

NATIONAL SECURITY

SCIENCE

EXPLORING OUR SOLAR SYSTEM AND BEYOND

INVESTIGATING OUR MOON AND MARS

DECIPHERING SIGNALS, ANALYZING SPACE

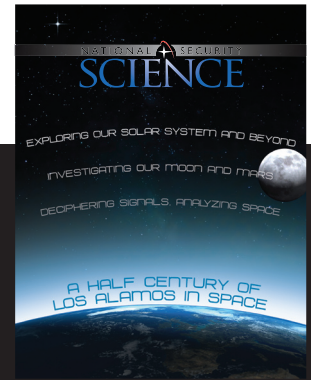
A HALF CENTURY OF
LOS ALAMOS IN SPACE



EST. 1943

About the Cover

Welcome to our Space Science Special Edition. From our moon to deep space, LANL has supported space missions for more than 50 years.



WILL REES

Los Alamos National Laboratory has a venerable reputation for delivering the technology necessary to respond effectively to significant threats of broad scope. This reputation is especially strong in the field of space science, which combines the underpinning of basic science with complex national security missions. Thanks to a topflight staff of permanent scientists and postdoctoral fellows, our payloads fly on a variety of satellites. Sometimes we design, build, and operate the entire spacecraft, such as FORTE and the Cibola Flight Experiment, and other times we execute the mission in close partnerships with other agencies and laboratories.

Los Alamos' ability to take on complex, multidisciplinary challenges—of not saying no when everyone else has said no—is part of what makes us who we are. This ability is key to our space-related efforts.

From the earliest days of space flight we have played a leading role. From the first nuclear nonproliferation satellites, Vela Hotel, to the modern Global Positioning System (GPS) satellites carrying advanced detectors, Los Alamos space sensors and space systems have flown far and wide. These and other space sensors collect data from the far reaches of the universe—indeed, a LANL-led team for the Interstellar Boundary Explorer (IBEX) gathered data from the greatest distance from Earth ever performed. The analysis of these data redefined the science community's thinking on interstellar interactions.

Our mission of reducing global threats is perhaps nowhere more clearly understood than in the laboratories and high bays in which equipment destined for space is painstakingly pieced together. The ability to design devices that can spend their operational lifetime thousands of miles from a human hand, devices that survive the rigors of a vibration-laden launch, space travel, and deployment, is a rare skill set. Helping those devices provide national and international security from their distant perch is a daunting mission. And yet, it is one we achieve with regularity.

A handwritten signature in black ink that reads 'Will Rees'.

Principal Associate Director for Global Security



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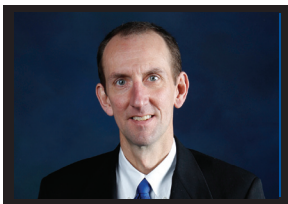
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Los Alamos in **SPACE**



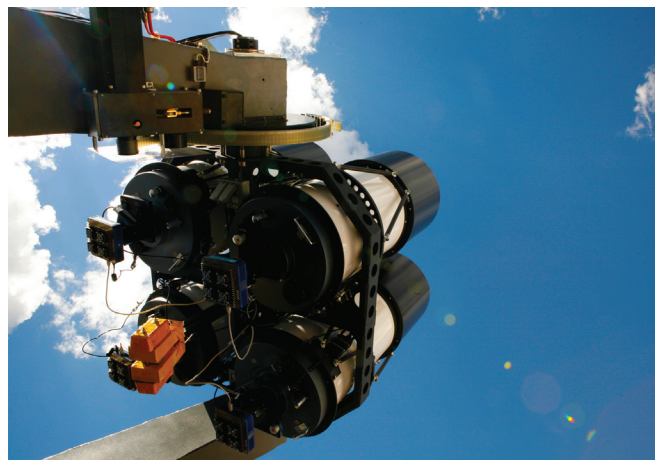
Since the launches of the first man-made objects (Sputnik and Explorer 1) to orbit the Earth more than a half-century ago, thousands of spacecraft have been launched, many of those carrying Los Alamos sensors and instrumentation systems. Our journey began with the research and development of a two-decade-long nuclear rocket program, Project Rover.

In the 1950s, Los Alamos scientists, building on their nuclear expertise, examined new methods for rocket propulsion into space. In December 1960, in the thick of the Cold War and during negotiation of the Limited Test Ban Treaty, the Atomic Energy Commission and the National Aeronautics and Space Administration (NASA) first met to discuss a space-based system to detect nuclear explosions in the atmosphere and space. The nation turned to Los Alamos for development of instruments to detect radiation from such a detonation as well as to understand the Earth's space environment, mostly unknown at the time.

Satellite-Based Monitoring of Nuclear Explosions

On October 17, 1963, one week after the test-ban treaty went into effect, the first Vela spacecraft launched with Los Alamos radiation detection and space-environment instruments. The Vela series of satellites, which spanned 1963-1984, carried Los Alamos-designed-and-built sensors for detecting x-rays, gamma rays, neutrons, and the natural background of radiation in space. These satellites also contributed significantly to astrophysics,

interplanetary physics, and our understanding of the Earth's magnetosphere. In 2003, NASA launched the Swift satellite that carried a massive (gamma-ray) burst-alert telescope and LANL triggering and imaging software. Data derived from these instruments led to our discovery of the Earth's plasma sheet, heavy ions, and high-charge states in solar wind. In 2009, Swift recorded the farthest object in the universe ever observed, thought to be a giant star. Gamma-ray bursts, also discovered by Los Alamos instruments on Vela, continue to provide deep insight into supernova and the final moments of stellar death and are the primary focus of "thinking telescopes," discussed later in this article.



LANL's robotic thinking telescope system, RAPTOR.

LANL instruments on Vela satellites and subsequent series of spacecraft provided security for the remainder of the Cold War and continue today both for treaty verification and to monitor the skies and detect aboveground nuclear detonations. Our nuclear-explosion expertise and experience has provided the necessary background for sophisticated nuclear detection. Today, Los Alamos and Sandia National Laboratories continue to supply nuclear-test-monitoring sensors deployed on U.S. satellite systems.

Our work on the Vela program was followed by a LANL/Sandia National Laboratories collaboration with the United States Air Force on the Defense Support Program (DSP) satellites, which provide early warning of ballistic missile launches or nuclear explosions. LANL-designed instruments for similar detection continue to be carried on several series of missions, including DSP and the Global Positioning System (GPS). LANL-led technology demonstration missions—or those using LANL's key subsystems— included Fast On-orbit Recording of Transient Events (FORTE), Array of Low Energy X-ray Imaging Sensors (ALEXIS), Multispectral Thermal Imager (MTI), and Cibola Flight Experiment (CFE). Many of these technologies, including GPS, contributed to current research, such as LANL's Dynamic Radiation Environment Assimilation Model (DREAM), developed to understand and predict hazards from the natural space environment and artificial radiation belts produced by high-altitude nuclear explosions.

A Mind of Their Own

The sensors built and flown for the Laboratory's national security mission also detect natural backgrounds and odd signals such as lightning flashes—so LANL experts were called upon to create more advanced sensors that also provided data for atmospheric sciences, space-plasma science, and astrophysics. By understanding the natural backgrounds observed by our national security payloads, we can provide information on nuclear detonations with greater certainty and reliability. Our research in gamma-ray bursts has evolved into a new astronomical paradigm of “thinking telescopes” of today, such as RAPTOR, which is an array of ground-based telescopes that troll the night sky looking for changes of astrophysical objects as well as objects orbiting Earth. Not only can this system decipher whether signals are noise of astrophysical origin or from an object orbiting Earth, but it can do so independently while also determining in real time which data are sufficiently important to be sent back to operators for further review. RAPTOR extracts

DREAM

The Dynamic Radiation Environment Assimilation Model (DREAM) was developed at Los Alamos National Laboratory to understand and to predict hazards from the natural space environment and artificial radiation belts produced by high altitude nuclear explosions. DREAM was initially developed as a basic research activity to understand and predict the dynamics of the Earth's radiation belts. It uses Kalman filter mathematical techniques to assimilate data from space environment instruments with a physics-based model of the radiation belts.

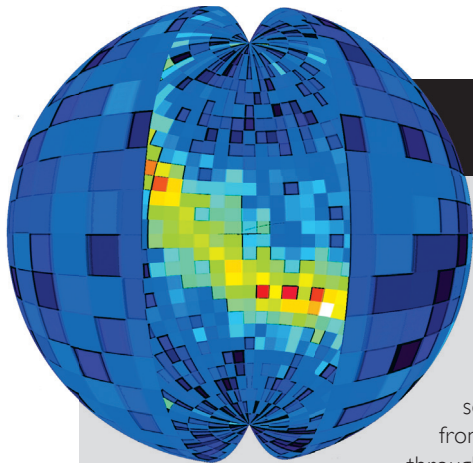
DREAM can assimilate data from a variety of types of instruments and data with various levels of resolution and fidelity by assigning appropriate uncertainties to the observations. Data from any spacecraft orbit can be assimilated but DREAM was originally designed to work with input from the LANL space environment instruments on geosynchronous and GPS platforms. With those inputs, DREAM can be used to specify the energetic electron environment at any satellite in the outer electron belt whether space environment data are available in those orbits or not. Even with very limited data input and relatively simple physics models, DREAM specifies the space environment in the radiation belts to a high level of accuracy. DREAM is currently being tested and evaluated as we transition from research to operations.

Los Alamos National Laboratory scientist Geoffrey Reeves leads the DREAM project.

key information of an anomalous astrophysical event or unknown Earth-orbiting object from massive amounts of information that includes noise, astrophysical objects that don't change in time or location, and known Earth-orbiting objects that follow expected trajectories in the sky. This system greatly eases the impossible task for human operators to sift through such massive amounts of data and search for threats or new astrophysical transients.

RAPTOR is LANL's agile, robotic telescope system currently located near Los Alamos that operates just like a human

We're one of the world's best at determining what happens to all those photons between the source and the instrument, and to fundamentally understand the neutron output effect of a nuclear weapon, said Herb Funsten, chief scientist for LANL's International, Space, and Response division.



IBEX Satellite Finds Ribbon-Like Structure at Edge of Heliosphere

The invisible structures of space are becoming less so, as scientists look out to the far edges of the solar wind bubble that separates our solar system from the interstellar cloud through which it flies. Using the High Energy Neutral Atom Imager, led by Los Alamos National Laboratory, the NASA Interstellar Boundary Explorer (IBEX) mission has sent back data that indicates a “noodle soup” of solar material has accumulated at the outer fringes of the heliosphere bubble.

As the solar wind streams out far beyond Pluto, racing a million miles per hour, it reaches the edge of our bubble and collides with the material between the stars, the interstellar medium. A shock wave forms at that intersection point. The Los Alamos camera is designed to detect the particles that are heated and stream away from that boundary, specifically the density and temperature of atoms that form the core of that layer. The High Energy Neutral Atom Imager instrument is particularly important because its design parameters are well matched to the temperature of most of the soup; about 1.8 million degrees Fahrenheit.

In a paper published in *Science*, author and Los Alamos scientist Herbert Funsten notes, “We have discovered an arc-shaped ribbon of high-pressure material that looks to be piled-up material from the Sun. The IBEX maps and the discovery of the ribbon are completely different from what we thought it should look like.”

What the mission has not found is what they were expecting, that is, evidence of large-scale dynamic processes that might be analogous to storms and tornados from the collision of a cold front and a warm front. A striking result is that “our maps show structure and energy spectra that are completely different from what any model has predicted,” he noted.

“The ribbon follows a circular arc of high pressure that we believe is centered on the direction of the magnetic field of the interstellar cloud through which we are moving,” Funsten said. This magnetic field seems to fundamentally organize the interaction region.

The results of IBEX not only reveal fundamental properties of the heliosheath but also provide key information about the properties of the interstellar cloud through which our galaxy is moving. We will be moving out of the cloud in about 10,000 years; the IBEX results will help LANL scientists understand how the Earth’s space environment might be different when this happens.

eye: it detects early optical light from gamma-ray bursts by using a collection of wide field-of-view telescopes and responds quickly—within several seconds anywhere in the night sky—with a higher magnification telescope. On a February night in 2006, Los Alamos astrophysicist Przemek Wozniak was awakened by a cell-phone call from RAPTOR, which had found something strange—a rapidly rising light signal coming from the position of a very short burst detected and located. These bursts announce the birth of stellar-size black holes, the most powerful events since the Big Bang. Following its own logic, RAPTOR recorded the light signal every 30 seconds and noted a doubling in brightness over four minutes—an afterglow that was rising rather than fading. Running real-time analysis software, RAPTOR decided to report the anomaly to a human.

“This was a first, an autonomous optical telescope finding an anomaly on its own with no human intervention,” said Tom Verstrand, a LANL scientist who made it his goal a decade ago to do things no one else had yet accomplished, combining robots with telescopes. “If humans had been in the loop, they would have said, as we did, ‘gamma-ray bursts don’t act like that. Forget it.’ And RAPTOR wouldn’t have found anything.”

Verstrand achieved his extraordinary goal. For the RAPTOR team, the discovery was significant: proof that RAPTOR has a mind of its own—truly a thinking telescope system.

The Los Alamos team is working to make RAPTOR a “discovery engine” for astronomy, scanning the entire night sky frequently, screening a hundred million visible objects and alerting us to something important. The same autonomous technology that detects eruptions at the edge of the universe can be used to detect objects orbiting the Earth—a pathfinder technology for exploring the dynamic universe in real time and making significant discoveries without human intervention.

Capabilities and experts needed for our space-based nuclear detonation detection program resulted in some amazing scientific discoveries—Los Alamos researchers developed a simple neutron spectrometer that uses the

This was a first, an autonomous optical telescope finding an anomaly on its own with no human intervention

speed of the spacecraft to detect low-energy (thermal) neutrons and discovered water on Mars and Earth's moon. Powerful cosmological surveys demand a new generation of simulations of structure formation in the universe. Large-scale computations are an essential resource for the Laboratory's nuclear weapons program, aided by LANL's Roadrunner, the world's first petaflop-per-second computing platform. Los Alamos scientists are now using one of the largest-ever computer models and applying uncertainty quantification, another key capability developed within the nuclear weapons program, to explore the origin and evolution of dark matter and dark energy in the universe.

