Improving Life on Earth and in Space

The NASA Research Plan, Executive Summary

The International Space Station

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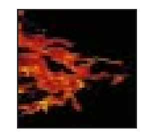
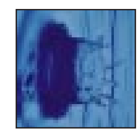
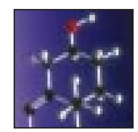
Improving Life on Earth and in Space: The NASA Research Plan, Executive Summary



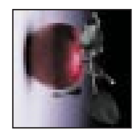
Combustion Science



Fluid Physics

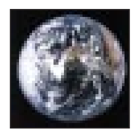


Materials Science



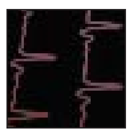
Fundamental Physics

Gravitational Biology and Ecology



Earth Science

Space Science



Biomedical Research

Medical Care

Advanced Human Support Technology

Biotechnology

An International Orbiting Laboratory

Benefiting Earth and Space

Enabling Exploration

Investing in Tomorrow

Building Research Capability

The International Space Station

In the world of human endeavor, the International Space Station (ISS) will break new ground. The ISS is a global undertaking of tremendous scientific and engineering magnitude. Beginning in 1998, at least 15 of the world's nations will collaborate to construct, operate, and utilize an orbiting space laboratory with capabilities that will far surpass current space research platforms. The ISS will afford scientists, engineers, and entrepreneurs a unique research facility in which to perform complex, long-duration experiments. The Station is configured to maximize the value of human intervention in the experimental process. Yet the ISS is much more than just a research laboratory in a novel environment; it is an international human experiment—an exciting "city in space." Our corps of astronauts will cooperate on Station experiments with a community of investigators on the ground. As we learn to live and work "off planet" alongside our international partners, investigators on Earth will manipulate orbiting experiments through the technologies of telescience, operating in virtual space to expand the boundaries of human participation in space research.

This grand human experiment will play out as the Station executes its concurrent roles as:

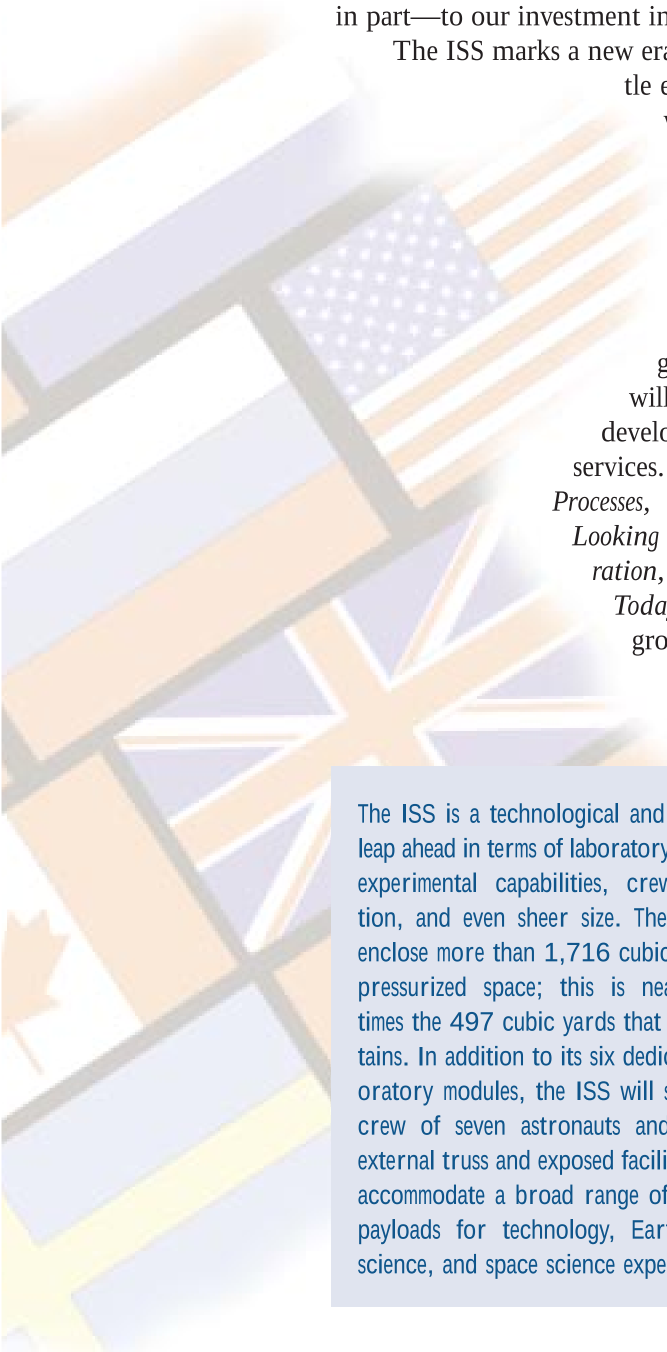
- An advanced testbed for technology and human exploration
- A world-class research facility
- A commercial platform for space research and development

