RADIATION DAMAGE IN GERMANIUM DETECTORS: IMPLICATIONS FOR THE GAMMA-RAY SPECTROMETER OF THE MARS OBSERVER SPACECRAFT;

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High-purity germanium (HpGe) detectors will be used in space missions to measure gamma-rays emitted by planetary bodies or astronomical sources. The upcoming NASA Mars Observer mission, scheduled for launch in 1992, will explore the surface of the planet Mars for 1 Martian year. One of the scientific instruments on-board the spacecraft will be a gamma-ray spectrometer (GRS) that will utilize a coaxial n-type HpGe detector. The GRS shall make high-resolution energy measurements of gamma rays emitted by the planetary surface. Cosmic-ray bombardment of the planetary surface induces gamma-ray emission due to subsequent primary and secondary nuclear interactions. Gamma-ray measurements made aboard the polar orbiting Mars Observer spacecraft can be used to infer chemical composition of the Martian surface.

Previous experiments [1] and flight experience [2] have indicated that HpGe detectors exposed to cosmic radiation can suffer significant radiation damage. As a result, the energy resolution of the HpGe detector will degrade to such a degree that it is not useful for further measurements.

The purpose of this experiment was to obtain more detailed information on the behavior of HpGe detectors under irradiation with high-energy charged particles in space and to test methods of annealing radiation-damaged HpGe detectors in a closed system. Basic scientific as well as engineering data on detector performance under simulated space exposure and operating conditions were collected. These data will be used to help in the design, control, and understanding of how to maintain the health of HpGe detectors during future space missions.

Several HpGe detectors were exposed to a proton irradiation at the French accelerator facility Saturne (Laboratoire National Saturne, Saclay). One detector was a flight-type version of the Mars Observer gamma-ray HpGe detector with a volume of 130 cm^3. Six other HpGe detectors having volumes of 90 cm^3 were grouped in pairs, each pair mounted in a special double-cryostat. Each pair consisted of a n-type and a p-type germanium crystal.

Simulation calculations on the interaction of protons with germanium were carried out by using the HERMES code system. Implications from the calculations and space environment conditions led to special requirements for the proton beam and detector setup. At the accelerator a 1.5-GeV proton beam with a cross sectional area of 20 cm in diameter and with an intensity distribution of less than 20 % variation was obtained. The proton flux was as low as about 10^5 protons $cm^{-2}sec^{-1}$ and was measured with plastic scintillation counters and monitor foils. The HpGe detectors were arranged inside the beam cross section in such a way that no Ge crystal was in the geometrical shade of another. By using a special heating device the detectors were held at operating temperatures of 90 K, 100 K, and 120 K to cover a temperature range expected for a planetary mission. The irradiation of the detectors occurred in several steps until an accumulated fluence of about 10^8 protons cm^{-2} was reached. The detectors were irradiated in predetermined increments of proton fluence. During irradiation interruptions, gamma-ray spectra of ^{60}Co were taken to evaluate the performance of the detectors as a function of accumulated charged particle fluence.

At completion of the irradiation, all detectors were characterized and cooled stepwise to LN_2 temperatures. Then, the detectors were transported in special containers to the laboratory at Mainz, where a detailed characterization of the their performance was carried out.

A total proton fluence of 10^8 protons cm^{-2} is about equivalent to one year of exposure in space. At elevated temperatures the observed energy resolution degradation after accumulation of this fluence would not allow for high-resolution gamma-ray spectroscopy. But, as shown later, annealing can remove the damage.

During the stepwise irradiation, the peak shape of the n-type detectors showed a significant change. Before the irradiation the shapes were either pure Gaussian or showed a little exponential tailing at the low-energy side. During the irradiation the exponential tailing evolved until it dominated the entire low-energy side of the the peak. A Gaussian shape was maintained at the high-energy side. More irradiation produced a new feature depending on the operating temperature: a broad Gaussian peak sitting on top of the exponential tailing (in a logarithmic display visible as a bump).

The full-width-at-half-maximum (FWHM) of the three 90-cm^3 n-type detectors is shown in Figure 1 as a function of proton fluence and operating temperature. The detector held at 90 K showed the best resistance against degradation of energy resolution. The detector held at 100 K (further on called "Yellow") exhibited an increase of degradation to 6 keV after being exposed to a fluence of 1.1×10^8 protons cm^{-2}; prior to the irradiation the resolution was 2.1 keV at 100 K. At an accumulated fluence of 6×10^7 protons cm^{-2}, which corresponds to about a half year of exposure in space, the energy resolution of detector Yellow was still below 3 keV. After the irradiation detector Yellow was cooled down to 90 K and its FWHM improved to 4.5 keV. The detector at 120 K showed an almost linear dependence of FWHM vs. fluence in contrast to the curve of Yellow, which led to an resolution degradation from 2 keV before the irradiation to 3 keV at an accumulated fluence of 3×10^7 protons cm^{-2}.

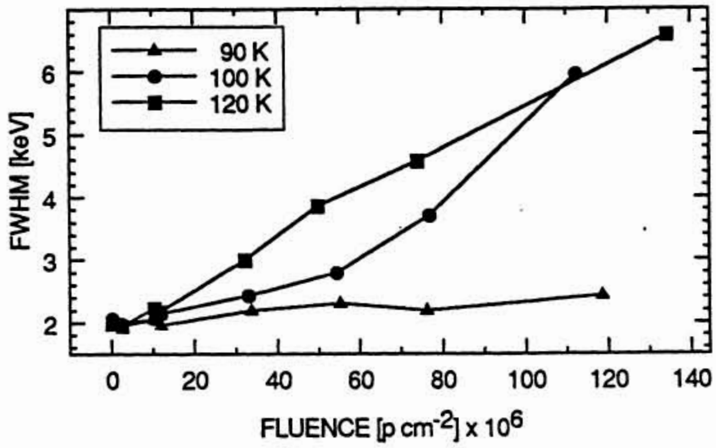

Fig.1 FWHM of the 1.3-MeV line of ^{60}Co for 3 n-type HpGe detectors at different temperatures as function of proton fluence.

Temperature cycling of damaged detectors between a reference temperature of 90 K and temperatures up to 130 K proved that irreversible additional loss in detector performance occurred above 120 K. For detector Yellow, it was observed that between 125 and 130 K an irreversible increase of damage occurred, *i. e.* if the detector was cooled down to 90 K after being at 130 K, its energy resolution had increased to 6.7 keV compared to 4.5 keV at 90 K. Heating up to room temperature produced only a small further increase of the resolution degradation (7.2 keV at 90 K).

During annealing (heating up to 100°C or higher) the detectors stayed in their special designed cryostat (the Ge crystal was encapsulated in a vacuum-tight inner can). After having annealed detector Yellow at a temperature of 105°C for 12 hours, almost all damage was removed (resolution improved from 7.2 to 2.4 keV). Further annealing of 24 hours at the same temperature brought the energy resolution back to its original value. A further indication of complete recovery of the annealed detector was the lack of variation in the intrinsic detector energy resolution as a function of temperature in the range 90 K to 120 K.

The irradiation and annealing cycles of the detectors simulated space exposure and operating procedures as closely as possible. The annealing temperatures applied to the detectors are available on the Mars Observer GRS. The study showed that HpGe detectors can successfully be used in long-term space experiments.

References: [1] Pehl R.H., Madden N.W., Elliott J.H., Raudorf T.W., Trammell R.C., and Darken L.S. (1979) IEEE Trans. Nucl. Sci. NS-26, 321-323. [2] Mahoney W.A., Ling J.C., and Jacobson A.S. (1981) Nucl. Instr. Meth. 185, 449-458.