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Estimation of radiation absorbed dose of aircrew in domestic flights

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Abstract

Objective
Cosmic radiations from outer space are continuously exposing the earth. Ambient dose rate at the atmosphere, apart from unusually and transient solar activities, is mostly a function of latitude and altitude. At aircraft altitude and temperate latitudes, it increases by a factor of 20-25. Therefore, aircrew and frequent flyers are exposed to high levels of cosmic radiation. This paper considers general radiation protection aspects of cosmic radiation exposure to aircrew in domestic flights in Iran.

Materials and Methods
Ambient dose rate in several domestic flights were measured using survey meter model RDS-110. Based on the measured data and duration of the flight, the effective doses of the aircrew were calculated and compared with that derived from radiation transport codes of CARI-6 introduced by Civil Aerospace Medical Institute, Oklahoma City, USA. Due to good agreement between measured and calculated values, the CARI-6 program was used to determine the dose rates in different altitude throughout the country to provide a simple algorithm for calculating route dose in domestic flights.

Results
Equivalent dose rate in domestic flight's altitude can be calculated from, $a(h)^b$ where h is the altitude in thousand feet; a and b are constants depending to geographic location. Based on the equivalent dose rate and the flight profile; simple algorithm provided to estimate the route dose in any domestic flights.

Conclusion
The annual dose limit of general population allows the aircrew to spend 290 hour in 27-33 thousand feet altitude in domestic flights; therefore, only female aircrew should be made aware of the need to control doses during pregnancy.

Keyword: Effective dose, Aircrew, Absorbed dose, Ambient dose equivalent.

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Introduction

The earth is continually bombarded by high-energy ionizing radiation from outer space. Cosmic radiation has a galactic component (GCR) which normally is dominant and a component from the sun called solar particle events (SPEs). The GCR in the local environments of the solar system consists of 2% electron and 98% nuclei, which are mostly protons and alpha particles with energy up to 10^{14} Mev. The SPEs are transient, unusually high levels of cosmic radiation, which are produced by sudden, sporadic release of energy in the solar atmosphere and by coronal mass ejection. Short-term perturbation in sun's magnetic field with increased solar activity causes the cosmic radiation dose in atmosphere extremely variable and depends on a 22-year solar activity cycle (1).

Near the earth the GCR and charged particle, from SPEs are affected by earth magnetic field; most of them deflected from equator and funneled into the Polar Regions. Therefore, cosmic dose rates are low near the equator and high in the polar regions (2). During SPEs (April 2001) significant increase in dose rate was observed for a period of 1 hour, the maximum dose rates was about double that for GCR, and total contribution to dose from SPEs was 20 μSv (3). Larger SPEs perhaps a few hundred μSv may occur with a frequency of about once a decade, and events of larger magnitude at a much lower frequency (4).

The dose rates from the combination of attenuation and particle production, increased with depth in the atmosphere reaching a maximum at 60000 ft (20 Km), then decreasing down to the earth's surface. At aircraft altitude and temperate latitudes, representative values of ambient dose equivalent are 55% due to neutron, 20% due to electron and positron, 15% due to proton, 5% due to photon, and 5% for muons. At see level, the dominant component of dose equivalent is due to the muon particles (1). At this height, the contribution to dose equivalent from energetic heavy charged particles is not significant (5).

To estimate radiation dose received by aircrew, personal dosimeter for routine use are not generally considered necessarily. The preferred approach for the assessment of dose of aircrew is to calculate effective dose per unit time as a function of geographic location, altitude and a solar cycle modulation; and then estimate the effective dose of aircrew individuals from these value and flight information profiles (6).

As cosmic radiation is included by ICRP in radiation protection recommendation, in this study it is aimed to provide a simple model for quick estimation of the effective dose of aircrew in domestic flights in Iran. Based on this data, the committed effective dose of the aircrew in one-year will be compared with the annual dose limits of the occupational radiation workers, general population and with the doses arising from some medical examinations.

Materials and Methods

As the effective dose is not a directly measurable quantity, the operational quantity of interest for radiation received by aircrew is ambient dose equivalent (7). There are numbers of radiation transport codes and program in current use to calculate ambient or route doses. In this study CARI-6, introduced by Civil Aerospace Medical Institute, Oklahoma City, USA, has been used. This program uses an anthropomorphic phantom to calculate effective dose of galactic cosmic radiation received by an adult on a nonstop aircraft flights during any month from 1958 to the present (web site at www.cami.jccbi.gov/radiation.html). It can also calculate the effective dose rate of any specific location in the atmosphere at altitude up to 60000 feet. The program takes into account the effects of solar activity and the geomagnetic field on galactic radiation levels for the date selected by the user. Radiation from SPEs is not taken into account by the program. Based on influence of aircraft shielding on the aircrew exposure, Ferrari et al. (2004) evaluated an effective dose coefficient to be used for dose and dose rate in radiation protection dosimetry (8) .To measure the radiation-absorbed dose of the aircrew in domestic flights, several measurements were performed using a survey meter model RDS-110. The meter was calibrated for X and gamma rays in the range of 50 KV to 1.25 MV by RADOS Technology OY. It can measure the radiation dose in the range of 0.001 to 1.000 mSv, and the dose rate from 0.05 µSv/h to 100 mSv/h. In each measurement, the survey meter was turned on in the aircraft before take off, and the displayed dose rate was recorded (5-10 in a minute) during the flight. Displayed values changed with aircraft's location. It is a function of altitude and the aircraft route. Variations of dose rates during some flights are shown in fig.1. Effective dose was calculated from, $\sum H.\Delta t$, where H is the recorded dose rate and Δt the time interval between the displayed values.

