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Verification of shielding effect by the water-filled materials for space radiation in the International Space Station using passive dosimeters

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Abstract

The dose reduction effects for space radiation by installation of water shielding material ("protective curtain") of a stack board consisting of the hygienic wipes and towels have been experimentally evaluated in the International Space Station by using passive dosimeters. The averaged water thickness of the protective curtain was 6.3 g/cm^2. The passive dosimeters consisted of a combination of thermoluminescent detectors (TLDs) and plastic nuclear track detectors (PNTDs). Totally 12 passive dosimeter packages were installed in the Russian Service Module during late 2010. Half of the packages were located at the protective curtain surface and the other half were at the crew cabin wall behind or aside the protective curtain. The mean absorbed dose and dose equivalent rates are measured to be 327 μGy/day and 821 μSv/day for the unprotected packages and 224 μGy/day and 575 μSv/day for the protected packages, respectively. The observed dose reduction rate with protective curtain was found to be 37 ± 7% in dose equivalent, which was consistent with the calculation in the spherical water phantom by PHITS. The contributions due to low and high LET particles were found to be comparable in observed dose reduction rate. The protective curtain would be effective shielding material for not only trapped particles (several 10 MeV) but also for low energy galactic cosmic rays (several 100 MeV/n). The properly utilized protective curtain will effectively reduce the radiation dose for crew living in space station and prolong long-term mission in the future.

Keywords: Space radiation dosimetry; Water shield; Dose reduction; Passive dosimeters; CR-39; TLD

1. Introduction

The International Space Station (ISS) crew is constantly exposed to space radiation consisting of different kind of charged particles with various energies and nuclear charges (Benton and Benton, 2001). The radiation dose comes mainly from protons and helium ions which are mostly present in space radiation. The contribution of heavy components ($Z > 2$ ions) makes increase of dose equivalent due

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to the high LET (linear energy transfer) with high quality factor related to the relative biological effectiveness (ICRP, 1991). Moreover, primary high energetic charged particles produce not only secondary charged particles but also fast neutrons due to nuclear interaction with materials. The biological effects by fast neutrons are also considerable component in terms of the space radiation dose equivalent (Lewis et al., 2012). The typical daily dose in the ISS is ranging from about 0.5 to 1 mSv depending on the solar activity and the altitude and attitude of the ISS (Lishnevskii et al., 2010; Ambrozova et al., 2011; Fino et al., 2011; Kodaira et al., 2013). The effective dose limits of 10 yr career for astronauts are recommended to be 400 mSv (female) and 700 mSv (male) for 25 yrs old (NCRP No. 142, 2002). The radiation risk of astronauts in the ISS is controlled under such recommended limitations with actual dose measurement.

The astronauts will be exposed to high dose of space radiation for up-coming long-term missions on the Mars and Moon. Especially, the cruising time in the interplanetary space is estimated to be ∼260 days (fast transit mission case) or ∼500 days (typical mission case) for a manned mission to the Mars (Hoffman and Kaplan, 1997). In addition to dose exposure during the transit, they will work on the Mars for 30 days (typical short mission case) or ∼458 days (typical long mission case). The radiation dose of interplanetary space cruising is recently reported to be 660 mSv for even shortest round-trip case to the Mars (Zeitlin et al., 2013). In the protection strategy using shielding materials (Wilson et al., 1997), an interplanetary spacecraft would require substantial shielding of 50 g/cm^2 of aluminum, if 500 mSv annual dose limit for astronaut exposure is not to be exceeded (Wilson et al., 2001).

The shielding effects have been verified for various materials such as aluminum and polyethylene on the ground-based beam experiments (e.g., Miller et al., 2003; La Tessa et al., 2005; Dewitt et al., 2009). In general, the hydrogenous materials would be most effective shields for space radiation due to the mass at both stopping and fragmenting of particles. However, at the current status, the radiation protection still depends on the material with the thickness of a few g/cm^2 of vehicle walls and the internal equipments of the ISS module. As an another protection method, the active shielding with electrostatic and magnetostatic fields deflecting ionized particles from a region surrounding the spacecraft has been verified long years ago (Sussingham et al., 1999). However, there are still several issues to be addressed, which are about the realistic configuration such as coils, power sources, refrigeration, and support structure and the advantage compared with the passive method from the viewpoint of total mass to be installed in spacecraft (Townsend, 2005).

In this paper, we present the dose reduction effects for space radiation by the additional water shielding material ("protective curtain") of stack board consisting of the hygienic wipes and towels which have been already delivered to ISS. These materials will be delivered in the future missions to interplanetary. In this meaning, it is considered that the protective curtain is as one of ideal shielding materials.

2. Protective curtain and dosimeters

2.1. Protective curtain

The material of the protective curtain consists of the hygienic wipes and towels which have been already installed in the Russian Service Module as shown in Fig. 1. The hygienic tools were stored into the protective curtain at 4 layers, which is corresponding to the additional water shielding thickness of 6.3 g/cm^2. The total mass of the protective curtain is 67 kg, it was installed along the outer wall of the starboard crew cabin in the Russian Service Module.

2.2. Passive dosimeter packages

A combination of thermoluminescence detectors (TLD) and plastic nuclear track detectors (PNTD) was employed as the dose evaluation method of space radiation, which covers whole LET range relevant to radiation protection in spaceflight. TLDs measure absorbed dose from photons and charged particles with high efficiency for $LET_\infty H_2O$ <10 keV/μm, while PNTDs measure the LET spectrum, absorbed dose, and dose equivalent from charged particles of $LET_\infty H_2O$ >10 keV/μm. The data from the two types of detectors were combined to yield values of total absorbed dose and total dose equivalent accumulated over the duration of the exposure (Doke et al., 1995; Benton et al., 2002; Hajek et al., 2008; Tawara et al., 2011).

Four types of TLDs provided from three participating institutes, as summarized in Table 1, and one of PNTD (CR-39 HARZLAS TD-1 manufactured by Fukuvi Chemical Industry, Japan) were employed. The size of PNTD was 26 mm × 26 mm × 0.9 mm. A dosimeter package consists of three layers which are two PNTD plates and one TLD holder. For the purpose of intercomparison of dose measurement by several types of TLD in space, each TLD has been independently analyzed in each institute following its own protocol. The PNTD has been analyzed in NIRS and NPI with a high speed imaging microscope system (Yasuda et al., 2005) after the chemical etching for 8 h in 7 N NaOH solution at 70 °C. The mean value of amount of bulk etch was 14.6 ± 0.7 μm. All detectors have been calibrated by means of heavy ion beams from HIMAC (Heavy Ion Medical Accelerator in Chiba) at NIRS (NIRS report, 2009).

3. Experiment

The 12 dosimeter packages (#001–#012) were installed in the Russian Service Module of the ISS from June 16, 2010 to November 26, 2010. The exposure duration was 163 days. Half of the packages were located at the