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Long-term dose measurements applying a human anthropomorphic phantom onboard an aircraft

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Abstract

The exposure of aircrew personnel to cosmic radiation has been considered as occupational exposure in the European Union since the European Council Directive 96/26/EURATOM became effective on 13th May 1996. In Germany the corresponding safety standards for aircrew are regulated by the German Radiation Protection Ordinance, which implemented the European law in 2001. The radiation exposure of the flight crew of the LUFTHANSA group is calculated by the DLR Institute of Aerospace Medicine in Cologne, applying the calculation program EPCARD in the framework of the aircrew dose determination system CALculated and Verified Aviation DOSimetry (CALVADOS). Besides the operational dose calculations, DLR performs measurements at airflight altitudes using active (e.g. TEPC, DOSTEL, etc.) and passive (Thermoluminescence detectors (TLDs), bubble detectors) radiation detectors to verify the calculation codes. Within these activities the project BOdy DOsimetry (BODO) comprised a long-term exposure of a RANDO© anthropomorphic phantom to measure the skin and the depth dose distribution inside a human torso applying TLDs at aviation altitudes for the first time. The torso was flown onboard a LUFTHANSA Cargo aircraft for 3 months from mid of July to mid of October 2004. Over 800 TLDs were positioned for depth dose measurements in the head, the thorax and the abdomen of the torso. In addition dosemeter packages have been distributed on the surface of the torso to measure the skin dose as well as in the transport container and on the flight deck.
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Keywords: Aircrew dosimetry; Thermoluminescence detectors; Depth dose distribution; TLD 600; TLD 700

1. Introduction/scope

The atmosphere of our Earth is a massive shield protecting life on Earth from cosmic radiation. At sea level the thickness of the atmosphere is 1033 g/cm^2. At aviation altitudes, ranging from 9 to 12 km, the shielding is reduced to 300–190 g/cm^2, resulting in a higher exposure to cosmic radiation. The radiation field in flight altitudes is composed of the primary radiation components and the secondary products produced by the interaction of the primary particles with the atoms of the atmosphere. The radiation exposure is dependent on the altitude, the latitude—due to the Earth magnetic field—and the solar cycle—due to the variation of the cosmic ray particle flux.

In its Council Directive 96/26/EURATOM (EURATOM, 1996) the European Union declared aircrew members as occupational workers. The European countries have a legal obligation to monitor the radiation exposure of aircrew. Monitoring is mostly achieved by the calculation of route doses applying accredited software. In Germany DLR is calculating the doses for LUFTHANSA in the framework of the CALculated and Verified Aviation Dosimetry (CALVADOS) system (Facius and Meier, 2005). Besides the calculation of route doses, DLR performs regular measurements in flight altitudes with active and passive radiation detector systems. As a part of these measurement campaigns, an anthropomorphic phantom equipped with passive thermoluminescence detectors (TDLs) of the types TLD 600 and TLD 700 was flown onboard a LUFTHANSA Cargo plane to measure the skin and the depth dose distribution for the first time.

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2. Materials and methods

2.1. The BODO experiment

From mid-July to mid-October 2004 an anthropomorphic upper torso was flown onboard a LUFTHANSA Cargo plane

Fig. 1. BODO inside the aluminum transport container.

