U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: In-Flight Radiation Exposure **Date:** 11/21/14 **AC No:** 120-61B
Initiated by: AFS-200 **Change:**

1. PURPOSE. This advisory circular (AC) provides basic background information and links to sources of more detailed information that can be used to improve air carrier programs that inform crewmembers about in-flight ionizing radiation exposure.

2. CANCELLATION. This AC cancels AC 120-61A, In-Flight Radiation Exposure, dated July 6, 2006.

3. DEFINITIONS.

a. As Low As Reasonably Achievable (ALARA). A basic principle in radiation protection. In an aerospace environment, applying this principle means making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as is practical and consistent with the activity while taking into account the state of technology, the economics of improvements in relation to the state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations.

b. Conceptus. Any stage of prenatal development from fertilized egg to birth.

c. Effective Dose. A dose quantity used to express exposure limits in radiation protection. It is a radiation exposure evaluation scheme that allows exposures to different organs from different types and energies of ionizing radiation to be evaluated in terms of risks of fatal cancer and other stochastic effects.

d. Ionizing Radiation. Refers to subatomic particles of matter (e.g., neutrons, protons, and electrons) and massless particles of energy (X-rays and gamma rays), with each particle having sufficient energy so that, on interacting with a material, it can cause an atom to lose an orbital electron. Low levels of ionizing radiation are a normal part of our environment. Substances that emit ionizing radiation are present in every cell in the body.

e. Galactic Cosmic Radiation. The ionizing radiation that originates outside the solar system, a main source of which is thought to be exploding stars (supernovae).

f. Solar Cosmic Radiation. Ionizing radiation that originates from the Sun; the particles interact with air atoms in the same way as galactic cosmic radiation.

g. Solar Particle Event. Also sometimes called a solar flare, this is a temporary increase in solar cosmic radiation levels. A severe disturbance in the Sun sometimes leads to a large increase in the amount of solar cosmic radiation that penetrates Earth's magnetic field and enters the atmosphere, increasing the dose rate of ionizing radiation to air travelers. While the increase is usually very small relative to the background rate from galactic cosmic radiation, on rare occasions it can be significantly greater than the galactic cosmic radiation dose rate. The period and amount of increase at any given time are difficult to predict accurately and may last from a few minutes to more than a day. The increase is greatest near the magnetic poles, where the Earth's magnetic field provides the least shielding, and decreases rapidly as latitude decreases toward the geomagnetic equator.

h. Stochastic Health Effect. Health effect for which the probability of occurrence is related to the dose, but the severity of the effect is not dependent on dose.

4. RELATED READING MATERIALS. The following reading materials (and many others) are useful as further guidance and in developing training program subject material. For information on how to obtain these materials, see subparagraph 10a.

a. U.S. Department of Transportation, Federal Aviation Administration, *Radiation Protection Guidance to Federal Agencies for Occupational Exposure*, 52 Federal Register (17) (January 1987), p. 2822-2834.

b. Nicholas, J. S., et al., *Galactic Cosmic Radiation of Air Carrier Crewmembers II*, Federal Aviation Administration Office of Aerospace Medicine Report, DOT/FAA/AM-00/33 (October 2000). Document available at http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/00_33.pdf.

c. Bagshaw, Michael, *Cosmic Radiation in Commercial Aviation*, International Academy of Aviation and Space Medicine (June 2004).

d. Hall, E. J., *Radiobiology for the Radiologist* (6th ed.) (Philadelphia, PA: Lippincott Williams & Wilkins, 2006).

e. International Commission on Radiological Protection (ICRP), *The 2007 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 103 (London, UK: Elsevier, 2007).

f. U.S. Department of Transportation, Federal Aviation Administration, *Order 3900.19B, Occupational Safety and Health Program, Chapter 14, Paragraph 1406a* (Washington, DC: Federal Aviation Administration, August 26, 2008).

g. National Council on Radiation Protection and Measurements (NCRP), *Ionizing Radiation Exposure of the Population of the United States*, NCRP Report No. 160 (Bethesda, MD: NCRP, 2009).

h. The American Conference of Governmental Industrial Hygienists (ACGIH), TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices (Cincinnati, OH: ACGIH, 2010).

i. Friedberg, W., and Copeland, K., *Ionizing Radiation in Earth's Atmosphere and in Space Near Earth*, Federal Aviation Administration Office of Aerospace Medicine Report DOT/FAA/AM-11/09 (May 2011). Document available at http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2010s/media/201109.pdf.

j. National Institute of Occupational Safety and Health (NIOSH), *The Flight Crew Research Program at NIOSH*. Available at http://www.cdc.gov/niosh/topics/flightcrew/. (Radiation is one of many topics covered at this Web site.)