Space systems used for the nuclear detonation detection program were continually upgraded for sensitivity, dynamic range, and background rejection. And although we made them more sophisticated, we also ensured they would survive a space launch and operate autonomously for more than a decade in the harsh environment of space. Los Alamos launched our first satellite, ALEXIS, in 1993 from Edwards Air Force Base in California. The ALEXIS satellite contained the two experiments: the ALEXIS telescope array, consisting of six EUV/ultrasoft x-ray telescopes utilizing multilayer mirrors, and a VHF ionospheric experiment. A ground station located at Los Alamos exclusively controlled the spacecraft.

Los Alamos technology frequently studies lightning to differentiate it from a nuclear blast and to better understand this electrical phenomenon. FORTE, an all-composite launch vehicle and satellite, was launched in 1997 to study optical and radio-frequency signals. FORTE possesses capabilities that also make it an outstanding platform for the study of the top layer of the atmosphere, the ionosphere. Another goal for LANL's space scientists? Predicting hurricane intensification by monitoring eyewall lightning.

Space science provides diverse information to protect people on the ground. LANL and Sandia National Laboratories' Multispectral Thermal Imager (MTI) satellite and GENetic Imagery Exploitation (GENIE) analysis of imagery from the core of the 2001 terrorist attack in New York provided information about ground temperatures and chemical plumes. Now in its eleventh year in orbit, the MTI satellite was designed to measure temperatures on the ground from space with an accuracy of one degree Celsius across 15 spectral bands.

As threats to our nation's security have emerged and evolved, our surveillance systems have changed. Los Alamos developed methods to detect and characterize facilities that might conceal weapons of mass destruction—an extremely

complicated task. Advanced imaging techniques were developed, many of which are not only now utilized in space but also at airports and border crossings, among other crowded facilities.

LANL Launches Four Tiny Satellites into Space



Colleagues from LANL's Applied Electromagnetics and International, Space, and Response divisions led a rapid-response satellite development capability (Perseus program) and successfully put four tiny "cubeSats"—satellites small enough to hold in one hand—into orbit in December of 2010.

The goal of the Perseus program is to develop a rapid-response satellite capability to enable many different mission types.

The first phase of the effort focused on (1) demonstrating the ability to build and launch a useful satellite quickly and at low cost, (2) gaining cubeSat build and orbital experience, and (3) validating the LANL design methodology (namely, keeping the design simple, designing to the mission, and using commercial off-the-shelf components combined with appropriate design to handle radiation, thermal challenges, and similar considerations for space operation). The satellites were designed and built (in less than six months) entirely at LANL at very low cost.

The satellites were launched on the SpaceX Falcon 9 rocket and have been functioning to the team's expectations. Successful tests include two-way communication, three-way communication (two ground stations and a satellite), and collection of telemetry. The success of this project opens the door to a major new capability at the Laboratory and will allow the development of new projects with existing and new sponsors.

Los Alamos instruments have been onboard many satellites for decades. For example, radioisotope thermoelectric generators pioneered at LANL powered the Cassini mission to Saturn in 1997. The Cassini mission led to the discovery of the Titan ionosphere and more recently the discovery at Saturn's moon Enceladus of jets of charged grains as well as water-group ions in the ionosphere.

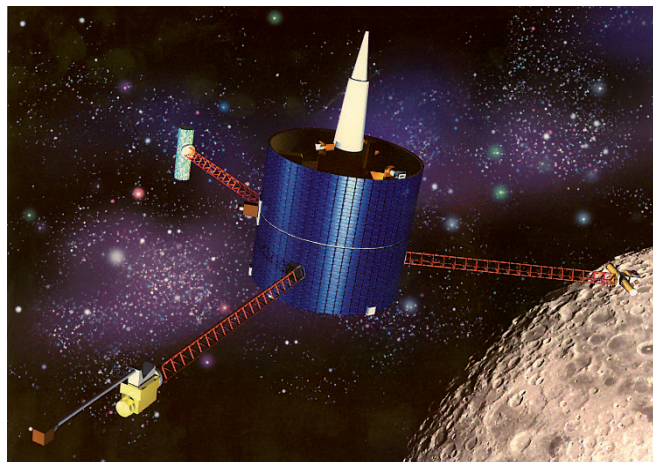
A Stepping Stone to Mars

In 1998, three LANL instruments flew aboard the revolutionary Lunar Prospector, which mapped our moon's surface composition and possible polar ice deposits. Lunar Prospector data, analyzed and interpreted by Los Alamos scientists, provided the first global maps of elemental abundances over the moon's surface of uranium, thorium, potassium, iron, titanium, oxygen, silicon, aluminum, magnesium, and calcium. Lunar Prospector also discovered the presence of hydrogen, possibly in the form of water, in permanently shadowed craters in the north and south polar regions. The spacecraft orbited the moon for nearly 19 months gathering data, prior to being intentionally crashed in a final attempt to extract additional information about the possibility of water on the moon.

Can Mars support life? Los Alamos hopes to answer that question via our instrument ChemCam, comprised of a remote micro-imager and laser-induced breakdown spectroscopy equipment for chemically analyzing rocks and soil. ChemCam, developed in collaboration with NASA and the French space agency, is being installed on the Mars Science Laboratory, a six-wheeled rover named Curiosity. NASA plans to launch Curiosity on a rocket this fall, with an expected landing on Mars in August 2012. Read more in this magazine's ChemCam article on page 8.

Discovery Science of Tomorrow

Los Alamos has a prominent role in nonproliferation, test-ban verification and space situational awareness (knowing the location of every object orbiting the Earth) but we also have a large role in space exploration and basic science. Since the 1970s, Los Alamos led instruments (or major parts of instruments) on NASA missions to study Earth, its moon, the sun, comets, asteroids, planets, and the outer heliosphere. Of particular importance is the study and monitoring of the space weather near Earth and the geomagnetic storms driven by bursts of solar material and energy that ride in the solar wind and interact with Earth. These storms can severely affect telecommunications, the electrical grid, satellites, and astronaut safety. Laboratory instruments detected a large geomagnetic storm in 1997, and Los Alamos was able to quickly alert other scientific



Lunar Prospector, a NASA Discovery mission, was launched into lunar orbit in 1998. Image courtesy of NASA

teams in advance, a "first" with our unique combination of spacecraft and ground-based monitoring capabilities. LANL has continued to help demystify space weather. Read more about Los Alamos' recent space-weather research in the HOPE article in this issue on page 10.

Using the High Energy Neutral Atom Imager led by Los Alamos National Laboratory, NASA's IBEX mission launched a satellite in 2008 that is measuring atoms ricocheting from the distant shock wave formed by the interaction of the expanding solar wind and the interstellar cloud through which we are moving. Last year the IBEX team reported a completely unexpected "noodle soup" of emissions from the outer fringes of our heliospheric bubble. Read more in this issue's IBEX sidebar on page 4.

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Los Alamos space science also aids our understanding of climate change. In a scientific article released last year, LANL scientists Petr Chylek and Manvedra Dubey plus collaborators described for the first time how they utilized remote sensing, modeling, and analysis to report an alternating, see-saw pattern in warming trends of the Arctic and Antarctic oceans. Understanding the relationship between climate changes in the Arctic and Antarctic regions is essential for scientists to predict the dynamics of the Earth's climate system. Understanding the nature of polar regions is critical if the world's policy makers are to address the possibility of global, human-caused (anthropogenic)

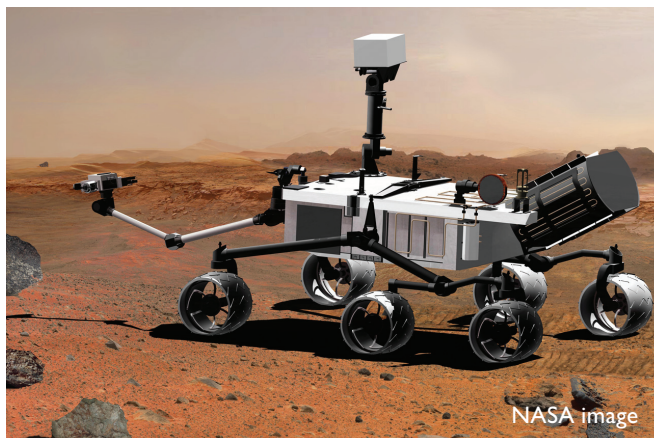
climate change caused by the melting of the polar ice sheets and the subsequent rise of the world's sea levels.

“It has significant impact on our understanding of and predictions for global warming,” said Herb Funsten, chief scientist for LANL’s International, Space, and Response Division. LANL models are sought worldwide by climate modeling groups.

From Signals to Interpretation

Even in today’s technology climate—smart phones, Internet, social networking—detection of hidden activities that threaten the safety of our citizens is extraordinarily difficult. More sensitive instruments, revolutionary measuring techniques, and the expertise to turn data into information for discovering nuclear, chemical, or biological weapons of mass destruction go hand in hand with discovering and understanding physical processes underlying the space sciences and their impact on our planet and its resources. LANL is adept at remote sensing, detecting signatures, data collection and analyses (enhanced by event response), signal propagation and instrument development, and performance analysis.

We have a long history of developing space systems for national security and scientific research. From the early days with rocket-borne diagnostics to today’s diverse and complex capabilities, we’ve strengthened national security



Artist's rendering of the Curiosity rover, which contains LANL's ChemCham, surveying the surface of Mars.

with our sensor and processing capabilities while also using these capabilities to explore space and provide cutting-edge results and technologies.

LANL has engaged in space projects with applications that range from fundamental science and military functions to commercial and civilian activities. LANL scientists have conducted advanced research in areas such as astrophysics, planetary science, space physics, and Earth sciences such as climate research. And our technology has far-reaching applications. ✦

-Kirsten Fox

Following is a partial list of NASA missions in which we have led instruments or led major instrument subsystems:

Interplanetary (beyond Earth):

Advanced Composition Explorer (ACE), studies the solar wind

Ulysses, first spacecraft out of the ecliptic plane to study the solar wind from the polar regions of the sun

Cassini, studies the space environment of Saturn and its moons

Lunar Prospector, mapped the elemental composition of the lunar surface and presence of water in permanently-shadowed craters

Deep Space I, studied the plume of comet Borrelly

Mars Odyssey, discovered and mapped the distribution of water on Mars

Genesis, studied the composition of the solar wind to understand the formation of the solar system

Mars Science Lab, scheduled to launch in 2012 to study the elemental and mineralogy of Mars

Dawn, study the composition of two asteroids, Ceres and Vesta

Earth-orbiting:

HETE, x-ray astronomy

IMAGE, global imaging of the Earth's plasma environment

TWINS, stereoscopic global imaging of the Earth's plasma environment

SWIFT, detects gamma-ray bursts to study supernova

IBEX, study the interaction of our heliosphere with the local interstellar medium

RBSP (launch in 2014), 1st mission designed to study the structure and dynamics of the radiation belts

NOTE: Plutonium-based radioisotope thermoelectric generators (RTGs) developed or fueled by LANL include the following NASA missions: Pioneer, Voyager, Viking, Apollo, Galileo, Ulysses, Cassini, New Horizons, and Mars landers



ChemCam

Photon Gun
Provides Mars Rover
Hands-Free Identification

cleans away the dust or weathering coatings before performing the rock analysis. There is no need to drive the rover to within reach of the target rock.

ChemCam is the first instrument of its kind. “We brought together a lot of new ideas to make this instrument a reality. It has been exciting to see this invention come together,” said Los Alamos National Laboratory’s scientist Roger Wiens, the instrument’s principal investigator.

The goal of Curiosity, a rolling laboratory, is to assess whether Mars ever had an environment capable of supporting microbial life and conditions favorable for

The ChemCam instrument has completed the first short leg of its long trip to Mars, arriving at the Jet Propulsion Laboratory from Los Alamos National Laboratory for installation aboard the next Mars rover, due to launch in late 2011. The NASA Mars Science Laboratory project’s rover, named Curiosity, will carry the newly delivered laser instrument to reveal which elements are present in Mars’ rocks and soils up to 7 meters (23 feet) away from the rover.

By firing intense pulses of laser light at distant targets, the ChemCam instrument uses a technique called laser-induced breakdown spectroscopy (LIBS) to measure the chemical content of the target samples. The laser beam vaporizes a pinhead-sized area on the target. A spectral analyzer then peers closely at the flash of light from the vaporized sample. Atoms ablated in ionized states emit light and each sample yields spectral emissions at unique wavelengths, revealing the elements present in the material.

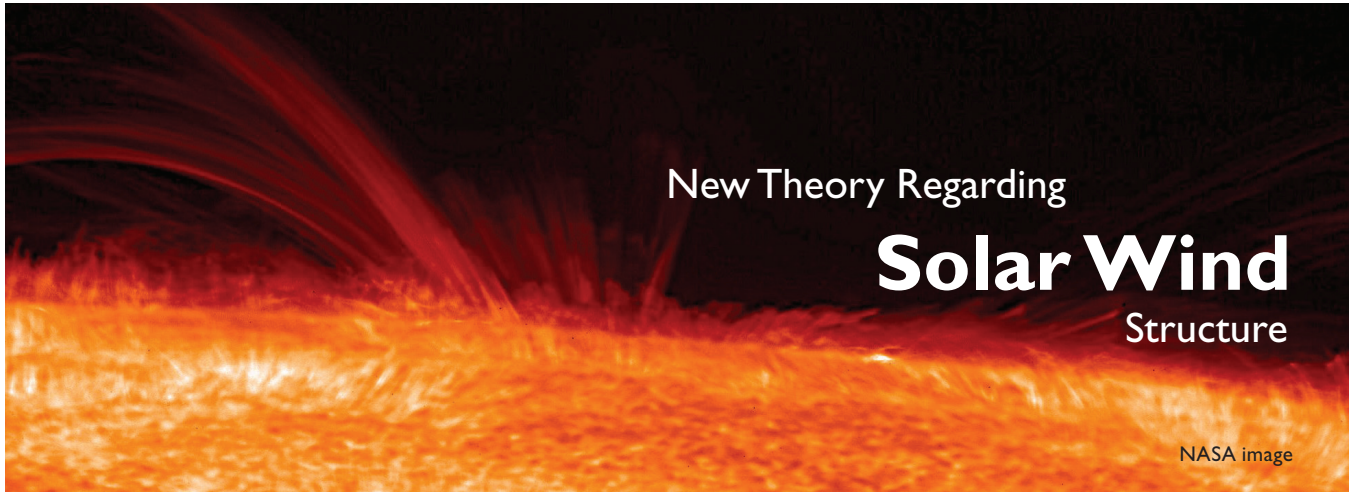
Like fingerprints, the emission line wavelengths can be matched to a library of known chemical compounds. Even dust-covered rocks will reveal their inner secrets to the ChemCam interrogation. On such samples, the laser first

preserving clues about life, if it existed. Curiosity is by far the biggest and most capable robot ever destined for Mars. It is nuclear-powered and comparable in size to a small car. The capsule that will be used to carry the rover into the Mars atmosphere is even larger than the Apollo capsule that housed three astronauts for missions to the moon. ChemCam is one of 10 instrument packages contained on the rover. The other instruments are capable of identifying minerals, sniffing out organic materials, observing the weather and radiation environment, and drilling several centimeters into the Martian rocks.

