

Assessment of Occupational Cosmic Radiation Exposure of Flight Attendants Using Questionnaire Data

JERI L. ANDERSON, MARTHA A. WATERS, MISTY J. HEIN,
MARY K. SCHUBAUER-BERIGAN, AND LYNNE E. PINKERTON

ANDERSON JL, WATERS MA, HEIN MJ, SCHUBAUER-BERIGAN MK, PINKERTON LE. *Assessment of occupational cosmic radiation exposure of flight attendants using questionnaire data*. *Aviat Space Environ Med* 2011; 82:1049–54.

Introduction: Female flight attendants may have a higher risk of breast and other cancers than the general population because of routine exposure to cosmic radiation. As part of a forthcoming study of breast and other cancer incidence, occupational cosmic radiation exposure of a cohort of female flight attendants was estimated. **Methods:** Questionnaire data were collected from living female cohort members who were formerly employed as flight attendants with Pan American World Airways. These data included airline at which the flight attendant was employed, assigned domicile, start and end dates for employment at domicile, and number of block hours and commuter segments flown per month. Questionnaire respondents were assigned daily absorbed and effective doses using a time-weighted dose rate specific to the domicile and/or work history era combined with self-reported work history information. **Results:** Completed work history questionnaires were received from 5898 living cohort members. Mean employment time as a flight attendant was 7.4 yr at Pan Am and 12 yr in total. Estimated mean annual effective dose from all sources of occupational cosmic radiation exposure was 2.5 ± 1.0 mSv, with a mean career dose of 30 mSv. **Discussion:** Annual effective doses were similar to doses assessed for other flight attendant cohorts; however, questionnaire-based cumulative doses assessed in this study were on average higher than those assessed for other flight attendant cohorts using company-based records. The difference is attributed to the inclusion of dose from work at other airlines and commuter flights, which was made possible by using questionnaire data.

Keywords: female, radiation dose, effective dose, absorbed dose, CARI-6.

FLIGHT CREWS, INCLUDING pilots and flight attendants, are routinely exposed to cosmic radiation, resulting in annual doses at levels similar to, or possibly greater than, other occupationally radiation-exposed groups (13). Female flight attendants may have a higher risk of breast and lympho-hematopoietic cancer and malignant melanoma than the general population (20). This may be due to occupational exposure to cosmic radiation or to other factors, including disruption of circadian rhythms due to travel across multiple time zones or work at night, lifestyle factors, age at first birth, age at menarche and menopause, and family history.

The purpose of this work was to estimate occupational exposure from cosmic radiation for a cohort of female flight attendants who worked for Pan American World Airways (Pan Am) as part of a forthcoming epidemiological study of breast and other cancer incidence.

Individual cumulative domicile (home base) era-specific cosmic radiation doses have already been estimated for 10,164 flight attendants in the Pan Am cohort (21) for a mortality study (in progress). For that study, exposure estimates for work at Pan Am were based on an assumed 80-block-hour month (block time = flight time plus taxi time). No work history information was available for work at other airlines (except for National Airlines, which was bought by Pan Am in 1981), or commuter travel (flights taken to travel to the domicile to which the flight attendant was assigned) (21). For the forthcoming incidence study, the exposure assessment incorporated information abstracted from questionnaires completed by approximately 5900 of the study subjects in an effort to increase accuracy in the assigned exposures.

METHODS

Study Cohort

The cohort was assembled from personnel records of former Pan Am employees which were available for employees who terminated employment with Pan Am in 1953 or later. The cohort included 9617 women who were employed as a flight attendant for at least 1 yr by Pan Am prior to the cessation of operations in 1991. For National Airlines flight attendants who transferred to Pan Am after it was purchased by Pan Am in 1981, the time at National was counted toward the 1-yr minimum. The personnel records contained demographic information and work histories. The work histories included job title and domicile with the corresponding employment dates at Pan Am and National, but did not include

From the National Institute for Occupational Safety and Health, Division of Surveillance, Hazard Evaluations and Field Studies, Cincinnati, OH.

