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Comparative Analysis of Cosmic Radiation Exposure Dose Due to the Russian Detour Route

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Since the World Health Organization (WHO) officially announced a global pandemic on March 12, 2020, the aviation industry in the world has been experiencing difficulties for a long time. Meanwhile, the Ukraine war broke out in February, and from March 15, domestic airlines must operate air routes bypassing Russian airspace despite the longer flight time. Therefore, as the flight time increases, the cosmic radiation exposure dose of the crew members is also expected to increase. Here we compare the radiation exposure dose between the route doses for the eastern United States and Europe before and after the detour route usage. Through the comparison analysis, we tried to understand how cosmic radiation changes depending on the flight time and the latitude and which one contributes more. We expect that this study can be used for the policy update for the safety management of cosmic radiation for aircrews in Korea.

Keywords: cosmic radiation, exposure dose, pandemic, Russian detour route, Ukraine war

1. INTRODUCTION

Covid-19 began on December 8, 2019, in Wuhan, China, and was officially declared a "worldwide pandemic" by the World Health Organization (WHO) on March 12, 2020. Many countries strengthened their containment policies, causing the aviation industry to suffer. While domestic airlines were trying to minimize damage, such as self-rescue efforts and government support, the aviation industry faced a massive crisis as Russia unexpectedly invaded Ukraine on February 24, 2022.

It is the implementation of active political, economic, and international sanctions, such as the prohibition of entry into Russian airspace and territorial waters. On February 28, 2022, the European Union (EU) announced that it would close its airspace against Russia, and Korean Air decided on March 15, 2022, to operate Europe and the US Eastern departure routes to avoid Russian airspace for safety. As a result, the average flight time for the passengers increased significantly, and the fuel costs increased, which caused the inevitable shrink of global air route operations. Recently, in Korea, it became a social issue that the sixth industrial accident was recognized due to the space radiation exposure of a flight attendant. And inevitably, increased flight time and latitude changes due to the Russia-Ukraine war might cause the unexpected radiation exposure increase. So we decided to analyze whether these concerns are valid or not quantitatively.

In this study, we compared and analyzed the exposure dose change of space radiation according to the Russia detour route by using a space radiation prediction program for eight air routes; four in the eastern United States and four in Europe. Finally, we found how the detour route affects the radiation exposure, flight time, and latitude of space radiation. We expect that these results can contribute to the establishment of policies for the safety management of space radiation for aircrews and passengers.

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2. DATA

2.1 Statistics of Numbers of International Flights

2.1.1 US Eastern Routes

Table 1 shows the statistics of flight numbers to the eastern United States from Incheon to New York, Chicago, Washington, and Boston from 2019 to 2021 for three years. Due to covid-19, it has been confirmed that there exist apparent changes in flight numbers, but they are not so significant. Instead, the increase in some routes could be attributed to the increase in cargo flights rather than passenger flights. As shown in Table 2, there was no significant difference in flights operated on US eastern routes after the Ukraine war occurred in March 2022.

2.1.2 European Routes

In the last three years, major air routes for Europe have changed significantly due to covid-19. Unlike the US eastern routes, the number of passenger flights has decreased noticeably, as shown in Table 3. However, in the case of Frankfurt Airport, operating both passenger and cargo planes, the number of flights has increased because of increased cargo flights. On the other hand, in cases of the other flights for Amsterdam, Paris, and London have decreased due to covid-19. But for the effect of war, there was no significant difference in the changes of the four European routes after the Ukrainian war in March 2022—the trend of increasing passenger planes as the covid-19 period is ending, as shown in Table 4.

