EFFECTS OF SOLAR PARTICLES ON THE MARS ODYSSEY GAMMA-RAY SPECTROMETER*.

L. G. Evans[1], R. C. Reedy[2], and W. V. Boynton[3], [1]Science Programs, Computer Sciences Corp., Lanham, MD 20706 USA (larry.evans@gsfc.nasa.gov), [2]Inst. of Meteoritics, MSC03-2050, Univ. New Mexico, Albuquerque, NM 87131 USA (reedy@cybermesa.com), [3]Lunar & Planetary Laboratory, Univ. Arizona, Tucson, AZ 85721 USA (wboynton@lpl.Arizona.edu).

Summary: Solar energetic particles affect the Mars Odyssey Gamma Ray Spectrometer. These particles distort the measured spectra and create many gamma rays. Gamma rays from some radionuclides made by the energetic solar particles persist after the event. Spectra taken during and some time after an event should only be used after major corrections.

Introduction: The gamma rays measured from Mars can be used to infer the composition of the top few tens of centimeters of the surface [1, 2]. Gamma rays are made by the decay of the naturally radioactive elements K, Th, U and by fast and thermal neutrons produced by galactic-cosmic-ray (GCR) particles. The Mars Odyssey Gamma-Ray Spectrometer (GRS), which consists of a large cooled germanium crystal [1, 2], has been working in a 400 km polar orbit around Mars since February 2002.

Energetic particles from the Sun are accelerated by various processes near the Sun and in interplanetary space. Their energies are typically ~1-100 MeV, in contrast to GCR particles, most of which are ~0.1-10 GeV. For periods of the order of a day, the fluxes of solar energetic particles (SEPs) can be much higher than those of GCR particles [3]. During and shortly after solar particle events (SPEs), the spectra measured by the Mars Odyssey GRS are seriously affected. Several large solar particle events have been observed by the GRS, and their effects on the GRS are reported here.

Solar Particle Events: Energetic particles associated with the Sun occur irregularly. Large SPEs can occur almost any time except near the minimum in solar activity [4]. The next solar minimum is due in about 2007, so large SPEs could occur until 2005. SEPs are about 98% protons, 1% alpha particles, and 1% heavier ions. The fluxes of solar protons drop rapidly with energy, with few particles having energies above 100 MeV in most SPEs [3]. Most SEPs are stopped by a few g/cm^2 of matter. Almost none penetrate the martian atmosphere to reach the surface.

Radiation Damage to the Ge GRS: High-energy particles induce radiation damage in Ge detectors. A fluence equivalent to that of 1 year of GCR particles is enough to degrade the resolution of a Ge GRS [5]. If the detector is kept colder than about 100 K, this damage is not observed for several years. If the detector is warmed above this temperature and then cooled to operational temperatures, the damage is observed in the spectra. This radiation damage can be annealed by heating the detector to high temperatures. Several times since the launch of Mars Odyssey in April 2001, high fluxes of SEPs have occurred at the spacecraft. The fluxes of SEPs during the early parts of the cruise to Mars were low, and the gamma-ray spectra measured in July and August 2001 had good energy resolution [6]. The GRS was turned off and allowed to get warm at the end of August 2001. It was not cooled and turned on until February 2002. The detector's energy resolution then was seriously degraded due to radiation received from large SPEs in September and November 2001. The resolution was partially restored by heating the Ge to about 50 degrees C for about 14 days, and later almost completely restored by heating to about 73 degrees C for about 10 days.

Effects during and after a SPE: The flux of particles during a SPE increases rapidly at the start of the event and then decays slowly over several days. Often the response of the GRS was seriously affected by the high fluxes near the peak of an SPE, but not affected late in the event's decay phase (Fig. 1). Some intensities of gamma rays are not affected by an SPE, such as those from the long-lived natural radioactive elements K, Th, and U and all neutron-capture gamma rays. However, many of the peaks observed in the GRS during non-SPE times [7] are significantly enhanced. A few new peaks are observed.

Continuum. The energetic particles that pass through the Ge during a SPE raise the count rates, increasing the GRS's dead time and making it harder to detect gamma rays unchanged by the SPE, such as on July 20. Other rates from the GRS also are enhanced during an SPE, such as the detector's leakage current and the continuum levels.

Prompt gamma-ray peaks. SEPs also induce reactions that make gamma rays, such as by (p,pγ) reactions and the production of gamma-ray-emitting radionuclides. During a SPE, several broad gamma-ray peaks were observed from prompt reactions in the martian atmosphere, including an enhanced one at 4438 keV from excited ^{12}C and previously unobserved peaks from ^{16}O at 6915 and 7115 keV.

