AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

Conf-9404169--1

LA-UR-

94-1862

Title: A High Precision Gamma-Ray Spectrometer
for the MARS-94 Mission.

Author(s): I.G. Mitrofanov, D.S. Anfimov,
A.M. Chernenko, V.Sh. Dolidze,
A.S. Pozanenko, D.A. Ushakov,
G.F. Auchampaugh, M. Cafferty,
D.M. Drake, E.E. Fenimore,
R.W. Klebesadel, J.L. Longmire,
C. E. Moss, R. C. Reedy, and J. E. Valencia.

Submitted to: Proceedings of the International
Conference on Low-Cost Planetary Missions;
Laurel, Maryland; 12-15 April 1994.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

Los Alamos
NATIONAL LABORATORY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

A HIGH PRECISION GAMMA-RAY SPECTROMETER FOR THE MARS-94 MISSION

I. G. Mitrofanov, D. S. Anfimov, A. M. Chernenko,
V. Sh. Dolidze, A. S. Pozanenko, and D. A. Ushakov,
Institute for Space Research, Moscow 117810, Russia;

G. F. Auchampaugh, M. Cafferty, D. M. Drake,
E. E. Fenimore, R. W. Klebesadel, J. L. Longmire,
C. E. Moss, R. C. Reedy, and J. E. Valencia
Los Alamos National Laboratory, Los Alamos, NM 87545, USA.

The high precision gamma-ray spectrometer (PGS) is scheduled to be launched on the Mars-94 mission in October, 1994, and to go into an elliptical polar orbit around Mars. The PGS consists of two high-purity germanium (Ge) detectors, associated electronics, and a passive cooler and will be mounted on one of the solar panels. The PGS will measure nuclear gamma-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 using 4096 energy channels.

INTRODUCTION

The Mars-94 Mission

Mars-94 is a Russian planetary mission scheduled for a Proton launch from the Baikonur cosmodrome in October, 1994. The Mars-94 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-94 will arrive at Mars in September, 1995, and have a nominal lifetime of 2.5 years in a ≈ 15 -hour elliptical polar orbit around Mars. Its “pericenter” altitude above Mars will be ~ 300 km.

The primary objective of the Mars-94 mission is planetary studies of Mars. Some instruments will be on landers or penetrators for detailed studies of several specific regions of the martian surface. Some experiments will be on the two platforms that can be used to point narrow field-of-view instruments. Others will be mounted to the spacecraft or its two solar panels. Some scientific instruments will collect data during the cruise phase to Mars for astrophysical and solar studies, secondary objectives of the Mars-94 mission. Most will study the martian surface, atmosphere, and environment. Scientists from 20 countries are participating in the Mars-94 program.

There are three gamma-ray spectrometers (GRS) scheduled to fly on Mars-94 spacecraft for orbital measurements, and another gamma-ray spectrometer is planned for a penetrator. The PHOTON GRS, on the orbiter, consists of two detection units, both using

CsI scintillators. One crystal will be inside a bismuth germanate collimator and will be 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 expected energy resolution of these spectrometers is about 7.5% at 661 keV. The high precision gamma-ray spectrometer (PGS) with two high-purity germanium (Ge) detectors will be mounted on a solar panel. Although the PGS has less efficiency for detecting gamma rays than the PHOTON GRS, its very-high energy-resolution (~ 3 keV at 1.3 MeV) enables it to differentiate many gamma-ray lines. The PGS experiment will measure nuclear gamma-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.