This manuscript was received for review in April 2011. It was accepted for publication in August 2011.

Address correspondence and reprint requests to: Jeri L. Anderson, Ph.D., M.S., National Institute for Occupational Safety and Health, 4676 Columbia Pkwy., MS R-14, Cincinnati, OH 45226; jlanderson@cdc.gov.

Reprint & Copyright © by the Aerospace Medical Association, Alexandria, VA.

DOI: 10.3357/ASEM.3091.2011

information on specific routes flown or number of block hours worked.

Questionnaire Abstraction

Questionnaire data were collected from living cohort members and next of kin (proxy) of deceased cohort members by computer-assisted telephone interviews. The questionnaire focused on demographic information, reproductive history, lifestyle factors (including smoking and alcohol use), medical history (including information on incident breast cancer and other cancers, and medical diagnostic and therapeutic radiation), family history, and flight attendant work history. Work history information collected from living cohort members included all airlines at which the flight attendant was employed, assigned domiciles, start and end dates for employment at each domicile, and number of block hours worked and number of commuter segments flown per month while based at each domicile. Neither residence history nor information on the length of the commuter flight segments was collected. As part of the questionnaire, living cohort members were provided information obtained from company records on assigned domiciles and start/end dates for employment at each domicile for work at Pan Am or National, and asked to correct this information as necessary. Living cohort members were also asked to provide information on work at airlines other than Pan Am or National. In the case of deceased cohort members, next of kin (i.e., proxy) were asked to provide general work history information (i.e., start/end dates and how many years total) only for work at airlines other than Pan Am or National.

Exposure Assessment

The exposure assessment for the mortality study is completely described in Waters et al. (21) and briefly here. First, a database created based on information in the Official Airline Guide™ (OAG™; 16) included a record for each flight segment terminating at nine Pan Am domiciles (Hong Kong, Honolulu, London, Los Angeles, Miami, New York, San Francisco, Seattle, and Washington, DC) and one National domicile (Miami). Information was abstracted for flights in the month of April from multiple years (i.e., 1940, 1945, 1950, 1955, 1961, 1965, 1970, 1980, and 1990, depending on domicile) and included airline, origin and destination airport, year of flight, number of flights per week for the segment, local departure and arrival times, and aircraft type. No data were available for 1960 so data from 1961 were used. Cosmic radiation absorbed and effective doses for these flight segments were calculated using CARI-6P. Assumptions were made to predict required input variables from the data available in the OAG™ (21). Estimates for April of each abstracted year were applied to eras defined by the midpoints between dates (e.g., April 1945 estimates were applied to the era from 1 October 1942 to 30 September 1947).

The program CARI-6P calculates effective and absorbed dose from exposure to galactic cosmic radiation

of an individual on an aircraft flying a great circle route between two airports (14). The CARI-6P code uses a database created by running the LUN transport code, which uses a deterministic solution to the Boltzmann equation to provide cosmic ray spectra (fluence) for a given location in the Earth's atmosphere (i.e., altitude and geomagnetic longitude and latitude) for a given heliocentric potential (i.e., solar activity). Absorbed dose is calculated at a depth of 5 cm in a 30-cm semi-infinite soft-tissue slab phantom, assuming isotropic geometry (15). The 5-cm depth is a reasonable approximation of whole body or bone marrow absorbed dose. To estimate effective dose, the CARI-6P code also incorporates fluence to effective dose conversion coefficients calculated by Ferrari et al. using an anthropomorphic phantom and assumed isotropic geometry (1–6). Effective dose was calculated using the proton and neutron radiation weighting factors assumed in Publication 60 of the International Commission on Radiation Protection (8).

