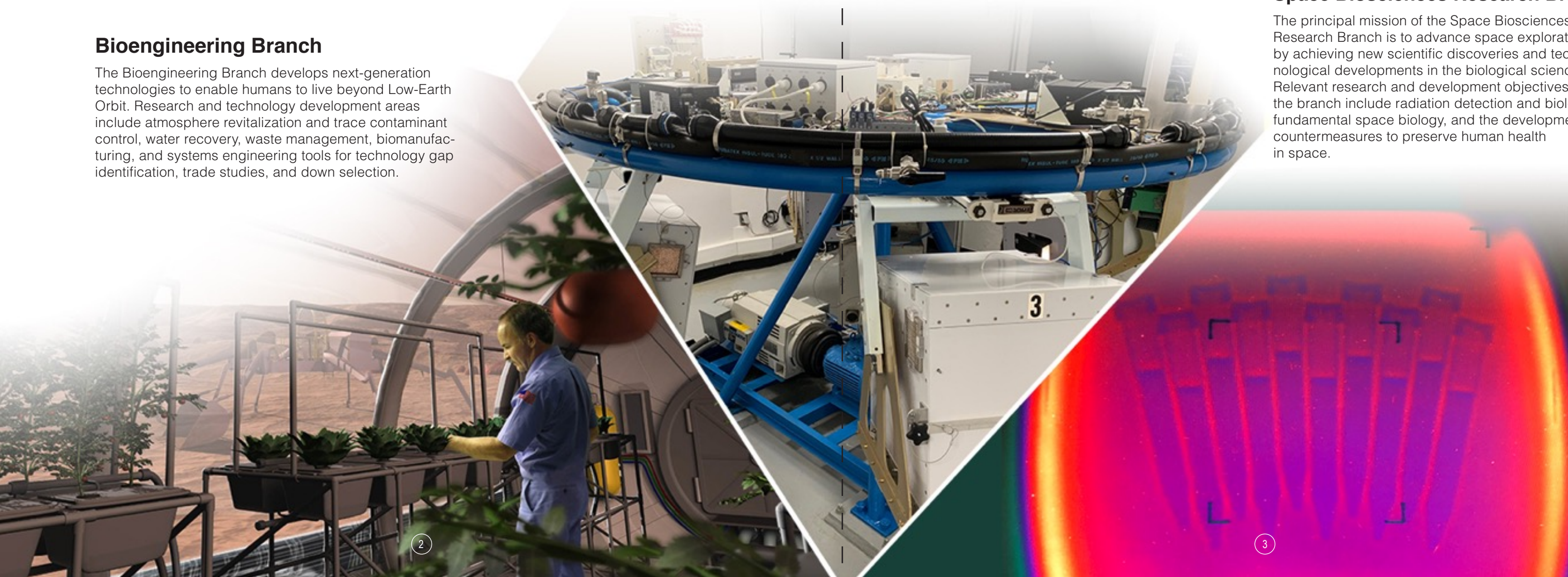
The Flight Systems Implementation Branch integrates science, engineering, and operations to ensure mission success in the development and integration of bioscience payloads. Payload capabilities can include design, fabrication, requirements definition, flight certification, operations, and project management of bioscience experiments for manned and unmanned spaceflight projects. Over 100 payloads have been developed and flown by the Flight Systems Implementation Branch.

Space Biosciences Research Branch

The principal mission of the Space Biosciences Research Branch is to advance space exploration by achieving new scientific discoveries and technological developments in the biological sciences. Relevant research and development objectives of the branch include radiation detection and biology, fundamental space biology, and the development of countermeasures to preserve human health in space.

Bioengineering Branch

The Bioengineering Branch develops next-generation technologies to enable humans to live beyond Low-Earth Orbit. Research and technology development areas include atmosphere revitalization and trace contaminant control, water recovery, waste management, biomanufacturing, and systems engineering tools for technology gap identification, trade studies, and down selection.



Development Capabilities Highlights

The following highlights reflect the highly collaborative nature of the research and technology development capabilities of the Space Biosciences Division. Long-term exploration of space is enabled by understanding the effects of the space environment on living organisms and life support systems, painting a picture of the effects on humans living in space, and applying the gathered data to safely send humans on long duration space travel.

We are working towards a future where humans will be able to safely explore the Moon, Mars, and beyond.

“ It’s human nature to stretch, to go, to see, to understand. Exploration is not a choice really; it’s an imperative. ”

*– Michael Collins,
Apollo 11 Astronaut*



BioNutrients Uses Microorganisms to Produce Nutrients

To thrive in space, humans on long-duration spaceflights will need adequate nutrition to sustain their health. Astronauts currently receive nutrients from preserved foods and supplements, but some essential nutrients can degrade significantly over time.

