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ASSESSING ANNUAL EXPOSURES DOSE AND OTHER RADIOLOGICAL PARAMETERS FROM COSMIC RADIATION AMONG FLIGHT CREWS IN NIGERIA LOCAL AIRLINE

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ABSTRACT

Cosmic radiation is high-energy radiation generated in outer space that increases with altitudes. This study uses aircrew cosmic radiation exposure to measure radiation dose received by monitoring individual crew members (a total of 179 members for all the crews in the three routes for 2011 to 2022) using computer model calculator (CARI – 6M) on Nigeria's local airlines crews and evaluated other radiological parameters. The finding shows that annual effective dose (AED) received by the air crew members between 2011 and 2022 across the three routes (Lagos – Kano, Lagos – Abuja and Lagos – Port Harcourt) ranges between 0.230 and 1.90 µSv y^{-1} and there is a direct relationship between the time of flight and the effective dose received by the crew members. This result is lower than the recommended value of 20 µSv y^{-1} by International bodies. The result also revealed that Annual Gonadal Dose Equivalent (AGDE) across the three routes ranges from 7.20 – 380 µSv y^{-1} with only Lagos – Kano route in year 2017 (380 µSv y^{-1}) were above the maximum permissible value of 300 µSv y^{-1}. The findings indicated low AED however; the significant excess lifetime cancer risk that increases with cumulative doses and dependent of the flight route constitute a risk. This implies that, there are possibilities of the crew members developing cancer during their lifetime. It's therefore recommended that Nigerian Civil Aviation Authority should introduce regulations and training program to reduce potential sources of radiation exposure of Nigerian flight crews.

Keywords: Annual effective dose, Cosmic radiation, Excess lifetime cancer risk**,** Flight crews

INTRODUCTION

The aviation industry plays a vital role in global transportation, enabling millions of people to travel across long distances swiftly and efficiently (Wensveen, 2023). While the benefits of air travel are undeniable, there exists a potential occupational hazard that concerns the health and safety of the flight crews, especially those operating in regions with significant exposure to cosmic radiation (Ramsden, 2011). Cosmic radiation, originating from sources beyond Earth's atmosphere, presents a unique challenge to flight crews working at high altitudes (Sóbester, 2011). The presence of cosmic radiation in the aviation environment raises concerns about its potential health effects on flight personnel (Wilson, 2000). In the quest to ensure the well-being of airline employees, the issue of cosmic radiation exposure has gained increasing attention in recent years. Cosmic radiation is composed of high-energy particles, primarily protons and heavy ions, which can penetrate the Earth's atmosphere and reach the cruising altitudes of commercial flights (Paschoa and Steinhäusler, 2010). The impact of cosmic radiation on the human body and the potential health risks associated with prolonged exposure have led to growing interest in the field of radiation protection among flight crews.

Cosmic radiation exposure in commercial aviation has been a subject of global concern. Studies worldwide have shown that flight crews are exposed to higher levels of ionizing radiation due to their frequent and prolonged exposure at cruising altitudes (Paschoa and Steinhäusler, 2010). The potential health risks associated with this exposure have led to a growing body of research aimed at understanding and mitigating the effects of cosmic radiation (Nelson, 2016). These studies often involve estimating annual radiation protection quantities to assess the risk. Several international organizations have provided guidelines and recommendations for managing cosmic radiation exposure among flight crews. The International Commission on Radiological Protection (ICRP) and the International Air Transport Association (IATA) have issued publications that set dose limits and provide guidance on monitoring and reducing radiation exposure. These guidelines serve as a foundation for assessing the radiation protection needs of flight crews in Nigerian local airlines.

The health effects of cosmic radiation exposure are of paramount concern. Research has shown that ionizing radiation can increase the risk of developing cancer and other health issues. A study by (Grajewski et al., 2015) found that flight crews faced an increased risk of melanoma and other cancers. This underscores the importance of estimating radiation protection quantities to assess and manage these risks. Cosmic radiation exposure varies with geographical location and altitude. Flight crews operating in different regions may face varying levels of exposure due to factors like latitude and solar activity. Studies by (Beck et al., 2017; Zhang et al., 2020) have emphasized the significance of considering geographical and altitude variations when estimating annual radiation protection quantities for flight crews in Nigerian local airlines.

