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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

IMPLEMENTATION OF THE RECOMMENDATIONS OF THE SECOND UNITED NATIONS CONFERENCE ON THE EXPLORATION AND PEACEFUL USES OF OUTER SPACE

International cooperation in the peaceful uses of outer space: activities of Member States

Note by the Secretariat

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INTRODUCTION

1. The Working Group of the Whole to Evaluate the Implementation of the Recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82), in the report on the work of its ninth session (A/AC.105/605, annex II), made recommendations concerning the preparation of reports and studies by the Secretariat and the compilation of information from Member States.

1. In paragraph 9 of its report, the Working Group recommended that, in the light of the continued development and evolution of space activities, the Committee on the Peaceful Uses of Outer Space should request all States, particularly those with major space or space-related capabilities, to continue to inform the Secretary-General annually, as appropriate, about those space activities that were or could be the subject of greater international cooperation, with particular emphasis on the needs of the developing countries.

2. The report of the Working Group was adopted by the Scientific and Technical Subcommittee at its thirty-second session (A/AC.105/605, para. 22), and the recommendations of the Working Group were endorsed by the Committee on the Peaceful Uses of Outer Space at its thirty-eighth session.[1]

3. Subsequently, in a note verbale, dated 4 August 1995, from the Secretary-General to all permanent representatives to the United Nations, the Secretary-General requested all Governments to communicate to the Secretariat, by 31 October 1995, the information requested in the above-mentioned recommendations.

4. In addition, the Secretary-General, in his note verbale, drew the attention of Governments to the following recommendation of the Committee that the Secretariat should invite Member States to submit annual reports on their space activities. In addition to information on national and international space programmes, the reports could include information in response to requests from the Working Group of the Whole as well as information on spin-off benefits of space activities and other topics as requested by the Committee and its subsidiary bodies.[2]

5. In accordance with the recommendation of the Committee, the Secretary-General, in his note verbale, suggested that Governments could submit in a single report on national space activities information in response to those requests, as well as information on topics as requested by the Working Group, in particular information on the following topics:

(a) Those space activities that were or could be the subject of greater international cooperation, with particular emphasis on the needs of the developing countries;

(b) Spin-off benefits of space activities;

(c) National and international research concerning the safety of nuclear-powered satellites;

(d) Studies conducted on the problem of the collision of nuclear power sources with space debris;

(e) National research on space debris.

6. The present document was prepared by the Secretariat on the basis of information on the topics listed in subparagraphs 6 (a) and (b) above, received from Member States by 31 October 1995. Information received subsequent to that date will be included in addenda to the present document. Information received regarding the topics listed in subparagraphs 6 (c) to (e) above is presented in a separate document (A/AC.105/619).

Notes

[1] *Official Records of the General Assembly, Fiftieth Session, Supplement No. 20* (A/50/20), para. 27.

[2] Ibid., para. 156.2

REPLIES RECEIVED FROM MEMBER STATES*

UNITED STATES OF AMERICA

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A. Astronomy and space physics

During Fiscal Year 1994 (FY 1994), space scientists continued to add to the fund of information about the universe gathered not only through instruments located on Earth, but also from those on satellites above the distorting medium of the home planet's atmosphere. For example, scientists working on the Hubble Space Telescope team made a number of important discoveries during FY 1994, including images of an exploding star (Nova Cygni 1992). Many of these findings preceded the highly successful servicing mission in December 1993 when astronauts on STS-61 replaced several faulty parts and installed a sophisticated package of corrective optics to compensate for the spherical aberration in HST's primary mirror. Coin-sized mirrors on the Wide Field and Planetary Camera 2 and Corrective Optics Space Telescope Axial Replacements units have since served as "contact lenses" for HST. While the telescope has always had a view of the sky unobstructed by haze from the Earth, scientists since have been able to accomplish all the astronomical goals initially planned for the most sophisticated observatory ever built. In the process, HST's first servicing mission proved the capability of NASA's highly trained astronauts to work productively in space.

As one fruit of their efforts, an astronomer from the Smithsonian Astrophysical Observatory (SAO), heading an international team, used HST's Wide Field Planetary Camera 2 in May 1994 to obtain valuable new images of Supernova 1994I, discovered by amateur astronomers in April 1994 in the inner regions of the "Whirlpool Galaxy," M51. HST has the unique capability of imaging and measuring the spectra of distant supernovae in ultraviolet light. As the M51 supernova ages, Hubble will "see" more deeply into the interior of the exploding star. This will permit astronomers to probe the chemical composition of the debris and learn more about the type of star that exploded. The team of scientists hope thereby to learn which stars explode as supernovae, what chemical elements are ejected, and how to use these bright events as yardsticks for measuring the size of the universe.

In June 1994, two scientists using the HST discovered disks of protoplanetary dust around stars in the Orion Nebula region of the Milky Way galaxy. This revelation indicates that the formation of planets may be relatively common both in the Milky Way and in other parts of the universe. The newly found disks contain many of the same basic chemicals that compose the planets in our solar system. Because planets are the only heavenly bodies that can support life as we know it, the existence of planets around other stars would raise the likelihood of life in other parts of the universe.

Then in July 1994, an international team of astronomers using HST's Faint Object Camera confirmed that helium is widespread throughout the early universe, a key hypothesis of the Big Bang theory. The discovery of helium in the constellation of Cetus, which is 13 billion light years away, gives scientists valuable information about conditions at the time of the universe's initial evolution. Additionally, this finding lends further weight to the scientists' conception of chemical evolution in the universe; scientists believe that hydrogen and helium evolved within three minutes after the Big Bang, while heavier elements such as oxygen and carbon came later.

In other developments, scientists analyzing data from the Compton Gamma Ray Observatory (CGRO), which was launched in April 1991, found new evidence that gamma-ray bursts extend into the far reaches of the universe and thus bear an imprint of the universe's expansion. These huge explosions come from all directions, suggesting a cosmological cause; until this discovery it was believed that the bursts were limited to within the Milky Way galaxy. Because the bursts come from so far away, they demonstrate "time dilation," an effect created when time

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seems to be running more slowly at the bursts' source than at their destination, since the universe itself is thought to be expanding.

Relatedly, the CGRO's Energetic Gamma Ray Experiment Telescope (EGRET) provided the first detailed all sky map of highly energetic gamma ray objects, pointing out several different types of gamma ray sources. Scientists believe, for example, that the interactions of cosmic ray particles with gas between the stars produce diffuse gamma ray emissions from our Milky Way galaxy. Within this band are gamma ray pulsars and other unidentified sources of gamma rays. Astronomers analyzing EGRET's data have also identified what they think are massive black holes in the middle of distant galaxies that are sending gamma rays in Earth's direction.

Similarly, the Extreme Ultraviolet Explorer (EUVE), launched in June 1992, produced the first all-sky map in four extreme ultraviolet wavelength bands. This survey has identified large numbers of very hot stars such as white dwarfs and active corona stars. For purposes of comparison, scientists also surveyed a companion area along half the ecliptic plane on which Earth travels around the Sun.

Space physicists using the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX), launched in June 1992, discovered a radiation belt of trapped anomalous cosmic rays in the magnetosphere. They have determined the chemical composition and electrical charge of these rays in the region beyond the Earth's upper atmosphere where the planet's magnetic field affects charged particles. In addition, these scientists have learned a lot about the effects of electrons in the upper atmosphere. SAMPEX's mission is to monitor energetic electrons and atomic ions from the Sun and from interplanetary, interstellar, and magnetospheric space.

Space physicists also achieved breakthroughs in computer modeling. In particular, complex numerical modeling has led to a detailed conception of the Earth's magnetosphere. As a result, scientists are now able to predict "space weather" caused by solar-terrestrial interactions. Investigators using computer simulations have also gained a refined understanding of the heliopause, the boundary of the solar system where the solar wind's outward flow is balanced by the pressure of the interstellar medium. This model's parameters are expected to be confirmed or denied when the two Voyager spacecraft reach this area and transmit their data back to Earth sometime within the next decade. (Voyager 1 was launched in September 1977 and Voyager 2, in August 1977.)

SPARTAN 201-2, a small satellite deployed and then retrieved several days later by the Space Shuttle Discovery in September 1994, examined the Sun's hot outer atmosphere, or extended corona, and the solar wind, the flow of charged ions from the Sun. On its second of four planned missions aboard the Shuttle, SPARTAN contained two instruments--the NASA-designed White Light Coronograph to measure the density and distribution of the electrons in the coronal holes and polar plumes of the Sun and the Ultraviolet Coronal Spectrometer, designed by the SAO. Together, the two instruments can determine the velocity of the solar wind as it accelerates out of the Sun so that scientists can grasp exactly how and when the Sun creates this wind as well as what the shape and spectroscopy of the solar corona may be. The measurements made by SPARTAN 201 will be used in conjunction with those from the Ulysses spacecraft, which was launched in October 1990 and which detected the solar wind from the south polar corona as SPARTAN observed the source region of that wind as well as other portions of the Sun's corona. Data from SPARTAN 201 will also calibrate measurements to be made by the European Space Agency (ESA)-NASA Solar and Heliospheric Observatory, scheduled for launch in 1995. Scientists hope to derive practical information from these missions about exactly how the solar wind produces magnetic storms near the Earth that can disrupt communication systems and trigger power outages, resulting in losses estimated at $100 million each year worldwide.

Ulysses, meanwhile, became the first spacecraft to fly over a polar region of the Sun when, in June 1994, it began its primary mission to observe the solar wind at high-solar latitudes. Built by ESA and equipped with both European and United States instruments, Ulysses will take direct measurements of many complex solar phenomena that cannot be observed remotely. Scientists are eager to learn more about the Sun's polar magnetic fields, which reverse polarity every 11 years in conjunction with the solar cycle; they play an important role in the Sun's corona and solar wind. The ionic composition of the solar wind, measured by Ulysses, indicates that its source in the coronal

gas measures just over a million degrees Centigrade. This is not hot enough to make the wind go as fast as it does, indicating that some unknown electromagnetic process near the Sun is responsible for accelerating the solar wind.

In a separate development, researchers from the University of Alaska in Fairbanks recorded spectacular upper atmospheric flashes occurring above electrical thunderstorms. For many years, pilots have noticed these bright blue and red flashes that last only a few thousandths of a second. Using special low-light-level cameras mounted on two small aircraft, scientists recently captured these flashes on video for the first time. They extended upward as high as 100 kilometers and some even reached through the Earth's ozone layer to the ionosphere. After coordinating their measurements with scientists at other institutions, the researchers came to suspect that the flashes are a form of electrical discharge. The scientists plan further study to understand the origin of the flashes and their potential impact on aircraft safety. More broadly, this phenomenon links the weather in the Earth's lower atmosphere to upper atmospheric layers that form our planet's border to space.

In other weather-related space science, NASA conducted a series of sounding rocket flights during FY 1994 to examine the Alaskan auroras. Space physicists are interested in these colorful phenomena known as "Northern Lights" because they are caused by variations in the solar wind's interaction with the Earth's magnetic field. Equipped with sophisticated payloads, sounding rockets flew directly through the auroras, allowing scientists to take direct measurements of the ions' energy levels. Researchers hope to gain a better understanding of how these particles are accelerated and energized. This campaign of eight rocket flights formed a significant part of the Space Physics Division's 41 rocket flights this fiscal year.

Because of their extreme luminosity at maximum light, Type Ia supernovae have proved themselves to be valuable in measuring both the local rate of expansion of the universe and the rate of change of that expansion. Recent work by Mark Phillips of the Cerro-Tolodo Interamerican Observatory in Chile has shown that there is a significant spread in the intrinsic radiated energy in visible light of this key subtype of supernova. That spread can introduce a bias in samples of distant supernovae, leading to erroneous estimates of universal deceleration. Phillips and his collaborators found a good correlation between the rate of decline with time of the luminous output of supernovae and their peak brightness. They also found that silicon absorption features easily detected in the spectra of supernovae are strongly correlated with both the rate of decline and peak brightness. The strength of the spectral features can be used to increase the accuracy of the estimate of each supernova's intrinsic brightness and therefore, its distance. The use of this technique now places supernovae among the most accurate of the standard candles, suitable for use as distant probes measuring features of the early universe.

