The Radiation-Measuring Complex of the CIPPUT VI System


1 Institute of Medical and Biological Problems, Khoroshevskoe sh. 76a, Moscow, 123007 Russia
2 Skobeltsyn Institute of Nuclear Physics, Moscow State University, Vorobyevy gory, Moscow, 119992 Russia
3 Ioffe Physicotechnical Institute, Russian Academy of Sciences, Politekhnicheskaya ul. 26, St. Petersburg, 194021 Russia
4 Institute of Experimental Physics, Slovak Academy of Science, Kosice, Slovakia

Received December 18, 2000; in final form, July 2, 2003

Abstract—The radiation-measuring complex of the CIPPUT VI system is designed to determine the absorbed dose and values of heavy-nuclei fluxes under a program for investigating isolated failures in microcircuits. The complex is composed of active and passive elements. It is used to measure the total absorbed dose and the radiation doses received by exposed microelectronic elements behind shields of <0.3 and >1 g/cm² (across the range of 10⁻³–5 Gy), establish a link between isolated failures and the actual radiation environment, detect nuclear fluxes with a charge of Z > 2 and energies of 30–200 MeV/nucleon, and determine the fluence of heavy charged particles across the range of 1 to 10⁵ cm⁻².

At the present stage of space exploration, it is evident that the effectiveness of basic and applied research is closely related to the problem of the reliability and a longevity of a space vehicle, its systems, and equipment. Onboard equipment is acted upon by various factors in the environment of outer space, including ionizing radiations. It has been found experimentally that the exposure of onboard equipment to cosmic radiation may result in the distortion of data and codes in the memory units of onboard computers and, hence, in malfunctions of their microprocessor systems. In the majority of cases, these effects are brought about by isolated failures in digital integrated circuits. Such failures are associated primarily with the high energy losses of low-energy cosmic-ray particles in the material of an integrated circuit [1].

Knowledge of the radiation-field characteristics (the particle flux and energy spectrum) allows one to estimate the response of their effect on the components of onboard equipment (the linear energy transfer spectrum and dose). Moreover, it is necessary to take into account not only the type of the radiation field, but the dynamics of the magnetosphere as well, including the short-term variations in it (magnetic storms) associated with changes in the level of solar activity.

Within the program for the study of materials in [2], these considerations dictated the necessity of including a radiation-measuring complex as a component of the CIPPUT VI system with the aim of determining (1) the cumulative absorbed dose of cosmic radiation received by components of the onboard equipment during a long flight; (2) the rate of the absorbed cosmic radiation dose; (3) the linear energy transfer coefficient; (4) the fluence of heavy charged particles; (5) the energy spectrum of heavy cosmic ray nuclei with a charge Z > 2; and (6) the radiation dose received by exposed elements behind shields of <0.3 g/cm² and >1 g/cm².

The main sensors of the radiation-measuring complex are shielded semiconductor detectors (SCDs); dielectric solid-state track detectors (SSDs); and thermoluminescent detectors (TLDs), which are found in both the active and passive parts of the system.

In addition, the complex allows the frequency of isolated failures in microcircuits to be attributed to the actual radiation environment on the flight path of orbital complexes. An experiment aboard the Mir orbital complex included the in-flight testing of some elements of the dosimetry system for the Russian segment of the International Space Station.

A block diagram of the radiation monitoring complex is shown in Fig. 1.

The main components of its active part are four 16-mm-diameter semiconductor detectors. Two of them were used in the Ï-Î unit inside the Kvant-2 module of the Mir station (under shielding of >1 g/cm²), while the other two (the elements of detectors Dp and D₁ [3]) were placed on the outer surface of the module, virtually just above the location of the Ï-Î unit (under shielding of >1 g/cm²). The first two SCDs were n–p detectors 300 µm thick. One of them was coated with a 50-µm-thick foil of beryllium bronze, while the other was shielded with a 2.5-mm-thick layer of lead. The remaining SCDs, 200 µm and 2 mm thick, were shielded with films of 5-µm-thick Mylar and 100-µm-thick aluminum, respectively.

The readout electronics consisted of identical assemblies containing (1) a charge-sensitive amplifier with a shaping amplifier for electrical signals arriving from the n–p detector; (2) amplitude- and time-scaling amplifiers; (3) a comparator for the detection threshold.
and the logic for triggering a 12-bit analog-to-digital converter (ADC), which ensured that it would operate when the amplitude signal reached its peak; (4) a microcontroller with programs for acquiring spectra, calculating the total radiation count above the detection threshold, and computing the total energy release, along with a protocol for communicating with the СПРУТ-ВІ central-processor module; and (5) an RS-485 interface, through which the data were transmitted to the data acquisition unit and the commands defining the operating conditions were received from the electronic module of the СПРУТ-ВІ system.

A functional diagram of a data acquisition channel is shown in Fig. 2.

In response to a ready-to-receive signal from a СПРУТ electronic unit, the information acquired in the dosimeter is transmitted through the RS-485 interface to the СПРУТ-ВІ module, where a telemetric frame is formed. The frame contains the acquisition time for the measured parameters; the radiation count for the period of acquisition; the dose received during this time; the total dose taken since the instrument has been turned on; and the amplitude spectra of high-energy charged particles, recorded in 20 logarithmic channels and 20 linear channels (for the detectors inside the station and the external detectors, respectively).

Figure 3 shows the time variation of electron fluxes with different energies, measured with the СПРУТ-ВІ equipment during geomagnetic disturbances. The respective examples of absorbed dose and dose rate measurements are also presented.

The passive part of the complex, located inside a pressurized compartment, consisted of ПЛАТАН-МВ and Д-С radiometers and ИД-3М1 and ИД-3М2 dosimeters (mounted in mutually perpendicular planes). The sensors of the radiometers were a set of dielectric solid-state track detectors with different sensitivities; thermoluminescent detectors were used as sensors in the dosimeters.