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Radiation Exposure of Air Carrier Crewmembers II

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16. Abstract

The cosmic radiation environment at air carrier flight altitudes is described and estimates given of the amounts of galactic cosmic radiation received on a wide variety of routes to and from, and within the contiguous United States. Radiation exposure from radioactive air cargo is also considered. Methods are provided to assess health risks from exposure to galactic radiation.

On the flights studied, the highest dose of galactic radiation received annually by a crewmember who worked as many as 1,000 block hours a year would be less than half the annual limit recommended by the International Commission on Radiological Protection for a nonpregnant occupationally exposed adult. The radiation exposure of a pregnant crewmember who worked 70 block hours a month for 5 months would exceed the recommended 2-millisievert pregnancy limit on about one-third of the flights.

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1. INTRODUCTION

Aircrews are exposed to cosmic radiation* levels that are higher than the cosmic plus terrestrial radiation levels normally encountered on the ground. Cosmic radiation is a mixture of various types of ionizing radiation.† Other naturally occurring sources of ionizing radiation exposure include the radioactive isotopes in our bodies and in the earth. Exposure to ionizing radiation also occurs during medical and dental X-ray examinations.

This report, which is an updated revision of FAA Advisory Circular 120-52 issued March 1990, provides information about cosmic radiation at air carrier flight altitudes and possible associated health risks to individual crewmembers and their offspring. Also considered is the radiation received from radioactive air cargo.

2. GALACTIC COSMIC RADIATION

The cosmic radiation at air carrier flight altitudes is the result of a process whereby high-energy subatomic particles (mainly protons and alpha particles), originating for the most part outside the solar system, collide with and disrupt atoms of nitrogen, oxygen and other constituents of the atmosphere. From these collisions, photons and additional subatomic particles are produced. The impacting particles and those generated may have enough energy to disrupt other atmospheric atoms and produce still more photons and particles, and so on. The particles from beyond the solar system and the photons and particles produced in the atmosphere are referred to collectively as galactic cosmic radiation.

2.1. Variation with 11-Year Solar Cycle

The number of galactic radiation particles entering the atmosphere, and as a consequence the radiation levels at air carrier flight altitudes, varies inversely with an approximate 11-year cycle of rise and decline in solar activity (1). This variation in the galactic radiation is brought about by magnetic fields associated with the low-energy subatomic particles (solar wind) continuously being emitted from the sun. The magnetic fields deflect lower energy galactic particles that would otherwise enter the atmosphere. The particles that comprise the solar wind are themselves too low in energy to affect the radiation level at flight altitudes.

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* Galactic cosmic radiation and solar cosmic radiation are described in sections 2 and 3.

† Radiation is transmitted through space and matter in the form of packets of energy (photons) or subatomic particles. The term "ionizing radiation" is used if individual photons or particles produce one or more ions in the material irradiated. An ion is an electrically charged atom or group of atoms. Ionization is the principal means by which radiation exposure leads to biological effects.

2.2. Variation with Latitude

The earth's magnetic field (geomagnetic field) provides some shielding from incoming cosmic radiation particles. The shielding is greatest over the geomagnetic equator (near the geographic equator) and decreases to zero as one approaches the north or south polar regions. Thus, at a given cruise altitude, the galactic radiation dose-rate increases with distance north or south of the equator until it reaches a plateau at high latitudes. In the northern hemisphere, at a constant altitude, the galactic radiation level shows little or no increase above about 50 degrees geographic latitude in North America and 60 degrees in Europe and Asia. Radiation levels over the polar regions at air carrier cruise altitudes are about twice those over the equator at the same altitudes (table 1).

2.3. Variation with Altitude

The atmosphere provides considerable shielding from cosmic radiation. The lower the altitude the thicker the atmospheric layer and, therefore, the greater the protection. For example, in Oklahoma City the galactic radiation level at the surface of the earth (about 1,200 feet above sea level) is approximately one-half of 1 percent of the galactic radiation level at 39,000 feet (table 1).

