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Occupational radiation dose estimation for Finnish aircraft cabin attendants

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Key terms: aircraft cabin attendant; airline cabin attendant; cabin crew; cosmic radiation; epidemiology; Finland; flight attendant; occupational exposure; occupational radiation; radiation; radiation dose estimation

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Occupational radiation dose estimation for Finnish aircraft cabin attendants

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Objectives The objective of this study was to develop a method for assessing dose radiation on the basis of individual flight history and to estimate whether this method is applicable for cabin attendants without flight log data.

Methods Questionnaire data were collected to determine attendants' flight history covering up to three decades. Finnair timetables and an expert panel of pilots were used to determine one to four representative flights in five route categories. The cumulative career and annual doses were calculated on the basis of the flight histories and route-specific exposure data.

Results Questionnaire data were obtained from 544 flight attendants. The mean number of active workyears was 10.5 (range 0–30) years, and the mean cosmic radiation dose was 3.2 (range 0–9.5) mSv per active workyear. The mean cumulative career dose for all the cabin attendants was 34.0 (range 0–156.8) mSv.

Conclusions If no flight log data are available, survey data are needed for individual dose estimation when possible radiation effects on cabin crew are evaluated in epidemiologic studies. This method provides a crude procedure for assessing cosmic radiation exposure among attendants when survey data are missing.

Key terms cabin crew, cosmic radiation, epidemiology, occupational exposure.

The assessment of cosmic radiation exposure became of interest when the International Commission on Radiation Protection (ICRP) recommended that aircrew be classified as radiation workers (1). Aircraft personnel are exposed to cosmic radiation that mainly consists of neutrons, protons, electrons, and photons (2). Quantification of individual cosmic radiation doses is necessary if the potential health effects of such occupational exposure is to be assessed. Several cosmic radiation dose measurements and dose rate assessments for cabin crew and pilots have been performed using various methods (3–13). However, none of them have tried to assess individual dose rates.

Unlike pilots, who have a license for a specific aircraft type with a limited range of routes at a time, Finnair cabin attendants fly a variety of routes and aircraft at any time during their work history. At Finnair, the route distribution depends mainly on seniority. Young and newly graduated cabin attendants fly primarily domestic routes, while more experienced personnel have a wider selection of options and typically prefer to fly European and intercontinental routes. Hence the routes vary both between workers and for a given flight attendant over his or her career. As seniority largely defines the routes, variability over time is more pronounced than variability between workers.

Despite the need for individual dose information in retrospective epidemiologic research, few previous studies have attempted to develop methods applicable to individual exposure assessment. Such methods would be especially important for cabin crews, as most airline companies have not routinely recorded their flight histories.

Neutron dosimetry is more complex than the assessment of gamma radiation, and personal dosimetry systems are inadequate for this purpose. Furthermore, retrospective exposure estimation is not possible with personal portable dosimeters.

For Finnair pilots, information on every flight since 1971 is available in a computerized database. This

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database contains information on aircraft type, flight route, and block times (ie, time from departure from the gate to the arrival at the gate including taxi time, climb, and descent). For Finnair cabin crews, such information is not available for years prior to 1991, and therefore questionnaire data are the only source of information for the number and type of flights. The aims of our study were, first, to develop a method for assessing occupational exposure to cosmic radiation on the basis of individual flight history and, second, to estimate whether this method is applicable also for attendants without survey data. The rationale was to develop an exposure assessment method applicable also to flight attendants without questionnaire information (eg, those who were deceased).

Participants and methods

Finnair is a Finnish airline company that has been in operation since 1923. It operates a range of short-haul and long-haul routes. In 2001, the Finnair fleet consisted of 60 planes: nine Aerospatiale ATR-72 short-haul turbopropellers (ATR 72), 40 McDonnell Douglas and Airbus medium-haul turbojets (MD-82, MD-83, DC-9, A319, A320, A321), and four McDonnell Douglas long-haul turbojets (MD-11). Seven Boeings (B757) constituted the charter fleet, and these jets have been used in both medium- and long-haul operations. Currently Finnair has approximately 10 000 employees. The company flew approximately 7 million passengers in 2001 [from: About Finnair. Available from: URL: http://www.finnair.com (accessed 22.01.2003)].

