

COMPREHENSIVE DATA CONCERNING COSMIC RADIATION DOSES AT GROUND LEVEL AND IN-FLIGHTS FOR TURKEY

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Cosmic radiation doses of individuals living in 81 cities in Turkey were estimated by using CARI-6 software. Annual cosmic radiation doses of individuals were found to be between $308 \mu\text{Sv y}^{-1}$ and $736 \mu\text{Sv y}^{-1}$ at ground level. The population-weighted annual effective dose from cosmic radiation was determined to be $387 \mu\text{Sv y}^{-1}$ for Turkey. Cosmic radiation doses on-board for 137 (60 domestic and 77 international) flights varied from $1.2 \mu\text{Sv}$ to $83 \mu\text{Sv}$. It was estimated that six or over long-route round-trip air travels may cause cosmic radiation dose above the permissible limit for member of the public i.e. 1 mSv y^{-1} . According to the assumption of flights throughout 800 hours on each route, cosmic radiation doses were found to be between 1.0 mSv and 4.8 mSv for aircrew.

INTRODUCTION

The earth is continuously bombarded with high-energy particles, which are known as cosmic radiation. They are generated by sun or come from outside of the solar system. High-energy particles interact with nuclei of atmospheric constituents until they lose their energies. Cascade interactions of high-energy particles cause formation of various secondary reaction products. High-energy particles as well as secondary reaction products are responsible for the cosmic radiation exposure.

The atmosphere provides a special shielding to the earth against cosmic radiation. Particles from outer space penetrate into the atmosphere and interact with its constituents until they lose their energies. Low-energy cosmic particles are adsorbed in the upper atmosphere. Only high-energy cosmic particles can reach to the sub layers of the atmosphere. Therefore, the cosmic radiation intensity decreases from the outer layer of the atmosphere towards the ground. The cosmic radiation exposure of individual increases from the ground level towards upper layers of the atmosphere accordingly. The cosmic radiation dose doubles for individuals for each 4,500 ft increment (1). At the altitude of 30,000 ft, the effective dose rate is approximately 90 times higher than the rate at sea level due to the dominance of the neutron component of cosmic radiation. The neutron component of cosmic radiation is dominant over 10,000 ft (2).

Passengers and flight crew are exposed to cosmic radiation during long-haul flights at high altitudes. Many researchers have paid special attention to flight radiation doses of individuals or occupational exposures of aircrew (3, 4). There are also some studies performed about health effects of cosmic radiation and concerns about cosmic radiation-induce carcinogenesis (5).

According to the recommendation of International Commission on Radiological Protection (ICRP), given in publication 60, cosmic radiation exposure of aircrew should be regarded as occupational exposure (6). European Commission expressed that each member state shall ensure make arrangements for undertakings operating aircraft to take account of exposure to cosmic radiation of aircrew that are liable to be subject to exposure to more than 1 mSv per year, according to the Euratom Directive 96/12 in Article 42 (7). Article 42 refers to article 10 and recommends special protection during pregnancy and breastfeeding for female crew. The exposure of aircrew is recommended to be accepted as planned exposure situation in 26 of later Euratom Directive 2013/59 (8). The article 35 of Directive 2013/59 recommended that relevant requirements should be applied for aircrew whose exposure is exceed 6 mSv y^{-1} , allowing for the specific features of this exposure situation. The article 35 of Directive 2013/59 states that competent authority requires the undertaking to take appropriate measures for aircrew whose effective dose is above 1 mSv y^{-1} . Relevant requirements are given in aforementioned article (8).

Figure 1 shows the airline passenger statistic made in Turkish airports between 2003 and 2014 (9, 10, and 11). The statistic gives an important hint about increment of air travels in the future. This means that more people will be exposed to cosmic radiation originated from air travels in the coming years. However, there is no comprehensive study or data to evaluate cosmic radiation doses of individuals or flight crew in Turkey.

