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The Estimation of Annual Exposure to the Irish Population from Cosmic Radiation due to Air Travel

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Anytime that someone travels by air they will receive a dose of ionising radiation in the form of cosmic radiation. The aim of this study was to estimate the average dose of cosmic radiation received by a member of the Irish public over the period of a typical year due to air travel. The frequency of air travel by Irish residents to several regions was determined using data from various sources. The total dose that one would receive for a typical flight to and from the region was then calculated using software available for flight crews to estimate the radiation dose that they have received through flying. The annual effective dose for an Irish person as a result of cosmic radiation from air travel was estimated to be 68 μSv.

Key words: cosmic radiation, EPCARD, dose assessment, air travel, public exposure

1. Introduction

Cosmic radiation is the term used to describe both the high-energy, charged particles of extraterrestrial origin that strike the earth's atmosphere (primary particles), as well as the secondary reaction products that result from the interaction of those high-energy, extraterrestrial particles with the nuclei of atmospheric constituents (secondary particles)[1].The intensity of exposure from cosmic rays is strongly dependent on altitude and there is also a dependence on latitude but that is less significant[1]. Cosmic radiation is a source of ionising radiation at all altitudes, but because the intensity of cosmic radiation increases with increasing altitude, aircraft passengers and crew are subject to higher rates of cosmic radiation exposure compared to cosmic radiation exposure at ground level[1]. The goal of this study was to estimate the average radiation dose received by a member of the Irish public due to air travel over the course of a typical year.

This study was conducted as part of a larger assessment, which is currently ongoing as of early 2023, with the goal of estimating the annual effective dose of the typical Irish person from all sources of ionising radiation. Despite the fact that estimations of annual effective dose from cosmic radiation due to air travel have been made before, it was deemed necessary to conduct a new study due to changes in the flying habits of the Irish population and changes in flight patterns in the period since the previous studies were conducted.

2. Methods

2.1. Travel Statistics 2019

The Central Statistics Office (CSO) is Ireland's national statistical office whose purpose is to publish detailed and accurate statistics about Ireland's people, society and

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economy[2]. The CSO publishes data on the frequency of international trips undertaken by Irish residents. This data is collected by the CSO via a household travel survey[3]. The data is categorised by the frequency of travel to several discrete regions and is provided in tables of data available to be downloaded or viewed on the CSO website[4-6]. The CSO data provides information on the total number of Irish residents who have visited each of the regions each year, but they do not distinguish between different modes of transport.

Due to its status as an island, international travel from Ireland must take place either via sea or via air (excluding Northern Ireland but there are no regularly scheduled flights to Northern Ireland from Ireland). The CSO also publishes data on maritime travel from Ireland[7]. The only regions that regularly receive maritime passengers from Ireland are Great Britain, France and Spain[7]. Data on the number of visitors who arrived in the UK by sea in 2019 is provided by VisitBritain[8]. Since there are no regular maritime passenger services from Ireland to Northern Ireland it was assumed that all of these maritime passengers travelled to Great Britain. Data on the number of Irish residents who visited France by sea in 2019 was acquired using CSO data on total outbound maritime passengers[7]. It was assumed in this study that 50% of total maritime passengers who travelled to France from Ireland were visitors to France who were resident in Ireland. Maritime travel to Spain from Ireland was negligible compared to the overall number of Irish residents who visited Spain in 2019. Using the data on maritime passengers available and the assumptions outlined above, data on the number of visitors who travelled to Great Britain and France by air could be calculated by subtracting the assumed number of maritime passengers from the total visitor figures given in the CSO data on Irish visitors to these regions[6]. For all other regions it was assumed that 100% of Irish visitors to the region travelled there by air.

The regional breakdown of places visited by Irish residents provided by the CSO was, for certain regions, not sufficient for the purposes of this study. This occurred when the region was large, members of the Irish public were flying to numerous destinations within these regions or there was large variability in the radiation dose that one would receive from flying to the different destinations within a region. The regions identified as having this issue were Spain and North America.

