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Effects of Radiation Exposure on Air Carrier Crew Members Examined

Air crews are exposed to higher levels of radiation than those who work on the ground. Although long-term health effects are as yet impossible to predict, some pregnant air crew members could be exposed beyond recommended limits.

by
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Air crews 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.

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.

This report, which is an updated revision of U.S. Federal Aviation Administration (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 crew members and their offspring. Also considered is the radiation received from radioactive air cargo.

Galactic Cosmic Radiation Defined

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.

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.

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).

Table 1

Galactic Cosmic Radiation*

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

* Current stage of solar cycle.
† Above sea level.

Source: U.S. Federal Aviation Administration

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 [366 meters] above sea level) is approximately one-half of one percent of the galactic radiation level at 39,000 feet (11,895 meters) (Table 1).

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.

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

The radiation at flight altitudes resulting from solar particle events is produced the same way as previously described for galactic cosmic radiation. 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 six solar particle events during which the radiation level at 41,000 feet (12,505 meters) over the polar regions probably rose above 100 microsieverts per hour (2). At these locations the long-term average galactic radiation level is about 12 microsieverts per hour (3, 4). (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.)

Radioactive Cargo Adds to Dose Issue

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 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 crew members less than 0.01 millisievert (5, 6). It has been estimated for air crews 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 crew members 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 air crew 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).

Limits Recommended for Radiation Exposure of Aircrews

The amount of galactic radiation received by air carrier crew members was estimated on 32 nonstop flights on a wide variety of routes to, from and within the contiguous United States (Table 2, page 4). 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 crew member who worked 900 block hours a year on these flights would receive an annual radiation dose of between 0.21 and 7.2 millisieverts. [(0.023 millisievert/100 block hours) x 900 block hours = 0.21]. These values are considerably lower than the occupational limit of 20 millisieverts per year (five-year average), recommended by the International Commission on Radiological Protection for a nonpregnant adult (8).

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 two millisieverts during the remainder of the pregnancy (8). In addition, the U.S. 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 - 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 five months, her accumulated dose would be 2.8 millisieverts, which is in excess of the recommended pregnancy limit of two millisieverts.

Health Concerns Include Cancer, Genetic Defects

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).

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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 (pages 5, 6 and 7).

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 (7,320 meters) are in radiation group A.

- Flights between the contiguous United States and Europe at average en route altitudes of 33,000 to 40,000 feet (10,065 to 12,200 meters) are generally in radiation group C.

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 crew member worked 700 block hours a year for 30 years, exclusively on flights with average en route altitudes of 33,000 to 40,000 feet between the contiguous United States and Europe (radiation group C), then the estimated risk of radiation-induced fatal cancer would be between one in 250 and one in 120 (Table 3).

A risk of one 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.

Table 2
Galactic Radiation on Air Carrier Flights

Origin - Destination* (1)	Single nonstop one-way flight: Altitude, feet in thousands: Highest (2)	Average en route† (3)	Block hours‡ (4)	Dose rate, millisieverts per 100 block hours: Current (5)	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 (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 (RJAA) - Los Angeles (KLAX)	37	35	9.2	0.43	0.47
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 (KJFX)	37	37	2.1	0.46	0.52
London (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 (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 (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 (EGLL) - Chicago (KORD)	39	37	8.3	0.65	0.77
Athens (LGAT) - New York (KJFK)	41	40	9.7	0.80	0.93

* 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 block before takeoff and end when it reaches the blocks after landing.
§ Long-term average galactic radiation levels.

Source: U.S. Federal Aviation Administration

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	Maximum of 1 in 2,000	1 in 2,000 to 1 in 740	1 in 740 to 1 in 360
900	Maximum of 1 in 1,500	1 in 1,500 to 1 in 580	1 in 580 to 1 in 280
1,100	Maximum of 1 in 1,300	1 in 1,300 to 1 in 470	1 in 470 to 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	Maximum of 1 in 990	1 in 990 to 1 in 370	1 in 370 to 1 in 180
900	Maximum of 1 in 770	1 in 770 to 1 in 290	1 in 290 to 1 in 140
1,100	Maximum of 1 in 630	1 in 630 to 1 in 240	1 in 240 to 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	Maximum of 1 in 660	1 in 660 to 1 in 250	1 in 250 to 1 in 120
900	Maximum of 1 in 510	1 in 510 to 1 in 190	1 in 190 to 1 in 94
1,100	Maximum of 1 in 420	1 in 420 to 1 in 160	1 in 160 to 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.