The United States is partnering with Russia, Europe, Japan, and Canada to fund, build, and operate the ISS. European states are represented through membership in the European Space Agency (ESA). Current ESA members cooperating on the ISS are Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom. NASA also holds bilateral agreements with Brazil and Italy to supply certain station components in exchange for research accommodations.

An Investment in America's Future

Over the past quarter century, commercial, academic, and Government researchers have made dramatic use of Skylab, the Space Shuttle, *Mir*, and other space platforms to explore new theories. Our Nation's investment in space has already produced concrete benefits for life in space and on Earth. Services and products ranging from satellite communications to internal pacemakers and cardiac defibrillators owe their existence—at least in part—to our investment in space.

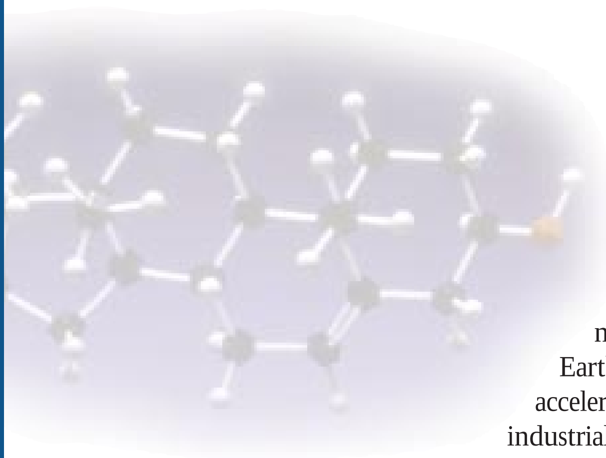
The ISS marks a new era in research and development. Shuttle experiments are limited to about two weeks in space, but the ISS will reside continuously in space for more than a decade of operations. The ISS will provide innovative space laboratory facilities, increased onorbit experiment time, and access by human researchers. The growth of low-Earth orbit research will provide incentives for the private development of space infrastructure and services. Whether it is *Improving Industrial Processes*, *Increasing Fundamental Knowledge*, *Looking After Our Health*, *Enabling Exploration*, or *Researching Tomorrow's Products Today*, ISS research will complement ground-based research to generate tangible returns, improving life on Earth and in space.



The ISS is a technological and scientific leap ahead in terms of laboratory facilities, experimental capabilities, crew habitation, and even sheer size. The ISS will enclose more than 1,716 cubic yards of pressurized space; this is nearly four times the 497 cubic yards that *Mir* contains. In addition to its six dedicated laboratory modules, the ISS will support a crew of seven astronauts and provide external truss and exposed facility sites to accommodate a broad range of attached payloads for technology, Earth system science, and space science experiments.

