From the Project Manager

The first phase of orbiter integration testing was completed in November 1983. This test series, designed to establish electrical interface compatibility, was conducted using flight electronics mounted to mock-up structure. On December 1, the electronics and cabling were removed from the mockup structure and returned to the laboratories for necessary rework including replacement of component parts and modifications identified during testing. On January 16, 1984, flight structure was delivered to the Spacecraft Assembly Facility (SAF) at JPL, and modified cabling and electronics were re-delivered. Delivery of the electronic sub-systems will be phased between January and April 1984. Four orbiter instruments will also be retrofitted, and the orbiter's command and data system (CDS) is undergoing redesign of the memory "keep alive" circuits.

The flight probe was delivered to JPL from Hughes Aircraft Company in February for integration with the orbiter and ground systems. This probe contains engineering models of four of its six instruments, as well as the data and command processor (DCP). These will be retrofitted in June before environmental testing begins.

Prevention of single event upsets (SEUs) in the spacecraft computers due to heavy ions and cosmic rays continues to be the major concern of the Project. Two solutions are being pursued in parallel until sufficient confidence is attained in one to allow the other to be dropped. One solution involves replacing semiconductors sensitive to SEUs with functionally equivalent radiation-hardened parts. The second solution involves replacing the microprocessor used in the Attitude and Articulation Control Subsystem (AACS), with a new processor built to be insensitive to SEUs.

The design of the replacement parts at Sandia National Laboratories is complete (about one month ahead of schedule), mask preparation is in process, and wafer production has begun. Verification of this solution will be possible when the new parts are available for substitution into the hardware and hardware performance can be verified, probably in June 1984.

The second solution uses an adaptation of the Radiation Hardened Emulating Computer (RHEC), developed by the Air Force, as the replacement processor. The design of the processor is essentially complete, and design analysis and layout of the processor board is in progress. System timing and interface compatibility will be verified by testing an operating prototype of the new processor and its required circuitry in the AACS.

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J.R. Casani

RTGs

Nuclear-powered spacecraft have orbited the Earth and probed deep space for over twenty years. Nuclear power supplies a constant source of electricity over a long lifetime with high reliability, insensitivity to the chilling cold of the outer reaches, and virtual invulnerability to high radiation fields such as Earth's Van Allen belts and Jupiter's sizzling magnetosphere.

The Galileo mission will be the 24th U.S. space mission since 1961 to be powered partially or totally by nuclear power sources. These missions, for both the U.S. military and NASA, have included Earth-orbiting weather, communications, and navigational
sateilites, as well as the Apollo, Pioneer, Viking, and Voyager space programs. The Soviet Union uses nuclear-powered spacecraft as well. The Galileo orbiter will carry two 285-watt (electrical)* general purpose heat source (GPHS) radioisotope thermoelectric generators (RTGs) while approximately 112 one-watt (thermal) radioisotope heater units (RHUs) will warm scientific instruments onboard both the orbiter and the probe.

An RTG basically consists of two parts: a source of heat and a system for converting the heat to electricity. The source heat contains a radioisotope, such as plutonium-238, that becomes physically hot from its own radioactive decay. This heat is converted to electricity by a thermoelectric converter which uses the Seebeck effect, a basic principle of thermoelectricity discovered in 1822. An electromotive force, or voltage, is produced from the diffusion of electrons across the junction of two different materials (e.g., metals or semiconductors) that have been joined together to form a circuit when the junctions are at different temperatures. Junctions of different metal wires are used to measure temperatures and are called thermocouples.

Doping semiconductor materials such as silicon-germanium with small amounts of impurities such as boron or phosphorus produces an excess or deficiency of electrons, and therefore makes the semiconductor a more efficient power converter than metals. The joining of these thermoelectric materials with hot radioisotopes produces a reliable source of power with no moving parts. The temperature difference between the hot and cold junctions in these thermocouples is about 700 Kelvin.