A series of systematic observations by astronomers has long suggested the existence of a "Great Attractor," a concentration of mass that causes a bulk flow of galaxies toward it. Scientists discovered this large-scale flow by comparing the motion of the local group with respect to clusters versus the motion with respect to the cosmic microwave background, which is assumed to be a "stationary" reference. The strength of such large-scale flows can distinguish among models that explain the formulation of galaxies and clusters in the early universe. More recently, astronomers have begun to examine large volumes of space to search for structure and flows on even larger scales. Work by Todd R. Lauer (National Optical Astronomy Observatories) and Marc Postman (Space Telescope Science Institute), using the Kitt Peak National Observatory's 4- and 2.1-meter telescopes in Arizona and the Cerro-Tolodo Interamerican Observatory's 1.5-meter telescope in Chile, suggests that bulk flows can be identified over scales as large as some 600 million light-years, almost three times larger than those found in previous investigations. They used the brightest galaxies to measure the distances and velocities of 119 clusters, creating the cluster reference frame. The motion of the local group of galaxies derived with respect to these galaxy clusters was significantly different from the one derived with respect to the cosmic microwave background. The most straightforward interpretation of this result is that all the galaxies in the volume of space defined by these clusters are streaming with a velocity of nearly 700 kilometers per second and that any "attractor" has to lie beyond the boundaries of the original search. A structure this large cannot be explained by any current theoretical model and opens fruitful new directions for understanding the scale of the largest structures in the universe.

The application of seismology to the study of the solar interior has advanced almost solely by the prediction and measurement of the Sun's frequencies of oscillation. Thomas L. Duvall (Goddard Space Flight Center), Stuart Jeffries (Bartol), Jack W. Harvey (National Solar Observatory, Tucson) and Martin A. Pomerantz (Bartol) have shown that it is also possible to obtain direct measurements of the travel times and distances of individual acoustic (sound-like) waves, which is the predominant approach in terrestrial seismology. The basic concept is simple: At the surface, a wave propagating upward from the interior is reflected back downwards by the steep change in the density of the gas at the Sun's surface. As the wave travels into the interior, its path is curved back toward the surface by refraction, caused by the strong increase of temperature with increasing depth. If the upward wave causes a brightening in the area of the Sun's surface, then there will be a correlated brightening where the wave resurfaces at a later time. By measuring this time difference as a function of the distance of separation of two surface locations, it is possible to develop a plot of the travel time versus the distance of separation, a plot familiar from terrestrial seismology. The initial work showed that acoustic waves with frequencies of oscillation greater than a critical value predicted from the physical conditions in the solar atmosphere are not significantly reflected by the atmosphere, with less than 2-percent reflection coefficient. This approach opens the way for seismic studies of local solar phenomena, such as inhomogeneities beneath the Sun's surface near sunspots. It should also help refine models of the gas velocities below the Sun's surface.

Drs. Joseph Taylor and Russell Hulse of Princeton University won the 1993 Nobel Prize in Physics for their discovery using the Arecibo radio telescope in Puerto Rico of the binary pulsar PSR B1913+16 and their subsequent monitoring and analysis of this object. Their work demonstrated convincingly the appropriateness of general relativity as a theory of gravitation under extreme conditions and indirectly confirmed the existence of the gravitational radiation Albert Einstein had predicted. In more recent use of the Arecibo radio telescope, continued timing of the millisecond binary pulsar PSR B1257+12 by its discoverer, Alexander Wolszczan of Pennsylvania State University, has greatly strengthened the case for the previously-announced pair of planets that orbit this object; the observations have begun to show the expected effects that the planets' mutual gravity has on their orbital motion. The observations have also revealed the presence of a third planetary body, with a mass only 1.5 percent that of the Earth, that orbits the central neutron stars at a distance of only 0.2 astronomical units.

Observations of gas clouds associated with the high-redshift quasar PC 1643+4631A using the 42 and 12-meter radio telescopes at the National Radio Astronomy Observatory (NRAO--Kitt Peak, Arizona) have revealed the presence of carbon monoxide emission. Clouds such as this have been identified previously with the progenitors of current galaxies. The red shift of the molecular spectral lines indicates that they were emitted when the universe was about one-fifth of its present age. The observations by David T. Frayer, NRAO associate director Robert L. Brown, and NRAO director Paul A. Venden Bout are striking in that they indicate a molecular mass of 4.5 trillion solar masses. This equals the stellar mass of a large galaxy, but here the material apparently lies in an extended, gaseous, prestellar state. Also noteworthy are the substantial quantities of carbon and oxygen that make up the carbon monoxide molecules; these elements must have themselves been produced in a burst of massive star formation preceding the observed protogalactic state.

The National Science Foundation's (NSF) Center for Astrophysical Research in Antarctica (CARA) made wintertime astrophysical observations from NSF's observatory at South Pole for the first time during the austral winter of 1994. CARA's South Pole Infrared EXplorer (SPIREX) telescope was able, because of its unique location, to image more of the impacts of Comet Shoemaker-Levy 9 with Jupiter than any other instrument. Also, site measurements by SPIREX confirmed that the sky at South Pole is darker by a factor of at least three than any other site previously surveyed. Another of CARA's experiments is on the Cosmic Background Radiation Anisotropy; at the end of the fiscal year, it consisted of a suite of two telescopes designated PYTHON and VIPER. PYTHON has made measurements at South Pole during the past two austral summers and has now been operated for the first time during winter. It has made important confirmation of the Cosmic Microwave Background (CMB) anisotropy first measured by the Cosmic Background Explorer (COBE), launched in 1989, and it has begun to make a finer scale map of the CMB than is possible with the smaller antennas of COBE. The quiet atmospheric conditions at South Pole have allowed PYTHON to make measurements of unprecedented sensitivity.

Using new data from the Advanced Satellite for Cosmology and Astrophysics (ASCA, launched by Japan in February 1993) about two supernova remnants (designated E0519-69.0 and N103B) in the Large Megallanic Cloud, a binational team of astronomers led by SAO's John P. Hughes discovered significant amounts of iron, calcium, and other newly synthesized elements. ASCA gives astronomers a better tool for direct observation of the emissions from many atoms, including oxygen, silicon, calcium, and iron, in the ejected gas of supernovae, lasting for many hundreds of years after the explosion that created the supernova. Scientists believe that the explosions which created the remnants occurred somewhere between 500 and 1,500 years ago. The obvious presence of iron emissions coupled with the lack of strong oxygen emission suggests that these remnants belong to the select group of supernova explosions that produced the bulk of the iron in the universe, according to Hughes. Further study of the new data should help astronomers refine current models of supernova explosions and "because of the ubiquitous presence of iron throughout the universe," Hughes expected the results to have a large influence on astronomy in general.

Two other SAO scientists, Dong-Woo Kim and Giuseppina Fabbiano, discovered a huge, hot, gaseous halo surrounding a distant galaxy, perhaps providing evidence for the presence of both dark matter and so-called cooling flows. This, in turn, may shed new light on whether the universe is open or closed. The two astronomers used the joint German-United States-U.K. x-ray satellite Roentgen Satellite (ROSAT), launched in June 1990, to observe an x-ray-bright elliptical galaxy, NGC 507, some 300 million light years from Earth. Measuring the temperatures of x-ray-emitting hot gas, they observed a steady decrease of heat toward the galaxy's center. They believe this fall in temperatures may result from cooling flows in the central region. Also, uncertainty in measurements of the mass of NGC 507 suggest that a large amount of dark matter may be present. Observations indicate that baryonic matter (mass seen as stars and gas in all wavelengths) makes up some 15 percent of the estimated total mass of the galaxy. Since current cosmological theory predicts that baryonic mass must be less than 5 percent to "close" the universe, this finding has implications for cosmology. However, similar measurements of many other systems will be necessary before scientists can determine whether the universe is open or closed.

B. Solar system exploration

Closer to home, scientists were also making new discoveries about our own solar system. For example, ground observations conducted under the Near Earth Object program detected the Shoemaker-Levy 9 comet in 1993 and predicted its impact upon Jupiter in July 1994. This event marked one of the more spectacular results of a detailed, long-term telescopic survey of the night sky at Palomar Observatory, California, by United States Geological Survey (USGS) geologist Eugene M. Shoemaker and two volunteers, Carolyn S. Shoemaker and David H. Levy. It was the first totally disrupted (fragmented) comet ever to be observed, and the first to be seen orbiting and impacting a planet. For the first time, the worldwide scientific community was able to predict and track such a crash. Astronomers using most available ground-based observatories and a variety of operating spacecraft from Galileo (launched in October 1989) to the HST and the Kuiper Airborne Observatory obtained an array of interesting and revealing data about the composition of comets and Jupiter including a wide range of effects on the planet's atmosphere and plasma environment from the impact. A total of 21 observable fragments collided with Jupiter over a week-long period. The impact, observed in regions of the electromagnetic spectrum ranging from the ultraviolet to long radio wavelengths, produced fireballs that left major visible marks on the planet; it revealed a clearcut need for an inventory of comets and asteroids that may someday collide with Earth. During the last few months of the fiscal year, scientists under contract to the Defense Nuclear Agency (DNA) used their expertise in simulation and modeling of the nuclear effects in the Earth's atmosphere to explain the enhanced radio emission data resulting from measurements in various radio frequency bands from Jupiter's magnetosphere during the impact. Their findings, in line with a shock acceleration model, suggest a greater effect than had previously been assumed. As the fiscal year ended, previous calculations were being refined in collaboration with a variety of radio and optical observers and investigators. In anticipation of the collision of the comet with Jupiter, the Divisions of Astronomical Sciences and Atmospheric Sciences within the NSF and the Solar System Exploration Division of NASA sponsored a special program to support observational and theoretical investigations into the mechanism of energy deposition into different regions of Jupiter's atmosphere. Theoretical models account for the amount and velocity of material ejected during the collisions as well as the chemical reactions that occur as a result of the interaction of this material with the neutral and ionized components of Jupiter's atmosphere. The impact is expected to have generated dust that, on

being charged through exposure to the plasma environment, will form new dust rings around the planet. Data obtained from a variety of instruments strategically deployed to observe the effects of the impacts will test the theoretical predictions.

NASA scientists also made exciting new strides in lunar studies while working on the Department of Defense (DoD)-sponsored Clementine mission. This effort, in which lunar research was only one of the goals, was conducted by the Naval Research Laboratory (NRL) with the support of NASA, Lawrence Livermore National Laboratory and Jet Propulsion Laboratory (JPL) in California. Launched on January 25, 1994, the Clementine spacecraft entered lunar orbit on February 19, 1994. For the next 2 1/2 months, four cameras took 1.8 million images of the surface of the Moon in 11 discreet wavebands with coarse altimetry over most of the lunar surface, resulting in the first comprehensive digital map of that surface. In addition, NASA scientists are excited to have multispectral surface data covering 11 colors in the visible and infrared spectra. Instruments such as a laser ranger, a charged particle telescope, advanced thermal imagers, and radio tracking gear also contributed significant new information about the Moon's topography, surface composition, and charged particle environment. For example, the lidar system compiled a complete map of lunar elevations, discovering a 12-kilometer-deep impact crater at the lunar south pole in the process. An in-flight contrived experiment to use the communications transmitter for active, bistatic measurements produced supportive but not conclusive evidence for the existence of ice in the permanent shadows of craters near the lunar poles. NASA planned to sponsor a series of multiyear grants to scientists to examine Clementine's lunar data in expectation of discovering new insights about the Moon's formation. The USGS has begun processing the Clementine data to produce global digital maps, as well. A secondary mission of Clementine, a deep-space encounter with the asteroid 1620 Geographos, could not be completed because of a problem that occurred after completion of the lunar mapping mission.

