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SPADA: A project to study the effectiveness of shielding materials in space

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Summary. — The SPADA (SPAce Dosimetry for Astronauts) project is a part of an extensive teamwork that aims to optimize shielding solutions against space radiation. Shielding is indeed an irreplaceable tool to reduce exposure of crews of future Moon and Mars missions. We concentrated our studies on two flexible materials, Kevlar® and Nextel®, because of their ability to protect human space infrastructures from micrometeoroids. We measured radiation hardness of these shielding materials and compared to polyethylene, generally acknowledged as the most effective space radiation shield with practical applications in spacecraft. Both flight test (on the International Space Station and on the Russian FOTON M3 rocket), with passive dosimeters and accelerator-based experiments have been performed. Accelerator tests using high-energy Fe ions have demonstrated that Kevlar is almost as effective as polyethylene in shielding heavy ions, while Nextel is a poor shield against high-charge and -energy particles. Preliminary results from spaceflight, however, show that for the radiation environment in low-Earth orbit, dominated by trapped protons, thin shields of Kevlar and Nextel provide limited reduction.

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1. – Introduction

Radiation assessment and protection in space is the first step in planning future exploratory-class missions to the Moon and Mars, because of the increase in mission

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duration and number of space travellers [1]. Cosmic rays consist of 99% H and He ions and only 1% heavier nuclei, but this small fraction represents the dominant component of the equivalent dose. Because swift charged particles produce fragments in the spacecraft materials, it is very important to identify the best shielding solutions against space radiation for astronaut's radiation protection.

Studies of effectiveness of shielding materials to reduce the dose to astronauts prove that low-Z materials are more effective for their higher stopping power and fragmentation cross-section of the projectile [2]. In fact polyethylene slabs have been added in the sleeping quarters of the International Space Station (ISS) to reduce exposure.

The SPADA project aims to test the shielding effectiveness of two flexible materials, Kevlar® and Nextel®, largely used in the construction of spacecrafts because of their ability to protect human space infrastructures from micrometeoroids. The chemical compositions of these materials are described elsewhere [3]. For comparison with Kevlar and Nextel, we used a plastic material with excellent shielding properties in space: low-density polyethylene (LDPE). We have exposed these materials to high-energy heavy ions accelerated at the NASA Space Radiation Laboratory (NSRL) at the Brookhaven National Laboratory (Upton, NY), and these accelerator-based tests have clearly demonstrated that Kevlar is an excellent shield for heavy ions, close to polyethylene, whereas Nextel has poor shielding ability. In this paper we also report the preliminary results of the flight tests. We have exposed these materials onboard the ISS, with passive dosimeters positioned under the shielding to measure radiation dose. For comparison with Kevlar and Nextel, we used also polyethylene and low-density foam (simulating absence of shielding). Shielding blocks were also attached on the active detector ALTEINO [4] on ISS to measure the relative attenuation of the different components of the cosmic radiation spectrum.

Kevlar properties were also studied in PARIDE, PARticle and Ion Dosimetry Experiment, a short duration flight during the LIFE mission on the Russian rocket FOTON M3. A series of passive radiation detectors were shielded with aluminium and Kevlar. Bubble detectors were used to evaluate the neutron flux, while thermoluminescence detectors (TLD) were used to measure charged particle radiation.

2. – Materials and methods

2˙1. *Dosimetry*

Accelerator-based tests—Bragg curves of 1 GeV/n ^{56}Fe-ions were measured at the NSRL at the Brookhaven National Laboratory (USA) using a calibrated egg-ionization chamber. Beam size was a circle of approximately 20 cm diameter (disuniformity $< 5\%$), while targets were parallelepiped with variable thickness and $5 \times 5\,\mathrm{cm}^2$ area perpendicular to the beam. The experiment was repeated twice in two different NSRL runs, and results were found perfectly overlapping.

Flight-tests—The SPADA project plans the use of active and passive detectors to compare and complement the measurements. The active detector Sileye-3/Alteino is used to identify the effect of shielding material to the different nuclei and to separate the contributions of the different cosmic-ray components [4]. The data are under analysis.

Passive solid-state detectors are largely used to determine the radiation exposure of the astronauts because they are easy to handle, comparatively light-weight, do no require power consumption, and give integral information about dose by post-flight evaluation.

Passive dose measurements were obtained using TLD-100 (LiF:Mg,Ti) in the first four ISS flights in which INFN was involved (increments 11-14). Since the fifth flight

Fig. 1. – Multimaterial tiles divided into four sections, each composed of a different material.

(expedition 15), when SPADA was approved, we used TLD-700 (^{7}LiF:Mg,Ti). TLD-700 have higher efficiency, that is dependent not only upon the LET but also on the ion charged [5]. The TLD used were $3.2 \times 3.2 \times 0.89$ mm.

TLD-100 were annealed in air at 400 °C for 1 hour prior to exposition. Post-flight reading of TLDs was performed by an Harshaw model 3500 manual TLD reader installed at the Department of Physics in Naples.