Nuclear safety is a major factor in the design of these power sources. Plutonium-238 decays primarily by emitting alpha particles, which are completely absorbed in the heat source to produce heat; thus, no special radiation shielding is necessary to absorb these particles. (Moderate neutron and gamma-ray fields exist external to the RTG, requiring isolation of the RTGs from the rest of the spacecraft to prevent interference with the scientific measurements. Therefore, each RTG will be mounted at the end of a 5-meter boom.) The principal safety objective connected with the use of plutonium-238 is to keep it contained to prevent contamination of the surrounding environment. The half-life of 238Pu is about 87.8 years, and nuclear-powered Earth-orbiting satellites have been placed in orbits where they will not reenter the Earth's atmosphere until the radioactive material has decayed to harmless levels. After the Soviet Cosmos 954 satellite (which carried a nuclear reactor) fell to Earth over Canada in 1978, the U.N. established a working group on the use of nuclear power sources in outer space which concluded that nuclear power sources "can be used safely in outer space provided that all necessary safety requirements are met."

Each 122-pound GPHS RTG contains approximately 24 pounds of plutonium dioxide fuel, pressed into 72 solid ceramic-like cylindrical 1 inch by 1 inch pellets.

Each heat source consists of 18 separate modules, each of which multiply encases four Pu-238 pellets. The modules are designed to survive under a range of postulated accidents: launch vehicle explosion or fire, reentry into the atmosphere followed by land or water impact, and post-impact situations. Graphitic outer coverings provide protection against the structural, thermal, and ablative environments of a potential reentry; additional graphitic components provide impact protection, and iridium cladding of the actual fuel cells provides post-impact containment. The GPHS RTGs are designed to release the 18 modules individually in the event of an accidental reentry.

The RTGs for the Galileo project are identical to those to be used for the International Solar Polar Mission (ISPM). The current development program includes RTGs for both Galileo and ISPM, as well as a spare.

The Office of Special Nuclear Projects of the U.S. Department of Energy (DOE) is responsible for the government RTG program, while the General Electric Company at Valley Forge, Pennsylvania, is the system contractor responsible for the design and development of the electrical converter and heat source. The fuel is fabricated and encapsulated in the iridium cladding at DOE's Savannah River Plant, South Carolina, and shipped to DOE's Mound Plant in Miamisburg, Ohio, where the pellets are loaded into the graphite modules. Here, the heat source modules are also installed into the generators and qualification and flight acceptance tests are conducted. Oak Ridge National Laboratory, Tennessee, provides graphite insulation and iridium for the post-impact containment structure. Safety testing is conducted at Los Alamos National Laboratory, New Mexico, with independent reliability and quality assurance support provided by Sandia National Laboratories, Albuquerque.

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*The thermal power at the beginning of the mission will be 4,410 W per generator.

New Mexico. Independent safety and technical support is supplied by the Applied Physics Laboratory, NUS Corporation, and Fairchild Industries.

The thermoelectric converter for the qualification unit has been fueled at Mound, and is currently undergoing testing. The flight thermoelectric converters for Galileo have been fabricated but will not be fueled until later. The RTGs will be stored until shipment to Kennedy Space Center, Florida, where they will be installed on the spacecraft and tested. They will then be removed and stored until final installation on the spacecraft in the Shuttle payload bay on the launch pad several days before launch in May 1986.

Thanks to G. L. Bennett, DOE, and R. W. Campbell, JPL, for source material and review comments.

Meet the Team

Don Kindt

Wolfgang Hagenest

Wolfgang Hagenest is the Project Manager for Galileo at Deutsche Forschungs- und Versuchsanstalt für Luft und Raumfahrt e.V. (DFVLR) an agency for the Federal Ministry for Research and Technology of the Federal Republic of Germany. He has been associated with Galileo since its inception, primarily managing the development of the retropropulsion module (RPM), which was built by Messerschmitt-Bölkow-Blohm (MBB) in Ottobrunn, Federal Republic of Germany.

After graduating from the Technical University in Aachen, Wolfgang spent four years in Egypt working on aircraft aerodynamics. Returning to Köln, he worked on a number of national and international spacecraft projects at DFVLR’s predecessor. In 1969 he became a spacecraft system engineer for launch vehicle interfaces and launch operations for Helios, a two-spacecraft mission to study the Sun. In conjunction with Helios, he and his family spent a year in 1969-70 in the U.S. at NASA’s Goddard Space Flight Center, Lewis Research Center, and Kennedy Space Center. Because of his strong contacts from Helios and Galileo, he is often consulted at DFVLR on issues of international relations.

"The triangular relationship among DFVLR, JPL, and MBB has presented challenges in considering the interests of each," he notes.