We used a self-administered questionnaire to collect information on the monthly number of domestic and European round-trip flights, as well as on destinations in the Far East, North America, and other areas outside Europe (mainly the Canary Islands). This information was collected separately for the 1960s, 1970s, and 1980s (study period). In addition, the first and last dates of active employment were asked, as well as leaves of absence from cabin work. The number of active work-years in the study period was calculated using this reported information. A total of 1041 cabin attendants, who were born before 1960 and had worked for at least 2 years for Finnair, were identified from the files of Finnair and the Finnish Cabin Crew Union. A questionnaire was mailed to all 1041, and a total of 544 cabin attendants returned a completed questionnaire. All the study participants gave their written consent for participation. Any cabin attendants who reported only clerical work for Finnair and no cabin work were excluded.

On the basis of the individual flight histories, a typical flight pattern was constructed by decade on the basis of the number of flights by destination. This group-level estimation was assessed by comparing dose estimates calculated according to the individual questionnaire data (number of flights reported by attendants) with dose estimates calculated using information at the group level (average number of flights to different destinations during a decade). Group-level information on number of flights was obtained using Finnair timetables with the aggregate number of flights to different destinations divided by the average number of flight attendants in a decade.

To complement the questionnaire data, we also collected information on the frequency of flights on each route from Finnair's timetables and selected representative routes in each route category (domestic, Europe, other Europe, North America, and Far East) and each decade (1960s, 1970s, and 1980s). A route was selected if it had both a representative flight time and a relatively large proportion of flight hours in the flight category. We also consulted an expert panel of pilots (consisting of three experienced pilots who had flown a range of different aircraft from the 1950s or 1960s until the 1980s or 1990s) to determine the number of flights, aircraft types, and flight profiles (ascent and descent time, as well as cruising altitudes). One to four routes were selected for each route category and assigned a weighting factor representing the proportion of flights within the route category (table 1). For example, in the 1980s, three representative domestic routes were Helsinki–Kuopio, flown with DC9 jets, and Helsinki–Turku and Helsinki–Vaasa, both flown with ATR turbopropeller aircraft. Approximately 40% of the domestic flights were comparable to the Helsinki–Turku route, providing a weighting factor of 0.4. Approximately 20% of the flights were comparable with the Helsinki–Vaasa flight, giving a weighting factor of 0.2, and for the Helsinki–Kuopio flight the weighting factor was 0.4. These flights were used to represent the entire domestic flight schedule in the 1980s.

The cosmic radiation dose for every route was calculated using CARI-6, a software package developed for this purpose by the United States Federal Aviation Authority (14). The effective dose of galactic cosmic radiation for each route was calculated as a function of altitude, latitude, solar activity (heliocentric potential), and flight time. The CARI-6 effective dose is calculated from the particle fluences (15). As solar activity is a determinant of the dose rate and it varies over time, for simplicity, the average value of each decade's solar activity was used in the calculations. The mean solar activity was assigned as 709 MV for the 1960s, 617 MV for the 1970s, and 786 MV for the 1980s. We did not have any empirical measurement data. However, the doses calculated using CARI software were consistent with direct measurements.

Table 1. Representative routes (destinations from Helsinki airport) of Finnish airline companies by time and route category with the weighting factor, aircraft, flight profile information, dose rate, and dose per round trip flight given.