Various technologies are available for monitoring cosmic radiation exposure. Personal dosimeters, such as thermoluminescent dosimeters (TLDs) and electronic dosimeters, are commonly used by flight crews to measure their individual exposure. Aircraft-based monitoring systems also play a crucial role in assessing radiation doses during flights. The Nigerian Civil Aviation Authority (NCAA) and other relevant authorities have established regulations and guidelines for radiation protection in the aviation industry (Osunwusi, 2020). These regulations may need to be aligned with international standards, considering the unique challenges and geographical context of Nigeria (Gomes et al., 2012). The literature discusses the importance of regulatory compliance and the development of specific measures to protect flight crews in Nigerian local airlines.

Effective communication is vital in ensuring that flight crews and the public are aware of cosmic radiation exposure and its associated risks (Ali et al., 2020). The literature highlights the importance of transparency, education, and communication within the Nigerian aviation industry to build awareness and confidence in radiation protection measures. This research focuses on estimating the annual radiation exposures for flight crews operating in local Nigerian airlines. The aviation industry in Nigeria has experienced substantial growth over the years, and it is imperative to assess and manage the radiation risks faced by flight personnel operating within the country. This study aims to contribute to the understanding of cosmic radiation exposure among Nigerian flight crews, as well as to assess the adequacy of current radiation protection measures in place.

The research involves comprehensive data collection and calculations of key radiation parameters, such as absorbed dose rates, annual gonadal dose equivalents, and excess lifetime cancer risks. These estimates provide valuable insights into the level of cosmic radiation exposure and potential health risks faced by flight crews in Nigeria's local airlines. Additionally, the findings will assist in the development of effective radiation protection strategies and guidelines to ensure the safety and well-being of airline personnel. Ultimately, this research endeavors to bridge the knowledge gap regarding cosmic radiation exposure among flight crews in Nigerian local airlines safety standards in the aviation industry, while safeguarding the health of those who make air travel accessible and efficient.

MATERIALS AND METHODS

This study collected data on flight moment statistics, flight plan data and airport locations data. The data were collected through Nigerian Airspace Management Agency (NAMA) Lagos, Nigeria. Three Nigeria flights (Lagos – Abuja; Lagos - Port Harcourt and Lagos – Kano) from Muritala Muhammed International Airport, Lagos (MMIA) were selected. The three selected flights took place between 2011 and 2022 with a 60, 75, and 44 crew members respectively. This enables the researchers to compare the levels of cosmic radiation exposures received by individual crew members within the period specified. CARI- 6M (Civil Aero Medical Research Institute) is an instrument that store and process multiple flight profiles as well as calculate dose rates at user specified locations in the atmosphere was used for this study. It estimates the effective dose (in μsv) received by an individual in aircraft flying and were also determined the Annual Effective Dose received by flying crew members (Hwang et al., 2014). The workflow for calculating Annual Effective Dose adopted for the study is shown in Figure 1.

Figure 1: Workflow for calculating Annual Effective Dose using CARI 6M (Hwang et al. 2014)

MATLAB and EXCEL software packages were used to analyze and plot the data for the period of 12years under consideration (2011-2022)

Table 1: Origin Airport Coordinate and Elevation

S/N	Airport Location	1 CAO Co	Latitude	Longitude	Altitude
1.	Lagos	DNMM	6^0 34.55N	3^0 19.20^1 E	135

Table 2: Destination Airport Coordinate and Elevation

S/N	Airport Location	1 CAO Co	Latitude	Longitude	Altitude
1.	Kano	DNKN	12^0 2.50^1N	8^0 30.80^1E	1565
2.	Abuja	DNAA	9^0 0.30^1N	7^0 15.90^1E	1123
3.	Port Harcourt	DNPO	5^0 0.90^1N	6^0 56. 80^1E	81

Effects of Altitude, Sun's activities and geographic positions on Air Crew members

For this present research, the altitude of Lagos is 135 ft, Abuja is 1123 ft, Portharcourt is 81 ft and Kano is 1565 ft. The effects of this varying altitude on a total of 179 crew members have been analyzed. The effect of altitude radiations on individual crew shows that as altitude increases, the concentration of oxygen in the air decreases (Onuh et al.,2023). This can lead to hypoxia, a condition where there is insufficient oxygen reaching body tissues. Symptoms of hypoxia include dizziness, lightheadedness, impaired judgment, and eventually unconsciousness if not addressed. Furthermore, altitude exposure, especially during long flights or in pressurized cabins, can contribute to fatigue due to disrupted sleep patterns, increased physical demands, and environmental factors such as noise and vibration. Also, at higher altitudes, aircrew members may be exposed to increased levels of cosmic radiation, which can pose long-term health risks such as an increased risk of cancer (Ali et al., 2020). However, these risks are typically low for commercial aircrew members due to regulatory limits on exposure.

