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Publicly available database of measurements with the silicon spectrometer Liulin onboard aircraft

Ondrej Ploc [a, b, *], Iva Ambrozova [a], Jan Kubancak [a, c], Ivan Kovar [a], Tsvetan P. Dachev [d]

[a] Nuclear Physics Institute, AS CR, Prague, Czech Republic
[b] Chalmers University of Technology, Göteborg, Sweden
[c] Czech Technical University in Prague, Czech Republic
[d] Space and Solar-Terrestrial Research Institute of BAS, Sofia, Bulgaria

HIGHLIGHTS

- We've performed measurements with the silicon detector onboard aircraft since 2001.
- We created online database of aircrew doses and energy deposition spectra.
- High number of records ($>10^5$) provides good statistics of the results.
- The database is aimed on verification of routine calculations of aircrew doses.
- The database enables studies via dependencies of dose rates on flight parameters.

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ABSTRACT

Aircrew members are exposed to ionizing radiation due to their work onboard aircraft. ICRP recommended the monitoring of their effective doses because they regularly exceed the limit of 1 mSv per year for the public exposure. The effective doses are routinely calculated by computer codes that take into account flight parameters like altitude, geographic position, and solar activity. This approach was preferred against personal dosimeters method because the effective dose cannot be evaluated experimentally. However, it is generally accepted, that these calculations should be periodically verified by measurements of $H^*(10)$ which is frequently used as a surrogate for effective dose. This report refers about the database (available online http://hroch.ujf.cas.cz/~aircraft/) of long-term measurements with the silicon spectrometer Liulin onboard aircraft. The measurements have been performed since March 2001; so up to date, the database covers a period of 11-years (with a few interruptions) which is usually the duration of the whole solar cycle. The database comprises more than 10^5 individual records of energy deposition spectra, absorbed dose rates, and ambient dose equivalent rates. Each record contains also the information on all flight parameters needed for calculation of dosimetric quantities by the computer codes, and thus the database represent an useful tool for verification of the routine dosimetry of aircraft crews.

1. Introduction

The International Commission on Radiological Protection has recommended (ICRP, 1991) that the radiation exposure due to the cosmic radiation onboard aircraft should be taken into account as a part of an occupational exposure. This recommendation was incorporated into the legislation of many countries, and thus all airlines operating at these countries are obliged to monitor annual effective doses of their pilots and flight attendants. This duty is fulfilled via calculations by computer codes; however, they should be periodically verified by measurements not only because of the recommendation given by (ICRP, 1997) but also because of exploration of systematical errors in the routine method of aircrew dosimetry. Many measurements have been performed at flight altitudes (Lindborg et al., 2004) but long-term measurements covering the whole solar cycle were missing. Here, we are presenting unique, publically available database of such long-term measurements performed onboard aircraft with the semiconductor

* Corresponding author. Nuclear Physics Institute, Department of Radiation Dosimetry, Na Truhlářce 39/64, 18000 Prague, Czech Republic. Tel.: +420 266 177 220; fax: +420 283 842 788.
E-mail address: ploc@ujf.cas.cz (O. Ploc).

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spectrometer Liulin. The detector has been placed in the cabin of Czech Airlines aircraft since March 2001. The database, which comprises several thousand flights and more than 10^5 individual records with information on the energy deposition spectra, absorbed dose rates and ambient dose equivalent rates measured with the Liulin, is available on the internet (http://hroch.ujf.cas.cz/~aircraft/). It can be applied for instance for the verification of computational programs routinely used for the estimation of aircrew exposure to cosmic radiation. For example, the routine aircrew dosimetry in the Czech Republic (Malusek et al., 2011) is performed with the CARI-6 code (Friedberg et al., 1992). Therefore, most of results in this paper are presented via the measured ambient dose equivalent $H^*(10)$ related to the effective dose E calculated with the CARI-6.

As mentioned above, the effective dose is used for the purposes of dose limitation and control; it can be calculated by the computer codes but cannot be measured experimentally. Therefore, $H^*(10)$ is usually measured in experiments and, for the radiation fields in the aircraft, it is a conservative estimate of the effective dose E (ICRU, 2010). More about the relation of these two quantities is described in Lindborg et al. (2004). New radiation weighting factors for protons and neutrons introduced in ICRP 103 recommendation (ICRP, 2007) are not considered in the CARI 6 code. According to Mares et al. (2009) and the EXcel-based Program for calculating Atmospheric Cosmic-ray Spectrum (EXPACS) (Sato and Niita, 2006), the effective doses at flight altitudes calculated using the ICRP 103 weighting factors are between 19% and 25% (depending mainly on altitude and VCR) lower than those calculated using ICRP 60 weighting factors. CARI 6 also does not consider shielding by the structure of the aircraft; the E is calculated in free atmosphere. The real doses inside the plane can be lower (depending on the type of aircraft, position inside, amount of fuel, number of passengers etc. (Ferrari et al., 2004). Therefore the measurements with the detector onboard aircraft are important also due to the effect caused by the construction materials of aircraft.