Route category	Weighting factor	Aircraft	Ascent time (min)	1. altitude		2. altitude		Descent time (min)	Dose rate (μSv/h)	Dose (μSv)
				Feet [a]	Time (min)	Feet [a]	Time (min)			
Domestic										
In 1960s										
Helsinki-Oulu	0.4	Convair	15	15000	35	·	·	15	0.32	0.70
Helsinki-Oulu	0.5	Caravelle	15	30000	15	·	·	15	1.87	2.80
Helsinki-Turku	0.1	Convair	5	5500	20	·	·	5	0.08	0.08
In 1970s										
Helsinki-Kuopio	0.5	DC9	10	24500	15	·	·	10	1.17	1.36
Helsinki-Turku	0.4	Convair	5	5500	20	·	·	5	0.08	0.08
Helsinki-Oulu	0.1	Caravelle	15	30000	15	·	·	15	1.73	2.80
In 1980s										
Helsinki-Kuopio	0.4	DC9	10	24500	15	·	·	10	1.08	1.26
Helsinki-Turku	0.4	ATR	10	7500	10	·	·	5	0.09	0.07
Helsinki-Vaasa	0.2	ATR	10	7500	20	·	·	5	0.10	0.11
Europe										
In 1960s										
Helsinki-Stockholm (Arlanda)	0.4	Convair	15	11500	35	·	·	15	0.18	0.40
Helsinki-Copenhagen (Kastrup)	0.25	Caravelle	20	33000	45	·	·	15	3.15	8.40
Helsinki-Stockholm (Arlanda)	0.25	Caravelle	15	28000	10	·	·	15	1.29	1.72
Helsinki-Frankfurt (Main)	0.1	Caravelle	20	33000	100	·	·	15	3.60	16.20
In 1970s										
Helsinki-London (Heathrow)	0.6	Caravelle	20	34000	130	·	·	20	4.24	24.00
Helsinki-Stockholm (Arlanda)	0.1	Convair	15	11500	35	·	·	15	0.19	0.42
Helsinki-Frankfurt (Main)	0.3	Caravelle	20	33000	100	·	·	15	3.73	16.80
In 1980s										
Helsinki-London (Heathrow)	0.4	DC9	20	34000	130	·	·	20	3.92	22.20
Helsinki-Hamburg	0.3	DC9	15	33000	60	·	·	15	3.33	10.00
Helsinki-Stockholm (Arlanda)	0.2	DC9	15	33000	15	·	·	15	2.27	3.40
Helsinki-Copenhagen (Kastrup)	0.1	DC10	20	34000	45	·	·	20	3.18	9.00
Other European										
In 1970s										
Helsinki-Las Palmas (Gran Canaria)	1.0	DC8	20	34000	295	·	·	25	3.58	40.60
In 1980s										
Helsinki-Las Palmas (Gran Canaria)	1.0	DC10	20	34000	300	·	·	20	3.46	39.20
North America										
In 1970s										
Helsinki-NY (KJFK)	0.8	DC10	20	31000	185	35000	210	30	4.65	69.00
Helsinki-Montreal	0.2	DC10	20	33000	395	·	·	20	4.69	68.00
In 1980s										
Helsinki-NY (KJFK)	0.7	DC10	20	31000	185	35000	210	30	4.26	63.20
Helsinki-Montreal	0.3	DC10	20	33000	395	·	·	20	4.30	62.20
Far East										
In 1970s										
Helsinki-Bangkok [b]	1.0	DC8	20	33000	560	·	·	20	2.95	59.00
In 1980s										
Helsinki-Bangkok	0.5	DC8	20	28000	240	33000	310	20	2.28	44.80
Helsinki-Tokyo (New Tokyo) [c]	0.5	DC10	25	29000	515	33000	250	20	3.19	86.00

[a] 1 foot = 0.3048 meters.
[b] Via Tashkent.
[c] Polar route.

The cumulative career dose in the study period was calculated as the sum of the cosmic radiation doses received in all the five flight categories during a career. The annual dose was calculated as the cumulative career dose divided by the number of active workyears.

The individual career dose was calculated as the sum of typical radiation doses of different periods and route types as follows:

$$\sum_{i=1960}^{1980} 12 n_i N_i (Dom_i + Eur_i + OutEur_i + NA_i + FarE_i),$$

where n_i represents the attendant's reported monthly number of round trip flights (in a given decade i). n_i was multiplied by 12 in order to obtain the yearly number of flights. N_i stands for the attendant's reported number of active workyears during decade *i*. Explanations for the other symbols in the equation are given in table 2.