2·2. *Tests on International Space Station.* – Although SPADA project was approved by Istituto Nazionale di Fisica Nucleare (INFN) at the end of 2006 and started at the beginning of the 2007, a collaboration between ASI and INFN of Naples and Rome Tor Vergata, along with Thales Alenia Space, started in 2004, in the framework of ESCHILO experiment (ESperimento di SCHermatura In Low Orbit), carried out during the ENEIDE mission to ISS, in April 2005.

In the course of this short-term test, 56 days, TL-dosemeters were exposed on ISS in two pouches behind shields in Kevlar, Nextel, polyethylene and low-density foam to simulate absence of shielding (fig. 1). We placed a TLD and a CR-39 under each material.

The second TLD experiment aboard ISS was performed in the first long-term test (expedition 12), started at the end of December 2005 (106 days). In this case INFN of Naples collaborated with INFN of Rome for the ALTCRISS experiment. In this project, we provided two more tiles, in addition to the multimaterial tiles, composed in polyethylene. These tiles are located on top and bottom of the bidirectional acceptance window of the detector. Two pouches with TLD dosimeters were interposed between the two polyethylene tiles and the acceptance windows of the Alteino detector (fig. 2).

A control pouch with TLD was placed close to the detectors and moved in the different locations of the Station.

On April 2006 we started the third experiment (expedition 13) of 154 days duration and on September 2006 we started the fourth (expedition 14). In these tests, dosimeters were exposed in the same configuration as for expedition 12.

The shielding materials thickness in each multimaterial tiles was 5 g/cm^2.

In each mission, a ground control pouch followed the others in all phases up to launch in Baikonur (Kazakhstan).

Fig. 2. – Polyethylene tiles positioned on top and bottom of the bidirectional acceptance window of the Alteino detector on ISS.

2·3. *Test on FOTON.* – In 2006 we collaborated with ASI and Kayser Italia in the framework of LIFE (Life Investigation in Foton Experiment mission) mission on FOTON with the PARIDE experiment. The objective was to use particle and neutron dosimeters to measure the radiation field in FOTON and the effectiveness of shielding with different materials. Bubble detectors were used to evaluate the neutron flux, while TLDs were used for the ionizing radiation. These dosimeters during the FOTON launch were shielded with aluminium and Kevlar.

The unmanned FOTON spacecraft was launched on September the 14th from Baikonur Cosmodrome, in Kazakhstan. The FOTON-M3 spacecraft spent 12 days in low-Earth orbit.

Materials used as shields were aluminium and Kevlar.

Dosimeters and shields are hosted in an aluminium box called Biokon (Biokon 1). Figure 3 shows the flight configuration for the PARIDE equipments.

Aluminium-type were Al-2219-T851 slabs. The aluminium shield had the shape of a $30 \times 35 \times 90$ mm box where the walls were 0.48 mm thick. Kevlar utilized was Kevlar Fiber 129 HT 812. The Kevlar shield had the shape of a cylindrical pouch with 35 mm diameter and 145 mm length. The Kevlar pouch was constituted by several layers of Kevlar fibres, so to guarantee its structural stiffness Kapton tape was utilized to hold the layers.

Inside the aluminium and Kevlar boxes took we inserted one neutron bubble dosimeter and two TLDs. In addition, a bubble dosimeter and two TLDs, were positioned near the shield to evaluate the unshielded radiation flux present inside the Biokon.

Two TLDs were also inserted in the other two Biokon boxes (Biokon 4 and 5) that contained biology experiments.

3. – Results

Accelerator-based experiment—Measured Bragg curves are shown in fig. 4. The shape of the Bragg curve is the one typically expected with 1 GeV/n Fe-ions [6-8] *i.e.* an initial decrease caused by projectile fragmentation, followed by the Bragg peak and a long tail produced by light fragments. The data show that the minimum dose is the lowest for LDPE and the highest for Nextel and that Bragg peak is found first in LDPE, then in Kevlar and finally in Nextel.

Fig. 3. – Flight configuration for the PARIDE equipments in Biokon 1.