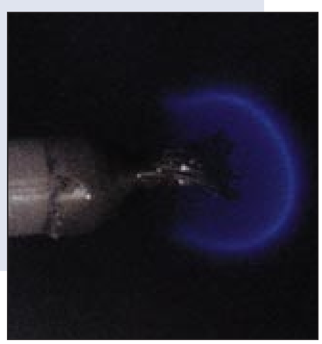
Ultimately, the ISS partners will put to use our firsthand experiences, research results, and technology products to take the next steps in the human exploration of the solar system. It is our intention that the ISS stands not alone in the history of human endeavor, but as the first step in a permanent and continuous expansion of human activity beyond Earth orbit.

Improving Industrial Processes



The ISS offers an incomparable microgravity laboratory for extensive and uninterrupted research in fields such as combustion science, fluid physics, and materials science—areas of research that are at the forefront of industrial applications. Space is an excellent environment in which to study processes normally masked by gravity-driven forces here on Earth. Station operations early next century promise to accelerate investigations into phenomena that will improve industrial processes for Earth and space.

Microgravity enables us to obtain critical measurements needed to understand and resolve practical combustion problems. Gravity-driven flows cause hot air to rise through flames, producing the flickering, elongated shape we associate with campfires. This buoyancy is absent in space, however, enabling researchers to study aspects of combustion that are normally obscured. ISS research should produce knowledge applicable to a wide variety of goods we use here on Earth. Combustion plays a central role in heating our homes, powering our cars, and producing a broad range of synthetic materials. Even small improvements in controlled combustion efficiency could help us decrease pollution while saving the United States billions of dollars annually.



On Earth, hot air rises through a candle flame, causing it to flicker and take on an elongated shape (top). In space, however, no such distortion takes place, giving the flame a spherical, steady shape (right) and allowing researchers to study aspects of combustion impossible to observe on the ground.

We can use the microgravity environment of space to investigate little-known aspects of fluid behavior. Forces that are often negligible on Earth, such as surface tension, can predominate in microgravity. ISS research into fluid physics could provide a foundation for predicting, controlling, and improving a vast range of natural and technological processes. The efficiency of a power plant, for instance, depends in part on fluid flow characteristics. The construction of more earthquake-safe buildings demands a thorough understanding of the fluid-like behavior of soils under stress. One day, a base on Mars may need to mix gases extracted out of Martian rocks and air to create fuel for onsite power generation or a return trip on Earth.

Materials science investigates the relationships among the structure, properties, and processing of materials. Often, gravity influences the formation of imperfections in materials that degrade their performance. ISS materials science efforts will use the space environment to study how gravity influences the characteristics of a variety of materials. With this information, researchers will be able to design better products for use on Earth, ranging from contact lenses to car engines.

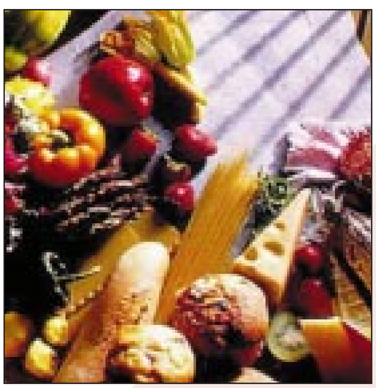
Increasing Fundamental Knowledge

While all the research outlined in this summary will increase fundamental scientific knowledge, foremost among our Nation's efforts to advance basic science via space-based research are our plans for fundamental physics, gravitational biology and ecology, Earth science, and space science.

Some of the fundamental laws that govern our physical world are difficult to test on Earth. It is often necessary to use space to obtain measurements of the highest possible accuracy. This is so when extremely uniform samples—free from compression because of their own weight—are required, when objects must be freely suspended in space, or when the mechanical disturbances present in Earthbound laboratories must be eliminated. ISS research will allow us to test some basic physical laws beyond the distorting influence of gravity.

Scientists will use this space-based laboratory to learn how plants and animals that evolved under the influence of terrestrial gravity respond to long-term exposure to microgravity. In doing so, we further our understanding of the role of gravity in life processes on Earth. In the future, an understanding of how plants respond to the space environment will be important as we try to control spacecraft environments and grow food for long-duration space travel. The ISS will play a critical role as the only research facility where both microgravity and partial gravity can be used as experimental variables in a laboratory setting.