We calculated career doses on the assumption that all flights were flown at an optimal altitude. In practice, the optimal altitude is selected in terms of velocity, available flight levels, and also optimal fuel consumption. The optimal altitude is determined mainly by aircraft type, length of flight, and aircraft weight (fuel and passengers carried aboard). However, flying at the optimal altitude is not always possible due to, for instance, other traffic or weather. In order to assess the impact of the assumed altitude, we carried out a sensitivity analysis using cosmic radiation doses received on a lower flight altitude than the optimal altitude. We presumed that all flights that, under optimum conditions, would have been flown at an altitude of ≥28 000 feet (≥8534.4 m) were flown 2000 feet (609.6 m) below the optimal altitude. Flights normally flown at ≤27 999 feet (≤5834.09 m) were assumed to be flown 1000 feet (304.8 m) below the optimal altitude in the sensitivity analysis. The career doses calculated at optimal altitude were then compared with doses that were calculated using either 2000 feet (609.6 m) or 1000 feet (304.8 m) lower altitudes.

We carried out a linear regression analysis to estimate the dependency between the career dose and the following two possible explanatory variables: number of active workyears and starting decade of cabin attendant work. STATA-7 software was used in all the statistical and mathematical procedures (16).

Table 2. Radiation doses and number of flight attendants' reported flights in a month by decade and route category (Finnair destinations from Helsinki airport).

Route category by decade	Radiation dose (μSv)	Flights	
		Mean number	95% CI
Domestic			
1960 (Dom60)	1.67	7.9	6.9–8.9
1970 (Dom70)	0.99	7.8	7.3–8.3
1980 (Dom80)	0.55	4.7	4.3–5.1
European			
1960 (Eur60)	4.31	8.7	7.4–9.9
1970 (Eur70)	19.48	8.8	8.3–9.3
1980 (Eur80)	13.36	8.8	8.4–9.3
Other European			
1960 (OutEur60)	.	.	.
1970 (OutEur70)	40.60	1.1	1.0–1.2
1980 (OutEur80)	39.20	1.3	1.2–1.4
North America			
1960 (NA60)	.	.	.
1970 (NA70)	68.8	1.1	1.0–1.2
1980 (NA80)	62.90	1.1	1.0–1.2
Far East			
1960 (FarE60)	.	.	.
1970 (FarE70)	59.00	0.5	0.4–0.5
1980 (FarE80)	65.40	0.8	0.7–0.9

Results

Flight history

The participation rate in the survey was 52%. Attendants who were still working (typically younger) responded more frequently (62%) than those who no longer did cabin work (typically older) (43%). The mean number of workyears was 20.7 (range 2–39, median 22.0, SD 9.1) years for all the cabin attendants (N=539) in the analysis. The mean number of active workyears during the study period was 10.5 (range 0–30, median 10.0, SD 6.5) years. Work as a cabin attendant was started on the average at 23 (range 19–32, median 24, SD 2.1) years of age. The average monthly number of cabin attendants reporting round trip flights by decade and route category varied from 0.5 to 8.8 (table 2).

Career dose

The mean career dose calculated for the study period for all the cabin attendants was 34.0 (range 0–156.8, median 27.9, SD 29.4) mSv. For the women who had already completed their career as a cabin attendant (N=180), the mean career dose was 26.4 (range 0–127.4, median 13.0, SD 31.1) mSv. The average career dose for the attendants' whose entire career was included in the study period (N=101) was 18.2 (range 0–99.4, median 10.9, SD 19.7) mSv.

Career doses seemed to increase in a fairly linear fashion with the number of active workyears (figure 1). In addition, the starting decade of cabin work was related to career dose. For the attendants (N=37) who started cabin work in the 1950s, the mean career dose was lower, 21.0 (range 0–117.2, SD 35.6) mSv, than for those who started work in the 1960s (N=105), 45.3 (range 0–156.8 mSv, SD 40.6) mSv, or the 1970s (N=279), 38.9 (range 0–113.9, SD 24.5) mSv. For the attendants (N=113) who started work in the 1980s, the average career dose was 16.7 (range 0–51.3, SD 11.4) mSv.