Due to the variation of each country's living conditions, geography and industry, many countries investigate country-specific exposure of members of public originated from natural and artificial radiation sources. It requires to determine the amount of each

component constituting the radiation dose in order to achieve this. The cosmic radiation dose is a component which cannot be neglected among them. Therefore, cosmic radiation doses of individuals living in eighty-one cities of Turkey were calculated by using CARI-6 software (12). The population-weighted annual effective dose from cosmic radiation was estimated for Turkey. Both for domestic and international flights, cosmic radiation doses on-board were calculated in this study. It is considered that results of the study will provide a considerable contribution to national and also regional and world data related to cosmic radiation exposures of individuals. This study can also help researchers who need to know the contribution of cosmic radiation dose in dating of archaeological samples.

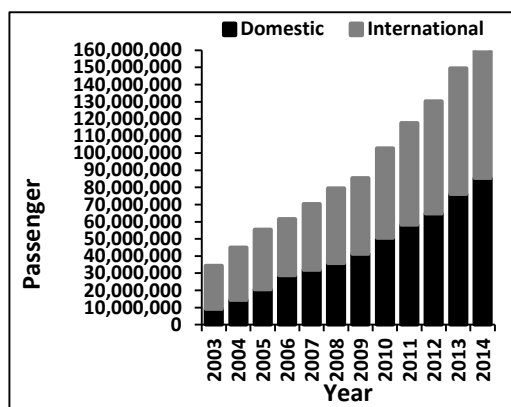


Figure 1. Airline passenger statistics of Turkey

MATERIALS AND METHODS

Cosmic radiation doses at ground level

The CARI-6 computer program, developed by the Federal Aviation Administration's (FAA) Civil Aerospace Medical Institute, calculates the flight radiation dose received by an individual or aircrew (12). The program calculates doses by using changes in altitude and geographic location of airports. Software has also capable of calculating the effective dose rate from galactic radiation at any location in the atmosphere at altitude up to 60,000 ft. CARI-6 can calculate the average on 12 months cosmic dose rate for any year from 1958 to 2014. Exposures were calculated by using altitude, coordinate information and mean value dose rate of 2014 in this study (13, 14). In the calculations, it was not taken into consideration the backscattered or secondary reaction products of cosmic radiation that come from soil.

Cosmic radiation doses at flights

Cosmic radiation dose estimation in high altitudes is a challenging task due to particle composition, their energies and complex interactions. To overcome this challenging task, many software have been developed during the last decade by research projects focused on this problem. Flight time, ascending and descending time, geographic information (latitude, longitude) and route information are basic parameters of codes that are used for calculations (15).

Dose calculations were performed with two different approaches as domestic and international flights in the study. Istanbul and Ankara are bustling metropolises of Turkey and most of flights (including connecting flights) are made from these airports. Cosmic radiation doses from domestic flights were calculated by using thirty-two routes from Atatürk Airport (Istanbul) and twenty-eight routes from Esenboğa Airport (Ankara). Durations of domestic flights are generally no more than two hours and they were considered to be performed at the altitude of around 32,000 ft. Exposures were calculated by using CARI-6 software. Flight times were taken from Turkish Airlines website (16). Ascending and descending times were regarded as 40 minutes (20 minutes take off and 20 minutes landing). There was no information about local airports and latest heliocentric potentials in the database of CARI-6. Therefore, local airports' information (coordinates, altitudes) was obtained from General Directorate of State Airports Authority (DHMI) (9). Recent heliocentric potentials were also obtained from Federal Aviation Administration website (12).

Almost all international flights are carried out from Istanbul in Turkey. Thus, cosmic radiation doses of flights from Istanbul to international airports were calculated by using CARI-6 computer codes. Ascending and descending times, number of en-routes, en-route altitudes and en-route times are required parameters for flight dose calculations for the program. CARI (via FAA website) also allow users to make online free flight dose calculations.

For international flights, most of cruising data used to calculate cosmic radiation doses were derived from similar studies performed in literature (3, 17) and Radiation Protection 88 report of the European Commission (18). Accordingly, international flights were considered to be performed in two altitudes as 34,000 ft and 39,000 ft. Each of ascending and descending times were accepted as 30 minutes (total 1 hour) and flight times were taken equal for 34,000 ft (50% of flight) and 39,000 ft (50% of remain flight). Cosmic radiation dose results were given based on the monthly average of 2014.