The ISS will take advantage of its unique human-tended capabilities to run an adaptable and novel series of observations that further our understanding of our home and its extended neighborhood, the universe. Access to ISS resources such as electrical power, data communications, and human intervention will, in some cases, enable longer and more flexible experiment runs than possible with autonomous operations (that is, as a free-flying satellite). These Earth and space science experiments will complement broader, ongoing research agendas in these disciplines.



The availability and quality of food on long-duration space missions will depend on how well we understand the effects of gravity on the growth and reproduction of plants. The ISS will serve as a powerful laboratory where we can advance our understanding of the role of gravity in the origin and evolution of life.

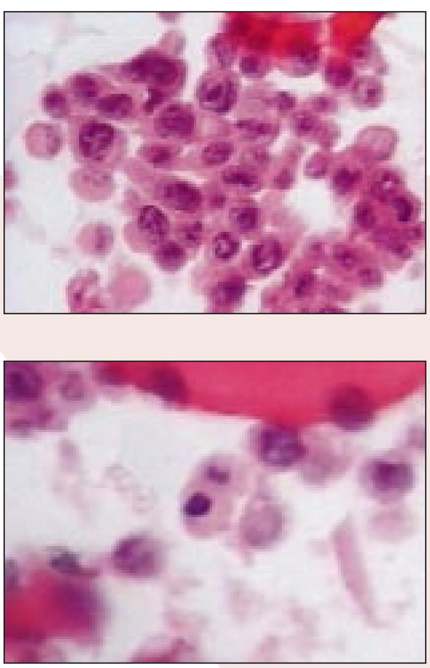
Looking After Our Health

Space flight poses both challenges and opportunities for human health. Exposure to the microgravity environment causes a number of changes within the human body itself. However, a study of these changes helps us mitigate their effects on space travelers and better understand the human body as a whole. Advances in caring for astronauts in space have the added benefit of advancing health care technologies here on Earth. At the same time, microgravity is an additional laboratory tool in certain biotechnology pursuits, such as protein crystal growth and tissue culturing.

Adaptations in the body from space flight can have adverse effects on astronauts when they return to Earth. Many of these effects, such as bone and muscle loss, seem to increase with the length of time spent in microgravity. The capabilities of the ISS will enable unprecedented study of the effects of long-duration space travel on the human body. Researchers will use ISS data to design better countermeasures to some of these effects for our astronauts. Effective countermeasures will become increasingly important as we contemplate sending astronauts beyond low-Earth orbit and deeper into the solar system.

The ISS will be a testbed for advanced medical and life support technologies designed specifically for space travelers. Some of these technologies have already found terrestrial applications. NASA-developed telemedicine systems have been used to provide high-quality medical advice, instruction, and education to underserved parts of our Nation and the world. Autonomous medical capability and "smart" robotic technologies will be an important part of keeping our astronauts safe when our Nation and its international partners expand human activity in space.

The influence of gravity can have unwanted consequences in the growth of certain highly delicate protein crystals and cultured tissues. Space offers an environment where researchers can study protein crystal growth and tissue culturing beyond gravity's disturbing influence. Researchers can take the knowledge gained from microgravity experimentation to improve Earth-based methods in these fields. Sometimes, certain space-grown crystals can be used directly to discern a protein's structure. This information can then be used in structure-based drug design. Microgravity research on the ISS will enable scientists to grow and analyze protein crystals on orbit. ISS cell culturing work will help us understand the factors influencing the growth and differentiation of tissues.