Table 1. The number of flights operated by US Eastern routes, based on international airlines departing from Incheon international airport

Year	New York	Chicago	Washington	Boston
2019	3,109	1,974	730	365
2020	3,240	2,479	417	209
2021	3,426	3,541	418	313

Table 2. The number of flights operated by US Eastern routes before and after the Ukrainian war occurred in March 2022

Time	New York	Chicago	Washington	Boston
January 2022	298	259	44	27
February 2022	252	240	44	24
April 2022	244	245	37	26
May 2022	258	256	35	26

Table 3. The number of flights for European routes, based on international airlines departing from Incheon international airport

Year	Frankfurt	Amsterdam	Paris	London
2019	4,144	1,227	2,173	2,342
2020	3,612	1,024	913	1,209
2021	4,064	993	653	804

2.2 Flight Time and Latitude Change due to Russian Detour Route

2.2.1 US Eastern Routes

To compare and analyze the direct effect of the Russian detour routes after the war in Ukraine, the flight time and highest flight latitude for the routes departing from the eastern United States (New York, Chicago, Washington, and Boston) were analyzed based on the flight plans. The data we used are flights in April 2021 and April 2022 obtained from Korean Air. Flights from New York are 19 flights in 2021 and 28 flights in 2022, and flights from Chicago are 19 flights in both years. Flights from Washington are 15 flights in 2021 and 17 flights in 2022; those from Boston are 13 flights in both years. The average flight time and the highest latitudes are summarized in Table 5.

From Table 5, we found that before the war in 2021, the North Pole and Russian routes were operated over 70 degrees north, whereas after the war in 2022, all flights were flying below 70 degrees north to avoid flying over Russian airspace. And this latitude change in the air route resulted in a net increase in flight time. As a result of comparing the average flight time, the difference in flight time before and after the Russian detour route was up to 1 hour and 20 minutes for flights departing from Boston and at least 42 minutes for flights departing from Chicago.

2.2.2 European Route

Similarly, we analyzed the geographic information of flight plans of European departure routes for Frankfurt, Amsterdam, Paris, and London after the war. The flights from Frankfurt are 15 flights in 2021 and 17 flights in 2022; from Amsterdam are five flights and eight flights; from Paris are nine flights in both years; and from London are 12 flights and 19 flights. The average flight time and average latitude are shown in Table 6.

Table 4. The number of flights for European routes before and after the Ukrainian war in March 2022

Time	Frankfurt	Amsterdam	Paris	London
January 2022	310	80	55	71
February 2022	269	70	46	62
April 2022	363	70	53	82
May 2022	386	71	61	79

Table 5. Flight time and highest latitude data for the eastern US routes before and after the Ukrainian war

Time		New York		Chicago		Washington		Boston	
		Flight time	Latitude	Flight time	Latitude	Flight time	Latitude	Flight time	Latitude
April 2021	Average	13 h 47 m	N81	13 h 25 m	N76	13 h 45 m	N79	13 h 31 m	N79
	Maximum	14 h 25 m	N82	13 h 36 m	N79	14 h 12 m	N82	14 h 3 m	N81
	Minimum	13 h 6 m	N75	13 h 19 m	N75	13 h 31 m	N75	13 m 1 m	N75
April 2022	Average	14 h 58 m	N65	14 h 7 m	N62	14 h 50 m	N63	14 h 51 m	N66
	Maximum	15 h 25 m	N70	14 h 25 m	N66	15 h 24 m	N67	15 h 15 m	N70
	Minimum	14 h 35 m	N61	13 h 36 m	N58	14 h 28 m	N59	14 h 24 m	N62

Table 6. Flight time and highest latitude data for European routes before and after the Ukrainian war

Time		Frankfurt		Amsterdam		Paris		London	
		Flight time	Latitude	Flight time	Latitude	Flight time	Latitude	Flight time	Latitude
April 2021	Average	9 h 56 m	N59	9 h 49 m	N61	10 h 17 m	N61	10 h 19 m	N60
	Maximum	10 h 17 m	N60	10 h 13 m	N63	10 h 43 m	N63	10 h 37 m	N63
	Minimum	9 h 30 m	N56	9 h 22 m	N60	9 h 46 m	N56	9 h 51 m	N56
April 2022	Average	11 h 4 m		11 h 26 m		11 h 37 m		11 h 52 m	
	Maximum	11 h 40 m	N49	11 h 51 m	N52	11 h 51 m	N48	12 h 17 m	N51
	Minimum	10 h 41 m	N37	11 h 13 m	N37	11 h 25 m	N37	11 h 33 m	N37

