Space radiation dosimeter: PADLES

In 2007, the Space Environment Utilization Center of Japan Aerospace Exploration Agency and the Radiation Science Center of KEK jointly succeeded in the development of a PAssive Dosimeter for Life-science Experiments in Space (PADLES). The Japanese Experiment Module, Kibo, is installed on the International Space Station in 2008. Various life-science experiments will be conducted on board Kibo while Japanese astronauts will engage in long-term stays on board the International Space Station from 2009. PADLES will be utilized for radiation dosimetry for biological samples on board Kibo, personal radiation dosimetry for Japanese/Asian astronauts, and area radiation monitoring inside Kibo. Figure 1 shows the outward appearances of two types of PADLES packages.

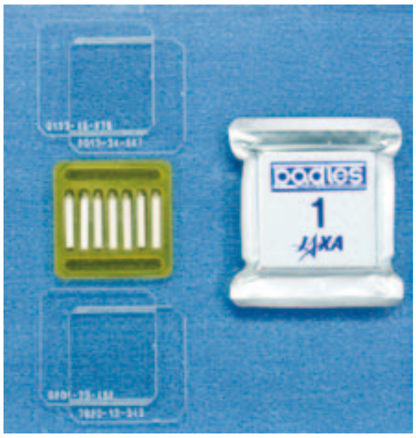

Fig. 2. Standard PADLES package.

A standard PADLES package includes four CR-39 plastic nuclear track detector plates and seven thermoluminescence dosimeter elements, as shown in Fig. 2. The CR-39 plates are made of antioxidant-doped CR-39 plastic (HARZRAS TD-1, Fukuvi Chemical). The thermoluminescence dosimeters comprise white Mg_2SiO_4:Tb powder sealed in glass tubes with Ar gas (TLD-MSO-S, Kyokko). The CR-39 plates and the thermoluminescence dosimeters are hermetically sealed in an aluminized polyethylene bag with air. Because the PADLES package is light, compact, and battery-less, it is convenient for use in space: it requires less crew time, is maintenance free, can be installed extremely close to biological samples, and can be easily attached to astronauts' clothing or an extravehicular activity suit.

Fig. 1. Area PADLES for area radiation monitoring (upper) and Crew PADLES for personal dosimetry (lower).

The International Space Station is in low earth orbit at an altitude of 300–500 km, where the radiation dose rate is a few hundred times higher than that on the ground. The primary radiation sources outside of the International Space Station are galactic cosmic rays, solar particle events, and protons trapped in the earth's radiation belts. The radiation environment inside the International Space Station is further complicated by the interaction of the primary radiation with the "mass" of the International Space Station, which produces many kinds of secondary radiation.

The primary and secondary radiations that directly contribute to the radiation dose inside the International Space Station mainly comprise energetic, heavy charged particles (nuclei from H to Fe). When an energetic charged particle passes through matter, the energy of the particle is imparted to the matter along the particle path. Linear energy transfer (LET) [keV/μm] is defined as the energy imparted per unit path length. The absorbed dose [Gy = J/kg] is defined as the energy imparted per unit mass of matter. Such energy transfer initiates various types of physical and chemical damage. High-LET particles (several keV/μm or more), in particular, can cause more severe biological damage in living tissue than low-LET particles, even if the absorbed doses are equal. The LET distribution of space radiation ranges from 0.2 keV/μm to 1000 keV/μm or more. In the International Space Station, the contribution of the high-LET radiation to biological effects is quite significant. Therefore, it is very important to measure the LET distributions of the high-LET components of space radiation for life-science experiments in space.

From the point of view of radiation protection for astronauts, the dose equivalent [Sv] is generally used, which is the absorbed dose weighted by quality factors that are determined depending on the LET. The quality factors recommended by the International Commission on Radiological Protection are shown in Fig. 3. These were determined by considering the risk of carcinogenesis on human exposure to radiation.

So far, various kinds of thermoluminescence dosimeters have been used for measuring absorbed doses in space. However, such thermoluminescence dosimeters underestimate the absorbed dose because of their low sensitivity to high-LET particles. In contrast, CR-39 plates

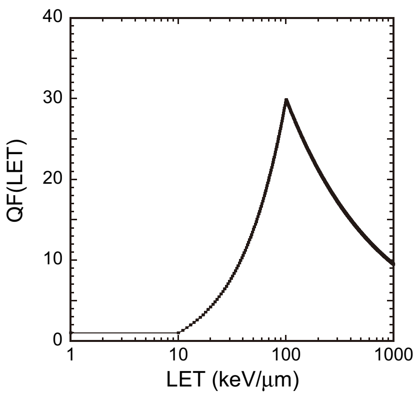

Fig. 3. Recommended quality factors (QF) determined by the International Commission on Radiological Protection in 1990.

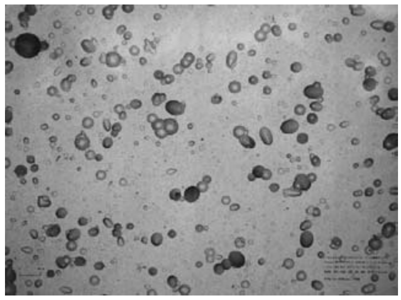

Fig. 4. Etch pits created by high-LET space radiation particles on the surface of a CR-39 plate over 71 days on board the Russian service module of the International Space Station.

can be used to measure the LET distributions of particles with a LET of 4 keV/μm or more. Energetic, heavy charged particles create permanent damage trails along their path on a CR-39 plate. When the CR-39 plate is soaked in a NaOH solution at 70 °C, the damage trail grows up as a visible etch pit. The LET of the particle can then be determined from the shape of the etch-pit opening. Figure 4 shows an example of etch pits created by high-LET space radiation particles.

In 1995, Doke *et al*. proposed a new method for estimating the absorbed dose and dose equivalent of space radiation by combining the data from thermoluminescence dosimeters and CR-39 plates. This formed the basis for the development of PADLES. To put PADLES to practical use in space, the characteristics of CR-39 plates and thermoluminescence dosimeters for high-energy, heavy charged particles were intensively investigated by using heavy ion beams from the HIMAC accelerator at NIRS, Japan. Two computer programs, TLDPADLES and AutoPADLES, were also developed for prompt and routine analysis of PADLES. These programs drastically reduced the maximum analysis time of the PADLES package, typically down to about two weeks.