Evaluation of cosmic radiation exposures of flight crew for epidemiologic studies

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Introduction

Flight crew are exposed to elevated levels of cosmic ionizing radiation of galactic and solar origin and are among the more highly exposed occupational groups to ionizing radiation in the U.S., with annual doses ranging from approximately 0.2-5 mSv. Cosmic radiation dose depends primarily on altitude and geomagnetic latitude and to a lesser degree on solar activity and phase of the solar cycle. NIOSH is conducting several epidemiologic studies examining the relationship between cosmic radiation exposure, among other factors, and reproductive health of female flight attendants. Estimation of historical cosmic radiation dose is an essential component of these studies. One aim of this study was to measure cosmic radiation doses on a series of flights as a function of altitude, distance flown, latitude and longitude, and to compare dose-equivalent data collected on specific flights with doses estimated using the CARI computer program developed by the Federal Aviation Administration. CARI estimates will be used for dose reconstruction for the epidemiologic studies.

Methods

Flight segments (n=38) were selected to include north-south, east-west, trans-arctic circle and trans-equatorial flights within three flight duration categories: <2, 2-8, and >8 hours. Pilots recorded flight altitude and geographical position every 30 minutes and for every change in altitude.

Measurements were made with a tissue-equivalent proportional counter (TEPC) with a 5-inch spherical detector made of a tissue-equivalent plastic wall filled with 7 mmHg of tissue-equivalent gas to simulate a cell size of 2 microns. The detector was connected to a 256 bin multichannel analyzer with a lineal energy range from 0.2-1000 keV/*u*m. The energy resolution was 0.1 keV/*u*m below 20 keV/*u*m and 5 keV/*u*m above 20 keV/*u*m. The full lineal energy spectrum was recorded every minute from gate departure to gate arrival. Absorbed dose was calculated by summing the number of events per channel times the mean energy of each channel and multiplying by a factor which includes the mass and area of the simulated site. Dose equivalent data were calculated based on quality factors in International Commission on Radiological Protection Publication 60, Table A-1 (ICRP, 1991). Two TEPCs were used on each flight and were placed in the overhead compartment mid-aircraft.

Estimates of cosmic radiation dose were computed using CARI-3C (2) for the same origin-destination city pairs as the survey flights, using pilot records of altitude and time. Input parameters included origin and destination cities, flight date, ascent time(s), each altitude level and time at altitude, and descent time.

Results

Measurements for 17 of the flight segments are given in Table 1. In general the CARI-3C estimates of equivalent dose were lower than the measurements for the same flight segments, although for one very short high latitude flight (Nome (65°N) to Anchorage (61°N)) and for a trans-equatorial flight the model estimate was higher than the measured dose equivalent. The percent difference ranged from +11% to -46% for flights less than two hours long, from -1.5% to -56% for flights between two and eight hours in length, and from -14% to -44% for flights longer than 8 hours. No trend in % difference between measured and estimated doses by flight time was found. With respect to the relationship between flight latitudes and % difference, the measured dose was in fairly good agreement with the estimated dose for the two trans-equatorial flights. However, the comparability between the two metrics was reduced at higher latitudes.

Table 1. Measured dose equivalent and CARI-3C estimated equivalent dose with percent difference for flights ranging from 36-540 minutes (n=17).

Origin-destination	altitudes (K ft)	flt time (min)	measured (μSv)	estimated (μSv)	% diff
Kotzebue-Nome	25	36	0.64	0.34	-47
Anchorage-Nome	33	74	3.3	2.8	-15
Nome-Anchorage	33	83	2.78	3.1	+12
San Francisco-Seattle	35	96	5.84	3.87	-33
Miami-Dallas	22/ 31	143	7.15	2.95	-56
Miami-Boston	29/ 27	160	5.80	4.2	-28
Boston-Miami	35	175	12.0	8.93	-26
Seattle-Anchorage	35	181	12.5	11.3	-11
Anchorage-Seattle	33	198	15.6	10.9	-30
Tokyo-Saipan	37	201	6.02	5.90	-1.5
Dallas-San Francisco	35/23	208	13.0	8.36	-34
Saipan-Tokyo	29	225	4.42	3.70	-13
Seattle-Miami	37/41	311	32.0	23.3	-27
Miami-Buenos Aires	33/37	475	16.4	15.9	-2.8
Buenos Aires -Miami	28/29/35/37	521	16.9	17.7	+4.4
Tokyo-LA	31/33/35/37	534	37.0	24.5	-34
Seattle-Tokyo	31/35/36/38	540	50.9	32.6	-32

Discussion

The measured radiation doses measured represent a complex function of duration of flight, latitude, and altitude. One aim of this work was to compare CARI dose estimates with measured doses on a limited number of flights to assess the suitability of estimating flight segment doses using CARI from flight attendant work histories. CARI-3C estimates of equivalent dose ranged from 11% higher than TEPC measurements of dose equivalent to 56% lower (median 26% lower). Less model bias was observed for low latitude flights. Possible explanations for the observed bias are: (1) the TEPC detector simulates a measurement of dose equivalent at the body's surface, whereas CARI-3C model estimates the equivalent dose to the bone marrow and skeletal tissue; and (2) the measurements are made in an aircraft, whereas the CARI-3C estimate does not take into account any effect of aircraft shielding. However, by comparison with balloon measurements, Foelsche (1) has shown that aircraft masses did not increase neutron spectra and doses by more than 5-10%. The relationship between latitude and model bias will be explored further by partitioning flight segments into periods of relatively constant latitude and comparing measured with estimated doses for these shorter periods of flight.

To estimate historical cosmic radiation doses for epidemiologic studies where individual flight histories are available, the CARI model and a set of standard assumptions for altitudes and times for each phase of flight can be used to estimate cosmic radiation doses per flight segment with some bias as described here. These doses can be subsequently cumulated over the time period of epidemiologic interest.

Conclusions

Few cosmic radiation measurement data exist for aircraft flying commercial transport routes. The measurements described here were compared to an empirical model for estimating cosmic radiation dose for a variety of flight segments. Doses computed from TEPC measurements tend to be greater that those estimated by the CARI model. Differences in measured versus modeled data should be considered when assigning doses estimated from the use of CARI for epidemiologic studies.

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Preface

This book contains the extended abstracts to the X2001 Conference on Exposure Assessment in Epidemiology and Practice in Göteborg, Sweden, June 10-13, 2001. The excellent work performed by the contributing scientists has made this book a first-class, up-to-date, state of the art review on what is known about exposure assessment today.

The outstanding scientific quality of the extended abstracts was secured through the work of five international programme committees. The chairmen for the committees were: Chemical, Patricia Stewart; Ergonomic, Alex Burdorf; Physical, Ulf Bergqvist; Psychosocial, Annika Härenstam and Biological, Jean-Francois Caillard.

Financial support to the conference and thereby to the publishing of this book was made possible by contributions from The National Institute for Working Life, Stockholm, Sweden; The Swedish Council for Working Life and Social Research, Stockholm and Volvo. Without the excellent skills of the organizing committee - Ulrika Agby (administration and layout), Ann-Sofie Liljenskog Hill (administration) and Christina Lindström Svensson (administration) - the production of this book would not have been possible.

We want to express our gratitude to the contributing authors, session chairmen and to the participants who presented papers and contributed in the discussions, for making X2001 an outstanding meeting.

Göteborg in June 2001

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