CARI-6 has been validated by measurements (19). Differences between measurement and simulations remain below 20%. (15, 19). Detailed information related to uncertainties of dose assessment can be found in the European Commission report of Radiation Protection 140 (19).

RESULTS AND DISCUSSIONS

Effective doses at ground level for Turkish provinces

Cosmic radiation doses at ground level were calculated by CARI-6 software by using coordinates and altitudes of Turkish provinces. Annual cosmic radiation doses of individuals living in each province are given in Figure 2.

Cosmic radiation doses were found to be between $308 \mu\text{Sv y}^{-1}$ and $736 \mu\text{Sv y}^{-1}$ with an average of $429 \mu\text{Sv y}^{-1}$ for eighty-one provinces. The maximum cosmic radiation dose was determined for Ardahan, with an altitude of 1870 m, and the lowest dose was calculated for İçel which is only 6 m above the sea level.

Population-weighted annual effective dose from cosmic radiation at ground level for Turkey

The majority of cities, where the population is crowded, are located at altitudes below 1,000 meters in Turkey. Istanbul with 13.9 million people is the most crowded city of Turkey and its population corresponds approximately 20 percent of country's population. For cosmic radiation exposure, population-weighted effective dose was calculated to be $387 \mu\text{Sv y}^{-1}$ for Turkey. According to UNSCEAR 2000 report, average worldwide exposure from cosmic radiation is $390 \mu\text{Sv y}^{-1}$. Calculation result of population weighted effective dose is consistent with literature.

Cosmic radiation doses for domestic flights

It is very difficult to estimate the flight profile of airliners. Each aircraft tries to fly at an altitude where has the maximum benefit depending on the load, distance, fuel consumption and weather conditions. Thus, pilots can use more than one route or altitude in their flights (20). Durations of flights from Istanbul to domestic airports vary between 55 minutes and 130 minutes with an average of 94 minute. Ağrı and Van cruises take the longest time in domestic flights. Cosmic radiation doses of flights from Istanbul to domestic airports are presented in Figure 3.

