Training Guide for Aircrews From the FAA's Radiobiology Research Team Web Site

WHAT COMMERCIAL-AIRCRAFT CREWMEMBERS SHOULD KNOW ABOUT THEIR OCCUPATIONAL EXPOSURE TO IONIZING RADIATION

1. What is ionizing radiation?

Ionizing radiation refers to particles of matter and of energy which individually are sufficiently energetic to cause an atom to lose an electron or even to break apart the nucleus of an atom. Such occurrences in tissues and organs may lead to health effects. Examples of ionizing radiation are neutrons, protons, electrons, x-rays, and gamma rays.

Ionizing radiation is a normal part of our environment (**Table 1**). Substances that emit ionizing radiation are present in every cell in the body. We are exposed to ionizing radiation emanating from substances in the ground and in building materials. Ionizing radiation is used in some medical procedures. The principal ionizing radiation to which air travelers are exposed is galactic radiation (also called galactic cosmic radiation). A main source of galactic radiation is believed to be exploding stars (supernovae). On infrequent occasions, air travelers are also exposed to ionizing radiation from the Sun.

Galactic radiation consists of fast-moving particles (mostly protons), which when entering the Earth's atmosphere, collide with the nuclei of nitrogen, oxygen, and other air atoms, generating additional radiation particles. The particles that enter the atmosphere and those generated are referred to collectively as galactic radiation. At aircraft flight altitudes, the galactic radiation consists mostly of neutrons, protons, electrons, x-rays, and gamma rays.

The amount of ionizing radiation received by a person is expressed in units of effective dose. For a pregnant woman, the dose of ionizing radiation to the conceptus (any stage of development from the fertilized egg to birth) is expressed in units of equivalent dose. For an explanation of the terms *effective dose* and *equivalent dose*, see "References and Notes" in FAA Office of Aerospace Medicine technical report **DOT/FAA/AM-00/33** "Galactic Cosmic Radiation Exposure of Pregnant Aircrew Members II."

The unit of effective dose and of equivalent dose is the sievert. The sievert is a measure of potential harm from ionizing radiation.

1 sievert = 1000 millisieverts.
1 millisievert = 1000 microsieverts

In the questions and answers that follow, radiation refers to ionizing radiation.

2. How can a crewmember find out the effective dose of radiation received on a flight? If the crewmember is pregnant, how can she find out the equivalent dose of radiation received by the conceptus?

Computer program CARI-6 can be used to calculate the effective dose of galactic radiation received by a crewmember flying an approximate great-circle route (the shortest distance) between two airports. For a pregnant crewmember, the effective dose of galactic radiation is a reliable estimate of the equivalent dose received by the conceptus. An interactive Web version of CARI-6 can be run, at no charge, at the Radiobiology Research Team Web site.

http://www.cami.jccbi.gov/aam-600/610/600radio.html

Also, there are two versions of the CARI program that can be downloaded from the same site, CARI-6 and CARI-6M. The downloadable version of CARI-6 is more sophisticated than the interactive Web version. Both assume a great-circle route between origin and destination airports, but the downloadable version allows the user to enter, store, and process multiple flight-profiles, and to calculate dose rates at user-specified locations in the atmosphere. CARI-6M allows the user to specify the flight path by entering the altitudes and geographic coordinates of way points.

3. What are the recommended occupational radiation exposure limits for crewmembers?

The FAA recommends occupational radiation limits for commercial-aircraft crewmembers. These include a 5-year average effective dose of 20 millisieverts per year, with no more than 50 millisieverts in a single year. For a pregnant crewmember, starting when she reports her pregnancy to management, the recommended limit for the conceptus is an equivalent dose of 1 millisievert, with no more than 0.5 millisievert in any month.

4. What are the health concerns associated with a crewmember's occupational exposure to radiation?

An increased risk of fatal cancer is the principal health concern associated with occupational exposure to radiation at the doses received by commercial-aircraft crewmembers. The following example shows how the increased risk can be estimated. Suppose a crewmember worked 700 block hours per year for 25 years flying between New York, NY, and Chicago, IL. Based on flight data in **Table 2** and assuming the flight dose is the same in both directions, the effective dose of galactic radiation would be 0.0039 millisievert per block hour. In 25 years, the dose to the crewmember would be

25 years x 700 block hours per year x 0.0039 millisievert per block hour = 68 millisieverts.