For the incidence study, radiation effective dose, total absorbed dose, and absorbed dose due to electromagnetic showers (EMS), neutrons, protons, muons, and pions was calculated for each flight segment in the database using CARI-6P. Domicile era-specific radiation absorbed dose rates (dose per block hour) for all particle types except pions were calculated using methods described in Waters et al. (21). Since cohort members may have worked for Pan Am at other domiciles and many cohort members additionally reported working as a flight attendant for other airlines/domiciles as part of the questionnaire, era-specific absorbed and effective dose rates were calculated as a weighted average of effective and absorbed dose rates for all flight segments in the existing database for each era (i.e., 1940, 1945, 1950, 1955, 1961, 1965, 1970, 1980, and 1990). Both domicile era-specific and era-specific dose rates were weighted by block time, number of flights per week, and number of flight attendants per flight (21).

Living flight attendants with complete questionnaire data were assigned daily absorbed and effective doses for work at Pan Am and National using the domicile era-specific or era-specific dose rate combined with self-reported domiciles, employment dates, and block hours. When block hour information was missing, the average number of block hours for the domicile based on the distribution of reported hours from other flight attendants was used. For subjects with complete questionnaire data regarding other airline work, self-reported domicile, employment dates, and block hours were combined with domicile era-specific or era-specific dose rates. Proxy respondents did not provide information on work history at Pan Am and National or commuter segments flown and are not further described here.

Domicile era-specific commuter flight segment lengths were imputed using the mean number of block hours of all flights flown into each of the nine domiciles in the existing database (i.e., Miami-Pan Am, Miami-National, Hong Kong, Honolulu, London, Los Angeles, New York, San Francisco, Seattle, and Washington, DC) for each era. For domiciles other than these, era-specific commuter

flight segment lengths were imputed using the average of the domicile era-specific flight segment lengths for each era. Commuter travel dose was calculated using domicile era-specific or era-specific dose rates and imputed commuter flight segment lengths in combination with the self-reported domiciles, employment dates, and number of commuter segments flown per month.

Statistical Analysis

Annual and cumulative dose estimates for individual flight attendants were summarized using descriptive statistics. The Pearson product moment correlation test was used to compare dose estimates estimated using questionnaire data with dose estimates estimated using company-based work history records.

RESULTS

Completed work history questionnaires were received from 5898 living female cohort members (61%). Information provided included airline, domicile, start/end dates for employment at the corresponding domicile, number of block hours worked per month, and number of commuter segments flown per month. Response rates for each work history record were 94% or greater for this information.

Mean employment time as a flight attendant for questionnaire respondents was 7.4 yr at Pan Am and 12 yr (range 1 mo–48 yr) in total. The mean and median number of block hours worked per month was 65 and 75, respectively. Questionnaire respondents indicating commuter travel ($N = 2772$, 47%) reported a mean of 7 (range 1–60) commuter segments flown per month. In addition to the nine domiciles for which domicile era-specific dose rates were assessed, questionnaire respondents reported working as a flight attendant at 177 other airlines and 115 additional domiciles. However, the most common domiciles for all airlines were New York, Miami, San Francisco, Los Angeles, Honolulu, and Washington, DC.

Domicile era-specific absorbed dose rates for each particle type and total absorbed dose rates are shown by domicile in **Fig. 1A–J**. Era-specific particle absorbed doses rates and total absorbed and effective dose rates are shown in **Fig. 1K** and **L**, respectively. Pions provided only a fraction of a percent of the total absorbed dose, so pion doses are not explicitly reported. EMS (i.e., photons, electrons, and positrons) provided the largest contribution (29–65%) to the domicile era-specific and era-specific total absorbed dose rate. EMS, neutron (13–25%), proton (6–13%), and muon (9–49%) contributions to total absorbed dose rates varied depending on era due to the increasingly higher altitudes flown as commercial air travel moved into the jet age in the 1960s. At the lower altitudes flown during the 1940 era, muon dose dominates the total absorbed dose rate. Cumulative (career) absorbed doses (particle-specific and total) are shown in **Table I**. Mean annual effective dose for the 5898 questionnaire respondents from all sources of occupational cosmic radiation exposure was 2.5 ± 1.0 mSv

(median 2.4 mSv; range 0–17 mSv). When only exposure from work history at the nine domiciles in the existing database was considered, the mean annual effective dose estimated using questionnaire-based work history was 2.2 ± 0.5 mSv (median 2.2 mSv; range 0–6.4 mSv).