3. SOLAR FLARES

On infrequent occasions, during some large solar flares,* the number and energies of particles emitted from the sun may temporarily become high enough to cause a substantial increase in the ionizing radiation level at high flight altitudes, particularly over the polar regions. These solar particle events cannot be predicted reliably nor can one predict how high the radiation level will reach, even after the event has begun.

The radiation at flight altitudes resulting from solar particle events is produced the same way as previously described for galactic cosmic radiation (see section 2). The particles from the sun and the photons and particles they produce in the atmosphere are referred to collectively as solar cosmic radiation.

Between 1956 and October 1991, inclusive, there were about 6 solar particle events during which the radiation level at 41,000 feet over the polar regions probably rose

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* A solar flare is an intense magnetic disturbance on the sun, accompanied by an explosive emission of various kinds of radiation.

above 100 microsieverts* per hour (2). At these locations the long-term average galactic radiation level is about 12 microsieverts per hour (3).

4. RADIOACTIVE CARGO

Radioactive material transported in air carrier aircraft consists mostly of pharmaceuticals used in medical diagnosis and treatment. Federal regulations specify the packaging and stowage of such cargo in order to limit radiation levels in areas occupied by people and animals.

In passenger aircraft carrying radioactive cargo in the United States during 1975, the estimated average annual radiation dose to flight attendants from the cargo was 0.06 millisievert and to flight-deck crewmembers less than 0.01 millisievert (6). It has been estimated for aircrews who work only on flights out of airports serving major radiopharmaceutical producers that flight attendants receive up to 0.13 millisievert annually and flight-deck crewmembers up to 0.025 millisievert (6). The radiation from cargo, received by individuals in each of the groups cited above, is less than 10 percent of the estimated galactic radiation dose to aircrew members. Combined 1981-1983 surveys indicate that since 1975 there was a slight decrease in the number of packages of radioactive material transported by air (7).

5. RADIATION EXPOSURE OF AIRCREWS AND RECOMMENDED LIMITS

We estimated the amount of galactic radiation received by air carrier crewmembers on 32 nonstop flights on a wide variety of routes to and from, and within the contiguous United States (table 2). At the current stage of the solar cycle, the galactic dose ranges from 0.023 to 0.80 millisievert per 100 block hours† (table 2, column 5). A crewmember who worked 900 block hours a year on these flights would receive an annual radiation dose of between 0.21‡ and 7.2 millisieverts. These values are considerably lower than the occupational limit of 20 millisieverts per year (5-year average), recommended by the International Commission on Radiological Protection for a nonpregnant adult (8).

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* When considering health effects of ionizing radiation, the amount of radiation received by a person is expressed in terms of sieverts. The sievert is a measure of the biological harm that ionizing radiation may cause and is the present international unit for this measurement. The sievert replaces the rem.

1 sievert = 100 rem
1 sievert = 1,000 millisieverts
1 millisievert = 1,000 microsieverts

† Block hours is defined in a footnote to table 2.

‡ (0.023 millisievert / 100 block hours) X 900 block hours = 0.21

5.1. Special Considerations During Pregnancy

There are recommendations concerning occupational exposure that apply only to pregnant women. The International Commission on Radiological Protection recommends that once a woman declares that she is pregnant, her occupational exposure to ionizing radiation should not exceed 2 millisieverts during the remainder of the pregnancy (8). In addition, the National Council on Radiation Protection and Measurements recommends that exposure of the unborn child not exceed 0.5 millisievert in any month (excluding medical exposures), once a pregnancy becomes known (5). For radiation protection purposes, it is assumed that the unborn child receives the same dose of cosmic radiation as the mother.

On some flights the galactic radiation received by an unborn child may exceed the recommended limits, depending on the woman's work schedule. For example, if she worked 70 block hours a month, exclusively on the flight with the highest dose rate per 100 block hours (table 2, Athens GR - New York), her monthly dose at the current stage of the solar cycle would be 0.56 millisievert. This exceeds the recommended monthly limit of 0.5 millisievert. In 5 months her accumulated dose would be 2.8 millisieverts, which is in excess of the recommended pregnancy limit of 2 millisieverts.

6. HEALTH CONCERNS

At the low radiation doses and dose rates associated with air travel, the health concerns are cancer, genetic defects that can be passed on to future generations, and harm to a child irradiated in utero (9).