Galileo, on the other hand, did complete its encounter with the asteroid Ida and in the process made the curious discovery of the first confirmed moon around an asteroid. This was the 1.5-kilometer-in-diameter satellite, Dactyl. Although scientists previously believed that natural satellites of asteroids probably existed, they now contend that such moons may be more widespread than previously considered. As the fiscal year ended researchers were busy examining data about Ida's moon to learn how both bodies were formed. One possibility is that the moon was formed during the explosion of a larger asteroid of heterogeneous composition that also gave birth to Ida. Spectral analysis by Galileo's near-infrared mapping spectrometer revealed that Dactyl is composed of different amounts of specific compounds than Ida, indicating that it did not come directly from Ida. New data gathered by Galileo indicate that Ida's composition is more diverse than previously thought. By examining the moon's orbital parameters, scientists, including those from NASA and the USGS, can better determine Ida's mass. Combining this information with prior data on Ida's size will enable scientists to deduce the asteroid's density and composition. While on its way to Jupiter, Galileo also examined another asteroid, Gaspra, which, like Ida, travels in the main asteroid belt orbiting the Sun between Mars and Jupiter.

In other planetary exploration, the Magellan spacecraft, launched in May 1989, determined that Venus is still geologically active. After completing the mapping of the planet's surface, Magellan began collecting information about its density. By tracking the spacecraft's precise speed over specific areas of the planet, ground controllers back on Earth calculated the strength of gravity in these locations and thus the subsurface density. The data indicate that Venusian areas of high gravity correspond to areas of high elevation, in contrast to the situation on Earth, where mountain ranges correspond to gravitational lows. Relatedly, the USGS successfully completed the first full-resolution global radar mosaic of Venus (1:1,500,000 scale); a series of 170 CD-ROMs containing the same spacecraft data was in production as the fiscal year ended. Nearly half of the 1:1,500,000-scale geologic base map quadrangles have been completed to support NASA's Venus Geologic Mapping Program.

In addition, the USGS has been involved in planning for unpiloted missions NASA proposes to send to Mars, including Pathfinder (a lander with a small rover projected for 1996-97), at least two orbiters named Mars Global Surveyor, and a series of Mars Surveyor landers. Geologists from the Survey served on the Pathfinder imaging team and helped plan for a wide range of Pathfinder experiments and geologic observations, including selection of a

landing site at the mouth of a large Martian outflow channel. Survey personnel also helped plan for Surveyor orbiter and lander missions projected to take place between 1998 and 2005.

C. Other space science

NASA made significant strides in microgravity and life sciences research during FY 1994, beginning with the Spacelab Life Sciences-2 (SLS-2) mission in October 1993. Its payload consisted of 14 experiments that examined physiological responses of humans and rodents to microgravity and their subsequent readaptation to Earth's gravity. As an extension of the SLS-1 mission in June 1991, research on SLS-2 focused on identifying and further characterizing the changes in physiological systems during and after space flight and on increasing our knowledge about underlying mechanisms so we can minimize or counteract changes adverse to human health before the international Space Station begins its operations. Important findings from SLS-2 included independent demonstration by three different investigator teams that current models for understanding the effects of gravity on the heart, lungs, and circulation could not predict the observed physiological responses during space flight. These studies will yield important new understanding of blood pressure regulation, in health and disease, and of cardio-pulmonary disorders. Researchers also learned that a surprising degree of neural plasticity results from exposure to microgravity. These results will improve our understanding of the nervous system's adaptation to change. Research into the role that physical loading (gravity) plays in maintaining muscle function--combining anatomy, biochemistry, and functional measures--will help the joint NASA-National Institutes of Health (NIH) program in muscle physiology.

The flight of a cosmonaut on STS-60 in February 1994 began Phase 1 of the international Space Station. In August, the first launch of United States research hardware aboard a Russian Progress rocket included an acceleration measurement system to support both United States and Russian research programs. Additional United States hardware is being tested and shipped to Russia for launch aboard Progress rockets next year. Ultimately, a planned International Space Research and Technology Institute will sponsor new interdisciplinary teams consisting of biologists, technologists, physicists, and material scientists to do research both on Earth and in the Space Station, bringing fresh insight and methodology to bear on problems humans face.

Meanwhile, in March 1994 NASA flew the USMP-2--a facility exposed to the space environment in the Shuttle payload bay that provides power, cooling, and data collection for a variety of experiments. The Isothermal Dendritic Growth Experiment advanced our knowledge of materials science. Dendrite growth is the common form of crystal growth encountered when metals, alloys, and many other materials solidify in most industrial processes. Study of the formation of dendrites in orbit showed conclusively that in order to provide rigorous tests of fundamental theories of dendrite formation and development, long-duration, high-quality microgravity conditions are required. These theories are needed to predict and achieve in solidified materials the desired microstructures that control many of their physical and chemical properties such as their mechanical strength and resistance to corrosion. The Crystal Growth of Solid Solution Semiconductors Experiment, using the Advanced Automated Directional Solidification Furnace on its first mission, successfully grew a crystal of mercury cadmium telluride alloy, a semiconductor, to study the physics of additive thermal- and composition-driven convection during crystal growth. The in-situ monitoring available in the MEPHISTO (French--Material pour l'Etude des Phenomenes Interessant la Solidification sur Terre et en Orbite) apparatus enabled the study of transport and kinetic phenomena during crystal growth of bismuth/tin alloys. The MEPHISTO furnace, developed by the French Space Agency and shared by United States and French investigators under a cooperative agreement, has the unique ability to study the formation of microstructures in solidifying materials to help understand how metals acquire their physical properties. The Critical Fluid Light Scattering Experiment studied phase transition phenomena near the critical point of the element, xenon. Studying an area known to physicists as dynamic critical phenomena, this experiment provided theorists with new guidance for modeling how systems with many degrees of freedom respond to fluctuations. Such models can help interpret such varied phenomena as atmospheric turbulence, human population dynamics, and superconductivity.

IML-2 in July 1994 continued IML-1's exploration of the effects of gravitational force on biological, physical, and chemical systems. Some 82 investigations sent into orbit by 75 principal investigators from 13 countries showed how crewed space laboratories can be used with high efficiency in international investigations such as those to be

done on the Space Station. On IML-2, 11 major United States microgravity experiments used new flight apparatuses developed by NASA's international partners. Four United States investigator teams used the German electromagnetic containerless processing facility (TEMPUS) to conduct studies of nucleation in solidification while also measuring thermophysical properties. One United States investigator used ESA's Advanced Protein Crystallization Facility, flown on its first long-duration mission, to study crystallization of macromolecules using the "liquid-liquid diffusion technique." Another United States investigator successfully completed protocols to study the phenomenon of liquid-phase sintering--a process used to produce alloys of novel compositions from high-temperature materials--in the National Space Development Agency (NASDA) of Japan's Large Isothermal Furnace. Two United States investigator teams studied liquid-phase interactions using ESA's Bubble, Drop, and Particle Unit, and one United States investigator group studied phase changes, employing ESA's Critical Point Facility. Preliminary results from the mission include new insights into the transport of mass and energy in systems at vapor-liquid critical point--a unique condition of matter that promises to reveal important new understanding of complex systems on scales ranging from the atom to global weather and of subtle changes such as the magnetization of an iron bar or the way substances transition from conductivity to superconductivity; and observations of surface-tension driven motions of drops and bubbles under conditions of strongly-coupled heat and momentum transport. The IML-2 studies of radiation biology showed damage to living cells as an effect of the natural space environment. Nematode worms showed a significant number of mutations compared to control specimens but no unusual reproductive behavior. Investigations on animals and plants exhibited the effects of microgravity and radiation on growth patterns, genetic material, bone development, cell differentiation and reproduction, and the effectiveness of antibiotics. The first documented, successful vertebrate reproduction in space involved mating and hatching Medaka fish eggs. One fry resulting from in-space fertilization actually hatched and survived, as did prefertilized eggs. Two newt eggs, laid on orbit, survived, and a high percentage of pre-orbit selected eggs remained viable as embryos and larvae. In another first occurrence in space, researchers established a gravity threshold, the point where gravity's effects can be observed, for two organisms--Euglena and jellyfish. Fruit flies exposed to microgravity exhibited hyperactivity compared to control specimens on Earth, indicating an accelerated aging process in space.

At the request of the governments of Ukraine and the Republic of Georgia, NASA life scientists associated with Space Radar Laboratory-2 received data in October 1994 on Shuttle passes over the two countries. This data will support technological developments and environmental monitoring in response to concerns of those governments about pollution and disease control.

NASA continued in FY 1994 to make strides in the field of Telemedicine, the practice of medicine across distances using a phone line, satellite, microwave or other telecommunications medium. The Spacebridge to Moscow Telemedicine Demonstration Project, a flagship program in this arena begun in November 1993, uses two-way, interactive video between clinical consultants at the Moscow Hospital of the Ministry of Information and four clinical sites in the United States. Remote aid in diagnosing patients under this project constitutes a successful follow-on to the Spacebridge to Armenia in 1988.

Regenerative life support research has led to significant advance in the development of new biofilm resistant coatings using application techniques common in industry. NASA initiated this research to control or prevent the buildup of medically harmful microorganisms in the air, water, and trace-contaminant control systems of long-duration on crewed spacecraft. Preliminary results (independently confirmed by the Center for Biofilm Engineering at Montana State University) show a 50 to 90+ percent reduction in buildup of a common biofilm-forming organism when the coating is applied to plastics or metal. The coated surface is heat-stable, thus allowing sterilization and reuse. Of particular note, the coated surface is also extremely easy to clean. These coatings may have application to preventing biofilm buildup in a number of commercially important areas. Preliminary estimates by the Center for Biofilm Engineering and the EPA conservatively estimate the commercial potential of these technologies in the hundreds of millions of dollars.

NASA also continued its close cooperation with other Government agencies in research. A joint biotechnology program between NASA and the NIH emphasized establishing joint centers to accelerate transfer of NASA technology and allow its application to biomedical research, developing advanced tissue-culturing technology for

application to biomedical research and developmental biology; advanced protein crystallization technologies to advance structural biology and drug design to fight diseases; and technology for early detection of cataracts. At the end of the fiscal year, NASA had 18 cooperative agreements with 10 institutes of NIH as well as the National Library of Medicine. Under an interagency agreement between NASA and the NIH, the two agencies established a Center for Three-Dimensional Tissue Culture at the National Institute of Child Health and Human Development. This agreement supports the transfer of NASA's bioreactor technology to NIH, its further development with NASA support, more protein crystal growth flight experiments, and new investigations of microgravity cell culture. Additionally, NASA and NIH have selected 22 investigators to fly life science experiments on the Space Shuttle in the period 1994-1996, the first such NASA/NIH spaceflight experiments; and 34 investigators for Neurolab, a Spacelab mission to fly on the Shuttle in 1998, dedicated to brain and behavioral sciences. NASA has also signed agreements with the National Cancer Institute, the National Library of Medicine, and the National Institute of Child Health and Human Development to do research in areas of common interest. In 1994 NASA received 141 proposals in biotechnology in response to a research announcement. Peer reviews in FY 1995 will determine which will be pursued further. NASA and the National Cancer Institute will apply the imaging technology used in HST and elsewhere to the diagnosis and treatment of breast cancer. Three projects in particular offer the promise of developing direct digital mammography systems with high resolution and a wide field of view. With the National Institute of Mental Health, NASA will help to apply recent advances in computer and information sciences to the brain and related health sciences.

In related endeavors, NASA, the Air Force, and GTE Corporation recently completed a program studying the growth of gallium arsenide in the space environment. NASA also funds a protein crystal growth program at the Naval Research Laboratory, and under a NASA agreement with the DoD, Walter Reed Army Institute of Research has been conducting cell culture research in a flight system. A memorandum of understanding between NASA and the NSF has committed those two agencies to collaborative research in environmental signal transduction and cell differentiation in plants in response to environmental stimulation, especially gravity. Another agreement between NASA and the Multiple Sclerosis (MS) Association of America will use the technology developed for cooling systems in space suits to develop cool suit technology for victims of MS who have trouble regulating internal body temperature. A result from a joint project development effort between NASA's Ames Research Center and the NSF's Closed Ecological Life Support System Antarctic Analog Project will be NASA's largest-scale application to date in bioregenerative life support technology and will also feature a recycling system to support Antarctic researchers. Designed to increase the habitability of the Amundsen-Scott South Pole research station and help the United States meet its international obligations to maintain the Antarctic environment in a pristine condition, this project will allow NASA to meet the goal of obtaining long-duration experience in a similar environment to test regenerative life-support candidates for planetary habitats by deploying regenerative food, water, and waste-processing systems for use at the South Pole.