Objectives of the PGS

Many planetary and space missions have included gamma-ray spectrometers. A few gamma-ray spectrometers have been used on planetary missions to determine surface elemental compositions using nuclear gamma-ray lines.¹ The major gamma rays used to map elemental abundances are those made by the decay of naturally-occurring long-lived radionuclides and by prompt cosmic-ray-produced gamma rays made by inelastic-scattering, $(n,n\gamma)$, and neutron-capture, (n,γ) , reactions.¹ Gamma-ray spectrometers using NaI(Tl) scintillators on the Apollo 15 and 16 missions mapped the distribution of thorium, iron, titanium, potassium, and magnesium over about 22% of the Moon's surface.² Several gamma-ray spectrometers using scintillators have been in orbit at Mars on the Russian missions Mars-5³ and Phobos-2.^{4,5} These missions only mapped small regions of the martian surface for short periods of time and yielded abundances for only a few elements.⁶ A high-resolution solid-state germanium gamma-ray detector⁷ was on the Mars Observer mission that failed three days before insertion into orbit at Mars in August 1993. Gamma-ray lines observed at orbit come from depths down to tens of centimeters in the surface,¹ and some gamma rays can escape without interactions through an atmosphere that is as thin as the martian one.⁸ Fluxes of gamma-ray lines escaping from Mars depend on the water content of the martian surface and the thickness of the martian atmosphere.⁹ Gamma-ray spectrometers can be used at Mars for many studies,⁷ including studies of H₂O and CO₂, the major martian volatiles.¹⁰

Numerous other space missions have carried gamma-ray spectrometers. These have measured the cosmic gamma-ray background, emission from continuous sources, and brief transient events. Gamma rays are the highest energy form of electromagnetic radiation and are used for many astrophysical studies. Numerous applications of astrophysical studies in the X-ray and gamma-ray regimes were described at the 1989 *Conference on High-Energy Astrophysics in the 21st Century* and were reported in the proceedings of that conference.¹¹ A modest, uncollimated GRS, such as the PGS, is useful in monitoring gamma-ray bursts, a phenomenon still poorly understood in spite of two decades of study.¹² Spectral features have been reported at energies below 100 keV¹³⁻¹⁵ and (with lower confidence) at several hundreds of keV.^{13,16} If the higher-energy emission features can be confirmed, resolution of the details of the line(s) can provide insight into the physical mechanisms involved.

The Sun is a well-known source of continuous, or slowly varying, high-energy X-rays and gamma rays. It is also a source of brief transient events associated with solar flares. A high-resolution gamma-ray spectrometer such as the PGS will provide data toward the further study of the spectral characteristics, particularly the line emissions, of solar events.¹⁷

THE HIGH PRECISION GAMMA-RAY SPECTROMETER

The PGS Sensor System

The PGS is a joint collaboration of the Institute of Space Research (IKI) in Moscow, Russia, and the Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico, USA. IKI will provide the passive cooling for the detectors, the 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.

The most important feature of the PGS is the pair of high-purity Ge n-type coaxial detectors. Each of the two Ge detectors of the PGS is similar to the one that was on the Mars Observer.⁷ 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 cm³. 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 volts and a leakage current of much less than 1 nA. When a gamma-ray photon or charged particle interacts in the crystal, many hole-electron pairs are made that rapidly are 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 counts it in a 4096-channel memory.

Each Ge crystal will be housed in its own aluminum can. The cans are sealed and there is some zeolite inside the can to remove impurity gases. After launch, when there is no danger of exterior gases getting onto the cold detectors, a vent on each can will be punctured with a heat-driven wax actuator that will punch a hole in an Al seal. Heaters on each detector will be used to anneal the Ge from radiation damage. Simulations at accelerators¹⁸ and the experience with the Mars Observer GRS show that the Ge detectors in one year, the time from launch to martian orbit, will suffer enough radiation damage from the exposure to galactic cosmic radiation that the resolution will have degraded from the nominal 3 keV to ~6 keV from the presence of radiation-created traps in the crystal. The high-energy particles in an intense solar particle event would increase the amount of radiation damage. The pulse shape after one year in space has a long low-energy tail¹⁸ that make analysis by standard peak-fitting routines and resolution of closely-spaced lines very difficult. The radiation damage in a Ge detector can be annealed by heating to ≈ 100 C° for about 1 day. The present plan, if the radiation damage is not excessive after arriving at Mars, is to collect spectra for several months in martian orbit and then anneal the detectors just before a period when routine communications is limited while the Sun is between Mars

and the Earth. This plan reflects some concern that raising the detectors' temperatures from 90 K to about 100 C° for an anneal could possibly result in the loss of a detector.

