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Development of an advanced dosimeter in mixed-radiation fields: position-sensitive tissue-equivalent proportional chamber (PS-TEPC)

Detectors require special techniques to evaluate the radiation dose in mixed-radiation fields, where different types of radiation exist, e.g., around accelerators and in space. A position-sensitive tissue-equivalent proportional chamber (PS-TEPC) has been developed as a detector that can measure the radiation dose in such mixed-radiation fields. PS-TEPC has the capability to measure not only the energy deposition, but also the three-dimensional trajectory of an incident charged particle using a time projection chamber method [1]. Dividing the energy deposition by the path length of the trajectory, PS-TEPC can measure L as the linear energy transfer (LET) of the incident particle. Therefore, the dose equivalent, which is defined as the product of the absorbed dose and the quality factor $Q(L)$, can be derived for each incident radiation. Furthermore, PS-TEPC uses tissue-equivalent plastic A-150 and the methane-based tissue-equivalent gas (CH_4: 64.4%; CO_2: 32.4%; N_2: 3.2%), which makes it possible to mimic the interactions of the incident radiation with soft tissues in the human body. Therefore, in such cases, the dose equivalent can be directly derived using PS-TEPC without any conversion and assumptions regarding the difference between the detector material and soft tissue.

Space dosimeters are one of the major applications of PS-TEPC because the area inside a crewed spacecraft, such as the International Space Station (ISS), is known to be a mixed-radiation field of protons and heavy ions as cosmic rays. In addition, the neutrons generated by the interactions of these particles with the hull of the spacecraft also contribute to the radiation dose.

It has taken over 15 years to develop PS-TEPC as a space dosimeter. For demonstration tests in an actual spacecraft, an experiment on board ISS was carried out from December 2016 to March 2018. The flight model of PS-TEPC (FM PS-TEPC), which was installed inside the Japanese experimental module Kibo, is shown in Fig. 1. FM PS-TEPC has two detector units, which consist of a gas chamber, high-voltage supplies, and pre-amplifiers, and a control unit, which has analog-to-digital converter modules, a field programmable gate array, and a computer to digitize and record the signals from the detector units.

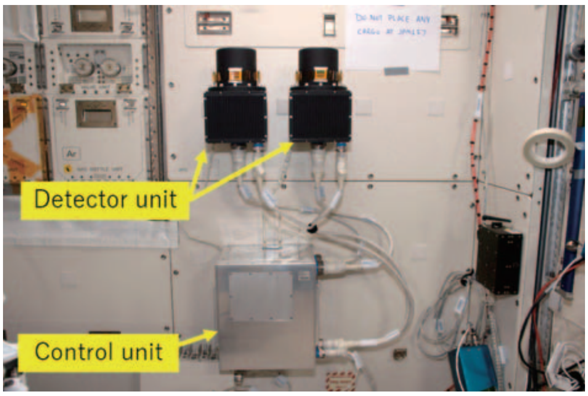

Fig. 1. FM PS-TEPC installed inside the Japanese experiment module of ISS. (©NASA/JAXA)

The detector units of FM PS-TEPC operated well throughout the experimental duration, and the acquired data were transferred by telemetry to KEK via the Tsukuba Space Center of Japan Aerospace Exploration Agency (JAXA) for storage. The data is being analyzed and several results have been obtained.

Figures 2 and 3 show the contour plot of the event rate on the flight map and the time variation of the event rate during the same period, respectively. ISS turned around Earth at an altitude of 400 km in 90 min with an inclination angle of 52° during the experiment. The color contour in Fig. 2 corresponds to one period of the orbit. Figure 3 clearly indicates that the event rates drastically change depending on the region passed along the flight path in Fig. 2. The high event rates shown at (A) and (C) in Fig. 3 correspond to locations (A) and (C) in Fig. 2, respectively. The change in event rates is because the geomagnetic shielding effect, which prevents cosmic radiation from entering in the surface of Earth, is weaker in high-latitude regions than in low-latitude regions. The highest event rate, shown at (B) in Fig. 3, corresponds to (B) in Fig. 2. This region is known as the "South Atlantic Anomaly (SAA)", which is a weakened geomagnetic field region centered in southeast South America. These well-synchronized correlations between the event rates and locations demonstrate that FM PS-TEPC can precisely capture events caused by cosmic radiation.