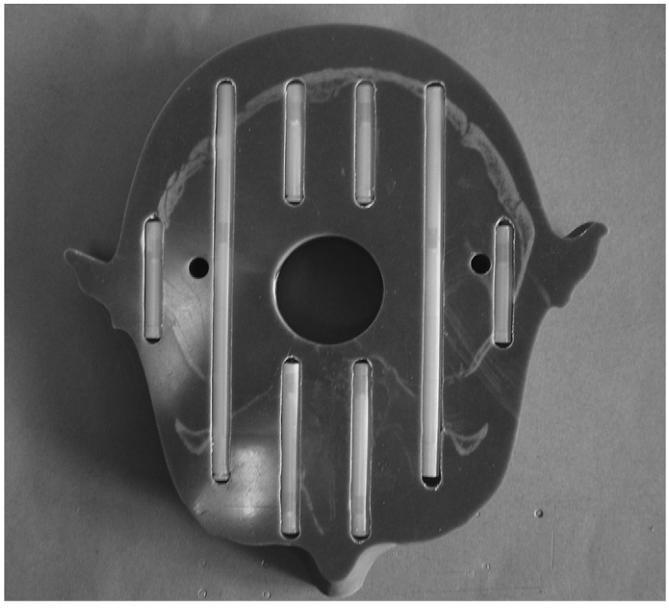

Fig. 2. Slice #4 equipped with TLD tubes for the depth dose measurement into the phantom head.

(see Fig. 1). The torso made of human bones embedded in polyurethane takes into account the different density of the lungs and consists of 28 slices—each 25 mm in height. Three of the slices (#4—head, #16—shoulder, #24—lower torso) were equipped with TLDs ($3.4 \times 3.4 \times 0.9$ mm) of the types TLD 600 (^{6}LiF : Mg, Ti) and TLD 700 (^{7}LiF : Mg, Ti). The TLDs were put into polyethylene tubes. Spacers of polyethylene are used inside the tubes, to enable measurement positions every 25 mm. Fig. 2 shows the flight configuration of the Slice #4. Each measurement point consists of 4 × TLD 700 and 4 × TLD 600 detectors.

Besides the TLDs in the phantom, TLDs were distributed in polyethylene holders (seven packages) to measure the skin dose as well as the dose on the aluminum container and in the flight deck (see Table 1 for the location of the packages). Each package contained 8×TLD 600 and 8×TLD 700. Due to storage reasons the phantom was positioned lying on its back for the whole exposure period, which summed up to 900 flight hours during the 3 months.

2.2. Dosemeter readout, calibration and analysis

TLD 600 and TLD 700 produced by Thermo Fisher Scientific Inc.—formerly Harshaw—in the dimensions of 3.4 × 3.4 × 0.9 mm were selected for the project. The TLDs were individually calibrated at the "Material Testing Institute MPA—NRW" with a secondary standard ^{137}Cs-calibration source approved by the National Metrology Institute, PTB, Germany. All readouts were performed with a Harshaw 5500 reader, using flow of pure nitrogen (purity 5.0) with a heating rate $\beta = 5\,^{\circ}$C/s from 100 to 400 °C. For the subtraction of the background signal, each TLD was heated a second time. Data evaluation was performed by using the peak 5 heights of the glowcurves. Annealing was performed for 1 h at 400 °C, following 2 h at 100 °C and slow cool down to room temperature. The total duration of the Body Dosimetry (BODO) experiment was 2160 h, whereas the total duration of the BODO experiment onboard the aircraft was only 900 h. Since the average background dose measured at the laboratory at DLR accounts to 80 nGy/h, the background dose which needs to be subtracted from the flight measurements has been calculated to be 101 μG. All dose values shown are averaged data over four to eight TLD measurements.

Table 1
Absorbed dose values for TLD 600 and TLD 700 for the seven "skin" dose packages. Also given is the γ-equivalent neutron dose derived by subtraction of the TLD 700 from the TLD 600 dose value

Position #	Dose (mGy) TLD 600	Dose (mGy) TLD 700	γ-Equivalent neutron dose (mGy)
#1 Upper torso front	2.39 ± 0.12	1.38 ± 0.02	1.01 ± 0.12
#2 Lower torso front	2.26 ± 0.03	1.40 ± 0.04	0.86 ± 0.05
#3 Lower torso right side	2.35 ± 0.02	1.32 ± 0.05	1.03 ± 0.06
#4 Lower torso left side	2.26 ± 0.08	1.37 ± 0.02	0.89 ± 0.08
#5 Aluminum box lower torso	2.10 ± 0.08	1.43 ± 0.04	0.67 ± 0.09
#6 Aluminum box torso head	2.18 ± 0.03	1.45 ± 0.03	0.73 ± 0.04
#7 Flight deck	2.54 ± 0.08	1.48 ± 0.03	1.07 ± 0.09

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