Solar activity has massive effects on aircrew members from time to time. Aircrew are exposed to higher levels of UV radiation at higher altitudes due to thinner atmosphere, and this exposure can increase the risk of skin cancer, cataracts, and other UV-related health issues if adequate protection is not used. Sun glare can affect visibility for pilots, especially during takeoff and landing (Nelson, 2016). This glare can cause eye strain and reduce the ability to see instruments and other aircraft. Sunlight can cause temperature fluctuations within the aircraft cabin, affecting the comfort and well-being of the crew (Hwang et al., 2014). Adequate climate control systems are necessary to mitigate these effects. Sun exposure can lead to increased dehydration, especially in aircraft cabins where humidity levels are typically lower. Aircrew must stay hydrated to maintain alertness and cognitive function.

Geographical positions of aircrew across the three different routes Lagos – Kano, Lagos – Abuja and Lagos – Port Harcourt is given as *45°*, 237.03°, *112.5°* respectively and their geographical latitude and longitude are as shown in table 3.1 and 3.2. This different geographic location considered in this research work gives flights different time zones and can lead to disruptions in the body's circadian rhythm, resulting in jet lag. Aircrew members may experience symptoms such as fatigue, difficulty sleeping, irritability, and impaired cognitive function as their bodies adjust to the new time zone (Grajewski et al., 2015).

Evaluation of other radiological parameters

Annual gonadal dose equivalent (AGDE)

An increase in AGDE has been known to affect the bone marrow and can damage red blood cells which can cause blood cancer. The annual gonadal dose equivalent (AGDE) is calculated using equation (1) as used in the work of Okedeyi et al., (2022).

$$AGDE = F_R \; X \; E \qquad (1)$$

Where F_R is the radiation- specific factor for the gonads, which represents the fraction of the effective dose that is received by the gonads. The value of F_R depends on the type and energy of radiation involved.

Excess Lifetime Cancer Risk (ELCR)

This is the probability of developing cancer over a lifetime at a given exposure level, considering 70 years as the average duration of life for human being. ELCR was calculated using equation (2) as used in the research of Ugbede and Echeweozo, (2017).

$$ELCR = AED \times DL \times RF \qquad (2)$$

where: AED is the Annual Effective Dose, DL is the average duration of life (estimated to 70 years), and RF is the Risk Factor = 0.05

RESULTS AND DISCUSSION

Effective Annual Dose (AED)

The result in Figure 2 shows that the annual effective dose (AED) received by the air crew members between 2011 and 2022 across the three routes of Lagos – Kano, Lagos – Abuja and Lagos – Port Harcourt ranges between 0.230 and 1.90 µSv y^{-1}. It also revealed that annual effective dose received was minimal between 2011 and 2015, moderate between 2018 and 2022 while the highest values were recorded in 2016 and 2017 and there is a direct relationship between the time of flight and the effective dose received by the crew members. The highest recorded dose of 1.90 µSv y^{-1} were in agreement with previous studies by Waters et al. (2000) and Feng et al. (2002) that has very low AED values. The result is lower than the recommended value 20 µSv y^{-1} recommended by International Commission on Radiological Protection (ICRP). Hence, the crew members on these routes are safe from cosmic radiation exposures.

