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Galactic Cosmic Radiation Exposure of Pregnant Aircrew Members II

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16. Abstract
In its 1990 recommendation regarding occupational exposure during pregnancy, the International Commission on Radiological Protection apparently assumed that the equivalent dose to a pregnant woman's abdomen is reduced by half in traversing the body to the conceptus. This assumption was tested with respect to galactic cosmic radiation, the principal ionizing radiation to which aircrews are exposed. We calculated the equivalent dose that would be received at depths of 0, 5, 10, and 15 centimeters in a 30-centimeter thick, soft-tissue slab phantom, at several locations in the atmosphere and on two air carrier flights, and found that the dose was almost the same at all the tissue depths studied. Thus, the assumption of considerable shielding of the conceptus by the woman's body is not valid with respect to galactic cosmic radiation. The effective dose of galactic radiation to the mother was found to be a good estimate of the equivalent dose to the conceptus.

17. Key Words
Aerospace Medicine, Pregnancy, Galactic Cosmic Radiation

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GALACTIC COSMIC RADIATION EXPOSURE OF PREGNANT AIRCREW MEMBERS II

1. INTRODUCTION

This report is an updated version of a previously published Technical Note in the journal *Aviation, Space, and Environmental Medicine* (1). The main change is that improved computer programs were used to estimate galactic cosmic radiation. The calculations also cover a greater range of altitudes. Small differences in the calculated doses were obtained, but the conclusions are the same.

The International Commission on Radiological Protection (ICRP) and the Federal Aviation Administration (FAA) consider aircrews to be occupationally exposed to ionizing radiation (2, 3). Although the United States has no regulations limiting aircrew exposure to cosmic radiation, the FAA has recommended limits. For pregnant crewmembers, starting when the pregnancy is reported to management, the FAA recommends: a) a limit of 1 millisievert to the conceptus for the remainder of the pregnancy, in accordance with the ICRP policy/recommendation (2, 4), and b) a monthly limit of 0.5 millisievert to the conceptus, as recommended by the National Council on Radiation Protection and Measurements (NCRP) (5). Here we address, principally, the ICRP policy.

The stated ICRP policy is that a standard of radiation protection for any conceptus be broadly comparable with that provided for members of the general public, i.e., a yearly limit of 1 millisievert. In their 1990 recommendations (2), the ICRP indicated that this standard could be met by limiting the equivalent dose to the surface of the pregnant woman's abdomen to 2 millisieverts for the remainder of the pregnancy, once declared. They apparently assumed that the equivalent dose to the conceptus would be about half the dose to the surface of the abdomen. We tested this assumption with respect to galactic cosmic radiation, the principal ionizing radiation to which aircrews are exposed.

2. METHODS

Using computer program CARI-LF3 (6), we calculated the equivalent dose rate at depths of 0, 5, 10, and 15 centimeters in a 30-centimeter thick, soft-tissue slab phantom at several locations in the atmosphere (Table 1) and the equivalent dose, at the same tissue depths, on two air carrier flights (Table 2).

Table 1. Galactic Radiation Dose Rates at Several Locations in the Atmosphere: Effective Dose Rate Compared With Equivalent Dose Rate at Various Tissue Depths. *

Geographic Coordinates	Altitude (feet)	Effective Dose Rate (μSv/h)	Equivalent Dose Rate (μSv/h) at a Depth of 0-cm	5-cm	10-cm	15-cm
0°, 20°E	0	0.028	0.029	0.028	0.028	0.028
	20,000	0.54	0.52	0.52	0.52	0.52
	30,000	1.6	1.5	1.5	1.5	1.5
	40,000	3.0	2.8	2.9	2.9	2.9
40°N, 20°E	0	0.037	0.037	0.037	0.036	0.036
	20,000	0.76	0.74	0.72	0.71	0.71
	30,000	2.3	2.3	2.3	2.2	2.2
	40,000	4.7	4.5	4.5	4.5	4.5
80°N, 20°E	0	0.041	0.041	0.040	0.040	0.040
	20,000	1.1	1.1	1.1	1.0	1.0
	30,000	4.1	4.0	3.8	3.8	3.7
	40,000	9.1	8.8	8.6	8.5	8.5

* Calculated doses for February 1998. Effective and equivalent dose rates were calculated by CARI-6 and CARI-LF3, respectively.

Table 2. Galactic Radiation Doses Received on Two Air-Carrier Flights: Effective Dose to an Adult Compared With Equivalent Dose at Various Tissue Depths.*

One-Way Flight	Effective Dose (μSv)	Equivalent Dose (μSv) at a Depth of 0-cm	5-cm	10-cm	15-cm
Athens, Greece (LGAT) to New York, NY (KJFK) †	67	65	64	64	64
Houston, TX (KIAH) to Austin, TX (KAUS) ‡	0.17	0.17	0.17	0.16	0.16

* Calculated doses for February, 1998. Effective and equivalent doses were calculated by CARI-6 and CARI-LF3, respectively.