The flights in table 2 are grouped according to the amount of galactic radiation received per 100 block hours. The group designation (radiation group A, B or C) is used to access the health risk estimates in tables 3, 4 and 5.

For some flights, whether or not listed in table 2, the radiation group can be identified from general information in the flight plan:

- Flights in which the average en route altitude does not exceed 24,000 feet are in radiation group A.
- Flights between the contiguous United States and Europe at average en route altitudes of 33 to 40 thousand feet are generally in radiation group C.

6.1. Fatal Cancer

Death from cancer is the principal health concern associated with occupational exposure to ionizing radiation. Table 3 provides estimates of the risk of eventually dying of cancer as a result of exposure to galactic radiation during a career of flying (8, 10).

For example, if a crewmember worked 700 block hours a year for 30 years, exclusively on flights with average en route altitudes of 33 to 40 thousand feet between the contiguous United States and Europe (radiation group C), then the estimated risk of radiation-induced fatal cancer would be between 1 in 250* and 1 in 120 (table 3).

Flights between Los Angeles and Honolulu shown in table 2 are in radiation group B. Based on the work schedule specified above (700 block hours per year for 30 years), the risk would fall between 1 in 660 and 1 in 250 (table 3).

If a crewmember worked 900 block hours a year for 20 years on flights that do not exceed 24,000 feet (radiation group A), the estimated maximum risk of fatal cancer would be 1 in 770 (table 3).

In the general population of the United States about 1 in 5 adults will eventually die of cancer (11). The likelihood of developing fatal cancer because of occupational exposure to galactic radiation is a small addition to the general population risk.

6.2. Genetic Defects

A child conceived after exposure of the mother or father to ionizing radiation is at risk of inheriting 1 or more radiation-induced genetic defects (12). The consequences of a genetic defect may be an anatomic or functional abnormality apparent at birth or later in life. Table 4 provides estimates of the risk to a liveborn child of a serious handicap of genetic origin, resulting from one parent's occupational exposure to galactic radiation before the child was conceived.

For example, if the father worked 700 block hours per year for 10 years on flights in radiation group C before the child was conceived, then the risk to the child from the father's occupational exposure would fall between 1 in 30,000 and 1 in 14,000 (table 4). If both parents were occupationally exposed to radiation before the child was conceived, then the risk to the child would be approximately the sum of the risks from the mother and father.

About 1 in 40 children of parents in the general population are born with 1 or more serious anatomic abnormalities (10). Any risk to a child of a serious handicap of genetic origin because of a parent's occupational exposure to galactic radiation would be a very small addition to health risks experienced by all children.

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* A risk of 1 in 250 means that if 250 persons are exposed to galactic radiation under the working conditions specified, it would be expected that one of these individuals will die of radiation-induced cancer.

6.3. Harm to an Unborn Child

For a child irradiated in utero, the risk of harm depends on the stage of its development at the time of exposure as well as the dose received. Table 5 provides estimates of the risk to the child of incurring one or more serious health defects from prenatal exposure to galactic radiation as a result of the mother's occupation. The possible consequences of radiation exposure taken into account in these risk estimates are severe mental retardation and both fatal and nonfatal childhood cancer (13, 14).

For example, if a woman worked 80 block hours a month on flights in radiation group B (table 2) during the first 5 months of her pregnancy, the risk to the child would be between 1 in 5,500 and 1 in 2,100 (table 5).

The risk to a child of incurring a radiation-induced health defect as a result of the mother's occupational exposure to galactic radiation would be a small addition to health risks experienced by all children.

7. CONCLUSIONS

On the 32 flights studied, the largest amount of galactic radiation received annually by a crewmember who worked as many as 1,000 block hours a year, is less than half the average annual limit of 20 millisieverts recommended by the International Commission on Radiological Protection for a nonpregnant occupationally exposed adult. Thus, radiation exposure is not likely to be a factor that would limit flying for a nonpregnant crewmember.

For a pregnant crewmember the situation is different. For example, if she worked 70 block hours a month (equivalent to 770 hours in an 11-month work year), the radiation dose she would receive in 5 months at the current stage of the solar cycle would exceed the recommended pregnancy limit of 2 millisieverts on about one-third of the flights studied.