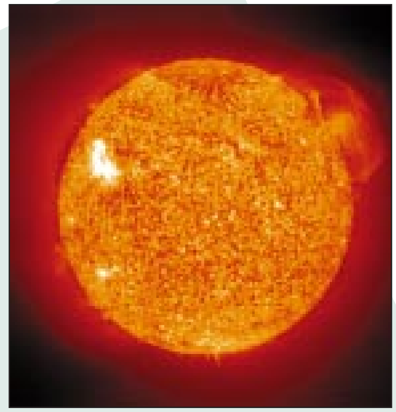


A stationary cell culture of colon cancer (bottom left) fails to take on the three-dimensional shape that the tissue takes in the human body itself. In microgravity, however, the structure of the tissue culture more closely resembles the natural state of the cancer (top). Researchers will use the ISS to better understand the factors influencing the growth of tissue outside the human body.

Enabling Exploration

The space frontier beckons to us with the promise of new and exciting discoveries. Humans will be an integral component of a comprehensive and vigorous program of solar system exploration. A person's adaptability, resourcefulness, and autonomy are irreplaceable for tasks such as the construction of a robust lunar outpost and advanced geologic field work on Mars. Many challenges remain before living and working in space become natural extensions of our lives here on Earth.

Human exploration of the solar system will require long periods of space travel far from home. Space vehicles will need to sustain the astronauts for months, even years, without resupply from Earth. ISS research into advanced recycling and environmental monitoring technologies will make it possible for spacecraft designers to develop advanced life-support systems for vehicles such as the conceptualized interplanetary transport pictured here.



Researchers will use the ISS to monitor the Sun's activity while testing technologies that might help shield space travelers from dangerous solar events, such as the Sun's coronal mass ejections, pictured here.

The ISS is the next logical step in our quest to send humans to explore and develop the solar system. The ISS will be a *technological testbed*, a *microgravity laboratory*, and a *commercial platform;* with it, we may eventually understand exactly what adjustments to our Earth-based methods we need to make before we send our astronauts to Mars and beyond.

ISS research to enable exploration can be broken down into two primary categories: *engineering* research into the technology, mission architecture, and operational standards necessary to live and work far from Earth; and the *science* that will serve as the bedrock for our understanding of how to utilize this new environment. ISS research will yield more robust, closed-loop life-support systems, advanced robotic capabilities, high-efficiency space power generation and storage, and special protective coatings for the space environment. Fundamental research into microgravity's effects on the human body and plant and animal development will set the standards for engineering systems to support life far from Earth. Advances in fields such as combustion, materials science, and fluid physics will teach us how to make use of extraterrestrial resources as fuel sources to power our spacecraft back home. The ISS is a critical step in humanity's exploration of the solar system.

Researching Tomorrow's Products Today

NASA will use virtual reality applications, such as the headset and gloves pictured here, to train ISS astronauts in a virtual Space Station environment. Virtual reality is just one example of NASA's technology investment benefiting the private sector.

In the 20th century, space exploration has profoundly impacted the way we view ourselves, our world, and the way we live. Our Nation's investment in space has resulted in a myriad of services and products that affect our everyday lives. Whether we are making a transpacific telephone call, creating with a computer-aided design tool, using our mobile phone, wearing a pacemaker, or undergoing an MRI, we are using technology that space exploration either developed or improved.

Commercial involvement in microgravity research and space development has been limited to date by scarce flight opportunities and only sporadic access to orbit. With a continually operating and accessible space laboratory, commercial interests can now begin planning how to best use the environment of space to their advantage, bringing about the next boom in space development.

ISS research holds the key to Earth-based benefits that span industrial sectors. Further research into the physiology of plants could lead to new categories of plant-based technologies. Work in gravitational biology and ecology could help us design hardier crops for space farms and onboard food production as well as more efficient, biologically based waste management systems. Crystals grown in space can help improve catalysts used to extract oil, enhancing the yield of American petroleum products. The use of microgravity and vacuum production techniques in space might trigger the next generation of highly pure and accurate semiconductors for use in our electronics. Three-dimensional structural analyses of certain protein crystals grown in space have already helped us model pharmaceuticals that are now in clinical trials. Demands for resources such as power and data communications may spur private space development investments to provide commercial services to space experimenters. For all these reasons and more, the ISS will serve as a laboratory and testbed for the development of new processes, products, and services to benefit life on Earth and in space.