The five-year BioNutrients experiment aboard the International Space Station provides a potential new solution: have microorganisms produce vital nutrients in space for on-demand consumption by astronauts. NASA Space Biosciences researchers genetically engineered *Saccharomyces cerevisiae* (baker's yeast), a common and shelf-stable food microorganism, to produce zeaxanthin and beta-carotene, nutrients commonly found in vegetables and critical for eye health. The dormant yeast is stored in packages and can be activated to grow and produce nutrients simply by adding water. The BioNutrients mission also examines a wide range of other genetically engineered biomanufacturing and probiotic microorganisms stored at ambient temperature aboard the ISS.

The collaborative effort at NASA Ames Research Center Space included both genetically engineering the yeast for nutrient production and developing the hardware and mission operations for hydration, growth, study, and storage of these samples. The first mission (BioNutrients-1) launched successfully on Northrop Grumman's 11th Cargo Resupply Service mission in April 2019.



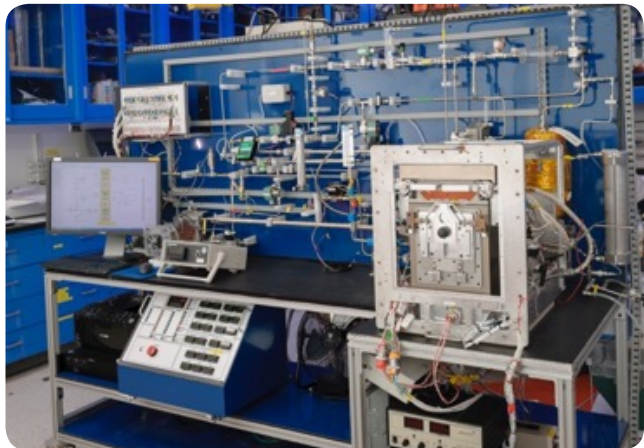
For the BioNutrients experiment, the specially engineered yeast and its powdered food source are held in the container at the left. Its lid holds a membrane that allows carbon dioxide from the yeast to escape. The clear tube at right protects another filter system leading into the compartment with the microorganisms. To activate the yeast and begin the experiment, astronauts on board the space station will inject water through the filter, making it sterile. The water will dissolve the nutrient powder and the yeast will grow and multiply in this liquid environment, producing an important nutrient for human health. (Image credit: NASA / Dominic Hart)

Heat Melt Compactor Manages Waste in Space

Enabling travel to the Moon, Mars, and beyond means limiting waste, recovering valuable resources from waste, and reducing the pollution of space. Thus, NASA is developing a trash processing system to manage the estimated one kilogram of trash per crew member per day. The current practice of collecting and returning trash aboard a recycled delivery spacecraft and burning it in the Earth's atmosphere will simply not work on long-distance spaceflights.

NASA Ames Research Center Space Biosciences researchers engineered a prototype Heat Melt Compactor (HMC) system. It can compact most astronaut trash into nine-inch square "tiles" that take up less than one-eighth of the original volume. The compacted trash is heated to 150 degrees Celsius (more than 300 degrees Fahrenheit) to sterilize the material, boil off water, and vent off noxious gases. The gases can be released to the vacuum of space or potentially processed into safe gases released into a spacecraft's air revitalization system. The boiled-off water can be recovered for onboard needs, and the tiles – free of bacterial growth and undesirable smells – can be used for radiation shielding.

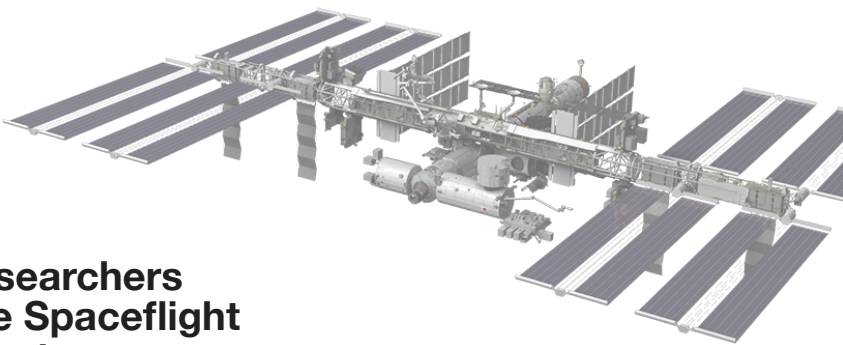
The HMC presents many resourceful options for dealing with waste, and the first prototype has been tested extensively on Earth. Through commercial partnerships, NASA will be able to develop a model to send to the International Space Station and eventually on longer flights to deep space.



