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Analysis of neutron and gamma ray doses accumulated during commercial Trans-Pacific flights between Australia and USA

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Abstract

During recent commercial Trans-Pacific passenger flights between Sydney and several major cities in the USA, the neutron and gamma dose equivalents in the aircraft cabin were evaluated with superheated Bubble dosimeters, thermoluminescence dosimeter chips (TLD-600 and TLD-700) and a miniature electronic dosimeter. After a total 73-hour flight time the accumulated neutron and gamma dose equivalents were evaluated to be 39.7 μSv and 74.0 μSv respectively. The thermoluminescence (TL) glow curves of the dosimeter chips were assayed at a ramp heating rate of 10°C s^{-1} up to 400°C. By using the Bubble and electronic dosimeter data it was possible to isolate explicitly the neutron and gamma dose components from the deconvoluted TL-glow curve of the TLD-600 chips. The application of Bubble dosimeter and TLD for an accurate estimation of the radiation exposure to air crews and frequent flying passengers is suggested.

1. Introduction

At high cruising altitudes the cabin crews, pilots and passengers in commercial jetliners are exposed to radiation fields above the natural background level (O'Brien et al., 1992). These radiations are primarily fast neutrons, muons and bremsstrahlung photons produced by the galactic cosmic ray induced reactions in the upper atmosphere and to a lesser extent in the structure of the aircraft itself (Reitz, 1993). The levels of the radiation exposure in the high altitude aircraft are directly related to flight duration, altitude, geographical latitudes traversed by the flight path, time of the year and the intensity of the solar activity (Reitz, 1993).

The radiation doses in commercial passenger jet airliners during the flights in numerous Northern Hemisphere destinations in Europe (Reitz, 1993; Regulla and David, 1993; Bartlett, 1993) and in America (Lewis et al., 1994) have been evaluated using various types of active and passive dosimeters and reported elsewhere. Also, the in-flight radiation dose data in Frankfurt–Singapore–Sydney–Melbourne (Regulla and David, 1993) and in major Australian domestic routes (Wilson et al., 1994) have been investigated. On the other hand, no relevant data for the commercial flights between south-pacific region to North America has yet been published. In this paper the results of an in-flight neutron and gamma dose analysis experiment between Sydney and some major US cities are presented.

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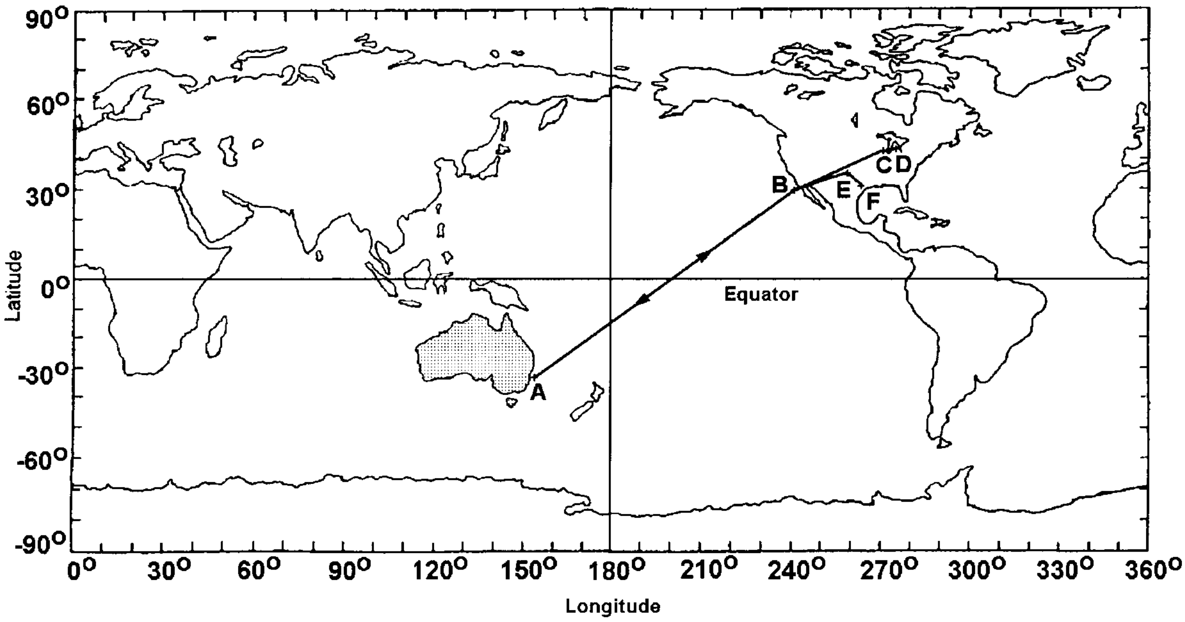