Of the 5898 questionnaire respondents, 5277 had effective doses calculated previously by Waters et al. (21) using company work history records. **Table II** shows the distribution of cumulative effective dose from exposure to cosmic radiation estimated for work history at the nine domiciles using questionnaire data compared to the distribution of cumulative dose estimated by Waters et al. (21) using company records-based work history information. **Fig. 2** provides a one-to-one comparison of cumulative effective dose calculated by both methods for each flight attendant. Pearson product moment correlation coefficient indicates a near perfect linear relationship ($r = 0.99$; $P < 0.01$).

DISCUSSION

The estimated mean annual effective dose of 2.5 mSv for the 5898 cohort members who completed the work history questionnaire was comparable to the mean annual dose of 3.1 mSv (median 3.2 mSv; range 0–9.5 mSv) reported in another questionnaire-based exposure study of 544 Finnish flight attendants (9). Other studies of cosmic radiation exposure among flight attendants reported estimated mean annual doses of 0.7 to 3.8 mSv (10,17,22). Mean cumulative dose for this group (mean 30 mSv, median 19 mSv, range 0–280 mSv) was also similar to the Finnish questionnaire study (mean 34 mSv, median 28 mSv, range 0–160 mSv).

For the subgroup of 5277 cohort members for which exposure estimates were previously reported by Waters et al., the mean annual effective dose from work at the nine domiciles in the existing database was 2.2 mSv compared to 2.38 mSv estimated by Waters et al. (21). This small difference is due primarily to corrections respondents made to the work histories obtained from company records and the use of self-reported block hours per month vs. the assumed 80-block-hour month. The corresponding cumulative effective doses were essentially the same (19 ± 17 mSv). The advantage of the questionnaire-based approach was the additional information available on employment at airlines other than Pan Am and National and commuter travel, increasing the mean cumulative (career) effective dose to 29 mSv.

Basing all dose-rate estimates (i.e., domicile era-specific and era-specific dose rates) on data only for Pan Am and National flights into nine domiciles and for only nine eras introduces significant uncertainty. Also, assumptions made to develop CARI-6P input parameters from the OAGTM data introduced some systematic bias, contributing to uncertainty. Factors which influence variability in dose include geomagnetic latitude, altitude flown, and level of solar activity, which varies within an 11-yr cycle (19). For a given altitude, dose rates near the poles are 2–3 times greater than dose rates near the equator (12), thus domicile era-specific dose rates