A potential trash management system for future, long-duration space missions, the current version of the Heat Melt Compactor, seen here in its ground configuration, has been tested extensively at NASA's Ames Research Center. (Image credit: NASA / Dominic Hart)



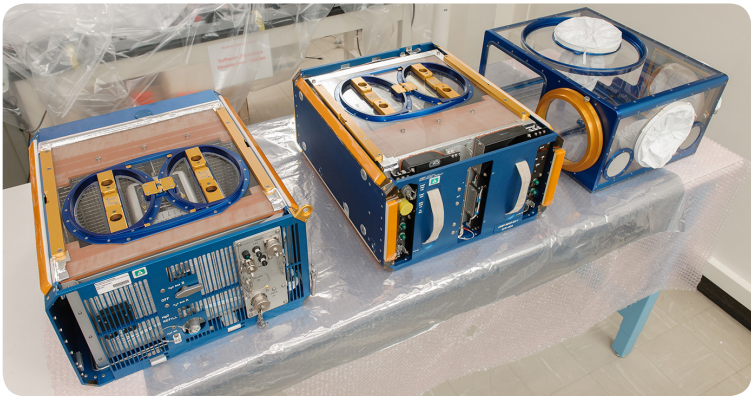
A sample trash tile, compressed to less than one-eighth of the original trash volume, was produced by the Heat Melt Compactor. (Image credit: NASA / Dominic Hart)



Rodent Research Hardware System Allows Researchers to Study Rodents Exposed to the Spaceflight Environment

In space, far from Earth’s gravity, astronauts experience physiological changes that can take a toll on their health. Model organisms like rodents offer a way for humans to observe and understand the effects of microgravity and radiation on whole living systems, as well as how to manage and treat these changes. Using a mammalian model system helps us to understand in a systematic way the effects of the spaceflight environment on the human body. The faster development and shorter life span of rodents reveal the effects of microgravity and radiation on a shorter timescale, which along with defined genetic backgrounds, help researchers gain insight that can be translated to human health. Although ground studies using simulated microgravity techniques, like hind-limb unloading (developed by NASA Ames Research Center), has elucidated some interesting findings, the ability to fly dozens of small rodents to the ISS yields unique data that can only be generated from a spaceflight mission. This provides vital knowledge for developing a future where humans can travel and live in space.

NASA’s Ames Research Center scientists and engineers use their decades of experimental expertise with Space Shuttle missions to develop the Rodent Research Hardware System for the ISS. Making use of its equipment and protocols, scientists from NASA and other institutions have conducted a variety of experiments with this unique research platform. Today’s system makes longer-term fundamental and applied research in space possible.



The Rodent Research Hardware System includes three modules: (left) habitat, (center) transporter, and (right) animal access unit. (Image credit: NASA / Dominic Hart)

Bioculture System Allows Researchers to Research the Effects of the Spaceflight Environment on a Cellular Level

Biologists can learn a lot about the effects of the spaceflight environment by studying different types of cells grown in the ISS. The Bioculture System, developed at NASA Ames Research Center, allow researchers to observe the effects of microgravity on a variety of cell cultures. Studies address stem cell differentiation, cell-cell interactions, transcriptional regulation, and signal changes induced by the spaceflight environment.

The Bioculture System is a miniaturized and automated research facility in a box for use onboard the ISS. It enables scientists to carry out long-term cell biology studies on diverse cell and tissue types using minimal space and resources. In particular, this automated system requires very little crew intervention, further increasing the amount of scientific data that can be obtained on the ISS. Specimen types that have been studied by this system include heart cells (cardiomyocytes) and bone cells (osteocytes). The Bioculture System hardware provides real-time, remote monitoring of cell and tissue cultures and gives researchers precise control over culturing conditions. The individual cassettes within the Bioculture System consists of tubing and chambers for liquid samples and are designed to allow researchers the ability to control temperature, fluid flow rates and circulation, sampling volume and timelines, and gas exchange.



Bioculture System research facility shown open. (Image credit: NASA / Dominic Hart)



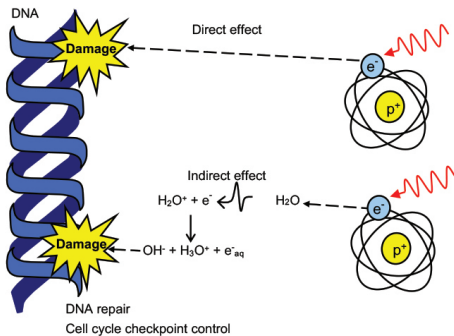
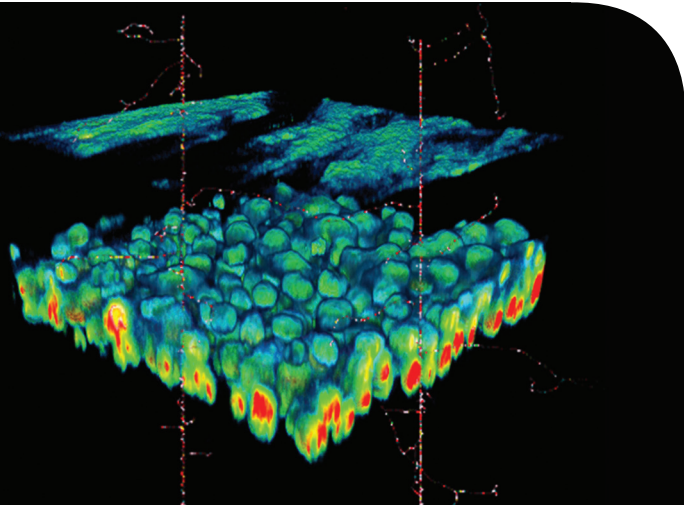
Interior view of an incubator Cassette. (Image credit: NASA / Dominic Hart)