5. SOURCES OF EXPOSURE.

a. Natural Sources. The average annual doses of ionizing radiation a person in the United States typically receives from background sources are shown in Table 1, Average Annual Doses of Ionizing Radiation a Person in the United States Typically Receives from Background Sources (NCRP Rep. 160):

TABLE 1. AVERAGE ANNUAL DOSES OF IONIZING RADIATION A PERSON IN THE UNITED STATES TYPICALLY RECEIVES FROM BACKGROUND SOURCES (NCRP REP. 160)

Source	Effective dose (millisieverts)	% of total
Galactic and Solar Cosmic Radiation (Whole-body exposure)	0.33	11
Inhaled Radon and Thoron (Primarily to bronchial epithelium)	2.28	73
Radioactive Material in the Ground (Whole-body exposure)	0.21	7
Radioactive Material in Body Tissues (Tissue doses vary)	0.29	9
Total	3.11	100

b. Sources in Aviation. In aviation, ionizing radiation from natural sources is considered occupational exposure because of the high levels of galactic cosmic radiation at commercial cruise altitudes. In its 2000 report, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) ranked aircrews as the fourth most exposed group of employees, with an average annual effective dose of 3 millisieverts (mSv). Sources of less consistent importance include solar cosmic radiation, shipments of radioactive materials, clouds of radioactive gases, and terrestrial gamma-ray flashes (TGF), which are very rare and are associated with lightning. Table 2, Flight Data and Effective Dose Calculated with CARI-7 for 27 Single Nonstop One-Way Air Carrier Flights for ICRU Mean Solar Activity (Jan. 2000) with Quiet Solar Conditions (KP=0), shows estimated doses for an assortment of U.S.-based domestic and international routes.

TABLE 2. FLIGHT DATA AND EFFECTIVE DOSE CALCULATED WITH CARI-7 FOR 27 SINGLE NONSTOP ONE-WAY AIR CARRIER FLIGHTS FOR ICRU MEAN SOLAR ACTIVITY (JAN. 2000) WITH QUIET SOLAR CONDITIONS (KP=0)

			Effective dose [A] / μSv		
AIRPORTS Origin – Destination	Max. flight level	Air time/ h	CARI-7 E_{103}, Jan. 2000	CARI-7 E_{60}, Jan. 2000	% change in E_{60} from CARI-6
Houston TX – Austin TX	200	0.5	0.19	0.21	23.
Miami FL – Tampa FL	240	0.6	0.41	0.48	23.
St. Louis MO – Tulsa OK	350	0.9	1.41	1.77	4.0
Tampa FL – St. Louis MO	310	2.0	4.06	4.92	4.9
New Orleans LA – San Antonio TX	390	1.2	2.71	3.34	2.8
Los Angeles CA – Honolulu HI	350	5.2	12.2	14.8	1.4
New York NY – San Juan PR	370	3.0	8.12	9.99	0.1
Honolulu HI – Los Angeles CA	400	5.1	13.5	16.5	1.2
Los Angeles CA – Tokyo JP	400	11.7	35.1	43.1	-0.2
Tokyo JP – Los Angeles CA	370	8.8	26.9	33.2	0.0
Washington DC – Los Angeles CA	350	4.7	15.1	18.7	-1.6
New York NY – Chicago IL	390	1.8	6.60	8.29	-6.3
Lisbon PG – New York NY	390	6.5	22.4	27.9	-2.8
London UK – Dallas/Ft. Worth TX	390	9.7	33.2	41.0	-5.5
Seattle WA – Washington DC	370	4.1	16.4	20.6	-7.2
Dallas/Ft. Worth TX – London UK	370	8.5	29.7	36.9	-6.1
Chicago IL – San Francisco CA	390	3.8	14.7	18.4	-3.6
Seattle WA – Anchorage AK	350	3.4	12.4	15.5	-7.7
San Francisco CA – Chicago IL	410	3.8	15.6	19.6	-4.9
New York NY – Seattle WA	390	4.9	20.2	25.5	-8.3
London UK – New York NY	370	6.8	27.3	34.2	-7.8
New York NY – Tokyo JP	430	13.0	55.1	69.2	-7.5
Tokyo JP – New York NY	410	12.2	50.7	63.7	-7.7
London UK – Los Angeles CA	390	10.5	44.6	56.0	-8.3
Chicago IL – London UK	370	7.3	30.8	38.7	-9.2
London UK – Chicago IL	390	7.8	34.0	42.8	-9.1
Athens GR – New York NY	410	9.4	44.6	56.5	-7.2

[A] $E_{103 \text{ and}}$ E_{60} indicate effective dose calculated using tissue and radiation weighing factors as recommended in International Commission on Radiological Protection (ICRP) Publication 103 and Publication 60, respectively.