There is a clear difference between the European and eastern US routes. The European route initially flew through Russian airspace for a long time, but they could not pass through Russian airspace after war; the latitude of the Europe airport is the highest on the route, and the flight time became longer. According to the above analysis results, the average flight time between flying Russian routes before and after the war they were increased by up to 1 hour 37 minutes from Amsterdam and at least 1 hour 8 minutes from Frankfurt.

3. COMPARATIVE ANALYSIS OF EXPOSURE DOSES ON SIGNIFICANT ROUTES

3.1 Theory and Model Description

3.1.1 Cosmic Radiation

In the universe, various radiations are flying toward the earth, collectively referred to as cosmic radiation. This cosmic radiation is divided into the Galactic Cosmic Rays (GCR) starting from the galaxy and the Solar Cosmic Rays (SCR) beginning from the sun. GCR pours from distant galaxies, such as supernova explosions, and SCR is caused by solar proton events. When the exposure dose is analyzed at an altitude of 9 to 12 km, which is the cruising altitude of a commercial aircraft, cosmic radiation varies greatly depending on the altitude and the solar activity, especially in the polar region. In contrast, in the equatorial region, the dependence on altitude and solar activity is relatively very weak compared to the polar region (KOFONS 2018).

Fig. 1 shows that the dose rate change of cosmic radiation increases as the flight altitude increases, latitude increases (polar and equator), and solar activity is low (solar minimum and solar maximum). In an aircraft altitude, lowering the altitude by 600 m (2,000 ft) has an average reduction of 13.2% compared to the exposure dose received at that altitude (Ahn et al. 2020). Ambient does an equivalent rate of cosmic radiation during the solar minimum changes from 4.8 to 9 μSv/hr in the polar region, but it changes from 1.2 to 1.7 μSv/hr in the equator region. During the solar maximum, it changes from 3 to 4.9 μSv/hr in the polar region and from 1.5 to 2 μSv/hr in the equator region (Kim 2022). In 2021, the Ministry of Land, Infrastructure, and Transport (MLTM) revised the space radiation safety management regulations for crew members. It stipulated that the annual accumulation dose for aircrew should not exceed six mSv (Korea Law Information Center 2016).

3.1.2 Korean Radiation Exposure Assessment Model for Aviation Route Dose (KREAM)

The Korean Radiation Exposure Assessment Model for aviation route dose (KREAM) is a radiation exposure dose prediction model jointly developed by the Korea Astronomical Research Institute (KASI) and the Korea Meteorological Administration (KMA). Recently the KREAM webpage has been opened to the public, and one can calculate his radiation exposure per flight. The radiation calculation page of the KREAM homepage is shown in Fig. 2. KREAM is an original model that reflects not only GCR but also solar proton event