Studying Simulated Space Radiation on Human Cells at the NASA Space Radiation Laboratories

Exposure to galactic cosmic rays and energetic particle radiation is one of the main health hazards associated with long-duration space exploration beyond the protective magnetic field of the Earth. Galactic cosmic rays (GCRs), are a mixture of protons (~90%), Helium (He) ions (~9%) and nuclei of heavier elements (~1%), that cause DNA damage and oxidative stress to human cells. The space radiation environment differs significantly from terrestrial exposures. Therefore, it is crucial to understand the mechanisms involved in regulating radiation responses and to develop countermeasures to protect astronauts on long-duration trips.

Using Ames Research Center resources as well as a NASA funded facility at NASA Space Radiation Laboratories, the Brookhaven National Lab (BNL) allows researchers to replicate the radiation found in space on Earth. At BNL, cells, tissue models or experimental animals can be exposed to individual or combined particles similar to ones that form galactic cosmic rays. Researchers then measure the outcomes of irradiation such as DNA damage, cell death, and oxidative stress, and other consequences. One example of current research in space radiation includes a large comparative study of primary immune cells from over 750 healthy donors to investigate the differences in human responses to ionizing radiation. Researchers hope to uncover the demographic factors (age, gender, body mass index) that are associated with these differences. Identifying the genes and pathways linked to increased or decreased human sensitivity to space radiation will enable researchers to develop countermeasures that target these pathways and reduce the harm done by space radiation to astronauts. In addition, the knowledge gained from this study could be repurposed for medical care on Earth and personalization of care for cancer patients who receive radiotherapy.

Confocal reconstruction of Mattek 3D human skin construct. Modeled Fe ionization tracks overlay. (Image Credit: NASA/Marianne Sowa)

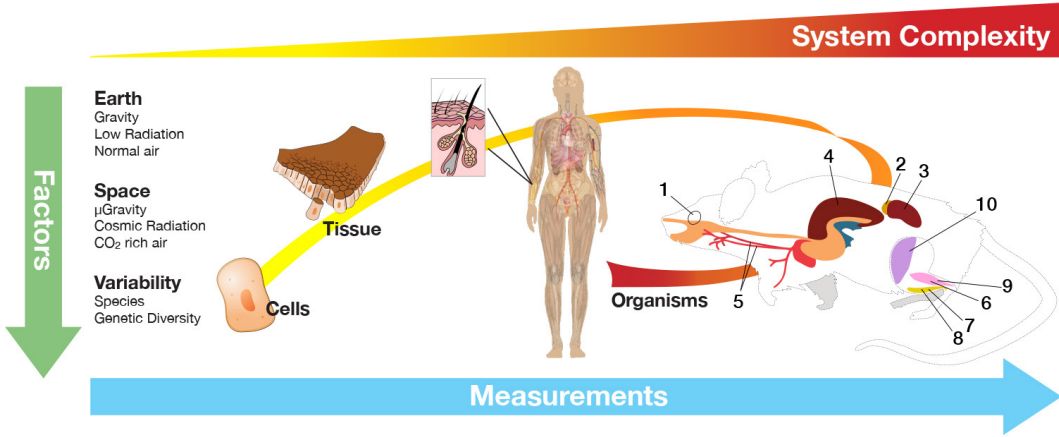


DNA damage induced by ionizing radiation. (Image Credit: NASA/Marianne Sowa)

Multi-omics Analyses with GeneLab

Determining the biological impact of spaceflight through nonbiased high-throughput screening approaches are essential to reduce the health risks to astronauts for long-term space missions. One resource for scientists to access information and uncover potentially novel biological mechanism responsible for health risks for astronauts is NASA's GeneLab Data Systems. GeneLab hosts a multitude of omics datasets and technology to characterize the relationships between various biological molecules, that can be used to develop new hypotheses. Data sets include transcriptomics, proteomics, epigenetics, and genomics – each covering a certain aspect of cellular and physiological activity.

