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Verification of cosmic neutron doses in long-haul flights from Japan

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ABSTRACT

International Commission on Radiological Protection recommends that aircraft crew and frequent flyers be informed of their individual doses received from cosmic radiation onboard aircrafts. The cosmic radiation dose in aviation is generally assessed by model calculations. In Japan, the code "JISCARD EX" is used since 2007 for management of cosmic radiation exposure of aircraft crew. In the present study, the precision of this code was investigated in regard to neutrons which contribute the most to the effective dose in aviation. Measurements of cosmic neutrons were performed with two moderator-type neutron monitors having different response functions: a conventional-type rem meter (NCN1) and an extended energy-range rem meter (WENDI-II) in four long-haul flights to Singapore, Sydney, Washington, D.C. and London from Japan (Narita or Kansai airport). Through the combined analyses of these measurements, the contribution of high-energy (> 15 MeV) neutron component was estimated. The ambient dose equivalents, H*(10), measured with WENDI-II agreed well with the calculations made by JISCARD EX, while the contribution of the high-energy component obtained as the difference between the measured H*(10) values of two monitors was systematically higher than the model calculations.

1. Introduction

We are continuously exposed to galactic- or solar-origin cosmic-ray particles (hereafter "cosmic radiation"). The dose level of the cosmic radiation is elevated with altitude; it becomes about 100 times higher at the cruising altitude of a commercial jet aircraft than on ground. Thus, the International Commission on Radiological Protection (ICRP) recommends that exposures to cosmic radiation of aircraft crew be considered as an occupational exposure (ICRP, 1991; 2007). Following the recommendations of ICRP, the European Union introduced a revised Basic Safety Standards Directive which included cosmic radiation exposure of aircraft crew as occupational exposure (European Union, 1996). The revised Directive has been incorporated into laws and regulations in the European Union Member States (Bartlett, 2004). Also, the Government of Japan established a guideline for management of cosmic radiation exposure of aircraft crew (MEXT, 2006; Yasuda et al., 2011). In addition, ICRP recently recommended that frequent flyers also be informed of their dose levels in aviation while their exposure be categorized as public exposure (ICRP, 2016). The points of this recommendation are summarized in Table 1.

The individual doses received by aircraft crew and frequent flyers onboard aircrafts are generally assessed using numerical codes. Several easy-to-use program packages for aviation dose calculations were developed and have been offered by different groups (FAA, 2018; HMGU, 2018; IRSN, 2018; PCAire Inc., 2018; QST, 2018). For verification of the accuracies of those programs, measurements of cosmic radiation in aviation were performed by using portable instruments such as battery-operated Si semiconductor detectors and tissue-equivalent proportional counters (TEPC) on chartered or commercial aircrafts and compared to the calculations made by various numerical codes (Beck et al., 1999; Schrewe, 2000; Spurny et al., 2003; Bottollier-Depois et al., 2004; Wissman et al., 2004; EC, 2005; Lillhok et al., 2007; Latocha et al., 2007; Yasuda et al., 2009; Ploc et al., 2011; Kubančák et al., 2015; Meier 2016). However, a considerable uncertainty still remains in neutron doses at aviation altitudes, particularly contribution of the high-energy neutron component because of the intrinsic low sensitivity of the semiconductor detector or TEPC; the small mass of the sensor probe could have limited recoil reactions produced by neutrons. It was reported that TEPC could measure lineal energy (y_D) for monoenergetic neutrons up to 20 MeV and then would need extrapolation to total dose equivalents including the contribution of the higher energy component with a help of numerical simulation (Lillhök et al., 2007). In general, measurements of high-energy neutrons require a large-scale device coupled with a bulky moderator which is often difficult to use on a

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Table 1
Recommendations of ICRP for the individuals exposed to cosmic radiation in aviation (ICRP, 2016).

Reference level	Exposed individuals	Recommendations	Categories of exposure
To be selected as a lower value in the 5–10 mSv per year range	Occasional flyers	General information	Public
	Frequent flyers	General information	Public[a]
		Self-assessment of doses	
		Adjustment of flight frequency as appropriate	
	Aircraft crew	Individual information	Occupational
		Assessment of individual doses	
		Recording of individual doses	
		Adjustment of flight schedules as appropriate	

[a] Some groups of frequent flyers may be managed in a manner similar to those occupationally exposed on a case-by-case basis according to the prevailing circumstances.

commercial aircraft due to the limitations of space and weight.

While, the accuracy of the calculated neutron dose in aviation is important because it is known that neutrons are strongly contributing to the effective dose at aviation altitudes, in particular, the high-energy neutrons with energies greater than 20 MeV (Sato et al., 2008). With this thought, we consulted airline companies in Japan for using moderator-type neutron monitors onboard commercial aircrafts and successfully got their permission and support to perform measurements of cosmic neutrons in selected long-haul flights.

