

Radiological risk assessment of cosmic radiation at aviation altitudes (a trip from Houston Intercontinental Airport to Lagos International Airport)

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ABSTRACT

Radiological risk parameters associated with aircrew members traveling from Houston Intercontinental Airport to Lagos International Airport have been computed using computer software called EPCARD (version 3.2). The mean annual effective dose of radiation was computed to be 2.94 mSv/year. This result is above the standard permissible limit of 1 mSv/year set for the public and pregnant aircrew members but below the limit set for occupationally exposed workers. The Risk of cancer mortality and excess career time cancer risk computed ranged from 3.5×10^{-5} to 24.5×10^{-5} (with average of 14.7×10^{-5}) and 7×10^{-4} to 49×10^{-4} (with average of 29.4×10^{-4}). Passengers and aircrew members should be aware of the extra cosmic radiation doses taken in during flights. All aircraft operators should monitor radiation doses incurred during aviation trips.

Key words: Aviation; cosmic radiation; Houston; Lagos; radiological

Introduction

The earth's atmosphere is continuously bombarded by radiation from varying sources. They include by-products of cosmic rays from the sun (solar cosmic radiation) and charged particles that originate outside the solar system (galactic cosmic radiation). Cosmic radiation reaching the earth's atmosphere is affected basically by four phenomena namely; the solar cycle, earth's atmosphere, earth's magnetosphere, and altitude.

The magnitude of cosmic radiation getting to the earth partly and grossly depends on the sun's activity at a particular period. Occasionally, the sun releases spontaneous outburst

of electromagnetic radiation in the forms of gamma rays, X-rays and radio waves. This phenomenon gets to its maximum every 11 years (solar cycle) and during this period, the earth yields to additional radiation intake. Impressively, the intensity of cosmic radiation reaching the earth is influenced by the earth's atmosphere as well as its magnetosphere. According to Bagshaw,^[1] the atmosphere absorbs most of the particles associated with cosmic rays. Furthermore, the magnetosphere deflects partly the cosmic radiation that would have reached the earth's surface. Deflections are maximum at the equator and minimum at the poles where the cosmic radiation penetration depth is maximum.

At altitudes <15.2 km above sea level, the intensity of cosmic radiation begins to decrease speedily.^[2] The mass thickness of the air above a given altitude is called atmospheric depth and is proportional to the air pressure at that point. This decreases approximately exponentially as altitude increases.^[3] This assertion implies that regular

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air travelers at aviation altitudes are more prone to cosmic radiation interaction relative to the public and other nonradiation workers. The earth's atmospheric layer provides a shielding effect from cosmic radiation equivalent to 13 feet of concrete. This is reflected by the fact that at sea level, the exposure rate is about $0.06 \mu\text{Sv/h}$; at 35,000 feet above sea level (the cruising altitude of most subsonic commercial aircraft) it is 100 times more, $6 \mu\text{Sv/h}$; and at 60,000 feet above sea level (the cruising altitude of the supersonic Concorde) the exposure rate is much higher.^[4]

Apart from direct measurements in aircrafts using dosimeters to ascertain the extent of radiation exposure to aircrew members and passengers, computer programs can aid in the computation of radiation effective doses received on board at aviation altitudes. The assessment of each individual aircrew dose is made by combining route dose with crew roster data. Route dose estimates can be calculated using computer programs such as EPCARD and CARI-6, which are specifically designed to calculate route dose, and these programs are recognized by the United States Environmental Protection Agency.^[2] In 1991 and subsequently in 2007, the International Commission on Radiological Protection (ICRP)^[5] recommended that exposure of flight crew members to cosmic radiation in jet aircraft should be considered as part of occupational exposure to ionizing radiation. Based on this recommendation, most European countries went into research to develop theoretical and experimental methods of calculating natural exposure to ionizing radiation at aviation altitudes. Consequently, a German institute (GSF), German Research Center for Environmental Health, Institute of Radiation Protection with the support of European Commission developed EPCARD 3.2 in February 2002.^[6] For a typical journey between Europe and North America, an individual receives a dose rate of between 4 and $8 \mu\text{Sv/h}$.^[7] The ICRP recommends that systematic control of radiation exposure doses for aircrew members be taken because they receive higher radiation levels than workers exposed to medical or industrial radiation, although their annual radiation doses are generally below 6 mSv, aircrew are exposed to continuous radiation over long work hours.^[8]