Research Capability Evolution

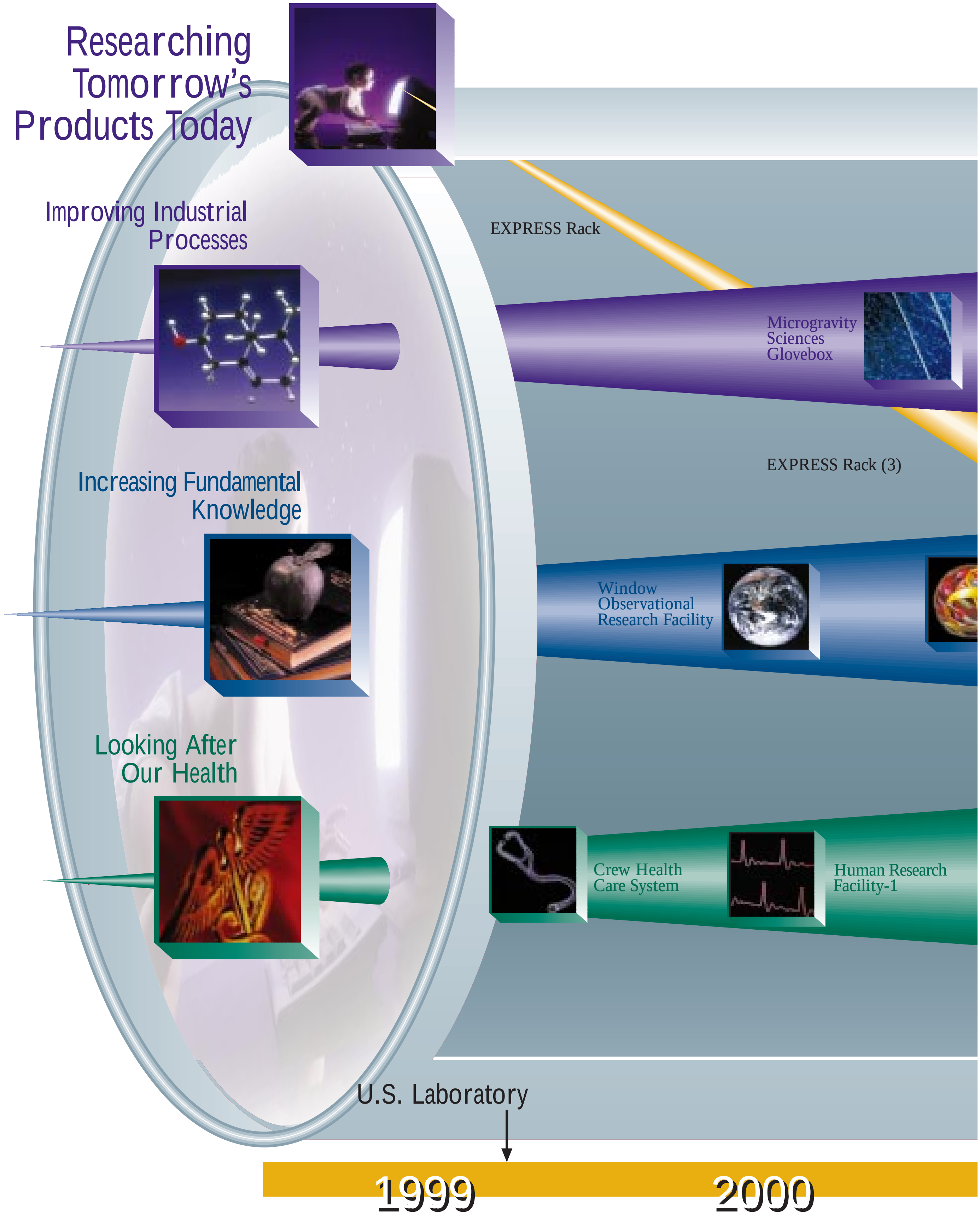
Outfitting the ISS for research operations will take place over a number of years. The U.S. Laboratory will be placed on orbit in 1999. Experimental facilities that fit inside the U.S. Laboratory and on attached sites will follow in subsequent years. As ISS assembly proceeds, NASA's onorbit research capability will grow as additional experimental facilities are deployed. To plan and manage the growing research capabilities of the Station, NASA and the ISS partners maintain an evolving facility deployment and assembly schedule. This sequence may change as the ISS program and Station payload plans mature. The Schedule for Research Capability Evolution summarizes the arrival of experimental facilities at the ISS, as known in May 1998.