Although one cannot exclude the possibility of harm from exposure to cosmic radiation at the doses likely to be received during a career of flying, it would be impossible to establish that an abnormality or disease in a particular individual resulted from such exposure.

In estimating radiation-induced health risks, we used dose-effect relationships equivalent to or derived from those recommended by national and international organizations concerned with radiation effects on humans. However, the recommended values are based on observations at much higher doses and dose rates than are likely to be received during air travel, and this is a major source of uncertainty in estimating risks.

REFERENCES AND NOTES

1. National Council on Radiation Protection and Measurements. Exposure of the Population in the United States and Canada from Natural Background Radiation. NCRP Report No. 94. Bethesda, MD, 1987. (sec. 2.1)

2. International Civil Aviation Organization. Technical Panel on Supersonic Transport Operations Fourth Meeting. Montreal. Doc 9076.SSTP/4. July 3-20, 1973. (pp. 4-10, 4-31)

   Gary R. Heckman and Herbert H. Sauer of the National Oceanic and Atmospheric Administration provided information on solar particle events that occurred since 1972.

3. The galactic radiation doses and dose rates in this report are computer generated estimates. The radiation data base used in the computer program was calculated by use of an unpublished version of a cosmic radiation transport code developed by O'Brien (4), and a world grid of vertical cutoff rigidities provided by M.A. Shea and D.F. Smart of the Air Force Geophysics Laboratory, Hanscom Air Force Base, MA.

4. O'Brien, K. 1978. LUIN, A Code for the Calculation of Cosmic Ray Propagation in the Atmosphere (Update of HASL-275). Report EML-338. New York, NY: Environmental Measurements Laboratory, Department of Energy. NTIS EML-338.

   The most important unpublished revisions of LUIN involve quality factors. We doubled the quality factors for neutrons as recommended by the National Council on Radiation Protection and Measurements (5), and since cosmic ray protons and charged pions generate radiation fields in tissue similar to those generated by neutrons we also doubled the quality factors for these particles.

5. National Council on Radiation Protection and Measurements. Recommendations on Limits for Exposure to Ionizing Radiation. NCRP Report No. 91. Bethesda, MD, 1987. (sec. 4.3, p. 30)

6. Nuclear Regulatory Commission 1977. Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes. Report NUREG-0170 (Vol. 1). NTIS PB-275529. (secs. 4.3.1.1.2, 4.3.1.1.3)

7. Javitz, H.S., T.R. Lyman, C. Maxwell, E.L. Myers and C.R. Thompson 1985. Transport of Radioactive Material in the United States: Results of a Survey to Determine the Magnitude and Characteristics of Domestic, Unclassified Shipments of Radioactive Materials. SRI International, Sandia National Laboratories Report SAND84-7174, TTC-0534. NTIS DE85016198. (p. 40)

8. International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. New York, NY: Pergamon Press, 1990. (p. 42, par. 178; p. 46, table 6)

    To estimate the lifetime risk of developing radiation-induced fatal cancer in crewmembers, we used a risk coefficient of 4 in 100,000 per millisievert (p. 20, par. 83).

9. Environmental Protection Agency 1987. Radiation Protection Guidance to Federal Agencies for Occupational Exposure. Federal Register 52(17) Tuesday, January 27, 1987, pp. 2822-2834. (see p. 2824)

10. Committee on the Biological Effects of Ionizing Radiations. Health Effects of Exposure to Low Levels of Ionizing Radiation. BEIR V. Washington, DC: National Academy Press, 1990.

    An evaluation of BEIR V by the Environmental Protection Agency indicates a lifetime risk of radiation-induced fatal cancer of 4 in 100,000 per millisievert for a working-age population exposed at low dose rates (A.C.B. Richardson, personal communication).

    The incidence of congenital abnormalities in the general population is between 2 and 3 percent, a risk of about 1 in 40 (p. 86 and p. 87, table 2-3).