However, the aim of this paper is to present the database of measurements with silicon detector Liulin. The discussion on problems with comparison of calculated and measured data is behind the scope of this paper.

2. Liulin

The active detector Liulin measures mixed radiation fields, such as those onboard spacecraft (Dachev et al., 2011b), aircraft (Spurny and Dachev, 2002; Ploc et al., 2011), at alpine observatories and at heavy ion accelerators (Dachev et al., 2011a). In a radiation field, the Liulin spectrometer detects the energy, ε, deposited in its active volume (silicon diode) in a single energy deposition event. The built in electronics records the spectrum of ε by incrementing by one the content of the bin corresponding to this energy. The 256 channel spectrum is then used to calculate the absorbed dose to silicon and the flux of particles that imparted a detectable amount of energy to the active volume of the detector. Energy deposition calibration and absorbed dose calculation is described in Uchihori et al. (2002). After an appropriate calibration, Liulin also gives an estimation of the ambient dose equivalent $H^*(10)$.

The procedure of $H^*(10)$ evaluation for radiation field onboard aircrafts with Liulin is performed in several steps, as follows. First, the energy deposition spectra are transformed to the absorbed dose in silicon, D_{Si}, using the following equation

$$D_{Si} = \frac{1}{m}\sum_{i=1}^{256} N_i\varepsilon_i \qquad (1)$$

where $m = 1.398\ 10^{-4}$ kg is the mass of the active volume of the detector, ε_i is the deposited energy in the centre of the imparted energy bin i, and N_i is the number of events corresponding to bin i.

The absorbed dose is then divided into two parts, $D_{\rm low}$ and $D_{\rm neut}$ defined as

$$D_{\rm low} = \sum_{\varepsilon<1\ \rm MeV} N_i\varepsilon_i \qquad (2)$$

and

$$D_{\rm neut} = \sum_{\varepsilon\geq 1\ \rm MeV} N_i\varepsilon_i, \qquad (3)$$

supposing that detector's signal bellow and above 1 MeV is caused by low LET particles (electrons – including those from photon interactions, positrons, muons, and high energy protons and alphas) and neutrons or neutron-like particles (low energy protons and alphas), respectively. Finally, $H^*(10)$ is calculated as

$$H^*(10) = k_{\rm low}D_{\rm low} + k_{\rm neut}D_{\rm neut} \qquad (4)$$

where $k_{\rm low}$ and $k_{\rm neut}$ are calibration coefficients obtained in the CERN-EU high energy Reference Field (CERF) facility. CERF provides a reference on-ground base for testing, intercomparing and calibrating passive and active instruments before their use on-board aircraft (Mitaroff and Silari, 2002). The coefficient $k_{\rm low}$ was evaluated as ratio of the low-LET-component (<10 keV/μm) of the ambient dose equivalent measured in CERF with the tissue-equivalent proportional counter (TEPC) HAWK (Lillhök et al., 2007) and $D_{\rm low}$. The coefficient $k_{\rm neut}$ was evaluated as ratio of the CERF's neutron reference value of the ambient dose equivalent calculated with Geant4 (Mitaroff and Silari, 2002) and $D_{\rm neut}$. More information about the calibration method of Liulin in terms of $H^*(10)$ and its use onboard aircraft can be found, for example, in Ploc et al. (2011). The total uncertainties of $H^*(10)$ evaluated with Liulin onboard aircraft is estimated as 15% according to Lindborg et al. (2004).

3. The database

Liulin has been used for long-term cosmic radiation measurements onboard the Czech Airlines aircraft since March 2001 (Spurny et al., 2007; Ploc and Spurny, 2007; Malusek et al., 2011). The detector has been mounted inside the aircraft close to and inside the aircraft cockpit, oriented with the largest area (2 cm^2) of the PIN diode up to the sky. After a certain period of time (run), the data recorded in the Liulin memory were downloaded and batteries were changed.

During the monitored period (2001–2011), both – the Liulin type and the aircraft type were changed: MDU-5 (run 1–21), MDU-6 (runs 22–31), Airbus A310-300 (runs 1–26), and Airbus A319-112 (runs 27–31). Because both Liulin units were calibrated in the same radiation field (CERF) they give the same results within ±5%. The effect of different aircraft type can also be a few percent (ICRU, 2010; Battistoni et al., 2005); since the detector was placed at the pilot location (wall between corridor and cockpit in the case of A310 and cockpit in the case of A319) and the detector's side with Si-diode was always facing towards the sky, we suppose that the change of the aircraft had only a minor effect to the resulted data. The run duration was 48 days and 69 days on average for MDU-5 and MDU-6, respectively.

Many routes from Europe to North- and South America have been measured as well as inner European routes and some routes to the east. From 2001 to 2009, the most frequent were transatlantic