The Ge crystals need to be operated below about 130 K. Both Ge detectors will be inside a two-stage passive radiator cooler. The radiators have a thermally-tuned coating and cool the detectors by radiating to space. The PGS is on the back of a solar panel about 70 cm from the spacecraft, which insures that the radiators do not see the Sun. The radiators are extended from the solar panel and tilted so that they do not see any part of the spacecraft. The spacecraft orientation and orbit will minimize radiation onto the radiators from the martian surface. The detectors are mounted to the inner radiator, which is circular with a radius of 36 cm. This radiator is mounted inside an outer radiator with radius of 48 cm. These radiators are designed to keep the Ge detectors at about 90 K when Mars is not in the radiators' field of view. 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.¹⁹ 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

Instrument electronics include analog electronics, intimately associated with the sensors; power converters, providing low voltages and the high voltages biasing the sensors; and digital processing and control electronics. Two parallel channels of electronics are provided, each of which serves one of the two sensors. The 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 analog electronics provide amplification and pulse shaping for the sensor signal, producing a 0–5 volt signal with 2 μ s gaussian shaping corresponding to 0–8 MeV energy deposited in the sensor. The buffered analog signals are routed through a 15-meter cable to the digital processing electronics. Pulse amplitude is measured through a 4096-channel pulse height analyzer, accomplishing the conversion by successive approximation in 4 μ s. Data are stored in arrays and formatted in gamma-burst mode by a microprocessor-based data handling system.

Data Modes

Data are telemetered in several different modes. In the pericenter mode, pulse-height data are acquired in arrays that preserve full spectral resolution and that are transmitted at intervals selectable between 1 and 5 minutes. Counting-rate time histories in several energy intervals are also recorded over the same intervals. In the background mode, which is to be used during the cruise phase of the mission and during a major fraction (about 14 of the 15 hours) of the orbital period, the same data are recorded and transmitted at intervals of 5 to 30 minutes.

The burst mode is enabled by command but must also be triggered by a rapidly-rising counting rate. Background-mode data are acquired whenever the instrument is not triggered into the burst mode. Burst-mode data are stored, for each photon event, in 4 byte (32 bit) words, representing the sensor identification, pulse height, and time (relative to the spacecraft clock) with resolution of 4 μ s. Spacecraft clock times are recorded at intervals of about one second to limit the number of bits required to time-tag each photon event.

Fabrication and Integration of the PGS Spectrometer

Integration of the prototype instrument was successfully complete at LANL in September 1993. The measured energy resolution for the ^{60}Co gamma ray at 1.3 MeV was about 3.0 keV (FWHM) for both detectors. During a thermal-vacuum test at IKI of the passive cooling system, the orbit around Mars was simulated and the Ge detector thermal models were maintained at an adequate operational temperature.¹⁹

Operation during the Mars-94 Mission

Shortly after launch, the PGS detectors and cooler will be deployed from the solar panel. After the detectors have cooled to well within their operational temperature range (below about 130 K), the voltages on the crystals will be slowly increased and the performance of the detector monitored. The operational voltage will be as low as possible while still being high enough to ensure that small changes in the voltage do not affect the performance of the detectors. The backgrounds will be collected and monitored. Some backgrounds from the production of radionuclides in (e.g., 1.63-day ^{69}Ge) and around (e.g., 2.6-year ^{22}Na from Al) the Ge crystals²⁰ can be identified by the characteristic half-life in which they grow into the spectra. Continuous backgrounds, such as impurities of thorium, uranium, and ^{40}K and prompt reactions such as $^{27}\text{Al}(n,n\gamma)^{27}\text{Al}$, need to be determined with good counting statistics.