Recently, a group of scientists used GeneLab to investigate a hypothesis that spaceflight may trigger the body to react to changes caused by processes within mitochondria, an organelle that produces energy for the cell. The body's adverse reaction is thought to have led to a metabolic disorder that stemmed from the liver, but directly impacted the function of other organs and tissues. The scientists implemented a systems biology approach using GeneLab datasets that involved in vitro experiments performed at the low Earth orbit, in vivo experiments involving mice flown to space, and human physiological data from astronauts. A comprehensive multi-omics approach was implemented to analyze all the corresponding datasets. This approach led the scientists to confirm the hypothesis that spaceflight affects the mitochondrial pathways and leads to increases in health risks in astronauts. Integrating research with GeneLab omics datasets increases the power from spaceflight data and has the potential to target and develop countermeasures to mitigate other health risks to astronauts for deep space missions.



A schematic of how the omics data from GeneLab can be utilized for investigation of different hypotheses. (Image Credit: NASA/Afshin Beheshti)

Research and Technology Development Capabilities

Fundamental Biology Research

Ground and flight experiments with model organisms to study the effects of microgravity and space radiation on skeletal health, using developmental biology, vestibular and nervous systems, immunology, metabolic control, and biopharmaceutical stability. Research on electromagnetic field effects, lunar dust toxicity, and microbiology of the built environment of spacecraft.

Flight Studies

Experiments on the International Space Station, satellites, and suborbital platforms such as scientific balloons. Science leadership on projects including Rodent Research, Cell Science, Fruit Fly Lab, Wetlab-2, BioSentinel, and E-MIST.

Radiation Ground Studies

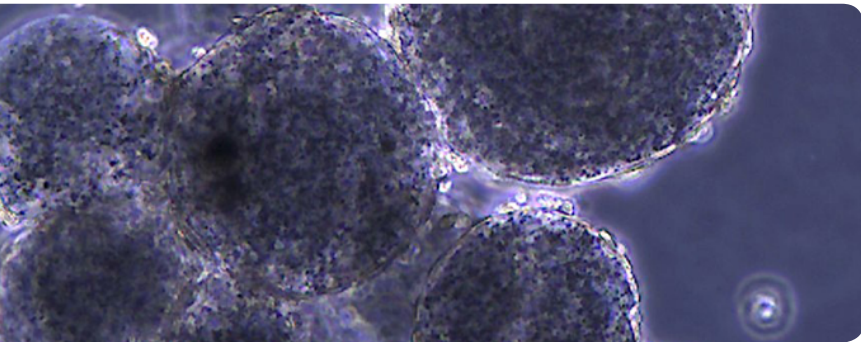
Space Radiation expertise and low dose rate gamma irradiation setups for cell cultures, organs-on-a-chip, and model organisms, at NASA Ames Research Center to understand biological sensitivity and responses to radiation. Identifying biomarkers and developing countermeasures for deep space exploration and assessing combined effects with gravity and other environmental factors.

Gravity Ground Studies

Researching the effects of altered gravity environments on biological systems, using the unique suite of centrifuge facilities at NASA Ames Research Center to apply increased centripetal force, or “hypergravity”, to biological specimens, and the Ames-developed technique of hindlimb unloading to simulate microgravity for rodents.

Radiation Detection Technologies

Development of small active radiation dosimeters for the Moon, Mars, and beyond. Ground-based validation and testing, and near-Earth radiation measurements using balloons in support of atmospheric science and space weather models.



Cardiomyocyte cells that were flown to space inside the NASA Ames Research Center-developed Bioculture System. (Image credit: NASA)



Astronaut Kate Rubins working with WetLab-2, a molecular biology system that allows gene expression analyses to be conducted from start to finish aboard the International Space Station. (Image credit: NASA)

Analytical Chemistry Lab

Full-service analytical chemistry lab supporting a wide variety of gas and liquid sample analysis needs.

Atmosphere Revitalization

Development of advanced technologies to efficiently and reliably remove carbon dioxide and other contaminants from cabin environments and to facilitate their transformation into safe and useful products.

Water Recovery

Development of technologies to significantly and efficiently improve water recovery rates, increase reliability and safety, and reduce use of consumables.

Waste Management

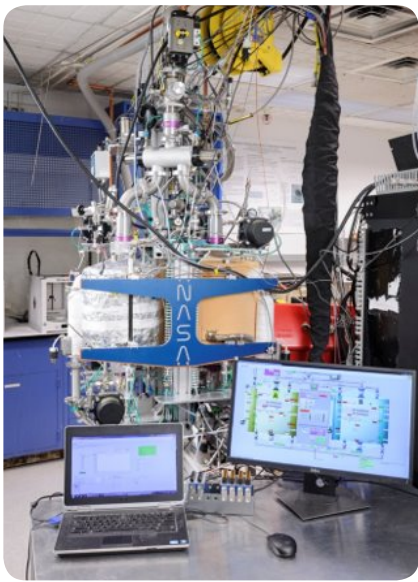
Development of technologies to reduce waste volume, recover water and other resources from waste, and provide microbial and chemical safening and repurposing of waste materials.