The CSO data only provides information on the total number of visitors to Spain and does not provide any information on the distribution of visitors between the different regions within Spain, there is no indication of whether a visitor to Spain travelled to mainland Spain (including the Balearic Islands) or the Canary Islands[6]. This is an issue because the Canary Islands receive a relatively large number of Irish visitors[9] and there is a significant difference between the dose received from a flight from Ireland to one of the Canary Islands, off the coast of west Africa, compared with a flight to a destination within mainland Spain including the Balearic Islands. Assumptions were made by looking at data published by the CSO and comparing the total number of passengers that travelled from Dublin airport to each of the airports in Spain for which direct flights were available[9]. Only flights from Dublin airport were investigated because it handled the vast majority (86%) of Irish aviation passengers in 2019[9]. It was thus assumed in this study that 76% of visits by Irish residents to Spain were to the mainland or the Balearic Islands, while 24% were to the Canary Islands. Assumptions about the distribution of trips to North America were also made using the same method utilising this data from the CSO[9]. The North American region consists of the US and Canada and for this region it was assumed that 63% of trips by Irish residents were made to the Northeast, 9% to the Southeast, 15% to the Midwest and 13% to the Western region of North America. This assumption is based on CSO data on the number of passengers who flew direct from Dublin Airport to the international airports within these regions[9].

For all European and North American regions, to choose a representative destination for each region, the aforementioned CSO data on total passenger numbers was used[9]. The aim in choosing a representative destination for each region was to have a destination for which a dose estimation could be made for a return flight between Dublin and that destination. This dose would then be assumed to represent a typical dose for a visitor flying to and returning from the region in which the representative destination was located. In most cases the destination within a region which received the highest volume of passengers from Dublin airport on direct flights in 2019 was chosen as the representative destination for that region. If the destination which had received the highest volume of passengers was considered unrepresentative due to its geographical location, then a different destination which had still received a high volume of passengers but was located in a more representative location within the region would be chosen. For example, within mainland Spain including the Balearic Islands, the three locations which received the highest volume of passengers from Dublin Airport in 2019 were: Malaga with 329,649 passengers, Barcelona with 320,048 passengers and Madrid with 273,035 passengers[9]. Both Malaga and Barcelona are located at or near the edge of mainland Spain, with Malaga being located near the Southern tip of Spain and Barcelona being located in the Northeast. That is why, despite receiving less passengers from Dublin Airport than both Barcelona and

Malaga in 2019, Madrid was chosen as the representative destination for mainland Spain including the Balearic Islands. This was due to it being located relatively centrally between the two locations which received the highest volume of passengers from Dublin Airport in 2019 while also having received a relatively large number of passengers from Dublin Airport itself.

In the case of the Africa, Asia, Oceania and "Other America" regions there were little or no direct flights to most destinations within these regions. As a result of this, there was not enough data from the CSO publication of passenger numbers to choose a representative destination using the method that had been used for the regions within Europe and North America. In the case of Africa, Nairobi was chosen as the representative destination due to its location in the centre of the continent. There was no data available on the number of Irish visitors to different regions within Africa, so it was assumed that the distribution of Irish visitors was uniform throughout the continent. The "Other America" region consists of all of the other countries in the Americas not previously mentioned. Buenos Aires was chosen as the representative destination of this region due its size and its relatively central location within the region as there was no data available on the frequency of Irish residents' trips to Central and South America by region. Sydney was chosen as the representative destination for the Oceanic region due to it being the largest city in the region[10], and it is located relatively centrally within the region. Bangkok was chosen as the representative destination for Asia due to its size and its central location within the Asian continent.