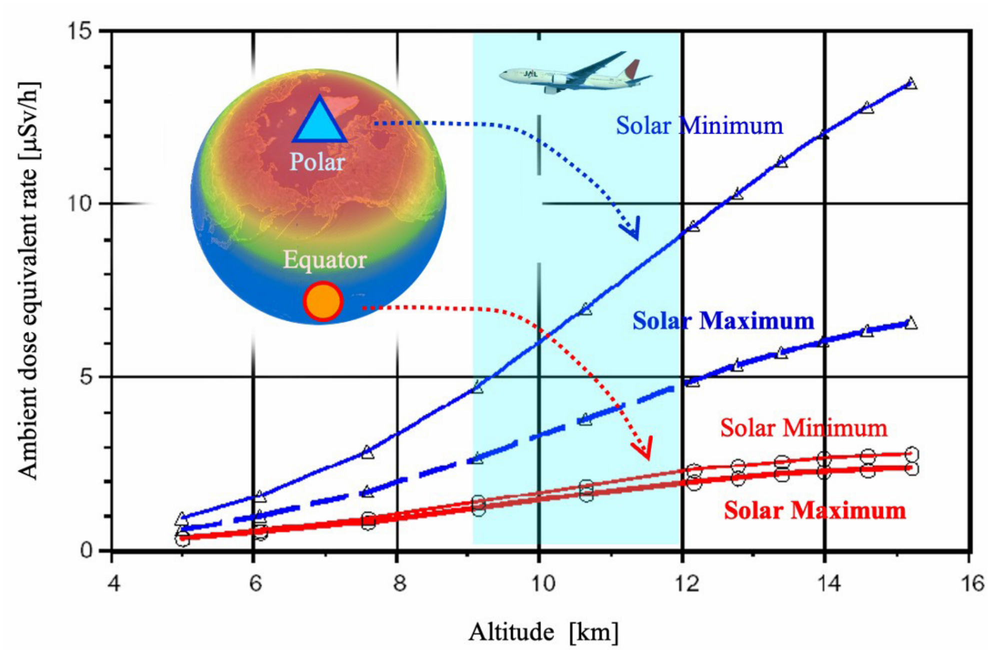

Fig. 1. Cosmic radiation dose characteristics depend on altitudes, latitudes, and solar activities.