The mean career dose calculated from the individual questionnaire information was considerably higher than that obtained from the aggregate data using timetables, 19.3 (range 0–49.8, median 17.6, SD 13.4) mSv. The analyses at the individual level showed that the career doses calculated from the individual information obtained with the questionnaire were approximately

80% higher than those calculated using information at the group level [regression coefficient β_1 1.8, 95% confidence interval (95% CI) 1.7 to 1.9, R^2 0.70] (figure 2).

Annual dose

The mean annual dose per active workyear was 3.1 (range 0–9.5, median 3.2, SD 1.7) mSv for all the attendants combined. Overall, there was some variability in the annual doses, even among those with a similar number of active workyears. The attendants who worked only a few years had more dose variation than those who worked longer.

The annual dose rate tended to increase slightly from the 1960s on. In the 1960s, the mean dose was 0.6 (range 0–1.4) mSv per active workyear, whereas the corresponding value was 3.3 (range 0–8.2) mSv in the 1970s and 3.5 (range 0–9.5) mSv in the 1980s. The first decade of cabin work was also related to annual dose. The mean annual dose was 1.1 (range 0–4.9) mSv for the attendants who started their cabin work in the 1950s, 2.5 (range 0–6.0) mSv for those who started during the 1960s, 3.6 (range 0–9.5) mSv for those who started in the 1970s, and 3.2 (range 0–7.9) mSv for those who started in the 1980s.

Sensitivity analysis

When the actual flight altitude for all flights was assumed to be either 2000 feet (609.6 m) or 1000 feet (304.8 m) below the optimal altitude, the mean career dose decreased by approximately 16%, 34.0 (range 0–156.8) mSv versus 28.5 (range 0–131.7) mSv.

Linear regression analysis

In the univariate linear regression analysis, the career dose increased with the number of active workyears (regression coefficient β_1 3.2, 95% CI 2.9–3.5, R^2 0.49). When the starting decade of cabin attendant work was also included in the model (multivariate analysis, R^2 0.52), both the number of active workyears (regression coefficient β_1 3.5, 95% CI 3.2–3.8) and starting decade of work (regression coefficient β_2 6.0, 95% CI 3.6–8.4) remained positively associated with career dose.

Discussion

Our Finnish cabin attendant cohort provided little exposure contrast for our epidemiologic study, primarily because there was not much variability in the annual doses of those who worked in the same time periods (eg, among those who were approximately the same age)

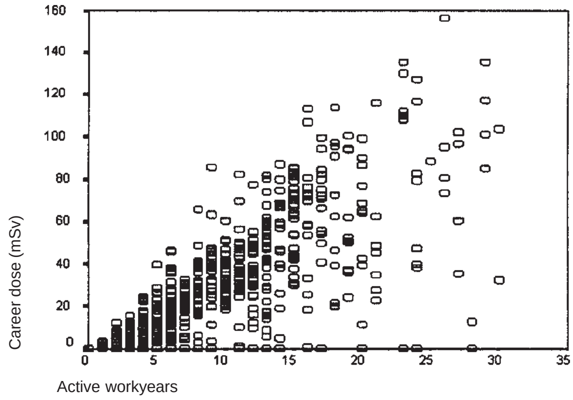

Figure 1. Career dose by number of active workyears in the study period for Finnish airline cabin crews.

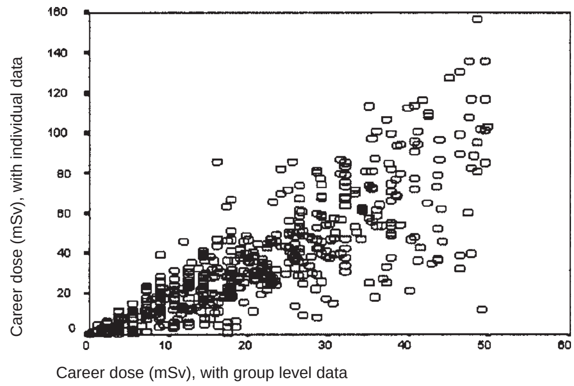

Figure 2. Career doses calculated with the use of the individual questionnaire data (of number of flights) and doses with the use of aggregate data on timetables (of number of flights) to different destinations.