Synthetic Biology

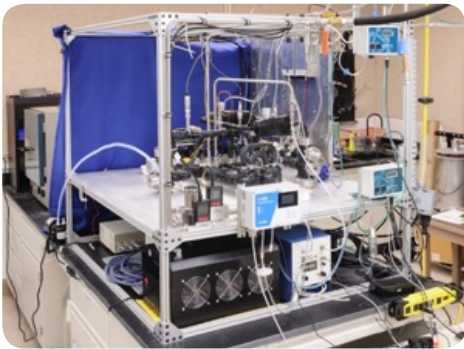
Engineering biological systems to provide critical resources for exploration, including food, life support systems, and materials.

Systems Engineering

Architecture analysis, modeling, and simulation to support design and technology trade studies of safe ultra-reliable life support systems for missions beyond Low-Earth Orbit.



Thermally-Coupled CO₂ Temperature Swing Adsorption Compression (Image credit: NASA/Dominic Hart)



Cold Surface CO₂ Deposition System (Image credit: NASA/Dominic Hart)

Research and Technology Development Capabilities

Payload Development and Integration

Payload development for biosciences, life support, and synthetic biology flight experiments. Support of existing payload systems for Rodent Research, Cell Science, Plant Growth, and Fruit Fly projects. Modification of Commercial Off-The Shelf (COTS) payloads. Manned and unmanned payload integration.

Space Flight Verification Testing and Analysis

Development of experiment and payload hardware requirements. Selection and certification of COTS equipment for space. Complete end-to-end verification and certification of flight capabilities for payloads using on-site verification capabilities

Payload Management and Operations

Project oversight for payload development, science and operations management, schedule, budget, and risk management. International experiment coordination and operations

Payload Support

Pre- and post-launch logistics support. Payload operations coordination and process development. Data and biospecimen collection and archiving.

Ground Acceleration Facilities

Centrifuges for human, non-human, and hardware research and testing. Customization of centrifuge protocols for needs of individual experiments. In-house design and manufacture of unique hardware for individual experiments. Data collection using biosensors, video monitoring, and other instrumentation.



Science operations in space are often supported by an entire team of experts on the ground, working together with the astronauts for a successful experiment. (Image credit: NASA)

Next Generation Scientists

The Space Biosciences Division is dedicated to equipping the next generation of scientists to continue the fundamental biology research needed for deep space exploration by allowing hands-on experience in the discipline. Throughout the year, the division hosts programs where principal investigators actively mentor students in their laboratories. GeneLab for High School (GL4HS) is a four-week intensive training program that immerses rising high school juniors and seniors in the space life sciences with a focus on omics-based bioinformatics. The Space Life Sciences Training Program (SLSTP) is a summer internship that provides professional experience in space life science disciplines to undergraduate students entering their junior or senior years. The NASA Postdoctoral Program (NPP) is a one- to three-year fellowship that allows post-doctoral students to advance NASA's missions in many fields of research including space biosciences.

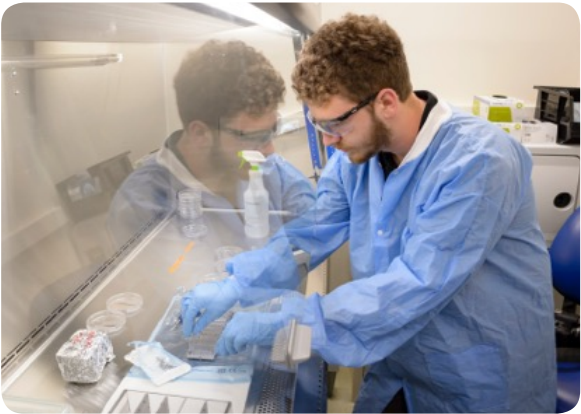
For current internship opportunities at NASA, please visit intern.nasa.gov.

“ This program is the most educational and beneficial program that I have had in high school so far, and I am really thankful for the opportunity. ”

– 2017 GL4HS student



A GL4HS student learns the basics of space life sciences during the summer program. (Image credit: NASA/Dominic Hart)



SLSTP student prepares samples for an experiment (Image credit: NASA/Dominic Hart)

“ SLSTP was the most important professional experience of my life, and once of the most exciting and educational experiences I have ever had. I now look forward to my future in space biology that started with this opportunity. ”

– 2019 SLSTP student

Significant Research Publications

A sample of journals that have published NASA Space Bioscience research.



Patents

NASA Space Biosciences has filed the following patents.