6. EXPOSURE VARIABLES.

a. Galactic and Solar Cosmic Radiation. Less radiation will be received on a lower-latitude flight because of the greater amount of radiation shielding provided by the Earth's magnetic field. This shielding is greatest near the equator and gradually decreases to zero as one goes north or south. Galactic cosmic radiation levels over the polar regions are about twice those over the geomagnetic equator at the same altitudes. Because solar particle peak energies are much lower than galactic particle peak energies, solar cosmic radiation dose rates are negligible near the geomagnetic equator. A map of high-latitude areas of concern is available on the

following FAA Web site:
www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/solarradiation/.

(1) The Solar Radiation Alert System developed by the FAA's Civil Aerospace Medical Institute (CAMI), with data provided by the Space Weather Prediction Center of the National Oceanic and Atmospheric Administration (NOAA), alerts users of the beginning of a disturbance on the Sun that can lead to high-dose rates of ionizing radiation in the Earth's atmosphere. Solar radiation alerts are sent worldwide to subscribers to the NOAA Weather Wire Service (NWWS). A message is sent at the beginning and end of an alert, along with status updates during the alert period. A test message is sent daily if no alert is ongoing. Responding to an alert by flying at a lower altitude can significantly reduce radiation exposure in high-latitude areas of concern. The latest space-weather-related NWWS messages are found at http://www.nws.noaa.gov/view/national.php?prodtype=space and http://weather.noaa.gov/pub/data/raw/wo/woxx50.kwnp.alt.pav.txt.

(2) The FAA's Solar Radiation Alert System is described in the Office of Aviation Medicine technical report DOT/FAA/AM-09/06, Solar Radiation Alert System, available at: http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/200906.pdf.

b. Shipments of Radioactive Materials. The dose from any radioactive cargo that might be present will depend on the cargo and how it was packed. Most passenger-carrying flights do not carry radioactive cargo. In calculating total exposure to ionizing radiation, consider exposure to radioactive cargo in addition to exposure to galactic and solar cosmic radiation. The carriage of such cargo is limited and controlled by the following regulations:

(1) Radiation Level Limitations. Title 49 of the Code of Federal Regulations (49 CFR) part 173, § 173.441.

(2) Notification of Pilot in Command (PIC). Title 49 CFR part 175, § 175.33.

(3) Special Limitations and Requirements for Class 7 (Radioactive) Materials. Title 49 CFR part 175, § 175.700.

c. Clouds of Radioactive Gases. Such clouds occur most often as the results of an accident, such as those at the Chernobyl and Fukushima powerplants, and responsible government agencies quickly restrict travel into areas where dose rates are above acceptable levels as part of the coordinated response to such an event.

d. TGFs. On rare occasions, lightning is associated with the large transient pulse of gamma rays called a terrestrial gamma-ray flash directed upward toward space. This phenomenon is still poorly understood and is under study.

7. RECOMMENDED LIMITS. The FAA accepts the most recent recommendations of the American Conference of Government Industrial Hygienists. For a non-pregnant air carrier crewmember, the FAA-recommended limits for exposure to ionizing radiation are the same as those recommended by the International Commission on Radiological Protection (ICRP).

a. Dosage. When considering the harmful health effects of postnatal (child or adult) exposure to ionizing radiation, the current practice is to express the amount of radiation received in terms of effective dose. If the radiation exposure is to a conceptus, dose is expressed in terms of equivalent dose. The unit of both effective dose and equivalent dose is the sievert (Sv), which is a measure of the biological harm that ionizing radiation may cause: 1 Sv = 1000 mSv.

b. Recommended Exposure Limit. The recommended occupational exposure limit for ionizing radiation is a 5-year average effective dose of 20 mSv per year, with no more than 50 mSv in a single year. Radiation exposure as part of a medical or dental procedure is not subject to recommended limits. It is important to note that these limits are not thresholds beyond which the dose is intolerable but instead are upper limits of acceptability based on the current risk coefficients and the desire to limit doses such that the health risks associated with exposure do not exceed those of what is normally considered a safe industry.

c. Pregnancy and Exposure. A pregnant woman, in addition to other medical and personal concerns, should consider limiting the ionizing radiation exposure of her conceptus. In the case of a pregnant crewmember, in addition to the normal occupational limits of subparagraph 7b, the FAA recommends she limit ionizing radiation exposure of her conceptus to no more than 0.5 mSv per month. Two technical reports regarding radiation exposure during pregnancy may be viewed at the following links below:

(1) "Air Travel During Pregnancy" (published by the American College of Obstetricians and Gynecologists) at: http://www.acog.org/~/media/Committee%20Opinions/Committee%20on%20Obstetric%20Practice/co443.pdf?dmc=1&ts=20120402T1214440751.