According to **Table 3**, a crewmember who received 68 millisieverts will incur an increased lifetime risk of fatal cancer of about 1 in 360 (0.3%). In the general population of the United States, approximately 24% of adult deaths are from cancer.

Genetic defects passed on to future generations are other possible consequences of exposure to radiation. A child is at risk of inheriting genetic defects because of the radiation received by the parents before the child's conception. Suppose one of the child's parents worked 700 block hours per year for 5 years flying between New York, NY, and Chicago, IL, before the child was conceived. As indicated in the previous example, the effective dose of galactic radiation received by the parent would be 0.0039 millisievert per block hour. In 5 years, the dose to the parent would be

5 years x 700 block hours per year x 0.0039 millisievert per block hour = 14 millisieverts.

According to **Table 4**, if one parent received 14 millisieverts before the child was conceived, the increased risk to the child of inheriting a severe genetic defect would be about 1 in 33,000 (0.003%). If both parents were exposed to radiation, the increased risk to the child would be based on the sum of the doses they received before the child was conceived. Of children in the general population, 2-3% have one or more structural abnormalities present at birth, including but not limited to those of genetic origin.

5. How can a crewmember reduce the amount of radiation received without working fewer hours?

Fly short flights at low latitudes. Short flights are flown at lower altitudes than long-distance flights; consequently, there is more radiation shielding on a short flight because of the greater amount of air above the aircraft. If two flights are flown at different geographic latitudes but at the same altitude and for the same length of time, the radiation level on the lower-latitude flight will usually be the lower of the two because of the greater amount of radiation shielding provided by the Earth's magnetic field. This shielding is at a maximum near the equator and gradually decreases to zero as one goes north or south. For example, during the period January 1958 through December 2000, at an altitude of 30,000 feet the average galactic radiation level over Reykjavik, Iceland (64° N, 22° W), was approximately twice that over Lima, Peru (12° S, 77° W).

6. If a crewmember works during pregnancy, what are the health consequences for the child and how long could the crewmember work without the radiation dose to the conceptus exceeding recommended limits?

For a child irradiated in utero, major risks are structural abnormalities, mental retardation, death in utero, and fatal cancer. The available data indicate that even if the conceptus received a dose as high as 20 millisieverts -- which might occur during an unusually large solar-proton event (see answer to question 7) -- no radiation-induced structural abnormalities or mental retardation would be observed. However, irradiation of the conceptus during the first day of development, even with a dose considerably less than 20 millisieverts, would result in an increased risk of prenatal death. The risk would depend on the stage of development of the conceptus at the time of irradiation and the radiation dose. If death did occur, the conceptus would most likely be aborted before the woman was aware of being pregnant. At a later stage of development, a dose of 20 millisieverts to the conceptus would not affect prenatal survival.

A child irradiated during prenatal development will incur an increased lifetime risk of fatal cancer. Suppose a pregnant crewmember worked 70 block hours per month flying between New York, NY, and Chicago, IL. As in the earlier examples, the effective dose of galactic radiation would be 0.0039 millisievert per block hour. With galactic radiation, the effective dose to the pregnant crewmember is a reliable estimate of the equivalent dose to the conceptus. Therefore, the estimated monthly equivalent dose to the conceptus would be

70 block hours per month x 0.0039 millisievert per block hour = 0.27 millisievert per month.

This is well below the recommended monthly limit of 0.5 millisievert. At a monthly dose of 0.27 millisievert, the pregnant crewmember could work

1 millisievert limit / 0.27 millisievert per month = 3.7 months

without the dose to the conceptus exceeding the recommended limit of 1 millisievert. According to **Table 5**, the increased lifetime risk of fatal cancer from 1 millisievert received during prenatal development is 1 in 10,000 (0.01%). In the general population of the United States (all ages), approximately 23% of all deaths are from cancer.