D. Space shuttle

The Space Shuttle's primary purpose continued in FY 1994 to be transporting people and cargo safely into low-Earth orbit (180 to 600 kilometers above the Earth). As of the end of the year, NASA had four active orbiters in its fleet: Columbia, Discovery, Atlantis, and Endeavour. During FY 1994 Atlantis completed its Orbiter Maintenance Down Period (OMDP) in the Orbiter Facility in Palmdale, California. During OMDP, Atlantis was outfitted with the modifications necessary to dock with the Russian Mir space station, with the first docking mission scheduled for the third quarter of FY 1995. As the year ended, the orbiter Columbia was being prepared for delivery to Palmdale for an OMDP.

During the year, NASA initiated a redesign of the external tank for structural weight reduction, which will improving the performance of the Shuttle system. The redesign involved substitution of aluminum lithium for the existing aluminum alloy, thus taking advantage of the greater strength per unit of weight characteristic of the new material. The first launch of the resultant super lightweight tank will be in late calendar year 1997.

The Space Shuttle Main Engine program aggressively pursued the development and implementation of safety and reliability improvements in FY 1994. In the current engine, five major components were in the process of being upgraded in two block changes. Block I incorporates the new phase II+ powerhead, the single-coil heat-exchanger, and the alternate high pressure oxidizer turbopump. Block II contains the Block I improvements and adds the alternate high pressure fuel turbopump and the large throat main combustion chamber. Engineers conducted 101 ground tests in FY 1994 for a total of 47,775 seconds in support of the development and current flight programs. To date, the oxidizer turbopump has satisfied its requirements for total development seconds and the first of two formal certification units has successfully completed its 20 test series. The first Block I certification engine, which contained the second oxidizer turbopump certification unit, began testing in October 1994. As of the end of the fiscal year, Block I was scheduled for its first flight in June 1995. Engineers involved in the oxidizer turbopump development successfully resolved all of the major technical problems encountered early in development. Due in large part to this success, Congress approved the resumption of development work on the fuel turbopump, which had been in caretaker status since 1991. Development testing of the fuel turbopump was underway at the end of the fiscal year, and the Block II configuration was scheduled to enter service in September 1997. The Space Shuttle Main Engine program has also been pursuing performance enhancing changes in engine operation for Block II--part of the overall Shuttle performance enhancement program to support Space Station objectives.

The Solid Rocket Booster successfully supported the eight Shuttle flights begun during FY 1994. There was one static test firing of a heavily instrumented flight support motor. Efforts began to transition Redesigned Solid Rocket Motor nozzle production from Utah to the former Advanced Solid Rocket Motor site in northeast Mississippi. Elimination of ozone-depleting substances in booster manufacturing continued. Engineers have been developing two performance enhancements related to the booster as part of the overall Shuttle performance enhancement program to support Space Station objectives. A motor nozzle exit cone extension will increase the vacuum specific impulse of the motor. The lightweight booster program will replace the current nylon parachutes with kevlar versions and will include minor structural weight reductions.

In the area of Space Shuttle Systems Integration, the Day-of-Launch I-Load-Update (DOLILU I) system was available for all FY 1994 missions. The system updates the flight trajectory to account for the actual winds on the day of launch. The DOLILU II system, which will incorporate the main engine control tables, solid rocket trim data, and aerodynamic control data on the day of launch, will further optimize the ascent trajectory of the Shuttle. NASA expected the first flight using this improvement to occur in May 1995. Integration efforts during FY 1994 also included analyses of structural loads; resolution of in-flight anomalies, waivers, and changes; and software development and testing for the control of each mission. To support the international Space Station mission requirements, NASA has initiated efforts to identify, develop, and baseline Shuttle performance enhancements. Engineers have developed systems integration plans to ensure their orderly implementation into the Space Shuttle program. Analyses were underway at the end of the year to ensure the compatibility of design modifications to the external tank, main engine, solid rocket boosters, and the orbiter itself. Engineers have specified design analyses and test requirements to provide definition of flight margins. All of the enhancements have been specified in support of the first international Space Station assembly flight scheduled for December 1997.

During 1994, the Space Shuttle ground processing team at KSC achieved several innovations and enhancements that increased efficiency, improved scheduling, and reduced costs. A reliability-centered maintenance program continually adjusted procedures based on actual performance data and operational experience. An integrated work control system, still under development, has already streamlined and automated work control functions related to more than 10,000 major tasks performed in preparing an orbiter's 22 major systems for flight. It has prestaged work packages, provided automated notification of needs for parts and material, and thereby reduced the numbers of tasks experiencing holds. Another improvement in ground processing involves selecting a team leader from a work unit, training him or her, and defining the responsibilities and authority for processing tasks from planning to completion. This enables problems to be resolved at the lowest operational level while providing structure and cohesiveness to the effort. The task team leader concept has enhanced Shuttle processing, facilitated teamwork, minimized delays, and improved quality. Over 4,400 NASA and contractor personnel have received training in this concept, which has been employed successfully in all areas of the operation.

E. Satellites

Following the loss of Landsat-6 in October 1996, the National Oceanic and Atmospheric Administration (NOAA) continued to rely on Landsat-5, in operation since 1984. The Landsat series has provided regular observations of the surface of the Earth for two decades, monitoring renewable and nonrenewable resources. Landsat data applications support programs such as global change research, coastal zone monitoring, timber management, regional planning, and environmental monitoring. On May 10, 1994, the White House announced the Landsat Remote Sensing Strategy, which provides for continuity of existing Landsat and future Landsat-type data. The strategy assigned Landsat-7 program responsibilities jointly to NASA, NOAA, and USGS. NASA assumed the satellite-development responsibilities for Landsat-7 from the DoD. NASA and NOAA will jointly develop the ground system, which NOAA will operate in cooperation with the USGS. The Earth Resources Observation Systems (EROS) Data Center of the USGS will continue to be responsible for maintaining Government archives of Landsat and other land-related remote-sensing data. Landsat-7, planned for launch in December 1998, will carry an improved Enhanced Thematic Mapper (ETM-Plus).

The successful April 13, 1994, launch of Geostationary Operational Environmental Satellite (GOES)-I, renamed GOES-8 once it achieved orbit, resulted in more precise and timely weather observation and provision of data on the atmosphere. Its design, featuring three-axis stabilization, permits the satellite's sensors to observe the Earth continuously, compared to only 5 percent of the time for current spin-stabilized satellites. The first in a series of five advanced weather satellites to be launched over the next several years, GOES-8 was checked out and fine-tuned by NASA for 6 months after launch. Thus, NOAA did not obtain control over the satellite until after the end of the fiscal year. During checkout, the satellite was positioned at longitude 90 degrees W., but plans called for it to be moved to longitude 75 degrees W. once it became operational, and for GOES-7, still operational seven years after launch, to move from longitude 112 degrees W. to longitude 135 degrees W. so the two satellites together could provide continuous coverage of the Western Hemisphere. NASA, which procures launches and checkouts for the GOES series of satellites and manages their design, development, and launch, planned to launch GOES-J in 1995 to replace GOES-7, which has already exceeded its expected lifetime. NOAA is responsible for the operations, including command and control, data receipt, and product generation and distribution for the satellites.

In a totally different area, NOAA announced at the beginning of the calendar year that two new ground stations had been added to the network of satellite search and rescue facilities throughout the United States. Located in Guam and Puerto Rico, they were the final of six new, fully automated installations designed to upgrade the satellite search and rescue system, which helps to bring emergency assistance to mariners, ground-based users, and pilots in distress. The stations and four others installed in the United States over the preceding year and a half are part of an international satellite search and rescue system known as COSPAS-SARSAT (from a Russian acronym meaning Space System for Search of Vessels in Distress and an English one for Search and Rescue Satellite-Aided Tracking System). The system enables distress signals from ships or airplanes to be received and processed more quickly than before. It uses a total of six NOAA environmental satellites and Russian navigational satellites, plus a network of ground stations to pick up radio and beacon signals from the distressed individuals and send them via mission control centers like NOAA's in Suitland, Maryland, to rescue coordination centers. Since the inception of the system in 1982, a total of 4,310 lives had been saved as of September 30, 1994--960 of them during calendar year 1993.

The Small Expendable Tether Deployable System-2 (SEDS-2), conceived and designed by SAO, was a secondary payload on a Delta II rocket launched at 10:40 p.m. EST on March 9, 1994, from Cape Canaveral AFS, Florida. At a length of nearly 20 kilometers, it was the longest object ever placed in space. At 11:45 p.m., the Delta's second stage ejected the 23-kilogram SEDS-2, using a spring-loaded device. The minisatellite reached a final deployed length of 19.8 kilometers in just 1 hour 48 minutes, achieving the primary purpose of the experiment, to suspend such a payload with a minimum of swing. Thereafter, SEDS-2 remained in space to determine the resistance of its braided polyethelene to micrometeoroids, space debris, and atomic oxygen. The tether apparently was severed by a micrometeoroid (or debris) on March 15. Thereafter, the end of the tether reentered the upper atmosphere and burned, while about 10 to 12 kilometers of its length remained attached to the rocket's second stage and continued

orbiting until May 8, 1994. This marked the third SAO-developed tether launched within the past year, each on time and with an increasingly ambitious goal.

F. Space station

Fiscal year 1994 was a time of tremendous accomplishment for the international Space Station program. In October 1993, the program formally developed an initial set of specifications, including Russian elements as part of the design. In December 1993, the original 12 participating nations in Space Station Freedom (the United States, Canada, Italy, Belgium, The Netherlands, Denmark, Norway, France, Spain, Germany, United Kingdom, and Japan) extended an official invitation to Russia to join the partnership, and Russia accepted. The existing Shuttle/Mir program was then expanded and made Phase I of the international Space Station program. In February 1994, the Phase I activity officially began when Sergei Krikalev became the first Russian to fly on the Space Shuttle. NASA astronauts Bonnie Dunbar and Norm Thagard have been training to fly on the Mir space station since March 1994 at the Russian Cosmonaut Training Center in Star City. The first American was scheduled to be launched on a Russian spacecraft to Mir in March 1995. All of the international Space Station program partners took part in a successful systems design review at Johnson Space Center (JSC), Texas, in March 1994. On June 23, 1994, NASA Administrator Daniel S. Goldin and Russian Space Agency (RSA) Director General Yuri N. Koptev signed a NASA/RSA interim agreement on Space Station and a $400 million contract. The agreement permits Russian participation in joint program management bodies and the contract covers Russian provision of hardware and data in the program's early phases (primarily for Shuttle-Mir activities). Additionally, on August 31, 1994, NASA and the Boeing Company signed a memorandum of agreement that defined the content and maximum cost of the prime contract, scheduled for signature by late 1994. Also during August, the program completed a vehicle architecture review. Finally, on September 28, 1994, the Space Station Control Board examined the vehicle architecture review and ratified its recommended modifications to the assembly sequence and element requirements for the Space Station.

The redesign of the Space Station that resulted from these activities preserved the best of the previous Space Station Freedom program's hardware and capability, while adding increased research capability and user flexibility. The new international Space Station costs $5 billion less than Freedom. It has adopted a streamlined management structure and significantly reduced the number of civil service personnel and contractors assigned to the program. It has adopted an integrated product team approach, using the skills of the civil service workforce to develop a number of Station elements more economically and efficiently, saving millions of dollars in the process. Furthermore, Russian cooperation has added greater capability to the international Space Station and further reduced United States costs, making the Station an important aspect in the new and evolving relationship between the two countries. To date, the program has produced 12,000 kilograms of Space Station hardware--about 1,000 kilograms more than projected. There has been a number of successful technical interchange meetings with the Russians, and Russia has begun delivery of items called for in the contract signed in June. Before the end of the fiscal year, a NASA liaison team was in place in Moscow, and NASA was working with the Russians to get their liaison office established in Houston. At a technical interchange meeting in August 1994, NASA and the RSA agreed on a number of important integration and operations issues, such as how command and control orders would be sent to the Space Station. Joint management team discussions in Moscow the following month continued and expanded these efforts, resulting in agreement on matters necessary for working together, such as the use of English as the common language.