Fig. 1. Map showing the paths of the Trans-Pacific flights originated from Sydney Australia and the destinations in the USA. Legend: (A) Sydney, (B) Los Angeles, (C) Chicago, (D) Lansing, (E)Denver, (F) Austin.

2. Materials and methods

A pair of superheatd Bubble dosimeters (Model: BD100R) developed and marketed by the Bubble Technology Industries Inc, Chalk River, Canada (Ing et al., 1997), a miniature battery powered personal electronic dosimeter (Model: RAD-50 S, manufacturer: Rados Technology Oy, Turku, Finland) and a Hankins type personnel dosimeter (Hankins, 1973) consisting of TLD-600 and TLD-700 thermoluminescent dosimeter chips (manufacturer: Harshaw Chemical, Cleveland, USA) were carried in hand luggage during the flights between Sydney and the USA destinations (Fig. 1) in two trips separated by two weeks. The details of the flight schedules are presented in Table 1.

Prior to boarding the aircraft the Bubble dosimeters were initialised by loosening the piston-lid and placed in the airtight aluminium can (Ing, 1991). The TLD dosimeters consisting of five pairs of TLD-600 and TLD-700 dosimeter chips (Dimension: $0.32 \times 0.32 \times 0.09$ cm^3) were annealed (400°C for 1 h, then naturally cooled to ambient temperature) in a hot air oven (Mukherjee, 1997), and finally enclosed in a Hankins-dosimeter cartridge (dimension: 40 mm $\times$ 28 mm $\times$ 9 mm). The dosimeter cartridge was from a 3.2 mm thick polyethylene sheet housed in a cadmium box of 1.5 mm wall thickness (Hankins, 1973). During the air travel critical fight data including the altitudes and flight duration was carefully recorded (Table 1).

The BD100R Bubble dosimeters and the RAD-50 S personal electronic dosimeter were read out immediately upon completion of each flight section and the results are shown in Table 1. A week after the end of the second trip all TLD chips were evaluated with a computerised TLD reader (Model: RIALTO, Nuclear Enterprise, UK) at the ramp heating rate of 10°C s^{-1} to 400°C and the glow curves were stored in the computer memory.

Five pairs of the same type of dosimeter chips kept as control at our laboratory in Sydney, were evaluated simultaneously and glow curves were subtracted from the corresponding dosimeters of the previous batch to produce the resultant glow curves as shown in Figs. 2(a) and 2(b). The high temperature (~280°C) glow peak of the TLD-600 dosimeters (Fig. 2(b)) were deconvoluted using the Podgorsak approximation of the first order TL-kinetics model (Mukherjee, 1997).