- Autogenic-Feedback Training Exercise (AFTE) Method and System
- Controlled Patterning And Growth of Single Wall And Multi-Wall Carbon Nanotubes
- A Versatile Platform for Nanotechnology Based on Circular Permutations of Chaperonin Protein
- Carbon Nanotube Growth Density Control
- Provision of Carbon Nanotube Bucky Paper Cages for Immune Shielding of Cells, Tissues, and Medical Devices
- Carbon Nanotube Purification
- Ordered Biological Nanostructures Formed From Chaperonin Polypeptides
- Provision of Carbon Nanotube Bucky Paper Cages for Immune Shielding of Cells, Tissues, and Medical Devices
- Portable Medical Diagnosis Instrument
- Compact Science Experiment Module
- Solid and Liquid Waste Drying Bag
- Retinal Light Processing Using Carbon Nanotubes
- Methylotrophic Microorganisms Expressing Soluble Methane Monooxygenase Proteins
- Estimation of Alga Growth Stage and Lipid Content Growth Rate
- Algae Bioreactor Using Submerged Enclosures with Semi-Permeable Membranes

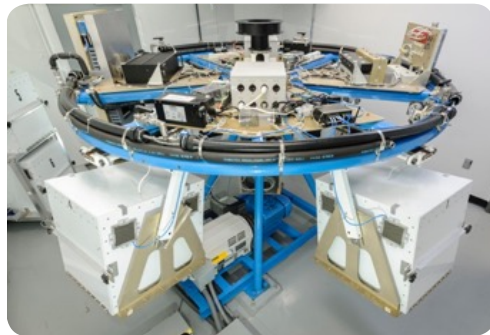
Collaboration Facilities



An artist rendition of the Collaborative Biosciences Laboratory

Collaborative Biosciences Laboratory

The Collaborative Biosciences Laboratory at NASA's Ames Research Center is home to state-of-the-art laboratories specifically designed to foster interdisciplinary research. The three divisions in our Science Directorate each have a presence in this state-of-the-art facility. As NASA gears towards returning to the moon and heading towards Mars, the research done in the Collaborative Biosciences Facility including astrobiology, animal and organismal biology, microbiology, life detection, and technology development will provide the scientific foundations that support NASA's missions here on Earth and beyond.



The 1.22-meter radius Centrifuge of the Life Sciences Acceleration Research Facilities. (Image credit: NASA/Dominic Hart)

Life Sciences Centrifuge Facilities

The Life Sciences Acceleration Research Facilities house a unique suite of acceleration systems that enable researchers to evaluate the effects of variable g-forces on humans, hardware, and various biological specimens. The four centrifuges – 1.22-meter radius, 1-meter radius, 8.84-meter radius, and 1.98-meter radius Centrifuge – are all uniquely configured to accommodate different types of experimental payloads. The centrifuges offer unique and innovative ways to conduct research and train participants to cope with the effects of acceleration. Combined with resident staff expertise and supporting resources, the Life Sciences Acceleration Research Facilities allow researchers to conduct studies at Ames that cannot be performed in any other NASA facility.

Collaborative Capabilities



GeneLab: Open Science for Life in Space

GeneLab is an interactive, open-access resource for Systems Biology and Bioinformatics studies where scientists can upload, download, search, share, transfer, visualize and analyze omics data from spaceflight and corresponding analogue experiments. New discoveries made using GeneLab have already begun and will continue to deepen our understanding of biology and help us to discover cures for diseases, to create better diagnostic tools, and to ultimately enable astronauts to better withstand the rigors of long-duration spaceflight for deep-space missions.

For more information visit please visit genelab.nasa.gov.



