Innovative Dosimeter for Space Applications

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ABSTRACT

Space radiation is a constant threat to the success of a mission away from the Earth's protective magnetosphere. During a space mission there is a high risk of coming into contact with different radiation events including galactic cosmic rays or solar particle events. Radiation measurements of the mixed environment represent an excellent opportunity to improve the mission safety. HERADO has developed an innovative compact radiation dosimetry system having small dimensions, low weight and high accuracy to measure the mixed field of radiation environment. A strong indication about quality and the innovation of our system is its inclusion in the MARE (Matroshka AstoRad Radiation Experiment) project on the Orion NASA vehicle. MARE is a radiation science payload proposed to fly on Artemis-1 by German Aerospace Center (DLR) and the Israel Space Agency (ISA) supported by Lockheed Martin and subsequently accepted and manifested by NASA. Greece is accepted to participate in these experiments by providing four ALMAR real time dosimeters developed by HERADO. The characteristics, the operation principles of ALMAR dosimeter as well as the added value to smallsat will be presented.

KEYWORDS

Dosimetry; MARE, HERADO ALMAR; Specialists' meeting; Space radiation

1.0 INTRODUCTION

Space radiation dosimetry presents one of the greatest challenges in the discipline of radiation protection. This is a result of both the highly complex nature of the radiation fields encountered in Low-Earth Orbit (LEO) and interplanetary space and of the constraints imposed by spaceflight on instrument design. The radiation environment in space is typified by a wide variety of primary particles covering an extended range of energies. When passing through the mass of a spacecraft and its contents, these particles can participate in a number of different types of nuclear interaction, producing a complex complement of both charged and neutral secondary particles. While the number of different particle species is large and the energy spectrum which they occupy is quite broad, their fluxes are often low. Relatively rare events associated with solar flares and Coronal Mass Ejections (CMEs) can produce sudden and dramatic increases in flux. Thus, the instrumentation required to measure the radiation field aboard spacecraft must be both extremely sensitive and robust. The constraints imposed by spaceflight often mean that ordinary, off-the-shelf dosimeters cannot be used and specialized instrumentation and techniques must be developed. Figure 1 shows the three principal sources of primary ionizing radiation in LEO: 1) Galactic Cosmic Rays (GCRs) are charged particles that originate from beyond the solar system; 2) Energetic electrons and protons are trapped in the geomagnetic field and make up the Earth's Radiation Belts (ERBs); and 3) Solar Particle Events (SPEs) are high fluxes of charged particles encountered during rare but intense solar flares and CMEs. In LEO, a fourth source, albedo neutrons and protons, is sometimes also mentioned. These are secondary particles, produced in interactions between GCRs and the Earth's atmosphere, with trajectories that take them back up into space. The albedo component is small and of low energy and as such is usually not considered a significant source of radiation exposure.