Suppose the pregnant crewmember worked on high-altitude, high-latitude, long-distance flights between Athens, GR, and New York, NY. Based on the data in **Table 2**, and assuming the flight dose is the same in both directions, the effective dose to the pregnant crewmember, and therefore the equivalent dose to the conceptus, would be 0.0063 millisievert per block hour. The pregnant crewmember could work

0.50 millisievert monthly limit / 0.0063 millisievert per block hour = 79 block hours per month

without the dose to the conceptus exceeding the recommended monthly limit of 0.5 millisievert. At a monthly dose of 0.5 millisievert, the pregnant crewmember could work

1 millisievert limit / 0.50 millisievert per month = 2.0 months

without the dose to the conceptus exceeding the recommended limit of 1 millisievert.

7. What should a crewmember know about radiation from the Sun?

Occasionally a disturbance in the Sun's atmosphere leads to an explosive emission of huge amounts of matter and energy in the form of particles. The most important of these particles, in terms of radiation exposure of crewmembers, are high-energy protons. When entering the Earth's atmosphere, these particles interact with air atoms in essentially the same way as galactic particles (see answer to question 1).

The term *solar-proton event* is used when the protons emitted from the Sun meet energy and intensity criteria specified by the National Oceanic and Atmospheric Administration. Other names for a solar-proton event are *solar-particle event*, *solar energetic-particle event*, and *solar cosmic-ray event*. The term *solar flare* is sometimes used to indicate such an event, but it is also used to indicate solar phenomena unrelated to radiation at flight altitudes. Solar-proton events occur more frequently during the active phase of the Sun's approximate 11-year cycle of increasing and decreasing activity. During such an event there may be an increase in radiation levels at commercial-aircraft flight altitudes, but usually any increase would be small. Only on rare occasions does a solar-proton event lead to a substantial increase in the radiation at flight altitudes.

The most energetic of the particles from a solar-proton event reach the Earth's atmosphere within 20 minutes. The initial particles come from the direction of the Sun, but soon they are coming from all directions because of the spreading effect on the particles caused by the interplanetary and Earth's magnetic fields. Between 20 minutes and 3 hours after the start of an event, radiation levels in the atmosphere on the dark and light sides of the Earth will be almost the same. Thus, radiation from these events cannot be avoided by flying only at night. Solar-proton events cannot be reliably predicted, nor is it known how high the radiation levels will reach even after the event has begun.

The solar-proton event that caused the largest known increase in the radiation at commercial-aircraft flight altitudes occurred February 23, 1956. There is considerable uncertainty concerning the dose rates during this event. However, the available information indicates that recommended radiation limits for pregnant crewmembers would probably have been exceeded on a high-latitude flight (see answer to question 5) at 40,000 feet. The dose to nonpregnant crewmembers could also have exceeded the recommended limit.

Radiation levels at flight altitudes during the solar-proton event of September 29 and 30, 1989, were among the highest, if not the highest, since the 1956 event. The highest effective-dose rates at 40,000 feet, at various locations at high latitudes, ranged from about 0.009 to 0.09 millisievert per hour. The effective dose rate from galactic radiation at the same locations and altitude immediately prior to the event was 0.007 millisievert per hour. Recommended radiation limits for nonpregnant or pregnant crewmembers would not likely have been exceeded on a high-latitude flight at 40,000 feet during the event. Obviously, this does not take into account exposure to galactic radiation both before and after the solar-proton event.

The Aurora Borealis and Aurora Australis (northern and southern lights) are colorful displays in the Earth's atmosphere that result from the interaction of solar particles with the air in the upper atmosphere. Such displays are not an indication of increased radiation levels at flight altitudes.

CONCLUDING REMARKS

Although one cannot exclude the possibility of harm from occupational exposure to 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 for aircrews and their progeny, we used dose-effect relationships recommended by national and international organizations recognized for their expertise in evaluating radiation effects in humans. However, there is considerable uncertainty in the estimates because much of the data come from studies on individuals exposed to radiation at higher doses and dose rates and generally of lower energy than the galactic radiation to which aircrews are exposed. These differences are the major reasons that ongoing and planned epidemiology studies involving aircrews are particularly important. There is some epidemiological evidence that aircrews are at risk of job-related health effects, but the role of radiation has not been ascertained.

With regard to occupational exposure to radiation during pregnancy, the pregnant crewmember and management should work together to ensure that radiation exposure of the conceptus does not exceed recommended limits.