11. Seidman, H., M.H. Mushinski, S.K. Gelb and E. Silverberg 1985. Probabilities of Eventually Developing or Dying of Cancer -- United States, 1985. Ca-A Cancer Journal for Clinicians 35(1): 36-56. (p. 52)

12. Committee on the Biological Effects of Ionizing Radiations. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980. BEIR III. Washington, DC: National Academy Press, 1980.

    To estimate the risk of a serious genetic disorder in a liveborn child, resulting from one parent's exposure to ionizing radiation before the child was conceived, we used a risk coefficient of 1 in 1,000,000 per millisievert (p. 5).

13. Stather, J.W., C.R. Muirhead, A.A. Edwards, J.D. Harrison, D.C. Lloyd and N.R. Wood 1988. Health Effects Models Developed from the 1988 UNSCEAR Report. NRPB-R226. National Radiological Protection Board, Chilton, Didcot, Oxon OX11 ORQ, Great Britain.

    To estimate the risk of severe mental retardation resulting from irradiation during the 9th through the 16th week of pregnancy, we used a risk coefficient of 4.5 in 10,000 per millisievert (p. 48, par.15).

For childhood cancer, we used a risk coefficient of 6 in 100,000 per millisievert (p. 48, par. 16) and assumed the risk to be the same during the entire pregnancy (reference 14, p. 338, par. 418).

14. United Nations Scientific Committee on the Effects of Atomic Radiation. Genetic and Somatic Effects of Ionizing Radiation. Annex C: Biological effects of pre-natal irradiation. New York, NY: United Nations, 1986.

    To estimate the risk of severe mental retardation resulting from irradiation during the 17th through the 26th week of pregnancy, we used a risk coefficient of 1 in 10,000 per millisievert (p. 338, par. 416).

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Table 1. GALACTIC COSMIC RADIATION*

Location	Altitude, feet†	Microsieverts per hour
Oklahoma City	1,200	0.04
" "	39,000	8
Polar region	"	9
Equator	"	4-5

* Current stage of solar cycle.

† Above sea level.

Table 2. GALACTIC RADIATION ON AIR CARRIER FLIGHTS

Origin - Destination[*] (1)	Single nonstop one-way flight: Altitude, feet in thousands: Highest (2)	Single nonstop one-way flight: Altitude, feet in thousands: Average en route[†] (3)	Single nonstop one-way flight: Block hours[‡] (4)	Dose rate, millisieverts per 100 block hours: Current (5)	Dose rate, millisieverts per 100 block hours: Long-term average[§] (6)
RADIATION GROUP A (maximum of 0.18 millisievert per 100 block hours)[§]					
Seattle (KSEA) - Portland (KPDX)	21	21	0.6	0.023	0.025
Houston (KIAH) - Austin (KAUS)	20	20	0.6	0.025	0.027
Miami (KMIA) - Tampa (KTPA)	24	24	0.9	0.042	0.046
RADIATION GROUP B (from 0.18 to a maximum of 0.48 millisievert per 100 block hours)[§]					
St Louis (KSTL) - Tulsa (KTUL)	35	35	1.1	0.17	0.19
Tampa (KTPA) - St Louis (KSTL)	31	31	2.2	0.24	0.27
San Juan PR (TJSJ) - Miami (KMIA)	35	34	2.5	0.26	0.28
Denver (KDEN) - Minneapolis (KMSP)	33	33	1.5	0.28	0.33
New Orleans (KMSY) - San Antonio (KSAT)	39	39	1.4	0.30	0.33
Los Angeles (KLAX) - Honolulu (PHNL)	35	35	5.6	0.34	0.36
New York (KJFK) - San Juan PR (TJSJ)	37	36	3.5	0.37	0.40
Honolulu (PHNL) - Los Angeles (KLAX)	40	38	5.6	0.39	0.41
Chicago (KORD) - New York (KJFK)	37	37	2.0	0.38	0.45
Los Angeles (KLAX) - Tokyo JA (RJAA)	40	35	12.0	0.42	0.45
Tokyo JA (RJAA) - Los Angeles (KLAX)	37	35	9.2	0.43	0.47

CONTINUED ON FOLLOWING PAGE

RADIATION GROUP C (from 0.48 to a maximum of 0.99 millisievert per 100 block hours)§