A chemist’s son, Wolfgang was born in Köln and now lives with his family in Meckenheim, a suburb of Bonn. His daughter is studying in Munich to be a physical therapist, and his son plans to study chemistry at the university after graduating this year from the gymnasium (equivalent to high school and two years of college in the U.S.). Wolfgang’s hobbies include travel, photography, railroad models, and classical music, especially German composers. In recent years he and his wife Uta have taken up hiking, and enjoy the hut systems in Switzerland. A big thrill last year was hiking on a glacier. In 1986, they plan to celebrate their 25th wedding anniversary by hiking near Zermatt, where they spent their honeymoon.

Meet the Team

Don Kindt remembers the days when an entire project team could meet in one room. Today’s complex missions require thousands of people to design, build, and fly a mission. Don joined the Galileo project in 1980 as the Probe Interface Manager to coordinate the various organizations involved in the probe mission. The design and testing of the interface between the probe and orbiter is a primary function of his effort. He has been associated with Galileo since the study phases, and supported Ames Research Center (ARC) during the source evaluation period, which ultimately led to the selection of a contractor to build the probe.

Natives of Milwaukee, Don and his wife Joan traveled West after he received his MSEE degree from the University of Wisconsin. His first job at JPL involved testing the radio inertial guidance for the Jupiter missile, followed by work on the Sergeant missile. He later worked on power systems for the Ranger spacecraft and was responsible for the Ranger television system that took the first closeup pictures of the moon. As supervisor of the launch vehicle (and payload) integration group, he was responsible for the interface design between the Viking orbiters and landers. This experience led to his current role.

“Coordinating the interface between several organizations is like being a combination of interpreter, referee, and diplomat,” Don says. “Sometimes you have to represent the non-JPL organizations to the point that the JPL people involved want to check your JPL badge.”

Don likes to travel, but most of it lately has been job-related, with many trips to NASA/Ames Research Center near San Jose, CA, where the probe was developed; to Hughes Aircraft Company, El Segundo, CA, where it was built; and to New Mexico, where it was tested in a realistic drop from a high-altitude balloon.

The Kindts have raised three children in their Glendale home, and now Don has more time to play with his shiny red ’67 Mustang.

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Probe Delivery

"The Galileo mission could be a Rosetta stone for unlocking the origin of the universe," says Nick Vojvodich, deputy manager for the Galileo probe project at NASA/Ames Research Center. "In a five-hour journey, we will learn more (about Jupiter) than have all the spacecraft that have preceded us."

The 742-pound probe will hitch a ride to Jupiter on the Galileo orbiter, which will target the probe and release it 150 days before the atmospheric entry date.

In August 1988, the acorn-shaped probe will plunge into Jupiter's clouds at nearly 100,000 miles an hour — the fastest atmospheric entry speed of any man-made object at any heavenly body. Flying overhead, the orbiter may be able to photograph the probe's meteoric trail through the clouds. At Mach 1, a parachute will deploy, and within seconds the probe will slow to about 2000 miles an hour, losing about half its mass as the heat shield burns away from the friction of the entry. The probe will not be able to communicate through the sheet of ionized gases surrounding it at entry, so the probe will store its deceleration information until the worst of the entry buffeting is over.

Spinning slowly on its parachute lines, the probe will begin to sample and measure the alien atmosphere — shining light beams into it, sucking small samples into its chambers, and recording the temperature and pressure. Its tiny transmitter will relay data to the mother ship passing overhead, where the data will be recorded for later transmission to Earth.

Project officials described the probe mission and presented the flight hardware for inspection on February 9 at Hughes Aircraft Company, El Segundo, CA as the probe was readied for delivery to the Jet Propulsion Laboratory for integration with the orbiter.

Joel Sperans, Galileo Probe Project Manager at Ames, noted that the probe's descent module is a miniaturized atmospheric sciences laboratory. Special challenges in the development of the probe included the deployment of a parachute behind a blunt body at transonic speeds, the transmission of the signal through a difficult atmosphere, and the intense radiation at Jupiter.

"We have electrically connected the probe and orbiter and are checking out the equipment that will process the probe's data when it is received at Earth," reports Don Kindt, the probe integration manager at JPL.

The orbiter and probe will undergo environmental testing this summer at JPL, and will be shipped to Kennedy Space Center in January 1986 in preparation for their May 1986 launch date.