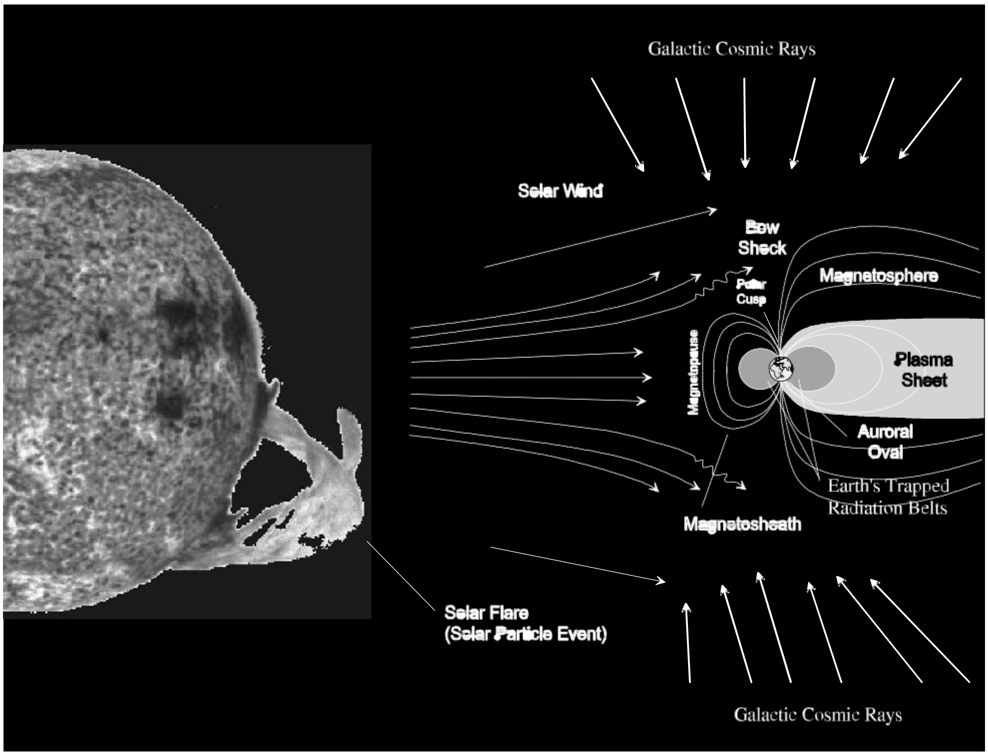

Figure 1: The three principal sources of space radiation: 1) galactic cosmic rays, 2) trapped radiation in the ERBs; and 3) solar particle events. All three sources are affected by the Earth's magnetic field [1].

The relative size, energy and charge distribution of each component depends on a large number of parameters including the altitude and inclination of the spacecraft's orbit, the orientation of the spacecraft relative to the Earth and Sun and the particular phase of the 11-year solar cycle. Trapped radiation, of course, is not found in interplanetary space, but the fluxes GCRs and SPEs encountered in interplanetary space are more intense due to lack of protection afforded by the geomagnetic field.

1.1 Galactic cosmic rays

Galactic cosmic rays are charged particles that originate from sources beyond our solar system. The distribution of GCRs is believed to be isotropic throughout interstellar space. The energies of GCR particles range from several tens up to 10 MeV [2] and, within the solar system, the GCR spectrum is peaked around 1 GeV. The GCR spectrum consists of 98% protons and heavier ions (baryon component) and 2% electrons and positrons (lepton component). The baryon component is composed of 87% protons, 12% helium ions (alpha particles) and the remaining 1% heavy ions of charge 3 (Li)-92 (U). Fig. 2 shows the relative abundances of GCRs [3]. Highly energetic particles in the heavy ion component, typically referred to as HZE particles, play a particularly important role in space dosimetry. HZE particles, especially iron nuclei which are relatively plentiful compared to the other high Z ions, possess high-LET and are highly penetrating, giving them a large potential for radiobiological damage.