2.2. Dose Estimation

The average dose received by a visitor to each of the regions was determined by the dose one would receive as a result of flying from Dublin Airport to the representative destination of the region and back again. The calculations were made using the European Program Package for the Calculation of Aviation Route Doses (EPCARD) software[11]. The EPCARD software is a tool that calculates the dose received on a flight once specified parameters are input. It has been approved for official dose calculation for flying personnel by the German Federal Aviation Authority[12]. It has also been approved by the European Commission for use in estimating occupational radiation exposure of aircrew[13]. EPCARD requires the following input parameters to make a dose calculation: the date of the flight, the departure airport, the destination airport, the ascending and descending times and the cruising altitude. Estimations for the return trip doses were made by taking the sum of the outbound and return flight average doses. The average doses for the outbound and return flights were estimated by making an EPCARD calculation for each flight with the date set as the 15th day of each month of the year and getting the average value by taking the sum total of all the doses for each of the 12 months and dividing this by 12. This was done to account for variations in the cosmic ray flux throughout the year[14]. Dublin airport is by far the busiest airport in Ireland, it handled 86% of total Irish commercial air passengers in 2019, so it was used as the departure airport for all dose calculations[9, 15]. The destination airport was taken as the primary international airport within the representative destination of each region.

The ascending and descending times and the cruising altitudes were chosen based on the categorization of the flight into one of three categories: short-haul, medium-haul or long-haul. Flights under 3 hours were considered short-haul, flights between 3-6 hours were considered medium-haul and flights over 6 hours were considered long-haul for this study[16]. For short-haul flights, the ascending and descending times were taken as 20 minutes respectively and the cruising altitude was assumed to be 36,000 feet. For medium-haul flights, the ascending and descending times were taken as 25 minutes respectively and the cruising altitude was assumed to be 38,000 feet. For long-haul flights, ascending and descending times were taken to be 30 minutes respectively with an assumption that the plane would be at a cruising altitude of 37,000 feet 50% of the time and 41,000 feet for the other 50%[17]. Flight times were taken from online flight time calculators[18, 19]. The travel statistics from Table 1 were then used to find the collective dose (manSv) for each region. This was achieved by multiplying the return dose that was estimated using EPCARD by the number of visitors to each region.

3. Results

The number of visitors from Ireland by air to each region considered as part of this study in 2019 are outlined in Table 1.

The return trip dose and collective dose for each region considered as part of this study is outlined in Table 2. The total collective dose for all of the flights over a year was 334 manSv. Dividing this by the population of Ireland in 2019, which was 4,921,500, gives an annual effective dose of 68 μSv. In 2019 there had been a 26% increase in international trips by Irish residents since the most recent study on cosmic radiation exposure due to air travel in Ireland that had been conducted previously[14].

4. Discussion

Due to the covid-19 pandemic, air travel in Ireland decreased dramatically during the years 2020 and 2021[20] so the average radiation dose received during these

Table 1. Number of trips by air by Irish residents to the representative destinations of the regions in 2019

Region	Representative destination	Return trips (1000s)
Austria	Vienna	89
Belgium	Brussels	99
Germany	Frankfurt	261
Spain-Mainland and Balearics	Madrid	1430
Spain-Canary Islands	Lanzarote	451
Spain Total		**1881**
France	Paris	527
Italy	Milan	590
Netherlands	Amsterdam	205
Poland	Krakow	171
Portugal	Faro	522
Great Britain	London	1727
Denmark/Finland/Sweden	Copenhagen	83
Other EU28*	Budapest	494
Other Europe	Istanbul	208
North America Northeast	New York City	368
North America Southeast	Orlando	53
North America Midwest	Chicago	88
North America West	San Francisco	76
North America Total		**584**
Africa	Nairobi	57
Asia	Bangkok	301
Oceania	Sydney	73
Other America	Buenos Aires	63

*EU28 includes the UK as they were still a member of the European Union in 2019

Table 2. Return and collective dose for each region.