Washington, DC (KIAD) - Los Angeles (KLAX)	35	35	5.0	0.44	0.50
Minneapolis (KMSP) - New York (KJFK)	37	37	2.1	0.46	0.52
London EN (EGKK) - Dallas/Ft Worth (KDFW)	39	33	10.1	0.46	0.53
Dallas/Ft Worth (KDFW) - London EN (EGKK)	37	34	8.8	0.48	0.56
New York (KJFK) - Chicago (KORD)	39	39	2.3	0.48	0.57
Lisbon (LPPT) - New York (KJFK)	39	36	6.9	0.51	0.58
Seattle (KSEA) - Anchorage (PANC)	35	35	3.7	0.49	0.59
Chicago (KORD) - San Francisco (KSFO)	39	38	4.1	0.59	0.66
Seattle (KSEA) - Washington DC (KIAD)	37	37	4.4	0.59	0.68
London EN (EGLL) - New York (KJFK)	37	37	7.3	0.58	0.68
New York (KJFK) - Seattle (KSEA)	39	37	5.3	0.60	0.72
Chicago (KORD) - London EN (EGLL)	37	37	7.7	0.62	0.73
Tokyo JA (RJAA) - New York (KJFK)	41	37	12.6	0.62	0.73
San Francisco (KSFO) - Chicago (KORD)	41	39	4.1	0.63	0.73
London EN (EGLL) - Los Angeles (KLAX)	39	37	11.0	0.63	0.74
New York (KJFK) - Tokyo JA (RJAA)	43	38	13.4	0.64	0.74
London EN (EGLL) - Chicago (KORD)	39	37	8.3	0.65	0.77
Athens GR (LGAT) - New York (KJFK)	41	40	9.7	0.80	0.93

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* Flight data given for only one direction between two cities is considered representative of the other direction.

† Time averaged.

‡ The block hours of a flight begin when the aircraft leaves the blocks before takeoff and end when it reaches the blocks after landing.

§ Long-term average galactic radiation levels.

Table 3. ESTIMATED ADDED RISK OF FATAL CANCER RESULTING FROM EXPOSURE TO GALACTIC COSMIC RADIATION*

Block hours per year	RADIATION GROUP A†	RADIATION GROUP B‡	RADIATION GROUP C§
	10 Years of Flying		
500	Maximum of 1 in 2,800	1 in 2,800 to 1 in 1,000	1 in 1,000 to 1 in 510
700	" " 1 in 2,000	1 in 2,000 " 1 in 740	1 in 740 " 1 in 360
900	" " 1 in 1,500	1 in 1,500 " 1 in 580	1 in 580 " 1 in 280
1100	" " 1 in 1,300	1 in 1,300 " 1 in 470	1 in 470 " 1 in 230
	20 Years of Flying		
500	Maximum of 1 in 1,400	1 in 1,400 to 1 in 520	1 in 520 to 1 in 250
700	" " 1 in 990	1 in 990 " 1 in 370	1 in 370 " 1 in 180
900	" " 1 in 770	1 in 770 " 1 in 290	1 in 290 " 1 in 140
1100	" " 1 in 630	1 in 630 " 1 in 240	1 in 240 " 1 in 110
	30 Years of Flying		
500	Maximum of 1 in 930	1 in 930 to 1 in 350	1 in 350 to 1 in 170
700	" " 1 in 660	1 in 660 " 1 in 250	1 in 250 " 1 in 120
900	" " 1 in 510	1 in 510 " 1 in 190	1 in 190 " 1 in 94
1100	" " 1 in 420	1 in 420 " 1 in 160	1 in 160 " 1 in 77

* Based on long-term average galactic radiation levels.

† Maximum of 0.18 millisievert per 100 block hours.

‡ From 0.18 to a maximum of 0.48 millisievert per 100 block hours.

§ From 0.48 to a maximum of 0.99 millisievert per 100 block hours.