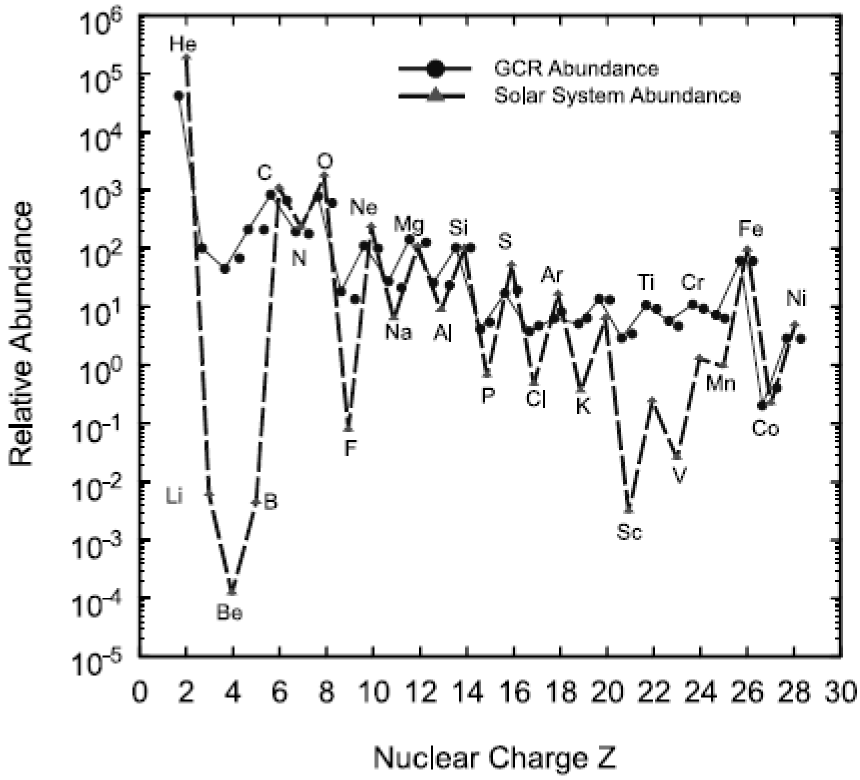

Figure 2: Abundance of GCR from He to Ni. Also shown are solar system abundances for these same elements [3]. Abundances of nuclei of Z greater than Ni fall well below the scale of this plot

1.2 Earth's trapped radiation belts

The Earth is surrounded by intense regions of energetic protons and electrons referred to as the Van Allen Belts or the Earth's trapped Radiation Belts (ERBs). These particles are trapped by the geomagnetic field where they follow a complex motion.

1.3 Solar particle events

The third source of ionizing radiation takes the form of energetic particles emitted by the sun during solar flares and CMEs. These fluxes included electrons, protons and heavier charged particles up to iron. From the space radiation health perspective, we are most concerned with protons due to a combination of their relative abundance and their high energy. Solar particle events are relatively rare and occur most often during the solar maximum phase of the 11-year solar cycle.

2.0 SPACE DOSIMETRY METHODS

The demands and constraints placed on instruments designed to carry out radiation dosimetry aboard spacecraft are much more stringent. These constraints are of three basic types. First and foremost is safety. This applies to obvious things like high voltage power supplies in active detectors, but also applies in more subtle ways – for example, in the use of glass, the outgassing of polymers, etc.

The second type of constraint has more to do with economics. Because of the high cost of launching equipment and supplies into orbit, instrumentation must be relatively small and of low mass. The instrument should also be of a robust design, able to withstand a large amount of use and abuse without failing, since the on-orbit availability of spare parts is minimal and cost to return an instrument to the ground for repair is prohibitive. In space there is always more demand for electrical power than can be provided by solar arrays so the detector needs to use as little power as possible. Similarly, on orbit, there are always a lot more data needing to be transmitted to the ground than there is available bandwidth. This is an additionally parameter in the case of active detectors, large capacity data storage is often required. The size and mass constraints that apply to personal dosimetry on the ground also apply in space

The third and possibly most challenging constraint concerns the large dynamic range of sensitivities required of the detectors in terms of particle energy, flux, resolution, etc. Particle fluxes are of- ten quite low - depending on the type of particle, often less than one particle per minute will be registered by the detector. However, in rare situations such as during a large SPE, fluxes can increase by several orders of magnitude. The different sources of primary charged particles combined with the effects of spacecraft shielding in modifying the primary flux lead to a radiation environment inside a spacecraft consisting of many different types of particles and occupying an extremely broad range of energies. The optimal radiation monitoring instrument needs to be sensitive to as much of this environment as possible. It is desirable to have good charge, energy and Linear Energy Transfer (LET) resolution in order to identify the different particles and to assign appropriate values of quality factor. This is especially relevant in the case of neutrons where it is often difficult to discriminate between the charged particle component and the neutron flux. As in all situations, active detectors have the advantage of time resolution over passive detectors.