Meanwhile, the new Canadian government recently reaffirmed support for the international Space Station. Canada has been restructuring government spending to reduce its debt. In the face of difficult budget decisions, the Canadian government has continued to recognize its responsibility for developing the Mobile Servicing System, which will provide external Space Station robotics. Canada also planned to develop the Special Purpose Dexterous Manipulator for more delicate robotic operations. ESA has continued to develop the Columbus Orbital Facility (COF--a pressurized laboratory) and laboratory support equipment for early scientific use. ESA has also been developing the Ariane V launch vehicle and associated transfer vehicles; as FY 1994 ended, it was involved in discussions with NASA on a possible role for these vehicles in Space Station logistics resupply. ESA conducted a design-to-cost exercise on the COF, coordinating the technical and management changes closely with NASA. The

Europeans have expressed interest in examining the possibilities for providing a crew rescue vehicle and also an automated transfer vehicle, which would provide propellant resupply and reboost. Japan has been developing the Japanese Experiment Module (JEM), consisting of a multipurpose pressurized laboratory element, an unpressurized exposed facility, a remote manipulator system, and experiments logistics modules. Japan's Space Station program has been making steady progress, with 63 percent of its development funds contracted out.

G. Nuclear energy

To date, the United States has successfully employed 37 Radioisotope Thermoelectric Generators (RTG's) on over 20 spacecraft launches. An RTG is a device without moving parts that converts the heat from the decay of the radioisotope Plutonium-238 (Pu-238) into electricity. RTG's have shown the flexibility and ability to operate beyond specified mission lifetimes demanded by a variety of space missions. For instance, the multi-hundred-watt RTG on the Voyager 2 spacecraft, launched in 1977, has continued to operate as it has travelled beyond Neptune into space. The Department of Energy (DoE) has developed a new model RTG with a more efficient fuel design called the General Purpose Heat Source (GPHS). The GPHS-RTG operated successfully on the Galileo and Ulysses missions, launched in 1989 and 1990, respectively. DoE program activities in 1994 focused on production of both GPHS components and GPHS-RTG thermoelectric converters to meet the requirements for power of the Cassini mission to Saturn, scheduled for a 1997 launch. The Savannah River Plant in South Carolina processed the majority of the Pu-238 needed to fuel the three new RTG's. In 1994, Oak Ridge National Laboratory in Tennessee completed production of all the iridium parts that will be used to encapsulate the Pu-238 fuel. Los Alamos National Laboratory, New Mexico, pressed the initial flight pellets of Pu-238 and welded these pellets into the iridium capsules. The agency will release the preliminary safety analysis report in late 1994. The Mound Plant of EG&G Mound Applied Technologies in Miamisburg, Ohio, was proceeding according to plan with RTG assembly preparation activities as the fiscal year ended. The prime system contractor, Martin Marietta Astrospace, completed the production of all thermo-electric elements for all three RTG's during the year, and fabrication activities on other portions of the RTG's remained on schedule. DoE also developed new conceptual designs for smaller and lighter-weight RTG's for the Pluto Fast Flyby mission, whose specifications call for it to be powered by RTG's. Later in 1994, DoE will issue a comprehensive report responding to a General Accounting Office inquiry regarding the long-term production capability of RTG's. DoE intends to retain its unique capabilities to provide special nuclear power sources for other agencies' needs.

H. Other space technology

During FY 1994, NASA made significant progress in measuring, modeling, and mitigating the orbital-debris environment. This completed the third year that the Haystack Orbital Debris Radar, operated for NASA by MIT's Lincoln Laboratory, has measured and monitored such debris. This powerful radar can detect debris as small as a pea orbiting 600 kilometers out in space. At low altitudes (400-600 kilometers) it measured less debris than predicted--good news for the international Space Station. However, at higher altitudes (800-1000 kilometers) the debris population was greater than NASA had predicted. Because objects in higher orbits are not significantly affected by changes in solar activity, their lifetimes can exceed 1,000 years, meaning that they will not pose a hazard to the Space Station, but they are a threat to scientific, Earth observation, weather, and communications satellites. On February 9, 1994, the Orbital Debris Radar Calibration Spheres (ODERACS-1) were deployed from Space Shuttle Discovery. The purpose of these six spheres ranging in diameter from 5 to 15 centimeters, is to improve the ability of ground based radars to detect and track small debris objects. The spheres are expected to remain in orbit providing valuable calibration data until mid-1995. NASA also developed a portable telescope that is capable of detecting objects as small as one-half inch in diameter at altitudes ranging from that of the Space Station (400-650 kilometers) through Sun-synchronous altitudes (800-1000 kilometers) and objects as small as 5 to 10 centimeters at geosynchronous altitude (36,000 kilometers). This Liquid Metal Mirror Telescope (LMMT) concept is based on the research of Dr. E.F. Borra of Laval University in Quebec, Canada, in the area of liquid mercury mirrors. The prototype 3-meters-diameter LMMT now in operation at NASA's JSC is the 17th largest telescope in the world. It was built at a cost of about $500,000--1/100th the cost of comparable Earth-based astronomical telescopes. To reduce construction costs, NASA designed the LMMT to be housed in a grain silo purchased on the

commercial market. Operational software costs were minimized by modifying software previously developed for JSC's Charge Coupled Device Debris Telescope.

In a somewhat related effort to forecast space weather and thus to assess the likelihood of damage to satellite components, scientists at Rice University developed sophisticated computer models to calculate the density and energy of particles at any point in space. They constructed maps similar to those used by meteorologists showing the flow of plasma in the ionosphere and the characteristics of ions and electrons precipitating into the atmosphere. Using high time resolution, the scientists calculated the way in which the plasma flow changed in response to conditions in the solar wind. They displayed the results graphically as a movie. More than 50 scientists then carried out coordinated observational campaigns to validate the results of the model.

I. Communications satellites

There were three new commercial domestic fixed satellites launched for the United States during FY 1994. Galaxy 1R(S), launched on February 19, 1994, will provide video services into the next decade. The satellite replaced another one that was nearing the end of its useful life; it is located at longitude 133 degrees W. General Dynamics Commercial Launch Services successfully launched the Telstar 401 communications satellite from Cape Canaveral aboard an Atlas IIAS on December 15, 1993. The satellite completed systems checkout and in-orbit testing at longitude 89 degrees W. in January 1994 and was then moved to longitude 97 degrees W. to begin providing television and data communications services for United States customers in early February. Unfortunately, the September 9, 1994, launch of Telstar 402 by an Ariane launch vehicle from Kourou, French Guiana, was not as successful. The launch itself went fine, but operators lost contact with the satellite after it evidently began spinning as it passed over the Indian Ocean. Customers such as Fox Broadcasting and ABC will continue to use Telstar 401 until Telstar 403, redesignated Telstar 402R, is launched.

Two other communications satellites that were not in the domestic fixed category but did provide domestic service were the first Direct Broadcast Satellites (DBS). Launched by an Ariane booster from Kourou, French Guiana, on December 17, 1993, DBS-1, as the satellite is designated by its co-owners, DirecTv and United States Satellite Broadcasting, offered some 75-80 channels of television service after April 1994 to United States subscribers or those purchasing the equipment necessary for reception. Located at longitude 101 degrees W., the HS 601 satellite built by Hughes Space and Communications Company provided broadcasting to all of the contiguous 48 states. It was followed on August 3, 1994, by DBS-2, successfully launched from Cape Canaveral AFS by a Martin Marietta Atlas IIA. It increased the number of channels available on the service to 150. Still another communications satellite placed into orbit during the fiscal year was PanAmSat's PAS-2--designated PAS-4 by the Federal Communications Commission (FCC). An Ariane 4 rocket launched it into space from Kourou, French Guiana, on July 8, 1994. The 2,920-kilogram satellite was built by Hughes Aircraft Co. and became PanAmSat's first private international satellite for the Pacific Ocean Region, providing television coverage from the Western United States to the Asian mainland. It marks the second of four satellites scheduled to constitute PanAmSat's Global Satellite System, begun with PAS-1 launched in June 1988 and providing services to the Atlantic Ocean Region. Also a Hughes HS 601 satellite, PAS-4 can carry more than 320 digital channels transmitted on 16 63-watt Ku-band and 16 34-watt C-band transponders.

The International Telecommunications Satellite Organization (INTELSAT), a consortium established in 1964 and consisting (in September 1994) of 134 member nations that owned and operated the world's most extensive global communications satellite system with service in more than 200 countries and territories, successfully launched its INTELSAT 701 satellite on October 22, 1993, aboard an Ariane 44LP rocket. The first in its series of high-powered INTELSAT VII spacecraft, INTELSAT 701 began commercial service on January 15, 1994, with the transfer of traffic from the INTELSAT 510 satellite launched in March 1985. Situated at longitude 174 degrees E., the Space Systems/Loral satellite began providing expanded telephone, television, and other services to INTELSAT customers in the Pacific Ocean Region, including the west coast of North America, the islands in the Pacific, and the east coast of Asia. Most long-distance carriers of telephone service in North America and the Asia-Pacific Region began using the new satellite, which handles 90,000 telephone calls at once versus the 75,000 transmitted by the 510 satellite. In addition, the 701 transmits three television channels at a time instead of the two channels transmitted by INTELSAT 501.

On June 17, 1994, INTELSAT successfully launched the second of nine VII-VII-A satellites ordered from Space Systems/Loral aboard an Ariane 44LP launch vehicle from Kourou, French Guiana. After moving from its in-orbit test location, INTELSAT 702 began commercial service on August 13, 1994, at longitude 359 degrees E., replacing the lower-capacity INTELSAT 512. Serving as the only direct one-hop communications link between the Indian subcontinent and America (North and South), INTELSAT 702 provides expanded communications services to INTELSAT's customers in Africa, Europe, the Indian sub-continent, the Middle East, the Eastern United States, and South America. The new satellite is the 50th that INTELSAT has launched; 22 of these remain in operation providing customers such business services as international video, teleconferencing, facsimile, data, and telex.

The International Maritime Satellite Organization (Inmarsat), a London-based international entity with 75 member countries as the fiscal year ended, did not add to its complement of four INMARSAT II and seven older satellites providing mobile satellite communications in the air, on land and sea for almost 40,000 users of mobile terminals in more than 165 countries. Among the organization's accomplishments during the year was the world's first satellite voice connection to a cellular-sized phone, Inmarsat announced in March 1994. The event occurred during trials for a future global handheld phone system to test the power margins needed to provide voice service between 1998 and 2000. Meanwhile, in September 1994, a London department store began selling the INMARSAT-M briefcase satellite telephone. The lid of the briefcase serves as the antenna for the telephone inside. Also during the year, the United States Communications Satellite (Comsat) Corporation, which holds (roughly) a 23-percent share in Inmarsat, opened a new station in Kuantan, Malaysia, on July 1, 1994. This new station plus existing ones in Santa Paula, California, and Southbury, Connecticut, made Comsat the first Inmarsat service provider to operate digital mobile satellite services around the globe.

J. Space network

On November 29, 1993, NASA repositioned its first Tracking and Data Relay Satellite (TDRS-1), launched in 1983 and already serving beyond its 10-year lifetime, to recover scientific data from the Compton Gamma Ray Observatory (GRO), launched in 1991. A significant portion of GRO data would otherwise have been lost due to the failure of a tape recorder on the spacecraft. NASA installed a highly automated ground terminal, GRO Remote Terminal System (GRTS), at its Deep Space Network location in Australia to control TDRS-1. This terminal is remotely operated from the TDRS System (TDRSS) ground stations in New Mexico. TDRS-1 started relaying data operationally on December 6, 1993, during the shift from its former to its new location, a year from project start. TDRS-1 was in position at longitude 85 degrees E. over the Indian Ocean by February 7, 1994, and NASA declared GRTS to be operational on April 1, 1994, with a proficiency of over 97 percent. With TDRS-1 and GRTS, NASA has extended real-time data retrieval to the full orbit for GRO, which is studying the evolution of the universe, the nature of puzzling astronomical objects, and the processes that produce very-high-energy radiation.

NASA has begun making TDRSS available to United States industry to conduct experiments and demonstrations of innovative satellite communications technologies and concepts free of charge. The intent of this Mobile Satellite Communications via the TDRSS (MOST) program is to enhance the competitiveness of the United States industry in the global satellite communications arena. TDRSS enables testing of lightweight, mobile, handheld satellite communication terminals in a variety of environmental conditions. Already, the tracking system has been used to demonstrate satellite broadcast of compact disk (CD)-quality radio to conduct measurements of path diversity for commercial mobile satellite communications. Applications of the technologies validated by MOST include, for example: listening to CD-quality radio while driving across the country; communicating by handheld, wireless devices anywhere in the world, no matter how remote; and communication by hikers in remote areas during emergencies. The MOST activity does not interfere with the primary TDRSS mission of relaying commands to and data from scientific spacecraft.

