SPACE DOSIMETRY WITH APPLICATION OF 3D SILICON TELESCOPE AND PILLE ONBOARD TLD DEVICE

Thesis

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Related publications

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Further Publications

12. S. Deme, I. Goricsán, E. Láng, T. Pázmándi, L. Sági, Zs. Szepesi: Radiation fields near buildings in case of radionuclide leakage, IRPA Regional Congress on Radiation Protection in Central Europe, Croatia, ISBN 953-96133-3-7, 2001
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BACKGROUND, MAIN OBJECTIVES

Cosmic radiation with a high intensity above the ionosphere is weakened by the magnetosphere of the Earth and the atmosphere, equivalent with 10 meter deep water. The dose rate is hundred times higher in Low-Earth Orbit than natural radiation on Earth, and higher with an order of two magnitudes also at commercial aviation altitudes.

One of the many risks of long duration space flights is the dose burden from cosmic radiation, which has great importance particularly during solar flares and higher sun activity. Radiation exposures in space can exceed ten times the dose limits of workplaces, consequently radiation exposure could limit the flight time. Because of this, being aware of the radiation field and the resulting dose rate is essential, and hence monitoring is carried out on the basis of wide international cooperation.

The recently used measuring equipment are only suitable for measuring certain radiation field parameters changing in space and time, so a combination of measurements and calculations is required to characterise the radiation field.

I have been working on the development of a three axis silicon linear energy transfer (LET) spectrometer and an evaluation software of the measured spectra during my PhD work. I have also taken part in the evaluation of the results measured by the Pille thermoluminescent dosimeter on the International Space Station and in the development of the new device as well.

The Pille-Tritel combined device will be applicable for the measurement of the absorbed dose and the quality factor which is a function of the LET spectrum.

METHODS

The radiation field is very complex at the altitude of the space station, and several conflicting arrangements can be found in the literature for its characterisation, where the aspects of the source, type and other parameters are confused.

I have recommended a new, clearly arranged division for the components of the radiation field. Considering the source of the particles, I have distinguished solar and galactic particles. In the case of a space station in Low-Earth Orbit, trapped and untrapped particles could be specified, and during periods of intensive solar activity a further component could be added.

According to the division of the radiation field in Low-Earth Orbit, I have evaluated the results measured by the Pille thermoluminescent dosimeter on the International Space Station (ISS).

The objective of DOSMAP (DOSimetric MAPping) experiment – carried out between May and August 2001 – was to investigate the distribution of the radiation field inside the ISS by dosimeters located throughout the spacecraft at different shielding points. Several different devices – semiconductor, thermoluminescence and track detectors – measured the parameters of the radiation field.

The Pille thermoluminescent dosimeter (TLD) system developed at the KFKI Atomic Energy Research Institute (KFKI AEKI) consists of a set of bulb dosimeters and a small, compact, TLD reader suitable for the on-board evaluation of dosimeters. According to the measurements of the Pille system, I have determined the dose rate as a function of time as well as the ratio of the trapped and untrapped component. I have proven the increase of the dose rate above the South Atlantic Anomaly.

I have determined the daily dose as well. Dose rate decreased gradually from May (8 µGy/h) to the end of June (6 µGy/h). In July it has approached 7 µGy/h. Results are in line with the changing of air density at high altitude. Measurements were made at several places of the International Space Station and the dose distribution inside the ISS were also studied.

The findings were compared with previous results. I have established that the dose rate inside ISS (6,2 µGy/h) was considerably less than in Mir (12 µGy/h), and the variance was explained by the flight parameter deviations and the solar cycle.

Results were compared with the results of other measurements taken during the DOSMAP experiment. I have established that variance of the TL measurements carried out by three research groups was about 10%. Polish KR 700H type dosimeters measured 10% below, and the German DLR 700H type 10% above the average. Results of the Pille measurements differ only some percent from the average.

Besides the evaluation of the data measured by the Pille thermoluminescent dosimeter on the International Space Station I have taken part in the development of the new Pille thermoluminescent dosimeter system as well. I determined the dosimetric peak and other parameters of the glow curve as a function of temperature for the $CaSO_4$:Dy dosimeter.

UTILISATION OF THE RESULTS

Application of the elaborated algorithm provides the determination of the LET spectra and direction distribution of the cosmic radiation field. It provides information about the radiation weighting factor and the complex system will be applicable for the on-board calibration of the TL dosimeters and for the determination of the equivalent dose.

The 3-dimensional silicon telescope should be the first such device used for measuring the dose the astronauts are subjected to. Development of the LET spectrometer determining directly the equivalent dose the astronauts are exposed to would represent a new opportunity not only for the KFKI Atomic Energy Research Institute, but also for the whole Hungarian space research. Russian space research institutes show a keen interest in the new device and they are prepared to provide flight opportunities for it on the external platform of the International Space Station and also on board a space probe to Mars in the future. Such systems can be applied for the dosimetry of aircrew as well.