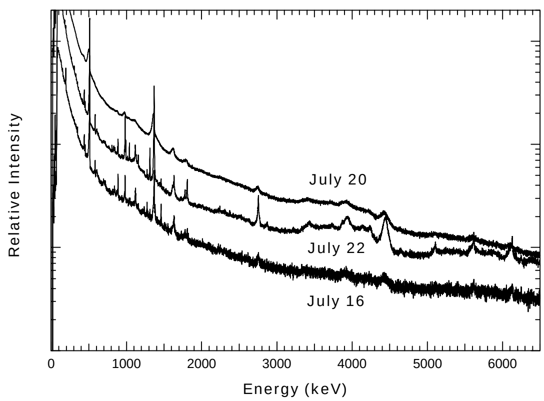

Fig. 1. Time normalized gamma-ray spectra taken before an SPE (July 16) and after (July 20 and 22).

Broad peaks were also observed from very-shorted-lived excited levels in ^{24}Mg in the GRS at energies of 4641, 4238, 3866, and 2870 keV that were not observed earlier.

Many non-broadened prompt peaks are observed from GCR particles reacting in the Mg, Ti, Zn, and other elements in the structural material around the Ge. Most of these peaks were strongly enhanced during SPEs (Fig. 2). Many of these prompt peaks are good monitors that indicate there is an SPE occurring. The fluxes of some prompt gamma rays were not significantly affected, such as the 5269 keV from excited ^{15}N made mainly by neutron-induced reactions with ^{16}O.

Decay gamma rays. The activities of many gamma-ray-emitting radionuclides made in and near the GRS were enhanced during and after an SPE (Fig. 3). The intensities of gamma rays from radionuclides with half-lives less than a day tracked those from prompt reactions as the flux of SEPs decreased with time over several days, such as those at 1369 and 2754 keV from 15 hour ^{24}Na. Gamma rays from radionuclides with half-lives greater than about a day persisted after the SPE. Such gamma rays were observed from 39 hour ^{69}Ge, 58.6 hour ^{44m}Sc and its ^{44}Sc daughter, and 16 day ^{48}V (Fig. 3). A decay peak that is normally very weak but that was enhanced during and after a SPE is that at 606.9 keV from 17.8 day ^{74}As made by (p,n) reactions with ^{74}Ge. This peak interferes with the one at 609.3 keV from the ^{214}Bi daughter of uranium.

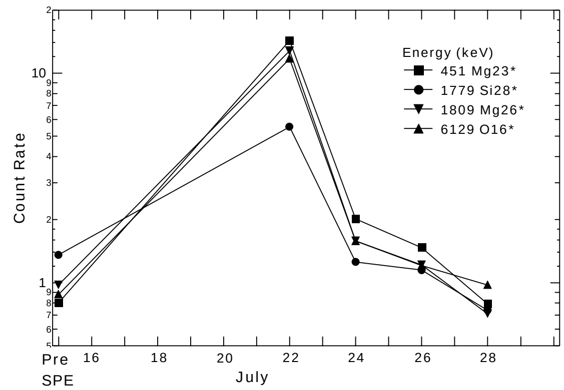

Fig. 2. Intensity of some inelastic-scattering gamma rays before and after the July SPE.

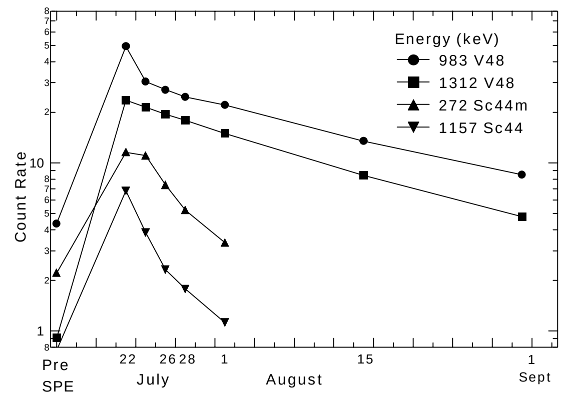

Fig. 3. Intensity of gamma rays from some long-lived isotopes after the July 2002 SPE. Note the difference in time scales compared to Fig. 2.

Unidentified peaks. Several peaks that were enhanced during a SPE have not been identified. Peaks at 1494, 1667, and 1823 keV were also observed in a long sum at Mars [7], suggesting that they originate in matter near the GRS. Some peaks that were enhanced that were not expected to be enhanced from the identifications for the long Mars sum, suggesting that such identifications are incorrect or that there is an additional gamma ray at or very near that energy.

References: [1] Boynton W. V. et al. (2003) *Space Sci. Rev.,* in press [2] Boynton W. V. et al. (2002) *Science 297,* 81-85. [3] Reedy R. C. and Arnold J. R. (1972) *J. Geophys. Res. 77,* 537-555. [4] Feynman J. et al. (1993) *J. Geophys. Res. 98,* 13281-13294. [5] Brückner J. et al. (1991) *IEEE Trans. Nucl. Sci. 38,* 209-217. [6] Evans L. G. et al. (2002) *SPIE Proc. 4784,* in press. [7] Reedy R. C. et al. (2003) *LPS 34,* this conference. *This work was supported by NASA's Mars Odyssey Program. We thank the GRS team members at the University of Arizona for preparing the database and for their assistance.