The National Council on Radiation Protection and Measurements recommends a permissible dose limit of 0.5 mSv per month whereas, ICRP recommends radiation permissible limit of 1 mSv per annum during pregnancy.^[5] Only flight crews flying both a large number of hours during pregnancy (for example, 100 h in a month) and strictly the highest dose-rate routes (typically global routes such as the United States to Buenos Aires or the United States to Tokyo) would exceed these guidelines.^[9] By law, an airline pilot may not fly more than 85 h a month or 1000 h a year. However, the average pilot works more than 100 h a

month counting ground duties such as filing flight plans, working on reports, briefing crews and attending training classes.^[10] Flight durations of this range per annum for aircrew members may result to an elevated level of effective radiation doses.

Radiological risk assessment is an estimate of the probability of a fatal cancer risk as a result of exposure to low-level doses of radiation. It is, therefore, important to carry out frequent radiological assessment of aircrew members to avert unnecessary exposure to cosmic radiation at aviation altitudes.

Methodology

Study area and data collection

This study was carried out on an aviation trip from Houston Intercontinental Airport, Houston, United States of America to Lagos International Airport, Lagos, Nigeria on a United Airlines flight in 2013. The air route map showing the flight route from Houston Intercontinental Airport to Lagos International Airport is presented in Figure 1. The data collected were the flight geographical locations and altitudes at strategic locations [Table 1].

Method of computation of radiological risk parameters

The effective radiation dose rates (ED_h) at strategic locations (effective dose per hour- ED_h) were computed using a computer software program called EPCARD-version 3.2 (European Package for Calculation of Aviation Route Doses, German Research Center for Environmental health). This computer software is certified by the European Commission for computation of cosmic radiation exposure of aircrew members and passengers.^[11] In other to run this software program, the following parameters were keyed in; date of the trip, geographical locations of selected points

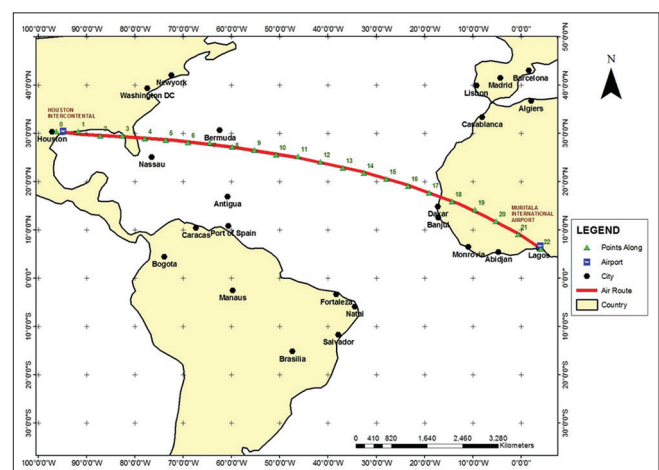


Figure 1: Air route map showing the flight route from Houston Intercontinental Airport to Lagos International Airport

Table 1: Points of computation of cosmic radiation doses at aviation altitudes

<i>Geographical location</i>	<i>Flight altitude (feet)</i>
96° 16' W; 30° 25' N	16,000
91° 42' W; 30° 25' N	22,180
87° 08' W; 29° 30' N	34,999
82° 33' W; 29° 30' N	35,001
77° 52' W; 28° 55' N	35,255
73° 32' W; 28° 36' N	35,370
68° 58' W; 28° 07' N	35,542
64° 31' W; 28° 01' N	36,305
59° 49' W; 27° 13' N	36,700
55° 15' W; 26° 31' N	36,895
50° 40' W; 25° 36' N	37,000
46° 13' W; 25° 16' N	37,001
41° 32' W; 24° 07' N	37,002
36° 51' W; 22° 52' N	37,200
32° 30' W; 21° 50' N	38,500
27° 49' W; 20° 36' N	38,900
23° 21' W; 19° 06' N	39,000
19° 01' W; 17° 43' N	39,002
14° 13' W; 15° 54' N	39,001
09° 31' W; 14° 11' N	39,000
05° 11' W; 11° 47' N	39,001
04° 36' W; 10° 59' N	38,998
02° 46' W; 10° 59' N	31,862
01° 00' W; 09° 23' N	20,985

and flight altitudes. These three parameters took care of the dependence of cosmic radiation exposure on solar cycle, geographical latitude, and altitude, respectively.