Source: U.S. Federal Aviation Administration

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 one in 660 and one in 250 (Table 3).

If a crew member 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 one in 770 (Table 3).

In the general population of the United States about one in five 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's risk.

A child conceived after exposure of the mother or father to ionizing radiation is at risk of inheriting one 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 one in 30,000 and one 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 one in 40 children of parents in the general population is born with one 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.

For a child irradiated in utero, the risk of harm depends on the stage of its development at the time of exposure as

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	Maximum of 1 in 160,000	1 in 160,000 to 1 in 60,000	1 in 60,000 to 1 in 29,000
900	Maximum of 1 in 120,000	1 in 120,000 to 1 in 46,000	1 in 46,000 to 1 in 22,000
1,100	Maximum of 1 in 100,000	1 in 100,000 to 1 in 38,000	1 in 38,000 to 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	Maximum of 1 in 79,000	1 in 79,000 to 1 in 30,000	1 in 30,000 to 1 in 14,000
900	Maximum of 1 in 62,000	1 in 62,000 to 1 in 23,000	1 in 23,000 to 1 in 11,000
1,100	Maximum of 1 in 51,000	1 in 51,000 to 1 in 19,000	1 in 19,000 to 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	Maximum of 1 in 40,000	1 in 40,000 to 1 in 15,000	1 in 15,000 to 1 in 7,200
900	Maximum of 1 in 31,000	1 in 31,000 to 1 in 12,000	1 in 12,000 to 1 in 5,600
1,100	Maximum of 1 in 25,000	1 in 25,000 to 1 in 9,500	1 in 9,500 to 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.

Source: U.S. Federal Aviation Administration

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 five months of her pregnancy, the risk to the child would be between one in 5,500 and one in 2,100 (Table 5).

Again, 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.

On the 32 flights studied, the largest amount of galactic radiation received annually by a crew member 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 crew member.

For a pregnant crew member 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 five months at the current stage of the solar cycle would exceed the recommended pregnancy limit of two 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

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 year	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	Maximum of 1 in 13,000	1 in 13,000 to 1 in 4,900	1 in 4,900 to 1 in 2,400
80	Maximum of 1 in 9,900	1 in 9,900 to 1 in 3,700	1 in 3,700 to 1 in 1,800
100	Maximum of 1 in 7,900	1 in 7,900 to 1 in 3,000	1 in 3,000 to 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	Maximum of 1 in 7,300	1 in 7,300 to 1 in 2,800	1 in 2,800 to 1 in 1,300
80	Maximum of 1 in 5,500	1 in 5,500 to 1 in 2,100	1 in 2,100 to 1 in 1,000
100	Maximum of 1 in 4,400	1 in 4,400 to 1 in 1,700	1 in 1,700 to 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	Maximum of 1 in 6,300	1 in 6,300 to 1 in 2,300	1 in 2,300 to 1 in 1,100
80	Maximum of 1 in 4,700	1 in 4,700 to 1 in 1,800	1 in 1,800 to 1 in 850
100	Maximum of 1 in 3,800	1 in 3,800 to 1 in 1,400	1 in 1,400 to 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.

Source: U.S. Federal Aviation Administration

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, Maryland, United States,1987. (sec. 2.1)

2. International Civil Aviation Organization. *Technical Panel on Supersonic Transport Operations Fourth Meeting*. Doc 9076.SSTP/4. Montreal, Canada, July 3-20, 1973.

   Gary R. Heckman and Herbert H. Sauer of the National Oceanic and Atmospheric Administration provided information on solar particle events that have 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, Massachusetts, United States.

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, New York, United States: 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, Maryland, United States, 1987. (sec. 4.3, p. 30)

6. Nuclear Regulatory Commission. *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) 1977.

7. Javitz, H.S.; Lyman, T.R.; Maxwell,C.; Myers, E.L. and Thompson, C.R. *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. 1985.

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

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

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

10. Committee on the Biological Effects of Ionizing Radiations. *Health Effects of Exposure to Low Levels of Ionizing Radiation*. BEIR V. Washington, D.C., United States: 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 (page 86 and page 87, Table 2-3).

11. Seidman, H.; Mushinski, M.H.; Gelb, S.K. and Silverberg, E. “Probabilities of Eventually Developing or Dying of Cancer.” *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*. BEIR lll. Washington, D.C., United States: 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.

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

    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, New York, United States: 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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