2. Measurement procedure

2.1. Instruments

Two transportable neutron monitors that are commercially available were employed for in-flight measurements of cosmic neutrons. The monitors were (1) a conventional moderating rem meter composed of a ϕ1.5 cm ^{3}He proportional counter and a ϕ25 cm polyethylene sphere (NCN1, Fuji Electric Systems Co. Ltd., Tokyo, Japan) and (2) an extended-energy-range rem meter consisting of a 1.5 cm ^{3}He proportional counter with a tungsten powder shell embeded in a ϕ25 cm polyethylene column (WENDI-II, Ludlum Measurements Inc., Texas, USA, as of 2009). The appearances of these monitors are shown in Fig. 1. Each monitor gives an ambient dose equivalent, H*(10), as the product of the pulse counts generated from ^{3}He (n, α)Li reactions with moderated thermal neutrons and a specific conversion coefficient determined using various neutron sources. Major physical properties of these monitors are summarized in Table 2. More details on the dosimetric properties of NCN1 have been reported by Nakane et al., (2004) while those of WENDI-II were presented by Olsher et al., (2000; 2008).

The coefficient values for converting the counts obtained by the two monitors to the H*(10) values were confirmed by the authors through calibrations using a traceable standard ^{241}Am-Be neutron source at the Institute of Radiation Measurements, Ibaraki, Japan (IRM, 2018). It was confirmed that both monitors had negligibly low sensitivities to photons from ^{60}Co and ^{137}Cs sources; thus, the threshold for n/γ discrimination was set as a default value. In addition, their negligible responses to energetic protons (~230 MeV) were roughly confirmed at Heavy Ion Medical Accelerator in Chiba (HIMAC) in Japan. An exclusive commercial data logger (Model 2350–1, Ludlum Measurements Inc.) was connected to WENDI-II and an originally developed data logger with the USB2.0 interface was used for NCN1.; both data loggers were operated with dry batteries. The combined set of each monitor and the data logger were put into a carry-on bag made of vinyl sheet as shown in Fig. 1.

2.2. Flights

Cosmic neutron measurements onboard commercial aircrafts were carried out during the solar minimum from February to March 2009 on four long-haul flights from Tokyo/Narita (IATA airport code: NRT; location: N35.8°, E140.4°) or Osaka/Kansai (KIX; N34.4°, E135.2°), Japan, to four cities: Singapore/Changi (SIN; N1.4°, E104.0°), Washington DC/Dulles (IAD; N39.0°, W77.5°), Sydney (SYD; S33,9°, E151.2°) and London/Heathrow (LHR; N51.5°, W0.5°). The flight routes are illustrated in Fig. 2 and selected information on the flight conditions are shown in Table 3. The carry-on bags containing the monitors and the data loggers (see Fig. 1) were fixed to two passenger seats except for one flight to Washington, DC, in which the monitors were placed inside a container in the middle of the cabin space.

Time-lapse changes of the atmospheric pressure altitudes during the flights were automatically recorded with a built-in altimeter. The maximum cruising altitudes ranged from 37,000 ft to 40,000 ft. It was also confirmed with the companies that the temperature inside the aircraft was maintained in the range of 20–25 °C and the cabin pressure of 0.8–1.0 atm. Pulse counts were recorded on the data loggers at 2-min

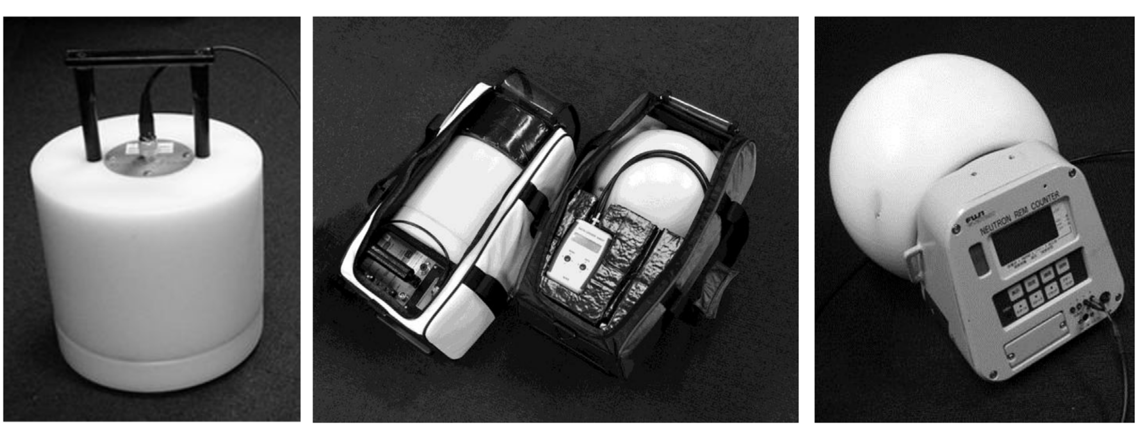

Fig. 1. The moderator-type neutron monitors employed for the in-flight measurements: WENDI-II (left) and NCN1 (right); those were coupled with the exclusive data loggers and then contained in carry-on bags of vinyl sheets (center).