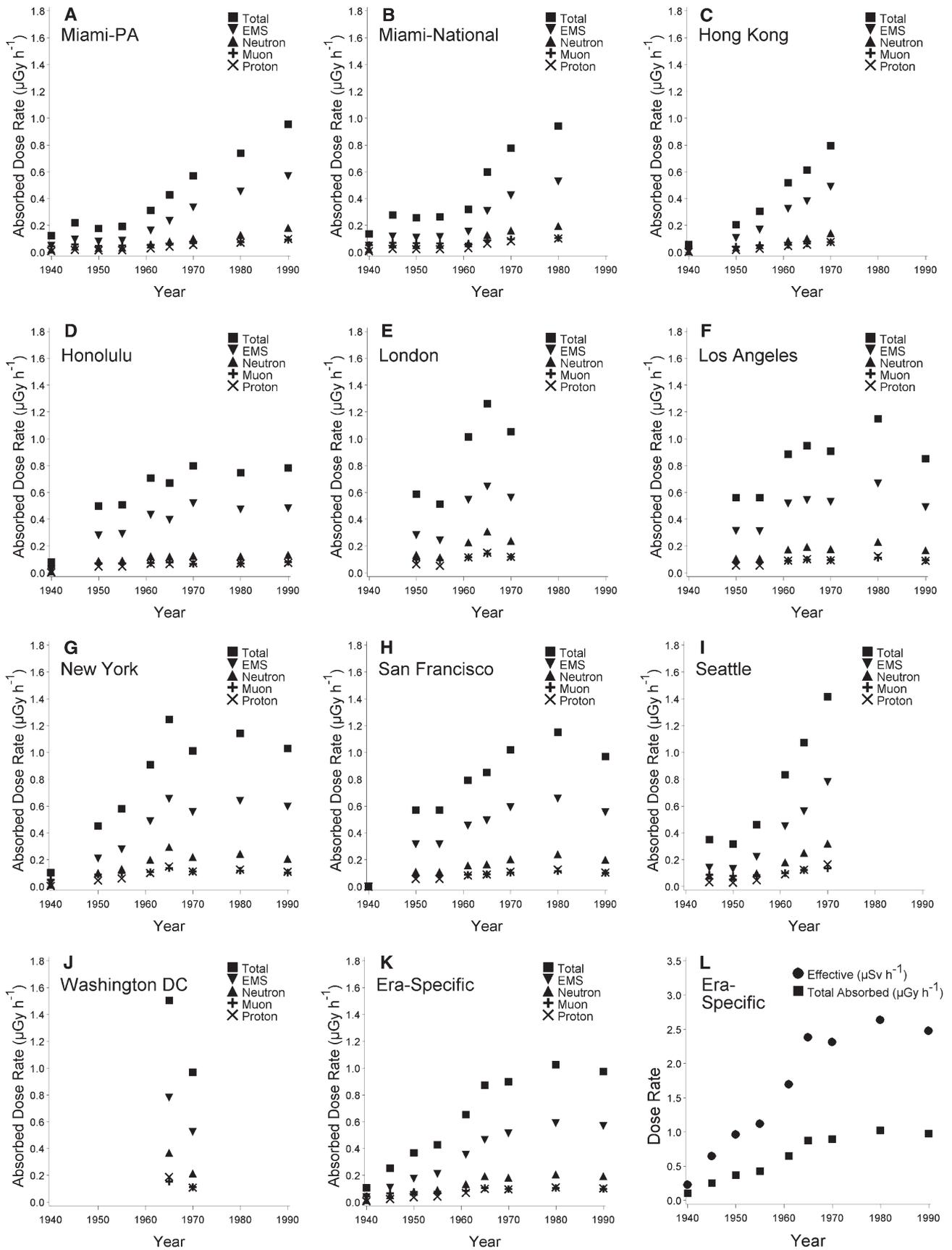


Fig. 1. A-J) Domicile specific absorbed dose rates ($\mu\text{Gy} \cdot \text{h}^{-1}$) by year for the nine Pan Am domiciles and one National domicile; K) era-specific absorbed dose rates ($\mu\text{Gy} \cdot \text{h}^{-1}$) by year; and L) era-specific effective ($\mu\text{Sv} \cdot \text{h}^{-1}$) and total absorbed ($\mu\text{Gy} \cdot \text{h}^{-1}$) dose rates. Total absorbed dose rate includes EMS, neutrons, protons, muons, and pions.

TABLE I. CUMULATIVE (CAREER) PARTICLE-SPECIFIC AND TOTAL ABSORBED DOSE (IN mGy) FOR LIVING QUESTIONNAIRE RESPONDENTS FROM EXPOSURE TO COSMIC RADIATION.