The ChemCam instrument was conceived, designed, and built by a U.S.-French team, led by Los Alamos National Laboratory in New Mexico, the Jet Propulsion Laboratory in California, and France’s Centre for the Study of Radiation and space agency, Centre National d’Études Spatiales.

Curiosity is due to launch from Florida in November of 2011 and is expected to arrive at Mars in August 2012. ✦

Curiosity is by far the biggest and most capable robot ever destined for Mars.



A LANL scientist examining the solar wind suggests that our understanding of its structure may need significant reassessment. The plasma particles flowing from the Sun and blasting past the Earth might be configured more as a network of tubes than a river-like stream, according to Joseph Borovsky of Los Alamos National Laboratory's Space Science and Applications group.

In *Physical Review Letters*, "Contribution of Strong Discontinuities to the Power Spectrum of the Solar Wind," published in September of 2010, Borovsky challenges the concept that the solar wind is of fairly uniform structure, and therefore, our entire interpretation of spacecraft data may not be correct.

"For decades we have been interpreting the spectrum of fluctuations in the solar wind as a measurement of turbulence in the wind. However, it turns out that impurities (discontinuities) in plasma dominate the signal. Hence, the spectrum is not a clean measurement of turbulence, and it may not even be a measurement of turbulence," Borovsky said. In simpler terms, perhaps, we couldn't see the forest for the trees.

"Because we might be misunderstanding the solar wind, we might be misunderstanding its impact on the Earth's environment. Understanding solar wind allows us to understand the initiation and evolution of geomagnetic storms," said Herbert Funsten, chief scientist for the International, Space, and Response Division at Los Alamos.

Borovsky argues that the discontinuities are part of a structure to the solar wind that looks like spaghetti, with the discontinuities being the boundaries between adjacent

New Theory Regarding Solar Wind Structure

NASA image

Because we might be misunderstanding the solar wind, we might be misunderstanding its impact on the Earth's environment. Understanding solar wind allows us to understand the initiation and evolution of geomagnetic storms

noodles (magnetic tubes). In this concept, the wind plasma is structured rather than being homogeneous. He suggests that the spaghetti structure of the solar-wind plasma reflects the "magnetic carpet" on the surface of the Sun, with the spaghetti in the wind being loose strands of the magnetic carpet.

"We have also argued that the spectrum measured in the wind is a 'remnant' of the carpet on the Sun rather than a signature of turbulence in the wind plasma," Borovsky says.

The research data came from NASA's ACE satellite, which has been operating upstream of the Earth since 1998. A satellite "sits" in the wind and makes measurements as the wind blows past supersonically (typically Mach 8 or so, 300–700 km/sec). The information about the measurements is telemetered to Earth and delivered to institutions such as Los Alamos, where data-analysis software converts the satellite readings into physical measurement quantities, such as wind speed, wind density, wind temperature, and magnetic-field direction. Those physical quantities are put into publicly available data sets, which researchers can use to interpret the space weather, to make comparisons with theoretical models, and generally try to better understand the space environment surrounding the planet. ✦

HOPE for All Mankind



HOPE team members prepare the spectrometer for testing and calibration.

Scientists at Los Alamos National Laboratory are one step closer to putting a plasma analyzer in space that may provide critical information about how the sun affects Earth, life, and society. In late January, a Los Alamos team recently completed construction of the Helium Oxygen Proton Electron (HOPE) spectrometer, installing it into a vacuum chamber at Los Alamos for testing and calibration. Next, the spectrometer will be exposed to environmental tests such as vibration, temperature fluctuations, and electromagnetic interference.

The HOPE instrument is part of NASA's Radiation Belt Storm Probes (RBSP) mission, designed to help better understand the Sun's influence on Earth and near-Earth space by studying the Earth's radiation belts on various scales of space and time.

LANL's role is to build the HOPE plasma spectrometer (successfully accomplished in January), to set up and run the Energy Particle, Composition, and Thermal Plasma Suite (ECT) Science Operations Center, and to lead the ECT science analysis team.

The five instruments on NASA's Living With a Star Program's (LWS) RBSP mission will provide the measurements needed to characterize and quantify the plasma processes that produce very energetic ions and relativistic electrons—especially those that generate hazardous space weather effects, detailed below.

Making Life Better on Earth

According to NASA, understanding the radiation belt environment and its variability has extremely important practical applications in the areas of spacecraft operations, spacecraft and spacecraft-system design, and mission planning and astronaut safety. But the significance is far

greater than space science; unpredictable changes in space weather greatly affect society via power grid problems, telecommunications, satellite malfunction, astronaut safety, oil pipeline leaks caused by corrosion as a result of charged particles, and even GPS accuracy, which greatly affects safe airline travel.

“During the last solar cycle, a dramatic change in our understanding of the Earth’s radiation belts took place... The radiation belts were found to be highly dynamic and full of new surprises,” said Geoffrey Reeves, LANL scientist and a member of NASA’s LWS team. “For reasons we still don’t understand, the fluxes of relativistic electrons are seen to suddenly increase or decrease by factors of hundreds or more.”

Ruth Skoug, a Los Alamos space physicist who coauthored the HOPE proposal in 2005, said changes in the radiation belt could be partially in response to geomagnetic storms, and scientists need to understand why energy particles change.

RBSP instruments will measure the properties of charged particles that comprise the Earth’s radiation belts, the plasma waves that interact with them, the large-scale electric fields that transport them, and the particle-guiding magnetic field. Specifically, the goal of the NASA mission is to understand the acceleration, global distribution, and variability of energetic electrons and ions in the radiation belts.

The probes (i.e., spacecraft) will carry several instruments that support five experiments designed to address the mission’s science objectives. Because it is vital that the two probes make identical measurements to observe changes in the radiation belts through both space and time, each probe will carry the following: the ECT, Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS), the Electric Field and Waves Suite (EFW), the Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE), and the Relativistic Proton Spectrometer (RPS).

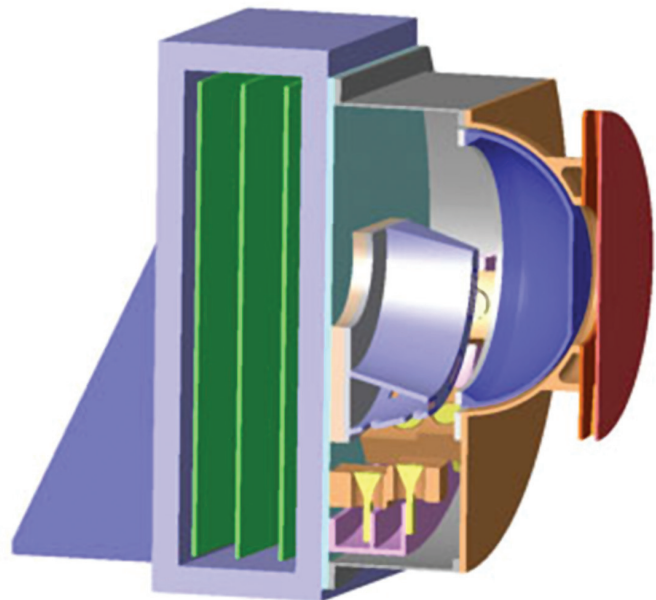
But the significance is far greater than space science—unpredictable changes in space weather greatly affect society via power grid problems, telecommunications, satellite malfunction, astronaut safety, oil pipeline leaks caused by corrosion due to charged particles—even GPS accuracy, which greatly affects safe airline travel.

Containing HOPE, the two spin-stabilized RBSP probes will have nearly identical eccentric (deviating from a circle) orbits. The orbits cover the entire radiation belt region and the two spacecraft lap each other several times over the course of the mission. The RBSP in situ measurements discriminate between spatial and temporal effects, and compare the effects of various proposed mechanisms for charged particle acceleration and loss. The two spacecraft will be launched simultaneously at slightly different speeds to separate time and provide more accurate data from two different “views”.

When space weather intensifies, the probes will not have the luxury of going into a safe mode, as many other spacecraft must do during storms. Consequently, these probes and instruments must be resilient enough to continue working even in the harshest conditions.

How it Works

The HOPE mass spectrometer instrument uses an electrostatic top-hat analyzer and time-gated coincidence detectors to measure electrons, protons, plus helium and oxygen ions with energies from less than or equal to 20 eV (electronvolts) or spacecraft potential (whichever is greater) to greater than or equal to 45 keV (kiloelectronvolts) while rejecting penetrating backgrounds.



Schematic of HOPE mass spectrometer.

Understanding the Magnetosphere

Earth has two regions—or belts—of trapped fast particles: electrons, protons, and heavier atomic ions that are trapped in our planet's magnetic field. The compact inner radiation belt extends about 4,000 miles above the equator, almost equal to our planet's radius. Further out is the large region of the ring current, and this belt fluctuates widely, rising when magnetic storms inject fresh particles from the tail of the magnetosphere, then gradually falling off again. The ring's current energy is mainly carried by the ions, most of which are protons.

The Earth's radiation belts are just one part of the system called the magnetosphere, a highly dynamic structure that responds dramatically to solar variations. The sun periodically releases billions of tons of matter in what are called coronal mass ejections; these immense clouds of material can cause large magnetic storms in the magnetosphere and the upper atmosphere.

The study of the region of space near the Earth helps to determine changes in the Earth's magnetosphere, ionosphere, and upper atmosphere in order to enable specification, prediction, and mitigation of their effects.

A Hopeful Prospect

The RBSP mission's instruments include LANL's HOPE spectrometer, which will measure the ion composition and plasma distributions in space that generate electromagnetic

waves and control the dynamics of the Earth's magnetosphere and radiation belts.

The RBSP mission, LANL's traditional satellite nuclear-detection network, and the DREAM space weather model are being integrated to forecast hazards for national security. LANL scientists developed DREAM, the Dynamic Radiation Environment Assimilation Model, to understand and to predict hazards from the natural space environment and artificial radiation belts produced by nuclear explosions. DREAM was recently implemented for real-time space weather applications.

HOPE's other applications include analyzing the effects of a nuclear bomb detonation. "Could we mitigate the effects of a nuclear bomb? We're not there, but we're working to understand the effects," said Skoug.

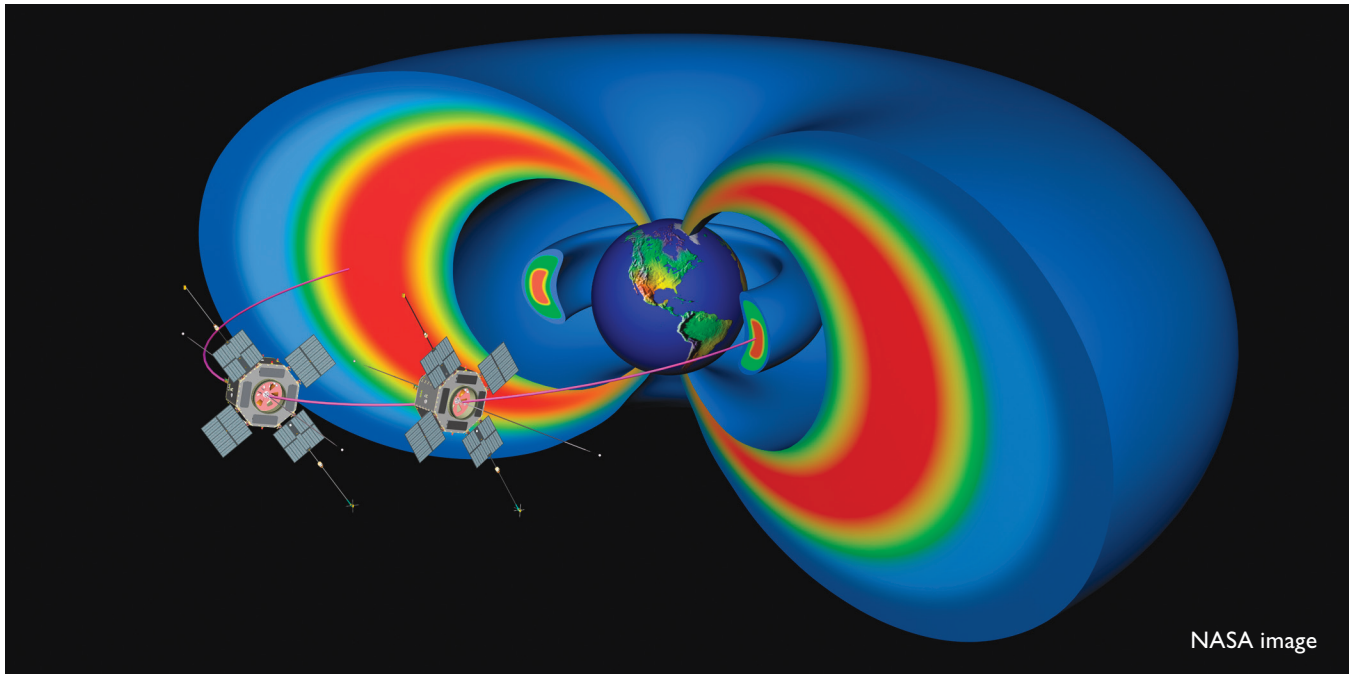
The Los Alamos HOPE team is led by Herb Funsten, Arthur Guthrie, and Ruth Skoug. The spacecraft are being built by the Johns Hopkins University Applied Physics Laboratory. Many LANL scientists, engineers, and technicians are involved with the RBSP project, including researcher Geoff Reeves who heads the ECT suite and was part of a team that generated the first-ever images of changes in these radiation belts.