† Air time 9.4 hours, maximum altitude 41,000 feet.

‡ Air time 0.5 hours, maximum altitude 20,000 feet.

CARI-LF3 uses radiation weighting factors recommended by the ICRP (2). For the same locations in the atmosphere and the same flights, computer program CARI-6 (7) was used to calculate the effective dose rates and doses to an adult (Tables 1 and 2). CARI-6 incorporates fluence to effective dose conversion coefficients calculated by Ferrari et al. (8, 9, 10, 11, 12, 13). See O'Brien et al. (14) for a description of the physics and dosimetry that is the basis of CARI-LF3 and CARI-6.

3. RESULTS AND DISCUSSION

Results in Table 1 show that, at each of a wide range of locations in the atmosphere, the equivalent dose rates from galactic cosmic radiation are almost the same at 0, 5, 10, and 15 centimeters depth in a 30-centimeter thick slab phantom. Also, at each location, the effective dose rate is close to the equivalent dose rates at the various tissue depths.

As additional comparisons, consider two air carrier flights (Table 2): a) a 9.4 hour (time airborne), high-altitude flight from Athens, Greece, to New York City and b) a 0.5 hour, low-altitude flight from Houston, Texas, to Austin, Texas. On the flight from Athens to New York City, equivalent doses at the tissue depths studied are 64 or 65 microsieverts and the effective dose 67 microsieverts. On the flight from Houston to Austin the equivalent doses at the various depths are 0.16 or 0.17 microsievert and the effective dose 0.17 microsievert. Thus, on each of the two flights, the equivalent doses are almost the same at all the tissue depths studied, and the effective dose is close to the equivalent doses.

Results in Tables 1 and 2 indicate that, during air travel, exposure of the body to galactic radiation is almost uniform and therefore, as expected, the equivalent dose to any part of the body is close to the effective dose to the whole person. Thus, for galactic radiation exposure during air travel, the equivalent dose to a conceptus can be estimated by the effective dose to the mother. We used effective dose as an estimate of the equivalent dose to the conceptus to obtain the results that follow.

Consider a crewmember who declares pregnancy after 1 month and continues working 80 airborne hours per month on the long, high-altitude flight from Athens to New York City. The monthly dose to the conceptus would be about 0.57 millisievert, which would exceed the recommended monthly limit of 0.5 millisievert. The recommended limit to the conceptus of 1 millisievert for the duration of the declared pregnancy would be reached in less than 2 months. In contrast, if she were airborne the same number of hours per month on the short, low-altitude flight from Houston to Austin, the dose per month would be 0.027 millisievert. This is well below the recommended monthly limit; the total dose to the conceptus would not exceed the recommended 1 millisievert limit, regardless of the number of months flown.

4. CONCLUSIONS

The mother's body provides no significant shielding for a conceptus from galactic radiation received during air travel. The effective dose to the mother, as calculated with CARI-6, is a good estimate of the equivalent dose to the conceptus from galactic radiation. By restricting occupational exposure to a maximum effective dose of 1 millisievert during her pregnancy, starting when it is reported to management, a pregnant crewmember will comply with the recommendation of the FAA and the ICRP regarding the total radiation exposure of the conceptus. Pregnant crewmembers can minimize occupational exposure to galactic radiation by working on short, low-altitude, low-latitude flights (15).

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1. Nicholas, J.S., K.A. Copeland, F.E. Duke, W.Friedberg, and K.O'Brien III (2000). Galactic Cosmic Radiation Exposure of Pregnant Flight Crewmembers. *Aviation, Space, and Environmental Medicine,* 71(6):647-8.

2. International Commission on Radiological Protection (1991). 1990 Recommendations of the ICRP, ICRP Publication 60, Annals of the ICRP **21(1-3)**. New York: Pergamon Press. (For recommended dose limits for the conceptus, see p. 42, pars. 177-178 and p. 46, Table 6.)

Equivalent dose (pp. 82-83):

When considering health effects of ionizing radiation, the amount of radiation received by a person is often expressed in terms of equivalent dose. Equivalent dose is a measure of the biological harmfulness of ionizing radiation and takes into account that equal amounts of absorbed energy from different types of ionizing radiation are not necessarily equally harmful. For each type of radiation (e. g., 20 MeV neutrons), the equivalent dose is the product of the absorbed dose (which may be different for different tissues/organs under the same irradiation conditions) and the appropriate radiation weighting factor. This factor takes into account the particular type of radiation's potential for causing biological harm. For mixed radiation fields (multiple particle types and/or energies), the resultant equivalent dose is the sum of the contributions from each of the component radiations.