During the 315-day cruise to Mars, and during martian orbital operation exclusive of "pericenter mode," the PGS will be enabled to look for gamma-ray bursts. When triggered into the "burst mode" by a rapid increase in counting rates, photons measured by each detector are individually recorded. For each burst photon, the detector is identified, the energy is determined, and the arrival time is recorded with a resolution of 4 μ s. Integrated time histories and spectral distributions are separately recorded. Additional data are recorded for events observed to be in coincidence ($<1 \mu$ s) from the two detectors.

During the "pericenter mode" of instrument operation, when the spacecraft is within ~ 1000 km of the surface and the martian gamma-ray emission is measured, and during the "background mode," when the background is measured, the time history and the energy spectra are recorded into integrated arrays by each detector independently.

SUMMARY

The high precision gamma-ray spectrometer (PGS) will provide two major advances for space science. The operation of a high-resolution GRS for a long period of time should

enable many spectra to be obtained of gamma-ray bursts. The fine-scale features in these spectra could be very diagnostic about these poorly known astrophysical high-energy phenomena. The PGS will also provide the first high-energy-resolution spectra of gamma-ray lines from the martian surface. 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 oxygen, magnesium, silicon, sulfur, chlorine, potassium, calcium, iron, thorium, and uranium, should be determinable for several large regions of Mars that can answer some basic questions about this very interesting planet.

ACKNOWLEDGMENTS

We thank our many colleagues at LANL and IKI for their support in this work. We also thank J. I. Trombka, Johannes Brückner, and William V. Boynton for their contributions to this work. S. Konev of the Luikov Heat and Mass Transfer Institute in Minsk, Belarus, and K. A. Woloshun and M. A. Merrigan of LANL helped in the design and testing of the PGS thermal control system. Some of the work at LANL was support by NASA and the work at LANL was done under the auspices of the U.S. Department of Energy.

REFERENCES

1. Reedy, R. C. 1978. Planetary gamma-ray spectroscopy. In *Proceedings of the Ninth Lunar and Planetary Science Conference*, pp. 2961-2984. Pergamon Press.
2. Metzger, A. E. 1993 Composition of the Moon as determined from orbit by gamma ray spectroscopy. In *Remote Geochemical Analysis: Elemental and Mineralogical Composition*. (C. P. Pieters and P. A. J. Englert, eds.), pp. 341-365. Cambridge Univ. Press.
3. Surkov, Yu. A., Moskaleva, L. P., Manvelyan, O. S., and Kharyukova, V. P. 1981. Analysis of the γ radiation of martian rocks based on the data of the Mars 5 spacecraft. *Cosmic Research* 18:453-460.
4. d'Uston, C., Atteia, J.-L., Barat, C., Chernenko, A., Dolidze, V., Dyatchkov, A., Jourdain, E., Khariukova, V., Khavenson, N., Kozlenkov, A., Kucherova, R., Mitrofanov, I., Moskaleva, L., Niel, M., Pozanenko, A., Scheglov, P., Surkov, Yu., and Vilchinskaya A. 1989. Observations of the γ -ray emission from the martian surface by the APEX experiment. *Nature* 341:598-600.
5. Surkov, Yu. A., Barsukov, V. L., Moskaleva, L. P., Kharyukova, V. P., Zaitseva, S. Ye., Smirnov, G. G., and Manvelyan O. S. 1989. Determination of the elemental composition of martian rocks from Phobos 2. *Nature* 341:595-598.
6. Trombka, J. I., Evans, L. G., Starr, R., Floyd, S. R., Squyres, S. W., Whelan, J. T., Bamford, G. J., Coldwell, R. L., Rester, A. C., Surkov, Yu. A., Moskaleva, L. P. Kharyukova, V. P., Manvelyan, O. S., Zaitseva, S. Ye., and Smirnov, G. G. 1992. Analysis of Phobos

Mission gamma ray spectra from Mars. In *Proceedings of the 22nd Lunar and Planetary Science Conference* pp. 23–29. Lunar and Planetary Institute, Houston.