(2) "Galactic Cosmic Radiation Exposure of Pregnant Aircrew Members II" (FAA technical report DOT/FAA/AM-00/33) at: http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/00_33.pdf.

8. RISK ASSOCIATED WITH EXPOSURE.

a. Mechanisms of Harm. While estimates of harm at the low doses and dose rates involved are based on exposures at much higher doses and dose rates, individuals exposed to ionizing radiation are believed to incur increased risk of cancers, passing on genetic defects to future generations, and possibly other adverse health effects. Ionizing radiation can cause changes in the cell chemicals such as DNA and proteins, which can cause cell damage or cell death. In some cases, there may be no effect. In other cases, the cell may survive but become abnormal, either temporarily or permanently, which can eventually lead to adverse health effects in the exposed individual.

b. Risk of Cancer. Based on current scientific thinking, any exposure to radiation can be harmful and increase the risk of cancer. At very low exposures, however, the estimated increases in risk are very small. The likelihood of developing cancer because of occupational exposure to galactic cosmic radiation is a small addition to health risks experienced by the general population. Currently, it is not possible to establish that an abnormality or disease in a particular individual resulted from exposure to galactic cosmic radiation at the doses likely to be received while flying.

9. MANAGING EXPOSURE.

a. How to Calculate Exposure. For doses on individual flights, a Web-based version of CARI-6 is available. For analysis of one's flight history, the FAA provides applications CARI-6 and CARI-6M, which can be used to estimate the effective dose of galactic cosmic radiation. No FAA programs and or Web sites/applications are currently available for use in estimating the effective dose received from a solar particle event. The dose of ionizing radiation that an individual might receive during a solar particle event cannot be estimated in advance. Research is currently being conducted on how best to estimate flight doses on the basis of satellite and ground-level measurements made during an event.

(1) CARI-6. This Web application calculates the effective dose of galactic cosmic radiation received by an individual (adult) on an aircraft flying a great-circle route between any two airports in the world. The Web application takes into account changes in altitude and geographic location during the course of a flight, as derived from the flight profile entered by the user. 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 Web application also calculates the effective dose rate from galactic cosmic radiation at any location in the atmosphere at altitudes up to 60,000 feet. The Web sites for CARI-6 are: http://jag.cami.jccbi.gov./cariprofile.asp (a CARI-6 based flight dose calculator) and www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/cari6/.

(2) CARI-6M. This Web application does not require a great-circle route between origin and destination airports; it allows the user to specify the flight path by entering the altitude and geographic coordinates of waypoints. The Web site for CARI-6M is: www.faa.gov/data_research/research/med_humanfacs/aeromedical/radiobiology/cari6m/.

b. How to Reduce Exposure. Exposure management should be based on the ALARA principle. The amount of galactic cosmic radiation exposure received while flying depends on the amount of time in the air, altitude, latitude, and solar activity. Lowest dose rates at a given altitude are found near the equator and increase as one approaches the poles. For any location at commercial flight altitudes, a higher altitude will incur a higher dose rate. Responding to a solar radiation alert by flying at a lower altitude can significantly reduce radiation exposure in high-latitude areas of concern, particularly if the response is rapid.

10. FURTHER INFORMATION.

a. In-Flight Radiation Exposure. For questions regarding in-flight radiation exposure, contact:

U.S. Department of Transportation
Federal Aviation Administration
Office of Aerospace Medicine
Radiobiology Research Team, AAM-610
Civil Aerospace Medical Institute

Oklahoma City, OK 73125
Office: 405-954-6275
Fax: 405-954-1010
9-amc-aam610-radiation@faa.gov
http://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2010s/media/201109.pdf.

b. Radioactive Cargo. For questions regarding radioactive cargo, contact:

U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration
Office of Hazardous Materials Technology
Hazardous Materials Information Center
Office: 800-HMR49-22, or 800-467-4922, or 202-366-4488 (local)
Fax: 202-366-3753
FAX-ON-DEMAND: (800) 467-4922 x 2

John S. Duncan
Director, Flight Standards Service