The annual effective dose of radiation (AEDR) was computed using the formula;

$$\text{AEDR} = \text{ED}_h \times K \quad (1)$$

where $K = 1000$ is a constant representing the mean number of block hours a typical pilot or aircrew member flies in a year.

The cancer risk models used in this computation were developed by US EPA. The dose to risk conversion (RF) factor was calculated using the DCAL (dose and risk calculation software, Developed by Oak Ridge National Laboratory, Tennessee, USA) – a comprehensive system for calculating dose and risk coefficient using age-dependent models. This dose-to-risk conversion factor is recognized by organizations such as the ICRP and the United Nations Scientific Committee on the Effects of Atomic Radiation.^[12]

The risk of cancer mortality (R_{CM}) which is the potential for an aircrew member exposed to cosmic radiation doses during aviation trips for a year to have a fatal cancer was computed using the formula below;

$$R_{\text{CM}} = \text{AEDR} \times \text{RF} \quad (2)$$

where RF given as 5×10^{-2} per Sievert (or 5×10^{-5} permSv) is the “Dose to risk conversion factor for cancer mortality.”

The “excess career time cancer risk (ECTCR)” which is an estimate of the probability of a fatal cancer occurrence as a result of exposure to low-level doses of radiation during a pilot’s period of active career expectancy (CE) estimated to be 20 years on the average was calculated as:

$$\text{ECTCR} = R_{\text{CM}} \times \text{CE} \quad (3)$$

we have chosen $\text{CE} = 20$ years because early career pilots start their career at about 25 years to retire at 65 years (40 years of service). Pilots work for 14 days in a month (about half a month) and consequently, they effectively fly for 20 years during their active service.^[13,14]

Then, the mean results of each of these parameters, ED_h , AEDR, R_{CM} or ECTCR was calculated using the expression;

$$X_m = \frac{\sum x}{n} \quad (4)$$

where $n = 24$ number of measurement points considered.

Results and Discussions

The results of the ED_h , AEDR, R_{CM} , and ECTCR have been presented in Table 2. The results show that during this aviation trip which lasted for approximately 14 h, the computed ED_h ranged from 0.7 to 4.9 $\mu\text{Sv/h}$ (with a mean of 2.9 $\mu\text{Sv/h}$) and 9.8–68.6 $\mu\text{Sv/14 h}$ (with a mean of 41.16 $\mu\text{Sv/14 h}$). This amounted to an AEDR of between 0.7 and 4.9 mSv/year, with an average of 2.94 mSv/year. This average result is above the standard permissible limit of 1 mSv/year set for the public and pregnant aircrew members but below the limit of 20 mSv/year set for occupationally exposed workers by International Commission on Radiological Protection, Federal Aviation Administration and Council of the European Union.^[1] Recall that since pilots and other aircrew members are classified as radiation workers, pilots, and aircrew members who fly the surveyed routes at similar altitudes are likely not to receive dosages beyond recommended limit.^[5] The magnitude of radiation dose received by pilots and aircrew members can be appreciated more if we note that for comparison sake, a single chest X-ray provides roughly 0.02 mSv^[15] and the average annual human exposure on earth due to natural background radiation is 2.4 mSv (1.26 mSv due to air inhalation, 0.29 mSv due to food and body contents, 0.4 mSv due to terrestrial radiation and 0.39 mSv due to cosmic radiation reaching the earth).^[16] Management and staff of airline operators are obliged to ensure that the principle of ALARA is upheld so

Table 2: Results of radiological risk parameters at aviation altitude for the present survey