	EMS	Neutron	Protons	Muons	Total
Pan Am/National (N = 5898)					
Mean ± SD	4.2 ± 3.7	1.5 ± 1.3	0.79 ± 0.71	0.78 ± 0.70	7.3 ± 6.5
Median (range)	2.7 (0-19)	1.0 (0-7.6)	0.52 (0-3.9)	0.51 (0-4.0)	4.8 (0-35)
Other airlines (N = 2349)					
Mean ± SD	4.1 ± 3.2	1.4 ± 1.1	0.77 ± 0.60	0.74 ± 0.57	7.1 ± 5.5
Median (range)	4.6 (0.0010-18)	1.6 (0.00037-6.1)	0.85 (0.00020-3.3)	0.82 (0.00020-3.2)	7.9 (0.0018-30)
Commuter flights (N = 2772)					
Mean ± SD	2.0 ± 3.1	0.70 ± 1.1	0.37 ± 0.58	0.35 ± 0.55	3.4 ± 5.3
Median (range)	1.0 (0.00019-51)	0.34 (0.000077-19)	0.18 (0.000037-10)	0.17 (0.00011-9.0)	1.7 (0.00041-90)
All sources* (N = 5898)					
Mean ± SD	6.7 ± 6.6	2.4 ± 2.3	1.3 ± 1.2	1.2 ± 1.2	12 ± 11
Median (range)	4.2 (0-61)	1.5 (0-23)	0.80 (0-12)	0.78 (0-11)	7.3 (0-110)

* All sources include work history reported at Pan Am/National (nine domiciles), at other airlines (including other Pan Am/National domiciles), and commuter travel.

can vary significantly between domiciles. Monthly estimates of heliocentric potential (solar activity) used in CARI-6P varied by as much as ~120% over the assigned dose era (e.g., October 1952 through March 1958) from the heliocentric potentials used in the flight segment dose estimates (e.g., April 1955).

Another source of uncertainty in the assessed doses for individuals is the lack of information on routes flown by individual flight attendants, specifically origin and destination of each flight segment flown. Dose rates for flight segments within domiciles could vary significantly. For example, in 1990 a flight from Washington-Dulles into John F. Kennedy (JFK) airport in New York has a calculated effective dose rate of 0.29 μSv · block-hour⁻¹, whereas a flight from Frankfurt, Germany, into JFK airport has a calculated effective dose rate of 3.4 μSv · block-hour⁻¹. The calculated domicile-era-specific dose rate for New York in 1990 was 2.7 μSv · block-hour⁻¹. For a flight attendant working 80 block hours per month for a year, the cumulative dose could be as low as 0.28 mSv if the regular route flown was the shuttle between JFK and Dulles or as high as 3.3 mSv if the regular route flown was the transatlantic flight between Frankfurt, Germany, and JFK. The assigned dose for this hypothetical flight attendant using the method reported here

would be 2.6 mSv, which could be underestimating or overestimating cumulative dose by 21% or 830%, respectively. However, since doses from individual flights were cumulated and the variance thus averaged, this within-domicile within-era dose variability is not expected to introduce significant uncertainty.

Additional variations in dose are caused by solar particle events, ground level enhancements, and interplanetary shock waves resulting in a temporary reduction of galactic cosmic radiation levels (Forbush decrease) (11). Location of the flight attendant within the aircraft, quantity of fuel on board, and number of passengers can also affect the dose rate (7). None of these factors are accounted for in the CARI-6P/LUIN codes. Also, the choice of isotropic irradiation for the exposure geometry may not be a good approximation for the high-energy component of the radiation field at aircraft altitudes, as the field is peaked in the forward direction (18). However, this potential discrepancy is only a matter of a few percent at civil aviation altitudes.

The strength of this exposure assessment was the self-reported work history at other airlines in addition to Pan Am, self-reported number of block hours worked per month while based at each domicile, and self-reported information on commuter travel during employment as

TABLE II. CUMULATIVE (CAREER) EFFECTIVE DOSE (IN mSv) FOR LIVING QUESTIONNAIRE RESPONDENTS FROM EXPOSURE TO COSMIC RADIATION BY WORK HISTORY RECORD SOURCE.