The accuracy of the RAD-50 S electronic dosimeter and BD100R bubble dosimeter pair were evaluated in our laboratory by irradiating them with standard neutron and gamma radiation fields (Regulla and David, 1993). The RAD-50 S electronic dosimeter was exposed successively five times to 100 μSv using a ^{60}Co standard source (activity: 3.7 GBq). The BD100R bubble dosimeters were also irradiated five times with neutrons from a ^{241}Am/Be neutron source (strength:

Table 1
Showing the details of the transpacific flights from Australia to USA undertaken during 31 October–20 December 1998. The total exposure time of the dosimeters for the two flights was 73 hours. The integrated neutron and gamma dose equivalents were evaluated with the superheated bubble dosimeter (BD100R) and personal electronic dosimeter (RAD-50 S) were found to be 39.7 μSv ± 13% and 74.0 ± 10% μSv respectively. The standard deviations shown in columns 7 and 8 were calculated from a separate set of experimental data obtained by irradiating the dosimeters with known neutron and gamma doses from the standard sources

Route	Geographical location	Date	Carrier[a]	Duration	Altitude (m)	Gamma dose	Neutron dose
Sydney/LA	33°52′S, 151°13′E/34°03′N, 118°13′W	31-10-98	+ B747	13 h 25 min	11000 ± 550	17 μSv ± 10%	12.7 μSv ± 13% (28 bubbles)
LA/Chicago	34°03′N, 118°13′W/41°54′N, 87°38′W	31-10-98	+ B757	03 h 53 min	8000 ± 400		
Chicago/Lansing	41°54′N, 87°38′W/42°45′N, 84°30′W	01-11-98	Unknown	00 h 53 min	~ 5000		
Lansing/Chicago	42°45′N, 84°30′W/41°54′N, 87°38′W	04-12-98	+ + A320	00 h 53 min	8000 ± 400	20 μSv ± 10%	11.6 μSv ± 13% (26 bubbles)
Chicago/LA	41°54′N, 87°38′W/34°03′N, 118°13′W	04-12-98	+ B757	03 h 53 min	8000 ± 400		
LA/Sydney	34°03′N, 118°13′W/33°52′S, 151°13′E	06-12-98	+ B747	13 h 25 min	11000 ± 550		
Sydney/LA	33°52′S, 151°13′E/34°03′N, 118°13′W	14-12-98	+ B747	14 h 12 min	11000 ± 550	20 μSv ± 10%	5.45 μSv ± 13% (12 bubbles)
LA/Denver	34°03′N, 118°13′W/39°46′N, 104°56′W	15-12-98	+ B757	02 h 20 min	9000 ± 450		
Denver/Austin	39°46′N, 104°56′W/30°18′N, 97°41′W	15-12-98	+ B737	01 h 40 min	9000 ± 450		
Austin/Denver	30°18′N, 97°41′W/39°46′N, 104°56′W	19-12-98	+ B757	02 h 00 min	9000 ± 5%	17 μSv ± 10%	9.99 μSv ± 13% (22 bubbles)
Denver/LA	39°46′N, 104°56′W/34°03′N, 118°13′W	19-12-98	+ B727	02 h 06 min	9000 ± 5%		
LA/Sydney	34°03′N, 118°13′W/33°52′S, 151°13′E	20-12-98	+ B747	14 h 20 min	11000 ± 5%		

[a] + Boeing, + + Airbus.