Geographical location	Flight altitude (feet)	Effective radiation dose ($\mu\text{Sv}/\text{h}$)	AEDR (mSv/year)	R_{CM} (10^{-5})	ECTCR (10^{-4})
96° 16' W; 30° 25' N	16,000	0.7	0.7	03.5	7.0
91° 42' W; 30° 25' N	22,180	1.6	1.6	08.0	16.0
87° 08' W; 29° 30' N	34,999	4.8	4.8	24.0	48.0
82° 33' W; 29° 30' N	35,001	4.9	4.9	24.5	49.0
77° 52' W; 28° 55' N	35,255	4.9	4.9	24.5	49.0
73° 32' W; 28° 36' N	3,370	4.7	4.7	23.5	47.0
68° 58' W; 28° 07' N	35,542	4.5	4.5	22.4	45.0
64° 31' W; 28° 01' N	36,305	4.0	4.0	20.0	40.0
59° 49' W; 27° 13' N	36,700	4.1	4.1	20.5	41.0
55° 15' W; 26° 31' N	36,895	3.6	3.6	18.0	36.0
50° 40' W; 25° 36' N	37,000	3.1	3.1	15.5	31.0
46° 13' W; 25° 16' N	37,001	2.9	2.9	14.5	29.0
41° 32' W; 24° 07' N	37,002	2.7	2.7	13.5	27.0
36° 51' W; 22° 52' N	37,200	2.5	2.5	12.5	25.0
32° 30' W; 21° 50' N	38,500	2.6	2.6	13.0	26.0
27° 49' W; 20° 36' N	38,900	2.5	2.5	12.5	25.0
23° 21' W; 19° 06' N	39,000	2.5	2.5	12.5	25.0
19° 01' W; 17° 43' N	39,002	2.4	2.4	12.0	24.0
14° 13' W; 15° 54' N	39,001	2.4	2.4	12.0	24.0
09° 31' W; 14° 11' N	39,000	2.3	2.3	11.5	23.0
05° 11' W; 11° 47' N	39,001	2.3	2.3	11.5	23.0
04° 36' W; 10° 59' N	38,998	2.3	2.3	11.5	23.0
02° 46' W; 10° 59' N	31,862	1.6	1.6	08.0	16.0
01° 00' W; 09° 23' N	20,985	0.7	0.7	03.5	07.0
Parameter mean (X_m)		2.94	2.94	14.7	29.4

R_{CM} : Risk of cancer mortality, ECTCR: Excess career time cancer risk, AEDR: Annual effective dose of radiation

Table 3: Comparison of results of the mean radiological risk parameters for the present survey with previous researches

Radiological risk parameters	Present survey (mean)	[15]	[1]	[17]
AEDR (mSv/year)	2.94	1.8-4.0	5.4-5.76	2.0-9.0
R_{CM} (%)	0.015	0.009-0.02	0.027-0.029	0.01-0.045
ECTCR (%)	0.294	0.18-0.40	0.54-0.58	0.20-0.90

The results of R_{CM} (%) and ECTCR (%) presented in Table 3 were computed using the referenced researchers' AEDR (mSv/year). AEDR: Annual effective dose of radiation, R_{CM} : Risk of cancer mortality, ECTCR: Excess career time cancer risk

that exposure of workers to cosmic radiation could be kept "As Low As Reasonably Achievable" to minimize the effects of ionizing radiation.

The "Excess career time cancer risk" which is an estimate of the probability of a fatal cancer occurrence as a result of exposure of aircrew members and pilots to low level doses of radiation during their period of active career (estimated to be 20 years) has been presented in Table 2 and ranged between 7×10^{-4} and 49×10^{-4} with an average of 29.4×10^{-4} . The results of the radiological risk parameters

associated with the present survey are within the range of the results presented in Table 3.^[1,15,17]

Conclusion

The results of the computed radiological risk parameters have been presented in this work. These results are above the standard permissible limits set for the public and pregnant women who are aircrew members but below the limit set for occupationally exposed persons. Long-term continuous exposure to cosmic radiation at aviation route between the Houston Intercontinental Airport and Lagos International Airport is likely to increase the overall risk.