	Questionnaire-Based Records				Company-Based Records [†]
	Pan Am/ National	Other Airlines	Commuter Flights	All Sources*	
All respondents					
N	5898	2349	2772	5898	
Mean ± SD.	19 ± 17	18 ± 14	8.8 ± 14	30 ± 30	
Median (range)	12 (0-94)	20 (0.0047-78)	4.3 (0.0010-240)	19 (0-280)	
Respondents matched to Waters et al. (21) cohort					
N	5277	1741	2376	5277	5277
Mean ± SD.	19 ± 17	21 ± 13	8.8 ± 14	29 ± 29	19 ± 17
Median (range)	12 (0-94)	24 (0.0047-78)	4.3 (0.0010-240)	18 (0.10-280)	13 (1.0-99)

* All sources include work history reported at Pan Am/National (nine domiciles), at other airlines (including other Pan Am/National domiciles), and commuter travel.

† Cumulative doses reported in Waters et al. (21) based on company records at the nine Pan Am/National domiciles and assumed 80-block-hour month.

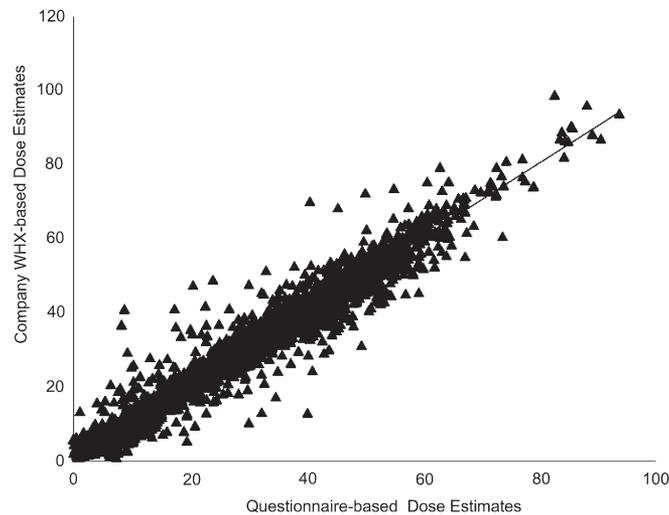


Fig. 2. Correlation of Pan Am/National cumulative effective dose (mSv) estimated using the company work history records vs. questionnaire data ($N = 5277$).

a flight attendant. Questionnaire-based cumulative doses estimated in this study were on average higher than those estimated for this cohort using company-based work history records. The difference can be attributed to the inclusion of dose from work history at other airlines and from exposure during commuter flights, which was made possible by using questionnaire data. Annual effective doses were similar to doses assessed for other flight attendant cohorts. The results of this study suggest that use of questionnaire data combined with company-based work history provides a reasonable method for estimating individual doses from exposure to cosmic radiation.

ACKNOWLEDGMENTS

The authors wish to thank Mr. Steve Allee for programming assistance. This study was funded in part through an interagency agreement with the National Cancer Institute.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Authors and affiliation: Jeri L. Anderson, Ph.D., M.S., Martha A. Waters, Ph.D., M.P.H., Misty J. Hein, Ph.D., M.S., Mary K. Schubauer-Berigan, Ph.D., M.S., and Lynne E. Pinkerton, M.D., M.P.H., National Institute for Occupational Safety and Health, Cincinnati, OH.