Region	Representative destination	Return trips (1000s)	Return trip dose (μSv)	Collective dose (manSv)
Austria	Vienna	89	35	3.1
Belgium	Brussels	99	19	1.9
Germany	Frankfurt	261	24	6.3
Spain-Mainland and Balearics	Madrid	1430	27	38.6
Spain-Canaries	Lanzarote	451	37	16.7
Spain Total		1881		55.3
France	Paris	527	20	10.5
Italy	Milan	590	28	16.5
Netherlands	Amsterdam	205	20	4.1
Poland	Krakow	171	41	7.0
Portugal	Faro	522	24	12.5
Great Britain	London	1727	15	25.9
Denmark/Finland/Sweden	Copenhagen	83	29	2.4
Other EU28*	Budapest	494	40	19.8
EU 28 Total*				165.3
EU 27 Total				139.4
Other Europe	Istanbul	208	54	11.2
North America Northeast	New York City	368	142	52.3
North America Southeast	Orlando	53	162	8.6
North America Midwest	Chicago	88	168	14.8
North America West	San Francisco	76	230	17.5
North America Total		584		93.1
Africa	Nairobi	57	73	4.2
Asia	Bangkok	301	140	42.1
Oceania	Sydney	73	160	11.7
Other America	Buenos Aires	63	95	6.0

*EU28 includes the UK as they were still a member of the European Union in 2019

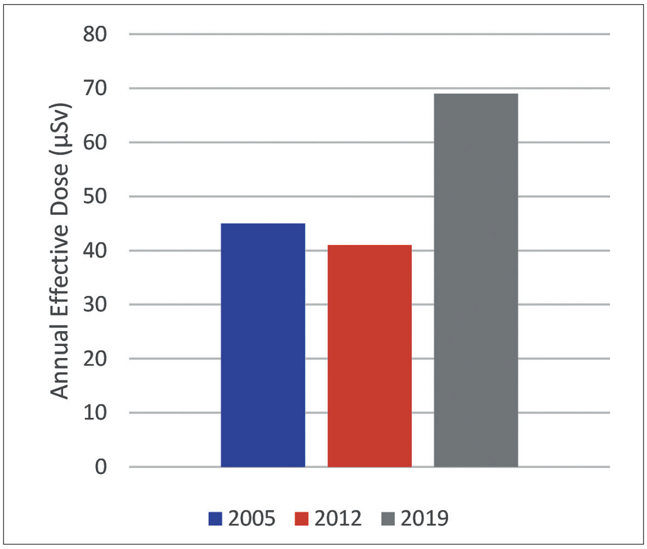

Fig. 1. Annual effective doses from cosmic radiation due to air travel in 2005, 2012 and 2019, in µSv.

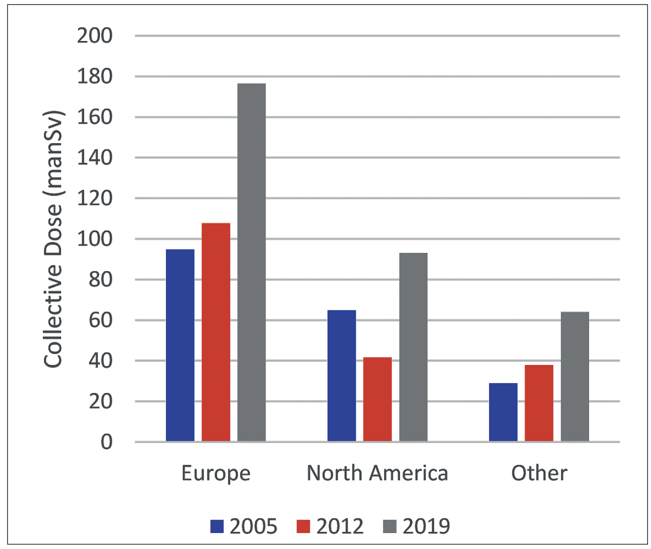

Fig. 2. Annual effective doses for different regions in 2005, 2012 and 2019, in µSv.

two years would not be representative of the average dose that one would expect to receive in a typical year. This is the reason why data from 2019 is used in this study, as it is the most recent year, not impacted by the covid-19 pandemic, that representative data was available to estimate an annual effective dose for an Irish person as a result of cosmic radiation from air travel. Domestic flights were not considered as part of this study. Due to the fact that Ireland is relatively small in size, there are very few domestic flights within Ireland. Due to the very low frequency, low altitude and short durations of Irish domestic flights it was deemed that domestic flights would represent a negligible impact to the annual effective dose calculations from air travel and they were not included in the overall dose assessment.