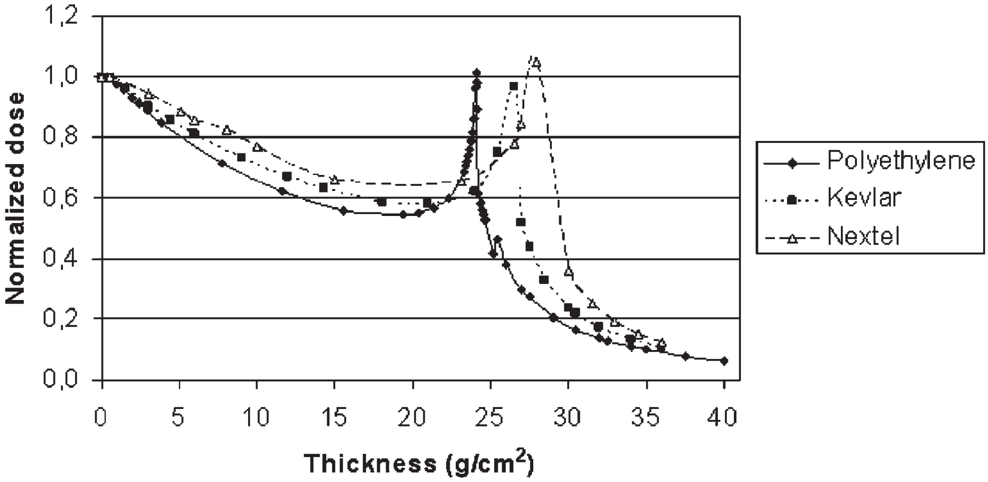

Fig. 4. – Bragg curves of 1 GeV/n ^{56}Fe ions measured in polyethylene, Kevlar and Nextel.

TABLE I. – *Average dose rate (mGy/d) measured by TLD interposed between the two polyethylene tiles and the acceptance windows of Alteino detector.*

Flight test	Dose (polyethylene)	Dose (space control)
Expedition 12	0.20 ± 0.01	0.22 ± 0.01
Expedition 13	0.22 ± 0.01	0.26 ± 0.01
Expedition 14	0.21 ± 0.01	0.23 ± 0.01

TABLE II. – *Average dose rate (mGy/d) measured under different shielding materials in the flight tests.*

Flight test	Dose polyethylene	Dose Kevlar	Dose Nextel	Dose no shield
Eneide	0.27 ± 0.01	0.27 ± 0.01	0.28 ± 0.01	0.29 ± 0.01
Expedition 12	0.23 ± 0.01	0.26 ± 0.01	0.28 ± 0.01	0.28 ± 0.01
Expedition 13	0.25 ± 0.01	0.25 ± 0.01	0.26 ± 0.01	0.29 ± 0.01
Expedition 14	0.21 ± 0.01	0.21 ± 0.01	0.21 ± 0.01	0.22 ± 0.01

Flight-experiments—Table I shows the average dose values measured with TLDs on ALTCRISS experiment on ISS. The comparison between dose values obtained by TLDs under polyethylene shielding and TLDs utilized for space control, confirms that polyethylene is a good material in low-Earth Orbit.

In table II we show the results of ESCHILO experiment. In ENEIDE and in Expedition 14 there are no significant difference among dosimeters shielded with different materials, with respect to unshielded position. Results show a little difference in Expedition 12 and 13, that suggest a higher effectiveness in shielding of Kevlar compared to Nextel. Overall, however, the data do not indicate significant effects of shielding, suggesting that thin shields in low-Earth Orbit have little effect on absorbed dose.

In table I and II average dose rate measures (mGy/d) are reported to compare immediately the results obtained in the different time duration missions. The errors take in account the sensitivity's variation of each dosimeters.

The different results obtained under polyethylene shield in ALTCRISS and ESCHILO experiments are probably due to Alteino detector that is a more shield for TLDs.

FOTON results are currently under analysis.

4. – Discussion and conclusions

The accelerator-based tests, that characterize the radiation properties of Kevlar and Nextel, show that Kevlar is a better shield for cosmic radiation than Nextel. In fact, the expected dose reduction for GCR heavy ions is approximately 80–90% of that produced by the same mass of polyethylene, while a double mass of Nextel is necessary to have the same reduction as LDPE. Measurements onboard the International Space Station show that for the radiation environment in low-Earth orbit, dominated by trapped protons, thin shields of Kevlar and Nextel provide limited reduction.

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REFERENCES

[1] CUCINOTTA F. A. and DURANTE M., *Lancet Oncol.*, **7** (2006) 431.
[2] DURANTE M., *Int. J. Mod. Phys.*, **17** (2002) 1713.
[3] LOBASCIO C., BRICCARELLO M., DESTEFANIS R., FARAD M., GIALANELLA G., GROSSI G., GUARNIERI V., MANTI L., PUGLIESE M., RUSEK A., SCAMPOLI P. and DURANTE M., *Health Phys.*, **94** (2008) 242.

[4] Casolino M., Altamura F., Minella A., Minori M., Picozza P., Reali E., Esposito A., Bedogni R., Mazzenga G., Ricci M., Durante M., Pugliese M., Roca V., Galper A., Korotkov M., Popov A., Benghin V., Lobascio C., Guarnieri V., Fortezza R. and Castagnolo D., *Nucl. Instrum. Methods A*, **572** (2007) 235.
[5] Berger T., Hajek M., Summerer L., Fugger M. and Vana N., *Radiat. Prot. Dosim.*, **120** (2006) 365.
[6] Zeitlin C., Heilbronn L. and Miller J., *Radiat. Res.*, **149** (1998) 560.
[7] Zeitlin C., Guetersloh S. B., Heilbronn L. H. and Miller J., *Nucl. Instrum. Methods B*, **252** (2006) 308.
[8] Lowenstein D. I. and Rusek A., *Radiat. Environ. Biophys.*, **46** (2007) 91.