The results of measurements from four Mashhad-Tehran and two Mashhad-Esfehan routine flights with their flight profiles are shown in table 1. Mean and standard deviation of the measured equivalent dose rate at constant altitude are calculated and presented in table 1. Effective route dose and equivalent dose rate of these flights derived from CARI-6 program are also shown in table 1.

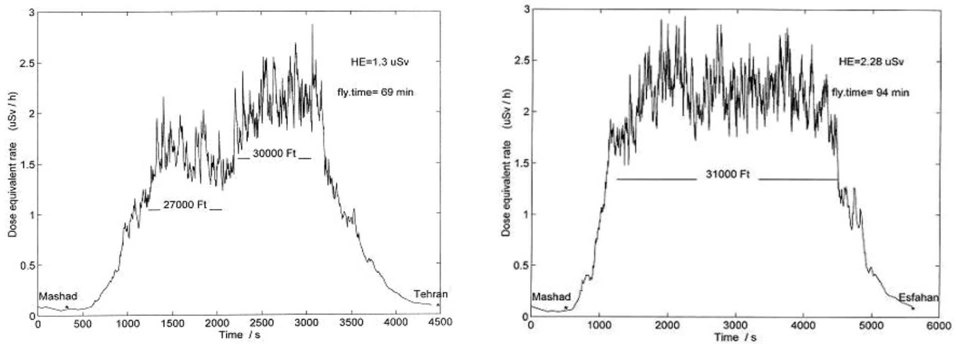

Fig. 1: Variation of dose equivalent rate in different flights from Mashhad to Tehran and Esfehan at various heights.

Table1: Measured and calculated effective dose and ambient dose rates in some domestic flights.

No	Flight From - to	Altitude feet	Time of flight in Minute			Effective route dose µSv		Equivalent dose rate µSv/h	
			ascending	Constant altitude	descending	measured	computed	measured	computed
1	Mashhad-Tehran	33000	13	44	22	2.3	2.2	2.50 ± 0.21	2.28
2	Tehran-Mashhad	27000	16	15		1.3	1.3	1.46 ± 0.27	1.45
		30000		18	20			2.12 ± 0.15	1.93
3	Mashhad-Esfehan	31000	11	55	19	2.28	2.2	2.11 ± 0.17	2.10
4	Esfehhan-Mashad	28000	9	16		1.52	1.6	1.57 ± 0.19	1.37
		33000		22				2.14 ± 0.34	2.46
		27000		4	16			1.41 ± 0.16	1.45
5	Mashhad-Tehran	30000	13	47	15	1.55	1.8	1.70 ± 0.16	1.93
6	Tehran-Mashad	29000	18	30	18	1.05	1.2	1.58 ± 0.17	1.76

Results and discussion

Values of effective and equivalent dose rate, measured and computed from CARI-6 program for six domestic flights at different altitude are shown in table 1. As the two sets of data, measured and calculated values, are in good agreement, therefore the CARI-6 program can be utilized to compute the dose rates in different altitude and throughout the country to provide a simple algorithm for calculating route dose in domestic flights.

Bartlett (2004) has shown that the results of in-flight measurements with different types of devices are more or less similar (1). He appreciated the results of Goldhagen (2002); He reported the ambient dose equivalent rates at temperate latitude (40-60ºN) measured during solar minimum activity (1997-1999) at 33 and 35 thousand feet as 4.6 ± 0.6 and 4.9 ± 0.5μSv/h, from which 2.9 ± 0.3 and 2.8 ± 0.5μSv/h are due to the neutron component, respectively (9). As the survey meter, used in this study is not designated to measure neutron, therefore, the measured data are radiation dose and dose rate arise from non-neutron component of the cosmic rays, which is similar to values calculated by CARI-6 program. The results would be in agreement with the report of Bartlett (2004), by taking into account 55% of cosmic rays to be neutron at those altitudes.

To introduce a simple algorithm for calculating route dose in domestic flights, the dose rates at different altitude and location were calculated by employing CARI-6 program. Measured and calculated data are shown in figure 2.

The best fitted line through each series of data for each location found to be as $a(h)^b$, where h is the altitude in thousand feet; a and b are constants related to each location (latitude & longitude) and are presented in table 3.