K. Ground networks

NASA uses ground-based telecommunications facilities to provide telemetry, command, and navigation services to a number of NASA, other United States, and international spacecraft such as the Space Shuttle; other Earth-orbiting spacecraft; planetary orbiters; and international spacecraft. These spacecraft include the Space Shuttle and Earth-orbiters; planetary orbiters such as Galileo and Magellan; and the Voyager and Pioneer spacecraft travelling to the outer reaches of our solar system. Other uses of ground network facilities include tracking and data acquisition services to sounding rocket, high-altitude balloon, and aeronautical research missions. This worldwide capability has enabled mission operators to navigate their spacecraft, configure them for scientific observations, and recover the resulting scientific data. During the past year, the recovery of additional image data from the 1993 encounter of the Galileo spacecraft with the asteroid Ida showed the asteroid had a moon. Magellan, which had been providing scientific data about Venus for several years, concluded its mission in a final experiment as its orbit decreased and it entered the planet's atmosphere. In addition, radar image data received from the Clementine spacecraft provided

detailed maps of the Moon's surfaces, and data from the international solar mission, Ulysses, provided unique observations of the southern hemisphere of the Sun.

L. Terrestrial studies and applications

Terrestrial studies themselves encompass a broad range of activities. Among them was NASA's demonstration during FY 1994 of two new techniques for observing the environment from space. The first of these was a multifrequency, multipolarization radar--the most complex civilian radar ever flown in space--to study the ecology, water cycles, vegetative cover, as well as oceanography, geology, and volcanology. In cooperation with Italy and Germany, the Space Radar Laboratory flew on the Space Shuttle Endeavour during April (SRL-1) and September-October 1994 (SRL-2). These missions have enabled a team of 52 scientists and ground teams around the world to observe the shifting boundaries between temperate and boreal (northern) forests, plus other natural phenomena. The results will be used for mapmaking, study, and interpretation. For example, the USGS has begun studying the Sahara in North Africa, the southern part of Africa, Asia, and the Southwestern United States using images from the SRL. Because radar signals penetrate dry sand and produce images of geologic features otherwise concealed by windblown sand in desert regions, the radar laboratory's images are being used to map the distribution of various geologic indicators of climate change and of untapped resources, particularly those related to old, dry river systems.

During April and May of 1994, NASA and the Canadian Government conducted a campaign known as the Boreal Ecosystem-Atmosphere Study (BOREAS)--a large-scale, ground-based and remote-sensing investigation of how the forests and the atmosphere exchange energy, heat, water, carbon dioxide, and other trace gases. SRL-1 repeatedly imaged BOREAS ground sites, allowing scientists to compare the spaceborne data with their readings from ground and aircraft investigations. Sample results indicate that water evaporation rates in the boreal (northern) forests of central Canada are extremely low. This data will correct current models that over-predict atmospheric moisture. In a tangentially related development, in August 1994 NASA, NOAA, and the Canadian Space Agency reached final agreement on the data policy for the Canadian Radarsat spacecraft. Once launched, Radarsat will map the world, collecting all-weather data of particular value over ice and oceans. The program plan calls for tilting the satellite to provide a complete mapping of Antarctica as one of the mission objectives.

The second of NASA's new techniques for environmental observation was lidar--using a laser in a manner similar to radar by bouncing it off objects (e.g. clouds, pollutants, the Earth's surface) and then making environmental measurements from the reflected energy. The LIDAR In-Space Technology Experiment (LITE) flew on the Space Shuttle Discovery in September and observed clouds invisible to conventional weather satellites, dust clouds over Africa, and the structure of a super typhoon in the Pacific, including the top level of clouds and the storm's eye.

In June 1994, meanwhile, NASA announced that it had competitively selected two industry-led teams to build, launch, and operate two experimental satellites--each no bigger than a console television set and commonly referred to as "Lewis and Clark"--as part of NASA's small spacecraft technology demonstration. The entire contract process lasted only 70 days instead of the standard 6 months to a year. "Lewis" will be the first-ever space-based "hyperspectral" imaging system, with wide applications in Earth science and new commercial business opportunities. "Clark" will help city planners and developers evaluate sites and construction needs through the use of an optical element with very high spatial resolution and capabilities for stereo imaging. Both spacecraft will carry additional instruments that will provide information on the dynamics of global atmospheric pollution for NASA's Mission to Planet Earth (MTPE).

MTPE has included education and public awareness as part of its vision to ensure that the public has sufficient information and understanding to support development of prudent policy in the future regarding global environmental change. Significant efforts are underway at the Federal and agency levels and within MTPE to coordinate and convey program results more effectively. In this connection, so as to be a catalyst for progress, NASA has begun addressing educational challenges at several levels--training the next generation of Earth scientists who will approach global change from an interdisciplinary perspective, training teachers at the undergraduate level to provide the tools to teach Earth system science, and educating the public at the societal level to build confidence in and understanding of

scientific methods. One of the priorities of the United States Global Change Research Program (USGCRP) is to address and contribute to scientific education and communications. In April 1994, Vice President Gore announced Global Learning and Observations to Benefit the Environment (GLOBE), a major new initiative to have students from around the world make measurements, submit them to a central source for processing, and analyze the collective findings. Scientists will be able to use the results in their environmental research. NOAA and NASA have been leading this effort with contributions from NSF, EPA, the State Department, and other agencies. The agencies of the USGCRP made significant progress during the year in improving coordination in education and outreach, including development of teacher training materials, provision of fellowships in environmental research, and contributions to new national standards for the teaching of science.

NASA-sponsored analysis of data from Landsat-4 and -5 for 1978 and 1988 showed that deforestation in the Brazilian Amazon Basin was lower than some previous estimates had suggested. However, the fragmentation of the rain forest and the "edge effects" on the perimeters of these fragments were greater than had been believed, potentially increasing the threat of species extinction. Tropical forests are home to nearly half of all plant and animal species on Earth. Researchers concluded that while the area of deforestation had nearly tripled in the 10-year period, the total deforested area was smaller than predicted by many other studies. Working in close cooperation with researchers from Brazil, the authors of the study validated the use of Landsat data for estimating deforestation in the Amazon, previously an issue of substantial controversy. Other researchers also demonstrated Landsat's effectiveness by combining its imagery with GIS technology to identify types and location of landscape elements associated with the risk of Lyme disease in Westchester County, New York. Also, analysis of data from a combination of Landsat, airborne, and ground-based scanners continued to be used to battle pest damage to California's $10 billion-a-year wine industry. About 65 percent of Napa and Sonoma counties' vineyards are planted with a grape rootstock vulnerable to a new variety of phylloxera, an aphid-like insect that kills grapevines by sucking juice from their roots. The spatial and spectral analysis from Landsat's scanners can detect problems before they become visible to vintners.

Relatedly, USGS' EROS Data Center is the Distributed Active Archive Center (DAAC) for data about land processes to be acquired and distributed in support of the Earth Observation System (EOS). Its functions include storage, management, and distribution of data from the Moderate Resolution Imaging Spectrometer and Advanced Spaceborne Thermal Emission and Reflection Radiometer, which will fly on the first EOS platform in 1998, and from Landsat-7. The EROS Data Center was also planning to archive and distribute other data sets through its Land Processes DAAC, including data from the Advanced Very High Resolution Radiometer (AVHRR) on NOAA's polar-orbiting satellites, digital aircraft scanner data, digital topography, and associated ancillary data. The EROS Data Center DAAC component of the EOS Data and Information System (EOSDIS) Version 0 became operational in FY 1994, providing user access to electronic networks, interoperable catalogs, and data distribution capabilities at the EROS Data Center as well as the other DAACs. The center was in the process of converting historical Landsat data from aging magnetic media to new cassette tapes to preserve them for future use. It completed conversion of 352,000 Landsat Multispectral Scanner scenes acquired since 1979, and it also converted about 30 percent of the Landsat Thematic Mapper (TM) data in the archive.

The National Geophysical Data Center (NGDC) within NOAA had a fully operational center for processing, archiving, and disseminating data from the Defence Meteorological Satellite Program (DMSP). It became fully operational during the fiscal year, processing data within 48 hours of collection by the Air Force and provided browse images routinely on the Internet. Also available on Internet, NGDC's geophysical online data was accessed by an order of magnitude more users than just a year before. Also, NGDC employees visited more than 30 different classrooms in local schools throughout the year to present workshops on such subjects as earthquakes, volcanoes, and geomagnetism.

Information management is one of the main program elements of NOAA's Climate and Global Change (C&GC) program. It provides the scientific community with the data and information necessary to evaluate the variability of the global environment, distinguish between natural and human-induced change, and perform integrated assessments of changes in climate and their societal impacts. Foci of the program include data base development (rescue, digitization, and assembly of high-priority data sets); data access and archive management, which provide

the means to make the data sets available to scientists; and Pathfinder, which is developing community-consensus algorithms for the reprocessing and dissemination of large-volume, multidecadal, global-scale, operational-satellite data sets. In FY 1994, the program supported governmental and academic researchers in 31 projects.

As part of the Landsat Pathfinder program, the USGS has been producing standardized Landsat Multispectral Scanner data sets from three periods (1973, 1986, and 1992) to support the EPA's North American Landscape Characterization Program. In FY 1994, it produced about 400 out of a total of 4,000 scenes for parts of the United States, Mexico, and Central America. USGS has also been cooperating with NASA plus the Universities of New Hampshire and Maryland to produce similar three-date-time-series Landsat data sets for the Humid Tropical Forest Inventory Project, which is studying the tropical forest regions of the Amazon Basin, Central Africa, and Southeast Asia. These data sets will serve to monitor changes in land cover over these areas during the 20-year period since the beginning of the Landsat program. In a separate project using lower-resolution satellite data, since 1992 the USGS has been working with NASA, NOAA, ESA, and more than 31 foreign ground receiving stations to collect AVHRR data (1-km resolution) for each afternoon pass of the NOAA polar-orbiting satellite over the Earth's land surface. This Pathfinder project had collected over 93,000 AVHRR scenes by the end of the fiscal year. They were being used to produce a global land-cover map and to monitor vegetation conditions (greenness) on a periodic basis throughout the year. Routine production of cloud-free composite data for a vegetation index of all global land areas was also underway at the end of the year. The USGS was cooperating with the EPA, NOAA, and the United States Fish and Wildlife Service to prepare a baseline of global, multiscale data on environmental characteristics and to develop mechanisms for identifying, monitoring, and assessing environmental change. The resulting Multi-Resolution Land Characteristics Monitoring System will be essential for understanding the dynamics of the Earth as a system.

Through a directive from OSTP, an interdisciplinary, interagency Scientific Assessment and Strategy Team formed to provide scientific advice to Federal officials making decisions about recovery and river-basin management following the severe flooding of the Upper Mississippi and Missouri River basins in 1993. The team included specialists from USGS, the United States Fish and Wildlife Service, National Biological Survey, Soil Conservation Service, Army Corps of Engineers, EPA, and the Federal Emergency Management Agency. Working at the EROS Data Center, the team produced numerous maps and analyses, as well as a substantial environmental information system for the two basins using remotely sensed, map, and environmental data. This includes a wide variety of data made available on Internet. The team's preliminary report documents the data and analysis provided to the Interagency Floodplain Management Review Committee, which was providing policy recommendations to the Administration.

In other Department of Interior (DoI) activities, the Bureau of Reclamation used remote sensing and GIS's to aid in the management of water resources. During FY 1994, it used aerial photographs and multispectral data from the Landsat TM and SPOT to map irrigated lands, riparian vegetation, and open water at a number of locations in the Western United States. It used these maps and other spatial data in a GIS with environmental models to estimate consumptive water use. Airborne video and thermal infrared scanner imagery were used to map river habitat for endangered fish in the Colorado River system, enabling managers to release water from reservoirs in such a way as to maximize survival of the endangered species.