While the radiation environment aboard the International Space Station (ISS), has been studied in great detail, a similar level of detail is lacking regarding the ionizing radiation environment in the Earth's atmosphere and beyond. To put it bluntly, we know far more about the radiation environment 400 km above our heads than at 40 km above our heads or in higher orbits. Small satellites provides an opportunity to measure the radiation environment, thereby providing important information regarding the impact on the health of high altitude aircrew and passengers and on possible effects on radiation sensitive avionics. In addition, suborbital tourism is on the cusp of becoming a reality and passengers on flights to the highest altitudes in our atmosphere will naturally be concerned about their radiation exposure during such flights. Measurements made aboard small satellites can directly address and alleviate their concerns regarding radiation exposure as give important importations for the development and protection of their electronics. Radiation has always been an issue for satellites. Back in 1962, Telstar 1 was an early high-profile casualty, its transistors suffering degradation by passage through the inner Van Allen radiation belt.

3.0 RESULTS AND DISCUSSION

A detector that we propose is the ALMAR dosimeter currently developed by HERADO, Athens, Greece. The ALMAR is a compact, battery powered dosimeter with real-time readout designed specifically for measuring the absorbed dose and ambient dose equivalent from both directly and indirectly ionizing radiation, including neutrons, encountered during atmospheric flight. Given the capabilities and dimensions of the ALMAR dosimeter, it has potential to serve the personal dosimeter needs of future space crews, including satellites, space tourists, small spacecraft as well as the personal dosimeter needs of pilots, flight attendants and passengers on commercial, business and military aircraft [4,5,6]. The ALMAR measures ambient dose equivalent, important for crew exposure as well as absorbed dose important for evaluation of the radiation field. ALMAR active dosimeters measure the radiation mixed environment every minute of elapsed flight time. Placement of ALMAR in different positions inside a space vehicle can provide radiation measurements for non-crewed space vehicles to measure the effectiveness of radiation shielding. ALMAR is the only compact dosimeter that can measure the low LET radiation (e.g. x/gamma rays, electrons/positrons, relativistic protons) and high LET radiation (e.g. neutrons, heavy ions, low energy protons). Measured radiation data from the ALMAR instrument can be used in the validating the results from the FAA CARI-7, NASA LaRC NAIRAS and OSU AIREC or different computer models.