REFERENCES

- Ferrari A, Pelliccioni M, Pillon M. Fluence to effective dose and effective dose equivalent conversion coefficients for photons from 50 keV to 10 GeV. *Radiat Prot Dosimetry* 1996; 67:245–51.
- Ferrari A, Pelliccioni M, Pillon M. Fluence-to-effective dose equivalent conversion coefficients for muons. *Radiat Prot Dosimetry* 1997; 74:227–33.
- Ferrari A, Pelliccioni M, Pillon M. Fluence to effective dose and effective dose equivalent conversion coefficients for electrons from 5 MeV to 10 GeV. *Radiat Prot Dosimetry* 1997; 69:97–104.
- Ferrari A, Pelliccioni M, Pillon M. Fluence to effective dose conversion coefficients for neutrons up to 10 TeV. *Radiat Prot Dosimetry* 1997; 71:165–73.
- Ferrari A, Pelliccioni M, Pillon M. Fluence to effective dose conversion coefficients for protons from 5 MeV to 10 TeV. *Radiat Prot Dosimetry* 1997; 71:85–91.
- Ferrari A, Pelliccioni M, Pillon M. Fluence to effective dose conversion coefficients for negatively and positively charged pions. *Radiat Prot Dosimetry* 1998; 80:361–70.
- Ferrari A, Pelliccioni M, Villari R. Evaluation of the influence of aircraft shielding on the aircrew exposure through an aircraft mathematical model. *Radiat Prot Dosimetry* 2004; 108:91–105.
- ICRP. 1990 Recommendations of the International Commission on Radiological Protection. Publication 60. *Ann ICRP* 1991; 21:1–201.
- Kojo K, Aspholm R, Auvinen A. Occupational radiation dose estimation for Finnish aircraft cabin attendants. *Scand J Work Environ Health* 2004; 30:157–63.
- Kojo K, Helminen M, Leuthold G, Aspholm R, Auvinen A. Estimating the cosmic radiation dose for a cabin crew with flight timetables. *J Occup Environ Med* 2007; 49:540–5.
- Lantos P, Fuller N, Bottollier-Depois JF. Methods for estimating radiation doses received by commercial aircrew. *Aviat Space Environ Med* 2003; 74:746–52.
- Lewis BJ, Desormeaux M, Green AR, Bennett LG, Butler A, et al. Assessment of aircrew radiation exposure by further measurements and model development. *Radiat Prot Dosimetry* 2004; 111:151–71.
- NCRP. Ionizing radiation exposure of the population of the United States. Report No. 160. Bethesda, MD: National Council on Radiation Protection and Measurements; 2009. Report No.: 160.
- Nicholas JS, Copeland K, Duke FE, Friedberg W, O'Brien K III. Galactic cosmic radiation exposure of pregnant aircrew members II. Washington, DC: Office of Aviation Medicine, Federal Aviation Administration; 2000. Report No.: DOT/FAA/AM-00/33.
- O'Brien K, Friedberg W, Sauer HH, Smart DF. Atmospheric cosmic rays and solar energetic particles at aircraft altitudes. *Environ Int* 1996; 22(Suppl. 1):S9–44.
- OAG™. Official airline guide, periodical vols. 1940–1990. Downers Grove, IL: OAGWorldwide, Inc.
- Oksanen PJ. Estimated individual annual cosmic radiation doses for flight crews. *Aviat Space Environ Med* 1998; 69:621–5.
- Pelliccioni M. The impact of ICRP publication 92 on the conversion coefficients in use for cosmic ray dosimetry. *Radiat Prot Dosimetry* 2004; 109:303–9.
- Reitz G. Radiation environment in the stratosphere. *Radiat Prot Dosimetry* 1993; 48:5–20.
- Tokumaru O, Haruki K, Bacal K, Katagiri T, Yamamoto T, Sakurai Y. Incidence of cancer among female flight attendants: A meta-analysis. *J Travel Med* 2006; 13:127–32.
- Waters MA, Grajewski B, Pinkerton LE, Hein MJ, Zivkovich Z. Development of historical exposure estimates of cosmic radiation and circadian rhythm disruption for cohort studies of Pan Am flight attendants. *Am J Ind Med* 2009; 52:751–61.
- Wilson OJ, Young BF, Richardson CK. Cosmic radiation doses received by Australian commercial flight crews and the implications of ICRP 60. *Health Phys* 1994; 66:493–502.