THE MARS-96 PGS GERMANIUM GAMMA-RAY SPECTROMETER;*

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MARS-96 is a Russian planetary mission scheduled for a Proton launch from the Baikonur cosmodrome in November 1996. The MARS-96 spacecraft is a three-axis-stable spacecraft similar to the two used for the Phobos mission in 1988–1989 but with modifications based on the experience during the Phobos mission. MARS-96 will arrive at Mars in late 1997 and have a nominal lifetime of 2.5 years in a ≈43-hour elliptical polar orbit around Mars. Its "pericenter" altitude above Mars will be about 300 km. The primary objective of the MARS-96 mission is planetary studies of Mars. Some scientific instruments will collect data during cruise to Mars and at "apocenter" for astrophysical and solar studies, secondary objectives of the MARS-96 mission.

There are three gamma-ray spectrometers (GRSs) scheduled to fly on the MARS-96 spacecraft for orbital measurements, another GRS is planned for a penetrator, and several small GRSs are being considered for gamma-ray burst detection. The PHOTON GRS, on the orbiter, consists of two detection units, both using cesium iodide (CsI) scintillators with about 7.5% energy resolution at 662 keV. One crystal is inside a bismuth germanate collimator mounted on a steerable platform to perform high-spatial-resolution measurements. The other is a large uncollimated CsI crystal on a solar panel to get better counting statistics of Martian gamma rays.

The third GRS, the high precision gamma-ray spectrometer (PGS), has two high-purity n-type germanium (Ge) detectors, each similar to the one used on the Mars Observer mission [1], and is mounted on a deployment mechanism behind a solar panel. Although the PGS has less efficiency for detecting γ rays than the PHOTON GRS, its very good energy resolution (~3 keV at 1.3 MeV) enables it to differentiate many γ-ray lines. The PGS experiment will measure nuclear γ-ray emissions from the Martian surface, cosmic gamma-ray bursts, and the high-energy component of solar flares in the broad energy range from ~50 keV to 8 MeV in 4096 energy channels.

The primary objective of these gamma-ray spectrometers is to map the Martian surface's elemental composition using nuclear γ-ray lines [2,3]. The major γ rays used to map elemental abundances are those made by the decay of naturally-occurring long-lived radionuclides and by cosmic-ray-produced γ rays made by inelastic-scattering, e.g., $(n,n\gamma)$, and neutron-capture, (n,γ), reactions. Gamma-ray lines observed at orbit come from depths down to tens of centimeters in the surface [2]. Fluxes of γ-ray lines escaping from Mars depend on the surface's water content and the atmospheric thickness [4]. Gamma-ray spectrometers can be used at Mars for many studies [1] including studies of H_2O and CO_2, the major Martian volatiles [5,6].

Several gamma-ray spectrometers using scintillators have been in orbit at Mars on the Russian missions Mars-5 [7] and Phobos-2 [8,9]. These missions mapped only small regions of the Martian surface for short periods of time and yielded abundances for only a few elements and with large uncertainties [10]. There was a high-resolution solid-state Ge GRS [1] on the Mars Observer mission that failed three days before insertion into orbit at Mars in August 1993.

The PGS is a joint collaboration of the Institute of Space Research (IKI) in Moscow and the Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico. IKI will provide the passive cooling for the detectors, the low- and high-voltage supplies, the pulse-height analyzers, and the data processing units. The detectors and cooling system will be mounted behind a solar panel on a Russian designed and built deployment mechanism. LANL will provide the two high-purity Ge detectors and the analog electronics. See [11,12] for initial reports on the PGS.

Each Ge detector has a single crystal of Ge in the shape of a cylinder 5.65 cm long and 5.6 cm in diameter and an active detector volume of 130 cm^3. Electrodes are implanted or diffused into each n-type Ge crystal such that the crystal becomes a diode. The diode is operated in the reverse bias mode with a potential of ≈2500 V and a leakage current ≪1 nA. When a γ-ray photon or charged particle interacts in the crystal, many hole-electron pairs are made that are rapidly collected at the electrodes. A charge-sensitive preamplifier collects this charge and produces a pulse with a height (voltage) proportional to the energy deposited in the Ge crystal. After the pulse is amplified and shaped, it is sent to a pulse-height analyzer that digitizes the pulse and stores it in a 4096-channel memory. Each crystal is contained in a titanium can with Helicoflex metal seals.