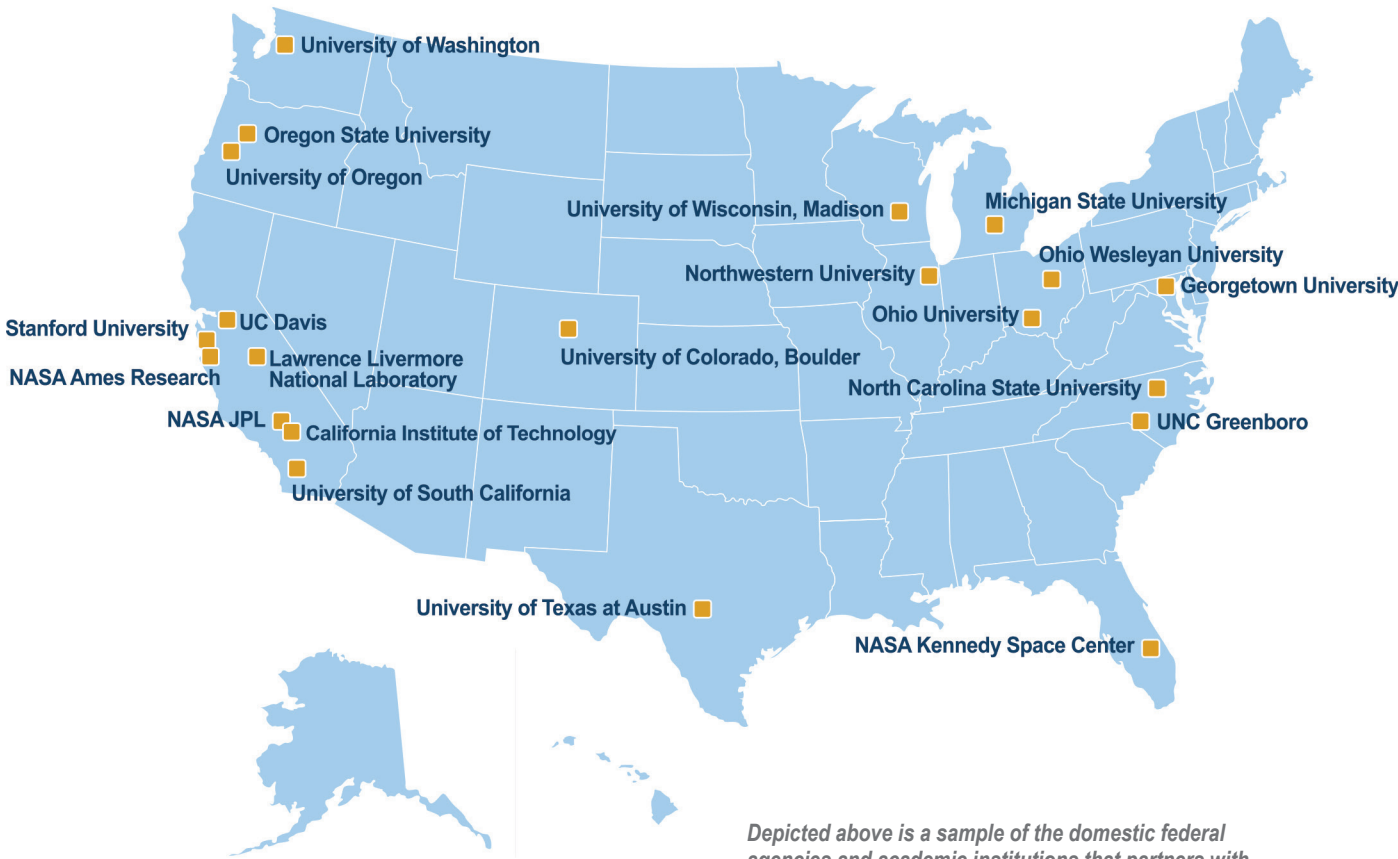
NASA Ames Life Sciences Data Archives | Biospecimen Sharing Program

The NASA Institutional Scientific Collection (ISC) at NASA Ames Research Center (ARC), managed by the NASA Ames Life Sciences Data Archives (ALSDA), stores non-human biospecimens from spaceflight investigations and associated ground controls. Available specimens range from as far back as the Russian COSMOS flights and Space Shuttle program experiments, to more recent experiments from the International Space Station. The biospecimens are collected through the Biospecimen Sharing Program and can be made available to anyone by request through the NASA ISC at ARC to maximize the scientific return from biological spaceflight investigations and encourage broader participation of the science community in space biology-related research.

For more information visit please visit genelab.nasa.gov/bsp.

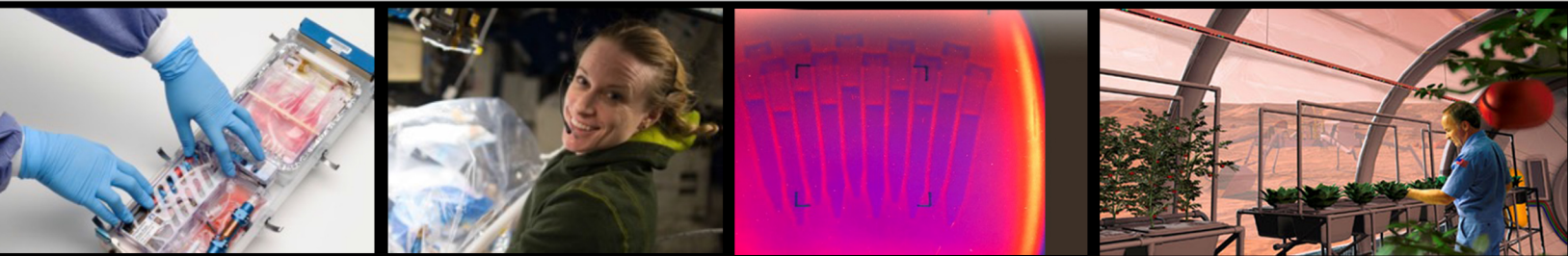
Partnerships with Federal Agencies and Academic Institutions

The Space Biosciences Division forms partnerships with federal agencies, academic institutions, and international collaborators to further our understanding of the effects of space on living systems. Together, these partnerships support NASA's mission for long-term human space exploration.



Depicted above is a sample of the domestic federal agencies and academic institutions that partners with NASA Space Biosciences Division.





National Aeronautics and Space Administration

Ames Research Center

Space Biosciences

<https://www.nasa.gov/ames/research/space-biosciences>

www.nasa.gov

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