However, it is worth noting that studies on radiation-induced cancer at low dose rates through the use of a simple proportional relationship between increments of dose and increased risk is a scientifically plausible assumption and as such has its associated uncertainties.^[18]

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Conflicts of interest

There are no conflicts of interest.

References

1. Bagshaw M. Cosmic Radiation in Commercial Aviation, Positon Paper-2014, Centre of Human and Aerospace Physiological Sciences, King's College London; 2014. Available from: <http://www.iaasm.org/documents/IAASMPaperCosRad2014.pdf>. [Last retrieved on 2016 Jan 10].
2. EPA (United States Environmental Protection Agency). Air Travel and Cosmic Radiation. Johnstown Castle Estate Wexford, Y35 W821; 2015. Available from: <http://www.epa.ie>. [Last retrieved on 2016 Jan 09].
3. Campbell RD, Bagshaw M. Human Performance and Limitations in Aviation. 3rd ed. Oxford: BSP; 2003.
4. Lim MK. Cosmic rays: Are air crew at risk? *Occup Environ Med* 2002;59:428-32.
5. ICRP Publication 103, the 2007 Recommendations of the International Commission on Radiological Protection. Available from: [http://www.icrp.org/docs/ICRP_Publication_103-Annals_of_the_ICRP_37\(2-4\)-Free_extract.pdf](http://www.icrp.org/docs/ICRP_Publication_103-Annals_of_the_ICRP_37(2-4)-Free_extract.pdf). [Last retrieved on 2016 Apr 26].
6. Institute of Radiation Protection German. Research Center for Environmental Health. Institute of Radiation Protection; Neuherberg; Germany: 2016. Available from: <http://www.helmholtz-muenchen>. [Last accessed on 2016 Apr 15].
7. Hughes JS, Watson SJ, Jones AL, Oatway WB. Review of the radiation exposure of the UK population. *J Radiol Prot* 2005;25:493-6.
8. Lee J, Nam U, Pyo J, Kim S, Kwon Y, Kim M, et al. Short-term variation of cosmic radiation measured by aircraft under constant flight conditions. *Space Weather* 2015;13:797-806.
9. Waters M, Bloom TF, Grajewski B. The NIOSH/FAA working women's health study: Evaluation of the cosmic-radiation exposures of flight attendants. Federal Aviation Administration. *Health Phys* 2000;79:553-9.
10. Avjobs, Inc., Airline Captain Career Overview; 2016. Available from: <http://www.avjobs.com/index.asp>. [Last retrieved on 2016 Jan 18].

11. European Commission, 2004. Cosmic Radiation Exposure of Aircrew, Compilation of Measured and Collected Data; 2004.
12. Smith KP 2011. Overview of Radiological Dose and Risk Assessment. IAEA Training Course on Nuclear Facility Decommissioning and Environmental Remediation Skills, Environmental Science Division Argonne National Laboratory Argonne, Illinois; 4-15 April, 2011.
13. National Business Aviation Association, 2016. Mandatory Age Retirement for Pilots. Washington DC; 2016. Available from: <https://www.nbaa.org>. [Last retrieved on 2016 Apr 24].
14. Malmquist S. Available from: <http://www.jetcareers.com> [Last retrieved on 2016 Apr 15].
15. Australian Radiation Protection and Nuclear Safety Agency, 2015. Flying and Health – Cosmic Radiation Exposure for Casual Flyers and Aircrew; 2015. Available from: <http://www.arpansa.gov.au>. [Last retrieved on 2016 Jan 05].
16. UNSCEAR, 2008. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, General Assembly Official Records Sixty-Third Session Supplement No. 46; 2008. Available from: <https://www.iaea.org>. [Last retrieved on 2016 May 25].
17. Shantha E, Lewis C, Nghiem P. Why do airline pilots and flight crews have an increased incidence of melanoma? *JAMA Oncol* 2015;1:829-30.
18. Preston RJ. 2011. Radiation Effects, ICRP Symposium on the International System of Radiological Protection October 24-26, 2011 – Bethesda, MD, USA; 2011. Available from: <http://www.icrp.org/docs/Julian>. [Last retrieved on 2016 Apr 15].