7. Boynton, W. V., Trombka, J. I., Feldman, W. C., Arnold, J. R., Englert, P. A. J., Metzger, A. E., Reedy, R. C., Squyres, S. W., Wänke, H., Bailey, S. H., Brückner, J., Callas, J. L., Drake, D. M., Duke, P., Evans, L. G., Haines, E. L., McCloskey, F. C., Mills, H., Shinohara, C., and Starr, R. 1992. Science applications of the Mars Observer gamma-ray spectrometer. *J. Geophys. Res.* 97:7681–7698.
8. Metzger, A. E., and Arnold, J. R. 1970 Gamma ray spectroscopic measurements of Mars, *Appl. Opt.* 9:1289–1303.
9. Masarik, J., and Reedy, R. C. 1994. Numerical simulations of gamma-ray emission from the martian surface. In *Lunar and Planetary Science XXV*, pp. 845–846. Lunar and Planetary Institute, Houston.
10. Evans, L. G., and Squyres, S. W. 1987. Investigation of martian H₂O and CO₂ via orbital gamma ray spectroscopy. *J. Geophys. Res.* 92:9153–9167.
11. *High-Energy Astrophysics in the 21st Century*. 1990. AIP Conference Proceedings #211. (P. C. Joss, ed.). American Institute of Physics.
12. *Proceedings of the 1990 Los Alamos Workshop on Gamma-Ray Bursts*. 1992. (C. Ho, R. Epstein, and E. Fenimore, eds.) Cambridge Univ. Press.
13. Mazets, E. P., Golenetskii, S. V., Aptekar', R. L., Gur'yan, Yu. A., Il'inskii, V. N. 1981. Cyclotron and annihilation lines in γ -ray bursts. *Nature* 290:378–382.
14. Murakami, T., Fujii, M., Hayashida, K., Itoh, M., Nishimura, J., Yamagami, T., Conner, J. P., Evans, W. D., Fenimore, E. E., Klebesadel, R. W., Yoshida, A., Kondo, I., and Kawai, N. 1988. Evidence for cyclotron absorption from spectral features in gamma-ray bursts seen with Ginga. *Nature* 335:234–235.
15. Fenimore, E. E., Conner, J. P., Epstein, R. I., Klebesadel, R. W., Laros, J. G., Yoshida, A., Fujii, M., Hayashida, K., Itoh, M., Murakami, T., Nishimura, J., Yamagami, T., Kondo, I., and Kawai, N. 1988. Interpretation of multiple absorption features in a gamma ray burst spectra. *Astrophys. J. (Lett.)* 335:L71–L74.
16. Teegarden, B. J., and Cline, T. L. 1981. High-resolution spectroscopy of two gamma-ray bursts in 1978 November. *Astrophys. J. (Lett.)* 236:L67–L70.
17. Lingenfelter, R. E., Higdon, J. C., Leventhal, M., Ramaty, R., and Woosley, S. E. 1990. The goals of gamma-ray spectroscopy in high energy astrophysics. In *High-Energy Astrophysics in the 21st Century*. AIP Conference Proceedings #211. (P. C. Joss, ed.), pp. 56–73. American Institute of Physics.

18. Brückner, J., Körfer, M., Wänke, H., Schroeder, A. N. F., Filges, D., Dragovitsch, P., Englert, P. A. J., Starr, R., Trombka, J. I., Taylor, I., Drake, D. M., and Shunk, E. R. 1991. Proton-induced radiation damage in germanium detectors. *IEEE Trans. Nucl. Sci.* NS-38:209-217.
19. Chernenko, A. M., Kostenko, V. I., Mitrofanov, I. G., Konev, S., Woloshun, K. A., and Merrigan, M. A. 1993. Thermal control of the germanium precision gamma spectrometer aboard the Mars-94 spacecraft. In *Proceedings of the 29th National Heat Transfer Conference, Atlanta*. American Society of Mechanical Engineers, New York.
20. Dyer, C. S. 1984. Calculation of energy deposition spectra for radioactivity induced in germanium gamma-ray spectrometers by various space environments. *IEEE Trans. Nucl. Sci.* NS-31:1061-1065.

DATE

FILMED

7/7/94

END