Heaters on each detector will be used to anneal radiation damage in the germanium crystals. Simulations at accelerators [13] and the experience with the Mars Observer GRS show that the Ge detectors will suffer enough radiation damage from the exposure to galactic cosmic radiation in one year, the time from launch to Martian orbit, that the resolution will have degraded from the nominal 3 keV to ~6 keV from the presence of radiation-created traps in the crystal. Annealing is planned after spectra have been gathered for several months in Martian orbit.

The Ge crystals need to be operated below ≈130 K. The detectors are cooled via heat pipes attached to a two-stage passive radiator. The radiators have a thermally-tuned coating that cools the detectors by radiating to space and are designed to keep the Ge detectors below 100 K during the interplanetary flight. The PGS is on the back of a solar panel about 4 meters from the spacecraft, which insures that the radiators do not see the Sun. After launch, the radiators are extended 1 m from the solar panel, which also tilts them so that they do not see any spacecraft element. Each Ge detector will be coupled to the inner radiator with a stainless-steel/nitrogen diode heat pipe that allows heat from the detector to easily get to the radiator but strongly hinders heat transfer from the radiator to the detector. These heat pipes will keep the temperatures of the detectors from rising above ≈120 K in the worst case of Martian albedo falling on the radiators.

Instrument electronics include first-stage analog electronics, mounted on each crystal can; power converters, providing low voltages and the high voltages biasing the sensors; and digital processing and control electronics. Additional analog electronics are contained within a single housing that is mounted on the deploying platform directly beneath the thermal radiators and relatively near the sensors. The power converters are mounted on the solar panel, near the base of the deploying platform. Digital electronics are located on the body of the spacecraft. The electronics include two 4096-channel pulse height analyzers. Two parallel channels of electronics are provided and can be cross-switched by telecommands.

Shortly after launch, the PGS detectors and cooler will be deployed from the solar panel. After the detectors have cooled to well below ≈130 K, the detector voltages will be slowly increased and the detectors' performances monitored. The operational voltages will be as low as possible while still high enough to ensure good energy resolution. Spectra will be collected continuously with accumulation times from 8 to 134 minutes to look for background γ rays that grow into the spectra as a result of production of radionuclides by cosmic rays reacting in (e.g., 1.63-day ^{69}Ge) and around (e.g., 2.6-year ^{22}Na) the Ge crystals. Constant backgrounds, such as Th, U, and ^{40}K, and prompt reactions, such as ^{48}Ti(n,nγ)^{48}Ti, also need to be determined with good counting statistics.

Data are telemetered in several different modes. In the pericenter mode, when the spacecraft is within ~1000 km of the surface, spectra of γ rays from the Martian surface are accumulated at intervals selectable between 2 and 34 minutes. In the background mode, which is to be used during cruise and most (≈42 of the 43 hours) of the orbital period, spectra are recorded for each detector at intervals from 8 to 134 minutes. A "burst" mode is enabled by command but must also be triggered by a rapidly-rising counting rate. Burst-mode data, including pulse height and time, are stored for each photon event during intervals from 32 to 64 seconds after a burst trigger.

In November 1995 integration of the flight detectors with flight electronics and testing of the complete system cooled by the passive radiator were successfully completed. The Martian orbit cycle of 43 hours was successfully reproduced in the thermal-vacuum chamber of IKI. The energy resolution degraded to ≈3 keV. Extensive calibrations with radioactive sources are in progress.

The planetary results obtained by PGS will be less than that expected by the Mars Observer GRS because of the elliptical orbit and the lack of a charged-particle anti-coincidence "shield" around the Ge detectors. However, abundances of a number of elements, such as O, Mg, Si, S, Cl, K, Ca, Fe, U, and Th, should be determinable for several large regions of Mars that can answer some basic questions about this very interesting planet.

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