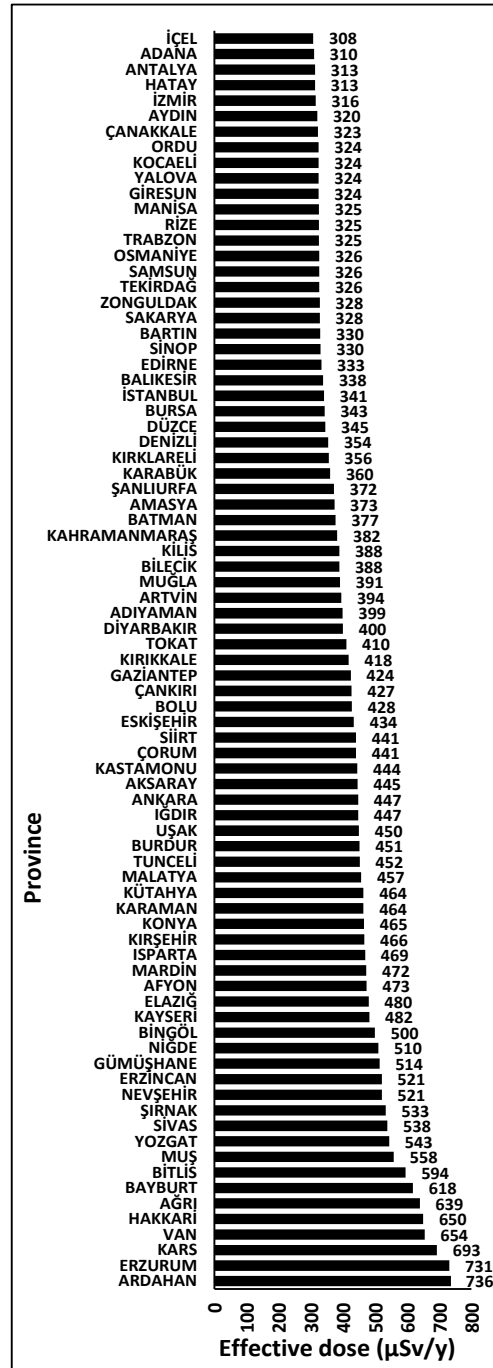


Figure 2. Annual cosmic radiation doses for provinces

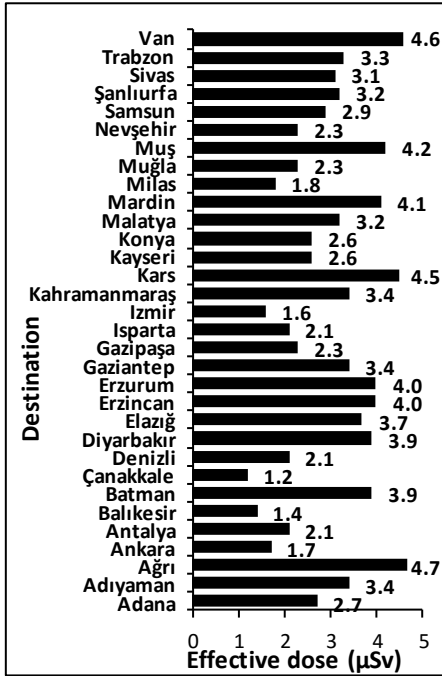


Figure 3. Cosmic radiation doses of flights from Istanbul to domestic airports

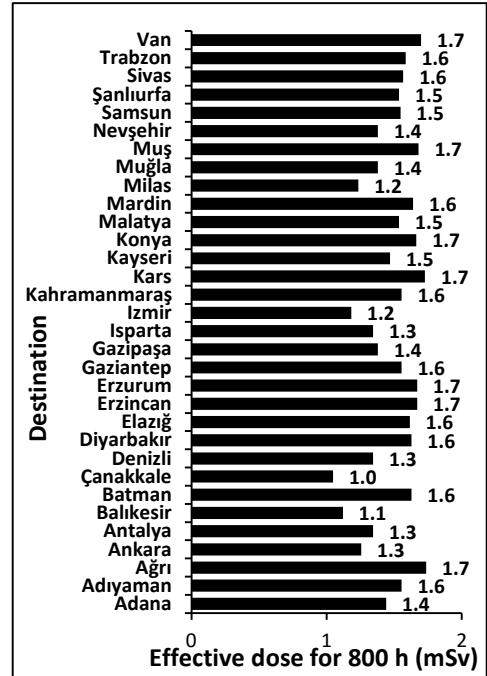


Figure 4. Cosmic radiation doses of flights from Istanbul to domestic airports throughout 800 hours

The highest dose (4.7 μSv) in domestic flights was calculated for Ağrı, which has longest duration. For Çanakkale-Istanbul flight, passengers or crewmembers receive the lowest dose (1.2 μSv). According to the Turkish regulation, annual flight time shall not exceed 1,000 hours for aircrew (21). However, 800 hours was considered to be acceptable value for annual flight time. Figure 4 gives effective doses of typical flights throughout 800 hours flying on these routes. Effective doses of flights from Istanbul to domestic airports throughout 800 hours were calculated to be between 1.0 mSv and 1.7 mSv.

Ankara is located in the central region of the country when compared with Istanbul. Cosmic exposures are given in Figure 5. Flight durations from Ankara to domestic airports are lower from Istanbul (between 55 minutes and 95 minutes). Cosmic radiation doses received by aircrew or passengers during flights from Ankara to domestic airports were found to be between 1.2 μSv (Samsun) and 3.1 μSv (Kars). Effective doses of typical flights throughout 800 hours are presented in Figure 6. They were calculated to be between 1.0 mSv and 1.6 mSv for 28 routes from Ankara to domestic airports.