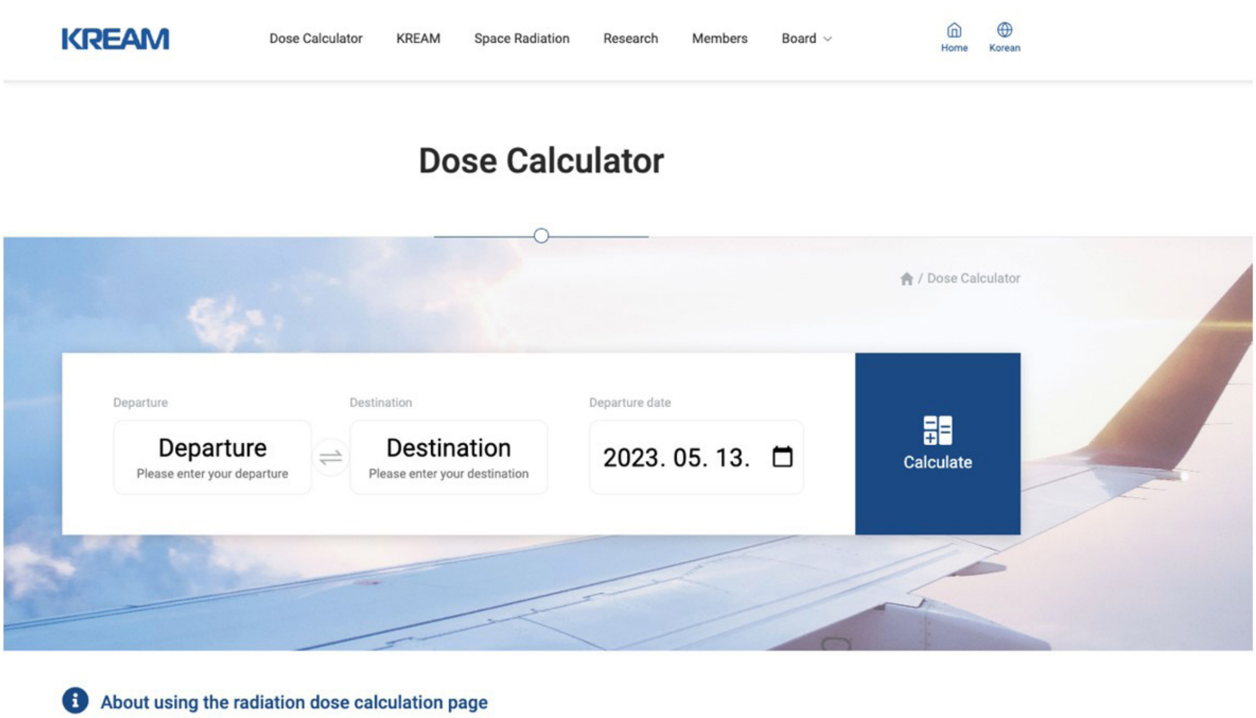

Fig. 2. Cosmic radiation route dose calculator page on KREAM homepage. Adapted from KREAM webpage operated by KASI (http://kream.kasi.re.kr).

effects from the sun and is an improved model that can reflect real-time space weather using the geosynchronous proton data (KMA 2015). KREAM is an enhanced model from previous models such as CARI-6 and NAIRAS because it can include instantaneous space weather changes within a short update period of about 5 minutes for proton observations by geosynchronous satellites (Hwang et al. 2010, 2014, 2020). All comparisons of exposure doses in the air routes in this study utilized the values calculated by KREAM.

3.1.3 CARI-6/6M

CARI-6/6M was developed by Federal Aviation Administration (FAA) Civil Aerospace Medical Institute (CAMI) and is a program that calculates an effective dose rate using the heliocentric potential (HCP) values (O'Brien et al. 2005). CARI-6/6M calculates radiation dose using flight date, departure, and arrival airports, and route information (altitude, flight time). Currently, air carriers can select and use the cosmic radiation exposure radiation dose evaluation program according to Chapter 5 of the Safety Guidelines for Safety Management of Radiation in the Living Environment. Four airlines, Korean Air, Asiana, Jeju Air, and Jin Air, use CARI-6M, while five airlines, Air Busan, Air Seoul, Air Incheon, T-way, and Fly Gangwon, use CARI-6 to evaluate the exposure dose of their flight attendants (KINS 2022). In this study, a comparison of CARI-6/6M exposure dose was not studied. Instead, we use the model which is most recently developed.

3.2 Comparative Analysis of Changes in Average Monthly Exposure Dose

Fig. 3 shows the comparative analysis of the average monthly exposure dose before and after using the Russian bypass route caused by the Ukrainian war on four routes in the eastern United States and four routes in Europe between September 2021 and September 2022. Although the flight path was based on the path and altitude of the flight plan, there can be some path and altitude differences for actual flights, but errors are negligible. We found that there are significant diminishing of radiation exposure after the war, which is due to the usage of the Russian detour route. And this tendency is more noticeable for the European routes than the US eastern routes.

Fig. 3. Comparison of exposure dose before and after the Russian detour route. ORD, Chicago O'Hare; JFK, New York John F. Kennedy; BOS, Boston; IAD, Washington Dulles International Airport; CDG, Paris Charles de Gaulle Airport; FRA, Frankfurt am Main Airport; LHR, London Heathrow; AMS, Amsterdam Airport.

3.2.1 US Eastern Routes

Table 7 shows a comparison of the average monthly exposure dose of the normal routes (in September 2021) and the North Pacific route (in September 2022). The normal route various routes such as the Arctic route, Russian route, and North Pacific route. The decrease in exposure dose due to the bypass route was in the largest order of Chicago (11.39 μSv), New York (10.51 μSv), Washington (7.33 μSv), and Boston (2.64 μSv). This seems to be because the exposure dose was calculated low according to the low latitude in the bypass route. The bypass routes are usually 13 to 16 degrees lower than the normal routes.