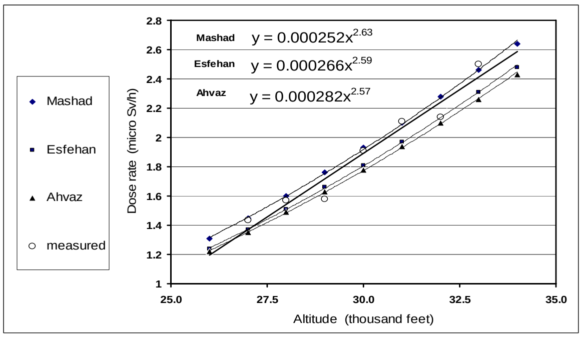

Fig 2: Variation of dose rates with altitude at different location, Measured and calculated by CARI-6 program.

Table3: Coefficients *a* and *b* for calculating dose rates at different altitudes and locations.

Location	a	b
Abadan	271	2.578
Ahvaz	282	2.571
Bandar-Abas	288	2.542
Esfehan	266	2.594
Hamadan	254	2.618
Kerman	275	2.569
Kermanshah	258	2.612
Kish	290	2.537
Mashhad	252	2.627
Ramsar	263	2.623
Rashte	261	2.631
Sanandaj	269	2.605
Shiraz	275	2.568
Tabriz	257	2.644
Tehran	270	2.607
Yazd	276	2.578
Zahedan	271	2.568

Effective route dose can be calculated by the sum of effective dose on ascending, flight at constant height and descending time by the following formula:

$$\text{Effective route dose} = \int_{\text{٠}}^{t_{rais}} H_{(h)}.dt + \sum_{i=\text{١}}^{n} H_{(h=const)}.\Delta t + \int_{t_{land}}^{t_{desc}} H_{(h)}.dt$$

As the dose rates (H), vary with height (h) and the height depends on time after take off; by assuming a constant speed (v) and angle (α) for aircraft during take off and landing, the effective dose can be calculated for these time intervals from the following equation:

$$\int_0^t H_{(h)}.dt = \frac{1}{v.Sin\alpha}\int_0^h a(h)^b.dh = \frac{H_{(h)}.t}{b+1}$$

Where, t is the time of take off to (or landing from) height h with effective dose of H. Effective route doses obtained by this method for flight shown in table 1 are in good agreement with those calculated by CARI-6 program.

The mean and SD of the equivalent dose rate at 33000 feet, over the year 2000 and its variation over 13 years period (before 2004) by CARI-6 program are 2.26 ± 0.02 and 2.32 ± 0.05 respectively; which has no significant difference from 2.14 ± 0.34 measured in this study. Therefore, data given in table 3 can be used to estimate the effective dose at different altitude and effective dose of the flights with an appreciable accuracy by the purposed algorithm in domestic flights in Iran.

Comparison of the committed measured effective dose of the aircrew in 1-hour flying time at 27-33 thousand feet in domestic flights with annual dose limit of the occupational radiation worker, general population, some medical examination dose, and equivalent dose of background radiation at normal area are shown in table 4.

Table 4: Comparison of effective route dose with effective dose and dose limits from different sources.

Effective route dose of aircrew in domestic flight at 27-33 thousand feet (μSv/h)		1.89 ± 0.63
Dose limit (mSv/y)	radiation-workers	20
	general population	1
Effective dose (from diagnostic application) (mSv)	Waters	0.11
	Chest	0.21
	Spinal	0.30
	Skull	0.40
Natural background equivalent dose (μSv/h)		
Mean of few large cities of Iran (Haghparast) (9)		0.105
At sea level (unscar) (10)		0.032

From the measurements and discussion above, we can conclude that:

I- Effective route dose of aircrew, at flying altitude of 27-33 thousand feet, which is more than 18 fold relative to corresponding dose from normal area on the earth's surface, varies by factor of 1.75 in domestic flights. This would be larger for higher altitudes. Bartlett (2004) believes that the effective dose at flying altitudes (26-39 thousand feet) varies by a factor of two.

II-The annual dose limit of general population allows the aircrew to fly at these heights at least for 529 hours in domestic flights. By taking into account the contribution of effective dose of the neutron, (55-60% as reported by Bartlett 2004 and Goldhagen 2002); this time is reduced to ≈290 hours, which nearly agrees with the range reported by Bartlett (2004). He concluded that aircrew members flying ≈250, 200 and 150 hour at 33, 35 and 39 thousand feet respectively in temperate latitude would receive effective dose less than 1mSv. Airlines generally define working hours in terms of "block hours" that may be considerably greater than flying hours. As the exposure of cosmic radiation to the body is essentially uniform and the maternal abdomen provides no effective shielding to the fetus, i.e. the amount of equivalent dose to the fetus is equal to that of the effective dose received by the mother, therefore female aircrew should be made aware of the need to control doses during pregnancy.

Conclusions

Effective dose arising from traveling by commercial aircrafts could be estimated (by a reasonable accuracy) by the sum of the effective dose on ascending flight at certain height and descending time. Ambient dose rates in domestic flights in Iran could be defined as $a(h)^b$ where h is the altitude in thousand feet; a and b are constants depending to each location as shown in table 3.

Effective route dose of the aircrews would be less than general population dose limit for at least 290 hours flying at 27-33 thousand feet altitude in domestic flights; therefore, only the female aircrew should be made aware of the need to control radiation doses during pregnancy.

Acknowledgments

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