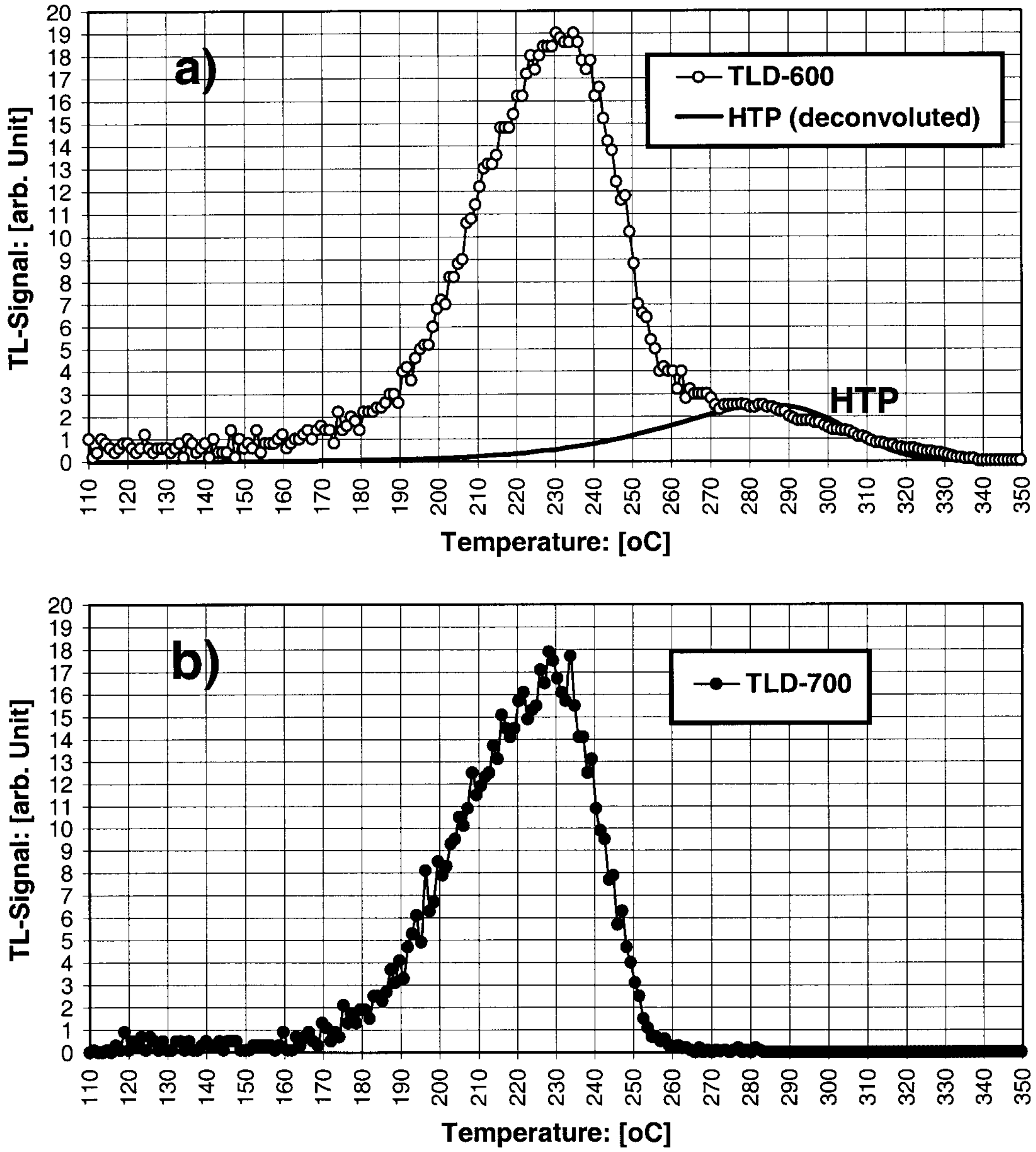

Fig. 2. Showing the background subtracted glow curves of: (a) TLD-600 and (b) TLD-700 chips exposed during the Trans-Pacific flights to USA. The TLD chips were read at a heating rate of 10°C s^{-1} to 400°C. Each data point indicates the average TL-signal output from five chips in the corresponding batch. The high temperature glow peak (HTP) of the TLD-600 glow curve was deconvoluted suing the Podgorsak approximation of the first order TL kinetics model.

2.176×10^7 neutron s^{-1}) to 50 μSv. After each radiation exposure, the electronic gamma dosimeter (RAD-50 S) and bubble neutron dosimeter (BD 100R) were evaluated, and then initialised according to the prescribed operating procedure for the following exposure run. The neutron and gamma radiation exposures took place in the air-conditioned laboratory at about 22°C, emulating the cabin temperature of a commercial passenger aircraft.

3. Results and discussion

The present investigation demonstrates the use of superheated Bubble dosimeters, and Geiger–Mueller tube based electronic personal dosimeter to estimate the in-flight neutron and gamma exposures accurately to low dose levels. The neutron and gamma dose equivalents for the two Trans-Pacific flights of 73 hours total duration were found to be 39.7 μSv and 74.0 μSv respectively (Table 1).