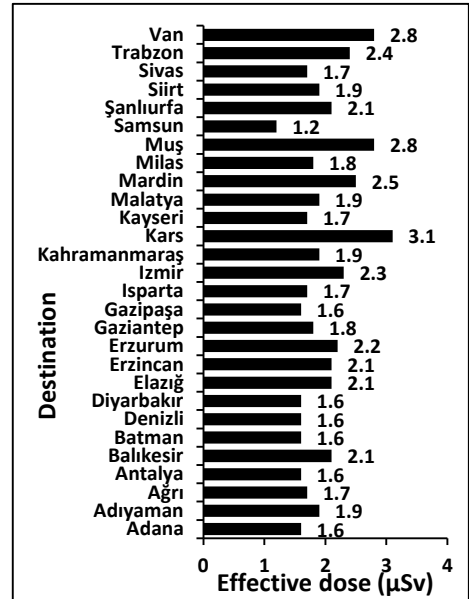


Figure 5. Cosmic radiation doses of flights from Ankara to domestic airports

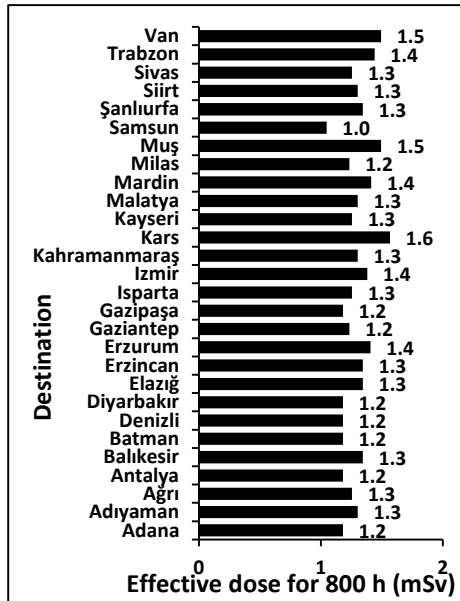


Figure 6. Cosmic radiation doses of flights from Ankara to domestic airports throughout 800 hours

Cosmic radiation doses for international flights

CARI-6 software was used to calculate route doses for seventy-seven international flights during the period of 2014. Cosmic radiation dose results calculated by CARI-6 are presented in Figure 7. The smallest dose was calculated to be 4 μSv for Tel Aviv route which has the shortest duration (2 hours). The highest cosmic radiation dose was found to be 83 μSv for Los Angeles route which has the highest duration of about 14 hours. Effective doses of international flights routes throughout 800 hours are given in Figure 8. They were calculated to be between 1.8 mSv and 4.8 mSv.

Results of the current study reveal that aircrew is exposed to relatively more cosmic radiation on international flights especially long-haul routes in comparison with domestic flights. If the maximum exposure value (83 μSv for Los Angeles route) is used for dose calculation, six round-trip long-haul air travels can cause a cosmic radiation dose over the recommended value of 1 mSv y^{-1} for member of public.