Under U.S. law, it is unlawful for an employer to limit, classify, or segregate an employee in any way that would deprive or tend to deprive him or her of employment opportunities or otherwise affect the status of an employee because of sex or pregnancy.

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Table 1. Average Annual Doses of Ionizing Radiation From Natural Sources Received by a Member of the Population of the United States

Source	Effective dose, millisieverts (% of total)
Cosmic radiation (Uniform whole-body exposure)	0.27 (9%)
Radioactive material in the ground (Uniform whole-body exposure)	0.28 (9%)
Inhaled radon (Primarily to bronchial epithelium)	2.0 (68%)
Radioactive material in body tissues (Tissue doses vary)	0.40 (14%)
	Total = 2.95 (100%)

Table 2. Effective Doses of Galactic Radiation Received on Air-Carrier Flights

	Single nonstop one-way flight				
Origin - Destination 1	Highest altitude, feet in thousands 2	Air time 3	Block hours* 4	Milli-sievert** 5	Milli-sievert per block hour*** 6
Seattle WA - Portland OR	21	0.4	0.6	0.00016	0.0003
Houston TX - Austin TX	20	0.5	0.6	0.00017	0.0003
Miami FL - Tampa FL	24	0.6	0.8	0.00039	0.0005
St. Louis MO - Tulsa OK	35	0.9	1.1	0.00169	0.0015
Tampa FL - St. Louis MO	31	2.0	2.2	0.00474	0.0022
New Orleans LA - San Antonio TX	39	1.2	1.3	0.00325	0.0025
Los Angeles CA - Honolulu HI	35	5.2	5.6	0.0146	0.0026
New York NY - San Juan PR	37	3.0	3.4	0.00995	0.0029
Honolulu HI - Los Angeles CA	40	5.1	5.5	0.0164	0.0030
Chicago IL - New York NY	37	1.6	2.0	0.00654	0.0033
Los Angeles CA - Tokyo JP	40	11.7	12.0	0.0433	0.0036
Tokyo JP - Los Angeles CA	37	8.8	9.3	0.0335	0.0036
Washington DC - Los Angeles CA	35	4.7	4.9	0.0191	0.0039
New York NY - Chicago IL	39	1.8	2.3	0.00890	0.0039
Lisbon PG - New York NY	39	6.5	6.9	0.0290	0.0042
London UK - Dallas/Ft. Worth TX	39	9.7	10.2	0.0437	0.0043
Seattle WA - Washington DC	37	4.1	4.4	0.0191	0.0043
Dallas/Ft Worth TX - London UK	37	8.5	9.0	0.0396	0.0044
Chicago IL - San Francisco CA	39	3.8	4.3	0.0194	0.0045
Seattle WA - Anchorage AK	35	3.4	3.7	0.0169	0.0046
San Francisco CA - Chicago IL	41	3.8	4.3	0.0208	0.0048
New York NY - Seattle WA	39	4.9	5.6	0.0280	0.0050
London UK - New York NY	37	6.8	7.3	0.0373	0.0051
New York NY - Tokyo JP	43	13.0	13.6	0.0754	0.0055
Tokyo JP - New York NY	41	12.2	12.5	0.0697	0.0056
London UK - Los Angeles CA	39	10.5	11.0	0.0616	0.0056
Chicago IL - London UK	37	7.3	7.7	0.0429	0.0056
London UK - Chicago IL	39	7.8	8.3	0.0475	0.0057
Athens GR - New York NY	41	9.4	9.7	0.0615	0.0063

* The block hours begin when the aircraft leaves the blocks before takeoff and end when it reaches the blocks after landing