The dose readouts of the dosimeters exposed to standard neutron and gamma radiation fields were analysed. The mean dose equivalent and standard deviation ($\pm\sigma\%$) for five each gamma and neutron exposures were evaluated to be 98 μSv ± 10% (gamma) and 46 μSv ± 13% (neutron). These experimentally determined uncertainties were considered to be valid for the actual irradiation scenarios during the flight and therefore, included in the dose results shown in columns 7 and 8 of Table 1.

The areas under the glow curves of the TLD-600 and TLD-700 dosimeters were evaluated to be 939 counts and 682 counts respectively (Figs. 2(a) and 2(b)). The higher counts of the TLD-600 net glow curve area and the presence of the characteristic high temperature glow peak (HTP) at ~280°C imply that the TLD-600 dosimeters are sensitive to both neutrons and photons. In particular, the high temperature peak, which corresponds to a distribution of deeper traps in the TL phosphor was solely caused by the neutron induced $^{6}Li(n, \alpha)^{3}H$ reaction (Noll et al., 1996). Hence, the count data from the deconvoluted glow curve of the TLD-600 chips (Fig. 2(a)) was used to separate the neutron and gamma doses. The neutron (kn) and gamma (kg) dose coefficients of the TLD-600 chips were calculated as follows:

$$\text{kn}\ [\mu\text{Sv/count}] = \text{Dn}/A_{\text{HTP}} \quad (1a)$$

$$\text{kg}\ [\mu\text{Sv/count}] = \text{Dg}/(A_{\text{TOTAL}} - A_{\text{HTP}}) \quad (1b)$$

where Dn = accumulated neutron dose = 39.7 μSv (Table 1); Dg = accumulated gamma dose = 74.0 μSv (Table 1); A_{HTP} = counts under the deconvoluted high temperature glow peak = 136 (Fig. 2(a)); A_{TOTAL} = counts under the entire glow curve = 939 (Fig. 2(a)).

By substituting Dg, Dn, A_{HTP} and A_{TOTAL} in Eqs. 1(a) and 1(b) the values of kn and kg were calculated to be 2.92×10^{-1} [μSv/count] and 9.23×10^{-2} [μSv/count] respectively. It is evident that the neutron and gamma doses due to high altitude air travel could be estimated by deconvoluting the glow curve from a single TLD-600 chip and applying the neutron (kn) and gamma (kg) dose coefficients. The implementation of the miniature light weight Hankins type dosimeters described in this paper are found to be more suitable than the bulkier Bonner-Sphere based dosimeter described elsewhere (Noll et al., 1996). Further investigations to check the conformity of the values of kn and kg from other in-flight exposure data have been undertaken.

The RAD-50 S electronic gamma dosimeter is based on a miniature Geiger–Mueller (GM) tube filled with a mixture of methane (CH_4), Argon (Ar) and a trace amount of a quench halogen-gas (CF_3Br) at a very low pressure (Leo, 1994). The GM-detectors are insensitive to fast neutrons and the resulting recoiled charged particles (ICRU, 1977). Furthermore, the GM-detectors are primarily sensitive to gamma rays and their responses are independent of gamma energy over a wide range (Regulla and David, 1993). The response characteristics of the BD100R bubble dosimeters for fast neutrons from an ^{241}Am/Be source (Matiullah et al., 1998) and neutrons from a high energy particle accelerator (Tume et al., 1998) have been investigated by various researchers and found to be in compliance with the ICRP-60 recommendations. Hence, the above findings justify the experimental methods described in this paper.

Although these results generally confirm the radiation dose to aircrew and to passengers does have a substantial neutron component, as expected, the results also indicate that for flights within the commercial height range, aircrew, and frequent flying passengers, may well be subject to radiation dose levels significantly above that permitted for members of the 'public' under statutory recommendations (ICRP-60, 1990). It is therefore recommended that a more thorough investigation be carried out, particularly on the Pacific region long-haul routes.

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