Table 4. ESTIMATED ADDED RISK TO A LIVEBORN CHILD OF A GENETIC DEFECT CAUSED BY ONE PARENT'S EXPOSURE TO GALACTIC RADIATION BEFORE THE CHILD WAS CONCEIVED*

Block hours per year	RADIATION GROUP A†	RADIATION GROUP B‡	RADIATION GROUP C§
		5 Years of Flying	
500	Maximum of 1 in 220,000	1 in 220,000 to 1 in 83,000	1 in 83,000 to 1 in 40,000
700	" " 1 in 160,000	1 in 160,000 " 1 in 60,000	1 in 60,000 " 1 in 29,000
900	" " 1 in 120,000	1 in 120,000 " 1 in 46,000	1 in 46,000 " 1 in 22,000
1100	" " 1 in 100,000	1 in 100,000 " 1 in 38,000	1 in 38,000 " 1 in 18,000
		10 Years of Flying	
500	Maximum of 1 in 110,000	1 in 110,000 to 1 in 42,000	1 in 42,000 to 1 in 20,000
700	" " 1 in 79,000	1 in 79,000 " 1 in 30,000	1 in 30,000 " 1 in 14,000
900	" " 1 in 62,000	1 in 62,000 " 1 in 23,000	1 in 23,000 " 1 in 11,000
1100	" " 1 in 51,000	1 in 51,000 " 1 in 19,000	1 in 19,000 " 1 in 9,200
		20 Years of Flying	
500	Maximum of 1 in 56,000	1 in 56,000 to 1 in 21,000	1 in 21,000 to 1 in 10,000
700	" " 1 in 40,000	1 in 40,000 " 1 in 15,000	1 in 15,000 " 1 in 7,200
900	" " 1 in 31,000	1 in 31,000 " 1 in 12,000	1 in 12,000 " 1 in 5,600
1100	" " 1 in 25,000	1 in 25,000 " 1 in 9,500	1 in 9,500 " 1 in 4,600

* Based on long-term average galactic radiation levels.

† Maximum of 0.18 millisievert per 100 block hours.

‡ From 0.18 to a maximum of 0.48 millisievert per 100 block hours.

§ From 0.48 to a maximum of 0.99 millisievert per 100 block hours.

Table 5. ESTIMATED ADDED RISK TO A CHILD OF ONE OR MORE SERIOUS HEALTH DEFECTS CAUSED BY PRENATAL EXPOSURE TO GALACTIC RADIATION*

Block hours per month	RADIATION GROUP A†	RADIATION GROUP B‡	RADIATION GROUP C§
	3 months of flying		
40	Maximum of 1 in 20,000	1 in 20,000 to 1 in 7,400	1 in 7,400 to 1 in 3,600
60	" " 1 in 13,000	1 in 13,000 " 1 in 4,900	1 in 4,900 " 1 in 2,400
80	" " 1 in 9,900	1 in 9,900 " 1 in 3,700	1 in 3,700 " 1 in 1,800
100	" " 1 in 7,900	1 in 7,900 " 1 in 3,000	1 in 3,000 " 1 in 1,400
	5 months of flying		
40	Maximum of 1 in 11,000	1 in 11,000 to 1 in 4,100	1 in 4,100 to 1 in 2,000
60	" " 1 in 7,300	1 in 7,300 " 1 in 2,800	1 in 2,800 " 1 in 1,300
80	" " 1 in 5,500	1 in 5,500 " 1 in 2,100	1 in 2,100 " 1 in 1,000
100	" " 1 in 4,400	1 in 4,400 " 1 in 1,700	1 in 1,700 " 1 in 800
	7 months of flying		
40	Maximum of 1 in 9,400	1 in 9,400 to 1 in 3,500	1 in 3,500 to 1 in 1,700
60	" " 1 in 6,300	1 in 6,300 " 1 in 2,300	1 in 2,300 " 1 in 1,100
80	" " 1 in 4,700	1 in 4,700 " 1 in 1,800	1 in 1,800 " 1 in 850
100	" " 1 in 3,800	1 in 3,800 " 1 in 1,400	1 in 1,400 " 1 in 680

* Based on long-term average galactic radiation levels.

† Maximum of 0.18 millisievert per 100 block hours.

‡ From 0.18 to a maximum of 0.48 millisievert per 100 block hours.

§ From 0.48 to a maximum of 0.99 millisievert per 100 block hours.

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