HOPE is projected to launch on RBSP spacecraft in May 2012. ✨

-Kirsten Fox



HOPE team members Keith Kihara, Juan Baldonado, Rick Ortiz, and Ruth Skoug place the spectrometer into a vacuum chamber for testing.



Artist's view of the twin probes in the two donut-shaped regions of Earth's magnetic field.

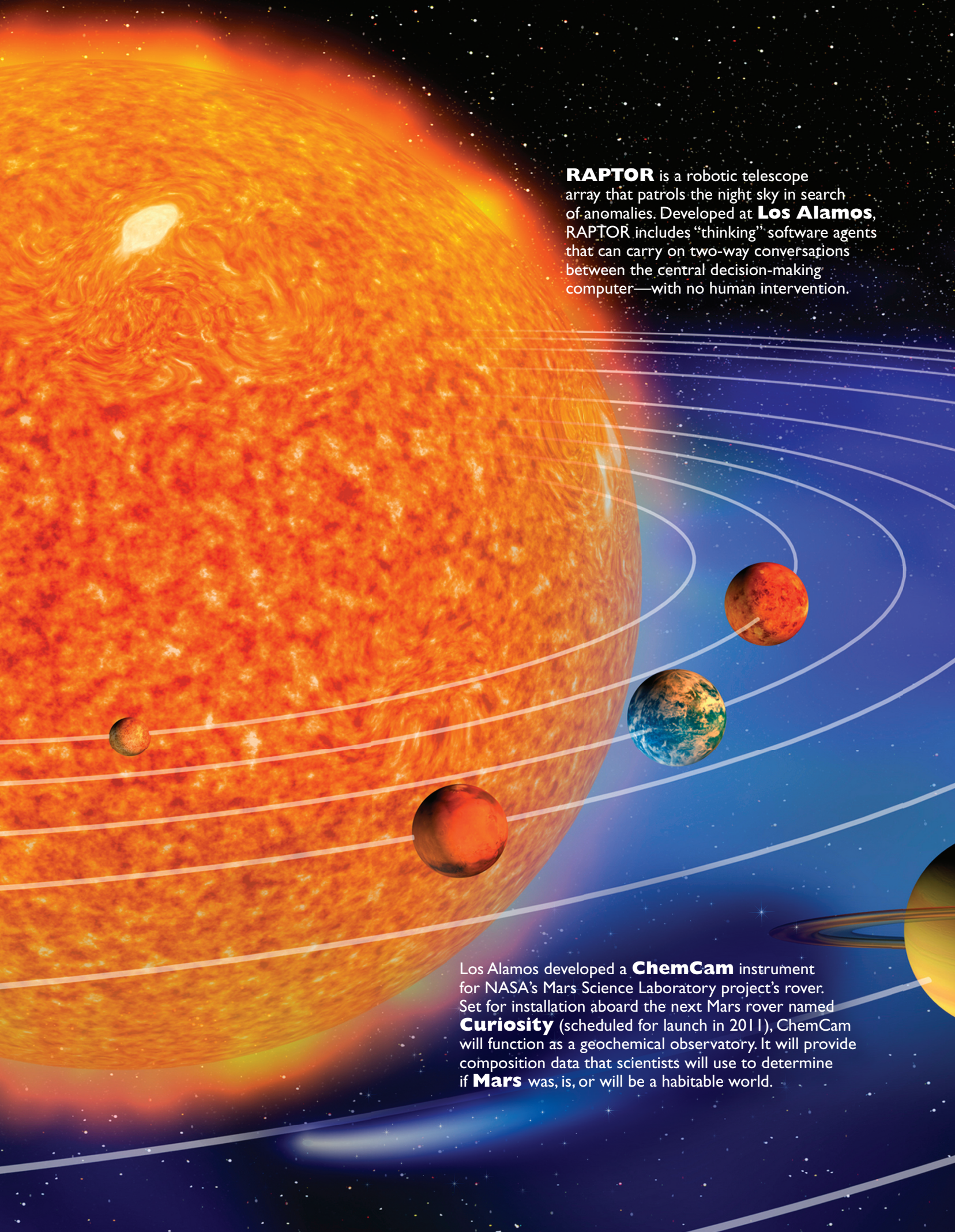
Tightening the Belt

The RBSP Mission (explained in the HOPE article on page 10) aims to increase our understanding of the Earth's radiation belts. The inner belt is marked by great stability, but the outer belt is constantly changing. Radiation belt particles are lost, e.g. by collision with the rarefied gas of the outermost atmosphere, and new ones are frequently injected from the comet-like tail of the magnetosphere (the magnetotail). The particle population of the outer belt fluctuates widely and is generally weaker in energy (less than 1 MeV or one million electronvolts), rising to energies of order 10 MeV when geomagnetic storms occur. Geomagnetic storms are temporary disturbances of the magnetosphere (the space environment around Earth) usually driven by effects which occur on the sun. These storms (usually driven by the solar wind) cause fresh particles to be injected into the radiation belts from the magnetotail. The energy of the radiation belts falls to more typical quiet time levels during the subsequent days, known as the storm recovery phase.

It is this constant variability of the radiation belts that is of most interest to scientists. There are known phenomena which give rise to these changes but the radiation belts do not always

respond in the same way to the drivers. For example, there is a close, but by no means simple, relationship between storms at Earth and changes in the radiation belts. Each of these storms was preceded by similar solar conditions. Due to complex processes that can occur simultaneously during the storm period, the radiation belts can be enhanced, depressed, or essentially unchanged compared with conditions before the storm.

In addition, temporary new belts can be created during magnetic storms, sometimes within minutes of the storm's onset. Solar energetic protons, accelerated at shock waves that emanate from the sun, can provide the "seed" population for new proton belts. Although it was once thought that the behavior of the radiation belts was well-understood, observations over the last decade have given rise to new and fundamental questions about the physical processes involved in the enhancement and decay of the belts and in the formation of new ones.



RAPTOR is a robotic telescope array that patrols the night sky in search of anomalies. Developed at **Los Alamos**, RAPTOR includes “thinking” software agents that can carry on two-way conversations between the central decision-making computer—with no human intervention.

Los Alamos developed a **ChemCam** instrument for NASA’s Mars Science Laboratory project’s rover. Set for installation aboard the next Mars rover named **Curiosity** (scheduled for launch in 2011), ChemCam will function as a geochemical observatory. It will provide composition data that scientists will use to determine if **Mars** was, is, or will be a habitable world.



Launched in 2008, **IBEX** (Interstellar Boundary Explorer) satellite carries a compact Los Alamos device called the **High Energy Neutral Atom Imager**. The satellite's purpose is to create the world's first map of the boundary between our solar system and interstellar space. IBEX has already sent back data that indicates a "noodle soup" of solar material has accumulated at the outer fringes of the heliosphere bubble. According to Los Alamos scientist Herb Funsten, researchers were expecting a "tie-dye" formation.

Los Alamos developed early "nuclear batteries" known as **PMCs** (plutonia-molybdenum-cermet) for the Pioneer 10 and 11 missions to **Jupiter and Saturn**, as well as for the **Viking Lander** missions to **Mars**. To fabricate a PMC, researchers hot-pressed microspheres of molybdenum-coated plutonia into hockey-puck-shaped discs, which were then stacked and encapsulated in a refractory alloy.

Launched in 2001, NASA's **Mars Odyssey** contained several Los Alamos instruments that by 2002 had sent back enough data to scientists that they predicted that there was water on **Mars**. In 2008, NASA's **Phoenix lander** confirmed the presence of water on **Mars**.

Launched in 1998, **Deep Space 1** carried aboard a Los Alamos instrument known as **PEPE** (Plasma Experiment for Planetary Exploration), which was designed to collect data that scientists can use to better understand the origins of the solar system. Deep Space 1 flew by asteroid **Braille** in 1999 and Comet **Borrelly** in 2001, at which time it completed its successful mission.

From the 1970s to today, Los Alamos has crafted general-purpose heat sources to meet the power requirements of **Galileo (Jupiter and its moons)**, **Ulysses (the Sun)**, **Cassini-Huygens (Saturn)**, and the New Horizons spacecraft, which will rendezvous with **Pluto** and its moons in July 2015.

NUCLEAR ROCKETS: To Mars and Beyond

Nuclear Rockets: Then and Now

In 1961, President John F. Kennedy in his address to Congress outlined a new and bold space program. What many Americans remember is Kennedy's national goal of "landing a man on the moon and returning him safely to Earth" by the end of the decade. Few Americans remember that Kennedy also outlined an effort to go beyond the moon, perhaps to Mars and beyond.

In this issue of *National Security Science*, we tell the story of this lesser-known effort, one in which scientists at Los Alamos National Laboratory successfully built and tested a variety of nuclear rockets. Although the program officially ended in 1972, research to further improve the basic design of nuclear rockets has continued in other organizations, with current designs based on the Pewee-2 engine (1969–1972) now having specific impulses of 925 seconds.



In 1961, President John F. Kennedy in his address to Congress declared a national goal of “landing a man on the moon and returning him safely to Earth” by the end of the decade. From 1961 to 1975, America’s space program used Apollo spacecraft and Saturn rockets to explore the moon, establish the Skylab program, and support a joint United States–Soviet Union mission in 1975. Saturn rockets (Fig. 1) were chemically based, making them huge—the Saturn V rocket stood 111 meters (363 feet) tall. Fully fueled, the rocket had a total mass of 3,000 metric tons (6.5 million pounds).

Having missions successfully reach the moon, the National Aeronautics and Space Administration (NASA) scientists and engineers set their sights on Mars and beyond. Their goal was to develop the technology to visit such faraway places, and Los Alamos would play a key role.

Although chemical rockets took astronauts to the moon and could take them to Mars, there are many drawbacks to the technology. For example, chemical engines produce relatively little power, making astronauts rely on planetary alignments, or “launch windows,” to provide an extra gravitational slingshot effect that helps catapult space vehicles into space. Moreover, chemical rockets are slow, making long trips to places like Mars impractical for manned missions.

“It is a most important decision that we must make as a nation. But all of you . . . have seen the significance of space and the adventures in space, and no one can predict with certainty what the ultimate meaning will be of mastery of space.”

John F. Kennedy, May 25, 1961

A more feasible technology is nuclear propulsion. Nuclear rockets are more fuel efficient and much lighter than chemical rockets. As a result, nuclear rockets travel twice as fast as chemical-driven spacecraft. Thus, a nuclear rocket could make a trip to Mars in as little as four months, and a trip to Saturn in as little as three years (as opposed to seven years). Such condensed trip times would help reduce astronaut and instrument exposure to harmful radiation emitted from the cosmic rays and solar winds that permeate interplanetary space.

The concern with nuclear rocketry lies in the radioactive components of nuclear power and these inherent safety



Fig. 1. The Apollo 11 lifts off. This Saturn V rocket was the first to land humans on the moon. NASA successfully launched 13 Saturn V rockets with no loss of crew or payload. This rocket remains one of the largest and most powerful launch vehicles ever brought to operational status (from the standpoint of height, weight, and payload). Image courtesy of NASA.

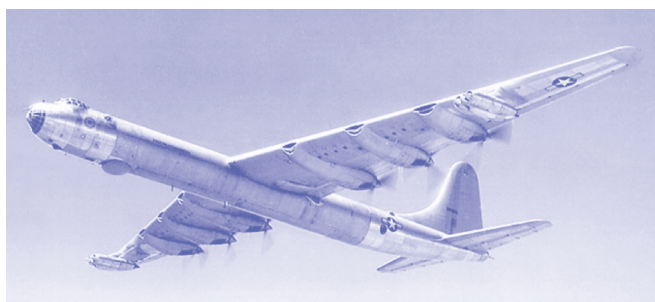


Fig. 2. Built by Convair, the B-36 “Peacemaker” was the first bomber capable of delivering all the nuclear weapons in the United States arsenal. Image courtesy of the United States Air Force.

challenges. Such concern has discouraged, and even prevented, space programs from implementing nuclear-powered missions to Mars and beyond.

The Atomic Age

In 1945, the United States ushered in the Atomic Age by detonating two atomic weapons over Japan, thus hastening the end of World War II. For approximately four years only the United States possessed nuclear weapons, but in 1949 the Soviet Union successfully tested its own nuclear bomb, bringing about the beginning of what would eventually become the Cold War.



Fig. 3. Robert Hanrahan stands between the Kiwi-A (left) and Phoebus-I (right). Phoebus-I is now at the Atomic Testing Museum in Las Vegas, Nevada. Hanrahan is now director of the Office of Nuclear Experiments for the National Nuclear Security Administration. *Archival photo courtesy of Robert Hanrahan.*



Fig. 4. The Kiwi-A is test-fired, making it the world's first nuclear-rocket reactor to undergo such testing. This image shows an incandescent plume of hot hydrogen gas exiting the reactor's rocket nozzle.

One of the principal problems related to early atomic weapons consisted of their delivery systems. These early atomic weapons weighed about five tons each, making it impossible for aircraft to carry them over intercontinental distances. Indeed, the B-29s that dropped the first weapons over Hiroshima and Nagasaki flew only a few hundred miles from Tinian Island to reach their targets in Japan. The radioactive components for the atomic weapons reached Tinian by ship.

To solve the problem of delivering nuclear weapons thousands of miles, the United States began to develop heavy-lift, long-range weapons-delivery systems. These systems included strategic bombers such as the Convair B-36 "Peacemaker" (Fig. 2), ground-based rockets, and nuclear-powered aircraft. The unique characteristics of these systems provide options for decision makers. Rockets provide prompt response (approximately 30 minutes) and superior accuracy. Whereas aircraft can be launched to demonstrate resolve and subsequently be recalled as events warrant. Another competing design was the nuclear ramjet, although this design did not come into being until the 1960s.