3.2.2 European Routes

Four European routes also showed a decrease in exposure dose on bypass routes, as shown in Table 8. The difference between each route was analyzed in the largest order of Frankfurt (22.15 μSv), Paris (19.75 μSv), London (18.2 μSv), and Amsterdam (14.82 μSv). Compared to the US eastern route, it is clearer the radiation exposure dose was diminished due to the bypass route. This might be due to the fact that the bypass route flew at a low latitude of fewer than 50 degrees north, although the flight time increased compared to the usual route that passed for a long time at a high altitude of more than 50 degrees north. The latitude change has more significant effect than the flight time.

3.3 Comparative Analysis of Radiation Exposure over Time on Routes to the Eastern United States and Europe

3.3.1 Radiation Exposure from New York/Chicago to Incheon Route

Fig. 4 show the comparative radiation exposure of the North Pacific route with a green line and the Russian detour route with a red line route on September 21, 2021, and September 21, 2022, respectively. In the case from New York John F. Kennedy (JFK) international airport to Incheon (ICN) Airport shown in Fig. 4(a), the exposure route dose of the

Table 7. Average annual exposure dose rate change for the US Eastern routes before and after the Ukrainian war (μSv)

Time		New York	Chicago	Washington	Boston
September 2021 (normal routes)	Average	100.67	97.35	95.76	96.68
	Deviation	0.80	0.73	0.74	0.78
September 2022 (bypass routes)	Average	90.16	85.96	88.43	94.04
	Deviation	1.42	1.34	1.39	1.47

Table 8. Average annual exposure dose change for the European routes before and after the Ukrainian war (μSv)

Time		Frankfurt	Amsterdam	Paris	London
September 2021 (normal routes)	Average	63.95	62.52	63.16	66.58
	Deviation	0.38	0.37	0.48	0.46
September 2022 (bypass routes)	Average	41.80	47.71	43.41	48.38
	Deviation	0.19	0.20	0.21	0.21