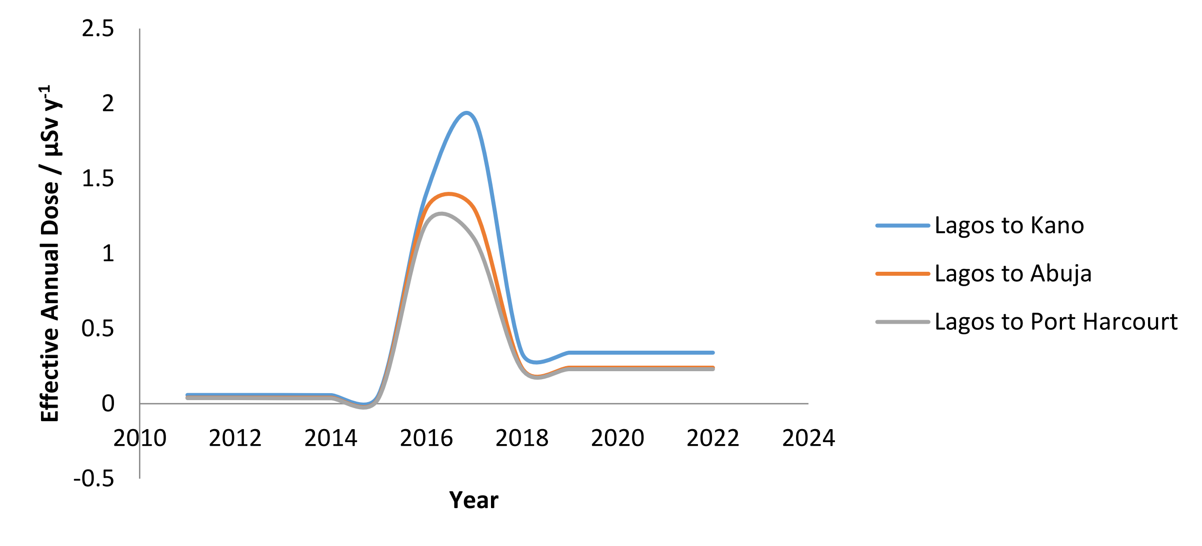

Figure 2: Graph of annual effective dose for Lagos – Kano, Lagos – Abuja and Lagos – Port Harcourt route between 2011 and 2022 against Year

Annual Gonadal Dose Equivalent (AGDE)

Table 3.3 depicts the Annual Gonadal Dose Equivalent (AGDE) across the three routes (Lagos – Kano, Lagos – Abuja and Lagos – Port Harcourt).The results showed that AGDE values range from 7.20 – 380 µSv y^{-1}. The result also revealed that only Lagos – Kano route in year 2017 (380 µSv y^{-1}) are above the maximum permissible value of 300 µSv y^{-1} recommended (UNSCEAR, 2000; Okedeyi et al., 2022) as can be seen in Figure 3.

Table 3: Annual Gonadal Dose Equivalent for the three routes between 2011 to 2022

Years	Annual Gonadal Dose Equivalent (µSv y^{-1})		
	Lagos to Kano	Lagos to Abuja	Lagos to Port Harcourt
2011	11.60	8.00	7.40
2012	11.60	8.00	7.40
2013	11.60	8.00	7.20
2014	11.40	8.00	7.20
2015	11.60	8.00	7.20
2016	280.00	260.00	240.00
2017	380.00	260.00	220.00
2018	68.00	48.00	46.00
2019	68.00	48.00	46.00
2020	68.00	48.00	46.00
2021	68.00	48.00	46.00
2022	68.00	48.00	46.00

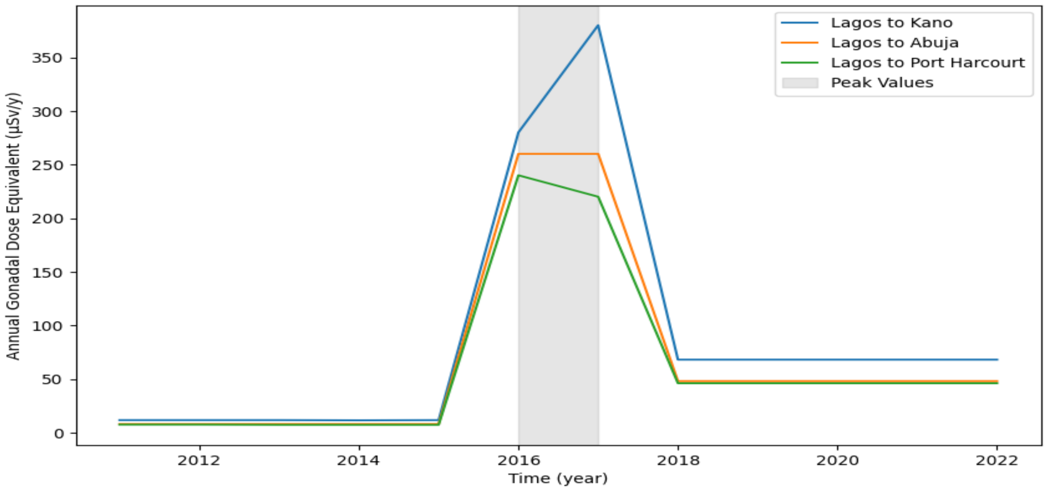

Figure 3: Annual Gonadal Dose Equivalent for the three routes between 2011 to 2022

Excess lifetime cancer risk (ELCR)

The excess lifetime cancer risk is the possibilities of crew members developing cancerous cell due to exposure to cosmic radiation in their lifetime. The calculated ELCR of the study indicated that values from year 2016 – 2022 across the three routes (Lagos – Kano, Lagos – Abuja and Lagos – Port Harcourt) as revealed in table 3.3 were higher than average standard value of 0.29 x 10^{-3} by (UNSCEAR, 2008). Figure 4 show the time series plot of the ELCR. The finding is in agreement with earlier report by (Ugbede and Echeweozo, 2017). The implication of this result is that there are possibilities of the crew members between year 2016 and 2022 of developing symptoms of cancer within their lifetime.