Project Rover

From 1955 through 1972, Los Alamos Scientific Laboratory (as the Laboratory was known then) conducted Project Rover, a program whose goal was to develop the technology for a nuclear-thermal rocket for space applications. Project Rover was part of the NASA space program, with the nuclear reactor portion falling under the Atomic Energy Commission (AEC).

The genesis of Project Rover can be traced to 1942, when scientists began to address the idea of using nuclear energy to propel an aircraft or rocket. These ideas were formulated soon after Enrico Fermi and his associates conducted the first successful test of a fission reactor. As early as 1944, scientists at the University of Chicago's Metallurgical Laboratory and Los Alamos began to discuss the possibility of using a fission reactor to heat a gas to high temperatures and propel a rocket—the basic idea behind a "nuclear-thermal" rocket. These scientists published several reports that explored the potential for this type of rocket.

The reports attracted the attention of the United States Air Force, which funded secret, small-scale, studies of nuclear-thermal rockets at Oak Ridge, Tennessee, from 1947 to 1949. Interest in nuclear rockets waned until 1954, when Robert Bussard of Oak Ridge Laboratory (now Oak Ridge National Laboratory) published a detailed engineering

Project Rover: Main Series of Nuclear-Rocket Engines

Kiwi-A

Named after the large, flightless bird, Kiwi was the first phase of Project Rover. Kiwi consisted of eight reactors that scientists tested between 1959 and 1964. The first reactor, dubbed Kiwi-A, was fired for the first (and only) time on July 1, 1959, at Jackass Flats in the Nevada Test Site (now the Nevada National Security Site).

Kiwi-B

The Kiwi-B series increased power by ten-fold while maintaining the same size of the Kiwi-A series. The Kiwi-B reactors experienced a problem similar to Kiwi-A: Internal vibrations caused by dynamic flow instability fractured portions of the fuel elements. Scientists resolved this problem when they developed Kiwi-B4.

Phoebus-1

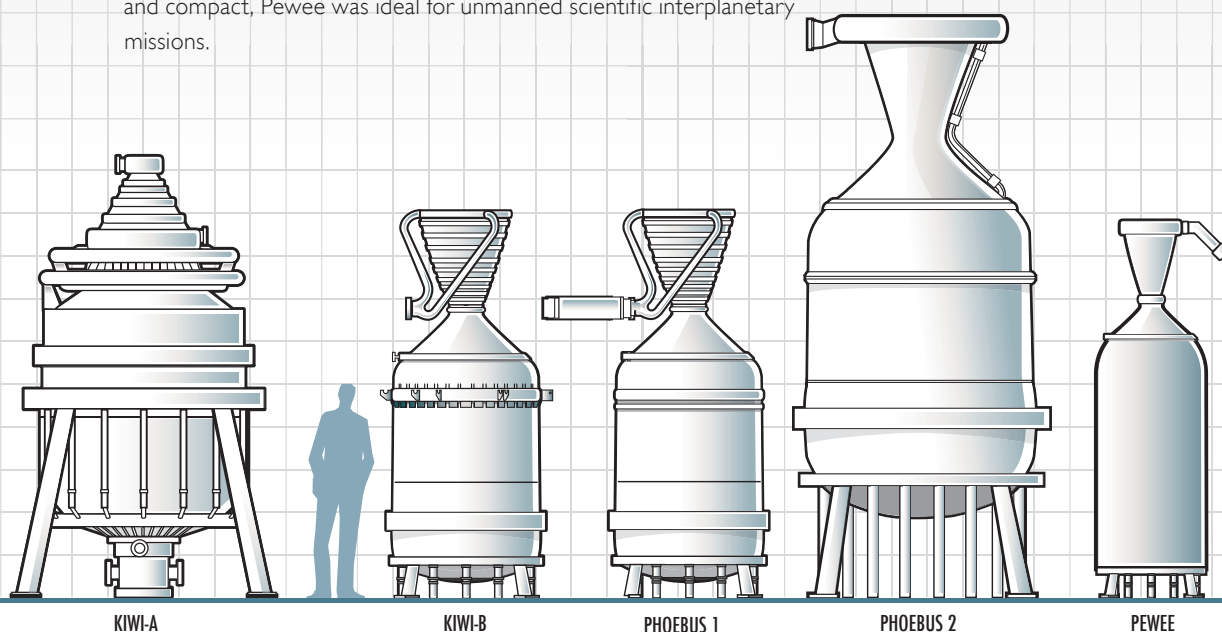
During the 1960s, scientists developed the Phoebus series of nuclear reactors to meet the needs of an interplanetary mission, such as a manned mission to Mars. Phoebus-1 was developed to study how best to increase power density. Phoebus A-1 was successfully tested on July 25, 1965, at Jackass Flats.

Phoebus-2

Scientists increased power density even further with the Phoebus-2 series. However, a limiting factor proved to be the cooling in the aluminum pressure vessel. Despite this limitation, tests run with the Phoebus-2 were considered highly successful. The final Phoebus-2 test in June 1968 ran for more than 12 minutes at 4,000 megawatts—for its time, it was the most powerful nuclear reactor ever built.

Pewee

Considered as a smaller version of Kiwi, Pewee was fired several times at 500 megawatts to test coatings made of zirconium carbide. Scientists also increased Pewee's power density. Easy to test and compact, Pewee was ideal for unmanned scientific interplanetary missions.



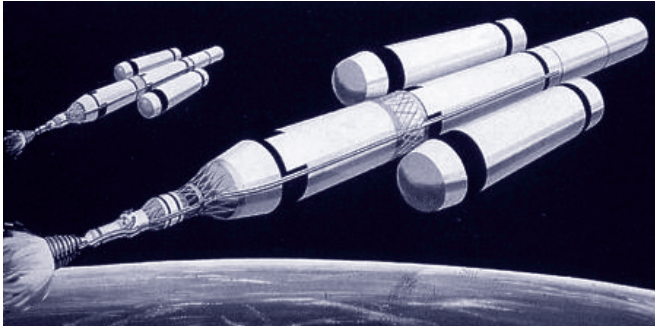


Fig. 5. A conceptual illustration of a spacecraft for a manned Mars mission proposed by NASA's Wernher von Braun in August 1969. Two spacecraft would make the trip in tandem, each one powered by three NERVA-type engines. Image courtesy of NASA.

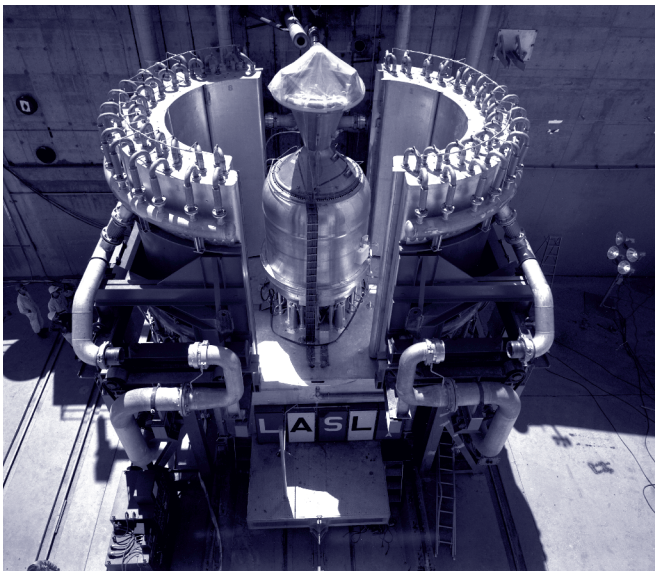


Fig. 6. The Phoebus-2A being prepared for testing at Los Alamos Scientific Laboratory. Photo courtesy of Richard Malenfant.

study of several nuclear-thermal-rocket applications. The Air Force commissioned Los Alamos Scientific Laboratory, Lawrence Radiation Laboratory at Livermore (now Lawrence Livermore National Laboratory), and others to perform more theoretical studies of nuclear-thermal-rocket performance.

Early in 1955, Los Alamos summarized its investigations in a now-declassified report, on nuclear-powered second stages for intercontinental ballistic missiles. The report touted the performance advantages of nuclear-powered rockets, which garnered support for materials research in the field. This report and similar information from Lawrence Livermore led to the start of serious nuclear-rocket-reactor work at both laboratories.

In 1956, Lawrence Livermore was redirected to work on nuclear ramjets, with Los Alamos continuing to develop rockets under Project Rover. As atomic weapons became smaller and lighter, chemical rockets became a viable delivery system. In 1957, the Air Force stated that nuclear rockets no longer had any military value and recommended that space applications be pursued for them instead.

Project Rover consisted of three principal phases: Kiwi (1955 to 1964), Phoebus (1964 to 1969), and Pewee (1969 to the project's cancellation, at the end of 1972). Nuclear reactors for the Project Rover were assembled at Los Alamos' Pajarito Site. For each engine there were actually two reactors built, one for "zero-power critical" experiments conducted at Los Alamos and another used for full-power testing at the former Nevada Test Site (now the Nevada National Security Site). Fuel and internal engine components for the engines were fabricated in the Sigma complex at Los Alamos. Figures 3 and 4 show some of the reactors. The Project Rover illustration on page 19 provides additional information for each phase.

NERVA: Nuclear Engine for Rocket Vehicle Application

In 1961, NASA and the AEC embarked on a second nuclear-rocket program known as NERVA. Taking advantage of the knowledge acquired as scientists designed, built, and tested Project Rover research reactors, NERVA scientists and engineers worked to develop practical rocket engines that could survive the shock and vibration of a space launch. From 1964 to 1969, Westinghouse Electric Corporation and Aerojet-General Corporation built various NERVA reactors and rocket engines.

In 1969, NERVA's successes prompted NASA-Marshall Space Flight Center director Wernher von Braun to propose sending 12 men to Mars aboard two rockets, each propelled by three NERVA engines (Fig. 5). The mission would launch in November 1981 and land on Mars in August 1982.

Although the mission never took place, engines tested during that time met nearly all of NASA's specifications, including those related to thrust, thrust-to-weight ratio, specific impulse, engine restart, and engine lifetime. When the Project Rover/NERVA program was canceled in 1972, the only major untested requirement was that a NERVA rocket engine should be able to restart 60 times and operate for a total of 10 hours.

There was one engine, however, that exceeded some NERVA specifications. Designed, built, and tested at Los Alamos, the Phoebus-2A Project Rover engine (Fig. 6) produced up to 4,000 megawatts of thermal power. In those terms, it was the most powerful nuclear propulsion reactor ever built.



Fig. 7. The Kiwi-B4A reactor awaits testing at the Nevada Test Site in 1962. At the left is Norris Bradbury, Laboratory Director from 1940–1970.

Nuclear-Thermal Reactors

During the Project Rover/NERVA projects, scientists conducted 22 major tests of nuclear-thermal-rocket engines (Fig. 7). Many of these tests explored potential solutions to complex problems that arise when using reactors to propel rockets with hot hydrogen. Significant issues with materials stability, compatibility, and corrosion beyond those encountered in terrestrial power reactors had to be addressed to produce practical rockets.

The principal difference between reactors used for space propulsion and electricity generation is the temperature of the cores. A reactor core consists of (1) fuel elements that contain the radioactive material to produce fission; (2) structures designed to hold the fuel elements in place; (3) structures that control the reactor's operation by absorbing, reflecting, or slowing ("moderating") neutrons produced by the fission reactions; and (4) a cooling system. The cooling system or "working fluid" (a gas or liquid) absorbs heat produced by the fuel elements and transfers the heat or energy to other parts of the system to generate propulsion or electricity.

Figure 8 shows a simplified schematic of a nuclear power reactor. The schematic shows uranium fuel elements,

which cause fission reactions. The radiation-protection barrier limits radiation exposure to plant workers and the environment.

In a nuclear-thermal-rocket reactor, the temperature must be as high as possible to achieve optimum performance (see the article "The Basics of Nuclear Rocketry" on page 25). Thus, the core temperature for the Kiwi-A test was 2,683 Kelvin (K) or 4,370°F, whereas the core of pressurized-water reactors used for nuclear power plants is only around 600 K (620.6°F).

A major difference between a nuclear-thermal-rocket reactor and a power-plant reactor is the cooling systems. Nuclear rockets use hydrogen, whereas U.S. power plants use water. Hydrogen is the best propellant gas for a nuclear-thermal rocket. Nevertheless, working with hydrogen at these high temperatures presents many challenges.

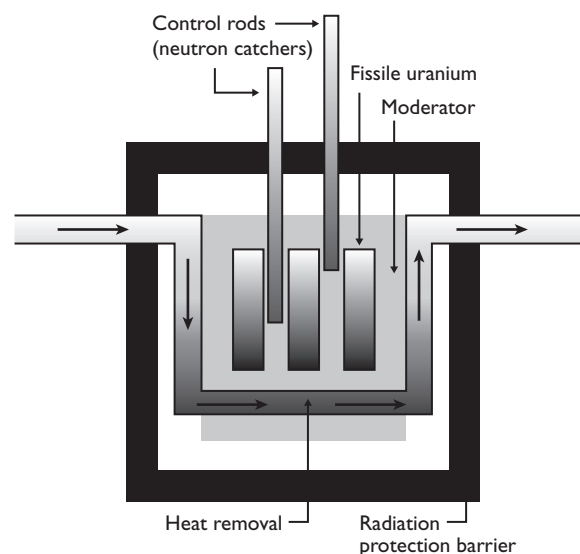


Fig. 8. This general schematic shows the major nuclear reactor components. Uranium fuel elements produce fission reactions and neutrons. The neutrons help produce more fission reactions, leading to a sustained chain reaction. Operators move control rods in and out of the reactor to absorb neutrons, and thus control the chain reaction. This controls the power at which the reactor operates. The moderator improves reactor efficiency by slowing down the neutrons, thus increasing their likelihood of producing fission reactions. The reactor heats the water, which passes through the core, thus generating steam. The steam turns an electrical generator, thus producing electricity. Original figure courtesy of the European Nuclear Society; redrawn by Los Alamos National Laboratory to enhance clarity.