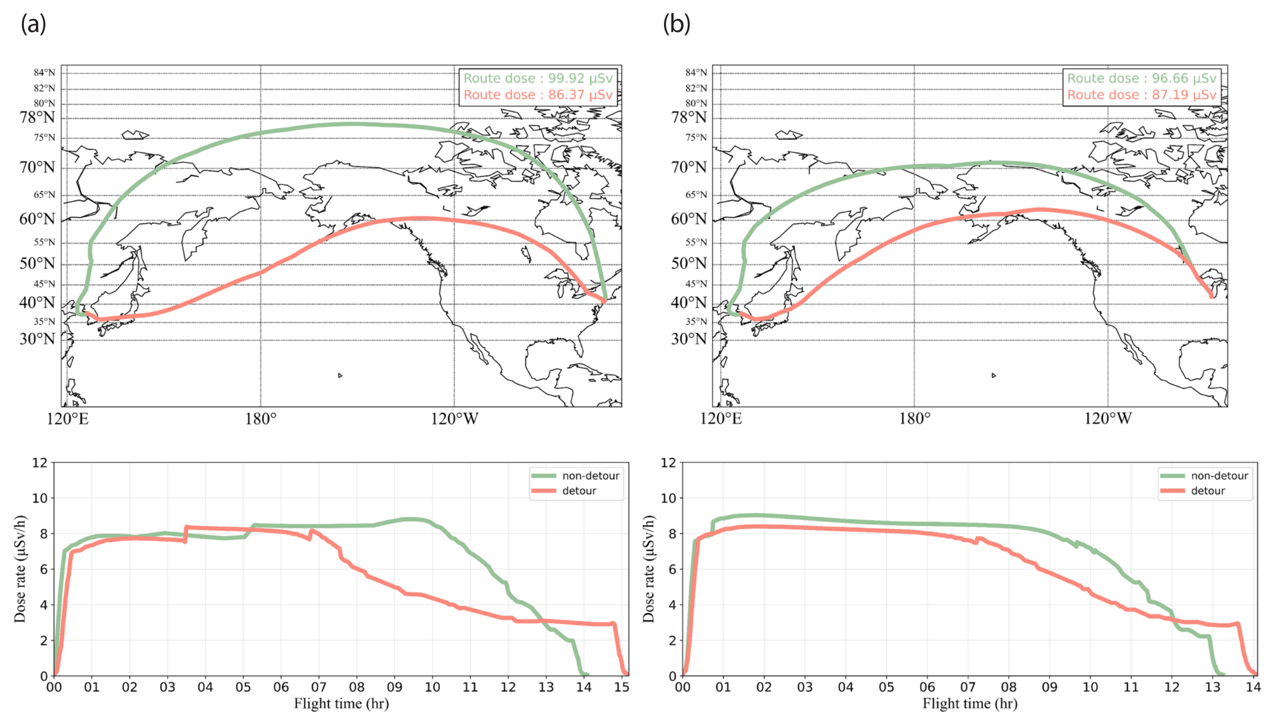

Fig. 4. Radiation exposure from New York/Chicago to Incheon route. Comparison (a) between the normal North Pacific route (green line) and detour route (red line) from JFK to ICN exposure dose rate, (b) between the normal North Pacific route (green line) and detour route (red line) from ORD to ICN exposure dose rate. JFK, New York John F. Kennedy; ICN, Incheon Airport; ORD, Chicago O'Hare.

bypass route (red line) was 86.37 μSv, and the original route of the North Pole route (green line) was 99.92 μSv showing a decrease of 14% route dose. From Chicago O'Hare (ORD) international airport to Incheon Airport, shown in Fig. 4(b), the exposure route dose of the bypass route (red line) was 87.19 μSv, and the original route of the North Pole route (green line) was 96.66 μSv showing a decrease of 10% route dose. As can be seen in the dose rate in Fig. 4(a) and 4(b), the difference in exposure dose according to latitude is not large above about 50 degrees of north latitude, but at lower latitudes below that, the exposure dose was significantly lower than that of the high latitude area.

3.3.2 Radiation Exposure from London/Frankfurt to Incheon Route

A similar analysis for the European route was performed, and we found the decrease amount is much more significant for European routes. Fig. 5(a) shows the route dose from London Heathrow (LHR) airport to Incheon Airport, and Fig. 5(b) shows the from Frankfurt am Main Airport (FRA) to Incheon Airport. The exposure dose of the bypass route from