Figure 4 shows the LET distribution of the events obtained by FM PS-TEPC. The events obtained in the SAA region were eliminated for this analysis. Various LET events from 0.2 to 600 keV/μm were measured. This LET range corresponds to the overall range in which the cosmic radiation contributes to the dose equivalent in a spacecraft [2]. The results indicate that FM PS-TEPC has a sufficient dynamic range to measure the dose equivalent in a spacecraft.

We plan to conduct a detailed analysis to evaluate the adequacy of the results and establish a method to derive precise dose equivalents on a real-time basis. We also intend to design a practical model of PS-TEPC, that is, a compact, light space dosimeter with a long lifetime, and low power consumption.

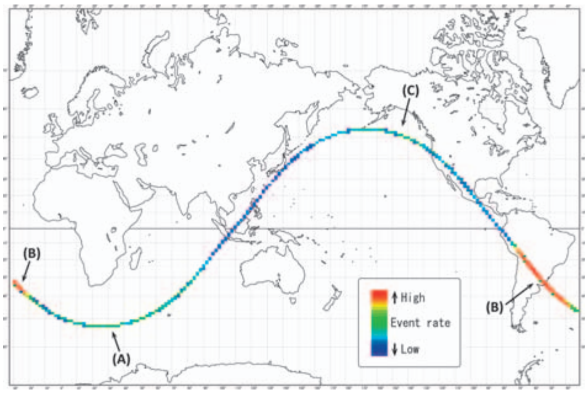

Fig. 2. Contour plot of the event rate on the flight map.

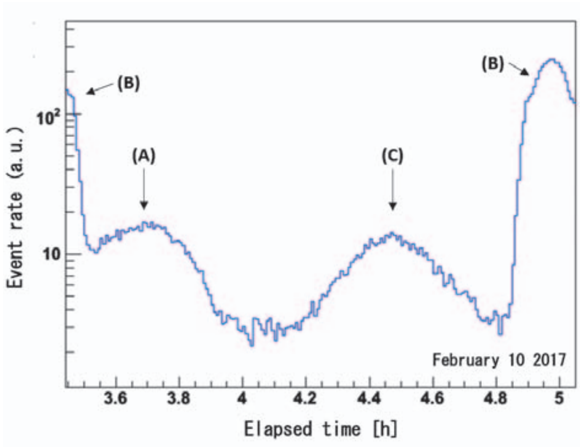

Fig. 3. Time variation of the event rate.

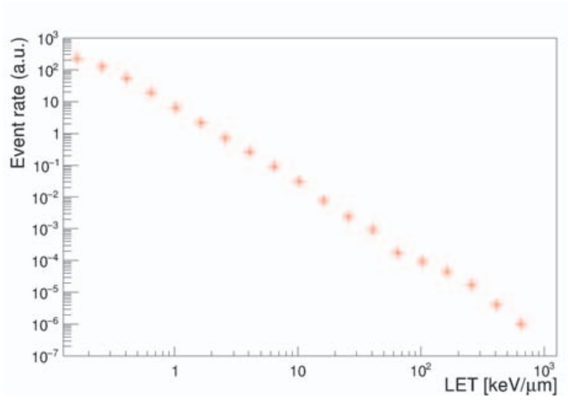

Fig. 4. LET distribution obtained by FM PS-TEPC.

References

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[2] T. Sakaguchi *et al.*, Nucl. Instum. Methods Phys. Res. A**437**, 75 (1999).