It Comes Down to the Cores

All the Project Rover/NERVA reactors had solid cores. As detailed in “The Basics of Nuclear Rocketry” on page 25, researchers designed liquid- and gas-core reactors for nuclear-thermal-rocket propulsion—and even conducted small-scale experiments on components for these designs, but only solid-core reactors were built. Few materials, however, remain solid at the temperatures in the core of a nuclear-thermal-rocket reactor. Structurally, several metals and ceramics with high melting points (so-called “refractory” materials) may be used to build a core, but the way these materials interact with neutrons also plays a key role in their selection.

For example, the metal with the highest melting point—tungsten, at 3,695 K (6,191.6°F)—strongly absorbs neutrons, particularly “slow” ones, which have energies much less than one electronvolt. Project Rover cores were capable of operating with tungsten as a fuel matrix. However, the development of tungsten required technology development that proved to be beyond the capabilities of the program at the time. Consequently, Project Rover focused on graphite core reactors.

As a crystalline form of carbon, graphite behaves well at high temperatures because it has the highest melting point of any element. Graphite not only retains its strength at high temperatures but also actually becomes stronger. Graphite has long been used in various high-temperature industrial applications; therefore, scientists began considering its use in the design of Project Rover reactors.

The first fission reactor—and many reactors built after it—consisted of graphite bricks stacked in a “pile,” with rods of uranium dispersed throughout. Graphite was chosen to build piles mainly because of its good neutronics properties and because it was a weak neutron absorber and a good reflector and moderator of neutrons. However, graphite in a simple pile never encounters the extreme conditions as it would in the core of a nuclear-rocket reactor. Graphite’s response to these extreme conditions was unknown.

Hot Hydrogen Complicates Things

Scientists suspected early on that graphite could pose a serious problem when used in a nuclear-thermal-rocket reactor. The best propellant gas for this type of rocket is hydrogen. In the Project Rover engines, large amounts of hydrogen passed over the rocket nozzle and some reactor components before being forced through channels in fuel elements within the reactor core. This process heated the hydrogen, and the hot hydrogen quickly corroded the graphite in the reactor.

To protect these channels, scientists coated their inner surface with a thin niobium carbide (NbC) film. At first, scientists used a gaseous mixture of niobium chloride (NbCl₅), hydrogen chloride (HCl), and hydrogen (H) to deposit NbC onto the channel’s inner surfaces, using a process called chemical vapor deposition (CVD). However, as core designs evolved, the lengths of the fuel elements increased. To meet these longer fuel-element designs, researchers vertically stacked shorter fuel-element sections to make longer fuel elements. Eventually, researchers perfected the technique for fabricating longer fuel elements.

The CVD process could not deeply penetrate the longer channels to coat evenly the inner surfaces of the fuel elements. Therefore, researchers developed a new coating method. Thin niobium tubes were inserted into the channels and heated in place under a hydrogen chloride gas, which converted the Nb to NbC. The outer surfaces of the fuel elements were also coated. Later, the program evolved to zirconium carbide (ZrC) coatings

Fueling the Reactor

The fuel elements in the cores of the Project Rover/NERVA reactors consisted of uranium-loaded graphite, made using a new method developed by Haskell Sheinberg, who is now a retired Los Alamos National Laboratory Fellow. Unlike the proven high-temperature method for making graphite parts, the new method worked at room temperature, thus making it easier to fabricate fuel. Also, the new method produced stronger, denser graphite than the traditional method. Sheinberg’s method is still in use today.

The fuel elements in the Kiwi-A core consisted of flat plates molded and pressed at room temperature from a mixture of fine graphite powder called graphite flour, fine carbon powder, graphite flakes, a resin binder, and uranium oxide (UO₂) particles. The fuel elements underwent baking from 318 K (113°F) to 453 K (356°F) over a period of 36 hours, followed by a heat treatment under vacuum at 1,073 K (1,472°F). During this two-stage baking process, the resin decomposed into amorphous carbon and gas. The final baking of the elements was at 2,723 K (4,442°F) to crystallize the amorphous carbon into graphite. Graphite is stronger and a better heat conductor than amorphous carbon, which is brittle.

During this graphitization process, the UO₂ particles are thermally converted to uranium carbide (UC₂) particles. After graphitization, the fuel elements were machined to fine tolerances, as required for reactor operation. The flat-plate fuel elements in the Kiwi-A core were the only fuel elements used during Project Rover/NERVA that were not clad or coated to reduce hydrogen corrosion.

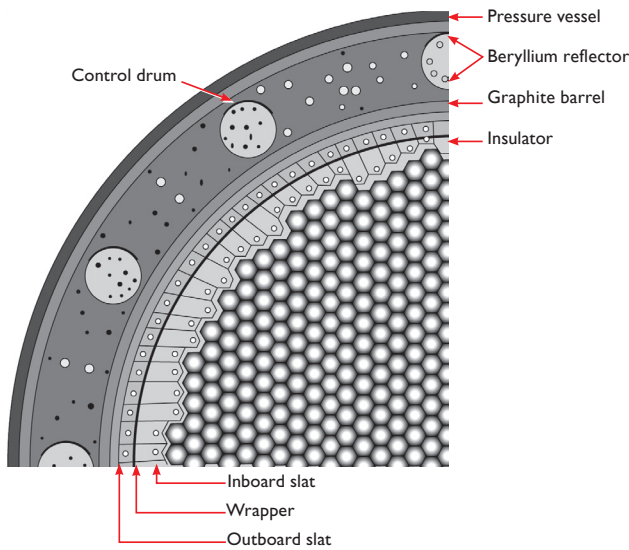


Fig. 9. A cross-sectional schematic of a typical Rover/NERVA nuclear-rocket reactor. Figure taken from Los Alamos National Laboratory manuscript LA-12784-MS; redrawn by Los Alamos National Laboratory to enhance clarity.

The fuel elements for all the Kiwi reactors after Kiwi-A (except the last one, Kiwi-B4E) were extruded into their near-final shapes and dimensions from a “green mix”—which consisted of graphite flour, fine carbon powder, resin binder (partially polymerized—or “set” furfuryl alcohol), UO_2 particles, and a catalyst (maleic anhydride). After extrusion, the elements were baked to 523 K (482°F) for approximately 56 hours to polymerize the resin. Then they were heated to as high as 1,123 K (1,562°F) to remove gases produced during polymerization. Finally, the elements were graphitized around 3,000 K, and then machined to final specifications.

The extruded fuel elements had a diameter of approximately one inch, and were approximately four feet in length. In the early reactors, extruded fuel elements consisted of cylinders with a circular cross-section. Later, the cylinders had a hexagonal cross-section, so the assembled core resembled a honeycomb. The number of channels in each fuel element and the channel diameters also changed as reactor designs evolved. Figure 9 shows a cross-sectional schematic of a typical Project Rover/NERVA reactor.

In early 1962, Project Rover scientists and engineers encountered a “back-reaction” problem with UO_2 particles in the fuel elements that had been converted, during graphitization, to UC_2 particles. Uranium carbide particles are extremely reactive and revert back to oxide in air, particularly humid air. During fuel-element processing, storage, and during reactor operation, the back reaction generated carbon dioxide (CO_2) gas and degraded the fuel elements. Oxidation of the UC_2 particles during storage of the fuel elements made them swell as much as 4%, so that

their final dimensions exceeded the fine tolerances required for the reactor.

To resolve this problem, scientists replaced UO_2 particles with pyrolytic-graphite-coated UC_2 particles. Eventually, uranium carbide particles were developed that could withstand 2,873 K (4,550°F) for 30 minutes. The Kiwi-B4E, Phoebus-1, Phoebus-2, Pewee, and NRX-A reactors/engines all used fuel elements containing pyrolytic-graphite-coated UC_2 particles. This type of fuel element became the “standard” fuel element. The NRX-A series of nuclear reactors were developed to demonstrate that Kiwi-B4 reactors could be adapted to withstand launch loads. During NRX-A6 and Pewee tests, the standard fuel elements operated for one hour at hydrogen exhaust temperatures between 2,400 K and 2,600 K (3,860.6–4,220.6°F).

Meanwhile, Los Alamos researchers continued to develop fuel elements capable of performing at ever-higher core temperatures. In 1972, Los Alamos tested two new fuel-element concepts in their Nuclear Furnace (NF-1) reactor, specifically designed to test such concepts. The NF-1 reactor was a heterogeneous, water-moderated, beryllium-reflected reactor for performing high-temperature nuclear tests. The first fuel element was a pure carbide (U,ZrC). The second element was a “composite” fuel element.

Both the standard and composite fuel elements performed well when tested in the NF-1 reactor for 109 minutes at 2,450 K (3,950.6°F). Projections at that time indicated that the composite fuel elements would be good for 2 to 6 hours at 2,500–2,800 K (4,040.6–4,580.6°F). The researchers achieved similar endurance times at 3,000–3,200 K (4,940.6–5,300.6°F) for the carbide fuel elements, once an improved cross-section design reduced a cracking problem. For 10 hours of operation, fuel elements were limited to hydrogen exhaust temperatures of 2,200–2,300 K (3,500.6–3,680.6°F) for standard elements, nearly 2,400 K (3,860.6°F) for composite, and approximately 3,000 K (4,940.6°F) for pure-carbide fuel elements.

Mission: Cancelled

NASA’s plans for NERVA included a visit to Mars in 1979 and a permanent lunar base by 1981. NERVA rockets would be used for nuclear “tugs” designed to take payloads from low-Earth orbit to higher, larger orbits as a component of the later-named Space Transportation System. The NERVA rocket would also be used as a nuclear-powered upper-stage component for the Saturn rocket (a chemical-based rocket), which would enable the upgraded Saturn engine to launch much larger payloads (up to 340,000 pounds) to low-Earth orbit.

In 1973, Project Rover/NERVA was cancelled. Although the projects proved very successful, the space mission itself

never took place. No nuclear-thermal rockets were ever used to send explorers on long-range space missions.

It was the Mars mission that led to NERVA's termination. Members of Congress judged the manned mission to Mars was too expensive and that funding the project would continue to foster a costly "space race" between the United States and the Soviet Union.

By the time NERVA was cancelled, the NERVA-2 would have met all the mission's objectives. Two of these engines would have been fitted to a NERVA stage capable of powering a manned interplanetary spacecraft.

During its lifetime, Project Rover/NERVA achieved the following records:

- 4,500 megawatts of thermal power
- 3,311 K (5,500.4°F) exhaust temperature
- 250,000 pounds of thrust
- 850 seconds of specific impulse
- 90 minutes of burn time
- thrust-to-weight ratios of 3 to 4

Beyond proving the feasibility of nuclear space propulsion, Project Rover/NERVA enabled scientists to produce approximately 100 technical papers that covered the properties of graphite, graphite flour, and other forms of carbon. The program also produced several important spin-offs, including Sheinberg's room-temperature graphite-fabrication process and methods for coating graphite with thin films of metal carbides.

Moreover, the technology for coating UC_2 particles with pyrolytic graphite eventually led to the TRISO fuel beads now used in commercial high-temperature, gas-cooled reactors to generate electricity. However, the program's most important spin-off—by any measure—was the heat pipe (see the "Inspired Heat-Pipe Technology" article on page 28).

The heat pipe is currently the centerpiece of the Los Alamos research program known as Heatpipe Power System (HPS) reactors. As envisioned by heat pipe inventor Los Alamos physicist George Grover, HPS reactors use heat pipes to transfer heat from a reactor core to thermoelectric elements or heat engines.

In 2000, NASA created Project Prometheus to develop nuclear-powered systems for long-duration space missions.

This project was NASA's most serious consideration of nuclear power for space missions since the cancellation of Project Rover/NERVA in 1972. For the Jupiter Icy Moons Orbiter (JIMO), a spacecraft designed to explore Europa, Ganymede, and Callisto, NASA intended to use an HPS reactor. The JIMO (Fig. 10) design used a fission reactor to power a Brayton-cycle heat engine that ran an electrical generator. The electricity would then power scientific instruments and an ion-propulsion unit. In 2005, NASA canceled the Prometheus Project as a result of budget constraints.

Because scientists continue to look back and build upon the technical advances developed during Project Rover/NERVA, those enduring advances are likely to one day play a major role in humanity's exploration of the solar system and beyond. ✦

-Brian Fishbine, Robert Hanrahan, Steven Howe, Richard Malenfant, Carolynn Scherer, Haskell Sheinberg, and Octavio Ramos Jr.

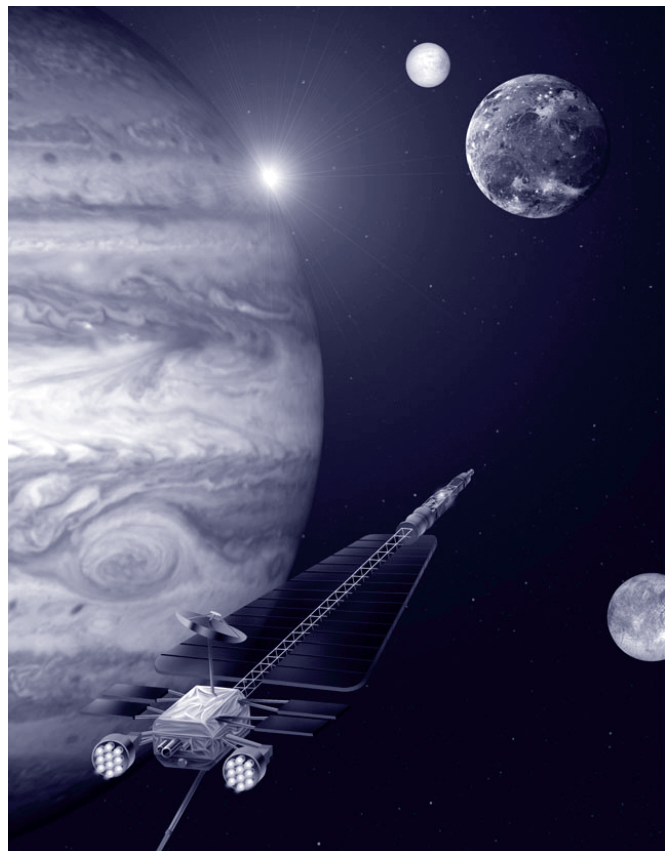


Fig. 10. An artist's conception of JIMO as it nears Jupiter and its icy moons: Europa, Ganymede, and Callisto. *Illustration courtesy of NASA.*

The Basics of Nuclear Rocketry



A nuclear reaction typically releases ten million times the energy of a chemical reaction. Thus, it would seem that the weight of the fuel necessary for a nuclear rocket to deliver a certain payload would be significantly less than the weight of the fuel a chemical rocket would need to heave the same weight the same distance. So, a larger fraction of a nuclear rocket's total weight—including the weights of the rocket engine(s), the airframe, the fuel, and the payload—could go into the payload weight.