RESULTS

1. According to the division of the radiation field in Low-Earth Orbit, I have evaluated the results measured by the Pille thermoluminescent dosimeter on the International Space Station. I have determined the dose-rate as a function of time as well as the ratio of the trapped and untrapped component. I have proven the increase of the dose rate above the South Atlantic Anomaly. The findings were compared with previous results, and the variance was explained by the flight parameter deviations and the solar cycle. (Chapter 7)

2. During the development of the new Pille thermoluminescent dosimeter system, I determined the dosimetric peak and other parameters of the glow curve as a function of temperature for the $CaSO_4$:Dy dosimeter. I have elaborated a new, prompt method for the dark-current correction of the photomultiplier. I have determined the response of the dosimeters as a function of the angle, in addition to the response linearity and the value of the residual dose. (Chapter 8)

3. I have elaborated a method for the conversion of the dose and the LET in the case of different materials, and I have proven the importance of energy dependence. I have recommended 1.23 for protons and 1.33 for alpha particles to make a conversion between silicon and tissue. (Chapter 11)

4. I have suggested the application of a 3-dimensional silicon telescope for the determination of the radiation field. I have defined the geometric parameter of the system, and I used the results of previous measurements as a benchmark. I have scrutinised the features of various types and sizes of telescopes. I pointed out that the bigger the difference between the radii of the detectors, the less the angle-dependence of the system is. (Chapter 9 and 10)

5. I have determined the response function of the system, I have considered the dependence on the arrangement and on the type and energy of the particle. I took into consideration the changing of the LET of the charged particles in the detector and the effect of the particles stopping in the detector. I analysed the effect and importance of the shielding in front of the telescope. I proved that the use of very thin detectors do not have a considerable benefit in the case of determining the LET. I have defined the parameters of the inverse algorithm, restoring the characteristics of the field from the measured spectra. I verified the algorithm with numerical databases and realistic measured spectra. (Chapter 13 and 15)

I have determined the brilliance of the built-in LED source as a function of temperature. I have elaborated a new, prompt method for the dark-current correction of the photomultiplier. It could be used for the correction of the background with three approx. 0.1 sec measurements each.

I have determined the linearity of the response of the dosimeters in the range of 1 – 3000 mGy. I have established that below 300 mGy the response does not differ more than 3 % from the real value. Above this the linearity is deteriorated and supralinearity can be observed. This can be corrected numerically. During the development of the new Pille thermoluminescent dosimeter system, I have determined the response of the dosimeters as a function of the angle. If we executed rotation in line with the axis of the dosimeter, the sensitivity did not decrease below 90%. In the case of perpendicular rotation the sensitivity dropped below 70%.

My proposals made on the basis of the measurements were accepted and observations were utilised during the development of the new device as well.

The radiation weighting factor is used to convert the absorbed dose to the equivalent dose (Sv). The values of the radiation weighting factor are broadly compatible with values of the quality factor, which are related to the linear energy transfer (LET).

Since space radiation mainly consists of charged heavy particles (protons, alpha and heavier particles), the equivalent dose significantly differs from the absorbed dose. The recently used measuring equipment is not fully suitable to measure both quantities simultaneously. With the Pille TLD system only the absorbed dose could be determined and the efficiency is decreasing for high LET particles.

I have suggested a new combined device, which consists of an on-board thermoluminescent dosimeter reader (Pille) and a three axis silicon linear energy transfer spectrometer. On the basis of the measured LET spectra, the results of the Pille system could be corrected and the quality factor could be determined.

The combined device in automatic readout mode will be able to determine the absorbed dose (Gy) and the equivalent dose (Sv) of the space radiation.

Interaction of radiation and matter and the corrections of the dose values between different targets play an important role in several respects. During the measuring process, track detectors, TL materials and silicon spectrometers are used. Since we are interested in the equivalent dose in tissue, the results of the TL measurements and the LET spectra have to be corrected, too. We need correction for the comparison of the different measurements as well.

I have elaborated a method for the conversion of the dose and the LET in the case of different materials, and I have proven the importance of energy dependence. I have recommended 1.23 for protons and 1.33 for alpha particles to make a conversion between silicon and tissue.

If the radiation field consists of different particles, these values should be averaged on the basis of the relative incidence or the ratio of the doses. Results of the calculations made for the International Space Station were compared with the results of other authors. The discrepancy of the mean values with and without considering the energy spectrum could be more than 5%.

I have suggested the application of a 3-dimensional silicon detector telescope for determining the parameters of the radiation field. The system engineering related development of the three-axis telescope has been implemented in several phases. At first I have defined the geometric parameter of the system, which required compliance with contradictory conditions. I have recommended $q = p/r = 1.23$ value for the quotient of the distance (p) and the radii (r) of the detectors.

I have scrutinised the features of various types and sizes of telescopes. I pointed out that the bigger the difference between the radii of the detectors, the less the angle-dependence of the system is.

I have determined the response function of the system, I have considered dependence on the arrangement and on the type and energy of the particle. In the calculations made with the application of the new method, I took into consideration the changing of the LET of the charged particles in the detector and the effect of the particles stopping in the detector. I used the algorithm for the determination of the response spectra of well-known radiation fields. I analysed the effect and importance of the shielding in front of the telescope. I proved that in the case of protons with 20 MeV energy, a 1 mm thick aluminium layer causes significant distortion in the response function. However, above 200 MeV the effect of a 10 mm thick aluminium layer could be neglected.

Since it has been raised in scientific circles that the use of thinner than 300 μm, e.g. 100-150 μm detectors would be reasonable for the more accurate determination of the LET spectra, I have analysed the advantage of using thinner detectors. In the model I theoretically cut the detector into ten 30 μm thick slices and made a calculation for monitoring the particles passing through the detectors.

I have proven that – despite the fact, that in case of low energy the absorbed energy shows a wide range distribution in the slices of the detector – there was not a significant difference in the LET values of the incident particles.

Because of this the use of very thin detectors does not have a considerable benefit in the case of determining the LET. I verified the results by Monte-Carlo calculations, which use quite different principles than the mathematical algorithm discussed above and in fact applies different LET data bases and cross section libraries. I have found that the estimated value did not differ significantly, and hence I proved the accuracy of the algorithm.

By utilising the calculation results, I have defined the parameters of the inverse function, which restored the characteristics of the field from the measured spectra and then I developed the algorithm. I verified the algorithm with numerical databases and realistic measured spectra.