The international unit of equivalent dose is the sievert. The sievert replaces the rem:

1 sievert (Sv) = 100 rem
1 sievert = 1000 millisieverts (mSv)
1 millisievert = 1000 microsieverts (μSv)

Effective dose (pp. 6-9):

When irradiation of the body is not uniform, an additional group of factors called tissue weighting factors are applied to take into account that the risk of biological harm to a person from stochastic effects of radiation (specifically: cancer, hereditary effects to all generations, and length of life lost) depends on the specific tissues/organs irradiated, as well as the equivalent doses received. The effective dose to an irradiated person is the sum of the products of equivalent dose and tissue weighting factor for each irradiated organ. The unit of effective dose is the sievert.

In the case of a uniform whole-body exposure, the equivalent dose to each tissue/organ is the same as the effective dose to the person. This is essentially the case with galactic cosmic radiation exposure of air travelers (see Tables 1 and 2 of this report).

3. Federal Aviation Administration (1994). Crewmember Training on In-Flight Radiation Exposure, Advisory Circular No. 120-61, Washington, DC.

4. International Commission on Radiological Protection (1997). General Principles for the Radiation Protection of Workers, ICRP Publication 75, Annals of the ICRP 27(1). New York: Pergamon Press. (For the recommended dose limit for the conceptus, see p. 25, par. 124.)

5. National Council on Radiation Protection and Measurements (1993). Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116, Bethesda, MD. (For the recommended monthly equivalent dose limit for the conceptus, see p. 38.)

6. CARI-LF3 (computer program). Oklahoma City, OK: FAA Civil Aeromedical Institute.

CARI-LF3 can be used to calculate many dosimetric endpoints, including equivalent dose. It takes into account changes in altitude and geographic location during the course of a flight (assumed to follow a great circle route or a reasonable approximation). Based on the date of the flight, appropriate databases are used to account for effects of changes in the earth's magnetic field and solar activity on galactic radiation levels.

7. CARI-6 (computer program). Oklahoma City, OK: FAA Civil Aeromedical Institute. (Available at Web site http://www.cami.jccbi.gov/AAM-600/610/600radio.html).

CARI-6 calculates the effective dose of galactic cosmic radiation received by an individual (adult) on an aircraft flying a great circle route (or a reasonable approximation) between any two airports in the world. The program takes into account changes in altitude and geographic location during the course of a flight. Based on the date of the flight, appropriate databases are used to account for effects of changes in the earth's magnetic field and solar activity on galactic radiation levels. The program also calculates the effective dose rate from galactic radiation at any location in the atmosphere at altitudes up to 87,298 feet. CARI-6 requires MS-DOS and can be run on most personal computers.

8. Ferrari A., M. Pelliccioni, M. Pillon (1996). Fluence to Effective Dose and Effective Dose Equivalent Conversion Coefficients for Photons From 50 keV to 10 GeV. *Radiation Protection Dosimetry*, 67(4): 245-51.

9. Ferrari A., M. Pelliccioni, M. Pillon (1997). Fluence to Effective Dose and Effective Dose Equivalent Conversion Coefficients for Electrons From 5 MeV to 10 GeV. *Radiation Protection Dosimetry*, 69(2): 97-104.

10. Ferrari A, M. Pelliccioni, M. Pillon (1997). Fluence to Effective Dose Conversion Coefficients for Protons From 5 MeV to 10 TeV. *Radiation Protection Dosimetry*, 71(2): 85-91.

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12. Ferrari A, M. Pelliccioni, M. Pillon (1997). Fluence-to-Effective Dose Equivalent Conversion Coefficients for Muons. *Radiation Protection Dosimetry*, 74(4): 227-33.

13. Ferrari A, M. Pelliccioni, M. Pillon (1998). Fluence to Effective Dose Conversion Coefficients for Negatively and Positively Charged Pions. *Radiation Protection Dosimetry*, 80(4):361-70.

14. O'Brien K., W. Friedberg, H.H. Sauer, and D.F. Smart (1996). Atmospheric Cosmic Rays and Solar Energetic Particles at Aircraft Altitudes. *Environment International,* 22 (Suppl. 1): S9-S44.

15. Friedberg W., K.Copeland, F.E. Duke, K.O'Brien III, and E.B. Darden Jr. (1999). Guidelines and Technical Information Provided by the US Federal Aviation Administration to Promote Radiation Safety for Air Carrier Crew Members. *Radiation Protection Dosimetry*, 86(4): 323-7.