** 43-year average effective flight-dose, January 1958 through December 2000

*** Column 6 = Column 5 / Column 4

Table 3. Increased Lifetime Risk of Fatal Cancer Because of Occupational Exposure to Ionizing Radiation *

mSv **	Risk	mSv	Risk	mSv	Risk
2	1 in 13000 (0.008%)	20	1 in 1300 (0.08%)	120	1 in 210 (0.5%)
3	1 in 8300 (0.01%)	30	1 in 830 (0.1%)	140	1 in 180 (0.6%)
4	1 in 6300 (0.02%)	40	1 in 630 (0.2%)	160	1 in 160 (0.6%)
5	1 in 5000 (0.02%)	50	1 in 500 (0.2%)	180	1 in 140 (0.7%)
6	1 in 4200 (0.02%)	60	1 in 420 (0.2%)	200	1 in 130 (0.8%)
7	1 in 3600 (0.03%)	70	1 in 360*** (0.3%)	225	1 in 110 (0.9%)
8	1 in 3100 (0.03%)	80	1 in 310 (0.3%)	250	1 in 100 (1.0%)
9	1 in 2800 (0.04%)	90	1 in 280 (0.4%)	275	1 in 91 (1.1%)
10	1 in 2500 (0.04%)	100	1 in 250 (0.4%)	300	1 in 83 (1.2%)

* In the general population of the United States, approximately 24% of adult deaths are from cancer.

** mSv is the abbreviation for millisievert(s)

*** A risk of 1 in 360 at a dose of 70 millisieverts means one expected death from radiation-induced cancer for every 360 persons receiving a dose of 70 millisieverts.

Table 4. Increased Risk of Severe Genetic Defects in First Generation Offspring Because of Parental Exposure to Ionizing Radiation Prior to Offspring's Conception *

mSv **	Risk	mSv	Risk	mSv	Risk
10	1 in 33000*** (0.003%)	110	1 in 3000 (0.03%)	210	1 in 1600 (0.06%)
20	1 in 17000 (0.006%)	120	1 in 2800 (0.04%)	220	1 in 1500 (0.07%)
30	1 in 11000 (0.009%)	130	1 in 2600 (0.04%)	230	1 in 1400 (0.07%)
40	1 in 8300 (0.01%)	140	1 in 2400 (0.04%)	240	1 in 1400 (0.07%)
50	1 in 6700 (0.01%)	150	1 in 2200 (0.05%)	250	1 in 1300 (0.08%)
60	1 in 5600 (0.02%)	160	1 in 2100 (0.05%)	260	1 in 1300 (0.08%)
70	1 in 4800 (0.02%)	170	1 in 2000 (0.05%)	270	1 in 1200 (0.08%)
80	1 in 4200 (0.02%)	180	1 in 1900 (0.05%)	280	1 in 1200 (0.08%)
90	1 in 3700 (0.03%)	190	1 in 1800 (0.06%)	290	1 in 1100 (0.09%)
100	1 in 3300 (0.03%)	200	1 in 1700 (0.06%)	300	1 in 1100 (0.09%)

* Of children in the general population, 2-3% have one or more structural abnormalities present at birth, including but not limited to those of genetic origin.

** mSv is the abbreviation for millisievert(s)

*** A risk of 1 in 33000 at a dose of 10 millisieverts means one expected severe genetic defect from radiation for every 33000 children born to parents receiving a dose of 10 millisieverts prior to conception.

Table 5. Increased Lifetime Risk of Fatal Cancer Because of Prenatal Exposure to Ionizing Radiation *

mSv **	Risk	mSv	Risk	mSv	Risk
1.0	1 in 10000*** (0.01%)	1.6	1 in 6300 (0.02%)	4	1 in 2500 (0.04%)
1.1	1 in 9100 (0.01%)	1.7	1 in 5900 (0.02%)	5	1 in 2000 (0.05%)
1.2	1 in 8300 (0.01%)	1.8	1 in 5600 (0.02%)	6	1 in 1700 (0.06%)
1.3	1 in 7700 (0.01%)	1.9	1 in 5300 (0.02%)	7	1 in 1400 (0.07%)
1.4	1 in 7100 (0.01%)	2	1 in 5000 (0.02%)	8	1 in 1300 (0.08%)
1.5	1 in 6700 (0.01%)	3	1 in 3300 (0.03%)	9	1 in 1100 (0.09%)

* In the general population of the United States (all ages), approximately 23% of all deaths are from cancer.

** mSv is the abbreviation for millisievert(s)

*** A risk of 1 in 10000 at a dose of 1 millisievert means one expected death from radiation-induced cancer for every 10000 concepti receiving a dose of 1 millisievert.