However, the following components significantly increase the nuclear rocket's total weight: a nuclear-thermal rocket's reactor vessel, reactor core (excluding the fuel), radiation shielding, liquid-hydrogen tanks, and hydrogen-circulation equipment. As a result, a nuclear-thermal rocket can deliver only approximately twice the payload weight of a chemical rocket. Even so, early atomic weapons were so heavy that the theoretical increased "throw weight" of nuclear rockets managed to spark the United States Air Force's interest in them.

No More "Gravity Assists"

An additional advantage of a nuclear-thermal rocket is that it could travel directly between planets, without gravity assists (also known as slingshot effects), at least twice as fast as a chemical rocket could, cutting the transit time between planets. For example, a trip to Saturn using chemical rockets would take seven years—nuclear rockets could make the same trip in as little as three years. Although gravity assists (Fig. 1) conserve fuel during interplanetary missions, such assists make the trips much longer—a trip to Mars could take more than one year, for example.

The higher speed results from the fact that the exhaust velocity for a nuclear-thermal rocket is about twice that for a chemical rocket. The exhaust velocity, V_e , is the speed with which the propellant gas leaves the rocket nozzle.

A gas-propelled rocket's ultimate speed and its exhaust velocity are related by the following ideal rocket equation:

$$\Delta V = V_e \log \frac{m_i}{m_f},$$

where ΔV is the rocket's maximum change in velocity—produced by acceleration during lift-off, changes in direction during mid-course corrections, or braking at the

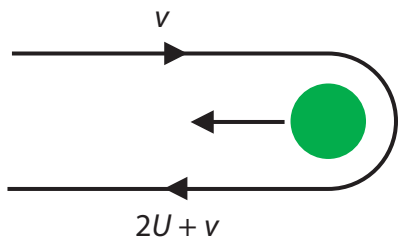


Fig. 1. In this simplified schematic, a spacecraft moves at speed v while a planet moves at speed U . As the spacecraft moves closer to the planet, it moves at speed $U+v$, relative to the planet's surface, because the planet is moving in the opposite direction. Because the planet is moving at speed U , the total velocity of the spacecraft will consist of the velocity of the moving planet plus the velocity of the spacecraft relative to the planet. Thus, the velocity of the spacecraft would be $U+(U+v)$, or $2U+v$.

rocket's destination (no other external forces act). The other variables in this equation are m_i , the rocket's initial weight, including the propellant; and m_f , the rocket's final weight, when the "fuel tank" is empty. Rocket performance is often given in terms of the specific impulse, I_{sp} , rather than V_e . However, the two terms are simply related as follows: $V_e = I_{sp} g$, where g is the acceleration of gravity at the Earth's surface.

For example, to escape Earth's gravitational pull (the minimum requirement for traveling from the Earth to space, such as going to the moon or another planet), a rocket's velocity must go from zero at Earth's surface to at least 7 miles per second—the "escape velocity." If V_e is too small, ΔV will be less than the escape velocity, and the rocket will merely go into orbit around the Earth or fall back.

This argument applies to a single rocket stage. If the payload is going to another world aboard a chemical rocket, several stages must be used to obtain a ΔV for the final stage that exceeds the escape velocity, largely because the maximum

value of V_e for a chemical rocket is typically only about 4 km/s (2.5 miles per second). A solid-core nuclear-thermal rocket will have a maximum V_e of about 8 km/s (5 miles per second).

The rocket equation also says that higher values of ΔV are possible when the fuel comprises a larger fraction of the rocket's total initial weight. For example, only 1.6 percent of the lift-off weight of an Apollo Saturn V rocket went all the way to the moon. Most of the lift-off weight was in fuel.

Chemical vs. Nuclear: It's About the Gas

Note that V_e is proportional to $(T/M)^{1/2}$, where M is the molecular weight of the propellant gas and T is the temperature (in Kelvin) of the gas after it is heated—by the nuclear reactions in the core of a nuclear-thermal-rocket's reactor or by the chemical reactions in a chemical rocket's engine—but before the gas enters the rocket nozzle. This relation shows that a nuclear-thermal rocket has the highest exhaust velocity when a propellant gas with the lowest-possible molecular weight is heated in the core of a reactor operating at the highest-possible temperature. Hydrogen has the lowest molecular weight of any gas (2 atomic mass units) and is, therefore, the ideal propellant gas when heated by either chemical or nuclear reactions.

With a chemical rocket, one is stuck with the propellant gases produced and heated by a chemical reaction. For example, the space-shuttle boosters (Fig. 2) burn a mixture of hydrogen and oxygen to produce a propellant gas of hot water vapor. The gaseous product of this chemical reaction has one of the lowest molecular weights (18 atomic mass units) and the highest temperatures—and therefore one of the highest exhaust velocities—of any of the chemical reactions used to propel rockets. The molecular weight of water vapor is considerably higher—nine times higher—than the molecular weight of hydrogen.

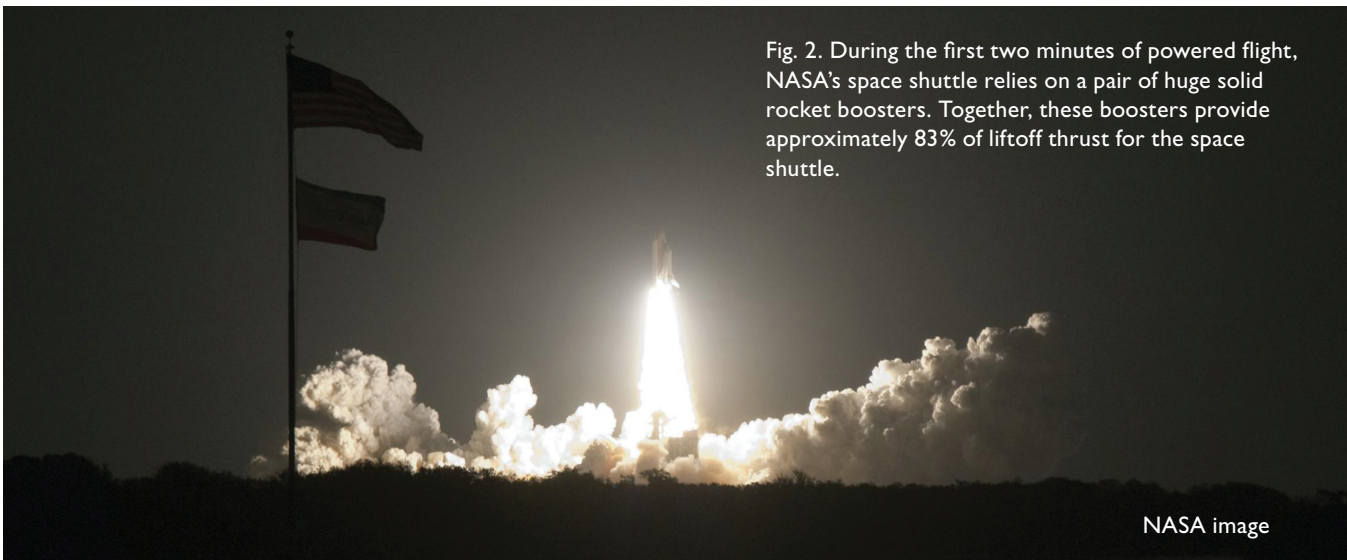


Fig. 2. During the first two minutes of powered flight, NASA's space shuttle relies on a pair of huge solid rocket boosters. Together, these boosters provide approximately 83% of liftoff thrust for the space shuttle.

NASA image

However, the propellant gas for a nuclear-thermal rocket can be freely chosen, because in this case, a chemical reaction does not produce or heat a gas. The propellant gas flows through the core from a storage tank; the nuclear reactions from the reactor core heat the propellant gas.

The temperature of the gas heated in a solid-core reactor is unlikely to exceed the temperature of the gas produced and heated by a chemical reaction. Burning a mixture of hydrogen and oxygen produces water vapor at a temperature of 5,555 K (9,540°F), twice the maximum temperature in a solid-core reactor (2,750 K or 4,490°F). But water vapor's molecular weight is eight times that of molecular hydrogen (2). The nuclear-thermal rocket's advantage is that one can choose the best-possible propellant gas—hydrogen—to obtain an exhaust velocity about twice that possible with a chemical rocket, according to the above relation for V_e .

The gas temperature that can be reached in a solid-core reactor is limited by chemical reactions at the absolute extreme by the melting points of the core's materials. As mentioned in "Nuclear Rockets: To Mars and Beyond" on page 16, Project Rover reactors had solid cores. But fission reactions can also take place in molten or gaseous cores (modes of operation that have been studied), especially for rocket propulsion, although these rockets were never tested at full scale. Nominal core temperatures for solid, molten, and gaseous cores are 2,750 K (4,490°F), 5,250 K (8,990°F), and 21,000 K (37,340°F), respectively. The much higher temperatures of molten and gaseous cores would produce higher exhaust velocities than are possible with solid cores.

In addition to its potential effects on a solid-core reactor's structural integrity, the core temperature can also affect the form of the propellant gas. When heated in a solid-core reactor, hydrogen molecules remain molecules. But at about

5,000 K (8,540°F), slightly below the predicted temperature of a molten core, hydrogen molecules thermally dissociate almost completely into hydrogen atoms. Moreover, atomic hydrogen thermally dissociates into plasma (a mixture of positively charged hydrogen ions and negatively charged electrons) at the temperature predicted for a gaseous core.

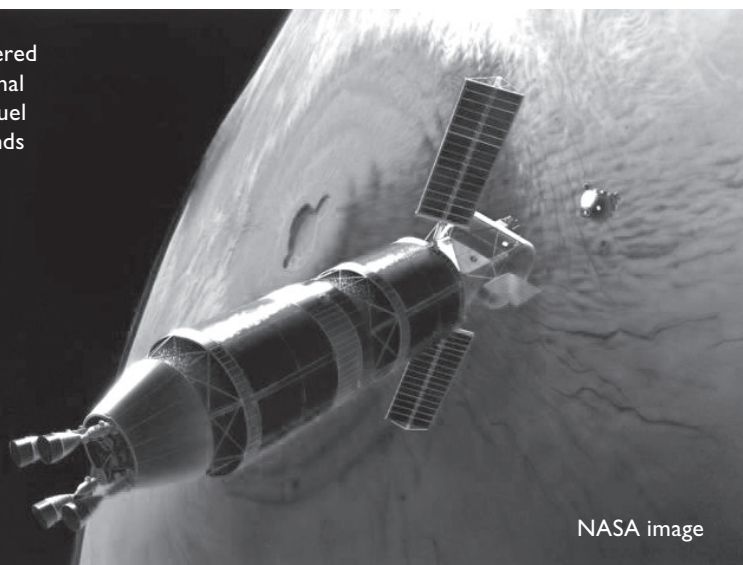
Other Nuclear-Rocket Schemes

Another promising scheme for nuclear space propulsion is to use heat produced by a fission reactor to produce electricity. Electricity is produced by using a thermoelectric element or a heat engine to drive an electrical generator, as is done in nuclear power plants. The electricity is then used to accelerate ions to high speeds. In this case, the ions are the propellant gas. This scheme, called nuclear-electric propulsion (Fig. 3), can reach much higher exhaust velocities than are possible with nuclear-thermal propulsion, but at much lower thrust.

Other nuclear-rocket schemes studied over the years include propelling a rocket with a succession of atom-bomb explosions or with nuclear fusion. Matter-antimatter reactions were considered, although a method to produce significant amounts of the second half of the fuel—the antimatter—needs development. These rockets could have much higher thrusts and specific impulses than those of nuclear-thermal rockets. To date, however, researchers have only built and tested nuclear-thermal-propulsion engines. ✦

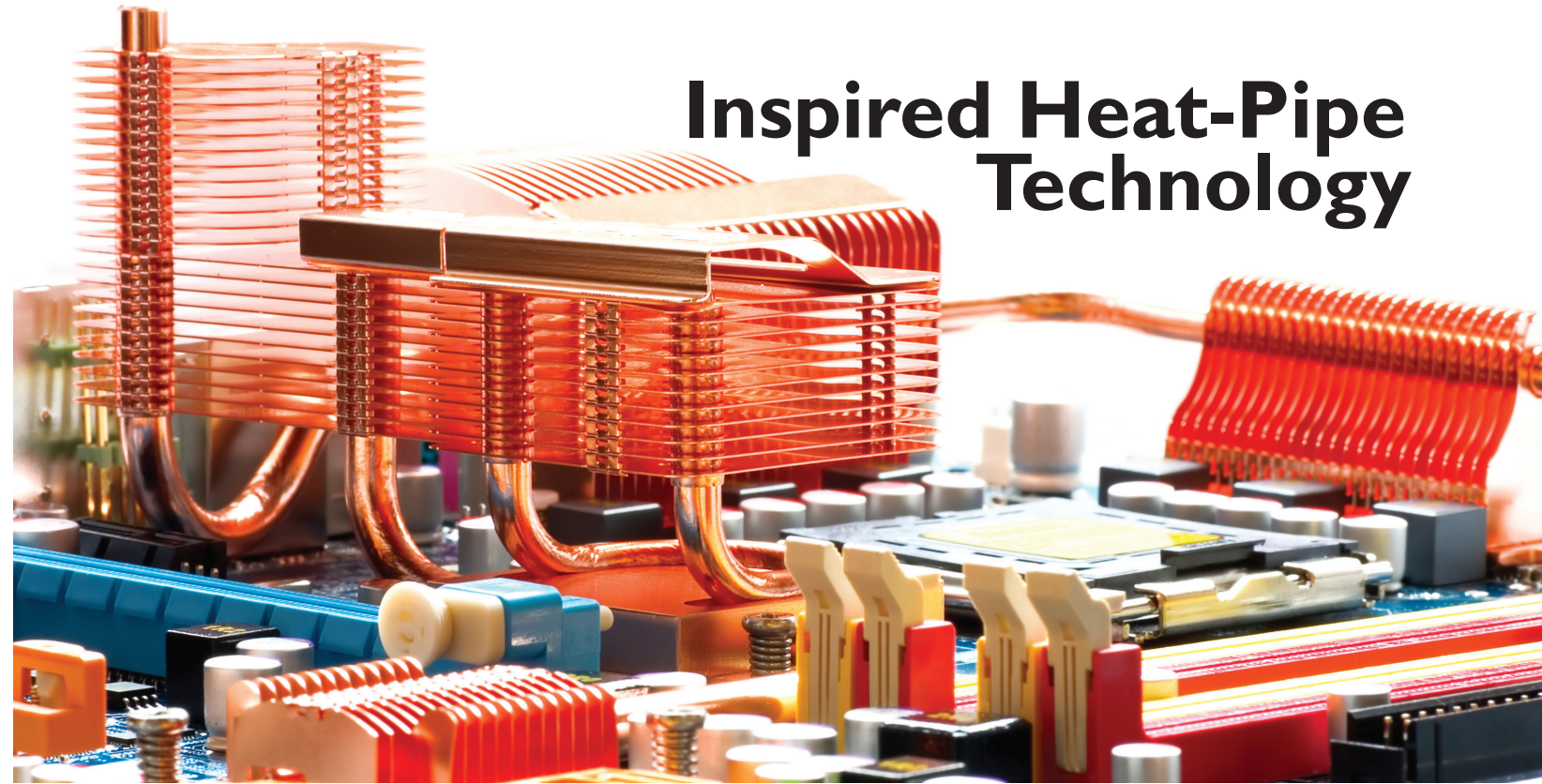
-Octavio Ramos Jr.