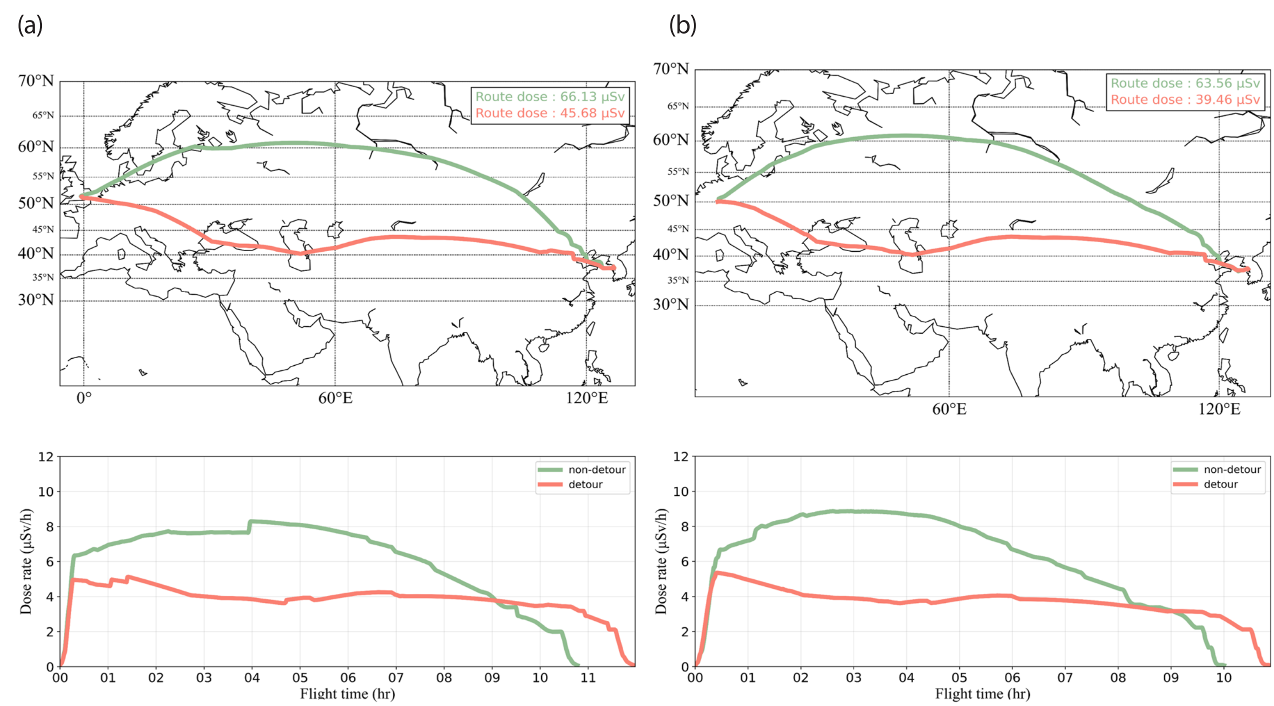

Fig. 5. Radiation exposure from London/Frankfurt to Incheon route. Comparison (a) between normal North Pacific route (green line) and detour route (red line) from LHR to ICN exposure dose rate, (b) between normal North Pacific route (green line) and detour route (red line) from FRA to ICN exposure dose rate. LHR, London Heathrow; ICN, Incheon Airport; FRA, Frankfurt am Main Airport.

London to Incheon route was 45.68 μSv, and the exposure dose of the original route passing through Russian airspace was 66.13 μSv showing a decrease of 31% route dose. For the Frankfurt route, the exposure dose of the bypass route was 39.46 μSv, and the exposure dose of the original route was 65.36 μSv showing a decrease of 41% route dose. As can be seen in Fig. 5, in the case of European routes, routes bypassing Russian airspace fly for a longer time at latitudes below 50 degrees north latitude, where the radiation exposure rate varies greatly. In contrast, the original routes usually fly at higher latitudes, and radiation exposure at high latitudes usually is bigger than at lower latitudes. Since the staying time at the lower latitude region was longer, the exposure dose in the detour route was about 20 μSv lower than that of the original route.

4. CONCLUSIONS

Since Russian airspace cannot be used due to the war in Ukraine, most airline companies have been forced to operate detour routes. As a result, airline companies, flight attendants, and passengers suffer from increased flight times. So in this study, we analyzed the actual change in cosmic radiation exposure dose due to the difference in flight time and latitude between the regular and detour routes and found significant differences between the two. For the eastern US routes, the usual and bypass routes operating in high latitudes more than 50 degrees north latitude were not significantly affected by latitude. But it is noticeable that the radiation exposure of bypass routes has decreased somewhat due to an increase in the ratio of flying time in mid-latitude areas. Compared to the US route, where the difference was relatively small, the difference in radiation exposure on the European route was much larger. In European routes, we found that the difference in latitude between the normal route operating in high latitude and the bypass route in mid-latitude significantly affected radiation exposure. As a result, the reduction in radiation exposure due to the operation of the bypass route to Russia on the US East route and the European route was 7.97 μSv and 18.73 μSv on average, respectively.

In conclusion, it is desirable to select an appropriate route according to latitude when allocating the crew's flight time and schedule since the latitude greatly reduces radiation exposure. We know that the bypass route might cause some reduction in cosmic radiation exposure. In addition, it is expected that solar activity will increase as it is close to the solar maximum period, which is estimated in 2025, so cosmic radiation research in aircraft altitude should be continued.

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