Schedule for Research Capability Evolution

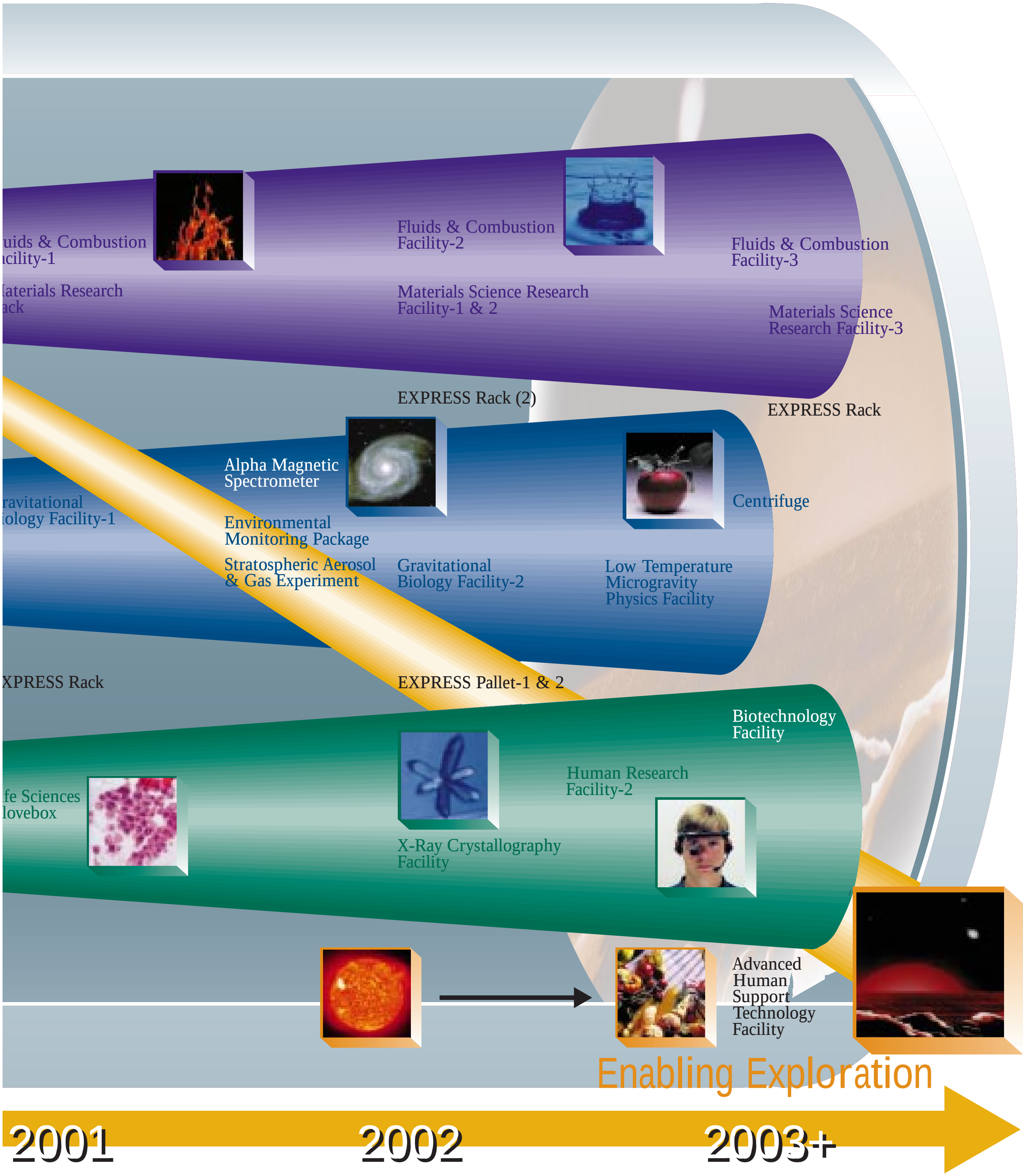
Flight	Equipment Deployed	Research Area
1999	EXPRESS Rack	* Multidisciplinary
2000	Human Research Facility-1	Biomedical Research
	Window Observational Research Facility	Earth Observations
	Microgravity Sciences Glovebox	* Biotechnology, Combustion, Fluid, and Materials Science
	EXPRESS Rack (3)	* Multidisciplinary
2001	Gravitational Biology Facility-1	Gravitational Biology & Ecology
	Materials Research Rack	* Materials Science & Physics
	Fluids and Combustion Facility-1	* Combustion Science
	Life Sciences Glovebox	Biomedical Research, Biotechnology, and Gravitational Biology & Ecology
	EXPRESS Rack	* Multidisciplinary
2002	Alpha Magnetic Spectrometer	Space Science/Space Physics
	Stratospheric Aerosol & Gas Experiment	Earth Science
	Environmental Monitoring Package	* Space Science/Space Plasma Physics
	Gravitational Biology Facility-2	Gravitational Biology & Ecology
	Fluids and Combustion Facility-2	* Fluid Physics
	Materials Science Research Facility-1 & 2	Materials Science
	X-Ray Crystallography Facility	* Biotechnology/Gravitational Biology
	Human Research Facility-2	Biomedical Research
	EXPRESS Pallet-1 & 2	* Engineering Research
	EXPRESS Rack (2)	* Multidisciplinary
2003	Low Temperature Microgravity Physics Facility	Fundamental Physics
	Centrifuge	* Gravitational Biology & Ecology
	Biotechnology Facility	* Biotechnology/Gravitational Biology
	Fluids and Combustion Facility-3	* Fluids & Combustion Science
	Advanced Human Support Technology Facility	Life Support/Environmental Monitoring
	Materials Science Research Facility-3	Materials Science
	EXPRESS Rack	* Multidisciplinary