Fig. 3. This artist's conception shows a spacecraft powered by nuclear-electric propulsion. Similar to nuclear-thermal propulsion, this form of propulsion does not heat the fuel to accelerate it. Instead, it ionizes the fuel and then sends it through an electric field to propel the spacecraft at extremely high velocities.



NASA image

Inspired Heat-Pipe Technology



The heat pipes (copper pipes) in this computer help cool its microprocessor.

In 1963, Los Alamos physicist George Grover successfully demonstrated his invention of the heat pipe. Grover's inspiration for the heat pipe came from rudimentary heat-conducting pipes used by British bakers more than 170 years ago. The development of such pipes began in 1839, when American inventor Jacob Perkins patented the hermetic tube boiler. Angier March Perkins (Jacob's son) modified the tube boiler, and in 1936 he patented what he called the Perkins Tube, which saw widespread use in locomotive boilers and working ovens (including a mobile oven for the British Army). The Perkins Tube served as a "jumping off point" for Grover's development of modern heat pipes, which depending on their application can be as short as a hypodermic needle, or up to 24 feet long.

A heat pipe is a heat-transfer device that consists of a sealed metal tube with an inner lining of a wick-like capillary material and a small amount of fluid in a partial vacuum. One end of the pipe absorbs heat through fluid vaporization while releasing at the other end, through

vapor condensation. There are a variety of liquids and wicks used in heat pipes, but the principle is the same: A liquid evaporates into a gas that travels to the cooler end of the pipe, where it condenses back into a liquid and returns via the wick.

Grover originally developed the heat pipe to conduct heat from a nuclear reactor's core to a thermoelectric element or a heat engine. A thermoelectric element generates electricity from the temperature difference between a heat source (the reactor core) and a heat sink. A heat engine produces mechanical motion from this temperature difference.

From Water or Sodium to Lithium

Early Los Alamos heat pipes contained water or sodium. In the mid-1980s, Los Alamos developed a lithium heat pipe that transferred heat energy at a power density of 23 kilowatts per square centimeter—to understand the intensity of that amount of heat energy, consider that the heat emitted from the sun's surface is only 6 kilowatts per square centimeter. Lithium is placed inside a molybdenum pipe, which can operate at white-hot temperatures approaching 1,477 K (2,200°F). Once heated inside the pipe, the lithium vaporizes and carries heat down the pipe's length.



In this photo taken in the early 1960s, physicist George Grover tests a heat pipe.

Space Applications

Although heat pipes were not used to conduct heat from a nuclear reactor's core, they have been successfully used to manage temperatures inside spacecraft, where the heat generated by electronic equipment can build up and damage equipment. Because spacecraft travel in an excellent thermal insulator—the vacuum of space—the only way a spacecraft can dissipate heat is to radiate it to space. Heat pipes efficiently conduct the heat generated by electronics inside the spacecraft to heat radiators on the spacecraft's exterior.

In 1996, the space shuttle Endeavor carried into space three Los Alamos heat-pipe prototypes. The designs of these liquid-metal prototypes were for use in advanced spacecraft. The pipes operated at temperatures in excess of 900°F, and performed flawlessly in all tests. In 2000, Los Alamos worked with NASA's Marshall Space Flight Center in developing heat pipes to generate electricity and propulsion in spacecraft designed to journey to the solar system's outer limits.

Because heat pipes work efficiently in zero gravity environments, routine applications for them are to cool electronic elements aboard geostationary communication satellites.

Other Applications

Currently, miniature heat pipes cool central- and graphics-processing units in mainframe computers, as well as microprocessors found in laptop computers.

In addition, heat pipes increase the efficiency of solar water heaters. In such an application, heat pipes are sealed within a copper tube with distilled water inside, thus enabling efficient conduction of heat along the tube's length. Once placed in an evacuated glass tube, sunlight heats the copper tube. This "evacuated-tube" solar collector is up to 40% more efficient than the more-traditional "flat-plate" solar collectors used to heat water. Evacuated-tube collectors also do not need the antifreeze additives that flat-plate collectors require.

Heat pipes are also used to dissipate heat at the Trans-Alaska Pipeline. Without such pipes, heat picked up by the oil from its underground sources (120°F) and through friction and turbulence (as the oil moves through the pipeline) would go down the pipeline's supports anchored to the ground and would likely melt the permafrost. If the permafrost melted, the pipeline would sink. To prevent such a disaster, more than 124,000 heat pipes mounted on top of the pipeline's vertical supports keep the permafrost frozen and intact by conducting heat from the supports to the ambient air.

In Closing

Today's modern electronics generate heat that can cause damage. In space, such damage is irreparable. With its ability to transfer and dissipate heat, the heat pipe will continue to play a crucial role in cooling electronics such as computers, pipes along the Trans-Alaska Pipeline, and heat-sensitive electronics aboard satellites and spacecraft. ✦

-Octavio Ramos Jr.



Heat pipes on the Trans-Alaska Pipeline supports prevent hot oil moving through the pipeline from melting the permafrost. *Photo courtesy of the United States Geological Survey.*



Obama speaks at a NASA space conference.

NASA's 2012 Budget Proposal Released, Could Affect LANL Projects

President Barack Obama proposed restricting expenses at NASA, sending a 2012 budget outline to Congress in mid-February that requests a five-year freeze on spending levels—\$18.7 billion annually through fiscal 2016. Los Alamos National Laboratory hosts many NASA-sponsored space projects.

NASA said the budget supports all elements of NASA's 2010 Authorization Act, which was passed by a strong bipartisan majority of Congress and signed into law by President Obama. The President's fiscal year 2011 budget proposed increasing NASA's budget by \$6 billion throughout the next five years. The 2012 NASA budget includes \$4.3 billion for the Space Shuttle and International Space Station programs, \$5 billion for science, \$3.9 billion for future exploration systems and \$569 million for aeronautics research.

"This budget requires us to live within our means so we can invest in our future," NASA Administrator Charles Bolden told news conference attendees.

The new budget announcement comes just as NASA's space shuttle fleet is scheduled to be retired early this spring.

Last year, President Barack Obama relayed his plans for space exploration during a speech at Florida's John F. Kennedy Space Center. President Obama committed NASA to a series of development milestones he said would lead to new spacecraft for astronauts to ride to the International Space Station, a modified Orion capsule developed as an emergency return spacecraft, and a powerful new rocket. There will be no funding for NASA's planned missions to the moon called the Constellation Program.

Following are excerpts from the President's 2010 speech.

So let me start by being extremely clear: I am 100 percent committed to the mission of NASA and its future....We will ramp up robotic exploration of the solar system, including a probe of the Sun's atmosphere; new scouting missions to Mars and other destinations; and an advanced telescope to follow Hubble, allowing us to peer deeper into the universe than ever before....We will increase Earth-based observation to improve our understanding of our climate and our world....And we will extend the life of the International Space Station likely by more than five years.

Next, we will invest more than \$3 billion to conduct research on an advanced "heavy lift rocket"—a vehicle to efficiently send into orbit the crew capsules, propulsion systems, and large quantities of supplies needed to reach deep space. In developing this new vehicle, we will not only look at revising or modifying older models; we want to look at new designs, new materials, new technologies that will transform not just where we can go but what we can do when we get there. And we will finalize a rocket design no later than 2015 and then begin to build it.

At the same time, after decades of neglect, we will increase investment—right away—in other groundbreaking technologies that will allow astronauts to reach space sooner and more often, to travel farther and faster for less cost, and to live and work in space for longer periods of time more safely. That means tackling major scientific and technological challenges. How do we shield astronauts from radiation on longer missions? How do we harness resources on distant worlds? How do we supply spacecraft with energy needed for these far-reaching journeys? These are questions that we can answer and will answer....Early in the next decade, a set of crewed flights will test and prove the systems required for exploration beyond low Earth orbit. And by 2025, we expect new spacecraft designed for long journeys to allow us to begin the first-ever crewed missions beyond the moon into deep space. So we'll start—we'll start by sending astronauts to an asteroid for the first time in history. By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow. And I expect to be around to see it.

Critical to deep space exploration will be the development of breakthrough propulsion systems and other advanced technologies....We will partner with industry. We will invest in cutting-edge research and technology. We will set far-reaching milestones and provide the resources to reach those milestones....For pennies on the dollar, the space program has improved our lives, advanced our society, strengthened our economy, and inspired generations of Americans. And I have no doubt that NASA can continue to fulfill this role. ✦

KEVINSAEGER



An interview with LANL's International, Space, and Response (ISR) new Division Leader

Kevin Saeger was appointed Los Alamos National Laboratory International, Space, and Response Division Leader in 2010. Formerly a Decision Applications Division group leader, Saeger has worked at the Laboratory for ten years. Saeger has a bachelor's degree in aerospace engineering, and master's and doctoral degrees in aeronautics and astronautics from the Massachusetts Institute of Technology.

NSS: Your experience has been diverse—aerospace engineering, software design, working at the Pentagon, and leading a LANL risk analysis group to halt terrorism. What attracted you to ISR?

ISR is unparalleled in its ability to successfully integrate science, engineering, and technology to deliver custom sensors to the field. ISR has an end-to-end approach that is rare today. In a single organization, we design and deliver sensors; operate them and analyze their data streams; and use these data to refine our understanding and develop new theories of the underlying phenomenology. This cycle of design, deploy, operate, analyze, and innovate harkens back to the roots of the Laboratory.

NSS: What are your overall goals for ISR? Any changes in direction for the division?

I have been given the great responsibility of leading one of the premier science and engineering divisions of the laboratory. My overall goal is to ensure that we maintain our high standards for excellence and foster the next generation of staff that will be the core of the division in ISR in 2020 and beyond. While there are no planned changes in course, there will be a renewed emphasis on integrating the vast resources of the division and partnering effectively with the other technical divisions on solving the Nation's problems.

NSS: What projects are you most excited about this year?

Choosing a top project is like choosing your favorite family member—impossible to do and fraught with danger. We are making great advances on multiple fronts: advances in machine learning and low-light imaging, a mission to Mars, new architectural standards for future space missions, continued advances in our nuclear detonation detection mission, and development of a high-energy free-electron laser system for the United States Navy. All these projects are exciting and important. If they weren't, we wouldn't be pursuing them.

NSS: ISR balances space exploration and nonproliferation/space-situational awareness. How do these fields contribute to mutual success while protecting our nation?

These areas are all mutually supporting. In order to reliably execute our nuclear detonation detection mission, we must have an exquisite understanding of all the naturally

occurring phenomena that provide the background for our sensors. From lightning strikes in the radiation field to gamma-ray bursts and coronal mass ejections from the Sun, scientists and engineers in ISR are making revolutionary advances in describing and understanding these natural phenomena. These measurement and analysis techniques are applicable to space exploration, treaty verification, and space weather.

NSS: Are there prominent changes at NASA or at the federal level (related to ISR) worth mentioning?

The day-to-day vagaries of federal budgets and continuing resolutions can be distracting. However, in the long run, we believe that there is an enduring mission that ISR is uniquely qualified to fulfill.

NSS: How is the science performed in ISR imperative to LANL's overall mission?

The science base is essential for developing and sustaining some of the best capabilities in the world to solve some of the most difficult national security problems of today. This includes attracting and retaining top scientists and engineers. Additionally, many of signals that we need to measure for our national security programs have natural backgrounds that we must understand, such as lightning, space weather, natural CO₂ variations, and terahertz emissions from natural sources. Understanding these backgrounds provides a portal to outstanding science across many disciplines. ✦





President John F. Kennedy discusses Project Rover at the Laboratory in 1962 with Director Norris Bradbury, center, and Senator Clinton Anderson, right.

Then . . .

“Secondly, an additional 23 million dollars, together with 7 million dollars already available, will accelerate development of the Rover nuclear rocket. This gives promise of some day providing a means for even more exciting and ambitious exploration of space, perhaps beyond the moon, perhaps to the very end of the solar system itself.”

President John F. Kennedy
May 25, 1961

. . . is now.

“And by 2025, we expect new spacecraft designed for long journeys to allow us to begin the first-ever crewed missions beyond the Moon into deep space. . . . By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow. And I expect to be around to see it.”

President Barack Obama
April 15, 2010



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