Table 4: Excess lifetime cancer risk for the three routes between 2011 and 2022

Years	Excess Lifetime Cancer Risk x 10^{-3}		
	Lagos to Kano	Lagos to Abuja	Lagos to Port Harcourt
2011	0.2030	0.14	0.1295
2012	0.2030	0.14	0.1295
2013	0.2030	0.14	0.1260
2014	0.1995	0.14	0.1260
2015	0.2030	0.14	0.1260
2016	4.9000	4.55	4.2000
2017	6.6500	4.55	3.8500
2018	1.1900	0.84	0.8050
2019	1.1900	0.84	0.8050
2020	1.1900	0.84	0.8050
2021	1.1900	0.84	0.8050
2022	1.1900	0.84	0.8050

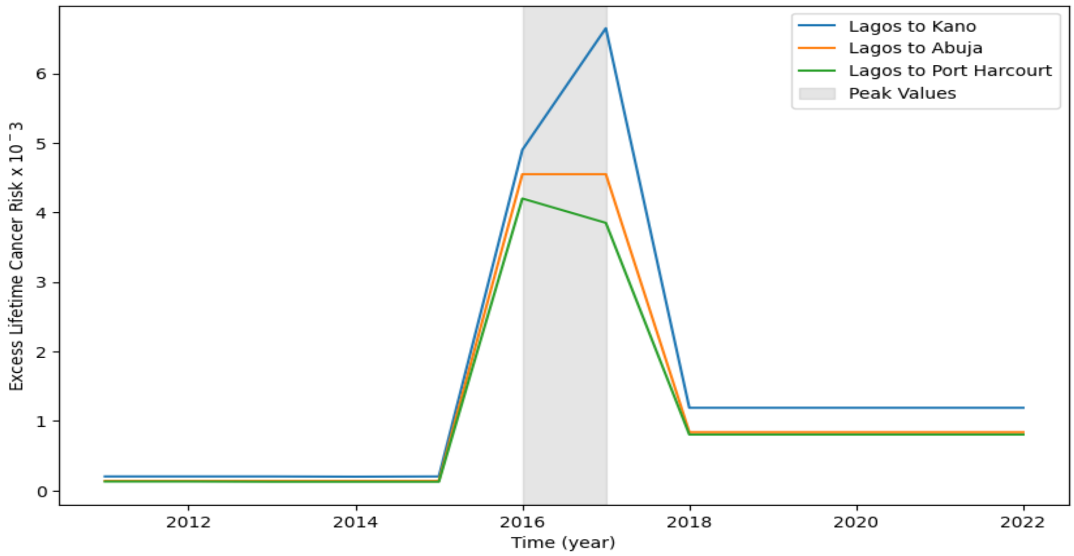

Figure 4: Time series plot of ELCR for the three routes between 2011 and 2022

CONCLUSION

This study assesses the annual exposures dose and other radiological parameters from cosmic radiation among flight crews in Nigeria local airline using aircrew cosmic radiation exposure estimation methods of radiation dose measurements and computer model calculations (computer code – CARI – 6M). The finding of the study shows that annual effective dose (AED) received by the air crew members (Lagos – Kano, Lagos – Abuja and Lagos – Port Harcourt) ranges between 0.230 and 1.90 µSv y^{-1}. This finding is lower than earlier studies by Friedberg et al., (2000) and Feng et al., (2002) that reported 6.6 - 9.7 µSv and 2.19 - 2.38 µSv. The result also indicated that there is direct relationship between the time of flight, flight altitude and the effective dose received by the crew members. The Annual Gonadal Dose Equivalent (AGDE) across the three routes ranges from 7.20 – 380 µSv y^{-1} with only Lagos – Kano route in year 2017 (380 µSv y^{-1}) above the maximum permissible value of 300 µSv y^{-1}, while the Excess Lifetime Cancer Risk (ELCR) values from year 2016 – 2022 across the three routes were also higher than average standard value of 0.29 x 10^{-3}. The AED follows the trends of solar cycle however; it is within the average background radiation levels. The associated significant excess lifetime cancer risk increases with cumulative doses and dependent of the flight routes. The implication of the finding is that there are possibilities of the crew members developing symptoms of cancer within their lifetime. It's therefore recommended that, Nigerian Civil Aviation Authority should introduce regulations to reduce flight crew exposure as well as training programs that can identify potential sources of radiation exposure as well as safety of Nigerian flight crews.

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