even though the variability in annual dose was more pronounced between cabin attendants than between different calendar periods. The annual doses increased slightly with calendar period, and this finding reflects the increasing number of high-altitude, long-haul flights due to the increasing proportion of jet aircraft. Thus the starting period of cabin work can be used as a determinant of the annual dose. Women with a higher number of active workyears did not necessarily have higher annual doses, in spite of the assumption that the more the attendant worked, the more he or she flew on longer routes. Therefore, our findings indicate that the number of active workyears does not appear to be a valid surrogate measure for annual dose for cabin crew. However, the career dose did increase in a rather simple fashion with active workyears. Therefore, it may be possible to use active workyears as a rough surrogate measure for career dose. However, results on career doses must be interpreted with caution, since the study period investigated did not represent the whole career for all the cabin attendants in the study (eg, those who started before 1959 and those working after 1989).

Questionnaire data provide the only opportunity for individual dose assessment if valid records, such as flight log data, are not available. Yet, individual questionnaire data may be difficult to collect, and information on aggregate level can be obtained more easily. In addition, the information on duration of career as a cabin attendant, as well as leaves of absences, is usually available even if the flight distribution is not recorded. According to our results, the career doses calculated at the group level (using average number of flights estimated on Finnair timetables) gave lower estimates of career doses than those derived from individual questionnaire data, this outcome suggesting that aggregate data may underestimate the true career doses. An alternative explanation is that participating cabin attendants overestimate their number of flights (information bias) or those with the highest exposure are more likely to participate in a survey (selection bias). Thus the typical flight pattern obtained from survey data may overestimate the true cosmic radiation exposure. In addition, the cabin attendants indicated that the number of flights by decade and route category was particularly difficult to remember. Therefore, any results on calculated annual and career doses must be interpreted carefully. However, the cabin attendants were able to provide fairly detailed information on active workyears.

The doses calculated for suboptimal flight altitudes gave approximately 16% lower career doses than those calculated for optimal flight altitudes. Yet this scenario is not realistic, since, in reality, only a minor proportion of flights is actually flown below optimal altitude. Our results indicate, however, that flight altitude is an important exposure determinant. Deviations from true flight altitudes may lead to dose estimation error, even in less extreme situations.

The use of a few representative routes per flight category simplified the exposure assessment considerably. It would be extremely laborious to collect information on all actual flight sectors, which can amount to up to hundreds per year for large airline companies. Our method can be used for radiation dose estimation also in other companies, provided that information on routes corresponding to the flight distribution is available. The selection of the number of typical flights depends solely on the flight distribution of a given flight company. Thus a larger flight company than Finnair would have to consider taking into account more flight categories and more typical flights in a given category. The more flights used in typical flight assessment, the greater precision. Similarly, the use of the average value of each decade's solar activity simplified the calculations considerably. This simplification did not impair the dose assessment either, since the variability of cosmic radiation to aircrew exposure due to occasional solar particle events is minor.

The participation rate in the survey was relatively low and, therefore, may have caused selection bias if the flight history was different among the participants and nonparticipants. The group that we used for dose estimation may not have been representative of all Finnish flight attendants. Furthermore, flight information was not obtained from deceased attendants. However, the career doses were the most influenced by flights from the 1980s on since the predominance of jet aircraft with higher flight altitudes and a larger number of long-haul flights resulted in higher dose rates. We had to rely on the participating cabin attendants' own estimations of number of flights, and dependence may have led to random error. Therefore, information on flight distribution should be collected prospectively to improve validity.

A cohort study of the incidence of cancer among Finnish cabin attendants showed a significant excess of breast cancer and bone cancer and a nonsignificant excess of leukemia and melanoma (17). In that study the radiation dose was estimated at 2–3 mSv a year, and the cumulative career dose was 15–20 mSv. In the cohort study, the annual dose corresponded with our results, but the career dose estimates were considerably lower than ours.