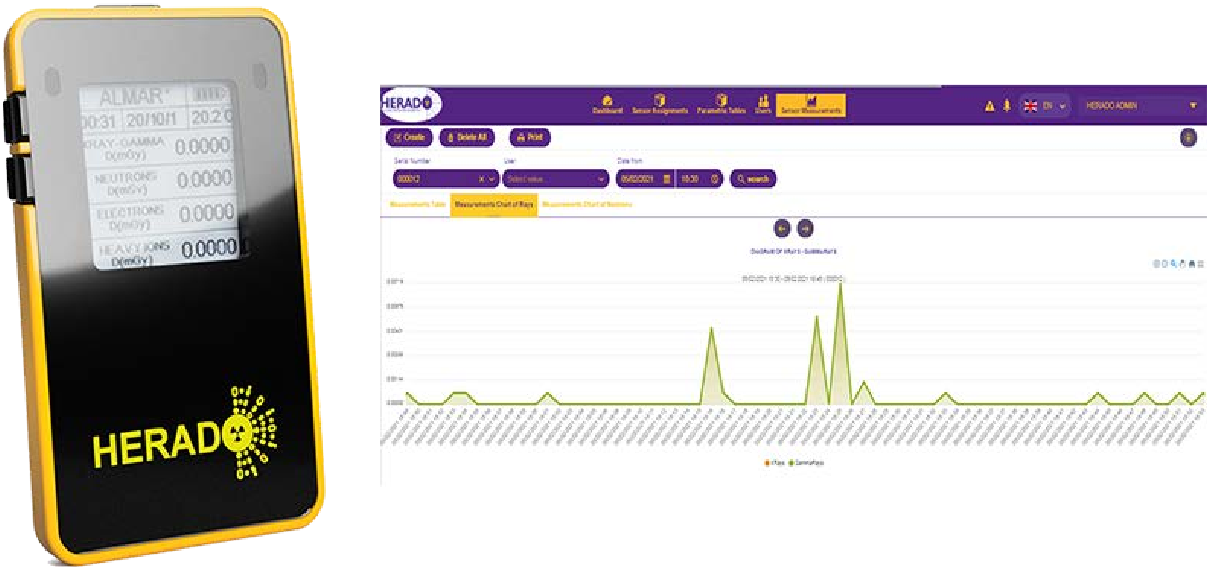

Figure 3: HERADOs, ALMAR dosimeter and software

The ALMAR personal aviation dosimeter (Figure 3) currently developed by HERADO, Athens, Greece, uses a unique combination of two radiation sensitive silicon-based sensors under different shielding in order to discriminate between the radiation signal produced by low LET radiation (e.g. x/gamma rays, electrons/positrons, relativistic protons) and high LET radiation (e.g. neutrons, heavy ions, low energy protons). Due to the type of the detector and the low power consumption electronics used ALMAR has unique characteristics detailed presented at the table 1 that are very important for their use in space applications. Especially for small satellites in which the small dimensions, low weight and very low power consumption are crucial. The individual ALMAR dosimeter measures 7.5 x 5.5 x 0.6 cm, has a mass of 25gr and is battery powered with autonomy 4 months without the need to be recharged. It possesses WiFi connectivity, as well as a USB port, so data can be easily transferred for further analysis. ALMAR can be operated in an internal data logging mode so that there is no need for data interface with the spacecraft. However, the dosimeter can also be configured to transfer data directly to the spacecraft for telemetry to the ground or on-board analysis.

Table 1: Specifications of ALMAR dosimeter to gammas and neutrons.

SPECIFICATIONS	ALMAR^{+} NEUTRONS	ALMAR
	Neutron Hp(10)	Gamma X-Rays Hp(10)
DETECTOR	Silicon based	Silicon based
MEASUREMENT RANGE	Dose: 1,5 µSv-10 Sv Dose rate 1 µSv/h-10 Sv/h	Dose: 0,65 µSv-10 Sv Dose rate: 1 µSv/h –10 Sv/h
ACCURACY	Dose: ± 10% AmBe	Dose: ± 10% Cs-137
DOSE RATE LINEARITY	Dose Rate : 5% AmBe	Dose Rate : 5% Cs-137

ENERGY RESPONSE	Linear up to 10 Sv Thermal-epithermal 0.025 eV to 100 keV intermediate fast 100 keV to 5 MeV	Linear up to 10 Sv From 3 KeV-100 MeV
ANGULAR DEPENDENCE	5 %	5 %
WEIGHT	25 gr	25 gr

Testing and calibration of the ALMAR dosimeter was performed at HIMAC accelerator in Japan as well as at Los Alamos Neutron Science Center (LANSCE) to particles and energies relevant to space dosmetry, i.e. protons, heavy ions and neutrons. The results of those irradiations and blind experiments at different particles and energies are summarized in tables 2 and figures 5.

Table 2: Irradiations of ALMAR dosimeter at HIMAC accelerator in Japan to protons and heavy ions.

Irradiation with 160 MeV protons

Dose measured	0,01633 ± 0,0016 mGy

Blind Experiments

Irradiation with heavy ions C 400 MeV/ n

Dose measured	0,035 ± 0,035 mGy
Dose irradiated	0,035 mGy

Irradiation with 150 MeV/ n He

Dose measured	0,6138 ± 0,0613 mGy
Dose irradiated	0,57 mGy

According to the results summarized in the above table the dose measured by the ALMAR dosimeter was in good agreement with the irradiated dose during the blind experiments with protons, helium and Carbon in energies spanning the LET of importance in space.