The Bureau of Indian Affairs continued to conduct natural resource inventories, image mapping projects, and GPS training services to support its Indian Integrated Resource Information Program. Analysts used Landsat TM data to classify land use on several Indian Reservations for forestry and wildlife management applications. The Bureau continued land cover inventories on reservations in New Mexico and Arizona with emphasis on modeling the potential burn rate of different vegetation types in response to fires. Landsat TM and SPOT panchromatic data enabled the Bureau to prepare image maps for three reservations, while GPS training supported resource inventory programs.

The Bureau of Land Management used remotely sensed data and GPS to monitor the health of public lands and the effectiveness of ecosystem-based management practices. Landsat, SPOT, and AVHRR satellite data plus aerial

photographs supported ecosystem-based management of mineral resources; land-use planning; fire fuels mapping; characterization of wildlife habitat; and delineation of hazardous materials and their impacts at a number of sites on public lands throughout the United States. GIS and GPS technology supported much of this analysis.

The National Biological Survey, now one year old, has continued a wide variety of remote sensing projects transferred from other DoI bureaus. The Gap Analysis Program, a statewide and national program to identify land areas not being protected and managed to maintain biological diversity, was one such program transferred from the United States Fish and Wildlife Service. The program is based on mapping of actual natural vegetation from Landsat TM and other data using a nationwide classification system for vegetation. Standardized mapping methods and data formats permit aggregation of State-level data for comparison at regional and national levels. At the end of the year, projects were underway in 36 States with data from Nevada and Washington nearing completion. With adequate funding, complete national-level data sets will be available by 1999.

The National Park Service initiated a comprehensive, multi-year program in FY 1994 to map vegetation in 235 units of the National Park System, excluding Alaska. The program will provide consistent baseline digital data about the composition and distribution of vegetation to support the National Park Service Inventory and Monitoring program. Mapping will be done through interpretation of medium-scale (1:20,000) natural color and color-infrared aerial photographs using a nationwide standardized classification system. The National Biological Survey is working closely with the Park Service to plan and direct the project, beginning with pilot studies in a variety of selected park environments.

With transfer of research activities to the National Biological Survey in FY 1994, the United States Fish and Wildlife Service began emphasizing use of computerized mapping, aerial photographs, and Landsat and SPOT data for day-to-day operations, especially managing wildlife habitat from an ecosystem perspective. It has used remotely sensed data and GIS technology to evaluate the effects of habitat changes on migratory birds, assess threats of environmental contaminants to biological resources like endangered species, and identify the most valuable lands for inclusion in new refuges like Canaan Valley, West Virginia. The Service also led a Federal Geographic Data Committee effort to develop national standards for mapping wetlands and was active in a similar attempt to define a standard for mapping upland vegetation. These activities will reduce costs for acquiring remotely sensed data and increase the consistency of the resultant maps of these resources.

The United States Bureau of Mines has directed its remote sensing research to the development of applications to abandoned mine land areas. This innovative technology will address the identification and characterization of mineralogy of waste materials and associated potential for development of acid mine drainage and occurrence of heavy metals at these sites. The applications utilize Landsat TM satellite images and airborne multispectral scanner data and were field tested in the Cripple Creek Mining District in central Colorado. The successful completion of this research will provide a quick procedure for inventorying and initial characterization of noncoal mine waste materials, providing land management agencies with an increased ability to focus on the remediation of these sites.

Within the United States Department of Agriculture (USDA), the remote sensing program of the Foreign Agricultural Service (FAS) continued to be a critical element in the analysis of domestic and foreign agricultural production, supply, and demand--providing timely, accurate, and unbiased estimates of global area, yield, and production. The agency used satellite imagery, crop models, and remotely sensed weather data to support State Department assessments of food needs in the States of the former Soviet Union, particularly the drought-affected Ukraine. The FAS also prepared detailed analyses of the performance of India's summer monsoon, frost damage to Brazil's coffee crop, and drought in Australia's eastern wheat regions. Satellite-derived early warning of unusual crop conditions allowed for price adjustments in commodity markets and helped maximize United States farmers' returns. In addition, the FAS used satellite imagery to monitor domestic crop production areas in support of work carried out by the Agricultural Stabilization and Conservation Service (redesignated the Farm Service Agency in October 1994).

The National Agricultural Statistics Service (NASS) used remote sensing data in constructing area frame samples (using data from small sample areas as an aid to estimating crops and acreages), crop-specific land cover mapping, direct estimation of planted crop area, and assessment of crop conditions. Products from the first three areas were mainly based on Landsat-5 TM and SPOT MultiSpectral Scanner data. Crop condition assessment used data from the NOAA-11 satellite. In 1994, NASS completed a California area frame for conducting 1994 surveys, New York and South Carolina frames for survey use in 1995, and it initiated work on a KS frame. Among a host of other activities, NASS improved biweekly vegetative index map products for the 1994 crop season, based on NOAA-11 AVHRR data, and distributed them to NASS offices and USDA policy makers for their use. Starting in the fall of 1993, NASS entered into a cooperative agreement with the Intertribal Agricultural Council to collect pilot-level data on Native American farm operator production. One result of the agreement was a crop-specific land-cover map of the Crow and Northern Cheyenne Reservations in Montana, delivered in September 1994. Another satellite data application was the Delta Remote Sensing Project in Arizona. It regressed multitemporal, computer-classified Landsat TM data against ground information to provide estimates with reduced sampling error for rice, cotton, and soybean acreage. The resulting data provided county acreage estimates for the 1993 season in tabular form and in colored theme-map and tabular form. NASS continued to produce biweekly vegetative index map products based on NOAA-11 AVHRR data during the 1994 crop season. It distributed the maps to USDA decisionmakers and to various NASS state statistical offices to aid in assessments of crop conditions. In 1994, NASS improved the maps in several ways, such as adding the capability to compare the current value with a meridian of several previous years. However, due to the aging NOAA-11 satellite, on which one AVHRR ceased to function in September, and a relatively unstressed crop year, the 1994 maps contained less information than those of 1993 when the Midwest flood and the Southeast drought were featured in the maps.

The Agricultural Research Service (ARS) used remote sensing and GIS technologies to provide information about the extent and spatial dynamics of leafy spurge, a troublesome weed, in the Theodore Roosevelt National Park, ND, among many other applications. The results contributed to the development of a management plan for leafy spurge in the park and provided insight into the application of integrated spatial technologies for natural resource management. Other uses of remote imaging together with data from the ground included maps of soil salinity, biomass, crop management, and crop yields. For example, a cooperative program was undertaken examining commercial cotton fields in the San Joaquin Valley of California, aimed at developing integrated tools to produce crops that maximize economic return, support efficient use of natural resources, and minimize detrimental impacts on the environment. ARS researchers also developed fluorescence techniques and a prototype fluorescent instrument to discriminate and quantify crop residues. The effective management of these remains from the harvest minimizes soil erosion and improves water quality. In the area of hydrology, ARS scientists, in close cooperation with NASA and the Department of Commerce (DoC), used ground-based and remotely sensed data to aid in understanding how conditions in river basins influence climate and climate change. ARS also is using space signals to help develop "precision farming systems" that permit land managers to adjust the treatment (with fertilizers, pesticides, or seeding rates) continuously across a field based on detailed local knowledge.

In 1994, the Forest Service (FS) used remote-sensing and associated technologies to assist in fighting fires throughout the Western United States as well as to detect high-risk fire zones, assess damage, monitor national and foreign ecosystems, and administer/manage more than 191 million acres of National Forest System lands and works. The number of wildfires reached a record high in 1994, with more than 66,000 fires and over 3.8 million acres burned. To combat these blazes, the FS employed airborne scanners, including Firefly developed by JPL, to help map and determine both speed and direction of the fires. Throughout the year, the FS used such remote sensing technology as AVHRR imagery from NOAA satellites to implement early-warning measures. Once fires started, the FS shifted to greater use of imagery from aircraft. When fires had been suppressed, the FS employed satellite imagery to map and assess changes in the landscape caused by the fires. Other uses for remote sensing included mapping, vegetation classification, the rehabilitation and restoration of ecosystems, research for global greenhouse gas emissions, land management, identification of critical wildlife habitat, support of law enforcement, and inventory programs. The FS initiated partnerships with international, Federal, State, and private organizations for ecosystem assessment, leading to greater use of satellite data and increased understanding of global ecological processes. For example, technical exchanges continued with Russia, Brazil, Indonesia, Mexico, Canada, Australia, and Kenya

among other countries. FS research and development of airborne video, digital cameras, radar, and GPS systems continued to address numerous ecosystem management applications. Integration of remotely sensed data into GIS's proved to be cost effective in supporting land management decisions.

The Soil Conservation Service (redesignated the Natural Resources Conservation Service or NRCS in October 1994) adopted digital orthophotography as the common framework for collecting and managing natural resource geospatial databases. The Service cooperated with other Federal and State agencies to acquire aerial photography and digital orthophotography. In addition, it and other USDA agencies agreed with the DoD to purchase GPS units to collect georeferences for natural resource data to be included in a GIS.

The United States Environmental Protection Agency (EPA), primarily through its Environmental Monitoring Systems Laboratory in Las Vegas, Nevada (EMSL-LV), with assistance from its Atmospheric Research and Exposure Assessment Laboratory in Research Triangle Park, NC, also routinely conducted research and provided technical support using remote sensing as part of its overall environmental monitoring program. The Agency used large-scale aerial photography to develop site characterization data during the remedial actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as well as to support site selection and monitoring at hazardous waste facilities operated under the Resource Conservation and Recovery Act (RCRA). It developed and used remote-sensing systems to support the provisions of the Clean Water Act. In FY 1994, the EMSL-LV completed approximately 150 aerial-photographic site-characterization projects under CERCLA and RCRA, and satellite imagery played a part in helping engineers develop detailed site characterizations. Aerial photography and satellite data also supported a broad variety of pollution, global change, pollution prevention, compliance, and other ecosystem monitoring studies in FY 1994, such as those of critical-habitat areas for wildlife. In support of activities associated with the identification of the impacts and hazards resulting from severe flooding along the Mississippi River and its tributaries in FY 1993, the EPA's Environmental Photographic Interpretation Center (EPIC--a branch of EMSL-LV) analyzed aerial photographs acquired, in cooperation with the Army Corps of Engineers, to identify flood impacts on industrial and agricultural facilities for assessment of hazardous and toxic waste movement and containment. Additional analysis of pre- and postflood aerial photographs by EPIC in FY 1994 identified and mapped changes that have occurred at known waste disposal sites affected by the flooding.

M. Atmospheric studies

NASA's and NOAA's efforts to monitor ozone depletion continued to reflect the effects of the Mount Pinatubo eruption in June 1991. Data from NASA instruments such as the Total Ozone Mapping Spectrometer aboard the Russian Meteor-3 satellite (launched in 1991) as well as NOAA instruments aboard balloons and the NOAA-9 satellite have enabled scientists to study the global cooling effects and loss of ozone that resulted from the eruption. These are the first unambiguous, direct measurements of large-scale changes in the Earth's radiation budget caused by a volcanic eruption. Ozone, a molecule made up of three atoms of oxygen, forms a thin layer of the atmosphere that absorbs harmful ultraviolet radiation from the Sun. The term "ozone hole" describes a large area of intense ozone depletion that occurs over Antarctica during late August through early October and typically breaks up in late November. Scientists have determined that chlorine products from human activities, such as electronics manufacturing, air conditioning, and refrigeration, are a primary cause of ozone hole formation. The Antarctic ozone levels for 1994 were nearly as small as the record lows from October 1993. The slight recovery in 1994 probably resulted from fewer sulfuric acid particles remaining from the eruption of Mount Pinatubo. The NSF's Office of Polar Programs continued during the year to support researchers studying the cause and effects of the Antarctic ozone hole at each of three year-round stations. Both balloons for in situ measurements and remote sensing instruments were used. There was a particularly strong effort during the late austral winter and early spring of 1994 to support the NASA-sponsored ER-2 aircraft flights from Christchurch, New Zealand, to study the ozone levels. The Microwave Limb Sounder (MLS) on the Upper Atmosphere Research Satellite (UARS--launched in 1991) continued, meanwhile, to make unprecedented measurements of global chlorine monoxide (ClO) concentration, observing the spatial relationships of ClO, ozone, temperature and other atmospheric variables. These measurements provide the first global picture of the reactive form of chlorine that destroys ozone. Even though regulations will phase out the production of chlorofluorocarbons in the future, the removal of chlorine from the stratosphere is a very

slow process (taking decades or centuries), and stratospheric chlorine will continue to increase for at least the next few years, as chlorine already released into the lower atmosphere reaches the stratosphere. The MLS is providing the only global monitoring of this process during the critical period in which stratospheric chlorine is increasing to record levels.