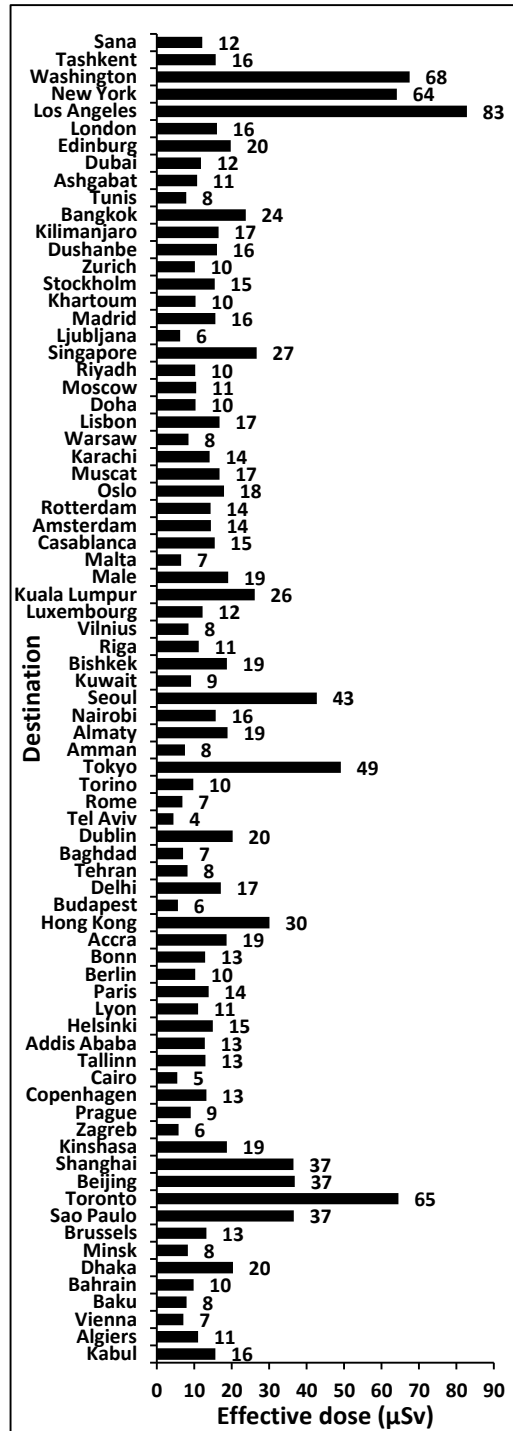


Figure 7. Cosmic radiation dose results for international flights

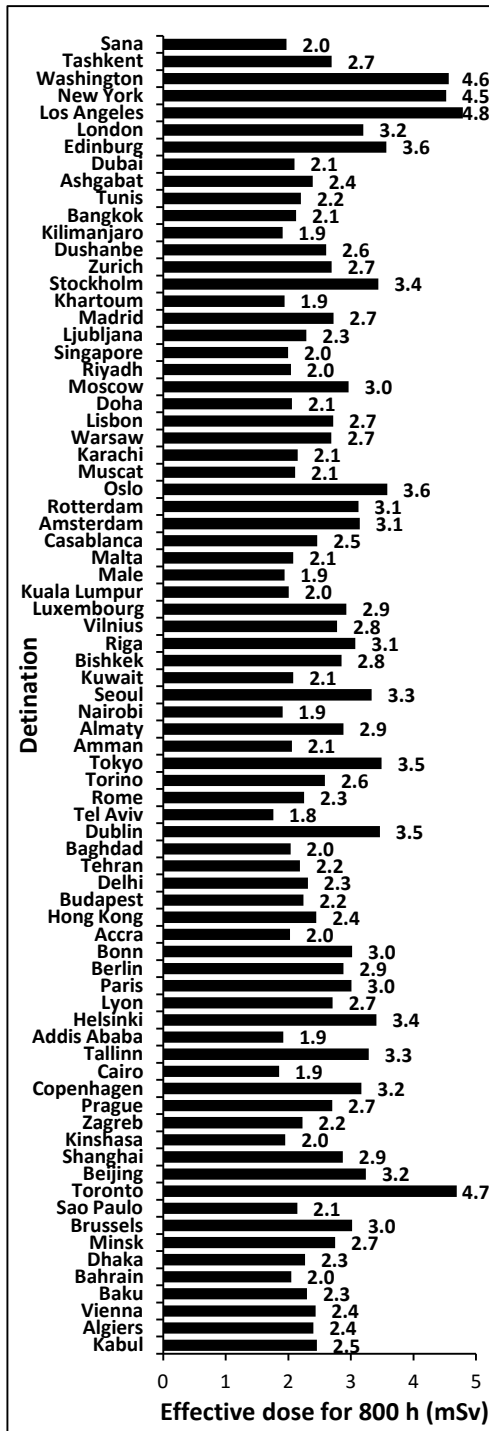


Figure 8. Cosmic radiation doses of international flights throughout 800 hours

CONCLUSION

Cosmic radiation doses at ground level were calculated for Turkish provinces by using CARI-6 software. Results ranged from 308 $\mu\text{Sv y}^{-1}$ to 736 $\mu\text{Sv y}^{-1}$. Population-weighted annual effective dose originated from cosmic radiation at ground level was calculated to be 387 $\mu\text{Sv y}^{-1}$.

Cosmic radiation doses on-board were estimated for 137 routes (60 domestic 77 international). According to the assumption 800 hours on each route, effective doses were calculated to be between 1.0 mSv and 4.8 mSv. Therefore, as Turkish aircrew are exposed to cosmic radiation within a range from 1 mSv y^{-1} to 6 mSv y^{-1} , individual dose estimation is required. Radiation exposure should be assessed for all flights and crewmembers should be informed regarding possible effects. National studies concerning assessment of the magnitude of aircrew doses should be encouraged.

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