* Denotes commercial participation as of December 1997.

The Crew Health Care System will be deployed in 1999 on assembly flights; while contributing to biomedical research, the system's primary purpose will be to serve the operational health needs of the astronauts.


Researching Tomorrow's Products Today
Improving Industrial Processes
Increasing Fundamental Knowledge
Looking After Our Health
EXPRESS Rack
Microgravity Sciences Glovebox
EXPRESS Rack (3)
Window Observational Research Facility
Crew Health Care System
Human Research Facility-1
U.S. Laboratory
1999
2000

Roadmap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Human Research
Facility-2
X-Ray Crystallography
Facility
Advanced
Human
Support
Technology
Facility
Enabling Exploration
2001
2002
2003+

This executive summary is the stand-alone accompaniment to the separately published document, *The International Space Station: Improving Life on Earth and in Space, The NASA Research Plan, An Overview.* This document was developed by the NASA Enterprise for the Human Exploration and Development of Space (HEDS) through the Office of Life and Microgravity Sciences and Applications (OLMSA). Technical assistance was provided by the Johnson Space Center's Space and Life Sciences Directorate and Futron Corporation.

For an electronic copy of this document or for more information on ISS research, please visit the OLMSA web site at *http://www.hq.nasa.gov/office/olmsa.* Also visit the Station web site at *http://station.nasa.gov.*

A technical ISS Research and Technology Utilization Guide will also be made available in 1998.