A major focus of the Upper Atmosphere Research Program (UARP) in 1994 was the Airborne Southern Hemisphere Ozone Experiment/Measurements for Assessing the Effect of Stratospheric Aircraft campaign. The goal of this effort in the Pacific was to obtain in-situ measurements of atmospheric trace gases related to stratospheric ozone. Full analysis of the data combined with model calculations will improve our understanding of the chemistry and processes of midlatitudes. Scientists from NASA and NOAA contributed to the recently completed "Assessment of Ozone Depletion: 1994," developed under the auspices of the World Meteorological Organization and the United Nations Environment Programme. This periodically issued report provides the scientific basis for policy decisions by parties to the Montreal Protocol (the international agreement limiting the use and production of chlorofluorocarbons) and its amendments. NASA's ozone measurements are part of the Agency's MTPE program, which includes measurements from instruments on free-flying spacecraft and the Space Shuttle; aircraft, in situ, and ground-based observations; a comprehensive data and information system to process and distribute the findings; and a modeling effort designed to help understand, and eventually predict, the behavior of and changes in the Earth's system as well as to distinguish the effects of natural and human-induced global climatic change. The first phase of MTPE includes the flight by NASA and partners of more than two dozen missions through 1998. Data from MTPE and other global change research efforts will enable policymakers to formulate prudent policies regarding the future of the global environment.

The second phase of MTPE is the EOS program, a series of spacecraft planned to carry a variety of sophisticated instruments to make the most comprehensive measurements ever of the interrelated elements of the global environment. NASA's program is part of the international Earth Observing System, in which satellites and instruments from the United States, Europe, Japan, and Canada are being closely coordinated to provide complementary data on different aspects of the Earth's environment. In support of NOAA's GOES program, NASA participated in the successful launch of the GOES-8 satellite in April 1994. GOES-8 and subsequent GOES satellites (J-M) are the prime observational platforms for dynamic weather and the near-Earth environment for the 1990s and beyond. In mid-1994, the EOS program was redesigned to respond to a reduction in program budget through the year 2000. NASA's objectives were to preserve the scientific integrity of EOS as a global change program and to maintain the target launch schedule for core EOS missions. Realigning the EOS program meant placing greater reliance on both domestic and foreign partners, in addition to deferring some data products and measurements. However, some high-priority scientific items were added to the program or scheduled sooner, such as flight of an additional Stratospheric Aerosol and Gas Experiment (SAGE) instrument in the year 2000 and the incorporation of a Landsat-type instrument on the EOS AM-2 spacecraft (AM indicating a morning crossing time over the equator). In September, NASA released a major solicitation seeking proposals for a "common" spacecraft bus for several of the subsequent EOS flights with selection expected in 1995. Meanwhile, development continued on the EOSDIS, the means by which information from MTPE observations and analysis will be archived and made available to researchers and other worldwide users; NASA modified its planning for EOSDIS architecture, making it more extensible and accessible. In August 1994, NASA released Version O, a working prototype for EOSDIS, designed for the general Earth science community for use in scientific research.

Pathfinders constitute a recent application of Earth-science and other data sets, developed specifically to study global environmental change. They focus on processing, reprocessing, archiving, maintaining, and distributing existing data sets to make them more useful to researchers. In FY 1994, the focus of the joint NASA-NOAA Pathfinder was on generating data for the benchmark period April 1987 to November 1988, but additional data sets included TOPEX/Poseidon, an educational CD-ROM, the First International Satellite Cloud Climatology Regional experiment, and the UARS. Using Pathfinder data sets, NASA scientists combined NOAA-7, -9, and -11 data on vegetation dating back to 1981 to predict the likelihood of famine and locust plagues in Africa, for use by the United States Agency for International Development to locate drought areas and locust swarms. NASA also solicited broadened application of its scientific and technological assets via Internet. A significant number of the resultant

proposals and awards involved using the Internet to make environmental information more readily available for educational purposes.

The NSF also studied global change. Under the Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) program, scientists at the University of Tennessee, Urbana, organized a campaign referred to as ALOHA-93 (Airborne Lidar and Observations of the Hawaiian Airglow). Involving experimenters from several academic and commercial research institutions, its purpose was to study the source and dynamics of gravity waves over the mid-Pacific in October 1993. Gravity waves are a major source of energy and momentum coupling between different layers of the atmosphere from the troposphere to the lower thermosphere. In ALOHA-93, a sodium lidar, optical imager, and spectrometer gathered data from an aircraft, the flights being coordinated with selective overpasses of NASA's UARS (launched in 1991). The campaign obtained important information on midocean storms and generation, propagation, and filtering of gravity waves in the mesosphere and stratosphere. This should lead to better parameterization of gravity waves in global circulation models. The airborne observations also revealed rich horizontal structure in sporadic sodium layers observed in conjunction with substantial increases in mesopause temperature. These metal layers, formed through meteoric ablation, appear to be sensitive to global atmospheric changes related to changing levels of atmospheric carbon dioxide and methane. Also, the CEDAR program sponsored a special competition to encourage the development of innovative technical approaches, resulting in a number of projects to improve instrumentation and techniques.

The NSF has supported studies of how variations in the energy output from the Sun and anthropogenic effects contribute variously to global change. The SunRISE (Radiative Inputs of the Sun to Earth) program supports the development and deployment of a precision photometric telescope designed for measurements of sunspots, faculae, and other features thought to be sources of variations in solar brightness. The program also supports measurements of the solar diameter and analysis of the historical measurements of the plage phenomena (bright, granular areas in the chromosphere of the Sun), which are possible indicators of changes in radiance. A second area of emphasis in the last year has been space weather, conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can significantly influence the performance and integrity of important space-borne and ground-based technological systems. The NSF supported a study conducted by scientists at Johns Hopkins University in which they used data from a Swedish satellite to predict electrical currents induced in a power grid at Chalk Point, MD; they successfully correlated intense electrical currents in the ionosphere with the induced currents on the ground. Other studies of ionospheric currents used magnetometer arrays deployed by scientists from Boston College, Augsburg College, and the University of Michigan. The scientists will use data from these newly created arrays in Canada and Greenland to study dynamic variations in ionospheric currents that originate from the entry of energetic particles from the Sun into Earth's atmosphere.

Another atmospheric and environmental concern in recent years has been global warming. In the first international, interdisciplinary effort to discuss this issue broadly, 37 scientists from 10 countries met near the beginning of the fiscal year at a conference sponsored by DoE and NOAA. Among the findings of the conference were that while the global average temperature has been rising in recent decades, the warming has not been truly global and has occurred mainly at night. Scientists believe that the cause of higher nighttime temperatures may be the combined result of an increase in greenhouse gases and cloud cover over continents combined with increased sulfur emissions produced by the burning of fossil fuels. A climatic model developed by James Hansen of NASA that took all three factors into account came closer to simulating observed temperature changes than had previous models. While nighttime warming may lengthen the growing season and reduce killing frosts, it might increase insect infestations, reduce crop-growing areas, and raise heat-related death rates among humans. In a study relevant to this issue, NIST has been studying isotropic measurements for NASA to identify and quantify the presence of tropospheric methane (CH_4), which is second only to carbon dioxide (C_2O) in its effects on global warming. Although the tropospheric CH_4 concentration is a small fraction (5 percent) of that of CO_2, CH_4 accounts for about 12 percent of the global temperature rise, due to strong absorption in a relatively transparent part of the infrared. Intensive CH_4 measurement and modeling is underway because of significant uncertainties in both anthropogenic and natural emission data that are critical for estimating the global CH_4 budget. To serve these needs, NIST has compiled a data base of global source and ambient isotropic measurements.

N. Oceanographic studies

TOPEX/Poseidon, a satellite jointly sponsored by the French Space Agency, Centre National d'Etudes Spatiales (CNES), and NASA (launched in August 1992) continued to provide valuable information during 1994. The satellite uses a radar altimeter to yield precise measurements of sea-surface height. Data analysis shows the seasonal change in sea level in the Northern Hemisphere is about 50 percent larger than in the southern half of the globe. This was a previously unknown asymmetry and indicates the air-sea heat exchange is much stronger in the Northern Hemisphere. Data from the satellite have also enabled scientists to track disturbances caused by the lingering effects of the El Niño event of 1991-93, the longest one in the last 40 years. El Niño is a warm inshore current annually flowing south along the coast of Ecuador around the end of December and extending about every 7 to 10 years down the coast of Peru; it can bring devastating weather to several global regions, including heavy rains and flooding as well as colder than normal winters across the United States, and severe droughts and dust storms in Australia. Observations made by TOPEX/Poseidon in the North Pacific revealed a northward shift of the Kuroshio, the swift current southeast of Japan, which has been traced back to the El Niño event of 1982-83. Meteorologists believe that the position of the Kuroshio is drastically affecting the weather of North America. NASA, CNES, and NOAA held discussions in 1994 on a TOPEX/Poseidon Follow-On (TPFO) mission, in which NOAA, the new partner, would provide the ground segment. TPFO would meet both operational and research needs.

NASA also participated in the international Tropical Ocean Global Atmosphere (TOGA)-Coupled Ocean-Atmosphere Response Experiment (COARE) program. Measurements from NASA's ER-2 and DC-8 aircraft have produced significant improvements in our understanding of precipitation, convection, clouds and radiation, air-sea interaction and oceanographic processes. Results from the 1993 TOGA-COARE field exercise in oceanography and long-term atmospheric effects will be presented in Melbourne, Australia, in April 1995.

Meanwhile, the NIST Radiometric Physics Division has been continuing its collaboration with the NASA Sea-viewing Wide Field-of-view Sensor (SeaWiFS) project and associated investigators. SeaWiFS, scheduled for launch in 1995, is designed to provide global observations of photosynthetic pigment concentrations contained in the microscopic marine plants called phytoplankton. Among other things, these measurements will help to assess how much carbon dioxide transferred to the ocean from the atmosphere is being transformed into oceanic plant biomass. Accurate calibration of the SeaWiFS instrument is critical to the mission's success. Also, sea-based optical measurements for validation of the post-launch calibration and various products derived from the satellite observations must be equally accurate. NIST's role is to help ensure that these observations are traceable to radiometric standards and that instrument calibrations are performed properly. NIST has designed, constructed, and characterized a portable, multichannel spectroradiometer (SeaWiFS Transfer Radiometer or SXR) to compare the calibrations of field instruments and to check the calibration sources at different institutions. The device was used during the second and third SeaWiFS Round Robins in June 1993 and September 1994. NIST also used the device during a NASA/NOAA field experiment in February 1994 at the Marine Optical Buoy (MOBY) support facility in Hawaii. MOBY will be used to verify the postlaunch SeaWiFS calibration and other future ocean color satellite instruments to be launched later in this decade under the EOS program.

Near the end of the fiscal year, NOAA announced completion of initial flight tests of a new system for mapping coastal ocean salinity. Called the scanning low-frequency microwave radiometer, the new system is smaller than older ones and can be operated from small, single-engine aircraft rather than the four-engine C-130. Consisting of a microwave radiometer, an infrared radiometer, a GPS instrument for locating measurements, and a computer, the new system can produce salinity maps at the rate of 100 square kilometers per hour. NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) anticipated collaborating with other NOAA and Federal agencies and academia in coastal-ecosystem health, hydrological, and coastal forecasting activities where data on salinity are critical, such as in studies of the distribution of brown shrimp in the Mississippi Delta and Gulf of Mexico.

Additionally, NOAA/NESDIS's Office of Satellite Data Products and Distribution forged a partnership with NASA for the development and joint funding of a United States ground system to support real-time collection of

high-priority scatterometer and ocean color data from the Japanese Advanced Earth Observing Satellite, scheduled for launch in 1996.