The value of 68 µSv for the annual effective dose of cosmic radiation from air travel received by an Irish resident estimated in this study is higher than previous estimated doses, 41 µSv in 2012 and 45 µSv in 2005, as demonstrated in Figure 1[14, 17]. There are a number of potential reasons for this. Firstly, there had been an increase in air travel between 2012 and 2019 which was significantly greater than the increase in population during that period, there was a 25.6% increase in international return trips as opposed to a 7.2% increase in population in that period[4, 14, 21]. In addition, many of the estimations made in this study for the dose received for a return flight were higher than they had been in previous studies for the same destination. This could partly be due to variations in the intensity of the cosmic ray flux for the years being assessed but that would be unlikely to account for the entire increase[14]. Most of the parameter values used in this study were consistent with the values used in previous studies[17, 22] apart from the dates of the flights and the flight times (there was also a slight difference arising from the fact that previous studies did not include a medium-haul flight category)[17]. In terms of the flight times, it is possible that reliable data was harder to source in the past, or perhaps the shortest possible flight time between destinations was used previously, which would result in a lower dose estimation. The flight time calculators used in this study gave an average flight time based on actual flight times provided by airlines. This flight time would be more representative of the amount of time that people actually spent in the air, and hence the dose they would have received, compared to the shortest possible flight time that was used in previous studies. There were also different representative destinations used in this study than those that had been used previously for certain regions, possibly reflecting the rise and fall in popularity of international destinations with Irish residents.

In addition, there was variability between the distribution of passenger visits to the different regions between this study and the previous studies. For example, In the 2012 study there were 19,000 visits to the North America West region[14]. This had increased to 76,000 in 2019, a 300% increase[3]. North America West had the highest estimated dose for a return visit out of all of the regions. This was not the only example of a shift in visits to regions with a higher return dose, North America as a whole received a larger share of visitors in 2019 than it did in 2012. See Figure 2.

A potential for inaccuracy in the dose estimation in this study could come from the variability in estimated dose that could arise due to the choice of a different representative destination. Within Europe the variability between destinations within regions would be relatively small and the choice of representative destination was usually an obvious one based on passenger volume data. Within the North American region, the passenger volume data also allowed for a relatively well-informed decision to be made on which destination to choose as the representative destination. However, with the other regions, there was limited data available to determine the choice of representative destination. However, it is possible to make an estimation of potential variability between destinations within a region.

Within Asia, for example, Bangkok was chosen due to its size, assumed popularity (no data could be found on the actual number of Irish visitors to Bangkok) and central location. There was no data available on the frequency at which Irish residents to travel to different destinations within Asia, but Dubai and Tokyo are both major Asian cities, so the assumption could be made that they both receive a significant number of visitors from Ireland. Dubai is one of the closest destinations to Ireland within Asia while Tokyo is one of the furthest Asian destinations from Ireland. A typical return trip dose for Dubai in 2019 was estimated at 81 μSv while a dose for a return visit to Tokyo in 2019 was estimated at 259 μSv. Comparing these values with the return dose of 140 μSv estimated for Bangkok in this study, it can be seen that there is quite a large amount of variability between different destinations in Asia. Comparing the estimated dose of 73 μSv for Nairobi with an estimated dose of 112 μSv for a return visit to Johannesburg, and an estimated dose of 55 μSv for a return visit to Cairo, it can be seen that the variability of dose between destinations within Africa is less than the variability of dose between destinations within Asia. This is, in part, due to the close proximity of the African destinations to the equator, because the intensity of cosmic radiation is lowest closer to the equator and highest closer to the poles[23]. Considering the relatively low number of visitors to Africa in 2019 the uncertainty arising from the choice of the representative destination in the African region would be relatively small.