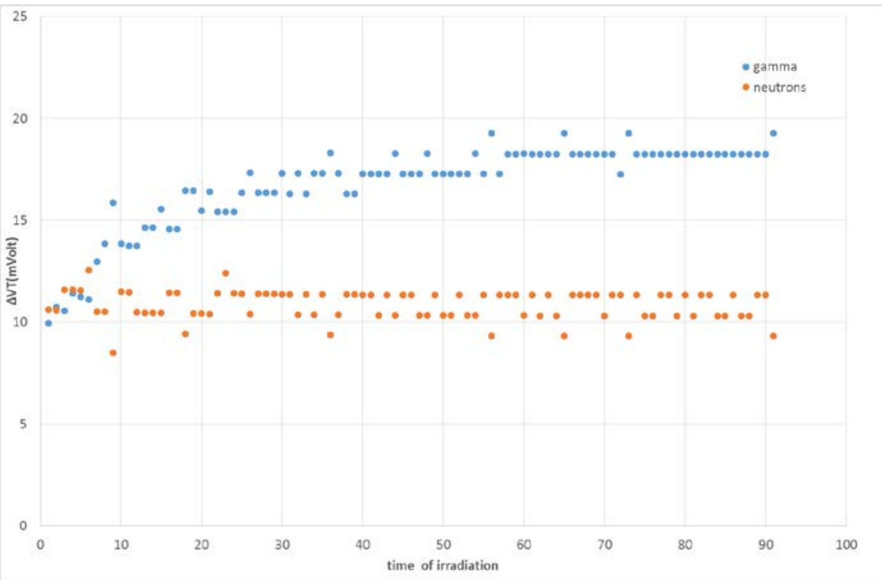

Figure 5: Irradiations of ALMAR dosimeter at LANCE Los Alamos (spallation source).

Figure 5 presents the results of the irradiation of the dosimeter in spallation neutron source at Los Alamos, in a radiation environment similar to that of space, are presented. The dosimeter in the mixed field of the spallation neutron source is able to discriminate gammas and high energy neutrons with high accuracy. There is no other dosimeter that can measure and discriminate different types of radiation (ie. Protons, heavy ions and neutrons) [7,8]. Characteristic that it is very important in a mix field like the radiation field in space. Because each type of radiation penetrates different leading on different problems. Radiation sensitivity has increased with reduced feature sizes we have to be concerned not only with heavy ion-related effects but also increasingly with proton effects. Proton-induced effects are particularly problematic due to their high fluxes in Earth orbit Standard integrated circuits would gradually degrade or even catastrophically fail when exposed to the space radiation environment. High-energy particles traversing EEE components generate a transient electric charge that can have various consequences: software upsets, memory bit flips, transistor gate ruptures or even 'latch-up' – a runaway short circuit phenomena that burns out the entire circuit. Special radiation-hardened components are essential for satellites. Even so, radiation remains one of the leading causes of satellite anomalies – and as technology advances, the risk increases. The advanced electronics driving this trend run a serious threat in orbit from the invisible onslaught of space radiation. In the case of satellites each single space component has more transistors than an entire satellite carried 20 years ago, making modern space systems much more powerful and versatile. The challenge we face is finding ways to go on applying novel terrestrial technology advances to space in a safe way, to make future missions more capable still while ensuring reliability. Radiation effects are typically imperceptible visually – although latch-ups cause visible damage, and optical materials and solar arrays can darken over time – but still have serious, even mission-ending, consequences. . So, it very important the concept of adding on a small satellites a detector to identify radiation-based errors.

4.0 CONCLUSION

According to the results from the irradiation the ALMAR dosimeter has linear response from μGy up to 10 Gy can measure and discriminate with high accuracy different types of radiation spanning the LET (Liner Energy Transfer) of importance in space. Additionally ALMAR has advantages like low weight, small dimensions and low power consumption. Based on these facts as well as the unique set of features of the HERADO ALMAR dosimeter, the HERADO ALMAR technology has a most promising future in the space and atmospheric dosimetry.

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