Our results suggest that cabin crew members are typically exposed to relatively low doses of cosmic radiation during their career. Although career doses are increasing, they are so low that a cancer risk of expected magnitude would be almost impossible to detect by epidemiologic means (18). Yet there is variability between individuals in both annual and career doses. Individual career or yearly cosmic radiation doses cannot be assessed accurately enough for epidemiologic purposes using only the number of active workyears or flight hours. They provide only preliminary, rough estimates for the whole cabin attendant population, and information from questionnaires or work history records is needed. On the average, the Finnish population is exposed to a radiation dose of 3.7 mSv a year, which translates into a gamma radiation level of approximately 2 mSv (1 mSv from medical exposures and 1 mSv from terrestrial gamma radiation) (2). All cabin attendants are assumed to be exposed to the same levels of background radiation. Because this study focuses on an internal comparison among cabin attendants, nonoccupational radiation dose becomes irrelevant.

In conclusion, individual quantification of occupational cosmic radiation dose is difficult, and thus the assessment of possible health effects is complicated. Our method provides an option for estimating individual and longitudinal dose rates and indicates that survey data are needed if flight log data are not available. This method provides only a crude assessment of cosmic radiation exposure for attendants without survey data.

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References

1. International Commission on Radiological Protection (ICRP). The 1990 recommendations of the Internal Commission on Radiological Protection. Oxford: Pergamon Press; 1991. ICRP publication 60.
2. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources and effects of ionizing radiation. New York (NY): United Nations; 2000. UNSCEAR 2000 report to the general assembly, with scientific annexes, vol 1.
3. Bagshaw M. High fliers. Radiol Prot Bull 1998;(203):10–3.
4. Gundestrup M, Storm HH. Radiation-induced acute myeloid leukaemia and other cancers in commercial cockpit crew: a population-based cohort study. Lancet 1999;354:2029–31.
5. Hammer GP, Zeeb H, Tveten U, Blettner M. Comparing different methods of estimating cosmic radiation exposure of airline personnel. Radiat Environ Biophys 2000;39:227–31.
6. Irvine D, Davies DM. British Airways flightdeck mortality study, 1950–1992. Aviat Space Environ Med 1999;70:548–55.
7. Kyllönen J-E, Lindborg L, Samuelson G. Cosmic radiation measurements on-board aircraft with the variance method. Radiat Prot Dosim 2001;93:197–205.
8. Lewis BJ, Tume P, Bennett LGI, Pierre M, Green AR, Cousins T, et al. Cosmic radiation exposure on Canadian-based commercial airline routes. Radiat Prot Dosim 1999;86:7–24.
9. Oksanen PJ. Estimated individual annual cosmic radiation doses for flight crews. Aviat Space Environ Med 1998;69:621–25.
10. Nicholas JS, Lackland DT, Butler GC, Mohr LC, Dunbar JB, Kaune WT, et al. Cosmic radiation and magnetic field exposure to airline flight crews. Am J Ind Med 1998;34:574–80.
11. Tveten U, Haldorsen T, Reitan J. Cosmic radiation and airline pilots: exposure pattern as a function of aircraft type. Radiat Prot Dosim 2000;87:157–65.
12. Rafnsson V, Hrafnkelsson J, Tulinius H. Incidence of cancer among commercial airline pilots. Occup Environ Med 2000;57:175–9.
13. Grajewski B, Waters MA, Whelan EA, Bloom TF. Radiation dose estimation for epidemiologic studies of flight attendants. Am J Ind Med 2002;41:27–37.
14. Friedberg W. A computer program for calculating flight radiation dose. Fed Air Surg Med Bull 1999;99:9–11.
15. Pelliccioni M. Overview of fluence-to-effective dose and fluence-to-ambient dose equivalent conversion coefficients for high energy radiation calculated using the FLUKA code. Radiat Prot Dosim 2000;88:279–97.
16. Stata Corporation. STATA 7.0. College Station (TX): Stata Corporation; 2001.
17. Pukkala E, Auvinen A, Wahlberg G. Incidence of cancer among Finnish airline cabin attendants, 1967–92. BMJ 1995;311:649–52.
18. Boice JD Jr., Blettner M, Auvinen A. Epidemiologic studies of pilots and aircrew. Health Phys 2000;79:576–84.

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