The dose for a return visit to Perth was estimated at 138 μSv compared to the 160 μSv dose estimated for a return visit to Sydney, so there is not much of a variation between different destinations within Australia when comparing the dose for a return trip from Ireland. It is difficult to estimate the typical dose for a trip to Auckland as there is a very large amount of variability in where flights from Dublin will connect through, with many flights from Dublin to Auckland having at least two connections. Looking at one of these flights which connects through San Francisco as an example, the dose for a return trip was estimated at 305 μSv. This is much larger than the 160 μSv dose for a return trip to Sydney. However, it was assumed in this study that visits to New Zealand did not make up a large portion of Oceanic visits. In addition, total visits to Oceania were relatively small compared to the total number of Irish outbound trips so this variability would not have a huge effect on the uncertainty on the total collective dose estimation for all regions. For the "Other America" region, a return visit to Havana and a return visit to Sao Paulo were estimated at 143 μSv and 89 μSv respectively compared to the value of 95 μSv estimated for a return visit to Buenos Aires. Once again due to the relatively low number of visits to the region, the uncertainty to the overall estimation that would arise due to this variability is small.

Given that the collective dose for Asia was much larger than it was for other regions where there were similar difficulties in picking a suitable representative destination, the Asian region is likely to be the biggest contributor to potential uncertainty within this study. This is because the variability between doses flying to and from different destinations within the region is large. Despite the fact that the European and North American regions made up a much greater distribution of the overall estimated collective dose, the potential uncertainty that could arise from these regions is lower. This is due to the fact that there is less variability between potential representative destinations within these regions and there is sufficient flight data available for the European and North American regions when compared to Asia.

It is also worth noting that since the previous dose surveys on the annual effective dose for an Irish person as a result of cosmic radiation from air travel[17, 22] the EPCARD software has been updated to ensure compliance with the latest European Basic Safety Standards Directive[13], where a new methodology for calculating doses was introduced, based on the latest scientific evidence on radiation risks and radiation and tissue weighting factors from the International Commission on Radiological Protection (ICRP 103)[24]. A study by Mares *et al.*[25] found that the updated radiation weighting factors recommended by ICRP 103 for neutrons, and protons results in a dose difference of less than 8% when compared to older recommended radiation weighing factors used in previous versions of the EPCARD software. This change in dose per flight is insignificant when compared to the overall dose estimated as part of this survey.

5. Conclusion

In summary, the estimated figure for the annual effective dose of cosmic radiation due to air travel in this study was higher than previous estimates. In this study, the estimated annual effective dose of cosmic radiation due to air travel for a typical Irish was 68 μSv, compared with an estimate of 41 μSv in 2012 and 45 μSv in 2005[14, 17]. In 2014, the overall annual effective dose of ionising radiation received by a typical member of the Irish public from all sources of ionising radiation was estimated to be 4,037 μSv[14]. It can be seen from this value that cosmic radiation exposure is not a major source of ionising radiation when compared to other sources of ionising radiation received by a typical person in a year. 2014 is the most recent year that data was available on the total dose of ionising radiation that the typical Irish person could expect to receive in a year. The 68 μSv value for cosmic radiation exposure in 2019 estimated in this study would comprise only approximately 2% of the total annual effective dose of ionising radiation a typical Irish person would receive, assuming the total dose was similar to the value estimated in 2014[14].

The potential reasons for the estimated annual effective dose in this study being higher than in previous studies include:

- An increase in per capita international air travel by Irish residents up to 2019
- A greater proportion of international air travel being on higher dose routes in 2019 compared to previous years
- The fact that the flight times used in this study were the average flight times as opposed to the shortest possible flight times, which may have been the flight times used in previous studies. Longer flight times would give a higher dose as they would lead to a greater duration of exposure

The greatest potential for uncertainty in this study is from the estimation made for the collective dose for air travel to Asia. This is due to the large variability in return trip doses for different destinations within Asia, the relatively large number of Irish visitors to this region and because of the uncertainty in choosing the representative destination due to a lack of available data on the number of Irish visitors to specific locations in Asia.

Declaration

The authors declare that they have no conflict of interest.

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